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The Energy Absorption of Combined Structure Subjected to Axial Compression

by

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Abstract

An experimental investigation on the energy absorption of two staged combined structures is presented, which deals with the plastic collapse test as a series of research on soft bow structure involved in a ship collision.

The principle of arithmetic superposition of energy absorption is derived upon experimental analysis and based upon the characteristics of the energy absorptions of component structures.

This relationship is related to the further approach toward the design of soft bow.

1. Introduction

The efforts of risk-minimization due to ship-collision have been concentrated on structural behavior using theoretical and experimental analysis procedure.

The ship collision problem is very complicated and the majority of investigations published in this area have been conducted on experimental models. Most of the theoretical approaches to the energy absorption characteristic of ship structures are based on the assumption that the absorbed energy is essentially proportional to the volume of damaged steel in the collision-participated ships.

Due to the varied and complex nature of the collision process, all experimental and theoretical approaches rely on a number of simplifications and are highly dependent on the nature of the considered problem. In former study [1], a fundamental investigation on the analysis of the energy absorption characteristic of thin plates is carried out through experimental verification.

The objective of the study is to obtain knowledge of the crushing behaviour of combined structures and the consequence of absorbed energies in order to develope rational design criteria for soft bow structure.

2. Dimension of Test Specimens

The series of crushing tests with axially compressed structures contain eight combined models, of which lower models are the type of box cylinders and their former test results [1] are to be incorporated with. The dimensions and data for the test specimens are given as follows. The round stiffening on the joint position is kept during the tests, so that the true simulation of each single component model can be evaluated. The superposition principle of the energy absorption should be demonstrated from the results of test cylinder with blunt wedge, box cylinder with pyramid as well as box cylinder with wedge.

3. Experiments and Results

The universal testing machine installed together with all the necessary service and working apparatus is used for the experiment. The maximum force of

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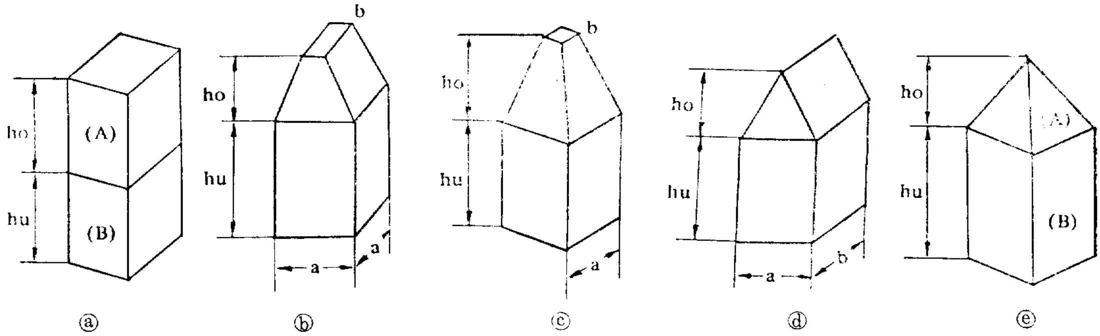


a) Box cylinder with Box Cylinder

Thickness	: 3.2mm	Thickness	: 3.2mm
Edge Length	: 300mm	Edge Length	: 300mm
Model height(ho)	: 250mm	Model height(ho)	: 600mm
(hu)	: 450mm	(hu)	: 600mm

b) Box Cylinder with blunt wedge

Thickness	: 1.6mm	Thickness	: 3.2mm
Edge Length(a)	: 300mm	Edge Length(a)	: 300mm
(b)	: 300mm	(b)	: 100mm
Model height(ho)	: 600mm	Model height(ho)	: 600mm
(hu)	: 450mm	(hu)	: 450mm
	600mm		600mm

c) Box cylinder with blunt pyramid

Thickness	: 3.2mm
Edge Length(b)	: 100mm
(a)	: 300mm
Model height(ho)	: 600mm
(hu)	: 600mm

d) Box cylinder with wedge

Thickness	: 1.6mm	Thickness	: 3.2mm
Edge Length(a)	: 300mm	Edge Length (a)	: 300mm
Model height(ho)	: 250mm	Model height(ho)	: 250mm
(hu)	: 450mm	(hu)	: 450mm
	600mm		600mm

e) Box cylinder with pyramid

Thickness	: 3.2mm
Edge Length	: 300mm
Model height(ho)	: 250mm
(hu)	: 450mm

the machine amounts to 2000KN at a maximum hydraulic cylinder stroke of 300mm. The breath of the compression plates is 400mm by which the maximum size of test model is limited.

