**Zeitschrift:** IABSE reports = Rapports AIPC = IVBH Berichte

**Band:** 42 (1983)

**Artikel:** Collision prevention device of floating guide-line type

**Autor:** Oda, Kazuki / Kubo, Sunao

**DOI:** https://doi.org/10.5169/seals-32441

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# Collision Prevention Device of Floating Guide-Line Type

## Ecran de protection anti-collision de type ligne d'ancrage flottante

## Stoßdämpfer mit dem flotten Führungstau

**Kazuki ODA**
Prof. of Hydraulic Eng.
Osaka City Univ.
Osaka, Japan

**Sunao KUBO**
Assist Prof.
Osaka City Univ.
Osaka, Japan

azuki Oda, born 1941, received his M.E. and D.E. egrees from the Osaka City University in 1965 and 1976, espectively. Most of his subsequent researches have een concerned with studies of mooring dynamics of uoys and tankers, wave forces on structures and safety avigation problems relating to the Honshu-Shikoku ridges.

Sunao Kubo, born 1934, graduated from Osaka Institute of Technology in 1957 with a bachelor degree in civil engineering. Since then, he has been mainly engaged in studies of wave forces on breakwaters and hydraulic model experiments on planning and layout of ports.

### SUMMARY

This paper deals with the theoretical and experimental analyses on the collision prevention device of floating guide-line type, and describes the outline of the device put into practical use for preventing ship collisions with a floating platform for geological survey of the seabed.

### RÉSUMÉ

L'étude traite de l'analyse théorique et expérimentale d'un écran de protection anti-collision, type ligne d'ancrage flottante; il décrit les écrans utilisés de façon préventive contre les collisions des navires avec des plates-formes flottantes utilisées pour le relevé géologique du fond de la mer.

### ZUSAMMENFASSUNG

Der Aufsatz behandelt die theoretische und experimentelle Analyse von Kollisionsschutzmaßnahmen, insbesondere von schwimmenden Schutzmitteln. Es wird über die Anwendung für eine schwimmende Plattform berichtet, welche für geologische Aufnahmen des Meeresbodens verwendet wird.

## 1. INTRODUCTION

Since December in 1975, the construction works of the long bridges, which aim to link the Shikoku Island to the Main Land of Japan, have been carried out at different three routes by the Honshu-Shikoku Bridge Authority.

Since most of their piers have been constructed and are to be constructed in narrow straits under severe circumstances for navigation: strong currents, fogging, and extremly frequent marine traffic, a great possibility of ship-bridge pier collisions can be anticipated.

Therefore, since 1970, various kinds of appropriate measures to prevent the ship-bridge pier collision and to protect those bridge piers against ship impacts have been investigated under the Safety Navigation Committee for the Construction of Honshu-Shikoku Bridges.

The collision-prevention device presented here is one trial of those measures and of a floating guide-line type capable of turning a ship, which is rushing to the pier, at a relatively small angular velocity away from her original traveling course. The device was put to practical use in 1973 for preventing ship collisions with a floating platform for geological survey of the seabed at the projected construction location of the piers of Honshu-Shikoku Bridges.

## 2. STRUCTURAL OUTLINE OF DEVICE

The device is structured by two floating guide-lines stretched in V-shape on the water surface and three large buoys maintaining both ends of each guide-line which are anchored to the sea bottom as shown in Fig.1. Each guide-line is composed of pneumatic rubber fenders tied in a row, tightened with restoring forces of anchored buoy systems.

