U.S. Department
of Transportation

**United States
Coast Guard**

M/V SANTA CLARA I

BOARD OF INQUIRY REPORT

CONCERNING THE LOSS OF HAZARDOUS MATERIALS

NEAR THE NEW JERSEY COAST

ON 3 JANUARY 1992

U.S. Department of Transportation
United States Coast Guard

Commandant
U.S. Coast Guard

Washington, DC 20593-0001
Staff Symbol: G-MMI-1
Phone: (202) 267-1424

16732
MAY 14 1992

M/V SANTA CLARA I (PN)- BOARD OF INQUIRY CONCERNING LOSS
OF HAZARDOUS MATERIAL IN THE ATLANTIC OCEAN NEAR THE NEW JERSEY COAST ON 4 JANUARY 1992

ACTION BY THE COMMANDANT

The report of the Board of Inquiry convened to investigate this accident has been reviewed and is approved subject to the following comments.

CAUSE OF THE CASUALTY

I concur with the Board's determination that the loss of cargo was caused by the crew's failure to adequately secure containers on deck. Contributing causes included mechanical weaknesses in the cargo securing system and various operational shortcomings.

COMMENTS ON CONCLUSIONS

Conclusion 4.b : Other factors which may have contributed to the loss of cargo include inadequate blocking and bracing of the contents of the containers, a condition which was exacerbated by palletizing the drums for container shipment.

Comment : I partially concur with this conclusion. Inadequate blocking and bracing appear to have contributed to the loss of cargo. However, I do not agree that palletization in itself made it more difficult to block and brace the drums. When properly palletized, drums can be effectively blocked and braced within containers.

ACTION ON RECOMMENDATIONS

Recommendation 1: Develop, in coordination with RSPA, a regulatory package to implement IMO Resolution A.714(17), Code of Safe Practice for Cargo Stowage and Securing, for all vessels transiting U.S. waters with dangerous cargo.

Action : I concur with this recommendation. Commandant (G-MVI) will develop the recommended regulatory package.

Recommendation 2: Propose that the IMO improve Resolution A.714(17) in view of the detailed findings of this inquiry, and recommend that it be made mandatory under the SOLAS Convention for ships carrying cargoes addressed by the IMDG Code.

Action: I concur with this recommendation. Commandant (G-MVI) will propose changes to IMO Resolution A.714(17) based on information contained in this report. Further, a recommendation will be made to make the Resolution mandatory under SOLAS for ships carrying cargoes addressed by the IMDG Code.

Recommendation 3: Develop a compliance inspection program for securing gear and securing arrangements, addressing the need for complete securing before a ship leaves the dock or enters pilot waters inbound.

a. Propose to the International Association of Classification Societies that they make the design, construction and maintenance of container securing systems a condition of class for all container-carrying vessels.

b. Consider use of the National Cargo Bureau to assist in operational inspections, to take advantage of existing expertise.

Action: I generally concur with this recommendation. Commandant (G-MVI) will evaluate various options for implementation.

Recommendation 4: Examine the failure and repair history for FRP containers to determine their suitability for continued unrestricted use.

Action: I concur with this recommendation. Commandant (G-MVI) will conduct the recommended study of FRP containers.

Recommendation 5: Develop a container inspection program for assessing the adequacy of blocking and bracing inside containers, and enforcing the existing regulations on packing.

Action: I concur with this recommendation. Commandant (G-MPS) has submitted a Resource Change Proposal for fiscal year 1994 for additional billets for use in establishing a nationwide container inspection oversight program. In addition, a change to the Marine Safety Manual is currently under review which proposes placing more emphasis on container packing, adequacy of cargo stowage and cargo segregation.

Recommendation 6: Initiate a quantitative risk analysis regarding on-deck stowage of marine pollutants, in coordination with the IMO Subcommittee on the Carriage of Dangerous Goods.

Action: I concur with this recommendation. At the 44th Session of the IMO Subcommittee on the Carriage of Dangerous Goods in October of this year, we will submit a U.S. paper on this casualty for informational purposes and to propose analyzing the relative risks of stowage locations.

Recommendation 7: Refer the case to the Department of Justice (DOJ) for pursuit of any available criminal and civil penalties regarding the owner's failure to notify the Coast Guard of spilled hazardous materials below deck in Baltimore.

Action: I concur with this recommendation. This case will be referred to DOJ for pursuit of criminal and/or civil penalties as they deem appropriate.

Recommendation 8: Forward a copy of this report to the government of Panama, the International Maritime Organization, the International Association of Classification Societies, the National Cargo Bureau and Lloyd's Register of Shipping for information

Action: I concur with this recommendation. Copies of the report will be provided to the listed organizations.

J.W. Kime

J. W. KIME
Admiral, U. S. Coast Guard
COMMANDANT

Technical Report Documentation Page

1. Report No. USCG 16732/03 HQS 92	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MARINE BOARD OF INQUIRY M/V SANTA CLARA I		5. Report Date
		6. Performing Organization Code G-MMI
7. Author(s)		8. Performing Organization Report No. 16732/03 HQS 92
9. Performing Organization Name and Address COMMANDANT (G-MMI) U.S. COAST GUARD WASHINGTON, DC 20593-0001		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. COAST GUARD WASHINGTON, DC 20593-0001		13. Type of Report and Period Covered MARINE BOARD OF INQUIRY 18 MAY 92
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report examines the circumstances surrounding the loss of 4 containers of arsenic trioxide, a hazardous substance, overboard from the Panamanian M/V SANTA CLARA I during heavy weather approximately 40 miles off the New Jersey coast on January 3, 1992. 17 additional containers were also lost during the accident. While the vessel incurred minor structural damage, there were no injuries to the crew.

The Commandant concurred with the Board of Inquiry's determination that the primary cause of the cargo loss was that the cargo containers were not adequately secured on deck. Contributing causes included mechanical weaknesses in the cargo securing system and various operational oversights.

17. Key Words Hazardous materials, arsenic trioxide, magnesium phosphide, containers, heavy weather, securing system, IMDG Code, RSPA, CERCLA, IMO, container ship, cargo loss	18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, VA 22121

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages	22. Price

PORTS AND WATERWAYS SAFETY ACT BOARD OF INQUIRY

M/V SANTA CLARA I (PN) LOSS OF HAZARDOUS MATERIAL
IN THE ATLANTIC OCEAN OFF THE NEW JERSEY COAST
ON 4 JANUARY 1992

SYNOPSIS

On the afternoon of January 3,1992 the M/V SANTA CLARA I departed Port Elizabeth, New Jersey enroute Baltimore, Maryland with forecast dangerous storm warnings. As the ship headed south off the New Jersey coastline, the weather deteriorated throughout the night, with winds gusting to over 50 knots and seas up to 28 feet. Between 0130-0230 the following morning, the ship lost 21 containers and one piece of machinery overboard from stowage on the #2 hatch; four of the lost containers were loaded with Arsenic Trioxide. Ten palletized drums of Magnesium Phosphide in the #1 upper tween deck also broke loose and were breached during the storm. While the drums were clearly labeled, they were not manifested as dangerous cargo, and none of the crew or shoreside personnel who worked in the hold properly identified the hazard from the spilled product until the ship later arrived in Charleston, South Carolina. (Evidence of knowledge and failure to report the hazard to the Coast Guard is referred for possible action by the Department of Justice.)