According to the type of test specimen the model differences of crushing behaviour and end strengthening are shown during the test. In case of test model of same sized components, i.e. box type

Table 1. Results of tests with combined models

Type		Box Cylinder with Box Cylinder		Box Cylinder with Blunt Wedge			
Plate thickness	mm	3.2		1.6		1.6	
edge length	mm	300		300		300	
height	mm	250+450	600+600	600+450	600+600	600+450	600+600
end length:							
measured	mm	87	146	97	102	120	136
from recorder	mm	86	144	97	97	118	135
ultimate load	KN	495	490	124	96	481	470
number of fold		3	6	6	7	5	6
energy absorbed before end strengthening	KN Cm	9225	18317	4492	5276	16030	17900
energy absorbed by end strengthening	KN Cm	4108	9984	2820	2904	7380	9800
total energy	KN Cm	13333	28301	7310	8180	23410	27700
damaged length	%	87.6	87.8	90.8	91.5	88.6	88.7

Table 2. Results of tests with combined models

Type		Box Cylinder with Pyramid	Box Cylinder with Blunt Pyramid	Box Cylinder with Wedge			
plate thickness	mm	3.2	3.2	1.6		3.2	
edge length	mm	300	300	300		300	
heigh	mm	250+450	600+600	250+450	250+600	250+450	250+600
end length:							
measured	mm	80	136	54	72	73	99
from rdcorder	mm	78	137	54	71	74	100
ultimate load	KN	175	425	113	104	320	315
number of fold		5	6	5	6	5	6
energy absorbed before end strengthening	KN Cm	9537	17724	3540	4200	11250	14900
energy absorbed by end strengthening	KN Cm	5011	9126	1640	1920	4400	4840
total energy	KN Cm	14548	26850	5180	6120	15650	19740
damaged length	%	88.6	88.7	92.3	91.5	89.6	88.4

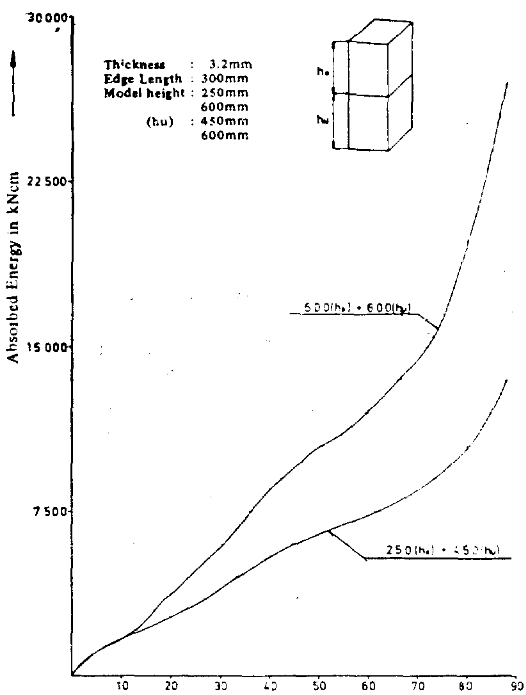


Fig. 1. Absorbed energy vs. Compression in % of model height

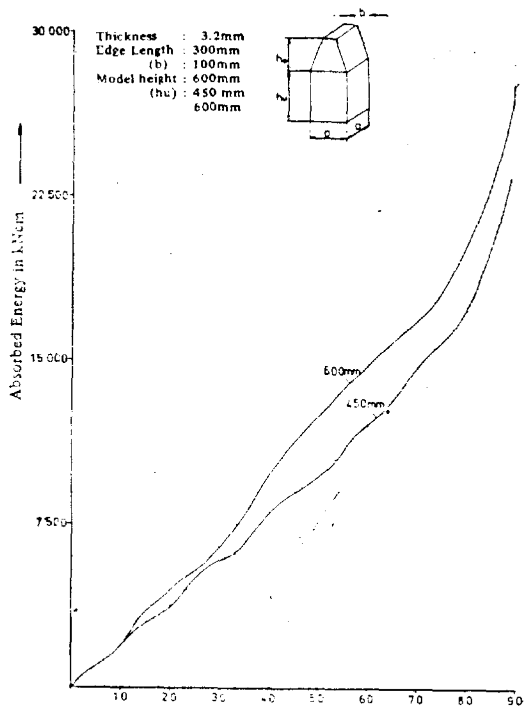


Fig. 2. Absorbed energy vs. Compression in % of model height

cylinders, the lower box cylinder begins to fold first and then continues to fold step by step to the form of buckling waves as the case of same single model, until the compression load reaches the ultimate load of the upper boxtype model. During the crushing process of the lower model the upper one remains in elastic behaviour. After that point begins the upper one to fold plastically while the folded lower