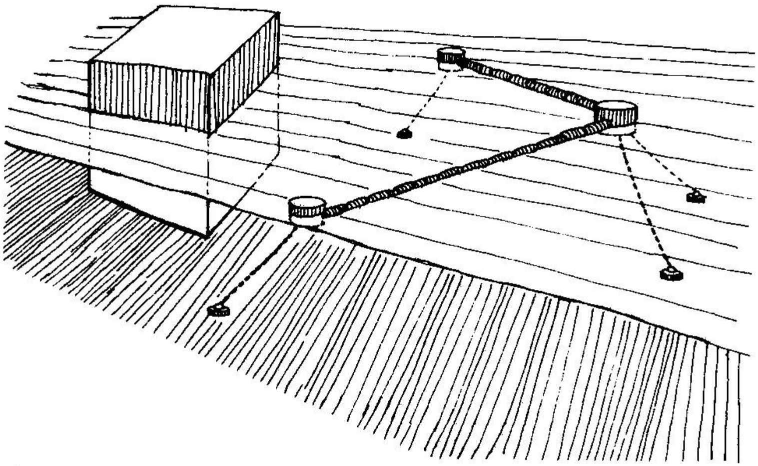

Fig. 1 Structure of the Collision-Prevention Device

## 3. THEORETICAL AND EXPERIMENTAL ANALYSES

### 3.1 Theory

Using a set of co-oridinate axes $x_G$ and $y_G$ with the origin fixed at the center of ship as shown in Fig.2, we can write the basic equations of ship motions in horizontal plane as

$$\left.\begin{aligned} m(\dot{u}_G - \omega v_G) &= X \quad \text{(sway)} \\ m(\dot{v}_G + \omega u_G) &= Y \quad \text{(surge)} \\ I_{zz}\,\dot{\omega} &= N \quad \text{(yaw)} \end{aligned}\right\} \qquad (1)$$

in which m = ship mass; $I_{zz}$ = moment of inretia about the vertical axis; $u_G$, $v_G$, $\dot{u}_G$ and $\dot{v}_G$ = components of ship velocity and acceleration in the $x_G$- and $y_G$-direction, respectvely; $\omega$ and $\dot{\omega}$ = angular velocity and acceleration about the vertical axis; and X, Y and N = external forces and moments including hydrodynamic and non-hydrodynamic ones.

For analyzing the motions of ship while contacting with the floating guide-line, take the co-ordinate system and the symbol definition as shown in Fig.2, and introduce the following assumptions to simplify the subsequent, theoretical analyses:

(a) While the ship contact with the guide-line AB, the movements of the main buoy A, another guide-line AC and the sub-buoy C can be ignored.
(b) The hydrodynamic forces on the sub-buoy B and the guide-line AB, and the frictinal force of the guide-line on the ship hull can be also ignored.
(c) The configulation of mooring line can be regarded as a straight, and the elongations of mooring lines and the guide-line can be ignored.
(d) The propulsive force of the ship is constant, and the rudder angle of the ship is stationarily zero.
(e) The ship holds on contacting with the guide-line at the bow shoulder.

Then, the external forces X and Y exerted on the ship, and the external moments N in Eq.(1) are approximately expressed by (1)

$$\left.\begin{aligned} X &= -\,m_x\dot{u}_G + f_x \\ Y &= -\,m_y\dot{v}_G - cv_G^2 + f_p + f_y \\ N &= -\,J_{zz}\dot{\omega} + f_\phi \end{aligned}\right\} \qquad (2)$$

in which $m_x$ and $m_y$ = added masses in the $x_G$- and $y_G$- direction; $J_{zz}$ = added moment of inertia about the vertical axis; c = dimensional coefficient of total ship resistances; $f_p$ = propulsive force of ship; $f_x$, $f_y$ and $f_\phi$ = components of reactive forces and moments on the ship hull exerted by the deflection of guide-line AB in the $x_G$- and $y_G$-direction given by

$$\left.\begin{aligned} f_x = -\,T_{AB}\Bigl\{&\Bigl(\frac{x-b_x}{\sqrt{(x-b_x)^2+(y-b_y)^2}} + \frac{x}{\sqrt{x^2+y^2}}\Bigr)\cos\phi \\ &+\Bigl(\frac{y-b_y}{\sqrt{(x-b_x)^2+(y-b_y)^2}} + \frac{y}{\sqrt{x^2+y^2}}\Bigr)\sin\phi\Bigr\} \end{aligned}\right\} \qquad (3)$$

