Torsion Type Flap Gate for Docks

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Large repair docks came to be built to cope with increasing ship sizes, and those with such large gate spans as 80 m and 100 m have been built recently.

In this paper, torsion type flap gates for docks designed to be suitable for long spans are introduced: (1) superior features of this type, (2) actual examples, (3) special design features, (4) method of installation, (5) results of measurement of stresses, and (6) maintenance and inspection.

1. Introduction

The torsion type flap gate for dock introduced in this paper is the one developed for the Koyagi repair dock of our Nagasaki Shipyard & Engine Works in 1970 when jumboizing of ships was conducted in succession. This dock is the largest repair dock in the world, having a width of 100 m, length 400 m and height at dock sill 13.5 m. This type of gate was adopted later for the repair dock of Mitsubishi Singapore Heavy Industries (called "MSHI" for short) established by the Government of Singapore and Mitsubishi Heavy Industries with joint contribution, which has a width of 80 m.

Gates for repair docks need be opened and closed more frequently than those for building docks and because of this, most of the existing gates for repair docks are flap gates. In the past, those equipped with box girders on top were frequently used[1][2], but in a large gate with a span close to 100 m, many problems are anticipated in weight, construction work, water tightness, etc. This torsion type flap gate was developed in order to solve these problems.

The reason for having postponed the publication of this paper till now when the tendency to jumboize ships has settled down is concerned with patent. We have by now obtained patents for this device in the United States, the United Kingdom and Singapore as well as in Japan and the patent in the Republic of Korea is pending.

This paper introduces the torsion type flap gate, focusing on its features, design concept, topics relating to manufacture and installation, the results of comparison between measured and calculated stresses, and the gate removing work carried out in the Koyagi dockyard in August 1979.

2. Features of this gate

2.1 Types of dock gates

The types of dock gates can be roughly divided into pontoon type and flap gate type (**Figs. 1, 2**). The pontoon type incorporates valves and is so designed as to change the draft automatically and attach to or detach from the door stop as water is poured into or discharged from each section of it through the valves. However, as this type has no facility to move itself, a tug boat is required to move it from the dock sill at the time of docking-in or -out of ship, and it

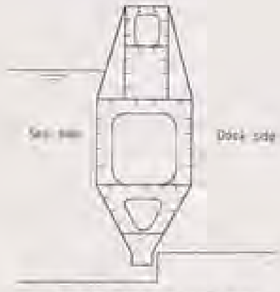

Fig. 1 Pontoon type gate

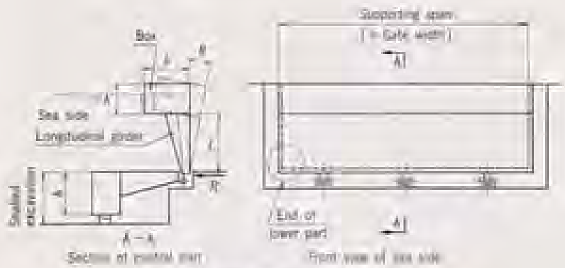

Fig. 2 Box girder type flap gate

takes about 1 hour for opening or closing in the case of a dock of 1 million-ton class.

In the case of building docks, the frequency of docking-in and -out of ships is 4 times a year on the average and the duration of time required for open/close does not become a problem. In the case of repair docks, on the other hand, it is as many as 3 times a month on the average and open/close of the gate must be performed quickly. The flap gate takes only less than one-fifth that required for the pontoon type, and it can be said that the pontoon type is suitable for building docks, and the flap gate for repair docks.

For reference, double leaf gate (stop log type)[4] and concrete gate[5] were reported as gates for large docks besides the above-mentioned ones. And as for flap gates, cantilever type[2] is also available besides the box girder type and torsion type.

2.2 Box girder type flap gate (conventional type)

The conventional flap gate for docks was of box girder

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type as shown in Fig. 2 and it disclosed the following defects with increasing width of the dock sill:

(1) Imperfect water tightness at lower ends

When water pressure acts on the gate from the sea side, the central part of the gate is deformed as shown with two-dot chain line in Fig. 2. As the section of the box on the upper part has high torsional rigidity, torsional force is transmitted to both ends of the gate mainly by the torsional rigidity of the box section, torsional rigidity being proportional to the square of the sectional area of the box.

On the other hand, the sectional area of the box is almost in proportion to the moment acting on it, on the assumption that the box is a beam subject to uniformly distributed load neglecting the reaction force acting on the lower part of the gate. Furthermore, since the moment acting on the box is proportionate to the square of the gate span, the tendency to rotate is proportional to the fourth power of the span. Therefore, if the span of the gate exceeds its limit, the moment which could check the rotation due to static water pressure yields, at both ends, to the rotational moment due to the deformation of its central part, causing the lower parts of both ends to turn to the sea side, or jump up with the upper parts as supporting points. This makes it difficult to secure perfect water tightness.

(2) Increase in bending moment on the longitudinal girders in central part

This phenomenon has a relative relation with the turning to the sea side of the lower parts of both ends of the gate mentioned in (1). That is, the bending moment which acts on the longitudinal girders in the central part of the gate is $R \times L$ as shown in Fig. 2, but since the reaction force at the bottom in the jumping-up parts of both ends mentioned in (1) is 0, the reaction force in the central part increases to that extent, causing an increase in bending moment, too. This tendency becomes stronger with increasing gate span, and members with extremely large sectional areas become necessary.

(3) Large excavation quantity for rolling flap gate

In order to keep stress at a constant value when bending moment increases in proportion to the square of the gate span, the breadth b of the box section should be increased proportionately. Therefore, for the complete rolling of the gate it is necessary to excavate the sea bottom on the sea side up to a quantity matching the breadth b of the box section.

