STRUCTURAL REPAIRS
IN
FORWARD AREAS
DURING
WORLD WAR II

December 1949

Bureau of Ships
Navy Department

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INTRODUCTION

The problem of effecting temporary repairs to damaged ships was encountered frequently during World War II and was handled with varying degrees of success. It was never feasible to make complete repairs to seriously damaged vessels in the forward area. Accordingly, repair work ordinarily was limited to that which would enable the ship to proceed to a larger repair activity and eventually to a shipyard. Repairs to machinery and electrical equipment were in most instances limited to rerouting piping, installation of spare parts, preservation and baking out of intact equipment that had been in flooded spaces, or repairs normally considered within the capacity of the ship's force. These types of repairs are treated thoroughly in manufacturers instruction books, the Bureau of Ships Manual, training instruction books and other readily available sources. Comparatively little data is available, however, concerning the more important repairs to seriously damaged structure which are required to enable a ship to withstand the hazards of a voyage in the open ocean.

Examples of repairs made during World War II are presented to familiarize repair activities with types of problems with which they may be confronted and to facilitate their solutions of them. The selection of examples has been influenced by the desire to include representative types of damage, the availability of information concerning the repairs made and the effectiveness of the repairs. In most instances, the action of the repair activity was soundly conceived and executed. The cases of O'BRIEN and ERIE are included in contrast to emphasize the serious consequences of inadequate repairs or poorly conceived procedures. For the sake of brevity, details of procedures for unwatering flooded spaces, making attachments between original and replacement structures, removing damaged structure and the results of stability and strength calculations are presented only for selected examples. However, these phases are of paramount importance in all cases of damage repairs.

Ideally, repairs should restore the ship to her condition before damage. Usually, sufficient plans are available aboard a ship to indicate the scantlings of essential structure. In the event no plans are available, it is possible to obtain measurements from adjacent structure. However, limitations of time, manpower, materials and facilities usually will necessitate some compromise with the ideal. Nevertheless, it is imperative that the repairs, even though temporary, embody sound engineering principles and practices, be adequate to permit safe passage of the ship and be accomplished safely and without hazard to the ship or personnel.

Design Data for plating and stiffeners is contained in the Bureau of Ships pamphlets listed below which are included in the technical files of every repair activity. The standards prescribed in them represent sound practice and should be followed insofar as possible when repairing damaged structure.

(a) Design Data for T Section Beams and Stiffeners. C&R No. 002213-A.
(b) Design Data for Tee Type Beam and Stiffener Brackets. BuShips No. 015025.
(c) Formulae for Determination of Scantlings for Flat Plating and Stiffeners subject to Water Pressure. C&R No. 002213.
(d) Design Data for Tee Stiffeners. Proportions for Lateral Stability and Requirements for Lateral Support to Prevent Tripping. BuShips No. 017969.

The principal features illustrated by the included cases are:

1. Stability During Repairs.

This problem is discussed in considerable detail in Chapter 88 of the Bureau of Ships Manual. Before repairs are begun on any ship that has appreciable flooding, a careful estimate of stability should be made. A continuing analysis should be made of the effect on stability of moving, removing, or adding stores, equipment, floodwater, ammunition, structure, etc. ERIE provides a most serious example of the result of failure to make these calculations. The care taken to maintain continuous knowledge of the stability condition of RENO throughout her repairs provides a welcome contrast.

2. Restoration of Longitudinal Strength.

Ordinarily, there will not be sufficient data on hand in the forward area to permit a complete strength calculation. However, it is comparatively easy to calculate the moment of inertia of a section incorporating planned repairs and compare it with that of the intact section. Such a calculation will establish the adequacy of planned repairs. Failure to provide sufficient replacement structure to restore the loss of strength resulting from damage and to provide adequate continuity of the replacement structure was responsible for loss of O'BRIEN which was not severely damaged by the initial explosion. The wide dissemination given this case aided in preventing similar occurrences during World War II. The cases of RENO, CANBERRA, HOUSTON, WADLEIGH and NEWCOMB illustrate more effective repairs to longitudinal strength.

3. Replacement of Local Strength.

Repairs to restore local strength and support for large weights are provided in the cases of RENO and SELFRIDGE. The goal of this type of repair is to insure continuity of support for massive items down to the shell.

