



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION



小水电技术导则 设计

第6-3部分：金属结构

SHP/TG 002-6-3: 2019



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6-3 :

鸣 谢

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中国政府推动了本导则的最终定稿，对其完成具有重要意义。

以下人士为编制本导则作出了贡献，包括有价值的投入、审查和提供建设性意见：Mr. Adnan Ahmed Shawky Atwa, Mr. Adoyi John Ochigbo, Mr. Arun Kumar, Mr. Atul Sarthak, Mr. Bassey Edet Nkposong, Mr. Bernardo Calzadilla-Sarmiento, Ms. Chang Fangyuan, Mr. Chen Changju, Ms. Chen Hongying, Mr. Chen Xiaodong, Ms. Chen Yan, Ms. Chen Yueqing, Ms. Cheng Xialei, Ms. Chileshe Kapaya Matantilo, Ms. Chileshe Mpundu Kapwepwe, Mr. Deogratias Kamweya, Mr. Dolwin Khan, Mr. Dong Guofeng, Mr. Ejaz Hussain Butt, Ms. Eva Kremere, Ms. Fang Lin, Mr. Fu Liangliang, Mr. Garaio Donald Gafiye, Mr. Guei Guillaume Fulbert Kouhie, Mr. Guo Chenguang, Mr. Guo Hongyou, Mr. Harold John Annegam, Ms. Hou ling, Mr. Hu Jianwei, Ms. Hu Xiaobo, Mr. Hu Yunchu, Mr. Huang Haiyang, Mr. Huang Zhengmin, Ms. Januka Gyawali, Mr. Jiang Songkun, Mr. K. M. Dharesan Unnithan, Mr. Kipyego Cheluget, Mr. Kolade Esan, Mr. Lamyser Castellanos Rigoberto, Mr. Li Zhiwu, Ms. Li Hui, Mr. Li Xiaoyong, Ms. Li Jingjing, Ms. Li Sa, Mr. Li Zhenggui, Ms. Liang Hong, Mr. Liang Yong, Mr. Lin Xuxin, Mr. Liu Deyou, Mr. Liu Heng, Mr. Louis Philippe Jacques Tavernier, Ms. Lu Xiaoyan, Mr. Lv Jianping, Mr. Manuel Mattiat, Mr. Martin Lugmayr, Mr. Mohamedain Seif Elnasr, Mr. Mundia Simainga, Mr. Mukayi Musarurwa, Mr. Olumide TaiwoAlade, Mr. Ou Chuanqi, Ms. Pan Meiting, Mr. Pan Weiping, Mr. Ralf Steffen Kaeser, Mr. Rudolf Hüpfel, Mr. Rui Jun, Mr. Rao Dayi, Mr. Sandeep Kher, Mr. Sergio Armando Trelles Jasso, Mr. Sindiso Ngwenga, Mr. Sidney Kilmete, Ms. Sitraka Zaraso Rakotomahefa, Mr. Shang Zhihong, Mr. Shen Cunke, Mr. Shi Rongqing, Ms. Sanja Komadina, Mr. Tareqemtairah, Mr. Tokihiko Fujimoto, Mr. Tovoniaina Ramanantsoa Andriampaniry, Mr. Tan Xiangqing, Mr. Tong Leyi, Mr. Wang Xinliang, Mr. Wang Fuyun, Mr. Wei Jianghui, Mr. WU Cong, Ms. Xie Lihua, Mr. Xiong Jie, Ms. Xu Jie, Ms. Xu Xiaoyan, Mr. Xu Wei, Mr. Yohane Mukabe, Mr. Yan Wenjiao, Mr. Yang Weijun, Ms. Yan Li, Mr. Yao Shenghong, Mr. Zeng Jingnian, Mr. Zhao Guojun, Mr. Zhang Min, Mr. Zhang Liansheng, Mr. Zhang Zhenzhong, Mr. Zhang Xiaowen, Ms. Zhang Yingnan, Mr. Zheng Liang, Mr. Zheng Yu, Mr. Zhou Shuhua, Ms. Zhu Mingjuan.

