

Super Large Torsion Type Gate

Emerging Type

TeraMatsu

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1. Introduction

As a torsion type structure is superior in its weight than any other structures such as a bending structure and the larger its scale becomes the more remarkable its superiority will be, it is conceivable that an application of the torsion type structure to a super large storm surge barrier gate will be very advantageous.

Table 1.-1 shows operation types of super large gates to which torsion type structures can be applied. The column shows directions of gate operation. Parallel movements are classified into flow direction, horizontal direction which is at right angles to the flow direction and vertical direction which is at right angles to other directions and rotational movements are classified into around flow axis, around horizontal axis which is at right angles to the flow axis and around vertical axis which is at right angles to other axis. The column shows possibility of torsion type structure application. The line 1 and the line 4 are impossible that is because a gate of the line 1 is very difficult to operate and gate operation around flow axis of the line 4 is not realistic for a gate having a few hundred meters width. The column shows candidates of a technical proposal. The line 5 is flap type which belongs to prior art. The column shows new technologies realizing a super large torsion type structure gate. The rolling type and the swing type in the column had already been

Table 1.-1 Operation type of super large torsion type gate

No.	① Operation mode		② Torsion type		③ Possibility of proposal	④ Name of technical proposal
	Movement	Direction	Possibility	Reason		
1	Parallel movement	Flow direction	×	Not operable	—	—
2		Horizontal	○		○	Rolling type
3		Vertical	○		○	Emerging type
4	Rotational movement	Flow axis	×	Not realistic	—	—
5		Horizontal axis	○		Prior art	—
6		Vertical axis	○		○	Swing type

studied and feasibility study of the emergency type is a purpose of this report.

Emerging type is a gate which removes vertically from a storage space provided in an excavated sea bottom, emerges from the sea and is further rising until it closes waterway space, and which has many practical and proposed examples (for instance, Saint Petersburg storm barrier, sluice gates on Mississippi river, Deep Draft Lock Plan of the Panama canal etc.). But the gates employed in these examples are bending type and purpose of this technical proposal is to reduce their construction cost by adopting torsion type in stead of a bending type and to realize further growing in their size economically.

Problems to be solved in the torsion type structure application to the emerging type are as following.

Cross-sectional restriction which can correspond to both storm surge pressure and tide flow pressure is required.

There are two states of gate body motion, i.e. a state of floating body and a state of submerged body.

Spatial interference between components of the cross-sectional restriction block.

1)Interference between restriction metals on a concrete wall (support brackets, wedges) and restriction metals on a gate body (reaction axles, wedges).

2)Interference between restriction metals on a concrete wall (support brackets) and a bottom seal rubber.

3)Interference between a concrete wall sealing sill (bottom seal rubber sill) and reaction rollers.

Sliding in stem direction of P type side seal rubber.

In this report, detail explanation of the problems is presented first, then means of solving the problems are explained on the two concept designs, and finally explanation on detail portion of the concept designs are presented including gate body stress half cutting method. Report structure is as follows.

- (1)Explanation on problems
- (2)Concept designs
- (3)Detail explanation on the concept designs

Following conclusions were obtained based on the study.

- (1)Emerging type super large torsion type gate is feasible.
- (2)It is believed that a big amount of cost reduction is possible by adopting an emerging type super large torsion type gate.
- (3) Strength examination of the support bracket anchor will be required at construction stage.

2 . Problems to be solved in the concept designs

2 . 1 Cross-sectional restriction

The torsion structure is characterized by (1) a thin wall closed cross-section and (2) a cross-sectional restriction. The cross-sectional restriction is a state of a gate body section restricted at a point whose restriction condition is parallel displacement restricted and rotational movement free. A storm barrier gate endures high tide pressure of hurricanes and is subject to tide flow pressure during its opening and closure operation. The restriction point is a reaction point of those loads. As the quality of the loads is prominently different from each other, duplicate cross-sectional restrictions will be required with gate size growing. Difference of their loading conditions is as follows.

(1) Loading conditions of high tide pressure

The load magnitude is dominantly big compared to the tide flow .

The load works on the gate of completely closed condition.

The load acts only from a sea side.

(2) Loading conditions of tide flow pressure

The load magnitude is dominantly small compared to the high tide.

The load works on the gate at all gate position during gate operation.

The load acts not only from a sea side but also from a port side.

2 . 2 A state of floating body and a state of submerged body

Existing emerging type gate are hoisted mechanically. In this case, a gate is only a heavy cargo and neither a floating body nor a submerged body. In case of a super large gate with a few hundred meters width, gate operation by floating tanks will become necessary. Accordingly, there exist states of a floating body and a submerged body whose stability mechanisms are completely different. In the description from right now, definition of both states are simply recognized as follows. The case that float tank is 100 % submerged is "state of submerged body" and the case that float tank is totally or partially emerges from the water is "state of floating body" where the float tank buoyancy equals the gate weight. Displacement of gate body steel member including ballast weight is not considered. Stability mechanism is completely different between both states. In the state of floating body, buoyancy and dead weight of a gate body are equal, but in the state of submerged body, a gate is getting

higher or lower and it is difficult for the gate to keep a rest state.

2.3 Spatial interference in cross-sectional restriction block

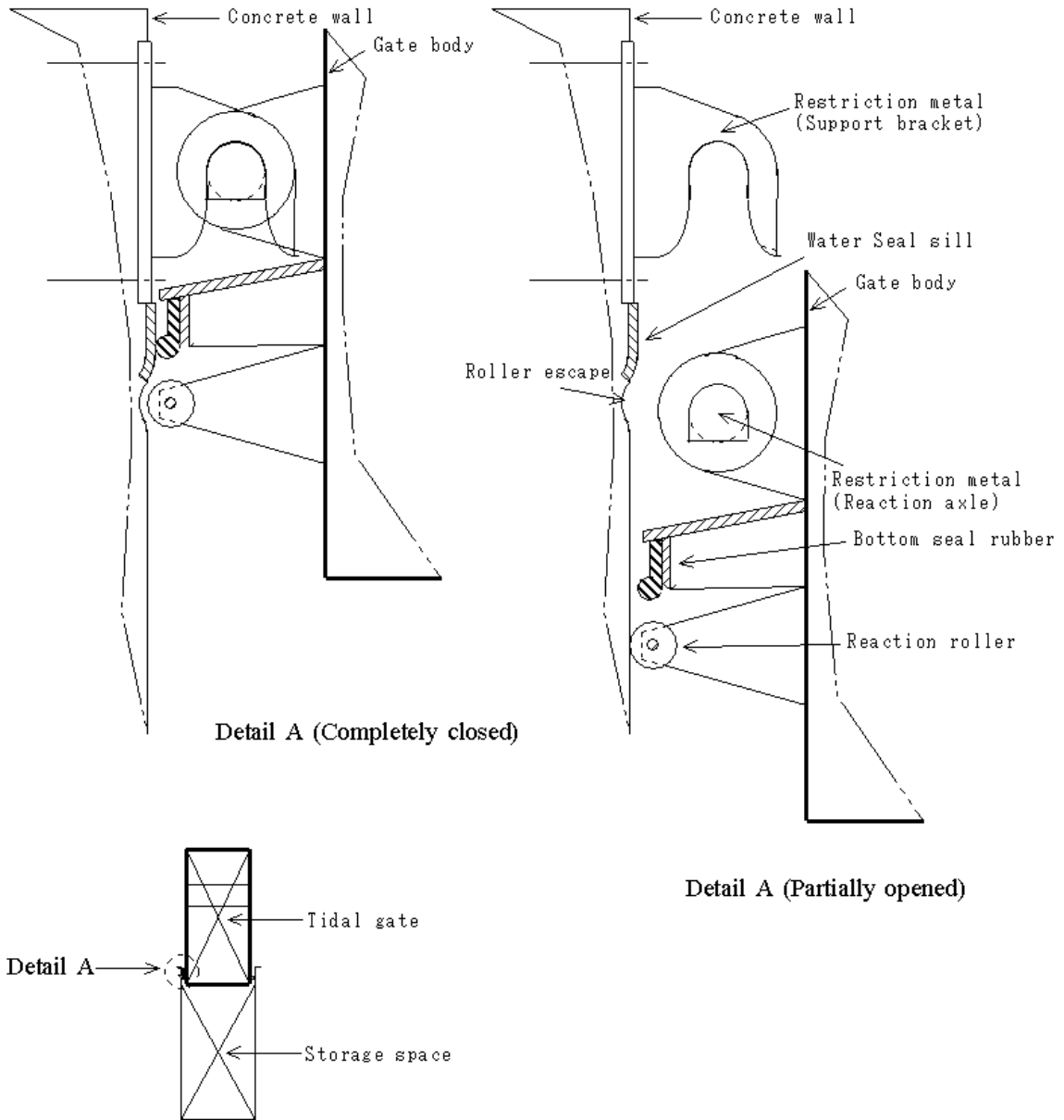


Fig. 2.-1 Cross-sectional restriction block

Fig. 2.-1 shows the cross-sectional restriction block. The restriction block includes mechanisms of the cross-sectional restriction and the bottom sealing. Section (Completely closed) shows gate body and storage space, and place of Detail A where the restriction block exists. Detail A (Completely closed) shows a gate body completely closed and Detail A (partially opened) shows a gate body partially opened. There are a restriction metal (Support bracket), a seal sill for a bottom seal rubber and a roller escape on the concrete wall. A restriction metal (Reaction axle), a bottom seal rubber and a reaction roller set on the gate body partially opened rise with the gate body and the reaction axle will mate to the support bracket and the seal rubber will mount the seal sill, and the gate bottom supporting and water sealing will finish up. The reaction roller works as a reaction point of the tide flow pressure acting on the gate body during its rising and will complete this role by resting on the roller escape when the gate is completely closed.

2 . 3 . 1 Interference of restriction metals

Although restriction metals on a concrete wall and a gate body will work without any interference as shown on Fig. 2.-1 during daily gate operation, gate descending and rising in a gate slot will be blocked by their spatial interference when the gate is inserted into or taken out from the gate slot during construction or maintenance period.

2 . 3 . 2 Interference of a restriction metal and a bottom seal

Although a restriction metal on a concrete wall (support bracket) and a bottom seal rubber on a gate body will work without any interference as shown on Fig. 2.-1 during daily gate operation, gate descending and rising in a gate slot will be blocked by their spatial interference when the gate is inserted into or taken out from the gate slot during construction or maintenance period.

2 . 3 . 3 Interference of a sealing sill and a reaction roller.

Although a sealing sill on a concrete wall (bottom seal rubber sill) and a reaction roller on a gate body will work without any interference as shown on Fig. 2.-1 during daily gate operation, gate descending and rising in a gate slot will be blocked by their spatial interference when the gate is inserted into or taken out from the gate slot during construction or maintenance period.

2.4 Sliding in stem direction of P type side seal rubber

Fig. 2.-2 shows sliding direction of a P type side seal rubber on a sill. The P type rubber bolted on a gate body by a clamp bar comprises a bulb and a stem. The figure shows four sliding directions in bulb and stem directions. Sliding direction of the rubber during gate operation is in bulb direction and will work without any trouble. Sliding in stem direction of the rubber will be necessary when the gate is inserted into or taken out from a gate slot during construction or maintenance period and the sliding direction with \times mark on the figure will decrease the seal life time eminently since the bulb is pinched between the clamp bar and the sill.

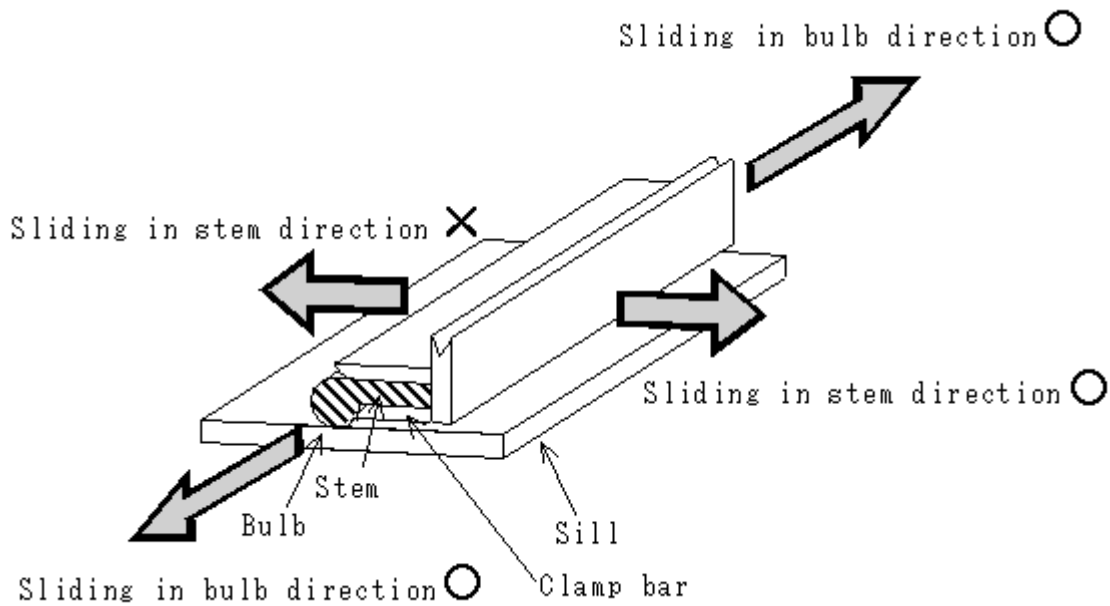


Fig. 2.-2 Sliding direction of P type seal rubber

3 . Concept designs

The purpose of concept design is a feasibility study of the proposed gate type. There can be many other cases besides the one being shown.

