CARD

SSC-261

PREVENTING DELAYED CRACKS IN SHIP WELDS

Part I

SHIP STRUCTURE COMMITTEE
1976

SHIP STRUCTURE COMMITTEE

AN INTERAGENCY ADVISORY
COMMITTEE DEDICATED TO IMPROVING
THE STRUCTURE OF SHIPS

ADDRESS CORRESPONDENCE TO:
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U.S. Coast Guard Headquarters
Washington, D.C. 20590

SR 210
17 AUG 1976

Delayed cracking is a matter of serious concern in some ship weldments.

The Ship Structure Committee undertook a project to prepare a shipyard guide to aid in preventing such cracks. This report contains that guide. It explains in simple and condensed form the causes of delayed cracking and means of prevention. It is intended to be useful for shipyard personnel who do not have a technical background. For this reason detailed technical explanations are avoided.

A technical report containing the background information has been prepared and is published separately as SSC - 262.

W. M Benkert
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

SSC-261

Technical Report

on

Project SR-210, "Delayed Cracking Phenomena"

PREVENTING DELAYED CRACKS IN SHIP WELDS

by

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Battelle Columbus Laboratories

under

Department of the Navy
Naval Ship Engineering Center
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1976

ABSTRACT

Delayed cracking is a continuing problem in ship steel weldments. However, with proper precautions, this type of cracking can be prevented. This document presents, in a simplified and condensed form, the causes of delayed cracking and the necessary preventive procedures. It is intended that this document will be used by shipyard personnel that do not have a technical background. Thus, detailed technical explanations are avoided.

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NOTES

PREVENTING DELAYED CRACKS IN SHIP WELDS

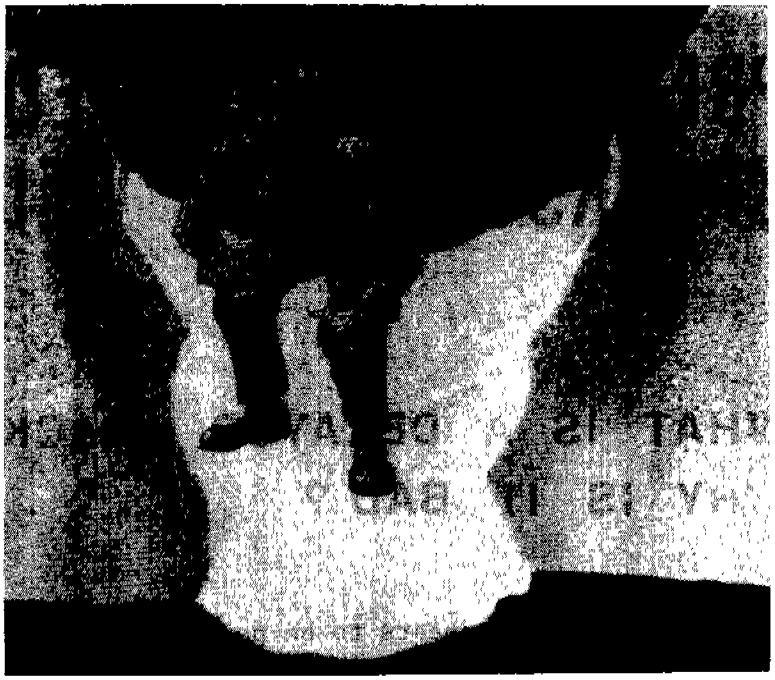
WHAT IS A DELAYED CRACK? WHY IS IT BAD?

A weld joint that appears to be perfectly sound sometimes has the uncanny ability to develop internal cracks after welding is completed. These cracks may form several hours or maybe even days after the weld is made, inspected, and given a clean bill of health. Because it takes time for these cracks to develop, they are called "delayed cracks".

DELAYED WELD CRACKS CAN BE THE CAUSE OF DELAYED FAILURES

When welds containing delayed cracks are stressed during service, the weld may fail with a considerable financial loss or even personal injury or loss of life. Thus, it is very important that every step be taken to prevent the formation of delayed weld cracks.

Delayed cracks sometimes are called underbead cracks. This is because the crack actually is in the heat-affected zone just under or at the side of the weld bead. Like as not, the crack doesn't come to the surface so, it can't be seen. Since the crack occurs after the weld is completed and isn't visible, you can be using procedures that cause delayed cracks and not even know it. Fortunately, though, procedures have been worked out that will prevent this cracking if they are followed properly.



