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Safeguard System of the Bisan-Seto-Bridge in Japan

Protection du pont Bisan-Seto, Japon

Schutz der Bisan-Seto Brücke in Japan

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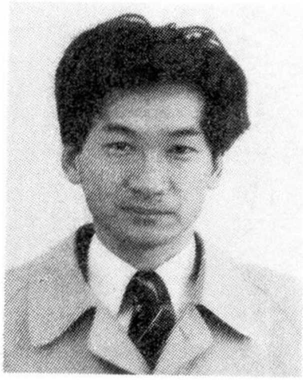

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SUMMARY

This paper deccribes the behaviours of ships passing near a bridge pier and of the colliding ships with the pier, and also deals with the deformation characteristics of ships and protections. The performance of the protection to be installed on one of the piers of the Honshu-Shikoku Bridges is presented.

RÉSUMÉ

L'article décrit le comportement de navires près des piles de pont et lors de collisions avec celles-ci. Il traite les caractéristiques des déformations des navires et des protections. L'article présente la protection qui doit être réalisée pour une des piles du pont Honshu-Shikoku.

ZUSAMMENFASSUNG

Dieser Aufsatz behandelt das Verhalten von Schiffen in der Nähe eines Brückenpfeilers sowie die Kollision mit dem Pfeiler. Verformungseigenschaften von Schiffen und Schutzwerken werden beschrieben. Der Schutz eines Pfeilers der Honshu-Shikoku-Brücken wird dargestellt.

1. INTRODUCTION

In Japan, the Kojima - Sakaide route of the Honshu-Shikoku bridge project is now under construction as shown in Fig.1. The main bridge of this route is the Bisan-seto Bridge which spans the main traffic route of ships. The traffic of this route is more than 450ships per day. The massive piers of the bridge are builded in this ship's passage of the Bisan Straits where the water depth is over 30m and the tidal current is about 4knots. Consequently the probability of ship collision with the piers is existed.

This paper describes the fundamental investigation about the safeguard system against the ship collision with the piers of the Bisan-seto Bridge and the details of the protection already installed on one of the piers tentatively as shown in Fig.2.

2. BEHAVIORS OF SHIP COLLISION WITH PIER

In this waterway the environmental conditions affected on the ship's handling are severe considerably. Because, the tidal current is very strong and moreover westerly wind becomes rough in winter. Sometimes these severe conditions adversely affect on ship's steering. In this chapter, the behaviors of the ship collision which is caused by such strong current or wind are presented.

Fig.1 The Kojima-Sakaide Route of the Honshu-Shikoku Bridges

2.1 Flow Pattern around the Pier in Current or Wind

The flow of the tidal current or wind around the pier is curved. Fig.3 and 4 show the velocity distribution or the streamline around the pier in the tidal current or wind. In Fig.3 the result by model experiment coincides with the result of full-scale measurement. Fig.4 is the example of the model experiment in the model basin with wind tunnel. It is observed that the velocity becomes high by 15 ~ 20% on the transverse side of the pier. These current or wind velocity distributions around the pier is almost represented by potential flow for the ideal fluid [1].

Fig.2 The Protection Installed on the No.5 Pier of the South Bisan-seto Bridge

2.2 Collision of Navigating Ship in Current or Wind

When a ship passes through

near the pier, she deviates her course from the original path by the unsymmetrical force and moment. This force and moment is occured by the sheer flow near the pier and occasionally brings on the ship collision with the pier. In Fig.5 and 6, the boundary of ship course clearance to the pier side (Y_o), for keeping on safe navigation are presented. They are obtained by the simulation which is used the steering motion equations of the ship[2].

The course clearance to the pier for keeping safe navigation which is shown by the ratio of Y_o to the pier width (B_p) is depended on the velocity of current or wind to ship speed (V_c/V_s or V_a/V_s).

