DEPARTMENT OF TRANSPORTATION

COAST GUARD

MARINE CASUALTY REPORT

STRUCTURAL FAILURE OF THE TANK BARGE I.O.S. 3301 INVOLVING THE MOTOR VESSEL MARTHA R. INGRAM ON 10 JANUARY 1972 WITHOUT LOSS OF LIFE

U.S. COAST GUARD
MARINE BOARD OF INVESTIGATION REPORT
AND COMMANDANT'S ACTION

ACTION BY
NATIONAL TRANSPORTATION SAFETY BOARD

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16. Abstract

On January 10, 1972, the 584-foot-long Tank Barge I.O.S. 3301 completed discharging its cargo of gasoline and furnace oil at Port Jefferson, N.Y., and was ballasted to permit turning around in the shallow harbor. As the last mooring line was being released, the vessel suddenly broke almost completely in half, and the two ends sank to the bottom. The barge was less than 1 year old.

This report contains the action taken by the National Transportation Safety Board in determining the probable cause of the casualty and in making recommendations to prevent its recurrence. The report also contains the Marine Board of Investigation report and the action taken by the Commandant, U.S. Coast Guard.

The National Transportation Safety Board determines that the probable cause of the catastrophic failure of Tank Barge I.O.S. 3301 was (1) the incapability of the steel, approved by the American Bureau of Shipping, to resist the initiation of the brittle fracture and (2) the failure of the "special material" crack arrestors to stop the crack propagation. Contributing to the casualty were (1) lack of a requirement in the design procedures for substantiation of the fracture-safe limitation of the vessel, and (2) failure of the steel-grading system to provide information about the transition temperatures of the steel installed in the hull and to guarantee that supposedly higher grade steels selected for critical locations have greater resistance to brittle fracture than adjacent lower grade steels.

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NATIONAL TRANSPORTATION SAFETY BOARD
DEPARTMENT OF TRANSPORTATION
WASHINGTON, D.C. 20591

TANK BARGE IOS-3301, PORT JEFFERSON, NEW YORK
10 JANUARY 1972

ACTION BY THE NATIONAL TRANSPORTATION SAFETY BOARD

This casualty was investigated by a U. S. Coast Guard Marine Board of Investigation convened at New York City, N. Y., on January 13, 1972. A representative of the National Transportation Safety Board attended the proceedings as an observer. The National Transportation Safety Board has considered only those facts in the investigative record which are pertinent to the Safety Board's statutory responsibility to determine the cause or probable cause of the casualty and to make recommendations.

SYNOPSIS

On January 10, 1972, the 584-foot-long Tank Barge I.O.S. 3301 completed discharging 103,826 barrels of gasoline and 49,434 barrels of furnace oil at Port Jefferson, N. Y. The vessel was then ballasted to permit turning around in the shallow harbor before departure through the dredged channel. As the last mooring line was being released, the vessel suddenly broke almost completely in half, and the two ends sank to the bottom. The vessel was less than 1 year old.

The National Transportation Safety Board determines that the probable cause of the catastrophic failure of Tank Barge I.O.S. 3301 was (1) the incapability of the steel, approved by the American Bureau of Shipping, to resist the initiation of the brittle fracture and (2) the failure of the "special material" crack arrestors to stop the crack propagation. Contributing to the casualty were:

1. Lack of a requirement in the design procedures for substantiation of the fracture-safe limitation of the vessel, and

2. Failure of the steel-grading system to provide information about the transition temperatures of the steel installed in the hull and to guarantee that supposedly higher grade steels selected for critical locations have greater resistance to brittle fracture than adjacent lower grade steels.

ANALYSIS

The Failure

Tank Barge I.O.S. 3301 split in a manner which has occurred many times at ambient temperatures in structures fabricated from mild- and low-alloy steels. The fracture surface pattern, the speed of crack propagation, and the tensile loading at the time of failure readily identify this failure as a brittle fracture, a problem which has been extensively researched, particularly with respect to ship structural failures in the early and middle 1940's.

To understand the cause and to devise countermeasures, this kind of failure can be divided into two phases -- initiation of the crack and propagation of the crack through the steel. Propagation may occur at very low nominal stress, as little as one-fourth of the yield stress.

Crack Initiation

Both metallurgical factors and engineering factors contribute to the probability of initiating a brittle fracture in a steel structure.

Metallurgical factors. Chemical composition of the steel, grain size, heat treatment, and manufacturing methods affect a steel's "toughness," or resistance to brittle fracture. A steel which is tough absorbs energy by plastic flow and thus limits the consequences to stretching rather than cracking. Various tests have been devised to measure toughness based on the steel's ability to absorb energy. Since energy-absoprtion capability varies with temperature, toughness can be stated in terms of foot-pounds of energy absorbed under a particular impact at a certain temperature. Another measure which can be used is the transition temperature, i.e., the temperature at which the steel loses its ductility and absorbs almost no energy by plastic flow. The steel is then classified according to its Nil Ductility Temperature (NDT). Different energy-absorption tests apply forces on steel in different ways and involve contributions from both crack initiation and crack propagation to varying degrees.

The steel plating used in constructing the hull of I.O.S. 3301 was classified as Grade B and C steel by the American Bureau of Shipping (ABS). Grade B and C steels are not required to be tested for any specific transition temperatures. However, data derived from various samples manufactured to ABS specifications have shown that Grade B steel can be expected to have 15-foot-pound Charpy V-notch "transition" temperatures from -35° F. to $+30^{\circ}$ F., a range of 65° F. ABS tests of samples from the I.O.S. 3301 Grade B fractured plating indicated 15-foot-pound Charpy V-notch values from -28° F. to $+30^{\circ}$ F., within the range expected from the ABS manufacturing specification. ABS determined that the NDT values of the fractured Grade B steel were -10° F. to $+10^{\circ}$ F., whereas tests conducted by the Naval Research Laboratory, using different size specimens from the same plating, indicated NDT values of $+10^{\circ}$ F. and $+20^{\circ}$ F.

ABS data concerning Grade C steel showed 15-foot-pound Charpy V-notch values from -40° F. to +7° F., whereas ABS tests of the fractured Grade C steel from the barge indicated values of -30° F. to +8° F. Corresponding NDT values on the fractured steel as determined by ABS were 0° F. and +10° F., and as determined by the Naval Research Laboratory were +20° F. and +30° F.

These data point up weaknesses in the ABS grading system, which was established to match steel characteristics with structural fracture-resistance needs. Although the grading system is supposed to provide that a Grade C steel is tougher than a Grade B steel, the spectra of transition temperatures for the two grades of steel are wide and overlap. Consequently, a vessel designed specifically to use a "better" Grade C steel in parts of its hull may actually receive Grade C plates less resistant to brittle fracture than adjacent Grade B plates. This appears to have occurred in the I.O.S. 3301. An even more hazardous condition can occur when both the Grade B and the Grade C plates used in a vessel have relatively low toughness. This combination results when the grading system permits such a large variation.

The energy-absorption curves for the fractured Grade B and C steels show rapid loss of toughness by any test as temperature drops from 100° F. to 0° F., which includes the range of ambient temperatures which most ships are likely to encounter during their service life. The point and rate at which the energy-absorption capability declines as temperature declines is extremely important in evaluating the risk of fracture. The results of the Charpy V-notch tests, however, indicated that the steels retained their energy-absorption capability at lower temperatures and compared favorably with many previously tested Grade B steels. Thus, neither a single point value (the 15-foot-pound test) nor a full curve of values over the normal temperature range (the standard tests) revealed the inadequacy of the steel at lower temperatures.

To summarize, the present wide spectrum of the 15-foot-pound Charpy V-notch values for Grade B and C steels, the lack of any requirement to identify these shipbuilding steels on an energy-absorption scale, and the misleading information provided by the commonly used Charpy V-notch tests prevent the logical matching of the correct steel to a vessel's structural needs. This problem in the control of a steel's resistance to brittle fracture is of primary importance and contributes directly to other sources of unpredictability in ship design and construction.

Since all brittle fractures initiate at a flaw, a flaw presumably existed at the point of crack initiation on I.O.S. 3301, even though the outline of a flaw could not be seen. The flaw was probably a small crack which, based on fracture-mechanics theory, could have been less than one-eighth of an inch long. It may have formed in the weld at the time of the vessel's construction or subsequently as a fatigue crack. The shipbuilding industry's quality control is not designed to detect or prevent such minor

flaws, because small flaws generally will not be a hazard to a ship structure. However, since welding frequently introduces defects, modifies the adjacent parent metal in ways which may reduce notch ductility, and is associated with localized design stress concentrations, most brittle fractures originate in weld regions.

Engineering factors. Because the loading of I.O.S. 3301 was static at the time of fracture, the speed of load application was not a factor in the casualty. However, the intersections of the deck and horizontal and longitudinal bulkheads resulted in localized stress concentrations. The doubler plate welded under the port kingpost further increased the notch effect of such an intersection and thereby increased the stress concentrations. This 3/4-inch plate also added to the massiveness of the intersection and increased the triaxial tensile stresses. The initiation of a second brittle fracture under the starboard kingpost verified the existence of stress concentrations as a result of this structural arrangement.