THIS IS WHAT A DELAYED CRACK LOOKS LIKE WHEN THE WELD IS CUT APART

To understand why these procedures are important, it helps to know -

WHAT CAUSES DELAYED CRACKS ?

Three conditions are necessary to cause a delayed crack. All three must be present simultaneously. They are:

1. Hydrogen dissolved in the weld metal
2. A hard structure in the heat-affected zone
3. Stresses in the weld joint.

THE REQUIREMENTS FOR DELAYED CRACKS

Hydrogen dissolves in the weld while the weld metal still is molten. This hydrogen can come from a variety of sources. The most common is moisture or organic material in the electrode covering or coating. Both moisture and organic materials contain hydrogen. The arc breaks down these hydrogen compounds to provide free hydrogen which dissolves in the weld.

SOURCES OF HYDROGEN

- **Electrodes with hydrogen-containing coatings, such as**
  E6010 E6011
  E7024 E6027
- **Moisture in electrode coatings**
- **Moisture on joint surfaces**
- **Foreign matter on electrodes (grease, food, oil, paint, perspiration)**
- **Foreign matter on joint surfaces (oil, rust, paint, grease, dirt, crayon markings)**

Two types of electrode coatings are made:

1. Those that contain organic materials or hydrogen-containing binders. These are the electrodes that have the following numbers in their designation:

E-XX10	E-XX12	E-XX14	E-XX24
E-XX11	E-XX13	E-XX20	E-XX27

2. Those that do not contain organic or hydrogen-containing materials. These are called "low-hydrogen" electrodes. Only those electrodes that have the following designations are low-hydrogen electrodes:

E-XX15	E-XX18
E-XX16	E-XX28

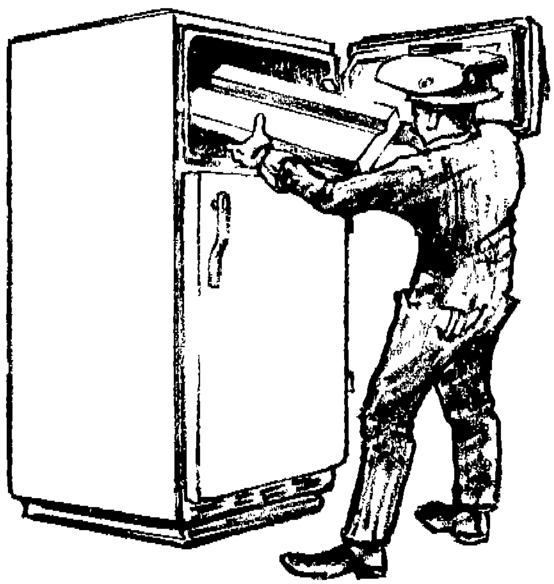
The low-hydrogen electrodes still can have moisture in their coatings if they aren't handled properly -- more about this later. Hydrogen can also come from any hydrogen compounds or moisture that gets into the arc. Some of these are listed over on the right.

Some steels, when welded, will form a hard microstructure in the heat-affected zone next to the weld. This is where the dissolved hydrogen will finally settle and cause the delayed cracks. As a rule of thumb, you can say that the higher the strength of the steel, the more likely it will have the hard microstructure after welding. Unfortunately, you can't tell if this hard structure has formed just by looking at the joint. To see this structure, a piece must be cut from the weld, polished, etched, and looked at under a microscope. This hard microstructure forms only when the hot metal cools too fast. Therefore, any welding practice that speeds up cooling will increase the probability of forming the hard microstructure. Any procedure that keeps the amount of heat generated in the weld joint low will also increase the cooling rate of the joint. Some of these "low-heat" procedures would include:

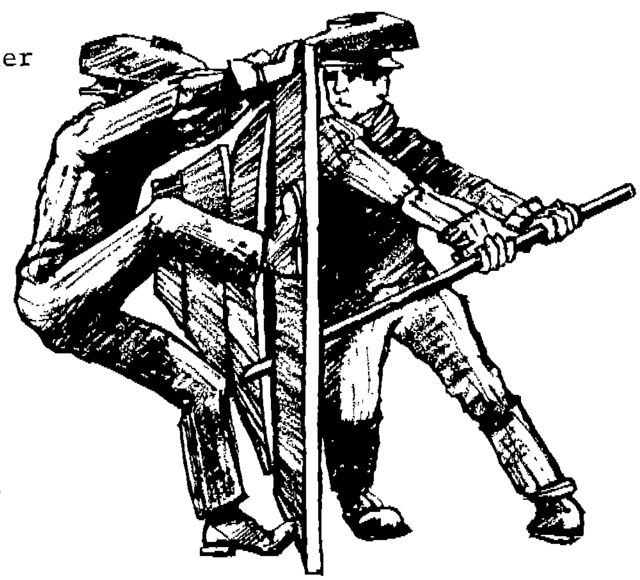
- low welding heat (low-current)
- fast travel
- no preheat
- low interpass temperature
- small electrodes

