Indentation Tests on Simplified Models of Ship Structures

Essais de déformation sur des modèles de navires

Verformungstest an vereinfachten Modellen von Schiffstragwerken

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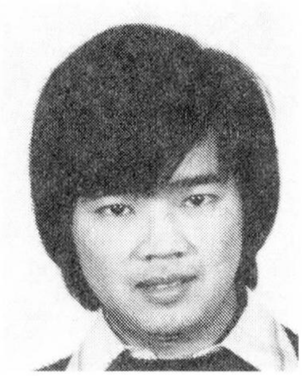

SUMMARY

The paper describes loading tests on scale models of ships' sides, indented by a stiff circular indenter representing the shaft of an offshore concrete platform. Simplified theoretical analyses based on large-deflection plastic theory are described and compared with the experimental results. Design forces for typical supply boats are derived.

RÉSUMÉ

La présente étude décrit des essais en charge effectués sur des modèles de flancs de navires gardant l'empreinte d'un objet rigide et circulaire, représentant le puits d'une plate-forme pétrolière en béton. Des analyses théoriques simplifiées, fondées sur la théorie plastique des grandes flèches, sont décrites et comparées aux résultats d'expériences. Il en est déduit les forces pour la conception des bateaux.

ZUSAMMENFASSUNG

Der Artikel beschreibt Lastversuche an Modellen von Schiffsseiten, die durch einen starren kreisförmigen Stempel verbeult werden, der einen Pfeiler einer küstenfernen Betonplattform darstellt. Vereinfachte theoretische Analysen im plastischen Zustand mit starker Durchbiegung werden beschrieben und mit den experimentellen Ergebnissen verglichen. Entwurfsregelungen für typische Schiffe werden abgeleitet.

INTRODUCTION

In recent years designers of offshore concrete platforms have become increasingly aware of the need to design for accidental loads arising from ship impact. Ship-offshore concrete platform collisions generally come into the category of "soft impact" problems and the deformation properties of the ship are then of crucial importance. In order to throw light on the deformation properties of the various components in the side structure of a ship as it is indented, a series of model tests has been carried out. A further objective of the tests was to help develop and verify simple methods of analysis to predict the force-indentation and hence energy absorption characteristics of the various structural components of a ship. There seems to be little published experimental work, with the notable exception of [1], on the deformation properties of ship structures indented by a body with a substantial radius of curvature. The test models used in [1] appear to have rather thicker plating than is of relevance to the problem of collisions between supply vessels and offshore concrete platforms.

2. TEST MODELS AND ARRANGEMENT

The test models were intended to reproduce, at a scale of approximately 1:10, the main structural features of supply vessels in the 1275 dwt category. Cold rolled mild steel sheets of thickness 1 mm were spot welded together to form simplified scale models of one or two bays of the side structure, each bay having a width of 360 mm. Fig. 1 shows the loading scheme used while Fig.2 and Table 1 give details of the test models. Both transversely and longitudinally stiffened models were tested. An attempt was made to simulate the support conditions for the indented part of the side structure thought to be afforded by the rest of the ship. Mild steel plates 3mm thick were spot welded to the edges of each test model to enable it to be bolted to a test rig constructed from standard laboratory channel sections. The models were loaded by means of a pair of screw jacks through a solid concrete indenter of part circular section and radius 720 mm so that first contact occurred either at a main transverse frame or between main transverse frames. The loading sequence was deflection controlled and the

