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Objekttyp: **Article**

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

Band (Jahr): **42 (1983)**

PDF erstellt am: **10.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-32426

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Rigid Bow Impacts on Ship-Hull Models

Chocs d'un arc rigide sur des modèles de coques de navires

Festbug-Aufprall gegen kleine Außenwandmodelle

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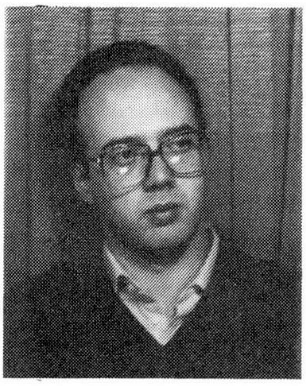

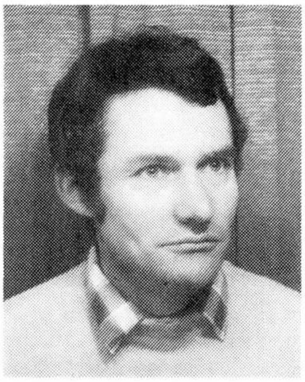

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Paul A. Frieze, born 1943, degree in Civil Engineering, followed by MSc and PhD at Imperial College, London. His research was concentrated on ultimate strength studies of bridge, ship and offshore structure, using experimental and numerical methods.

SUMMARY

Results of collision tests on rigidly-supported and freely floating models are reported. The models represent the central portion of a tanker with two longitudinal bulkheads. The striker was a V-shaped rigid bow. Comparisons with a theoretical model are also presented.

RÉSUMÉ

L'étude présente les résultats d'essais de collision sur des modèles à support rigide et en flottaison libre. Ces modèles représentent la partie centrale d'un pétrolier doté de deux cloisons longitudinales. Les chocs ont été provoqués par un arc rigide en V. Des comparaisons sont faites avec un modèle théorique.

ZUSAMMENFASSUNG

Die Ergebnisse von Zusammenstoß-Tests mit starr gestützten und frei treibenden Modellen werden aufgezeigt. Die Modelle stellen den Mittelabschnitt eines Tankers mit zwei länglichen Schotten dar. Der Aufprall wurde durch einen Festbug in V-Form erzeugt. Vergleiche mit einem theoretischen Modell werden ebenfalls aufgeführt.

1. INTRODUCTION

1.1 Marine Pollution and Ship-Collision

During the last decade or so, protection of the environment against pollution whether from accidental or wilful acts has been of major concern. In the field of Naval Architecture, the emergence of nuclear-powered ships, of fleets purveying hazardous cargoes, and of the increasing number of incidents involving oil-tankers [1] which has resulted in major pollution problems have marked a turning point in the philosophy on which regulations concerning marine safety have been based. The traditional approach to safety has been to provent death, personal injury and property loss or damage [2]. The 1954 Convention on pollution by oil discharged by ships dealt only with deliberate acts, whereas the MARPOL Convention of 1973 aims not only to prevent pollution arising from accidents but also to limit the extent of any such spillage or leakage [3]. However, in the absence of adequate data concerning the resistance to penetration of ship structures from collisions and/or groundings, the cost of such regulations can be significant both at the construction stage and during operation. For example, tankers are now required to have segregated wing-tanks so that longitudinal bulkheads might act as a second line of defence. Neither the position of these bulkheads nor their design appear to have been properly justified, although their cost has had to be borne by the industry. Also the wing-tanks can only be used for ballast and must be empty when the tanker is in-cargo. This requirement not only results in a loss of cargo space but also may not provide the benefit expected since there is evidence that the presence of water in wing-tanks can probably help absorb energy as well as dilute the effect of a collision by effectively spreading it to a greater number of supporting members. On the other hand, in an attempt to reduce the risk and therefore consequences of collisions involving hazardous cargo carriers, the U.K. appears to have adopted a "restriction-on-speed" policy whenever such vessels and others in close proximity are manoeuvring in port and harbour waters. At the moment such restrictions appear to be too strict thus adding time and therefore cost to journeys.