FAST COOLING IS NEEDED TO FORM THE HARD MICROSTRUCTURE

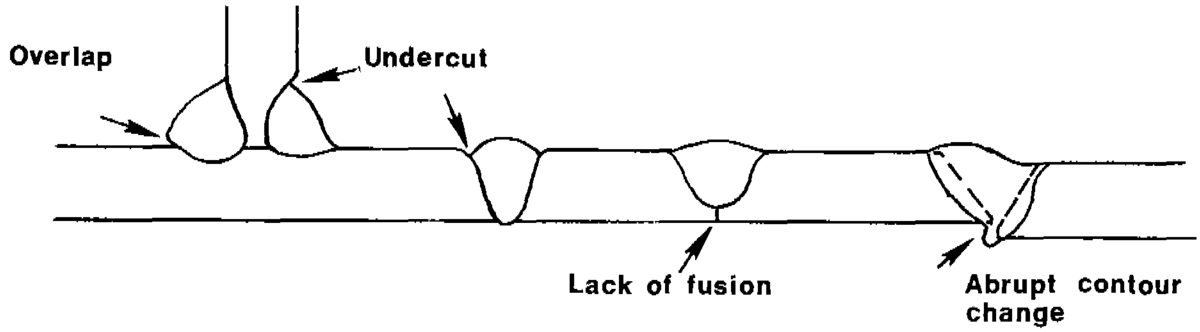
The lower strength steels require such a fast cooling rate to form the hard microstructure that the weld would have to be artificially cooled (quenching in water, for example). Under the cooling rates normal to welding, the hard microstructure does not usually form in weld joints in such low-strength steels as ABS Grades A, B, D, DS, CS, or E. Some hard microstructure may form in higher strength steels, though, at these cooling rates.



Stresses are created in all weld joints from the shrinkage of the weld as it cools. Forcing plates into alignment, lifting or moving a partially welded assembly or the unsupported weight of the parts being welded will add to these stresses. However, the shrinkage stresses alone may be enough to cause delayed cracking in the higher strength steels if hydrogen is present.



Sometimes delayed cracks will occur near an abrupt change in weld shape even though the overall stresses are too low to cause cracking. This is because stresses will build up around the shape change. That's why these shape changes are called "stress raisers". Typical stress raisers are undercutting, overlap, lack of fusion of the weld root, elongated slag inclusions, or a sharp change in contour due to poor fitup. These stress raisers have a major effect on the formation of delayed cracks.



SOME STRESS RAISERS THAT CAN CAUSE HIGH STRESSES IN LOCALIZED AREAS

HOW TO PREVENT DELAYED CRACKS

First, check to see if the steel to be welded is susceptible to delayed cracking. The lowest strength steels used in shipbuilding are ABS-A, ABS-B, and ABS-C. Delayed cracking won't occur in welds involving only these steels so they can be welded without any special precautions, other than good welding practice. Special precautions, though, are needed when welding any of the higher-strength steels. These precautions eliminate or minimize the three factors that cause delayed cracking. The three rules described in pages 6 through 9 cover these precautions.

