Torsion Type Swing Gate

Gate Operation in Tidal Flow

Inclination Angle

of The Gate Body

TeraMatsu

Contents

Page

１． Introduction

A swing type torsion gate has been proposed in the separate report "Swing Type" and its concept design has been shown also. The swing type is operated with the aid of tidal flow. The gate body running in the face of water-level difference of tide inclines due to gate bottom friction. The upright moment composed by the pulling-up force S and the buoyancy works on the gate body for the inclination control. This report tries to analyze the inclination angles and confirm a possibility of the inclination control by the pulling-up force S.

The analysis is made on the concept design shown on the proposal report. Table 1 shows data for the design planning.

Table－１ Planning data

Item		Data	Unit	Note
Gate dimension	Span	450	m	○○ Port Design A (Super Large Tidal Gate) (excluding steel weight.)
	Height	23		
	Width	12.5		
Hydrauric condition	Site depth	16		
	Tide def.	5		
	Freeboard	2		
Steel weight (rough estimation)	Gate leaf	18000	tf	
	Embedded part	1500		
	Machine	500		
	Toral	20000		

Following conclusions have been obtained in the analysis.

（１） The gate body inclination control is possible with the aid of the pulling-up force S.

（２） Concerning the concept design,

①It is more reasonable through a perspective of the gate body inclination control that the water bottom contact point of the friction shoe locates adjacent to the gate skin plate.

②The analyzed result is available for the maximum tide difference selection.

③The gate body inclination will not occur in case that friction coefficient ｆ≦0.3.

２． The gate body inclination factors and assumptions on the rotation axis

（１） The fall factors

①Friction force due to the shoe load (= the decreased amount of the operating buoyancy)

②Friction force due to the downward component of the tidal load

③The downward component of the tidal load

（２） The upright factors

①The pulling-up force Ｓ

②The shoe load

（３） Assumptions on the rotation axis

①The gate body: an axis which passes through the spherical seat center and is parallel to the gate span (Refer to Fig.－３).

②The friction shoe: an axis which passes the contact point on the shoe and is parallel to the gate span (Refer to Fig .－１ & ５).