Crack Propagation

Once initiated, a brittle fracture will propagate in metal until a zone of very low tensile stress or metal with high energy-absorption capability is encountered. In the I.O.S. 3301, the crack would have progressed at a characteristic speed of thousands of feet per second, which would have raised the stress in other areas and initiated additional brittle fractures around the hull until fracture ceased in the bottom plating. As the plating in the upper portions of the hull failed, the tensile loads left unsupported were transferred to the remaining hull plating, which created high tensile stress in previously lower stressed plating. This unstable process can be expected to occur in any hull with a large bending moment, because the speed of any reduction of vessel loading after crack initiation by relaxation of the ends of the vessel or by departure of any wave causing the loading will be slow compared with the speed of the crack propagation.

Crack arrestors, which were developed as a result of welded ship failures in World War II, originally consisted of riveted longitudinal seams or joints which terminated the continuous material necessary for the propagation of unstable fractures. Varying numbers of these riveted joints were required to insure preservation of sufficient longitudinal hull girder material to maintain acceptable stress levels. With the improvements in the energy absorption of steel, ABS permitted the use of welded strakes of "special material" in place of riveted crack arrestors. ABS "Rules for Building and Classing Steel Vessels" permits the use of such "special material" on ships in place of riveted crack arrestors according to the length of the ship and the location of machinery. For each grade of steel, the level of energy absorption is associated with a range of plating thicknesses and, in some cases, with normalizing heat treatment. In the I.O.S. 3301, the two radius shear strakes and the bilge strakes, which consisted

f Grade C steel, served as crack arrestors.[1/] Both ABS and the U. S. Coast Guard accepted the Grade C steel as satisfactory for its intended purpose; however, the steel did not arrest the crack. Furthermore, some research has indicated that because the loads which produce tensile stresses on a ship cannot be relieved quickly, a region of high stress will race ahead of the shifting neutral axis until essentially the total hull has failed. Therefore, a crack will not be arrested unless a mechanical barrier, e.g., a riveted seam, is interposed. Thus, this casualty questions the basic validity of using welded "special material" in place of riveted seams which interrupt crack paths.

Other Conditions Contributing to Failure

The degree of severity and uniqueness of the conditions which contributed to the failure of the I.O.S. 3301 are important in the selection of corrective measures that should be applied.

The Coast Guard report stated that the unusual ballasting of the barge created an "excessive" longitudinal bending moment which resulted in a 23,515-psi stress in the main deck plating. Since the allowable design stress, however, was 24,600 psi, the loading was not excessive on that basis. Similar stresses could be expected in heavy seas; in fact, the static loads at the dock produced a lower risk than dynamic loads at sea, because brittle fracture occurs more readily under high strain rates such as those which might result from dynamic loads at sea. A reduction in lesign stress by increasing the size of the structural members would be counterproductive, since thicker members are more susceptible to brittle fracture. Any reduction in stress level by reducing cargo loading would be of questionable value, since, when other factors are favorable, brittle fracture can occur at very low nominal stress. It is not certain that a loading manual for this barge predicated upon design stresses would have prohibited the ballast condition that was employed prior to leaving the harbor.

The minute size of the initial flaw suggests that at the crack origin, the stress level nearly equalled the yield stress of about 40,000 psi. The difference between the yield stress and the nominal stress was contributed by (1) residual stresses which resulted from welding, certain fabrication processes and thermal expansion and contraction and (2) stress concentrations which resulted from the design in the vicinity of the crack initiation and from the notch effect caused by the flaw in the weld. Although the individual contribution made by each of these factors cannot be isolated,

1/ The ABS rules permit this steel to serve as "special material" only in thickness from 0.63 inches to 0.89 inches, whereas the steel used in this barge was 1-inch thick. For 1-inch thicknesses, Grade C steel is required to be normalized if used as a crack arrestor. However, these rules do not apply to construction of barges; even the specific ABS rules for barges are silent as to the installation of "special material" in such locations on barges.

countermeasures are available for reducing the effects of each. For example, residual stresses can often be reduced by either pre- or post-fabrication heating, although in ship construction, many practical problems are encountered. Certain larger flaws in welds can be reduced by stricter quality control of welding. Stress concentrations caused by structural discontinuities can be reduced by making gradual transitions in structural cross sections. Although the severity of a design notch such as the structural assembly at the base of the port kingpost can be evaluated in broad qualitative terms, neither the designers, review authorities, nor shipbuilding inspectors identified the assembly as an unacceptably severe notch before the failure. There are no objective standards that can be used to determine limiting designs for such stress concentrations.

Although the steel involved in this fracture was very adequate with respect to its specifications, the steel was inadequate to perform the intended functions of resisting crack initiation and of arresting crack propagation when used in normal ship design and fabrication practice and subjected to ambient temperatures. Since the 46° F. temperature of the steel deck at the time of the casualty was well above the lowest temperature which this vessel could be expected to encounter on a winter day in its intended area of operation, the steel was not as brittle as it would have been in lower ambient temperatures.

Alternative Methods of Selecting Steel

In other countries, procedures have been proposed or are in use which permit selection of fracture-resistant steel suitable for a specific application. Selection criteria include minimum service temperature, stress levels, flaw size, plate thickness, and geometric constraints. One method uses these factors to determine a steel-toughness requirement which is generally related to a steel with a minimum Charpy-V value at a given temperature. Another method involves analysis by linear fracture-mechanics theory to determine maximum permissible crack size for a specific stress level.

Neither the engineer who selects the steel plating, the review authority who approves the design, nor the inspector who checks the ship knows the toughness of the steel actually used to build the ship. Any attempts to evaluate the effect of geometric notches, flaw sizes, residual stresses, etc., are of minimal value without knowledge of the basic fracture resistance of the steel. Consequently, the current procedure discourages any attempts to solve the problem more precisely and permits the unknown effects of these brittle-fracture-promoting factors to be combined with the unknown steel toughness to form a steel structure of essentially undefined resistance to brittle fracture.

A basic way to improve this present imprecise method of control would be to require that the toughness of the steel plate, at least in the highly stressed areas, be identified. Although the Charpy-V tests are widely

accepted, this accident has shown that both the 15-foot-pound Charpy-V fracture-toughness index and the full temperature/energy-absorption curve for Charpy V-notch tests overestimated the real margin of safety against brittle fracture. Other more adequate parameters exist; in some locations on a vessel, toughness values above the NDT will be required to assure an adequate margin of safety.

Under a formal design process, the steel toughness required for a particular ship should not be determined until minimum operating temperature, nominal stress, thickness, expected maximum flaw size, degree of construction constraints, and other factors which induce brittle fracture are evaluated, at least broadly enough to provide a margin of safety. If a reliable control system is instituted, a separate backup system for arresting cracks would not be necessary. If, however, plating with a high safety margin for toughness could not be used throughout high stress areas, a backup system of crack arrestors should be required. However, as mentioned above, the efficacy of welded crack arrest plating in shipboard application is of questionable value.

Any or all of the primary variables involved in brittle fracture -- toughness, ambient temperature, and nominal stress -- can be used to select steel. For each variable, a compensatory increment should be added or subtracted. A separate margin of safety could also be introduced to adjust the risk to the magnitude of the potential losses.

Postaccident Corrective Measures

To reduce the risk of another similar failure to the I.O.S. 3301, the boom installations were removed, and a loading manual was issued. The removal of the booms reduced the stress intensification effects caused by the geometry changes at these locations. The precise reduction in stress intensification is not determinable. What is known is the nominal stress level in the deck at the time of fracture. The Coast Guard report states that notch-toughness tests, other than the Charpy V-notch tests, "clearly established that the hull steel in the Tank Barge I.O.S. 3301 did not have adequate notch toughness for the stress level and temperature extant at the time of the casualty." Although the criteria for this conclusion are not described, they apparently did not exist before the casualty. As indicated above, a fracture-resistance rating system can be devised which would include a minimum "service" temperature. Once devised, the system could be applied to the I.O.S. 3301, since its steel characteristics are now known.

The route of the I.O.S. 3301 could reasonably have been expected to subject the above-water portion of the hull to temperatures much lower than the 30° NDT which some of the steel possessed. The loading manual limitations are predicated to avoid high stresses that may lead to unacceptable metal yielding and not to prevent brittle fractures. Furthermore, although loading manual limitations restrict the maximum stresses

imposed while the vessel is in port, stresses imposed at sea could still equal those which existed just before the accident.