使用中如有其他意见和建议，欢迎提供，以便再版更新。

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2	1
3	1
4	1
5	1
5.1	1
5.2	2
5.3	2
5.4	2
5.5	3
5.6	3
5.7	4
5.8	4
6	5
6.1	5
6.2	9
6.3	11
6.4	12
7	13
7.1	13
7.2	13
7.3	13
7.4	13
8	14
A ()	15
B ()	16

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6-3 : ()

1

2

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3

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4

4.1

4.2

4.3

a)

b)

c)

d)

e)

5

5.1

5.1.1

5.1.2

5.2

5.2.1

5.2.2

5.2.3

5.2.4

5.2.5

1.50 m

5.2.6

0.3 m~0.5 m

5.2.7

5.2.8

5.2.9

5.3

5.3.1

5.3.2

5.3.3

5.4

5.4.1

5.4.2

a)

b)

c)

d)

e)

5.4.3

a)

1 m~2 m

b)

0.5 m~1.0 m

- c) 0.5 m - 1.0 m
- 5.4.4
- a)
- b)
- c)
- d) () ;
- e)
- f) 0

5.5

5.5.1

5.5.2

5.5.3

5.5.4

5.5.5

5.5.6

5.5.7

5.5.8

5.6

5.6.1

a)

b)

c)

d) 1 - 2

e)

5.6.2

a)

b)

5.6.3

5.7

5.7.1

a)

b)

c)

d)

e)

5.7.2

a)

50 m

b)

c)

5.7.3

a)

1.5~1.7

b)

c)

5.8

5.8.1

a)

b)

2 m-4 m

c)

582

a)

b)

c)

3~6

6

4~6

d)

583

a)

b)

c)

d)

e)

5 m/min

f)

g)

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584

a)

b)

3~6

6

4~6

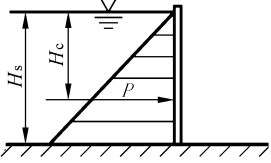
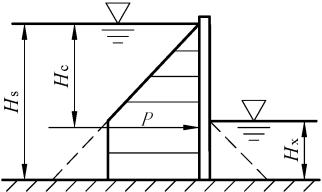
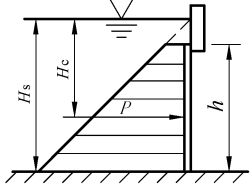
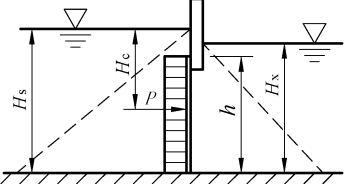
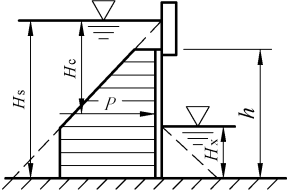
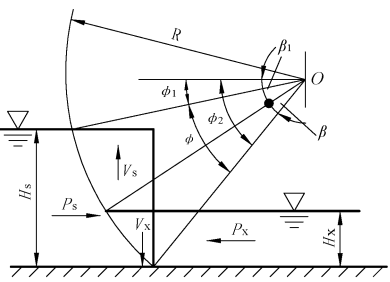
c)

6

6.1

6.1.1

1

<p>1</p>		$P = \frac{1}{2} \gamma H_s^2 B_{zs}$ $H_c = \frac{2}{3} H_s$
<p>2</p>		$P = \frac{1}{2} \gamma (H_s^2 - H_x^2) B_{zs}$ $H_c = \frac{1}{3} \left(2 H_s - \frac{H_x^2}{H_s + H_x} \right)$
<p>3</p>		$P = \frac{1}{2} \gamma (2 H_s - h) h B_{zs}$ $H_c = H_s - \frac{h}{3} \cdot \frac{3 H_s - 2 h}{2 H_s - h}$
<p>4</p>		$P = \gamma (H_s - H_x) h B_{zs}$ $H_c = H_s - \frac{1}{2} h$
<p>5</p>		$P = \frac{1}{2} \gamma [(2 H_s - h) h - H_x^2] B_{zs}$ $H_c = \frac{3 H_s H_x^2 - H_x^3 - 6 H_s^2 h + 6 H_s h^2 - 2 h^3}{3 H_x^2 - 6 H_s h + 3 h^2}$
<p>6</p>		$P = \frac{1}{2} \gamma H_s^2 B_{zs}$ $V_s = \frac{1}{2} \gamma R^2 \left[\frac{\phi}{180} + 2 \sin \phi_1 \cos \phi_2 - \frac{1}{2} (\sin 2 \phi_1 + \sin 2 \phi_2) \right] B$ $P_x = \frac{1}{2} \gamma H_x^2 B$ $V_x = \frac{1}{2} \gamma R^2 \left[\frac{\beta}{180} + 2 \sin \beta_1 \cos \phi_2 - \frac{1}{2} (\sin 2 \beta_1 + \sin 2 \phi_2) \right] B$ $P = \sqrt{(P_s - P_x)^2 + (V_s - V_x)^2}$