The first rule is ⇨ **GET RID OF THE HYDROGEN**

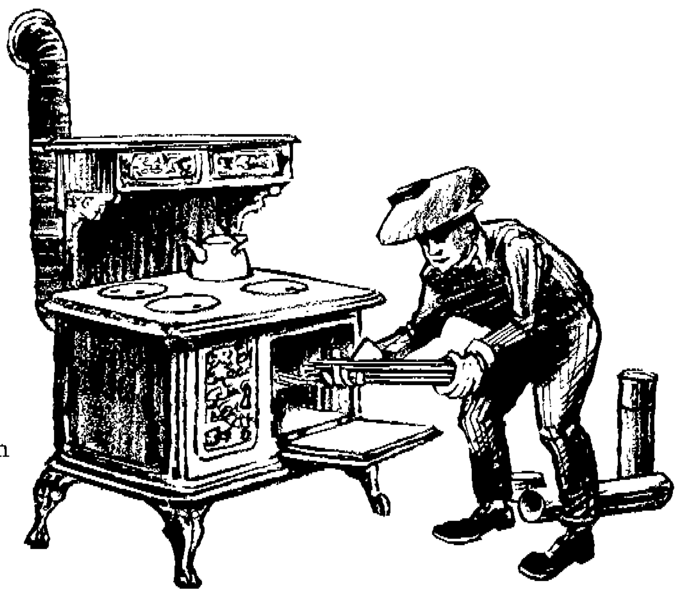
If you follow this basic rule, many delayed cracking problems will be solved. This is done quite simply by using properly dryed low-hydrogen electrodes, keeping the joint clean, and preheating.

Low-hydrogen electrodes have the numbers 15, 16, 18, or 28 in their designation - for example, E8016 or E11018. However, these electrodes must be treated properly since they'll quickly pick up moisture from the air and then they won't be low-hydrogen electrodes. The proper treatment for low-hydrogen electrodes is:

(1) Bake new electrodes to drive off any moisture left in the electrodes after they were made.

(2) Store the baked electrodes in an oven to keep them from picking up any more moisture.

(3) Handle the electrodes correctly so they won't get wet or dirty before you use them.

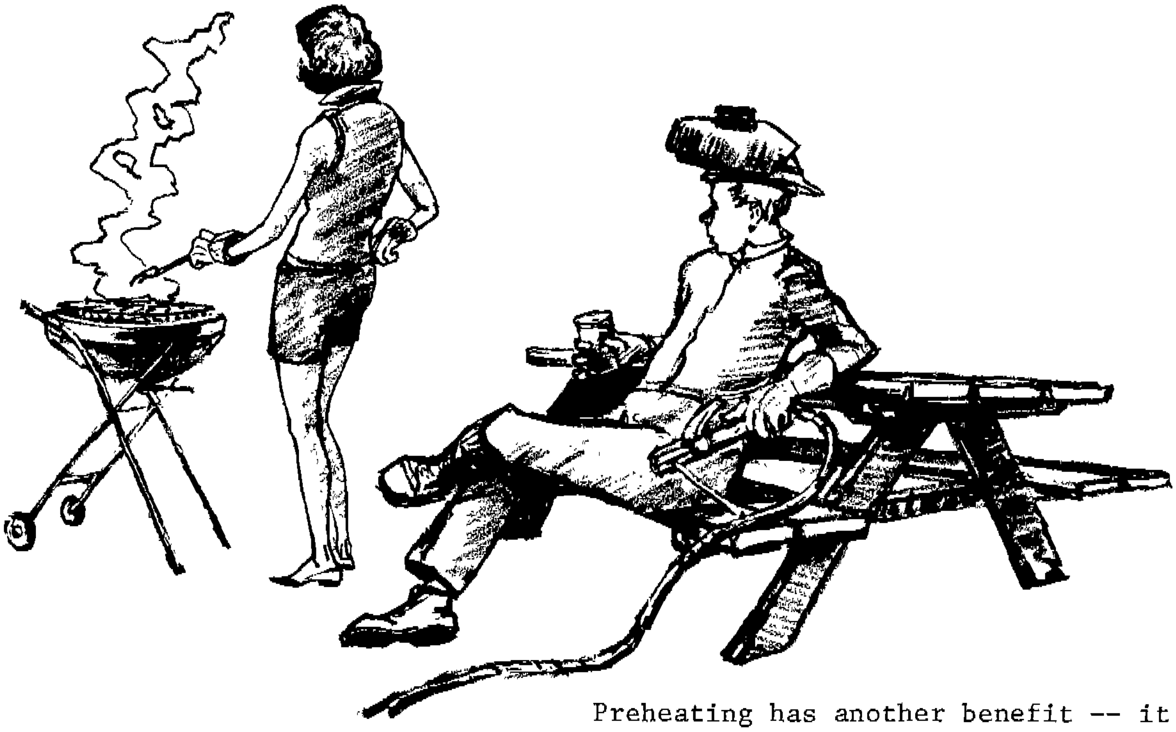


Specific rules for the care of low-hydrogen electrodes are given on page 11 at the end of this manual.

The joint should be clean before welding. There shouldn't be any grease, rust, dirt, paint or crayon markings on the joint faces when you start to weld. Wire brush or grind the joint surfaces to remove foreign matter. If you measure preheating or interpass temperatures with heat sensitive crayons, make the crayon marks on the base-plate surface, not on the joint surface.