3 . 1 Design data

Table 2.-1 Design 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		
	Tide def.	5		
	Freeboard	2		
Steel weight (rough estimation)	Gate leaf	18000	tf	
	Embedded part	1500		
	Machine	500		
	Toral	20000		
Gravity center	Horizontal	18.75	m	From the gate center
	Vertical	11		Gate height center

Table 2.-2 Condition of gate operation

Condition	Unit	Condition 1	Condition 2	Condition 3
Operation velocity	m/sec	1.00	1.30	1.60
	kt	1.94	2.53	3.11

Table 2.-1 and Table 2.-2 show design data and condition of gate operation which are basic data of the concept design. For the hydraulic condition on Table 2.-1, ordinary water height is given in the form of site depth and high tide water level is given as a tide difference (=5 m). In short, the port side depth is 16 m and the sea side depth is 21 m at high tide. Tide level is always moving and the port side level at construction, maintenance, gate operation or high tide cannot be constant. Nevertheless it is assumed because of a simplification that the port side sea level is constant and can be defined as site depth since the purpose of this study is feasibility

confirmation. In this report the site depth is sometimes called as site water level. The steel weight in the table is rough estimate. Opening and closure operation study has been made on the condition 3 of Table 2.-2.

3 . 2 General arrangement

Fig. 3.-1 and Fig. 3.-2 show general arrangements of two examples. Parts common to them are gate operation by floating tanks, a center divided gate body and one end support of the divided body, and a different part is closing method of an interval between a gate body and a concrete wall to complete gate side sealing. Fig. 3.-1 shows fixed side sealing and Fig. 3.-2 shows openable side sealing.

The general arrangement consists of a total arrangement, a tank arrangement and support and sealing mechanisms. The total arrangement and the tank arrangement of the two examples are exactly same and only a small difference exists at their support and sealing mechanisms.

3 . 2 . 1 Total arrangement

The total arrangement of the two examples is exactly same. It consists of Plan (completely closed state and completely opened state) and Section (completely closed state and completely opened state) whose both end sections follow it. The Plan A indicates a tidal gate, an interval gate and a side roller block. The Section A and B indicate a tidal gate and an interval gate and the Section A also indicates a storage space. Further the Section A indicates a watertight bulkhead, cross-sectional restrictions and a bottom roller on the tidal gate and a bottom roller mounting and a side roller guide at the storage space. And, the right end sections of the Section A and B indicate coupling wedges.

3 . 2 . 2 Tank arrangement and gate body inclination

The tank arrangement and gate body inclination of the two examples is exactly same. Gate weight including ballast equals 10061tf. The tank arrangement includes Left balance tank, Right balance tank and Descending tank. A buoyancy center of the balance tank conforms to the gate body gravity center including ballast and total buoyancy of them is just a bit bigger than the gate weight. Descending tank is located in Right balance tank and its center conforms to the gate gravity center. A buoyancy volume of the balance tank subtracted by Descending tank is just a bit smaller than the gate weight. Roof height of the balance tank conforms to the site water level (refer to Section A). Gate operation at working condition is made in the state of submerged body. The operation is made by pouring/discharging water into or from Descending tank. The states of the gate body inclination shown are submerged body (rising case), submerged body (descending case) and floating body. Buoyancy and gate body inclination of the three states are as following (Problem 2 . 2 State of floating body and state of submerged body).

【Submerged body state–descending】

Left balance tank = 4163 tf (Buoyancy)

Right balance tank = 6098 tf (Buoyancy)

Descending tank = -403tf (Filled)

Total buoyancy = 4163 + 6098 - 403 = 9858 tf

Dead weight = 10061 tf

Descending force = 10061 - 9858 = 203 tf

Inclination due to a difference between a roller friction force center and a gravity center = 0.51 ° (Counter clock–wise)

【Submerged body state–rising】

Left balance tank = 4163tf (Buoyancy)

Right balance tank = 6098tf (Buoyancy)

Descending tank = 0 tf (Empty)

Total buoyancy = 4163 + 6098 - 0 = 10261 tf

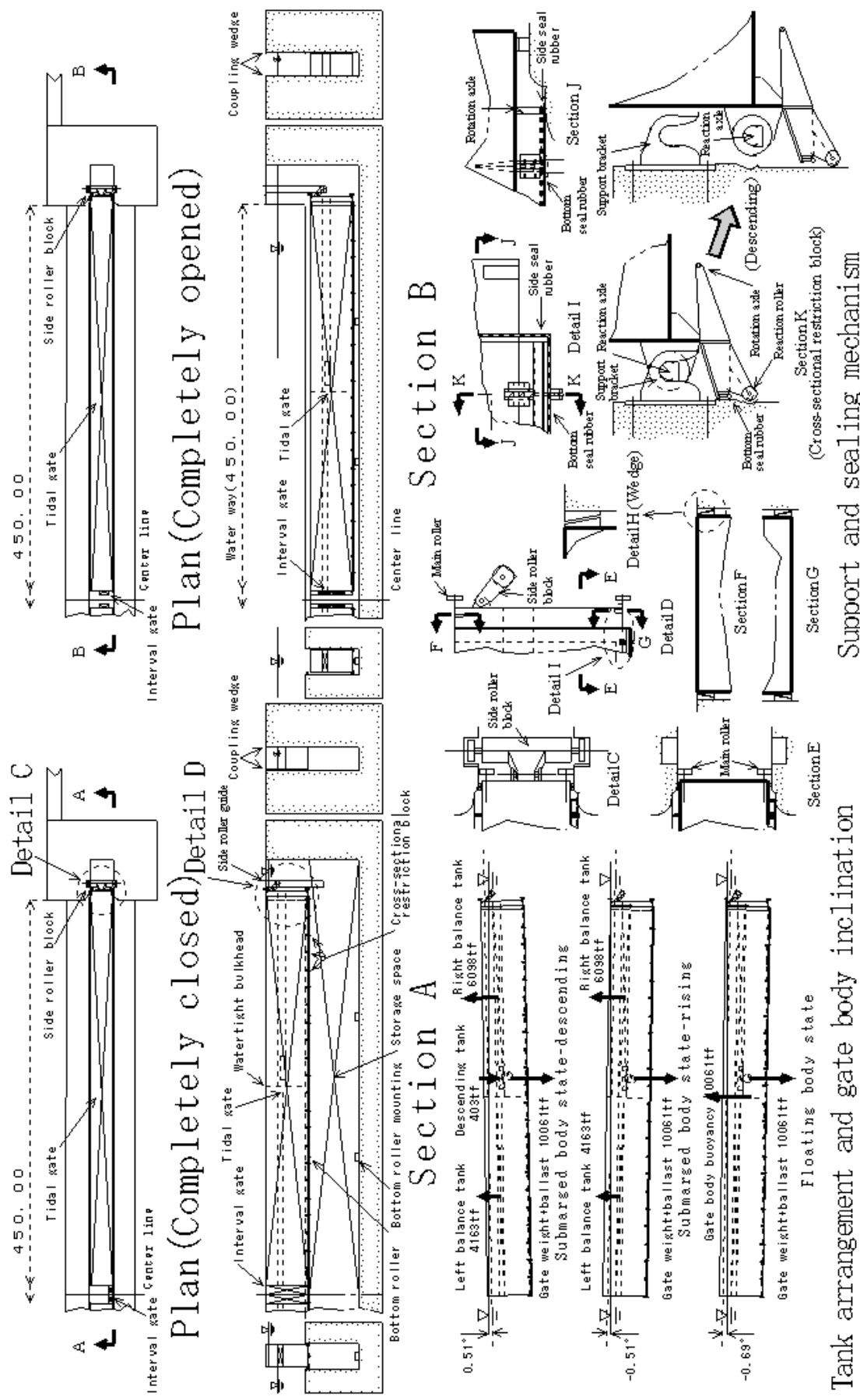


Fig. 3.-2 General arrangement (Side seal openable)

Dead weight = 10061 tf

Rising force = 10261 – 10061 = 200 tf

Inclination due to a difference between a roller friction force center and a gravity center = -0.51 ° (Clock-wise)

【Floating body state】

Gate body buoyancy = 10061 tf

Dead weight = 10061 tf

Inclination due to a difference between a buoyancy center and a dead weight center = -0.69 ° (Clock-wise)

3 . 2 . 3 Support and sealing mechanism

Two examples are exactly same except side sealing mechanism. Explanation is given separately to a common part and to side sealing mechanism.

【Common part】

Detail C and D shown on Plan (Completely closed) and Section A are entries of the Support and sealing mechanism. Detail C and D indicate a side roller block, Detail D and Section E indicate main rollers and Section F and G and Detail H indicate coupling wedges. Section I and J indicate a bottom seal rubber and a side seal rubber. Section K shows a cross-sectional restriction block with the gate at completely closed position and with the gate during descending. The block consists of a support bracket, a reaction axle, a reaction roller and a bottom seal rubber.

High tide pressure working on a completely closed gate body is supported by a support bracket and a reaction axle shown on Section K and remaining torsional moment in the gate body is carried to the gate end through torsional rigidity of the gate section and balances a coupling force working on wedges shown on Section F and G and Detail H. Tide flow pressure working on the gate body during opening and closure operation is supported by a reaction roller shown on Section K and remaining torsional moment in the gate body is carried to the gate end through torsional rigidity of the gate section and balance a coupling force working on main wheels shown on Detail D and Section E (Problem 2 . 1 Cross-sectional restriction).

A side roller block shown on Detail C and D is joined to the gate body by an axle and spatial interference between a support bracket and a reaction axle of Section K during gate operation in construction or maintenance period is evaded by a change of gate position in a gate slot through the block rotation around the axle

(Problem 2 . 3 . 1 Interference between restriction metals). A bottom seal rubber and a reaction roller shown on Section K are integral structure and spatial interference between a support bracket and a bottom seal rubber of Section K during gate operation in construction or maintenance period is evaded (Problem 2 . 3 . 2 Interference between restriction metals and a bottom seal) and spatial interference between a seal sill of Fig. 2.-1 and a reaction roller of Section K during gate operation in construction or maintenance period is evaded (Problem 2 . 3 . 3 Interference between a sealing sill and reaction rollers) by storing the bottom seal rubber and the reaction roller together under the gate body bottom through their rotation by 90 degree around the rotation axle shown on Section K.

【Side sealing mechanism】

A side seal rubber shown on Detail I and Detail J of Fig. 3.-1 (Side seal fixed) is fixed on the gate body whereas these of Fig. 3.-2 (Side seal openable) is joined to the gate body by axles and seal rubber sliding in stem direction marked by × on Fig. 2.-2 during gate operation in construction or maintenance period is evaded by opening or closing an interval between a gate body and a concrete wall by the side seal rubber rotation around the axles (Problem 2 . 4 Sliding in stem direction of P type side seal rubber). In case of the side seal fixed, this problem is resolved by a gate operation steps during construction or maintenance period.

4 . Detail explanation on the concept designs

Detail items of the concept designs presented in the previous chapter are explained.

4 . 1 Total arrangement

4 . 1 . 1 Ballast

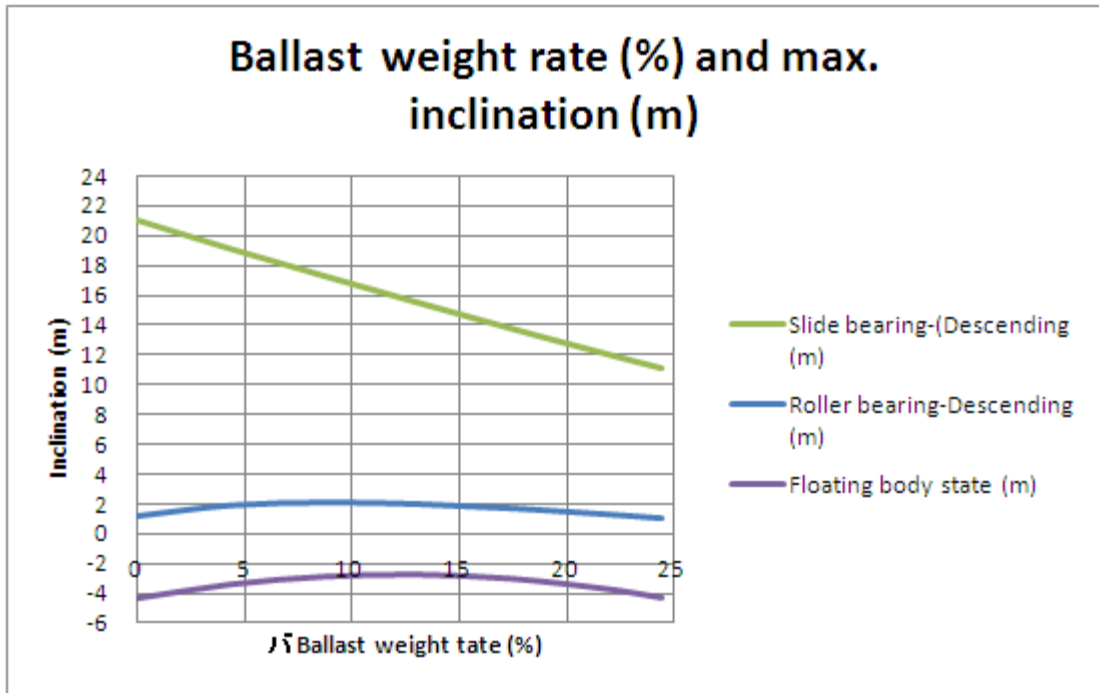


Fig. 4.-1 Ballast weight (%) and max. gate inclination (m)

As a gravity center of torsion type structures exists on a support end side and the gap between the center and a structure center is not small, a certain amount of steel ballast is loaded on a gate body to decrease inclination of the gate in floating body state. Nevertheless, impact of roller friction on the gate inclination is small since gate stability in floating body state is extremely big. Required quantity of the ballast is calculated according to following conditions.