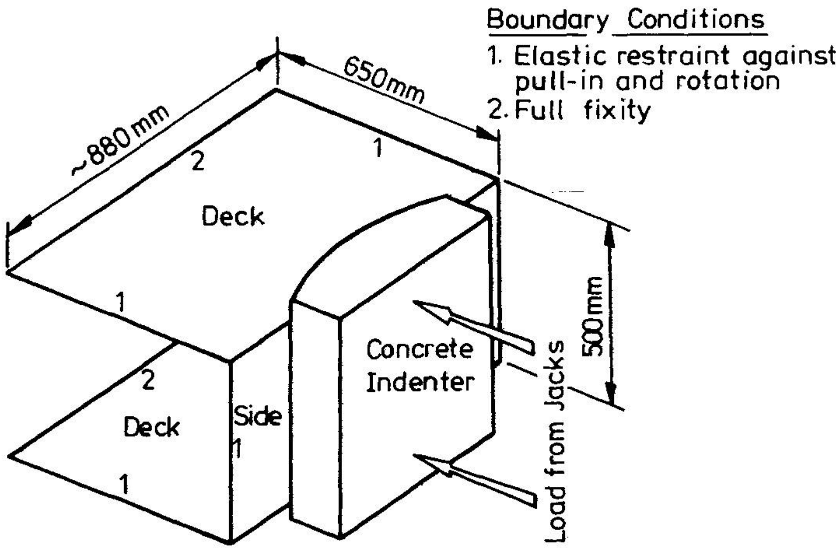

Fig.1 Overall dimensions of Typical Test Model and Loading Scheme

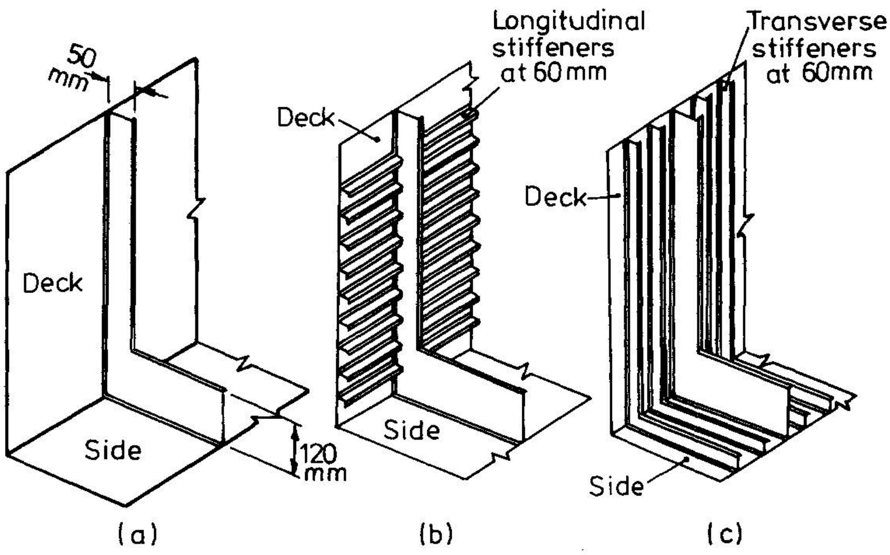

Fig. 2. Stiffener Arrangements used in Test Models

	Test Model	Stiffener Arrangement (ref. Fig.2)	Position of First Contact	Average Yield Stress σ_0 N/mm^2
m = midspan between main transverse frames. b = at a main transverse frame	TV/2/M	(a)	m	205
	TV/3/M	(a)	m	200
	LT/4/M	(b)	m	229
	LT/8/M	(b)	m	271
	TV/5/B	(a)	b	216
	LT/6/B	(b)	b	265
	TV/7/M	(c)	m	268

Table 1 Details of Test Models

stiff loading system enabled the falling parts of the load - indentation curves to be recorded. The maximum indentation in each test was of the order of 50 mm applied in discrete increments over a period of approximately 5 hours.

3. TEST INSTRUMENTATION

Instrumentation consisted of two compression load cells, strain gauges, dial gauges and a shadow moiré grid. The strain gauges were used to monitor the development of any membrane tension in the side plating. The indentation and deformed profile of one of the deck plates were determined by means of dial gauges. The profile of the second deck plate was determined by a shadow moiré technique, utilizing a coarse grid and point light source producing a fringe pattern giving contours of out-of-plane displacement over a large area.

4. ANALYSIS OF TEST RESULTS

The main test results in the form of force - indentation curves are given in Fig.3 (a)-(e). The basic approach adopted in a simplified theore-

