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Ultimate Strength of Bow Construction

Résistance structurale limite de la proue d'un navire

Bruchfestigkeit des Buges

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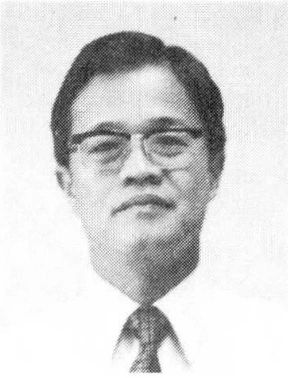

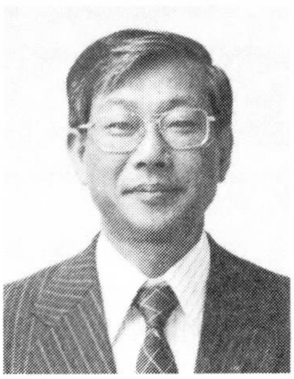

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SUMMARY

A study of the ultimate strength of the bow construction of two ships which have suffered a collision, has been made by means of a theoretical calculation by the FEM and experiments on static collapse by using 1/10 scale bow models have been conducted. It has been possible to estimate the load acting on the side structure of the struck ship and the bow deformation of the striking ship.

RÉSUMÉ

La résistance structurale limite de la proue de deux navires qui sont entrés en collision, a été déterminée par un calcul théorique au moyen la méthode des éléments finis et aussi par des expériences sur leur rupture statique au moyen des modèles réduits au 1/10^{e} des proues précitées. Il a été possible d'évaluer la charge exercée sur la structure latérale du navire endommagé et la déformation de la proue du navire opposé.

ZUSAMMENFASSUNG

Die Bruchfestigkeit des Buges zwei zusammenstossenden Schiffen – wurde anhand einer Berechnung mit finiten Elementen sowie einem Modell untersucht. Die Last auf der seitlichen Struktur des beschädigten Schiffes und die Umformung des Buges des gegnerischen Schiffes konnten geschätzt werden.

1. INTRODUCTION

So far the capacity of the collision-resisting structure of a nuclear-powered ship designed to protect its reactor from a collision has been evaluated in that it absorbs the kinetic energy of the striking ship through its own structural destruction. But it is reported that recent researches have developed collision-resisting structure of a resisting type intended to minimize the demage of one's own ship and mainly to destroy the bow of the striking ship in collision [1][2][3].

In order to design such a barrier of a resisting type it is necessary to precisely estimate the load acting on the side structure of the nuclear-powered ship. In the case of the side structure of a resisting type this load is found by the following procedure.

(1) To find the relation between the load and the deformation at the moment of collapse of the bows of the ships in collision.

(2) To find the bow deformation by carrying out a collision simulation analysis by means of the above-mentioned relation.

(3) To estimate the load corresponding to the bow deformation by using the load-deformation curve.

In order to find the collapse load it is necessary to analyze the ultimate strength of the bow construction but so far this analysis has scarcely been carried out [4] - [7], nor does any established method of its calculation seem to exist.

In this study, for the purpose of establishing the method of analyzing the ultimate strength of the bow construction and finding the load acting on the side structure, first, we have made a theoretical calculation by the FEM by means of an ideal mathematical model of the frame of bow construction. Next, in order to clarify the behavior of the bow collapse and verify the method of calculation, we have carried out static collapse experiments by using 1/10 scale models of the bows of a tanker and a container carrier and compared the results of the experiments with those of the theoretical calculation, thereby a reasonable agreement between the two has been confirmed. And further, we have estimated the collapse loads of bow construction of actual ships (tanker, container carrier and ice-strengthened ship) and obtained the load-deformation curves.

By using these load-deformation curves of bow construction we can estimate the load acting on other types of structure such as bridges, offshore structures when ships strike against them.

2. THEORETICAL ANALYSIS

When calculating the ultimate strength of bow construction, it is considered necessary, strictly speaking, to deal with bow construction as a plate structure. But then it will entail a complicated process and will take a much time for computation. Therefore, in order to obtain the load-deformation curves, we regard the bow construction as an ideal frame structure with effective plate width and analyze the ultimate strength by FEM, which utilizes the plastic hinge method.