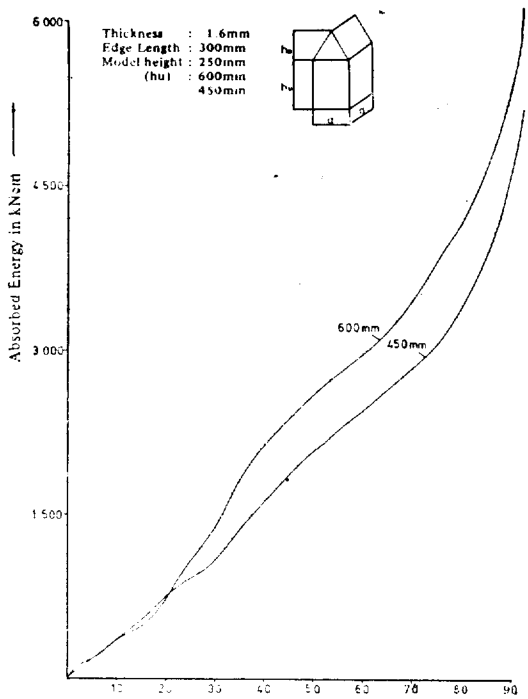


Fig. 3. Absorbed energy vs. Compression in % of model height

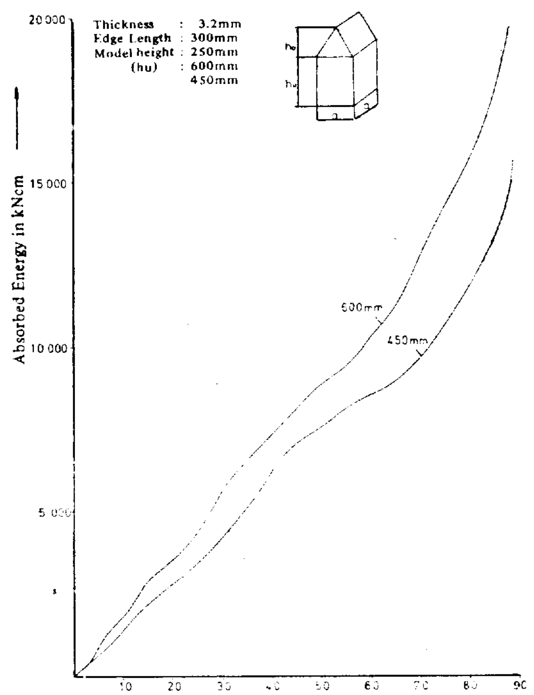


Fig. 4. Absorbed energy vs. Compression in % of model height

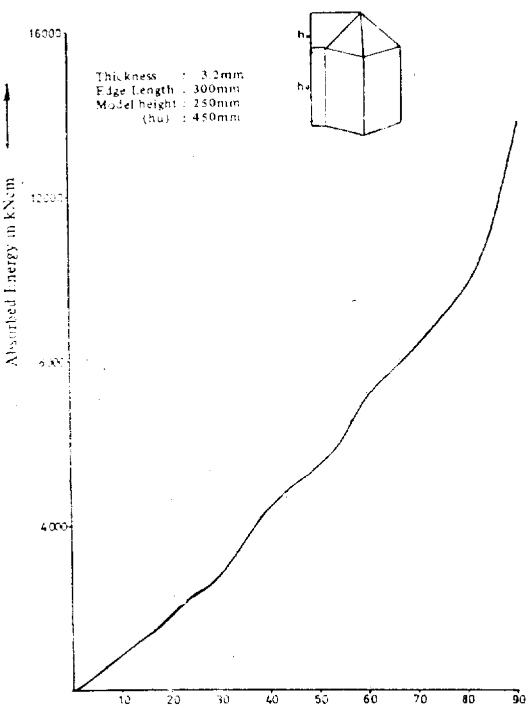


Fig. 5. Absorbed energy vs. Compression in % of model height

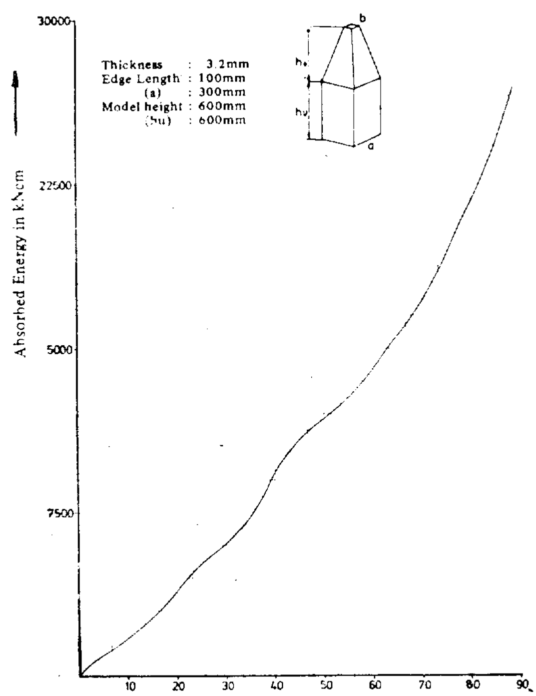


Fig. 6. Absorbed energy vs. Compression in % of model height one behaves underformed.

The end strengthening phase of upper model enters in common with lower one. In cases of test specimen of boxtype cylinder with smaller upper models, i.e. box cylinder, pyramid and wedge, the upper model folds first and then the endstrengthening follows until the compression load reaches the ultimate load of lower model and this crushes totally until the endstrengthening fully ends.