To permit tank barges to carry additional cargo, the regulations have required 25 percent less freeboard than is required for a tankship. As a result of this casualty, the Coast Guard will henceforth require the same freeboard for a tug/barge combination as for a tankship. Freeboard, as a parameter of safety, was once important to preclude overloading that might overstress the vessel or to provide some unspecified measure of reserve buoyancy. The adequacy of a vessel's strength is now determined by other means, and reserve buoyancy has become an ambiguous term that has little meaning by itself. Even if the additional freeboard could provide a margin for a certain amount of flooding without sinking the vessel, this provision would not necessarily prevent loss of the ship since there are no requirements for the vessel to be built with sufficient structural strength to withstand the additional stresses which result from loss of freeboard. Freeboard influences the extent of waves' washing over the decks and the degree of watertight closures and personnel protection required. Although the height of the deck above the sea is important to crew safety, this is not a fixed parameter. For example, short vessels have much lower freeboard than long vessels. Freeboard tables are entirely empirical. Since it is feasible to have safe submarine tankers, a specific freeboard is not necessarily a measure of a ship's safety. Provided that adequate provisions are made for strength, stability, sea-keeping, and watertight deck closures, a separate freeboard criterion may not be needed as a guarantee for ship safety.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of the catastrophic failure of Tank Barge I.O.S. 3301 was (1) the incapability of the steel, approved by the American Bureau of Shipping, to resist the initiation of the brittle fracture and (2) the failure of the "special material" crack arrestors to stop the crack propagation. Contributing to the casualty were:

1. Lack of a requirement in the design procedures for substantiation of the fracture-safe limitations of the vessel, and

2. Failure of the steel-grading system to provide information about the transition temperatures of the steel installed in the hull and to guarantee that supposedly higher grade steels selected for critical locations have greater resistance to brittle fracture than adjacent lower grade steels.

RECOMMENDATIONS

The National Transportation Safety Board concurs with the Commandant's decision to institute a program to define more meaningful criteria for the notch toughness of steel. This program, which need not involve costly original research, should evaluate one or more recently developed methods of measuring toughness.

The Safety Board also recommends that:

1. The Coast Guard develop criteria for safe design which will establish margins of safety against brittle fracture. These criteria should then be used as a basis for design approval, steel selection, construction control, and vessel inspection. (Recommendation No. M-73-10)

2. After the establishment of adequate safety margins, the Coast Guard determine and make known to the operators of Tank Barge I.O.S. 3301 the safe minimum temperature for the operation of this vessel. (Recommendation No. M-73-11)

3. In view of the unexplained failure of the welded "special material" and some research evidence that such applications cannot be reliable, the Coast Guard reevaluate the practice of allowing use of welded "special material" in lieu of riveted seams as crack arrestors. (Recommendation No. M-73-12)

4. The Coast Guard review the need for regulations concerning freeboard and determine to what extent they contribute to ship safety. (Recommendation No. M-73-13)

5. The Coast Guard require that the structure of any ship which must meet certain minimum buoyancy and stability conditions under various degrees of flooding also be designed so that the ship can survive the additional stresses imposed by the flooding. (Recommendation No. M-73-14)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Adopted this 28th day of December 1973:

[redacted], Chairman

[redacted] Member

[redacted] Member

[redacted] Member

[redacted], Member, was absent and did not participate in the adoption of this report.

DEPARTMENT OF TRANSPORTATION
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•5943/I.O.S. 3301 -
MARTHA R. INGRAM
C-3 Bd
31 MAY 1973

Commandant's Action

on

The Marine Board of Investigation convened to investigate circumstances surrounding the major structural failure of the unmanned Tank Barge I.O.S. 3301 involving the Motor Vessel MARTHA R. INGRAM on 10 January 1972 without loss of life

1. The record of the Marine Board of Investigation convened to investigate subject casualty has been reviewed; and the record, including the Findings of Fact, Conclusions and Recommendations, is approved subject to the following comments and the final determination of the cause by the National Transportation Safety Board.

SYNOPSIS OF FINDINGS OF MARINE BOARD OF INVESTIGATION

1. At approximately 0936 EST on 10 January 1972, the unmanned Tank Barge I.O.S. 3301 broke almost completely in half at her berth at the Consolidated Oil Company Terminal, Port Jefferson, New York. At the time of the casualty the barge was rigidly connected at her stern with the Towing Vessel MARTHA R. INGRAM in such a manner as to have them function as a single unit. There were no personal injuries or loss of life as a result of the casualty. The I.O.S. 3301 suffered major structural damage. The MARTHA R. INGRAM, the pier to which the vessels were moored, and the Tug NEW HAVEN which was located at the bow of the I.O.S. 3301 also incurred varying degrees of damage. Residue of the ruptured tanks on the barge and piping on the pier caused some minor petroleum pollution to the harbor.

2. The I.O.S. 3301 is a tank barge of 15,579 gross tons and 15,579 net tons. She is 583 feet 9 inches in length, 87 feet wide and 46 feet 4 inches in depth. The vessel was built in 1971 at the Alabama Drydocking and Shipbuilding Company, Mobile, Alabama. At the time of the casualty the vessel possessed a U. S. Coast Guard Certificate of Inspection, Load Line Certificate for a Type "A" ship with reduced freeboard, and American Bureau of Shipping Certificates for Hull and Machinery.

3. The MARTHA R. INGRAM is a towing vessel of 989 gross tons and 672 net tons. She is 154 feet 8 inches in length, 46 feet wide and 33 feet 4 inches in depth. The tug was built in 1971 and is fitted with twin screws and has a total of 11,000 horsepower. Since being placed in service the MARTHA R. INGRAM and the I.O.S. 3301 have always operated together as a single unit.

4. The combined unit, with a crew of 14 men, departed Deer Park, Houston, Texas on 1 January 1972. The barge was loaded with 229,550 barrels of gasoline and 48,929 barrels of furnace oil. The vessels arrived in Bridgeport, Connecticut on 7 January 1972. 130,000 barrels of gasoline were discharged and 1072 barrels of diesel fuel were loaded on board the towing vessel. The combined unit departed Bridgeport on 8 January 1972 and moored at Port Jefferson, New York on 9 January 1972. Here the remainder of the cargo on the barge was discharged and the cargo and ballast tanks at the extremities of the vessel were ballasted. The ballasting was accomplished by order of the master based on his experience to obtain drafts necessary to clear the harbor of Port Jefferson, New York. There was no loading manual available which could be used to evaluate the hull stress imposed by the ballasting arrangement.

5. The surface of the water within the harbor was calm. The air temperature was 46°F and the sea temperature was 40°F.

6. On the morning of 10 January 1972 the I.O.S. 3301 and the MARTHA R. INGRAM commenced their departure from the pier at Port Jefferson, New York. At approximately 0810 CST the stern of the combined unit was twisted away from the pier with the assistance of the Tug NEW HAVEN. At 0836 CST the forward spring line, the last remaining line of the dock, was being taken in and suddenly and without warning the I.O.S. 3301 broke amidships. The vessel assumed a hogging condition with the forward and after sections forming an angle of 21 degrees with the horizontal.

7. All personnel aboard the tug and barge were able to safely abandon ship. During the course of abandoning ship the crew attempted to utilize two inflatable liferafts. One of the rafts failed to inflate when its release lanyard was pulled. A subsequent inspection determined that the raft was improperly packed.

8. The fracture of the I.O.S. 3301 was generally in the vicinity of the transverse swash bulkhead at frame 49, which is 42.5 feet aft of the midpoint of the barge. The crack extended completely across the main deck, completely down the side shell port and starboard, and across approximately 46 percent of the bottom plating. Two king posts of tubular construction were located in the immediate vicinity of the failure. The base plate for these king posts, each measuring 28 inches in diameter, was centered over the swash bulkhead at frame 49 and one of the longitudinal oil tight bulkheads.

9. Calculations of hull strength and the stress attributable to the longitudinal bending moment of the I.O.S. 3301 at the time of the casualty reveal the following information:

a. The midship section modulus of the I.O.S. 3301 exceeded the requirements of the American Bureau of Shipping for tankships the size of the combined unit.

b. A maximum value of the still water bending moment was determined to be 686,700 foot tons located about 40.5 feet aft on the midpoint of the barge.

c. The magnitude of the hull stress attributable to the longitudinal bending moment was 23,515 psi in the main deck.

10. It was estimated that the vessel was hogged with a deflection of 12.4 inches at the time of fracture.

11. Several tests were conducted on numerous steel coupons taken in the vicinity of the fracture of the I.O.S. 3301 by the New York Testing Laboratories, Inc., Westbury, New York and the U. S. Naval Research Laboratory, Washington, D. C. These tests revealed that the hull steel complied in all respects with the A.B.S. specifications for Grade B and C plate. Metallurgical tests were also conducted by A.B.S., however, their report was not made part of the record since it was compiled subsequent to the submission of the report of the Marine Board. The A.B.S. test results confirm the results of the physical and chemical tests conducted by the other two laboratories. A Dynamic Tear Test conducted only by the Naval Research Laboratory clearly established that the hull steel in the Barge I.O.S. 3301 did not have adequate notch toughness for the stress level and temperature extant at the time of the casualty.

REMARKS

1. The primary cause of the casualty was the uneven distribution of cargo and ballast at the extremities of the vessel. The resultant hogging condition caused a high stress level in the main deck plating which led to a brittle fracture of the hull steel.