2.3 Features of torsion type flap gate

This gate is of totally enclosed section structure as shown in Fig. 3 and the breadth b of the section is smaller than about two-fifth of its height h. It is possible to reduce the size of the operating hoist for opening and closing the gate by providing a bouyancy tank in the interior and allowing it to balance with the weight of the gate. Three hinge brackets are fitted in the span direction, of which two at both ends only constrain reaction force as explained later, and one in the central part bears part of the difference between the weight of the gate and buoyancy only. Skin plates are outer plates of dock side and have drain

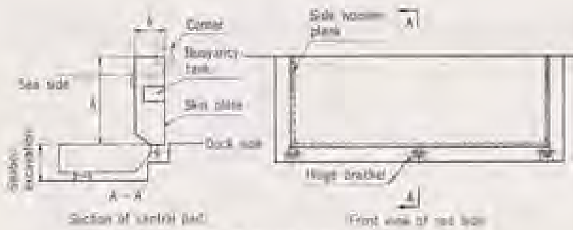


Fig. 3 Torsion type flap gate

holes near the bottom and top plates, allowing water to go in and out of the gate except the buoyancy tank. Besides, an air hole is bored on the top, and each skin plate has air pipe connection ports for use in the gate maintenance work. The details of these attachments are described later in this paper.

The new flap gate has not only eliminated all the defects of the conventional flap gate but also has many superior features. That is:

(1) Perfect water tightness

Having a totally enclosed section structure, the new flap gate has high torsional rigity. Rolling moment is generated when water pressure acts on the gate, but this rolling moment is transmitted to both ends of the gate by the torsional shearing and is balanced with the moment generated by the reaction forces acting from the side wooden plank and hinge brackets. That is, the lower parts of the ends are restrained by shifting the hinge brackets at both ends to the extreme ends, which eliminates the jumping-up of these parts, securing the perfect water tightness of the gate.

(2) No increase in moment in transverse girders

Water pressure acting on each cross section is considered, for the first approximation, to balance with the reaction force acting on its lower end, but the moment caused by difference in acting points is balanced with the torsional moment acting on the cross section of the gate leaf. As a result, the phenomenon of moment increase in the longitudinal girders inevitable in the girder type has been eliminated (**Fig. 4**).

(3) Small excavation quantity

The torsion type gate may be smaller in cross-sectional width as compared with the box girder type and this is because the box girder type bears load by bending rigidity only, while the torsion type bears it mainly by tor-

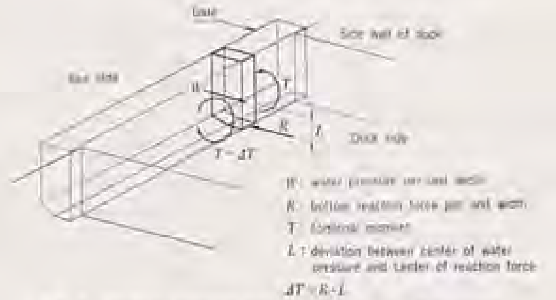


Fig. 4 Balance between torsional moment and moment due to reaction force at bottom

sional rigidity. That is, the modulus of section against bending increases in proportion to the breadth b of the section, while bending moment increases in proportion to the square of the gate span and therefore the breadth b of the box should be increased in proportion to the square of the breadth of the dock.

On the other hand, the modulus of section against torsion is proportional to the area of the section and torsional moment is proportional to the gate span. Therefore, it is not always necessary to increase the breadth b of the cross section with increasing breadth of the dock. In other words, there is roughly the following relation between the sectional shape and the breadth of the dock:

Bending rigidity: $b \times h' \propto (\text{breadth of dock})^2$

Torsional rigidity: $b \times h \propto$ breadth of dock

h : gate height

h' : box height

Consequently, the breadth b of the section of the torsion type gate is considerably smaller than that of the box girder type. According to a trial design, taking the Koyagi repair dock gate as an example, there were great differences between the two types as shown in **Table 1**.

Table 1 Comparison table between torsion type and box girder type

	Gate breadth b	Weight	Remarks
Torsion type	5.0 m	1 270 t	Dimensions of gate Width 100 m Height 13.5 m
Box girder type	9.0 m	1 900 t	

As is clear from the above-mentioned, the torsion type is reduced in section breadth b and therefore requires less excavation of the sea bottom on the sea side.

(4) Lighter in weight

Enclosed sectional form can resist torsion very effectively if its sectional area is large. Therefore it makes the design based on torsion possible and consequently reduces the plate thicknesses of necessary members remarkably, which results in a great decrease in the weight of gates. The relation between the dock dimensions and gate weight of the box girder type and that of the torsion type as obtained by trial calculation are roughly as shown in Table 1 and **Fig. 5**; the torsion type is much lighter in weight and more economical than the other in the case of gates with spans exceeding 50 m.

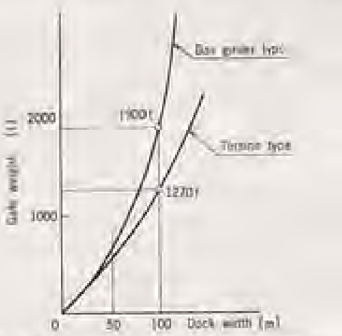


Fig. 5 Comparative weights of box girder type and torsion type gates

(5) Easy to manufacture

The torsion type is easy to manufacture as each component part is composed of stiffened panels and the whole structure is of enclosed section.

(6) Easy to open and close

As described in 2.1, the flap gate can be opened and closed more easily and quickly than the pontoon type. There are two methods of open/close system for flap gate, namely, compressed air system–gate is opened or closed by supplying compressed air from dock side into the gate or letting out from it[2][3], and operating hoist system–gate is opened or closed by hoist, via wire rope, fitted on dock side. By adopting the latter, this gate is opened or closed surely and quickly.

By the way, what always becomes a problem with the type using compressed air is the impact force just before the full-open or full-close condition during its open/close operation. For example, in rolling the gate, it begins to fall down slowly, but increases speed with the increase of its inclination, and falls down at the maximum speed just before the full-open. It is necessary to make thorough studies for reducing this impact force. Cases have been reported[2][3] in which a baffle wall as shown in **Fig. 6** was provided in order to reduce the impact force around the full-open of the gate as well as to prevent the gate from being flapped by a ship passing over it under fully opened condition. However, this baffle wall is not effective for the impact force at the full-close of the gate and it is necessary to make full investigations at the design stage.

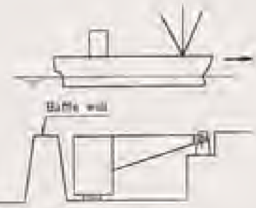


Fig. 6 Baffle wall

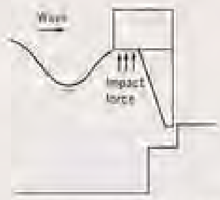


Fig. 7 Impact due to wave

(7) Strong resistance to waves

When the gate has protruded parts on sea side, it is necessary to design it with attention to waves from the sea (**Fig. 7**). That is, if waves get under the gate, the gate receives abnormally large impact force. Therefore, the height of the box girder is determined at the design stage so that the wave bottom would not come under the box[1] even if waves raid at low tide.