$$\left.\begin{aligned} f_y = -\,T_{AB}\Bigl\{&\Bigl(\frac{y-b_y}{\sqrt{(x-b_x)^2+(y-b_y)^2}} + \frac{y}{\sqrt{x^2+Y^2}}\Bigr)\cos\phi \\ &+\Bigl(\frac{x-b_x}{\sqrt{(x-b_x)^2+(y-b_y)^2}} + \frac{x}{\sqrt{x^2+y^2}}\Bigr)\sin\phi\Bigr\} \end{aligned}\right\} \qquad (4)$$

and $$f_\phi = -\,(af_x - bf_y) \qquad (5)$$

in which x,y = co-ordinates of the point of contact P with ship; $b_x$,$b_y$ = co-ordinates of anchor point $B_B$; $T_{AB}$ = tention of guide-line AB; $\phi$ = heading angle of ship to the Y-axis; and a,b = lengths of moment arm of $f_x$,$f_y$ around the gravity center of ship.

Forming the equilibrium equation of forces acting on the sub-buoy B, we obtain the equation for $T_{AB}$ as

$$T_{AB} = \{w_0 A_B(h_B - \sqrt{S_B^2 - l_B^2} - W_B\}\,\frac{l_B}{\sqrt{S_B^2 - l_B^2}} \qquad (6)$$

with $$l_B = \sqrt{x^2 + y^2} + \sqrt{(x - b_x)^2 + (y - b_y)^2} - l_{AB} \qquad (7)$$

in which $w_0$ = the specific weight of water; $A_B$ = the waterplane area of the sub-buoy B; $h_B$ = the water depth at anchor point $B_B$; $S_B$ = the length of the mooring line of sub-buoy B; $W_B$ = the weight of sub-buoy B; $l_B$ = the horizontal distance between the sub-buoy B and the anchor point $B_B$; and $l_{AB}$ = the original distance between the main buoy A and the sub-buoy B.

