

Super Large Torsion Type Gate

Swing Type

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1 . Introduction

Although author proposed a rolling type torsion gate as a storm surge barrier main gate because torsion type structure is superior in its weight than other structural type such as bending structure, swing type is proposed in this material as a secondary alternative to the rolling type. The purpose of the proposal is further cost reduction.

A torsion type flap gate whose bottom is supported by hinge bearings has historically long records but its structural superiority has increased since super large dock flap gates whose bottoms are supported continuously by dock concrete structures appeared*¹. The swing type was a conclusion after giving serious thought how to make use of this superiority.

The swing type gate body whose one end is a center of rotation moves to its completely closed position in swing motion with surplus buoyancy of the gate body and another end of the gate body mounts on a bottom of water due to disposal of the surplus buoyancy, and then the gate body is pushed by water pressure working on it and its bottom gets contact with the water bottom concrete structure and is supported by the concrete. Following two technical features make above concept be possible.

The support on the water bottom of the rotation center is in conditions of free in triaxial rotations and constraint in triaxial removes and bears a pull-up force.

Gate operations such as bottom mounting, sinking installation, surfacing are made by float tank operation.

Although gate open and closing operation in standing water is fundamental, there is much possibility of operating the gate within a flow of water. The gate operation with the assistance of tidal flow is also feasible.

A concept design was made to confirm feasibility of the swing type

*1(1) Hiroshi Terata, Noriaki Shigenaga, Torsion type flap gate for docks, Mitsubishi Heavy Industries, Ltd. TECHNICAL REVIEW June, 1980

and case studies were made on the rotation center support (the gate end support key) and the float tanks, and the gate operation with the assistance of tidal flow was studied. The results of them are shown according to following items.

- (1) Concept design of the swing type torsion gate
- (2) Float tanks
- (3) Operating condition

2 . Concept design of the swing type torsion gate

The purpose of the concept design is to confirm feasibility of the swing type. There could be other cases than the result shown.

2 . 1 Design data

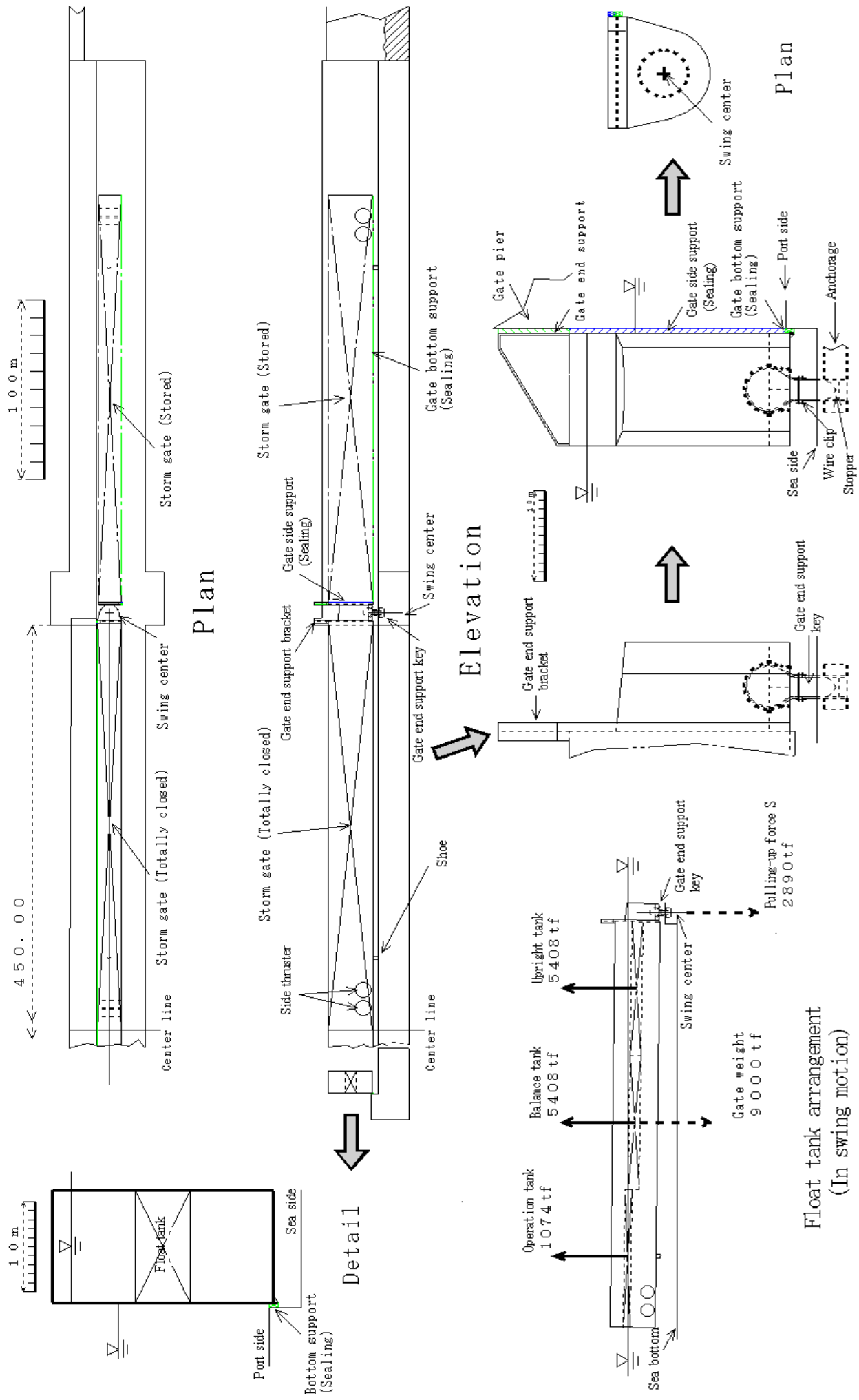
Table 2.-1 shows fundamental design data of the concept design. The steel weights on the table are very roughly calculated results.

Table 2.-1 Design data

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

2 . 2 General arrangement

Fig. 2.-1 shows a general arrangement of the concept design. Elevation and Plan of the whole gate, Details of a typical gate section, Gate end support mechanism and Float tank arrangement including the gate body inclination and buoyancy of the tanks during gate swinging operation are shown. Driving force of the swing motion is thrust of two side-thrusters installed on the gate body. Rolling and pitching center of the gate body during the swing motion locates at the center of the spherical seat bearing which covers the gate end support key head. The center of swing motion coincides with the center line of the key. High



Gate end support mechanism Side View

Fig. 2.-1 General arrangement

tide load working on the gate body when the gate is totally closed is carried to the gate bottom support and the torsion moment composed by the load and the bottom support reaction force is carried up to the gate body supported end through the gate body torsional rigidity and is transmitted to the gate pier through the gate end support bracket and the gate end support key (spherical seat). Stability of the gate body during working condition is maintained by the pulling-up force of the gate end support key and the float tank buoyancy. Stability of the gate body during maintenance work has to be ensured according to a stability theory of ships (a stability during releasing and setting the key is most critical). The wire-clip is used to release and set the key. The shoe load corresponds to absent part of the operation tank buoyancy when the gate body free end arrives at the water bottom.