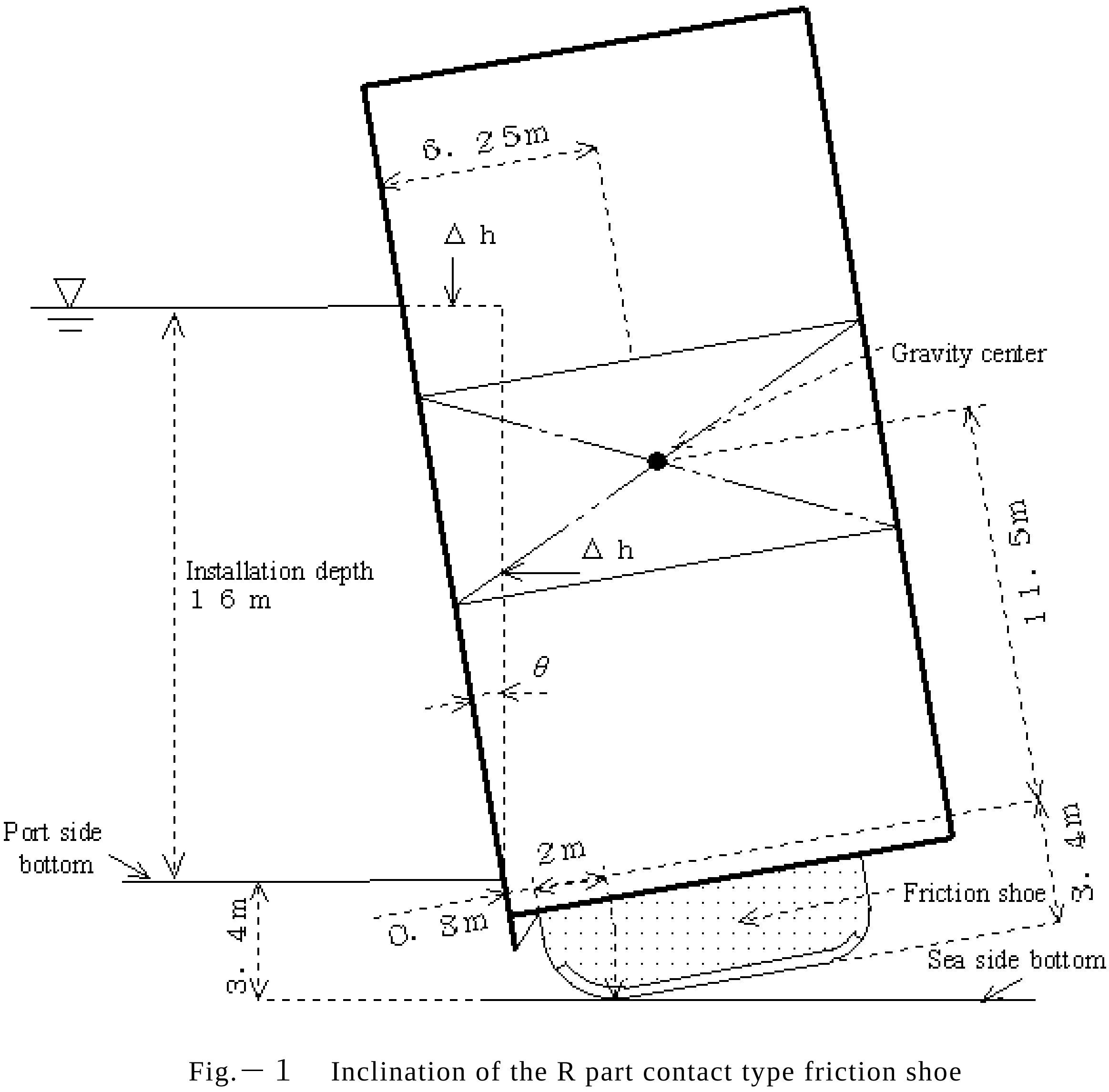

Fig.－１ Inclination of the R part contact type friction shoe

Fig.－1 shows inclination of the R part contact type friction shoe and its relative dimensions.

3. The R part contact type friction shoe

The inclination angle of the R part contact type friction shoe shown on the Fig.－1 is going to be analyzed

3.1 The fall moment

(1) The friction force due to the shoe load and the tidal load downward component

Fall moment 1 = Sd×（Ls ＋ tidal load downward component×3÷5）×f
= 11.4×（Ls ＋ Δh×tan(θ)×3600×3÷5）×f

Sd : The vertical distance between the tidal load center and the contact point
= 16÷2+3.4 = 11.4
Ls : The shoe load (= the amount of the operation buoyancy decrease)
The tidal load downward component: = Δh×16×tan(θ)×225
= Δh×tan(θ)×3600
Δh: The tidal load (tide difference)
θ: The gate body inclination angle
f : Friction coefficient

(2) The tidal load

The calculation formula of the horizontal distance between the tidal load and the friction shoe friction point is derived according to Fig.－2.

Fall moment 2 = tidal load downward component ×（3÷5×Sf ＋ 2÷5×Ss）=
tidal load downward component ×（Sf ＋ 1.38）＝Δh×tan(θ)×3600×
((9.4＋2.8×sin(θ))×tan(θ)＋2.8×cos(θ)＋1.38)
Remarks ①9.4 = 16÷2＋1.4
②2.8×sin(θ) = gh
③2.8×cos(θ) = gr
Sf: The horizontal distance between the tidal load downward component center and the friction point = 16×tan(θ)÷2＋ab＋er = 16×tan(θ)÷2＋(1.4(1－cos(θ))
＋2.8×sin(θ))×tan(θ)＋2.8×cos(θ)＋1.4×sin(θ)
＝8×tan(θ)＋1.4×tan(θ)－1.4×sin(θ)＋2.8×sin(θ)×tan(θ)
＋2.8×cos(θ)＋1.4×sin(θ)
＝(9.4＋2.8×sin(θ))×tan(θ)＋2.8×cos(θ)
Ss: The horizontal distance between the tidal load downward component center and the

pulling-up force = $Sf - fr + 12.5 \div 2 = Sf + 3.45$

$ab = bd \times \tan(\theta) = (1.4(1-\cos(\theta)) + 2.8\times\sin(\theta))\times\tan(\theta)$

$bd = (cf - de) = 1.4 - 1.4\times\cos(\theta) + 2.8\times\sin(\theta)$

$= 1.4(1-\cos(\theta)) + 2.8\times\sin(\theta)$

$cf = 3.4 - 2 = 1.4$

$de = cr\times\sin(\beta-\theta) = cr\times(\sin(\beta)\cos(\theta) - \cos(\beta)\sin(\theta))$

$= cr\times(cf \div cr\times\cos(\theta) - fr\div cr\times\sin(\theta))$

$= cf\times\cos(\theta) - fr\times\sin(\theta) = 1.4\times\cos(\theta) - 2.8\times\sin(\theta)$

$fr = 0.8 + 2 = 2.8$

$er = cr\times\cos(\beta-\theta) = cr\times(\cos(\beta)\cos(\theta) + \sin(\beta)\sin(\theta))$

$= cr\times(fr\div cr\times\cos(\theta) + cf\div cr\times\sin(\theta))$

$= fr\times\cos(\theta) + cf\times\sin(\theta) = 2.8\times\cos(\theta) + 1.4\times\sin(\theta)$