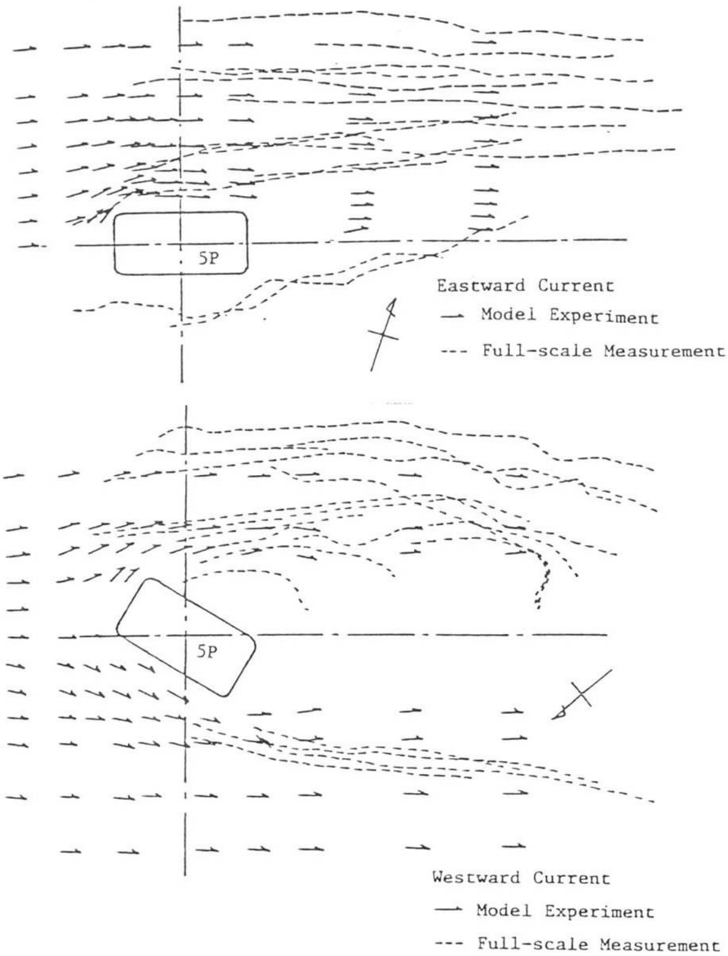


Fig.3 Flow Pattern around the No.5 Pier

2.3 Collision of Drifting Ship in Current or Wind

When a ship is unsteerable owing to her engine or rudder trouble she is just drifted by current or wind.

2.3.1 Drifting in Current

According to the model experiment the behaviors of unsteerable ship under current are as follows.

(1) drifting course
In Fig.7 the dangerous drifting course of ship to come into collision under the current is shown. It is noticeable that if the ship's heading obliques to the current direction, the ship is drifted not downstream but diagonally.

(2) colliding speed
In Fig.8, the ship's colliding speed (Vsc) with the pier under the strong current is presented with the ratio to the current velocity (Vc). The colliding speed increases as the growth of the transverse distance between the colliding position and the center of the pier (Y). The colliding speed increases by about 20% of current velocity (Vc) when the ship collides with the corner of the pier.