1 ()

<p>7</p>		<p>$\phi_1 < \phi_2$</p> <p>$P_s = \frac{1}{2} \gamma H_s^2 B$</p> <p>$V_s = \frac{1}{2} \gamma R^2 \left[\frac{\phi}{180} - 2 \sin \phi_1 \cos \phi_2 - \frac{1}{2} (\sin 2\phi_2 - \sin 2\phi_1) \right] B$</p> <p>$P_x = \frac{1}{2} \gamma H_x^2 B$</p> <p>$V_x = \frac{1}{2} \gamma R^2 \left[\frac{\beta}{180} + 2 \sin \beta_1 \cos \phi_2 - \frac{1}{2} (\sin 2\beta_1 + \sin 2\phi_2) \right] B$</p> <p>$P = \sqrt{(P_s - P_x)^2 + (V_s - V_x)^2}$</p>
<p>8</p>		<p>$\phi_1 > \phi_2$</p> <p>$P_s = \frac{1}{2} \gamma H_s^2 B$</p> <p>$V_s = \frac{1}{2} \gamma R^2 \left[\frac{\phi}{180} - \sin 2\phi_2 - \sin(\phi_1 - \phi_2) - 2 \sin \phi_1 \sin^2 \left(\frac{\phi_1 - \phi_2}{2} \right) \right] B$</p> <p>$P_x = \frac{1}{2} \gamma H_x^2 B$</p> <p>$V_x = \frac{1}{2} \gamma R^2 \left[\frac{\beta}{180} + 2 \sin \beta_1 \cos \phi_2 - \frac{1}{2} (\sin 2\beta_1 + \sin 2\phi_2) \right] B$</p> <p>$P = \sqrt{(P_s - P_x)^2 + (V_s - V_x)^2}$</p>
<p>9</p>		<p>$P_s = \frac{1}{2} \gamma (H_s + H'_s) h B$</p> <p>$V_s = \frac{1}{2} \gamma R^2 \left[\frac{\phi}{180} + 2 \sin \phi_1 \cos \phi_2 - \frac{1}{2} (\sin 2\phi_1 + \sin 2\phi_2) + \frac{2 H'_s}{R} (\cos \phi_1 - \cos \phi_2) \right] B$</p> <p>$P_x = \frac{1}{2} \gamma H_x^2 B$</p> <p>$V_x = \frac{1}{2} \gamma R^2 \left[\frac{\beta}{180} + 2 \sin \beta_1 \cos \phi_2 - \frac{1}{2} (\sin 2\beta_1 + \sin 2\phi_2) \right] B$</p> <p>$P = \sqrt{(P_s - P_x)^2 + (V_s - V_x)^2}$</p> <p> P_s ——— , kN; V_s ——— , kN; P_x ——— , kN; V_x ——— , kN; H_s ——— , m; H_x ——— , m; R ——— , m; γ ——— , 10 kN/m^3; B_{2s} ——— , m; B ——— , m; h ——— , m </p>

a)

1.1 ~ 1.2
1.0 ~ 1.2

b)

