

Torsion Type Swing Gate

Gate Operation in Tidal Flow

Impact Power **of The Gate Body**

T e r a M a t s u

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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. Although the gate body is accelerated by tidal force and comes to a stop due to collision of a gate bottom support seat against a water bottom concrete structure at a gate's totally closed position, tidal energy will be dissipated by a gate body friction force at certain rate and also gate body kinetic energy will be absorbed into the flexible gate body and convert to strain energy there and it is expected that the power of impact will remarkably mitigate. The purpose of this report is to analyze the gate body strain energy caused by the collision and to confirm feasibility of the energy dissipation by the friction force and the mitigation of impact power by the flexibility of gate body structure.

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		
Hydraulic condition	Site depth	16	m	
	Tide def.	5		
	Freeboard	2		
Steel weight (rough estimation)	Gate leaf	18000	tf	
	Embedded part	1500		
	Machine	500		
	Toral	20000		

In the report, the tidal force acting on the gate body is sometimes converted into water-level difference which is designated as tide difference h or h .

Firstable, the gate body strain energy was analyzed based on a condition that the strain energy caused by the collision is supposed to equal or be two times the strain energy caused by high tide and many useful information about the collision and upper limit of the gate body kinematic energy when it comes into collision have been obtained.

Secondly, constant function, linear function and parabolic function were introduced into distribution of h and kinetic energy of the three distribution functions was calculated. Although h of sea side to port side direction is working in all cases, there is no tidal flow on the gate port side in case of the constant function that means 0 working pressure on the gate body

port side and there is tidal flow on the gate port side in case of the linear and the parabolic functions and the flow impact to the working pressure on the port side of the parabolic function is bigger than the linear function. The three function's kinetic energies calculated on representative friction coefficients were graphically shown and observation of operation method in the tidal flow was made on each graph, that brought out following conclusions.

(1) The kinetic energy of the gate body gradually converts to the strain energy through the structural flexibility of the gate body and the forces acting on the gate due to collision can be quantified in the form of the inertia force and its reaction.

(2) In addition to the reaction force described above, the gate bottom support seat will get impact force which corresponds to the gate section's rotational acceleration due to collision. The seat shall have sufficient flexibility as well as high degree strength, accordingly.

(3) The tidal energy can be dissipated with the help of a friction force chart. The chart is prepared according to results of model and prototype experiments.

2 . Angular acceleration and strain energy of the gate body

2 . 1 Angular acceleration

A calculation formula of the gate body angular acceleration given by the tidal force is derived.

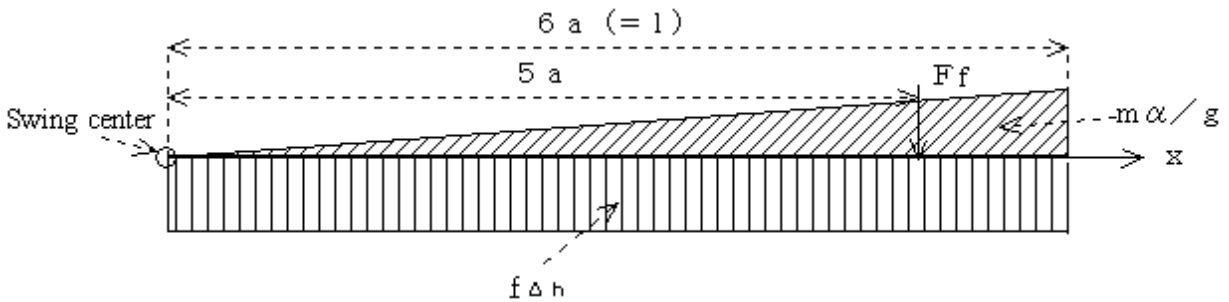


Fig. - 1 Working forces on the gate body

Fig. - 1 is a plan which shows a half span of gate body and forces working on it. The left end is a support end (swing center), the right end is a nonsupport end, l is the span $\div 2$, $F f$ is friction force of the friction shoe, m / g is unit width inertia force, m is unit width weight, α is acceleration, g is gravity acceleration, $f \Delta h$ is unit width thrust force of the tide difference Δh and x show direction of the x axis whose original point is the swing center. m is a total of virtual mass and the gate weight and is constant distribution.

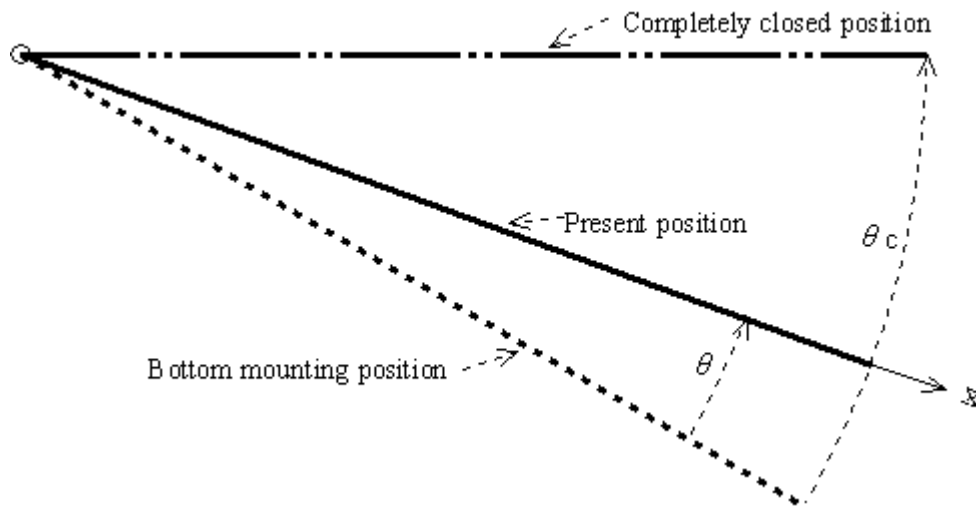


Fig. - 2 The gate body's present and completely closed position

Equation of motion is formulated as blow according to equilibrium of moment at the swing center.

$$\int_0^{6a} m \cdot g \cdot x \cdot dx + 5 a F f = \int_0^{6a} f \Delta h \cdot x \cdot dx \quad \dots\dots (2.1)$$

Fig. - 2 shows the present and the totally closed position of the gate body in angular, and c from its bottom mounting position. of formula (2.-2) is inserted into formula (2.-1), and formula (2.-3) is obtained after the integration.

$$\ddots = \ddots \times \dots\dots\dots (2.-2)$$

$$m \ddots a \ddots (\ddots a) \div (3 g) + 5 a F f = f \ddots h \ddots a (\ddots a) \div 2 \dots\dots\dots (2.-3)$$

m \ddots a = M (Total weight), f \ddots h \ddots a = F \ddots h (Total thrust) and \ddots a = l are inserted into the above formula and following angular acceleration formula is obtained.

$$\ddots = 3 g \div (2 M l) \times (F \ddots h - 5 F f \div 3) \dots\dots\dots (2.-4)$$

2 . 2 Strain energy

For a process simplification, strain energy includes only shearing strain which corresponds to external torsion moment and excludes all other elements. This approximation will not interrupt grasping the whole picture.

2 . 2 . 1 Shell plate thickness selection

The plate thickness selection is made for stress due to the external moment which works on the gate body at high tide condition. All other elements are considered in the allowable stress.

Steel grade and allowable stress: As shown in Fig - 2 .

Fig. - 2 Allowable shearing stress and yield point

Material (JIS etc.)		SM400	SM490	SM570	70HT	80HT	100HT
Yield point	Kgf/mm2	22	30	40.8	52	58.2	69.2
Shear \tau a		7.0	9.5	13.0	16.5	18.5	22.0

Selection : Allowable stress on Fig. - 2 and selection condition on Table - 3 are applied.

Table - 3 Thickness selection condition

Minimum constant thickness length	10	m
Minimum thickness	12	mm
Maximum thickness	50	mm

2 . 2 . 2 Calculation formula of strain energy

The strain energy formula is derived from below general formula which is shown in various handbooks.

$$U = \sum_{i=1}^n \frac{T_i^2}{8AG} \div t_i L_g L_i \dots\dots\dots (2.-5)$$

$$i = \frac{T_i}{2A t_i} \dots\dots\dots (2.-6)$$

where T_i : External torsion moment of i section

A : Area of a box section

G : Shearing elastic coefficient

t_i : Plate thickness of i section block

L_g : Girth length of A

L_i : Length of i section block

U : Shearing strain energy of the gate body

i : Shearing stress due to torsion of i section

T_i is derived from formula (2.-6), after replaced by $i = \tau_{ai}$ (allow able shearing stress of i section) and the strain calculation formula is obtained after the T_i in formula (2.-5) is replaced by it.

$$U = \sum_{i=1}^n L_g t_i \tau_{ai}^2 \div (2G) L_i \dots\dots\dots (2.-7)$$

In addition, t_i is derived from formula (2.-6), after replaced by $i = \tau_{ai}$ (allow able shearing stress of i section) and another strain calculation formula is obtained after the t_i in formula (2.-7) is replaced by it and the \sum in the formula is replaced by a integration mark.

$$U = \int_0^1 L_g \tau_{ai}^2 \div (4AG) T dx = C \int_0^1 T dx \dots\dots\dots (2.-8)$$

where C : A constant with regard to x

Formula (2.-5) gives strain energy with respect to the external torsion moment and formula (2.-8) and formula (2.-7) give strain energies with respect to respectively the calculated shell plate thickness and the selected shell plate thickness whose stresses are both in the state of the allowable level.

2 . 2 . 3 Torsion moment calculation formula of the collision

The gate body's torsion which occurs when the gate body bottom support seat hits the water bottom concrete structure is deemed to be due to the gate body inertia force. Suppose the inertia force acting on the gate body unit width section is in linear to speed of the section, the torsion moment externally acting on the section will be in the form of following.

$$m_i = a x \div l \quad \dots\dots\dots (2.-9)$$

where a : Constance

l : Gate span $\div 2$

x : A point on the x axis shown on Fig. - 1

As against this, the torsion moment acting on the gate body unit width due to water pressure of high tide will be in the form of following.

$$m_w = l \quad \dots\dots\dots (2.-10)$$

The two formulae are integrated from l to x along the x axis and the external torsion moment at arbitrary gate section is obtained.

$$\text{At collision: } T_i = a (l - x^2 \div l) \div 2 \quad \dots\dots\dots (2.-11)$$

$$\text{At high tide: } T_w = l - x \quad \dots\dots\dots (2.-12)$$

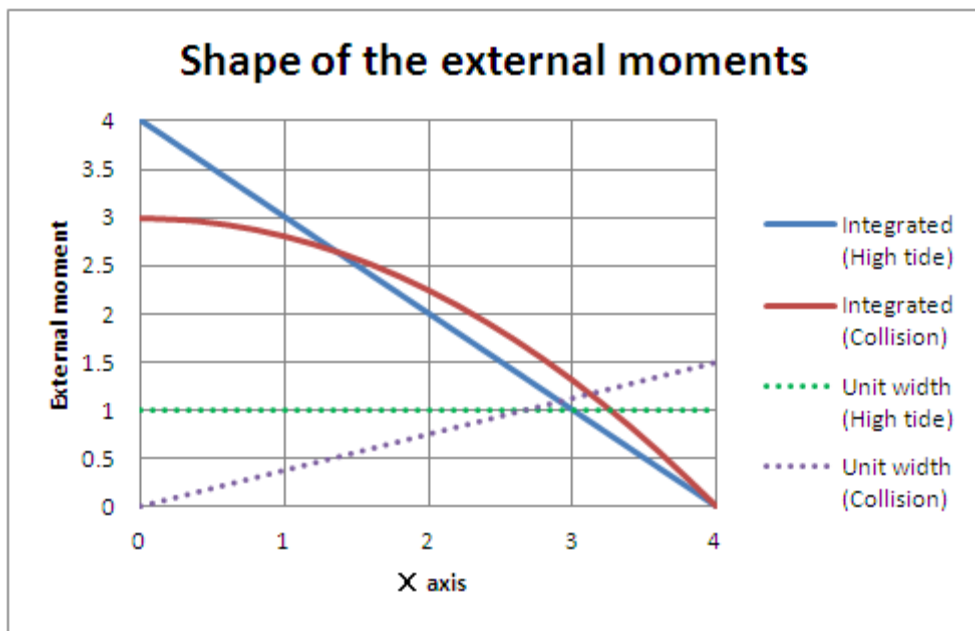


Fig. - 3 A shape of the external moments

The coefficient a is approximately determined according to formula (2.-8) so that that the strain energies due to the two external torsion moments may become equal.

$$\text{At collision: } U_i = C a \int_0^1 (1 - x^2) dx = a C \frac{1}{3} \dots\dots\dots (2.-13)$$

$$\text{At high tide: } U_w = C \int_0^1 (1 - x) dx = C \frac{1}{2} \dots\dots\dots (2.-14)$$

a = 1.5 is obtained by setting $U_i = U_w$. Fig. - 3 shows a shape of the external moments of formula (2.-9) through (2.-12). l is set 4 for a convenience of graphical expression. To increase the degree of approximation, the coefficient a is expressed by following formula where the modification factor is determined by numerical calculation of the strain energies.

$$a = 1.5 \times \text{Modification factor} \dots\dots\dots (2.-15)$$

2.2.4 Reaction force of the bottom support seat

Reaction force of the gate bottom support seat at collision is a part of coupling force which corresponds to the external moment of formula (2.-9) and its magnitude is given by following formula.

$$\text{Support seat reaction force} = \frac{\text{The external moment at high tide} \times a}{\text{vertical distance between the inertia force center and the support seat}} \dots\dots\dots (2.-16)$$

where l a : The a of formula (2.-15)

Although formula (2.-16) is a reaction force of the inertia force, it will be 0 at the instant of collision, increase gradually and become the value given by the formula when the strain energy accumulation amount arrives at the allowable maximum. The gate body will start to rotate around the bottom support seat when the support seat hits the water bottom concrete structure and the seat design will need a consideration to absorb the impact power which may result from the commencement of the rotation.

2 . 3 Results of calculation

2 . 3 . 1 The calculated shell thickness and the selected shell thickness

Table - 4 Calculated thickness and selected thickness

Block No.	1	2	3	4	5	6	7	8	9	10	11	12	
Block length(m)	5	10	10	10	10	10	10	10	10	10	10	10	
Point on x axis(m)	0	5	15	25	35	45	55	65	75	85	95	105	
External moment (tf-m)	Integrated $\times 10^{-3}$	204	200	190	181	172	163	154	145	136	127	118	109
	Unit width	907	907	907	907	907	907	907	907	907	907	907	907
τa (Kg/mm ²)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
Calculated thickness(mm)	49.6	48.5	46.3	44.1	41.9	39.7	37.5	35.3	33.1	30.9	28.7	26.5	
Selected thickness(mm)	50.0	50.0	48.0	46.0	42.0	40.0	38.0	36.0	34.0	32.0	30.0	28.0	
Ratio	1.01	1.03	1.04	1.04	1.00	1.01	1.01	1.02	1.03	1.04	1.05	1.06	
Block No.	13	14	15	16	17	18	19	20	21	22	23		
Block length(m)	10	10	10	10	10	10	10	10	10	10	10		
Point on x axis(m)	115	125	135	145	155	165	175	185	195	205	215	225	
External moment (tf-m)	Integrated $\times 10^{-3}$	100	91	82	73	63	54	45	36	27	18	9	0
	Unit width	907	907	907	907	907	907	907	907	907	907	907	907
τa (Kg/mm ²)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0		
Calculated thickness(mm)	24.3	22.1	19.9	17.6	15.4	13.2	11.0	8.8	6.6	4.4	2.2		
Selected thickness(mm)	25.4	24.0	20.0	18.0	16.0	14.0	12.0	12.0	12.0	12.0	12.0		
Ratio	1.05	1.09	1.01	1.02	1.04	1.06	1.09	1.36	1.81	2.72	5.44		

2 . 3 . 2 Weight of the gate body

Table - 5 Gate body weight

Block No.	1	2	3	4	5	6	7	8	9	10	11	12
Shell plate weight(tf)	141	283	271	260	237	226	215	203	192	181	170	158
Block No.	13	14	15	16	17	18	19	20	21	22	23	
Shell plate weight(tf)	144	136	113	102	90	79	68	68	68	68	68	
Weight (tf)	Shell total	3540										
	Others total	2124										
	Total	5665										

2 . 3 . 3 The modified a and the external moment

The modified a

Modification factor for the a is 1 . 0 6 6 which was obtained from the strain energy calculation. The a of formula (2.-15) is given as below, accordingly.

$$a = 1 . 5 \times 1 . 0 6 6 = 1 . 6 \dots (2.-17)$$

The external moments

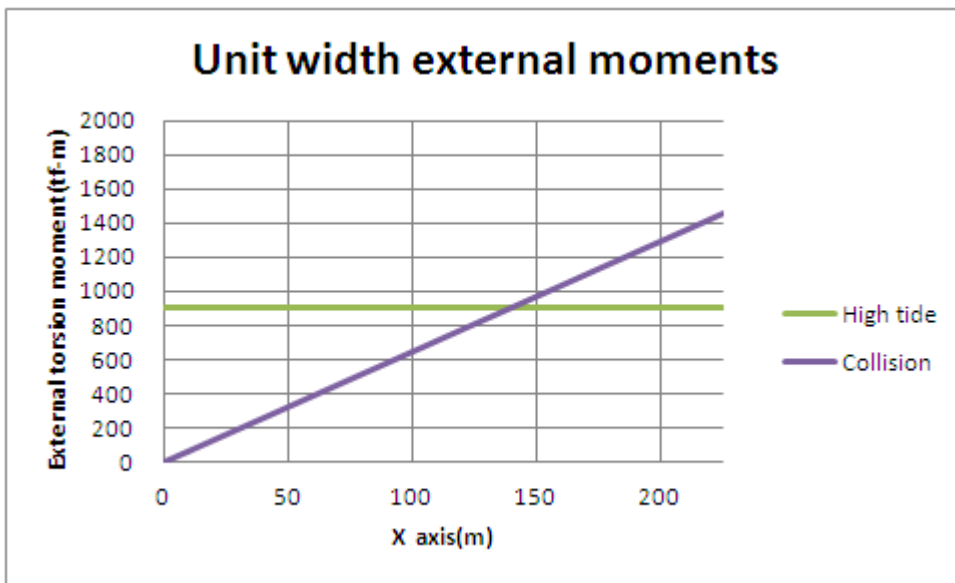


Fig. - 4 External moments (Unit width)

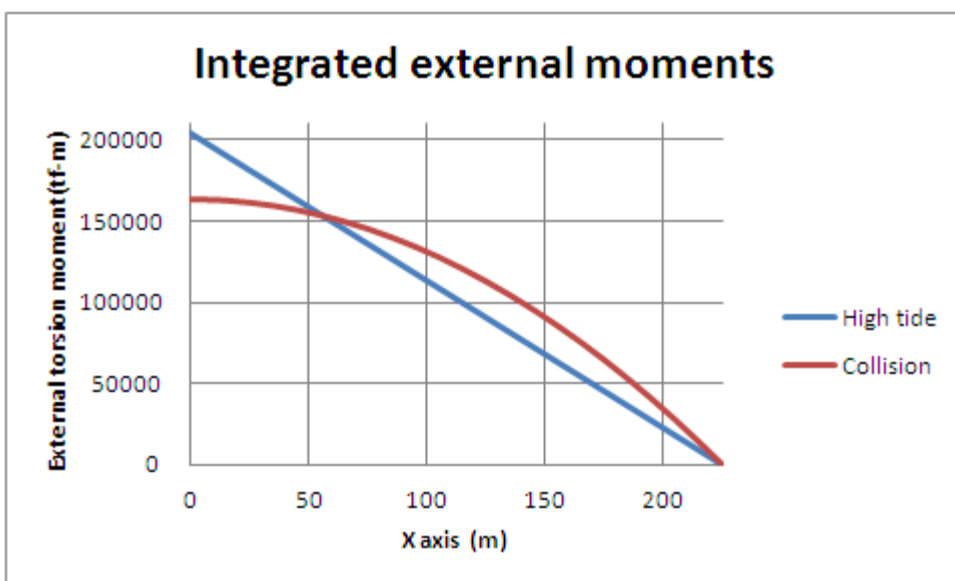


Fig. - 5 External moments (Integrated)

Fig. - 4 and 5 are calculated results of the external moments. Fig. - 4 shows unit width external moments distribution and Fig. - 5 shows their integration. The external moments of collision have been so determined that their gate body shearing strain energy may equal to these of high tide. The strain energy is calculated according to the integrated external moments.

2 . 3 . 4 Strain energy

Table - 6 Strain energy at high tide (U_w)

Block No.		1	2	3	4	5	6	7	8	9	10	11	12
External moment (tf-m)	Integrated $\times 10^{-3}$	204	200	190	181	172	163	154	145	136	127	118	109
	Unit width	907	907	907	907	907	907	907	907	907	907	907	907
U_w (tf-m)	$\tau = \tau_a$	55	109	105	100	92	87	83	79	74	70	66	61
	$\tau = 2\tau_a$	218	437	419	402	367	349	332	314	297	280	262	245
Block No.		13	14	15	16	17	18	19	20	21	22	23	
External moment (tf-m)	Integrated $\times 10^{-3}$	100	91	82	73	63	54	45	36	27	18	9	0
	Unit width	907	907	907	907	907	907	907	907	907	907	907	907
U_w (tf-m)	$\tau = \tau_a$	55	52	44	39	35	31	26	26	26	26	26	
	$\tau = 2\tau_a$	222	210	175	157	140	122	105	105	105	105	105	
Total U_w (tf-m)	$\tau = \tau_a$ (Limit1)	1368											
	$\tau = 2\tau_a$ (Limit2)	5472											

Table - 7 Strain energy at collision (U_i)

Block No.		1	2	3	4	5	6	7	8	9	10	11	12
External moment (tf-m)	Integrated $\times 10^{-3}$	163	163	162	161	159	157	153	150	145	140	134	128
	Unit width	0	32	97	161	226	290	355	419	483	548	612	677
U_i (tf-m)	$\tau = \tau_a$	34	69	71	73	78	79	80	80	80	79	77	75
	$\tau = 2\tau_a$	138	275	284	292	312	317	320	321	320	316	310	301
Block No.		13	14	15	16	17	18	19	20	21	22	23	
External moment (tf-m)	Integrated $\times 10^{-3}$	121	113	104	95	86	75	64	53	41	28	14	0
	Unit width	741	806	870	935	999	1064	1128	1193	1257	1321	1386	1450
U_i (tf-m)	$\tau = \tau_a$	74	68	70	65	59	52	45	30	18	8	2	
	$\tau = 2\tau_a$	296	274	282	261	237	210	179	120	71	33	9	
Total U_i (tf-m)	$\tau = \tau_a$	1369											
	$\tau = 2\tau_a$	5474											

Table - 6 and 7 are calculated results of the gate body strain energies. Table - 6

corresponds to the external moment at high tide and Table - 7 the external moments at collision. The strain energy was calculated for the shearing stress in the state of allowable level ($\tau = \tau_a$) and also in the state of twice the allowable level ($\tau = 2 \tau_a$). The total U_i of $\tau = \tau_a$ (limit 1) and $\tau = 2 \tau_a$ (limit 2) at the high tide (Table - 6) are supposed to be the allowable limits of the gate body kinetic energy created by tidal force. The limit 1 corresponds to the allowable stress level of the gate body and the limit 2 corresponds to about the 95 % yield point level. The strain energies at the collision (Table - 7) have been calculated corresponding to the energies of Table - 6. The modification factor of the formula (2.-15) was so determined that the energy value total of both tables may equal. For reference, the external moment of the limit 2 is twice the limit 1 and the strain energy four times.