Loading place: Full width of gate body bottom on un-support end side.

Ballast height: **0.1 m**

Ballast weight rate (%) is so determined that gate body inclination may become minimum.

$$(\text{Ballast weight rate (\%)} = \text{ballast weight} \div \text{gate steel weight} \times 100)$$

Ballast specific weigh : **7.85**

Fig. 4.-1 shows max. inclination (= an unsupported end draft – a supported end draft) of the gate body versus the ballast weight rate. Following results are obtained from the figure. Displacement of the gate body steel and the ballast is not counted in the calculation.

• Minimum inclination ballast rate of gate in floating body state = 12 %

• Ballast volume = 135 m³

• Loading length = 108 m

• Ballast weight = 1060 tf

4 . 1 . 2 Max. torsional moment and structural deformation

4 . 1 . 2 . 1 Maximum torsional moment

Since torsion moment composed by gate body buoyancy to keep the gate at completely closed position and reaction force of reaction axles is working on the gate body, the maximum torsion moment working on the gate body is a sum of high tide torsion moment and the buoyancy torsion moment. Fig. 4.-2 shows an increase of the torsion moment due to the buoyancy. "Design value" shown in the figure title is a magnitude of the high tide torsion moment corresponding to the designed high tide (i.e. 5 m) and magnitudes of the high tide torsion moment, the buoyancy torsion moment and a sum of them are divided by the design value and their increasing status versus the sea side depth increase is given on the figure in % where the design value is 100 %. An increase of torsion moment due to the buoyancy is around 7 %. The reduced torsion moment rate also shown on the figure is of the case that support brackets and reaction axles (cross-sectional restriction points) are arranged on the sea side as shown on Fig. 4.-3 and around 7 % of moment reduction is anticipated since buoyancy torsion moment in this case has a reverse sign and reduction effect on the sum will appear.

Fig. 4.-3 shows cross-sectional restriction point arrangement which can reduce the torsion moment through a reverse sign torsion moment of the buoyancy. Essential points of the arrangement are as follows.

Support brackets and reaction axles (cross-sectional restriction

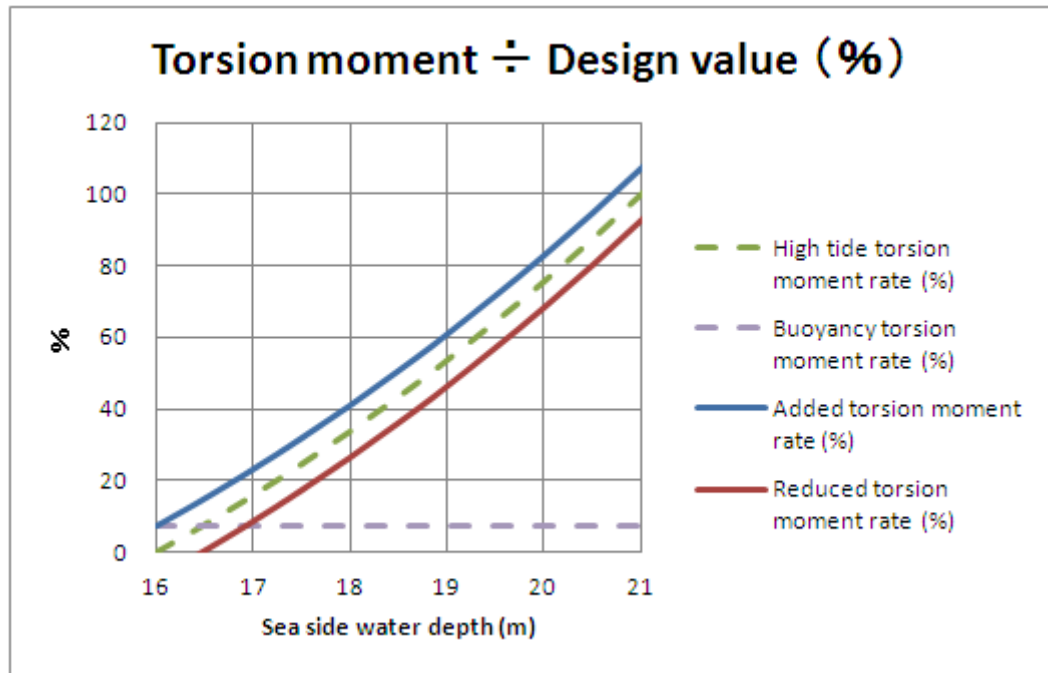


Fig. 4.-2 Torsion moment increase due to gate body buoyancy

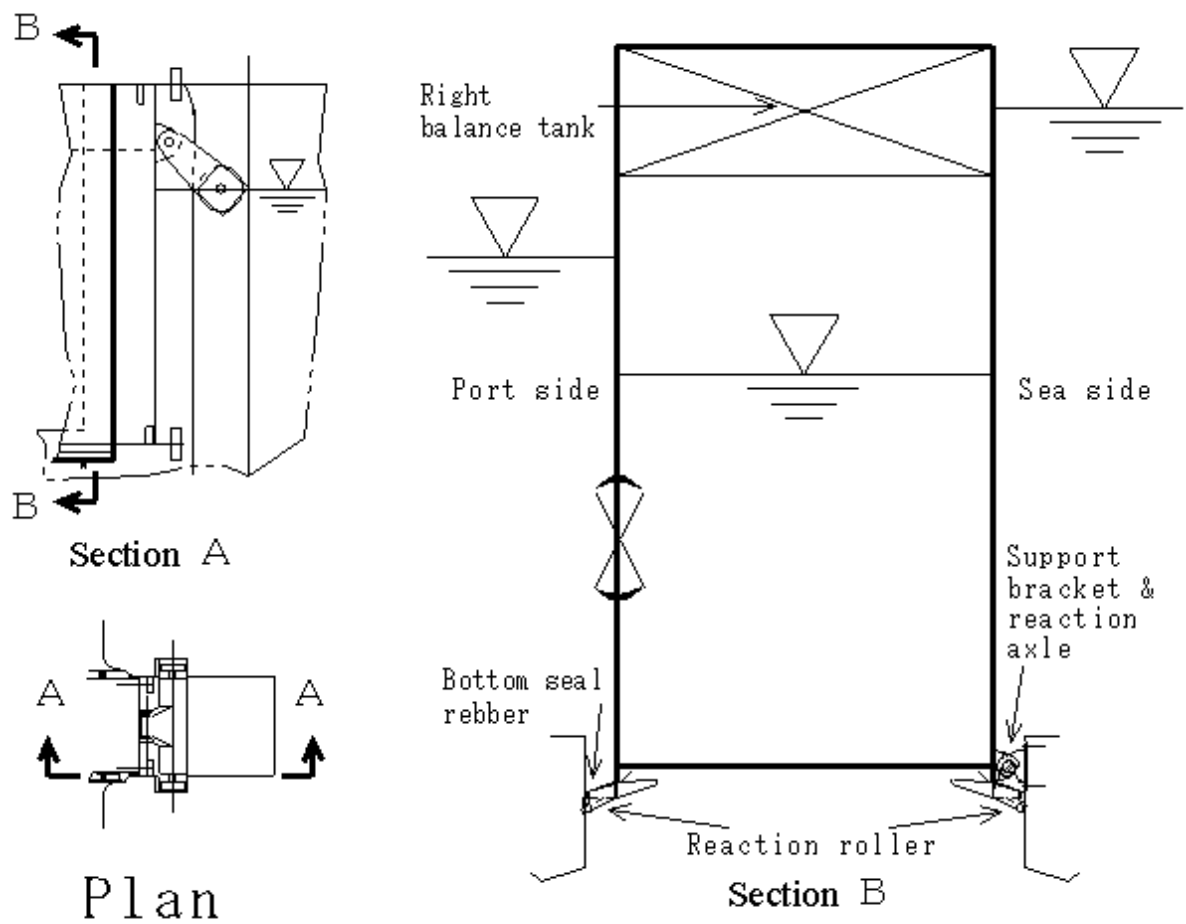


Fig. 4.-3 Cross-sectional restriction for torsion moment reduction

points) are arranged on the sea side.

Balance tank top height conforms to the gate body top.

Bottom seal rubber and Reaction roller arrangement is same as the concept design.

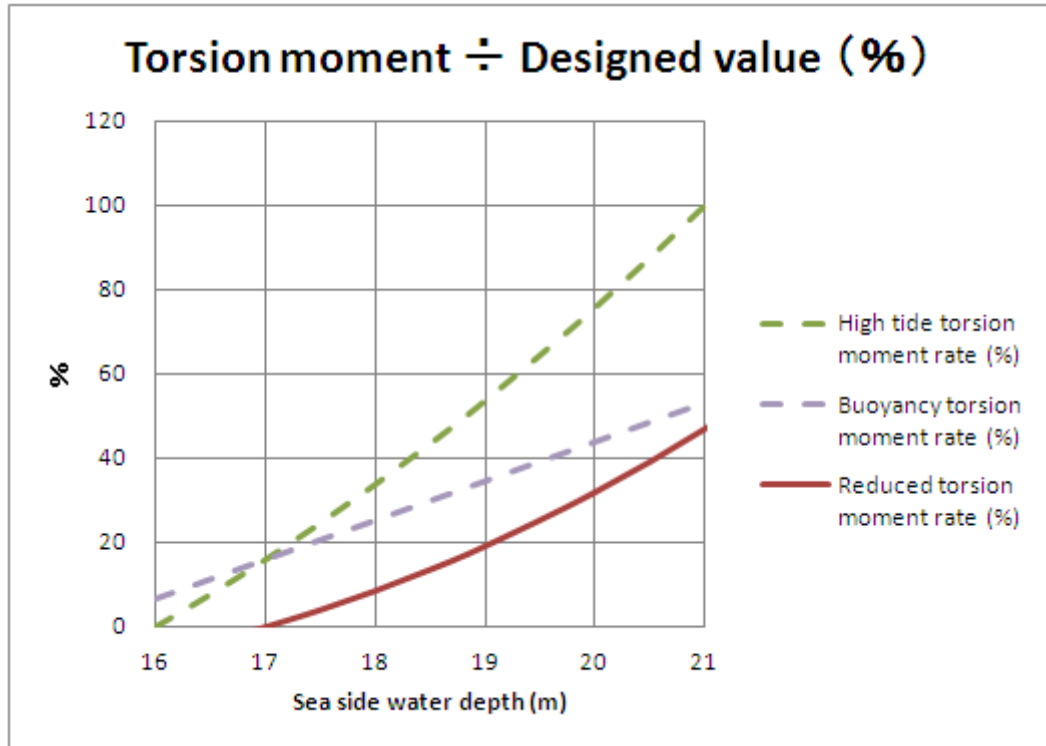


Fig. 4.-4 Effect of cross-sectional restriction point alternative

Fig. 4.-4 shows a result of cross-sectional restriction point arrangement alternative which can reduce torsion moment of the gate body through the use of the buoyancy. **53 %** reduction of the moment at the high tide can be expected. Although concrete wall cost may increase, a big cost merit dose not change. Calculation method of Fig. 4.-2 is shown in Appendix 1.

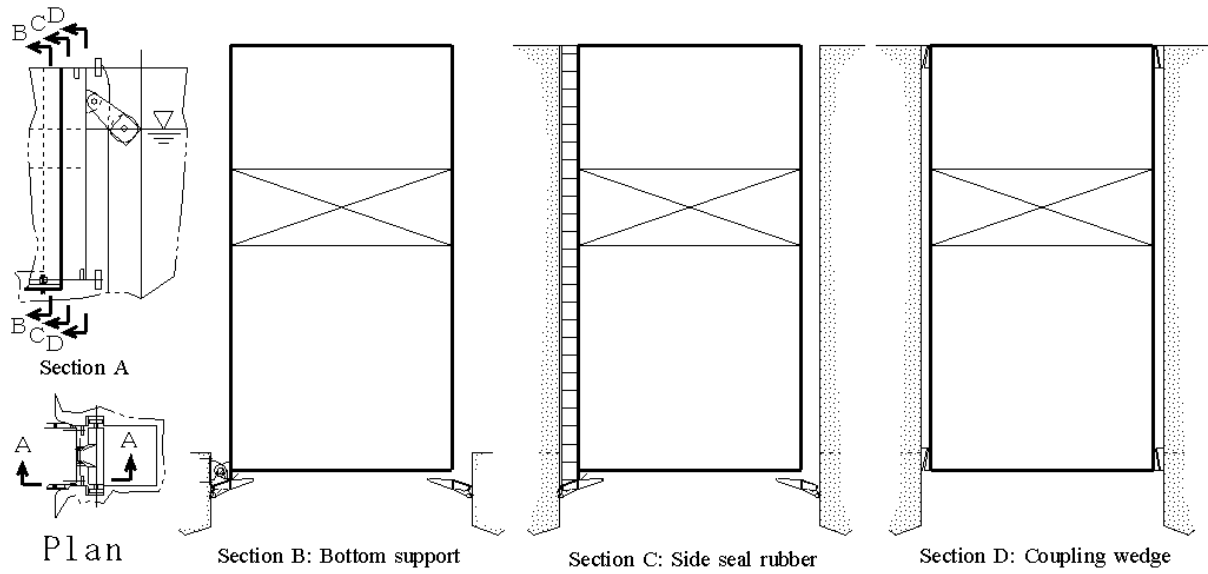
4 . 1 . 2 . 2 Gate body deformation

Rotation angle: = 1.20 ° (Max.)