1

(1)

$$P_t = \gamma \beta_t H_s D_1 B_{zs} \dots \dots \dots (1)$$

- P_t ———— , kN;
- H_s D_1 ———— 1 , m;
- B_{zs} ———— , m;
- γ ———— , kN/m³;
- β_t ———— ,

$\beta_t = 1.0$,

β_t 2

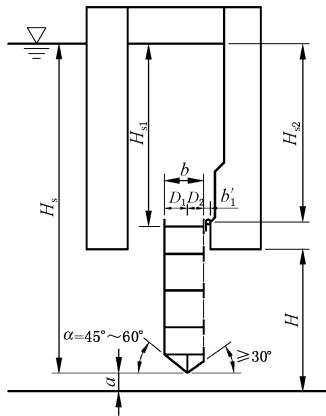
(H

; 2

; $0 < a < a_k$ (a_k

$0 < a < 0.5H$

$a_k = 0.5H$)



1

2

β_t

$\alpha(^{\circ})$	a/D_1				
	2	4	8	12	16
60°	0.8	0.7	0.5	0.4	0.25
52.5°	0.7	0.5	0.3	0.15	—
45°	0.6	0.4	0.1	0.05	—

a ———— , m;
 D_1 ———— , m;
 α ———— (1)

c)

(2)

1

$$P_s = p_s D_2 B_{zs} \dots\dots\dots (2)$$

P_s — , kN;
 D_2 — , m;
 p_s — D_2 , 20 kN/m² ,

6.1.3

$$(3) \quad (4)$$

$$P_n = \frac{1}{2} \gamma_n h_n^2 \tan^2 \left(45^\circ - \frac{\phi}{2} \right) B \dots\dots\dots (3)$$

$$\gamma_n = \gamma_0 - (1 - n) \gamma_w \dots\dots\dots (4)$$

P_n — , kN;
 γ_n — , kN/m³;
 γ_0 — , kN/m³;
 γ_w — , kN/m³;
 n — ;
 h_n — , m;
 B — , m;
 ϕ — , (°)

6.1.4

$$(5)$$

$$P_z = \frac{W_p v}{gt} \dots\dots\dots (5)$$

P_z — , kN;
 W_p — , kN ,
 v — , m/s;
 g — ;
 t — , s,

6.2

6.2.1

a)

1) (6) () ;

$$F_w = n_T (T_{zd} + T_{zs}) - n_G G + P_t \dots\dots\dots (6)$$

2) (7) :

$$F_T = n'_G G + G_j + W_s + P_x - P_t - (T_{zd} + T_{zs}) \dots\dots\dots (7)$$

3) (8) :

$$F_Q = n_T (T_{zd} + T_{zs}) + P_x + n'_G G + G_j + W_s \dots\dots\dots (8)$$

4) (9) :

$$T_{zd} = \frac{P}{R} (f_1 r + f) \dots\dots\dots (9)$$

5) (10) :

$$T_{zd} = \frac{Pf}{R} \left(\frac{R_1}{d} + 1 \right) \dots\dots\dots (10)$$

6) (11) :

$$T_{zd} = f_2 P \dots\dots\dots (11)$$

7) (12) :

$$T_{zs} = f_3 P_{zs} \dots\dots\dots (12)$$

- :
 F_w F_T F_Q ——— , kN;
 n_T ——— , 1.2;
 n_G ——— , 0.9~1.0;
 n'_G ——— , 1.0~1.1;
 G ——— , kN, ;
 W_s ——— , kN;
 G_j ——— , kN;
 P_t ——— , kN, (1)
 ;
 P_x ——— , kN, (2) ;
 T_{zd} ——— , kN;
 P ——— , kN;
 r ——— , mm;
 R_1 ——— , mm;
 R ——— , mm;
 d ——— , mm;
 f ——— , mm, A ;
 T_{zs} ——— , kN;
 P_{zs} ——— , kN;
 f_1 f_2 f_3 ——— , , ,

b) A
 5 m 1 m 1 m~

6.2.2 :

a) (13)

$$F_w = \frac{1}{R_1} [n_T (T_{zd} r_0 + T_{zs} r_1) + P_t r_3 - n_G G r_2] \dots\dots\dots (13)$$

b) (14) :

$$F_Q = \frac{1}{R_2} [n_T (T_{zd} r_0 + T_{zs} r_1) + n'_G G r_2 + G_j R_1 + P_x r_4] \dots\dots\dots (14)$$