2 . 3 . 5 The bottom support seat reaction force and the gate body speed due to collision

Table - 8 Bottom support seat reaction force

Calculation items		Mark	Calculation	Unit
Gravity center height		X_g	11.25	m
Vertical mass center height		X_a	7.75	m
Support seat center height		X_s	-0.5	m
Inertia force center height		X_i	8.536	m
Arm length of coupling force		L_a	9.036	m
Support seat reaction force	$\tau = \tau_a$	F_{limit1}	161	tf/m
	$\tau = 2 \tau_a$	F_{limit2}	321	tf/m

Table - 8 is a reaction force calculation result of the gate body bottom support seat which is subject to impact power of collision. The reaction force shown corresponds to the maximum external moment of Fig. - 4 and their magnitude level is within the range which usual civil technology can afford to manage. The reaction force at the instant of collision is zero and will reach at the table values when the gate body strain energy becomes the limit values. Besides this, the gate body will start to rotate around the bottom support seat when the support seat hits the water bottom concrete structure and the seat design will need a consideration to absorb the impact power which may result from the commencement of the rotation (Flexibility for the impact and high strength for the reaction force).

Table - 9 Gate body speed at collision

Energy condition		Limt1	Limit2
Inertia weight	tf	801.79	
Gravity acceleration	m/sec	9.8	
Half span	m	225	
Energy	tf-m	1368.1	5472.2
Angle speed	$^\circ$ /sec	0.26	0.51
Tip speed	m/sec	1.0	2.0

Table - 9 is calculation results of the gate body speed at collision. Angular speed and the tip

speed are shown on the table. The velocities were obtained by formulae (3.-8) and (3.-9) after the total U_w (energy levels of the limit 1 and the limit 2) of Table - 6 was inserted into W_k of these formulae. The result corresponds to the support seat reaction force of Table - 8. For reference, the inertia weight is a sum of the gate weight and the virtual weight (water) and the virtual weight of very low estimation accuracy occupies nearly 90 % of the sum. Suppose the inertial weight is half in quantity, the speed of the gate body would be 2 times the calculated result. It is estimated that real value may stay between the two.

3 . Kinetic energy of the gate body

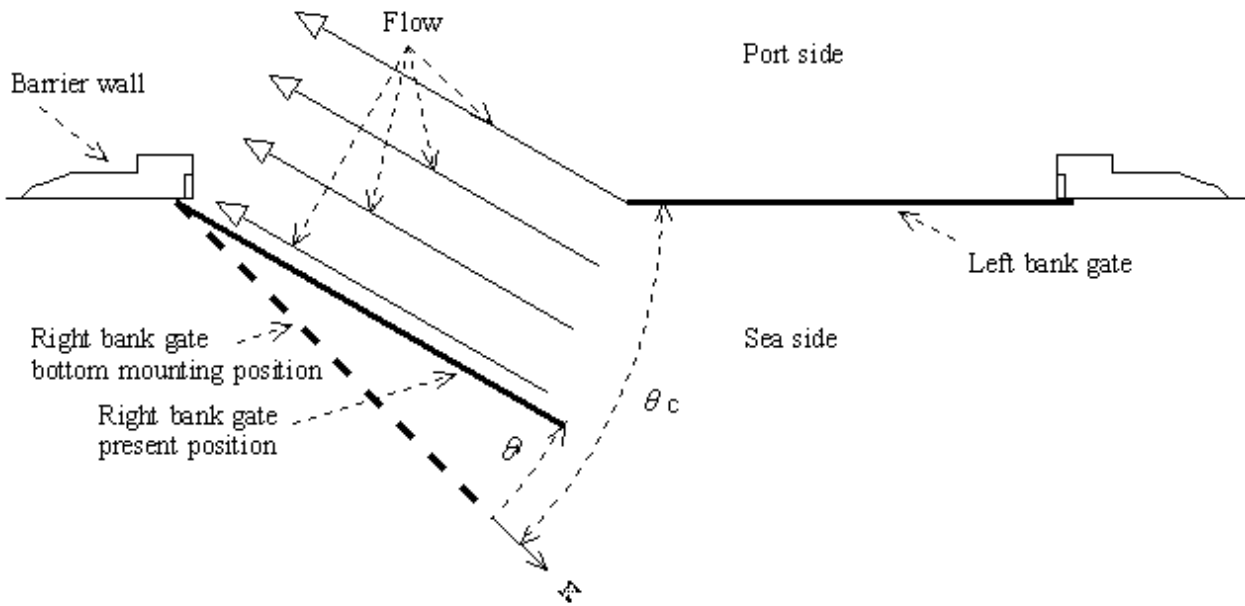


Fig. - 6 Effect of tidal flow

The kinetic energy of gate body can be grasped as amount of work made by acting force or as amount of kinetic energy in the gate body accumulated by acting force. Although the acting force is deemed to be water-level difference converted from tidal flow, in short, the tide difference h , or, merely h , there always exists tidal flow on the sea side and the port side of the gate body except when the gate is at completely closed position and the real magnitude of acting force is different from h because of the flow existence. Suppose, for instance, there is the tide difference h between the port side and the sea side on Fig. - 6 where θ is angle to the bottom mounting position of the gate body's present position and θ_c is angle of the completely closed position. Since tidal flow exists on the port side of the gate body and a slope of water surface forms there, the tide difference decreases by the slope height. The tide difference approaches h as the tidal flow impact range decreases due to θ increase and becomes h when $\theta = \theta_c$ and the tidal flow diminishes. The tide difference change like this is replaced by following 3 functions and their impact on the kinetic energy is grasped.

$$\text{Constant function: } h = h \quad \dots (3.-1)$$

$$\text{Linear function: } h = h \times \left(\frac{\theta}{\theta_c} \right) \quad \dots (3.-2)$$

$$\text{Parabolic function: } h = h \times \left(\frac{\theta}{\theta_c} \right)^2 \quad \dots (3.-3)$$

The constant function is the case whose energy level is higher than reality since the tide difference h works on the sea side and the tidal flow effect on the sea and port side is neglected. The linear function is the case whose energy level may be too high or too low since the

tidal flow effect on the sea side is neglected although that of the port side is considered. The parabolic function is the case whose energy level is the lowest among the three functions since the tidal flow effect on the port side is approximately considered and its effective intensity is much more than the linear function. In short, it may be full potential that the real energy level exists between the constant function and the parabolic function.

3 . 1 Formula to calculate kinetic energy of the gate body

3 . 1 . 1 Constant function

Calculation formula of the kinetic energy caused by the tidal force is derived in the form of work made by the tidal force and the kinetic energy accumulated in the gate body.

(1) Work (Ww)

$$W_w = \text{Force} \times \text{Travel distance} = \int_0^l c \times f_h \, dx = c l \times \frac{5}{6} F_f \dots\dots\dots (3.-4)$$

Above formula is integrated and a replacement is made by $f_h l = F_h$ to get below formula.

$$W_w = c l \div 2 (F_h - 5 F_f \div 3) \dots\dots\dots (3.-5)$$

(2) kinetic energy (Wk)

$$\begin{aligned} \text{Angle velocity} &= \dot{\theta} = \ddot{\theta} t \\ \text{Final angle} &= \theta = \ddot{\theta} t^2 \div 2 = c, \text{ Accordingly, } t = (2 \cdot c \div \ddot{\theta})^{1/2} \\ \text{Final angle velocity} &= \dot{\theta} = (2 \cdot c \div \ddot{\theta})^{1/2} = (2 \cdot c \cdot \ddot{\theta})^{1/2} \\ \text{Final velocity} &= v = \omega \times (2 \cdot c \cdot \ddot{\theta})^{1/2} \end{aligned}$$

$$W_k = \text{Mass} \times \text{Final velocity}^2 \div 2 = \frac{1}{2} m \div g \times \times 2 \cdot c \cdot \ddot{\theta} \, d x \div 2 \dots\dots\dots (3.-6)$$

Above formula is integrated and a replacement is made by $m l = M$, then below formula is obtained after formula (2.-4) is inserted.

$$W_k = c l \div 2 (F_h - 5 F_f \div 3) \dots\dots\dots (3.-7)$$

Consequently, Wk and Ww are equal.

Formula of the gate body speed at collision is derived.

$$\text{Gate velocity} = V = \dot{\theta} \times r$$

$$W_k = \text{Mass} \times \text{Final velocity}^2 \div 2 = \frac{1}{2} m \div g \times (x \dot{\theta})^2 d \times \div 2 = M (l \dot{\theta})^2 \div (6 g)$$

Accordingly,

$$\text{Gate angular velocity at collision} = \dot{\theta} = (6 g W_k \div M)^{1/2} \div l \dots\dots\dots (3.-8)$$

$$\text{Gate tip velocity at collision} = V = (6 g W_k \div M)^{1/2} \dots\dots\dots (3.-9)$$

3 . 1 . 2 Linear function

Calculation formula of the kinetic energy caused by the tidal force is derived in the form of work made by the tidal force and the kinetic energy accumulated in the gate body.

(1) Work (W_w)

$$W_w = \text{Force} \times \text{Travel distance} = \int_0^l f_h (\div c) \times d \quad d \times - \quad c l \times 5 F f \div 6 \dots\dots\dots (3.-10)$$

Above formula is integrated and a replacement is made by $f_h l = F_h$ to get below formula.

$$W_w = c l \div 2 (F_h \div 2 - 5 F f \div 3) \dots\dots\dots (3.-11)$$

Fig. - 7 shows the tide difference distribution along axis. axis, x axis (vertical to the paper) and c are as same as Fig. - 6 . The vertical axis is the tide difference and h_f is a value of h whose thrust force equals the shoe friction force. The area of a b c is linear to the first term of formula (3.-11) and the area of b c d e is linear to the second term of the formula. Consequently formula (3.-11) was overly deducted by e b f since the gate move due to the tide difference does not occur in the range of h h_f and the formula is modified as below accordingly.

$$W_w = c l \div 2 \{ F_h \div 2 \times (1 + h_f \div h) - 5 F f \div 3 \} \dots\dots\dots (3.-12)$$

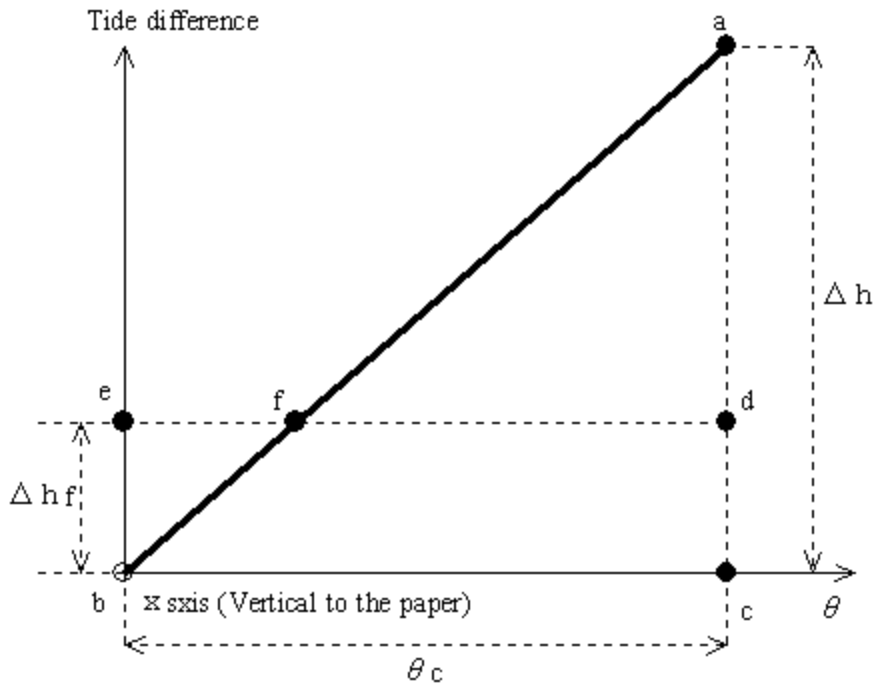


Fig. - 7 Tide difference distribution (Linear function)

(2) kinetic energy (Wk)

Formula (2.-4) is modified as below based on the assumption of the tide difference linear function.

$$\ddot{\theta} = 3g \div (2Ml) \{ F_h \times (\theta \div c) - 5Ff \div 3 \} \dots\dots (3.-13)$$

The mean angle acceleration is calculated.

$$\int_0^c \ddot{\theta} d\theta = 3g \div (2Ml) [F_h \times (\theta^2 \div 2c) - 5Ff \div 3 \times \theta]_0^c$$

$$= 3g \div (2Ml) \times c (F_h \div 2 - 5Ff \div 3)$$

$$\text{Mean angle acceleration} = \ddot{\theta}_m = \ddot{\theta} \div c = 3g \div (2Ml) \times (F_h \div 2 - 5Ff \div 3) \dots\dots (3.-14)$$

$$\text{Angle velocity} = \dot{\theta} = \ddot{\theta}_m t$$

$$\text{Final angle} = \theta = \ddot{\theta}_m t^2 \div 2 = c, \text{ accordingly, } t = (2c \div \ddot{\theta}_m)^{1/2}$$

$$\text{Final angle velocity} = \dot{\theta} = \ddot{\theta}_m (2c \div \ddot{\theta}_m)^{1/2} = (2c \ddot{\theta}_m)^{1/2}$$

$$\text{Final velocity} = v = \dot{\theta} \times (2c \div \ddot{\theta}_m)^{1/2}$$

$$Wk = \text{Mass} \times \text{Final velocity}^2 \div 2 = \frac{1}{2} m \div g \times \times 2c \ddot{\theta}_m \times \div 2 \dots\dots (3.-15)$$

Above formula is integrated and a replacement is made by $m l = M$, then below formula is

obtained after formula (3.-14) is inserted.

$$W_k = \frac{c l}{2} (F_h \div 2 - 5 F_f \div 3) \dots\dots (3.-16)$$

Consequently, W_k and W_w of formula (3.-11) are equal.

Formula (3.-16) is modified to get formula (3.-17) for the reason for which formula (3.-11) was modified to get formula (3.-12).

$$W_k = \frac{c l}{2} \{ F_h \div 2 \times (1 + \frac{h f}{h}) - 5 F_f \div 3 \} \dots\dots (3.-17)$$

3 . 1 . 3 Parabolic function

Calculation formula of the kinetic energy caused by the tidal force is derived in the form of work made by the tidal force and the kinetic energy accumulated in the gate body.

(1) Work (W_w)

$$W_w = \text{Force} \times \text{Travel distance} = \int_0^l \frac{c}{f} h \left(\frac{c}{h} \right)^2 \times d \quad d \times - \frac{c l}{2} \times 5 F_f \div 3 \dots\dots (3.-18)$$

Above formula is integrated and a replacement is made by $f h l = F_h$ to get below formula.

$$W_w = \frac{c l}{2} (F_h \div 3 - 5 F_f \div 3) \dots\dots (3.-19)$$

Fig. - 8 shows the tide difference distribution along x axis. x axis (vertical to the paper) and c are as same as Fig. - 6 . The vertical axis is the tide difference and $h f$ is a value of h whose thrust force equals the shoe friction force. The area $a b c$ is linear to the first term of formula (3.-11) and the area $b c d e$ is linear to the second term of the formula. Consequently formula (3.-11) was overly deducted by the area $e b f$ since the gate move due to the tide difference does not occur in the range of h $h f$ and the formula is modified as below accordingly.

$$W_w = \frac{c l}{2} \{ F_h \div 3 \times [1 + 2 \left(\frac{h f}{h} \right)^{3/2}] - 5 F_f \div 3 \} \dots\dots (3.-20)$$

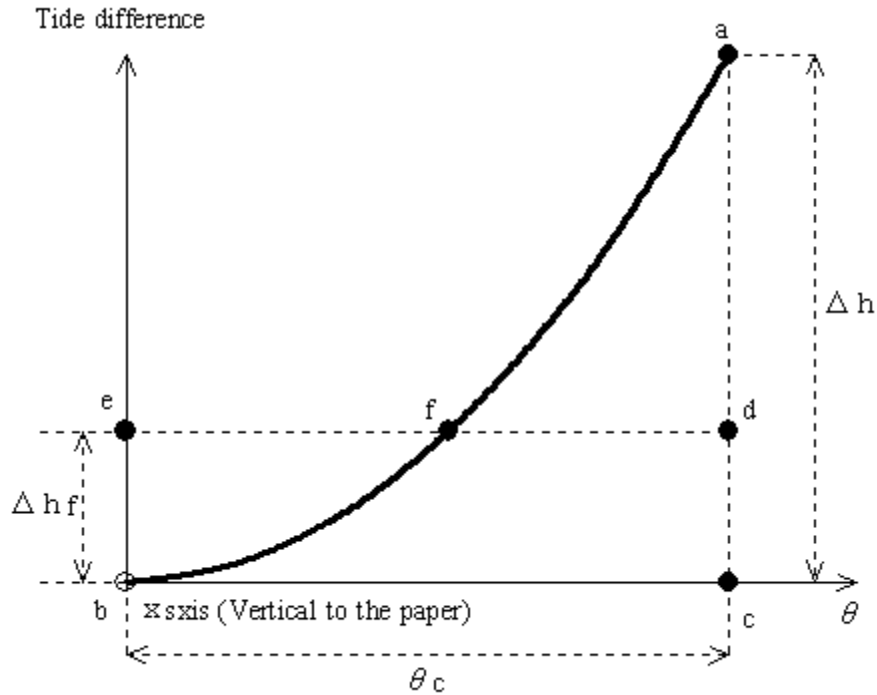


Fig. - 8 Tide difference distribution (Parabolic function)

(2) Kinetic energy (Wk)

Formula (3.-13) is modified as below based on the assumption of the tide difference parabolic function.

$$\ddot{\theta} = 3g \div (2Ml) \{ Fh \times (\frac{2}{c}) - 5Ff \div 3 \} \dots\dots (3.-21)$$

The mean angle acceleration is calculated.

$$\begin{aligned} \int_0^c \ddot{\theta} d\theta &= 3g \div (2Ml) [Fh \times (\frac{3}{3} \frac{2}{c}) - 5Ff \div 3 \times \theta]_0^c \\ &= 3g \div (2Ml) \times c (Fh \div 3 - 5Ff \div 3) \end{aligned}$$

$$\text{Mean angle acceleration} = \ddot{\theta}_m = \ddot{\theta} \div c = 3g \div (2Ml) \times (Fh \div 3 - 5Ff \div 3) \dots\dots (3.-22)$$

$$\begin{aligned} \text{Angle velocity} &= \dot{\theta} = \ddot{\theta}_m t \\ \text{Final angle} &= \theta = \ddot{\theta}_m t^2 \div 2 = c, \text{ accordingly, } t = (\frac{2}{\ddot{\theta}_m} c)^{1/2} \\ \text{Final angle velocity} &= \dot{\theta} = \ddot{\theta}_m (\frac{2}{\ddot{\theta}_m} c)^{1/2} = (2c \ddot{\theta}_m)^{1/2} \\ \text{Final velocity} &= v = \dot{\theta} \times (2c \ddot{\theta}_m)^{1/2} \end{aligned}$$

$$Wk = \text{Mass} \times \text{Final velocity}^2 \div 2 = \frac{1}{2} m \div g \times \times 2 c \ddot{\theta}_m \times \div 2 \dots\dots (3.-15)$$

Above formula is integrated and a replacement is made by $ml = M$, then below formula is

obtained after formula (3.-22) is inserted.

$$W_k = c l \div 2 (F h \div 3 - 5 F f \div 3) \dots\dots (3.-23)$$

Consequently, W_k and W_w of formula (3.-19) are equal.

Formula (3.-23) is modified to get formula (3.-24) for the reason for which formula (3.-19) was modified to get formula (3.-20).

$$W_k = c l \div 2 \{ F h \div 3 \times [1 + 2 (h f \div h)^{3/2} - 5 F f \div 3] \dots\dots (3.-24)$$

3 . 2 Results of calculation

The calculated results of the gate body kinetic energy when the gate arrives at its totally closed position and hits the water bottom concrete structure are shown on Fig. - 9 (constant function), Fig. - 10 (linear function) and Fig. - 11 (parabolic function). Each figure consists of sub-number 1 / 13 thru 13 / 13 which cover the friction coefficient $f = 0 \sim 0.4$. The lateral axis is tide flow (m / s), the vertical axis is kinetic energy $W_k (t f - m)$ and the group name is the bottom mounting angle c (= angle from the totally closed position). Furthermore, Limit 1 and Limit 2 which are supposed to be limit level of the kinetic energy during operation in tidal flow are added to the group name so that a combination of f and h which satisfies the energy limit level may be found by a graph on the figures. The graphs move to the right direction according to the f increase. That is a boost-up effect of the friction force on a flow velocity applicable to the gate operation. For reference, the f value equal or more than 0.2 may not be realistic because of costwise and technical reasons. Although the friction shoe load in the energy calculations was locked in $1074 t f$, two times friction force or three times friction force will be available if the locked number increases by two times or by three times and the calculated results of the two times f or the three times f will be applicable. A diagonally left down graph on the figures terminates at the tide flow axis and the graph terminal point moves right hand side as the f increases. The gate body cannot move on the left hand side axis of the point since the friction force dominates against the tidal force there.

3 . 2 . 1 Constant function

Fig. - 9 shows the results corresponding to the tide difference h distribution of the constant function. The tidal flow range of the kinetic energy within the energy limit is very narrow at the bottom mounting angle $c = 20^\circ$. It is a calculation assumption that there is no tide flow around the gate body except the tide difference h and this assumption may be energetically too severe and operationally too much since it is not realistic.

