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Design Specification of Buffer Structure

Spécification du projet pour la structure des butoirs

Entwurfs-Daten des Puffertragwerkes

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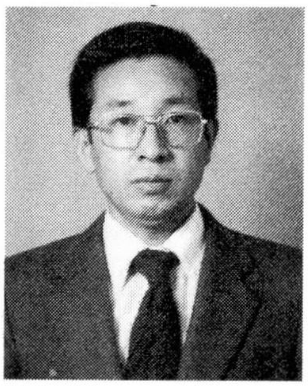

Hiroo Jin, born 1942, got his civil engineering degree at the Kyushu University, Fukuoka, Japan. For 9 years he has been involved in the design and construction works and is responsible for the design of the substructure of the bridges.

SUMMARY
This paper introduces the outline and principle of design of the multi-cell type buffer attached to the marine pier of the long-spanned suspension bridges under construction between Honshu and Shikoku of Japan. The multi-cell type buffer described in this paper is a box typed steel structure with stiffners, for the purpose of absorbing the collision energy by crushing itself when a ship collided with the pier, which will minimize the damage of the ship and protect the pier.

RÉSUMÉ
Ce document présente les principes du butoir de type multi-cellulaire fixé aux piles des ponts suspendus de grande portée en cours de construction entre Honshu et Shikoku (Japon). Le butoir de type multi-cellulaire décrit dans ce document est une structure d'acier en caissons avec des raidisseurs dans le but d'absorber le choc de la collision en se déformant lorsqu'un bateau entre en collision avec une pile, ce qui minimise l'endommagement du bateau et protège la pile.

ZUSAMMENFASSUNG
Die Entwurfsgrundlagen der Multizellen-Puffer an den Wasserstrompfeilern der langen Hängebrücken, die im Augenblick zwischen den japanischen Inseln Honshu und Hokkaido gebaut werden, werden dargestellt. Der Multizellen-Puffer ist ein Stahlkastentragwerk mit Versteifern, der die Kollisionsenergie beim Aufprall eines Schiffes auf den Strompfeiler durch Verformung absorbieren soll: dadurch wird der Schaden am Schiff verkleinert und der Strompfeiler geschützt.

1. PREFACE

At present, long spanned and large suspension bridges crossing the Seto-Inland sea between Honshu and Shikoku, are under construction by Honshu-Shikoku Bridge Authority. The clearance under the beam and the pier points of those bridges have been decided for the safety of navigation. Also, such navigation aid system as navigational signals, light equipments or radio beacons are installed, therefore the provability of a ship collision with the pier is very small. However, Seto-Inland sea is congested with many ships, therefore it is strongly required to prevent such accidents as the sinking of ships, run-off of oil, etc. even in the case of an unexpected ship collision with the pier e.g. due to mis-operation of the ship under bad weather. To comply with this requirements, the Authority has endeavoured for the various investigation for the buffer with the purpose of minimizing the damage of the ship and the pier when a ship collided with the pier. From these investigations, multi-cell type and composit material type buffers have been resulted and their design standards have been obtained. In this paper, we will mainly describe the outline and the principle of design of multi-cell type buffer.

2. OUTLINE OF THE MULTI-CELL TYPE BUFFER

Multi-cell type buffer is a steel structure composed with many cells with stiffeners, cross frames, cross beams, etc. and is installed around the rigid marine pier of bridges. It absorbs collision energy by crushing itself when fairly large ship collided with it and minimizes the damage of the ship before avoiding the damage to the pier.