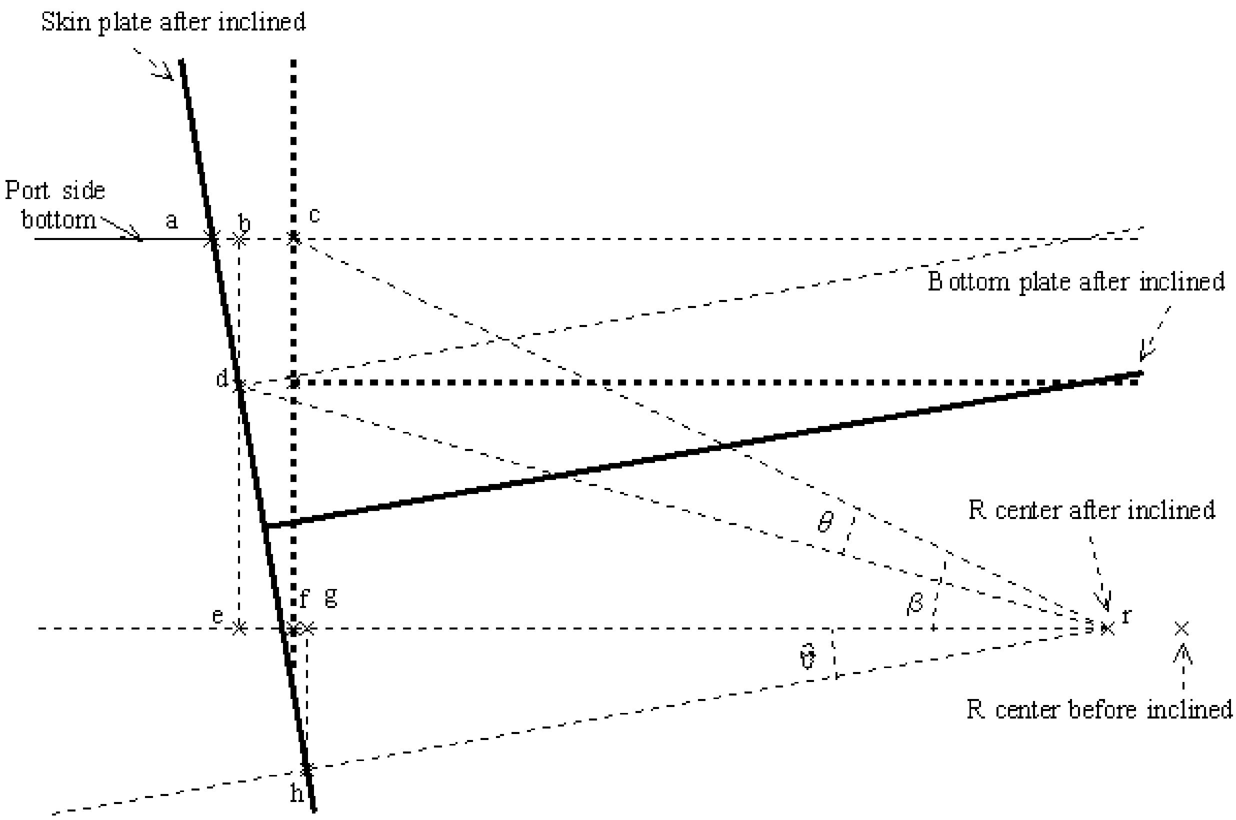

Fig.－２ The drawing to calculate horizontal distance between the tidal load and the friction show