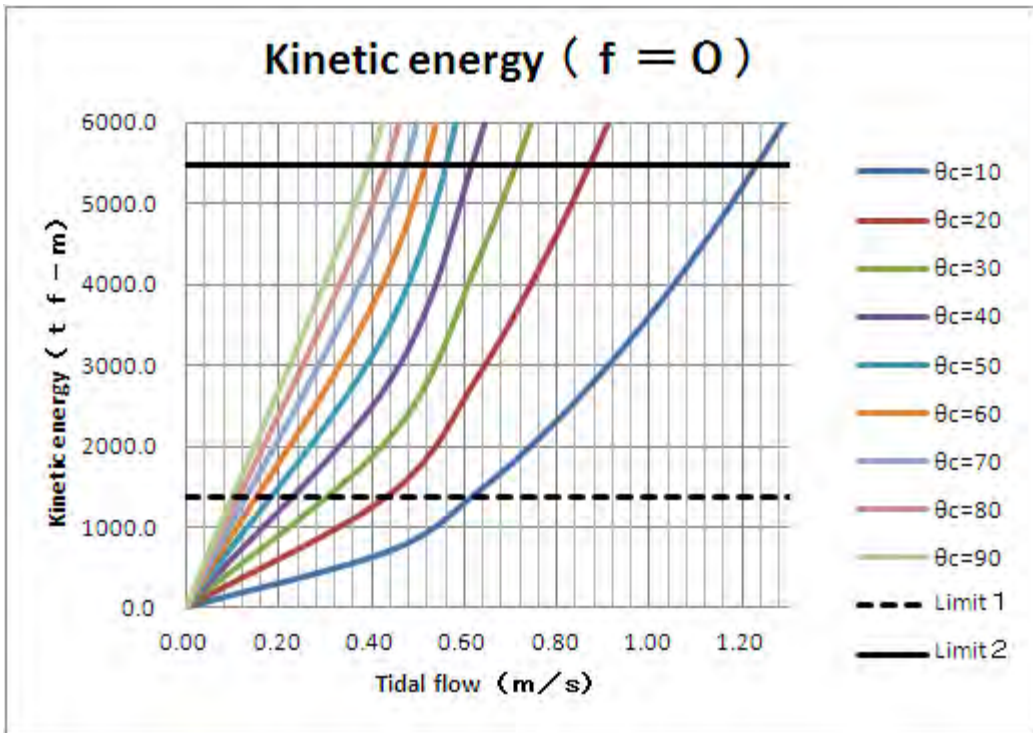


Fig. - 9 Kinetic energy of the constant function (1 / 1 3)

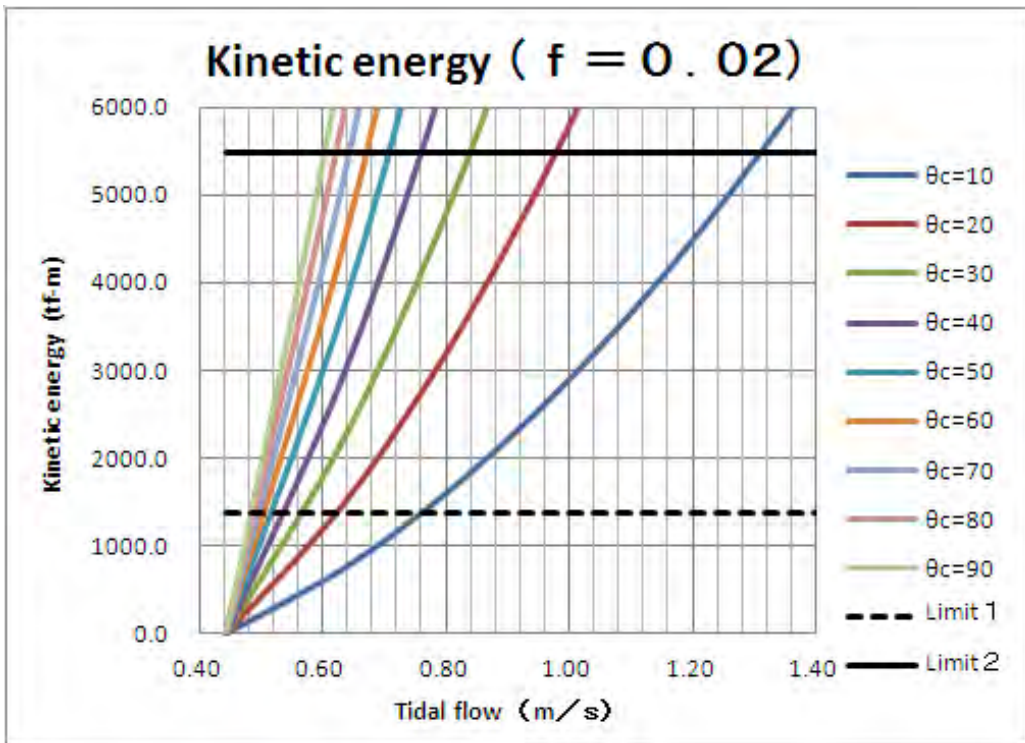


Fig. - 9 Kinetic energy of the constant function (2 / 1 3)

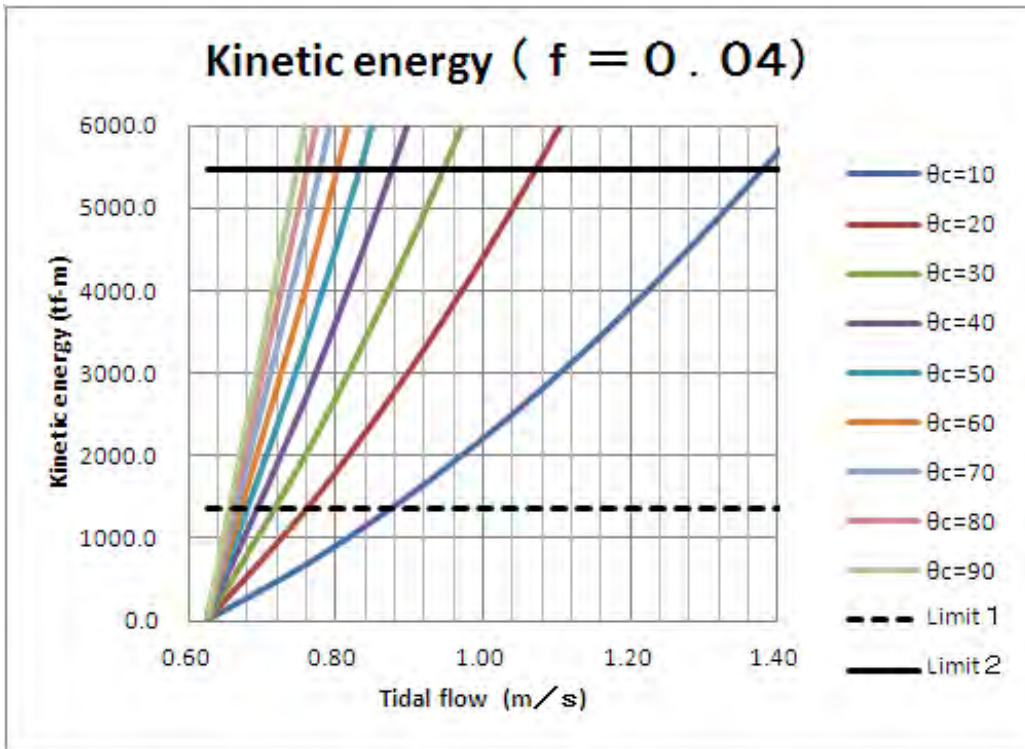


Fig. - 9 Kinetic energy of the constant function (3 / 1 3)

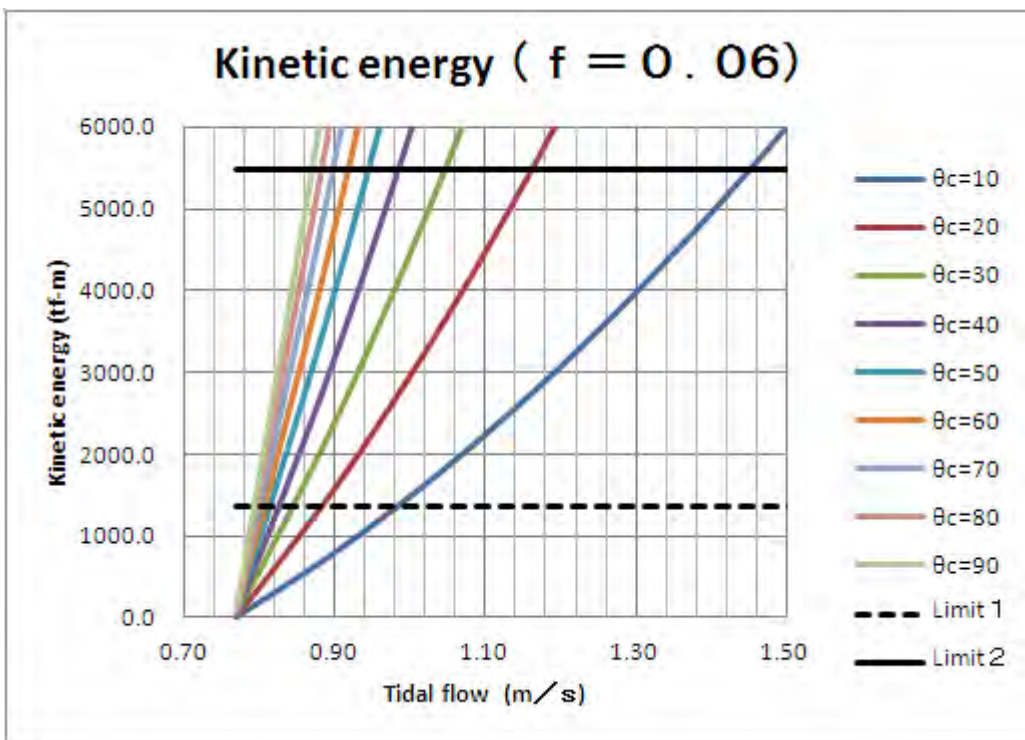


Fig. - 9 Kinetic energy of the constant function (4 / 1 3)

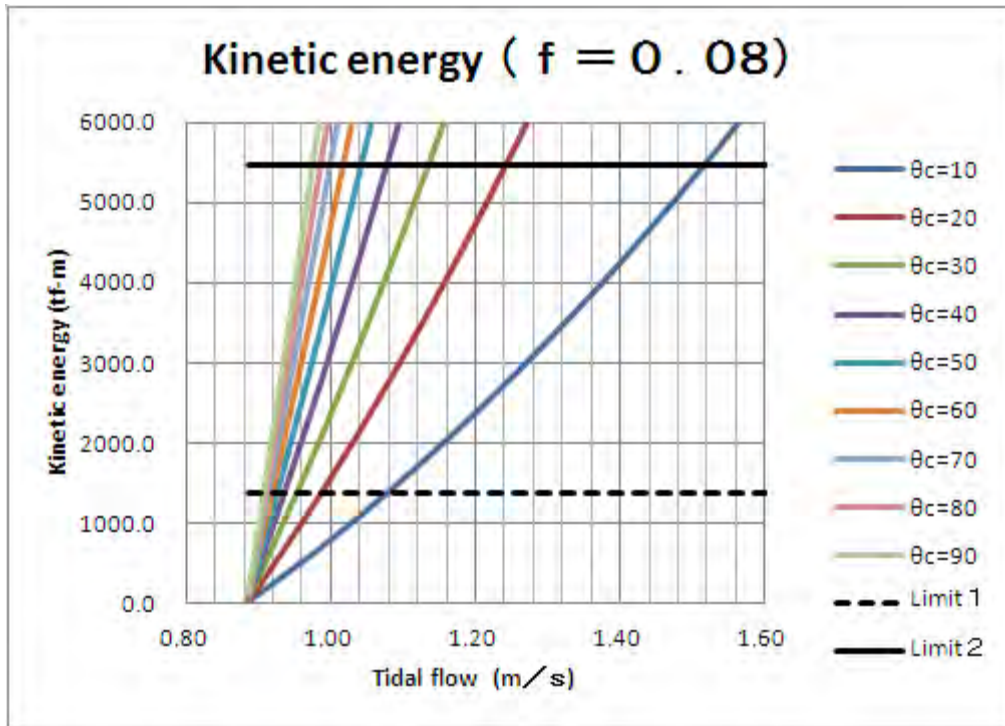


Fig. - 9 Kinetic energy of the constant function (5 / 1 3)

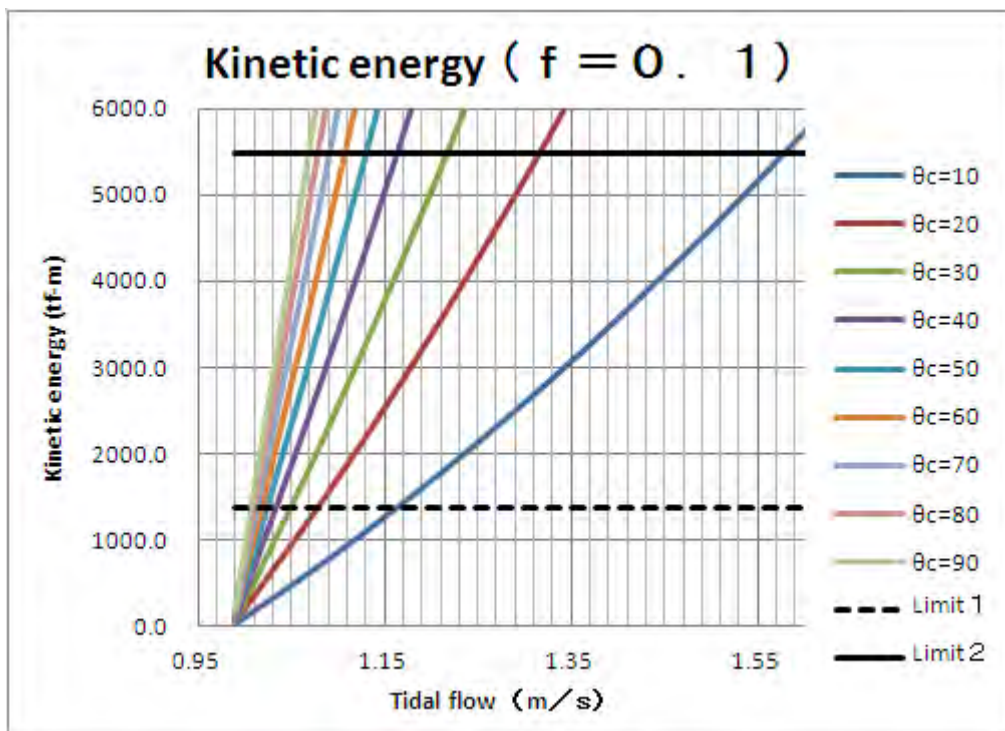


Fig. - 9 Kinetic energy of the constant function (6 / 1 3)

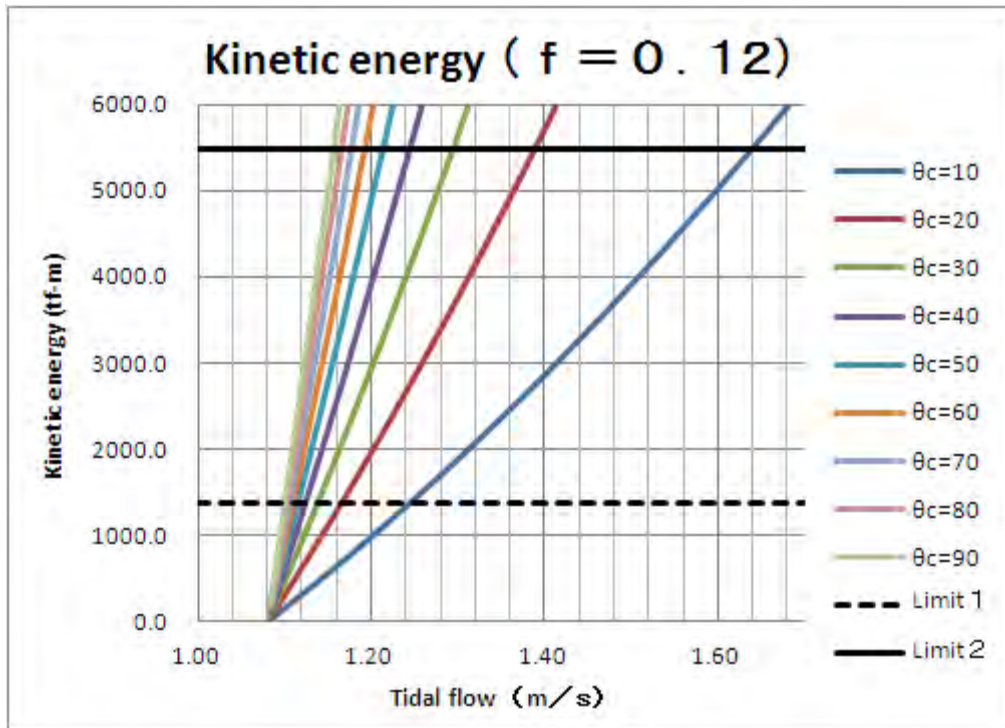


Fig. - 9 Kinetic energy of the constant function (7 / 1 3)

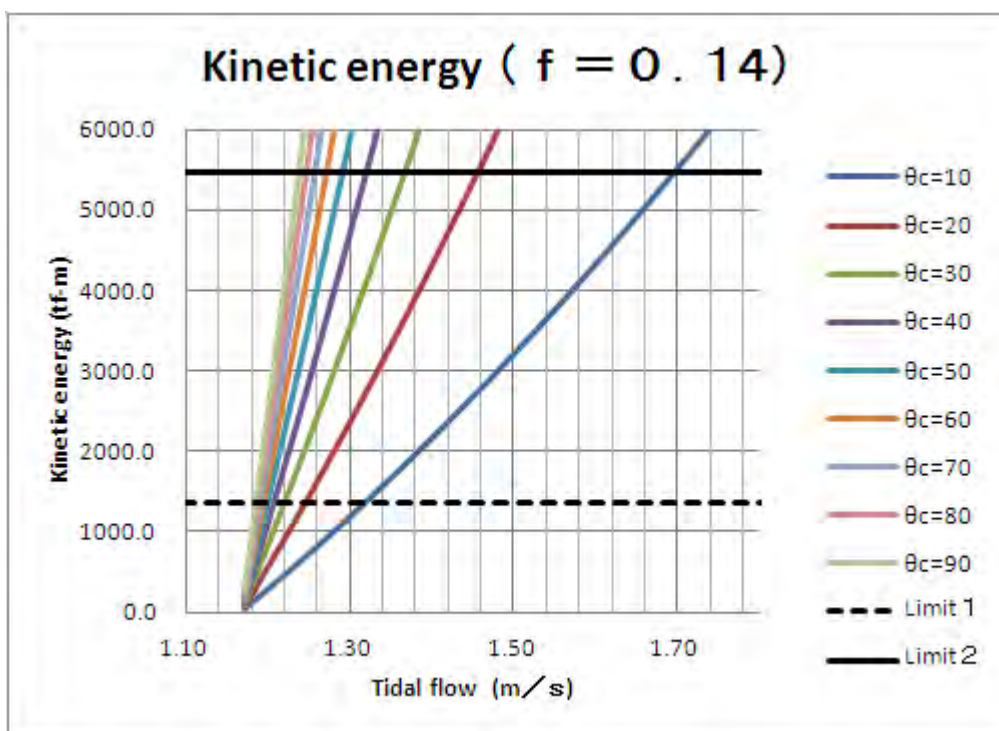


Fig. - 9 Kinetic energy of the constant function (8 / 1 3)

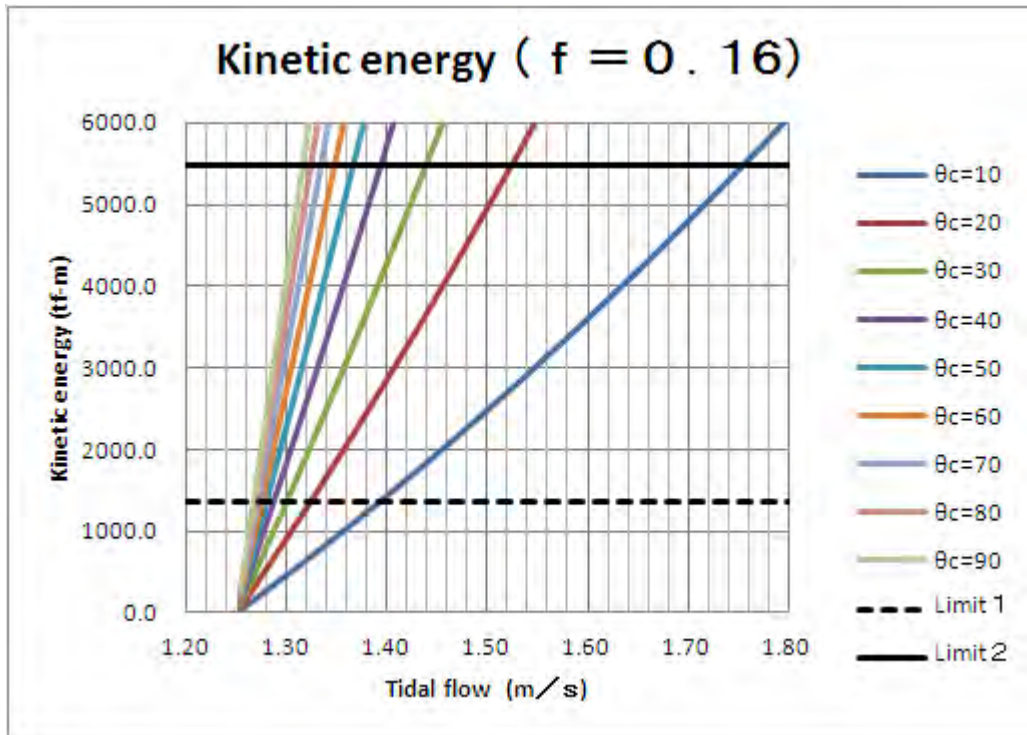


Fig. - 9 Kinetic energy of the constant function (9 / 1 3)

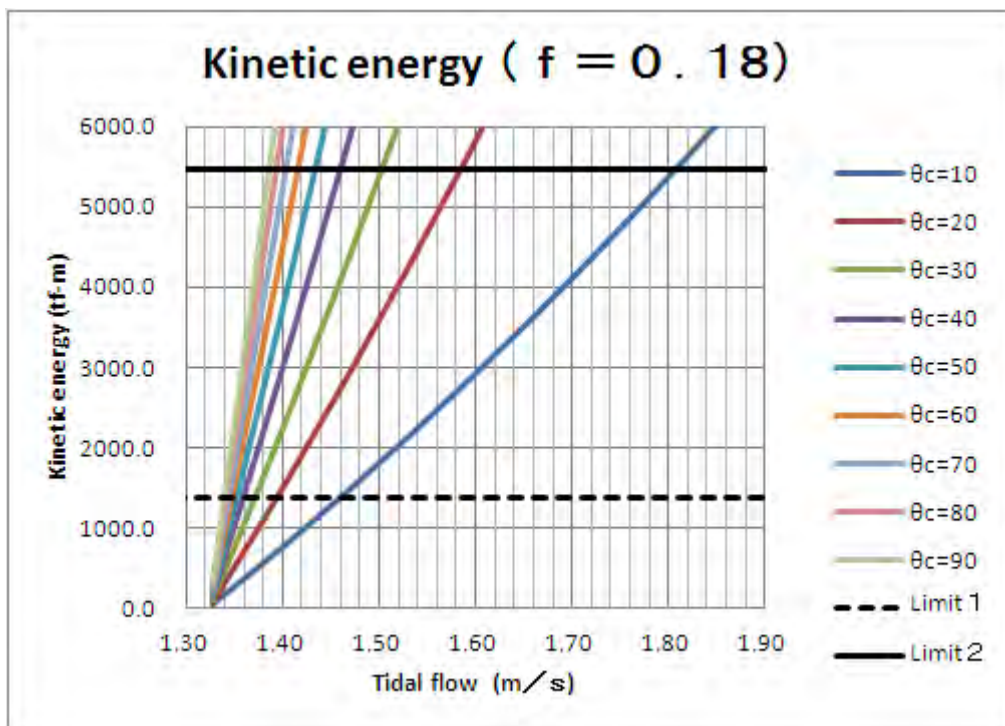


Fig. - 9 Kinetic energy of the constant function (1 0 / 1 3)