2.3 Gate end support key

Fig. 2.-2 shows details of the gate end support key. This is an

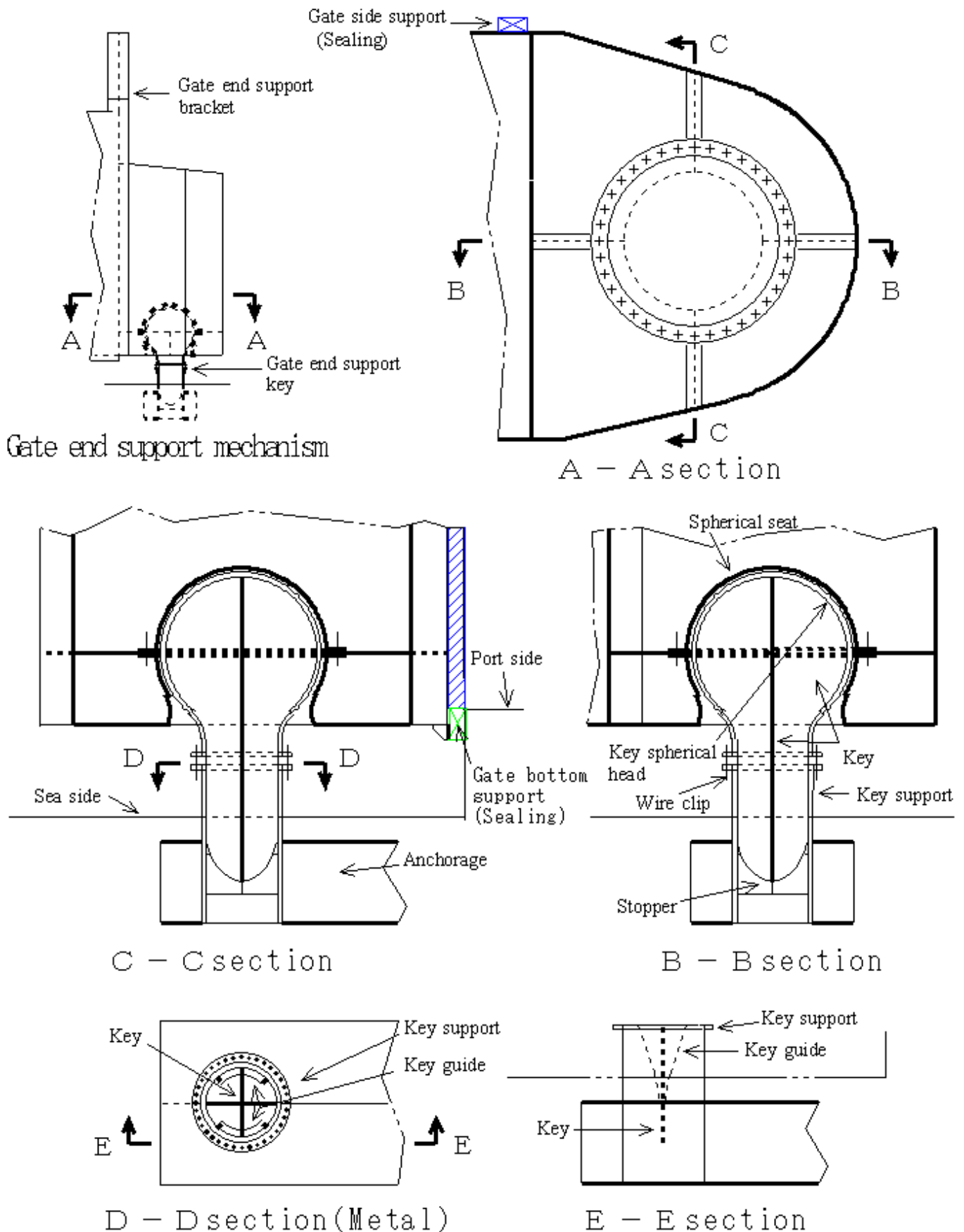


Fig. 2.-2 Details of the gate end support key

example of gate support method which satisfies condition of being free in triaxial rotations and constrained in triaxial removes and bears a pull-up force. The spherical seat of the gate body is free in any axial rotations around the key spherical head which is set on the water bottom and its vertical movement is restricted by the upper and lower half surface of the key head and its horizontal movement is restricted by the side surface of the key head. All contact surface of the spherical seat and the key head is a bearing surface. Loads on the key head are the pulling-up force, the thrust reaction force during the gate in swing motion, the gate end support force during the gate barricading a high tide and a minus pulling-up force at a maintenance. The gate end support force is the extremely biggest one among them but it statically works on the key head. Release and setup work of the gate end support key is required since maintenance of the gate will be carried out in a dry dock or on a floating dock. The key is joined with the key support by the wire clips. Main process of the releasing work is cancelling the pulling-up force removal of the wire clips pulling the key out from the key support. and are made by float tank operations and is underwater job. Main process of the setting up work is the gate body guiding inserting the key into the key support the clip setting pulling-up force setting. is to guide the key of the gate body to the key support of the water bottom and an off-shore technology is applicable for the guiding. The key will fit the confines of the key support with the aids of the key guides. and are made by float tank operations and is underwater job. The underwater job of the work is deemed to be critical in safety work control. Small interval is provided between the key and the key support so that key insert and key pulling-out may be made easily. The spherical seat load is directly transmitted to the key support through the key. The purpose of using the wire clips to the key setting is smooth load transmittance from the key to the key support through the small interval between them and to simplify the underwater job.

2 . 4 Other examples

Following shows ideas other than the concept design.

2 . 4 . 1 Seaside water tightness

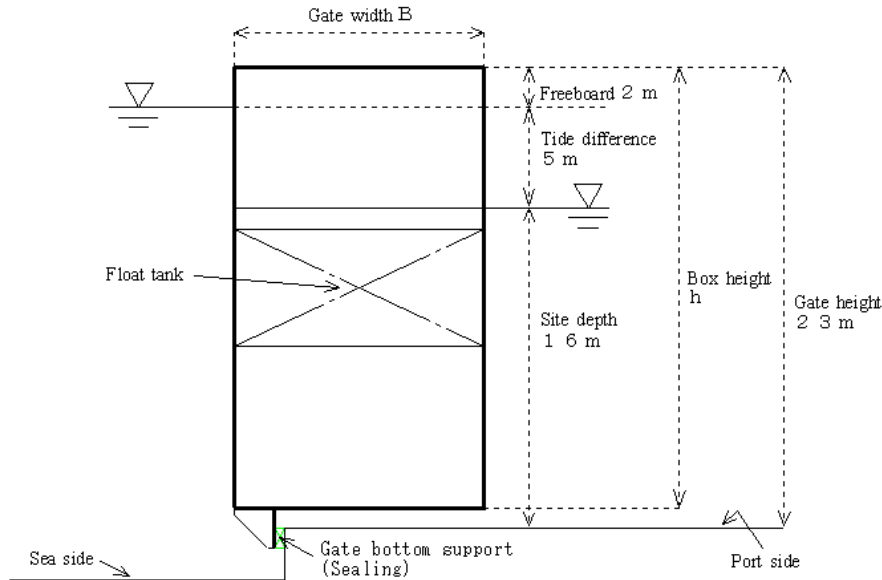


Fig. 2.-3 Seaside water tightness

Fig. 2.-3 shows the seaside water tightness whereas the concept design of the chapter 2 accords to the port side water tightness and other specifications are exactly same. Idea of Fig. 2.-3 aims to deduct a wave impact on the gate body, on the other hand, it is demerit of the idea that structural efficiency is just a bit lower than the original since the box height is less and the water tight line of the gate body is stereoscopic.

2 . 4 . 2 Roller support

Fig. 2.-4~6 shows a roller support type swing gate whose gate bottom and gate end are supported by rollers. Fig. 2.-4 shows bottom roller arrangement (port side water tightness), Fig. 2.-5 shows bottom roller arrangement (seaside water tightness) and Fig. 2.-6 shows gate end roller and swing axle arrangement. The axle is installed on the gate pier.