In this last phase of endstrengthening the remained part of the upper model takes the same crushing characteristics. (s. crushing behaviour of test model in appendix)

The compression load is measured continuously by the end of endstrengthening and plotted along with the axial displacement of the model.

By numerical integration the absorbed energy in the system is found as

$$\Delta E = \int_0^u F \cdot du$$

where integration is taken over the end shortening.

The test results from the experiment for the models shown in sec. 2 are listed in table 1, 2 from which the absorbed energy and the crushed length in percertage of original height are to be read, as for box cylinder with box cylinder, blunt wedge, pyramid and wedge respectively.

The curves in Fig. 1.-6. are drawn for the absorbed energy along with the end shortening in percentage of original length.

4. Evaluation

The ultimate load and energy absorption behaviour of the component structure are reported and comparison is made with the results of combined structures in Fig. 7.-14.

From the test results the ultimate load of the combined structure is found the same as the value of the greater component model and the total energy of the combined specimen is evaluated as the sum of the each component's energy. However, the differences between two values by the end phase are interpreted to the phase lag of crushing behaviour

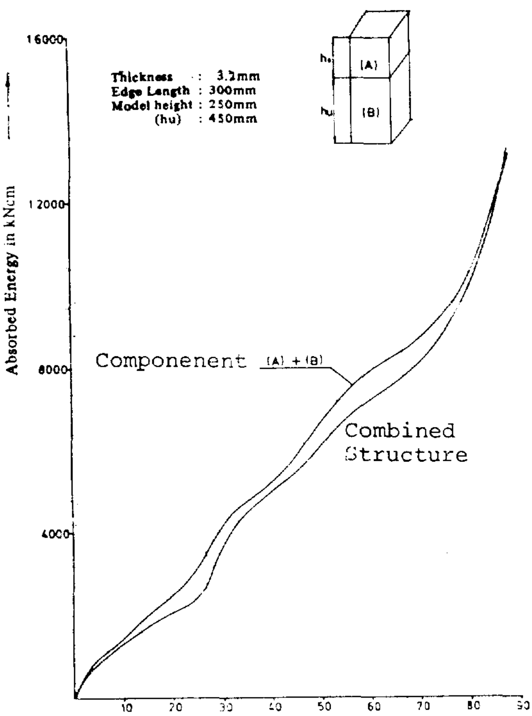


Fig. 7. Absorbed energy vs. Compression in % of model height

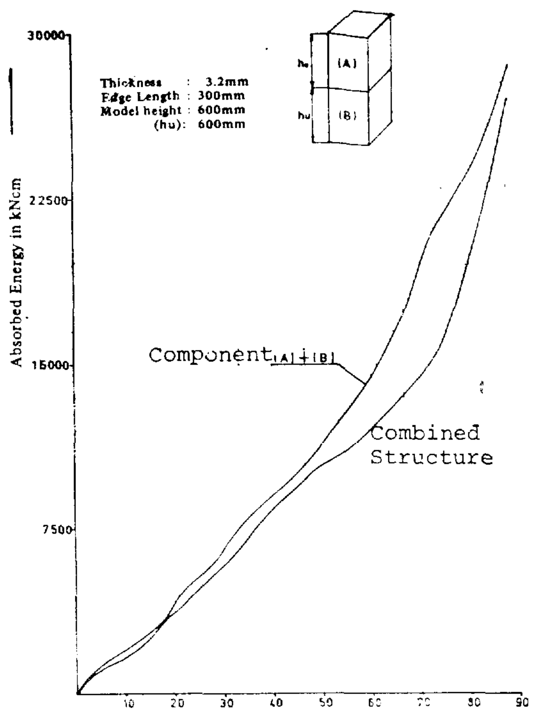


Fig. 8. Absorbed energy vs. Compression in % of model height

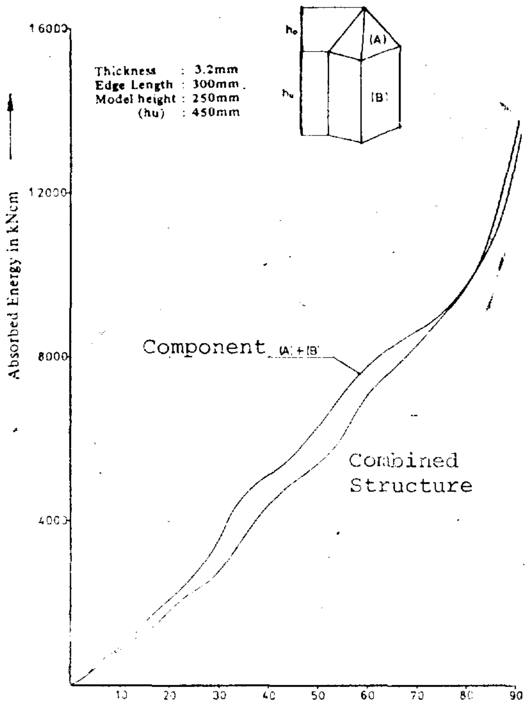


Fig. 9. Absorbed energy vs. Compression in % of model height

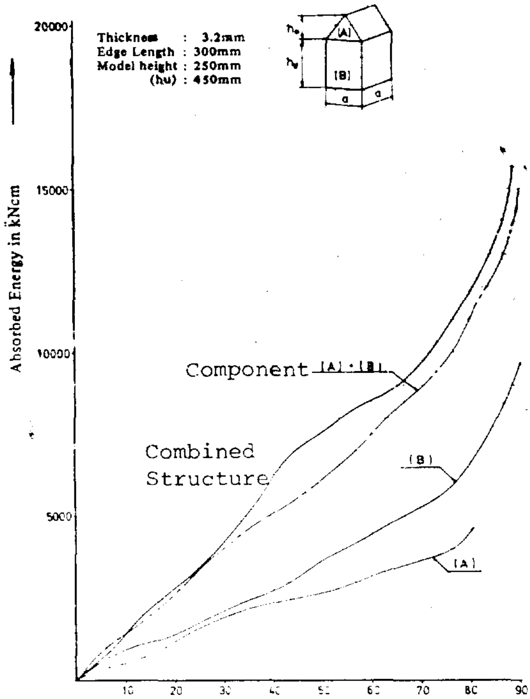


Fig. 10. Absorbed energy vs. Compression in % of model height

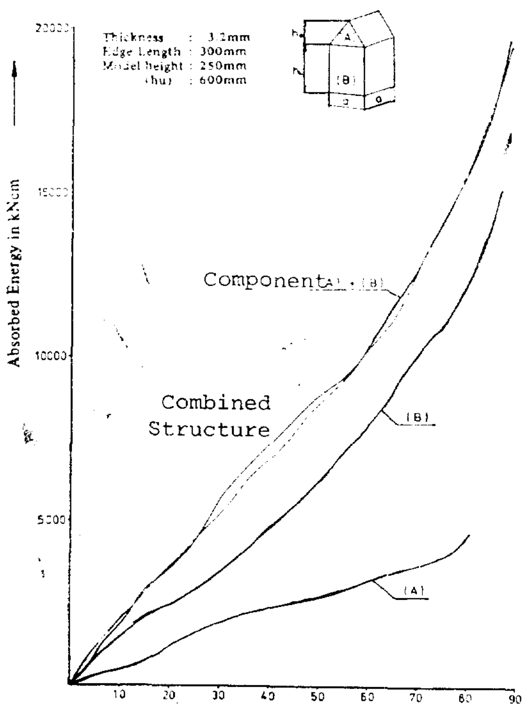


Fig. 11. Absorbed energy vs. Compression in % of model height

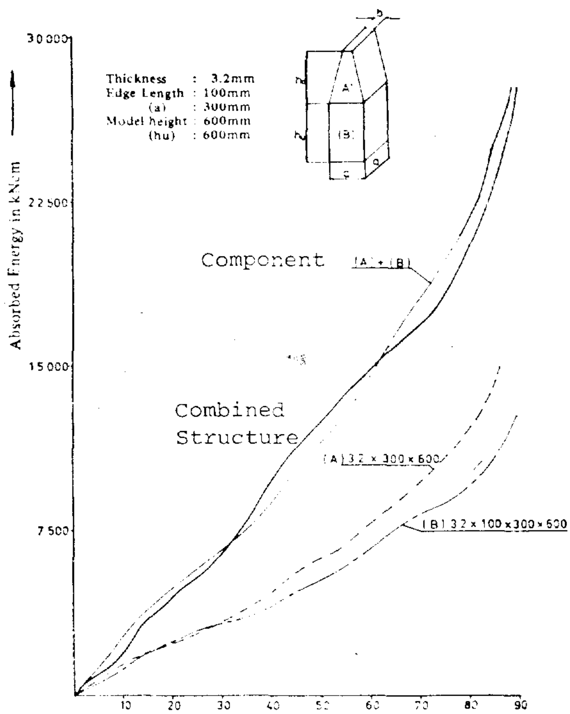


Fig. 12. Absorbed energy vs. Compression in % of model height

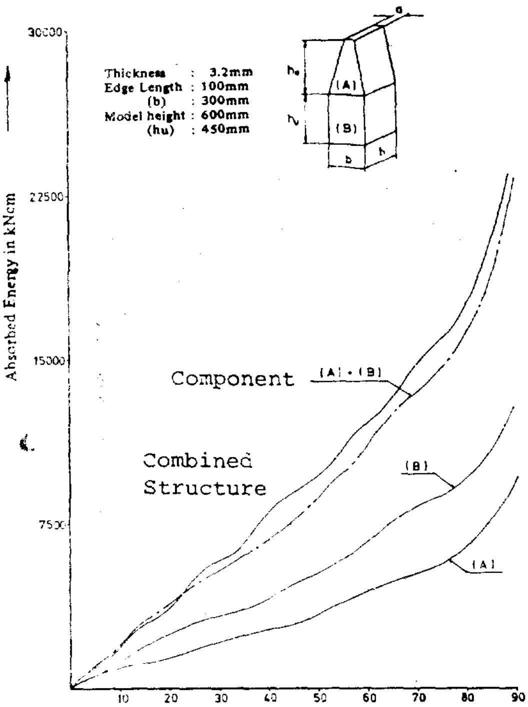


Fig. 13. Compression in % of model height

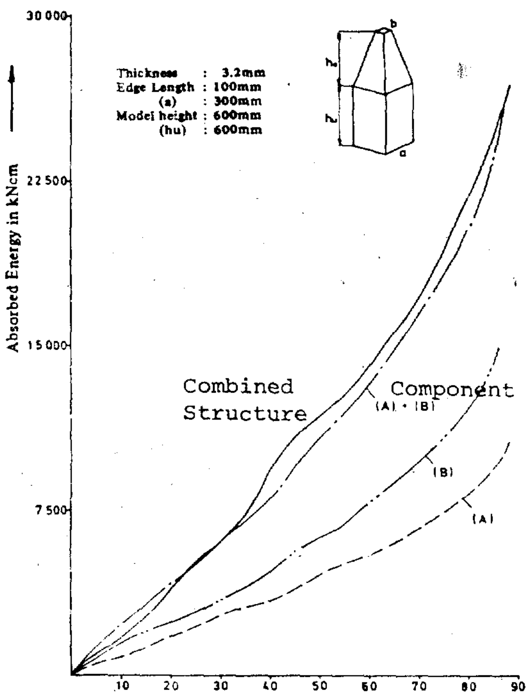
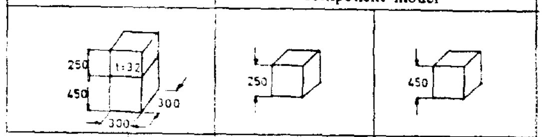
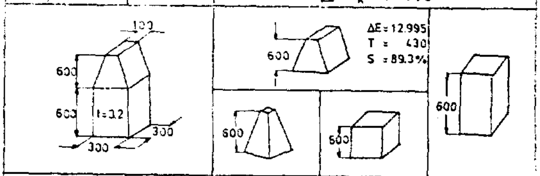
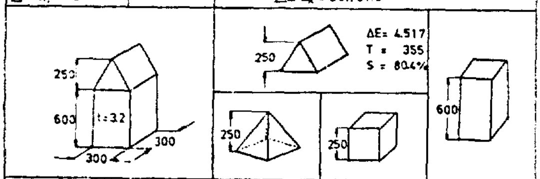


Fig. 14. Compression in % of model height

Table 3. Comparison of ultimate load and dissipation energy of combined model with component models

combined model		component model		
				
ΔE_z , ΔE_k [kNcm]	13.333	4.780		9.612
T [kN]	495	500		489
S [%]	87.6	96.8		91.1
$\sum \Delta E_k/\Delta E_z$ [%]	107.9	$\sum \Delta E_k$ = 14.392		
		ΔE = 12.995 T = 430 S = 89.3%		
ΔE_z , ΔE_k [kNcm]	27.700	10.625	15.230	15.230
T [kN]	470	420	510	510
S [%]	88.7	87.9	86.6	86.6