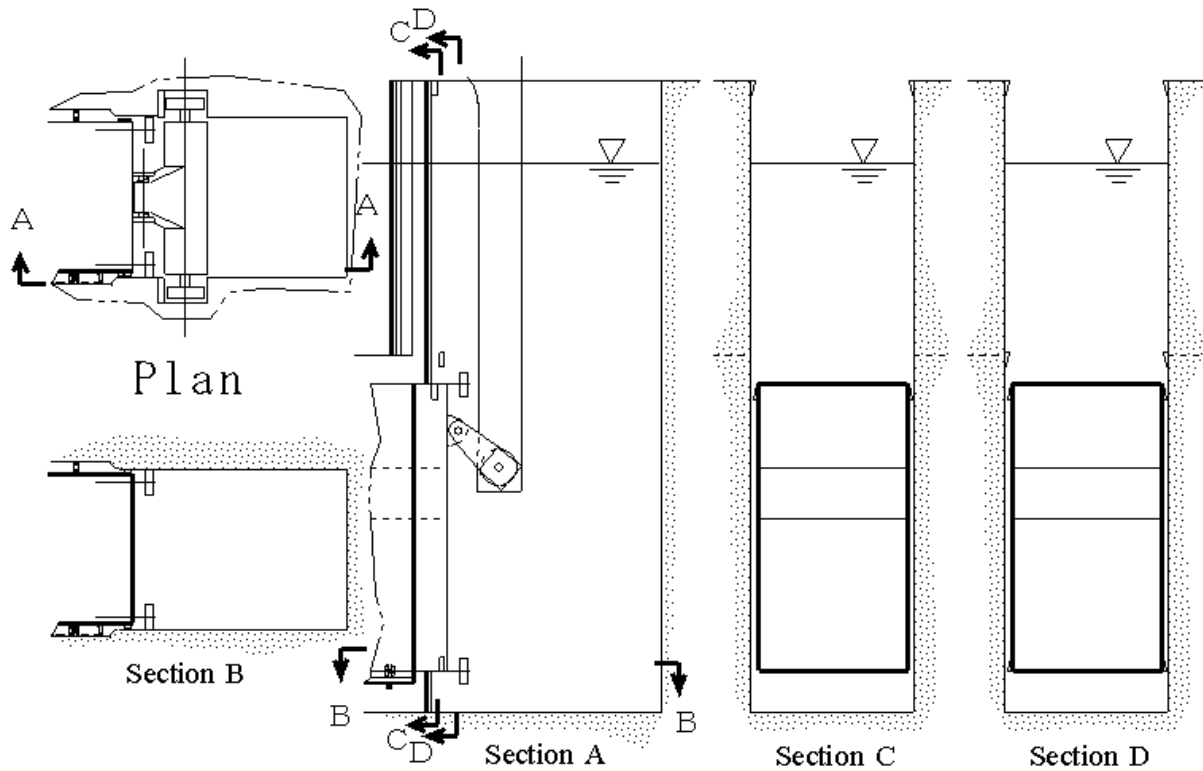
Displacement: = 49.2 cm (Max., at gate body top)

4 . 1 . 3 Completely closing and completely opening

4.1.3.1 Completely closed and completely opened



Completely closed status



Completely opened status

Fig. 4.-5 Completely closed and opened

Fig. 4.-5 shows a detail of gate body completely closed and opened. For the completely closed status, Section B, C and D show Bottom support, Side seal rubber and Coupling wedge respectively. For the completely opened status, Section A shows a gate body in a storage space and Section C and D show a detail of Coupling arrangement.

4 . 1 . 3 . 2 Impact force when completely closed

As a completely opened gate body keeps rising increasing its speed due to constant buoyancy force working on it, a big impact force may occur when accumulated energy is released when the gate body completely closes. The energy is transferred to the gate body strain energy and the impact force will be absorbed to a certain level (refer to the report "Swing type"). Strength exploration of support bracket anchors is required against the impact force at a construction stage.

4 . 2 Tank arrangement and gate body inclination

4 . 2 . 1 Balance tank and Descending tank

Balance tanks (left, right) and Descending tank are installed in the gate body. Purpose of Balance tank is to counterbalance dead weight of the gate body including ballast in submerged body state and that of Descending tank is descending and rising operation of the gate body in submerged body state.

(1) Balance tank

Heights of Left and Right balance tank are determined according to following conditions.

Tank width equals full width of the gate.

Tank length of the Left and the Right is a half of the gate length.

Tank buoyancy center conforms to the gate gravity center.

Tank displacement shall equal gate dead weight x 1.02 based on the assumption that the dead weight calculation error is less than 1 % (to get rising buoyancy by 1 thru 3 % of the dead weight).

Calculation results are as following.

Displacement of the gate body steel and ballast is not counted in the calculation.

• Displacement = = calculated result × 1.02 = 10260 m³

(adopted = 10266 m³)

• A half of the gate length = 225 m

• Gate width = 1 = 12.5 m

- Tank height Left: $a = 4.337$ m (calculated), **4.300** m (adopted)
Right: $b = 2.960$ m (calculated), **3.000** m (adopted)

(2) Descending tank

The tank length is determined according to following conditions.

Installation: Right balance tank bottom and its center conforms to the gate gravity center.

Tank width conforms to a full width of Balance tank.

Tank height = $h_{ch} = 2.5$ m

Tank displacement shall equal gate dead weight x **0.04** based on the assumption that the dead weight calculation error is less than **1 %** (to get descending weight by **1 thru 3 %** of the dead weight).

Calculated results are as following.

- Tank volume = $\times 0.04 = 402$ (calculated), = **403m³** (adopted)
- Tank length = **12.876** m (calculated), **12.9** m (adopted)
- Tank height = $h_{ch} = 2.5$ m
- Tank width = **12.5** m

4 . 2 . 2 Roller friction force due to gate operation.

4 . 2 . 2 . 1 Water pressure load and roller load

Tidal flow pressure works on the gate body during opening and closure gate operation. The gate operation is made at the operation condition **3** with the site water level and it is assumed that the tide pressure distributes uniformly over the gate body area which emerges above the gate body storage space and stays in water. Fig. **4.-6** and Fig. **4.-7** shows calculated results of water pressure load, external

torsion moment of the gate body and roller load, versus gate travel (height between the storage space top and the gate body top). The water pressure load corresponds to a half of the gate body, the external torsion moment is the value which arrives at the gate support end, the

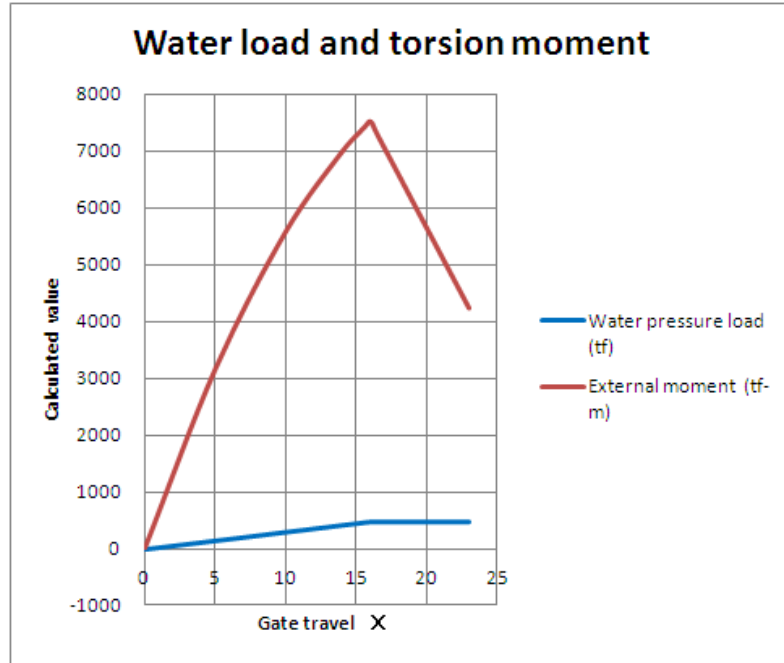


Fig. 4.-6 Water load and external torsion moment during operation

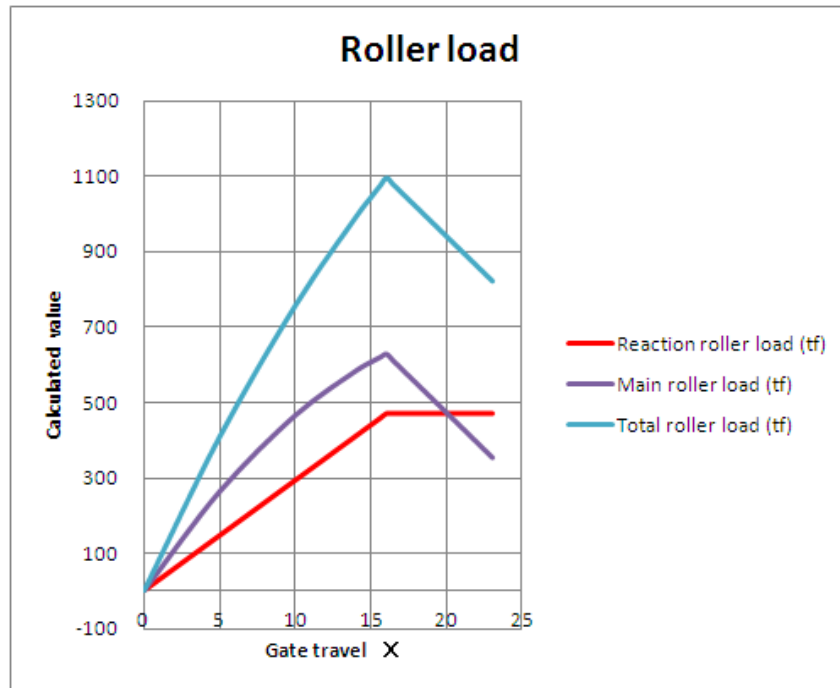


Fig. 4.-7 Roller load

reaction roller load is a sum of all the roller loads working on a half of the gate body and equals the water pressure load and main roller load is a simple sum of the two roller loads although they are coupling forces whose working directions are reverse each other.

4.2.2.2 Roller friction force

Roller friction force shown on Fig. 4.-8 arises because the loads shown on Fig. 4.-7 works on the reaction rollers and the main rollers during gate opening or closure operation. Bearing type of the reaction rollers and the main rollers is slide and roller and their rolling friction coefficients are 0.05 and 0.01 respectively. Results shown are sums of each rollers. Fig. 4.-9 shows ratio of the reaction roller friction force to the main roller that is reference information of gate inclination angles which will be shown on a separate article. A roller type bearing is