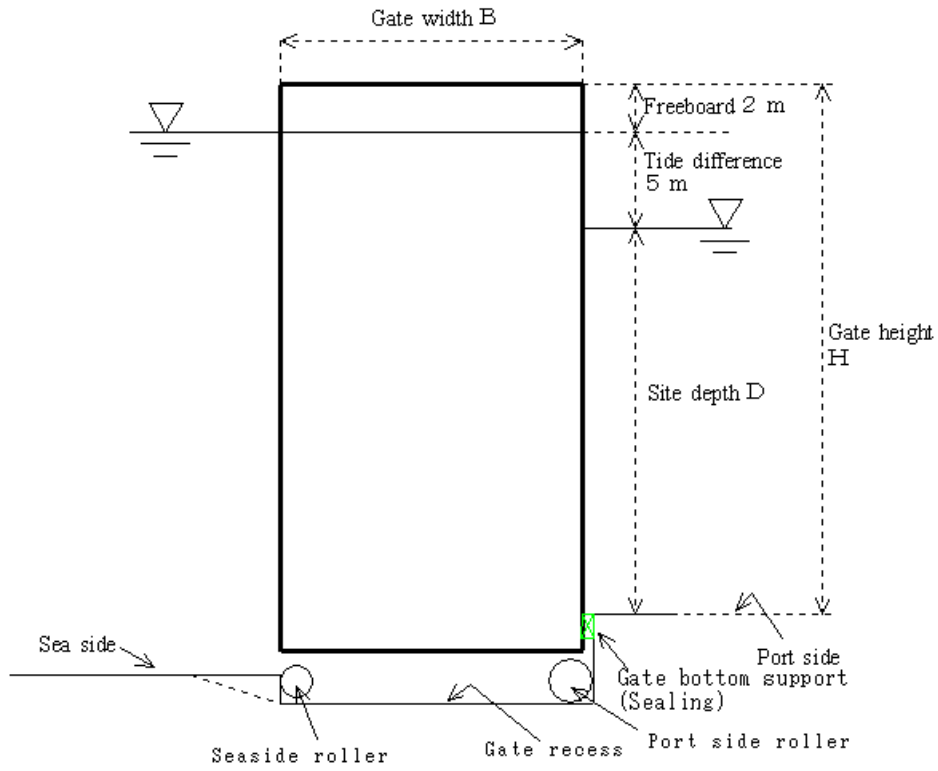


Fig. 2.-4 Bottom roller arrangement (Port side water tightness)

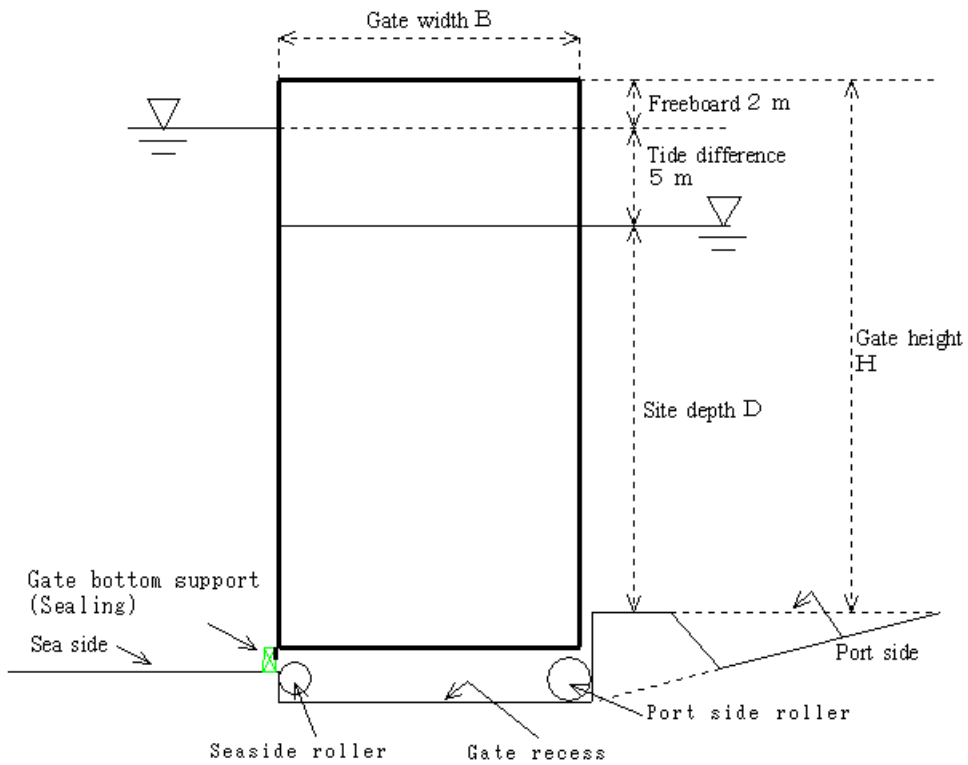


Fig. 2.-5 Bottom roller arrangement (Seaside water tightness)

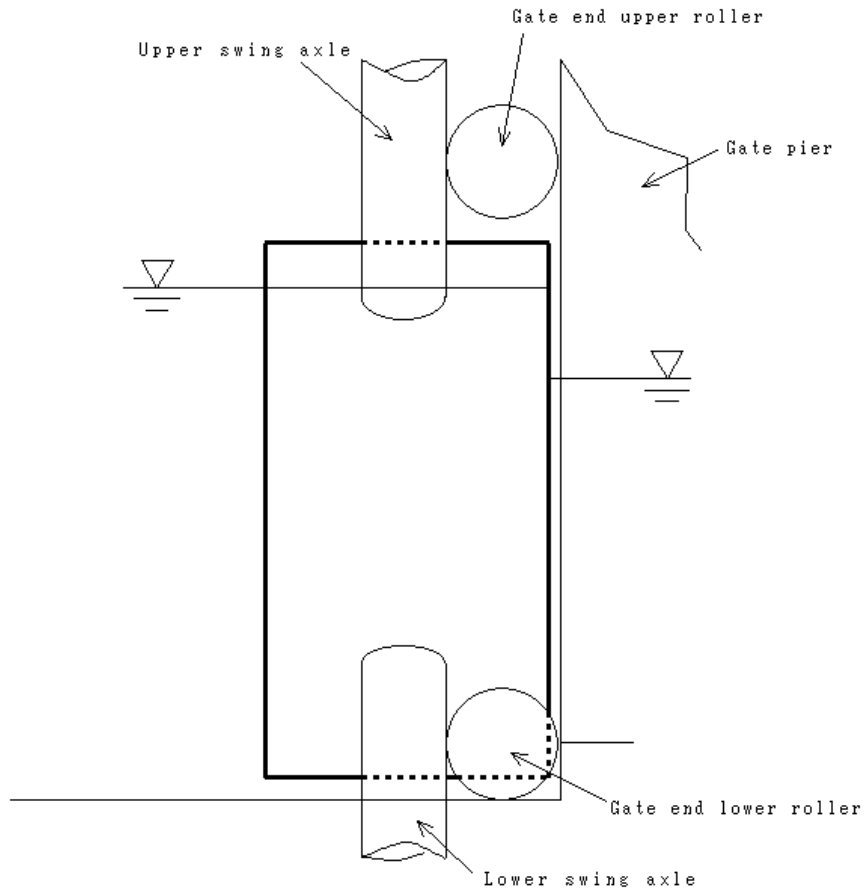


Fig. 2.-6 Gate end roller • Swing axle arrangement

The purpose of this proposal is bi-directional tidal loading on the gate and the gate flotation during loaded conditions and its demerit is a gate body motion due to water waves are not absorbed because of the swinging around the axle fixed on the gate pier and a cost merit is less than the original. Detail explanations of this proposal are skipped.

3 . Float tanks

The gate body operation during in working condition and at maintenance is made by water filling and discharge of the float tanks provided in the gate body. The float tank volumes and force acting on the gate body and its inclination are explained.

3 . 1 Float tank volumes

3 . 1 . 1 Tank arrangement

The operation tank, the balance tank and the upright tank which are shown on Fig. 3.-1 are provided in the gate body and used for its operation. The total buoyancy of the three tanks equals to the sum of the gate weight W and the pulling-up force S . Function of each tank is as follows.

Upright tank : Keeping the gate being upright with the aids of force S .

Balance tank : Balancing buoyancy with the gate weight W .

Operation tank : Operation of the gate body by fill/discharge of water.