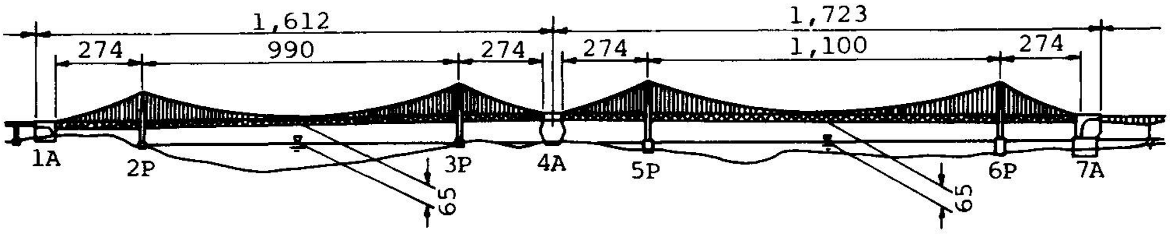

Fig. 1 General View of North-South Bisan-Seto Bridge

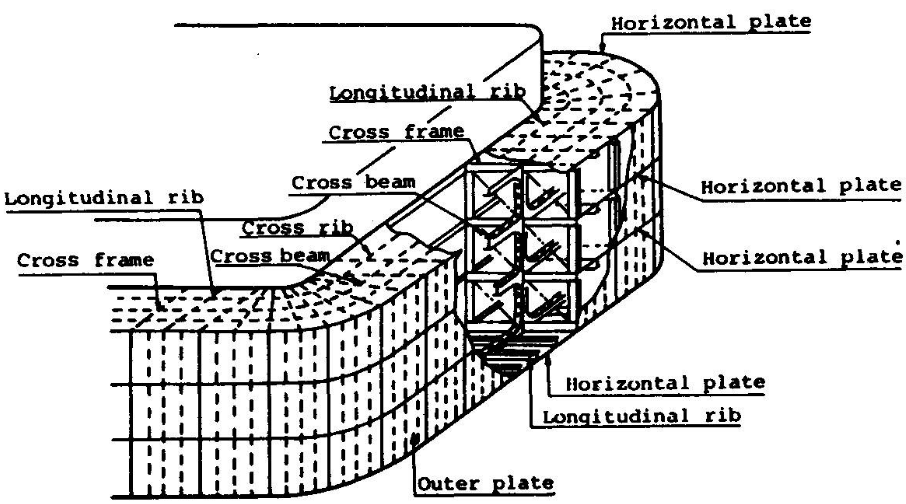

Fig. 2 Multi-cell Type Buffer

On the other hand, the composit material type buffer is the structure similar to the multi-cell type buffer, but inside is filled with such brittle materials as hard urethane foam. The principles of the both designs are almost same and only different with the multi-cell type buffer in the point of absorbing collison energy with the crush of the brittle filled material.

3. DESIGN

3.1 Conditions in Ship Collision

Generally, a ship has a bulkhead to the bow part and if the damage of collision is limited to the front side of the bulk head, it will not bring a serious accident. And in the case of the collision at the side of the ship, only plastic deformation of the shell structure of the vessel will be allowable, because crushing of the ship's side will result in such serious disasters as water immersion inside, sinking of the ship, etc.
Therefore, for the design of the buffer, allowable conditions for the deformation or partial crushing to the vessel and buffer at the time of collision are taken as shown in the Table-1.

		Allowable conditions
Ship hull	Bow	Crushing to the bulkhead of bow is to be allowed.
	Side	Conditions up to the occurrence of plastic deformation are to be allowed.
Buffer	Buffer body	Complete crushing is to be allowed.
	Attaching portion	Elastic design method is to be used as a rule.

Table 1 Allowable Conditions at the Time of Collision

The methods of calculating the collision energy and the strength of the vessel are different depending on the conditions of the collision and the modes of collision necessary to consider for the design are assumed in accordance with the place of the installation as shown in the Table-2.

Item	Contents
Kinds of collided ships	Travelling ship, drifting ship
Collided portions of ships	Bow, side, stern
Collided portions of underwater foundation	Surface perpendicular to waterway (surfaces parallel to bridge axis), surface parallel to waterway (surfaces perpendicular to bridge axis), corner
Conditions of collision	Head-on collision, diagonal collision, side collision, centripetal collision, eccentric collision

Table 2 Combination of Modes of Collision

Then, it is necessary to estimate the strength of the bow and the side parts of the vessel for the design of the buffer.
It is desirable to calculate the strength of the vessel at the bow and the side parts based on the structure and type of the ships in the actual navigation records, etc. Generally, the strength of the side part can easily be calculated, however, the structures and types of the bow part vary widely and it is necessary to standardize them.

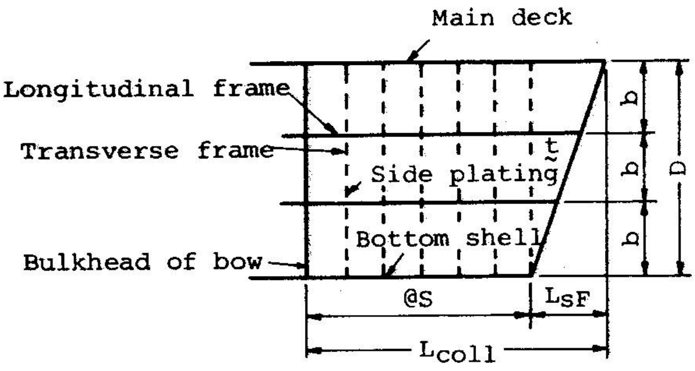

Fig. 3 Standard Shape of Bow

As a ship length L in common cases can conventionally be obtained depending on the ship size and a shape and dimension of the bow can be presumed using L as a parameter, the structure of the bow have been standardized as shown in Fig. 3 and Table-3, based on the investigation concerning to the actual navigation status in Seto-Inland sea.