The cargo loss was caused by failure to adequately secure containers and machinery on deck. Several operational deficiencies, especially the lack of a Cargo Securing Manual as described in IMO guidelines, contributed to the accident.

The IMO guidelines and Class Society rules systematically outline the elements of a good cargo securing system; however, neither the U.S. nor Panama has implemented the IMO guidelines by regulation. If the vessel operator had carefully applied these guidelines, the cargo loss may have been prevented.

The Board identified several operational weaknesses in preparing the ship for sea and operating in heavy weather. The Master, who was new to the vessel, left port with excessive metacentric height, adding to the forces acting on the deck-stowed cargo; constrained the lashing of cargo by the crew under time pressure while heading into a storm; and failed to take early action to avoid the storm or make appropriate course/speed changes in heavy weather. Each of these represents a departure from good marine practice, and is addressed generally in IMO guidelines, but does not violate any regulation.

Inadequate blocking and bracing of the Arsenic Trioxide drums in the intermodal containers may have contributed to the casualty, inducing shock loads on the containers and restraint system. An inherent weakness in construction of one container also may have contributed.

On a broader level, the Board highlights a special risk associated with on-deck stowage of Marine Pollutants, which is currently permissible under both IMO guidelines and U.S. regulation. With increasing transportation of chemicals to the U.S., increasing public intolerance of water pollution, and the myriad variables at sea, the risk of carrying many of these toxic cargoes on-deck where they are exposed to the greatest potential for loss may be too high even with cargo securing safeguards in place.

The U.S. should implement the IMO cargo securing guidelines in federal regulation for vessels carrying dangerous cargoes, and establish a compliance inspection program for oversight. The Coast Guard should evaluate in more detail the existing industry standards for the design of cargo restraint systems, and address shortcomings in those standards and in the IMO Codes at the international level. The Coast Guard, in coordination with IMO, should further study the risks and alternatives for regulating on-deck stowage of Marine Pollutant cargoes.

PORTS AND WATERWAYS SAFETY ACT BOARD OF INQUIRY

M/V SANTA CLARA I (PN) LOSS OF HAZARDOUS MATERIAL

IN THE ATLANTIC OCEAN OFF THE NEW JERSEY COAST

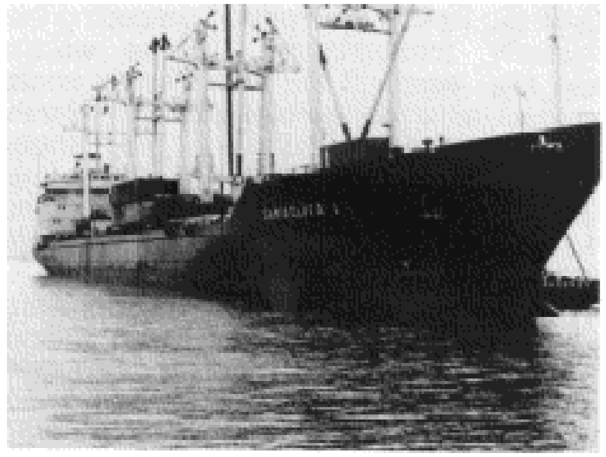
ON 4 JANUARY 1992

Table of Contents

Encl.: (1) Convening Order
(2) Reference List

VESSEL INFORMATION

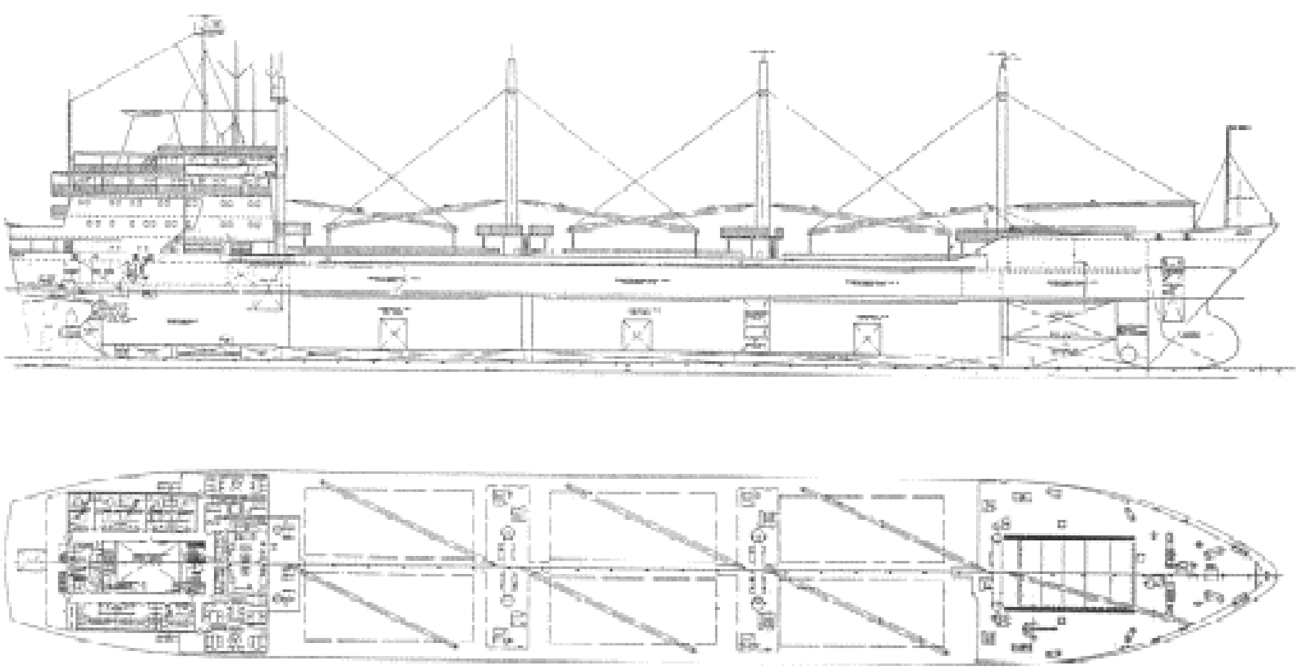
The SANTA CLARA I is a break-bulk ship of Panamanian registry, 479 feet in length, 9593 gross tons, built in 1974 and fitted for the carriage of containers on the hatch covers (at #2-4). In 1977 the ship was retrofitted with deck pedestals to increase the capacity for container stacks from six across to eight across above deck. The ship is diesel-direct propulsion, 7385 horsepower, with a maximum service speed of 16 knots loaded. Speed is controlled by a variable-pitch propeller.



M/V SANTA CLARA I

The SANTA CLARA I operates on a regular run between ports in South America and east coast ports in the U.S., generally carrying containers, trucks, and break-bulk cargo. It carried a total complement of 28, with a Spanish Master and mostly Peruvian crew. The Master, with 25 years experience at sea including 18 years commanding vessels, was making his first voyage with the company; he assumed command of the SANTA CLARA I on December 29, 1991, four days before the ship arrived in Port Elizabeth, New Jersey.

The ship is arranged with four cargo holds, 2-3 levels each spanning the width of the ship, with the house and machinery spaces aft.