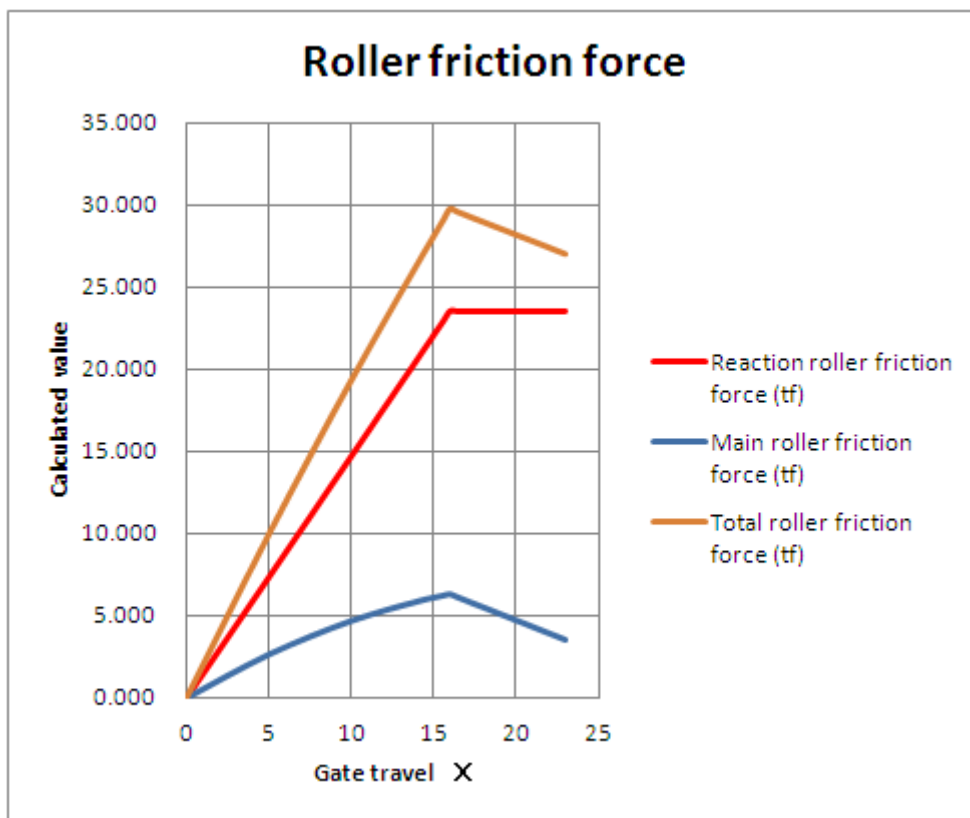


图4.-8 Roller friction force

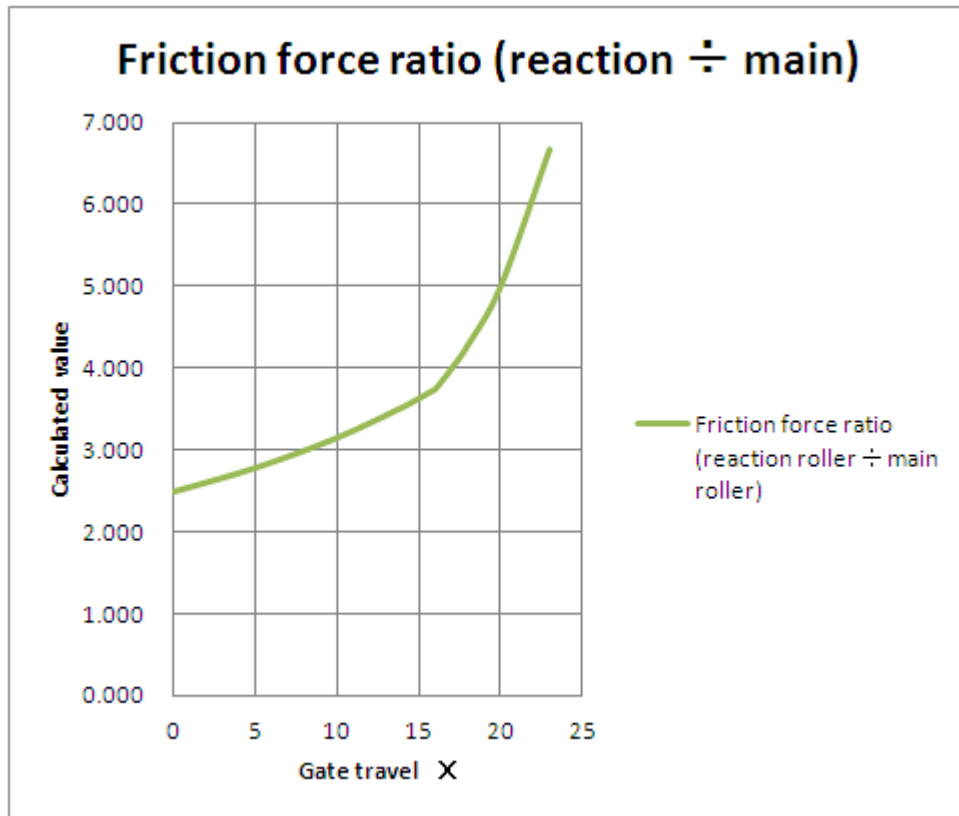


Fig. 4.-9 Roller friction force ratio

adopted for the main rollers to decrease inclination angle of the gate body during its opening or closure operation in the submerged body state. Fig. 4.-1 shows a difference of inclination angle from a slide bearing.

4 . 2 . 3 Gate body inclination angle during gate operation

4 . 2 . 3 . 1 Submerged body state

Gate opening and closure operation in the state of submerged body can be selected for all gate travel between the completely closed position and the completely opened position since the balance tank top height conforms to the site water level when the gate is completely closed. The gate body during opening or closure operation is subject to roller friction force shown on Fig. 4.-3 and inclines longitudinally due to the horizontal difference between the friction force center and the buoyancy/gravity center. The inclination will be in balance at an angle where incline moment becomes equal to upright moment which arises due to a difference between the buoyancy center and the gravity center. Fig. 4.-10 shows longitudinal

inclination angle ($^{\circ}$) due to gate operation in submerged state versus gate travel where + angle is anti-clockwise rotation. The gate travel is a height between the storage space top and a gate body top. Calculation method of Fig. 4.-10 is shown on Appendix 2.

Calculation conditions are as follows.

Tide level: The site water level

Balance tank: Empty

Descending tank: Full when descending, empty when rising

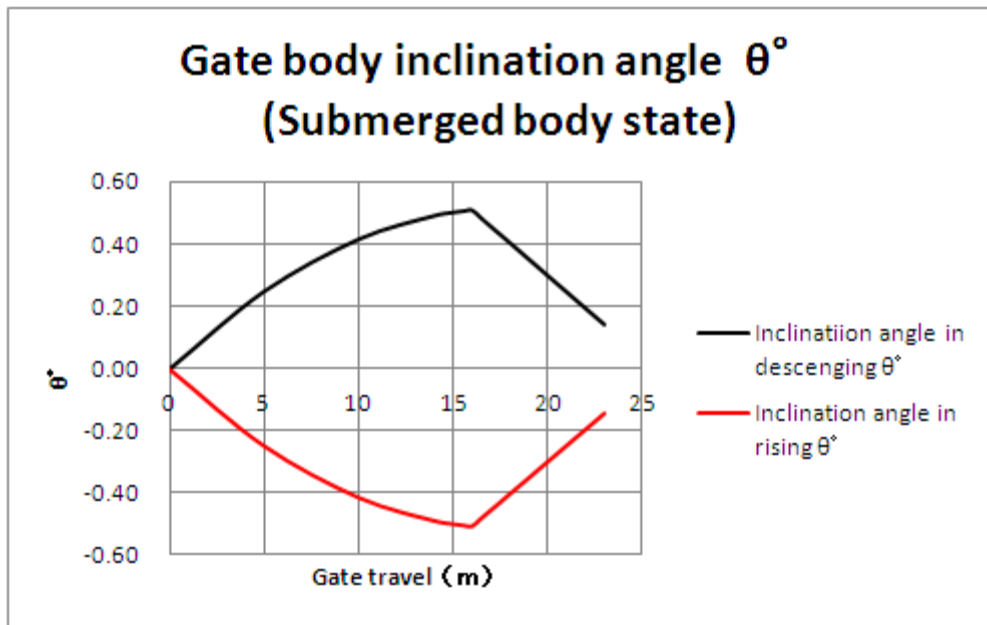


Fig.

4.-10

Longitudinal inclination in submerged gate operation

The inclination amount (= a difference of the drafts at both gate ends) which corresponds to the maximum inclination angle of Fig. 4.-10 is 2.01 m when descending (anti-clockwise) and -1.99 m when rising (clockwise) and no trouble on gate operation can be seen. Since friction force directions will change due to direction changes of rollers that are caused by gate body inclination, horizontal force which directs

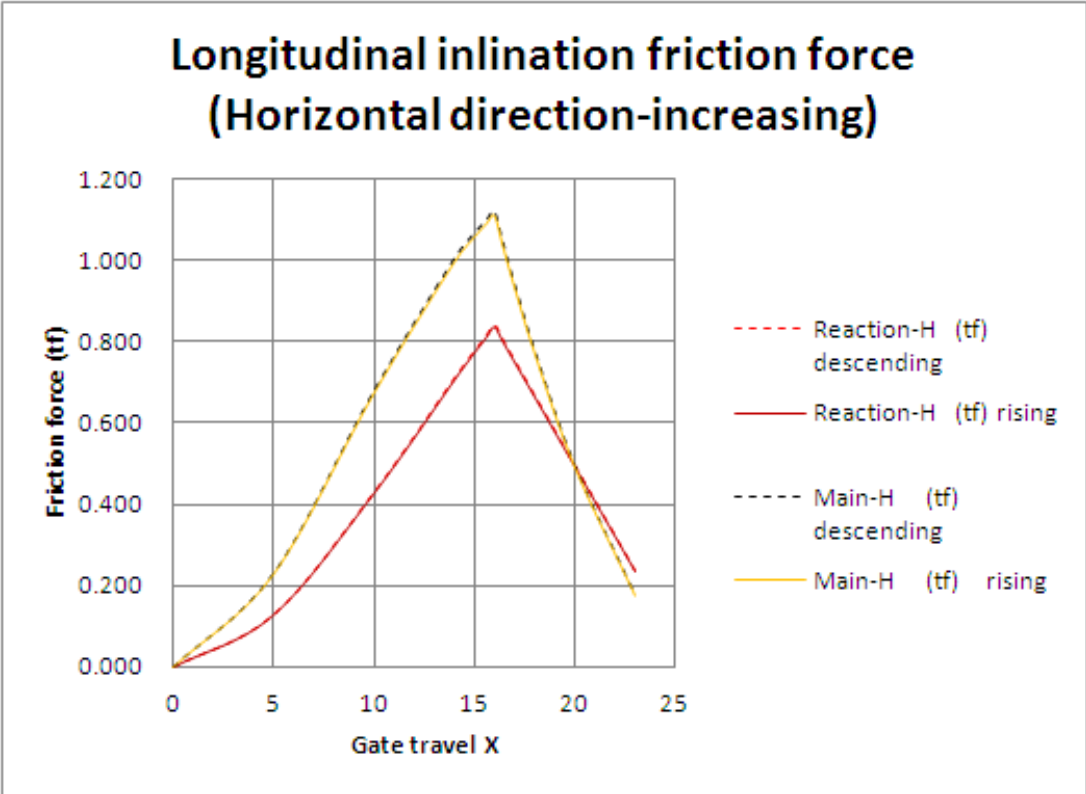


Fig. 4.-11 Friction change due to gate incline (Horizontal component)

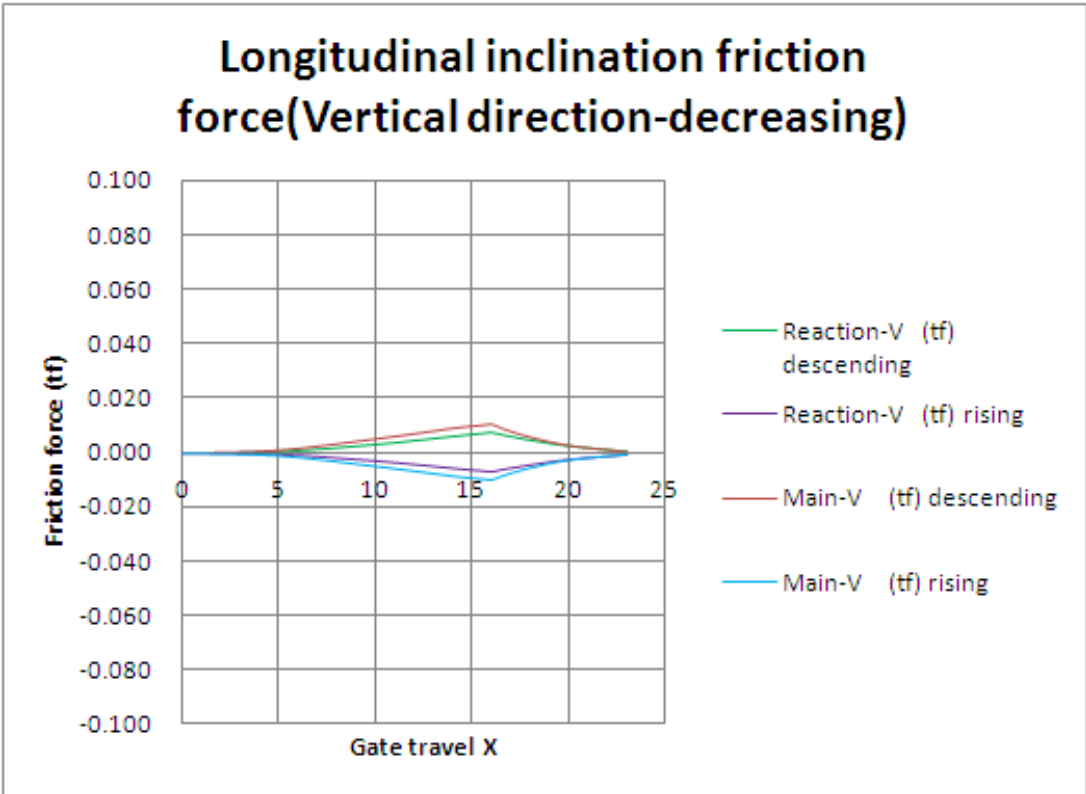


Fig. 4.-12 Friction change due to gate incline (Vertical component)

toward the gate support end will arise and vertical force will reduce. Fig. 4.-11 and -12 show friction changes due to the gate body inclination, Fig. 4.-11 gives arisen horizontal forces and Fig. 4.-12 gives a vanishing amount of the vertical component force. Both component forces are so small that their impact on feasibility of the torsion type emerging gate may be negligible. Calculation method of Fig. 4.-11 and Fig. 4.-12 is shown on Appendix 3.

4 . 2 . 3 . 2 Floating body state

An opening or closure operation in the floating body state selection is possible for the gate travel between a gate completely closed position and a gate top position conforming to the site water level. Since gate operation in the floating body state is required only for construction or maintenance work when a gate body is inserted into or taken out from a gate slot, the operation is made during no tide flow occasion at the gate travel above 21 m. Fig. 4.-13 shows longitudinal inclination angle (°) of a gate in the floating body condition versus the gate travel (= height between a storage space top and a gate body top). Tide flow pressure during gate operation will not make any impact on the calculation result since gate body stability in the floating body state is so big. Calculation method of Fig. 4.-13 is shown on Appendix 4.

The calculation conditions are as follows.

Tide level = The site water level, Tide flow = 0 kt.

Descending tank: Empty

Balance tank: Water filling ratio shall be adjusted according to gate travel (x).