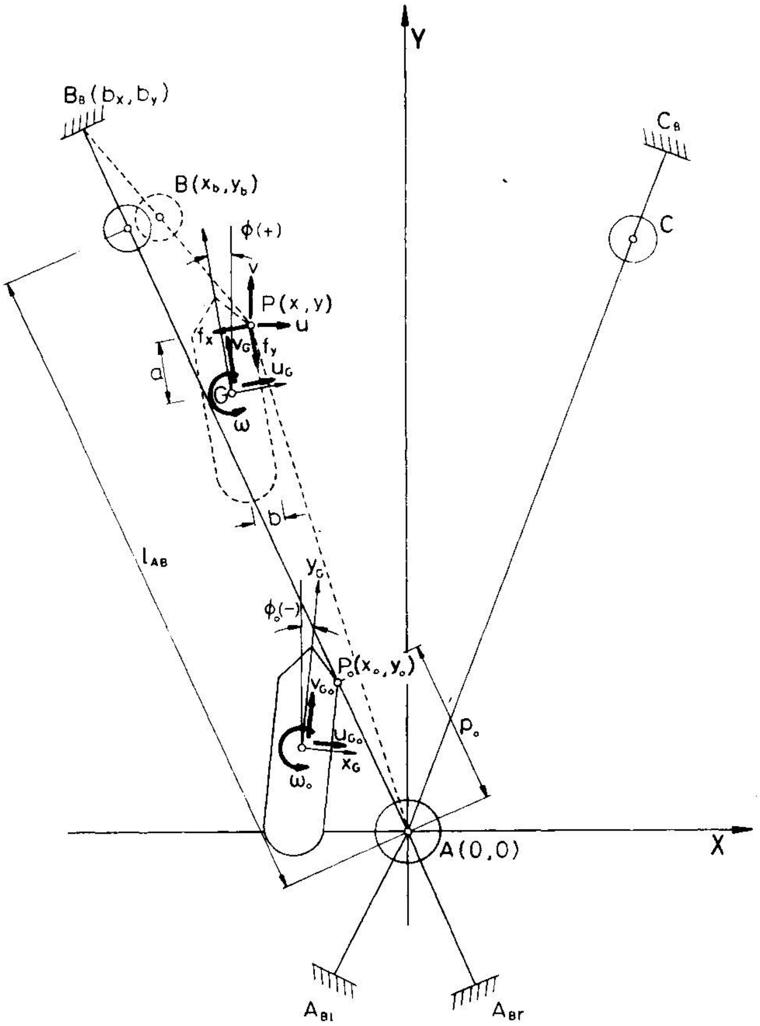

Fig.2 Co-ordinate system and symbol defenition of the collision-prevention device

On the other hand, reffering to Fig.2, we can express the relationship between the velocity components of ship parallel to the $x_G$- and $y_G$-axes fixed on the ship at her center of gravity and parallel to the x- and y-axes fixed on the earth at her point of contact P with the guid-line as

$$\left.\begin{aligned} u_G &= u\cos\phi + v\sin\phi + a\omega \\ v_G &= v\cos\phi - u\sin\phi - b\omega \end{aligned}\right\} \qquad (8)$$

with $$u = \dot{x},\ v = \dot{y} \text{ and } \omega = \dot{\phi} \qquad (9)$$

Finally, Eq.(1) can be rewritten into six simultaneous non-liner differential equations in terms of x and y, co-ordinates of the point of contact P and can be solved by means of numerical analysis using the Runge-Kutta-Gill method.

### 3.2 Numerical Analysis

Figs.3 and 4 show examples of neumerically calculated results of the maximum tension of guide-line $(T_{AB})_{max}$ and the maximum displacement of sub-buoy in the x-direction $(\delta_B)_{max}$ in the case that the device is symmetrically arranged with respect to the y-axis in the water with a uniform depth of 25 m; the ship of 1000G.T. is approaching at a velocity of 10 knots; $l_{AB}$ = 80 m; $A_B$ = 28.3 $m^2$; $2\beta_0$= $35^0$ in which $2\beta_0$ is the included angle between two guide-lines AB and AC; and $(T_{AB})_0$ = 50 tf ( 490 kN ) in which $(T_{AB})_0$ is the initial tension of guide-line.