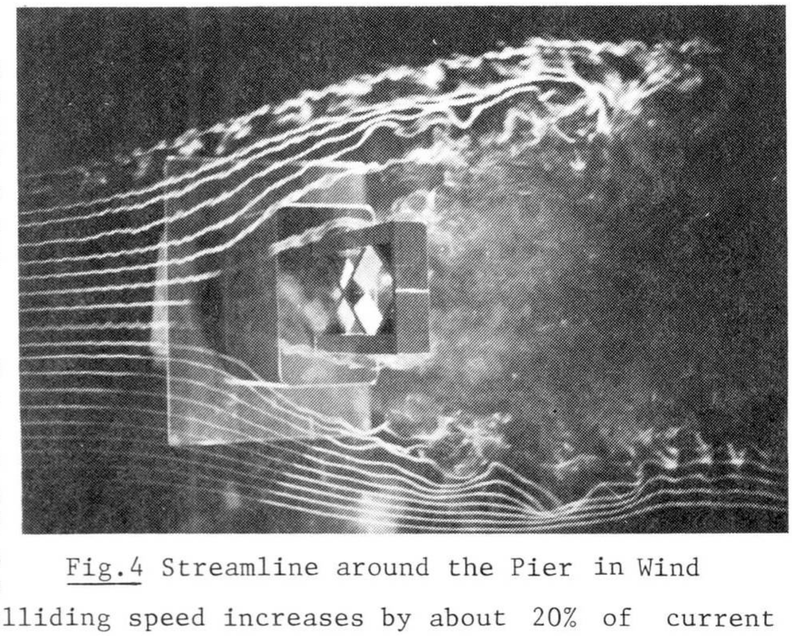
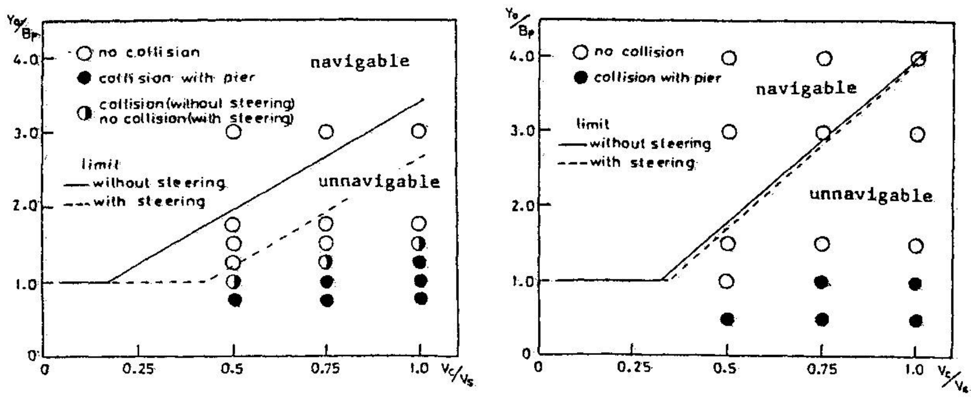


Fig.4 Streamline around the Pier in Wind

2.3.2 Drifting in Wind

According to the model test results the unsteerable ship is drifted by wind down abeam and the drifting speed is described as following formula,



(a) reverse current (b) fair current

Fig.5 Boundary of Navigability of Ship in Current
(Breadth of Pier / Length of Ship = 0.54)

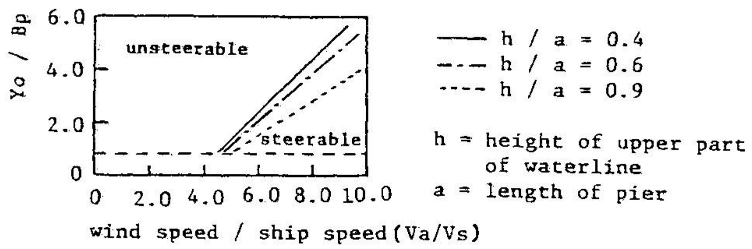


Fig.6 Boundary of Navigability of Ship in Beam Wind

$$Vs = 0.041\sqrt{\frac{S}{L\,d}}\ Va \qquad (1)$$

where Vs; drifting speed of ship in wind, S; transverse projected area of ship, L; length of ship, d; draft of ship, Va; velocity of wind.

Moreover the speed of the ship collided with the pier is increased by the confused wind around the pier as shown in Fig.9. The colliding speed increases by about 10% of the speed (Vs) obtained from the formula (1) on the case of collision with the corner of the pier [3].

3. STRENGTH CHARACTERISTICS OF SHIP AND PIER PROTECTION

3.1 Load-Deformation Characteristics of Ship

Static collapse tests were conducted to examine the load-deformation characteristics using steel bow models which simulate the transversely framed structure of cargo - type ship of 500 GT and 4000 GT. Calculated formulae to the load-deformation characteristics are as follows,