Since gate body buoyancy of floating body state is a difference between the site water level and water level in a gate body, water filling ratio of a balance tank and compartments at both sides of a watertight bulkhead in the gate body shall be adjusted according to the water level corresponding to the gate body buoyancy. Electronic control seems to be useful for the adjustment. Fig. 4.-14 shows relative height between inside water level **a ~ d** of the gate body and the balance tank. Fig. 4.-15 shows gate travel (= height between a storage space top and a gate body top) and water filling status of the balance tank using the inside water level **a ~ d** of gate body as a benchmark. An average value of the gate body inclination shown on Fig. 4.-13 was applied to the calculation of a gate travel

corresponding to an inside water level.

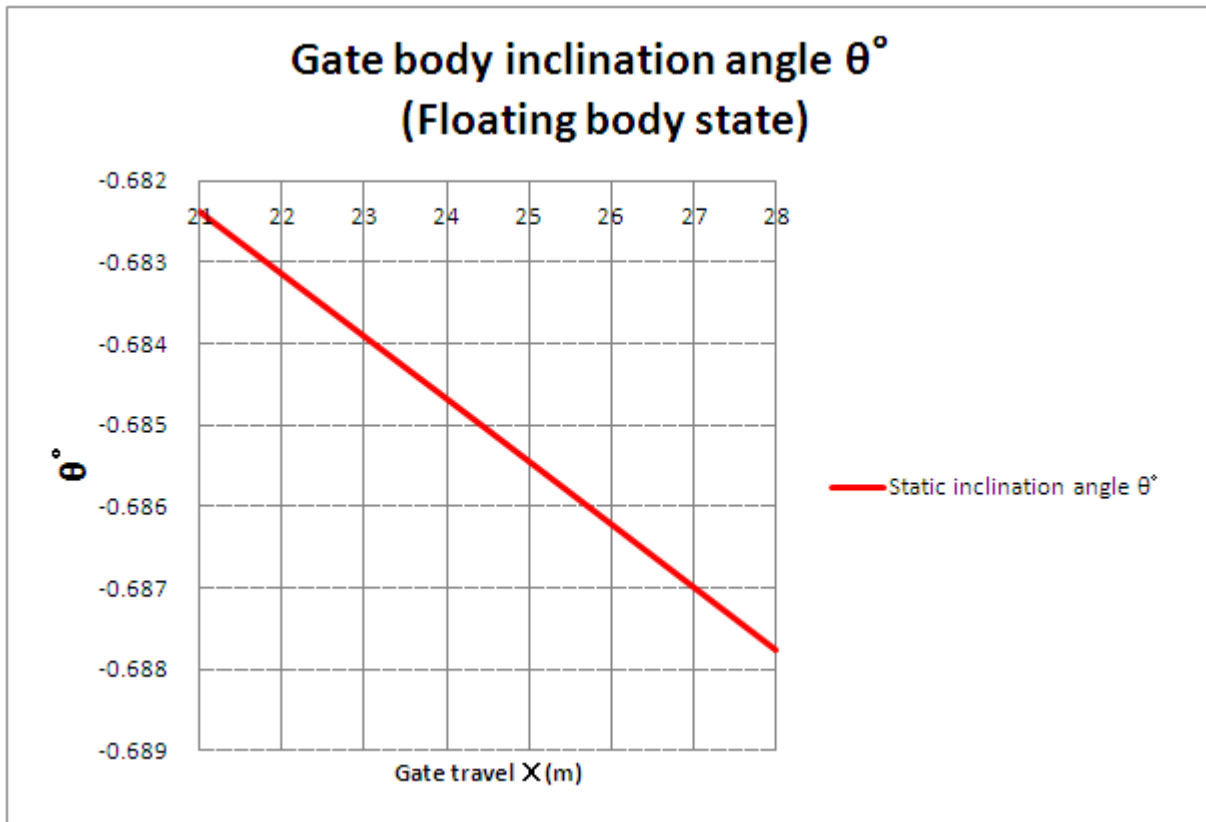


Fig. 4.-13 Inclination angle of a gate in floating body state ($^\circ$)

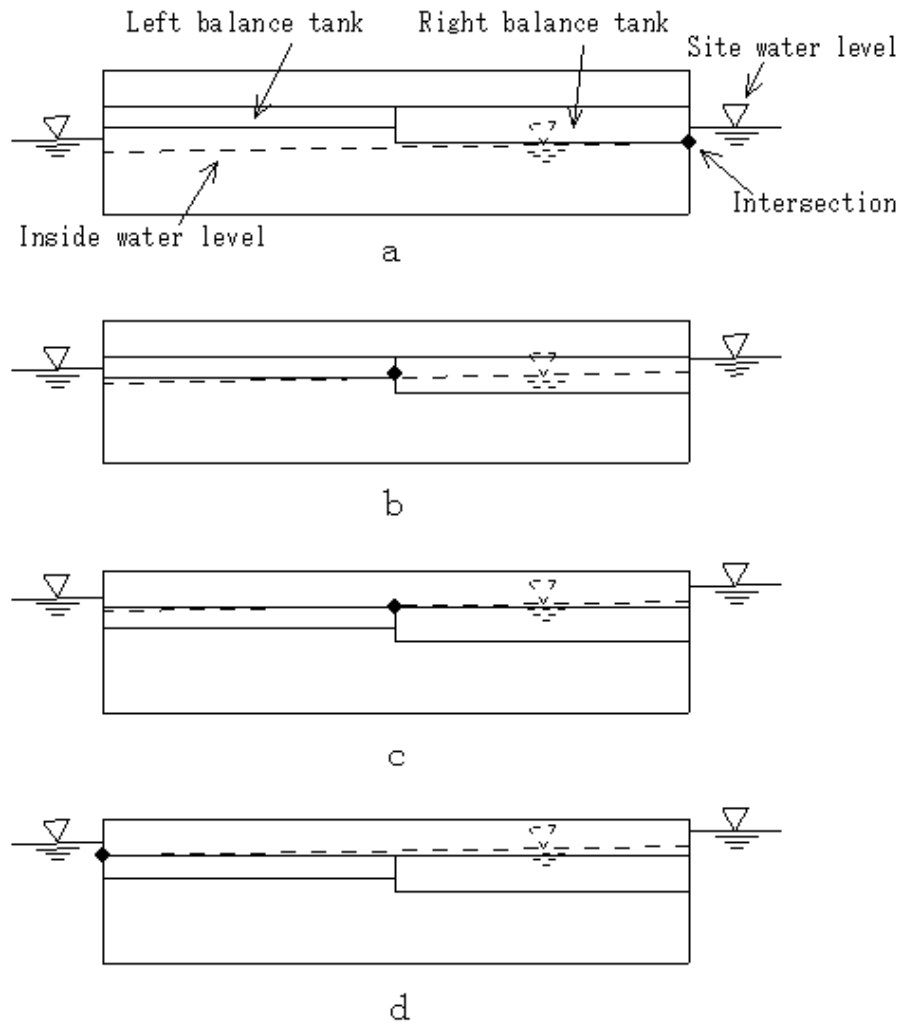


Fig. 4.-14 Relative height between Inside water level and Balance tank

Inside water level	Gate travel (X), m	Balance tank water filling rate	
		Left	Right
	↑	Empty	Empty
a	25.07		
	↕	Half filling	Half filling
b	22.42		
	↕	Half filling	Full
c	19.42		
	↕	Full	
d	18.08		
	↓		

Fig. 4.-15 Water filling rate of Balance tank

4 . 2 . 4 Stability

The stability referred here is that of gate body lateral inclination and concerns stability function of the gate body which stays in a gate slot with its reaction rollers being closed or which stays outside of a gate slot. Although floating body state and submerged body state have different stability mechanism, their stability function can be evaluated by a righting arm. A calculated result is Righting arm > 0 for both states.

4 . 2 . 4 . 1 Floating body state

Table 4.-1 is calculated results of righting arm in floating body state. Calculation method of table 4.-1 is shown on Appendix 5.

Table 4.-1 Righting arm of floating body state

Gate travel = X(m)	16	16.4	17	18	20	23
Draft=d=hb-(x-16)(m)	24	23.6	23	22	20	17
$\nabla = d \times L \times l(m^4)$	67500	66375	64688	61875	56250	47813
$BM = I / \nabla(m)$	0.54	0.55	0.57	0.59	0.65	0.77
$BK = d / 2(m)$	12	11.8	11.5	11	10	8.5
KG(m)	10.21	10.01	9.71	9.21	8.21	6.71
GM(m)	2.33	2.34	2.35	2.38	2.44	2.55
$GG0 = I / \nabla(m)$	0.54	0.55	0.57	0.59	0.65	0.77
Righting arm = GM-GG0 m	1.79	1.79	1.79	1.79	1.79	1.79

4 . 2 . 4 . 2 Submerged body state

Calculation method and its result are shown below.

Righting arm = $h = hb - hf - hg$

• Descending: Righting arm = **4.248** m

• Rising: Righting arm = **4.370** m

4 . 3 Support and sealing mechanism

4 . 3 . 1 Support mechanism

The support mechanism composes two systems one of which supports tide flow pressure working on a gate body during opening or closure operation and composes reaction points (reaction rollers) and main rollers and other of which supports high tide pressure working on a gate body of completely closed position and composes restriction points (reaction axles & support brackets) and coupling wedges. Water pressure working on a gate body and reaction force working on the restriction points form into torsion moment, which is carried through torsional rigidity of the gate up to a gate support end and consorts with a coupling force working on main rollers/coupling wedges. Adopted scantlings of parts which each support system is composed of are shown below as well as loads and allowable limits applied in their design.

4 . 3 . 1 . 1 Scantlings of tide flow pressure support system

(1) Reaction roller

Design load: **21 tf**

Allowable wheel pressure coefficient: **120 Kg/cm²**

Scantling: Diameter = **0.3 m**, Width = **0.07 m**

(2) Main roller

Design load: **627 tf**

Allowable wheel pressure coefficient: **120 Kg/cm²**

Scantling: Diameter = **2.125 m**, Width = **0.6 m**

4 . 3 . 1 . 2 Scantlings of high tide pressure support system

(1) Reaction axle

Design load: **925 tf**

Allowable bearing pressure: **450 Kg/cm²** (static load, oilless bearing)

Scantling: Diameter = **0.36 m**, Width = **0.3 × 2 = 0.6 m**

Bearing surface of the reaction axels (diameter = **360 mm**) slides by Max. **3.8 mm** due to high tide pressure. The bearing load seems to be static since tidal level change is slower pace (**3.8 mm/ 6 hours**).

(2) Support bracket

Design load: **925** tf

Allowable bearing stress: **26** Kg/mm² (**71** % of yield point)

Scantlings: Diameter = **0.36** m, Width = **0.2** m

(3) Coupling wedge

Design load: **8070** tf

Allowable bearing stress: **71** Kg/mm² (**71** % of yield point)

Scantlings: Height = **1.25** m, Width = **0.4** m

4 . 3 . 1 . 3 Cross-sectional restriction block detail

Fig. 4.-16 shows a cross-sectional restriction block detail. The block composes a support bracket, a reaction axle, a bottom seal rubber and a reaction roller. Side view shows the block with a gate body completely closed where the support bracket and the reaction axle coalesce and the seal rubber and the reaction roller close interval between the gate body and a concrete wall. The block with the gate body partially opened and the block with the seal rubber and the reaction roller opened are shown at head of two arrows. Section A shows a support bracket, Section B and C show a reaction axle, Section D, E and F show a cross-section of the reaction axle and Section G shows a back side of the reaction roller and the bottom seal rubber.

A set of a support bracket and a reaction axle is installed at a narrow interval between the gate body and the concrete wall. On the other hand, a load working on them is extremely big. A center section of the reaction axle (Section E) is hog-backed and formed according to bearing surface design and two oil-less bearings formed according to static load design are provided in the round sections (Section D and F) so that a set of the support bracket and reaction axle may be small sized. The bottom seal rubber moves away from a seal sill on the concrete wall by **22.2** mm due to torsional deformation of the gate body