$\sum \Delta E_k/\Delta E_z$ [%]	101.7	$\sum \Delta E_k$ = 28.157.5		
		ΔE = 4.517 T = 355 S = 80.4%		
ΔE_z ΔE_k [kNcm]	19.740	4.230	4.780	15.230
T [kN]	315	180	500	510
S [%]	88.4	90	86.8	85.5
$\sum \Delta E_k/\Delta E_z$ [%]	99.97	$\sum \Delta E_k$ = 19.735		

in lower and upper models during collapse.

From the energy comparison of the characteristic curves in Fig. 7.-14. a clear conclusion can be found that the total absorbed energy of the combined structure results in the sum of that of component structures respectively. As an example three cases of combined structures are shown in Table 3. The first case, box cylinder with box cylinder, the sum amount of absorbed energy for each component structures is 8% more than the total value of combined structure, which is interpreted due to the end shortening more than 90% of original height of the component model.

In cases of box cylinder with blunt wedge or wedge, the absorbed energy is represented as sum value of each component structure. However, for the case of model of higher slenderness the deviation of the two energy curves shows a little greater, which lies in the range of 5% differences. From the evaluation a clear relationship can be predicted that the linear superposition of the absoraed energy ef component elements represents the absorbed energy of it's combined structure. The available range of this principle is under investigation.