3．２　Upright moment

（１）The pulling-up force

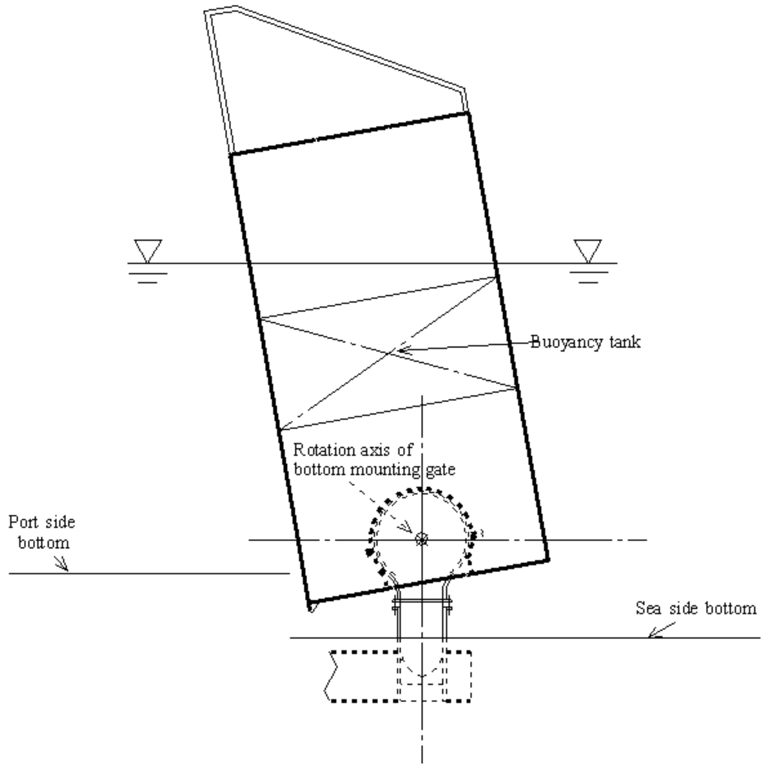

Fig.－３　Gate inclination（when bottom mounting）

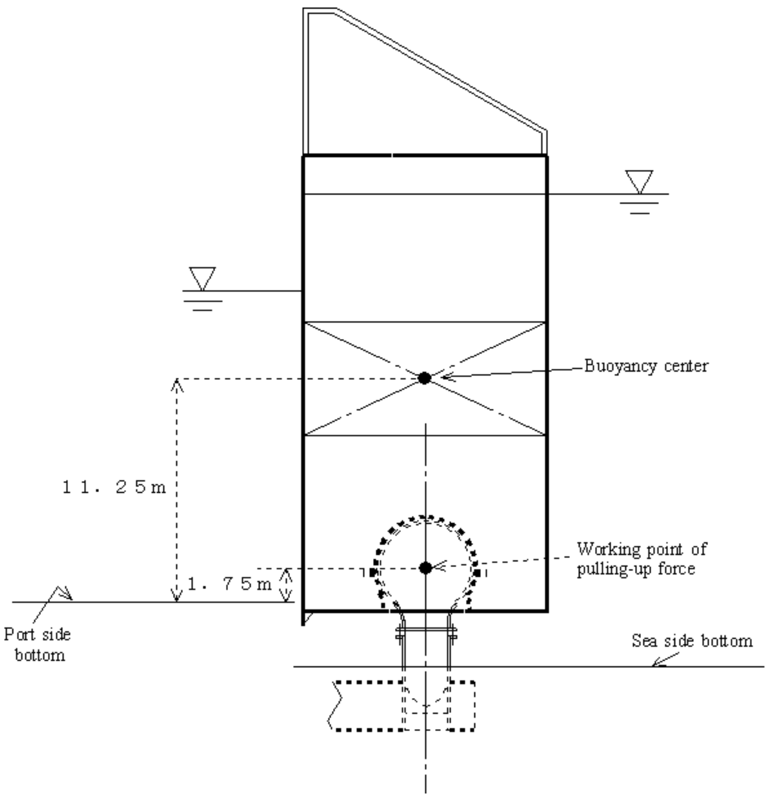

Fig.－４　The buoyancy center and the pulling-up force working point

Fig.－3 shows gate body inclination when the gate mounts on the sea bottom and Fig.－4 shows the gate body buoyancy center and the pulling-up force working point.

Upright moment 1 = $S_p \times \sin(\theta) \times S = 9.5 \times \sin(\theta) \times S$

S : Pulling-up force
S_p: Vertical distance between the buoyancy center and the pulling-up force working point
$= 11.25 - 1.75 = 9.5$

（2）Shoe load（= decreased amount of the operating buoyancy）

Upright moment 2 = $L_s \times (S_r + R \times \sin(\theta))$
$= L_s \times (3.45 - 14.65 \times \sin(\theta) + 2 \times \sin(\theta))$
$= L_s \times (3.45 - 12.65 \times \sin(\theta))$

S_r: Horizontal distance between the gravity center and the R center
$= 12.5 \div 2 - 0.8 - R - 14.65 \times \sin(\theta)$
$= 3.45 - 14.65 \times \sin(\theta)$
R: Curvature radius of the shoe bottom excurvation（R part）= 2m

3．3 Inclination angle equation

A condition for deriving the formula of θ is as following.

Fall moment 1 + Fall moment 2 = Upright moment 1 + Upright moment 2

Accordingly,

$$11.4 \times (L_s + \Delta h \times \tan(\theta) \times 3600 \times 3 \div 5) \times f + \Delta h \times \tan(\theta) \times 3600 \times ((9.4 + 2.8 \times \sin(\theta)) \times \tan(\theta) + 2.8 \times \cos(\theta) + 1.38)$$
$$= 9.5 \times \sin(\theta) \times S + L_s \times (3.45 - 12.65 \times \sin(\theta))$$

Following approximations are made based on an assumption that θ is small.

$\tan(\theta) = \theta$
$\sin(\theta) = \theta$
$\cos(\theta) = 1$

Accordingly,

$$11.4 \times (L_s + \Delta h \times \theta \times 3600 \times 3 \div 5) \times f + \Delta h \times \theta \times 3600 \times ((9.4 + 2.8 \times \theta) \times \theta + 2.8 + 1.38)$$
$$= 9.5 \times \theta \times S + L_s \times (3.45 - 12.65 \times \theta)$$

$$11.4\times(Ls+\Delta h\times\theta\times3600\times3\div5)\times f+$$
$$\Delta h\times\theta\text{^}2\times3600\times((9.4+2.8\times\theta)+\Delta h\times\theta\times3600\times4.18)$$
$$=9.5\times\theta\times S+Ls\times(3.45-12.65\times\theta)$$

$$3600\times2.8\times\Delta h\times\theta\text{^}3+$$
$$3600\times9.4\times\Delta h\times\theta\text{^}2+$$
$$(11.4\times3600\times3\div5\times\Delta h\times f+3600\times4.18\times\Delta h-9.5\times S+12.65\times Ls)\times\theta+11.4\times Ls\times f-3.45\times Ls=0$$

$$10080\times\Delta h\times\theta\text{^}3+33840\times\Delta h\times\theta\text{^}2+$$
$$(24624\times\Delta h\times f+15048\times\Delta h-9.5\times S+12.65\times Ls)\times\theta+11.4\times Ls\times f-3.45\times Ls=0$$

The above equation will be solved easily because the equation becomes a second degree formula if gh (= 2.8 ×sin (θ)) shown in the remark ② of Fall moment 1 is neglected because of its small quantity and in short,

$$33840\times\Delta h\times\theta\text{^}2+$$
$$(24624\times\Delta h\times f+15048\times\Delta h-9.5\times S+12.65\times Ls)\times\theta+11.4\times Ls\times f-3.45\times Ls=0$$

４. The tip contact type friction shoe

The inclination angle of the tip contact shoe bottom shown on Fig.－５ is analyzed. The calculation equation of the angle can be formulated by a simplification of the formulas shown at chapter 2 and 3.