On the other hand, torsion type gate is of totally enclosed section and has no protruded parts on the sea side, and impact force in the vertical direction of waves does not become a problem. The torsion type is advantageous in this point, too.

(8) Ease of maintenance and inspection

As aforementioned, the lateral force of the load acting on the hinge brackets at both ends of the gate works

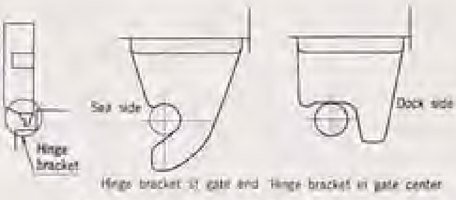


Fig. 8 Hinge bracket fitted to gate

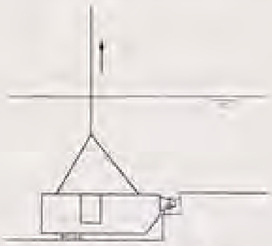


Fig. 9 Removal of gate

Fig. 10 Koyagi repair dock gate

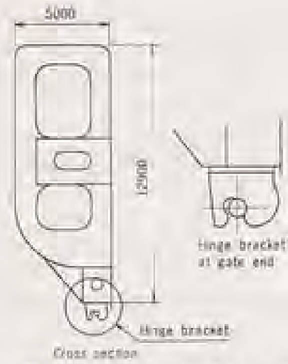


Fig. 11 Koyagi repair dock gate

Fig. 12 MSHI repair dock gate

in the direction from the dock side toward the sea side, while the vertical force always downward. And the hinge bracket in the central part bears part of the difference between the weight of the gate and buoyancy. Therefore, the hinge bearing can be shaped as shown in **Fig. 8**. These shapes have eliminated the underwater removing works of the hinge brackets(2) which have been performed by divers, also making gate removing and installing works extremely easy; for example, the gate can be lifted easily by crane in a rolled condition in water as shown in **Fig. 9**. Further, the adoption of plane structure for the outer plates on the sea side, to which marine life is apt to stick, facilitates cleaning.

3. Results of operation

The principal particulars of MHI's Koyagi repair dock gate (**Figs. 10, 11**) and MSHI repair dock gate (**Figs. 12, 13**) are shown in **Table 2**. Their structures are explained below on reference to Fig. 13.

The cross section of the gate is nearly of rectangular form having a breadth of 4.5 m and a height of 12.4 m and its sea-side bottom is partly trimmed so that it may not interfere with bottom concrete structure at the time of rolling down. The skin plates, i.e., plates on the dock side, are of totally enclosed section and have drain holes at its seaside bottom, allowing free entrance and exit of water so that excessive buoyancy may not be generated in the dock.

Buoyancy tanks having a breadth of 3.3 m and a height of 2.0 m are arranged over the entire span of the gate, and concrete ballasts are loaded in each buoyancy tank in order to make opening and closing operation surer. Buoyancy obtained by the buoyancy tanks is 555 tons and the weight of the concrete ballasts is 30 tons against the dry weight of the gate, which is 810 tons.

Diaphragms are provided at pitches of 3.16 m and each buoyancy tank is divided into 8 sections in order to increase safety. At the lower part of each end a hinge bracket (made of carbon steel casting), which can be said to be the vital part of this gate, is provided. For reference, reaction force acting on one piece of this hinge bracket is 1100 tons.

Reaction force acting on the upper part of each end is borne by wooden pressure bearing plates. The initial clearance between the pressure bearing plate on the concrete side and wood support metal coaming was set at more than 10 mm (**Fig. 14**). As for water-sealing rubber, easily deformable P type with a cavity in its head is adopted. The pressure bearing and water tight mechanisms of the bottom are the same as those of the side.

On the sea-side upper part of the gate, wooden planks are provided at 3 places for resting the gate, when rolled down on the base. Besides, fenders with a breadth of 300 mm and a height of 250 mm were provided over the entire span on the sea side in consideration of collision by ships. There are 4 man holes leading to the buoyancy tank rooms, 8 air holes at the top, and 8 air holes with valves each in the upper and lower parts for floating the gate on the water surface and for stabilizing it when it is afloat.

The plate thicknesses of the strength members are reduced toward the central part, where torsional moment is smaller, than at both ends, where the moment is bigger, thereby reducing the weight of the gate. The outer plates other than the skin plates are made thicker in the upper parts than the lower parts. This takes it into account that the direction of the shearing flow due to torsional moment