2. The following factors are deemed to have contributed to the casualty:

a. Inadequate notch toughness of the hull steel at a temperature of $46^{\circ}F$.

b. The probable presence of a small defect in the deck plating within the area subjected to the high stress level.

c. The significant increase in stress level in the main deck in the immediate vicinity of the king posts at frame 49 due to the locked-in weld stresses.

3. The Coast Guard has, within its responsibility for the safety of life and property at sea, given considerable attention to innovative ideas and systems to permit an expansion of maritime trade. This has, on occasions, been most difficult due to some inflexible and antiquated statutory requirements, however, a meaningful inspection and certification program has been established for these rigidly mechanically connected tug and barge units operating in the open ocean.

4. The Coast Guard considers a tug/barge concept involving a mechanical system connecting the propulsion unit, the tug and the cargo carrying unit, the barge, to be in effect a self-propelled motor vessel when operated on the open ocean. If such combined units are over 300 gross tons and operate on the high seas or are over 15 gross tons and carry freight for hire, they are subject to inspection and certification. The inspection requirements, although not as severe as those for a self-propelled motor vessel, have proven quite satisfactory and practical and consistent with our responsibilities.

5. Due to innovative design concepts these systems have undergone operational tests in addition to model basin tests and both units have been required to be seaworthy when combined or separated. Because the technology in the area of mechanical connections is so new, several additional technical requirements over and above the normal plan review were imposed. Some related to analysis of expected forces, moments and motions to be transmitted by the connection during various operating conditions. Some tests were related to structural analysis of connections and adjacent structures. All the additional requirements demonstrated acceptable levels for the safe operation of such units.

6. Crew members on the bow section were cut off from the primary lifesaving equipment and were completely without lifesaving devices of any kind. Additionally the casualty demonstrated that the tug cannot always be disconnected in time of trouble.

7. The fact that the inflatable liferaft failed to inflate when the painter was pulled has been referred to the Coast Guard Marine Inspection Office which inspected the raft at the servicing facility for appropriate corrective action.

ACTION CONCERNING THE RECOMMENDATIONS

1. The recommendation that the barge component in a rigidly connected tug/barge unit be designed and constructed in accordance with the American Bureau of Shipping Rules for the Building and Classing Steel Vessels is concurred with. Currently we are requiring that all future barge components be constructed, in all respects, in accordance with the aforementioned Rules. The length used in applying these Rules shall not be less than 96% and need not be greater than 97% of the length on the summer load waterline length of the combination unit.

2. The recommendation that a rigidly connected tug/barge combination be assigned, as a minimum, a Type A freeboard without a 25% reduction is concurred with.

3. The recommendation that all rigidly connected tug/barge combinations be furnished with Loading Manuals similar to those which are required for tankships has already been acted upon and Loading Manuals are now required for these combination units.

4. The recommendation that rigidly connected tug/barge combinations be provided with primary lifesaving equipment for a tankship is presently under study. In the meantime existing tug/barges engaged in international voyages are being outfitted with lifesaving equipment to meet the requirements of Safety of Life at Sea Convention and an inflatable liferaft will be installed forward on all barges.

5. The recommendation that the Coast Guard institute a research program to define a more meaningful criteria for the notch toughness of steel has already been undertaken. A research program is presently underway for the purpose of reexamining the toughness criteria for all the hull steels including A.B.S. Grades B and C as was installed on this vessel.

6. The recommendation that the design of the king posts at frame 49 be revised so as to eliminate stress concentrations has been acted upon. The king posts on the I.O.S. 3301 and future barges have been eliminated. The cargo hose handling equipment now installed eliminates the stress concentrations that may have existed in the original design.

7. The recommendation that further investigation under the suspension and revocation proceedings be initiated in the case of the master of the MARTHA R. INGRAM has been referred to the appropriate Officer in Charge, Marine Inspection for final disposition.

8. The recommendation that the Coast Guard reevaluate the position it has taken in the regulation of tug/barge combinations is concurred with. This has been and continues to be given active consideration by the Coast Guard. Units which are presently operating will continue to be evaluated, and as experience is gained standards will be modified or altered accordingly.

[redacted]

C. R. BENDER
Admiral, U. S. Coast Guard
Commandant

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

Address reply to:
COMMANDER (m)
Third Coast Guard District
Governors Island
New York, N.Y. 10004

5943

JUL 17 1972

From: Marine Board of Investigation
To: Commandant (GMVI)

Subj: Motor vessel MARTHA R. INGRAM, O.N. 533104, and the unmanned tank barge I.O.S. 3301, O.N. 531048, combined unit; major structural failure of the I.O.S. 3301 on 10 January 1972 without loss of life

- Findings of Fact -

1. At about 0936 EST on 10 January 1972, the unmanned tank barge I.O.S. 3301 broke almost completely in half at her berth at the Consolidated Oil Company Terminal, Port Jefferson, New York. At the time the barge was in ballast condition having completed discharge of all cargo. Also, the barge was rigidly connected, at her stern, with the towing vessel MARTHA R. INGRAM by means of a structural arrangement and mechanical devices intended to join the tug and the barge in such a manner as to have them function as a single unit. No personal injury, loss of life, or significant incidence of pollution resulted from the casualty. As the log maintained by the MARTHA R. INGRAM was kept in Central Standard Time (CST), all times hereinafter noted will bear that zone designation.

2. Vessel Data:

Name	:	I.O.S. 3301	MARTHA R. INGRAM
Official No.	:	531048	533104
Home Port	:	Wilmington, Delaware	Wilmington, Delaware
Type	:	Unmanned tank barge, ocean service	Towing
Where Built	:	Mobile, Alabama	Slidell, Louisiana
Date Built	:	1971	1971
Ship Builders	:	Alabama, Drydocking and Shipbuilding Co.	Southern Shipbuilding Corp.
Gross Tons	:	15,579.09	989.14
Net Tons	:	15,579	672
LOA	:	583'9"	154'8"
LBP	:	532'	140'
Beam, Molded	:	87'	46'
Depth, Molded	:	46'4"	33'4"
Propulsion	:	None	Twin Oil Screw
Horsepower	:	-	11,000 horsepower
Route	:	Oceans	Coastwise
Owners	:	Ingram Ocean Systems Inc. 100 West 10th St. Wilmington, Delaware, 19899	Ingram Ocean Systems Inc. 100 West 10th St. Wilmington, Delaware, 19899
Operator	:	Same as owner	Same as owner

3. The towing vessel is of steel construction, transversely framed with seven transverse, watertight bulkheads. It displaces about 3296 tons in the full load condition. It is powered by two diesel engines directly geared to two controllable pitch propellers developing a speed, when connected to the barge, of about fourteen knots. The MARTHA R. INGRAM does not have the conventional form of a towing vessel but is specially configured to lock into a notch of matching form provided in the stern of the barge I.O.S. 3301. The vessel possessed the following pertinent documents all of which were valid at the time of the casualty:

a. U. S. Coast Guard Certificate of Inspection
Inspected 1 July 1971
Expiration date 1 July 1973

b. Load Line Certificate
Type "B" ship
Issued 13 July 1971
Valid until 1 July 1976

c. A.B.S. Interim Certificates for Hull and Machinery
Al Towing Service
Issued 1 July 1971

4. The barge is longitudinally framed, of steel construction, and displaces about 42,634 tons in the full load condition. It is divided longitudinally into three cargo sections and each section is divided transversely into four cargo tanks providing a total of twelve cargo tanks. There is no inner bottom but there is additional subdivision in the form of a forepeak ballast tank, after ballast tanks, after void tanks, diesel fuel tanks and a pump room. The barge has a bow thruster directly geared to its own diesel engine. The notch in the stern of the barge is unique in that as well as matching the bow form of the towing vessel in the conventional manner; it matches, also its bottom forming, in essence, a shipway on which the towing vessel is "drydocked". The barge structure in way of the notch is substantially reinforced to accommodate the additional loads which are imposed by this arrangement. The barge possesses the following pertinent documents all of which were valid at the time of the casualty:

a. U. S. Coast Guard Certificate of Inspection
Inspected 9 March 1971
Expiration Date 9 March 1973

b. Load Line Certificate
Type "A" ship with reduced freeboard
Certificate valid only for unmanned operation
Issued 13 October 1971
Valid until 28 April 1976

c. A.B.S. Certificates for Hull and Machinery
Al Oil Barge
Issued 7 June 1971

5. In all operations, both underway and in port, the towing vessel and the barge are rigidly connected so as to be, effectively, a single unit with the intention of always maintaining the capability for rapid and safe disassembly into two units configured individually as a towing vessel and an unmanned tank barge. This capability is provided by the matching shapes of the forward section of the towing vessel and the notch in the stern of the barge which are held together by hydraulic mechanisms and by wedge-shaped projections within the notch which lock, port and starboard, into mating sections in the hull of the tug. The hydraulic mechanisms are two rams which extend from the side of the tug and bear against the walls of the notch. Also, on the centerline of the combined unit, there is a massive hydraulic ram, exerting either a pull or a thrust of approximately 2400 tons, which connects the bow of the tug to the stern of the barge. The integrity of the connection is such that in a seaway the combined unit responds to all sea motions as a single entity.