- :
 r_0 r_1 r_2 r_3 r_4 ——— , m;

$$\begin{aligned} R_1 \quad R_2 & \text{ ————— } (\quad) \quad , \text{ m;} \\ T_{zs} & \text{ ————— } , \quad (12) \end{aligned}$$

c)

6.2.3

a)

(15)

$$F_0 = n'_G G + n_m m \quad \dots\dots\dots (15)$$

$$F_0 \text{ ————— } , \text{ kN;} ;$$

$$n_m \text{ ————— } , \quad 1.2 ;$$

$$m \text{ ————— } , \text{ kN} ;$$

$$G \text{ ————— } , \text{ kN} ;$$

$$n'_G \text{ ————— } , \quad 1.0 \sim 1.1$$

b)

(15)

2 m

6.3

6.3.1

(16) (17)

(18) (19) (16) :

$$A_a = \frac{Q_a}{[v_a]} \quad \dots\dots\dots (16)$$

$$Q_a = 0.09 v_w A \quad \dots\dots\dots (17)$$

$$\beta = \frac{Q_a}{Q_w} = K (F_r - 1)^{[4n(F_r - 1) + b]} - 1 \quad \dots\dots\dots (18)$$

$$F_r = \frac{v}{\sqrt{9.81 e}} \quad \dots\dots\dots (19)$$

$$A_a \text{ ————— } , \text{ m}^2 ;$$

$$Q_a \text{ ————— } , \text{ m}^3/\text{s} ;$$

$$[v_a] \text{ ————— } , \text{ m/s} , \quad 40 \text{ m/s} , \quad 50 \text{ m/s} ;$$

$$v_w \text{ ————— } , \text{ m/s} ;$$

$$A \text{ ————— } , \text{ m}^2$$

$$\beta \text{ ————— } ;$$

$$Q_w \text{ ————— } , \text{ m}^3/\text{s} ;$$

$$F_r \text{ ————— } ;$$

$$v \text{ ————— } , \text{ m/s} ;$$

$$e \text{ ————— } , \text{ m} ;$$

$$K \quad a \quad b \text{ ————— } , \quad B$$

6.3.2

4% ~ 7%

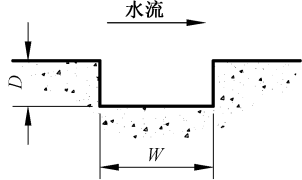
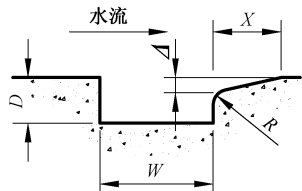
6.3.3

6.4

6.4.1

3

3

	<p>$W/D = 1.6 \sim 1.8$; $W/D = 1.4 \sim 2.5$; $K_1 = 0.38 (W/D)$ ($W/D = 1.4 \sim 3.5$)</p>	<p>12 m $K > 1.0$ (20 m/s) 30 m</p>
	<p>$W/D = 1.5 \sim 2.0$; $/W = 0.05 \sim$ 0.08; $/X = 1/10 \sim$ 1/12; R = 30 mm ~ 50 mm $R/D = 0.10$; $K_1 = 0.4 \sim$ 0.6 ()</p>	<p>$K > 0.6$ (30 m ~ 50 m, 20 m/s ~ 25 m/s) ; $K > 0.4$ 1.0 ; K > 0.8 ; 12 m, K > 0.8</p>