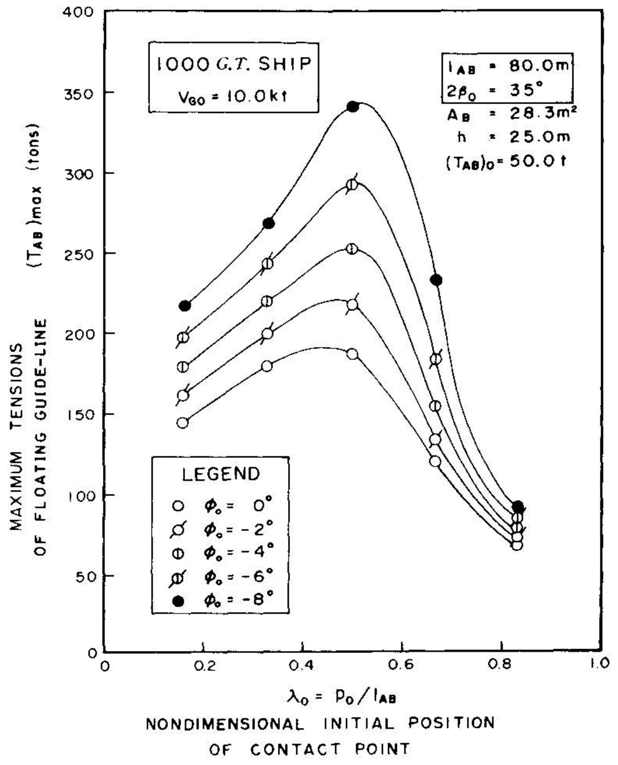

Fig.3 Example of calculated results of $(T_{AB})_{max}$

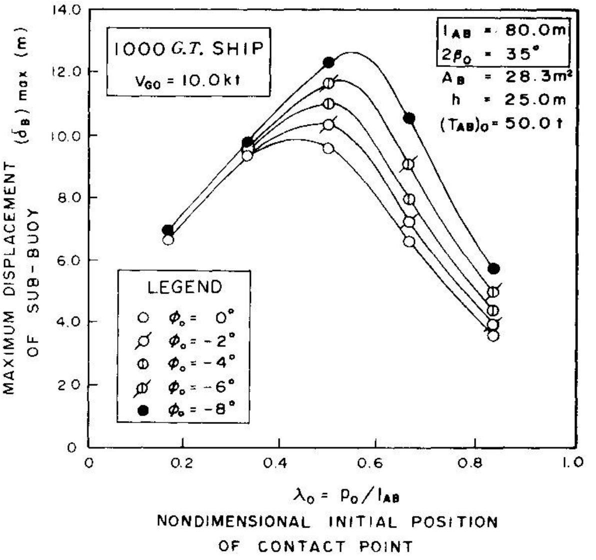

Fig.4 Example of calculated results of $(\delta_B)_{max}$

It can be seen in Figs.3 and 4 that both $(T_{AB})_{max}$ and $(\delta_B)_{max}$ are sharply affected by nondimensional initial contact position $\lambda_0 = p_0/l_{AB}$ in which $p_0$ is the distance between the initial contact point of ship with guide-line and the origin of co-ordinates A, and also show the peak values at $p_0 \simeq 0.5$ which increse with the initial heading angle of ship agaist the guide-line $\phi_0$.

### 3.3 Model Tests

Model tests were conducted on a scale of 1:20 in a water basin 42 m long, 12 m wide and 0.75 m deep. A radio-controlled model ship corresponding to 880 G.T. cargo ship in prototype was used.

The quantities measured in the model tests are the approaching velocity $v_{G\theta}$ and the initial heading angle $\phi_0$ of model ship; the position of initial contact point with guide-line $p_0$; the displacement of sub-buoy in the x-direction $\delta_B$; the tension of guide-line $T_{AB}$; the tension of the mooring line of sub-buoy $T_B$; the tension of the mooring line of main buoy on the right side $T_{Ar}$.

The tensions were measured with sensitive ring-gauges on which strain gauges are mounted. Custom-made mini-turnbuckle were used to facilitate the adjustment of the initial tension of guide-line.

The ship motions and displacement of sub-buoy in horizontal plane were measured by means of analyzing 16 mm movies taken from the top of tower 6 m high above the still water level. Fig.5 shows an example of frame-photographs printed from the 16 mm movie films.