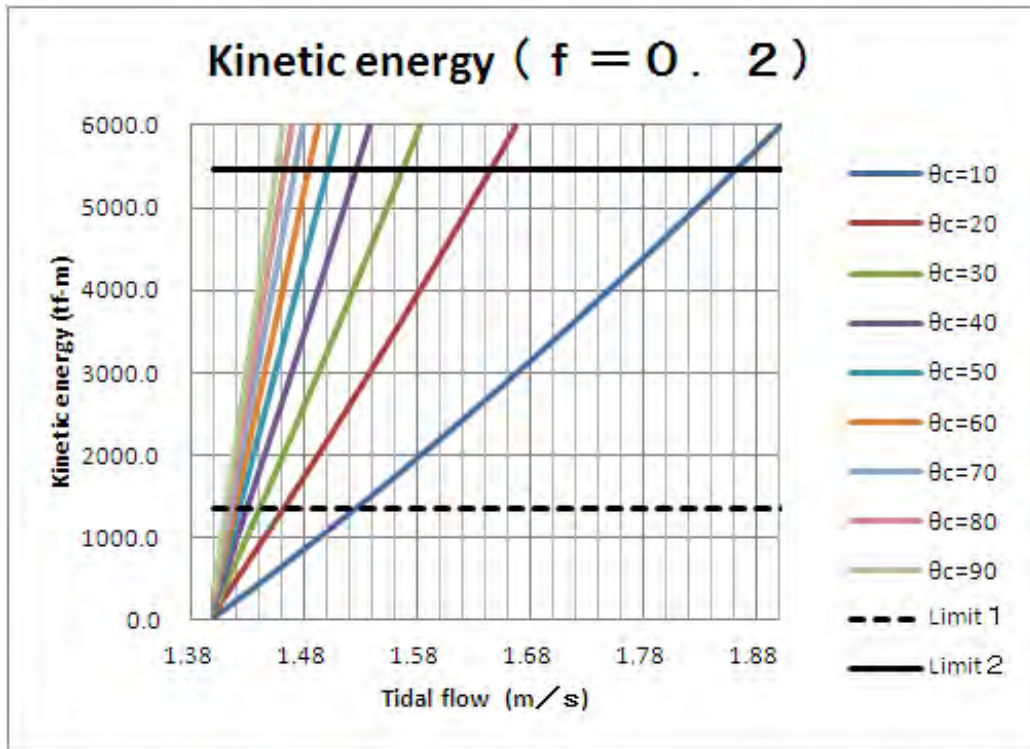


Fig. - 9 Kinetic energy of the constant function (1 1 / 1 3)

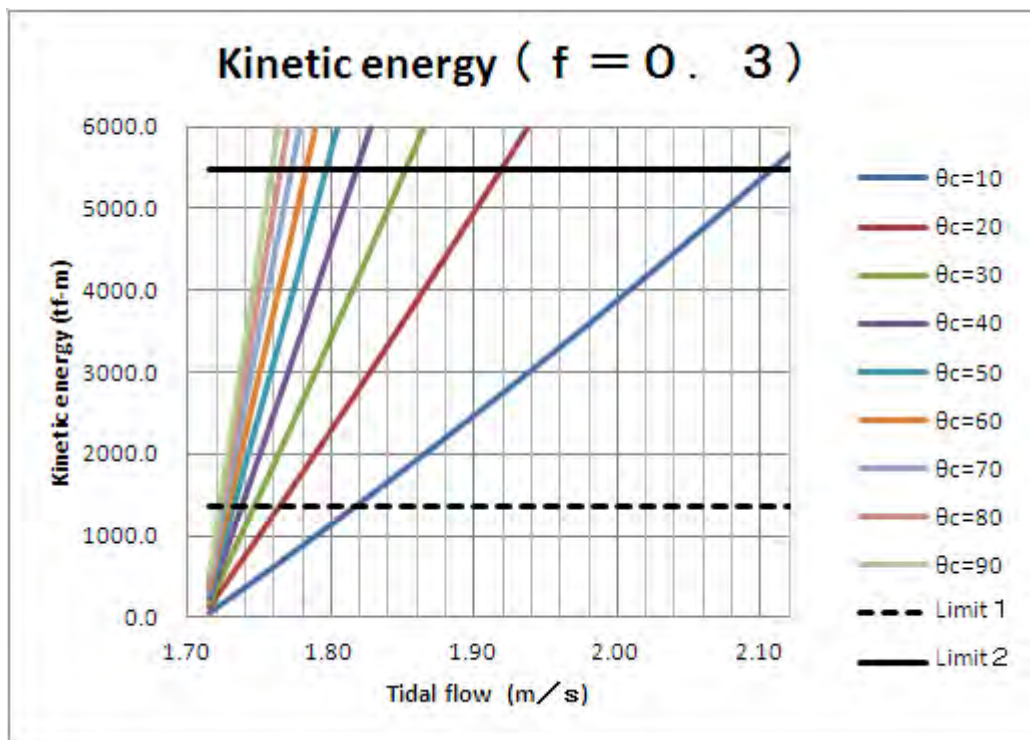


Fig. - 9 Kinetic energy of the constant function (1 2 / 1 3)

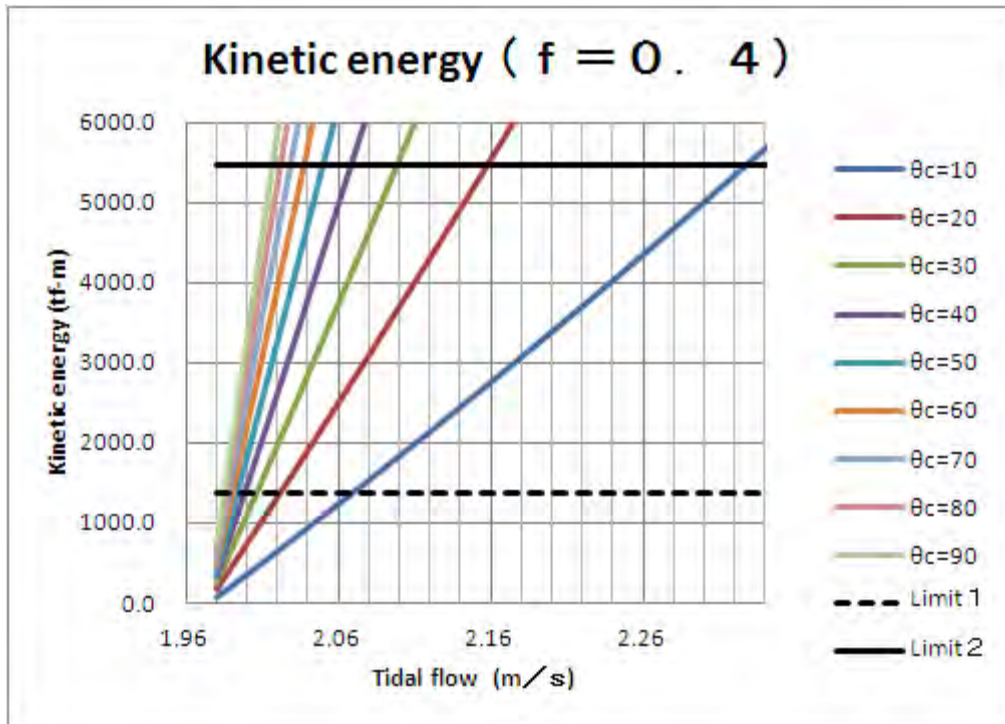


Fig. - 9 Kinetic energy of the constant function (1 3 / 1 3)

3 . 2 . 2 Linear function

Fig. - 1 0 shows the results corresponding to the tide difference h distribution of the linear function. The tidal flow range applicable to the gate operation is wider than the constant function. Quantitative reliability of the calculation results is low since effect of the assumption that the tidal flow exists on the port side of the gate has not be verified.

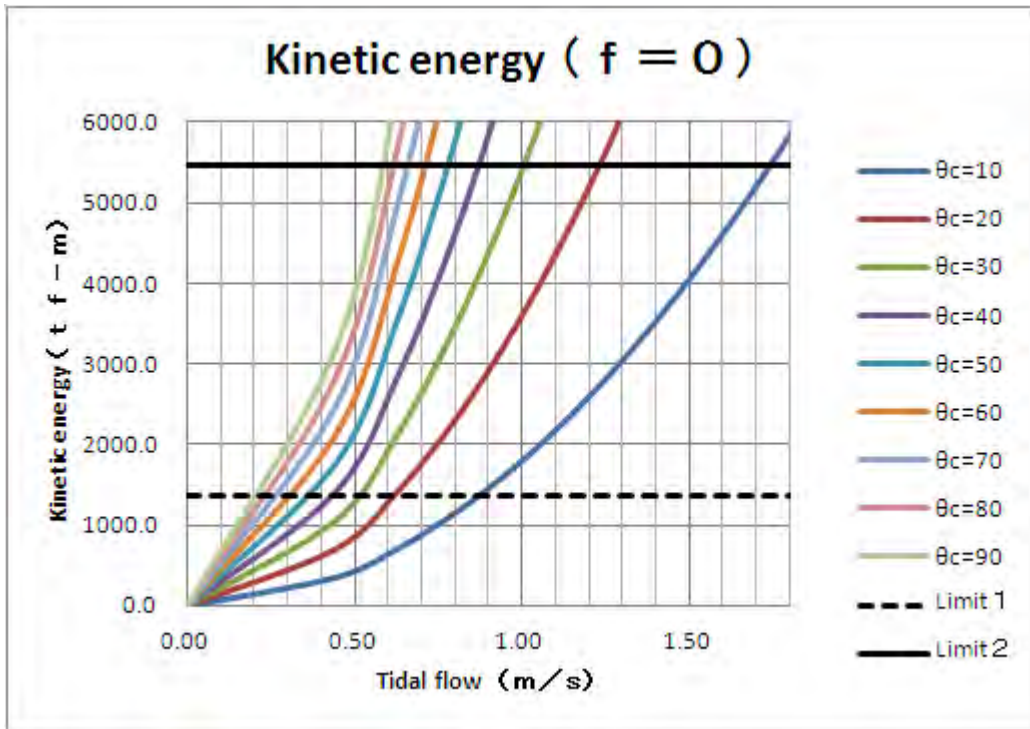


Fig. - 1 0 Kinetic energy of the linear function (1 / 1 3)

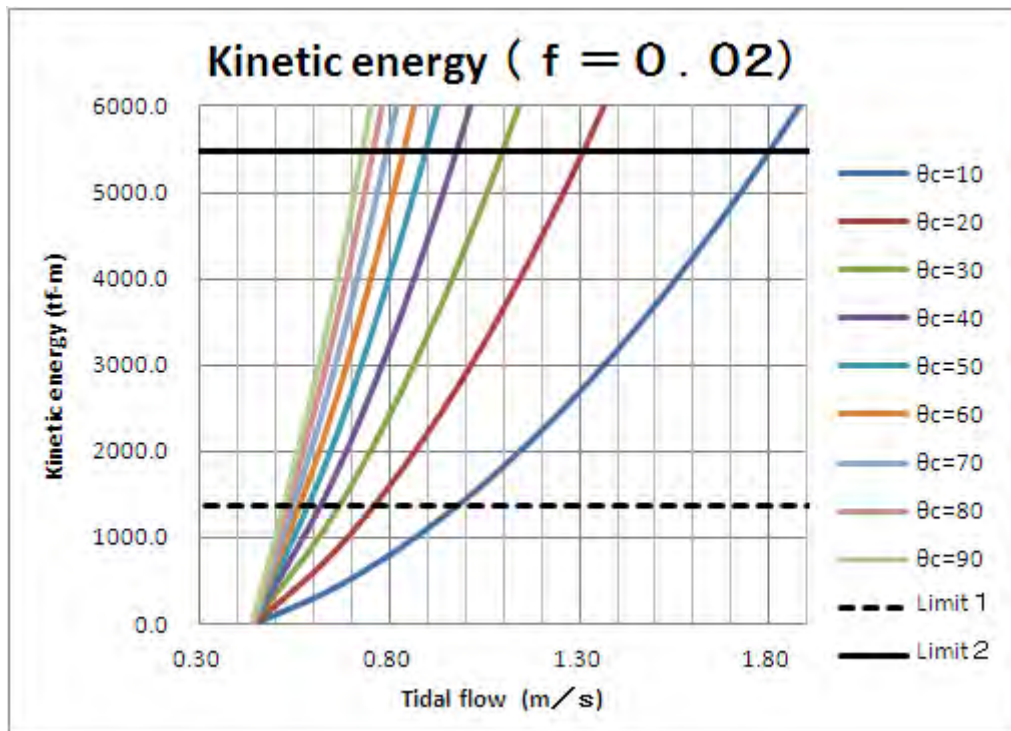


Fig. - 1 0 Kinetic energy of the linear function (2 / 1 3)

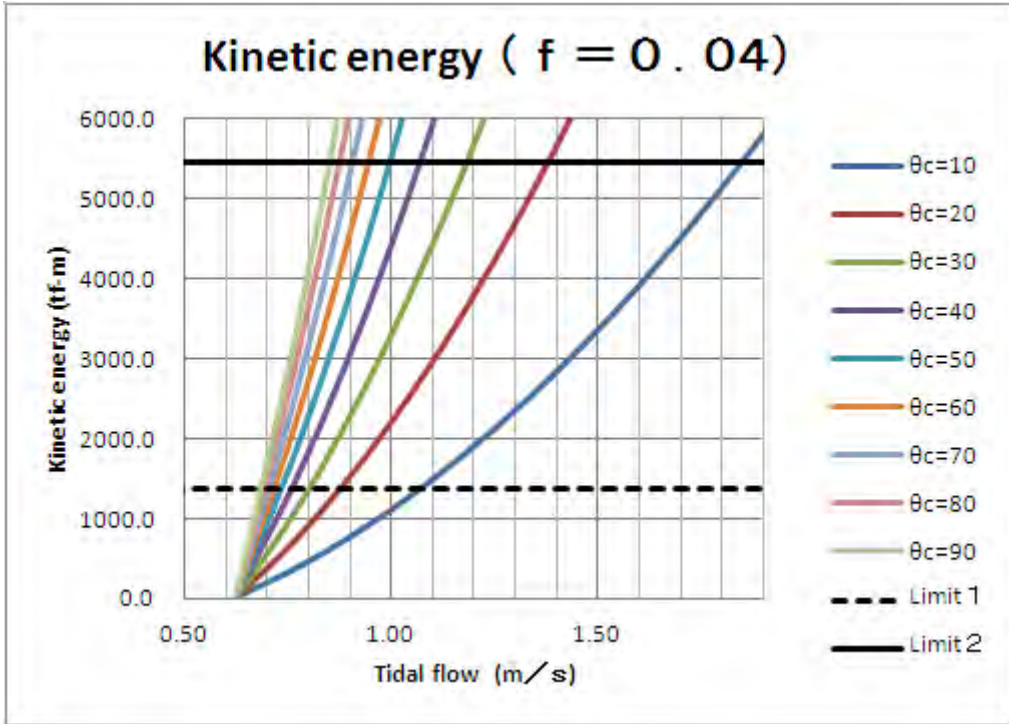


Fig. - 1 0 Kinetic energy of the linear function (3 / 1 3)

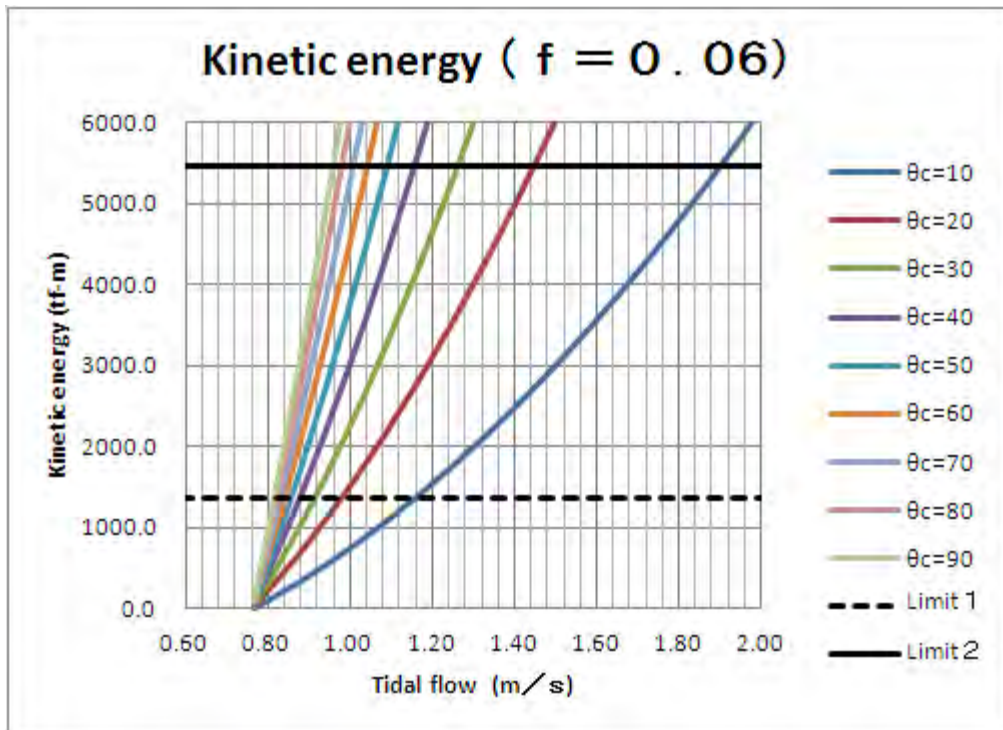


Fig. - 1 0 Kinetic energy of the linear function (4 / 1 3)

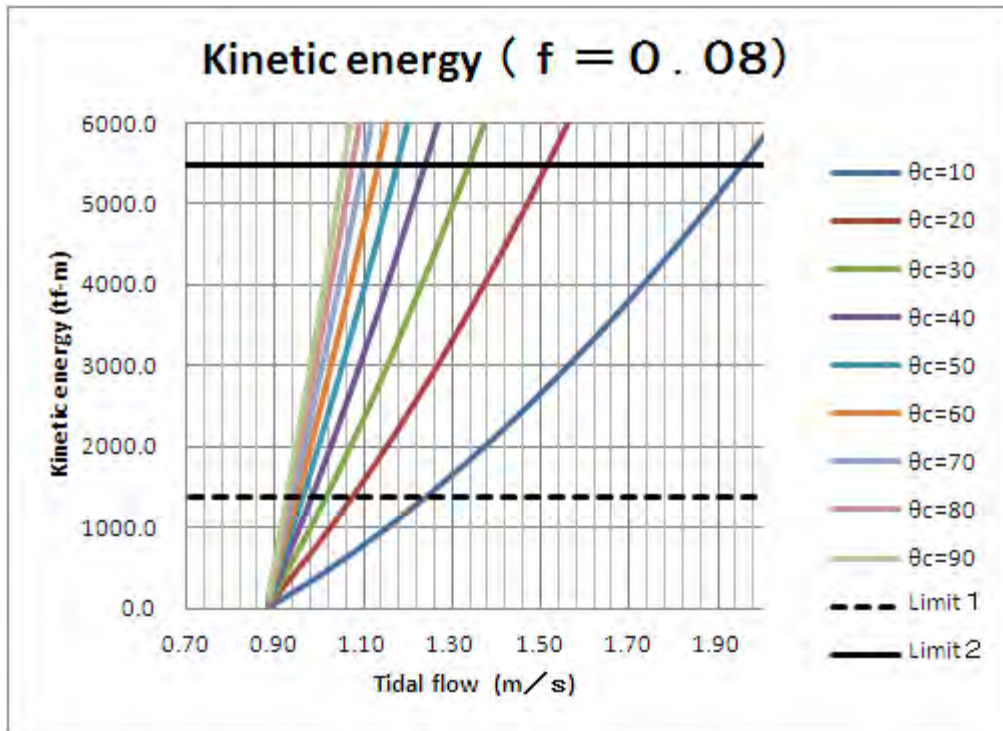


Fig. - 1 0 Kinetic energy of the linear function (5 / 1 3)

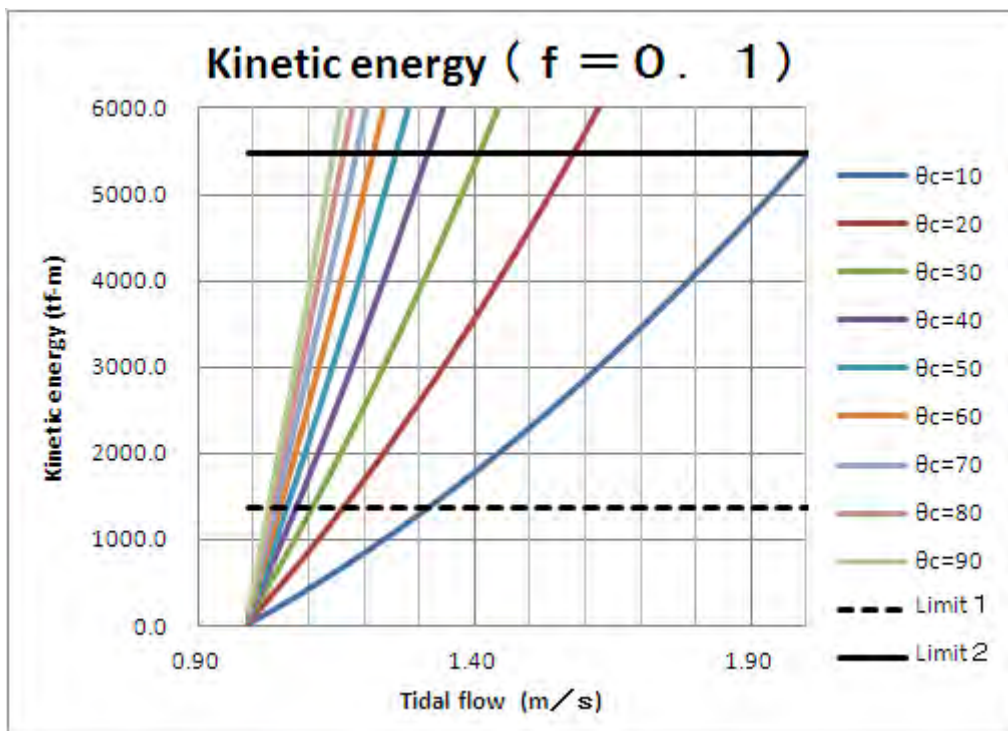


Fig. - 1 0 Kinetic energy of the linear function (6 / 1 3)

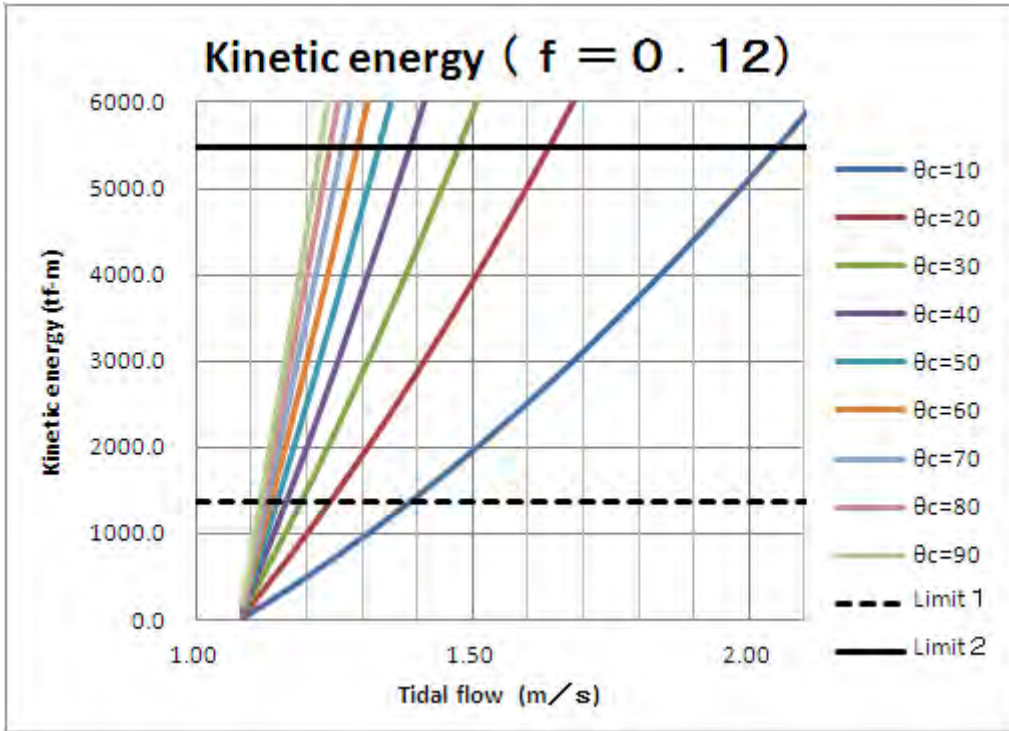


Fig. - 1 0 Kinetic energy of the linear function (7 / 1 3)