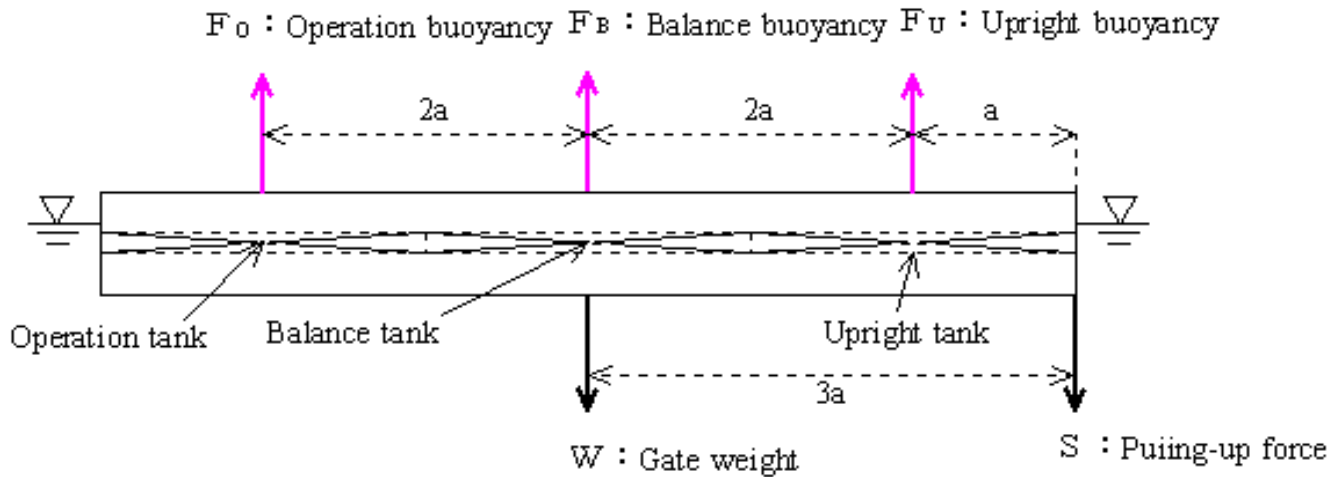


Fig. 3.-1 Float tank arrangement and Forces on the gate body

The centers of the upright tank and the balance tank approximately coincide with the gate weight center so that their impact on the gate body stability may become less (There may be a possibility of the pulling-force reduction due to the tank outcrop at the gate working condition in case the tank centers are too high or a possibility of the

gate stability reduction in case the tank centers are too low.). The operation tank center locates so higher than other tanks that enough gate stability may be obtained during the sinking installation of gate at its maintenance.

3 . 1 . 2 Force equilibrium

3 . 1 . 2 . 1 Condition of equilibrium

The calculation model of Fig. 3.-1 includes following approaches which simplify a derivation of the equilibrium condition.

Approach 1 . The pulling-up force works on the upright tank right end.

Approach 2 . Buoyancy center of float tanks coincide with their centers.

Approach 3 . The gate steel displacement is neglected.

Equilibrium of buoyancy forces, W , and, S working on the gate body during its operation is expressed by following formula.

$$F_O + F_B + F_U = W + S \quad \dots\dots(3.-1)$$

Equilibrium of their moments around S working point is expressed by following formula.

$$F_O \times 5 a + F_B \times 3 a + F_U \times a = W \times 3 a \quad \dots\dots(3.-2)$$

Formula (3.-1) $\times 5 a$ gives following.

$$F_O \times 5 a + F_B \times 5 a + F_U \times 5 a = W \times 5 a + S \times 5 a \dots\dots(3.-3)$$

Formula (3.-3) - formula (3.-2) gives following.

$$F_B \times 2 a + F_U \times 4 a = W \times 2 a + S \times 5 a \quad \dots\dots(3.-4)$$

Accordingly,

$$S = \{ 2 (F_B - W) + F_U \times 4 \} \div 5 \quad \dots\dots(3.-5)$$

Accordingly,

$$F_0 = W + S - F_B - F_U = \{3(W - F_B) - F_U\} \div 5 \dots\dots(3.-6)$$

Following replacements are made.

$$F_0 = f_0 \times W \quad (f_0 : \text{Operation buoyancy ratio})$$

$$F_B = f_B \times W \quad (f_B : \text{Balance buoyancy ratio})$$

$$F_U = f_U \times W \quad (f_U : \text{Upright buoyancy ratio})$$

$$S = s \times W \quad (s : \text{Pulling-up force ratio})$$

And they are inserted into Formula (3.-5) and (3.-6), then following equation of equilibrium is obtained. The formula gives the pulling-up force ratio and the upright buoyancy ratio (s and f_0) which will correspond to arbitrarily selected the balance buoyancy ratio and the upright buoyancy ratio (f_B and f_U).

$$s = \{2(f_B - 1) + f_U \times 4\} \div 5 \dots\dots(3.-7)$$

$$f_0 = \{3(1 - f_B) - f_U\} \div 5 \dots\dots(3.-8)$$

And following formula is obtained from formula (3-1).

$$T = f_B + f_B + f_U - s = 1 \dots\dots(3.-9)$$

3 . 1 . 2 . 2 Numerical calculation

Formula (3.-7), (3.-8), and, (3.-9) and the total of buoyancy ratios were numerically calculated on the concept design shown in Chapter 2. Table 3.-1 shows the pulling-up force ratio s , table 3.-2 shows the operation buoyancy ratio f_0 , table 3.-3 shows the total of buoyancy force ratios ($f_0 + f_B + f_U$), and, table 3.-4 shows T ($f_0 + f_B + f_U -$

s). Fig. 3.-2 shows the pulling-up force ratio (s) and the operation buoyancy ratio (f₀) and Fig. 3.-3 shows the buoyancy ratio total (f₀ + f_B + f_U). Well-matched volume selection of each float tank is possible after repeating trial calculation of these values with a consideration to total tendency of the values shown on these figures.

Table 3.-1 Pulling-up force ratio s

Index	fU=0	fU=0.1	fU=0.2	fU=0.3	fU=0.4	fU=0.5	fU=0.6	fU=0.7	fU=0.8	fU=0.9	fU=1
fB	s										
0	-0.4	-0.32	-0.24	-0.16	-0.08	0	0.08	0.16	0.24	0.32	0.4
0.1	-0.36	-0.28	-0.2	-0.12	-0.04	0.04	0.12	0.2	0.28	0.36	0.44
0.2	-0.32	-0.24	-0.16	-0.08	0	0.08	0.16	0.24	0.32	0.4	0.48
0.3	-0.28	-0.2	-0.12	-0.04	0.04	0.12	0.2	0.28	0.36	0.44	0.52
0.4	-0.24	-0.16	-0.08	4.44E-17	0.08	0.16	0.24	0.32	0.4	0.48	0.56
0.5	-0.2	-0.12	-0.04	0.04	0.12	0.2	0.28	0.36	0.44	0.52	0.6
0.6	-0.16	-0.08	0	0.08	0.16	0.24	0.32	0.4	0.48	0.56	0.64
0.7	-0.12	-0.04	0.04	0.12	0.2	0.28	0.36	0.44	0.52	0.6	0.68
0.8	-0.08	-2.2E-17	0.08	0.16	0.24	0.32	0.4	0.48	0.56	0.64	0.72
0.9	-0.04	0.04	0.12	0.2	0.28	0.36	0.44	0.52	0.6	0.68	0.76
1	-4.44E-17	0.08	0.16	0.24	0.32	0.4	0.48	0.56	0.64	0.72	0.8