6. The master of the MARTHA R. INGRAM who was in charge, also, of the barge I.O.S. 3301 at the time of the casualty was Richard D. Fasano. Captain Fasano, is [redacted] years old, holds a U. S. Coast Guard issued license as master steam or motor vessels any gross tons upon oceans, issue 1-4. He had served on the MARTHA R. INGRAM since July 1971 in the capacity of second mate and chief mate, and since November 1971 he has served as master. His seagoing experience prior to joining Ingram Ocean Systems consists of serving as a licensed officer on board tankers for Texaco Inc., from 1966 to 1971.

7. The weather at the time of the casualty was partly cloudy, fair visibility, and light airs out of the west. The surface of the water within the harbor was calm. The air temperature was 46° F and the sea water temperature was 40° F. The state of the tide at the time of the casualty, as determined from the Tide Tables was 2.9 feet above mean low water. The charted depth alongside the Consolidated Oil Terminal pier is 35 feet.

8. The combined unit, with a crew of 14 men including the master, departed Deer Park, Houston, Texas at 1120 CST on 1 January 1972, bound for Bridgeport, Connecticut. The barge was loaded with 229,550 barrels of gasoline and 48,929 barrels of furnace oil as determined from available ullage reports and the master's loading plan. The departure draft as indicated by the draft marks on the barge was 35 feet forward and 35 feet 6 inches aft. Except for periodic stopping of one engine or the other in order to make engine adjustments, the voyage proceeded without incident through the Gulf of Mexico and then up the Atlantic Coast until 5 January when some rough seas were encountered. During the period from 1600 CST, 5 January until 0400 CST, 6 January, the combined unit made a modest reduction in speed because moderate to heavy seas were being taken over the bow and port side of the barge. The weather moderated and the seas began to flatten out and eventually became calm late on 6 January.

9. The combined unit arrived at Bridgeport, Connecticut at 1704 CST on 7 January. The arrival draft as indicated by the draft marks on the barge was 35 feet forward and 35 feet aft. 130,000 barrels of gasoline were discharged from the barge at Bridgeport and 1,072 barrels of diesel fuel were loaded on board the towing vessel. The combined unit departed Bridgeport at 2338 CST, 8 January. The draft on the barge on departure was 18 feet forward and 26 feet, 9 inches aft. The cargo remaining on board as determined from available records was as follows:

TANK	AMOUNT	PRODUCT
1 Port	11,798 BBLS	Shell Regular Gasoline
1 Center	28,364 "	" " "
1 Starboard	11,786 "	" " "
2 Center	11,348 "	" " "
3 Center	49,434 "	#2 Furnace Oil
4 Port	20,265 "	Super Shell Gasoline
4 Starboard	20,265 "	" " "

10. At 0521 CST, 9 January the combined unit moored starboard side to at the Consolidated Petroleum Company Terminal, Port Jefferson, New York for the purpose of discharging the remaining cargo. Cargo temperatures recorded prior to discharging were as follows: gasoline 54 degrees F., No. 2 furnace oil 62 degrees F. Cargo operations commenced at 0640 CST and were completed at 2345 CST at which time the "dry certificate" was issued by the terminal representative. While the cargo was being discharged salt water ballast was taken aboard the I.O.S. 3301 in Nos. 7 and 8 ballast tanks, port and starboard. Upon completion of cargo discharge, ballasting was commenced in barge cargo tanks No. 1 port and starboard, and then in No. 1 center. This operation was completed at 0630 CST on 10 January, and shortly thereafter the Captain and the Second Mate read the drafts indicated by the draftmarks on the barge. The drafts recorded were 15 feet 10 inches forward and 22 feet aft.

11. At 0722 CST the engines of the MARTHA R. INGRAM were started for a warm-up period with both screws being rotated at zero pitch. At 0740 CST Mr. [redacted], the harbor pilot, boarded the MARTHA R. INGRAM. All lines on the combined unit were singled up and the tug NEW HAVEN was made fast on the port bow of the I.O.S. 3301. Next all lines were taken in except for the forward spring and the combined unit was manuevered so as to bring the stern away from the pier. This was accomplished by having the tug NEW HAVEN push on the port bow of the barge while the MARTHA R. INGRAM twisted with her port engine ahead dead slow and her starboard engine backing dead slow. This maneuver was commenced at 0810 CST. At 0816 CST, propulsion thrust on the INGRAM was reduced to zero and the engines on the tug NEW HAVEN were stopped while the combined unit continued her slow pivot away from the pier until properly aligned with the axis of the channel. At 0836 CST the pilot requested that the final line to the pier, the forward spring, be taken in. It was at this instant, while the deck gang was taking in the forward spring, that the barge I.O.S. 3301, suddenly and without forewarning, broke amidships with the

sections forward and aft of the break hogging upward at an angle of about 21 degrees. There was no explosion or fire but the sudden re-orientation of the vessel's buoyant volume generated a wave which broke against the Consolidated Oil Company pier causing some damage including the rupture of some of the piping on the pier. Also, as the midbody of the barge arched upwards its bow came down causing the port anchor on the barge to strike the stem of the tug NEW HAVEN forcing the bow of the latter underwater. The tug quickly righted herself with a limited amount of damage. There was some petroleum pollution of the harbor in the immediate vicinity of the casualty but this was minor and was probably attributable to residue escaping from both the fractured tanks on the barge and the ruptured piping on the pier. Because of the angle assumed by the after section of the barge, the stern of the MARTHA R. INGRAM was forced underwater. An open watertight hatch in the after side of the deckhouse permitted flooding of the after stowage locker, the CO2 room, and the steering engine room on the INGRAM.

12. At the time of the casualty the Chief Mate, the Second Mate, four able Seamen, and two Ordinary Seamen were on the starboard side forward on the I.O.S. 3301 with some of the seamen handling the springline. Immediately after the break they rigged an aluminum ladder from the barge to the pier and then abandoned ship in an orderly manner, first however, running out a line to secure the barge to the pier. Captain Fasano and the pilot were on the bridge at the time of the break. The Captain immediately pushed the emergency stop buttons to shut down the INGRAM'S engines and then he passed the word to abandon ship. The pilot called the Eaton's Neck Coast Guard Station on channel 16, notified them of the casualty and requested assistance. He then directed the tug NEW HAVEN to pick up any men on the forward section of the barge and then come around to the port quarter of the INGRAM to pick up the remaining crew members. When the casualty occurred the Chief Engineer and the First Assistant Engineer were in the engine room on the INGRAM, the cook and the utilityman were in the galley, and the second assistant was standing on deck near the stern of the barge. Personnel on deck generally described the noise which accompanied the break as a sharp crack or explosion, however, some of the people who were inside did not hear any noise but were aware of a sudden jolt or vibration.

13. While in the process of abandoning ship the master and several of the crew attempted to launch and inflate the two 15 man inflatable liferafts which were stowed on the stern of the INGRAM. The first raft put over the side did not inflate when its release lanyard was pulled. The second raft which was launched inflated properly. In any event both sections of the combined unit were evacuated in a short period either by the ladder to the pier or by being taken off by the tug NEW HAVEN. Shortly thereafter the Chief Mate went back on board to shut down a generator which was running in the pump room of the barge and, also, to secure the watertight door to the steering engine room of the MARTHA R. INGRAM. A Coast Guard 40 foot patrol boat, CG 40542, arrived on scene about twenty minutes after the initial notification ready to render assistance if needed.

14. The fracture of the I.O.S. 3301 was generally in the vicinity of the transverse swash bulkhead at frame 49, which is 42.5 feet aft of the midpoint of the barge. It extended completely across the main deck, completely down the side shell port and starboard, and across approximately 46 percent of the bottom plating. The fracture on the main deck was approximately 6 inches forward of the transverse swash bulkhead at frame 49 in 'K' strake port. Following the fracture line to starboard it continued to a point 15 inches forward of the swash bulkhead at the port longitudinal bulkhead just forward of the port king post. It continued approximately parallel to the swash bulkhead into "B" strake port where it crossed the swash bulkhead at approximately the middle of "B" strake. On the after side of the swash bulkhead it ran about 5 inches away from the swash bulkhead to "B" strake starboard, where the distance was reduced to 2 inches aft of the swash bulkhead. It then continued very close to the swash bulkhead up to the base ring of the starboard king post, approximately 37 inches to port of the starboard longitudinal bulkhead where it ran to a point 15 inches forward of the swash bulkhead at the starboard longitudinal bulkhead in "C" strake starboard. The fracture line continued to starboard into "K" strake starboard gradually reducing from 15 inches to 7 inches forward of the swash bulkhead. Most of the deck longitudinals fractured just aft of the swash bulkhead, frame 49. The after fractured edge of the deck plating showed the following chevron pattern.

a. From 'K' strake port the chevrons ran to starboard pointing to a point 15 inches forward of the transverse swash bulkhead at the intersection of the port longitudinal bulkhead and "C" strake port.

b. From 'K' strake starboard the chevrons ran to port pointing to the same point noted in (a).

c. The chevron pattern in to about 4 feet either side of the port king post did have a small shear lip that was not more than a tenth of an inch deep into the plate and very sharp.

d. A point directly forward of the port king post in the deck fractured surface showed a granulated area with no chevron pattern.