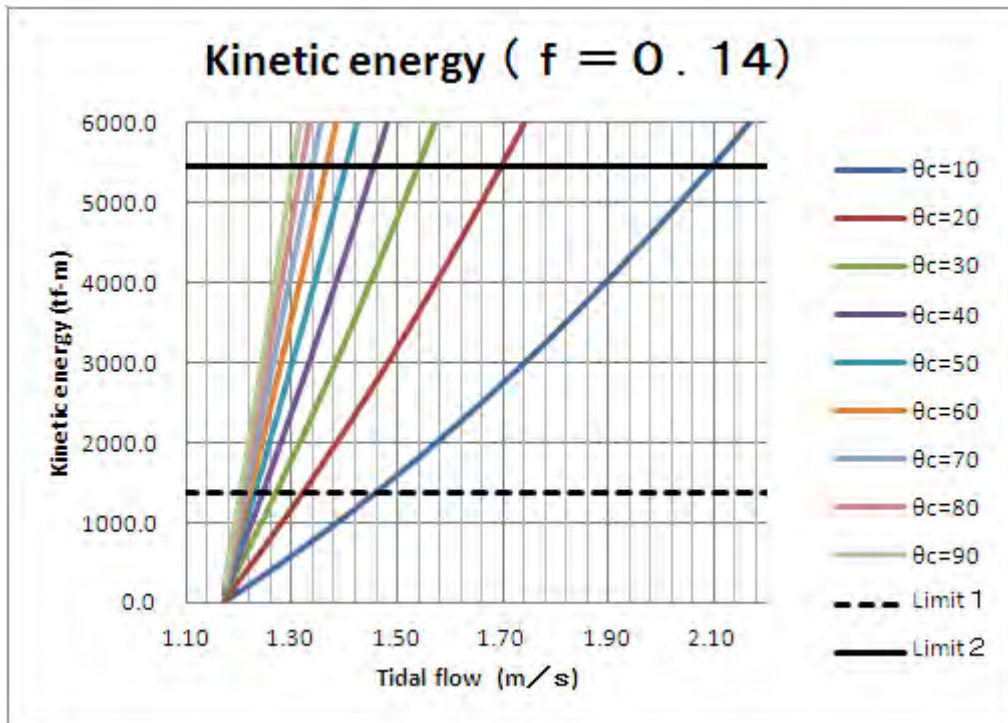


Fig. - 1 0 Kinetic energy of the linear function (8 / 1 3)

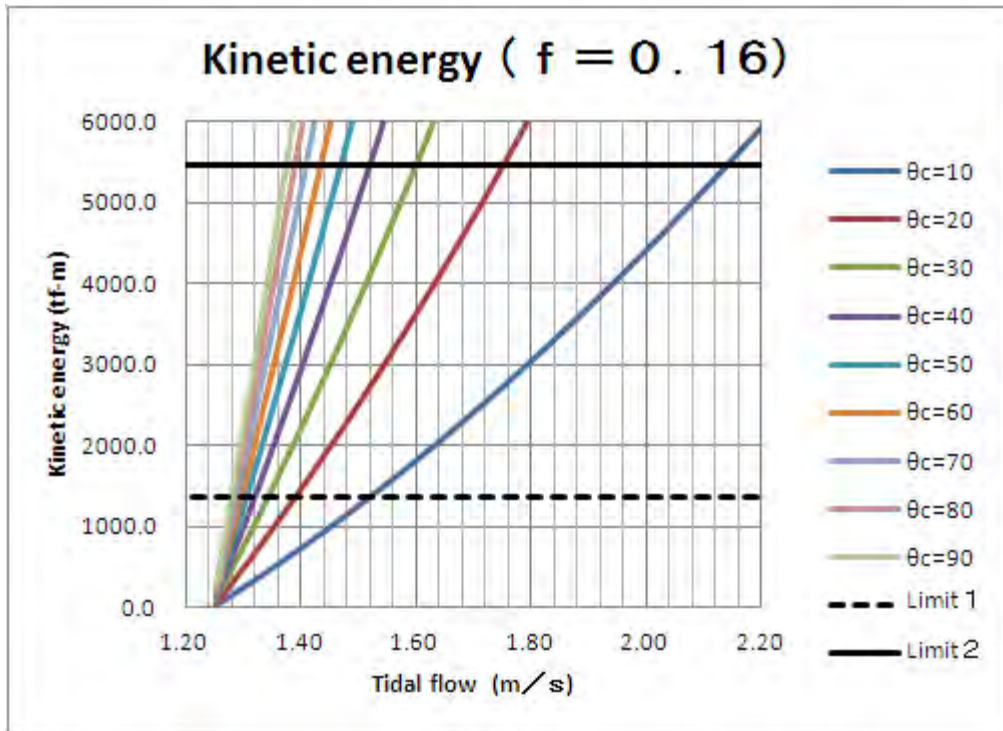


Fig. - 1 0 Kinetic energy of the linear function (9 / 1 3)

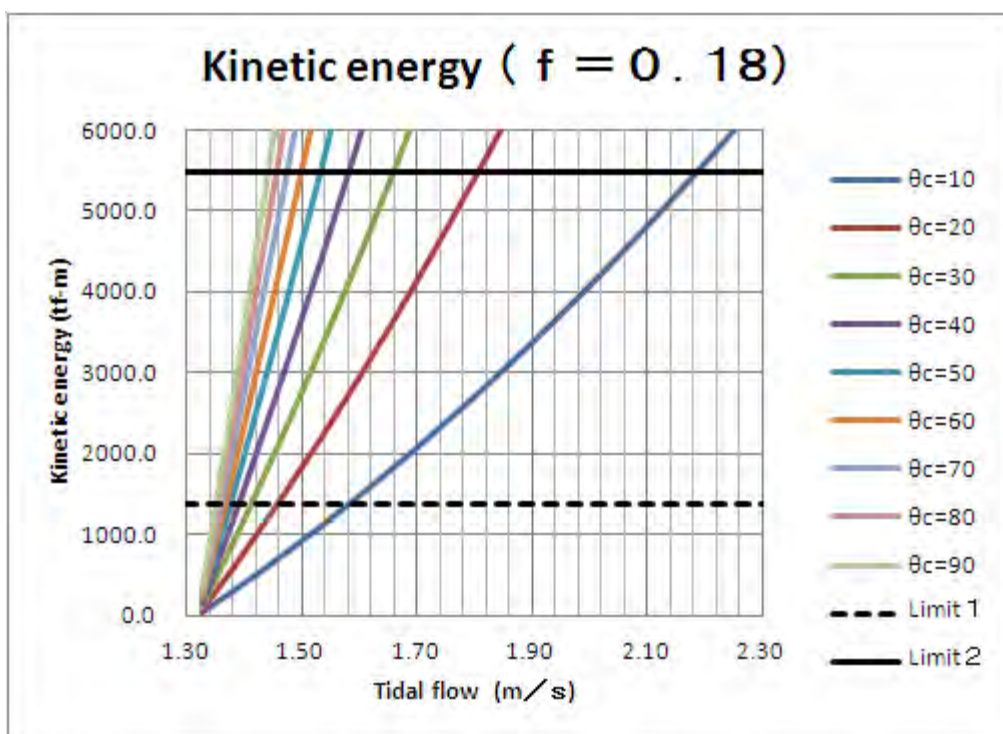


Fig. - 1 0 Kinetic energy of the linear function (1 0 / 1 3)

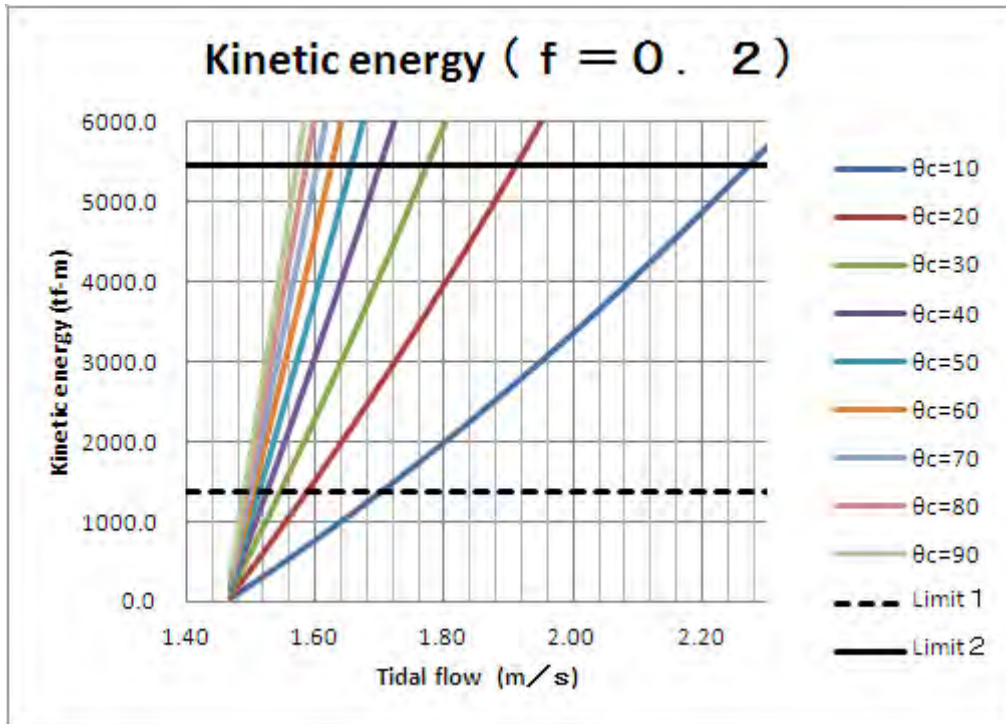


Fig. - 1 0 Kinetic energy of the linear function (1 1 / 1 3)

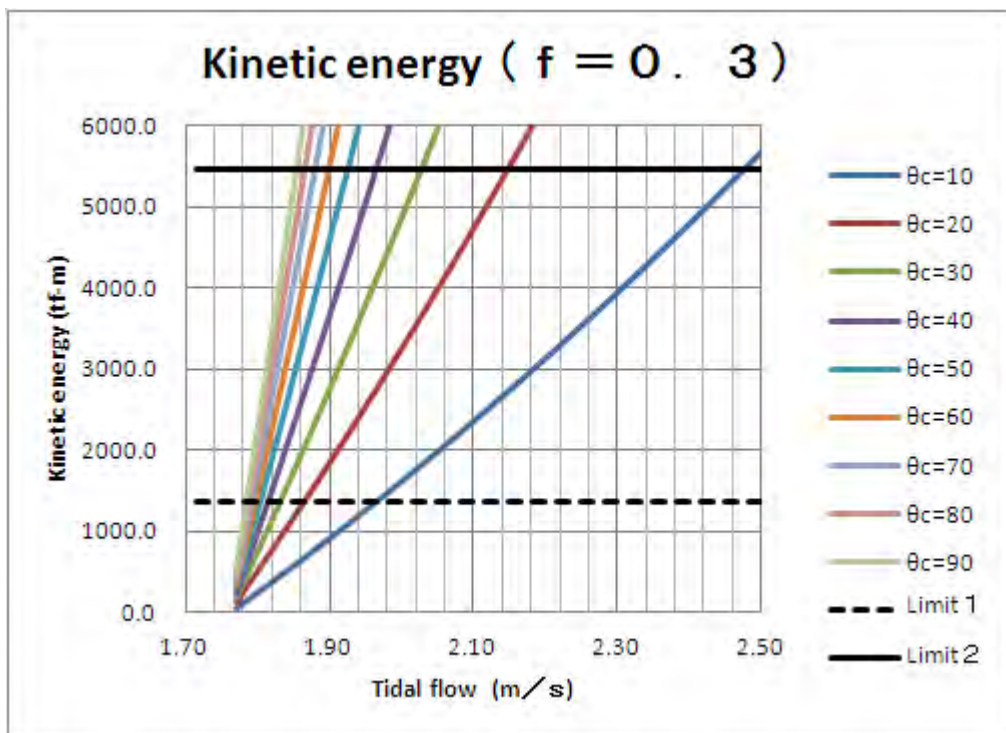


Fig. - 1 0 Kinetic energy of the linear function (1 2 / 1 3)

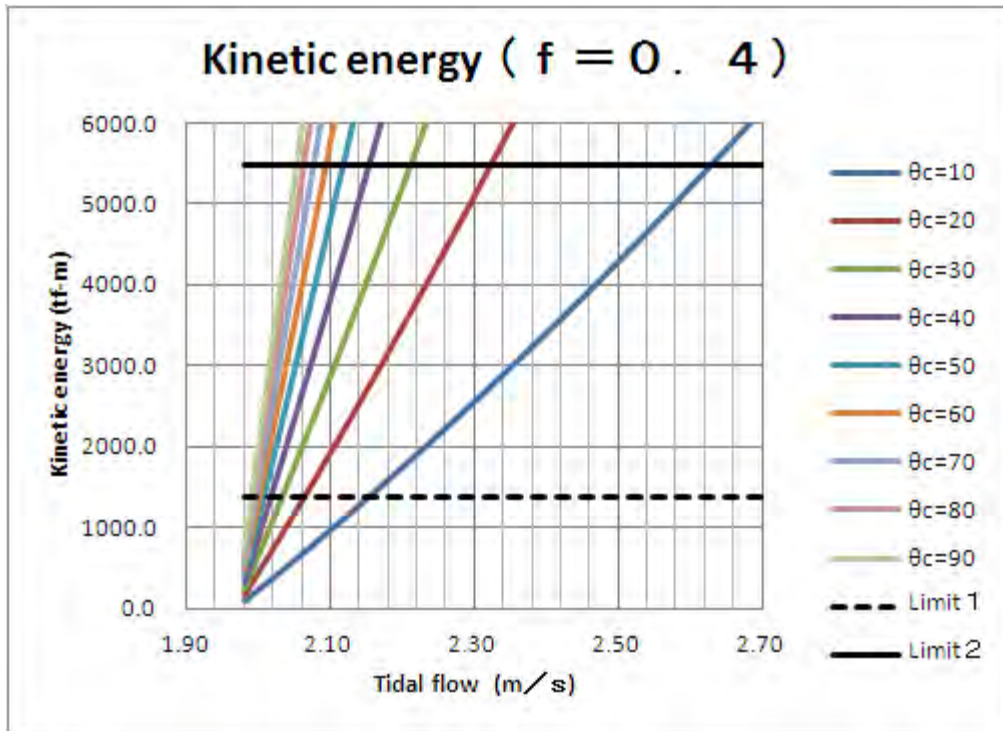


Fig. - 1 0 Kinetic energy of the linear function (1 3 / 1 3)

3 . 2 . 3 Parabolic function

Fig. - 1 1 shows the results corresponding to the tide difference h distribution of the parabolic function. The tidal flow range applicable to the gate operation is wider than the linear function. Although this is a result of the assumption that the tidal flow exists on the port side of the gate, quantitative reliability of the calculation results is low since the effect of assumption has not been verified. Although the distribution along (Refer to Fig. - 6) of the tidal difference converted from the tidal flow was assumed to be a parabolic function (Refer to Fig. - 8), the assumption may be energetically and operationally too small.

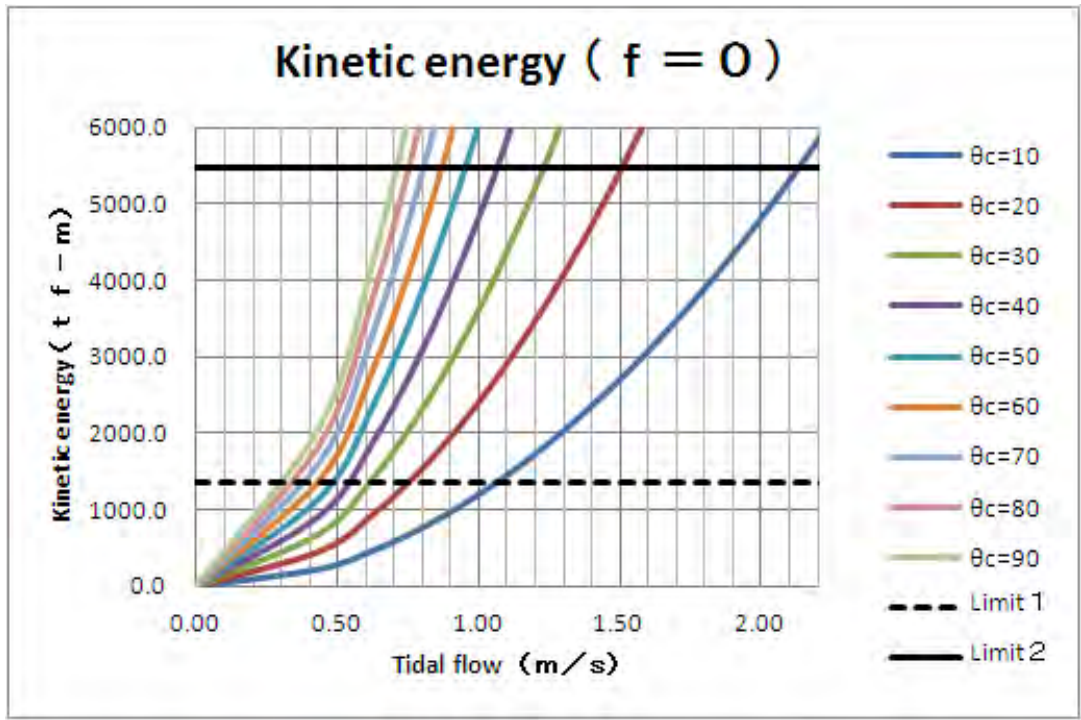


Fig. - 1 1 Kinetic energy of the parabolic function (1 / 1 3)

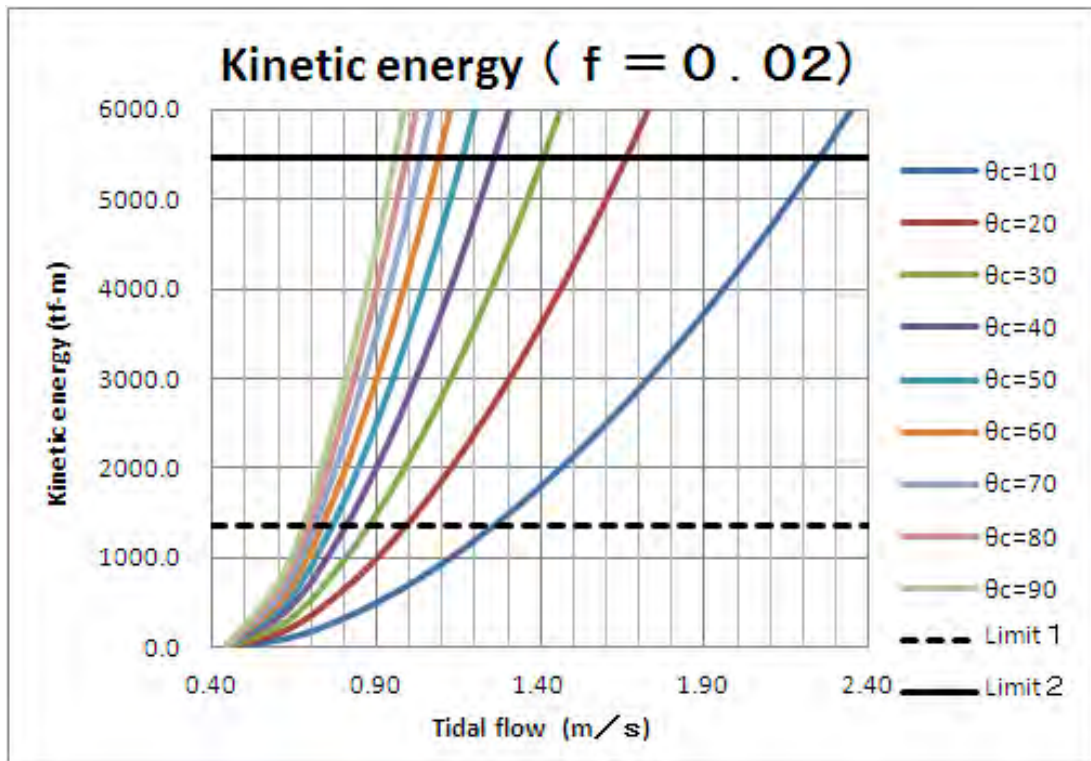


Fig. - 1 1 Kinetic energy of the parabolic function (2 / 1 3)

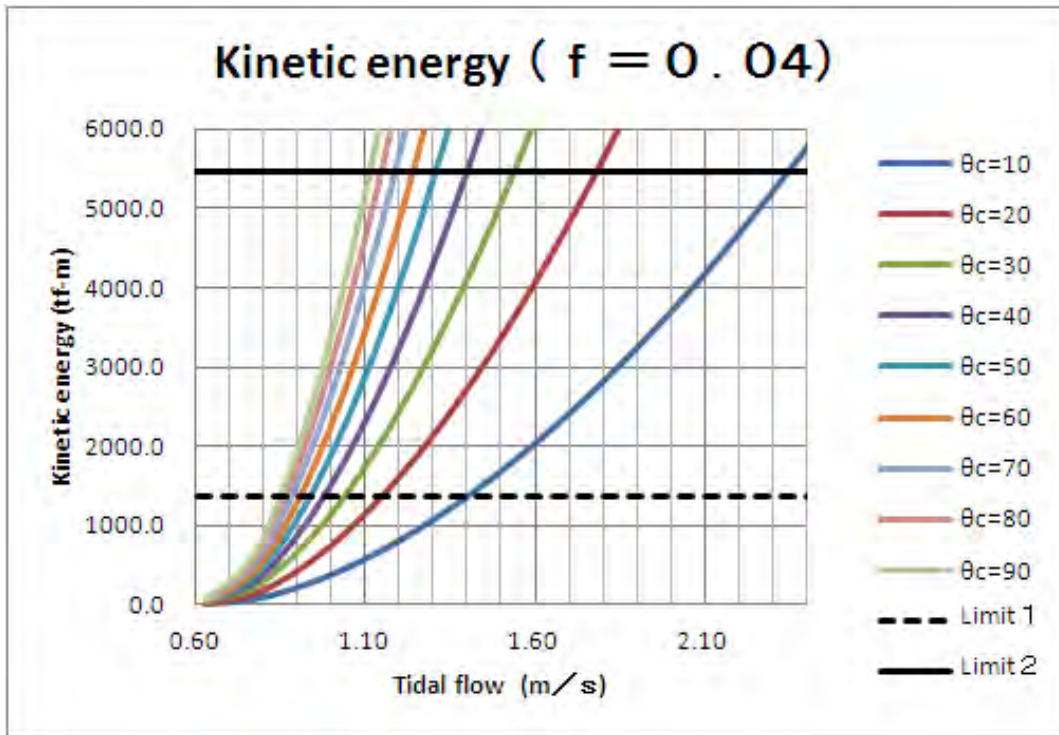


Fig. - 1 1 Kinetic energy of the parabolic function (3 / 1 3)