Cleanliness is next to . . . .

At night, moisture can condense on joint faces. The best way of getting rid of this source of hydrogen is to dry the joints by preheating them. If the temperature gets up to 75^{o}-85^{o} during the day, this moisture will evaporate. Until this temperature is reached, the joints should be heated until they are hot to the touch.



Preheating has another benefit -- it slows down the cooling rate of a joint after it is welded. This slower cooling will reduce the tendency for formation of a hard microstructure in the heat-affected zone. (Preheating also helps the hydrogen to diffuse out of the joint.) Interpass temperatures must be kept above the same level since the interpass temperature is somewhat the same as preheating. If the interpass temperature gets below the specified level, heat the joint up again before doing any more welding.

The second rule is

PREVENT FORMATION OF A HARD MICROSTRUCTURE

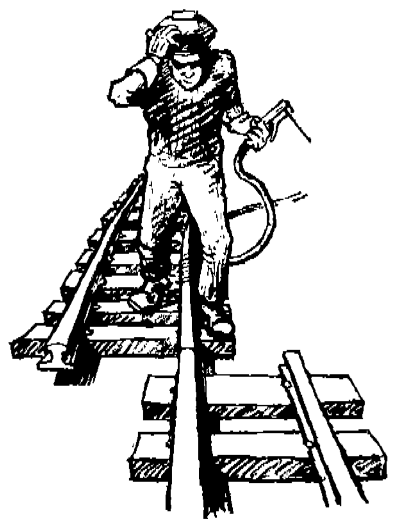
Preheat and interpass temperatures usually fall into the range of 75^{o}-250^{o}F. The temperature actually used, however, will be governed by the steel composition and thickness. The temperature to be used will be designated in the welding specification covering your job.

Special care is required with quenched and tempered steels. If these steels cool too slowly after welding, they will lose strength and toughness. Since preheating acts to slow down this cooling rate, these steels mustn't be preheated too high. A maximum limit of 300^{o}F generally is set on the preheat and interpass temperature for these steels.

The first two factors causing delayed cracking, hydrogen and hard microstructure, can be eliminated through the use of proper procedures. The third factor, high stresses, can only be reduced - stresses can never be completely eliminated. Getting rid of hydrogen and the hard microstructure generally will prevent delayed cracking even if high stresses remain. However, every little bit helps, so steps also should be taken to keep stresses down.

The third rule is ⇨ **MINIMIZE STRESSES**

This is not always easy to do but there are a couple of precautions that are helpful. First, try to maintain good alignment of the parts. This means lining up the parts correctly before tack welding with as little forcing as possible. Forcing just increases the joint stresses. Second, use welding procedures that will avoid the formation of stress raisers. Good alignment helps here, too. Especially important is the prevention of undercutting, lack of fusion, and abrupt contour changes. Third, use preheating and hold interpass temperature if more than one pass is to be made. A slower cooling rate helps reduce shrinkage stresses. And fourth, if possible, weld long joints from the center of the joint toward the joint ends. This technique will provide a more even distribution of shrinkage stresses.



Good alignment sure helps reduce stresses.

⇦ **There are some other ways that help too**

OTHER WELDING PROCESSES

Only stick or covered electrode welding has been considered so far. Delayed cracks can occur in MIG, flux-cored wire, or submerged-arc welding, too. The precautions to prevent or minimize delayed cracking, though, are basically the same. The only real difference is in the methods used to eliminate hydrogen. These are different only because some of the welding materials are different.

The electrode wires (both solid and flux-cored) and submerged-arc fluxes must be kept clean and dry. Each manufacturer has recommended rules for the care and storage of fluxes and flux-cored wires. These should be followed carefully. Unfused flux should not be reclaimed from welding for later use unless it is rebaked to remove moisture.

Keep welding torches in good repair. If the torches are water cooled, be sure fittings are tight and not leaking water. Leaking water could drip onto the joint or be carried to the arc by the shielding gas. In humid weather, moisture can condense on the parts of a water cooled torch. This condensed moisture also can drip or be carried into the weld area. Watch out for these moisture sources.

The other precautions relating to preheat and interpass temperatures, cleaning, stresses, etc., apply unchanged when MIG, flux-cored wire, or submerged-arc welding are used.