General Arrangement Plan - Profile and Plan Views

WEATHER

Over the 24-36 hour period preceding the casualty, forecasts for offshore waters and high seas off the New Jersey coast warned of a dangerous storm centered 100-150 miles south of the ship's trackline between Port Elizabeth and Delaware Bay, with northeast winds up to 40-60 knots and seas from 22-35 feet expected by Friday night, January 3. Storm warnings were issued for the area as early as the evening of January 2, and by 1100 on January 3 the forecasts described a "dangerous storm to marine interests developing." The storm was projected to move north-northeast through the area, with the northeast quadrant most dangerous.

Actual weather along the ship's trackline, taken from weather buoy data, showed winds increasing from 20 knots at the outset of the voyage to 34 knots (gusting over 40 knots) by 0200 on January 4, gradually shifting direction from 076° to about 055°True. During the same period seas increased from 7 to about 14 feet, while the wave period lengthened from 6 to 1 0-11 seconds. The most severe weather in this area, where wind/sea conditions equaled the forecasts, occurred several hours later - wind gusts reached over 50 knots between 04000600, and seas later reached up to 28 feet between 0800- 0900 on January 4.

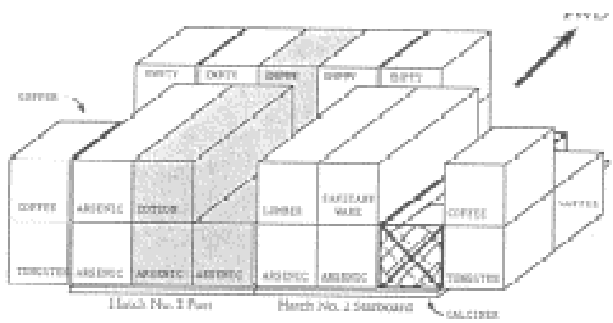
The storm was intense, causing heavy damage along the Maryland and New Jersey shorelines. Another ship lost two deck-stowed containers during the same storm - about 3 hours later in about the same location as those lost from the SANTA CLARA I.

THE VOYAGE TO BALTIMORE

The ship's voyage began in Valparaiso, Chile on December 2, 1991, with planned port calls in Chile, Peru, Ecuador, and the U.S. ports of Philadelphia, New Haven, Port Elizabeth, Baltimore, Charleston and Miami - a regular run for this ship.

After loading containers and general cargo, including 10 drums of Magnesium Phosphide in the #1 Upper Tween Deck, the ship sailed from Valparaiso to Coquimbo, Chile, where it loaded 25 containers of Arsenic Trioxide - 19 containers in the #2 hold and 6 containers on the #2 hatch. The ship continued its voyage uneventfully until its third U.S. port of call - Port Elizabeth, New Jersey.

The ship arrived in Port Elizabeth on Thursday, January 2, 1992, where longshoremen discharged containers from #2 and #3 hatches, restowed several containers onto the #2 hatch, and loaded containers and general cargo in the #3 hold and on the #1, #2 and #3 hatches. Upon completion, cargo stowage on the #2 hatch included 15 loaded containers, 10 empty containers, and one 50-foot calciner (a piece of machinery used in the mining industry) mounted on a steel frame and secured to a wooden skid.



Cargo stowage on #2 Hatch upon departure Port Elizabeth
(Shaded containers remained after casualty)

The Master declined use of the shoreside lashing gang in Port Elizabeth, opting to lash the cargo with ship's crew after leaving the dock, a common practice in U.S. ports for foreign vessels generally and for this ship in particular. However, union rules in Port Elizabeth prohibit the crew from beginning any lashing o securing while the ship is alongside the pier when shoreside lashing gangs are not used.

The Master was aware of the adverse weather forecasts, and he was anxious to get the ship loaded and underway, to "get out into deep water" before the storm. Before departing, he revised the planned trackline down the New Jersey coast, previously prepared by the Second Mate, to take the ship farther from the shallow waters along the coast. The initially planned course of 210°True (after leaving the traffic separation scheme outside New York harbor) was modified in pencil to about 207° (all courses are given in degrees True).

Longshoremen were ordered for late the next day (Saturday) in Baltimore.

Drafts on departure were 17'06" forward and 24'00" aft, as recorded in the Deck Log. The ship's fuel and ballast tanks were topped off. Prior to leaving port, and referring to the Stability Conditions Book and actual loading data, the Master calculated the vessel's metacentric height (GM) at 1.86 meters (6.1 feet), a condition he later described as "very good GM."

At 1517 (all times are Eastern Standard Time) on Friday, January 3, the ship left the dock with the docking pilot and Sandy Hook pilot aboard. The crew, supervised by the Bosun, began lashing/securing cargo and containers on deck at the #1,2 and 3 hatches and inside the #3 hold.

At 1600, the docking pilot disembarked, and the Sandy Hook pilot took control of the ship's maneuvering through the bay channels into deep water. As the ship left the harbor, the weather was described by the Master as "nice." The Master and pilot talked about the low pressure system coming up the coast, and the Master stated that he hoped he'd reach Cape Henlopen before the storm came through. During this time the ship was making about 6 knots, equal to the maximum speed of the pilot boat accompanying the ship out.

The Sandy Hook pilot, while walking between the port and starboard bridge wings, never saw any on-deck lashing activity while he was aboard. At 1740, he disembarked; by this time it was dark, and the crew had reported completing lashing of the cargo. The ship was one mile west of Ambrose Light, sailing on a course of about 180° T. and increasing speed to 12-14 knots; winds were about 20 knots from the east-northeast.

By 2000, at the beginning of the Third Mate's navigational watch, the weather as recorded in the Deck Log indicated barometer readings of 1018 millibars (mb), winds of 22-27 knots and seas at 12-18 feet, both from the northeast. Based on the ship's heading at the time, this put the weather about 45° abaft the beam (off the port quarter). The ship continued on its course of 180° until abeam of Barnegat, New Jersey at 2105, then set on a course of about 195°. (Note that the ship's course recorder was inoperative and turned off; courses described are based on charted positions and recollections of the ship's officers.)

By 2200, the crew reported that the weather had deteriorated substantially. The Master noted a drop in the barometer, and went up to the bridge. The Third Mate, still on watch at the time, noted the start of very bad weather by an entry in the Deck Log. Over the next two hours, the Master made several trips between his cabin and the bridge. The ship continued on a course of about 195°, with a speed between 11 13 knots.