Structural dimension	Symbol	Standard dimension	Unit
Depth	D	0.08L	m
Side plate thickness	t	$0.82\sqrt{L}+2.5$	mm
Spacing between frames	S	610	mm
Location of bulkhead of bow	Lcoll	0.1L	m
Spacing between longitudinals	b	3·S	mm
Width of slanted portion of bow	L_{SF}	0.25D	m
Angle of tip of bow	2θ	35° ∿ 70°	
Extreme breadth	B	L/10 + 3.81	m

Table 3 Standard Dimensions of Ship's Bow

3.2 Crushing in the Moment of Collision

When a ship collides with a buffer, the energy will be absorbed only with the crushing of the buffer because the bow or the side of the vessel could be considered as a rigid body.

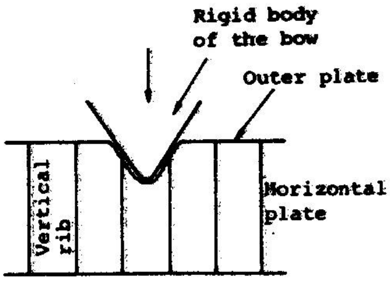

Fig. 4 Modeled Status of Crushing

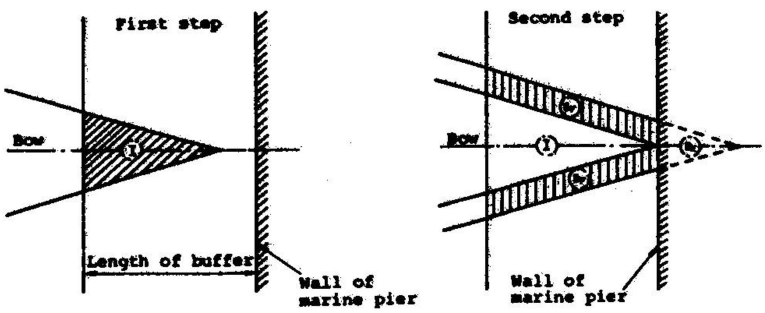

Fig. 5 Relation between Buffer and Bow in Collision

However, after the buffer is crushed in the collision with the bow and the bow has reached to the marine peir (rigid body), the collision energy will be absorbed by the crushing of the bow portion. (refer to Fig. 5)
Therefore the buffer should be designed with horizontal and vertical stiffners to be easily crushed by a vessel as a colliding rigid body. As breakage of the bow, after the crushing of the buffer, will be taken place by the buckling of the structural members of the bow, the maximum load will depend on the buckling load of the shell plate at the bow.

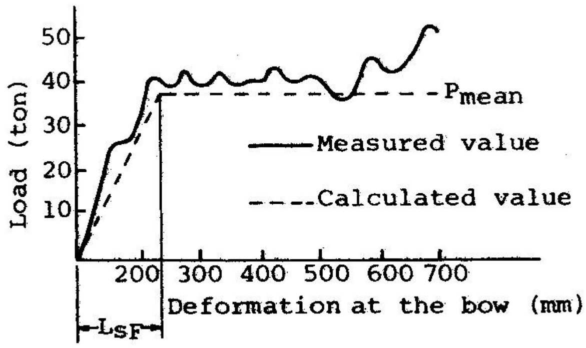

Fig. 6 Load-Deformation Curve

The crushed shapes and the maximum loads of the bow analyzed, have been checked with the results of statical crushing experiment by the models of 1/4 size of the 500 G.T ship and 1/8 size of the 4,000 G.T ship. Fig. 6 indicates the measured and calculated load-deformation curves of the experiment on the 1/4 model of the inclined bow of 500 G.T ship.

3.3 Design for Normal Time

The buffer shall be designed to keep its shape and have the durability against such loads as dead load, tidal current, wave pressure, static pressure except collision, same as the ordinary structures. Therefore, it shall be so designed that the stress of each members due to the combination of each load will be within the elastic limit.
For this reason, horizontal plate of the buffer shall be structured to have the function of buffer material in the case of collision, as well as to bear the loads to act to the buffer in normal time.