4. Watertight Integrity.

Repairs to restore lost watertight integrity are discussed in detail in Chapter 88 of the Bureau of Ships Manual. They figure in every case of primary damage to the underwater body and in many cases where the primary damage occurred above the waterline. This feature is illustrated particularly In the cases of NEWCOMB, CANBERRA, RENO and HOUSTON.

5. Temporary Bow Structure.

The case of SELFRIDGE Is used to illustrate this type of repair which was required on many ships of destroyer and cruiser types.

6. Temporary Stern Structure.

The case of FOOTE illustrates this type of repair to damage that was experienced in several instances by destroyers.

7. Temporary Steering Facilities.

The adverse effect of loss of deadwood aft was frequently observed in attempts to tow damaged ships. The fixed fins installed on FOOTE were very effective in reducing yaw during towing operations. In other cases of such damage to destroyers, temporary movable rudders that could be positioned by chain falls or by training of a gun mount proved equally effective. INTREPID was able to maneuver satisfactorily by use of her engines despite a damaged rudder that was positioned off-center. When the rudder was removed, however, the ship became unmaneuverable. A temporary rudder, positioned by cables that were run to the stern winch, restored her ability to maintain course within reasonable limits.

8. Use of External Cofferdam.

Underwater repairs to KEARNY were made In Iceland when no drydock facilities were available. A cofferdam that was positioned by hogging lines and secured to the ship's side by water pressure was used in this instance. Plans were made for repairing WADLEIGH by the same method. After the cofferdam was built, however, drydock facilities became available, so the cofferdam was not used.

9. Steel Repairs to Wood Vessel.

The completely satisfactory repairs to VIBURNUM exemplify the practicability of this type of repair.

USS ERIE (PG 50)

Ship:	USS ERIE (PG 50)
Cause of Damage:	Submarine Torpedo
Date:	12 November 1942
Place:	Willemstad, Curacao, N.W.I.
Class:	PG 50
Standard Displacement:	2000 tons
Length Overall:	328' 6"
Extreme Beam:	41' 3"
Draft Before Damage:	14' 2"
Launched:	29 January 1936

1. At 1733, 12 October 1942, a torpedo detonated about 5 feet below the waterline at frame 126, starboard (Plate 1, 2). The hull below the waterline was ruptured for a length of 45 feet. Transversely, the break extended from 5 feet to starboard of the keel up to the main deck and across the main deck almost to the port side (Photo 1). Fuel oil, diesel oil and gasoline tanks in way of the explosion were demolished, and the platform and second decks were ruptured. On the 2nd deck, bulkheads 119 and 131 were torn and the watertight door in bulkhead 107 was distorted and could not be closed. Oil and gasoline spread throughout the flooded 2nd deck compartments between bulkheads 99 and 141. This flooding represented about a 25% loss of waterplane area. A few seconds later a second explosion of considerable intensity occurred in the same area, probably the result of ignition of gasoline vapor. Fire, fed by gasoline and fuel oil, spread rapidly throughout the 2nd deck and through the after superstructure. Within 12 minutes, ready service ammunition for 6" mount 4 began to explode.

2. The torpedo detonation produced an initial list to port, but immediately thereafter ERIE began listing gradually to starboard and settling by the stern. Course across wind was maintained for a few minutes to prevent spread of the fire forward to the 6" ready service rooms and aft to the depth charge stowage. Increasing list and trim made sinking appear imminent, so course was changed to head for the beach about 4 miles away. List had increased to 15° and the main deck was underwater aft of frame 104 starboard when ERIE grounded at 1823. After grounding ERIE assumed a slight port list following the contour of the bottom.

3. After grounding, burning oil and gasoline spread forward and encircled ERIE, except for a small portion of the bow. Almost the entire superstructure was afire within 2 minutes. ERIE was abandoned at 1826, 3 minutes after

grounding. The uncontrolled fires had nearly burned out by 14 November when a party boarded ERIE and extinguished all fires above the 2nd deck. Fires below the 2nd deck were not extinguished until the following day. While ERIE was beached the port shaft alley flooded as the result of grounding damage.

4. Salvage operations under the direction of Merritt, Chapman and Scott were begun on 19 November. The topsides were stripped, debris was removed from the 2nd deck, stores were removed from the platform decks and several tanks were emptied. The anchors and chains were removed making the total weight removed about 375 tons. About 20 tons of oil remained in A-4F and A-418F. The stern aft of the damaged area remained buoyant during the entire time ERIE was beached.