Table 3.-2 Operation buoyancy ratio f_0

Index	fU=0(O)	fU=0.1(O)	fU=0.2(O)	fU=0.3(O)	fU=0.4(O)	fU=0.5(O)	fU=0.6(O)	fU=0.7(O)	fU=0.8(O)	fU=0.9(O)	fU=1(O)
fB	f_0										
0	0.6	0.58	0.56	0.54	0.52	0.5	0.48	0.46	0.44	0.42	0.4
0.1	0.54	0.52	0.5	0.48	0.46	0.44	0.42	0.4	0.38	0.36	0.34
0.2	0.48	0.46	0.44	0.42	0.4	0.38	0.36	0.34	0.32	0.3	0.28
0.3	0.42	0.4	0.38	0.36	0.34	0.32	0.3	0.28	0.26	0.24	0.22
0.4	0.36	0.34	0.32	0.3	0.28	0.26	0.24	0.22	0.2	0.18	0.16
0.5	0.3	0.28	0.26	0.24	0.22	0.2	0.18	0.16	0.14	0.12	0.1
0.6	0.24	0.22	0.2	0.18	0.16	0.14	0.12	0.1	0.08	0.06	0.04
0.7	0.18	0.16	0.14	0.12	0.1	0.08	0.06	0.04	0.02	4.44E-17	-0.02
0.8	0.12	0.1	0.08	0.06	0.04	0.02	4.44E-17	-0.02	-0.04	-0.06	-0.08
0.9	0.06	0.04	0.02	4.44E-17	-0.02	-0.04	-0.06	-0.08	-0.1	-0.12	-0.14
1	6.66E-17	-0.02	-0.04	-0.06	-0.08	-0.1	-0.12	-0.14	-0.16	-0.18	-0.2

Table 3.-3 Total of buoyancy ratios ($f_0 + f_B + f_U$)

Index	fU=0	fU=0.1	fU=0.2	fU=0.3	fU=0.4	fU=0.5	fU=0.6	fU=0.7	fU=0.8	fU=0.9	fU=1
fB	$f_0 + f_B + f_U$										
0	0.6	0.68	0.76	0.84	0.92	1	1.08	1.16	1.24	1.32	1.4
0.1	0.64	0.72	0.8	0.88	0.96	1.04	1.12	1.2	1.28	1.36	1.44
0.2	0.68	0.76	0.84	0.92	1	1.08	1.16	1.24	1.32	1.4	1.48
0.3	0.72	0.8	0.88	0.96	1.04	1.12	1.2	1.28	1.36	1.44	1.52
0.4	0.76	0.84	0.92	1	1.08	1.16	1.24	1.32	1.4	1.48	1.56
0.5	0.8	0.88	0.96	1.04	1.12	1.2	1.28	1.36	1.44	1.52	1.6
0.6	0.84	0.92	1	1.08	1.16	1.24	1.32	1.4	1.48	1.56	1.64
0.7	0.88	0.96	1.04	1.12	1.2	1.28	1.36	1.44	1.52	1.6	1.68
0.8	0.92	1	1.08	1.16	1.24	1.32	1.4	1.48	1.56	1.64	1.72
0.9	0.96	1.04	1.12	1.2	1.28	1.36	1.44	1.52	1.6	1.68	1.76
1	1	1.08	1.16	1.24	1.32	1.4	1.48	1.56	1.64	1.72	1.8

Table 3.-4 $T (f_0 + f_B + f_U - s)$

Index	fU=0	fU=0.1	fU=0.2	fU=0.3	fU=0.4	fU=0.5	fU=0.6	fU=0.7	fU=0.8	fU=0.9	fU=1
fB	$T = f_0 + f_B + f_U - s$										
0	1	1	1	1	1	1	1	1	1	1	1
0.1	1	1	1	1	1	1	1	1	1	1	1
0.2	1	1	1	1	1	1	1	1	1	1	1
0.3	1	1	1	1	1	1	1	1	1	1	1
0.4	1	1	1	1	1	1	1	1	1	1	1
0.5	1	1	1	1	1	1	1	1	1	1	1
0.6	1	1	1	1	1	1	1	1	1	1	1
0.7	1	1	1	1	1	1	1	1	1	1	1
0.8	1	1	1	1	1	1	1	1	1	1	1
0.9	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1

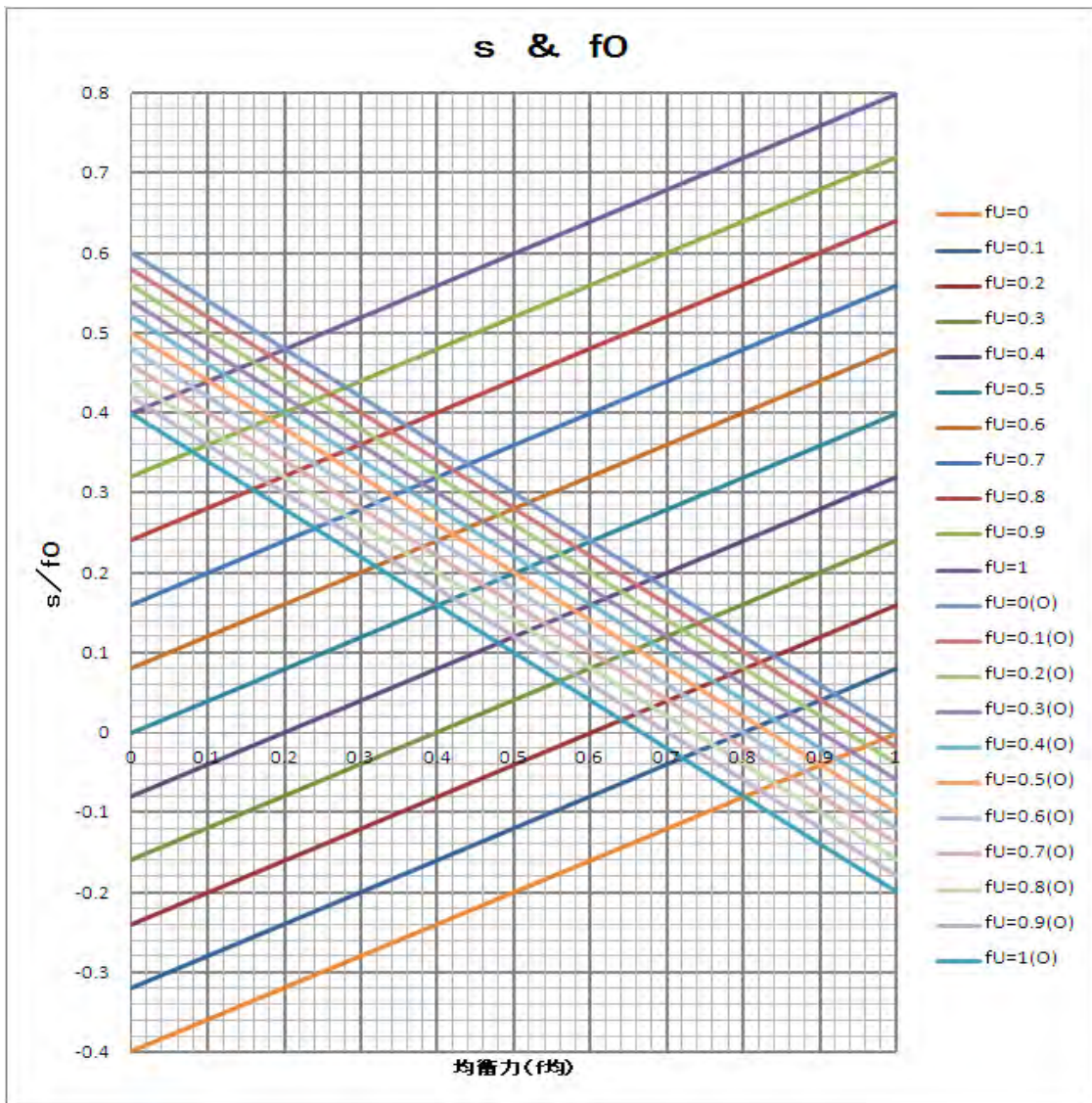


Fig. 3.-2 Pulling-up force ratio(s) and Operation buoyancy ratio(f_0)