RULES FOR CARE OF LOW HYDROGEN ELECTRODES

1. If the electrodes are in an airtight metal container, immediately upon opening the container place the electrodes in a ventilated holding oven set at 250°-300°F.
2. If the electrode can is not airtight (check for damage to can) or if the container is a cardboard box, put electrodes in a baking oven. Check with electrode vendor for correct baking temperature and time.
3. Transfer electrodes while still hot to a holding oven kept at a temperature of 250°F - 300°F. Keep electrodes in this oven until ready to use.
4. A supply of electrodes for welding should be kept in a portable heated electrode container at the welding site, if possible.
5. If a heated electrode container is not available, electrodes removed from the holding oven should be used within the following times:

E-70XX	4 hours
E-80XX	2 hours
E-90XX	1 hour
E-110XX	1/2 hour

   Sometimes E-70XX and E-80XX electrodes are substituted for E-90XX or E-110XX electrodes for tack or root-pass welding. In these cases, the electrodes should be baked to reduce their moisture content to the level of E-90XX and E-110XX electrodes and the maximum exposure times should be reduced to 1/2 hours.
6. Any electrodes unused at the end of these times or any electrodes remaining in a heated electrode holder at the end of 4 hours should not be returned to the holding oven. These electrodes should be rebaked as specified in Rule 2.
7. Electrodes should be rebaked only once. Electrodes requiring a second rebaking should be discarded.
8. Any electrodes exposed to rain or snow or perspiration, that get wet for any reason, that get dirty or pick up oil, grease, or any other contaminating material should be discarded at once.

Note: These rules are intended to insure dry electrodes under most unfavorable environments. They may be relaxed or made more restrictive by a shipyard to meet its specific needs.

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SSC-253, *A Guide for the Nondestructive Testing of Non-Butt Welds in Commercial Ships - Part One* by R. A. Youshaw and E. L. Criscuolo. 1976. AD-A014547.

SSC-254, *A Guide for the Nondestructive Testing of Non-Butt Welds in Commercial Ships - Part Two* by R. A. Youshaw and E. L. Criscuolo. 1976. AD-A014548.

SSC-255, *Further Analysis of Slamming Data from the S.S. WOLVERINE STATE* by J. W. Wheaton. 1976. AD-A021338.

SSC-256, *Dynamic Crack Propagation and Arrest in Structural Steels* by G. T. Hahn, R. G. Hoagland, and A. R. Rosenfield. 1976. AD-A021339.

SSC-257, *SL-7 Instrumentation Program Background and Research Plan* by W. J. Siekierka, R. A. Johnson, and CDR C. S. Loosmore, USCG. 1976. AD-A021337.

SSC-258, *A Study To Obtain Verification of Liquid Natural Gas (LNG) Tank Loading Criteria* by R. L. Bass, J. C. Hokanson, and P. A. Cox. 1976.

SSC-259, *Verification of the Rigid Vinyl Modeling Technique: The SL-7 Structure* by J. L. Rodd. 1976.

SSC-260, *A Survey of Fastening Techniques for Shipbuilding* by N. Yutani and T. L. Reynolds. 1976

SL-7 PUBLICATIONS TO DATE

SL-7-1, (SSC-238) - *Design and Installation of a Ship Response Instrumentation System Aboard the SL-7 Class Containership S.S. SEA-LAND McLEAN* by R. A. Fain. 1974. AD 780090.

SL-7-2, (SSC-239) - *Wave Loads in a Model of the SL-7 Containership Running at Oblique Headings in Regular Waves* by J. F. Dalzell and M. J. Chiocco. 1974. AD 780065.

SL-7-3, (SSC-243) - *Structural Analysis of SL-7 Containership Under Combined Loading of Vertical, Lateral and Torsional Moments Using Finite Element Techniques* by A. M. Elbatouti, D. Liu, and H. Y. Jan. 1974. AD-A 002620.

SL-7-4, (SSC-246), *Theoretical Estimates of Wave Loads on the SL-7 Containership in Regular and Irregular Seas* by P. Kaplan, T. P. Sargent, and J. Cilmi. 1974. AD-A 004554.

SL-7-5, (SSC-257) - *SL-7 Instrumentation Program Background and Research Plan* by W. J. Siekierka, R. A. Johnson, and CDR C. S. Loosmore, USCG. 1976. AD-A021337.

SL-7-6, (SSC-259) - *Verification of the Rigid Vinyl Modeling Technique: The SL-7 Structure* by J. L. Rodd. 1976.