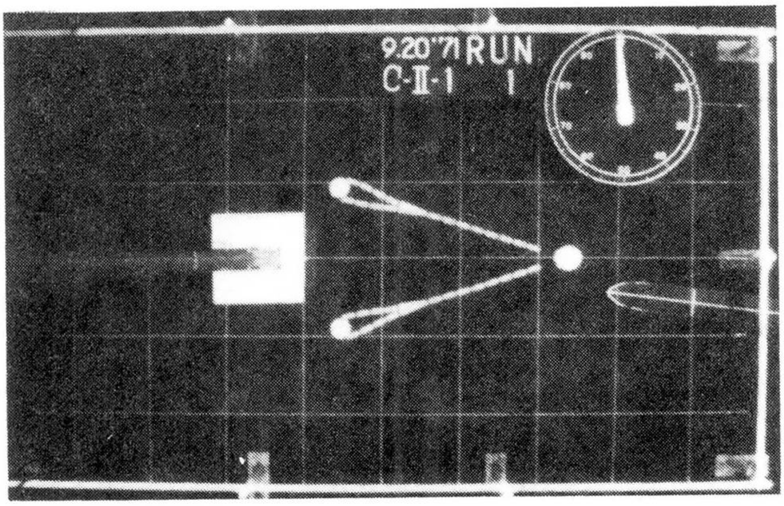

Fig.5 Frame-photograph of 16 mm movie films

### 3.4 Experimental Verification of the Theory

The theoretically calculated values of the maximum tentions of guide-line $(T_{AB})_{max}$ and moorig lines of buoys $(T_B)_{max}$ and $(T_{Ar})_{max}$ and also the maximum displacement of sub-buoy $(\delta_B)_{max}$ in the x-direction were compared with their experimental ones respectively.

Figs.6 and 7 show the comparisons between the calculated and experimental values for $(T_{AB})_{max}$ and $(\delta_B)_{max}$. The theoretical values are found, from these figures, to be in reasonably good agreement with the experimental ones in the case that $l_{AB}$ = 160 cm and $2\beta_0 = 37^0$, but poor in other two cases that $2\beta_0$ is relatively large. The same trends were found for the tensions of mooring lines of buoys $(T_B)_{max}$ and $(T_{Ar})_{max}$.

The major reasons for much deviation of the theoretical values from the experimental ones in the case that $2\beta_0$ is relatively large, may be considered to be in discrepancy of the assumptions (b) and (e) discribed in sub-chapter 3.1.

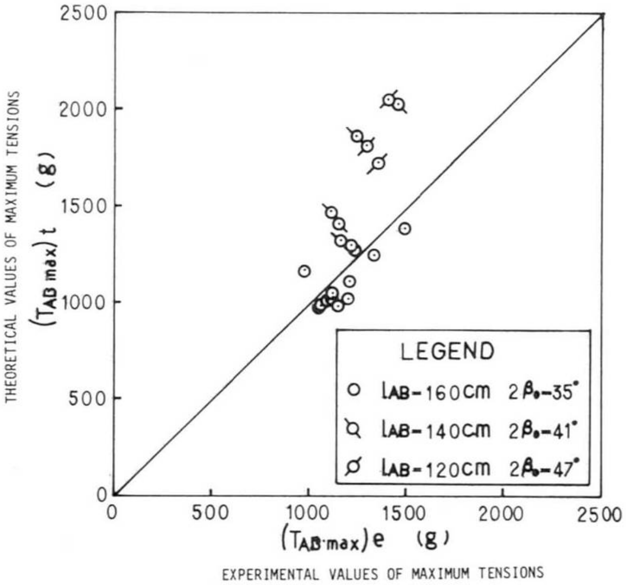

Fig.6. Comparison of the theoretical values of $(T_{AB})_{max}$ versus the experimental ones

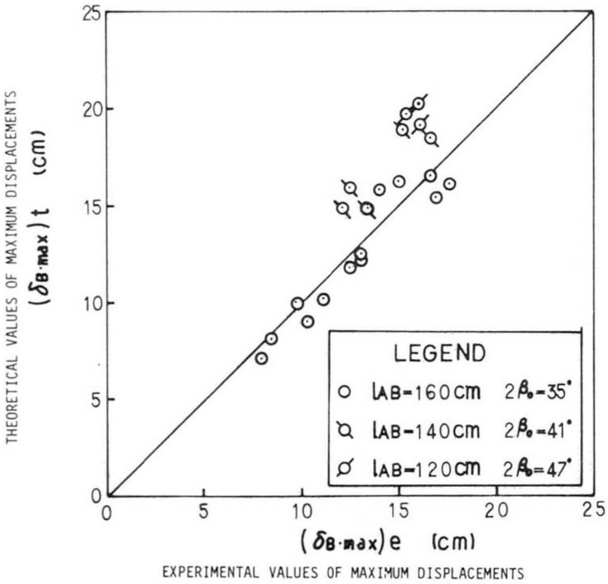

Fig.7. Comparison of the theoretical values of $(\delta_B)_{max}$ versus the experimental ones

Hense, it may be said that the present approximate theory should be applied to the case that $l_{AB}/L_{pp} \geqq 1.3$ and $\phi_0 \leqq 25^0$ in which $L_{pp}$ is the length between perpendiculars of ship and $\psi_0$ is the initial heading angle of ship relative to the guide-line, $\psi_0 = \beta_0 + \phi_0$.