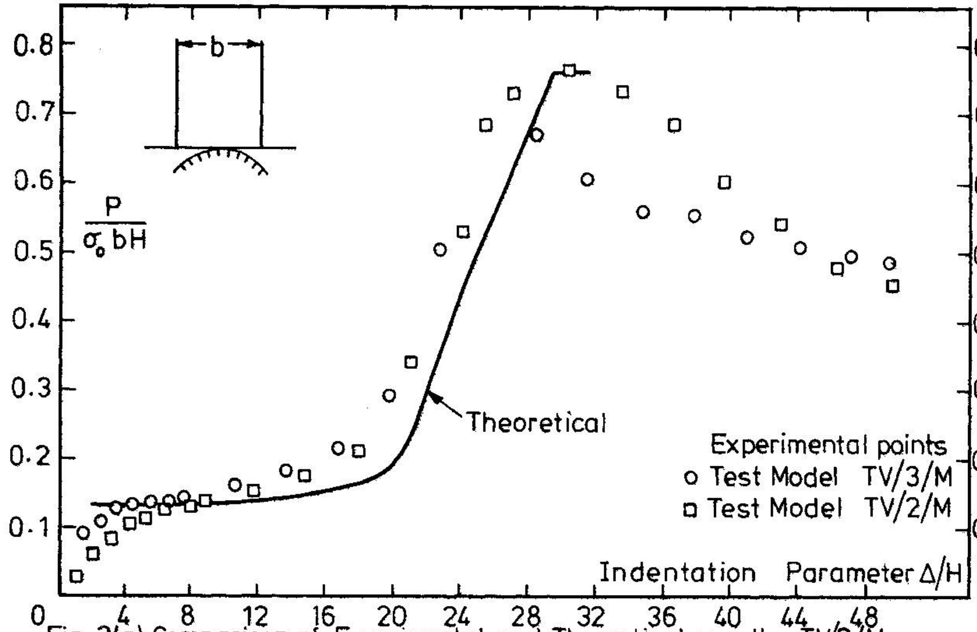

Fig. 3(a) Comparison of Experimental and Theoretical results: TV/3/M

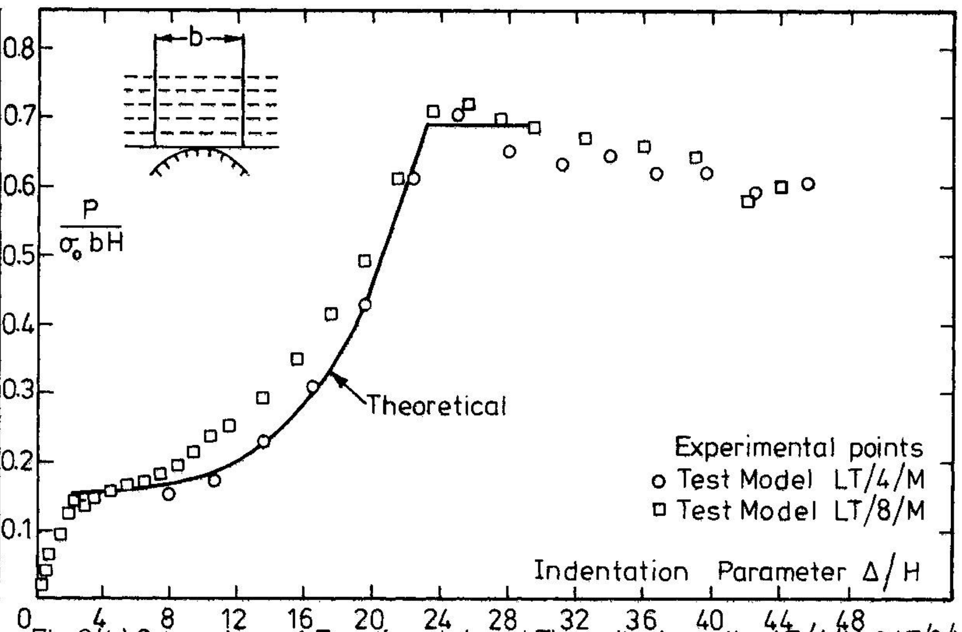

Fig. 3(b) Comparison of Experimental and Theoretical results: LT/4/M & LT/8/M

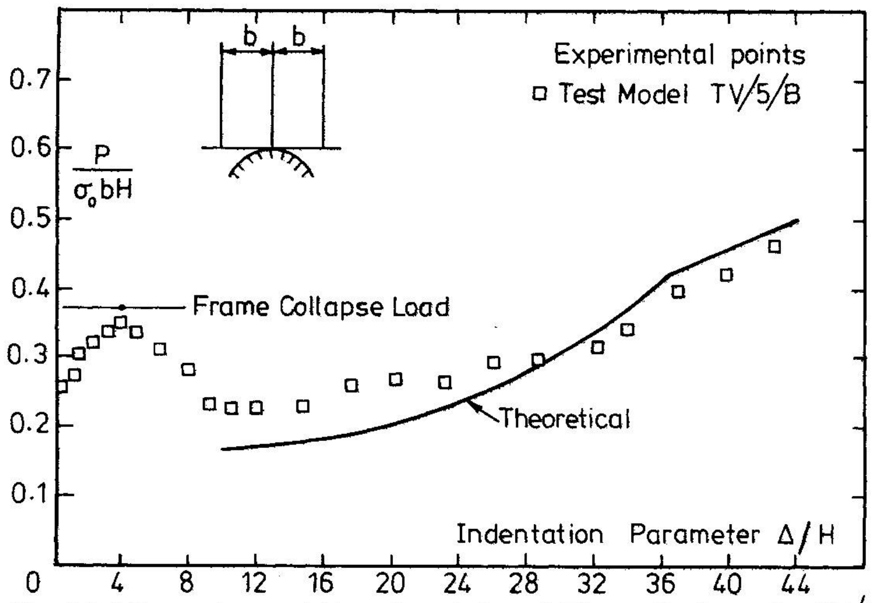

Fig. 3(c) Comparison of Experimental and Theoretical results: TV/5/B

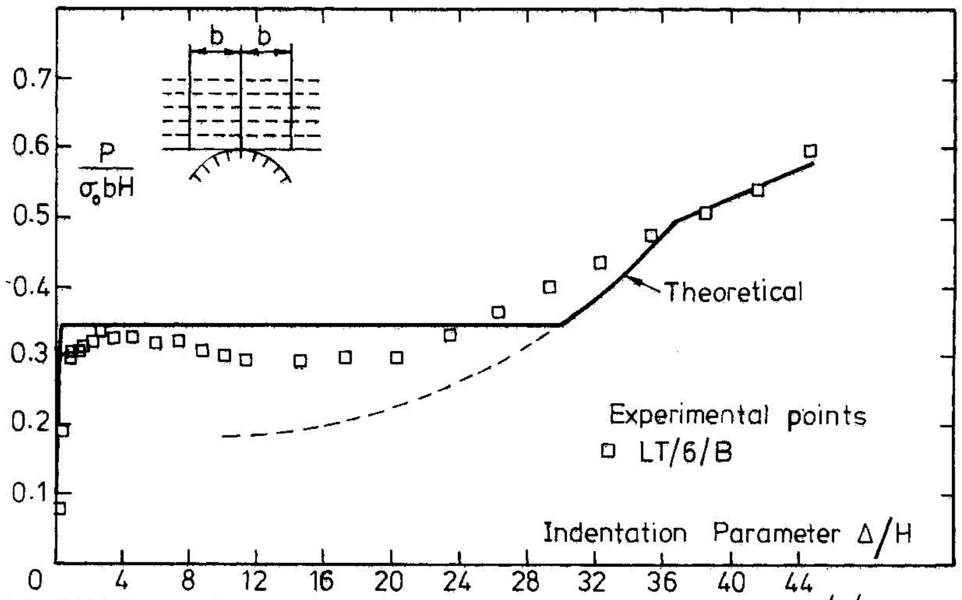

Fig 3(d) Comparison of Experimental and Theoretical results: LT/6/B

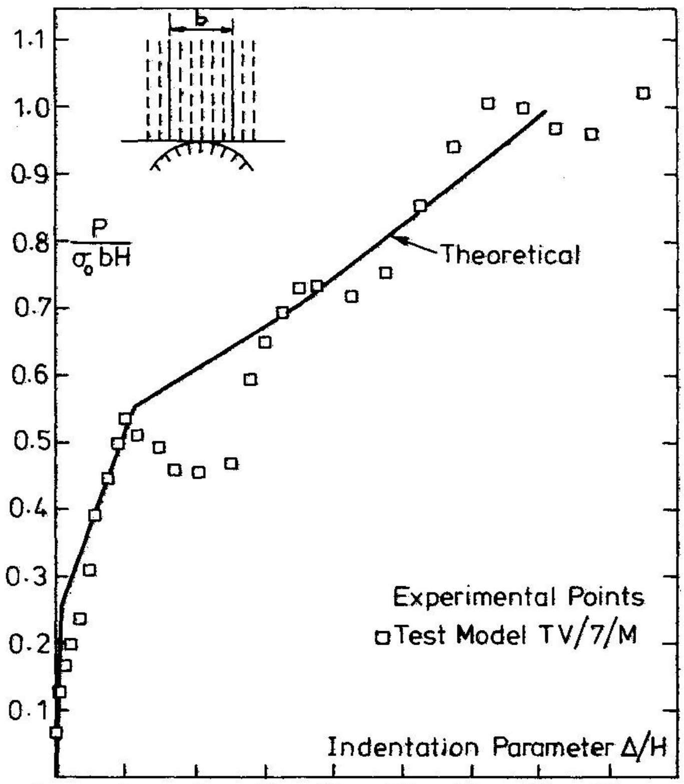

Fig.3 (e) Comparison of Experimental and Theoretical Results : TV/7/M

tical analysis of the models was to divide each model into simpler elements, to treat each element by an appropriate form of plastic theory allowing for large deformations, and to sum the force contributions of these elements at a given indentation.