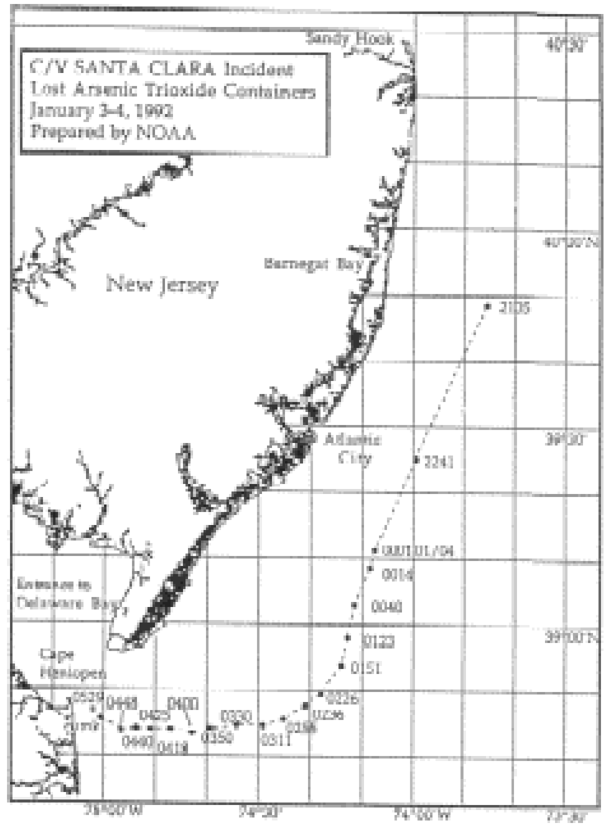
By 2400, the Master had noted a "big drop" in barometric pressure from 1018 to 1011 mb over four hours); and he had assumed the conn of the ship, with the Second Mate and helmsman assisting. The Second Mate, with one month experience aboard the SANTA CLARA I, plotted the ship's position, variously using radar, satellite or both. The Radio Officer meanwhile was obtaining and delivering to the Master frequent weather reports throughout the trip.

In heavy seas, the Master continued on an approximate heading of 195°,with the ship rolling heavily, pounding, surfing, and taking water on deck. He later expressed concern that he couldn't head further to starboard due to shallower water, and he couldn't turn to port for fear of losing the entire cargo or possibly the ship by getting caught in a trough. Several times he tried to slow down by adjusting propeller pitch, but claimed that he lost steering control at just under 11 knots (18 pitch). He kept the ship heading left of the planned trackline to stay away from shallow water near the shore and make a wider turn into Delaware Bay.

The weather continued to deteriorate, with the most severe ship motions noted between 0130-0230 on the morning of January 4th. At some point during this period, the wind and seas reportedly shifted from the port quarter to near the port beam, and rolling increased to an estimated 20-35° rolls by some accounts; the Chief Engineer reported one roll registering 35° on the bridge inclinometer. During the heaviest rolling, the Second Mate was knocked over and slid some 40 feet across the deck of the bridge, and several crewmembers reported being thrown out of their bunks. A 1500-pound spare piston broke loose from a bulkhead in the engineroom. The autopilot alarm began to sound frequently, indicating the ship was getting more than 10° off the desired course. Steering was switched to manual, and the Master ordered the helmsman to "steer easy" and not to use too much rudder.

Sometime shortly after 0151, as the ship was being battered by winds and seas off the port side and was approaching the entrance to Delaware Bay, just due east of Cape Henlopen, the Master let the heading begin to fall off to starboard. Over the next 35 minutes, the course made good was 216°. About this time, the decklights were turned on to check the deck-stowed cargo, but rain and poor visibility prevented any observations.

At 0226, another fix was taken, after which the Master ordered a course change to about 240°toward the entrance to Delaware Bay. Weather was observed to be off the port beam. As the ship turned, the Master and 2nd Mate noted it began to ride more easily in the seas.



Ship's trackline approaching Delaware Bay

At 0400, the weather was again recorded in the Deck Log, noting estimated winds of 48-55 knots and seas over 45 feet, both from the east; the barometer indicated 1001 mb pressure.

At 0603, the Delaware Bay pilot was taken aboard at Cape Henlopen. During the boarding operation, two of the crewmembers were hit with water coming over the bulwark on the port side while working the pilot ladder near the #4 hatch. By this time, measured winds (as recorded by nearby data buoys) were over 40 knots and gusting to 50 knots from the east-northeast; seas had built to 19 feet (measured). When the pilot reached the bridge, he reported to the Master that a container was hanging over the port side bulwark at the #2 hatch.

The Chief Mate directed an inspection for damages, and found four containers, all damaged, remaining aboard on the #2 hatch - all adrift from their stowed positions. The Chief Mate also reported blue drums and white powder on the deck and hatch cover. The Master confirmed by visual observation of the drums (as labeled) that they contained Arsenic Trioxide, and by reference to the International Maritime Dangerous Goods (IMDG) Code that Arsenic Trioxide was poisonous. He ordered the Chief Mate to keep everyone off the deck forward of the house until the ship reached Baltimore.

At 1355, the Master sent a Radiogram telex message to the ship's agent in Baltimore advising them of cargo loss and storm damage, and requesting arrangements be made for cleanup of "dangerous good[s]" at the #2 Hatch.

The ship arrived at the pier in Baltimore at 1525 on January 4th. Over the next several hours, it was boarded by the Maryland Port Authority Police, Fire Department, Coast Guard, and various shipping company representatives. A cleanup contractor was hired, and cleanup of the #2 hatch began at 0020 on the 5th. Later that morning, shoreside workers removed the damaged containers off #2, and longshoremen began working cargo.

During the ship's port call in Baltimore, the crew inspected the cargo in each of the holds, resecuring cargo not scheduled for discharge in Baltimore. Several containers, trucks, and break-bulk packages below deck were found broken loose and damaged. In the #1 Upper Tween Deck (UTD), two pallets of Magnesium Phosphide were upset, with the drums and contents mixed with loose lumber and damaged cartons of wine. At least two other dangerous cargoes were similarly adrift in other holds.

Longshoremen in Baltimore discharged the drums of Magnesium Phosphide, including six still intact on pallets and four loose and broken drums. After discharging the drums, one longshoreman working a forklift in the #1 UTD noticed sparks as the rubber tires on the forklift spun on the gray, granular product on the deck. He promptly exited the hold, and one of the supervisors reported the situation to the shipping company's Port Captain, indicating he "had a problem."

No further cargo work was done in the #1 Upper Tween Deck in Baltimore. Over 800 pounds of Magnesium Phosphide remaining on the deck inside the hold was left, and no report of any hazardous condition was made to the Coast Guard. The ship left Baltimore at 0645 on January 6, reaching the pier in Charleston at 2220 January 7.

Containers at Hatch #2 on arrival in Baltimore (looking aft)

CARGO HAZARDS

Arsenic Trioxide (UN Number 1561) is a poisonous metal oxide that is used as an insecticide, herbicide, and wood preservative. It is a dense, white amorphous powder, slightly soluble in water, and corrosive to metals in the presence of moisture. The cargo presents a hazard by inhalation and by ingestion (with a lethal dosage of 5 mg/kg, equivalent to 2 aspirin-sized tablets for an adult). It is also a suspected human carcinogen.

Arsenic Trioxide is regulated under 49 CFR 171-180 and the International Maritime Dangerous Goods (IMDG) Code for carriage aboard vessels. Stowage is permitted “On Deck or Under Deck.”

Arsenic Trioxide is further designated a “marine pollutant” in the IMDG Code. Under MARPOL 73/78 (Annex III), such cargoes are to be “properly stowed and secured so as to minimize the hazards to the marine environment without impairing the safety of the ship and persons onboard.” While Annex III is optional for MARPOL 73/78 parties, U.S. regulations to implement these guidelines are in the proposed rule stage by the Research and Special Programs Administration (RSPA). The regulation would modify the stowage for Arsenic Trioxide by adding: “Where stowage is permitted ‘on deck or under deck’, under deck stowage is preferred except when a weather deck provides equivalent protection.”

