Foreword

According to the requirements of Document JIANBIAO[2013] No. 6 issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) – "Notice on Printing and Distributing 'the Development and Revision Plan on National Engineering Construction Standards in 2013'", this code has been revised on the basis of GB 50384–2007 *Code for Design of Coal Mine Shaft and Chamber* (hereinafter referred to as original code) by Survey and Design Committee of China Coal Construction Association and China Coal Nanjing Design and Research Institute Co., Ltd of Technology & Engineering Group (CCTEG) and other relevant organizations.

The drafting group developed this code through extensive investigation and study, careful summarization of practical experience of shaft and chamber design and construction of coal system in China. The new and mature technology and process has also been introduced. This revision has been finalized on the basis of multiple revisions and widely soliciting for opinions from design, scientific research, teaching, construction and management organizations.

This code consists of 7 chapters and 7 appendix, covering: general provisions, terms and symbols, general requirements, materials, shaft equipments, shaft support, chamber, etc.

The main contents of revisions of this code are as follows:

(1) Adding "Corrosion and Protection of Shaft Equipment" in Section 5.7. Adding "Basic Requirements" in Section 6.1. Adding Article 3.0.8. Adding item 3 in Article 5.3.8. Adding item 6 in Article 5.4.1. Adding item 1 in Article 6.4.2. Adding mandatory Item 2 in Article 7.1.3.

(2) Structure importance coefficient has been modified. Design principles of shaft and chamber of coal mine have been adjusted to be safe and reliable, advanced, economic and reasonable. The experience value of bedrock shaft lining thickness has been converted to experience value of concrete shaft lining thickness in bedrock section.

(3) Coefficient 0.9 has been removed from the Formula $f_s = 0.9(f_c + \rho_{min} f'_y)$ of design value of strength of reinforced concrete of the shaft lining material. Contents of squared stone and concrete block have also been deleted. Appendix A and Appendix B, wooden shaft guide and relative contents of original code have been deleted.

The provisions printed in bold type are mandatory ones and must be implemented strictly.

This code is under the jurisdiction of and its mandatory provisions are interpreted by the Ministry of Housing and Urban-Rural Development of the People's Republic of China. China Coal Construction Association is responsible for its routine management, and Nanjing Design and Research Institute Co., Ltd of CCTEG is in the charge of the explanation of technical specifications. All relevant organizations are kindly invited to summarize and accumulate actual experiences when implementing this code. Relevant comments and recommendations, whenever necessary, should be submitted to Nanjing Design and Research Institute Co., Ltd of CCTEG (Address: Pudong Road 20, Pukou district, Nanjing city, Jiangsu province. Postcode: 210031. Fax: 025-58863059).

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Contents

1 General provisions

1.0.1 This code is prepared with a view to unify the engineering design standard of shaft of the coal mine, shaft equipment and chamber as well as to improve the design quality.

1.0.2 This code is applicable to the engineering design of the vertical shaft and relevant chamber of the coal mine.

1.0.3 The engineering design of shaft and chamber shall adopt the advanced technology and follow the principles of safety, applicability and cost-effectiveness.

1.0.4 Inspection borehole data of the shaft shall comply with the design requirements of coal mine shaft and chamber engineering design, and the optimal scheme shall be determined by widely soliciting of techno-economic comparison.

1.0.5 The properties, specifications and quality of materials used in shaft and chamber of coal mine shall be in compliance with current regulations of national and relevant standards.

1.0.6 The engineering design of shaft and chamber of coal mine shall be in compliance with this code as well as current regulations of national and relevant standards.

2 Terms and symbols

2.1 Terms

2.1.1 vertical shaft

Vertical passageways are developed in the formation for the service of coal, facilities, personnel elevations and ventilation.

2.1.2 shaft equipment

Bunton, guide, shaft beams, ladderway and all kinds of pipes, lines, ropes and other fixed facilities installed in the shaft.

2.1.3 guide

A guidance facilities for hoisting conveyance in a shaft. There are two kinds of guides, they are flexible guide and rigid guide. Common type of flexible guides is wire rope guide. Rigid guide includes rail guide, structural steel composite guide, cold bent square steel guide, cold drawing square pipe steel guide and composite guide of fiberglass, etc.

2.1.4 topsoil

Loose deposits overlying bedrock are collectively called topsoil.

2.1.5 conventional shaft sinking method

Adopting drilling and blasting or other conventional methods for shaft sinking in stable or less water formations.

2.1.6 special shaft sinking method

In the water-bearing and unstable formation, special technology, equipment and technology are adopted to form the shaft directly or using the conventional shaft sinking method after the formation has been dealt with.

2.1.7 single-layer shaft lining

Staged by once (or continuous by once), the underground cylindrical structure which is formed by the combination of one or larger materials as needed.

2.1.8 double-layer shaft lining

Double-layer shaft lining is composed of outer shaft lining and inner shaft lining. The outer shaft lining is constructed from top to bottom, with the construction of shaft sinking section. The inner shaft lining is constructed from bottom to top.

2.1.9 vertical additional surface force

The vertical downward surface force exerted by the formation on the lateral surface of the shaft lining when shaft lining is settled due to drainage and other reasons.

2.1.10 characteristic value of a load

The basic representative value of the load is the eigenvalue of the statistical distribution of the maximum load during the design reference period.

2.1.11 design value of a load

Product of characteristic value of load and safety coefficient of structure.

2.1.12 bearing capacity

Load bearing capacity of shaft lining.

2.1.13 thin shell tube

The ratio between lining thickness and outside radius of shell tube is less than the prescribed number. If the ratio between lining thickness (t) and outside radius of the shaft lining (r_w) is less than 1/10 $\left(\text{i.e.}\ \frac{t}{r_w} < \frac{1}{10}\right)$, in the vertical shaft, it is called thin shell tube.

2.1.14 thick shell tube

The ratio between thick lining and outside radius of shell tube larger than or equal to prescribed number. If the ratio between lining thickness(t)outside radius of the shaft lining(r_w)larger than or equal to 1/10 $\left(\frac{t}{r_w} \geqslant \frac{1}{10}\right)$ in the vertical shaft, it is called thick shell tube.

2.2 Symbols

2.2.1 Conventional shaft sinking method, freezing shaft sinking method and shaft support:

A_0 —Cross-sectional area of the shaft lining calculation.

A_n —Horizontal load coefficient of rock(soil)layer.

A_s —Reinforcing steel bars area per meter of shaft lining section.

b —Calculation width of shaft lining cross-section.

D —Outer diameter of shaft.

d —Inner diameter of shaft.

E_c —Elastic modulus of concrete.

E_s —Elastic modulus of reinforcement.

F_w —Calculation of surface area of the shaft lining above the cross section.

F_c —Design value of axial compressive strength of concrete.

$f_{cu,k}$ —Characteristic value of compressive strength of concrete cube.

f_s —Design value of the strength of the shaft lining material.

f_t —Design value of concrete tensile strength.

f'_y, f_y —Design value of compressive and tensile strength of reinforcing steel bars.

H —Depth of the calculated place of the shaft.

I —Moment of inertia of cross-section of the shaft.

L_0 —Calculated length of shaft lining ring.

M_0 —Moment of build-in level of shaft tower of the chosen level.

N —Calculated value of axial force on ring section of shaft lining of unit height.

N_0 —Axial force of build-in level of shaft tower.

P —Calculated value of the design load acting on shaft lining of chosen place.

P_0 —Characteristic value of the load on the structure.

P_k —Characteristic value of uniform load on structure.

$P_{A,k}, P_{B,k}$ —Characteristic value of minimum and maximum load on shaft lining.

$P_{f,k}$ —Characteristic value of vertical additional force on the outer surface of shaft lining above cross section.

$P^s_{n,k}, P^x_{n,k}$ —Characteristic value of uniform load on the n layer of rock roof and floor of the shaft lining.

Q_0 —Horizontal force of build-in level of shaft tower.

$Q_{1,k}$ —Characteristic weight value of shaft tower directly supported the shaft.

$Q_{2,k}$ —Characteristic weight value of the shaft equipment above the cross section.

$Q_{f,k}$ —Characteristic value for total vertical additional force on shaft lining above calculated cross-section.

$Q_{Z,k}$ —Characteristic value of vertical load on shaft lining.

$Q_{Zl,k}$ —Characteristic value of shaft lining dead load above cross section.

r_0 —Center radius of shaft lining.

R_n —Inner radius of shaft lining.

r_w —Outer radius of shaft lining.

t —Shaft lining thickness.

ϕ —Stability factor of axial compression member of reinforced concrete.

ϕ_1 —Stability factor of plain concrete.

φ —Friction angle in soil layer.

β_t —Non-uniform load factor of surface soil layer.

β_y —Non-uniform coefficient of horizontal load of rock formation.

ν_c —Poisson ratio of concrete.

ν_k —Safety coefficient of structure.

γ_h —Gravity density of concrete or reinforced concrete.

ρ —Steel ratio of shaft lining section.

ρ_{min} —Minimum steel ratio of shaft lining section.

σ_t —Tangential stress of ring section of shaft lining.

σ_{zl} —Calculated value of gravity stress of cross section shaft lining.

σ_z —Calculated value of vertical stress of cross section shaft lining.

σ_r —Calculated value of radial stress of the cross section of shaft lining.

2.2.2 Shaft sinking method and shaft support:

A_{sy} —Cross-sectional area of vertical reinforcement of shaft lining.

A_y, A'_y —Cross-section area of a reinforcement under tension.

D_s —Design diameter of clear section of shaft.

D_y —Efficient diameter of clear section of shaft.

h_z —Section height of shaft lining.

$N_{z,k}$ —Characteristic value of the vertical load on the shaft lining during hoisting.

n —Ratio of elastic modulus of reinforcement and concrete.

$P_{w,k}$ —Characteristic value of mud pressure.

$P_{n,k}$ —Characteristic value of floatation pressure.

P_g —Calculated value of the pressure at the bottom of the shaft.

P_w —Calculated value of mud pressure.

P_n —Calculated value of floatation pressure.

V_Q, V_T —Shell or shaft volume.

V_n —Shell volume at the shaft bottom and mud discharge volume of the shaft.

ν_f —Factor of safety against cracking.

λ —Shell constant.

η —The slope of shaft completion in design.

γ_w —Gravity density of mud.

λ_n —Gravity density of floatation.

2.2.3 Caisson sinking method and shaft support:

d —Design internal diameter of caisson.

d_1 —Effective inner diameter of caisson.

D —Outside diameter of caisson shaft.

D_1 —Outside diameter of blade.

D_2 —Inner diameter of casing shaft.

D_3 —Outer diameter of casing shaft.

E —Thickness of casing shaft lining.

F —Unit friction of contact surface between shaft lining and soil.

F' —Unit friction between shaft lining and mud.

G —Dead-weight of caisson shaft lining.

G' —Total weight of caisson shaft lining.

G_1 —Dead-weight of cutting edge of caisson shaft lining(include buoyancy).

G_2 —Caisson shaft weight(include buoyancy).

G_3 —Sludge barrel weight behind the caisson shaft lining.

h —Caisson shaft lining thickness.

H —Efficient depth of caisson shaft.

H_1 —Total depth of casing shaft.

H_2 —The height from the top of the cutting edge of the casing shaft to the steps of the cutting edge of the caisson shaft.

H_3 —Cutting edge height.

L_1 —The clearance between caisson shaft and casing shaft.

N —Head resistance of cutting edge.

R_t —Soil ultimate compressive strength.

S —Surface area of caisson shaft lining.

T —Total sinking resistance of caisson.

T_1 —Side resistance between outer cutting edge and soil.

T_2 —Frictional resistance between outer shaft lining and thixotropy mud.

W —Calculated weight ratio of shaft lining.

α —The depth of cutting edge compacted into the soil.

β —Intersection angle of cutting edge top.

η —Permissible skewness and slop rate of caisson.

μ —Skewness and slop rate of casing shaft.

2.2.4 Curtain wall shaft sinking method and shaft support:

B_0 —Thickness of casing shaft lining.

B —Efficient thickness of concrete curtain.

D —Borehole diameter.

H —Design depth of concrete curtain.

R —Net radius of the efficient thickness of curtain.

R_0—Net radius of shaft.

R_1—Center line radius of curtain.

i —Maximum allowable deflection rate of hole creation.

2.2.5 Others:

λ_0—Importance factor of structure.

f —The design strength values of tensile, compressive and bending of the steel.

f_v —Design strength value of resisting shear of steel.

f_{ce}—Design strength value of bearing stress of the end face of the steel.

3 General requirements

3.0.1 The selection of importance coefficient of shaft lining shall be in accordance with the following requirements:

1 The shaft with service life not less than 50a or large-scale shaft, or the topsoil depth of the shaft not less than 150m shall be selected according to 1.10 to 1.15.

2 The small and medium size shaft with service life less than 50a, and the topsoil depth less than 150m, shall be selected according to 1.05 to 1.10.

3.0.2 Structural safety coefficient selection of shaft lining and shaft equipment in different stress state shall be in accordance with Table 3.0.2.

Table 3.0.2 Structural safety coefficient

<table>
<tr><th colspan="4">Mechanical characteristic</th><th>Safety coefficient of structure (ν_k)</th></tr>
<tr><td rowspan="13">Shaft lining and the bottom of shaft lining</td><td rowspan="12">Shaft lining body</td><td colspan="2">Uniform water and soil pressure</td><td>1.35</td></tr>
<tr><td rowspan="2">Hydrostatic pressure</td><td>Permanent load</td><td>1.35</td></tr>
<tr><td>Temporary load</td><td>1.10</td></tr>
<tr><td colspan="2">Stability</td><td>1.30</td></tr>
<tr><td colspan="2">Vertical pressure of shaft tower</td><td>1.20</td></tr>
<tr><td colspan="2">Non-uniform pressure</td><td>1.10</td></tr>
<tr><td colspan="2">Frozen soil pressure</td><td>1.00–1.05</td></tr>
<tr><td colspan="2">Mud pressure</td><td>1.10</td></tr>
<tr><td colspan="2">Interface pressure</td><td>1.20</td></tr>
<tr><td colspan="2">Shaft lining suspension</td><td>1.20</td></tr>
<tr><td colspan="2">Additional pressure</td><td>1.20</td></tr>
<tr><td colspan="2">Hydrostatic pressure(permanent load)</td><td>1.80</td></tr>
<tr><td>Shaft lining bottom</td><td colspan="2">Hydrostatic pressure(permanent load)</td><td>1.80</td></tr>
<tr><td rowspan="2">Shaft equipment</td><td>Guide</td><td colspan="2">Load calculation</td><td>1.00–1.05</td></tr>
<tr><td>Bunton</td><td colspan="2">Load calculation</td><td>1.00–1.05</td></tr>
</table>

Note: When hoisting terminal load of the shaft, guide and bunton is less than 45t, the safety coefficient adopts 1.00. If the hoisting terminal load of the shaft is larger than 45t, the safety coefficient adopts 1.00 to 1.05.

3.0.3 The vertical shaft shall use a circular section, and the size of the section shall be dictated by the purpose, service life, shaft equipment, the rock formation which the shaft crossed, water gushing, shaft sinking method and support type.

3.0.4 For those shafts which may cause sedimentation of topsoil due to shaft construction or production, the shaft lining design shall be carried out with considering the influence of the topsoil sedimentation to the shaft. When the technical economy is reasonable, may use the lining structure which adapt to topsoil sedimentation.

3.0.5 The type of support in vertical shaft shall be dictated by the geological and hydrogeological data and drilling method, and the reinforced concrete or plain concrete should be used to support the shaft. When the geological conditions are complex and the ground pressure is large, other supporting structures may also be adopted.

3.0.6 In case borehole inspection data show that the formation containing water and related gases are corrosive, the design of vertical shaft and chamber, and the design of shaft equipment shall take into account the influence of corrosion on concrete, reinforced-steel, steel and other materials.

3.0.7 The section shape and support method of vertical shaft chamber shall be determined according to geological conditions, service requirements, service life and other factors, and shall be in accordance with the following requirements:

1 The chamber should select semicircle arch section. When the top pressure and lateral pressure are high, the hyperbolic arch section may be adopted. When the bottom pressure is high, the reverse arch may be added at the bottom of the chamber or the circular section may be adopted.

2 Vertical coal bunker should adopt circular section.

3 Fan drift, emergency exit and inclined coal bunker may select semi-circular arch or rectangular section.

4 The chamber may be supported by concrete, reinforced concrete or anchor spray metal mesh. Support parameters shall be determined by surrounding rock conditions, shape and size of chamber and ground pressure calculation. Other forms of support may also be used when conditions are special.

3.0.8 When the seismic intensity is above 7 degrees or in unstable rock formation, the fan drift and emergency exit and the shaft lining which at the top of the shaft within 30m must adopt the reinforced concrete structure.

3.0.9 Concrete pavements shall be adopted in the ingate of cage vertical shaft, skip loading chamber, coal feeder chamber, water pump house, drainage roadway, emergency exit of vertical air shaft, etc.

4 Materials

4.1 Concrete

4.1.1 Concrete strength grades for shaft and chamber support shall be in accordance with the following requirements:

1 The strength grade of concrete (except sprayed concrete) for chamber support and shaft support shall not be lower than C30.

2 In case that the unfurnished shaft is supported by sprayed concrete, the grade of concrete strength shall not be lower than C20.

4.1.2 In case that the shaft and chamber are supported by reinforced concrete, the characteristic value of concrete axial compressive and axial tensile strength, such as f_{ck}, f_{tk} shall be in accordance with Table 4.1.2-1. Design value of concrete axial compressive and axial tensile strength, such as f_c, f_t shall be in accordance with Table 4.1.2-2.

Table 4.1.2-1 Characteristic value of concrete strength (N/mm²)

Strength type	Concrete strength grade												
	C20	C25	C30	C35	C40	C45	C50	C55	C60	C65	C70	C75	C80
f_{ck}	13.4	16.7	20.1	23.4	26.8	29.6	32.4	35.5	38.5	41.5	44.5	47.4	50.2
f_{tk}	1.54	1.78	2.01	2.20	2.39	2.51	2.64	2.74	2.85	2.93	2.99	3.05	3.11

Table 4.1.2-2 Design value of concrete strength (N/mm²)

Strength type	Concrete strength grade												
	C20	C25	C30	C35	C40	C45	C50	C55	C60	C65	C70	C75	C80
f_c	9.6	11.9	14.3	16.7	19.1	21.1	23.1	25.3	27.5	29.7	31.8	33.8	35.9
f_t	1.10	1.27	1.43	1.57	1.71	1.80	1.89	1.96	2.04	2.09	2.14	2.18	2.22

4.1.3 The design value of axial compressive strength is calculated by data in Table 4.1.2-2 multiplied with coefficient 0.85 in case that shaft and chamber are supported by plain concrete and meet the relevant requirements of the current national standards of GB 50010 *Code for Design of Concrete Structures*.

4.1.4 The elastic modulus E_c of concrete shall be in accordance with Table 4.1.4.

Table 4.1.4 Elastic modulus of concrete ($\times 10^4$N/mm²)

Strength grade of concrete	Concrete strength grade												
	C20	C25	C30	C35	C40	C45	C50	C55	C60	C65	C70	C75	C80
E_c	2.55	2.80	3.00	3.15	3.25	3.35	3.45	3.55	3.60	3.65	3.70	3.75	3.80

4.2 Steel reinforcement

4.2.1 Load bearing reinforcing steel bars of reinforced concrete structure in vertical shaft and chamber shall use type HRB400, HRB500, HRBF400, HRBF500, and contact reinforcing steel bars may use type HPB300.

4.2.2 The characteristic value of reinforcing steel bars strength shall be in accordance with Table 4.2.2.

Table 4.2.2 Characteristic value of reinforcing steel bars (N/mm^2)

Mark	Symbol	Nominal diameter d (mm)	Characteristic value of yield strength f_{yk}	Characteristic value of ultimate strength f_{stk}
HPB300	A	6–22	300	420
HRB400 HRBF400	C C^F	6–50	400	540
HRB500 HRBF500	D D^F	6–50	500	630

4.2.3 Design value of tensile strength of reinforcing steel bars (f_y) and compressive strength of reinforcing steel bars (f_y') shall be in accordance with Table 4.2.3.

Table 4.2.3 Design value of reinforcing steel bars strength (N/mm^2)

Mark	Design value of tensile strength f_y	Design value of compressive strength f_y'
HPB300	270	270
HRB400 HRBF400	360	360
HRB500 HRBF500	435	410

4.2.4 Elastic modulus of reinforcing steel bars E_s shall be in accordance with Table 4.2.4.

Table 4.2.4 Elastic modulus of reinforcing steel bars ($\times 10^5 N/mm^2$)

Mark or type	Elastic modulus E_s
HPB300	2.10
HRB400, HRB500 reinforcing steel bars HRBF400, HRBF500 reinforcing steel bars	2.00

4.3 Steel products

4.3.1 Steel products selection in shaft and chamber shall be in accordance with the current national standard of GB 50017 *Code for Design of Steel Structures*. Carbon structural steel and low-alloy steel with high strength, good plasticity and weldability shall be used. Special steel may also be chosen for special requirements.

4.3.2 Design value of reinforcing steel bars shall be determined according to those specified in Table 4.3.2.

Table 4.3.2 Design value of reinforcing steel bars (N/mm^2)

Steel		Against tensile, bending and compression f	Against shearing f_v	Bearing stress (planing and push tightly) f_{ce}
Mark	Thickness or diameter			
Q235	≤16	215	125	325
	16–40	205	120	
	40–60	200	115	
	60–100	190	110	

Table 4.3.2(continued)

Steel		Against tensile, bending and compression f	Against shearing f_v	Bearing stress (planing and push tightly) f_{ce}
Mark	Thickness or diameter			
Q345	≤16	310	180	400
	16-35	295	170	
	35-50	265	155	
	50-100	250	145	
Q390	≤16	350	205	415
	16-35	335	190	
	35-50	315	180	
	50-100	295	170	
Q420	≤16	380	220	440
	16-35	360	210	
	35-50	340	195	
	50-100	325	185	

Note: The thickness in the Table refers to the steel thickness of the calculated point, and the axial tensile and axial compression components refer to the thickness of the thicker plate in the section.

4.3.3 The steel connection method in shaft and chamber design should use welding connection or bolt connection which shall meet the relevant requirements of the current national standard of GB 50017 *Code for Design of Steel Structures*, etc.

4.4 Glass fiber reinforced plastics

4.4.1 The base material of glass fiber reinforced plastics shall use unsaturated polyline resin, and the quality shall be in accordance with Table 4.4.1. When the design has special requirements, other resins may also be used as the base material.

Table 4.4.1 Quality index, characteristics and application of unsaturated polyline resin

Type	Appearance	Acid value (mg KOH/g)	Viscosity (min)	Resin content (%)	Gel time (min)	Heat endurance	Performance and use
191	Transparent yellow liquid	28 to 36	25℃, 6 to 13	60-66 (Solid content)	25℃, 10 to 25	25℃, 0.5a 80℃, 24h	It is a sort of polyresin with low viscosity and stable light which has good impregnation properties to glass fibers, and is often used in the manufacture of translucent wave-shaped tiles, ladderway components in coal mine shafts and other contact molding products

4.4.2 Steel type Q235, Q345, Q390, Q420 should be used in embedded steel core of glass fiber reinforced plastics (GFRP). The specification, size and quality shall meet the design requirements and relevant quality standards. The embedded steel core shall be rust-free and meet the international general standard level Sa2.5.

4.4.3 The anti-static index of the finished product of the glass fiber reinforced plastics material in the shaft and chamber shall not be larger than $3.0\times10^{8}\Omega$.

4.4.4 The flame retardant coefficient of GFRP finished products in shaft and chamber shall be larger than 26 oxygen index.

4.4.5 Mechanical and safety performance of finished products of glass fiber reinforced plastics in shaft and chamber shall be in accordance with those specified in Table 4.4.5.