We regard the side structure of a nuclear-powered ship as rigid and we consider such a case as the bow collapsing one-sidedly in collision. According to the results of the experiment, the sub-structure between the transverse frames collapses as a unit

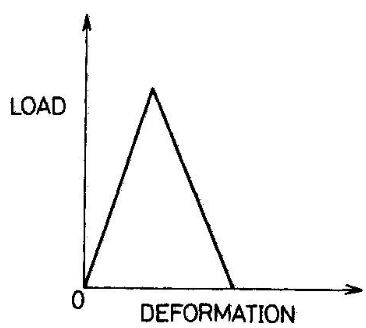

Fig.1 Load-deformation curve of longitudinal member

structure, and the weaker sub-structure collapses first. In calculation, we assume that the sub-structure collapses first at stem and down to stern. The load is applied to the frame section by forced displacement, and the loading point is shifted to the next frame after each sub-structure has collapsed.

As the side shell plate, the web plate of girders, etc. are considered to have already buckled under the maximum load, we have used the effective width of the buckled plate for an ideal mathematical model of the frame of the longitudinal member. The above-mentioned effective width is given in the following formula [8]

$$b_e = b \qquad \text{for} \quad \frac{b}{t} \leq \sqrt{E/S_y}$$

$$b_e = t\sqrt{E/S_y}\left(2 - \frac{t}{b}\sqrt{E/S_y}\right) \qquad \text{for} \quad \frac{b}{t} \geq \sqrt{E/S_y} \tag{1}$$

where b is the plate width, b_e is the effective width of the plate, t is the plate thickness, E is the young's modulus and S_y is the material yield stress. The results of the box column experiment carried out by the authors [9] are in good agreement with the results of the calculation made with the above formula. According to the above mentioned experiment, the load decreases rapidly after it has reached the maximum. Therefore in this calculation, the load-deformation curve of longitudinal member is assumed as shown in Fig. 1.

3. STATIC COLLAPSE EXPERIMENTS ON BOW CONSTRUCTION

Static collapse experiments have been carried out by using 1/10 scale bow models of a container carrier and a tanker (Fig.2, Fig.3). The test apparatus is shown in Fig. 4. The load acting on the bow model and the deformation and strain of the bow models were measured, and load-deformation curves and the mode of collapse were obtained.

Fig. 5 and Fig. 6 show the load-deformation curves of the models of a container carrier and a tanker. In these figures, peak load and the corresponding collapse mode are shown. The shaded portion collapsed under peak load and the blackened portion had collapsed before. The solid black circles in Fig. 5 and Fig. 6 show the results of the calculation by FEM, which are in good agreement with the results of the experiments.

The sub-structures between the frames are numbered ①,②, ----- in order fore and aft, as shown in Fig. 5 and Fig. 6. Regarding the container carrier, we considered that theoretical collapse occurs in the order of ① ③ ④ ⑤ ②, which, however, changed to ① ⑤ ④ ③ ② in experiment. This disagreement is considered to be due to the following reason. The difference in strength between ③ and ⑤ is so small that the strength of ⑤ decreased in experiment because of end effect. As for the tanker, the analytical and experimental orders of collapse agree with each other.

In the case of the model of the container carrier, the load decreases rapidly after peak load is reached, and the entire load-deformation curve is saw-toothed. In theoretical calculation, we can obtain only the peak load, and in order to obtain the entire load-deformation curve we must study further in the future. With the tanker model, the load does not decrease so rapidly after peak load is reached.

With the tanker model, a big discrepancy is noticed between calculation and experimentation when deformation exceeds 1200 mm. This is probably because experimentally the upper deck buckled totally at the moment of such deformation, and afterwards the loading capacity of the upper deck decreased remarkably. The total buckling of the upper deck is not treated in this calculation. For reference, we calculated the maximum load, supposing that the loading capacity of the upper deck is entirely lost after buckling. The results of calculation marked ◉, as shown in Fig. 6 approach the value obtained through experiments.