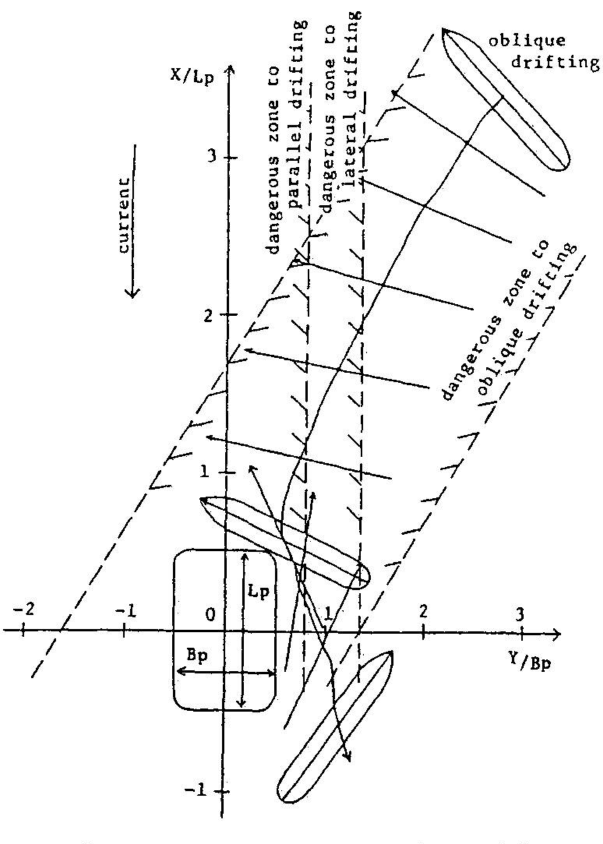


Fig.7 Dangerous Zone to the Drifting Ship in Current

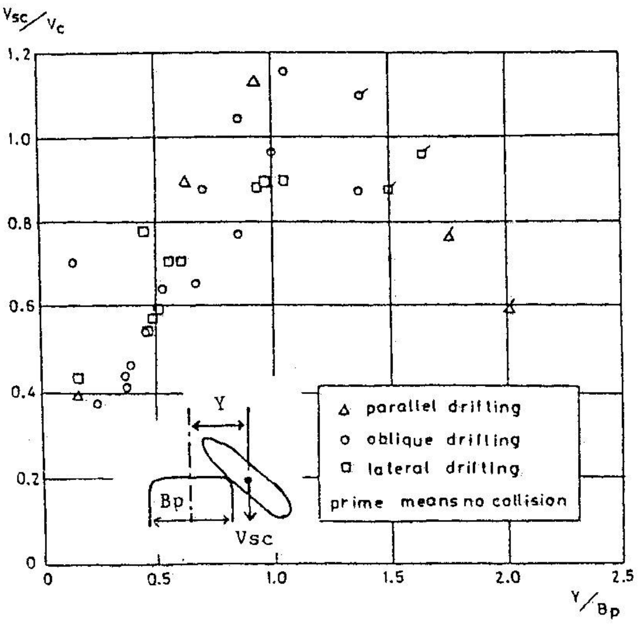


Fig.8 Colliding Speed of Drifting Ships in Current

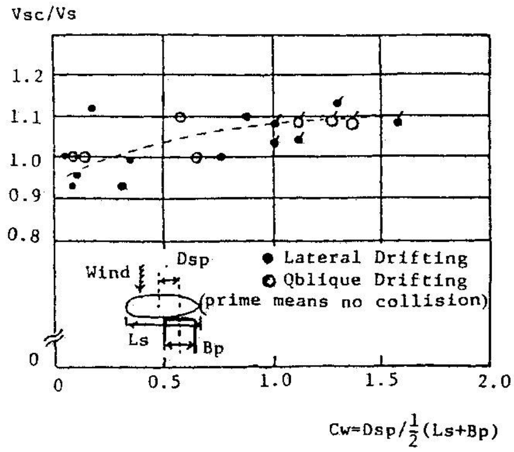


Fig.9 Colliding Speed of Drifting Ships in Wind

(1) bow collision with the straight-part of the pier

$$P = 2.72\delta_F^{-1} W^{1/3}(0.71W^{1/6}+1)^3 X \quad \text{in } 0<X<\delta_F \qquad (2)$$

$$P = 2.72W^{1/3}(0.71W^{1/6}+1)^3 \quad \text{in } \delta_F \le X \qquad (3)$$

(2) ship-side collision with the corner of the pier

$$P = 83.1r^{-1/3}(0.95W^{1/6}+1)(0.57W^{1/3}+4r)X^{1/2} \quad \text{in } 0<X<2r/9 \qquad (4)$$

$$P = 39.2r^{1/6}(0.95W^{1/6}+1)(0.57W^{1/3}+4r) \quad \text{in } 2r/9 \le X \qquad (5)$$

where P;collapse load (ton), X;deformation (m), W;gross tonnage (GT), δ_F;raked stem length, r;corner radius of the pier.