3.4 Detail of Structure

In the design of the horizontal plate of the buffer, relation between the acting load in plane and deformation of the horizontal plate in collision can be given as following:

$$F = 2 \cdot P_{cr} \tan\theta \cdot \delta \quad \text{..............................} \quad (1)$$

Where, F ; Load acting on the horizontal plate (collision load) (t)

P_{cr}; Ultimate load of the horizontal plate (t/m)

δ ; Deformation of horizontal plate (quantity of bow intrusion) (m)

θ ; 1/2 of bow angle

Further, for the load acting outside the plane of the plate in normal time, it is assumed that: (1) the plate is designed as fixed along its perimeter, (2) stiffening rib shall be a continuous beam having its span between transverse frames.

Ultimate load of the horizontal plate P_{cr} is given as following:

$$P_{cr} = \sigma_{crp}(\lambda \cdot t_d + A_R) + (\sigma_{crR} - \sigma_{crp})(A_R + b_e \cdot t_d)$$

Where, σ_{crp}; Buckling stress of the plate simply fixed along its perimeter

σ_{crR}; Buckling stress of the vertical rib as a simple column. (considering effective width of the horizontal plate)

λ ; Distance between the vertical rib

b_e ; Effective width of the horizontal plate

t_d ; Thickness of the horizontal plate

A_R ; Sectional area of the vertical rib

Furthermore, chain type, wire type, sliding type, etc. have been proposed as a structure of attachment of the buffer to the rigid foundation.

4. APPLICATION EXAMPLE OF BUFFER

Design standard of the multi-cell and composit material type buffers have been obtained on the basis of the results of years investigation and study. And the buffer based on this standard has been designed for the South and North Bisan-Seto Bridge pier 5P, fabricated and installed in 1981, and is still used practically.

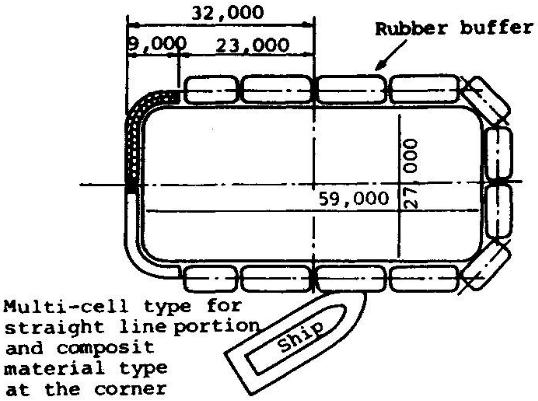

Fig. 7 General View of Buffer of Pier 5P of South Bisan-Seto Bridge

Fig. 7 indicates the general view of the buffer, and Table-4, -5, -6 indicate the ships under consideration, strength of the ship and the result of verification of the buffering function in collision.
Further, design procedure of the multi-cell type buffering is shown in Fig. 8.

Ships considered	Velocity in collision
200 G.T (Ship crossing Route)	8 knott
500 G.T (Ship crossing Route)	8 knott
500 G.T (Drifting ship)	5 knott

Table 4 Design Conditions of 5P Multi-cell Buffer

Ships considered	Inclination of bow	Strength of bow	Strength of side wall
200 G.T	0.83 m	186 tf	10 tf/m^2
500 G.T	1.13 m	366 tf	10 tf/m^2

Table 5 Calculation of the Strength of Bow and Side of Vessel

Item \ Gross ton \ Col. status		Collision of bow		Collision of side
		200	500	500
Collision energy E(tf/m)		450	1040	530
Absorbed energy (tf/m)	Buffer (E_f)	136	210	530
	Ship (E_s)	314	830	-
Displace-ment (m)	Buffer (δ_f)	Crushed	Crushed	1.86
	Ship (δ_s)	2.10	2.65	-
Allowance of crushed length (m)		2.18	3.1	-
Strength of side wall of vessel		-	-	σ_{cr} = 0.96 kg.f/cm^2 < 1.0 kg.f/cm^2