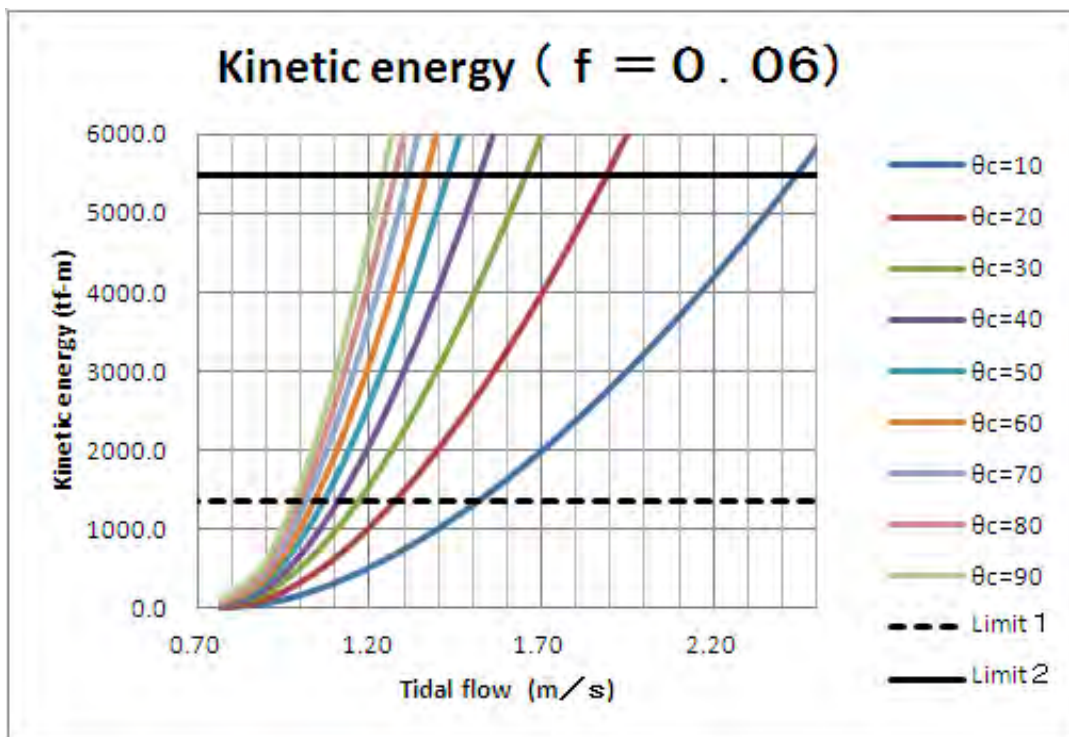


Fig. - 1 1 Kinetic energy of the parabolic function (4 / 1 3)

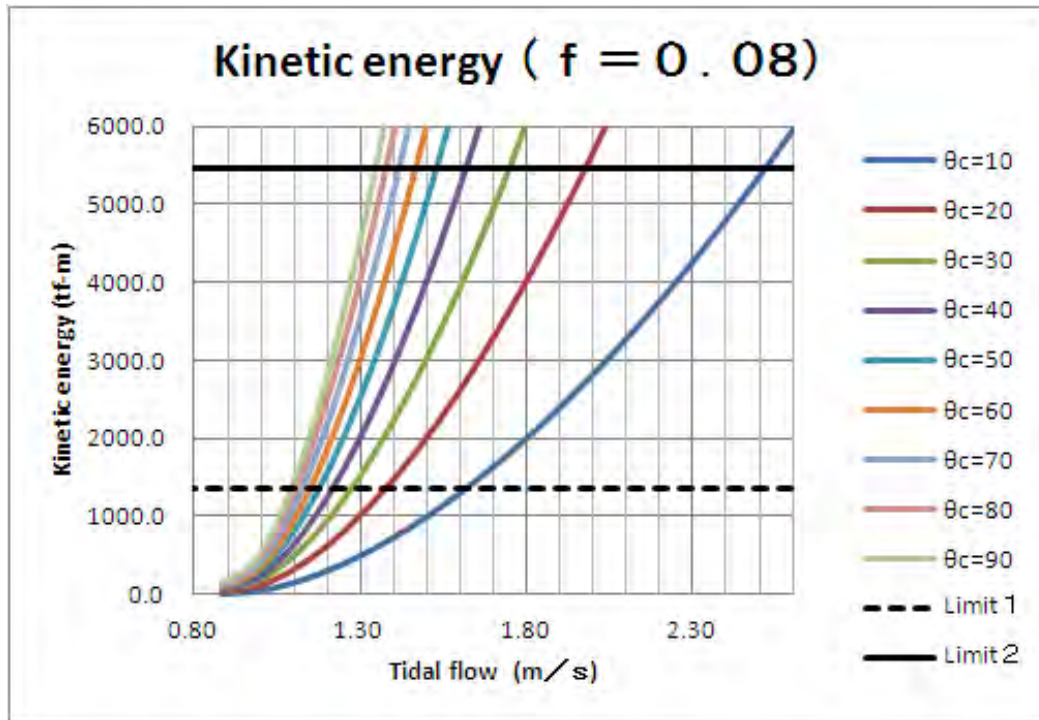


Fig. - 1 1 Kinetic energy of the parabolic function (5 / 1 3)

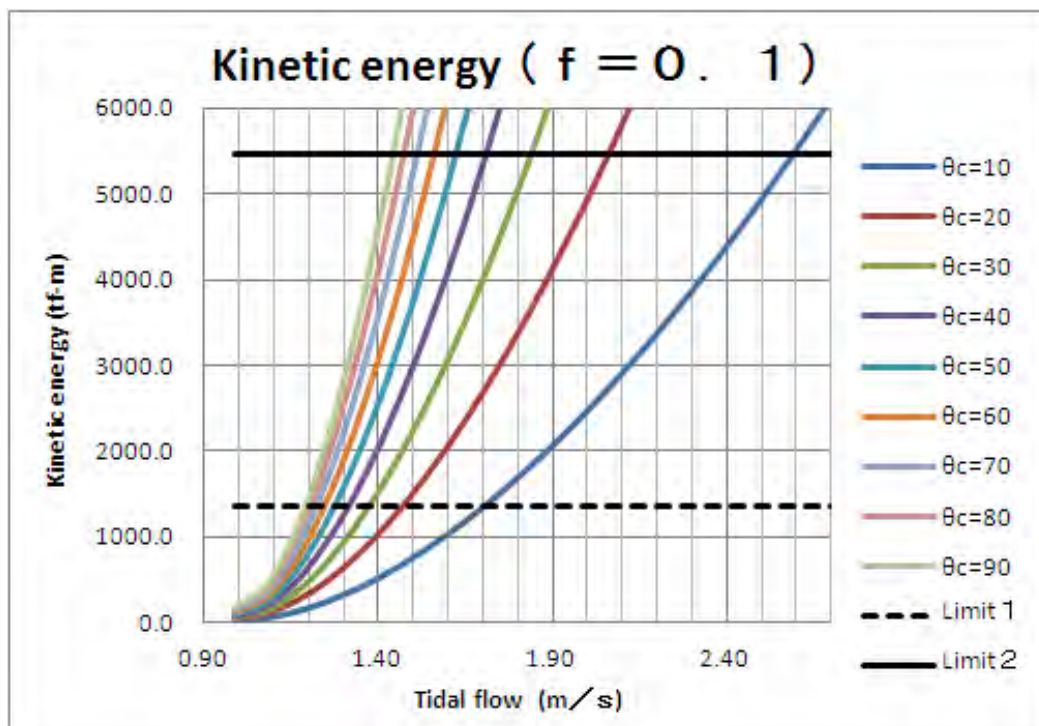


Fig. - 1 1 Kinetic energy of the parabolic function (6 / 1 3)

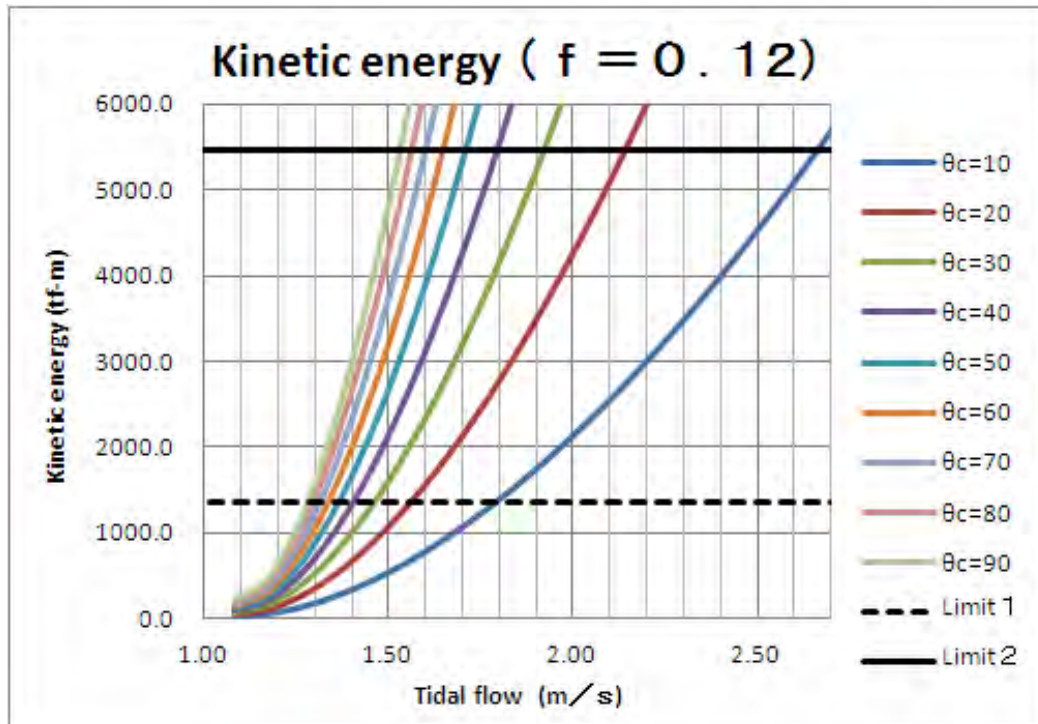


Fig. - 1 1 Kinetic energy of the parabolic function (7 / 1 3)

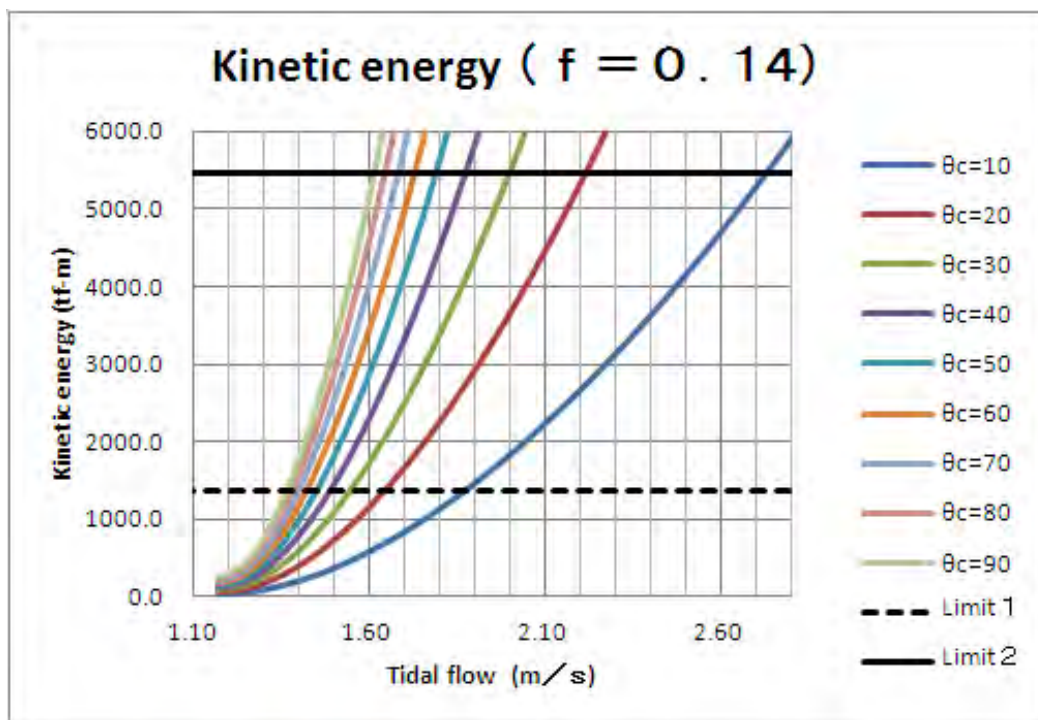


Fig. - 1 1 Kinetic energy of the parabolic function (8 / 1 3)

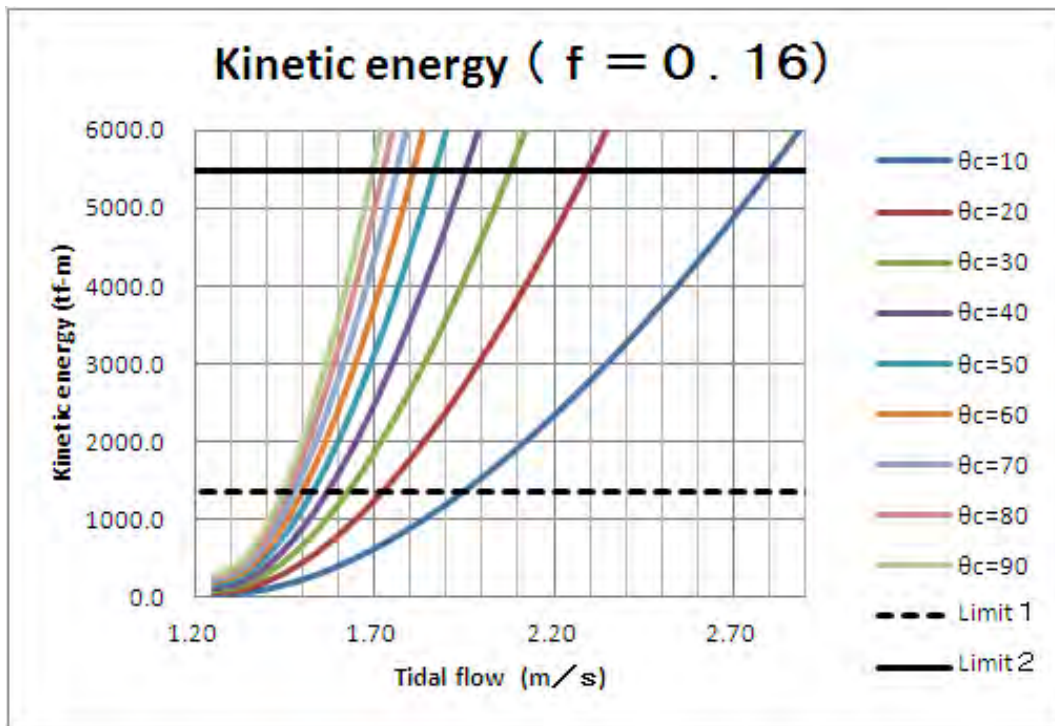


Fig. - 1 1 Kinetic energy of the parabolic function (9 / 1 3)

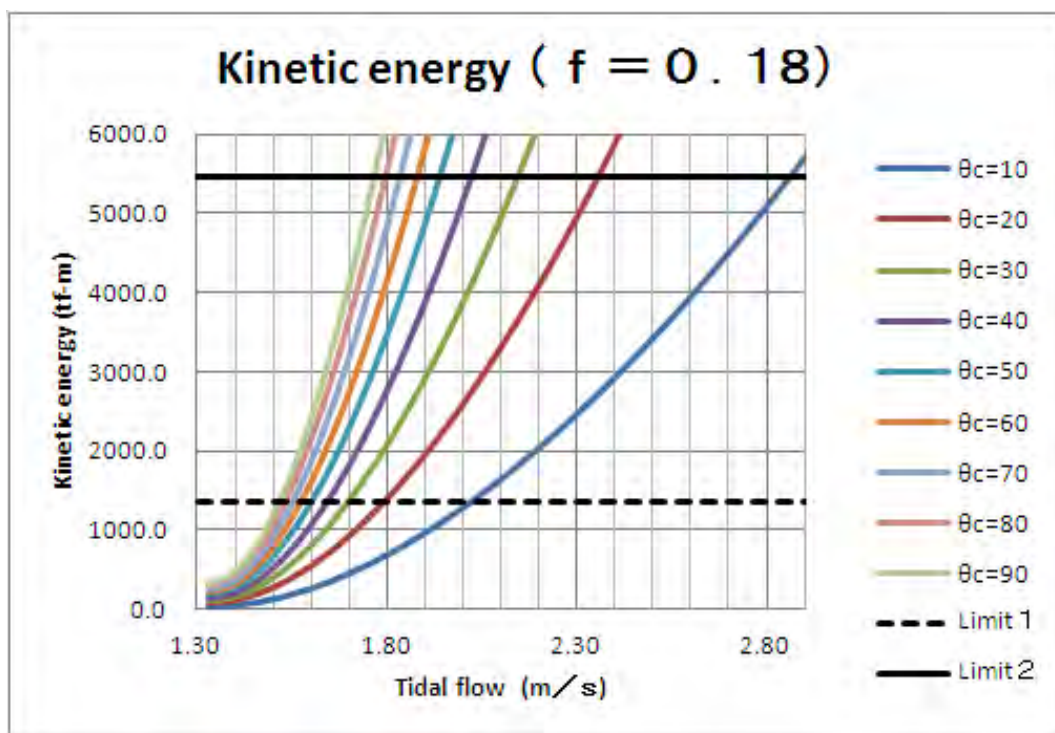


Fig. - 1 1 Kinetic energy of the parabolic function (1 0 / 1 3)

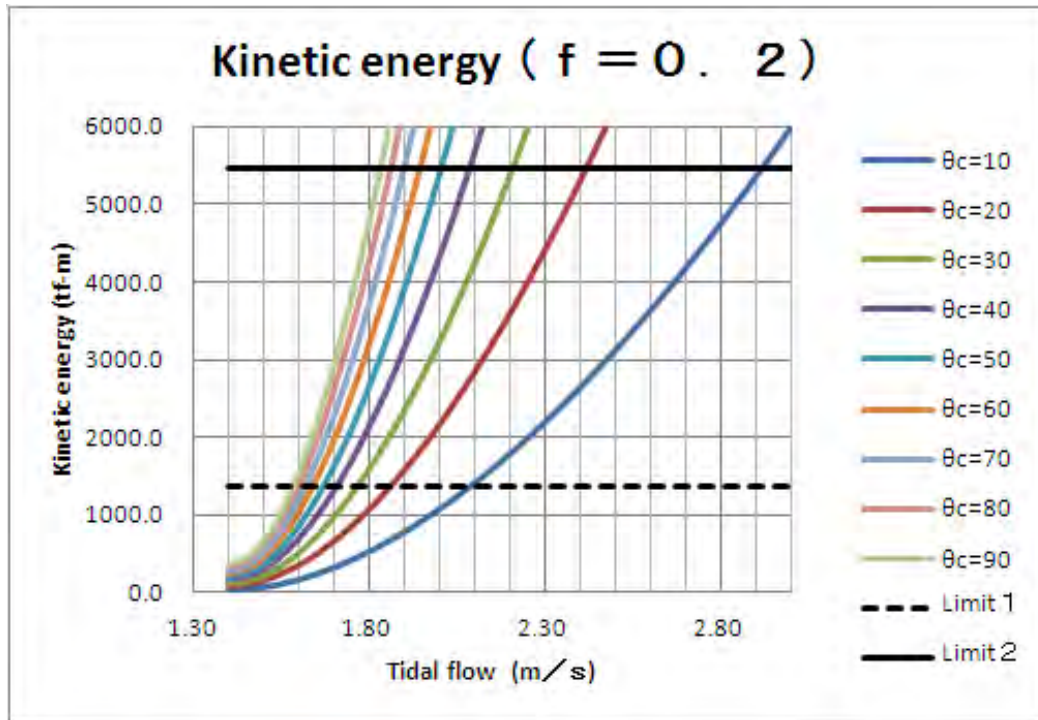


Fig. - 1 1 Kinetic energy of the parabolic function (1 1 / 1 3)

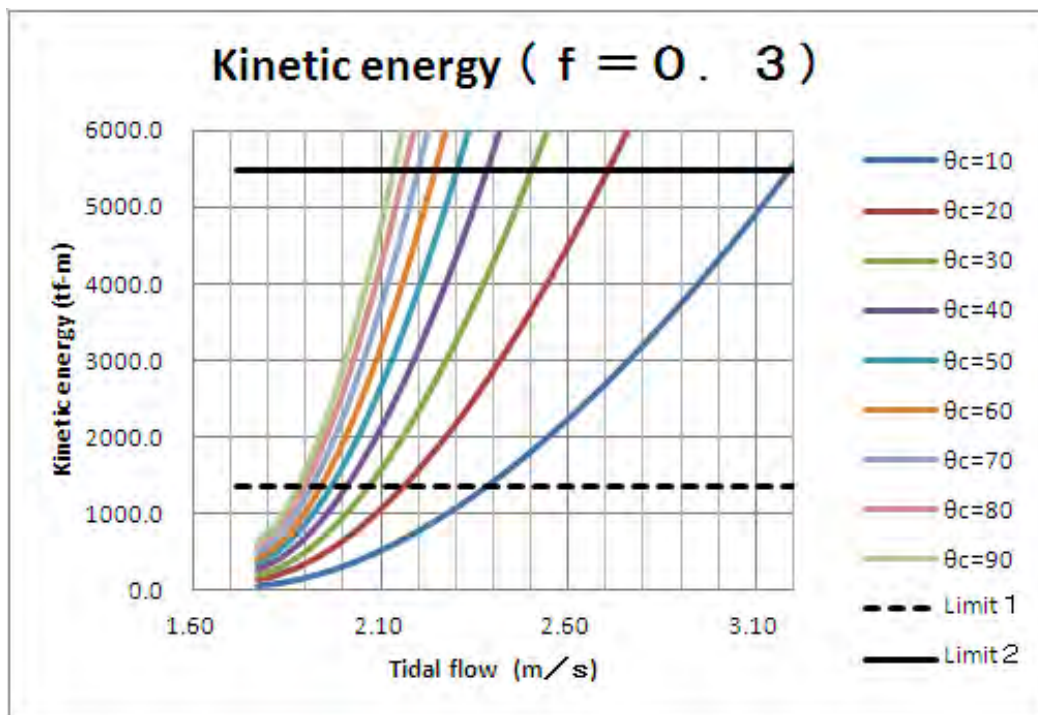


Fig. - 1 1 Kinetic energy of the parabolic function (1 2 / 1 3)

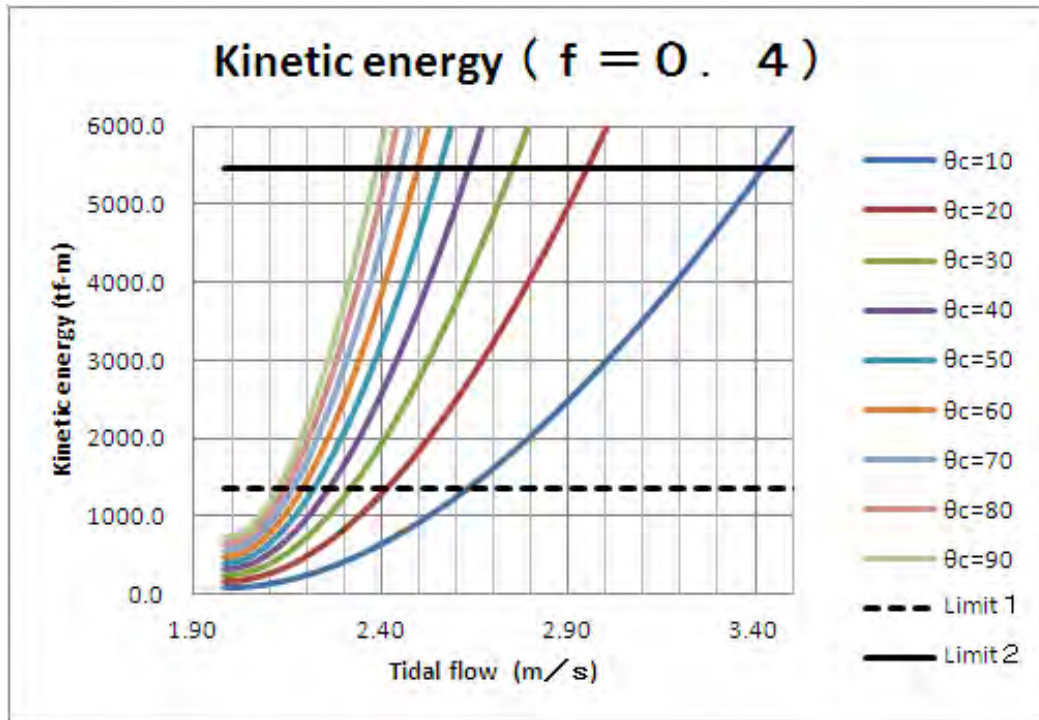


Fig. - 1 1 Kinetic energy of the parabolic function (1 3 / 1 3)

3 . 3 Operation method of the gate body

Firstable, the gate body strain energy was analyzed based on a condition that the strain energy caused by the collision is supposed to equal or be two times the strain energy caused by high tide and many useful information about the collision and upper limit of the gate body kinamatic energy when it comes into collision have been obtained.