5. On 28 November, ERIE was hauled off the beach and towed to Willemstad Harbor. When refloated, drafts were 8 1/2' forward and 24' aft and ERIE had a 8 1/2 port list. The stern drooped an estimated 24". Between 28 November and 5 December operations apparently were limited to removing accumulations of rainwater and seepage. At a conference on 3 December it was decided to place ERIE in a local drydock for sufficient temporary structural repairs to permit safe tow to a shipyard. It was decided to remove the list and reduce draft aft to 20' to prepare ERIE for drydocking. This was to be accomplished by removing additional scrap and debris, removing the fuel remaining in A-418F and A-4F, flooding forward compartments and placing counterweights on deck. On 4 December the anchors and chains were replaced and pumping of the two tanks was completed at 1930. This left ERIE with about a 5° port list.

6. At 0300, 5 December, 7 1/2 hours after pumping was completed, guards aboard observed that ERIE had righted and was beginning to list to starboard. Motion was slow and jerky and eventually stopped at about 10° when the hull rested against a fuel oil barge secured on the starboard side. D-1W, 43 tons capacity, which previously had been leaking at the rate of 200 gallons a day, was found to be full. Water was found to be running in on the 2nd deck from B-201-ILE, apparently through drains, and into C-201L. Flooding in C-201L extended at least to the centerline trunk since water was reported running down this hatch into the engine room. A slight gain was made on this flooding using a portable pump. A-418F and A-4F were completely filled to remove the list. About 12 minutes after this operation was completed, ERIE started to come upright, then passed the vertical and with increasing acceleration capsized to port.

Analysis of Stability, (Plates 2, 3)

7. The best estimate of ERIE'S displacement before damage is 2730 tons, giving a corresponding draft of 14' 2". This corresponds closely with Condition VI of the inclining experiment data. Curve A of plate 3 is the curve of statical stability for this condition. GM, uncorrected for free surface, was about 3.0'. Although the distribution of liquids is uncertain, free surface correction could not have been greater than 3" and is omitted. ERIE was in a condition which offered the greatest resistance to underwater damage and also provided satisfactory stability characteristics.

8. As determined from the inclining experiment, the metacentric radius (BM) before damage was about 11.1'. Flooding resulting from the explosion reduced the waterplane area by about 25%. A quick estimate of GM after damage which could and should have been made on the spot is as follows: Assuming BM varies linearly with length of the Intact waterplane, a 25% reduction in the length of the intact waterplane is accompanied by a 2.8" reduction in BM and approximately the same loss of GM. This hasty estimate indicates that before beaching GM was reduced to 0.2' a precarious condition of initial stability. More precise calculations made later indicated that GM, uncorrected for free surface in the forward tanks, actually was about zero. Curve B of plate 3 is the statical stability curve of ERIE immediately after damage. In this condition the maximum righting moment is 675 tons-feet, 14% of that before damage. The range of stability decreased from 70° to 43°. The total dynamic stability required to cause capsizing was reduced from 3567 to 283 foot-tons, a reduction of 92%, Flooding of the starboard shaft alley, D-403E, which was the only known unsymmetrical flooding, produced a heeling moment of 330 tons-feet which Curve B indicates would produce a list of 15°, the list actually reported by ERIE. The crosshatched area on Curve B is the residual dynamic stability with 15° list and shows that the dynamic stability in the upright condition was reduced about 2/3 when the 15° list was assumed. These detailed calculations reiterate the critical stability condition of ERIE when beached.

9. About 375 tons of weight were removed during salvage operations while ERIE was aground. Although all possible topside weights were removed, much of the removed weight, including 200 tons of liquid, was low. Therefore, the lowering of the center of gravity and increase in GM was comparatively small for the amount of weight involved.

The center of gravity was lowered only 0.4' and GM was increased only to 0.7'. Curve C of Plate 3 is the stability curve for this condition. At small angles, below about 15°, the effect of weight removal is not appreciable. The greatest effect was to increase the maximum righting moment to about 1900 tons-feet and to increase the range of stability nearly to the intact value. The total dynamic stability required for capsizing was increased to 1124 tons-feet, about 32% of the intact value. Although stability when ERIE was refloated was considerably better than it had been before beaching, ERIE was still in a critical condition. The 8 1/2° port list when ERIE was refloated could have been caused by unsymmetrical distribution of remaining weights. The flooding of the port shaft alley and the 20 tons remaining in A-4F and A-418F would have been sufficient to cause this list had ERIE been otherwise balanced.