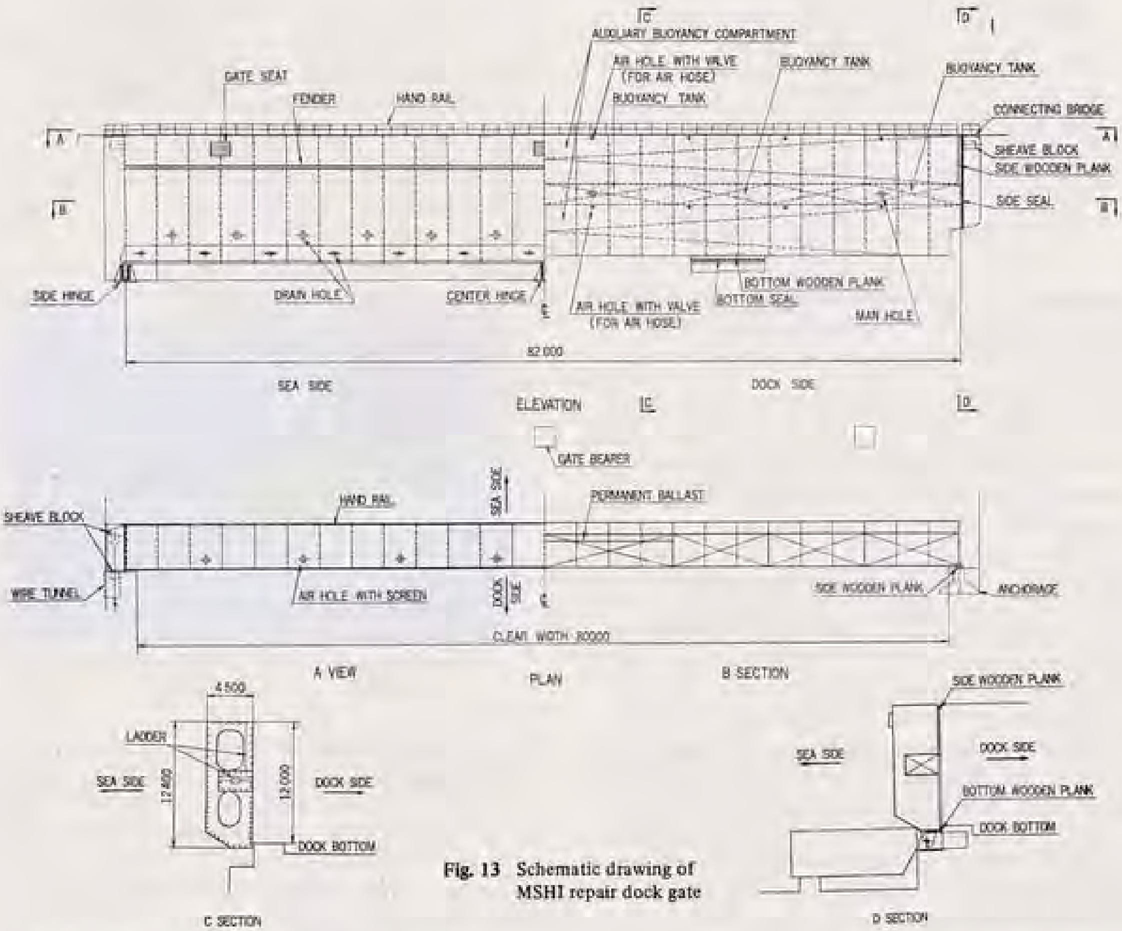


Fig. 13 Schematic drawing of MSHI repair dock gate

Table 2 Design criteria for Koyagi and MSHI repair dock gates

Item	Koyagi repair dock	MSHI repair dock	Remarks
1. Scale of dock	500 000 DWT	400 000 DWT	Max. ship that can be docked
2. Dimensions of dock sill	100m × 13.5m	80m × 12m	Breadth × height
3. Design criteria	Specifications for highway bridges	DIN	
4. Allowable stress			JIS SS41
Tensile stress	1 400 kg/cm²	1 450 kg/cm²	Against yield point of 2 500 kg/cm²
Shearing stress	800 kg/cm²	840 kg/cm²	
Orthogonal combined stress	2 100 kg/cm²	1 875 kg/cm²	
5. Dry weight of gate	1 270 t	780 t	Excluding ballast
6. Cross section	Fig. 11	Fig. 13	
7. Materials of main parts			
Outer plate	SS41, SM50	SS41 SMA41A,B,C	
Hinge bracket of gate leaf	SC49	SC49	
Pressure bearing plate at gate end	S35C	Kempus	
Wooden plank	Tub	Kempus	
Water tight rubber piece	Neoprene	Neoprene	
8. Anticorrosive plate	Alanode P-05	Alanode P-10S	

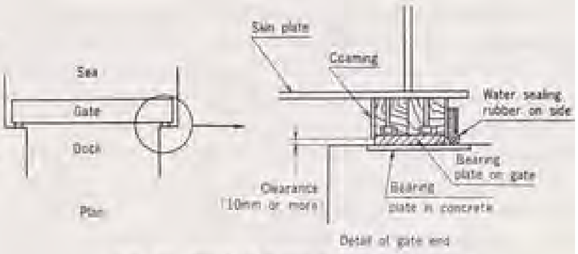


Fig. 14 Detail of water sealing mechanism

coincides with that caused by bending moment in the upper part but they are opposite in the lower part (**Fig. 15**). As regards plate thickness, the plates at both ends which bear almost all the reaction force of 1100 tons are thickest, being 65 mm and the average thickness of the outer plates is about 13 mm. A sheave box for mounting the sheave for open/close operation is provided in the upper part of each end.

As an important structure other than the gate leaf, there is a metal work, besides the embedded parts for securing water tightness, for transmitting reaction force (pulling force) of 1100 tons one side to the concrete walls. This metal work is composed of axles on which hinge brackets

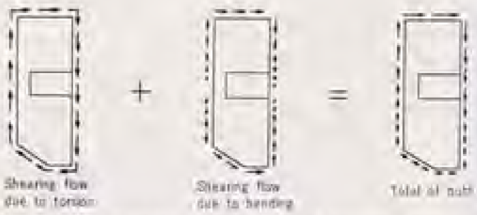


Fig. 15 Shearing stress on top and bottom plates

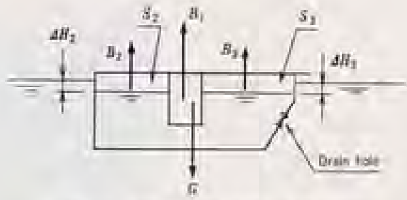


Fig. 17 Stability of MSHI dock gate

Fig. 18 Gate afloat on water surface for installation (MSHI)

of the gate leaf sit, pressure bearing plates for diffusing big load over the concrete and beams for transmitting the load received by the axles to the pressure bearing plates. This structure is, of course, installed in concrete.

After the completion of the Koyagi dock gate, the first unit manufactured by our company, we designed and manufactured the MSHI dock gate. This is a partially modified type of the Koyagi dock gate, the main improvements being as follows:

(1) Corner

In the case of the Koyagi dock gate, the corners of the section were rounded so as to allow torsional shearing to flow easily. On the other hand, in the case of the MSHI dock gate, knuckles were adopted for ease of manufacture (Fig. 3).

(2) Hinge brackets

The hinge brackets of the Koyagi dock gate were shaped as shown in Fig. 11 as the gate was planned to be lifted, when removing, after rolling about 10° from its full-close position. Those of the MSHI dock gate were so improved as to be removed in nearly horizontal condition by rolling down to its full-open condition (Fig. 8).