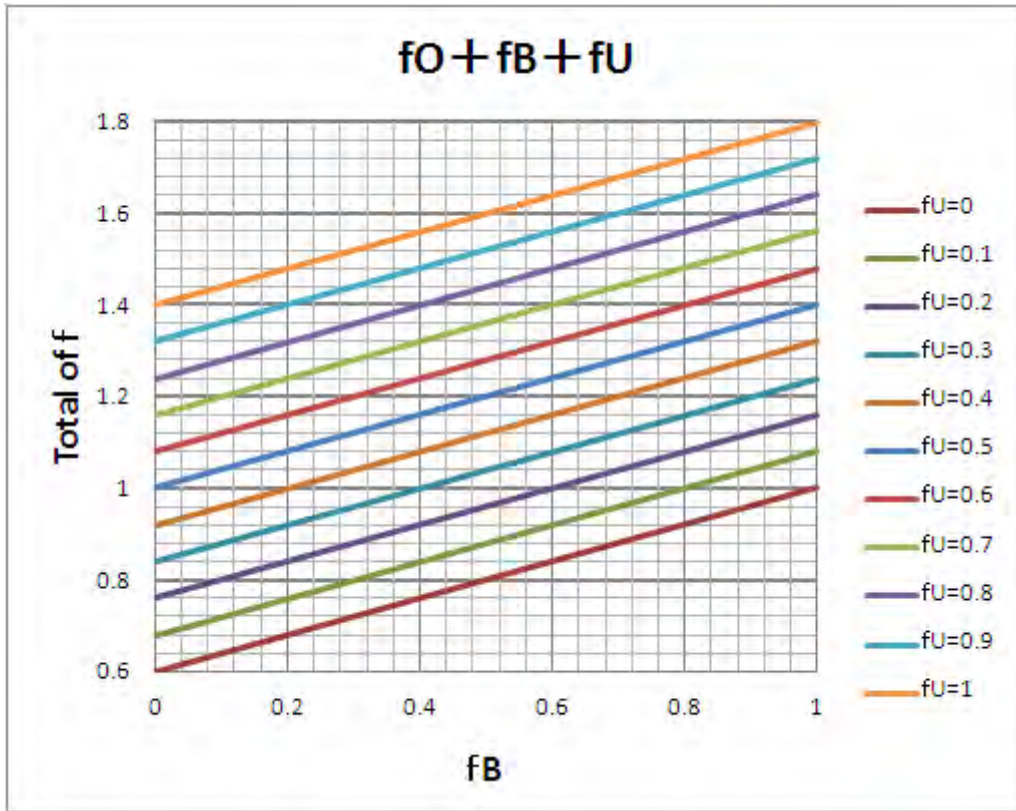


Fig. 3.-3 Buoyancy ratio total ($f_O + f_B + f_U$)

3.1.3 Tank volume

Table 3.-5 is a table of tank volume trial calculation. The f_U and f_B on the table are input data and the f_O and s are calculated results of formulas (3.-7) and (3.-8), and magnitude of forces acting on the gate body is computed by multiplying them by the gate weight W . The shoe load is the load supported by the shoe when the gate body mounts on bottom of water during swing operation and the operation buoyancy becomes less than the calculated magnitude, and the turnover safety ratio is a safety factor of avoiding the gate body turnover (the pulling-up force \div the shoe load). A calculated result which is nearest to the buoyancy selection conditions among all the trial ones is selected. A rough selection condition is as follows.

Buoyancy selection condition :

The pulling-up force S is not much less than 3000 tf.

The operation buoyancy is not extremely big (to keep the fill and exhaust air volume being less).

The turnover safety ratio is not less than 2 when the operation buoyancy = 0.

Fig. 3.-5 Trial calculation table of the tank buoyancy

Calculation case			Calculation table				Force acting on the gate body (tf)					
Name	Selected	No.	Input		Output		Upright buoyancy FU	Balance buoyancy FB	Operation buoyancy FO	Pulling-up force S	Shoe load	Turnover safety ratio
			f_U	f_B	f_O	s						
Trial 1	×	1	0.33	0.33	0.34	-0	2970	2970	3024	-36	3024	0.0
Trial 2	×	2	0.33	0.6	0.17	0.1	2970	5400	1566	936	1566	0.6
Trial 3	×	3	0.33	0.7	0.11	0.14	2970	6300	1026	1296	1026	1.3
Trial 4	×	4	0.5	0.7	0.08	0.28	4500	6300	720	2520	720	3.5
Trial 5	×	5	0.6	0.7	0.06	0.36	5400	6300	540	3240	540	6.0
Trial 6	○	6	0.6	0.6	0.12	0.32	5400	5400	1080	2880	1080	2.7
Trial 7	×	7	0.8	0.2	0.32	0.32	7200	1800	2880	2880	2880	1.0

Table 3.-6 shows selected tank volumes. Specific weight of water is assumed to be 1. The volume shown is just a bit differ from the selected case shown on Table 3.-5 since tank height has been replaced by a round number except the operation tank whose selected volume is more than twice of the selected case since this tank needs to have enough surplus buoyancy during the gate's swing operation and sinking installation. The surplus buoyancy during the sinking installation is indispensable also in keeping the gate body stability. Consequently the fill/discharge water volume at the swing operation has become 1126 ~ 2200 m³ and corresponding shoe load 0 ~ 1174 tf.

Tank name	Tank height (m)	Volume (m3)
Upright tank	5.9	5408
Balance tank	5.9	5408
Operation tank	2.4	2200

3.2 Forces on gate body and gate body inclination

Table 3.-7 shows forces on the gate body and gate body inclination at each work stage of the gate. Details of their calculation procedure are shown according to each work stage.

Table 3.-7 Forces and inclination of gate body

Gate work stage	Force acting on the gate body (tf)						Gate body inclination (degree)
	Upright buoyancy FU	Balance buoyancy FB	Operation buoyancy FO	Pulling-up force S	Shoe load	Turnover safty ratio	
Swing operation (removing)	5408	5408	1074	2890	0	-	0.37
Swing operation (bottm mounting)	5408	5408	1074	2890	1074	2.7	-
Maintenance (removing)	2200	4600	2200	0	0	-	2.08
Maintenance (sinking installation)	1800	5400	1800	0	0	-	0.13

3.2.1 Swing operation

3.2.1.1 When removing

【Upright buoyancy, balance buoyancy】

Data of Table 3.-6 are transcribed.

【Operation buoyancy, pulling-up force S】

Values of f_U and f_B are calculated based on F_U and F_B .

Input f_U and f_B into Table 3.-5, then f_O and s are output.

F_O and S are obtained by multiplying f_O and s by the gate weight W .

【Shoe load】

The gate is removing and there is no load on the shoe.