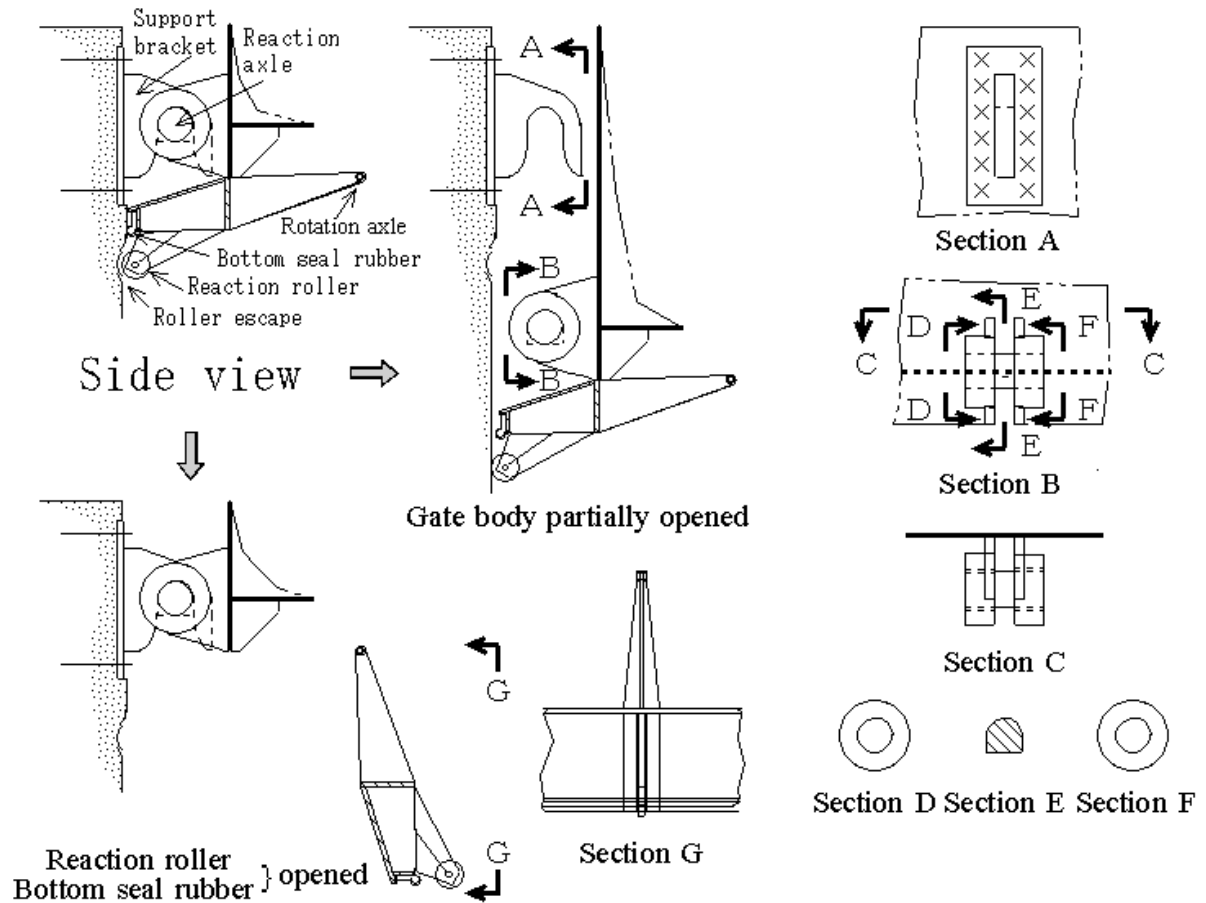


Fig. 4.-16 Cross-sectional restriction block detail

because of high tide pressure but an impact of the move is absorbed by a big bulb diameter (93.75 mm) of a seal rubber. The reaction roller moves by 30.1 mm due to the same reason. Roller escapes of 62.5 mm depth are provided on the concrete walls to avoid a damage of the opposite side rollers.

4.3.2 Side water sealing

4.3.2.1 Side water sealing detail

Fig. 4.-17 shows a side water sealing detail. Although a side rubber is a main subject of this figure, a bottom rubber is also shown since both rubbers spatially relate each other. The figure composes Detail A, Side sealing-fixed and Side sealing-openable.

【Detail A】

Detail A shows corner details of Side sealing–fixed and Side sealing–openable. Both types are seemingly similar except a corner rubber which belongs to the bottom rubber in the fixed case and the side rubber in the openable case.

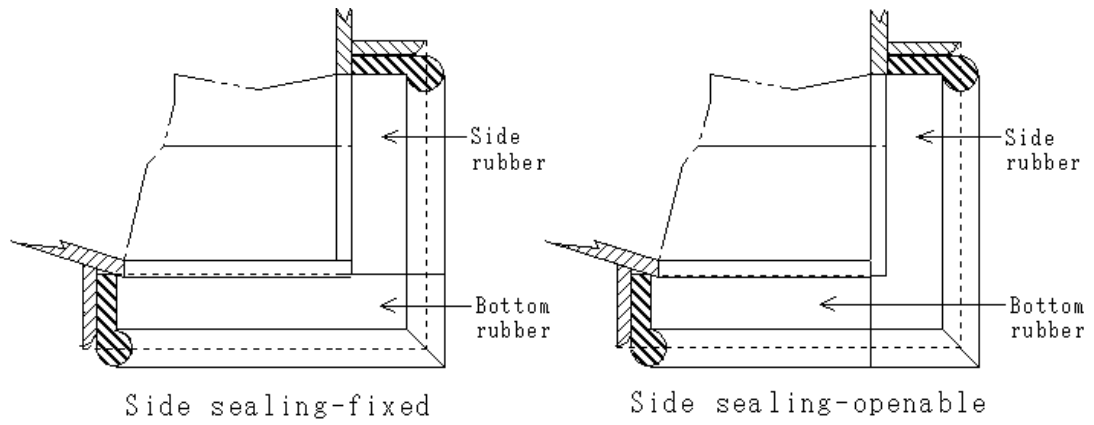
【Side sealing–fixed】

Elevation (Closed) is an end part elevation of the completely closed gate body and shows position of Detail B. Detail B shows a side rubber and a bottom rubber and also shows position of Detail A and directions of Section F and G. Elevation (Inserted) is an end part elevation of the gate body being inserted into a gate slot and shows position of Detail C. Detail C shows a side rubber and a bottom rubber and also shows directions of Section H and I.

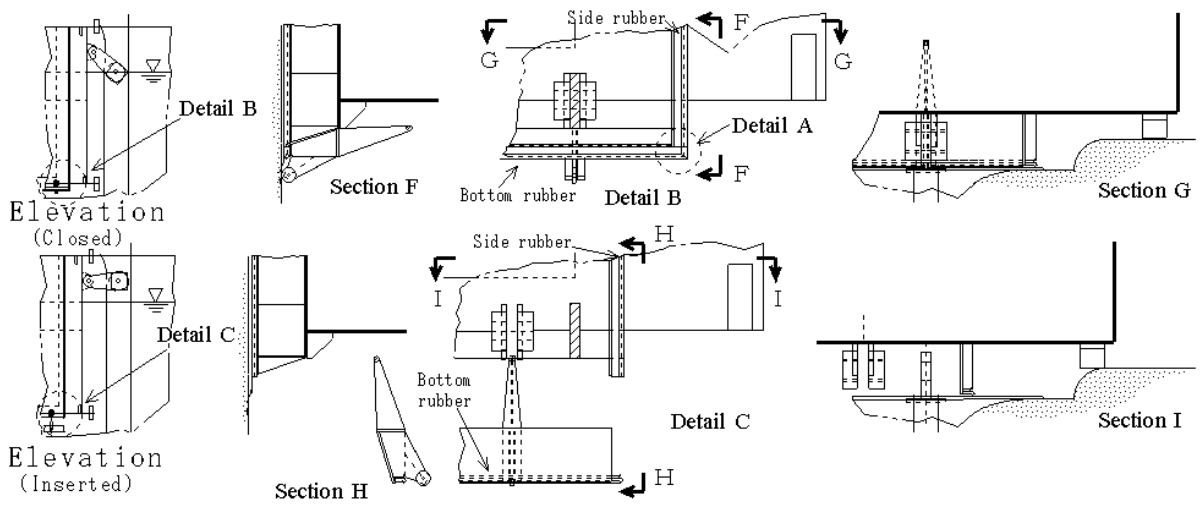
【Side sealing–openable】

Elevation (Closed) is an end part elevation of the completely closed gate body and shows position of Detail D. Detail D shows a side rubber and a bottom rubber and also shows position of Detail A and directions of Section J and K. Section K shows a rotation axle of the side rubber. Elevation (Inserted) is an end part elevation of the gate body being inserted into a gate slot and shows position of Detail E. Detail E shows a side rubber and a bottom rubber and also shows directions of Section L and M. Section M shows a rotation axle of the side rubber.

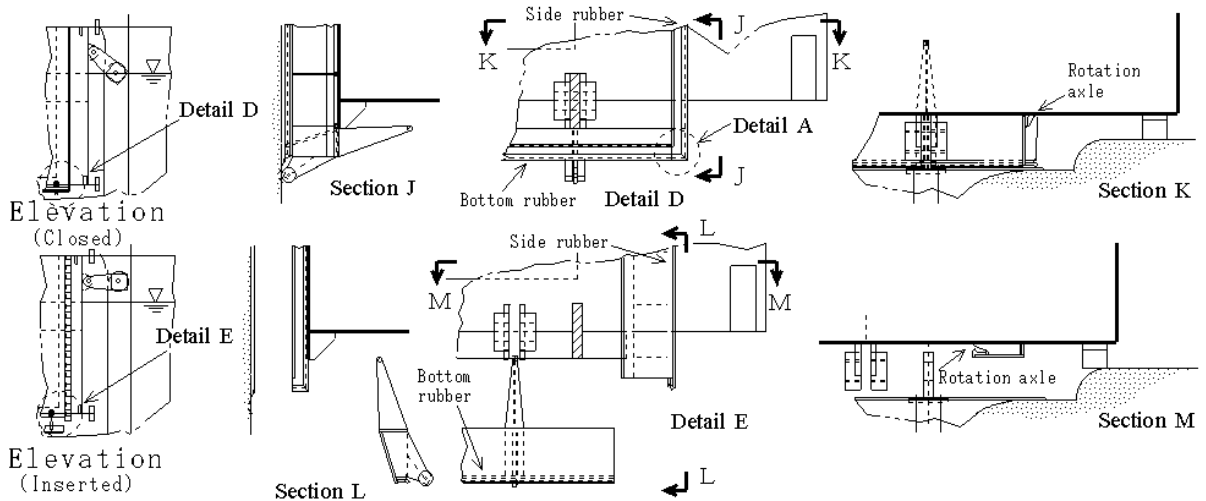
As shown in above, A difference of the fixed type and the openable type is a place the corner rubber belongs to (bottom or side) and an existence or not existence of the rotation axle. And there is no difference of gate body operation at working condition and a difference appears at construction and maintenance time when the gate body is inserted into a gate slot (refer to 4 . 3 . 2 . 2 Gate slot insert steps).



Detail A



Side sealing-fixed



Side sealing-openable

Fig. 4.-17 Side water sealing detail

4.3.2.2 Gate slot insert steps

Table 4.-2 and Fig. 4.-18 and 4.-19 show gate slot insert steps of a gate body. The inserting is carried out during construction and maintenance work. Table 4.-2 shows work content, open or close status of a side roller, a reaction roller, a bottom sealing and a side sealing at each step of Side sealing-fixed type and Side sealing-openable type. Works at gate height A and B and the height between them is done in floating body state and works at height between B and C is made in submerged body state. Fig. 4.-18 and Fig. 4.-19 shows insert steps of Side sealing-fixed type and Side sealing-openable type respectively. Both figures show a side roller, a side seal and a reaction roller & bottom seal. Steps 1 thru 3 of both types are same work contents and a difference of a side seal handling appears at step 4 and 5.

All steps of the openable type are made in floating body state. A side seal rubber fits into its working position without a stem direction sliding which is shown by x on Fig. 2.-2 since a side seal is closed after a side roller is closed at the step 4 (Problem 2.4 Sliding in stem direction of P type side seal rubber).

Table 4.-2 Insert steps of Side sealing fixed type and openable type

Step number	Side sealing-fixed						Side sealing-openable					
	Work content	Gate height	Status of open/close				Work content	Gate height	Status of open/close			
			Side roller	Reaction roller	Bottom seal	Side seal			Side roller	Reaction roller	Bottom seal	Side seal
1	Insert side roller	A	Op	Op	Bottom seal	CI	Insert side roller	A	Op	Op	Bottom seal	Op
2	Descending 1						Descending					
3	Close bottom seal	B					Close bottom seal					
4	Descending 2		CI	CI	Bottom seal	CI	Close side roller	B	CI	CI	Bottom seal	CI
5	Close side roller	C					Close side seal					
Explanatory note:		1. Gate height A: Side roller above concrete top, B: Restriction block lower than bottom seal sill, C: Completely closed										
		2. Status of open/close Op: Opened, CI: Closed										