Table 6 Result of the Verification of Multi-cell Type Buffer

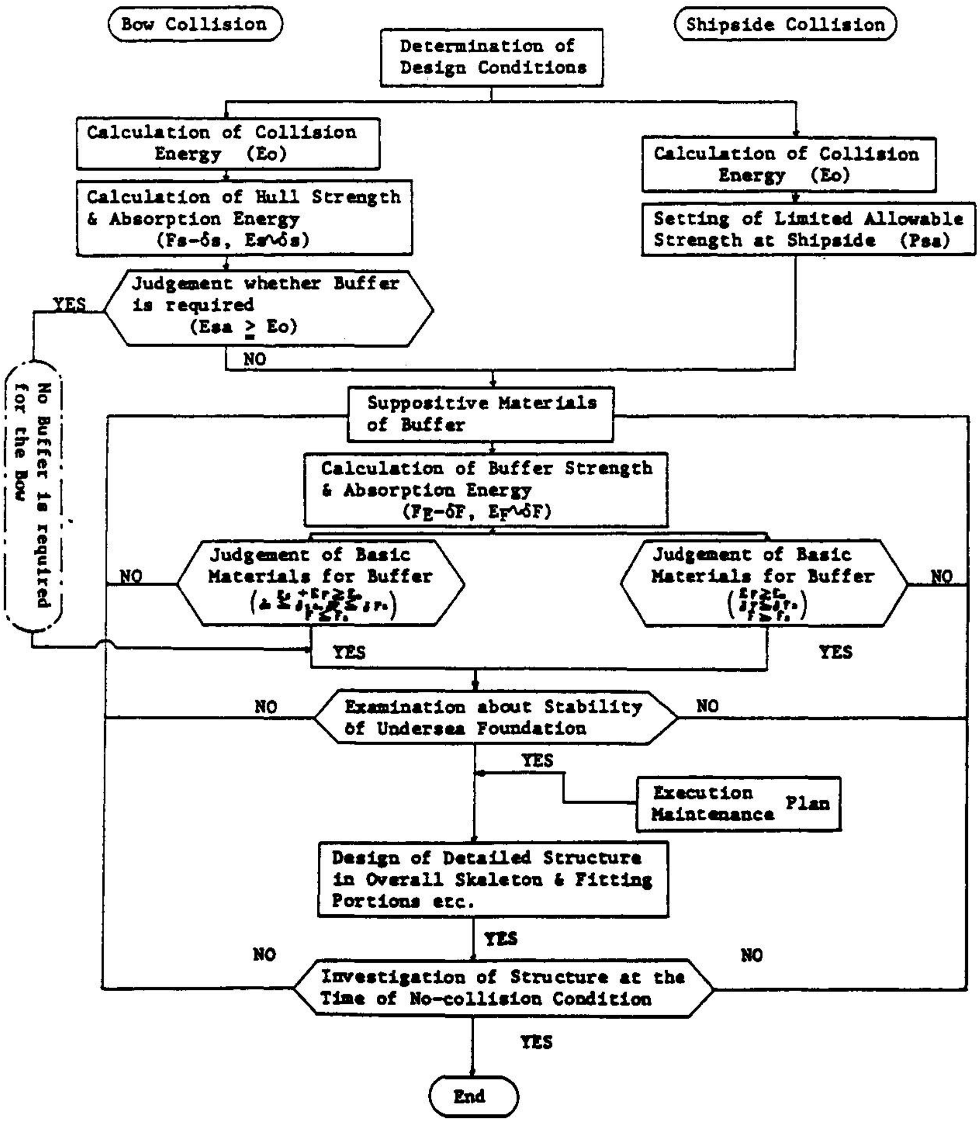

Fig. 8 Flow Chart for Design of Multi-cell Buffer

5. POSTSCRIPT

For the construction of bridges in the sea area occupied with navigation, it is necessary to prevent collision by navigational aid systems, in addition to consideration for clearance height, point of piers, etc. However, as far as collision might be assured, it is also necessary that the preventive facilities, based on the assumption of collision, shall be prepared. From such point of view, the Authority has developed multi-cell type and composit material type buffers as the facility to reduce the damage to ship and pier in the minimum and also to prevent oil pollution when a ship collided with the pier.

There still remain a few points to be studied further on the buffer in the future, such as durability, method of repairing after collision. But further investigation and study concerning to those points will be continued and it is believed that the buffer will play an important role for the safety of navigation and the structures.

Authors would expressed the highest gratitude the members of the committee "Investigation of Buffer" (the chairman: Prof. Iwai) in THE JAPAN ASSOCIATION FOR PREVENTING MARINE ACCIDENTS.