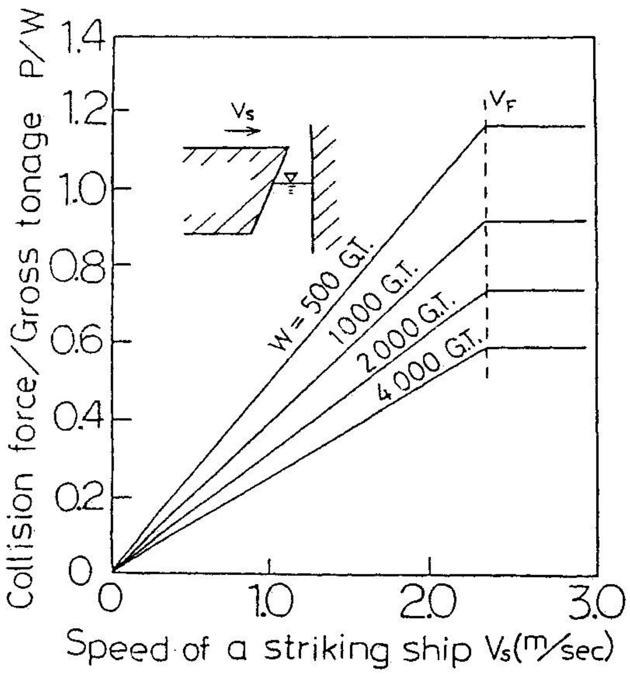


Fig.10 Estimated Impact Forces at the Bow Collision

Using the simplified load-deformation curve, ship impact forces can be estimated. In Fig.10 the estimated results are shown for the ship-bow collision with a right angle against a straight-part of the rigid bridge pier [4].

According to Fig.10, V_F which is the collided speed resulting in the full collapse of the part of the raked stem is equal to about 2.3 m/s for every ship ranging from 500 GT to 4000 GT. Maximum impact force is estimated to be about 580 tons for the 500 GT ship. Similarly load-deformation curve is estimated in the case of the ship-side collision against a corner of the rigid bridge pier.

Impact force which the drifting ship receives from the buffer is examined theoretically by one of authors [5]. Hereon, it is assumed that the ship is rigid and buffer is deformarable. Calculated formula is

$$P_M = (V_s + L_c\ \omega s \cos\theta)\sqrt{\frac{k}{1/M_{v\phi} + L_c^2 \cos^2\theta / I_v}} \tag{6}$$

where, $M_{v\phi}$; virtual mass of ship in ϕ direction($=M_{v\xi}\cos^2\phi + M_{v\eta}\sin^2\phi$), k ; spring constant of the buffer, V_s;drifting speed of ship, L_c;the length between center of ship and colliding point (oc), ω_s;angular velocity of ship, θ;angle between oY and oc, I_v ;virtual moment of inertia around center of ship, $M_{v\xi}$;virtual mass of ship in ξ direction, $M_{v\eta}$;virtual mass of ship in η direction, ϕ;angle between oξ and V_s. The experimented data of the impact force are rather good agreement with calculated value in Fig.11.