6.4.2

K

6.4.3

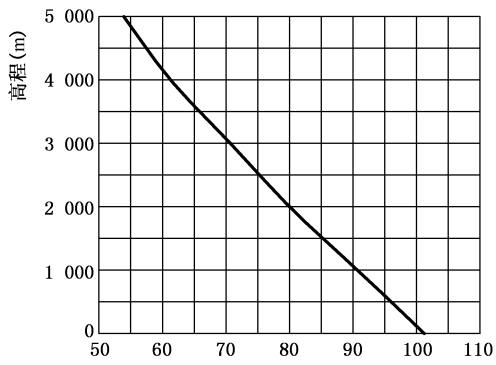
$K < 0.6$ (60 m, 30 m/s) ,

6.4.4

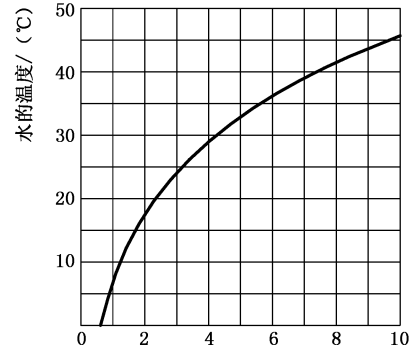
K (20) :

$$K = \frac{(P_1 + P_a - P_v) / \gamma}{\frac{v^2}{2g}} \dots\dots\dots (20)$$

- P_1 — , kPa;
- P_a — , kPa, 2;
- P_v — , kPa, 3;
- γ — , kN/m³;
- v — , m/s;
- g — , m/s²



2



3

6.4.5

K_i

$K_i < K_i$

$K > K_i$

$n = 1 \sim 2$

1.5, $K \sim nK_i$

7

7.1

7.1.1

7.1.2

3 :

a)

b)

c)

7.1.3

7.1.4

7.1.5

ISO 8501 | ISO 8502 | ISO 8503 | ISO 8504

7.2

7.2.1

7.2.2

7.3

7.3.1

7.3.2

3.0 mm

7.3.3

7.3.4

7.4

7.4.1

SHP/TG 002-6-3:2019

a)

;

b)

;

c)

;

d)

PH

7.4.2

7.4.3

7.4.4

8

:

a)

;

b)

;

c)

A
()

A.1

	()	0.5 ~ 0.6	0.15	
	()	0.35	0.16	
	()	0.65	0.3	
	<i>q</i>	$q > 2.5 \text{ kN/mm}$	0.09	0.04
		$q = 2.5 \text{ kN/mm} \sim 2.0 \text{ kN/mm}$	0.09 ~ 0.11	0.05
		$q = 2.0 \text{ kN/mm} \sim 1.5 \text{ kN/mm}$	0.11 ~ 0.13	0.05
$q = 1.5 \text{ kN/mm} \sim 1.0 \text{ kN/mm}$		0.13 ~ 0.15	0.06	
	$q < 1.0 \text{ kN/mm}$	0.15	0.06	
	()	0.30	0.16	
	()	0.25	0.12	
	()	0.12 ~ 0.14	0.05	
		0.70	0.35	
		0.50	0.20	
		0.20	0.05	
		1 mm		
		1 mm		
:	$R_a = 1.6 \mu\text{m}$	$R_a = 3.2 \mu\text{m}$		

B
()

B.1

		—————	F_r	$\beta = K(F_r - 1)^{[4n(F_r - 1) + b]} - 1$		
				K	a	b
	6.10 ~ 10.66	3.96 ~ 20.30	1.158	0.112	- 0.242	
		3.87 ~ 3.960	1.015 4	0	0	
	10.66 ~ 27.40	1.94 ~ 6.290	1.015 0	0.035	0.004	
		1.61 ~ 1.940	1.015 2	0	0	
	27.40 ~ 35.78	1.91 ~ 17.190	1.042	0.039	0.008	
		1.38 ~ 1.910	1.041 3	0	0	
35.78 ~ 77.00	1.08 ~ 15.670	1.130 0	0.028	0.144		
	6.10 ~ 10.66	4.57 ~ 32.590	1.342	0.173	- 0.438	
		3.49 ~ 4.570	1.015 3	0	0	
	10.66 ~ 27.40	1.70 ~ 18.06	1.054 0	0.019	0.013	
		1.56 ~ 1.70	1.051 5	0	0	
	27.40 ~ 35.78	2.45 ~ 10.81	1.073	0.053	0.070	
	35.78 ~ 77.00	2.33 ~ 8.310	1.170	0.182	- 0.019	

—————



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