A total of 25 containers of Arsenic Trioxide were loaded onboard, with six of those containers stowed on deck (over the #2 hatch cover). Each container was packed with 108 palletized drums of about 375 pounds each. During the storm, all six of the deck-stowed containers broke loose and opened up; four of these were lost overboard entirely, and a number of drums were spilled loose out on deck. Of the 648 total number of drums in deck stowed containers, 234 drums were recovered inside the two remaining containers or on deck in Baltimore.

Cleanup on deck was initiated in Baltimore on January 5 and was completed in Charleston on February 8, 1 992.

An assessment of the environmental hazard posed by the Arsenic drums on the ocean floor was prepared by the National Oceanic and Atmospheric Administration (NOM). In its assessment, NOM noted that absorption of the Arsenic by algae could be significant, but that Arsenic does not bioaccumulate up the food chain. Toxic effects on other marine life or birds outside the immediate vicinity were viewed as unlikely. While unbreached drums could remain essentially intact for years, dispersion of unconfined product would be expected over a period of a few days to a week. Higher risks were identified for the possibility of drums washing ashore or getting snagged in groundfishing gear, possibly contaminating a catch or exposing fishermen

On January 19, the Coast Guard initiated an underwater search for the lost containers. Using information from the Master regarding times (and associated positions) of heaviest rolling, and applying estimated drift, the search area was focused to the west of the ship’s 01510226 trackline. With remotely-operated vehicles (ROV’s) provided by EPA and the Navy Supervisor of Salvage, the field of containers and cargo was quickly located in the targeted search area. Three of the four Arsenic Trioxide containers were positively identified, although all three had opened and spilled at least some of their drums on the ocean floor. One large field of drums is thought to contain the cargo from the fourth Arsenic Trioxide container.

Recovery operations were initiated by the vessel owner on April 8, 1992.

Magnesium Phosphide (UN Number 2011) is used as a fumigant. It is shipped as a gray, granular powder, which reacts violently with water producing phosphine gas. The gas is highly poisonous and flammable. When the concentration of phosphine gas reaches a concentration of 1.8% by volume (18,000 ppm), it will spontaneously combust or explode.

Magnesium Phosphide is also regulated under 49 CFR and the IMDG Code for carriage aboard vessels, with stowage permitted “On Deck or Under Deck.” It is required to be labeled both “Poison” and “Dangerous When Wet.”

Sample labels of dangerous cargo

Although a regulated dangerous cargo, the Magnesium Phosphide was not listed on the ship’s Dangerous Cargo Manifest (DCM) as required by 49 CFR and the IMDG Code. And while clearly and properly labeled, it was not identified on the shipping papers (the precursor to the DCM) as a dangerous cargo.

Five pallets banded with two drums each were stowed in the #1 Upper Tween Deck, each drum containing about 396 pounds of product. Four of these drums were broken open, spilling product onto the deck inside the hold, mixing with loose lumber and broken cartons of wine.

Sometime after the storm, several crewmembers entered the enclosed #1 UTD to resecure cargo. Two crewmen became dizzy and one vomited - a typical reaction from phosphine gas exposure however neither reported to the ship’s medical officer or to the Master. At least four crewmembers including the Chief Mate observed the drums spilled in the #1 hold, but none recalled any hazard labels. Two of these crewmembers stated that they knew nothing about dangerous cargo labels - they relied completely on the Bosun for direction. The Bosun was familiar with dangerous cargo labeling, but pointed out that his ability to interpret them was limited; when he sees “pictures, it’s a good indication of a problem,” but if it’s written in English he “can’t read it.” In Baltimore, a cargo surveyor hired by the shipowner took photographs of the spilled drums of Magnesium Phosphide and other damaged hazardous cargoes below deck; nobody reported the hazardous condition to the Master or to the Coast Guard Captain of the Port (COTP) as required by 49 CFR Parts 171 and 176

Magnesium Phosphide drums spilled in #1 hold

In the port of Charleston, 37 longshoremen were sent to the hospital for observation and released, after exposure to Magnesium Phosphide in the #1 hold on January 8. Subsequent Draeger readings showed phosphine levels up to 400 ppm, twice the level “immediately dangerous to life and health (IDLH), based on NIOSH guidelines.

On January 8, the Coast Guard COTP Charleston ordered the ship evacuated, and later to anchor (with a skeleton crew) in Charleston harbor for response/ cleanup. With continuous mechanical ventilation of the hold, cleanup crews spent the next several weeks in a delicate operation of alternating dry- then wet deactivation of product, a single pound of material at a time. Cleanup was completed on February 6, with a total of 866 pounds recovered and deactivated.

ANALYSIS

Context

A striking aspect of this case is that it covers little territory previously unexplored. Container losses at sea have been reported since the early years of containerization over 30 years ago, and have been the subject of many detailed analyses and technical papers. The series of failures aboard the SANTA CLARA I repeat patterns seen before, and reflect fairly well understood processes. What makes this case unusual is the broad combination of failures all seen in one case, and especially its environmental visibility - certain cargo happened to be hazardous, and it posed a potentially serious threat to U.S. coasts and ports.

Development of standards over the years has been an iterative process, in each case refining the approximations used in calculating forces and design criteria. Classification societies began developing rules for the securing of containers onboard ships in 1973, and today all of the major classification societies have published rules. In 1981, IMO published guidelines to increase the standard of stowage and securing onboard noncellular container ships. Those guidelines as well as many other studies and texts provide a range of operating guidelines to avoid damage to deck-stowed cargo.

However, with all the developments of the past 30 years, the industry still lacks a standard approach to the securing of containers aboard ship. Each set of rules generates slightly different results. Classification Society certification of cargo securing systems remains optional, and evidently no government has issued regulations for cargo securing. Where nonstandard containers or special equipment are stowed together with standard intermodal cargo, securing systems are often improvised.

Containerships are particularly sensitive to heavy weather, and damage has been found to occur more frequently on ships designed as break-bulk vessels carrying containers on hatch covers (as the SANTA CLARA I does). Surveys often point to heavy rolling, in combination with green water on deck, as a common element in container losses. In the North Atlantic, the stormy winter months typically foster the greatest number of containerized cargo losses.

Nevertheless, most container losses aboard ship have been attributed to inadequate lashing, where securing systems are inadequate to withstand the static and dynamic loads imposed upon them. The stow may be also be undermined by inadequacies in securing the cargo inside the containers, or even by structural weaknesses or damage to the containers themselves.

The SANTA CLARA I presents a large menu of deficiencies, many combinations of which might have led to a catastrophic failure of the stow. The Board’s analysis, in most areas, pinpoints the contribution of these various deficiencies and establishes their probable role in the casualty scenario.

Stability Conditions

One of the first tears in the safety fabric was in the loading of cargo and fuel aboard the ship in Port Elizabeth. The stability of the ship was essentially misunderstood and mismanaged.

The stability characteristics of a ship fall within a range predetermined by hull design and center of gravity of the unladen vessel. Within this range, the stability conditions for any given voyage are determined principally by variables of cargo loading, fuel and ballast. The most significant factor - metacentric height (GM) - determines the ability of the ship to right itself and the overall “stiffness” of the ship, or its natural roll period.