Table 4.4.5 Mechanical and safety performance index of GFRP finished products

<table>
<tr><th colspan="3" rowspan="2">Item</th><th rowspan="2">Unit</th><th>Index</th><th rowspan="2">Testing method</th></tr>
<tr><th>Up to standard</th></tr>
<tr><td rowspan="6">Mechanical properties under normal temperature</td><td rowspan="2">Tensile strength</td><td>Glass yarn</td><td rowspan="6">MPa</td><td>120</td><td>GB/T 3354 Test Method for Tensile Properties of Orientational Fiber Reinforced Polymer Metrix Composite Materials</td></tr>
<tr><td>Glass fabric</td><td>130</td><td>GB/T 1447 Fiber-reinforced Plastic Composites-determination of Tensile Properties</td></tr>
<tr><td rowspan="2">compressive strength</td><td>Glass yarn</td><td>35</td><td rowspan="2">GB/T 1448 Fiber-reinforced Plastic Composites-determination of Compressive Properties</td></tr>
<tr><td>Glass fabric</td><td>40</td></tr>
<tr><td rowspan="2">Bending strength</td><td>Glass yarn</td><td>70</td><td>GB/T 3356 Test Method for Flexual Properties of Orientational Fiber Reinforced Polymer Metrix Composite Materials</td></tr>
<tr><td>Glass fabric</td><td>80</td><td>GB/T 1449 Fiber-reinforced Plastic Composites-determination of Flexural Properties</td></tr>
<tr><td rowspan="3">Safety</td><td colspan="2">Sheet resistance</td><td>Ω</td><td>The arithmetic average of upper and lower surface resistance is not larger than 3×10^{8}</td><td rowspan="3">GB 16413 Inspecting Specification of Glass Fiber Reinforced Plastic Product Safety Property for Coal Mining</td></tr>
<tr><td rowspan="2">Flame combustion test for alcohol-jet lamp</td><td>Flame burning time</td><td rowspan="2">s</td><td>After removing the blowtorch, the arithmetic average value of flame burning time of 6 specimens shall not be larger than 5, and the maximum single value of flame combustion continuation time of each specimen shall not be larger than 15</td></tr>
<tr><td></td><td>After removing the blowtorch, the arithmetic average value of the flameless combustion time of six specimens shall not be larger than 20, and the maximum single value of the flameless combustion continuation time of each specimen shall not be larger than 60</td></tr>
</table>

4.4.6 The mechanical, safety performance and technical requirements of GFRP finished guide products in shaft shall be in accordance with those specified in Table 4.4.6.

Table 4.4.6 The mechanical, safety performance and technical requirements of GFRP finished guide products

Item	Mechanical performance					Safety performance		Technical requirements	
	Tensile strength (MPa)	Flexural strength (MPa)	Elastic modulus (MPa)	Rolling wear 30a (mm)	Rolling wear 30a (mm)	Sheet resistance (Ω)	Flame retardant property(s)	Guide straightness (‰)	Guide distortion (‰)
Index	≥160	≥130	1.9×10^5	≤1	≤3	$\leqslant 3\times10^8$	≤15	0.7	0.7

Note: Flame retardant property is the total time of continuous flaming.

4.5 Other commonly used materials

4.5.1 The physical and mechanical properties of polystyrene foam board between frozen soil and freezing section of shaft lining shall be in accordance with those specified in Table 4.5.1.

Table 4.5.1 The physical and mechanical property index of polystyrene foam board

No.	Item		Density(kg/m^3) 21	Density(kg/m^3) 31
1	Compressive strength (MPa)	Compression 10 %	0.122	0.181
		Compression 25 %	0.144	0.216
		Compression 50%	0.305	0.364
		Compression 75 %	0.331	–
2	Tensile strength(MPa)		0.13	0.25
3	Flexural strength(MPa)		0.302	0.38
4	Impact strength(MPa)		0.046	0.049
5	Impact elasticity(%)		28	30
6	Heat resistance(Non deformation)(℃)		75	75
7	Freeze resistance(Non-deformation and non-fragile)(℃)		−80	−80
8	Volumetric water absorption(24h)(%)		0.016	0.004
9	Acoustic absorptivity(700Hz–2 000Hz)(%)		50–80(Must be carefully measured before use)	
10	Thermal conductivity [J/(m·s·℃)]		0.031 5	0.032 1
11	Moisture penetration [$g/(m^2 \cdot h)$]		0.38	0.31

4.5.2 The physical and mechanical properties of polyethylene plastic board between the outer shaft lining and inner shaft lining in the freezing section of the shaft shall be in accordance with those specified in Table 4.5.2.

Table 4.5.2 The physical and mechanical property index of polyethylene plastic board

Item	Index
Tensile strength(MPa)	≥17
Elongation at break(%)	≥450
Right angle tear strength(N/mm)	≥80
Water vapor permeability coefficient[g/(m·s·Pa)]	$\leqslant 1.0\times10^{-14}$
−70 ℃ embrittlement property of low temperature impact	Pass
Dimensional stability(%)	±3

4.5.3 The dimensions and mechanical properties of steel fibers for shaft and chamber support shall be in accordance with those specified in Table 4.5.3.

Table 4.5.3 Steel fibers property

Item	Index
Nominal length of steel fibers(mm)	15–60
Diameter or equivalent diameter of steel fiber section(mm)	0.3–1.2
Steel fiber length-diameter ratio or nominal length-diameter ratio	30–100
Tensile strength of steel fiber(MPa)	≥700

4.5.4 The concrete used for shaft and chamber support may be mixed with admixture such as water reducer, early strength agent. Admixture and the performance of the concrete which mixed with admixture shall meet the requirements of the current national standards of GB 8076 *Concrete Admixtures*, JC 475 *Concrete Anti-freezing Admixtures* and relevant regulations of design.

5 Shaft equipments

5.1 Plane layout of shaft

5.1.1 The plane layout of shaft shall make rational use of shaft section, compact arrangement, reduce the working amount of shaft construction, and save material consumption. The main factors that affect the layout of vertical shaft are as follows:

1 The type, quantity and maximum shape dimension of the hoisting conveyance.

2 Type, specification and layout dimensions of shaft equipment.

3 Safe clearance between hoisting conveyances; safe clearance between hoisting conveyance and shaft equipment; safe clearance between hoisting conveyance and shaft lining.

4 Shaft extension mode.

5 The amount of air that needs to pass through the shaft.

5.1.2 Shaft equipment may use rigid or flexible guide.

5.1.3 The minimum clearance between the hoisting conveyance and between the most protruding part of the hoisting conveyance and the shaft lining, bunton and shaft beam shall be in accordance with those specified in Table 5.1.3.

Table 5.1.3 The minimum clearance between the hoisting conveyances and between the most protruding part of the hoisting conveyance and the shaft lining, bunton and shaft beam (mm)

Layout of shaft guide and shaft beam		Clearance type				
		Between container and container	Between container and shaft lining	Between container and bunton	Between container and shaft beam	Note
Rigid guide	Guide on one side of the container	200	150	40	150	Between the ear and clamp of the guide is 20
	Guide on both sides of the container	–	150	40	150	The clearance between pulley and bunton shall be increased by 25 for Container with unloading pulley
	Guide is at the front of the container	200	150	40	150	–
Flexible guide (steel rope)		500	350	–	350	Minimum clearance is 200 between the containers if collision prevention rope is used

5.1.4 The net diameter of shaft should be recommended to be set at 0.5m intervals, with the exception of the net diameter is larger than 6.5m or the shaft which uses drilling, sinking, and curtain wall shaft sinking method.

5.2 Steel rope guide

5.2.1 The selection and arrangement of shaft equipment shall be in accordance with the following requirements in case that steel rope guide is used in vertical shaft.

1 The cage for man hoisting with single rope shall be equipped with a reliable safety catch device.

2 The cage rope shall use sealed or half sealed steel rope. 6 bundles with 7 threads of common steel wire rope may also be used for shaft with small hoisting terminal load and short service life.

3 Four corners arrangement should be used for each hoisting container guide, and one side of four ropes shall be used when conditions are limited. Two ropes diagonal or three ropes triangle arrangement may be adopted for shallow shaft with small hoisting terminal load.

4 Tensioning device of guide rope should use derrick hydraulic or screw tension method, or shaft bottom heavy hammer method. The tensioning force of each guide rope shall be 8kN/100m to 12kN/100m.

5 The tension of each rope in the same hoisting conveyance may varied from 5% to 10%. When the hoisting conveyance with two ropes, the tension of each rope shall be equal.

5.3 Rigid guide and bunton

5.3.1 When adopting rigid guide in shaft, the type of guide shall be determined by the requirements of hoisting conveyance, terminal load, hoisting speed and calculation result of structure, etc. Rail guide, profile steel combined guide and cold curved square type profile steel guide, cold-drawn square pipe profile steel guide, glass-reinforced plastic composite guide etc. may be used. Guide type is according to Table 5.3.1, and shall be in accordance with the following requirements:

1 Rail guide may use 38kg/m or 43kg/m rail track.

2 The profile steel combined guide may adopt the flat bulb steel combined guide or the channel steel combined guide. Flat bulb steel combined guide shall be welded by flat bulb steel and flat steel. Channel steel combined guide should be welded by channel steel and flat steel No.16, No.18 or No.20.

Table 5.3.1 Guide type

Guide type		Guide name				
		Rail guide	Profile steel combined guide		Cold curved and cold-drawn steel guide (mm)	Glass-reinforced plastic composite guide (mm)
			Flat bulb steel combined guide	Channel steel combined guide		
Type	1	38	180×188	180×160	160×160	160×160
	2	43	200×188	180×180	180×180	180×180
	3	–	–	200×200	200×200	200×200
	4	–	–	–	220×220	–
	5	–	–	–	250×250	–

3 The technical parameters of cold curved square steel guide and cold-drawn square pipe steel guide shall be in accordance with the current national standard of MT/T 557 *Shaft Road Tank with Cold-formed Rectangular Hollow Steel*, and GB/T 3094 *Cold Drawn Shaped Steel Tubes*.

4 The GFRP composite guide is made of inner lined steel core and outside wrapped GFRP, which is processed by moulding and heat curing. The steel core thickness of FRP composite guide shall be determined by calculation, but not less than 6mm, and the thickness of outside wrapped FRP shall not be less than 4mm. The processing quality of FRP guide shall be in accordance with sections 4.4 and 5.7 in this code.

5.3.2 The load on guide may be calculated according to the following formulas:

$$P_{y,k}=Q_k/12 \tag{5.3.2-1}$$

$$P_{x,k}=0.8P_{y,k} \tag{5.3.2-2}$$

$$P_{v,k}=0.25P_{y,k} \tag{5.3.2-3}$$

Where, $P_{y,k}$—Characteristic value of front horizontal force on guide and buntons(MN).

$P_{x,k}$—Characteristic value of lateral horizontal force on guide and buntons(MN).

$P_{v,k}$—Characteristic value of vertical force on guide and buntons(MN).

Q_k—Characteristic value of load for hoisting rope end (including hoisting conveyance deadweight, rolling cage ear, head rope suspension device, tail rope suspension device and sum of load)(MN).

5.3.3 The strength and rigidity of rigid guide shall be calculated in accordance with the following requirements:

1 Checking calculation of steel guide shall be in accordance with the following requirements:

$$\frac{M_{x1}}{W_{x1}}+\frac{M_{y1}}{W_{y1}}\leqslant f_1 \tag{5.3.3-1}$$

$$\frac{Z_1}{L_1}\leqslant\frac{1}{400} \tag{5.3.3-2}$$

Where, M_{x1}—The calculated value of maximum bending moment of the guide under the front horizontal force(MN·m).

M_{y1}—The calculated value of maximum bending moment of the guide under the lateral horizontal force(MN·m).

W_{x1}, W_{y1}—Net resistance moment of section on x-axis and y-axis(m^3).

f_1—Design strength value of guide material(MN/m^2).

Z_1—Deflection of guide(m).

L_1—Span of guide(m).

2 The GFRP composite guide shall convert the section of two materials to the equal section of one material. The strength and rigidity shall be calculated according to steel guide formula.

5.3.4 Rigid guide in the shaft may be arranged in the form of one-sided, double-side and end-face, and shall be in accordance with the following requirements:

1 If the hoisting speed is low and the terminal load is small, the cage or skip may be arranged on one side or both sides of the rail guide.

2 For the cage or skip with higher hoisting speed and larger terminal load, it is appropriate to adopt the end-face arrangement or double-side arrangement of the profile steel combined guide or FRP composite guide.

3 For cage or skip with high hoisting speed and large terminal load, End face or bilateral-side arrangement is advisable and using cold-bent square steel guide or cold-drawn square steel guide.

5.3.5 Bunton may adopt I-beam, channel steel combination, cold-bend rectangular hollow steel, cold-drawn rectangular hollow steel etc. The strength and rigidity of bunton shall meet the requirements of the following formulas:

$$\frac{M_{x2}}{W_{x2}}+\frac{M_{y2}}{W_{y2}}\leqslant f_2 \tag{5.3.5-1}$$

$$\frac{Z_2}{L_2}\leqslant\frac{1}{400} \tag{5.3.5-2}$$

Where, M_{x2}, M_{y2}—Calculated value of bending moment around x-axis and y-axis(MN·m).

W_{x2}, W_{y2}—Net resistance moment of section of x-axis and y-axis(m^3).

f_2—Design value of guide material strength(MN/m^2).

Z_2—Total deflection of bunton(include the deflection generated from concentrated load and dead weight of bunton)(m).

L_2—Span of bunton(m).

5.3.6 Bunton may be supported by simple beams, continuous beams or maytilever beams. When the maytilever beam is used, the maytilever length should not exceed 700mm. The strength check of the maytilever beam may be calculated as follows:

$$\frac{Q_x L}{W_x}\leqslant f_u \tag{5.3.6}$$

Where, Q_x—Calculated value of concentrated load on maytilever(MN).

L—Distance from point of concentrated load to shaft lining(m).

f_u—Design value of bending strength of maytilever material(MN/m^2).

W_x—Net resistance moment of net cross section of maytilever to x-axis(m^3).

5.3.7 The layer spacing of buntons shall be determined according to the type and length of the bunton, the load of the hoisting conveyance acting on the guide etc. When the rail guide is used, the layer spacing of the bunton should be 4.168m or 6.252m. The layer spacing of bunton should be 4m, 5m or 6m, when profile steel guide(exclusive of rail guide), profile steel combination guide, GFRP composite guide are used.

5.3.8 The way of fixing the beams on the shaft lining shall be in accordance with the following requirements:

1 Resin anchor bar, embedded steel plate or cylinderor beam nest embedded type should be used, and resin anchor bar fixation should be preferred.

2 Nest beam fixation must not be adopted in water-bearing and unstable topsoil layer in case that conventional shaft sinking method are adopted.

3 Nest beam fixation is must not be adopted in case that drilling shaft sinking method is used, every bunton in the drilling section. Nest beam fixation must not be adopted in the topsoil layer in case that other special sinking methods are used.

5.3.9 When the resin anchor bar is used to fix the shaft equipment, the anchoring length of the bolt shall meet the requirements of anchoring force, and should not exceed 4/5 of the inner shaft lining thickness in the double-layer shaft lining, and 3/5 of the single-layer shaft lining thickness.

5.3.10 The design of the resin anchor bar fixed support shall be in accordance with the following requirements:

1 The number of bolts fixed on the single support shall be determined on the basis of calculation, but not less than two pieces.

2 The distance between two adjacent bolt holes should not less than 180mm.

3 The anchor force shall be calculated as needed but the anchoring force of each bolt shall not less than 4.9×10^4N.

4 The anchoring force of each bolt shall be calculated according to the following formula:

$$P_{mg}=\pi d[\tau]L \quad (5.3.10)$$

Where, P_{mg}—Anchoring force of resin anchor bar(N).

d—Diameter of the bolt(mm).

L—Length of the bolt(mm).

$[\tau]$—Allowed cohesive force, adopt $2.5N/mm^2$.

5.3.11 The strength of the cantilever support of guide may be checked according to the following formula:

$$\frac{M_{x3}}{W_{y3}}+\frac{M_v}{W_{x3}}\leqslant f_3 \quad (5.3.11)$$

Where, M_{x3}—Calculated value of bending moment caused by horizontal force(MN·m).

M_v—Calculated value of bending moment caused by vertical force(MN·m).

W_{x3}, W_{y3}—Cross-section coefficient of x-axis and y-axis of maytilever abutment(m^3).

f_3—Design value of strength of maytilever abutment material(MN/m^2).

5.3.12 The joints of the two adjacent guides of the same hoisting shall not be arranged in the same horizontal plane; when multiple guides are installed on the same bunton, the joint positions of the two adjacent guides shall be staggered.

5.3.13 Joints of guide shall be arranged in accordance with the following requirements:

1 The joint of guide shall be located in the position where the guide is connected to the bunton and the maytilever support.

2 There shall be 2mm to 4mm clearance between guide joints.

5.3.14 In the shaft equipment, the joint of the bunton should not be installed. When the bunton must be composed of two sections, the joint shall be located in the section of which bending moment is less, and the joint of the upper and lower two-story bunton shall be staggered. The splint welding or bolt connection should be adopted when connecting the two buntons, and the strength at the connection shall not be less than the strength of the bunton.

5.3.15 The connection strength shall be enough with simple structure and convenient installation and maintenance.

5.3.16 When the shaft structure is vertical and yieldable, the relevant components of shaft equipment shall adopt the structural form which is suitable for the settlement of shaft lining.

5.4 Ladderway

5.4.1 The ladderway in the vertical shaft shall be in accordance with the following requirements:

1 The vertical shaft, which serves as a mine emergency exit, must be provided with ladder compartment from bottom to ground.

2 The air shaft may be provided with ladderway when used as emergency exit or for safety check.

3 When the conventional sinking method is adopted and the depth of the shaft is over 300m, a rest point may be set each 200m. The resting point is a chamber which is designed at the shaft lining near the ladderway, and connected with the ladderway.

4 When the depth of the construction section of freeze sinking method or drilling sinking method exceeds 300m, the platform area of ladderway should be increased or to set the rest platform properly; In case of entering into the construction section of conventional sinking method, a rest point shall be set at every 200m.

5 Rest chamber must not be set up in the water-bearing and unstable formation of the shaft constructed by conventional shaft sinking method.

6 Rest chamber must not be set up in the special drilling section of the shaft which is constructed by the special drilling method, with the exception of the grouting drilling method.

5.4.2 Arrangement of ladderway may be in the form of forward direction, foldback, etc., and fold-back type ladderway may be adopted.

5.4.3 The ladderway shall be arranged in accordance with the following requirements:

1 The gradient of the ladderway shall not be larger than 80°.

2 The vertical distance between the two platforms adjacent to the ladderway shall not be larger than 8m.

3 The left and right width of the ladder hole shall not be less than 600mm, and the front and rear length shall not be less than 700mm.

4 The width of the ladderway should not be less than 400mm, the spacing of the ladderway shall not be larger than 400mm, the platform extended from each ladderway shall not be less than 1 000mm, and the distance between the shaft lining and front bottom of the ladderway shall not be less than 600mm.

5.4.4 The ladderway should be made of GFRP or GFRP composite and may also be made of mental and other materials.

5.5 Overfalling protection and cage-stabilizing device

5.5.1 The overfalling protection device shall be installed at the bottom of hoisting shaft shall be in accordance with the following requirements:

1 The protective device shall have two functions: braking and support the cage.

2 The braking device should adopt the safe and reliable vertical shaft hoisting and overfalling protection device, or wedge type wooden guide or other effective energy absorbing and buffering device.

3 Steel cage support beam with a wood or rubber bumper may be adopted for the cage support device.

5.5.2 The design of the overfalling protection device at the bottom of the shaft shall be in accordance with the following requirements:

1 The overfalling distance shall meet the requirements of the current *Coal Mine Safety Regulations*.

2 The overfalling protection device shall be able to stop the full-speed overfalling container or balance hammer steadily and ensure that it does not rebound again.

3 The maximum braking deceleration of the overfalling protection device at the bottom of the shaft shall not be larger than 5g for empty container and balance hammer. For empty cage and heavy load container which is possible for human carrying, the maximum braking deceleration of the overfalling protection device shall not be larger than 3g.

4 When the friction hoist is overfalling, the braking starting point of the shaft bottom sinking container shall kick in earlier than the braking starting point of raising conveyance. When the overfalling protection device is lifted by vertical shaft, the advance distance value is 0.5m to 1.0m. When wedge type wooden guide is used, the the advance distance value is 1.5m to 2.0m.

5 The difference between the braking end point of the container at the shaft bottom and the brake end point of container at the portal shall not be larger than 4m in case of overfalling under any load condition.

6 The braking performance of the bottom overfalling protection device shall be kept stable for a long time. The overfalling protection device shall have the capability of fast unlocking, anticorrosion, dust-proof and resistant to continuous overwinding.

7 The installation of the cage support beam at the bottom of the shaft shall in accordance with the following requirements:

1) The maximum overwinding height on the ground shall not be larger than 2m of the maximum overfalling height at the bottom of the shaft.

2) The strength of cage support beam and its supported beam shall endure maximum braking load of 4 times without permanent deformation.

3) Top of the cage support beam and bottom of conveyance at its end braking point at maximum load shall be at a distance of no less than 1.5m.

8 The hoisting conveyance with tail rope shall be equipped with tail rope protection device, which shall have the functions of anti-kink, anti-wear and anti-smashing. The protective device shall be installed under the bunton for ease to repair.

9 The shaft equipment of the overfalling part at the bottom of shaft shall have practical maintenance measures.

5.5.3 For the shaft which carry persons up and down, cars at both entry and exit position of the underground horizontal tunnel, the shaft lining and the container above the ingate shall be equipped with anti-smash fender. Considering cage shaft with large water distributing, the underground horizontal tunnel above the ingate shall be equipped with catch drain along both sides of the pipe to a ditch. The catch drain and the anti-smash fender may also be installed together.

5.5.4 The steel frame shall be installed at the ingate of the cage shaft and loading chamber of the skip shaft to support the guide and the safety door etc and connected by bolt. The installation of steel frame and guide shall be in accordance with the following requirements:

1 The beam connection shall be added in the position not affecting the use of the casing frame column, the side column shall be supported laterally with the side lining, and the horizontal support shall be added to the shaft lining on both sides of the shaft.

2 The steel frame shall chang into rigid guide or quadrangle guide in the shaft which uses end-face rigid guide or rope guide. The quadrangle guide shall be able to withstand the normal horizontal force and loading impact of the container, and shall ensure stiffness and prevent deformation.

3 Skip shaft may only change its loading chamber into a corner guide, and the rear side may still be a continuous end steel guide.

4 At shaft pipe tunnel position of the end-face guide cage that cars do not often get in and out, the movable up and down stretching or left and right moving guide may be used and there is no need to change the form of the guide.

5 For the shaft cars which do not often drive in and out at the middle level tunnel of the rope guide cage, the movable quadrangle stabilizing device may be used.

5.5.5 Cage support beam, the mounting beam of overfalling protection device, wedge-shaped wooden guide top beam, roof beam and bottom beam of steel frame shall be fixed by reserved beam nest, other steel frame beam may be fixed by bolt supporting.

5.5.6 A double-layer or multi-layer cage for loading and unloading personnel at the same time, the pedestrian platform or pedestrian tunnel shall be set up at the bottom level. Pedestrian platform shall adopt open structure on the side of the unloading the long material. The net height from the two sides of the platform to the top shall not be less than 1.6m. The passage of the horizontal level of the track, pedestrian tunnel and the pipe tunnel which connect the underground shaft, the slabs shall be laid between the hoisting conveyance and the shaft lining or between the beam and the shaft lining. A guardrail shall be installed to the side of the slab to prevent personnel from falling into the shaft.

5.5.7 The safety clearance between water shed, anti-smashing board, shutting, pedestrian platform and various passageway plank and hoisting conveyance shall not be less than 50mm.

5.6 Pipeline and cable laying

5.6.1 The pipeline and cable laying in the shaft shall be in accordance with the following requirements:

1 The pipeline layout shall consider the convenience of installation, repair and replacement, and shall be arranged on one side to make use of the same pipe girder.

2 In the shaft provided with laddersway, the pipeline shall near the main beam of the ladderway or in parallel with the long side of the cage; the pipe guide beam shall make use of the bunton or ladder beam, and its layer spacing shall be the same with the bunton and the ladder beam.