On the port side, the fracture of the side plating occurred slightly forward of the transverse swash bulkhead at frame 49 and ran parallel to it except between side longitudinal #5 and #6 in 'H' strake where the fracture crossed 2 inches aft of the swash bulkhead and ran down parallel to it for a distance of 29 inches until it recrossed the bulkhead for about 2 inches and continued down parallel to the bulkhead into the bottom plating. The chevron pattern on the fractured plate edge of the portside shell plating point up towards the deck in all areas except between side shell longitudinal #5 and #10 ('H' and 'G' strakes) where they point down towards the bottom plating. The starboard side shell fracture continued from the fracture in the deck plating down the starboard side 10 1/2 inches forward of the swash bulkhead to the upper third of 'H' strake where there was a jagged tear

back to within 2 1/2 inches of the swash bulkhead. The fracture line thence continued down almost parallel to the swash bulkhead to the lower portion of 'F' strake where there was another jagged tear crossing to a point 9 inches aft of the swash bulkhead and then continuing through the bilge keel into the bottom plating. The chevron pattern on the fractured plate edge of the starboard shell plating point up towards the deck in all areas except between side longitudinal #4 - #6 ('H' strake) and #12 - #13 ('F' strake) where they point down towards the bottom plating. The fracture in the bottom plating on the port side was slightly aft of the longitudinal swash bulkhead extending from the turn of the bilge inboard to 'D' strake. On the starboard side the fracture line ran from the turn of the bilge, approximately 23 inches aft of the swash bulkhead, inboard through 'B' strake. The majority of the crack surface in the deck and shell plating was at a 90° angle to the plane of the plates showing a chevron pattern. The crack surface on the longitudinal bulkhead was at a 45° angle to the plane of the plates. The following additional conditions were noted in the area of the structural failure.

a. A plate lamination in 'E' or bilge strake starboard side.

b. Minor porosity noted in side and bottom longitudinals broken butt welds.

c. Cracks in some longitudinals parallel and some distance away from parted butt welds.

d. A slugged weld in way of a parted butt weld in the longitudinal in approximately #12 port shell longitudinal.

e. Buckled side shell longitudinals just aft of fracture line.

f. Side shell buckled in way of buckled side shell longitudinals.

g. Under forward bracket of port king post a gouge, the deepest point being 1/4 to 3/8 inch, was evident in the deck plating.

h. Deck and bottom plating fore and aft of the fracture line was fair.

15. There was an important structural detail in the immediate vicinity of the failure. Two steel king posts of tubular construction, 24 inches diameter by 40 feet high, were located on the main deck at frame 49 port and starboard. The base plate for each was an annular ring 28 inches in diameter with a cross section measuring 3 1/2 inches by 3/4 inches thick. Each ring was centered directly over the intersection of the transverse swash bulkhead at frame 49 with one of the longitudinal oil tight bulkheads. The deck plating, 1 inch thick, was attached to the intersecting bulkheads by double, continuous fillet welds. The base ring was attached to the deck by continuous 3/4 fillet weld on both the inside and outside diameters of the ring. The king post was landed concentrically on the ring and attached by a full penetration, single bevel weld. Additionally, four triangular, flanged brackets were symmetrically located around each king post, and double fillet welded to both the king post and the deck. The corner of each bracket was sniped at the intersection between the king post and the ring plate. The function of each king post was to support a cargo boom used mainly for handling cargo hose. At the time of the casualty both cargo booms were unladen and in the stowed position. The crack across the main

deck passed immediately tangential to the forward edges of the fillet welds on the outer diameter of the ring plates, i.e., passed between the ring plate and the bracket on the forward side of each king post.

16. As closely as can be determined from the testimony and the vessel's records, the loading condition of the I.O.S. 3301 at the time of the casualty was as follows:

TANK	BBLS	LIQ	TONS
Ballast Forepeak	empty	-	-
Cargo #1P	11573	SW	1856
Cargo #1C.L.	27116	SW	4350
Cargo #1S	11573	SW	1856
Cargo #2P	-	-	-
Cargo #2C.L.	-	-	-
Cargo #2S	-	-	-
Cargo #3C.L.	-	-	-
Cargo #4P	-	-	-
Cargo #4S	-	-	-
Cargo #4C.L.	-	-	-
Cargo #5P	-	-	-
Cargo #6S	-	-	-
Ballast #7P	-	SW	924
Ballast #7S	-	SW	924
Ballast #8P	-	SW	814
Ballast #8S	-	SW	814
D.O. #9P	-	D.O.	91
D.O. #10S	-	D.O.	97
Misc. Small Tanks	-	-	9.4

17. The loading condition of the MARTHA R. INGRAM at the time of the casualty, as closely as can be reconstructed from the testimony and the vessel's records, was as follows:

TANK	SIDE	FRAME	LIQ	TONS
FORE PEAK W. B.	P	65-F	-	0
BALLAST 1-P	P	56-65	SW	37.78
BALLAST 1-S	S	56-65	SW	36.49
BALLAST	P	50-56	-	0
BALLAST	S	50-56	SW	5.97
D.B. DIESEL 1-P	P	39-50	DO	4.15
D.B. DIESEL 1-S	S	39-50	-	0
FUEL OIL 2-P	P	42-50	DO	33.53
FUEL OIL 2-S	S	42-50	DO	44.25
FUEL OIL 3-P	P	36-42	DO	38.68
FUEL OIL 3-S	S	36-42	DO	40.40
FUEL OIL 4-P	P	22-36	DO	84.49
FUEL OIL 4-S	S	22-36	DO	84.71
F.O. SETTLING	P	38-50	-	* 0

L.O. CPP STORAGE	P	36-38	LO	* 6.6
L.O. STORAGE	S	44-50	LO	* 22.6
HYDRAULIC OIL	S	42-44	HO	* 6.9
F.O. SERVICE	S	36-42	-	* 0
DIESEL SERVICE	P	22-28	DO	11.28
DIESEL SETTLING	S	22-27	DO	37.90
F.O. DRAIN	P	34-39	-	* 0
DIRTY L.O. DRAIN	S	34-39	-	* 0
SEWAGE	P	30-37	-	* 0
SLUDGE	S	30-37	-	* 0
L.O. DRAIN	P	30-37	LO	* 3.70
L.O. DRAIN	S	30-37	-	* 0
L.O.	S	27-28	LO	* 4.2
L.O. CPP DRAIN	P	30-33	LO	* 3.1
L.O. CPP DRAIN	S	30-33	-	0
BALLAST 2-P	P	9-22	SW	30.11
BALLAST 2-S	S	9-22	SW	38.13
FRESH WATER	P	4-9	FW	38.6
FRESH WATER	S	4-9	FW	38.6
POTABLE WATER	P	5-8	FW	17.6
POTABLE WATER	S	5-8	FW	20.7
AFT PEAK W.B.	-	AFT 4	-	0

* Estimated

18. The ballasting, which existed at the time of the casualty, had been accomplished in accordance with the verbal orders of the Master. He chose it to provide a draft and trim which would facilitate the safe maneuvering within, and departure from, the harbor of Port Jefferson. There was no Loading Manual available which the Master could use to evaluate the hull stress imposed by the ballasting arrangement. There were no operating instructions relating to ballasting procedures. There was a typical ballast loading condition described in the barge's Trim and Stability Booklet, but this was not in the draft range desired for clearing Port Jefferson. Captain FASANO based the ballasting arrangement on his previous experience with tankships and on the prior practice he had observed on the I.O.S. 3301. However, there was a difference from the last time the combined unit was in Port Jefferson. At that time the desired drafts had been obtained by ballasting the forepeak, the Nos. 7 and 8 ballast tanks, and partially ballasting the No. 2 center cargo tank. This time the No. 1 cargo tanks were used instead of the forepeak and No. 2 center tank because the forepeak valve was inoperative and required repair. If the forepeak was ballasted it could not be drained by means of the installed piping system when it came time to de-ballast. The alternative ballast arrangement provided the desired drafts for clearing port, after which it was the master's stated intention to complete ballasting so as to comply with the draft restrictions in the stability letter.