４．１ Fall moment

（１） Friction force of the shoe load and the tidal load downward component

Fall moment 1 $= Sd\times(Ls+$ the tidal load downward component$)\times f =$

$$11.4\times(Ls+\Delta h\times\tan(\theta)\times3600\times3\div5)\times f$$

Sd: The vertical distance between the tidal load center and the contact point $= 16\div2+3.4=11.4$

Ls: The shoe load (= the amount of the operation buoyancy decrease)

The tidal load downward component: $= \Delta h\times16\times\tan(\theta)\times225 = \Delta h\times\tan(\theta)\times3600$

Δh: The tidal load (tide difference)

θ: The gate body inclination angle

f: Friction coefficient

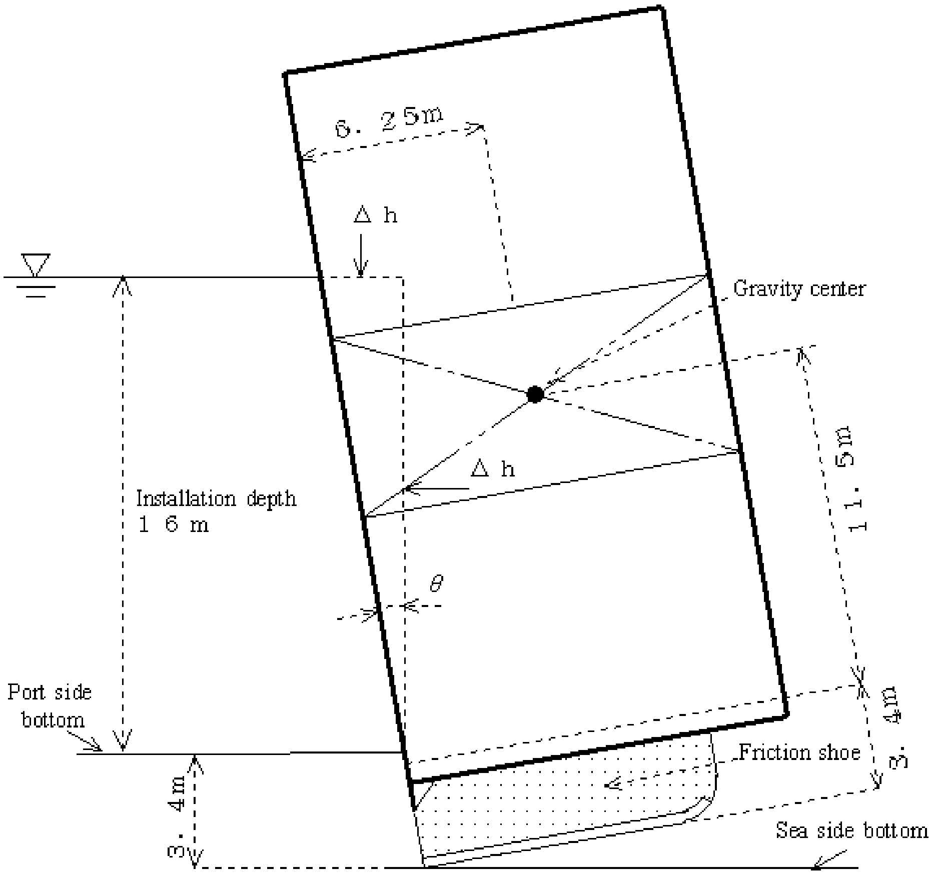

Fig.－５　Tip contact type shoe bottom

（２）Tidal load

Fall moment ２ = tidal load downward component×（Ｓf×３÷５＋Ｓs×２÷５）
= tidal load downward component ×（Ｓf＋２．５）
= Δｈ×tan（θ）×３６００×（１１．４×tan（θ）＋２．５）

Ｓf: The horizontal distance between the tidal load downward component center and the friction point
= １６×tan（θ）÷２＋３．４×tan（θ）= １１．４×tan（θ）

Ｓs: The horizontal distance between the tidal load downward component center and the pulling-up force S = Ｓf＋１２．５÷２ = Ｓf＋６．２５

４．２　Upright moment

（１）Pulling-up force

Upright moment １ = Ｓp×sin（θ）×Ｓ＝９．５×sin（θ）×Ｓ

S: The pulling-up force

S_p: Vertical distance between the buoyancy center and the pulling-up force working point

$= 11.25 - 1.75 = 9.5$

(2) Shoe load (= decreased amount of the operating buoyancy)

Upright moment 2 $= Ls \times Sr = Ls \times (6.25 - 14.65 \times \sin(\theta))$

S_r: Horizontal distance between the gravity center and the R center

$$= 12.5 \div 2 - (11.25 + 3.4) \times \sin(\theta)$$
$$= 6.25 - 14.65 \times \sin(\theta)$$

4.3 Inclination angle equation

$$11.4 \times (Ls + \Delta h \times \tan(\theta) \times 3600 \times 3 \div 5) \times f + \Delta h \times \tan(\theta) \times 3600 \times (11.4 \times \tan(\theta) + 2.5)$$
$$= 9.5 \times \sin(\theta) \times S + Ls \times (6.25 - 14.65 \times \sin(\theta))$$

Following approximations are made based on an assumption that θ is small.