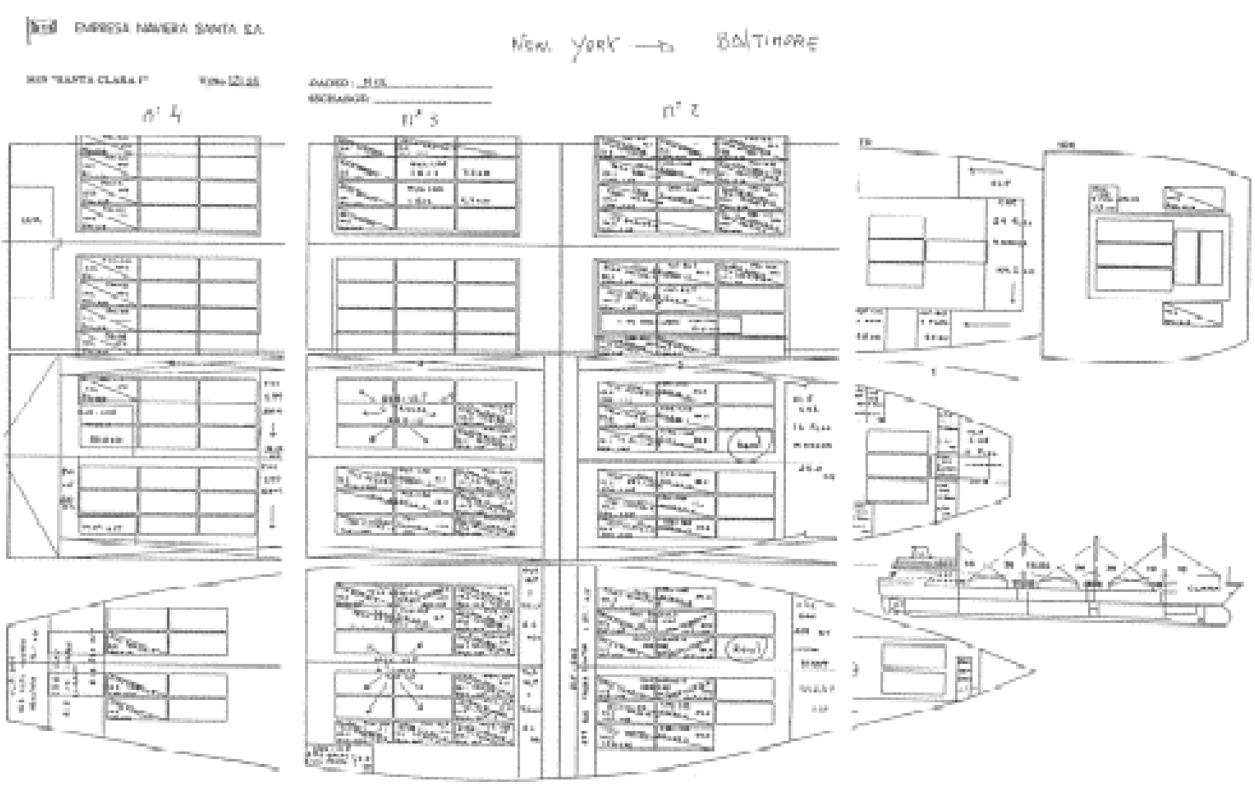
In general, higher values of GM indicate a vessel has greater tendency to remain upright, and is therefore considered to be more stable. However, when the vessel is somehow displaced from its upright position of equilibrium, excessive values of GM tend to increase the forces and accelerations that cause the vessel to return to the equilibrium position. This reduces the roll period and tends to result in “snappier” rolls. In addition to making the ship uncomfortable for the crew, these severe motions increase the forces on the cargo and cargo securing gear.

The industry widely acknowledges that containerships should be operated with the lowest GM *consistent with safety requirements.* Studies from as early as 1970 have recommended reducing GM to below 2 feet as one method of reducing container losses and damages. IMO cautions against “undue GM” to avoid the hazard of excessive accelerations, and seasoned deck officers acknowledge and validate the general approach.

A minimum GM (or GM-curve for various loading and operating conditions) is commonly established from formulae in regulation, as it is for U.S. flag vessels in 46 CFR 170.170. However, in the case of the SANTA CLARA I, such values were unavailable. By applying the formula from U.S. regulations to this ship, a rough benchmark of 0.444 meters (or 1.5 feet) minimum-GM was derived for the given departure condition.

The Master of the SANTA CLARA I calculated the GM to be 1.86 meters (6.1 feet) upon the vessel’s departure from Port Elizabeth. Subsequent review of those calculations by the Coast Guard Marine Safety Center (MSC) showed minor errors, but their result of 1.87 meters closely agrees with the Master’s calculations.

While a GM of 1.87 meters is not uncommon in the operation of larger ships, it is 21/2-6 times the value associated with sample loading conditions for containerized cargo (with deck stowage) as given in the stability book for the SANTA CLARA I.



Cargo Stowage Plan – New York to Baltimore

Using curves in the stability book, MSC determined that this higher GM would have reduced the ship's roll period from the range of 22 to 30 seconds (for the sample conditions) to 12 seconds (+ ½ second).

The management of GM is basic to everyday ship operations, predetermining how the ship will react at sea - a key responsibility of the Master. It can be controlled with good planning prior to loading the ship, or reduced after-the-fact by restowing cargo or deballasting to raise the center of gravity. The Board found no evidence that the preliminary loading plan, prepared even before the ship's arrival in Port Elizabeth, was changed to minimize or correct the vessel's GM before loading or departure.

The Master's characterization of a GM of 1.86 meters as "very good GM", and his departure from Port Elizabeth in that condition, are consistent with his larger vessel (tankship) experience, but are inconsistent with the requirements for smaller container-carrying vessels such as the SANTA CLARA I, on which he had served for just four days.

In view of the weather expectations, the Board's judgment is that the ship left Port Elizabeth with unsuitable stability for the carriage of containers on deck, setting the stage for higher exciting forces from wave action in rough weather.

Weather Conditions

Severe weather has been claimed by some as the sole cause of the casualty. The ship's officers and crew cited near hurricane conditions, the heaviest weather many had encountered in their careers, with the possibility of a giant wave dislodging the cargo. The conclusion is tempting, but unsupportable. Weather forecasts in fact projected winds up to 60 knots with heavy seas, but onscene conditions clearly didn't approach this level until several hours after the SANTA CLARA I lost its cargo overboard.

The route from New York to Delaware Bay is well-traveled by shipping, and extensively monitored through data buoys, light stations, and satellite. One major data buoy in particular (#44012) was situated less than 15 miles from the ship's position at the time of the cargo loss, near the entrance to Delaware Bay. A second data buoy (#44009) was located just 40 miles south of that buoy; a third was positioned just off Sandy Hook at the northern end of the ship's trackline on this voyage. Additional data buoys were located along and near the storm's trackline.

Weather conditions reported by the ship's crew during the transit described deteriorating weather, with the worst conditions noted between 0130-0230. The crew reported winds up to 50 knots and seas variously up to 20-25 feet (over 45 feet according to the Second Mate) both from the northeast, changing to easterly at about 0200. The seas were also described by the Master and Second Mate as strong waves with short periods, sometimes "confused . "

Observations by the pilots at either end of the offshore route roughly parallel the crew's observations. The Sandy Hook pilot noted easterly winds of 10-20 knots and seas of 3-4 feet as he took the vessel out of the harbor from Port Elizabeth. The Delaware Bay pilot estimated winds up to 80 knots by the time the ship reached Cape Henlopen.