10. The effects of the activities on 4 December, i.e., replacing the anchors and chain and removing 20 tons of liquid from A-4F and A-418F, was to reduce GM from 0.7' to 0.5', to reduce the port heeling moment by about 200 tons feet, thereby reducing the port list from 8 1/2° to 5°. Neither the removal of liquid nor adding of topside weight was advisable, even though initial stability remained positive after the operations. They indicate lack of appreciation of ERIE'S poor stability condition.

11. D-1W apparently flooded slowly, since the list did not change abruptly. This flooding produced a 667 tons-feet heeling moment, which from curve C would cause 18° total list. Since ERIE had a 5° port list, a 13° starboard list could be expected. Actually, the barge alongside prevented listing beyond 10°. Flooding of D-1W produced an after trimming moment of 5200 tons-feet which would cause a 34" change of trim, reasonably close to the 3' estimated by the Commanding Officer. Flooding of D-1W also caused a slight increase in GM.

12. The free surface effect, incident to the flooding on the 2nd deck, reduced GM by 1.6' to -0.9'. ERIE probably would have capsized to starboard had not the barge prevented. Counterflooding of A-4F and A-418F provided an ever increasing port moment. Curve D of Plate 3 is for D-1W flooded, free surface to the centerline of C-201L, and A-4F and A-418F empty. It is a close approximation of ERIE'S stability condition immediately before counter- flooding and capsizing. Since neither initial nor dynamic stability was positive, the only immediate action which could have saved ERIE was rapid removal of free surface in C-201L and cautious addition

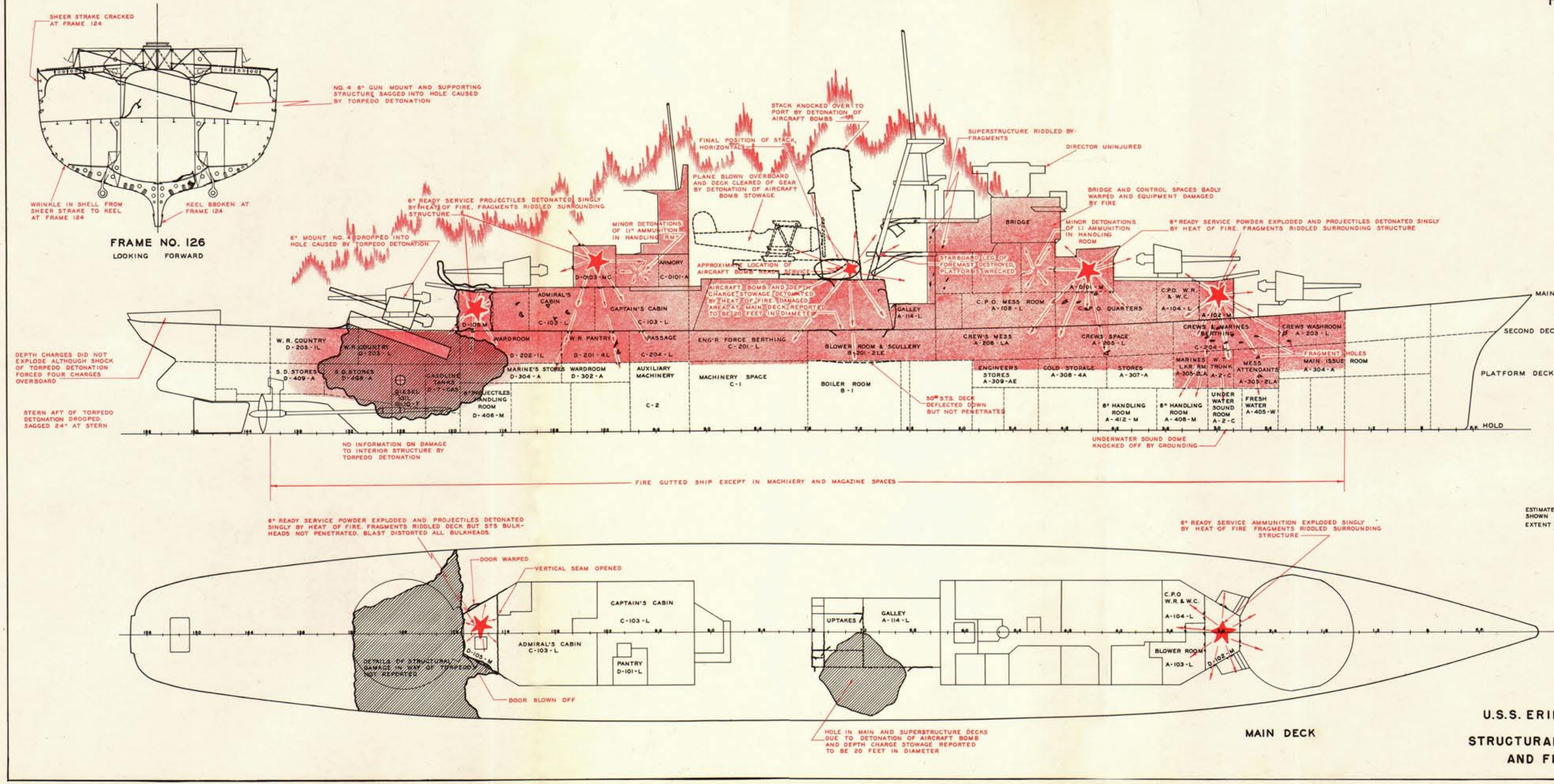
of low ballast either on or to starboard of centerline, thereby taking advantage of the support given by the barge in preventing capsizing to starboard. Although counterflooding A-4F and A-418F increased GM to -0.6', it produced a port heeling moment of 975 tons-feet and made capsizing to port inevitable. The negative stability curve explains the increasing acceleration of the roll to port.