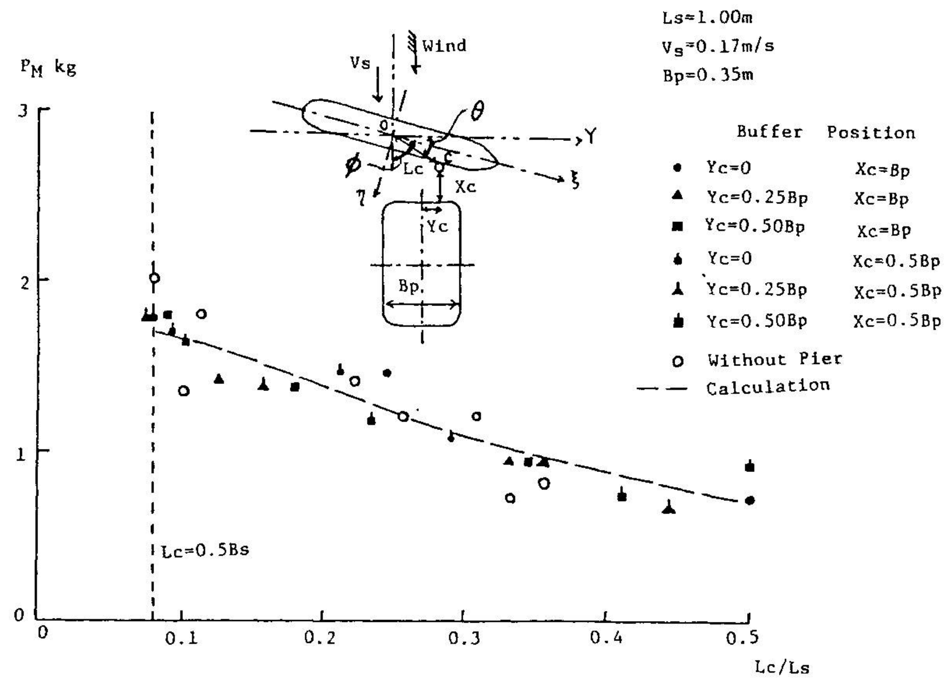


Fig.11 Impact Forces of Drifting Ship in Wind

3.2 Load-Deformation Characteristics of Protection

Judging from the viewpoint of designing the ship-pier protection, it may be said that the impact forces should be reduced to the values less than the buckling loads of the bow hull plate by means of effective buffer devices installed on the pier. The comparisons between the force - bow penetration curve for the four kinds of buffer devices are shown in Fig.12. It appears from Fig.12 that the composite type buffer device which is made from hard polyurethane foam has almost linear characteristics in the relationship between the force and the ship penetration while other three kinds of buffer devices have somewhat complicate characteristics.

It can be stated from the viewpoint of practical designing that the composite type is the most suitable buffer device among the proposed ones. The composed deformations of the bow and the respective buffer devices can be estimated from the linear combination of each load-deformation curves.

In case of the design of the protection installed on No.5 pier of the South Bisan-seto Bridge, it is based on these characteristics about the ship impact force and the bow penetration for the buffer device.

4. DETAILS OF PROTECTION INSTALLED ON THE NO.5 PIER

4.1 Collision Pattern and Size of Ship

The protection of No.5 pier of the South Bisan-seto Bridge was constracted tentatively. The behaviors of the ship collision to the pier are described in the chapter 2. Moreover, in the Bisan Straits the ship traffic route is already established according to the separation schemes by the IMO recommendation. It has the clearance of about 120m between the boundary of the traffic route and the pier.

From these situations, the conditions about the design of the protection installed on No.5 pier are set up as shown in Tables 1 and 2.

4.2 Design Conditions of No.5 Pier Protection

In order to design the protection of No.5 pier, the strength of the ship and the allowance of collapse are estimated as shown in Tables 3 and 4. Environmental conditions is that wind velocity is 37.5m/s, significant wave height is 2.5m, significant wave period is 4.8 s, significant wavelength is 35.9 m, maximum wave height is 4.5 m and tidal current velocity is 4.5 knots. The protection of No.5 pier is composed of grid-composite type buffer and rubber fender as shown in Fig.13.

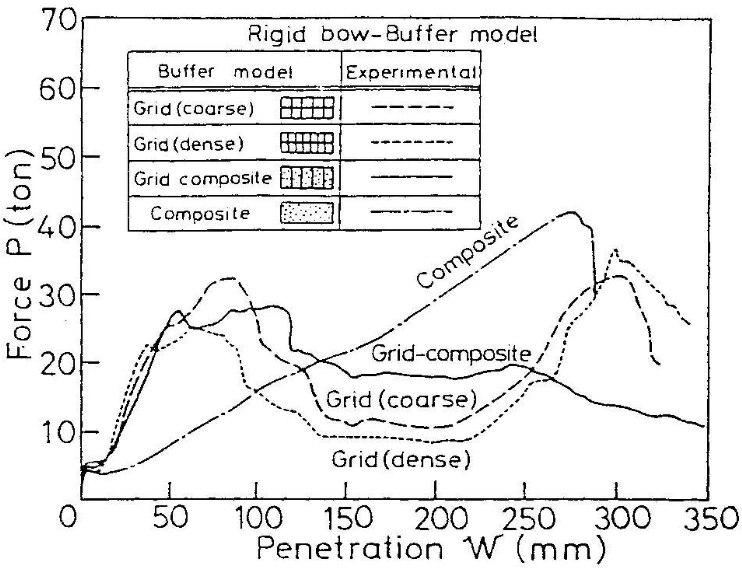


Fig.12 Comparisons between the Force-Bow Penetration Curves for Four Kinds of Buffer Devices