## 4. TRIAL FOR PRACTICAL USE

A trial use of the present collision-prevention device was made for preventing ship collisions with a floating platform for geological survey of the seabed at the projected construction site of the piers of Honshu-Shikoku Bridges. Fig.8 shows the schematic diagram of the practical device designed as a trial use, and Fig.9 shows one of photographs of the device taken from the floating platform placed in the Akashi Straits which is between the Main Land and the Awaji Island of Japan.

The device was designed for preventing the collision of 1000 G.T.-ship with a velocity of 10 knots. Each floating guide-line is composed of fourteen pneumatic rubber fenders (produced by the Yokohama Rubber Co.,LTD of Japan) 2 m in diameter and 5 m long, tied in a low with a steel anchor chain 95 mm in diameter having a break load of 920 $t_f$ (9016 kN). The same anchor chains were used for the mooring lines of the main buoy, which is 10.2 m in diameter and 4.8 m high, and the sub-buoys which are 8.5 m in diameter and 4.8 m high, respectively. Specially-moulded cast iron sinkers 300 $t_f$ (2940 kN) in weight were used for the buoy anchors.

The initial tensions of the guide-lines can be arbitrarily adjusted by changing a buoy draft by means of pulling up the anchor chains into the buoys using an

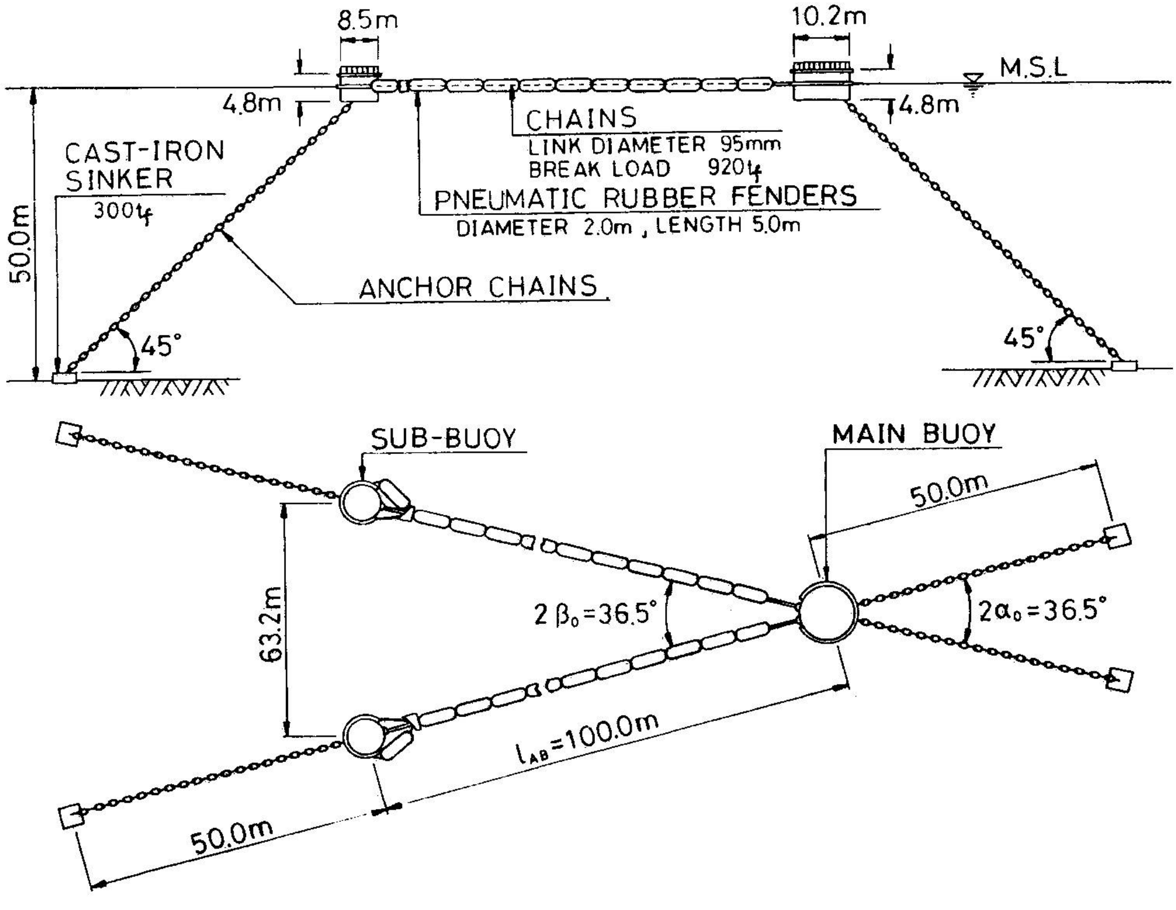

Fig.8. Schematic diagram of the trial collision-prevention device

oil pressure jack equipped on the respective buoy deck.

During the placing of the collision-prevention device in the Akashi Straits 1973 to 1975, it experienced several times the contacts of ships, which are relatively small in size ranging 200 G.T. in maximum, with itself, and showed to be very useful and effective for preventing ship collisions with bridge piers and/or offshore structures.

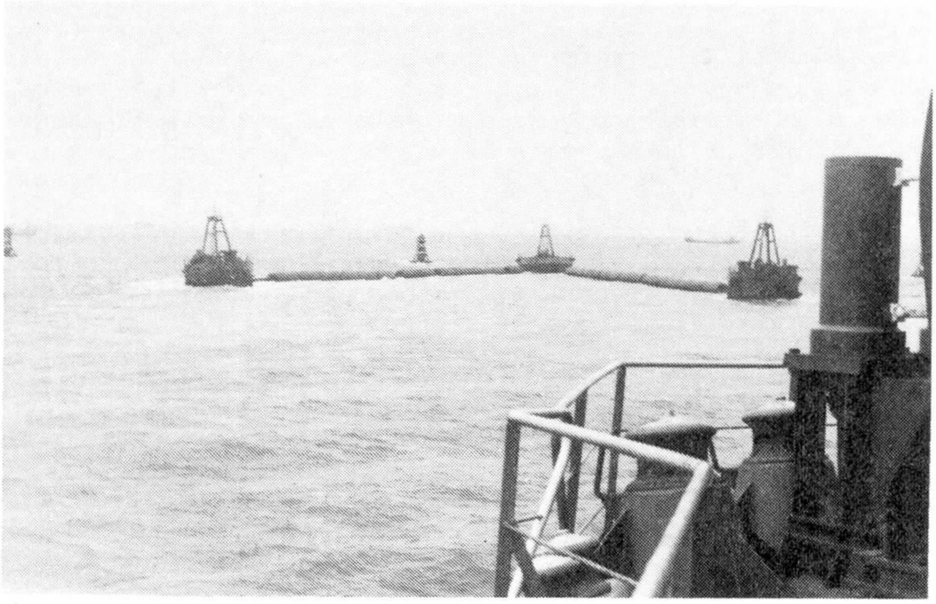

Fig.9. View of the trial collision-prevention device

## 5. ACKNOWLEDGEMENTS

Partial suport of the Honshu-Shikoku Bridge Authority and the Yokohama Rubber Co.,LTD is gratefully acknowledged.

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