13. From the available information, it appears that no formal estimates or calculations of ERIE'S stability were made at any time during the various phases of the operation. If her stability condition had been known, even approximately, it is probable that more active measures to improve stability would have been undertaken during the period 28 November to 4 December, that low liquids would not have been removed and high weights added on 4 December, and that A-4F and A-418F would not have been flooded so readily.

14. Preparing a vessel with low stability for drydocking is a complex problem and invariably requires a detailed stability analysis and carefully planned operations. It is impossible to establish a definite set of rules to be followed in such cases, since each case is a problem in itself. RALEIGH was successfully drydocked after damage at Pearl Harbor on 7 December 1941, even though GM was only a few inches, a port list existed, and the ship was trimmed 12' by the bow. A complete stability analysis was made and the program for correcting list and trim was worked out in chronological detail before operations began. All preparations for drydocking, including calculations, took about 2 weeks.

Photo 1: ERIE (PG 50) General view of torpedo and fire damage from off starboard quarter.

PLATE I

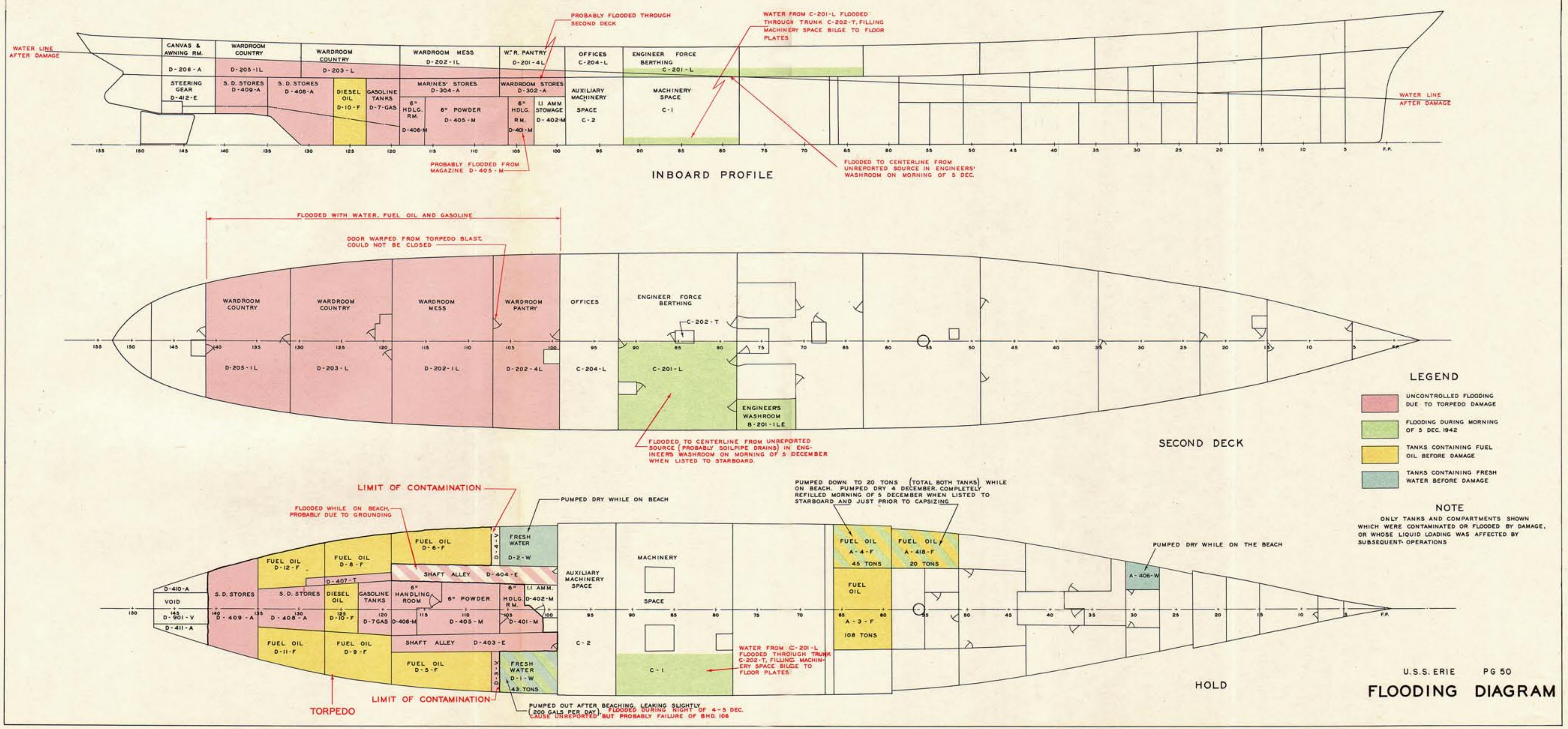


NOTES
ESTIMATED LIMITS OF DAMAGE SHOWN IN HEAVY LINES
EXTENT OF FIRE SHOWN IN RED

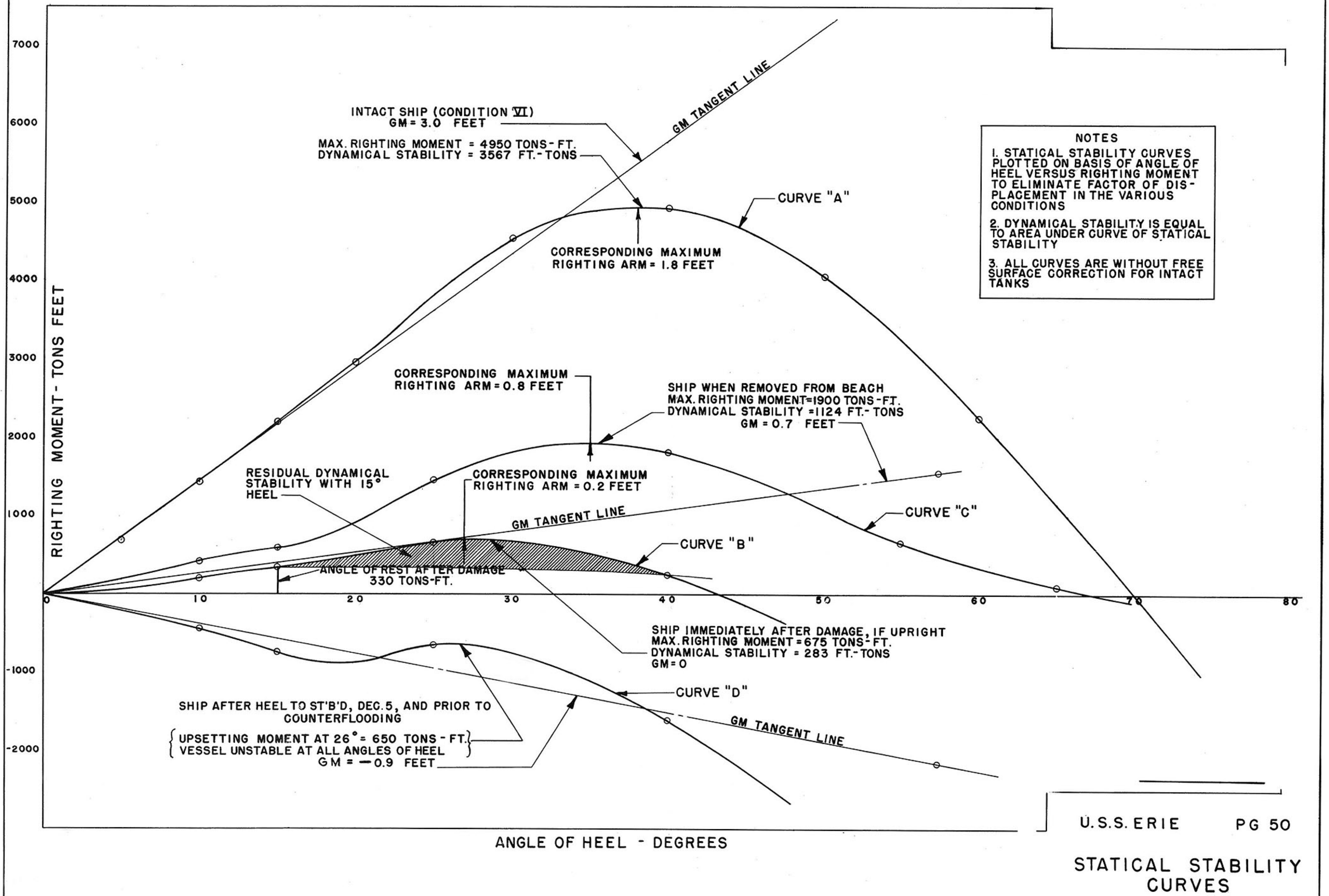
U.S.S. ERIE PG 50

STRUCTURAL DAMAGE AND FIRES

PLATE 2



FLOODING DIAGRAM


RIGHTING MOMENT - TONS FEET
7000
6000
5000
4000
3000
2000
1000
-1000
-2000
0
10
20
30
40
50
60
70
80
ANGLE OF HEEL - DEGREES
GM TANGENT LINE
INTACT SHIP (CONDITION VI)
GM = 3.0 FEET
MAX. RIGHTING MOMENT = 4950 TONS-FT.
DYNAMICAL STABILITY = 3567 FT.-TONS
CURVE "A"
CORRESPONDING MAXIMUM
RIGHTING ARM = 1.8 FEET
NOTES