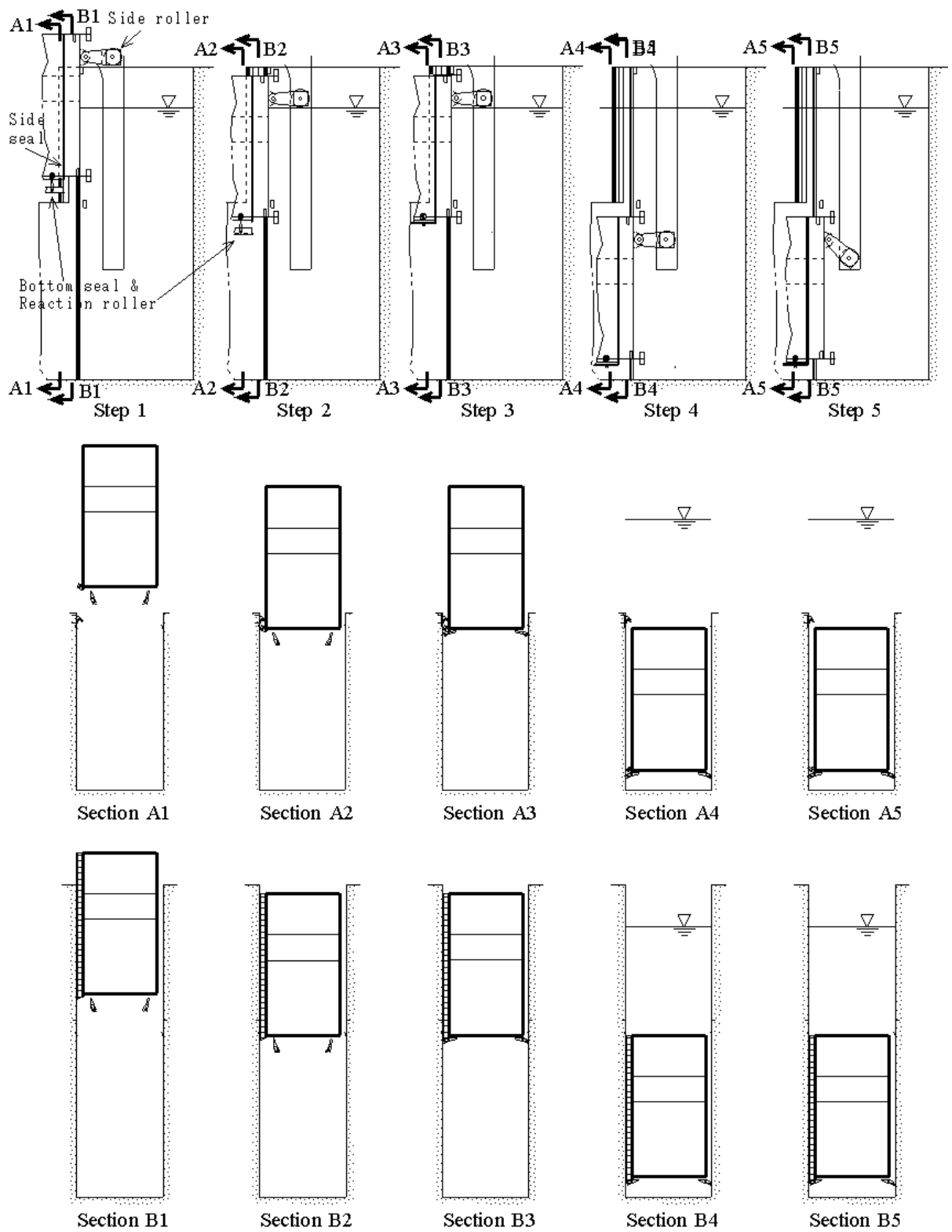


Fig. 4.18 Insert steps of Side sealing-fixed

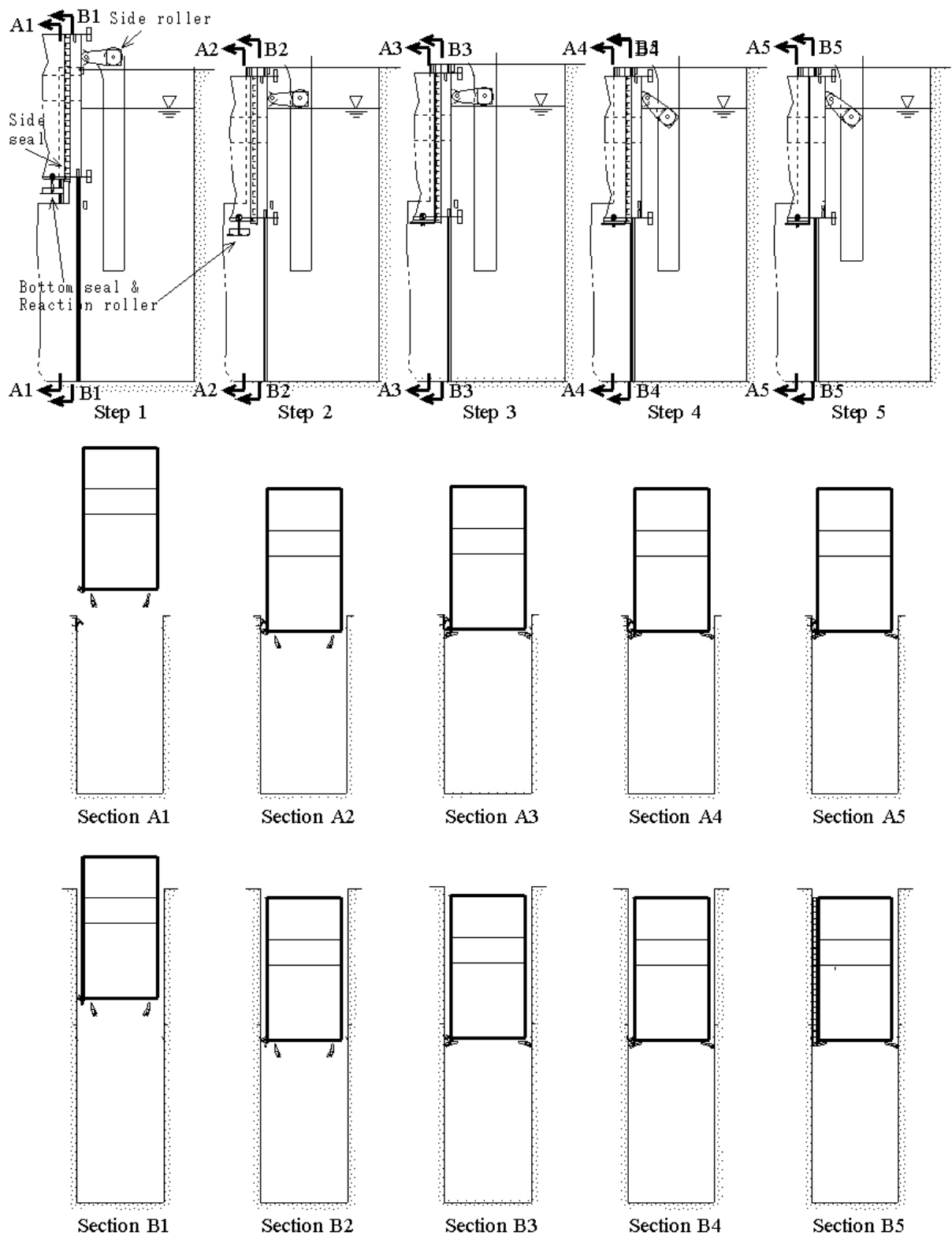


Fig. 4.19 Insert steps of Side sealing-openable

In case of the fixed type, gate body lateral remove in a gate slot is made at the gate completely closed position. A side seal rubber fits into its working position without a stem direction sliding which is shown by x on Fig. 2.-2 since a seal sill for the side seal rubber does not exist on a concrete wall at its gate position (Problem 2 . 4 Sliding in stem direction of P type side seal rubber). Although the lateral remove operation is made in a submerged state, it is made with a help of bottom rollers (refer to the general arrangement) without any difficulties (Problem 2 . 2 Floating body state and submerged body state).

Above is an explanation when a gate body is inserted and work steps when a gate body is taken out are reverse to this.

5 . Conclusion

Following conclusions were obtained based on this study.

- (1) Emerging type super large torsion type gate is feasible.
- (2) It is believed that a big amount of cost reduction is possible by adopting an emerging type super large torsion type gate.
- (3) Strength examination of the support bracket anchor will be required at construction stage (refer to 4 . 1 . 3 . 2).

Appendix 1 Calculation method: Torsion moment increase due to gate body buoyancy (Fig. 4.-2)

Gate body buoyancy (Submerged body state)

Assumption 1 .Completely closed

2 .Port side depth = 16 m

3 .Allowable shearing stress of concrete = 15 Kg/cm²

4 .Gate bottom support height = -0.5m

Submerged body state displacement = $g = 10261 \text{ m}^3$

Gate body steady buoyancy = $s = 2000 \text{ tf}$

Gate body total buoyancy = $g + s = 12261 \text{ tf}$

Floating stop load = Gate body total buoyancy - $(W_g + V_{bx}) = 2201 \text{ tf}$

Floating stop unit load = Floating stop load $\div L = 9.783 \text{ tf/m}$

Reduced torsion moment = High tide moment - buoyancy moment

Appendix 2 Calculation method: Longitudinal inclination in submerged gate operation (Fig. 4.-10)

Buoyancy center = $h_f = (a^2/2 + b^2/2)/(a+b) + t$

= 8.889 m (from gate top)

Gravity center during descending = $h_g = (W_g \times hb/2 + W_{ch} \times (hb - (a + t) + hch/2) + V_{bx} \times (Y_b + (hb - H)))/(W_g + W_{ch} + V_{bx})$

= 10.86 m (from gate box bottom)

Gravity center during rising = $h_g = (W_g \times hb/2 + V_{bx} \times (Y_b + (hb - H)))/(W_g + V_{bx}) = 10.74 \text{ m}$ (from gate box bottom)

Righting arm = $h = hb - hf - hg =$ Descending = 4.248 m

Rising = 4.370 m

Descend force = $W_g + W_{ch} + V_{bx} - F_b = 270 \sim 90 >$ Roller friction = 55

Rise force = $F_b - (W_g + V_{bx}) = 270 \sim 90 >$ Roller friction = 55

Upright moment during descending = $h \times \sin \alpha \times F_b$

Upright moment during rising = $h \times \sin \alpha \times (W_g + V_{bx})$

F_r = Reaction roller friction force

F_m = Main roller friction force

Friction force center = $L_f = (F_m \times L / 2) / (F_m + F_r)$

Friction inclination moment = $M_f = (L_f - L_g) \times (F_m + F_r)$

Inclination angle during descending = $\alpha = \sin^{-1} M_f / (h \times F_b)$

Inclination angle during rising = $\alpha = \sin^{-1} (-M_f) / (h \times (W_g + V_{bx}))$

Appendix 3 Calculation method: Friction change due to gate longitudinal inclination (Fig. 4.-11, Fig. 4.-12)

Calculation condition:

1 . Gate travel during submerged body state = $X = 23$ m 2 .

Side roller height = Water line height = $L_s = 17$ m

Sliding direction roller load = roller load $\times \sin$

Slide friction coefficient = C_{sf}

Sliding direction friction force = $F_s = \text{roller load} \times \sin \times C_{sf}$

$F_{s(\text{side component})} = F_s \times \cos$

$F_{s(\text{vertical component})} = F_s \times \sin$

$F_{r_{ss}} = \text{side component of } F_r = F_r \times \sin^2 \div 2 \times C_{sf}$

$F_{r_{sv}} = \text{vertical component of } F_r = F_r \times \sin^2 \times C_{sf}$

$F_{m_{ss}} = \text{side component of } F_m = F_m \times \sin^2 \div 2 \times C_{sf}$

$F_{m_{sv}} = \text{vertical component of } F_m = F_m \times \sin^2 \times C_{sf}$

Vertical friction center = $L_f = (F_{m_{sv}} \times L / 2) / (F_{m_{sv}} + F_{r_{sv}})$

$M_f = \text{Increase of } M_f \text{ due to longitudinal inclination}$

$= (L_f - L_g) \times (F_{m_{sv}} + F_{r_{sv}}) +$

$L_s \times (F_{m_{ss}} \div 2 + F_{r_{ss}}) - (\text{Box height} - L_s) \times F_{m_{ss}} \div 2$

Submerged Descending = $\sin^{-1} M_f / (h \times F_b)$

Rising = $\sin^{-1} M_f / (h \times (W_g + V_{bx}))$

Floating = $\sin^{-1} M_f / (\text{Righting arm} \times)$

Side roller vertical load = $F_{m_{ss}} + F_{r_{ss}}$

Appendix 4 Calculation method: Inclination angle of a gate in floating body state (Fig. 4.-13)

Assumption:

1 . Air pressure in both side of gate body water tight bulkhead under Balance tank equals.

Draft = $d = h_b - (x - 16)$

$= d \times L \times l$

$I = l \times L^3 / 12 = 11865234.38 \text{ m}^4$

$BM = I /$

$BK = d / 2$

$KM = BM + BK$

$$\begin{aligned}
d_b &= (W_g + V_{bx}) / (l \times L) = 3.5768 \text{ m} \\
KG &= \{ (W_g + V_{bx}) \times (L_g y + (h_b - H)) + (- (W_g + V_{bx})) (d - d_b) / 2 \} / \\
GM &= KM - KG = BM + BK - KG \\
\text{Number of gate body divide} &= n = 2 \\
i &= l \times (L / n) ^ 3 \times n / 12 = 2966309 \text{ m}^4 \\
GG0 &= (/ 0)(i /) \\
\text{Righting arm} &= GOM = GM - GG0 \\
\text{Static inclination moment} &= MS = (W_g + V_{bx}) \times L g_x = 106754.625 \text{ tf-m} \\
Fr &= \text{Reaction roller friction force} \\
Fm &= \text{Main roller friction force} \\
\text{Friction center} &= L f = (Fm \times L / 2) / (Fm + Fr) \\
\text{Friction inclination moment} &= (L f - L g_x) \times (Fm + Fr) = MF \\
\text{Inclination moment-descending} &= MS - MF = MD \\
\text{Inclination moment-rising} &= MS + MF = MR \\
\text{Static inclination angle} &= = \sin^{-1} MS / (\text{Righting arm} \times) \\
\text{Inclination angle-descending} &= = \sin^{-1} MD / (\text{Righting arm} \times) \\
\text{Inclination angle-rising} &= = \sin^{-1} MR / (\text{Righting arm} \times)
\end{aligned}$$

Appendix 5 Calculation method: Righting arm of floating body state (Table 4.-1)

Assumption:

1. Air pressure in both side of gate body water tight bulkhead under Balance tank equals.

$$\text{Draft} = d = h_b - (x - 16)$$

$$= d \times L \times l$$

$$I = L \times l^3 / 12 = 36621 \text{ m}^4$$

$$BM = I /$$

$$BK = d / 2$$

$$KM = BM + BK$$

$$d_b = W_g / (l \times L) = 3.5768 \text{ m}$$

$$KG = \{ W_g \times h_b / 2 + (- W_g) (d - d_b) / 2 \} /$$

$$GM = KM - KG = BM + BK - KG$$

Number of gate body divide = n = 1

$$i = L \times (1/n)^3 \times n / 12 = 36621 \text{ m}^4$$

$$GG_0 = (\quad / \quad 0) (i / \quad)$$

$$\text{Righting arm} = G_0M = GM - GG_0$$