(3) Auxiliary tanks

The Koyagi dock gate is fitted with auxiliary buoyancy tanks in its lower part besides the buoyancy tanks in the upper part which are in usual use. The auxiliary buoyancy tanks are used for towing the removed gate on the water surface in stable condition (**Fig. 16**).

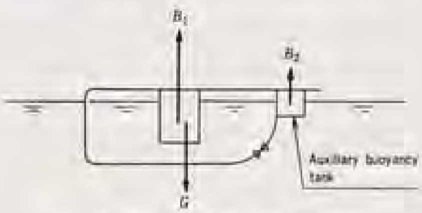


Fig. 16 Stability of Koyagi dock gate

On the other hand, the MSHI dock gate is not provided with auxiliary tanks and the buoyancy and stability of the gate afloating on the water surface are secured by making use of the space in the gate partitioned by the buoyancy tanks in the upper part. That is, the gate is floated on the water surface with the skin plates turned upward, so the air hole at the top of the gate is plugged beforehand, by which the sections S_2 and S_3 in **Fig. 17** are tightly closed. On the other hand, the water drain hole is left as it is so that water in the gate may go in and out freely. It is possible to float the gate by feeding air into the sections S_2 and S_3 with an air hose with the gate as lifted by a marine crane in this state (**Fig. 18**). This eliminates the need for auxiliary tanks in the lower part.

This method was employed for the installation of the gate, too.

4. Main items studied at design stage

Main items studied at the design stage are introduced below, centering on the MSHI dock gate.

4.1 Overall strength

The stress analysis of the strength members was made by replacing the gate structure with space frame.

(1) Calculation model (**Fig. 19**)

Constraint conditions were assumed as follows; that is, for nodal points 1, 4, . . ., n-2, which correspond to the bottom sill, and nodal point 2, which corresponds to the upper end part, displacement in the longitudinal direction (x axis) of the dock was constrained; for nodal point 3 at the end of the gate, which receives torsion mainly, rotation around the z axis, which is parallel to the dock sill, and displacement in the longitudinal direc-

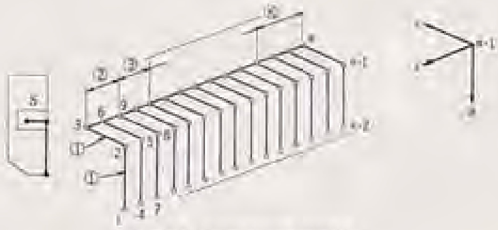


Fig. 19 Calculation model

tion (x axis) were constrained. Further, as the dock is symmetrical in the direction of the z axis, calculations for nodal points n-2, n-1 and n were made for one side only, and for n-2 displacements in each direction (x, y, z axes) and rotations around the x and y axes, which are parallel to the longitudinal and vertical axes of the dock respectively, were constrained; for n-1 and n displacement in the direction of the z axis and rotations around the x and y axes, which are parallel to the longitudinal and vertical axes of the dock, were constrained.

Members ②~Ⓚ were brought in line with the shear center, and the bending rigidity and torsional rigidity of the overall cross section of the gate were used. Member ① is a virtual member placed in the cross section at the position of the transverse member. As the deformation of the cross section is presumed to be small as compared with the overall strength of the gate, this member was regarded as a rigid member and a sufficiently high bending rigidity was used.

The design work was simplified by replacing the fairly complicated structure with a very simple model as mentioned above, but a sufficient accuracy required for the design could be obtained by this method, which was verified by strength test of a model gate with a span of 17 m and a height of 1 m.

(2) Input load

Load in 1 frame pitch was allowed to act concentratively on the shear center S, (nodal points 3, 6, . . . , n) (Fig. 19) and moment generated due to the deviation between S point and the center of water pressure was allowed to act on the S point simultaneously.

(3) Moment and displacement

Fig. 20 shows the results obtained in this way. Torsional moment reached max. 11000 t·m at the end, but bending moment was less than 3000 t·m in the central part. For reference, in the case of the box girder type (conventional type) bending moment was about 66000 t·m in the central part. This difference results from the fact that in the torsion type torsional rigidity is sufficiently larger than bending rigidity, making torsional moment dominant over bending moment. Herein an intrinsic feature of the torsion type is shown. Load transmitted to the end by bending rigidity is 430 tons out of the total load of 6410 tons. That is, 94% of the total load is transmitted by torsion. The calculated deflection of the central part obtained at this time was 84 mm, which corresponds to 1/976 of the supporting span.

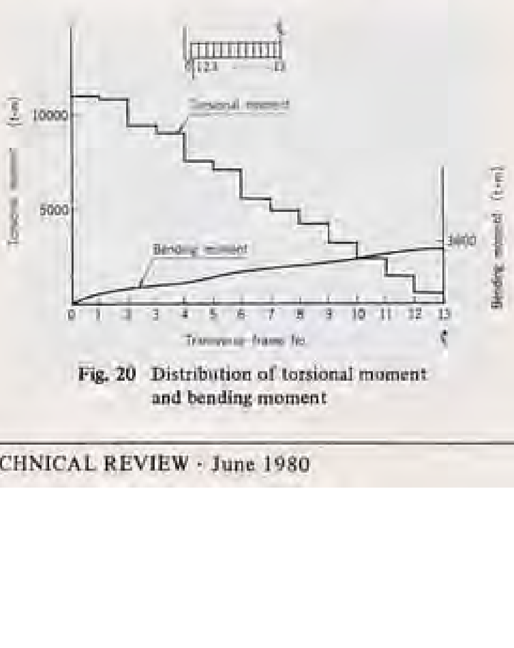


Fig. 20 Distribution of torsional moment and bending moment

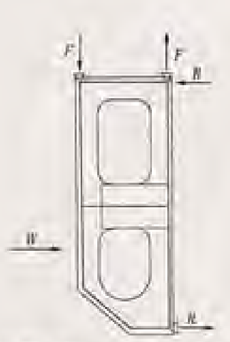


Fig. 21 Calculation model of transverse frame

Fig. 22 Bending moment on transverse frame

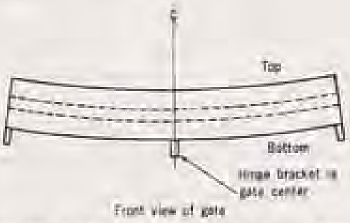


Fig. 23 Deformation of gate due to welding

4.2 Combined stresses

Stresses generated on the main section were obtained by use of the moment mentioned in 4.1. It is to be noted that local stress (out-plane bending of outer plates and bending of stiffeners) caused by water pressure was generated on the outer plates besides bending stress and shearing stress. For the combination of these stresses Mises's theory (shearing strain energy theory) was applied.