$\tan(\theta) = \theta$

$\sin(\theta) = \theta$

$\cos(\theta) = 1$

$$11.4 \times (Ls + \Delta h \times \theta \times 3600 \times 3 \div 5) \times f + \Delta h \times \theta \times 3600 \times (11.4 \times \theta + 2.5) = 9.5 \times \theta \times S + Ls \times (6.25 - 14.65 \times \theta)$$

$$3600 \times 11.4 \times \Delta h \times \theta^2 + (11.4 \times 3600 \times 3 \div 5 \times \Delta h \times f + \Delta h \times 3600 \times 2.5 - 9.5 \times S + 14.65 \times Ls) \times \theta + 11.4 \times Ls \times f - 6.25 \times Ls = 0$$

$$41040 \times \Delta h \times \theta^2 + (24624 \times \Delta h \times f + 9000 \times \Delta h - 9.5 \times S + 14.65 \times Ls) \times \theta + 11.4 \times Ls \times f - 6.25 \times Ls = 0$$

5. Rearrangement of coefficients in the inclination equation

(1) The R part contact type

Third degree equation

$$10080 \times \Delta h \times \theta^3 + 33840 \times \Delta h \times \theta^2 + (24624 \times \Delta h \times f + 15048 \times \Delta h - 9.5 \times S + 12.65 \times Ls) \times \theta + 11.4 \times Ls \times f - 3.45 \times Ls = 0$$

$a = 10080 \times \Delta h$
$b = 33840 \times \Delta h$
$c = 24624 \times \Delta h \times f + 15048 \times \Delta h - 9.5 \times S + 12.65 \times Ls$
$d = (11.4 \times f - 3.45) \times Ls$

Second degree equation (approximation)

$$33840 \times \Delta h \times \theta^2 + (24624 \times \Delta h \times f + 15048 \times \Delta h - 9.5 \times S + 12.65 \times Ls) \times \theta + 11.4 \times Ls \times f - 3.45 \times Ls = 0$$

$a = 33840 \times \Delta h$
$b = 24624 \times \Delta h \times f + 15048 \times \Delta h - 9.5 \times S + 12.65 \times Ls$
$c = (11.4 \times f - 3.45) \times Ls$

whereas Fall moment 2 equals 0 when the solution $\theta \leqq 0$. Accordingly, the coefficients are as following.

$a = 33840 \times \Delta h$
$b = 24624 \times \Delta h \times f + 15048 \times \Delta h - 9.5 \times S$
$c = 11.4 \times f \times Ls$

(2) The tip contact type

$$41040 \times \Delta h \times \theta^2 + (24624 \times \Delta h \times f + 9000 \times \Delta h - 9.5 \times S + 14.65 \times Ls) \times \theta + 11.4 \times Ls \times f - 6.25 \times Ls = 0$$

$a = 41040 \times \Delta h$
$b = 24624 \times \Delta h \times f + 9000 \times \Delta h - 9.5 \times S + 14.65 \times Ls$
$c = (11.4 \times f - 6.25) \times Ls$

whereas Fall moment 2 equals 0 when the solution $\theta \leqq 0$. Accordingly, the coefficients are as following.

$a = 41040 \times \Delta h$
$b = 24624 \times \Delta h \times f + 9000 \times \Delta h - 9.5 \times S$
$c = 11.4 \times f \times Ls$

6. Friction force limit condition

Limit condition: Friction force moment≦Tidal load moment

Friction shoe total load = $Ls +$ Tidal load = $Ls + \Delta h \times \tan(\theta) \times 3600 \times 3 \div 5$

Friction force = Friction shoe total load × Friction coefficient (f)
$= (Ls + \Delta h \times \tan(\theta) \times 3600 \times 3 \div 5) \times f$

Friction force moment = $(Ls \times 5a + \Delta h \times \tan(\theta) \times 3600 \times 3a) \times f$

Tidal load = $\Delta h \times 3600$

Tidal load moment = $\Delta h \times 3600 \times 3a$

Accordingly, the limit condition is

$$(Ls \times 5a + \Delta h \times \tan(\theta) \times 3600 \times 3a) \times f \leqq \Delta h \times 3600 \times 3a$$

$$f \leqq 10800 \Delta h \div (5Ls + 10800 \Delta h \times \tan(\theta))$$
$$= 1 \div (Ls \div (2160 \Delta h) + \tan(\theta))$$