3 When the vertical height of the pipeline is large, it is appropriate to set up some straight pipe socket and its supporting beam in the middle, and the spacing is 100m-150m.

4 When a supporting beam is installed at the upper end of the pipe section with rigid connection between the lower end and the supporting beam, the pipe expansion contraction device shall be installed.

5.6.2 The laying of all kinds of cables in the shaft shall be in accordance with the following requirements:

1 Cable laying shall be simple, easy to install, repair and replace.

2 The distance between cable suspension points shall not exceed 6m in the shaft, and it shall be consistent with the spacing of bunton and ladder beam.

3 The communication cable in the same shaft shall be located 0.3 away from the power cable.

4 All types of cable clamps shall be reserved for a reserve amount.

5.7 Corrosion and protection of shaft equipment

5.7.1 The corrosion grade and corrosion rate of steel structural components of shaft equipment may be determined according to the current industry standard of JGJ/T 251 *Technical Specification for Anticorrosion of Building Steel Structure*.

5.7.2 The anti-corrosion design of coal mine shaft equipment shall put forward a safe, reliable, feasible and economical anti-corrosion design scheme according to the factors such as corrosion environment, service life of mine design etc. And it shall be in accordance with the relevant regulations of current industry standard of MT/T 5017 *Technical Specifications for Anti-corrosion of Shaft Equipment in Coal Mine*.

5.7.3 According to the actual conditions of the mine, common anti-corrosion, heavy anti-corrosion and long-term anti-corrosion may be chosen.

6 Shaft support

6.1 General requirements

6.1.1 In shaft support, the bearing capacity design of the shaft lining structure shall adopt the following formulas:

$$\gamma_0 S(\nu_k P_0) \leqslant R \tag{6.1.1-1}$$

$$R = R(f_c, f'_y, \cdots) \tag{6.1.1-2}$$

Where, γ_0—Structure importance coefficient.

$S(\cdot)$—Calculation function of internal force combination.

ν_k—Structural safety coefficient.

P_0—Characteristic value of load acting on structure.

R—Structural bearing capacity.

$R(\cdot)$—Bearing capacity function of structure.

f_c—Design value of axial compressive strength of concrete(MN/m^2).

In case of calculating the bearing limit of the concrete components, the value and the checking calculation of the concrete strength in multi-axis stress state may comply with the current national standard of GB 50010 *Code for Design of Concrete Structures*.

f'_y—Design value of compressive strength of reinforcing steel bars(MN/m^2).

6.1.2 In case that conventional shaft sinking method, freeze sinking method, shaft drilling method and caisson sinking method are used to support shaft, the selection of structural safety coefficient ν_k under different stress conditions of shaft lining shall meet the requirements Table 3.0.2 of this code. In case of using curtain sinking method for shaft support, it shall meet the requirements of item 2 in Article 6.6.5 of this code.

6.1.3 The reinforcement of cast-in-place reinforced concrete of shaft lining shall be in accordance with the following requirements:

1 The total cross-section steel ratio shall not be less than 4%; when the strength grade of concrete is C60 or above, the steel ratio shall not be less than 0.5%.

2 The ratio of unilateral reinforcement of cross-section shall not be less than 0.2%.

3 The configuration of structure reinforcement should be in accordance with Table 6.1.3.

4 The thickness of the steel protective layer (the minimum distance from the outer edge of the reinforcing steel bars to the concrete surface) should be 50mm for the inner edge reinforcing steel bars and 70mm for the outer edge reinforcing steel bars.

Table 6.1.3 Shaft lining structural reinforcement

Shaft depth (m)	Minimum diameter of reinforcing steel bars (mm)	Maximum spacing of reinforcing steel bars (mm)	Minimum spacing of reinforcing steel bars (mm)
100	16	330	200
200	18	300	200
>300	20	300	150

Note: This table is applicable for shaft with depth not larger than 600m.

6.1.4 The calculation of shaft lining that is affected by the shaft tower shall be in accordance with the following requirements:

1 For the shaft constructed by conventional shaft sinking method and freeze sinking method, the shaft lining of shaft tower (headgear) affected section shall be calculated according to the requirements of Appendix B of this code. In case that the shaft tower is directly supported on the shaft body, the effect of loads such as N_0 (axial force at the embedding level of the shaft tower), Q_0 (horizontal force at the embedding level of the shaft tower), and M_0 (bending moment at the embedding level of the shaft tower) shall be calculated for the shaft lining of the shaft tower affected section.

2 The shaft which constructed by shaft drilling method, shaft sinking method and curtain sinking method in case of hoisting by shaft tower, the shaft tower adopts box foundation. The shaft lining which affected by the shaft tower section will be calculated according to the Appendix B. 1 of this code.

6.2 Shaft support by conventional shaft sinking method

6.2.1 The shaft with conventional shaft sinking method should adopt integral pouring concrete and reinforced concrete shaft lining support. The equipped shaft must not be permanently supported by sprayed concrete and metal mesh, sprayed concrete and rock bolt, metal mesh, sprayed concrete or stone, and concrete block.

6.2.2 Reliable water sealing measures shall be taken at the cementing part of shaft lining.

6.2.3 The characteristic value of radial load on the shaft lining shall be calculated in accordance with the following requirements:

1 The characteristic value of radial load on the shaft lining of the topsoil layer shall be calculated in accordance with the following requirements:

1) The characteristic value of uniform load shall be calculated according to the following formula:

$$P_k = 0.013H \qquad (6.2.3\text{-}1)$$

Where, P_k—Characteristic value of uniform load acting on structure (MPa).

0.013—Gravity-like density (MN/m^3).

H—Calculated depth of designed topsoil layer of shaft lining (m).

2) The characteristic value of non-uniform load shall be calculated according to the following formulas:

$$P_{A,k} = P_k \qquad (6.2.3\text{-}2)$$

$$P_{B,k} = P_{A,k}(1+\beta_t) \qquad (6.2.3\text{-}3)$$

$$\beta_t = \frac{\tan^2\left(45^\circ - \dfrac{\phi - 3^\circ}{2}\right)}{\tan^2\left(45^\circ - \dfrac{\phi + 3^\circ}{2}\right)} - 1 \qquad (6.2.3\text{-}4)$$

Where, $P_{A,k}$, $P_{B,k}$—Minimum and maximum characteristic value of load (MPa).

β_t—Non-uniform load coefficient of topsoil layer.

ϕ—Topsoil inner friction angle (°) according to shaft inspection hole data or Table 6.2.3.

Table 6.2.3 Table of horizontal load coefficient of rock(soil)layer

Qin rock(soil)layer classification	Physical and mechanical property					$\tan^2(45°-\phi_n/2)$ or $\tan^2(45°-\phi'_n/2)$	
	Unit weight (kN/m³)	Internal friction angle of soil ϕ		Internal friction angle of rock formation ϕ'			
		Minimum to maximum	Even	Minimum to maximum	Even	Maximum to minimum	Even
Quicksand	–	0° to 18°	9°	–	–	1.0–0.528	0.729
Friable rock(sand soil)	15–18	18° to 26°34′	22°15′	–	–	0.528–0.382	0.450
Soft formation(clay)	17–20	26°34′ to 40°	30°	–	–	0.382–0.217	0.333
Weak stratum f=1−3 (soft shale.coal ect.)	14–24	–	–	40°–70°	55°	0.217–0.037	0.099
Medium hard rock f=4−6(shale,sand rock,limestone)	24–26	–	–	70°–80°	75°	0.031–0.008	0.017
Hard stratum f=8−10(hard sand rock,limestone,pyrite)	25–28	–	–	80°–85°	82°30′	0.008–0.002	0.004

Note: In the table, f is the rock hardness coefficient(Protodrakonov coefficient of hardness).

2 The calculation of the characteristic value of the radial load on the shaft lining of the bedrock section shall be in accordance with the following requirements:

1)The characteristic value of uniform load may be calculated according to the following formulas:

$$P^{s}_{n,k}=(\gamma_1 h_1+\gamma_2 h_2+\cdots+\gamma_{n-1}h_{n-1})A_n \tag{6.2.3-5}$$

$$P^{x}_{n,k}=(\gamma_1 h_1+\gamma_2 h_2+\cdots+\gamma_n h_n)A_n \tag{6.2.3-6}$$

$$A_n=\tan^2(45°-\phi'_n/2) \tag{6.2.3-7}$$

Where, $P^{s}_{n,k}$, $P^{x}_{n,k}$—Characteristic value of uniform load on the shaft lining by N layer roof and floor of the rock formation(MPa).

$h_1,h_2,\cdots,h_n$—Rock formation thickness(m).

$\gamma_1,\gamma_2,\cdots,\gamma_n$—Gravity density of rock formation(MN/m³).

A_n—Horizontal load coefficient of rock(soil)formation should according to Table 6.2.3.

ϕ'_n—Rock formation internal friction angle of the nth layer(°)is subject to shaft inspection hole data,or according to Table 6.2.3.

2)The characteristic value of non-uniform load may be calculated according to the following formulas:

$$P_{A,k}=P^{x}_{n,k} \tag{6.2.3-8}$$

$$P_{B,k}=P_{A,k}(1+\beta_y) \tag{6.2.3-9}$$

Where, β_y—Non-uniform coefficient of horizontal load of rock rock formation, which is based on shaft inspection hole data,or when the inclination of the rock is less than or equal to 55° β_y may take 0.2.

3)The characteristic value of uniform load in rock fracture zone shall be calculated according to the following formulas:

$$P^{s}_{n,k}=(\gamma_{k+1}h_{k+1}+\gamma_{k+2}h_{k+2}+\cdots+\gamma_{n-1}h_{n-1})A_n \tag{6.2.3-10}$$

$$P^{x}_{n,k}=(\gamma_{k+1}h_{k+1}+\gamma_{k+2}h_{k+2}+\cdots+\gamma_n h_n)A_n \tag{6.2.3-11}$$

Where, k—Number of rock layer above fracture zone.

6.2.4 The characteristic value of the vertical load on the shaft lining of the topsoil section may be calculated according to the following formulas:

$$Q_{z,k}=Q_{zl,k}+Q_{f,k}+Q_{1,k}+Q_{2,k} \tag{6.2.4-1}$$

$$Q_{f,k}=P_{f,k}F_{w} \tag{6.2.4-2}$$

Where, $Q_{z,k}$—Characteristic value of vertical load on shaft lining(MN).

$Q_{zl,k}$—Characteristic value of shaft lining gravity above chosen cross section(MN).

$Q_{f,k}$—Characteristic value of the vertical additional total force on the shaft lining above the chosen cross section(MN).

$P_{f,k}$—Characteristic value of vertical additional force above the calculated cross section(MN/m^2).

F_w—External surface area of the shaft lining above the calculated cross section(m^2).

$Q_{1,k}$—Characteristic value of shaft tower weight directly situating on the shaft(MN).

$Q_{2,k}$—Characteristic value of shaft equipment weight above the calculated cross section(MN).

6.2.5 The shaft lining thickness may be determined as the following methods:

1 Preliminary formulated through engineering analogy.

2 The thickness of concrete shaft lining shall be preliminarily determined by the following formulas:

$$t = r_n\left(\sqrt{\frac{f_s}{f_s - 2\gamma_0 P}} - 1\right) \tag{6.2.5-1}$$

Concrete shaft lining: $$f_s=0.85f_c \tag{6.2.5-2}$$

Reinforced concrete shaft lining: $$f_s = f_c + \rho_{min} f'_y \tag{6.2.5-3}$$

$$P = \nu_k P_k \tag{6.2.5-4}$$

Where, t—Shaft lining thickness(m).

r_n—Shaft lining inner radius at calculation location(m).

f_s—Design value of shaft lining material strength(MN/m^2).

f_c—Design value of concrete axial compressive strength(MN/m^2).

f'_y—Design value of reinforcing steel bars compressive strength(MN/m^2).

P—Calculated value of design load acting on shaft lining on calculation location(MPa).

γ_0—Structure importance coefficient.

ν_k—Structural safety coefficient.

P_k—Characteristic value of uniform load acting on structure.

ρ_{min}—Minimum steel ratio of shaft lining cross section shall be determined by the requirements of Article 6.1.3 of this code.

6.2.6 The circumferential internal force and bearing capacity of the shaft ling of the topsoil section should be calculated according to Appendix A.1 of this code. The shaft lining bearing capacity under the action of three dimensional stress should be calculated according to the requirements of Appendix A.3 of this code. The structural strength around the interface between topsoil and bedrock should be calculated according to the requirements of Appendix A.4 of this code.

6.2.7 Vertical bearing capacity of shaft lining shall be in accordance with the requirements of following formula:

$$\gamma_0 \nu_k Q_{z,k} \leqslant f_c A_0 + f'_y A_z \tag{6.2.7}$$

Where, A_z—Cross-sectional area of vertical reinforcing steel bars(m^2).

A_0—Cross section area of shaft lining at calculated cross section(m^2).

f'_y—Design value of compressive strength of reinforcing steel bars(MN/m^2).

6.2.8 The shaft lining thickness of the bedrock section may be determined according to the following methods:

1 Determined by analogy method.

2 Using empirical values recommended by Table 6.2.8.

3 When conditions arepermited, it may be calculated according to the relevant formula in Article 6.2.3, 6.2.5 and Appendix A.1 of this code.

Table 6.2.8 Empirical values of shaft lining thickness of the bedrock section

Shaft diameter(m)	Shaft lining thickness(mm)
3.0–4.5	300
4.5–5.0	300–350
5.0–6.0	350–400
6.0–7.0	400–450
7.0–8.0	450–500

Note: This table applies to the shaft with a depth not larger than 600m and a diameter of 3.0m–8.0m. If the depth is larger than 600m or the shaft diameter larger than 8.0m, the thickness of shaft lining may be increased properly or intensify the strength grade of concrete.

6.3 Shaft support by freeze sinking method

6.3.1 According to the conditions of geology, hydrogeology, diameter of shaft, etc, the double layer composite shaft lining with interlayer, double layer shaft lining and single layer shaft lining shall be selected for vertical shaft supported by freeze sinking method. In case that the shaft is subjected to vertical additional force, "resisting" or "letting" may be used as the shaft lining structure. Shaft lining materials may according to load-bearing and water sealing requirements use concrete materials, steel (iron) materials or the composite of two kinds of materials.

6.3.2 Freeze sinking method shall be in accordance with the following requirements:

1 The shaft digging and laying depth of freeze sinking method must reach the stable bedrock and set up wall foundation.

2 In case that the wall foundation structure is adopted as the Figure 6.3.2 shown, the calculation of the wall foundation height shall meet the requirements of the following formula, and shall not be less than 10m.

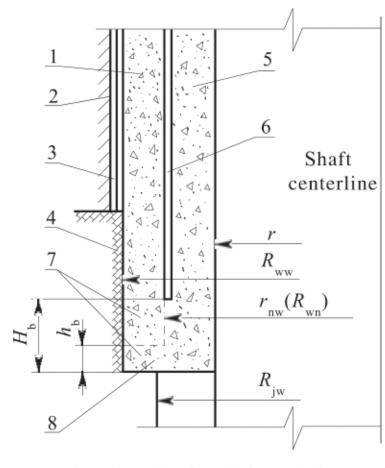

Figure 6.3.2 Design sketch of wall foundation and walling crib

1–Outer shaft lining; 2–Topsoil; 3–Foam plastic board; 4–Bedrock; 5–Inner shaft lining; 6–Plastic interlayer; 7–Wall foundation; 8–Walling crib

$$H_b \geqslant \frac{G + N_f - \pi(R_{ww}^2 - R_{jw}^2)[\sigma] - \pi(R_{jw}^2 - r^2) f_c}{2\pi R_{ww} \tau_n - G_1} \tag{6.3.2-1}$$

Where, H_b—Wall foundation height(m).

G—The calculated weight of the inner and outer shaft lining above the wall foundation(MN).

N_f—Calculated value of vertical additional force on shaft above wall foundation(MN).

r—Inner radius of shaft(m).

R_{wn}—Inner radius of outer shaft lining(m).

R_{ww}—Outer radius of outer shaft lining(m).

R_{jw}—Outer radius of shaft lining in bedrock section(m).

G_1—Calculated weight per linear meter of wall foundation(MN).

$[\sigma]$—Allowable compressive stress of surrounding rock under wall foundation(MPa).

f_c—Design value of axial compressive strength of concrete(MPa).

τ_n—Bonding strength between the outer edge of the wall foundation and surrounding rock(MPa). τ_n= 0.5MPa to 2.0MPa, In case that the strength grade of concrete is high, and the surrounding rock is of good lithology, τ_n adopts the upper limit, otherwise adopts the lower limit.

3 The inner and outer shaft lining should be integrally poured as walling crib at the bottom of the shaft excavated by freeze sinking method.

4 In case of the shaft depth of the frozen section is larger than that of the shaft-related chamber, and the double-layer shaft lining or double-layer composite shaft lining with interlayer is adopted, a walling crib for integral pouring of inner and outer shaft lining with a certain height should be set above the chamber.

5 The thickness of the walling crib shall not be less than the sum of the inner and outer shaft lining thickness; The height of the walling crib base shall be calculated according to Formula(6.3.2-2) based on the strength of surrounding rock, the load borne by the walling crib and the structure form of the shaft lining, but shall not be less than 4m; The shaft lining below the integral pouring part of the inner and outer shaft lining shall be gradually changed to the normal bedrock section shaft lining thickness.

$$h_b \geqslant \frac{G_n}{2\pi r_{nw}[f_j]} \tag{6.3.2-2}$$

Where, h_b—Integral poured section height of outer and inner shaft lining(m).

G_n—Calculated weight of inner shaft lining above integral poured section(MN).

r_{nw}—Outer radius of inner shaft lining(m).

$[f_j]$—Allowable shear strength of concrete(MN/m^2).

6 The foam plastic board with the thickness of 25mm to 75mm shall be laid between the freezing shaft lining and the cast-in-place concrete shaft lining according to the displacement of the freezing shaft lining.

7 The plastic interlayer with thickness of 1.5mm to 3.0mm or 2 layers of asphalt felt with good flexibility may be laid between the inner and outer shaft lining.

8 In case that the double layer shaft lining(or double layer composite shaft lining with interlayer) structure is adopted, the grouting shall be carried out between the inner and outer shaft linings, and in case that the single layer shaft lining is used, the shaft lining joint and rear of the shaft lining shall be grouted.

9 Inner and outer shaft lining thickness shall not be less than 300mm in the frozen section.

6.3.3 The characteristic value of radial load on the shaft lining shall be calculated in accordance with the following requirements:

1 The characteristic value of the radial load on the inner and outer shaft linings as a whole in the topsoil section shall be in accordance with the following requirements:

1) The characteristic value of the uniform load shall be calculated according to Formula(6.2.3-1).

2) The characteristic value of the non-uniform load shall be calculated according to the following formulas:

$$P_{A,k}=P_k \tag{6.3.3-1}$$

$$P_{B,k}=P_{A,k}(1+\beta_t) \tag{6.3.3-2}$$

Where, β_t—Non-uniform load coefficient of topsoil in case of using freeze sinking method, β_t euquals to 0.2 to 0.3.

2 The characteristic value of the radial load separatedly on the inner and outer shaft lining shall be calculated according to following formula:

1) The characteristic value of inner shaft lining load shall be calculated according to following formula:

$$P_{n,k}=0.01k_zH \tag{6.3.3-3}$$

Where, $P_{n,k}$—Characteristic value of inner shaft lining load(MPa).

k_z—Load reduction coefficient adopts 0.81 to 1.00.

0.01—Gravity density of water(MN/m^3).

H—Depth of calculated part of the shaft lining(m).

2) The characteristic value $P_{d,k}$ of freezing pressure on outer shaft lining should be selected according to the data of frozen soil(rock) test and actual measurement and other data, it may also be selected according to Table 6.3.3.

Table 6.3.3 Characteristic value of freezing pressure

Topsoil depth H(m)	100	150	200–400	400–500
Freezing pressure $P_{d,k}$(MPa)	1.2–1.5	1.5–1.8	0.01H	(0.01–0.012)H

Note: $P_{d,k}$ is statistic value of freezing pressure in different depth of clay layer.

6.3.4 The characteristic value of the vertical load on the shaft lining shall be calculated according to Formula(6.2.4-1) of this code.

6.3.5 Shaft support by freeze sinking method shall be in accordance with the following requirements:

1 In case that the double-layer shaft lining(or double-layer composite shaft lining with interlayer) structure is adopted, the inner shaft lining shall meet the requirements of bearing water pressure, vertical load, etc. The outer shaft lining shall meet the requirements of freezing pressure, shaft lining suspension, crack resistance and stability calculation, and the double layer shaft lining shall meet the requirements of bearing permanent soil and water pressure and vertical load.

2 In case that the single-layer shaft lining structure is adopted, during the construction the shaft lining shall meet the requirements of bearing freezing pressure, grouting pressure, shaft lining suspension and crack resistance. During the production, the shaft lining shall meet the requirements of bearing permanent soil and water(rock) pressure, vertical load, and stability calculation.

6.3.6 The shaft lining thickness of shaft by freeze sinking method shall be preliminarily determined by the following formulas:

$$t = r_{n}\left(\sqrt{\frac{f_{s}}{f_{s} - 2\gamma_{0} P}} - 1\right) \tag{6.3.6-1}$$

Concrete shaft lining:

$$f_{s} = 0.85 f_{c} \tag{6.3.6-2}$$

Reinforced concrete shaft lining:

$$f_{s} = f_{c} + \rho_{min} f'_{y} \tag{6.3.6-3}$$

$$P = \nu_{k} P_{k} \tag{6.3.6-4}$$

Where, P—Calculated value of designed load applied on the calculated section of the shaft lining(MPa). According to different stress conditions, the corresponding load values such as freezing pressure, uniform soil and water pressure, hydrostatic pressure, etc are used.

6.3.7 The ring internal force and bearing capacity of the shaft lining in the topsoil section shall be calculated in accordance with the Appendix A.1 of this code. The calculation of the structural strength around the interface between the topsoil and the bedrock shall be calculated in accordance with Appendix A.4 of this code.

6.3.8 The vertical bearing capacity of the shaft lining shall be calculated in accordance with the following requirements:

1 The vertical bearing capacity of the shaft lining under the combined action of gravity and vertical additional forces shall meet requirements of Article 6.2.7 of this code.

2 The bearing capacity of the outer shaft lining under the action of hanging force shall be calculated according to the following formulas:

$$\gamma_{0} N_{d} \leqslant f_{y} A_{z} \tag{6.3.8-1}$$

$$N_{d,k} = \pi \gamma_{h} h_{d} (R_{ww}^{2} - R_{wn}^{2}) \tag{6.3.8-2}$$

$$N_{d} = \nu_{k} N_{d,k} \tag{6.3.8-3}$$

Where, N_{d}—Calculated value of shaft lining hanging force(MN).

$N_{d,k}$—Characteristic value of shaft lining hanging force(MN).

h_{d}—Hanging force section height of shaft lining(m), h_{d}=15m–20m.

γ_{h}—Concrete(or reinforced concrete)gravity density(MN/m^{3}).

6.3.9 The reinforcing steel bars configuration of the shaft lining of shaft by freeze sinking method shall be in accordance with the following requirements:

1 The steel ratio of the shaft lining shall be determined by calculation, and the minimum steel ratio shall be in accordance with Article 6.1.3 of this code.

2 Vertical reinforcing steel bars should be connected with straight thread or taper thread, and the connection quality shall be in accordance with the highest grade of the relevant standard in the current industry standard of JGJ 107 *Technical Specification for Mechanical Splicing of Steel Reinforcing Bars*. The lap length of reinforcing steel bars shall meet the requirements of the current national standard of GB 50010 *Code for Design of Concrete Structures*.

3 The spacing of reinforcing steel bars may be 150mm to 330mm, and the configuration of reinforcing steel bars shall be in accordance with Table 6.1.3 of this code.

6.3.10 The circumference stability of the shaft lining shall be calculated according to the requirements of Appendix A.2.

6.3.11 The bearing capacity of the shaft lining under the action of the three dimensional stress may be calculated according to the requirements of Appendix A.3 of this code.