Measurements from weather buoy and light station data, on the other hand, show more conservative values.

By 0200 on January 4th - roughly the point of cargo loss - measured winds along the ship's trackline had gradually increased from 20 to about 34 knots (gusting to 41 knots); seas had increased from 7 to 14 feet; and wind direction had rotated to the left (counterclockwise, opposite the directional shift observed aboard the ship). The dominant wave period lengthened from about 5 seconds at the outset of the trip to a fairly steady

10-11 seconds by 2000 on the 3rd, six hours before the cargo loss.

WEATHER BUOY DATA JANUARY 3-4, 1992

Time	Barom. (mb)	-----Wind------ Dir	Spd	Gust	---Wave--- Ht	Period
1200	1017.7	091	22.4	26.6	6.6	7.7
1300	1016.4	086	22.6	27.4	6.9	8.3
1400	1015.6	089	24.8	28.4	7.2	8.3
1500	1015.3	086	22.6	26.8	7.5	8.3
1600	1014.8	082	25.2	29.2	8.2	8.3
1700	1014.2	076	25.2	29.6	8.2	9.1
1800	1013.6	074	26.6	31.4	8.9	9.1
1900	1013.3	072	27.0	32.2	9.2	9.1
2000	1013.0	071	27.2	33.4	9.8	9.1
2100	1012.0	071	20.6	33.2	10.5	9.1
2200	1011.6	071	27.4	33.2	11.5	10.0
2300	1010.4	070	27.2	32.2	11.5	10.0
2400	1008.9	070	29.0	34.4	12.8	10.0
0100	1007.4	058	30.0	36.8	15.1	11.1
*0200	1005.2	054	34.4	40.6	13.5	10.0
0300	1002.8	051	39.4	46.8	15.1	10.0
0400	1000.2	052	40.8	52.0	16.7	11.1
0500	998.8	055	40.8	52.0	16.7	11.1
0600	997.5	058	39.4	52.2	19.4	12.5
0700	997.6	063	37.0	45.0	24.0	12.5
0800	998.1	061	31.8	44.6	26.9	14.3
0900	999.3	076	29.8	35.4	27.9	14.3

Measurements from Data Buoy #44012
t0200 is approx. time of cargo loss)

The disparities between crew observations and data buoy records are common.

Instrumented measurements from data buoys come with a discrete and well documented margin of error. Data buoys provide wind speed accuracy within 2 knots or 10% (whichever is greater), wind direction within 10°, significant wave height within 0.7 feet or 5% (whichever is greater), and wave period within 1 second. The proximity of data buoys to the ship's trackline and position where the cargo was lost overboard, and the correlation between several stations, afford a high degree of reliability for determining actual weather conditions encountered by the ship.

Estimates from human observation on the other hand, are inherently inaccurate, and are further influenced by the location of the observer (on the bridge, furthest from the axis of the ship's motions and therefore subject to the greatest extremes of motion). In heavy weather, it is generally acknowledged to be quite difficult to judge the height of waves from a ship because of the severe heaving and rolling encountered. Looking up at a 14 foot wave from the bottom of a 35° roll can be considerably misleading. General weather conditions can also be magnified under certain resonant, or synchronous, conditions between ship and seas (as discussed further under Navigation and Shiphandling). Apparent winds are amplified by an increased airflow over and around the ship.

The crew's observations are further difficult to pinpoint in time. Measured conditions actually were fairly severe, but didn't peak until about 3-6 hours after loss of the cargo; crew recollections tend to blur this distinction. And finally, the consequences of the weather in this case - a loss of cargo with a high level of attention from the authorities - would be expected to exaggerate their recollections.

The Board places the greatest confidence in the more scientific sources of data.

Based on the evidence, the Board's judgment is that the actual onscene weather at the time of the cargo loss was less severe than reported by the crew. However, one key factor - wave period in combination with other stability and shiphandling factors, may have presented an inordinately severe response of the ship in moderately heavy seas. This issue is addressed in detail under Navigation and Shiphandling.

Tracking the Storm

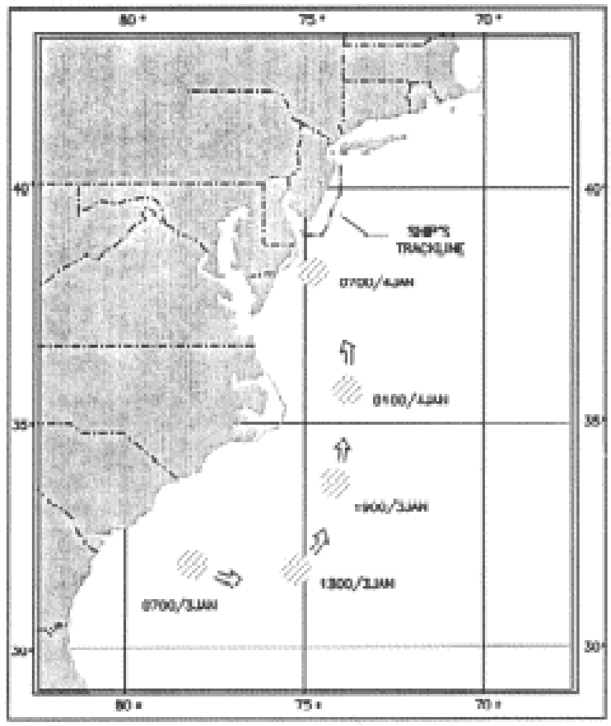
During interviews several weeks after the incident, the Master's reconstruction of the weather reports focused on a low pressure area he recalled south of Cape Hatteras, moving north at 10 knots, with forecast winds of about 20 knots (maximum) and 10-12 foot seas in the area of transit. In assessing the actual weather in retrospect, the Master believed that the low pressure area never went north from Cape Hatteras, but went northeast first. He speculated that the ship got caught between the low from the south and a high in the New York area.

Weather forecasts issued by the National Weather Service in Washington, D.C. for Offshore Waters (Beyond 20 NM Offshore) and for the High Seas (North Atlantic) were relevant to the case and were available onboard the ship.

The Offshore Waters Forecast included a storm warning for the area of transit from as early as 2230 on Thursday, January 2, 1992. That forecast identified a storm moving through the Cape Hatteras area (about 150 miles south of the entrance to Delaware Bay) by Saturday morning January 4, and projected northeast winds increasing to 45 to 55 knots and seas 15 to 20 feet in the area of the ship's transit by Friday night, January 3. Storm warnings were repeated in the forecasts issued at 1039, 1535, and 2300 on January 3, and at 0330 on January 4.

The High Seas Forecast at 2300 on January 2 warned of a storm at 37N075W (105 miles south of the entrance to Delaware Bay) with the most severe weather (winds up to 40-60 knots and seas from 22-35 feet) within 400 nautical miles (NM) in the NE quadrant. As subsequent forecasts throughout the day of January 3rd updated the position of the storm center, they consistently put the ship within range and in or near the most dangerous quadrant of this storm; they also repeated estimates of winds up to 60 knots and seas from 18-28 feet. The 1100 forecast highlighted a "Dangerous Storm to Marine Interests Developing."