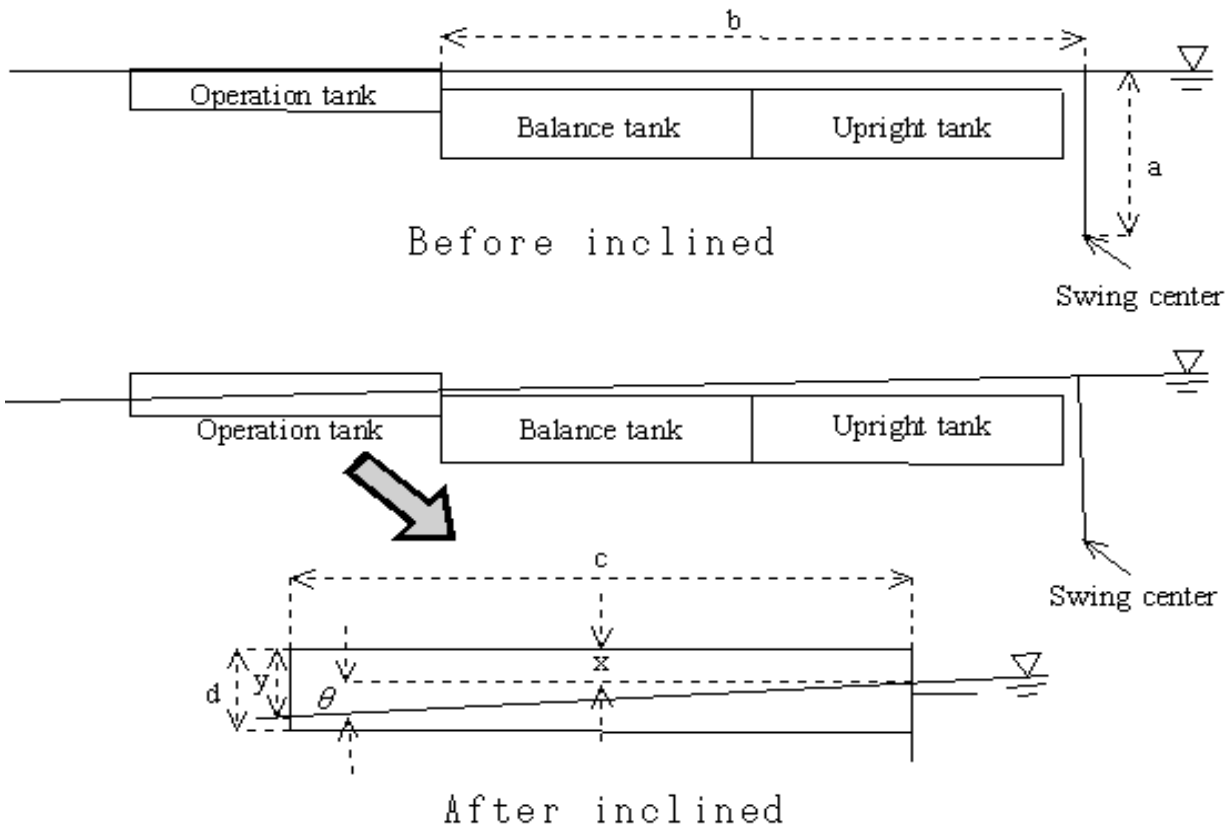
【Turnover safety ratio】

Not applicable.

【Inclination】

Fig. 3.-4 shows float tank arrangement of the concept design.

It is assumed that the balance tank and the upright tank always submerge and the gate inclination can be defined only by the operation tank buoyancy.



Float tank arrangement

Fig. 3.-4 Float tank arrangement

Derivation of inclination formula.

Specific weight is assumed to be 1. Below formulas are obtained from the figure.

$$x = \sqrt{b^2 - a^2 \tan^2(\theta)}$$

$$y = (b + c) - a \tan(\theta) - \sqrt{(b + c)^2 - a^2 \tan^2(\theta)}$$

$$\text{Operation tank buoyancy} = V = \{(d - x) + (d - y)\} \times l \times c \div 2$$

where l is tank width.

Following inclination formula is obtained from above three formulas.

$$a^2 \tan^2(\theta) - (c \div 2 + b) \times d - V \div (c \times l) = 0 \quad \dots\dots (3.-10)$$

3.2.1.2 When bottom mounting

The bottom mounting means that a free end of gate body at its completely closed position arrives at bottom of water due to disposal of the surplus buoyancy.

【Upright buoyancy, balance buoyancy】

Same to 3 . 2 . 1 . 1 (removing).

【Operation buoyancy, pulling-up force S】

Same to 3 . 2 . 1 . 1 (removing).

The operation buoyancy corresponds to the filling water to the tank of 1126 m³ (zero when the filling water is 2200 m³).

【Shoe load】

The shoe load corresponds to the filling water to the operation tank of 2200 m³ (zero when the filling water is 1126 m³).

【Turnover safety ratio】

The safety ratio = the pulling-up force S ÷ the shoe load

The turnover moment = the shoe load x vertical distance between the shoe and the gate gravity center.

The upright moment = the pulling-up force S x vertical distance between S working point and the gate gravity center.

The vertical distance between the shoe and the gravity center = the vertical distance between S working point and the gravity center.

【Inclination】

Inclination is 0 for the bottom mounting.

3 . 2 . 2 Maintenance

3 . 2 . 2 . 1 When removing

【Upright buoyancy, balance buoyancy】

Results calculated at **【Inclination】** are transcribed.

【Operation buoyancy, pulling-up force S】

The operation buoyancy calculated at **【Inclination】** are transcribed.

S = 0 is set.

【Shoe load】

The gate is removing and there is no load on the shoe.

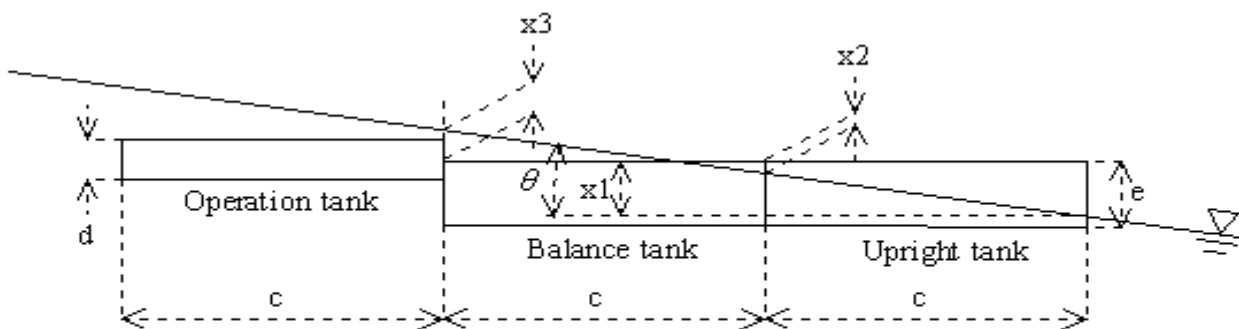
【Turnover safety ratio】

Not applicable.

【Inclination】

Fig. 3.-5 shows float tank arrangement of the concept design.

It is assumed that the operation tank always submerges and the gate inclination can be defined by the buoyancy of the balance tank and the upright tank.



Float tank arrangement

Fig. 3.-5 Float tank arrangement

Compatibility condition to the tank arrangement : Specific weight of water is assumed to be 1 . Below formulas are gotten from to the figure.

$$F_0 = d \times l \times c \quad \text{where } l \text{ is tank width.}$$

$$F_B = \{ e - x_2^2 \div [2 (x_2 - x_3)] \} \times l \times c$$

$$F_U = \{ e - (x_2 + x_1) \div 2 \} \times l \times c$$

$$x_2 = x_3 + c \times \sin(\theta)$$

$$x_1 = x_3 + 2 c \times \sin(\theta)$$

Equivalence condition : Formula (3.-1) is modified by $S = 0$ and formula (3.-2) is applied without any change. In short,

$$F_0 + F_B + F_U = W$$

$$F_{Ox} 5 + F_{Bx} 3 + F_{Ux} = Wx 3$$

Inclination formula : Below formula is obtained by eliminating x_1 , x_2 , and, x_3 from formulas of and .

$$(c x \sin(\))^2 \div 4 - (3 d + 3 e - 2 W \div l \div c) c x \sin(\) + (e - d)^2 = 0 \dots \dots (3.-11)$$

Fig. 3.-6 shows a solution of formula (3.-11). Although exposure of a shaded area of the operation tank above water surface conflicts with the assumption, it is taken no account since the area occupies only 2.4 % of the tank volume.



Fig. 3.-6 Solution of formula (3.-11)

Tank buoyancy : Following approximate values are obtained by inserting the solution of formula (3.-11) into the formulas of .

Operation buoyancy : $F_O = 2200$ tf

Balance buoyancy ; $F_B = 4600$ tf

Upright buoyancy : $F_U = 2200$ tf

3 . 2 . 2 . 2 When sinking installation

The sinking installation is a working stage that the gate body support end sinks up to bottom of water so that the key (at the gate body end) of the gate end support key may be inserted into the key support (water bottom side).