In an effort to provide some guidance on appropriate speed restrictions, and energy-absorption capabilities of stiffening configurations and of water ballast in wing-tanks, a programme of research was initiated at Glasgow University. It was to be a combined experimental-numerical investigation into low- to medium-energy collisions, the experimental results of which were to be used to substantiate the numerical procedure. This paper reports some of these test results. In particular, tests involving stiff-bow impacts on rigidly-mounted models ('dry' tests) having wing-tanks both full and empty of water and on free-floating models ('wet' tests) are described. Comparisons with a theoretical model are also presented.

1.2 Background

Collision tests have been conducted mainly in Japan, Italy and Germany. The Japanese tests are reported in [4]. Static and dynamic tests on simple models were conducted using rigid and deformable bows. Two different fracture types were identified depending on the extent of plastic deformations. The effect of stem angle and of angle of collision were also examined. Twenty-four tests conducted in Italy between 1963 and 1971 on reasonably complex models of scale 1:15 (22 tests) and 1:10 (2 tests) are reported in [5]. An attempt was made to simulate added mass effects by immersing wings bolted to the models'sides in water. Some of the 24 tests conducted in Germany on models of scale 1:7.5 and 1:12 have been reported in [6]. The models were very detailed and both energy-absorbing and resisting type configurations were tested. The effect of water in the fore-peak tank of the striker was investigated.

Proposals have been made for full-scale tests [7]. However, the most cost-effective method of achieving the desired results is probably a combined numerical-experimental research programme using small- to medium-scale models followed by a limited number of large-scale tests to confirm the adequacy of any allowance for scaling.