4.1 Side Plating

The side plating was analysed as a beam spanning between the main transverse frames and subject to a transverse spreading load applied through a rigid circular indenter (Fig.4). The analysis for such a loading case has been presented in [2]. The degree of restraint against pull-in at the beam supports was determined empirically and reflected the flexibility of the test rig as well as the model itself.

4.2 Main Transverse Frame

The post-buckling strength of the frame corners was assessed by means of an upper bound plastic analysis involving tension field theory (following [3]). The mechanism considered is shown in Fig.5. The total strength of a main transverse frame is then given by the sum of the frame corner load and the axial load in an effective width of associated deck plating. Dwight's [4] effective width formula has been used here but there is no objection to the use of other well-founded formulae.

4.3 Unstiffened Deck Plating (apart from main frames)

The strength of the unstiffened deck plating bounded by a pair of main transverse frames was determined by an ultimate load method proposed by Roberts and Rockey [5]. A portion (½) of the side plating has been assumed to act as a flange to each deck plate, and the flange plastic moment has

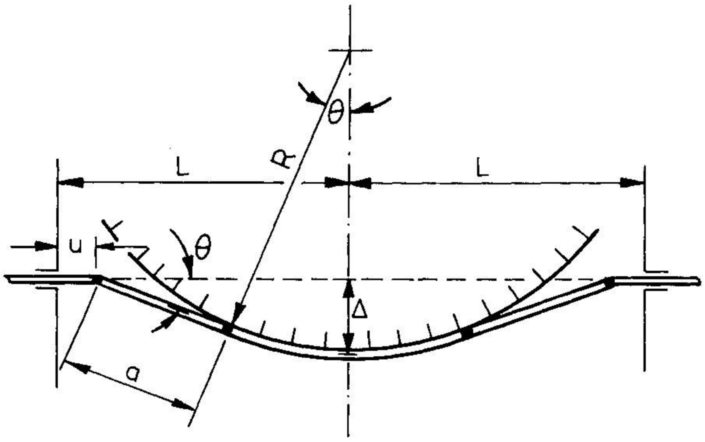

Fig. 4 Beam Loaded through a Circular Indenter

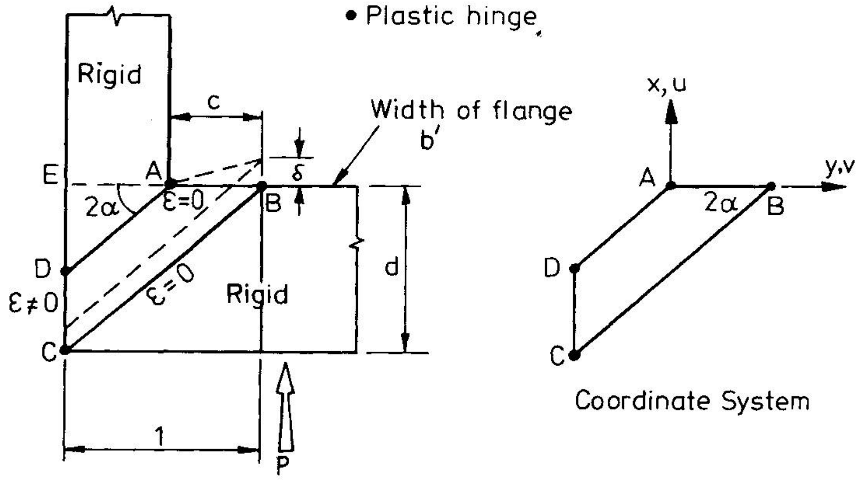

Fig. 5 Assumed Shear Collapse Mechanism

been reduced by an amount commensurate with the magnitude of axial force in the side plating.