On the basis of experimental data a simple technique is developed regarding the absorbed energy ΔE to the volume of damaged material V refering to the end shortening;

For the case of the absorbed energy before the end strengthening (~60% end shortening)

$\Delta E_{60}=33.0V$ [MN·m]

And for the case by end strengthening (~80% end shortening)

$\Delta E_{80}=46.5V$ [MN·m]

where V has the dimension [m^3]

As a reference the well known method developed by Minorsky [2] for the absorbed energy in ship collision is shown.

$\Delta E=47.2V+32.8$ [MN·m]

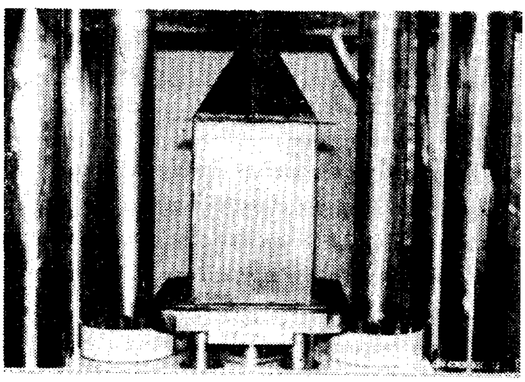
Where the volume of damaged steel material V (m^3) is represented as the projected value in the direction of penetration including the longitudinal shell plating of the struck vessel.

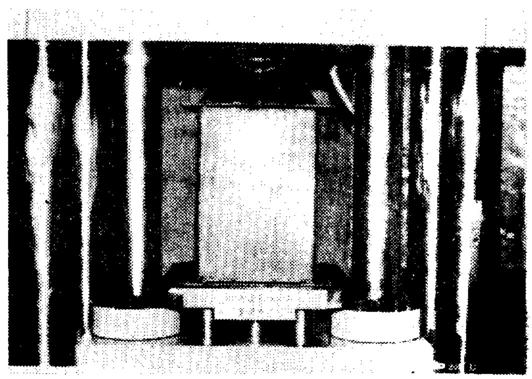
From the comparision of the former two relations with Minorsky's formula, which were derived from the collision data of real ships comprising tearing effects, the absorbed energy through crushing behaviour of the case, endshortening to 80% of model height, shows almost the same value of the first term of Minorsky's formula.

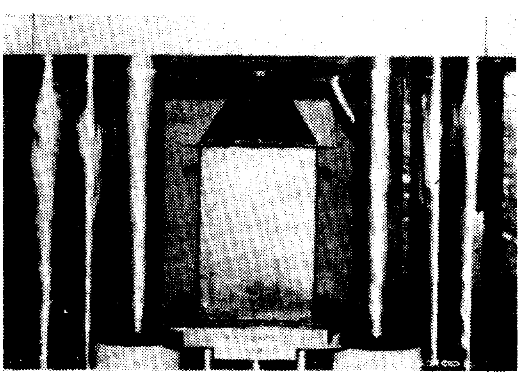
5. Conclusion

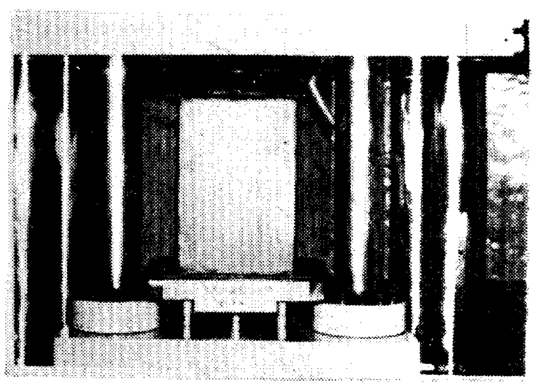
A relationship for the absorbed energy of the combined structures under axial compression is presented, which is based on experimental results. This experimental investigation on the energy absorption of combined structure deals with the plastic collapse involved in a ship collision.

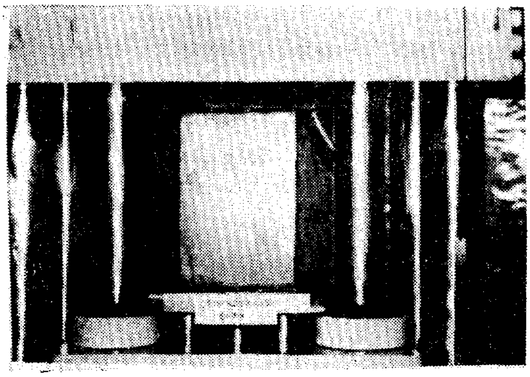
The further approach on the principle of arithmetic superposition of energy absorption is directed toward the development of an optimized bow