7． Results and conclusions

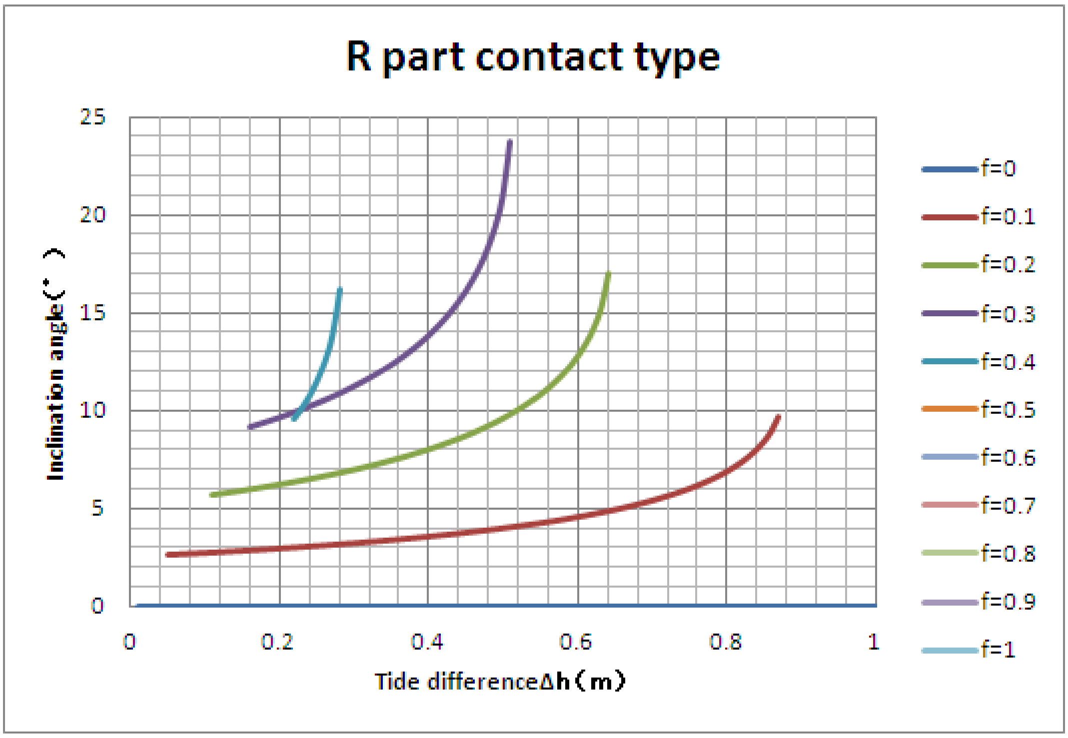

Fig.－6 Inclination angles of the R part contact type friction shoe

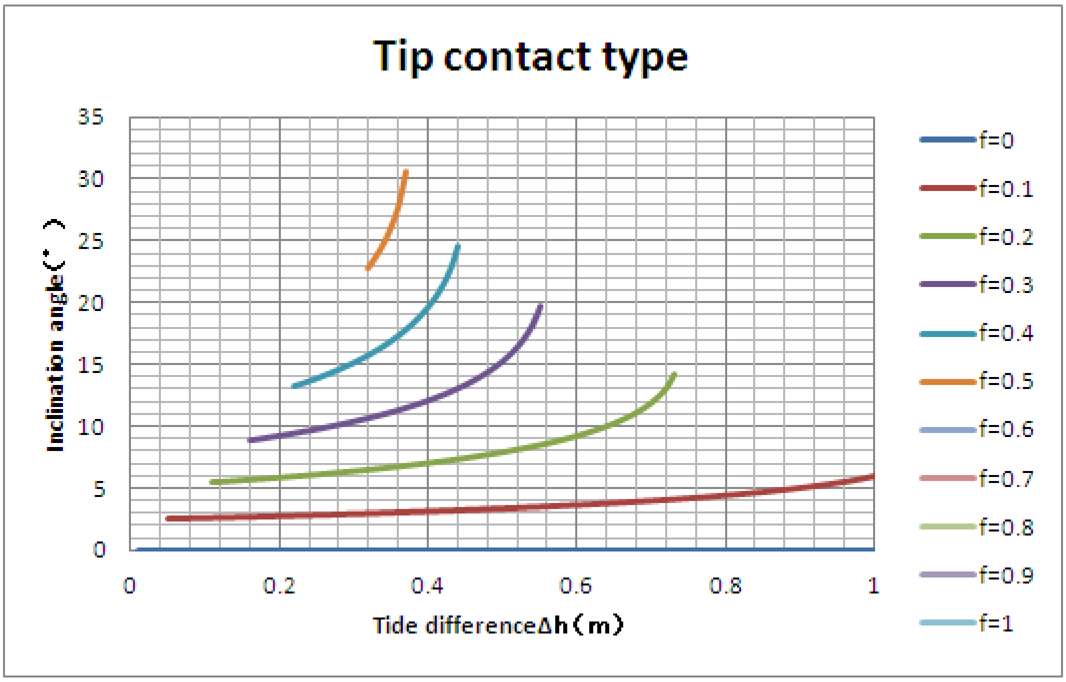

Fig.－7 Inclination angles of the tip contact type friction shoe

Fig.－6 shows results of the R part contact type friction shoe inclination angle and Fig.－7 shows that of the tip contact type. The results of the friction coefficient groups shown on the right hand side of the figures are given but these which do not appear on the figures（ｆ＝0.5～1.0）and the tide difference of the left hand side of each graph end are domains where the friction force ≧ the tidal load thrust and are not available for the gate open and closure operation. There is no solution of the angle equations in the right hand side domain of each graph ends that means the angles in these domain becomes infinite. Although Fall moment ２ of the equations equals 0 when θ = 0, its amount is prevails among other moments in the range of small θ and solutions satisfying the equations become negative. The negative solution cannot happen on the actual friction shoe and the analyses of the equations in the negative zone were made with Fall moment ２ = 0. Eventually, Fall moment ２ is 0 for ｆ = 0～0.3 of the R part contact type and for ｆ = 0～0.4 of the tip contact type. This is also a back ground of Fig.－６ where f = 0.4 graph does not fit in other f cases. It may be an actually happening phenomena that Upright moment ２ of a big quantity so works with an imperceptible θ increase that the contact point cannot easily shift toward the R part or the tip of the shoe bottom and eventually Fall moment １ and ２ do not happen to grow and the gate body keeps upright（in short, block by the shoe load works effectively）.