6.4 Shaft support by shaft drilling method

6.4.1 The shaft lining structure of shaft drilling method shall be designed according to the load and the bottom of shaft lining shall be able to support the inner and outer pressure when the shaft lining is suspension sinking.

6.4.2 The shaft support depth of shaft drilling method shall be in accordance with the following requirements:

1 **The shaft support depth of shaft drilling method must reach the impervious stable bedrock.**

2 The depth of entering the impervious stable bedrock shall be determined by the factors such as the retaining force required to prevent the shaft lining from slide, but the depth must not be less than 10m, and not be less than 3 times of the outer radius of the shaft bottom.

6.4.3 The net diameter of shaft design shall be in accordance with the following requirements:

1 In case that the coordinates of the shaft center may be adjusted according to the measured location of the shaft completion, the diameter shall be calculated according to the following formula:

$$D_s = D_y + H\eta \tag{6.4.3-1}$$

2 In case that the coordinates of the shaft center are not allowed to be adjusted according to the measured location of the shaft completion, the diameter shall be calculated according to the following formula:

$$D_s = D_y + 2H\eta \tag{6.4.3-2}$$

Where, D_s—Design diameter of net cross section of shaft(m).

D_y—Efficient diameter of net cross section of shaft(m).

H—Design depth of shaft lining(m).

η—skew ratio of shaft completion(‰). Hoisting shaft $\eta \leqslant 0.4$‰, Non-hoisting shaft $\eta \leqslant 0.6$‰.

6.4.4 According to the different supporting material and structure of the shaft, the shaft lining may be divided into reinforced concrete shaft lining and steel plate-concrete composite shaft lining etc. Reinforced concrete shaft lining should be adopted.

6.4.5 The concrete strength grade of steel plate-concrete composite shaft lining should not be less than C45. The steel plate cylinder should use steel type Q235, Q345, Q390, Q420, etc. The thickness of steel plate cylinder shall not only meet the calculation requirements, but also has a corrosion layer of 2mm. The thickness of steel plate cylinder should be 15mm to 50mm, the flange plate should use Q235 type steel.

6.4.6 The steel plate cylinder in the inner layer of the steel plate-concrete composite shaft lining shall be in accordance with the following requirements:

1 **Anti-corrosion treatment must be carried out on the inner side of the inner steel plate cylinder.**

2 Anchoring parts shall be arranged on the outside of the inner steel plate cylinder.

3 **The inner steel plate cylinder must design a drain hole.**

4 The diameter of drain hole should be 15mm to 25mm and the space between holes should not be larger than 2.5m.

6.4.7 The section height of the shaft lining shall be determined by the hoisting equipment capacity and other factors, and shall be adapted to the bunton interlamellar spacing of the shaft equipment. Apart from the uppermost section and several sections above the bottom of the shaft lining, the section height of the single shaft lining should be 3.5m to 8.0m.

6.4.8 The shaft lining shall be equipped with a upper flange and a lower flange. Flanges may be in the form of single steel plate flanges, profile steel flanges and beam-plate flanges. The plate thickness of single steel plate flange and beam-plate flange should not be less than 15mm. the type of profile steel flange should not be less than No.16 ordinary channel steel and the angle steel with side length 80mm to 100mm should be adopted. The thickness of stiffened rib plate should not be less than 10mm and the spacing should be 200mm to 300mm.

6.4.9 Continuous welding shall be used on the inner and outer edges of the flange plate. The shaft lining shall be grouted between sections, the grouting pipe shall be set up above the lower flange plate at the bottom of the shaft lining, and the grouting hole between sections is reserved at the lower end of the inner steel plate cylinder of the steel plate concrete shaft lining.

6.4.10 In case that the shaft depth is less than 400m, the shaft for developing ingate shall be set an inspection hole within the range of not less than 20m above the horse head gate. The shaft for continued tunneling shall install an inspection hole within the range of not less than 30m at the bottom and above the shaft lining bottom. In case that the shaft depth is larger than 400m, the scope of the reserved inspection hole behind the shaft lining above the ingate or shaft lining bottom structure should be enlarged. The inspection holes shall be evenly arranged around of the shaft lining, each layer shall not be less than 6 inspection holes, the spacing between the holes shall not be larger than 3m, the interval between the layers should not be larger than 5m, the upper and lower horizontal holes shall be centered and staggered, and the holes right above the ingate shall be ensured. The number of inspection holes at the shaft lining bottom shall not be less than 3.

6.4.11 The structure type of the shaft lining bottom shall be selected according to the shaft depth, hoisting equipment capacity, the quality level of concrete vibration, and the difficulty of shuttering processing. The cutting spherical shell, semi-ellipsoidal round flat spherical shell or hemispherical shaft lining bottom structure should be adopted, and the thickness of the shell should be the same with the shaft lining thickness.

6.4.12 Thickness of protective layer of concrete of loading bearing reinforcing steel bars in shaft lining and at the shaft lining bottom (minimum distance from outside edge of reinforcing steel bars to concrete surface): Shaft lining of reinforced concrete shall not be less than 40mm, Protective layer thickness of inner and outer reinforcing steel bars of inner steel plate cylinder and reinforced concrete composite shaft lining shall not be less than 25mm and 40mm.

6.4.13 The minimum steel ratio of shaft lining reinforcing steel bars shall meet the requirements of Item 1 in Article 6.1.3 of this code. The circular spacing of reinforcing steel bars shall not be less than 150mm, and the vertical spacing of reinforcing steel bars shall not be less than 220mm; the two ends of vertical reinforcing steel bars shall be welded with the flange of shaft lining.

6.4.14 The steel ratio of composite shell at the bottom of shaft lining shall not be less than 0.8%, the steel ratio of the shaft shall meet the requirements of Item 1 in Article 6.1.3 of this code. The reinforcement of inner layer and outer layer should be symmetrical. The reinforcing steel bars of the central part of the composite shell at shaft lining bottom may be replaced by circular steel plate as needed, and the steel content shall not lower than the amount of calculated reinforcing bars.

6.4.15 The radial reinforcing steel bars of composite shell at the shaft lining bottom shall be extended to the shaft lining cylinder as the vertical reinforcing steel bars of the shaft cylinder.

6.4.16 Connection of reinforcing steel bars of the shaft lining shall be in accordance with the following requirements:

1 Single reinforcing steel bars should be used in vertical reinforcing steel bars, and welding or mechanical connection shall be adopted when multiple reinforcing steel bars are needed.

2 The circumferential reinforcing steel bars should adopt welded joints, it may also use banding lap.

3 The joint connection quality shall be in accordance with the current national standard of GB 50010 *Code for Design of Concrete Structures*, the GB 50204 *Code for Quality Acceptance of Concrete Structure Construction*, and the current Industry standard of JGJ 18 *Specification for Welding and Acceptance of Reinforcing Steel Bars*, and the relevant requirements of JGJ 107 *Technical Specification for Mechanical Splicing of Steel Reinforcing Bars*; In case that welding or mechanical connection is used, the strength at the joint must not be lower than the strength of the base reinforcing steel bars matrix.

6.4.17 The setting of the suspension ring shall be in accordance with the following requirements:

1 The ring must be made of hot rolled carbon round steel, and cold bending is strictly prohibited.

2 Pre-embedding method shall be adopted and the buried depth shall not be less than $30d$ (d is the diameter of suspension ring round steel), and shall not be less than 1m, and shall be welded on the steel fabric.

3 The suspension ring shall be arranged symmetrically on the shaft lining, and the number of rings shall not be less than 8, and should be a multiple of 4.

6.4.18 The cross-sectional area of each suspension ring round steel may be calculated according to the following formula:

$$A_s = \nu_d \nu_1 \frac{Q_j}{f_{y,y}} \frac{1}{2n_d} \tag{6.4.18}$$

Where, A_s—Cross-sectional area of suspension ring round steel(mm^2).

ν_d—Hoisting dynamic coefficient, $\nu_d = 1.5$.

ν_1—Non-uniform loading coefficient of suspension ring, $\nu_1 = 1.35$.

Q_j—Weight of hoisting shaft lining(N).

$f_{y,y}$—Design value of tensile strength of round steel(N/mm^2).

n_d—Number of suspension ring(piece).

6.4.19 The connection and calculation of shaft lining flange plate shall meet the requirements of Appendix C of this code.

6.4.20 The processing and welding of steel plate cylinder and flanges shall be in accordance with the following requirements:

1 The steel plate cylinder and the shaft lining connecting flange plate in the steel plate-concrete composite shaft lining may be processed and welded in sections(pieces). The size of the section(piece) shall be determined by the diameter of the shaft, the section height of the shaft lining, the transportation, processing etc.

2 Butt weld shall be adopted between each section of steel plate cylinder and flange plate. The groove type and size of butt welding shall be in accordance with the current national standard of GB/T 985.1 *Recommended Joint Preparation for Gas Welding, Manual Metal arc Welding, Gas-shield Arc Welding and Beam Welding* and GB/T 985.2 *Recommended Joint Preparation for Submerged Arc Welding*.

3 The weld metal between the components of steel plate cylinder and flange plate should be adapted to the base metal. In case that the steels of different strength is connected to each other, the welding material suitable for the low strength steel may be adopted.

4 The quality of welding joint between the components of steel plate cylinder and flange plate shall be in accordance with the relevant requirements of current national standard of GB 50205 *Standard for Acceptance of Construction Quality of Steel Structures*.

6.4.21 The characteristic value of the external load on the shaft lining and at the bottom of the shaft lining shall be in accordance with the following requirements:

1 The characteristic value of the permanent radial uniform load on the shaft lining shall be calculated according to the following formulas:

$$\text{Topsoil section}: P_k = 0.012H \qquad (6.4.21\text{-}1)$$

$$\text{Bedrock section}: P_{j,k} = 0.010H \qquad (6.4.21\text{-}2)$$

Where, P_k—Characteristic value of radial uniform load on shaft lining of topsoil(MPa).

$P_{j,k}$—Characteristic value of radial uniform load on shaft lining of bedrock(MPa).

0.012—Gravity-like density(MN/m^3).

0.010—Water gravity density(MN/m^3).

2 The characteristic value of radial non-uniform load on the shaft lining shall be calculated according to the following formulas:

$$P_{a,k} = P_{A,k}(1+\beta_z \sin\theta) \qquad (6.4.21\text{-}3)$$

$$\text{Topsoil}: P_{A,k} = 0.012H \qquad (6.4.21\text{-}4)$$

$$\text{Bedrock}: P_{A,k} = 0.010H \qquad (6.4.21\text{-}5)$$

Where, $P_{a,k}$—The characteristic value of radial non-uniform load on the shaft lining(MPa).

$P_{A,k}$—Characteristic value of minimum load on shaft lining(MPa).

β_z—Uneven pressure coefficient take 0.10 to 0.20.

θ—Uneven load distribution angle(°)take 0° to 90°.

3 The characteristic value of vertical load on the shaft lining shall be calculated according to the Formula(6.2.4-1) and Formula(6.2.4-2).

4 During transportation(hoisting) of the shaft lining, characteristic value of dead-weight shall be calculated according to the following formula:

$$N_{z,k} = q_f h_z \qquad (6.4.21\text{-}6)$$

Where, $N_{z,k}$—characteristic value of dead-weight of shaft lining during transportation(hoisting)(MN).

q_f—Gravity per unit length of shaft lining(MN/m).

h_z—Section height of shaft lining(m).

5 The characteristic value of the temporary load at the shaft lining bottom shall be calculated according to the following formulas:

$$P_{w,k} = \gamma_w H_w \qquad (6.4.21\text{-}7)$$

$$P_{n,k} = \gamma_n H_n \qquad (6.4.21\text{-}8)$$

Where, $P_{w,k}$—Characteristic value of mud pressure(MPa).

$P_{n,k}$—Characteristic value of counter weight water pressure(MPa).

γ_w—Gravity density of mud(MN/m^3)is suitable to take $0.012MN/m^3$, at the early stage of shaft lining suspension sinking is suitable to take $0.010MN/m^3$.

γ_n—Gravity density of counter weight water take $0.010MN/m^3$.

H_w—Height from mud liquid level to shaft lining bottom(m).

H_n—Height from balance water to the bottom of shaft lining(m).

6.4.22 The shaft lining thickness of the shaft by the shaft drilling method shall be preliminarily determined by the following formula:

1 The shaft lining of thin walled cylinder($t<r_w/10$)shall be calculated according to the following formula:

$$t=\frac{\gamma_0 P r_n}{f_s-\gamma_0 P} \tag{6.4.22-1}$$

2 The shaft lining of thick walled cylinder ($t\geqslant r_w/10$) shall be calculated according to the following formulas:

$$t=r_n\left(\sqrt{\frac{f_s}{f_s-2\gamma_0 P}}-1\right) \tag{6.4.22-2}$$

$$f_s=f_c+\rho_{min}f'_y \tag{6.4.22-3}$$

$$P=\nu_k P_k \tag{6.4.22-4}$$

Where, P—Calculation value of design load acting on shaft lining. (MPa) According to different stress conditions, the corresponding load values such as uniform soil and water pressure, static water pressure, mud pressure etc are adopted.

ρ_{min}—Minimum steel ratio shall meet the requirements of Item 1 in Article 6.1.3 of this code.

6.4.23 The internal force and bearing capacity of shaft lining round ring under uniform pressure should be calculated according to the requirements of reinforced concrete shaft lining in Appendix A.1.1.

6.4.24 The internal force of round ring and reinforcement of circumferential reinforcing steel bars under non-uniform pressure should be calculated according to the requirements of Appendix D.1 and Appendix D.2 of this code.

6.4.25 The vertical reinforcement of shaft lining should be calculated according to the requirements of Appendix D.3 of this code.

6.4.26 Hemispherical and spherical shaft bottom should be calculated according to the requirements of Appendix E of this code.

6.4.27 The bottom of the shaft lining of the semi-elliptical rotary flat spherical shell should be calculated according to the requirements of Appendix F of this code.

6.4.28 The stability of shaft lining shall be checked in accordance with the the following requirements:

1 The circumferential stability of shaft lining shall be checked according to the requirements of Appendix A.2 of this code.

2 The vertical stability of equal thickness shaft lining shall be checked according to the following formulas:

$$H_{cr}=\sqrt[3]{\frac{AE_c I}{q}}\geqslant H \tag{6.4.28-1}$$

$$A=\frac{\pi^2}{4\times(0.131\,37-0.007\,66K_{CT}+0.002\,31K_{CT}^2)} \tag{6.4.28-2}$$

$$K_{CT}=\frac{F_s\gamma_w}{q} \tag{6.4.28-3}$$

$$q=q_s+q_w \tag{6.4.28-4}$$

Where, H_{cr}—Critical depth of shaft lining(m).

I—Cross section inertia moment of shaft(m^4).

q_s—Shaft lining weight per meter(N/m).

q_w—Balance water weight of shaft per meter(N/m).

F_s—External sectional area of shaft(m^2).

A—Coefficient values which may be selected according to Table 6.4.28.

K_{CT}—Coefficient values which may be selected according to Table 6.4.28.

Table 6.4.28 Coefficient value of vertical stability of shaft lining

K_{CT}	A	K_{CT}	A	K_{CT}	A
0.0	18.78	0.70	19.41	0.84	19.50
0.1	18.89	0.72	19.42	0.86	19.51
0.2	18.99	0.74	19.43	0.88	19.52
0.3	19.09	0.76	19.45	0.90	19.53
0.4	19.18	0.78	19.46	1.00	19.58
0.5	19.26	0.80	19.47	–	–
0.6	19.34	0.82	19.48	–	–

6.4.29 The bearing capacity of steel plate-concrete composite shaft lining shall be calculated according to the requirements of Appendix G of this code.

6.4.30 The grouting hole behind the shaft lining should be reserved in the middle of steel plate-concrete composite shaft lining.

6.4.31 During connection of the shaft lining of the steel plate cylinder, repair welding with the steel plate cylinder with thickness of not be less than 10mm may be used along the periphery of the joint as needed.

6.5 Shaft support by caisson sinking method

6.5.1 The cast-in-place reinforced concrete shaft lining should be used for shaft support by caisson sinking method and the strength of shaft lining shall meet the requirements of load and sinking of shaft lining at the same time.

6.5.2 The sinking depth of caisson shaft lining should be larger than 3.0m into the impervious stable formation. If the depth of caisson reach the impervious stable formation is less than 3m, back cover measures shall be taken.

6.5.3 The inner and outer diameters of the caisson shaft shall be calculated according to the following formulas:

$$d = d_1 + H\eta \qquad (6.5.3\text{-}1)$$

$$D = d + 2h \qquad (6.5.3\text{-}2)$$

Where, d—Design inner diameter of caisson shaft(m).

d_1—Efficient inner diameter of caisson shaft(m).

H—Efficient depth of caisson shaft(m).

D—Outer diameter of caisson shaft(m).

h—Shaft lining thickness of caisson shaft(m).

η—Skew ratio of caisson(%)shall not larger than 0.5%.

6.5.4 Grade Q235 or Q345 steel should be used in the steel plate cylinder of cutting edge.

6.5.5 The design of the cutting edge of caisson shaft lining shall be in accordance with the following requirements:

1 Sharp angle, obtuse tip and tread section shape should be used in the cutting edge.

2 The cutting edge should be reinforced concrete blunt point with steel boots composite structure.

3 The type and design of the cutting edge steel boots shall be in accordance with the following requirements:

1)Steel plate thickness of steel plate boots should not be larger than 20mm.

2)Round steel diameter of round steel boots should not be larger than 28mm.

3)Rail size of rail steel boots should not be larger than 24kg/m.

4 The cutting edge steel boots shall not be less than 500mm.

5 The outer lining of the cutting edge shall be tapered. The taper angle should be inclined outward and the inclination rate should be 1% to 2%.

6 The lateral steel tie bar shall be arranged in the cutting edge and welded with the reinforcement part of the steel boot.

6.5.6 The shaft which uses mud or air injection caisson, the slurry pipe or air injection pipe shall be embedded evenly in the shaft lining above the cutting edge.

6.5.7 The reinforcement of caisson shaft lining shall be in accordance with the following requirements:

1 The spacing of load bearing reinforcing steel bars of the shaft lining should be 150mm to 300mm.

2 Vertical spacing of connection reinforcing steel bars of shaft lining should not be larger than 600mm, horizontal spacing should not be larger than 1 000mm, diameter shall be 8mm to 12mm, vertical spacing of connection reinforcing steel bars of cutting edge should not be larger than 300mm, horizontal spacing should not be larger than 500mm, diameter shall be chosen according to 10mm to 24mm.

3 The hanging reinforcing steel bars shall be embedded in advance in the cutting edge, the diameter shall not be less than 16mm and the spacing shall not be less than 300mm.

6.5.8 Casing shaft for construction shall be in accordance with the following requirements:

1 The reinforced concrete structure shall be used in the casing shaft constructed by caisson method.

2 The inner diameter of the casing shaft shall be larger than the outer diameter of caisson shaft and the clearance between the inner edge of casing shaft lining and outer edge of caisson shaft lining must not be less than 500mm, and the inner and outer diameter of the casing shaft shall be calculated according to the following formulas:

$$D_2 = D + 2L_1 + H_1\mu \quad (6.5.8\text{-}1)$$

$$D_3 = D_2 + 2E \quad (6.5.8\text{-}2)$$

Where, D_2—Inner diameter of the casing shaft(m).

D_3—Outer diameter of the casing shaft(m).

L_1—Clearance between casing shaft and caisson shaft(m).

H_1—Total depth of casing shaft(m).

μ—Skew ratio of casing shaft(%), shall not larger than 0.5%.

E—Lining thickness of casing shaft(m).

3 The casing structure shall meet the requirements of operation of skewness correction and mud storage, and the depth should not be larger than 15m.

4 Working table for skewness correction shall be set up in the casing shaft, and its position shall be higher than the highest underground water level 1m to 2m.

5 The bottom of the casing shaft shall be located in the impervious clay layer, and should not be less than 3m from the lower sand layer.

6 The upper part of the casing shaft shall be connected with the locking plate as a whole.

6.5.9 The formation pressure of casing and caisson shaft shall be calculated according to the following formula:

$$P_k = 0.012H \tag{6.5.9}$$

Where, H—Depth of calculated part of the designed shaft lining.

6.5.10 Shaft support shall be in accordance with the following requirements:

1 Bearing capacity design of shaft lining structure of shaft dug by caisson sinking method shall be calculated according to Formula(6.1.1-1) and Formula(6.1.1-2) of this code.

2 The design and calculation of shaft support shall meet the requirements of radial load and ensure the integral stability of shaft.

6.5.11 The calculation of casing and caisson shaft lining thickness may be preliminarily determined by the following requirements:

1 Preliminary determined by engineering analogy.

2 The thickness of reinforced concrete shaft lining may be calculated and preliminarily determined by the following formulas:

$$t = r_n\left(\sqrt{\frac{f_s}{f_s - 2\gamma_0 P}} - 1\right) \tag{6.5.11-1}$$

$$f_s = f_c + \rho_{min} f'_y \tag{6.5.11-2}$$

$$P = \nu_k P_k \tag{6.5.11-3}$$

Where, ν_k—Safety coefficient of reinforced concrete structure.

ρ_{min}—Minimum reinforcement ratio of shaft lining ring section (%) which shall meet the requirements of Item 1 in Article 6.1.3 of this code.

6.5.12 Internal force and bearing capacity of shaft lining ring by caisson sinking method should be calculated according to the requirements of reinforced concrete shaft lining in Appendix A.1 of this code.

6.5.13 The thickness check of shaft lining structure of caisson shaft (Figure 6.5.13) shall be in accordance with the following requirements:

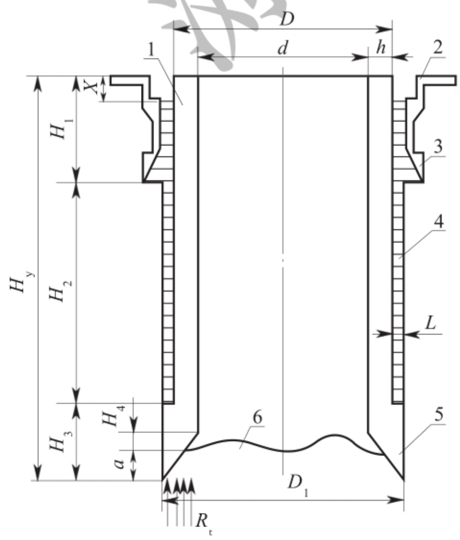

Figure 6.5.13 Calculation simplified diagram of caisson shaft lining structure

1-Shaft lining; 2-Casing shaft lining; 3-Cutting edge of casing shaft; 4-Mud; 5-Cutting edge of caisson shaft lining; 6-Working face of caisson shaft

Notes: H_y—Efficient depth of caisson shaft.

H_4—Distance between the protuberance of the cutting edge and the bevel point on the inside edge of the cutting edge.

L—Distance between the caisson shaft lining and sidewall(m), $L = \frac{1}{2}(D_1 - D)$.

1 Shaft lining weight ratio shall be calculated according to the following formula:

$$W = \frac{G}{S} \tag{6.5.13-1}$$

Where, W—The calculated weight ratio of shaft lining(kN/m^2)is 20kN/m^2 to 26kN/m^2.

G—Dead weight of caisson shaft lining(include buoyancy)(kN).

S—External area of caisson shaft lining(m^2).

2 In case of checking the calculation according to the sinking conditions, the following requirements shall be in accordance with:

$$G' > 1.15T \tag{6.5.13-2}$$

$$G' = G_1 + G_2 + G_3 \tag{6.5.13-3}$$

$$T = T_1 + T_2 + N \tag{6.5.13-4}$$

$$T_1 = \pi D_1 H_3 F \tag{6.5.13-5}$$

$$T_2 = \pi D(H_2 + H_1 - X)F' \tag{6.5.13-6}$$

$$N = R_t \pi(D_1 - \alpha \tan\beta)\alpha \tan\beta \tag{6.5.13-7}$$

Where, G'—Total weight of caisson shaft(kN).