【Upright buoyancy, balance buoyancy】

The balance buoyancy is a designated value.

The upright buoyancy is determined by making a simulation on the tank buoyancy trial calculation table (table 3.-5).

The object value of the simulation is the pulling-up force $S = 0$.

【Operation buoyancy, pulling-up force S 】

The operation buoyancy is a result of above simulation.

The pulling-up force S is an object value of above simulation.

Fig. 3.-7 is a float tank arrangement which shows buoyancy distribution and dimension marks necessary to calculate the gate inclination.

The pulling-up force shall have minus value with additional filling water of the upright tank when the gate end support key is at set-up stage.

The upright buoyancy is 0 tf, the operation buoyancy is 2160 tf, and, the pulling-up force S is -1440 tf when the additional filling water of the upright tank is 1800 tf.

【Shoe load】

No shoe load is working.

【Turnover safety ratio】

Not applicable.

【Inclination】

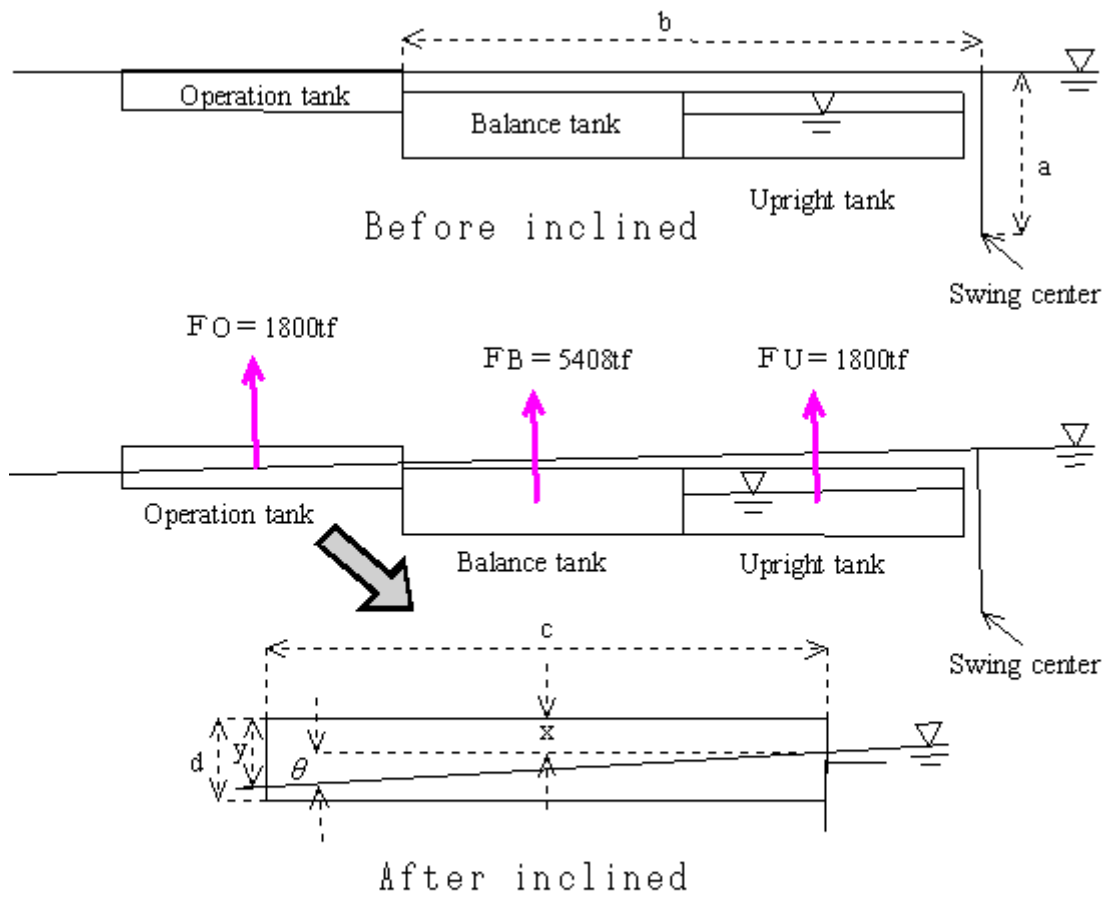
It is assumed that the balance tank and the upright tank always submerge and the gate inclination can be defined only by the operation tank buoyancy.

Inclination angle for the upright buoyancy 1800 tf is a solution of the formula (3.-10) with V of 1800 m³.

The solution above is 0.13 degree, and the mean freeboard is 44 cm.

Inclination angle for the upright buoyancy 0 tf is a solution of the formula (3.-10) with V of 2160 m³.

The solution above is 0.013 degree, and the mean freeboard is 4.4 cm.



Float tank arrangement

Fig. 3.-7 Float tank arrangement

4 . Operation condition

The proposed gate type is fundamentally operated in calm sea. A possibility of losing a chance of gate operation in calm condition due to information troubles, human errors, traffic jams, equipment troubles, power source breakdown or other incidental reasons cannot be actually denied and it is necessary to study a way of responding such case. A feasibility study on the gate operation with the assistance of tidal flow is made in this section.

4 . 1 Side thruster control limits

Table 4.-1 shows tide differences and water velocities that side thrusters on the gate body can control. The case 5 on the table corresponds to a tide difference of 1 m (most popular case) and is shown just for a comparison.

Table 4.-1 Control limit of a side thruster

Side thruster				Control limit	
Case No.	Thrust tf	Installed	Total thrust	Tide dif. cm	V. cm/s
1	40	1	40	2.2	66.0
2	50	1	50	2.8	73.8
3	40	2	80	4.4	93.3
4	50	2	100	5.6	104.3
5(for ref.)	50	36	1800	100.0	442.7

4 . 2 Gate operation with the aids of tidal flow

(1) Open operation by the port side high tide (Idea 1)

Advance preparation:

1) A gate levitation prevent apparatus is set on after the gate is closed.

2) Appropriate buoyancy is given to the operation tank by air filling. The port side tide pushes the gate when the sea side becomes less. The gate body sets off the levitation prevent apparatus and levitates. The gate body is opened completely by the port side pushing.

(2) Closing operation by the sea side high tide (Idea 2)

Remove the gate body to the gate's bottom mounting location with the aid of side thrusters.

Adjust the operating buoyancy to the preset value and let the gate mount on the water bottom.

The sea side pressure pushes the gate toward its closing direction (the gate body tip speed has to be less than a limiting value).

Remarks:

1) Energy dissipation rate is adjustable by the volume of operation buoyancy, the side thrusters etc.

The gate arrives at its closed position.

Confirm that the gate tip is at its right position.

Exhaust the operation buoyancy.

Shut down the side thrusters.

Actions after the gate is completely closed:

1) A gate levitation prevent apparatus is set on.

2) Appropriate buoyancy is given to the operation tank by air filling.

(3) Observations on the possibility of ideas

The gate keeps uprightness with the aids of the pulling-up force.*2

Possibility of Idea 1: It is feasible.

Possibility of Idea 2: It is feasible.*3

Following items are to be carried out at each project stage.

1) Prototype hydraulic experiments with the assistance of model tests.

2) Preparation of an operation manual.

*2Attached material 1: Inclination angle of the gate body.

*3Attached material: Power of impact on the gate body.

5 . Conclusion

Following conclusions have been obtained according to the study results mentioned in foregoing chapters.

(1) There is a possibility of a big cost reduction in realizing the swing type super large torsion gate.

(2) Gate operations are made by float tanks and side thrusters (tug-boats are also useful).

(3) The gate body uprightness is kept by the pulling-up force support which are in condition of free in triaxial rotations and constrained in triaxial removes.

(4) The gate body stability is supported by the pulling-up force except the maintenance time when it accords to a stability theory of ships and is most critical during the sinking installation.

(5) there is a possibility of gate operation with the aids of tidal flow.