19. The Merchant Marine Technical Branch, Third Coast Guard District, calculated the stress attributable to the longitudinal bending moment which existed, insofar as it can be determined, in the hull of the I.O.S. 3301 at the time of the casualty. For this purpose use was made

of the Lines plans for the tug and for the barge, the lightship weight curve for the combined unit (which was derived from designer's data and the results of the stability tests which were conducted on both the tug and the barge), the distribution of the deadweight on both units at the time of the casualty, and the barge's midship section plan. The calculations indicated the following:

a. The midship section modulus of the I.O.S. 3301, taking credit for the corrosion control provisions, is 71,088 inches squared feet for the deck and 78,492 inches squared feet for the bottom. This compares with 68,814 inches squared feet for the deck and 73,631 inches squared feet for the bottom as required by the rules of the American Bureau of Shipping for a tankship of the size of the combined unit. Also, it compares with 39,054 inches squared feet which would be the minimum section modulus required for an unmanned tank barge of the size and configuration of the I.O.S. 3301 alone. The section modulus based on the material actually provided, i.e., not including the permissible allowance for the corrosion control coating which was provided, is 65,414 inches squared feet for the deck and 72,011 inches squared feet for the bottom.

b. Since the vessel was in calm water at the time of the casualty the bending moment was calculated as a still water bending moment. For this condition it had a maximum value of 686,700 foot tons located at a station 306.5 feet aft of the forward perpendicular of the barge. This station is about 40.5 feet aft of the midpoint of the barge and approximately 2.5 feet forward of the median location of the fracture line.

c. The magnitude of the hull stress attributable to the longitudinal bending moment was 23,515 pounds per square inch in the main deck. This was based on the calculated maximum bending moment and the section modulus computed for the material actually provided.

d. The draft readings on the barge at the time of the casualty were reported to be 15 feet 10 inches forward and 22 feet 00 inches aft. There were no midship draft marks so it could not be ascertained if the vessel was hogged or sagged. However, based on the loading, a deflection of 12.4 inches (hogging) was estimated by calculation. Then using the reported drafts and the estimated hog, the displacement of the combined unit was calculated utilizing the lines plans for the tug and the barge. Additionally, the displacement of the combined unit was calculated by summing the lightship weights of each unit and the deadweight loads as determined from the testimony. Theoretically, the displacements calculated by each method should be the same. However, there was a five percent discrepancy. An effort was made to explain this discrepancy by verifying the basic data. To this end the hydrostatic information on each unit was re-checked and found to be correct. The draft marks on the barge were re-measured when the vessel was on drydock and found to be satisfactory. Also, a deadweight survey on the barge was conducted under Coast Guard supervision. The results of the original stability test were confirmed within 44 tons of displacement and 0.3 feet on LCB. Consequently, the five percent error could not

be resolved and it is assumed to be the cumulative effect of errors in reading the drafts, reporting the deadweight, and estimating the amount of deflection in the hull at the time the drafts were read prior to the casualty.

20. The Maritime Administration had contracted with Ingram Ocean Systems to instrument the I.O.S. 3301/MARTHA R. INGRAM in the attached mode to obtain stress/strain information for the combined unit. The main interest was in the notch area and the connection system, although other sensors were being strategically located on the tug and barge. Ingram Ocean Systems being the prime contractor, sub-contracted the physical installation of the equipment. During the installation phase the combined unit had encountered heavy weather seas which had caused damage to piping conduits containing the instrumentation cables. The instrumentation equipment had never been completely installed or operational and no information has ever been developed from this program.

21. On 1 February 1972, the members of the Marine Board of Investigation visited the barge I.O.S. 3301 on drydock at Todd's Shipyard, Brooklyn, New York. A detailed examination was made of the hull plating and the internal structural members in way of the fracture. Also, a general examination was made of the layout of the vessel and its overall condition was assessed insofar as this was externally evident. A Coast Guard hull inspector checked the scantlings and the details of construction of the barge and determined that they were in substantial compliance with the approved plans. Also in attendance at this time were the owner's representatives, A.B.S. surveyors, shipyard personnel, metallurgists, and materials testing specialists from the New York Testing Laboratories, Inc., Westbury, New York, and the U. S. Naval Research Laboratory, Washington, D. C. A consensus was reached as to the number, location, and marking of the test coupons which were to be taken as well as the specific tests which would be made and reported. All samples were marked and cut-out under the direct supervision of a Coast Guard inspector. It was arranged that the final reports from both New York Testing Laboratories and the Naval Research Laboratory would be received by the board as exhibits in the investigation. The board employed the services of a metallurgical consultant, Dr. [redacted], Professor of Civil Engineering at the University of Kansas, Lawrence, Kansas, to review the test reports and make an analysis thereof for the purpose of assisting the board in its deliberations. Dr. [redacted] report, which was prepared after he had examined the vessel and reviewed the test results, was received by the board as an exhibit in evidence.

22. There had been no structural damages sustained or structural repairs made to the I.O.S. 3301 since going to service in July 1971. The I.O.S. 3301 has always operated at sea with the tug MARTHA R. INGRAM, in the designed notch in her stern, except during periods of sea trials. The barge has been in severe weather in the western N. Atlantic and Gulf of Mexico while operating in the attached mode without incident. There were no known cracks in the hull structure amidships or elsewhere on the I.O.S. 3301 prior to the casualty on 10 January 1972. There is no

known history of fractures or structural weaknesses to the barge.

23. At 1435 CST, 29 September 1971, the combined unit, proceeding at slow speed, took a sheer in the Houston Ship Canal and the starboard bow of the I.O.S. 3301 touched a mud bank on the starboard side of the channel in the vicinity of Buoy No. 137. There was no apparent damage due to the grounding on 3 October 1971. Mr. [redacted] who was then Master, along with a diver, inspected the hulls of the barge and tug at Port Everglade and found no damage.

24. During early October 1971 a number of small fractures were discovered in the after hull plating of the MARTHA R. INGRAM. The fractures were located between the starboard propeller and starboard rudder in way of a fresh water tank. Repairs were accomplished by renewing the fractured plates and, also, new reinforcing structure was added to prevent reoccurrence. This work was done at Todd Shipyard, New Orleans, during October 1971.

25. At no time during the operation of the combined unit at sea did anyone remember any unusual vibration on the barge.

26. No welding had been done on the hull structure of the barge since the vessel went into service.

27. Captain FASANO, when he was Chief Mate, visually examined the tank coatings in the following tanks: No. 1C, 2C, 3C, 5P and 6S prior to the end of November 1971. During his examinations he had noted some bubbling of the coating on the overhead of each tank and some rust showing in the areas of welds.

28. The route used by the Master when making voyages from the Gulf of Mexico to the east coast of the United States and return was the standard tanker routes, which in many instances would be considerably in excess of 20 miles offshore.

29. The inflatable liferaft, U. S. Rubber Company, Serial No. 15/1018/055, which failed to inflate at the time of the casualty was sent to the Revere Supply Company, Inc., an approved servicing facility, for inspection and repacking. The raft was inspected by CWO [redacted], USCG, and Mr. [redacted], Revere's chief engineer. The raft was found to be improperly packed in its protective container. It was stowed wrong end to; so that the painter, instead of passing through a hole in the container directly to the activating mechanism, passed completely beneath the raft before reaching the activating mechanism. This misdirection of the painter within the container caused it to bind and thereby prevented its proper functioning. The liferaft was repacked and returned to service. Its records indicated that it was last serviced on 8 October 1971, by the J. B. Delaney Company, Inc., New Orleans, Louisiana.

30. No Oil Record Book was maintained for the I.O.S. 3301 as required by 33 USC 1008-1011.

31. At sea as well as when moored, the crew of the tug MARTHA R. INGRAM routinely were on board the I.O.S. 3301 to perform maintenance, conduct cargo transfer and ballasting operations, and for tank cleaning.

C O N C L U S I O N S

1. The casualty to the barge I.O.S. 3301, which occurred on 10 January 1972, resulted from the brittle fracture of the hull steel and was caused by the unfavorable interaction of the following physical conditions, namely:

a. A high stress level in the main deck plating,

b. Inadequate notch toughness of the hull steel at temperature 46 degree F., and

c. The probable presence of a small defect in the deck plating within the area subjected to the high stress level.

2. The fracture initiated at the toe of the fillet weld connecting the base plate for the port king post, to the main deck plating at frame 49. The crack propagated laterally port and starboard. When it intersected the starboard king post on its central axis, a second brittle fracture initiated at the toe of the fillet weld connecting the base plate of this king post to the main deck plating. Then both cracks continued to propagate laterally around the girth of the hull resulting in the complete failure of the structure.

3. The actual magnitude of the stress in the main deck plating at the point of failure is not known, however, it is established that the stress level was high--high enough to severely try the strength and design of the barge. The distribution of the ballast in tanks at the forward and after ends of the barge with all the tanks in the mid-length empty created an excessive longitudinal bending moment. The stress in the main deck plating in the vicinity of the fracture, as calculated for this loading condition, was 23,515 pounds per square inch.

4. The stress level attributable to longitudinal bending, while the principal component, was not the only component in the total stress level. It was significantly increased in the immediate vicinity of the king posts at frame 49, by locked-in weld stresses. The continuous 3/4 inch fillet weld which was laid along both the inside and outside circumferences of the "washer"-shaped base plates for the king posts placed a high amount of heat energy into a small area of the deck plating. And, to make matters worse, this area was highly restrained, triaxially, by its attachment beneath to the intersection of the longitudinal bulkhead and the transverse swash bulkhead. Conditions of high heat input coupled with severe restraint are conducive to significant weld stresses and it is reasonable to conclude that such stresses were present and augmented the general field stress level in the area where the crack was initiated.