G_1—Dead weight of cutting edge of caisson shaft lining(include buoyancy)(kN).

G_2—Shaft weight of caisson shaft(include buoyancy)(kN).

G_3—Sludge barrel weight behind the caisson shaft lining(include buoyancy)(kN).

T—Total resistance of caisson sinking(kN).

T_1—Lateral resistance between the outside of the cutting edge and the soil layer(kN).

T_2—Friction resistance between the outside of shaft lining and thixotropic mud(kN).

N—Frontal resistance of caisson shaft(kN).

D_1—External diameter of cutting edge(m).

D—External diameter of shaft(m).

H_3—Cutting edge(m).

F—Unit friction resistance(kN/m^2)of the direct contact surface between shaft lining and topsoil may be selected according to Table 6.5.13.

H_2—Height from the bottom the cutting edge tip of the casing shaft to cutting edge step of caisson shaft(m).

F'—Unit friction resistance between shaft lining and slurry(kN/m^2). When the depth of caisson shaft is less than 50m, it may take 3kN/m^2 to 5kN/m^2. When the depth of caisson shaft is 50m to 100m, it may take 8kN/m^2. In case that the depth of caisson shaft is larger than 100m, it may take 10kN/m^2.

α—Depth of cutting edge inserted into the soil may take 1m to 2m.

β—Intersection angle of cutting edge tip may take 25° to 30°.

R_t—Soil ultimate compressive strength, the clay layer is 250kN/m^2 to 500kN/m^2.

H_1—Total depth of casing shaft(m).

X—Depth from thixotropic mud liquid level to the portal of casing shaft(m).

Table 6.5.13 Unit friction resistance of soil

Soil classification	Friction resistance F(kN/m^2)
Clay and clayey soil	12.5–20.0
Sand clay and clay with gravel	25.0–50.0
Sludge	12.0–25.0

Table 6.5.13(continued)

Soil classification	Friction resistance F(kN/m^2)
Sand and fine sand	15.0–25.0
Gravel and coarse sand	20.0–30.0
Quicksand	12.0–25.0
Grait	15.0–30.0

6.6 Shaft support by curtain sinking method

6.6.1 The depth of the concrete curtain entering the impervious stable rock shall not be less than 3.0m.

6.6.2 The shaft constructed by curtain sinking method, the design of the shaft lining structure shall be in accordance with the following requirements:

1 Shaft with equipment, concrete curtain shall be used as temporary support. The curtain from the bottom to the top is covered by inner shaft lining as a permanent support.

2 For the Shaft without equipment, the concrete curtain may be used as permanent support.

6.6.3 Net radius of concrete curtain of curtain sinking shaft shall be calculated according to following formula:

$$R_1 = R_0 + B_0 + \frac{D+0.1}{2} + iH \qquad (6.6.3)$$

Where, R_1—Central line radius of curtain(m).

R_0—Net radius of shaft(m).

B_0—Casing shaft lining thickness(m).

R—Net radius of efficient thickness of curtain(m).

D—Diameter of borehole(m).

0.1—Borehole expanding amount of drilling(m).

i—Maximum allowable skewness of borehole drilling(%). In case that the depth of borehole is less than 30m, the skwe ratio may take 0.5%. In case that the depth of borehole is less than 50m, the skew ration may take 0.4%. When the depth of borehole is larger than 50m, the skew ratio may take 0.3%.

H—Design depth of concrete curtain(m).

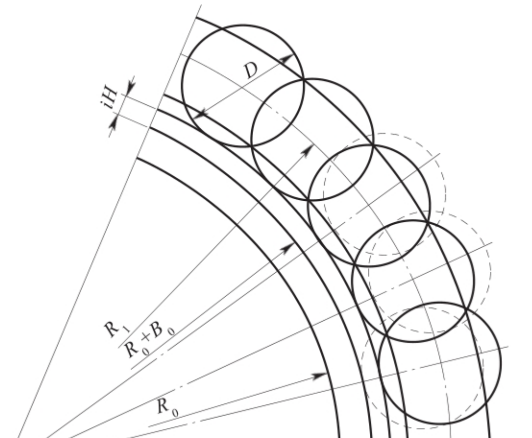

Figure 6.6.3 Calculation simplified diagram of concrete curtain

B–Efficient thickness of concrete curtain(m)

6.6.4 The calculation of characteristic value of radial load of shaft lining of shaft by curtain sinking method shall be in accordance with the following requirements:

1 The characteristic value of radial load of single shaft lining shall be calculated according to the following formula:

$$P_k = 0.013H \tag{6.6.4-1}$$

2 The characteristic value of radial load of inner shaft lining shall be calculated according to the following formula:

$$P_{n,k} = 0.01k_z H \tag{6.6.4-2}$$

6.6.5 The thickness of shaft lining by curtain sinking method may be determined by the following requirements:

1 The inner shaft lining thickness is preliminarily determined by engineering analogy which should not be less than 300mm, and should be equipped with constructional reinforcement.

2 Efficient thickness of concrete curtain or inner shaft lining thickness may preliminarily be determined by the following calculation.

1) Efficient thickness of concrete curtain may be calculated according to the following formula:

$$B = R\left(\sqrt{\frac{f_s}{f_s - 2\nu_k \gamma_0 P_k}} - 1\right) \tag{6.6.5-1}$$

2) Inner shaft lining thickness may be calculated according to the following formulas:

$$B_0 = R_0\left(\sqrt{\frac{f_s}{f_s - 2\nu_k \gamma_0 P_k}} - 1\right) \tag{6.6.5-2}$$

$$f_s = f_c + \rho_{min} f'_y \tag{6.6.5-3}$$

Where, f_s—Design value of curtain material strength (MPa).

ρ_{min}—The minimum reinforcement ratio (%) which shall meet the requirements of Item 1 and Item 2 in Article 6.1.3 of this code.

ν_k—Safety coefficient may take 1.7 in case that the concrete curtain is used as temporary support, and the safety coefficient may take 3.4 in case that the concrete curtain is used as permanent support.

7 Chamber

7.1 Ingate

7.1.1 The ingate may be divided into two-sided slant-top, two-sided flat-top and one-sided, etc.

7.1.2 The ingate size shall be in accordance with the following requirements:

1 Ingate hoisted by cages shall be provided with bilateral sidewalks with width not be less than 1.0m. The height and length shall meet the requirements of equipment arrangement and shall allow the longest material and biggest equipment to get through, as well as allow the cage to get in and get out at the same time, and meet the requirements of car operation equipment, the net height shall not be less than 4.5m.

2 The dimensions of ingate which is hoisted by skip shall be determined by maintenance, cleaning and construction needs.

3 The dimensions of air shaft ingate shall be determined by ventilation, long materials and construction needs.

7.1.3 The layout, cross-section shape and support of the ingate shall be in accordance with the following requirements:

1 Ingate shall be arranged in water-free (or weakly water-bearing) rocks stratum (seam), which is stable and hard, and the shape of the cross-section may be arched. When the lateral pressure is high, the horseshoe section may be adopted, and when the top pressure, side pressure and bottom pressure is high, the circular whole sealing section may be adopted.

2 Ingate must not be set up in rock formation (seam) with risk of outburst of coal (rock) and gas (carbon dioxide) as well as in coal seam with rock burst risk.

3 Ingate shall be supported by non-combustible material. Force analysis shall be carried out towards support structure. In case that ingate is located in soft rock formation, uranium (cable) spraying or uranium (cable) spraying combined with metal mesh may be used as temporary support, and observing the deformation of surrounding rock and the permanent support may be built at appropriate time.

4 The length of each side reinforced support section shall be determined by force calculation. The length of each side of ingate hoisted by cage shall not be less than 3 times of the net radius of the shaft, and the ingate and air shaft ingate hoisted by a skip shall not be less than 5m on each side.

5 The shaft lining near the ingate shall be reinforced with support, and the reinforced range from the top of the shaft lining to the bottom of the shaft lining shall not be less than 2.0m.

7.1.4 The signal room and control room shall be set in accordance with the following requirements:

1 The hoisting signal room at the bottom of cage shaft may be arranged on both sides of the ingate or upper parts of the ingate.

2 The car operation equipment control room may be arranged in conjunction with the signal room.

3 The signal room shall be located on two sides, and the control room may be concentrated on one side, or installed on both sides for the shaft with two sets of hoisting equipment.

4 The floor of the signal room and the control room shall be higher than 100m to 300m of the track level. In case that trackless transport is used, it shall be higher than 100mm to 300mm of the floor of ingate.

5 The signal room and control room shall higher than the roadway wall, within the sight of the signal operator, the fixed glass without window frame and the glass window shall be used in the exterior wall.

7.1.5 The cage shaft and the shaft bottom at every level shall communicate with each other by sidewalk, and the sidewalk shouldl be arranged jointly with the waiting room. When cage shaft use end ladderway, ingate or waiting room shall be provided with access to the ladderway.

7.2 Shaft coal bunker and skip loading chamber

7.2.1 Shaft coal bunker design shall be in accordance with the following requirements:

1 The selection of shaft coal bunker location shall be in accordance with the following requirements:

1) The position of the shaft coal bunker shall be determined by the hoisting of the shaft and the transportation mode of the main roadway, and shall be considered with the position of skip loading chamber and the belt conveyor roadway.

2) The shaft coal bunker and related chambers should be arranged in the stable and hard rock (seam) stratum, and shall avoid faults, collapse columns, strong aquifers and loose broken rock (seam) stratum and expansive rock formation.

2 The form and capacity of the shaft coal bunker shall be in accordance with the the following requirements:

1) The shaft coal bunker of the main shaft may be divided into vertical type, inclined type and horizontal type. The vertical type should be adopted.

2) The ratio of diameter and height of circular vertical coal bunker should be 0.22 to 0.42.

3) The inclination angle of inclined arch coal bunker shall not be less than 60° and sidewalks parallel to coal bunker shall be provided. Observation holes shall be set up on the partition wall between coal bunker and sidewalk.

4) Iron grate 300mm × 300mm shall be installed at the top of the coal bunker.

5) Anti-blocking measures shall be taken for the coal bunker, and the lower part of the vertical bunker may adopt hyperbolic shape or install arch breaking device.

6) Wear-resistant material shall be used for coal bunker laying.

7) The effective capacity of coal bunker shall be determined by rational balance of main transportation and hoisting conveyance.

8) In case that there are more than 1 coal bunkers, rock pillars shall be kept in coal bunkers, and the size of rock pillars shall be determined by the lithology of the surrounding rock. The size of the net rock pillar should not be less than 2.5 times of the excavation diameter of the largest coal bunker.

9) A gas discharge hole shall be installed at the upper part of the coal bunker.

3 The cross-section and support of shaft coal bunker shall be in accordance with the following requirements:

1) The cross-section forms of shaft coal bunker may be divided into circular, rectangular and semi-circular arch shape; the vertical coal bunker may choose circular cross-section and the inclined coal bunker may choose arch cross-section.

2)Bolt spray cast-in-place concrete or reinforced concrete may be used for support of shaft coal bunker according to the visible surrounding rock lithology or ground pressure. The funnel mouth of coal bunker may be supported by reinforced concrete.

7.2.2 The design of skip loading chamber shall be in accordance with the following requirements:

1 The layout of skip loading chamber shall be determined by the hoisting mode of the main shaft, the installation, repair, replacement of loading equipment and pedestrian safety.

2 Skip loading chamber may be arranged as pass type or non-pass type according to the loading equipment and loading mode. It may be arranged as one-side type or double-side type according to the requirements of hoisting equipment and hoisting vessel, and the non-pass type should be adopted The middle level with unilateral arrangement and allow multi-level simultaneous production may use pass type. The size of the chamber shall be determined by selected loading equipment specifications and layout methods.

3 The cross-section shape and supporting method of skip loading chamber shall be in accordance with the following requirements:

1)The shape of the cross-section may be rectangular or semicircular arch. In case that the lithology of the surrounding rock is poor and the earth pressure is large, the horseshoe-shaped fully sealing section should be adopted.

2)The reinforced concrete support should be used. In case that the surrounding rock is firm, the bolt spray support or concrete support may be adopted.

3)Steel reinforced concrete or steel structure shall be adopted for the structure bearing dynamic load in the chamber.

4)The shaft lining near the loading chamber shall be reinforced with support, and the top and bottom support range shall not be less than 3.0m.

4 The arrangement of loading chamber shall be in accordance with the following requirements:

1)Inspection pedestrian for belt conveyor roadway or slope bunker shal be installed in the chamber, which connects with the maintenance room of the main shaft bottom. There shall be a passageway between the upper and lower chamber.

2)The hoisting beam or hoisting ring shall be set up at the top of the chamber according to the mechanical arrangement, installation and maintenance requirements.

3)The pedestrian hole of the chamber and the hoisting hole shall be provided with a cover plate or a fence, a canopy shall be provided at the top of the connecting place between the chamber and the shaft, and a fence shall be installed on the platform.

4)Signal room and control room shall be installed on one side or both sides of the skip loading chamber(two sets of hoisting).

7.2.3 The roadway design of the loading belt conveyor shall be in accordance with the following requirements:

1 The loading belt conveyor roadway may be arranged in single machine or double-machine arrangement. On one side of the roadway shall be provided with a pedestrian access road in case of using the single machine arrangement. In case of using the double-machine arrangement, a pedestrian access road or a middle pedestrian access road shall be arranged on both sides of the roadway; the width of the pedestrian access road shall not be less than 800mm. The width of the non-pedestrian access road shall not be less than 500mm.

2 The section and supporting design of the roadway of the loading belt conveyor shall be in accordance with the following requirements:

1)The shape of the cross section may be semi-circular arch, and if the ground pressure is large, the horseshoe shape may be adopted.

2)Cross-section size, roadway pre-buried parts(holes) shall be determined by the requirements of mechanical equipment.

3)concrete arch walling should be adopted for support. In case that the surrounding rock is stable, anchor spray support may also be used, and the roadway shall be paved.

7.3 Skip shaft scattered coal cleaning chamber

7.3.1 Design of coal receiving hopper and scattered coal chute at the bottom of skip shaft shall be in accordance with the following requirements:

1 Skip shaft scattered coal cleaning system should be centralized arranged in the form of shaft bottom straight falling. The width of the isolated maintenance channel shall not be less than 800mm on both sides of the scattered coal roadway. Wear-resistant material or steel structure shall be adopted on the outer side of the inspection and repair roadway.

2 In case that the scattered coal cleaning system of skip shaft is arranged at the level of shaft station, the sedimentation cleaning pool shall be arranged at the bottom of the skip shaft, and after the precipitation, the coal slurry water should flow into the water silo of shaft station. If a reinforced concrete bell-shaped coal receiving hopper is used, the inclination of hopper wall may be 55° to 60°. Repair platform shall be installed in the hopper wall. The wet hopper shall have a repair hole on one side of the non-loading chamber with a climbing ladder on the shaft lining, and an iron cover plate on the top.

3 In case that the scattered coal cleaning system of skip shaft is arranged below the shaft station, the sink cleaning pool should be arranged on one side of the skip shaft, and the reinforced concrete asymmetrical bell-shaped coal receiving hopper should be used. The coal receiving hopper and coal scattered chute should be arranged in combination, and the inclination of floor may take 55° to 60°. Considering the shaft extension, the lowest point of shaft sump should not be higher than the level of sedimentation pool.

4 The section of coal-scatter chute should adopt semi-circular arch and concrete support. The side wall of the coal receiving hopper and chute floor shall be laid with wear-resistant materials.

7.3.2 Sedimentation pool chamber at the bottom of shaft shall be in accordance with the following requirements:

1 The capacity of the sedimentation pool may be determined by 3‰ to 5‰ of the daily output of the shaft, and according to the cleaning working system and the arrangement of the mechanical equipment.

2 Two sedimentation pools should be set up. The separation wall and drainage ditch shall be set up between the two sedimentation pools. The thickness of separation wall may take 200mm, the width of drainage ditch may take 500mm with a cover plate, and a railing should be installed on one side of the separation wall.

3 The sedimentation pool may be paved with wear-resistant and smooth materials, and the thickness may take 150mm to 200mm.

4 The slope of sedimentation pool may not be larger than 10° which lead to the top of the loading point of the scattered coal cleaning roadway, and transported by mine cart of coal discharging plate or small skip.

7.3.3 Scattered coal cleaning water sump at shaft bottom shall be in accordance with the following requirements:

1 In case that the scattered coal cleaning system of the skip shaft is set at the shaft station, the water sump shall not be set. In case that the spraying water of main shaft overflows from the sedimentation pool, it shall flow directly into the main water sump of the shaft bottom through the ditch.

2 In case that the scattered coal cleaning system of skip shaft is below the shaft station, the water sump and water pump shall be set in the scattered coal cleaning system, and discharge the water of main shaft scattered coal system to the main water sump at the shaft station. The design of the water sump shall be in accordance with the following requirements:

1) The water sump should be arranged in a single roadway, and the partition wall may be installed in the middle of the roadway which divided into two chambers.

2) The floor of the water sump shall be provided with integral track bed with a slope of 3%, and shall be toward the suction well.

3) The separation wall of the sump should be equipped with a baffle every 5m to 8m to change the flow direction and overflow baffle shall be set up about 15m away from the suction well.

4) The capacity of the water sump shall be calculated on the basis of the 4-hour inflow.

3 Pump room should be equipped with three pumps for working, backup and overhaul each one.

4 The water sump should be supported by semi-circular arch section and concrete.

7.3.4 The design of inclined drifts of scattered coal cleaning system at shaft bottom shall be in accordance with the following requirements:

1 The inclination of cleaning inclined drifts should not be larger than 25°. The slop starting point to the center line of the sedimentation pool chamber may take 4m to 5m.

2 Storage lines for 4–6 empty cars shall be set up in the upper part of the cleaning inclined drift.

3 A vehicle arrester or a stopper shall be provided in the slop changing point of the cleaning inclined drift. A rope wheel shall be set up at the slope changing point, and a ground roll shall be set every 15m on floor of cleaning inclined drift.

4 Water gutters, pedestrian steps and handrails shall be set up at the cleaning inclined drift. Water spray of auxiliary shaft may also be led to the cleaning inclined drift and drained into the shaft station through water sump pump room.

5 In case that the depth of the winch room of the cleaning inclined drift is larger than 6m, the return air roadway shall be set up.

6 Semi-circular arch section and anchor spray support should be adopted to clean inclined drift. In cast that faults, soft or broken lithology are met, measures of strengthening support shall be taken.

7.4 Cage shaft sump and cleaning

7.4.1 The layout of the cage shaft sump shall be determined by the hoisting equipment arrangement, the shaft is extended or not, the facilities in the shaft sump, the installation and repair, and the way of sump cleaning, and shall be in accordance with the following requirements:

1 For cage shaft which is not used to hoisting people, In case that the shaft does not need extension, the shaft sump shall keep 2m deep at least. In case that the shaft needs extension, the shaft sump shall keep deep 10m at least.

2 For cage shaft which is used to hoisting people when drainage roadway is settled and shaft extension is not considered, the shaft sump shall keep 5m at least. If the shaft extension is considered, it shall keep 10m at least. If the water pump is provided, the distance from the lowest point of shaft sump to highest water level of the sump may be 2m to 3m. The depth of sump below the water may be 5m.

7.4.2 Concrete support should be adopted in shaft sump. Reverse arch structure should be used at the bottom of the sump. The height of the bottom arch may be 1/10 of the inner diameter of the shaft.

7.4.3 Drainage and cleaning of cage shaft sump shall be in accordance with the following requirements:

1 Mechanical cleaning shall be adopted and sump drainage facilities shall be set up in case that inclined roadways and water pond are separately installed. The inclination angle of inclined roadway may not be larger than 25°.

2 In case that the main shaft is skip hoisting, and the coal cleaning and scattering system is arranged below the level of the shaft station, the vertical shaft bottom of the cage shall be equipped with cleaning drainage roadway, and the stone (coal) may be transported to the shaft bottom through the inclined roadway of the main shaft.

3 Cage shaft without hoisting person may adopt self-overflow drainage and bucket cleaning.

7.4.4 Repair ladderway shall be set up in the shaft sump which connected with the shaft bottom. Shaft sump section shall be provided with a wall ladder lead to the bottom of the sump.

7.5 Ventilation shaft mouth and shaft sump

7.5.1 The design of ventilation shaft mouth shall be in accordance with the following requirements:

1 All kinds of adit collar such as fan drift mouth on the shaft lining, safe outlet etc. must not be arranged on the same horizontal section or vertical section of the shaft lining.

2 In case that there is no water in the topsoil, the distance between the lower part of the fan drift and the shaft should not be less than 6m. In case that the topsoil is water-bearing, the elevation of the lower part of the fan drift may be raised appropriately.

3 The shaft mouth with main ventilator must be closed tightly, the outlet shall be fitted with explosion-proof door, the area of explosion-proof door must not be less than the cross-section area of the ventilation shaft, and shall be directly face the air flow of the ventilation shaft.

4 The safety outlet shall be arranged on one side of the ladderway of the ventilation shaft. The elevation of the flat floor which connected between the ventilation shaft and the safety outlet shall be 2m higher than the elevation of the air drift floor. The flat floor of the ground outlet shall be 500mm higher than the industrial site of the outlet.

7.5.2 The foundation design of explosion-proof door shall be in accordance with the following requirements:

1 In case that the foundation height of the explosion-proof door is larger than or equal to 1.5m, wall ladders and handrails shall be installed at the outside of the wall of the foundation.

2 The foundation shall be poured by concrete and the strength grade shall not be less than C20. The reinforced concrete structures shall be adopted when the designed seismic intensity is 8 degrees or more.

7.5.3 The design of safety outlet shall be in accordance with the following requirements:

1 Rectangular section or semi-circular arch section should be adopted for safety outlet, which shall be casted by concrete or reinforced concrete.

2 A length of 5m to 8m flat passage shall be installed to connect the safety outlet with the ventilation shaft. Two or three two-way air doors shall be installed, and the inclined sidewalk shall be installed lead to the ground.

3 The length of the inclined sidewalk and the inclination shall be determined according to the topography and surface features of the industrial site of the shaft mouth. The inclination angle may take 25° to 30° and the sidewalk shall be equipped with steps and handrails.

4 The ground outlet shall be provided with a flat road with the length not less than 2m and a one-way air door shall be installed for outward opening.

5 The one-way air door at the ground outlet should adopt the iron air door. In case that the service life is short, the wooden air door with the cover of iron, may be adopted and the air door shall be installed with an inclination of 3° to 5°windward.

6 The safety outlet shall be paved by concrete with the thickness of 100mm to 150mm.

7.5.4 The design of air drift shall be in accordance with the following requirements:

1 The intersection angle between air drift and shaft should be 40° to 50° and it may be larger than 50° in special circumstances. The connecting part between the air drift and shaft shall be made into a smooth curve.

2 The upper part of the air drift shall be connected with the air duct of ventilator by a circular curve. The radius of the vertical curve of the floor may take 6m to 8m, and the center angle may not be larger than 45°.

3 The velocity of air flow in air drift shall not be larger than 15m/s.

4 In case that the ventilation shaft is equipped with hoisting equipment and the steel rope cage guide is used, the air mouth shall be located on the narrow side of the hoisting equipment.

7.5.5 The sump of the ventilation shaft shall be in accordance with the following requirements:

1 In case that there is no hoisting equipment, the sump may not be installed at the bottom of the shaft. In case that there is hoisting equipment, the depth of the sump shall be determined by the requirements of the hoisting system.

2 In case that the shaft needs to be extended, the depth of sump may not be less than 10m.

Appendix A Calculation for internal force and bearing capacity of concrete shaft lining

A.1 Internal force of circle cross section of shaft lining and bearing capacity calculation.

A.1.1 The calculation of internal force and bearing capacity of circular cross section of concrete shaft lining height/unit under uniform pressure shall be in accordance with the following requirements:

1 Thin wall cylinder shaft lining($t<r_w/10$)shall be calculated according to the following formula:

1)Axial force of circle cross section shall be calculated according to Figure A.1.1-1:

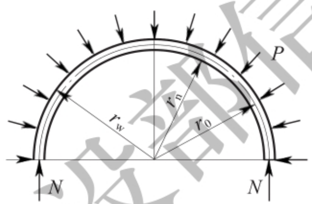

Figure A.1.1-1 Axial force of circle cross section calculation

$$N=r_wP \tag{A.1.1-1}$$

Where, N—Axial force of circle cross section of shaft lining per meter(MN/m).

r_w—External radius of shaft lining at the calculated position.