Table－２ Gate inclination analysis accuracy validation during operation with the aid of tidal flow

Friction coefficient f	Tide difference Δh(m)	Solution (θ°)	Correct answer (θ°)	Error %	Moment(tf-m)		Moment error %
					Fall	Upright	
0.1	0.05	2.65	2.65	-0.06	1268	1268	0.00
	0.50	4.00	4.02	-0.34	1924	1924	0.00
	0.66	5.03	5.08	-0.88	2430	2430	0.00
	0.87	9.68	10.11	-4.50	4902	4820	1.67
0.2	0.11	5.64	5.65	-0.26	2703	2703	0.00
	0.52	10.03	10.45	-4.17	4978	4978	0.00
	0.63	15.25	15.06	1.29	7437	7132	4.10
0.3	0.24	10.20	10.36	-1.51	4936	4936	0.00
	0.43	15.04	17.18	-14.17	8107	8107	0.00
	0.50	20.91	18.50	11.56	9411	8710	7.45
0.4	0.23	10.08	10.51	-4.26	6235	6235	0.00
	0.28	16.15	15.27	5.43	7535	7358	2.35

The analyses in Fig.－６ and ７ include approximations that are replacements of the trigonometric functions to θ and a transformation of the third degree function to the second degree function and they need accuracy validation. Table －２ is a result of the validation. The answers to the moments correspond to Fall moment and Upright moment whose difference is local minimum and they were obtained by hand operations. The inclination angle solution and the correct answer almost equal with θ less than 5 degrees and have a difference of a few % with θ of around 10 degrees and a dozen or so % with θ between 15 and 20 degrees. Fall moment, Upright moment and their difference in % are shown on the right hand side of the table. The cases whose moment error is other than 0 mean that their third degree equations have no solution or, in short, their inclination angles become infinite. Nevertheless, the purpose of the analysis is a feasibility study on the gate body inclination control by the pulling-up force and the analyzed results have sufficient accuracy for the study purpose.

Conclusions obtained through the analytical results shown on Fig.－６ and ７ are as following.

（１）The gate body inclination control by the pulling-up force is feasible.

（２）Concerning the concept design which is a subject of the analysis,

①It is more reasonable through a perspective of the gate body inclination control that the water bottom contact point of the friction shoe locates adjacent to the gate skin plate.

②The inside of the graphs shown on Fig. －８ is a selectable domain for the tide difference and the friction coefficient.

Remarks 1）The area upper than the graph: Inclination increasing zone.

2）The area lower than the graph: No moving zone.

3）Upright zone: f = 0 ~ 0.3 for the R part contact, f = 0 ~ 0.4 for the tip contact.

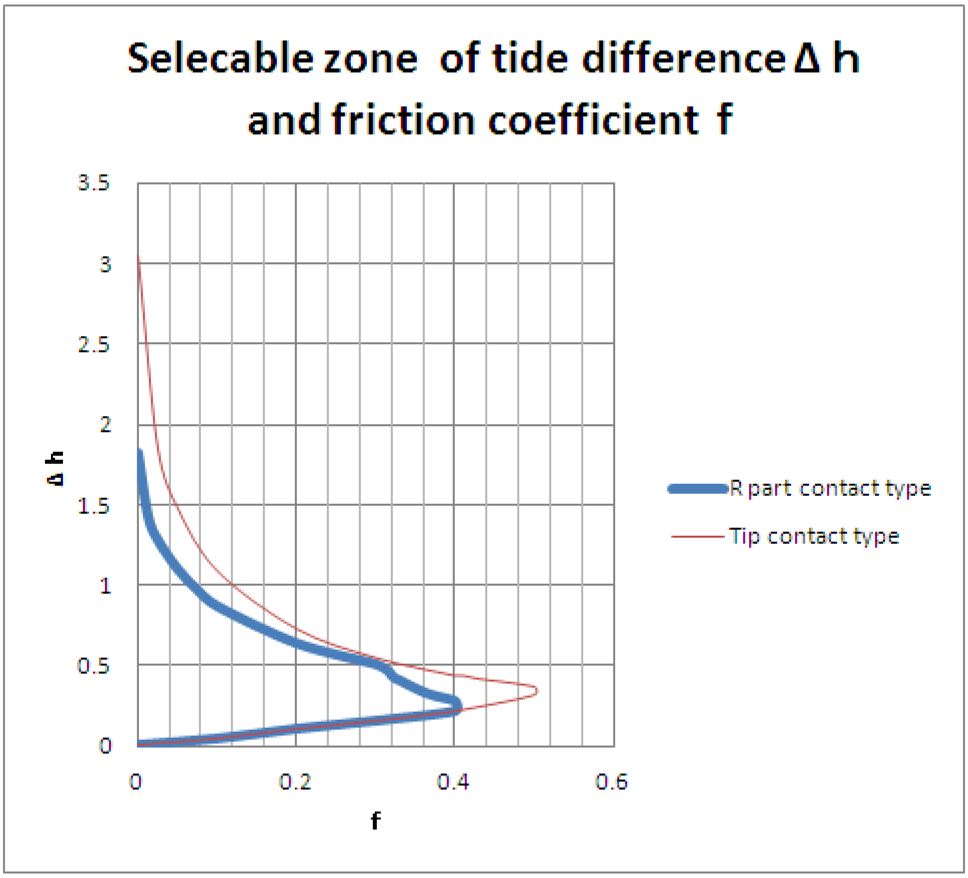

Fig.－８　Selectable zone of　tide difference and friction coefficient