2. EXPERIMENTS

2.1 Models, Rig and Runway

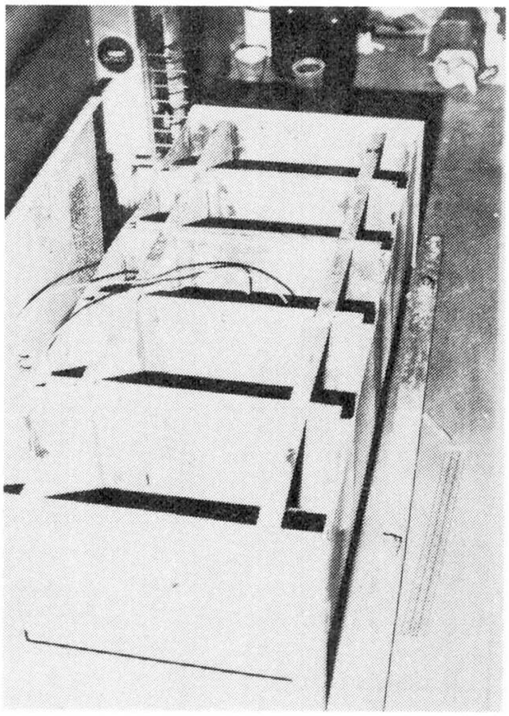


Fig. 1

Struck model

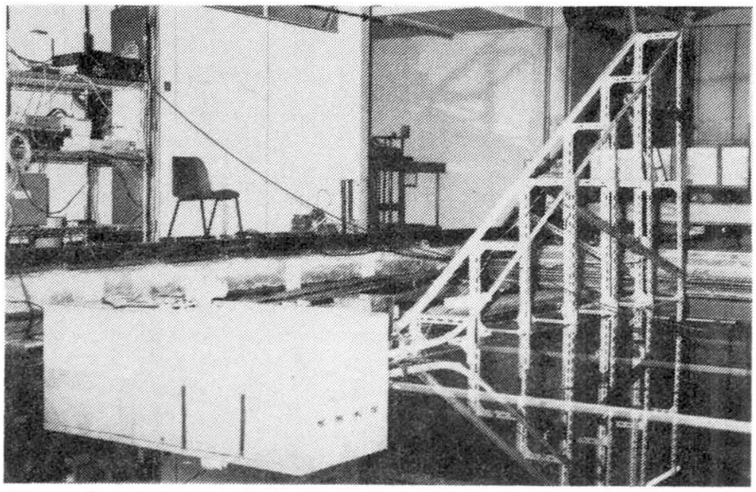


Fig. 2 Set-up for 'wet' tests

The models represent approximately 1:60 scale versions of a parallel-sided tanker with two longitudinal bulkheads and six transverse bulkheads, two of which form the ends of the model. The sides and bottom were formed from one piece of 0.79 mm thick plate to which the deck of the same thickness was rivetted. The bulkheads were made of plate 1.59 mm thick soldered to the bottom and sides of the shell and at their intersections. The models were 1.2 m long, .5 m wide and .3 m high and were fabricated from mild steel (Fig. 1). For 'dry' tests, the models were mounted between two stiff frames bolted to the laboratory floor and to the end bulkheads. For 'wet' tests, the models floated freely (Fig.2). The striker was a box mounted on four wheels to the front of which a V-shaped bow was bolted. It ran along a pair of L-shaped rails consisting of two straight sections and a curved section carefully bent according to the 1.5 power relationship. One straight section was inclined at 30° to enable the striker to gain energy, and the other was horizontal leading up to the point of impact. The mass of the striker was 10 kg which could be increased up to 60 kg by the addition of weights in the box.

2.2 'Dry' Tests

For these tests the velocities of the models just before and after impact were determined by the use of timers triggered by photo-cells activated by the passage of the striker between them. Deformations in the side-shell of the model were determined by scanning with transducers before and after the impact. Four tests have been conducted on one model, all on different tanks: details are given in Table 1. During tests 1 and 3 four tanks were filled with ballast water.

Test	B	M (Kg)	V_o (m/s)	V_a (m/s)	E_o (J)	E_a (J)	E_s (J)	E_s/E_o	S
1	0.81	28.6	3.3	-0.8	156	9	147	0.94	13.8
2	-	28.6	3.4	-0.9	165	12	154	0.93	17.0
3	0.94	39.9	3.4	-0.8	231	13	218	0.94	19.2
4	-	39.9	3.1	-0.9	192	16	176	0.92	16.7

B	ratio of the volume of ballast water to the volume of the tank
M	mass of the striker
V_o, V_a	velocity of the striker before and after the impact
E_o, E_a	kinetic energy of the striker before and after the impact
E_s	energy absorbed by the struck model = $E_o - E_a$
S	ratio of permanent deflection to thickness for the struck plate

Table 1 'Dry' Collision Tests Results

2.3 'Wet' Tests

Five tests were performed with the model floating freely in a towing tank except for a very small force generated by an electro-magnet used to just keep the model in position. The striker's input velocity and the side-shell permanent deflection were measured as for the 'dry' tests. The mass of the striker was kept constant at 55.4 kg and the initial velocity varied. In some instances the impact was arranged eccentrically with respect to the centre of the model. The results of the tests are given in Table 2 where e is the horizontal distance along the model's centreline between the centre of gravity and the point of impact. The mass of the model was 39.9 kg.

Test	e (m)	V_o (m/s)	E_o (J)	S
1	0	1.18	78	5.2
2	0	2.33	150	8.5
3	0.24	2.25	140	7.0
4	0.24	2.17	130	7.5
5	0.24	2.63	192	10.6