P—Calculated value of design load on the shaft lining at the calculated position(MPa).

2)Bearing capacity of circle cross section of concrete shaft lining shall be calculated according to following formulas:

$$N\leqslant 0.85\varphi_1 tf_c \tag{A.1.1-2}$$

$$L_0=1.814r_0 \tag{A.1.1-3}$$

Where, φ_1—Stability factor of plain concrete member(see Table A.1.1-1).

r_0—Central radius of shaft lining at the calculated position(m).

L_0—Calculation length of shaft lining ring at calculated position(m).

f_c—Design value of axial compressive strength of concrete(N/mm^2).

Table A.1.1-1 Stability factor of plain concrete member

L_0/b	<4	4	6	8	10	12	14	16
φ_1	1.00	0.98	0.96	0.91	0.86	0.82	0.77	0.72
L_0/b	18	20	22	24	26	28	30	–
φ_1	0.68	0.63	0.59	0.55	0.51	0.47	0.44	–

Note: b is equal to shaft lining thickness(m).

3)Bearing capacity of circle cross section of reinforced concrete shaft lining shall be calculated according to following formula:

$$N\leqslant\varphi(tf_c+A_sf_v') \tag{A.1.1-4}$$

Where, φ—Stability factor of axial compression member of reinforced concrete(see Table A.1.1-2).

A_s—The area of the reinforcement of the shaft lining cross section per meter(m^2/m).

f_v'—Design value of compressive strength of reinforcing steel bars(N/mm^2).

Table A.1.1-2 Stability factor of axial compression member of reinforced concrete

L_0/b	<8	10	12	14	16	18	20	22	24	26	28
φ	1.00	0.98	0.95	0.92	0.87	0.81	0.75	0.70	0.65	0.60	0.56
L_0/b	30	32	34	36	38	40	42	44	46	48	50
φ	0.52	0.48	0.44	0.40	0.36	0.32	0.29	0.26	0.23	0.21	0.19

Note: L_0 is the calculation length of member, and shall be calculated according to Formula (A.1.1-3).

2 Shaft lining of thick wall cylinder ($t \geqslant r_w/10$) shall be calculated according to the following formula:

1) Axial force of shaft lining ring (Figure A.1.1-2) shall be calculated according to Formula (A.1.1-1):

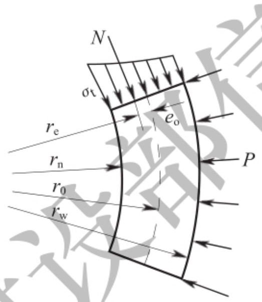

Figure A.1.1-2 Calculation diagram of axial force of shaft lining ring

2) Tangential stress of circle cross section of shaft lining shall be calculated according to the following formula:

$$\sigma_t = \frac{2r_w^2 P}{r_w^2 - r_n^2} \quad \text{(A.1.1-5)}$$

Where, σ_t—Tangential stress of circle cross section of shaft lining (MPa).

r_w—External radius of shaft lining calculated position (m).

r_n—Inner radius of shaft lining calculated position (m).

3) Bearing capacity of circle cross section of plain concrete shaft lining shall be calculated as follows:

$$\sigma_t \leqslant 0.85 f_c \quad \text{(A.1.1-6)}$$

4) Bearing capacity of circle cross section of reinforced concrete shaft lining shall be calculated according to the following formula:

$$\sigma_t \leqslant f_c + \rho f'_y \quad \text{(A.1.1-7)}$$

Where, ρ—Steel ratio of circle cross section of shaft lining (%).

3 Steel ratio of circle cross section of shaft lining (ρ) and cross section area of steel reinforcement (A_s) shall be determined by following method:

1) In case that $\sigma_t \leqslant f_c$, the reinforcing steel bar shall be equipped in accordance with the construction requirements. In case that $\sigma_t > f_c$, the steel ratio shall be calculated according to the following formula:

$$\rho = \frac{\sigma_t - f_c}{f'_y} \quad \text{(A.1.1-8)}$$

2) In case that $\rho > \rho_{min}$, A_s shall be calculated according to the following formula:

$$A_s = \rho b_n (r_w - r_n) \quad \text{(A.1.1-9)}$$

3) In case that $\rho \leqslant \rho_{min}$, A_s shall be calculated according to the following formula:

$$A_s = \rho_{min} b_n (r_w - r_n) \quad (A1.1\text{-}10)$$

Where, b_n—Calculation width of shaft lining cross section takes 1.0m.

ρ_{min}—The minimum steel ratio(%)shall be in accordance with Article 6.1.3 of this code, in case that conventional shaft sinking method or freeze sinking methods are used. When the shaft drilling method or caisson sinking method is used, it shall be in accordance with Article 6.1.3 of this code.

4)In case that the calculation result of σ is too large, the thickness of shaft lining shall be increased.

A.1.2 The calculation of the whole circular internal force and bearing capacity of the shaft lining under the non-uniform pressure shall be in accordance with the following requirements:

1 Axial force and bending moment of circular cross section of shaft lining(Figure A.1.2-1)shall be calculated according to the following method:

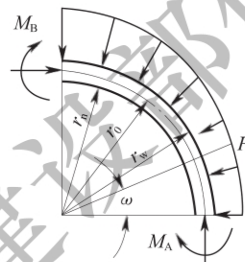

Figure A.1.2-1 Calculation diagram of axial force and bending moment of circular cross section of shaft lining

1)In case that $\omega=0°$, (A cross section), it shall be calculated according to the following formulas:

$$N_A=(1+0.785\beta) r_w P_A \quad (A.1.2\text{-}1)$$

$$M_A=-0.149\beta r_w^2 P_A \quad (A.1.2\text{-}2)$$

2)In case that $\omega=90°$(B cross section), it shall be calculated according to the following formulas:

$$N_B=(1+0.5\beta) r_w P_A \quad (A.1.2\text{-}3)$$

$$M_B=0.137\beta_w^2 P_A \quad (A.1.2\text{-}4)$$

$$P_B=P_A(1+\beta) \quad (A.1.2\text{-}5)$$

Where, N_A, N_B—Calculation value of axial force of cross section A and section B(MN).

M_A, M_B—Calculation value of bending moment of cross section A and section B(MN·m).

P_A, P_B—Pressure calculation value of cross section A and section B(MPa).

β—Non-uniform load coefficient, $\beta=\beta_t=0.2-0.3$ at topsoil. $\beta=\beta_y$, and β_y is 0.2 at the bed rock section.

3)Calculation according to, $\omega=0°$and $\omega=90°$, eccentricity and bearing capacity may be calculated as needed.

2 Bearing capacity of plain concrete shaft lining shall be calculated according to the following methods:

1)In case that the eccentricity $e_0<0.225\ t$, it shall be calculated according to the following formulas:

$$N \leqslant 0.85\varphi_1 f_c b_n (t-2e_0) \quad (A.1.2\text{-}6)$$

$$e_0 = \frac{M_A}{N_A} \text{ or } \frac{M_B}{N_B} \quad (A.1.2\text{-}7)$$

Where, e_0—The distance between the point of axial force and active point of composite force of the tensile bar(mm).

2) In case that $e_0 \geqslant 0.225\,t$, it shall be calculated according to the following formula:

$$N \leqslant \varphi_1 \frac{0.852\,5 f_t b_n t}{\frac{6e_0}{t} - 1} \tag{A.1.2-8}$$

Where, f_t—Design value of tensile strength of concrete(N/mm^2).

3 The eccentric compression bearing capacity and reinforcement configuration of reinforced concrete shaft lining shall be calculated according to the following formulas(Figure A.1.2-2):

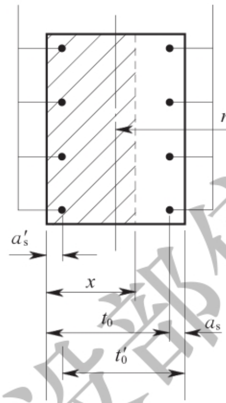

Figure A.1.2-2 The calculation diagram of eccentric compression bearing capacity and reinforcement configuration of shaft lining

$$N \leqslant a_1 f_c b_n x + f'_y A_{s1} - \sigma_s A_{s2} \tag{A.1.2-9}$$

$$Ne \leqslant a_1 f_c b_n x \left(t_0 - \frac{x}{2}\right) + f'_y A_{s1} (t_0 - a'_s) \tag{A.1.2-10}$$

$$e = e_i + \frac{t}{2} - a_s \tag{A.1.2-11}$$

$$e_i = e_0 + e_a \tag{A.1.2-12}$$

$$e_0 = \frac{M}{N} \tag{A.1.2-13}$$

$$M = C_m \eta_{ns} M_2 \tag{A.1.2-14}$$

$$C_m = 0.7 + 0.3 \frac{M_1}{M_2} \tag{A.1.2-15}$$

$$\eta_{ns} = 1 + \frac{1}{1\,300 (M_2/N + e_a)/t_0} \left(\frac{L_0}{t}\right)^2 \xi_c \tag{A.1.2-16}$$

$$\xi_c = \frac{0.5 f_c A_0}{N} \tag{A.1.2-17}$$

In case that $C_m \cdot \eta_{ns}$ is less than 1.0, $C_m \cdot \eta_{ns}$ take 1.0.

In addtion to the above mentioned requirements, the following requirements shall also be in accordance with:

1) For reinforcing steel bars A_{s2} of pulled edges or less compressed edges, σ_s shall be calculated according to the following methods:

In case that $\xi_x \leqslant \xi_b$, it is large eccentricity compression member, and the $\sigma_s = f_y$, Relative compression zone height is $\xi_x = x/t_0$ ($N = f_c b_n x$, the x value may be obtained). When $\xi_x > \xi_b$, it is small eccentric compression member, σ_s may be calculated according to the following formula:

$$\sigma_s = \frac{f_y}{\xi_b - \beta_1}\left(\frac{x}{t_0} - \beta_1\right) \tag{A.1.2-18}$$

2) In case that tensile reinforcing steel bars yielding and concrete of compression area damaging occur at the same time, the relative limit height ξ_b in compressive zone shall be according to Table A.1.2.

Table A.1.2 Relative limit height at tensile reinforcing steel bars yielding point

Steel bar strength grade Strength grade of concrete	≤C50	C55	C60	C65	C70	C75	C80
400MPa	0.518	0.508	0.499	0.489	0.480	0.472	0.463
500MPa	0.482	0.473	0.464	0.455	0.446	0.438	0.429

3) In case that reinforcing steel bars A_{s2} are involved in calculation, the height of compression area shall meet the condition $x \geqslant 2a'_s$. In case that the condition fails to meet, compressive bearing capacity of normal section shall be calculated according to the following formula:

$$Ne'_s \leqslant f_y A_{s2}(t - a_s - a'_s) \quad \text{(A.1.2-19)}$$

4) The cross-section area of reinforcement may be calculated according to the following approximate formula for small eccentrically compressed structures with double-sided symmetric reinforcement:

$$A_{s1} = A_{s2} = \frac{Ne - \xi(1 - 0.5\xi)a_1 f_c b_n t_0^2}{f'_y(t_0 - a'_s)} \quad \text{(A.1.2-20)}$$

5) Relative compressive height may be calculated according to the following formula:

$$\xi = \frac{N - \xi_b a_1 f_c b_n t_0}{\dfrac{Ne - 0.43 a_1 f_c b_n t_0^2}{(\beta_1 - \xi_b)(t_0 - a'_s)} + a_1 f_c b_n t_0} + \xi_b \quad \text{(A.1.2-21)}$$

Where, a_1—a_1 is the ratio between the stress value of rectangular stress diagram and the design value of axial compressive strength of concrete. When the strength of concrete does not exceed C50, a_1 is equal to 1.0. In case that the strength of concrete is C80, a_1 is equal to 0.94 which is determined by linear interpolation method.

M_1, M_2—The design value of composite bending moment for the same main axis which determined by elastic analysis of the structure at both ends of eccentrically compressed member, the large absolute value is M_2 and the small absolute value is M_1. When the member is bent according to the single curvature, M_1/M_2 is positive, otherwise is negative.

C_m—If adjustment coefficient of eccentric distance of structure section is less than 0.7, C_{mi} is equal to 0.7.

η_{ns}—Moment augment factor.

ξ_c—Sectional curvature correction factor, if the calculation value is larger than 1.0, ξ_c is equal to 1.0.

β_1—The ratio of neutralizing axis height to the height value of compression zone of the rectangular stress diagram. When the strength of the concrete does not exceed C50, β_1 is equal to 0.8. when the strength grade of concrete is C80, β_1 is equal to 0.74 which is determined by linear interpolation method.

x—Height of compressed zone on concrete(m).

A_{s1}, A_{s2}—The cross-section area of reinforcing steel bars in the tension zone and compression zone(m^2).

σ_s—Reinforcement stress on less tension side or less compression side(MN/m^2).

a_s, a'_s—The distance between the point of join force of the compressed reinforcing steel bars and the edge of the cross section of the member(m).

e—The distance between the point of axial force and the point of join force of the tensile reinforcing steel bars(m).

e_i—Initial eccentricity(m).

e_a—Additional eccentricity(m)takes the larger value between 1/30 of the maximum size of the eccentricity section and 0.02m.

e'_s—Distance between axial pressure point and join force point of reinforcing steel bars in compression zone(A_{s1})(m).

A.2 Calculation of circumferential stability of shaft lining

A.2.1 In order to ensure the circumferential stability of the shaft lining, the following basic requirements shall be in accordance with:

1 Pain concrete shaft lining:

$$\frac{L_0}{t} \leqslant 24 \tag{A.2.1-1}$$

2 Reinforced concrete shaft lining:

$$\frac{L_0}{t} \leqslant 30 \tag{A.2.1-2}$$

A.2.2 Circumferential stability of shaft lining may be calculated according to the following formula:

$$\frac{E_c t^3}{4r_0^3(1-\nu_c^2)} \geqslant P \tag{A.2.2}$$

ν_c is concrete Poisson ratio, $\nu_c=0.2$.

Where, E_c—Elastic modulus of concrete(N/mm^2).

A.3 Calculation of bearing capacity of shaft lining under three-dimensional stress

A.3.1 Bearing capacity of inner edge of shaft lining under three-dimensional stress.

$$\sqrt{\sigma_t^2+\sigma_r^2+\sigma_z^2-\sigma_t\sigma_r-\sigma_r\sigma_z-\sigma_z\sigma_t} \leqslant f_c+\rho f'_y \tag{A.3.1-1}$$

$$\sigma_z = \frac{Q_{z1,k}+Q_{1,k}+Q_{2,k}+P_{f,k}F_w}{A_0} \tag{A.3.1-2}$$

Where, σ_z—Calculated value of longitudinal stress of cross-section of shaft lining(MN/m^2).

σ_r—Calculated value of radial stress of cross-section of shaft lining(MN/m^2).

σ_t—Tangential stress of circular cross section of shaft lining(MN/m^2).

$Q_{zl,k}$—Characteristic value of dead weight of shaft lining above cross section(MN).

$Q_{1,k}$—Characteristic weight value of hoist tower which directly applied on the shaft(MN).

$Q_{2,k}$—Characteristic weight value of shaft equipment above the cross section(MN).

F_w—The external area of the shaft lining above the calculated cross section(m^2).

A_0—Cross section area of shaft lining(m^2).

$P_{f,k}$—Characteristic value of vertical additional force on the external surface of the shaft lining above the calculated cross section(MPa).

A.4 Calculation of the structural strength around the interfaces between the topsoil layer and the bedrock

A.4.1 Shear force and longitudinal bending moment of the shaft lining at the interface of the topsoil layer and bedrock may be calculated according to the following formulas (calculation diagram see Figure A.4.1).

$$V_{max} = \frac{P_0}{4\lambda} \tag{A.4.1-1}$$

$$M_{max} = \frac{0.0806 P_0}{\lambda^2} \tag{A.4.1-2}$$

$$\lambda = \sqrt[4]{\frac{3(1-\nu_c^2)}{r_0^2 t^2}} \tag{A.4.1-3}$$

Where, V_{max}—Calculation value of maximum shear force per meter of shaft lining at interface(MN).

M_{max}—Calculation value of maximum longitudinal bending moment per meter of shaft lining at interface(MN·m).

P_0—Calculation value of uniform soil and water pressure on shaft lining at interface(MPa).

λ—Shell constant(m^{-1}).

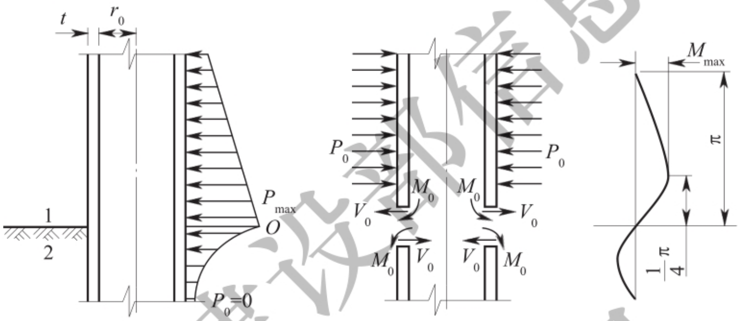

Figure A.4.1 Calculation diagram of shear force and longitudinal bending moment acting on the shaft lining at the interface between the topsoil and the bedrock.

O–Interface of topsoil and bedrock.1–Topsoil layer.2–Bedrock.P_{max}–Calculation value of maximum soil and water pressure on shaft lining in topsoil layer(MPa).V_0–Shear force at 0–0 cross section(N). M_0–Bending moment of shaft lining in 0–0 cross section by shear force(N·m).

A.4.2 The longitudinal reinforcement configuration shall be calculated in accordance with the following requirements:

1 The calculation of the cross-section area of the longitudinal reinforcement at the interface shall be considered as the shaft lining (per meter) of unit width should withstand the bending moment M calculated by Formula (A.4.1-2). The flexural bearing capacity shall be determined by the following formula.

$$M \leqslant a_1 f_c b_n x \left(t_0 - \frac{x}{2}\right) + f'_y A_{s1}(t_0 - a'_s) \tag{A.4.2-1}$$

2 The height of concrete compression region shall be in accordance with the following requirements:

1) The height of compression zone shall be determined by the following formula:

$$a_1 f_c b_n x = f_y A_{s2} - f'_y A_{s1} \tag{A.4.2-2}$$

2) The height of compression zone shall be in accordance with the following conditions:

$$x \leqslant \xi_b t_0 \tag{A.4.2-3}$$

$$x \geqslant 2a'_s \tag{A.4.2-4}$$

A.4.3 Shear strength of oblique section shall be calculated according to the following formula:

$$V_{max} \leqslant 0.25 \beta_c f_c b_n t_0 \tag{A.4.3}$$

Where, β_c—Influence coefficient of concrete strength. In case that the concrete strength is not larger than C50, β_c is equal to 1.0. In case that the concrete strength is C80, β_c is equal to 0.8 which is determined by linear interpolation.

t_0—Efficient thickness of shaft lining(m).

A.4.4 The reinforcing steel bars configuration shall be in accordance with the following requirements:

1 The length of reinforcing steel bars configuration beneath and above the interface shall not be less than one wave length, and the wave length may be calculated according to the following formula:

$$L = \frac{2\pi}{\lambda} \tag{A.4.4}$$

Where, L—wave length(m).

2 The same size of reinforcing steel bars should be arranged at the inside and outside of the shaft lining.

Appendix B Calculation for shaft lining affected by hoist tower(headframe)

B.1 Calculation of shaft lining affected by the hoist tower settled on the topsoil layer foundation.

B.1.1 The hoist tower(headframe) foundation is placed on the natural foundation, and the maximum lateral compressive stress is beneath the base of the foundation $h=L-A/2$. Maximum lateral pressure caused by different types of foundations on shaft lining (Figure B.1.1) shall be calculated in accordance with the following requirements:

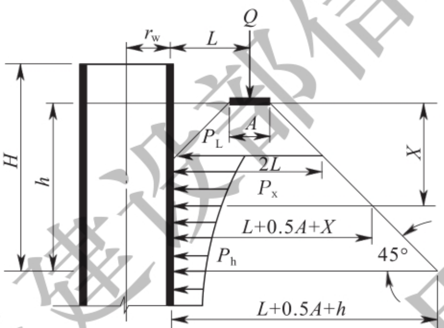

Figure B.1.1 Maximum lateral pressure on shaft lining caused by foundation

h–Base bottom to calculated depth distance(m). H–Distance from design elevation of the shaft mouth to calculated depth(m). X–The distance from the bottom of the foundation to a certain depth within the calculated depth(m). P_L–Lateral pressure on the shaft lining beneath the foundation bottom at the depth of L(MPa). P_h–Lateral pressure on the shaft lining beneath the foundation bottom at the depth of h(MPa). P_x–Lateral pressure on the shaft lining beneath the foundation bottom at the depth of x(MPa).

1 Strip foundation shall be calculated according to the following formula:

$$P_{max}=\frac{QA_n}{2L(2L-A+B)} \tag{B.1.1-1}$$

2 Circular foundation shall be calculated according to the following formulas:

$$P_{max}=\frac{QA_n}{\pi[(rw+2L)^2-r_w^2]w} \tag{B.1.1-2}$$

$$A_n=\tan^2\left(45°-\frac{\phi}{2}\right) \tag{B.1.1-3}$$

Where, P_{max}—The calculation value of the maximum lateral pressure on the shaft lining caused by foundation(MPa).

Q—Calculation value of total gravity at the upper part of the foundation(include dead weight of the foundation)(MN).

A_n—Horizontal load coefficient of rock (soil) layer which may be calculated according to Formula B.1.1-3 or Table 6.2.3 of this code.

ϕ—Internal friction angle of soil layer(°), see Table 6.2.2 of this code.

L—Distance from the center of the foundation to the outside of the shaft lining(m).

A—Strip foundation or circular foundation width(m).

B—Strip foundation or circular foundation length(m).

B.1.2 Internal force of circular cross section of the shaft lining shall be calculated inaccordance with the following requirements:

1 In case that the hoist tower (or headframe) foundation is strip foundation, internal force of circular cross section of the shaft lining (Figure B. 1.2) shall be calculated according to the following formula:

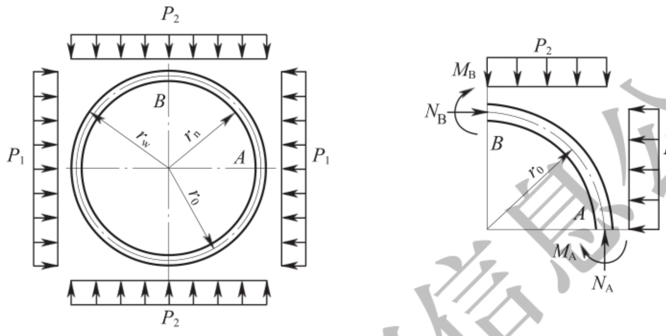

Figure B.1.2 Calculation diagramof internal force of circular cross section of the shaft lining

1) Internal force of A cross section shall be calculated according to the following formulas:

$$N_A = r_w P_2 \tag{B.1.2-1}$$

$$M_A = -0.25 r_w^2 (P_2 - P_1) \tag{B.1.2-2}$$

2) Internal force of B cross section shall be calculated according to the following formulas:

$$N_B = r_w P_1 \tag{B.1.2-3}$$

$$M_B = 0.25 r_w^2 (P_2 - P_1) \tag{B.1.2-4}$$

Where, P_1, P_2—Maximum lateral pressure in each direction shall be calculated according to Formula (B.1.1-1).

2 When the hoist tower (headframe) foundation is circular foundation, the calculation of the internal force of circular cross section of the shaft lining shall meet the relevant requirements of Appendix A.1 of this code.