1. STATICAL STABILITY CURVES PLOTTED ON BASIS OF ANGLE OF HEEL VERSUS RIGHTING MOMENT TO ELIMINATE FACTOR OF DISPLACEMENT IN THE VARIOUS CONDITIONS
2. DYNAMICAL STABILITY IS EQUAL TO AREA UNDER CURVE OF STATICAL STABILITY
3. ALL CURVES ARE WITHOUT FREE SURFACE CORRECTION FOR INTACT TANKS
CORRESPONDING MAXIMUM
RIGHTING ARM = 0.8 FEET
SHIP WHEN REMOVED FROM BEACH
MAX. RIGHTING MOMENT = 1900 TONS-FT.
DYNAMICAL STABILITY = 1124 FT.-TONS
GM = 0.7 FEET
RESIDUAL DYNAMICAL
STABILITY WITH 15°
HEEL
CORRESPONDING MAXIMUM
RIGHTING ARM = 0.2 FEET
GM TANGENT LINE
CURVE "C"
CURVE "B"
ANGLE OF REST AFTER DAMAGE
330 TONS-FT.
SHIP IMMEDIATELY AFTER DAMAGE, IF UPRIGHT
MAX. RIGHTING MOMENT = 675 TONS-FT.
DYNAMICAL STABILITY = 283 FT.-TONS
GM = 0
CURVE "D"
SHIP AFTER HEEL TO ST'B'D, DEC. 5, AND PRIOR TO
COUNTERFLOODING
UPSETTING MOMENT AT 26° = 650 TONS-FT.
VESSEL UNSTABLE AT ALL ANGLES OF HEEL
GM = -0.9 FEET
GM TANGENT LINE
U.S.S. ERIE
PG 50
STATICAL STABILITY
CURVES