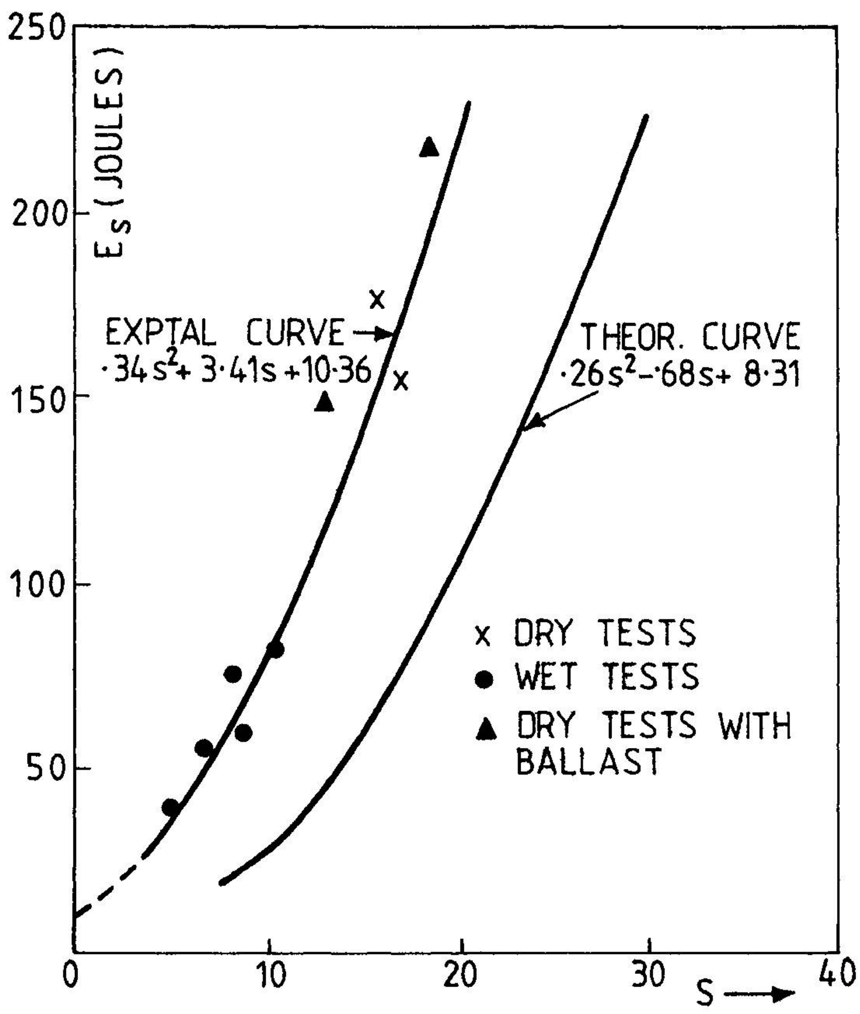
Table 2 'Wet' Collision Test Results

3. THEORY

Simulation of the tests has been affected by uncoupling the internal and external mechanics.

3.1 Internal Mechanics

The response of the side-shell has been determined using a dynamic elasto-plastic large-deflection analysis technique for a clamped-ended plate-strip. The technique is a Real-Time derivative of Dynamic Relaxation (RTDR) in which both the equations of motion and governing differential equations for equilibrium and kinematics are written in finite difference form. An elastic-perfectly plastic strain-rate sensitive material has been assumed. Yield was determined according to the von Mises criterion, and plastic flow via the Prandtl-Reuss rule. The effect of strain-rate on yield was calculated in accordance with reference[8]. A small parametric study has been performed using this technique on a plate-strip representative of the side-shell in the current models[9]. It showed that for



deflections greater than eight times the plate thickness, the permanent set was dictated by the energy of the striker. This led to a permanent set versus energy relationship that could be accurately represented by a parabola. The curve is shown in Fig.3 together with an expression which describes the parabola.