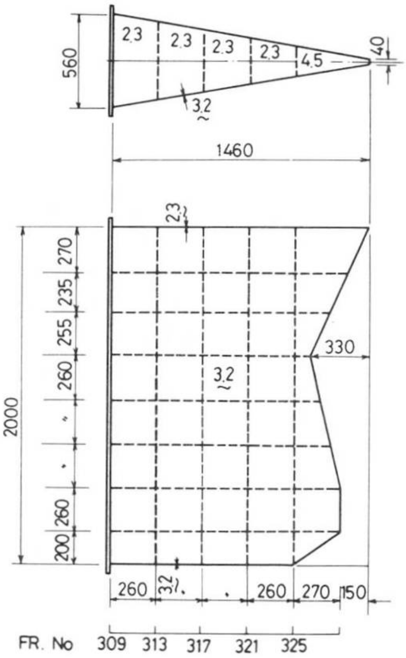

Fig.2 Bow model of container carrier

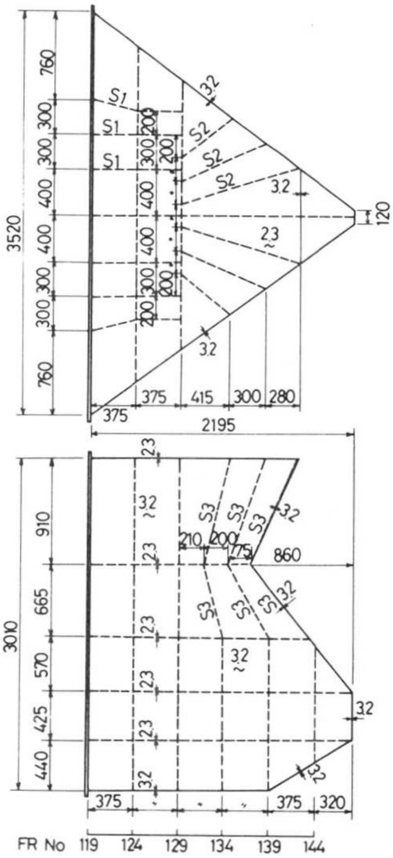

Fig.3 Bow model of tanker

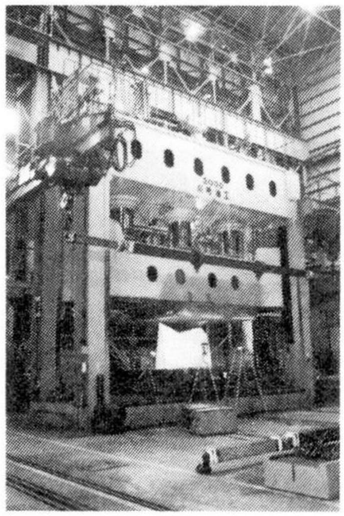

Fig.4 Test of Bow model

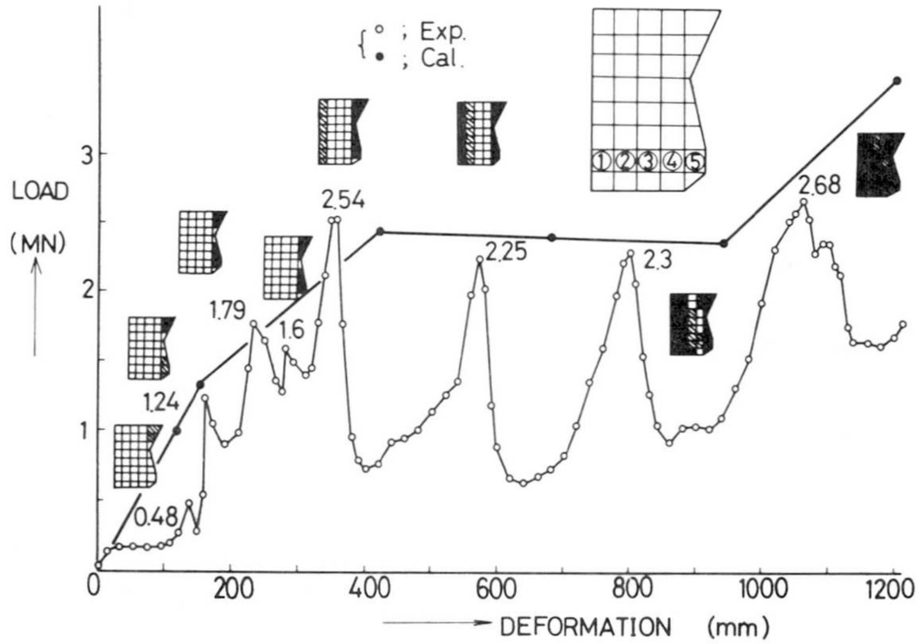

Fig.5 Load-deformation curve of container carrier model

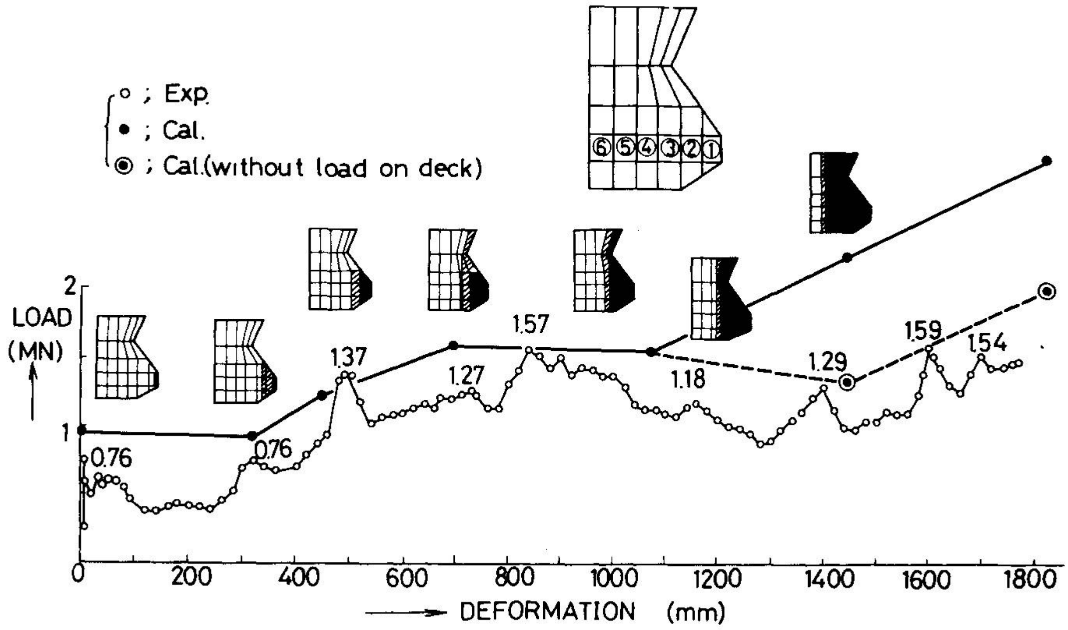

Fig.6 Load-deformation curve of tanker model

4. ULTIMATE STRENGTH OF BOW OF ACTUAL SHIP

As typical ships, we chose a container carrier, a tanker and an ice-strengthened ship. Their principal dimensions are shown in Table 1. The ultimate strength of the bow structure of these ships is calculated, based on the method mentioned in Chapter 2. In consideration of symmetry, we have modeled a counterpart of the bow construction for calculation. The ideal mathematical model of the frame is shown in Fig. 7 ∿ 9. The model is fixed at the collision bulkhead and the load is applied to the frame section by forced displacement. In the calculation, 242 MPa was used for yield stress. Fig. 10 ∿ 12 show the results of calculation. "Full yield" mentioned therein means the load caused when the longitudinal member yielded entirely by axial load. The load resulting from "full yield" becomes larger than that obtained through FEM. Fig. 7 ∿ 9 show with a mark ○ where the plastic hinge is produced when the maximum load is reached.

We compare the collapse loads of the bows of these three ships. As the collapse loads vary with sectional position we have taken up the collapse load arising midway between the forepeak and the collision bulkhead. These collapse loads are shown in Table 2. Generally the collapse load of the tanker is the largest, but when calculated per unit area, the load of the container carrier turns out largest. When we design the side structure of the struck ship, we must take into account not only the magnitude of the load but also the load per unit area.

5. SOME CONSIDERATIONS ON COLLISION ANALYSIS

When the side structure of the struck ships is rigid, the deformation of the bow and the load acting on the side structure are calculated by collision analysis by means of the load-deformation curves of the bow as mentioned in Fig. 10 ∿ 12. When the load-deformation curve is sawtoothed, the energy absorbing capacity of the bow is reduced, and the collapse deformation is intensified. Accordingly the load acting on the side structure becomes larger. But if the increase of load corresponding to the increase of deformation is not remarkable, the difference between the two is considered to be small.