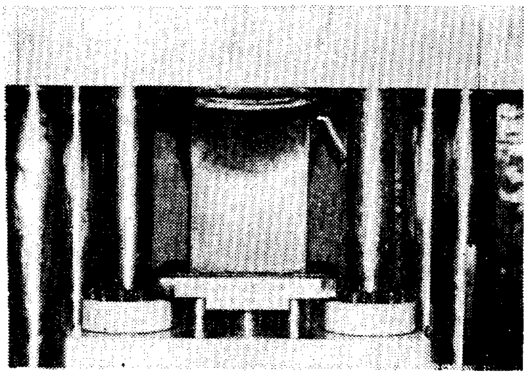


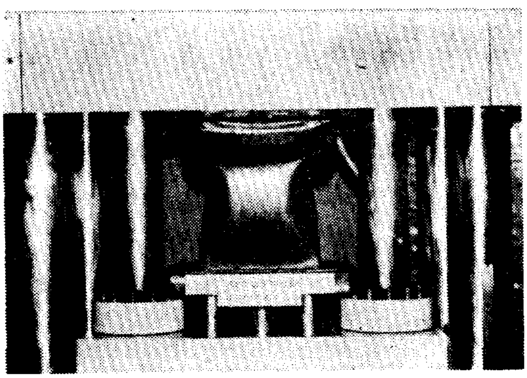


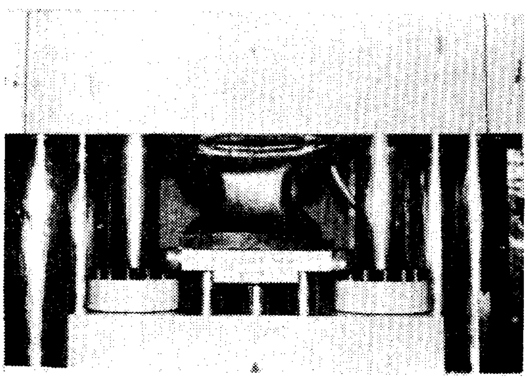


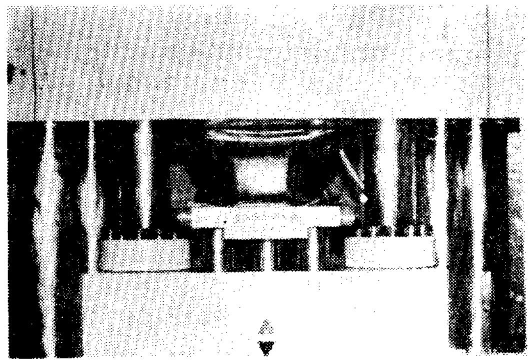


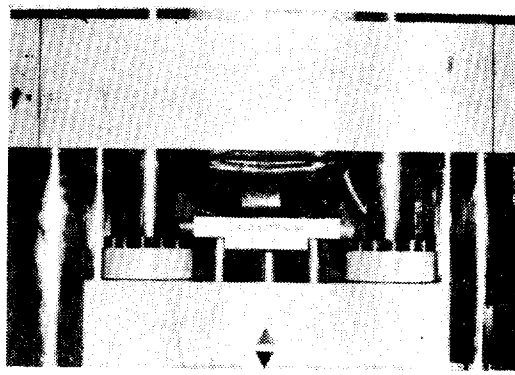


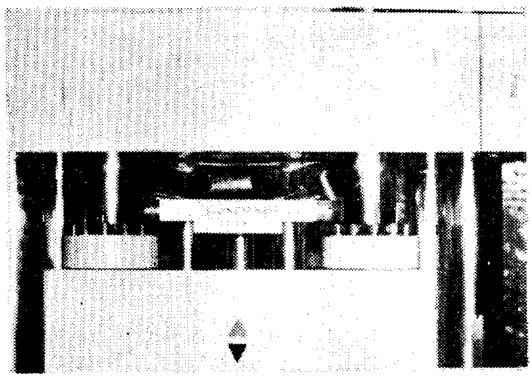


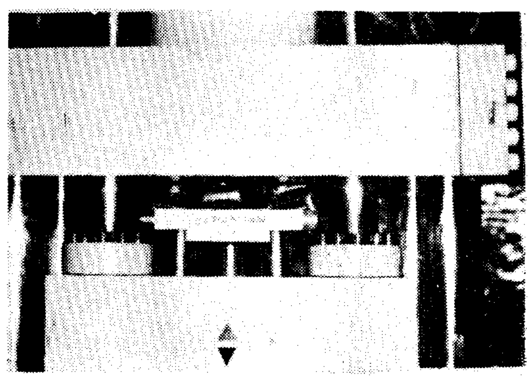












structure occuring in ship collision.

This study has been performed under the guidance of Prof. Schultz, T.H. Aachen in W/Germany.

6. References

〔1〕 Lee, J.W.; The Crushing Behaviour of thin Plates Subjected to Compression. KR-RPT 10045 3. 1980. Korean Register of Shipping.

〔2〕 Minorsky, V.U.; An Analysis of Ship Collisions with Reference to Protection of Nuclear Power Plants, Journal of Ship Resech, Vol. 3, 1959, p. -14.