Secondly, at the previous section, strain energy calculation formulae were derived on the constant function, the linear function and the parabolic function which were functions of gate opening and introduced into distribution of the tide difference h by way of actualizing the impact of tidal flow on the gate body kinetic energy.

Intensity of the tidal flow is different according to barrier construction sites () and varies according to time (). Intensity of the tidal flow is affected by barrier operation () and can be controlled by it (). Fig. - 1 2 shows an example where the intensity of flow around the main gate will abate if the gate close operation is made while all sluice gates being kept open. And, also, selection of the tide flow intensity for the gate operation will be made by needs of the facility users (). The gate operation method analysis is made on the calculation results of kinetic energy with above mentioned flow intensity understandings in mind and the gate operation in tidal flow will be discussed including results of the strain energy analysis in this section.

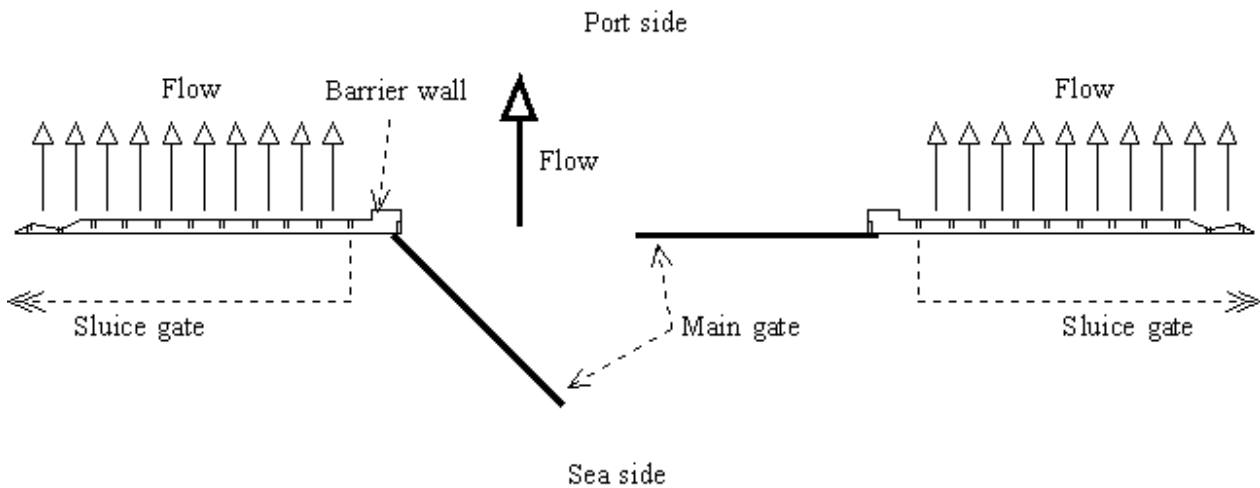


Fig. - 1 2 Tidal flow control by storm surge barrier operation

3 . 3 . 1 Operation conditions

Table - 1 0 Side thrusters on board and conditions of gate operation

Side thruster on board				
Specification	Thrust	40	tf	
	Number of unit	2		
	Total thrust	80	tf	
Control limit	Water-level difference	4.44	cm	
	Flow speed	0.93	m/sec	
Conditions of gate operation				
Items	Unit	Condition 1	Condition 2	Condition 3
Operation flow speed	m/sec	1.00	1.30	1.60
	kt	1.94	2.53	3.11
Bottom mounting flow speed	m/sec	0.80	0.80	0.80
	kt	1.56	1.56	1.56
Friction coefficient f		0.1		

Table - 1 0 shows specifications and control limits of the thruster on-board and the gate operation conditions which were set by way of discussion on the gate operation method. The operation flow velocity is maximum flow speed which is supposed to be set by the facility needs and the bottom mounting flow speed is the maximum flow speed at which the gate can move up to the bottom mounting position driven by the on-board thrusters. The specific thrust force of the side thruster is supposed to be determined including margin of safety ratio to the bottom mounting speed. The flow speed is shown both in m / s and kt . The friction coefficient f is locked in $0 . 1$ with a consideration that the magnitude of friction force is transmutable by the operation buoyancy adjustment.

3 . 3 . 2 Analysis on the calculation results

An operation method which corresponds to each of the 39 cases shown on Fig. - 9 thru 1 1 of the kinetic energy level judgment is explained referring to the operation conditions of Table - 1 0 . Output on Fig. - 9 (Constant function) is calculated on the assumption which is energetically too severe and operationally too much since the tidal flow effect on the gate body is not considered. Fig. - 1 0 (Linear function) and 1 1 (Parabolic function) consider the tidal flow effect but their quantitative reliability is not enough. Fig. - 1 1 (Parabolic function) is calculated on the energetically and operationally too small assumption. For reference, the operation buoyancy is shown in the operation method for the sake of adjusting the friction force by the shoe

load since the friction coefficient f is locked in 0.1 on Table - 10. The shoe load = 1074 - the operation buoyancy.

The bottom mounting position (Refer to Fig. - 6) is calculated by below formula which was derived from the tide difference distribution of group $c = 90^\circ$ on Fig. - 12.

$$\text{Bottom mounting angle} = c = 90 \times (1 - \text{Bottom mounting flow velocity} \div \text{Operation flow velocity}) \dots\dots (3.-25)$$

The friction flow speed (tidal flow whose thrust force equals the shoe friction force) is calculated by below formula.

$$\text{Friction flow velocity} = (2g \times \text{Shoe load} \times (5/3) \div \text{Skin plate wet area} \times f)^{0.5} \dots\dots (3.-26)$$

t which is an angle of gate body rotation driven by the side thruster after the gate mounts on the water bottom is calculated by below formula.

$$\text{Linear function: } t = c \times (\text{Friction flow velocity} \div \text{Operation flow velocity})^2 \dots\dots (3.-27)$$

$$\text{Parabolic function: } t = c \times \text{Friction flow velocity} \div \text{Operation flow velocity} \dots\dots (3.-28)$$

3.3.2.1 Operation condition 1

$$\text{Bottom mounting angle} = c = 90 \times (1 - 0.8) = 18^\circ$$

《Constant function · · Operation condition 1》

1) $f = 0$ (Fig. 1 / 13)

Bottom mounting at Operation buoyancy = 1074 $t f$

Friction flow speed = $0 \text{ m/s} < 1.0$

Thruster shutoff

Tidal flow travel (Kinetic energy $>$ Limit 2 · · damaged)

2) $f = 0.02$ (Fig. 2 / 13)

Bottom mounting at operation buoyancy = $1074 \times 4 \div 5 = 859$ $t f$

Friction flow speed = $0.44 \text{ m/s} < 1.0$

Thruster shutoff

Tidal flow travel (Kinetic energy Limit 2)

3) $f = 0.04$ (Fig. 3 / 13)

Bottom mounting at operation buoyancy = $1074 \times 3 \div 5 = 644$ $t f$

Friction flow speed = $0.62 \text{ m/s} < 1.0$

Thruster shutoff

Tidal flow travel (Limit 1 $<$ Kinetic energy $<$ Limit 2)

- 4) $f = 0 . 0 6$ (Fig. 4 / 1 3)
 Bottom mounting at operation buoyancy = $1 0 7 4 \times 2 \div 5 = 4 3 0$ t f
 Friction flow speed = $0 . 7 6$ m / s < $1 . 0$
 Thruster shutoff
 Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)
- 5) $f = 0 . 0 8$ (Fig. 5 / 1 3)
 Bottom mounting at operation buoyancy = $1 0 7 4 \times 1 \div 5 = 2 1 5$ t f
 Friction flow speed = $0 . 8 8$ m / s < $1 . 0$
 Thruster shutoff
 Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)
- 6) $f = 0 . 1$ (Fig. 6 / 1 3)
 Bottom mounting at operation buoyancy = 0 t f
 Friction flow speed = $0 . 9 9$ m / s < $1 . 0$
 Thruster shutoff
 Tidal flow travel (Kinetic energy Limit 1)
- 7) $f = 0 . 1 2$ (Fig. 7 / 1 3)
 Bottom mounting at operation buoyancy = $- 2 1 5$ t f
 Friction flow speed = $1 . 0 8$ m / s < $(1 . 0^2 + 0 . 8^2)^{0.5} = 1 . 2 8$
 Tidal flow + side thruster travel (Kinetic energy 0)
- 8) $f = 0 . 1 4$ (Fig. 8 / 1 3)
 Bottom mounting at operation buoyancy = $- 4 3 0$ t f
 Friction flow speed = $1 . 1 7$ m / s < $1 . 2 8$
 Tidal flow + side thruster travel (Kinetic energy 0)
- 9) $f = 0 . 1 6$ (Fig. 9 / 1 3)
 Bottom mounting at operation buoyancy = $- 6 4 4$ t f
 Friction flow speed = $1 . 2 5$ m / s < $1 . 2 8$
 Tidal flow + side thruster travel (Kinetic energy 0)
- 10) $f = 0 . 1 8$ (Fig. 1 0 / 1 3)
 Bottom mounting at operation buoyancy = $- 8 5 9$ t f
 Friction flow speed = $1 . 3 2$ m / s < $1 . 2 8$
 Impossible to move
- 11) $f = 0 . 2$ (Fig. 1 1 / 1 3)
 Bottom mounting at operation buoyancy = $- 1 0 7 4$ t f
 Friction flow speed = $1 . 4 0$ m / s < $1 . 2 8$
 Impossible to move
- 12) $f = 0 . 3$ (Fig. 1 2 / 1 3)
 Bottom mounting at operation buoyancy = $- 1 0 7 4 \times 2 = - 2 1 4 8$ t f
 Friction flow speed = $1 . 7 1$ m / s > $1 . 2 8$
 Impossible to move
- 13) $f = 0 . 4$ (Fig. 1 3 / 1 3)
 Bottom mounting at operation buoyancy = $- 1 0 7 4 \times 3 = - 3 2 2 2$ t f
 Friction flow speed = $1 . 9 7$ m / s > $1 . 2 8$

Impossible to move

《Linear function · · Operation condition 1》

1) $f = 0$ (Fig. 1 / 1 3) :

Bottom mounting at operation buoyancy = 1 0 7 4 t f

Friction flow speed = 0 m / s

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

2) $f = 0 . 0 2$ (Fig. 2 / 1 3) :

Bottom mounting at operation buoyancy = $1 0 7 4 \times 4 \div 5 = 8 5 9$ t f

Friction flow speed = 0 . 4 4 m / s

$$t = 1 8 \times (0 . 4 4 \div 1)^2 = 3 . 5 1 \text{ }^\circ$$

Rotation by side thruster: about 4 °

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

3) $f = 0 . 0 4$ (Fig. 3 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 3 \div 5 = 6 4 4$ t f

Friction flow speed = 0 . 6 2 m / s

$$t = 1 8 \times (0 . 6 2 \div 1)^2 = 7 . 0 2 \text{ }^\circ$$

Rotation by side thruster: about 7 . 5 °

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

4) $f = 0 . 0 6$ (Fig. 4 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 2 \div 5 = 4 3 0$ t f

Friction flow speed = 0 . 7 6 m / s

$$t = 1 8 \times (0 . 7 6 \div 1)^2 = 1 0 . 5 2 \text{ }^\circ$$

Rotation by side thruster: about 1 1 °

Thruster shutoff

Tidal flow travel (Kinetic energy Limit 1)

5) $f = 0 . 0 8$ (Fig. 5 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 1 \div 5 = 2 1 5$ t f

Friction flow speed = 0 . 8 8 m / s > Speed at bottom mounting = 0 . 8

Impossible to move by thruster

《Parabolic function · · Operation condition 1》

1) $f = 0$ (Fig. 1 / 1 3) :

Bottom mounting at operation buoyancy = 1 0 7 4 t f

Friction flow speed = 0 m / s

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

2) $f = 0 . 0 2$ (Fig. 2 / 1 3) :

Bottom mounting at operation buoyancy = $1 0 7 4 \times 4 \div 5 = 8 5 9$ t f

Friction flow speed = 0 . 4 4 m / s

$$t = 1.8 \times (0.44 \div 1) = 7.95^\circ$$

Rotation by side thruster: about 8°

Thruster shutoff

Tidal flow travel (Kinetic energy Limit 1)

$$3) f = 0.04 \text{ (Fig. 3 / 13)} :$$

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 3 \div 5 = 644 \text{ t f}$$

$$\text{Friction flow speed} = 0.62 \text{ m / s ,}$$

$$t = 1.8 \times 0.62 \div 1 = 11.24^\circ$$

Rotation by side thruster: about 11.5°

Thruster shutoff

Tidal flow travel (Kinetic energy << Limit 1)

$$4) f = 0.06 \text{ (Fig. 4 / 13)}$$

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 2 \div 5 = 430 \text{ t f}$$

$$\text{Friction flow speed} = 0.76 \text{ m / s}$$

$$t = 1.8 \times (0.76 \div 1) = 13.76^\circ$$

Rotation by side thruster: about 14°

Thruster shutoff

Tidal flow travel (Kinetic energy <<< Limit 1)

$$5) f = 0.08 \text{ (Fig. 5 / 13)} :$$

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 1 \div 5 = 215 \text{ t f}$$

$$\text{Friction flow speed} = 0.88 \text{ m / s} > \text{Speed at bottom mounting} = 0.8$$

Impossible to move by thruster

3 . 3 . 2 . 2 Operation condition 2

$$\text{Bottom mounting angle} = c = 90 \times (1 - 0.8 \div 1.3) = 34.6^\circ$$

《Constant function · · Operation condition 2》

$$1) f = 0 \text{ (Fig. 1 / 13)}$$

$$\text{Bottom mounting at operation buoyancy} = 1074 \text{ t f}$$

$$\text{Friction flow speed} = 0 \text{ m / s} < 1.3$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

$$2) f = 0.02 \text{ (Fig. 2 / 13)}$$

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 4 \div 5 = 859 \text{ t f}$$

$$\text{Friction flow speed} = 0.44 \text{ m / s} < 1.3$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

$$3) f = 0.04 \text{ (Fig. 3 / 13)}$$

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 3 \div 5 = 644 \text{ t f}$$

$$\text{Friction flow speed} = 0.62 \text{ m / s} < 1.3$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

4) $f = 0 . 0 6$ (Fig. 4 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 2 \div 5 = 4 3 0$ t f

Friction flow speed = $0 . 7 6$ m / s < $1 . 3$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

5) $f = 0 . 0 8$ (Fig. 5 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 1 \div 5 = 2 1 5$ t f

Friction flow speed = $0 . 8 8$ m / s < $1 . 3$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

6) $f = 0 . 1$ (Fig. 6 / 1 3)

Bottom mounting at operation buoyancy = 0 t f

Friction flow speed = $0 . 9 9$ m / s < $1 . 3$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

7) $f = 0 . 1 2$ (Fig. 7 / 1 3)

Bottom mounting at operation buoyancy = $- 2 1 5$ t f

Friction flow speed = $1 . 0 8$ m / s < $1 . 3$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

8) $f = 0 . 1 4$ (Fig. 8 / 1 3)

Bottom mounting at operation buoyancy = $- 4 2 9$ t f

Friction flow speed = $1 . 1 7$ m / s < $1 . 3$

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

9) $f = 0 . 1 6$ (Fig. 9 / 1 3)

Bottom mounting at operation buoyancy = $- 6 4 4$ t f

Friction flow speed = $1 . 2 5$ m / s < $1 . 3$

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

10) $f = 0 . 1 8$ (Fig. 1 0 / 1 3)

Bottom mounting at operation buoyancy = $- 8 5 9$ t f

Friction flow speed = $1 . 3 2$ m / s < $(1 . 3^2 + 0 . 8^2)^{.5} = 1 . 5 3$

Tidal flow + side thruster travel

Tidal flow travel (Kinetic energy 0)

11) $f = 0 . 2$ (Fig. 1 1 / 1 3)

Bottom mounting at operation buoyancy = $- 1 0 7 4$ t f

Friction flow speed = $1 . 4 0$ m / s < $1 . 5 3$

Tidal flow + side thruster travel (Kinetic energy 0)

12) $f = 0 . 3$ (Fig. 1 2 / 1 3)

Bottom mounting at operation buoyancy = $- 1 0 7 4 \times 2 = - 2 1 4 8$ t f

Friction flow speed = $1 . 7 1$ m / s > $1 . 5 3$

Impossible to move

13) f = 0 . 4 (Fig. 1 3 / 1 3)

Bottom mounting at operation buoyancy = $- 1 0 7 4 \times 3 = - 3 2 2 2$ t f

Friction flow speed = $1 . 9 7$ m / s > $1 . 5 3$

Impossible to move

《Linear function · · Operation condition 2 》

1) f = 0 (Fig. 1 / 1 3) :

Bottom mounting at operation buoyancy = $1 0 7 4$ tf

Friction flow speed = 0 m / s

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

2) f = 0 . 0 2 (Fig. 2 / 1 3) :

Bottom mounting at operation buoyancy = $1 0 7 4 \times 4 \div 5 = 8 5 9$ t f

Friction flow speed = $0 . 4 4$ m / s

$$t = 3 4 . 6 \times (0 . 4 4 \div 1 . 3)^2 = 3 . 9 9 ^\circ$$

Rotation by side thruster: about $4 ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

3) f = 0 . 0 4 (Fig. 3 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 3 \div 5 = 6 4 4$ t f

Friction flow speed = $0 . 6 2$ m / s

$$t = 3 4 . 6 \times (0 . 6 2 \div 1 . 3)^2 = 7 . 9 8 ^\circ$$

Rotation by side thruster: about $8 ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

4) f = 0 . 0 6 (Fig. 4 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 2 \div 5 = 4 3 0$ t f

Friction flow speed = $0 . 7 6$ m / s

$$t = 3 4 . 6 \times (0 . 7 6 \div 1 . 3)^2 = 1 1 . 9 7 ^\circ$$

Rotation by side thruster: about $1 2 ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

5) f = 0 . 0 8 (Fig. 5 / 1 3)

Bottom mounting at operation buoyancy = $1 0 7 4 \times 1 \div 5 = 2 1 5$ t f

Friction flow speed = $0 . 8 8$ m / s > Speed at bottom mounting = $0 . 8$

Impossible to move by thruster

《Parabolic function · · Operation condition 2 》

1) f = 0 (Fig. 1 / 1 3) :

Bottom mounting at operation buoyancy = $1 0 7 4$ tf

Friction flow speed = 0 m / s

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 • • Damaged)

2) $f = 0.02$ (Fig. 2 / 13) :

Bottom mounting at operation buoyancy = $1074 \times 4 \div 5 = 859$ t f

Friction flow speed = 0.44 m / s

$$t = 34.6 \times (0.44 \div 1.3) = 11.75^\circ$$

Rotation by side thruster: about 12°

Thruster shutoff

Tidal flow travel (Kinetic energy Limit 2)

3) $f = 0.04$ (Fig. 3 / 13) :

Bottom mounting at operation buoyancy = $1074 \times 3 \div 5 = 644$ t f

Friction flow speed = 0.62 m / s

$$t = 34.6 \times 0.62 \div 1.3 = 16.62^\circ$$

Rotation by side thruster: about 17°

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

4) $f = 0.06$ (Fig. 4 / 13)

Bottom mounting at operation buoyancy = $1074 \times 2 \div 5 = 430$ t f

Friction flow speed = 0.76 m / s

$$t = 34.6 \times (0.76 \div 1.3) = 20.35^\circ$$

Rotation by side thruster: about 21°

Thruster shutoff

Tidal flow travel (Limit 1 < Kinetic energy < Limit 2)

5) $f = 0.08$ (Fig. 5 / 13) :

Bottom mounting at operation buoyancy = $1074 \times 1 \div 5 = 215$ t f

Friction flow speed = 0.88 m / s > Speed at bottom mounting = 0.8

Impossible to move by thruster

3 . 3 . 2 . 3 Operation condition 3

$$\text{Bottom mounting angle} = \alpha = 90 \times (1 - 0.8 \div 1.6) = 45.0^\circ$$

《Constant function · · Operation condition 3》

1) $f = 0$ (Fig. 1 / 1 3)

$$\text{Bottom mounting at operation buoyancy} = 1074 \text{ t f}$$

$$\text{Friction flow speed} = 0 \text{ m / s} < 1.6$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

2) $f = 0.02$ (Fig. 2 / 1 3)

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 4 \div 5 = 859 \text{ t f}$$

$$\text{Friction flow speed} = 0.44 \text{ m / s} < 1.6$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

3) $f = 0.04$ (Fig. 3 / 1 3)

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 3 \div 5 = 644 \text{ t f}$$

$$\text{Friction flow speed} = 0.62 \text{ m / s} < 1.6$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

4) $f = 0.06$ (Fig. 4 / 1 3)

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 2 \div 5 = 430 \text{ t f}$$

$$\text{Friction flow speed} = 0.76 \text{ m / s} < 1.6$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