4.3 Strength of transverse frame

The strength of the transverse frame was analyzed by replacing it with a plane frame. **Fig. 21** shows the model. The distribution of bending moment is as shown in **Fig. 22**, the moment becoming the largest near the bottom sill and buoyancy tanks. When welding strain is released after the completion of the manufacture, it can cause deformation of the central part of the gate as shown in **Fig. 23**. In this case, if the water in the coffer-dam was drained at the time of installation of the gate, vertical load nearly equal to the total weight of the gate would act on the hinge brackets in the central part (**Fig. 24**). The strength of the frame in this case was analyzed three-dimensionally by the finite element method. The stress distribution obtained by this analysis is shown in **Fig. 25**, and displacement in **Fig. 26**. Stresses slightly exceeding the yield point existed locally, but as the gate leaf is a fairly flexible structure and its weight is diffused on the hinge brackets in the central part and at both ends, it was presumed that these stresses would have no practical effect. As the result, special reinforcement was not made at the time of installation.

Fig. 24 Middle transverse frame

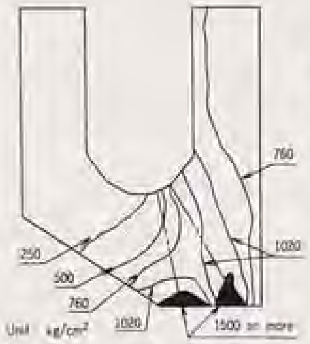


Fig. 25 Stress distribution on transverse frame

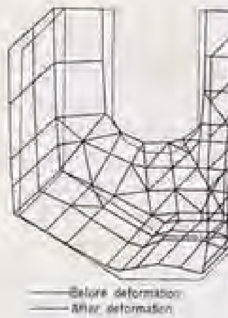


Fig. 26 Displacement of transverse frame

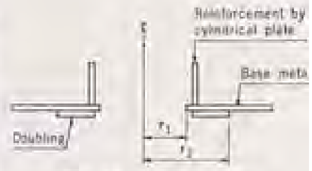


Fig. 27 Reinforcement for drain hole

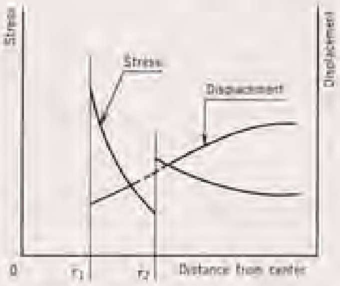


Fig. 28 Effect of reinforcement for drain hole

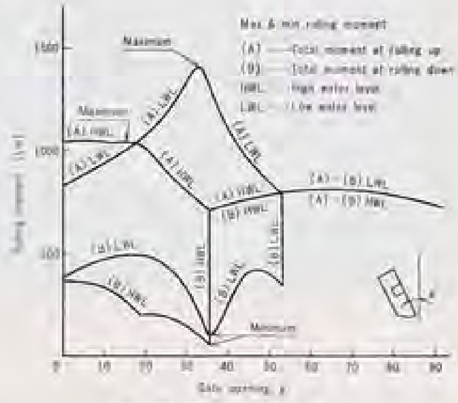


Fig. 29 Rolling moment

4.4 Reinforcement of drain holes

Drain holes were bored on the bottom plate so that water may go in and out of the gate leaf freely. Each hole was reinforced by the usual method of doubling and also by reinforcing the edge of the hole in cylindrical form as shown in **Fig. 27**. This reinforcement is aimed at reducing stress concentration around the hole and also at preventing buckling resulting from a decline in the rigidity near the hole. As data on cylindrical reinforcement[6] were few, the strength of the drain hole was analyzed by the finite element method. The stress distribution and displacement near the hole obtained in this way are shown in **Fig. 28**. Judging from displacement only, the cylindrical reinforcement attained the purpose; the rigidity near the hole after reinforcement increased more than twice that before reinforcement.

4.5 Stability of gate in open/close operations

The stability of the gate was investigated for the 2 cases; namely, at low tide and high tide, taking the following rolling moment into account:

(1) Rolling moment due to the weight of the gate (including buoyancy and ballasts)

(2) Moment due to the difference in water level between inside and outside of dock

If the upper part of the gate is above the water surface even slightly during open/close operation, water goes in or out of the dock through the clearance between the end of the gate and the side wall of the dock sill, making difference between the water level in the dock and that in the open sea. The water pressure caused by this difference in water level acts as resisting moment and prevents the gate from opening or closing.

(3) Moment due to difference in water level between inside and outside of gate

During the open/close operation of the gate, water goes in or out of the gate through the drain hole of the bottom plate. Delay in the entrance or exit of water causes difference in water level between inside and outside of the gate. As this pressure also acts as resisting moment, it was taken into account.

These moments were obtained by simulation or approximate calculation and the total rolling moment was arranged according to gate opening, which is shown graphically in **Fig. 29**. The time required for opening or closing the gate was about 10 minutes on the average.

4.6 Stability of gate at time of removal

When the gate is to be docked for maintenance or inspection, it is towed in the condition as shown in Fig. 17. Its stability was discussed not only when it is afloat on the water surface but also when it is stranded. Its stability when it is laid on the blocks in dock was also discussed.

4.7 Wave pressure

Horizontal wave pressure was taken into account by raising the design water level. That is, a water level higher than the water level at high tide plus the water level corresponding to the wave force obtained from Sainflou's formula was assumed (height of the dock wall) and was used as the design water level (**Fig. 30**).