5. For the stress level which existed and at the ambient temperature of 46 degrees F., the hull steel did not have sufficient notch toughness

to prevent catastrophic propagation of a crack once initiated. Although examination of the fracture surface in the area of initiation did not disclose a pre-existing defect this does not establish that one did not exist. Calculations made by Dr. [redacted], which were based on current fracture mechanics theory and the properties of the steel as determined by test, indicated that a flaw as small as 0.1 inch, under the conditions prevalent at the time of the casualty, would have been sufficient to trigger the non-arrestable crack which occurred. A defect of this size could not be detected after failure without making an immediate post-fracture examination under laboratory conditions. Such an examination was not made and could not have been made because of the circumstances of the casualty. The defect could have been a pre-existing flaw in the plate, a tiny crack within an arc strike, a minor fatigue crack, a defective weld, or some other deficiency.

6. The metallurgical testing of coupons from the barge, as conducted by both the New York Testing Laboratories, Inc., and the Naval Research Laboratory, established that the hull steel complied in all respects with the American Bureau of Shipping specifications for Grade B and C plate. These specifications define mechanical and chemical properties and do not explicitly address the matter of notch toughness. However, Charpy V-Notch tests were made by both laboratories and the results indicated that the steel had sufficient energy absorption to meet current Charpy V-Notch criteria. Additional testing was carried out by the Naval Research Laboratory using the Drop Weight Test for Nil Ductility Temperature and the Dynamic Tear Test. Notwithstanding the Charpy V-Notch results these tests clearly established that the hull steel in the barge I.O.S. 3301 did not have adequate notch toughness for the stress level and temperature extant at the time of the casualty.

7. There was some evidence, mainly adduced from the report made by the New York Testing Laboratories, that there were fractures in the internals of the barge that may have existed prior to the failure and, also, some defective welds and that these conditions, by reducing the overall strength of the hull, significantly contributed to the casualty. It is the opinion of the board that the total fractures in way of the butt welds in many of the longitudinal stiffeners in close proximity to the actual fracture line, were a direct result of and not a cause of the casualty. This is supported by the fact that such broken welds were not found in other areas of the barge. With regard to the defective welds--these were not apparent by visual inspection and were disclosed only by intensive examination and detailed radiographic inspection of the hull structure in the general vicinity of the fracture. Radiographic inspection is not required by the Rules of the American Bureau of Shipping for the construction of a barge. At the time it was built the barge was examined and found to be satisfactory by Coast Guard inspectors, A.B.S. surveyors, and the owner's representatives. Also, after the casualty the hull was examined by a Coast Guard inspector and excepting for the damage, was found to be generally satisfactory. One slugged weld and one small area of delamination in a hull plate were found but both were remote from the point of crack initiation. Conse-

quently, it is the opinion of the board that the workmanship and quality of construction of the barge I.O.S. 3301 was in general conformity with the standards usually found on unmanned tank barges.

8. The extreme angle of trim which the stern section of the combined unit assumed after the casualty demonstrated that the tug cannot always be disconnected in time of trouble and, therefore, should not be counted as a primary lifesaving vehicle. Additionally, the casualty pointed up the absence of a liferaft on the forward section of the combined unit as would be required for a tankship. Crew members on the bow section were cut off from the liferafts aft as well as from their life preservers and were completely without lifesaving devices of any kind.

9. At the time of the casualty the combined unit was not operating at its maximum draft so its load line assignment was not a contributory factor. The testimony and records indicated that the barge I.O.S. 3301 was authorized a 25 percent reduction in freeboard over the maximum permitted for a tankship. Such a reduction is authorized by 46 CFR 42.20-10(h) (Load Line Regulations) only for unmanned tank barges. However, the testimony has established that routinely while the combined unit is in operation it is, in fact, manned. Therefore, the reduction does not appear to be justified. Personnel on the combined unit are subject to the identical perils as are the personnel on a conventional tankship and they should have the same margin of safety as is provided by the reserve buoyancy of a tankship freeboard.

10. Testimony and the combined unit's log books indicated that on this and previous voyages the MARTHA R. INGRAM had not adhered to the route limitation specified on her Certificate of Inspection. The vessel was routinely operated on tracklines far in excess of the twenty miles offshore limitation imposed by her "Coastwise" route. This fact did not contribute to the casualty.

11. At the time of the casualty the combined unit was being operated in violation of the restrictions imposed by the stability letter which was issued to the MARTHA R. INGRAM. The letter prescribed a minimum draft for the barge when connected to the tug so as to insure that, at all times, the tug could be safely disconnected from the barge. At the time of the casualty the barge was at a lesser draft than the prescribed minimum. However, this fact did not contribute to the casualty.

12. The circumstance that there were no injuries or loss of life incident to the casualty is attributable solely to the fact that it occurred in port and the vessel grounded on the bottom. Had the fracture occurred at sea the barge would have undoubtedly broken completely in half. The severely canted angle of the stern section would have prevented the tug from being disengaged from the damaged barge. The submergence and flooding of the tug, even if it was no greater than that which actually occurred, would probably have caused the tug and stern section to sink very quickly with heavy loss of life.

Similarly, the consequences of the failure of the inflatable liferaft to function properly were minimized because the vessel was in port. Had the casualty occurred at sea this failure, also, could have been responsible for the loss of life.

13. There is no evidence, which indicates that any personnel of the Coast Guard or any other governmental agency contributed to this casualty.

14. The casualty would probably not have occurred if one or more of the following conditions had obtained:

a. If the combined unit had an approved Loading Manual as is required by the American Bureau of Shipping for a tankship. The tug/barge combination in the connected mode is essentially identical to a tankship with the machinery aft and, consequently, it is equally susceptible to unfavorable or even dangerous longitudinal bending moments due to improper weight distribution. The calculated stress at the time of the casualty was over two and one-half times as high as the longitudinal bending stress which would have been authorized in a Loading Manual for a conventional tankship of similar size when proceeding from port. Consequently a Loading Manual would have provided the master with information and instructions regarding loading and hull stresses and would have prohibited him from ballasting the barge in the manner he used immediately prior to the casualty.

b. If the king post installation at frame 49 was designed to take cognizance of the fact that it was located in the area of maximum hull bending stress and engineered so as to minimize locked-in weld stresses it is possible that this structural detail would not have been the focal point for crack initiation and that without such source the other contributory factors would not have been sufficient in themselves to cause the casualty.

c. If the American Bureau of Shipping specification for hull steel was as discriminatory with respect to notch toughness as the Naval Research Laboratory's dynamic tear test, it is probable that a tougher steel would have been specified and that a catastrophic, brittle fracture would not have been possible at a temperature of 46 degrees F., allowing the stress level which existed.

d. If the barge had strakes of crack arresting steel at the gunwale and at the turn of the bilge as is required for tankships by the Rules of the American Bureau of Shipping. Strakes of such material, e.g., A.B.S. Grade CS steel, are not required for tank barges. If such strakes were installed at the gunwale it is possible that they would have arrested the crack and prevented catastrophic failure. The designer provided Grade C steel in these locations and while this is in excess of the minimum requirement for a tank barge it does not meet the standard prescribed for a tankship.

RECOMMENDATIONS

1. It is recommended that the barge component in a rigidly connected tug/barge combination be designed and inspected in accordance with the American Bureau of Shipping Rules for the construction of ships and that the length of the combined unit shall be the length used in applying these rules.

2. It is recommended that a rigidly connected tug/tank barge combination be assigned, as a minimum, a Type A freeboard if it is qualified for same under the Load Line Regulations.

3. It is recommended that all rigidly connected tug/barge combinations be furnished with Loading Manuals similar to those which are required for tankships.

4. It is recommended that a rigidly connected tug/tank barge combination be provided with the primary lifesaving equipment for a tankship.

5. It is recommended that the Coast Guard institute a research program to define a more meaningful criteria for the notch toughness of steel than is afforded at present by the Charpy V-Notch criteria. The necessity for this is clearly demonstrated in this casualty by the conflicting indications obtained from the Charpy V-Notch tests and the dynamic tear tests of samples of identical material taken from the barge. Once the criteria is defined it is further recommended that the Coast Guard endeavor to have it incorporated into the basic specification for ship steel.

6. It is recommended that when repairs are made to the barge I.O.S. 3301 to restore it to service, the design of the king posts at frame 49 be revised so as to eliminate or, at least, minimize the unfavorable stress concentrations that existed in the original design.

7. It is recommended that further investigation under the suspension and revocation proceeding be initiated in the case of Richard D. Fasano, Master of the MARTHA R. INGRAM/I.O.S. 3301, License Number [redacted], for operation of the MARTHA R. INGRAM on a route which was not authorized by the Certificate of Inspection and, also, for failure to maintain an Oil Record Book for the I.O.S. 3301, as required by 33 USC 1008-1011 and the regulations promulgated thereunder.

8. In light of the above it is recommended that the Coast Guard re-evaluate the position it has taken in the regulation of the tug/barge combinations. When this has been done it is further recommended that guidance be promulgated which will provide direction for the field inspection of such vessels.

[redacted]

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