5) $f = 0.08$ (Fig. 5 / 1 3)

$$\text{Bottom mounting at operation buoyancy} = 1074 \times 1 \div 5 = 215 \text{ t f}$$

$$\text{Friction flow speed} = 0.88 \text{ m / s} < 1.6$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

6) $f = 0.1$ (Fig. 6 / 1 3)

$$\text{Bottom mounting at operation buoyancy} = 0 \text{ t f}$$

$$\text{Friction flow speed} = 0.99 \text{ m / s} < 1.6$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

7) $f = 0.12$ (Fig. 7 / 1 3)

$$\text{Bottom mounting at operation buoyancy} = -215 \text{ t f}$$

$$\text{Friction flow speed} = 1.08 \text{ m / s} < 1.6$$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

8) $f = 0.14$ (Fig. 8 / 1 3)

Bottom mounting at operation buoyancy = - 4 2 9 t f

Friction flow speed = 1 . 1 7 m / s < 1 . 6

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . . Damaged)

9) f = 0 . 1 6 (Fig. 9 / 1 3)

Bottom mounting at operation buoyancy = - 6 4 4 t f

Friction flow speed = 1 . 2 5 m / s < 1 . 6

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . . Damaged)

10) f = 0 . 1 8 (Fig. 1 0 / 1 3)

Bottom mounting at operation buoyancy = - 8 5 9 t f

Friction flow speed = 1 . 3 2 m / s < 1 . 6

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . . Damaged)

11) f = 0 . 2 (Fig. 1 1 / 1 3)

Bottom mounting at operation buoyancy = - 1 0 7 4 t f

Friction flow speed = 1 . 4 0 m / s < 1 . 6

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . . Damaged)

12) f = 0 . 3 (Fig. 1 2 / 1 3)

Bottom mounting at operation buoyancy = - 1 0 7 4 × 2 = - 2 1 4 8 t f

Friction flow speed = 1 . 7 1 m / s < (1 . 6² + 0 . 8²)^{0.5} = 1 . 7 9

Tidal flow + side thruster travel (Kinetic energy 0)

13) f = 0 . 4 (Fig. 1 3 / 1 3)

Bottom mounting at operation buoyancy = - 1 0 7 4 × 3 = - 3 2 2 2 t f

Friction flow speed = 1 . 9 7 m / s > 1 . 7 9

Impossible to move

《Linear function . . . Operation condition 3 》

1) f = 0 (Fig. 1 / 1 3) :

Bottom mounting at operation buoyancy = 1 0 7 4 t f

Friction flow speed = 0 m / s

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . . Damaged)

2) f = 0 . 0 2 (Fig. 2 / 1 3) :

Bottom mounting at operation buoyancy = 1 0 7 4 × 4 ÷ 5 = 8 5 9 t f

Friction flow speed = 0 . 4 4 m / s

t = 4 5 × (0 . 4 4 ÷ 1 . 6)² = 3 . 4 2 °

Rotation by side thruster: about 4 °

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . . Damaged)

3) f = 0 . 0 4 (Fig. 3 / 1 3)

Bottom mounting at operation buoyancy = $1\ 0\ 7\ 4 \times 3 \div 5 = 6\ 4\ 4\ t\ f$
Friction flow speed = $0\ .\ 6\ 2\ m / s$

$$t = 4\ 5 \times (0\ .\ 6\ 2 \div 1\ .\ 3)^2 = 6\ .\ 8\ 5\ ^\circ$$

Rotation by side thruster: about $7\ ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

4) $f = 0\ .\ 0\ 6$ (Fig. 4 / 1 3)

Bottom mounting at operation buoyancy = $1\ 0\ 7\ 4 \times 2 \div 5 = 4\ 3\ 0\ t\ f$
Friction flow speed = $0\ .\ 7\ 6\ m / s$

$$t = 4\ 5 \times (0\ .\ 7\ 6 \div 1\ .\ 6)^2 = 1\ 0\ .\ 2\ 8\ ^\circ$$

Rotation by side thruster: about $1\ 1\ ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

5) $f = 0\ .\ 0\ 8$ (Fig. 5 / 1 3)

Bottom mounting at operation buoyancy = $1\ 0\ 7\ 4 \times 1 \div 5 = 2\ 1\ 5\ t\ f$

Friction flow speed = $0\ .\ 8\ 8\ m / s >$ Speed at bottom mounting = $0\ .\ 8$

Impossible to move by thruster

《Parabolic function . . Operation condition 3 》

1) $f = 0$ (Fig. 1 / 1 3) :

Bottom mounting at operation buoyancy = $1\ 0\ 7\ 4\ t\ f$

Friction flow speed = $0\ m / s$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

2) $f = 0\ .\ 0\ 2$ (Fig. 2 / 1 3) :

Bottom mounting at operation buoyancy = $1\ 0\ 7\ 4 \times 4 \div 5 = 8\ 5\ 9\ t\ f$

Friction flow speed = $0\ .\ 4\ 4\ m / s$

$$t = 4\ 5 \times (0\ .\ 4\ 4 \div 1\ .\ 6) = 9\ .\ 5\ 5\ ^\circ$$

Rotation by side thruster: about $1\ 0\ ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

3) $f = 0\ .\ 0\ 4$ (Fig. 3 / 1 3) :

Bottom mounting at operation buoyancy = $1\ 0\ 7\ 4 \times 3 \div 5 = 6\ 4\ 4\ t\ f$

Friction flow speed = $0\ .\ 6\ 2\ m / s$ 、

$$t = 4\ 5 \times 0\ .\ 6\ 2 \div 1\ .\ 6 = 1\ 3\ .\ 5\ 0\ ^\circ$$

Rotation by side thruster: about $1\ 4\ ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 . . Damaged)

4) $f = 0\ .\ 0\ 6$ (Fig. 4 / 1 3)

Bottom mounting at operation buoyancy = $1\ 0\ 7\ 4 \times 2 \div 5 = 4\ 3\ 0\ t\ f$

Friction flow speed = $0\ .\ 7\ 6\ m / s$

$$t = 4\ 5 \times (0\ .\ 7\ 6 \div 1\ .\ 6) = 1\ 6\ .\ 5\ 3\ ^\circ$$

Rotation by side thruster: about $1\ 7\ ^\circ$

Thruster shutoff

Tidal flow travel (Kinetic energy > Limit 2 · · Damaged)

5) $f = 0 . 0 8$ (Fig. 5 / 1 3) :

Bottom mounting at operation buoyancy = $1 0 7 4 \times 1 \div 5 = 2 1 5$ t f

Friction flow speed = $0 . 8 8$ m / s > Speed at bottom mounting = $0 . 8$

Impossible to move by thruster

3 . 3 . 3 Add-up of the analysis

3 . 3 . 3 . 1 Add-up of operation methods

Table - 1 1 is "Add-up of operation methods " where the travel means and the kinetic energy in the results of previous item (Analysis on the calculation results) are listed.

Table - 1 1 Add-up of operation method s (1 / 2)

Item in common		Friction coefficient f	0.00	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.30	0.40	
		Shoe load	0	215	430	644	859	1074	1289	1503	1718	1933	2148	3222	4296	
		Shoe friction force (tf)	0	21	43	64	86	107	129	150	172	193	215	322	430	
		Friction flow speed (m/s)	0.00	0.44	0.62	0.76	0.88	0.99	1.08	1.17	1.25	1.32	1.40	1.71	1.97	
Operation condition 1 Flow speed at bottom mounting 0.8m/s Operation flow speed 1.0m/s $\theta_c = 18^\circ$	Constant function	Travel means (θ_c)	Thruster θt°	-	-	-	-	-	-	-	-	-	-	-	-	
			Tidal flow	○	○	○	○	○	○							
			Tidal flow + thruster							○	○	○	Inability	Inability	Inability	Inability
		Kinetic energy	≈ 0							○	○	○				
			< Limit 1													
			Limit 1 thru Limit 2		○	○	○	○	○							
	Linear function	Travel means (θ_c)	Thruster θt°	-	3.5	7.0	10.5	Inability								
			Tidal flow	○	○	○	○									
			Tidal flow + thruster													
		Kinetic energy	≈ 0													
			< Limit 1													
			Limit 1 thru Limit 2	○	○	○	○									
	Parabolic function	Travel means (θ_c)	Thruster θt°	-	8.0	11.2	13.8	Inability								
			Tidal flow	○	○	○	○									
			Tidal flow + thruster													
		Kinetic energy	≈ 0													
			< Limit 1			○	○									
			Limit 1 thru Limit 2	○	○											
Operation condition 2 Flow speed at bottom mounting 0.8m/s Operation flow speed 1.3m/s $\theta_c = 34.6^\circ$	Constant function	Travel means (θ_c)	Thruster θt°	-	-	-	-	-	-	-	-	-	-	-	-	
			Tidal flow	○	○	○	○	○	○	○	○	○				
			Tidal flow + thruster												○	Inability
		Kinetic energy	≈ 0												○	
			< Limit 1													
			Limit 1 thru Limit 2									○	○	○		
	Linear function	Travel means (θ_c)	Thruster θt°	-	4.0	8.0	12.0	Inability								
			Tidal flow	○	○	○	○									
			Tidal flow + thruster													
		Kinetic energy	≈ 0													
			< Limit 1													
			Limit 1 thru Limit 2													
	Parabolic function	Travel means (θ_c)	Thruster θt°	-	11.8	16.6	20.4	Inability								
			Tidal flow	○	○	○	○									
			Tidal flow + thruster													
		Kinetic energy	≈ 0													
			< Limit 1													
			Limit 1 thru Limit 2		○	○	○									
> Limit 2	○															

Table - 1 1 Add-up of operation methods (2 / 2)

Item in common		Friction coefficient f	0.00	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.30	0.40		
		Shoe load	0	215	430	644	859	1074	1289	1503	1718	1933	2148	3222	4296		
		Shoe friction force (tf)	0	21	43	64	86	107	129	150	172	193	215	322	430		
		Friction flow speed (m/s)	0.00	0.44	0.62	0.76	0.88	0.99	1.08	1.17	1.25	1.32	1.40	1.71	1.97		
Operation condition 3 Flowspeed at bottom mounting 0.8m/s Operation flow speed 1.6m/s $\theta_c = 45^\circ$	Constant function	Travel means (θ_c)	Thruster θt°	-	-	-	-	-	-	-	-	-	-	-	-		
			Tidal flow	○	○	○	○	○	○	○	○	○	○				
			Tidal flow + thruster												○	Inability	
		Kinetic energy	$\cong 0$													○	
			< Limit 1														
			Limit 1 thru Limit 2														
	Linear function	Travel means (θ_c)	Thruster θt°	-	3.4	6.9	10.3	Inability									
			Tidal flow	○	○	○	○										
			Tidal flow + thruster														
		Kinetic energy	$\cong 0$														
			< Limit 1														
			Limit 1 thru Limit 2														
	Constant function	Travel means (θ_c)	Thruster θt°	-	9.6	13.5	16.5	Inability									
			Tidal flow	○	○	○	○										
			Tidal flow + thruster														
		Kinetic energy	$\cong 0$														
			< Limit 1														
			Limit 1 thru Limit 2														
	Constant function	Kinetic energy	> Limit 2	○	○	○	○										
			> Limit 2	○	○	○	○										
			> Limit 2	○	○	○	○										

3 . 3 . 3 . 2 Explanation of the categories in the table

Table 1 / 2 shows the results of operation condition 1 and 2 and table shows that of operation condition 3. Each operation condition row consists of the constant function, the linear function and the parabolic function, and each function row consists of the travel means and the kinetic energy. The top column of each table is items in common to all the operation conditions. Each category is explained including detail categories (shown by " • ") of which it consists.

【Items in common】 : The item in common to all operation conditions and consists of the followings.

- Friction coefficient f : The f value shown on the figures (graphs) of kinematic energy
- Shoe load: The shoe load whose friction force corresponding to $f = 0.1$ (refer to Table - 1 0) equals the shoe friction force below (just for reference).
- Shoe friction force: $= 1 0 7 4 \ t \ f \times$ Friction coefficient f
- Friction flow speed: Flow speed whose thrust on the gate body equals the shoe friction force.
- 【Operation condition 1 thru 3】 : Refer to Table - 1 0 and its explanation.
- 【Constant function】 : Tide difference distribution on c is constant. Refer to Fig. - 6 for c .
- 【Linear function】 : Tide difference distribution on c is Linear (Refer to Fig. - 7).
- 【Parabolic function】 : Tide difference distribution on c is parabolic (Refer to Fig. - 8).
- 【Travel means (c)】 : Travel means of the gate body on the c area. It corresponds to the f .
- Thruster t : Gate rotation angle from $= 0$ aided by thruster. Constant function and $f = 0$ are not applicable (-).
- Tidal flow: Travel aided by the tidal flow (: Case concerned).
- Tidal flow + thruster: Travel aided by the tidal flow and thruster (: Case concerned).
- 【kinetic energy】 : A detail category concerned is selected referring to the kinetic energy graphs.
- 0 : Kinetic energy is almost 0 (No impact power exists).
- $< \text{Limit } 1$: Kinetic energy is less than Limit 1 (Impact power is small).
- $\text{Limit } 1 \text{ thru Limit } 2$: Kinetic energy is between Limit 1 and Limit 2, inclusive (Impact power is medium . . . Allowable).
- $> \text{Limit } 2$: Kinetic energy is more than Limit 2 (Impact power is big . . . Damaged).

【Supplementary explanation of the detail categories】

1)Shoe load: The operation buoyancy which is necessary to provide the friction force corresponding to the f value of each energy-level judgment graph is shown at 3 . 2 . 3 (Analysis on the operation method) depend upon the idea that the shoe load, in short, the friction force rises or falls according to the operating buoyancy selection since the f has been locked in 0.1 at the operation condition of Table - 1 0 (Shoe load = $1 0 7 4 \ t \ f$ - operation buoyancy). The shoe loads are also shown on Table - 1 1 (Add-up of operation methods) although the table is coordinated according to the f values so that a range of the shoe load selection may be found against the operation flow speed of Table - 1 0 .

2)Thruster t : The gate body needs the thruster aided movement of t° rotation at $= 0$ position (refer to Fig. - 6) in tide difference distribution of the linear function and the parabolic function since there will be the friction force although there is no tide difference. The thruster capacity limit is supposed to be the bottom mounting flow speed and "Inability" is keyed when it is less than the friction flow speed.

3)Tidal flow + thruster: It is the last means of the gate body movement within the c area and its capacity limit is given by below formula, and "Inability" is keyed when the capacity limit is less than the friction flow speed.

$$\text{Limit capacity of (tidal flow + thruster)} = (\text{Operation flow velocity}^2 + \text{Bottom mounting flow velocity}^2)^{0.5} \text{ (m / s)} \dots\dots (3.-29)$$

3 . 3 . 3 . 3 Travel means and kinetic energy

(1) Explanation of the coordinated results

【Operation condition 1】

• Constant function

Travel means: $f = 0$ thru 0.1 is the tidal flow, 0.12 thru 0.16 is the tidal flow + the thruster and $f = 0.18$ is "Inability".

Kinetic energy: In the tidal flow area, damaged at $f = 0$ and allowable at $f = 0.02$ thru 0.1 . In the (tidal flow + thruster) area, there is no impact force.

• Linear function

Travel means: $f = 0$ thru 0.06 is the tidal flow and $f = 0.08$ is "Inability".

Kinetic energy: $f = 0$ thru 0.06 is allowable.

• Parabolic function

Travel means: $f = 0$ thru 0.06 is the tidal flow and $f = 0.08$ is "Inability".

Kinetic energy: $f = 0$ thru 0.02 is allowable and $f = 0.4$ thru 0.6 is less than Limit 1.

【Operation condition 2】

• Constant function

Travel means: $f = 0$ thru 0.18 is the tidal flow, 0.2 is the tidal flow + the thruster and $f = 0.3$ is "Inability".

Kinetic energy: In the tidal flow area, damaged at $f = 0$ thru 0.12 and allowable at $f = 0.14$ thru 0.18 . In the (tidal flow + thruster) area, there is no impact force.

• Linear function

Travel means: $f = 0$ thru 0.06 is the tidal flow and $f = 0.08$ is "Inability".

Kinetic energy: $f = 0$ thru 0.06 is "damaged".

• Parabolic function

Travel means: $f = 0$ thru 0.06 is the tidal flow and $f = 0.08$ is "Inability".

Kinetic energy: $f = 0$ is "damaged" and $f = 0.02$ thru 0.06 is allowable.

【Operation condition 3】

• Constant function

Travel means: $f = 0$ thru 0.2 is the tidal flow, 0.3 is the tidal flow + the thruster and $f = 0.4$ is "Inability".

Kinetic energy: In the tidal flow area, damaged at all cases. In the (tidal flow + thruster) area, there is no impact force.

• Linear function

Travel means: $f = 0$ thru 0.06 is the tidal flow and $f = 0.08$ is "Inability".

Kinetic energy: $f = 0$ thru 0.06 is "damaged".

• Parabolic function

Travel means: $f = 0$ thru 0.06 is the tidal flow and $f = 0.08$ is "Inability".

Kinetic energy: $f = 0$ thru 0.06 is "damaged".

(2) Relation between the results

【Operation condition 1】

• Constant function

Travel means: The operation flow speed is the smallest and the shifting point of the travel means is to the left. "Inability" concerns the operation flow speed and its mark point is also to the left.

Kinetic energy: Damage occurs at $f = 0$ and disappears with the f increase. The tidal flow + the thruster is a kind of manual operation and no impact power work consequently. Selectable shoe load is between 215 and 1718 t f where 1289 thru 1718 needs thruster aid.

• Linear function

Travel means: "Inability" concerns the bottom mounting flow speed and occurs at the small f value and a range of the tidal flow travel is limited consequently. The range will vary according to the assumption of the tide difference distribution.

Kinetic energy: The allowable range of kinetic energy is limited with the same reason as the tidal flow travel range. The range will vary according to the assumption of the tide difference distribution. Selectable shoe load is between 0 and 644 t f .

• Parabolic function

Travel means: Identical with the linear function.

Kinetic energy: Identical with the linear function except that the energy level is less than the linear. Selectable shoe load is between 0 and 644 t f .

【Operation condition 2】

• Constant function

Travel means: The shifting f of the travel means is to the right than the operation condition 1 since the operation flow speed is higher. "Inability" mark point is to the right with the same reason.

Kinetic energy: The damaged area increased due to the higher set of the operation flow speed. The energy shifted to the allowable range with the f increase. The tidal flow + the thruster is a kind of manual operation and no impact power work consequently. Selectable shoe load is between 1503 and 2148 t f where the case 2148 needs thruster aid.

• Linear function

Travel means: "Inability" concerns the bottom mounting flow speed whose set value is the same as the operation condition 1 and occurs at the same f value and a range of the tidal flow travel is limited identically. The range will vary according to the assumption of the tide difference distribution.

Kinetic energy: The damaged area appeared due to a high operation flow speed setting. The area will shift to a allowable area as the restriction of bottom mounting flow speed abates, that will be more remarkable than the constant function.

• Parabolic function

Travel means: "Inability" concerns the bottom mounting flow speed whose set value is the same as the operation condition 1 and occurs at the same f value and a range of the tidal flow travel is limited identically. The range will vary according to the assumption of the tide difference distribution.

Kinetic energy: The damaged area appeared due to the higher operation flow speed setting. The

area has shifted to a allowable area with the f increase since the energy level is lower than the linear function. Selectable shoe load is between 215 and 644 $t f$

【Operation condition 3】

• Constant function

Travel means: The shifting f of the travel means is to the right than the operation condition 2 since the operation flow speed is even higher. "Inability" mark point is even to the right with the same reason.

Kinetic energy: The damaged area increased due to even the higher set of the operation flow speed. The energy shifted to the allowable range with the f increase. The tidal flow + the thruster is a kind of manual operation and no impact power work consequently. Selectable shoe load is 3222 $t f$ which needs thruster aid.

• Linear function

Travel means: "Inability" concerns the bottom mounting flow speed whose set value is the same as the operation condition 1 and occurs at the same f value and a range of the tidal flow travel is limited identically. The range will vary according to the assumption of the tide difference distribution.

Kinetic energy: The operation flow speed set is even higher. It is possible that the damaged area will shift to a allowable area as the bottom mounting flow speed restriction abates.

• Parabolic function

Travel means: "Inability" concerns the bottom mounting flow speed whose set value is the same as the operation condition 1 and occurs at the same f value and a range of the tidal flow travel is limited identically. The range will vary according to the assumption of the tide difference distribution.

Kinetic energy: The damaged area increased due to the even higher operation flow speed setting.

3 . 3 . 4 Discussion on the operation method

"Gate operating method with the help of tidal flow" which could be seen through the analysis of the previous section is summed up.

(1) Findings

Kinetic energy absorption by a gate body is possible.

The shoe friction force has a beneficial effect on the tidal flow energy dissipation.

Gate body operation with the help of tidal flow is possible.

Adequacy of above findings is felt in our bones through an image of the gate body drifting in tidal flow. It is difficult to imagine that the gate body speed grows to be much more than the tidal flow. Usual tidal flow speed is about 2 or 3 kt. (= 1 or 1.5 m/s), that seems to be the level at which energy dissipation by the shoe friction force works effectively.

(2) Implementation items at project stages

Hydraulic experiment

Prototype hydraulic experiments including model experiments are required to make friction force charts which are necessary in selection of the operating buoyancy at the gate operation with the aid of tidal flow. The experiment condition is supposed to be reflected by site tidal flow condition and needs of the facility users. The experimental results concerning the kinetic energy will be settled in points between the constant function and parabolic function with a distinct possibility.

Operation manual

Operation manuals including the experimental results mentioned above are required to be made.

(3) Reference information

Purpose of the hydraulic experiment

- 1) Grasping flow effect: Tidal flow speed, Hydraulic force versus gate opening (hydraulic force distribution) etc.
- 2) Verification of study results: Gate collision speed, Collision reaction force, Gate body stress, Friction coefficient etc.
- 3) Collecting information for design work: Operation buoyancy, Thruster capacity etc.

Operation method

- 1) Operation target value: Gate body tip speed, Gate body tip position
- 2) Target value maintenance means: Side thruster, Buoyancy operation valve etc.
- 3) Operation steps:
 - a) Travel to the bottom mounting position with the help of a side thruster
 - b) Bottom mounting after the operation buoyancy is set referring to the friction chart
 - c) Travel with the help of the tidal flow (Gate body tip speed <allowable limit)
 - d) Arrival at the gate completely closed position
 - e) Confirming the gate body tip position
 - f) Exhausting the operation buoyancy
 - g) Side thruster shutdown
 - h) Setting the gate levitation prevent apparatus on

Operation manual

- 1) Operation condition: Operation flow speed, Bottom mounting flow speed, Friction coefficient etc.
- 2) Friction force chart (to be prepared according to the experimental results)
- 3) Others

4 . Conclusion

(1) The kinetic energy of the gate body gradually converts to the strain energy through the structural flexibility of the gate body and the forces acting on the gate due to collision can be quantified in the form of the inertia force and its reaction force.

(2) In addition to the reaction force described above, the gate bottom support seat will get impact force which corresponds to the gate section's rotational acceleration due to collision. The seat shall have sufficient flexibility as well as high degree strength, accordingly.

(3) The tidal energy can be dissipated with the help of a friction force chart. The chart is prepared according to results of model and prototype experiments.