Size of Ship		Colliding Speed
Fishing Boat	(Displacement10ton)	4 knots
Passage Crossing Ship	(200 GT)	8 knots
Passage Crossing Ship	(500 GT)	8 knots
Drifting Ship	(500 GT)	5 knots

Table 1 Size of Ship and Colliding Speed

Kind of Ship	Colliding Forms	
	Ship	Pier
Navigating Ship	Bow	Straight-part
Drifting Ship	Ship-side	Corner

Table 2 Colliding Forms

Size of Ship	Raked Stem Length	Strength of Bow	Strength of Ship-side
10 Disp.ton	———	———	7 ton/m^2
200 GT	0.83 m	186 ton	10 ton/m^2
500 GT	1.13 m	366 ton	14 ton/m^2

Table 3 Strength of Ship

Part		Critical Allowance
Ship	Bow	the collapse within 2/3 length from bow to collision bulkhead
	Ship-side	the collapse within elastic deformation
Buffer Device		the collapse of the main structure
Bridge Pier		no movement, no overturn having not a bad effect on upper structure

Table 4 Allowance of Collapse

In case of design and selection of the pier protection, the problem about the water depth, the water area, the range of tide and the maintenance is also considered.

4.3 Evaluation

It is recognized by the members of the technical committee of the Honshu-Shikoku Bridge Authority that this safeguard system is effective through the experience of about one year after installation. Moreover it is under going to study about the several problems against the environmental conditions such as current and wave.

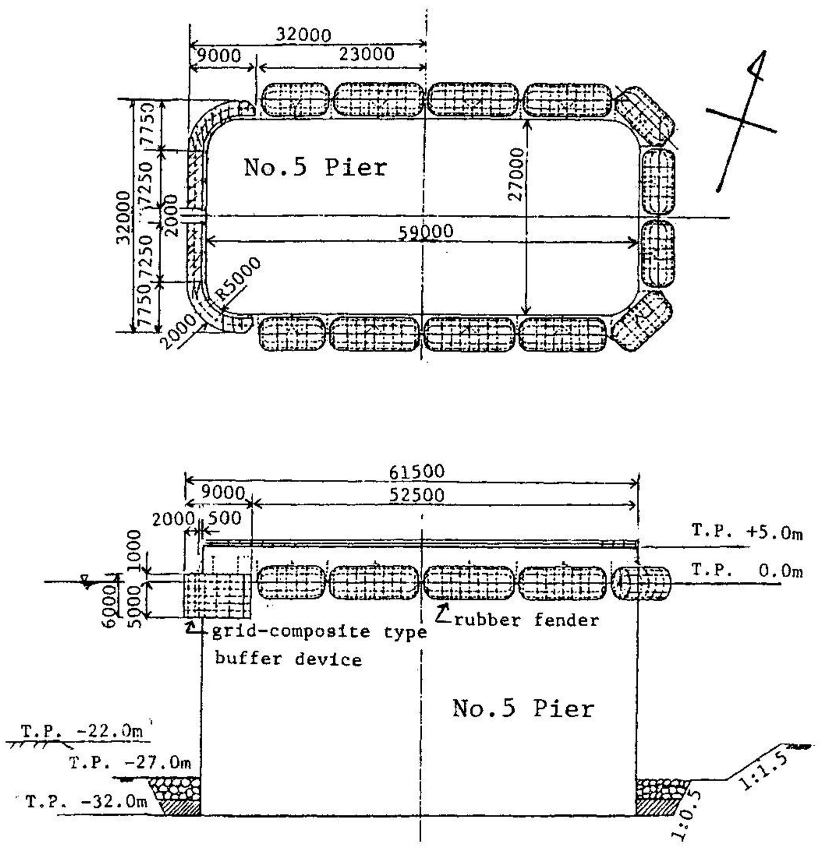


Fig.13 Details of Protection Installed on the No.5 Pier

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