Next, we consider the case where not only the bow construction but also the side structure of the struck ship collapses. Suppose the load-deformation curve of the side structure or other damaged structure is already obtained and is denoted by S_1 in Fig. 13. The load-deformation curve of the bow construction is

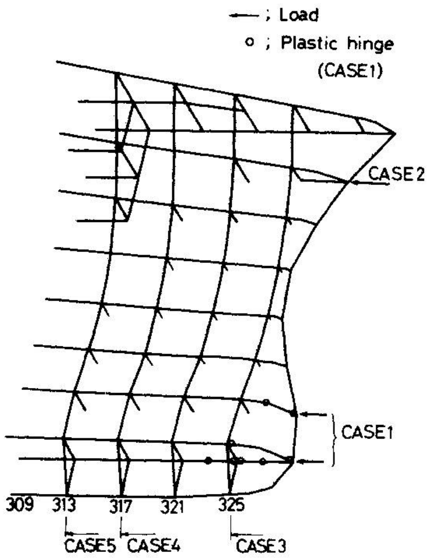

Fig.7 Idealized model of container carrier

Table 1 Principal dimensions

Item	Container carrier	Tanker	Ice strengthend ship
Lpp(m)	248.0	360.0	134.5
B (m)	32.2	69.0	32.2
D (m)	19.9	28.7	20.3
d (m)	12.0	22.75	7.8
DWT (ton)	35,000	409,000	11,200

Table 2 Comparison of bow strength

	P (MN)	A(m^2)	P/A(MN/m^2)
Container carrier	88	74	1.19
Tanker	245	602	0.41
Ice strengthend ship	98	108	0.91

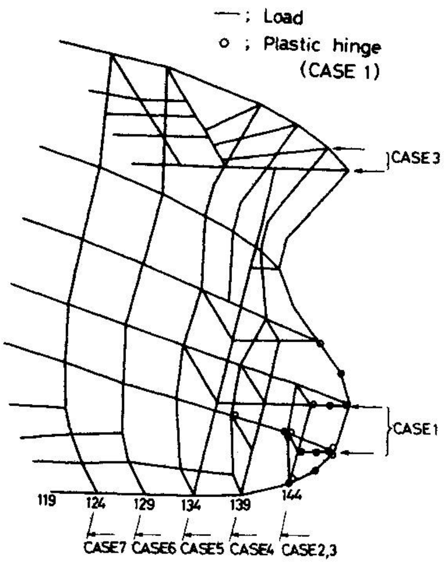

Fig.8 Idealized model of tanker

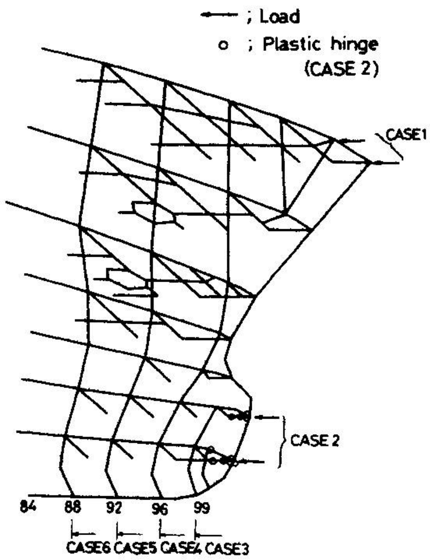

Fig.9 Idealized model of ice strengthend ship

denoted by S_2 therein. The collapse deformations corresponding to the load P_A are d_1 for the side structure and d_2 for the bow construction. The total deformation is $d_1 + d_2$, and the load-deformation curve is denoted by S_3. Through the collision analysis using S_3, we can obtain the deformation of the side structure and bow construction. If the load-deformation curve of the bow construction is sawtoothed, the treatment becomes slightly complex, but it is made possible to analyze in the same way.

6. CONCLUSION

In order to estimate the load acting on the side structure of the struck ship, we carried out experiments by using 1/10 scale bow models and studied the method of calculating the ultimate strength of the bow construction.