B.2 Calculation of shaft lining affected by hoist tower which directly sits on the shaft

B.2.1 In case that hoist tower directly sits on the shaft, the stress on the shaft lining in the influenced section shall be calculated by m method (Figure B. 2.1) and be in accordance with the following requirements:

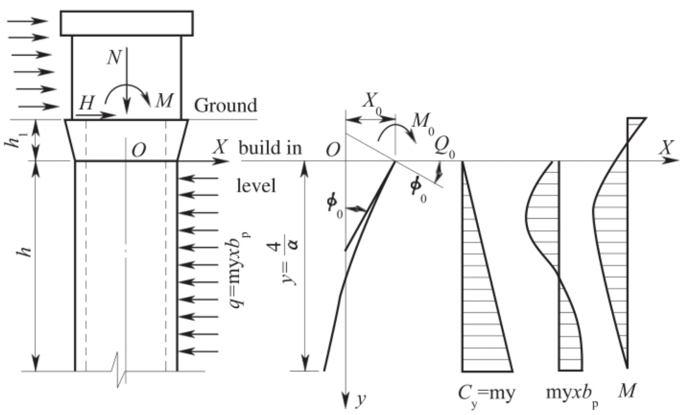

Figure B.2.1 Calculation diagram of m method

1 Calculation width of foundation(shaft)should calculated according to the following formula:

$$B_p = 0.9(D+1) \quad \text{(B.2.1-1)}$$

Where, B_p—Calculated width of foundation(shaft).

D—External diameter(m).

2 The deformation coefficient of the foundation shall be calculated according to the following formulas:

$$a = \sqrt[5]{\frac{mb_p}{E_c I}} \quad \text{(B.2.1-2)}$$

$$I = \pi(D^4 - d^4)/64 \quad \text{(B.2.1-3)}$$

Where, a—The deformation coefficient of the foundation(1/m).

m—The deformation coefficient of the foundation(MN/m^4) may be selected according to Table B.2.1-1.

d—Internal diameter of shaft(m).

I—Inertia moment of the shaft cross section(m^4).

Table B.2.1-1 The deformation coefficient of the ground

Classification of soil	The deformation coefficient of the ground M(MN/m^4)
Mud, mucky soil, saturated collapsible loess	2.5–6
Flow plastic clayl($I_L>1$, soft plastic clay($0.75<I_L\leq1$), $e>0.9$ silt, loose fine sand, loose and dense earth filling	6–14
Plastic clay($0.25<I_L\leq0.75$), collapsible loess $e=0.75-0.9$ silt, medium density earth filling, fine sand	14–35
Hard plastic clay($0<I_L\leq0.25$), hard clay($I_L\leq0$), collapsible loess, $e<0.75$ silt medium density medium coarse sand, dense earth filling	35–100
Medium dense and dense grit and gravel-soil	100–300

Note: I_L—Liquid index.

e—Void ratio.

3 The influence depth of hoist tower foundation on the shaft shall be calculated according to the following formula.

$$y = \frac{4}{a} \quad \text{(B.2.1-4)}$$

Where, y—The influence depth of hoist tower foundation on the shaft(m).

4 The transverse displacement x_0 and rotation angle Ψ_0 at the embedded level shall be calculated according to the the following formulas:

$$x_0 = Q_0\delta_{QQ} + M_0\delta_{QM} \quad \text{(B.2.1-5)}$$

$$\Psi_0 = -(Q_0\delta_{MQ} + M_0\delta_{MM}) \quad \text{(B.2.1-6)}$$

$$\delta_{QQ} = \frac{2.441}{a^3 E_c I} \quad \text{(B.2.1-7)}$$

$$\delta_{QM} = \delta_{MQ} = \frac{1.625}{a^2 E_c I} \quad \text{(B.2.1-8)}$$

$$\delta_{MM} = \frac{1.751}{a E_c I} \quad \text{(B.2.1-9)}$$

Where, x_0, Ψ_0—The transverse displacement and rotation angle at the embedded level of the hoist tower foundation.

Q_0, M_0—Calculation values of horizontal force and bending moment of the hoist tower acting on the foundation.

δ_{QQ}—Displacement when $M_0=0, Q_0=1$

δ_{QM}—Displacement when $Q_0=0, M_0=1$

δ_{MQ}—Rotation angle when $M_0=0, Q_0=1$

δ_{MM}—Rotation angle when $M_0=1, Q_0=0$

E_c—Elastic modulus of concrete(N/mm^2).

I—Inertia moment of shaft cross section(m^4).

5 The bending moment and lateral horizontal compressed stress along the shaft depth below the embedded level shall be calculated according to the following formulas:

$$M_y = a^2 E_c I X_0 A_3 + a E_c I \Psi_0 B_3 + M_0 C_3 + \frac{Q_0}{a} D_3 \quad \text{(B.2.1-10)}$$

$$\sigma_x = m \cdot y \left(x_0 A_1 + \frac{\Psi_0}{a} B_1 + \frac{M_0}{a^2 E_c I} C_1 + \frac{Q_0}{a^3 E_c I} D_1 \right) \quad \text{(B.2.1-11)}$$

Where, $A_3, B_3, C_3, D_3, A_1, B_1, C_1, D_1$—Coefficient see Table B.2.1-2.

M_y—The bending moment along the shaft depth below the embedded level(MN·m).

σ_x—Lateral horizontal compressed stress along the shaft depth below the embedded level(MN/m^2).

6 Bearing capacity of cross section of shaft lining at the upper part of the shaft shall be calculated in accordance with the following requirements:

1) According to, the maximum bending moment M_{max} and the vertical force N of this point in the depth $y=4/a$ ranage, the eccentricity shall be calculated according to the following formula (the sum of axial force at embedded surface N_0 and the dead weight of the shaft lining above the calculated position).

$$e_0 = \frac{M_{max}}{N} \quad \text{(B.2.1-12)}$$

2) Calculated length L_0 (longitudinal buckling length) shall be calculated according to the longitudinal buckling length:

$$\text{When } h<4/a, L_0=h_1+h \quad \text{(B.2.1-13)}$$

$$\text{When } h\geqslant 4/a, L_0=h_1+4/a \quad \text{(B.2.1-14)}$$

Where, h—The height from calculated level to embedded level(m).

h_1—Height of large block foundation of hoist tower above the shaft(m).

Table B.2.1-2 The values of *A*、*B*、*C*、*D* coefficients

Depth of the conversion $h=ay$	A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2
0	1.000 00	0.000 00	0.000 00	0.000 00	0.000 00	1.000 00	0.000 00	0.000 00
0.1	1.000 00	0.100 00	0.005 00	0.000 17	0.000 00	1.000 00	0.100 00	0.005 00
0.2	1.000 00	0.200 00	0.020 00	0.001 33	−0.000 07	1.000 00	0.200 00	0.020 00
0.3	0.999 98	0.300 00	0.045 00	0.004 50	−0.000 34	0.999 96	0.300 00	0.045 00
0.4	0.999 91	0.399 99	0.080 00	0.010 67	−0.001 07	0.999 83	0.399 98	0.080 00
0.5	0.999 74	0.499 96	0.125 00	0.020 83	−0.002 60	0.999 48	0.499 94	0.124 99

Table B.2.1-2 (continued)

Depth of the conversion $h=ay$	A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2
0.6	0.999 35	0.599 87	0.179 98	0.036 00	−0.005 40	0.998 70	0.599 81	0.179 98
0.7	0.998 60	0.699 67	0.244 95	0.057 16	−0.010 00	0.997 20	0.699 51	0.244 94
0.8	0.997 27	0.799 27	0.319 88	0.085 32	−0.017 07	0.994 54	0.798 91	0.319 83
0.9	0.995 08	0.898 52	0.404 72	0.121 46	−0.027 33	0.990 16	0.897 79	0.404 62
1.0	0.991 67	0.997 22	0.499 41	0.166 57	−0.041 67	0.983 33	0.995 83	0.499 21
1.1	0.986 58	1.095 08	0.603 84	0.221 63	−0.060 96	0.973 17	1.092 62	0.603 46
1.2	0.979 27	1.191 71	0.717 87	0.287 58	−0.086 32	0.958 55	1.187 56	0.717 16
1.3	0.969 08	1.286 60	0.841 27	0.365 36	−0.118 83	0.938 17	1.279 90	0.840 02
1.4	0.955 23	1.379 10	0.973 73	0.455 88	−0.159 73	0.910 47	1.368 65	0.971 63
1.5	0.936 81	1.468 39	1.114 84	0.559 97	−0.210 30	0.873 65	1.452 59	1.111 45
1.6	0.912 80	1.553 46	1.264 03	0.678 42	−0.271 94	0.825 65	1.530 20	1.258 72
1.7	0.882 01	1.633 07	1.420 61	0.811 93	−0.346 04	0.764 13	1.599 63	1.412 47
1.8	0.843 13	1.705 75	1.583 62	0.961 09	−0.434 12	0.686 45	1.658 67	1.571 50
1.9	0.794 67	1.769 72	1.751 90	1.126 37	−0.537 68	0.589 67	1.704 68	1.734 22
2.0	0.735 02	1.822 94	1.924 02	1.308 01	−0.658 22	0.470 61	1.734 57	1.898 72
2.2	0.574 91	1.887 09	2.272 17	1.720 42	−0.956 16	0.151 27	1.731 10	2.222 99
2.4	0.346 91	1.874 50	2.608 82	2.195 35	−1.338 89	−0.302 73	1.612 86	2.518 74
2.6	0.033 15	1.754 73	2.906 70	2.723 65	−1.814 79	−0.926 02	1.334 85	2.149 12
2.8	−0.385 48	1.490 37	3.128 43	3.287 69	−2.387 56	−1.754 83	0.841 77	2.866 53
3.0	−0.928 09	1.036 79	3.224 71	3.858 38	−3.053 19	−2.824 10	0.068 37	2.804 06
3.5	−2.927 99	−1.271 72	2.463 04	4.979 82	−4.980 62	−6.708 06	−3.586 47	1.270 18
4.0	−5.853 33	−5.940 97	−0.926 77	4.547 80	−6.533 16	−12.158 10	−10.608 40	−3.766 47

Depth of the conversion $h=ay$	A_3	B_3	C_3	D_3	A_4	B_4	C_4	D_4
0	0.000 00	0.000 00	1.000 00	0.000 00	0.000 00	0.000 00	0.000 00	1.000 00
0.1	−0.000 17	−0.000 01	1.000 00	0.100 00	−0.005 00	−0.000 33	−0.000 01	1.000 00
0.2	−0.001 33	−0.000 13	0.999 99	0.200 00	−0.020 00	−0.002 67	−0.000 20	0.999 99
0.3	−0.004 50	−0.000 67	0.999 94	0.300 00	−0.045 00	−0.009 00	−0.001 01	0.999 92
0.4	−0.010 67	−0.002 13	0.999 74	0.399 98	−0.080 00	−0.021 33	−0.003 20	0.999 66
0.5	−0.020 83	−0.005 21	0.999 22	0.499 91	−0.124 99	−0.041 67	−0.007 81	0.998 96
0.6	−0.036 00	−0.010 80	0.998 06	0.599 14	−0.179 97	−0.071 99	−0.016 20	0.997 41
0.7	−0.057 16	−0.020 01	0.995 80	0.699 35	−0.244 90	−0.114 33	−0.030 01	0.994 40
0.8	−0.085 32	−0.034 12	0.991 81	0.798 54	−0.319 15	−0.170 60	−0.051 20	0.989 08
0.9	−0.121 44	−0.054 66	0.985 24	0.897 05	−0.404 43	−0.242 84	−0.081 98	0.980 32
1.0	−0.166 52	−0.083 29	0.915 01	0.994 45	−0.498 81	−0.332 98	−0.124 93	0.966 67
1.1	−0.221 52	−0.121 92	0.959 75	1.090 16	−0.602 68	−0.442 92	−0.182 85	0.946 34
1.2	−0.287 37	−0.172 60	0.937 83	1.183 42	−0.715 73	−0.574 50	−0.268 86	0.917 12

Table B.2.1-2(continued)

Depth of the conversion $h=ay$	A_3	B_3	C_3	D_3	A_4	B_4	C_4	D_4
1.3	−0.364 96	−0.237 60	0.907 27	1.273 20	−0.837 53	−0.729 50	−0.356 31	0.876 38
1.4	−0.455 15	−0.319 33	0.865 73	1.358 21	−0.967 46	−0.909 54	−0.478 83	0.821 02
1.5	−0.558 70	−0.420 39	0.810 54	1.436 80	−1.104 68	−1.116 09	−0.630 27	0.747 45
1.6	−0.676 29	−0.543 48	0.738 59	1.506 95	−1.248 08	−1.350 42	−0.814 66	0.651 56
1.7	−0.808 48	−0.691 44	0.646 37	1.566 21	−1.396 23	−1.613 46	−1.036 16	0.528 71
1.8	−0.955 64	−0.867 15	0.529 97	1.611 62	−1.547 28	−1.905 77	−1.299 09	0.373 68
1.9	−1.117 96	−1.073 75	0.385 03	1.639 69	−1.698 89	−2.227 45	−1.607 70	0.180 71
2.0	−1.295 35	−1.313 61	0.206 76	1.646 28	−1.848 18	−2.577 98	−1.966 20	−0.056 52
2.2	−1.693 34	−1.905 67	−0.270 87	1.575 38	−2.124 81	−3.359 52	−2.848 58	−0.691 58
2.4	−2.141 17	−2.663 29	−0.948 85	1.352 01	−2.339 01	−4.228 11	−3.973 23	−1.591 51
2.6	−2.621 26	−3.599 87	−1.877 34	0.916 19	−2.436 95	−5.140 23	−5.355 41	−2.821 06
2.8	−3.103 41	−4.717 48	−3.107 91	0.191 29	−2.345 58	−6.022 99	−6.990 07	−4.444 91
3.0	−3.540 58	−5.999 79	−4.687 88	−0.891 26	−1.969 28	−6.764 60	−8.840 29	−6.519 72
3.5	−3.919 21	−9.543 67	−10.340 40	−5.854 02	1.074 08	−6.788 95	−13.692 40	−13.826 10
4.0	−1.614 28	−11.730 70	−17.918 60	−15.075 50	9.243 68	−0.357 62	−15.610 50	−23.140 40

3)Eccentric compression bearing capacity of cross section of shaft lining shall be calculated according to the following formulas:

$$N \leqslant a_1 a_0 f_c A_0 + (a_0 - a_t) f'_y A_z \quad \text{(B.2.1-15)}$$

$$N\eta e_i \leqslant a_1 f_c A_0 (r_n + r_w) \frac{\sin\pi a_0}{2\pi} + f_y A_z r_0 \frac{\sin\pi a_0 + \sin\pi a_t}{\pi} \quad \text{(B.2.1-16)}$$

Where, a_0—Ratio of compressed concrete section area to full concrete cross section area.

a_t—Ratio of tensile longitudinal reinforcing steel bar's cross section area to all longitudinal reinforcing steel bar's cross section area. When $a_0 > 2/3$, $a_t = 0$.

The coefficients and eccentricity moments in the above formulas shall be calculated according to the following formulas:

$$a_t = 1 - 1.5 a_0 \quad \text{(B.2.1-17)}$$

$$e_i = e_0 + e_a \quad \text{(B.2.1-18)}$$

7 In the depth range of $y=4/a$, the circumferential bearing capacity of the shaft lining shall be checked by maximum value of the combination of elastic resistance σ_x and soil and water pressure on the shaft lining caused by soil layer.

Appendix C　Connection and calculation for flange plate

C.1　Connection for flange plate

C.1.1　Flange plate connection of shaft lining shall be in accordance with the following requirements:

1　In case that the flange plate is required to be connected by bolt for the shaft lining hoisted by the embedded ring, the bolt spacing of the inner edge should be arranged according to 300mm to 500mm, and the diameter of the connecting bolt may be 16mm to 24mm. Continuous and full welding shall be adopted on the outer edge of shaft lining flange plate, and the height of weld joint shall not be less than 10mm.

2　In case that the shaft lining is lifted by hoisting cap, bolt holes may also be reserved on the outer edge of the upper flange plate as needed. The diameter of the connecting bolt may be calculated according to the following formula:

$$d_0 = \sqrt{\frac{4 \times 0.9 \times \nu_d \nu_2 Q_j}{\pi n f_t^b}} \tag{C.1.1}$$

Where, d_0—Connecting bolt diameter(mm).

ν_d—Hoisting dynamic coefficient, $\nu_d = 1.5$.

ν_2—Unevenly stressed coefficient, ν_2 equals to 1.2.

Q_j—Hoisting shaft lining dead weight(N).

n—Bolts number(piece).

f_t^b—Design value of tensile strength of bolt(N/mm^2).

0.9—Temporary hoisting and transportation checking discount coefficient.

C.2　Calculation of flange plate

C.2.1　Flange plate calculation of shaft lining be in accordance with the following requirements:

1　In case that the shaft lining is hoisted by hoisting ring or hoisting bolt, the type of profile steel or steel plate cylinder thickness of the shaft lining flange plate shall be selected according to the structural requirements.

2　In case that the shaft lining is lifted by hoisting cap, the thickness of steel flange plate or steel plate cylinder may be calculated according to the following formulas.

$$\delta = \sqrt{\frac{6\nu_3 M}{f}} \tag{C.2.1-1}$$

$$M = \beta q l_1^2 \tag{C.2.1-2}$$

$$q = \frac{0.9\nu_d \nu_4 Q_f}{A} \tag{C.2.1-3}$$

Where, δ—The thickness of steel flange plate or steel plate cylinder(mm).

ν_3—Unevenly stressed coefficient, $\nu_3 = 1.5$.

ν_4—Safety coefficient of strength design during transportation and hoisting, $\nu_4 = 1.5$.

M—Calculated bending moment(N·m/m).

f—Strength design value of flange plate material(N/mm^2).

β—Bending moment calculation coefficient may be selected from Table C.2.1.

q—Calculating load concentration on flange(N/mm^2).

A—Flange plate area(mm^2).

l_1—Flange stiffened intercostal distance(mm).

Q_f—Vertical hoisting force on flange when hoisting(N).

Table C.2.1 Bending moment calculation coefficient β

l_2/l_1	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	2.0	∞
β	0.06	0.074	0.088	0.097	0.107	0.112	0.120	0.126	0.132	0.133

Note: l_2 is the calculating width of flange plate(mm), profile steel flange is the flange width of box iron, steel flange plate is the width of the flange.

3 Leg-connection welding shall be used between the adapting piece of the flange, and the welding joint height may be calculated according to the following formula but it should not be less than 8mm.

$$h_f = \frac{0.9\nu_d \nu_3 Q_h}{0.7 L_w f_t^w} \qquad (C.2.1\text{-}4)$$

Where, h_f—Calculating height of fillet weld(mm).

Q_h—External force value acting on the welding joint in the calculation part(N).

L_w—Sum of calculated lengths of fillet welds(mm).

f_t^w—Design value of shear strength of fillet weld(N/mm^2).

Appendix D Calculation for circumferential internal force and reinforcement of shaft lining under non-uniform pressure

D.1 Calculation for circumferential internal force of shaft lining under non-uniform pressure

D.1.1 Axial force and bending moment of circumferential cross section of shaft lining shall be calculated according to the following formulas(Figure D.1.1):

1 In case that $\omega=0°$(cross section A), axial force N_A and bending moment M_A of circumferential cross section A of the shaft lining shall be calculated according to the following formulas:

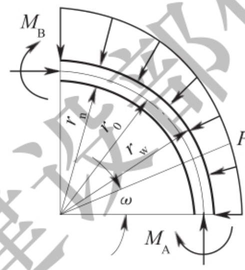

Figure D.1.1 Calculation for internal force of shaft lining

$$N_A=(1+0.785\beta_z)\,r_w\,P_A \tag{D.1.1-1}$$

$$M_A=-0.149\beta_z r_w^2\,P_A \tag{D.1.1-2}$$

2 In case that $\omega=90°$(cross section B), axial force N_B and bending moment M_B of circumferential cross section B of the shaft lining shall be calculated according to the following formulas:

$$N_B=(1+0.5\beta_z)\,r_w\,P_A \tag{D.1.1-3}$$

$$M_B=0.137\beta_z r_w^2\,P_A \tag{D.1.1-4}$$

$$P_B=P_A(1+\beta_z) \tag{D.1.1-5}$$

3 After calculation according to the formula $\omega=0°$ and $\omega=90°$, eccentricity and bearing force shall be calculated as needed.

D.2 Calculation for circumferential reinforcement

D.2.1 Circumferential reinforcement shall be calculated according to formula in Appendix A.1.2.

D.3 Calculation of vertical reinforcement

D.3.1 Vertical reinforcement of shaft hoisting shall be calculated according to the following formulas:

$$A_{sy}=\frac{\nu_3\nu_d N_z}{f_y} \tag{D.3.1-1}$$

$$N_z=N_{z,k} \tag{D.3.1-2}$$

Where, A_{sy}—Cross section area of vertical reinforcement of shaft lining(mm^2).

N_z—Vertical load calculation value on shaft lining during hoisting(MN).

D.3.2 In case of calculating vertical reinforcement according to crack resistance of shaft lining, it shall be calculated according to the following formulas:

$$\nu_d\nu_f N_z\leqslant f_t(A+2nA_{sy}) \tag{D.3.2-1}$$

$$n = E_s / E_c \qquad (D.3.2\text{-}2)$$

Where, ν_f—Safety coefficient of crack resistance equals to 1.5.

f_t—Design value of axial tensile strength of concrete(MN/m^2).

A—Cross section area of shaft lining(m^2).

n—Ratio of elasticity modulus between reinforcement and concrete.

E_s—Elasticity modulus of reinforcement(N/mm^2).

D.3.3 In case that vertical reinforcement is calculated according to vertical uniform ground pressure, it shall be calculated according to formula in Appendix A.4 of this code.

Appendix E　Calculation for hemispherical and snick bottom of shaft lining

E.1　Calculation of inner force of hemispherical or snick bottom of shaft lining

E.1.1　Inner force of hemispherical or snick bottom of shaft lining may be calculated according to the following formulas(Figure E.1.1):

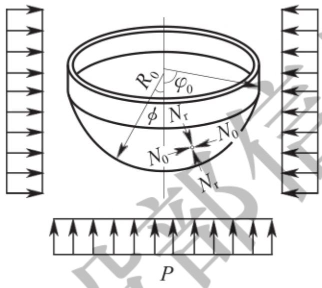

Figure E.1.1　Calculation diagram of inner force of hemispherical and snick bottom of shaft lining

$$N_r = \frac{1}{2} P_g R_0 \tag{E.1.1-1}$$

$$N_0 = \frac{1}{2} P_g R_0 \tag{E.1.1-2}$$

$$U = \frac{1}{4} P_g R_0^2 \sin 2\varphi_0 \tag{E.1.1-3}$$

$$P_g = P_w - P_n \tag{E.1.1-4}$$

$$P_w = \nu_{k,w} P_{w,k} \tag{E.1.1-5}$$

$$P_n = \nu_{k,n} P_{n,k} \tag{E.1.1-6}$$

Where, R_0—Average radius of spherical shell thickness(m).

P_g—Calculation value of pressure at the bottom of the shaft lining(MPa).

P_w—Calculation value of mud pressure(MPa).

$P_{w,k}$—Characteristic value of mud pressure(MPa).

P_n—Calculation value of additional water weight pressure(MPa).

$P_{n,k}$—Characteristic value of additional water weight pressure(MPa).

φ_0—Half of the central angle corresponding to the snick shell.

N_r—Calculation value of radial inner force of snick shell(MN/m).

N_0—Calculation value of zonal inner force of snick shell(MN/m).

$\nu_{k,w}$—Safety coefficient of shaft bottom under the action of mud.

$\nu_{k,n}$—Safety coefficient of shaft bottom under the action of additional water weight.

U—Calculation value of inner force of supporting ring(MN).

E.2　Calculation of reinforcement of hemispherical or snick bottom of shaft lining

E.2.1　Calculation of reinforcement of hemispherical and snick bottom of shaft lining shall be in accordance with the following requirements:

1　Reinforcement of hemispherical and snick bottom of shaft lining shall be calculated according to the following formula:

$$A_g = \frac{N - f_c t}{f'_y} \tag{E.2.1-1}$$

Where, N—Calculation value of inner force of snick shell(MN/m), $N=N_r$ or $N=N_0$.

t—Spherical shell thickness(m).