Fig. 3 Comparison of Experimental and Numerical Results

3.2 External Mechanics

Although the struck model after impact exhibited significant rolling, this was not felt to be an important degree of freedom as far as external mechanics were concerned. For this only sway and yaw were considered assuming a right-angled collision. On the basis of the recommendation in ref.[10] since the duration of the impact was short, the added mass for both degrees of freedom has been taken as 0.4. If the total translational and rotational energy of the striker plus the model after impact is considered, it can be shown[11] this is a minimum when the impact is purely plastic, i.e. the velocities of the striker and of the point of contact on the model are the same following impact. In this case, the minimum energy is given by

$$E_m = E_o(1 - \phi) \qquad (1)$$

Where E_o is the initial kinetic energy = $\frac{1}{2}MV_o^2$, and

$$\phi = \frac{1}{1 + \mu + \mu(e/r)^2} \qquad (2)$$

μ being the ratio of striker mass to the mass of the model plus added mass, and r^2 the ratio of mass plus added mass moment of inertia to mass plus added mass of the struck model. Assuming no other losses, the energy available for structural distortion is therefore:

$$E_s = E_o \phi \quad (3)$$

In order to apply this derivation to the present test series, it is strictly necessary to demonstrate that the velocity of the striker after impact was indeed equal to that of the point of contact on the model. Visual observations indicated that the striker maintained forward momentum after impact but at a reduced velocity which was indeterminable with the particular testing arrangement adopted.

Using equation (3), the wet test results were plotted in Fig. 3 along with the dry test results listed in Table 1. A least squares parabola was fitted to all the tests results except those involving ballast. The close fit to particularly both sets of test data demonstrated by this curve is encouraging except there are at least two different aspects which affect the position of this curve that are compensating. Firstly, if the impact is not entirely plastic then the energy available for structural action will decrease: this will effectively lower the wet test results shown in Fig. 3. Secondly, if the added mass is greater than the value of 0.4 assumed then ϕ will increase thereby effectively raising these same points.

3.4 Comparison Between Experimental and Numerical Results

From Fig. 3 it can be seen that the system describing the numerical behaviour is less stiff than that influencing the experimental response. This stiffness can be found from the second differential of the equations describing the two parabolae. In the previous section most of the energy-absorbing mechanisms affecting the free floating tests were accounted for. The theoretical response can be altered by making allowance for the fact that the numerical model does not represent the section of plate directly above and below the line of contact which, although distorting in a different pattern, clearly absorbs some energy. No distinct pattern of hinges was observed in these regions making comparisons of plastic work done inappropriate. Some simple calculations of the ratio of energy absorbed by the entire panel compared with just that involved in the impact region indicate this may be dependent on the ratio of panel length to the length of impact. This aspect however requires further examination and plans are underway to conduct a complete panel analysis.

Another feature of the numerical modelling which also has to be improved is to extend it beyond the supports into at least a three-bay analysis so that continuity can be more effectively represented. It was reported previously[9] that for behaviour in the plastic range, the presence of rotational restraint at the supports had little effect on the final deflected shape. Of greater importance however is the inplane restraint which can only be correctly modelled by an analysis involving more than one bay. This feature is currently being incorporated into the numerical technique.

4. CONCLUSIONS

Results of both dry and wet collision tests on simple 1:60 scale models of tankers are reported; in two of the dry tests water was present in some of the ballast tanks, including the impacted ones. The striker was a V-shaped rigid bow. Parallel structural analysis studies are also reported and a scheme that allows for added mass effects on the wet models described. From these studies it has been found:

- water in impacted ballast tanks did not appear to have a significant effect on the results, although in one pair of tests where the input energy was almost the same, the permanent set in the ballasted case was 19% less than the non-ballasted results
- by assuming fully plastic impacts and added mass coefficients of 0.4 for both sway and yaw motions for the wet test results, both sets of test data could be fitted by a parabola

- the stiffness of a parabola fitted to numerically derived results for impacts on plate strips was 24% less than that fitted to the test results. No allowance, however, was made in the numerical results for energy absorbed in the sections of plating above and below the line of impact by the bow.

ACKNOLWEDGEMENT

The authors would like to thank NATO (Research Grant No. 26881) and SERC for their financial support. They also thank the technical staff of the Hydrodynamics Laboratory of Glasgow University for their help in performing the experimental part of the work.

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