The theoretical calculation shows results in good agreement with those of the experiments and it is made possible to calculate the ultimate strength of the

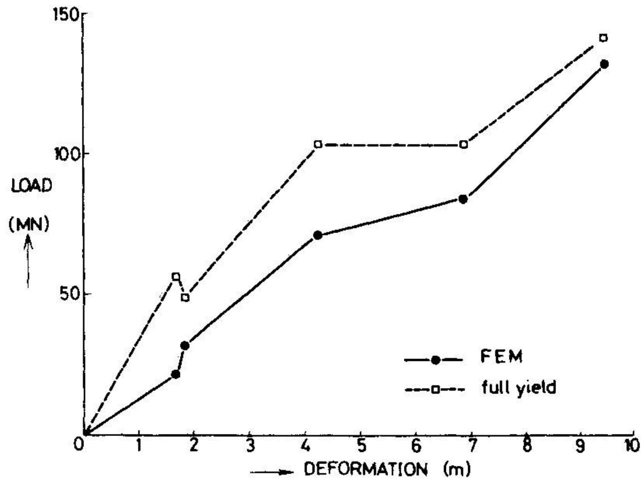

Fig.10 Load-deformation curve of container carrier by FEM

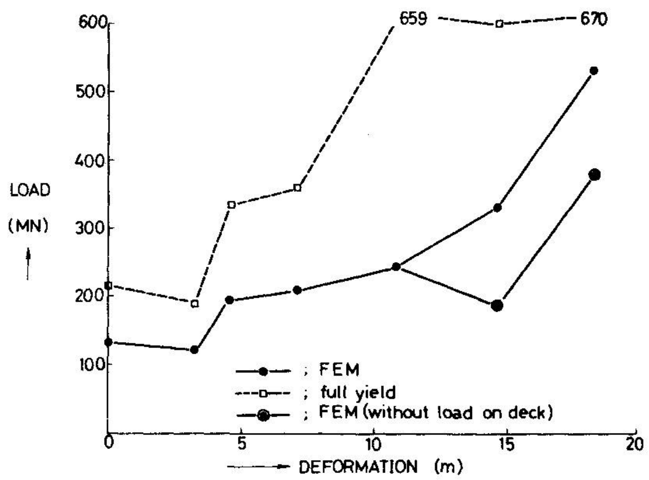

Fig.11 Load-deformation curve of tanker by FEM

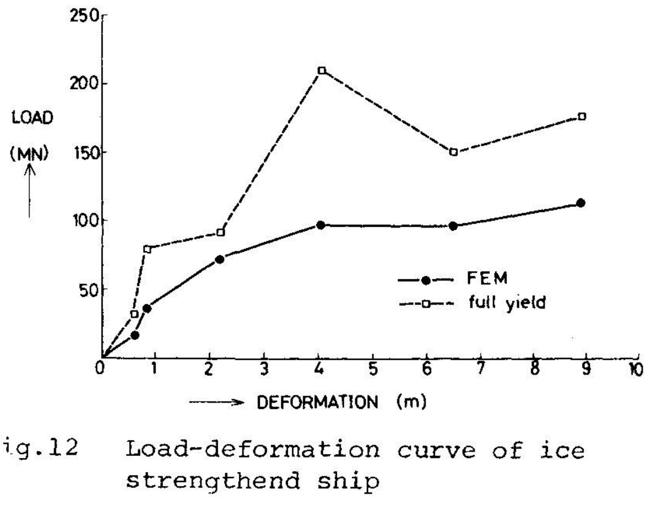

Fig.12 Load-deformation curve of ice strengthend ship

bow construction by FEM by using an ideal mathematical model of the frame.

Among the three ships treated in this paper, the collapse load of the bow of the tanker is the largest. But the load per unit area of the bow of the container carrier is also large. When we design the side structure of the struck ship, we must take into account not only the magnitude of the load but also the load per unit area.

Finally, the items to be pursued further are :

(a) To develope the method of obtaining entire load-deformation curves, and

(b) To establish the method of analyzing collision problems more precisely when not only the bow construction but also the side structure collapses.

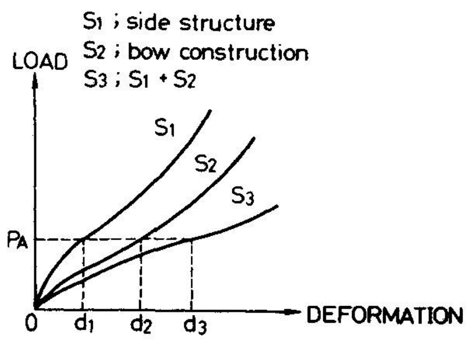

Fig.13 Load-deformation curve of bow and side structure

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