4.8 Effect of deposits

As the gate is of totally enclosed section construction and sea water can go in and out of the gate freely through

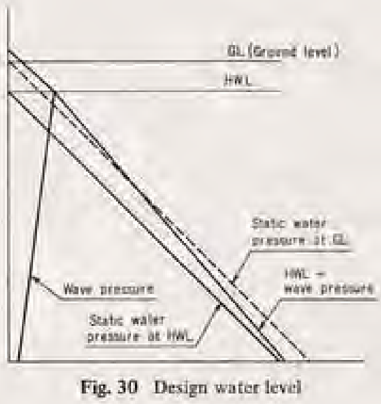


Fig. 30 Design water level

the drain hole at the bottom, muds and other foreign substances suspended in sea water precipitate in the gate, causing increase in opening or closing load. According to a calculation, if foreign substance with specific weight of 1.8 is deposited at the bottom to a thickness of 50 cm, opening or closing load increases by 6%; however, this value is not such a large value as to pose a problem. For reference, in the first inspection of the Koyagi dock gate carried out in August 1979 (6th year after the commencement of commercial operation) about 50 tons (underwater weight) of mud and marine life were found sticking to the inside and outside of the gate (**Figs. 31, 32**). This weight corresponds

Fig. 31 Gate dry-docked for maintenance (Koyagi)

Fig. 32 Shellfishes attached near hinge bracket (Koyagi)

to about 4% of the weight of the gate.

4.9 Wood

Kempus, which is easily obtainable and having a high strength exceeding 500 kg/cm^2, was adopted for ease of maintenance. Particularly, the material to be used for the contact surface with the embedded parts was worked up with special care, taking installation error into account, as 1100 tons of reaction force one side acts on the pressure bearing parts of the upper parts of both ends.

4.10 Anticorrosive positive plates

The hinge brackets to be embedded in the concrete layer cannot be replaced, repaired or even repainted. Therefore, as an anticorrosive measure, anodic positive plate was provided. This is aluminium electrode, Alanode P-10S and has a life expectancy of about 10 years. Two pieces were provided for each hinge bracket.

4.11 Load acting on concrete structure

As mentioned above, load acting on the concrete from this gate is different in tendency from that of the box girder type flap gate. As this is the most important point for the design and construction of the gate, it is explained in more detail below.

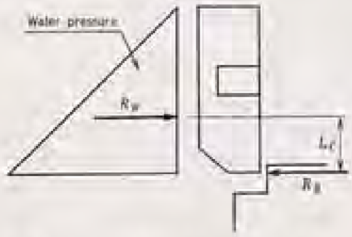


Fig. 33 External force acting near the center

Water pressure from the sea side acts on the part with a height L_C from the bottom of the gate (**Fig. 33**). On the other hand, reaction force acts on the bottom of the gate, and a difference in the acting points of 2 external forces causes the generation of moment. Since 6% of the total water pressure is transmitted to both ends by bending rigidity, reaction force R_B is slightly smaller than water pressure R_W. If reaction force is represented by R_B the intensity of moment becomes:

$$M = R_B \times L_C$$

This moment is transmitted to both ends by the torsional rigidity of the gate. In order to bear this moment, a wooden bearing seat was arranged in the upper part of each end where compressive force acts, and a supporting pin at the bottom where pulling force acts (**Fig. 34**). If the reaction force acting on the wooden bearing seat is represented by R_T, and that acting on the supporting pin R_H, R_H becomes almost equal to R_T. Assume that the distance between R_H and R_T is L_E. As the moment caused by these reaction forces ought to be balanced with the moment caused by external forces as mentioned above,

$$R_H \times L_E = 1/2M$$
$$= 1/2 \times R_B \times L_C$$

Consequently, the reaction force of the supporting pin can be given by the following expression:

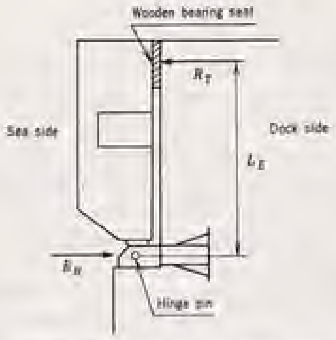


Fig. 34 Reaction force at both ends

$$R_H = 1/2 \cdot R_B \cdot \frac{L_C}{L_E}$$

The direction of the reaction force R_H is from the sea side toward the dock side and a large pulling force acts on the concrete of the end wall. The intensities of each external force and reaction are approximately as follows:

R_W = 78 t/m
R_B = 73 t/m (average)
$R_H = R_T$ = 1100 t

5. Installation procedure

The construction of the gate was carried out in the dock in parallel with that of the dock. With the completion of the gate, water was poured into the temporarily coffered dock, then the gate was floated (Fig. 18) and set at the specified position. The procedure is shown in **Table 3**. This procedure shortened the term of the work to a great extent.

6. Measurement of stress and deflection

After completion, water in the dock was drained and various functional tests including the measurement of stress and deflection were performed. This article shows the results of measurement performed in the MSHI dock gate in April and July 1976. The second measurement was to confirm that there had been no change in the gate with the lapse of time.

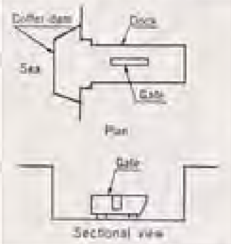
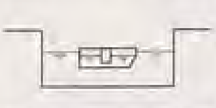
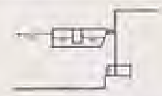
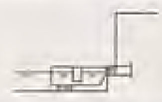
6.1 Results of stress measurement

In the measurement of stress, 45° three-direction strain gauges were fitted at 3 places, namely, at the end, central part, and their intermediate point of the top plate of the gate, and to secure the accuracy of measurement 2 pieces were attached at each point (**Fig. 35**). The results of the 2 times of measurement showed the same tendency, the experimental values being about 10% smaller than the calculated values. An example is shown in **Fig. 36**. There was no change in the structure of the gate with the lapse of time.

6.2 Results of deflection measurement

Deflection of the central part was measured by setting a scale on the top plate and peeping through a transit from both ends. **Fig. 37** shows the results, which are in good agreement with the calculated values.