2 Tensile reinforcement which is used for supporting ring at shaft bottom, the axial tension member under the action of uniform pressure shall be calculated according to the following formula:

$$A_g = \frac{U}{f_y} \tag{E.2.1-2}$$

3 In case that hemispherical shaft bottom is adopted, $\varphi_0=90°$, $U=0$, the reinforcement is according to the structure.

Appendix F Calculation for semielliptical rotary shallow spherical shell bottom of shaft lining

F.1 Calculation for inner force at the interface of shaft and shell

F.1.1 Calculation for inner force N_0 of semielliptical rotary shallow spherical shell bottom of the shaft lining (Figure F.1.1) and the interface of the shell shall be calculated according to the following formula:

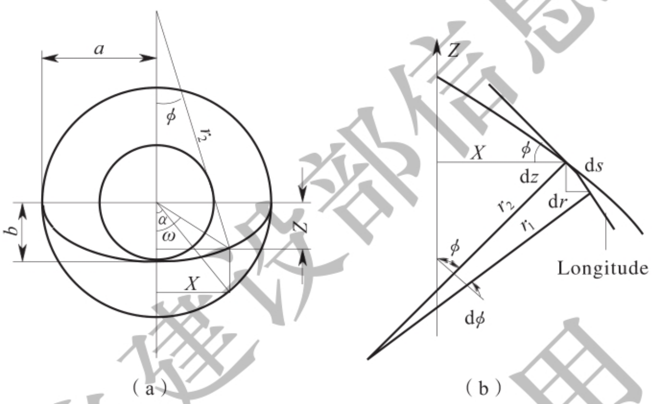

Figure F.1.1 Calculation diagram of semielliptical rotary shallow spherical shell bottom of shaft lining

$$N_0 = \frac{P_g a^2}{8\lambda b^2} \tag{F.1.1}$$

Where, N_0—Calculation value of inner force of shaft and shell interface (MN/m).

a—Radius of shaft thickness midline (m).

b—Height of shell thickness midline (m), $\frac{1}{2}a$ may be taken.

F.2 Calculation for inner force of shaft and reinforcement

F.2.1 Inner force of shaft under load (Figure F.2.1) may be calculated according to the following formula:

1 Circular inner force of shaft influenced by P_g should be calculated according to the following formula:

$$N_{2T}^{P_g} = P_g a \tag{F.2.1-1}$$

Where, $N_{2T}^{P_g}$—Calculation value of circular inner force of shaft influenced by P_g (MN/m).

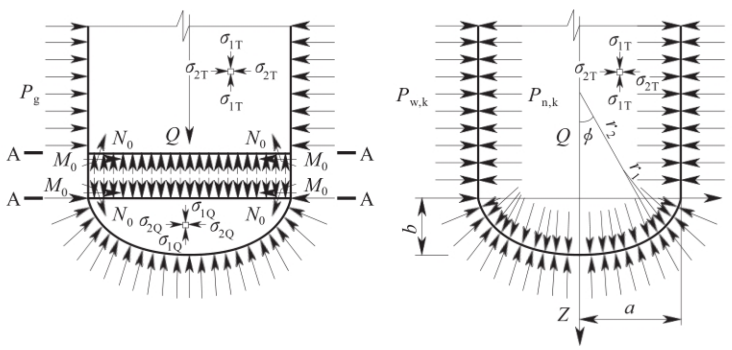

Figure F.2.1 Force diagram of semielliptical rotary shallow spherical shell bottom of shaft lining

2 Radial inner force of shaft influenced by shaft lining dead weight Q_{Z1} shall be calculated according to the following formula:

$$N_{1T}^{Q_{Z1}} = \frac{Q_{Z1}}{2\pi a} \tag{F.2.1-2}$$

Where, $N_{1T}^{Q_{Z1}}$—Calculation value of radial inner force of shaft influenced by Q_{Z1} (MN/m).

3 Inner force of shaft influenced by horizontal force N_0 shall be calculated according to the following formula:

1) Radial bending moment of shaft influenced by horizontal force N_0 should be calculated according to the following formula:

$$M_{1T}^{N_0} = \frac{1}{\lambda} N_0 e^{-\lambda x} \sin\lambda x \tag{F.2.1-3}$$

Where, $M_{1T}^{N_0}$—Calculation value of radial bending moment of shaft influenced by horizontal force N_0 (MN·m/m).

2) Circular inner force of shaft influenced by horizontal force N_0 should be calculated according to the following formula:

$$N_{2T}^{N_0} = -2N_0 \lambda a e^{-\lambda x} \cos\lambda x \tag{F.2.1-4}$$

Where, $N_{2T}^{N_0}$—Calculation value of circular inner force of shaft influenced by horizontal force N_0 (MN/m).

F.2.2 Reinforcement of shaft under load shall be calculated according to the following formulas:

1 Vertical reinforcement should be calculated according to the following formulas:

$$N_{1T}^{Q_{Z1}} e \leqslant 0.5 f_c b_n t_0^2 + f'_y A'_y (t_0 - a'_s) \tag{F.2.2-1}$$

$$e = \frac{t}{2} - a_s + e_0 \tag{F.2.2-2}$$

$$e_0 = \frac{M_{1T\max}^{N_0}}{N_{1T}^{Q_{Z1}}} \tag{F.2.2-3}$$

2 Circular reinforcement should be calculated according to the following formula:

$$A'_y = \frac{N_{\max} - f_c t}{f_y} \tag{F.2.2-4}$$

Where, $N_{\max}$—Sum of absolute values of maximum value of tensile and pressure of $N_{2T}^{N_0}$ according to Formula (F.2.1-4) (MN/m).

A'_y—Cross section area of reinforcement (m^2/m).

F.3 Calculation for inner force and reinforcement of the shell

F.3.1 Inner force of the shell influenced by the load shall be calculated according to the following formulas:

1) Inner force of the shell along the tangent line which influenced by P_g should be calculated according to the following formulas:

$$N_{1Q}^{P_g} = \frac{P_g r_2}{2} \tag{F.3.1-1}$$

$$r_2 = \frac{\sqrt{a^4 Z^2 + b^4 x^2}}{b^2} \tag{F.3.1-2}$$

Where, $N_{1Q}^{P_g}$—Calculation value of inner force of the shell along the tangent line which influenced by P_g (MN/m).

r_2—The length between the intersection point (normal and rotation axis of meridian) and the hook face of the shell (m).

Z, x—Coordinate value of calculated point (m).

2) Bending moment of the shell along the tangent line which influenced by N_0 shall be calculated according to the following formulas:

$$M_{1Q}^{N_0} = \frac{P_g a t}{\sqrt{12(1-\nu_c^2)}} e^{-\beta} \sin\beta \tag{F.3.1-3}$$

$$\beta = \sqrt[4]{3(1-\nu_c^2)} \sum \frac{\Delta S}{\sqrt{r_2 t}} \tag{F.3.1-4}$$

$$S = \int_0^\alpha \sqrt{a^2 - (a^2 - b^2)\sin^2\alpha}\, d\alpha \tag{F.3.1-5}$$

$$K = \sqrt{\frac{a^2 - b^2}{a^2}} \tag{F.3.1-6}$$

$$E(\alpha \cdot K) = \int_0^\alpha \sqrt{1 - K^2 \sin^2\alpha}\, d\alpha \tag{F.3.1-7}$$

In case that $\frac{a}{b} = 2$, K=0.866, $\sin^{-1}K$=60°elliptic integral numerical Table $\sin^{-1}K$=60°, the value of $E(\alpha \cdot K)$ of different a is as follows:

$$S = a \cdot E(\alpha \cdot K) \tag{F.3.1-8}$$

Where, $M_{1Q}^{N_0}$—Calculation value of bending moment of the shell along the tangent line which influenced by N_0(MN·m/m).

ν_c—Poisson's ratio of concrete.

3)Stress of the shell along the tangent line which influenced by load should be calculated according to the following formulas:

$$\sigma_{1Q}^{N_0} = \frac{6}{t^2} M_{1Q}^{N_0} \tag{F.3.1-9}$$

$$\sigma_{1Q}^{P_g} = \frac{1}{t} N_{1Q}^{P_g} \tag{F.3.1-10}$$

$$\sigma_1 = \sigma_{1Q}^{N_0} + \sigma_{1Q}^{P_g} \tag{F.3.1-11}$$

Where, $\sigma_{1Q}^{N_0}$—Calculation value of shell stress along the tangent line which influenced by N_0(MPa).

$\sigma_{1Q}^{P_g}$—Calculation value of shell stress along the tangent line which influenced by P_g(MPa).

σ_1—Calculation value of shell stress along the tangent line which influenced by load(MPa).

2 Circular inner force of shell which influenced by P_g and N_0 should be calculated according to the following formula:

1)Circular inner force of shell which influenced by P_g should be calculated according to the following formulas:

$$N_{2Q}^{P_g} = P_g \left(r_2 - \frac{r_2^2}{2r_1} \right) \tag{F.3.1-12}$$

$$r_1 = \frac{\sqrt{(a^4 Z^2 + b^4 x^2)^3}}{a^4 b^4} \tag{F.3.1-13}$$

Where, $N_{2Q}^{P_g}$—Calculation value of circular inner force of shell which influenced by P_g(MN/m).

r_1—Radius of curvature of meridians(m).

2)Inner force of the shell along the tangent line which influenced by N_0 should be calculated according to the following formula:

$$N_{2Q}^{N_0} = P_g a e^{-\beta} \cdot \cos\beta \tag{F.3.1-14}$$

Where, $N_{2Q}^{N_0}$—Calculation value of circular inner force of the shell which influenced by N_0(MN/m).

3)Circular stress of the shell which influenced by load should be calculated according to the following formulas:

$$\sigma_{2Q}^{N_0} = \frac{1}{t} N_{2Q}^{N_0} \tag{F.3.1-15}$$

$$\sigma_{2Q}^{P_g} = \frac{1}{t} N_{2Q}^{P_g} \tag{F.3.1-16}$$

$$\sigma_2 = \sigma_{2Q}^{N_0} + \sigma_{2Q}^{P_g} \tag{F.3.1-17}$$

Where, $\sigma_{2Q}^{N_0}$—Calculation value of circular stress of shell which influenced by N_0(MPa).

$\sigma_{2Q}^{P_g}$—Calculation value of circular stress of shell which influenced by P_g(MPa).

σ_2—Calculation value of circular stress of shell which influenced by load(MPa).

F.3.2 Reinforcement of shell under load shall be calculated according to the following formula:

1 The value of σ_1, σ_2 with different angle when ω =90°, 85°, 80°, 75°, ..., 0°, shall be obtained respectively during the calculation of shell stress which influenced by load. The reinforcement of shell shall be calculated according to σ_{1max}, σ_{2max}, the formula is as follows:

$$\sigma_{max} \leqslant f_c + \rho f'_y \tag{F.3.2-1}$$

Where, ρ—Steel ratio of shaft lining cross section(%).

σ_{max}—The maximum calculation value of shell stress along the tangent line and hoop stress which influenced by load according to Formula (F.3.1-11) and Formula (F.3.1-17), $\sigma_{max}=\sigma_{1max}$ or $\sigma_{max}=\sigma_{2max}$.

2 Steel ratio of shaft lining cross section ρ and cross section area of reinforcement A shall be calculated according to the following formula:

1) In case that $\sigma_{max} \leqslant f_c$, the reinforcement shall be according to the structure. When $\sigma_{max} > f_c$, the steel ratio should according to the following formula:

$$\rho = \frac{\sigma_{max} - f_c}{f_y} \tag{F.3.2-2}$$

2) In case that $\rho > \rho_{min}$, A_s should be calculated according to the following formula:

$$A_s = \rho b (r_w - r_n) \tag{F.3.2-3}$$

3) In case that $\rho \leqslant \rho_{min}$, A_s should be calculated according to the following formula:

$$A_s = \rho_{min} b (r_w - r_n) \tag{F.3.2-4}$$

Where, b—Calculated width of shaft lining cross section(m) takes 1.0m.

ρ_{min}—Minimum steel ratio(%), ρ_{min}=0.8%.

4) If ρ is too large, the shaft lining shall be thickened.

F.4 Calculation for shallow plate effect of the shell top

F.4.1 Shallow plate effect shall be calculated according to the following formula:

1 Shallow plate effect should adopt ϕ=10° (Figure F. 4.1) and calculated according to the following formulas:

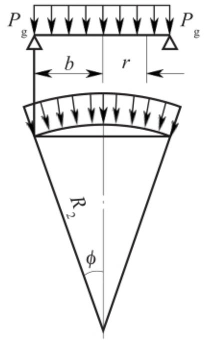

Figure F.4.1 Calculation diagram of shallow plate effect

$$R_2 = \frac{a^2}{(a^2 \sin^2\phi + b^2 \cos^2\phi)^{\frac{1}{2}}} \quad \text{(F.4.1-1)}$$

$$b = R_2 \sin\phi \quad \text{(F.4.1-2)}$$

2 Radial bending moment shall be calculated according to the following formula:

$$M_1 = \frac{P_g}{16}(3+\mu)(b^2 - r^2) \quad \text{(F.4.1-3)}$$

3 Tangential bending moment shall be calculated according to the following formula:

$$M_2 = \frac{P_g}{16}[(3+\mu)b^2 - (1+3\mu)r^2] \quad \text{(F.4.1-4)}$$

Where, M_1, M_2—Calculation value of tangential bending moment and radial bending moment of the top shell(MN·m/m).

4 In case that $r=0$, the calculation of M_{1max}, M_{2max} reinforcement. In case that the central part bending moment is large, the steel plate cylindermay displace reinforcement.

F.5 Checking calculation of float of the bottom of shaft lining

F.5.1 Float of the bottom of shaft lining shall be checked according to the following formulas:

$$V_n \gamma_w > (V_Q + V_T)\gamma_h \quad \text{(F.5.1-1)}$$

$$V_Q = \frac{2}{3}\pi(R_1^2 H_w - R_2^2 H_n) \quad \text{(F.5.1-2)}$$

$$V_T = \pi(R_1^2 - R_2^2)H_T \quad \text{(F.5.1-3)}$$

$$V_n = \pi R_1^2 H_T + \frac{2}{3}\pi R_1^2 H_w \quad \text{(F.5.1-4)}$$

Where, V_Q, V_T—Shell volume and shaft volume(m^3).

V_n—The volume of slurry discharged from shell and shaft at the bottom of shaft lining(m^3).

R_1, R_2—External and internal radius of shell and shaft(m).

H_w, H_n—External and internal height of shell(m).

H_T—Shaft height(m).

Appendix G Calculation for steel-concrete composite shaft linings by shaft drilling method

G.1 Bearing capacity calculation of inner steel plate and external concrete composite shaft lining

G.1.1 Inner steel plate cylinder shaft stress of inner steel plate cylinderand external concrete composite shaft lining(Figure G.1.1)shall be calculated according to the following formulas:

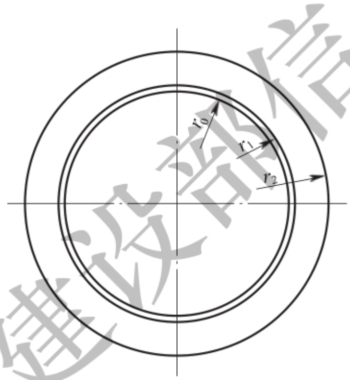

Figure G.1.1 Inner steel plate cylinder and external concrete composite shaft lining

$$\sigma_{gn} = \frac{-2P_{12}r_1^2}{r_1^2 - r_0^2} \tag{G.1.1-1}$$

$$\sigma_{gn} \leqslant f \tag{G.1.1-2}$$

$$P_{12} = \frac{f_3 P}{f_1 + f_2} \tag{G.1.1-3}$$

$$f_1 = (1+\mu_g)\left(\frac{1+t_1^2 - 2\mu_g t_1^2}{t_1^2 - 1}\right)\frac{r_1}{E} \tag{G.1.1-4}$$

$$f_2 = (1+\mu_h)\left(\frac{t_2^2 + 1 - 2\mu_h}{t_2^2 - 1}\right)\frac{r_1}{E_c} \tag{G.1.1-5}$$

$$f_3 = (1+\mu_h)\left[\frac{2t_2(1-\mu_h)}{t_2^2 - 1}\right]\frac{r_2}{E_c} \tag{G.1.1-6}$$

$$t_1 = \frac{r_1}{r_0} \tag{G.1.1-7}$$

$$t_2 = \frac{r_2}{r_1} \tag{G.1.1-8}$$

Where, P—Calculating value of formation load(MPa).

σ_{gn}—Calculating value of inner steel plate cylinder(MPa).

f—Design strength of steel plate cylinder(MPa).

μ_g—Poisson's ratio of steel plate cylinder materials.

μ_h—Poisson's ratio of shaft lining concrete materials.

f_1—Radial displacement of outer surface of steel plate cylinder shaft lining under unit external load (m).

f_2—Radial displacement of inner surface of external concrete shaft lining under unit external load (m).

f_3—Radial displacement of outer surface of external concrete shaft lining under unit external load (m).

P_{12}—Calculation value of external surface load of steel plate cylinder shaft lining(MPa).

E—Elastic modulus of steel plate cylinder material(MPa).

E_c—Elastic modulus of concrete material of shaft lining(MPa).

G.1.2 External concrete shaft lining stress shall be calculated according to the following formulas:

$$\sigma_h = \frac{(r_1^2 + r_2^2)}{r_1^2(t_2^2 - 1)} P_{12} - \frac{r_1^2 t_2^2 + r_2^2}{r_1^2(t_2^2 - 1)} P \tag{G.1.2-1}$$

$$\sigma_h \leqslant f_s \tag{G.1.2-2}$$

Where, σ_h—Calculating value of concrete stress(MPa).

G.2 Bearing capacity calculation of double steel plate cylinder concrete interlayer composite shaft lining

G.2.1 Inner steel plate cylinder stress of double steel plate cylinderconcrete interlayer composite shaft lining shall be calculated according to the following formulas:

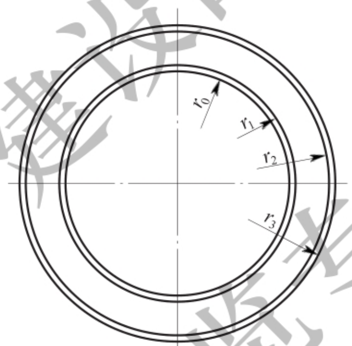

Figure G.2.1 Double steel plate cylinderconcrete interlayer composite shaft lining

$$\sigma_{gn} = \frac{-2P_{12} r_1^2}{r_1^2 - r_0^2} \tag{G.2.1-1}$$

$$\sigma_{gn} \leqslant f \tag{G.2.1-2}$$

$$P_{12} = \frac{f_3 P_{23}}{f_1 + f_2} \tag{G.2.1-3}$$

$$f_1 = (1 + \mu_g)\left(\frac{1 + t_1^2 - 2\mu_g t_1^2}{t_1^2 - 1}\right)\frac{r_1}{E} \tag{G.2.1-4}$$

$$f_2 = (1 + \mu_h)\left(\frac{t_2^2 + 1 - 2\mu_h}{t_2^2 - 1}\right)\frac{r_1}{E_c} \tag{G.2.1-5}$$

$$f_3 = (1 + \mu_h)\left[\frac{2t_2(1 - \mu_h)}{t_2^2 - 1}\right]\frac{r_2}{E_c} \tag{G.2.1-6}$$

$$t_1 = \frac{r_1}{r_0} \tag{G.2.1-7}$$

$$t_2 = \frac{r_2}{r_1} \tag{G.2.1-8}$$

G.2.2 Stress of the concrete interlayer in the middle shall be calculated according to the following formulas:

$$\sigma_h = \frac{r_1^2 + r_2^2}{r_1^2\left[\left(\frac{r_2}{r_1}\right)^2 - 1\right]} P_{12} - \frac{r_1^2\left(\frac{r_2}{r_1}\right)^2 + r_2^2}{r_1^2\left[\left(\frac{r_2}{r_1}\right)^2 - 1\right]} P_{23} \tag{G.2.2-1}$$

$$P_{23}=\frac{f_7 P}{f_5+f_6-\frac{f_3 f_4}{f_1+f_2}} \tag{G.2.2-2}$$

$$f_4=(1+\mu_h)\left[\frac{2t_2(1-\mu_h)}{t_2^2-1}\right]\frac{r_1}{E_c} \tag{G.2.2-3}$$

$$f_5=(1+\mu_h)\left(\frac{1+t_2^2-2\mu_h t_2^2}{t_2^2-1}\right)\frac{r_2}{E_c} \tag{G.2.2-4}$$

$$f_6=(1+\mu_g)\left(\frac{t_3^2+1-2\mu_g}{t_3^2-1}\right)\frac{r_2}{E} \tag{G.2.2-5}$$

$$f_7=(1+\mu_g)\left[\frac{2t_3(1-\mu_g)}{t_3^2-1}\right]\frac{r_3}{E} \tag{G.2.2-6}$$

$$t_3=\frac{r_3}{r_2} \tag{G.2.2-7}$$

$$\sigma_h \leqslant f_c \tag{G.2.2-8}$$

Where, P_{23}—Calculating value of external surface load of concrete interlayer of shaft lining(MPa).

f_4—Radial displacement of outer surface caused by the unit load applied on the inner face of concrete interlayer shaft lining(m).

f_5—Radial displacement of outer surface caused by the unit load applied on the outer face of concrete interlayer shaft lining(m).

f_6—Radial displacement of inner surface caused by the unit load applied on the inner face of steel plate cylinder shaft lining(m).

f_7—Radial displacement of inner surface caused by the unit load applied on the outer face of steel plate cylinder shaft lining(m).

G.2.3 Outer steel plate cylinder stress shall be calculated according to the following formulas:

$$\sigma_{gw}=\frac{(r_2^2+r_3^2)P_{23}-2r_3^2 P}{r_3^2-r_2^2} \tag{G.2.3-1}$$

$$\sigma_{gw} \leqslant f \tag{G.2.3-2}$$

Where, σ_{gw}—Calculating value of outer steel plate stress(MPa).

Explanation of wording in this code

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

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 code to indicate that it is necessary to comply with the requirements stipulated in other relative standards and codes.

List of quoted standards

GB 50010 *Code for Design of Concrete Structures*

GB 50017 *Code for Design of Steel Structures*

GB 50204 *Code for Quality Acceptance of Concrete Structure Construction*

GB 50205 *Standard for Acceptance of Construction Quality of Steel Structures*

GB/T 985.1 *Recommended Joint Preparation for Gas Welding, Manual Metal Arc Welding, Gas-Shield Arc Welding and Beam Welding*

GB/T 985.2 *Recommended Joint Preparation for Submerged Arc Welding*

GB/T 1447 *Fiber-reinforced Plastic Composites-determination of Tensile Properties*

GB/T 1448 *Fiber-reinforced Plastic Composites-determination of Compressive Properties*

GB/T 1449 *Fiber-reinforced Plastic Composites-determination of Flexural Properties*

GB/T 3094 *Cold Drawn Shaped Steel Tubes*

GB/T 3354 *Test Method for Tensile Properties of Orientational Fiber Reinforced Polymer Metrix Composite Materials*

GB/T 3356 *Test Method for Flexual Properties of Orientational Fiber Reinforced Polymer Metrix Composite Materials*

GB 8076 *Concrete Admixtures*

GB 16413 *Inspecting Specification of Glass Fiber Reinforced Plastic Product Safety Property for Coal Mining*

JC 475 *Concrete Anti-freezing Admixtures*

JGJ 18 *Specification for Welding and Acceptance of Reinforcing Steel Bars*

JGJ 107 *Technical Specification for Mechanical Splicing of Steel Reinforcing Bars*

JGJ/T 251 *Technical Specification for Anticorrosion of Building Steel Structure*

MT/T 557 *Shaft Road Tank with Cold-formed Rectangular Hollow Steel*

MT/T 5017 *Technical Specification for Anti-corrosion of Shaft Equipment in Coal Mine*