4.4 Longitudinally Stiffened Deck Plating

A fresh approach to analysing the behaviour of a longitudinally stiffened deck at finite out-of-plane deflection was made. This involves dividing the region in contact with the indenter into strips with the adjacent material in the panel on the point of buckling. An upper bound plastic analysis for the load-end shortening relationship of an axially loaded strip (Fig.6), which retains the geometrical effects of large rotations and allows for the interaction of bending moment and axial force, has been developed [6].

4.5 Transversely Stiffened Deck Plating

The load sustained by the transverse stiffeners in the deck plating was determined by an effective width approach and corner shear calculation, as described above for the main transverse frames. For the small transverse stiffeners, the value of c in Fig.5 is chosen equal to the distance AE. Both the main transverse frames and small transverse stiffeners were taken to have a residual strength of 25% of their ultimate strengths after

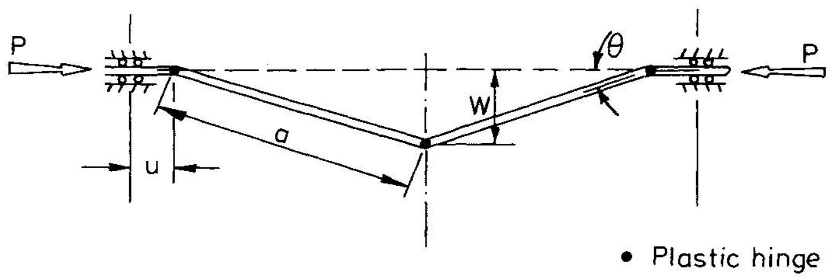

Fig.6 In-Plane Loaded Strip

collapse. This is an empirical figure which was found to work well and may be explained rationally by reference to the strip analysis outlined in 4.4.

5. COMPARISON OF EXPERIMENTAL AND THEORETICAL RESULTS

The theoretical predictions have been plotted on Fig.3 (a)-(e) for comparison with the test results. On the whole the agreement between the theoretical and experimental results is encouragingly good and reasonably consistent. In the theoretical predictions, no account has been taken of strain-hardening. At large out-of-plane deflections, structural elements which are loaded in compression in their initial planes would have lost a large proportion of their strength so that strain-hardening is unimportant to the theoretical predictions. Even in the case of plating with adequate restraint against pull-in at the unloaded edges, some out-of-plane buckling effects would counter any strain-hardening. For the side plating, the large radius of the indenter relevant to ship-offshore concrete platform collisions alleviates the effects of large concentrated strains so that strain-hardening may be ignored with no major loss in accuracy.

6. APPLICATION TO FULL SCALE SUPPLY VESSELS

The test results presented above refer to the static deformation properties of ship structures, and since this is purely a problem of structural plasticity non-geometrical scaling parameters need not be considered and the results should be applicable to full scale ships conforming with the idealizations underlying the tests. The understanding thus gained from the testing and analysis of the models has been applied to the analysis of two actual offshore supply vessels. Four cases of sideways and two cases of stern-on quasi-static collisions with a 10 m diameter concrete shaft have been studied. Design forces based on these studies, which considered wholly static deformation properties of the vessels, are proposed in Table 2 for

STERN COLLISION AT 0.5 m s^{-1}		
Maximum Force (MN)	Elliptical Contact area — Semi-axis dimensions	
8.80	133 x 48 (mm x mm)	
SIDEWAYS COLLISION AT 2 m s^{-1}		
Maximum Force (MN)	Cylindrical Contact area	
	Contact Arc (m)	Vertical Side (m)
14.81	0.013	6.75
26.94	1.633	"
33.80	3.259	"

Table 2. Design Forces : Collision with 10 m dia. Column

both sideways and stern collisions, the former for design against local bending failure and the latter for local punching shear failure. The forces determined for the stern collisions suggest that local punching failure of existing concrete shafts of typical platforms with multiple supports could occur.

7. CONCLUSIONS

The results of a series of tests on simplified ship structural models have been presented. The behaviour of these models may be predicted fairly well by analysis based on the theory of large plastic deformations.

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