Table 3 Installation procedure for MSHI dock gate

Step	Condition of gate	Explanation
1		Gate is constructed as one block in dock.
2	Water is poured into coffer-dam.	
3		When water has reached a specified level, air valve on skin plate is closed and gate floats up (Fig. 18).
4	Gate is towed to dock sill and half-turned.	
5		
6	Water is drained from coffer-dam.	
7		(1) Gate is set with hinge brackets. (2) Gate is wired to winch. (3) Water inside and outside gate is equalized by opening air valve, and the valve is closed again.
8	Water is poured into coffer-dam.	
9		When water level in coffer-dam has risen sufficiently high, gate is raised with winch.
10	Lay down is finished	

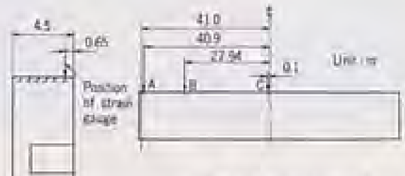


Fig. 35 Position of strain gauge

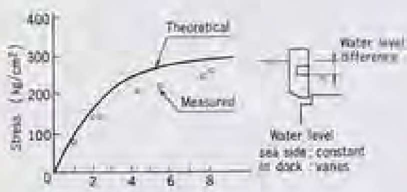


Fig. 36 Results of stress measurement

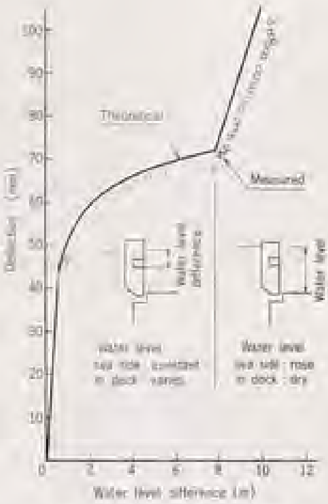


Fig. 37 Results of deflection measurement

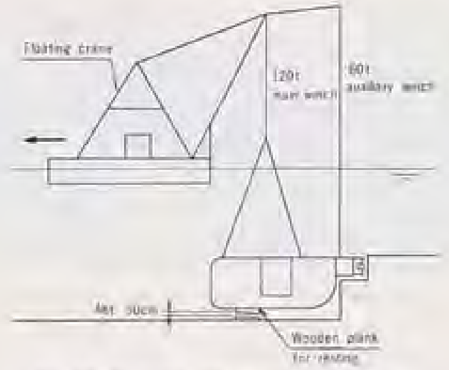


Fig. 38 Removal of Koyagi repair dock gate

6.3 Extension and contraction of gate

When the ends of the gate were inspected during measurement, shifts of 8 mm and 6 mm were measured on the left and right sides respectively against a change of 13°C in the atmospheric temperature. These values are in good agreement with the calculated value of 6.4 mm due to a temperature change of 13°C.

6.4 Opening and closing load

Opening and closing load estimated from the value of current flowing on the operating hoist was about 11 tons, indicating that the operating hoist has a margin of 18% in capacity compared with the design value of 13 tons. The difference between the estimated value and the calculated value is presumably because the behavior of water in the gate and that in the dock at the time of opening and closing was taken on the conservative side.

6.5 Other inspection items

In addition to the above-mentioned measurements, the following points were checked up in order to confirm the safety and design functions of the gate:

(1) Water sealing function
(2) Contact condition of the bottom and side planks
(3) Buckling strength
(4) Strength and function of supporting part

7. Maintenance of Koyagi dock gate

An overall periodical inspection was given to the Koyagi repair dock gate in August 1979 after 6 years from its completion. As this was the first experience for torsion type flap gates for docks, the results are reported below.

(1) Method of gate removal

At the beginning, it was scheduled to remove the gate by pulling it up almost right above, in the state inclined toward the sea side by about 10° from full-close condition, using a floating crane having a lifting capacity of about 500 tons. However, as the maximum capacity of the floating crane that could be borrowed in the Nagasaki Harbor at that time was 120 tons, similar method to that used in the MSHI dock was adopted in place of the above method. The deficiency in buoyancy was supplemented by use of auxiliary tanks. The procedure of removal is shown in **Fig. 38**; the underwater part of the gate was lifted up by the main winch of the crane until its wooden plank was off 30 cm above the top of the base. Then, by lifting up its bottom by the auxiliary winch, the gate was pulled out toward the sea side. This work was carried out smoothly and, after lifting up the gate released from the hinge brackets up to 3 meters below the water surface, it was docked in the adjacent building dock and laid on the blocks (Fig. 31).

(2) Facilities used and time spent for removal

The main facilities used from the start of the gate removing work till its laying on the blocks are as follows:

(a) 120-t floating crane	1 unit
(b) Tug boat	4 boats (including 2 boats for operation of building dock gate)

Besides, 3 divers were employed in this work to confirm the underwater condition of the gate. The work started at 5 a.m. and its laying work finished at 3 p.m. of the same day. Time required for the work was about 10 hours as scheduled.

(3) Inspection items

Overall inspection of this gate will be performed once in every 5 years with the following as the check points:

(a) Removal of marine life
(b) Removal of mud and other foreign matters
(c) Repainting
(d) Replacement of water-sealing rubber
(e) Replacement of wooden plank
(f) Replacement of anticorrosive plates
(g) Inspection of outer plates
(h) Inspection of sheave mounting beam
(i) Inspection of hinge brackets at both ends
(j) Inspection of pressure bearing plate on side
(k) Inspection of sheave bearing

(4) Results of inspection

There were no damage in the items stated in (g) to (k), showing the reliability of this gate.

8. Discussion

In the above, our design concept, structural details, actual examples, results of measurement, maintenance, and inspection of the torsion type flap gates for docks were described, which are summarized as follows:

(1) The superiority of the torsion type flap gate has been verified, i.e.:
 (a) Good water tightness
 (b) Superior in strength (light in weight)
 (c) Small excavation quantity at sea bottom
 (d) Easy to manufacture
 (e) Easy to open and close
 (f) Less trouble for maintenance and inspection

(2) The following improvements have been made through the 2 achievements in the Koyagi and MSHI repair docks, i.e.:
 (a) Hinge brackets can be so constructed as to be removable in full-open condition.
 (b) Auxiliary buoyancy tanks can be dispensed with if the enclosed section of the gate can be used as buoyancy tank.

(3) Differences between the design values and the experimental values of stresses and deflections were less than 10%, suggesting that the method of modeling adopted at the design stage is appropriate.

9. Conclusion

As described above, the torsion type flap gate is superior in all respects including economical advantages and safety for use in large docks. Further, valuable data were obtained through the design, manufacturing and operational experiences of the 2 units mentioned above. It is a great pleasure for us if this paper is of use in the planning of large (repair) docks in the future.

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