High Seas forecasts beginning at 2300 on January 3 tracked the actual position and movement of what was now being described as a "complex dangerous storm." Plotted at 1900, the storm was centered about 360 miles south of the ship's position off the New Jersey coast. Five hours later at 0100 on January 4, the storm was centered about 180 miles SSE of the ship's position near the entrance to Delaware Bay.



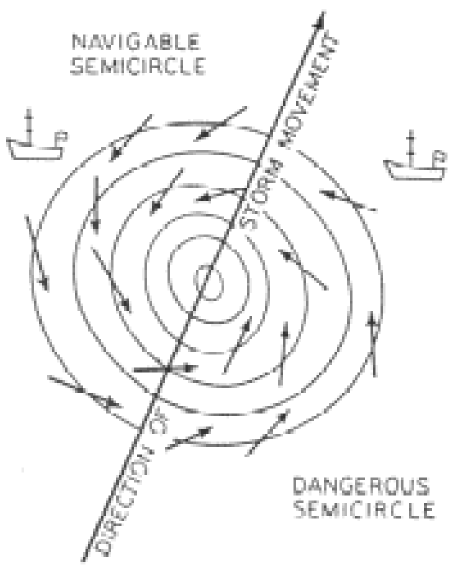
Actual storm track from satellite data

On the Atlantic coast, the most favored region for low-pressure, or cyclone, development is the Virginia Coast. Often called "Hatteras storms," these are frequently very intense. They tend to move northeasterly along the Gulf Stream, averaging about 30 miles per hour during winter months, although speed of storm movement is unpredictable and especially variable north of 30° N. latitude. Sudden accelerations up to 70 knots have been noted.

Tracking a storm, especially a dangerous one, requires careful assessment of forecasts, coupled with key weather readings and a good knowledge of storm behavior. During questioning, the Master was able to furnish little information regarding the storm's position, strength, or direction of movement. However, a number of tools and indicators are typically available.

Cyclones are marked by a steady decrease in barometric pressure from the periphery to a minimum at the center, with winds spiralling inward from all sides (counterclockwise in the northern hemisphere). The winds angle in anywhere from 20-30° all the way from the outer limits of the storm circulation up to the wall of the eye. The angle diminishes approaching the eye, and the winds blow stronger. Swells build ahead of the storm, characteristically lengthening in period from the normal 4-6 second interval to as much as 15-30 seconds. Rainfall is typically heavy.

The strongest winds occur to the right of the direction of storm movement. On the right side the forward motion of the storm is added to the observed wind velocity, and on the left side it is subtracted. For the mariner, these define the dangerous semicircle and navigable semicircle, respectively



Wind directions in a cyclonic storm

When a master is forewarned of the approach of a cyclonic storm, he must determine the location of the center and the estimated track of the storm, the proximity of his vessel to land or shoal water, and whether his vessel will be in the dangerous or navigable semicircle. An early decision allows him to use all necessary speed to gain the safest possible geographic position before the storm is upon him.

Key indicators include barometric pressure, and changes in wind speed and direction. A drop in pressure of 3-4 millibars over a period of 3-6 hours is significant, as is an increase in wind speed of 25% or more, in signalling the approach of the cyclone. Observations aboard the SANTA CLARA I noted a pressure drop of 7 mb over just four hours by 2400 on January 3, and substantially increasing winds - clear indicators of a storm's approach.

Furthermore, if the wind gradually veers to the right (clockwise) the ship is in the dangerous semicircle; if it shifts to the left, the ship is in the safe or navigable semicircle. While observations aboard the ship suggest a clockwise shift, relative wind was never plotted, and observations apparently took no account of significant changes in vessel course, speed and heading. A relative motion plot would have shown an actual counterclockwise (left) shift in the wind during the earliest hours of January 4, putting the ship in the navigable semicircle of the storm.

Radar offers another useful tool for tracking a storm. Even if the eye is out of range, the spiral bands may indicate its direction from the vessel. However, there is no indication the SANTA CLARA I used radar to track the storm, and in fact the Delaware Bay pilot found the quality of the radar image poor and even "useless."

While good tracking would have clarified the ship's position in the navigable - or safer - semicircle of the storm, it also would have provided the Master with a more clear picture of the forces acting on his ship and the options available to him in avoiding or riding out the storm.

The Master's reconstruction of forecasts shows possible misinterpretation, but his expressed concern at Port Elizabeth suggests he reasonably anticipated bad weather near the order of magnitude he reported encountering.

Overall, the Board's assessment is that the weather forecasts were timely, clear and an accurate portrayal of the weather in the geographic area. However, the storm tracking aboard the SANTA CLARA I was inexact - merely qualitativeand inadequate for making good navigational decisions.

Navigation and Shiphandling

Despite the relatively low intensity of the storm conditions onscene, the weather can be substantially amplified by situational factors.

In approaching a cyclonic storm, two objectives are foremost in maneuvering the ship - avoiding the center (and particularly the dangerous semicircle) of the storm, and minimizing the severe and often complex ship motions from the winds and waves. Several standard texts provide operating guidelines and detailed analyses of the ship/sea interactions.

Given an observed wind direction, and established wind patterns in a cyclone, a course can be determined which will provide the greatest distance between the ship and the storm center in the least amount of time. Maximum speed on such a course is the recommended avoidance action. In this case, the only available course for avoidance was to return to port in New York; any other direction would close the range of the storm or put the ship aground.

Once in heavy weather, each type of ship reacts differently to the waves. According to its mass distribution and righting characteristics, each ship has a natural frequency in roll and pitch. A ship will tend to roll at this frequency under all conditions of wave motion. For the SANTA CLARA I, with the given loading conditions, this frequency was about 12 seconds.

Rolling will tend to be minimized when running with the sea or directly into it, although heading into the waves usually produces more violent pitching actions and pounding instead. Rolls are considerably increased when heading diagonally across the seas, and reach their largest angle when the sea is on the beam or the ship is “in the trough” of the waves. The athwartships inclination of the surface of the water is greatest in this orientation, so the amplitude of the force which is initiating the roll is at its maximum.

The most threatening roll condition exists when the period of the waves (more specifically the incident period) approximates the natural period of the ship, setting up a synchronism between them. Each wave as it passes will add its rolling impulse to the accumulated effect of those which have preceded it, and the ship will roll more deeply until reaching the maximum roll of which the ship is capable, finally limited only by the offsetting damping forces which build as the depth of roll increases. The ship will continue to roll to the maximum limit until something is done to break up the synchronism.

Synchronous rolling can be interrupted by changing the course or speed, thus changing the *apparent* period of the waves.

The conditions for synchronous rolling were clearly present during the ship’s voyage along the New Jersey coast. With a natural rolling period of about 12 seconds, and a dominant wave period of 10-1 1 seconds, just a small angle of headway away from the overtaking waves produces an exact correlation. Even an approximate correlation would have been enough to develop a cumulative effect over several successive waves. Synchronous rolling by itself may account for the extremes of ship motion reported by the crew, even in the absence of the most severe weather.

A further effect when running at an angle to the seas is the tendency for the ship to align itself parallel to the trough, often “surfing” as the ship hangs on the crest of the wave, and yawing as unequal water pressures affect the bow and the rudder cyclically. The effects are most evident where shiplength is large compared to wavelength. Whereas a small boat might tend to simply rise and fall with the swells, a ship of substantial length such as the SANTA CLARA I (489 feet) would be expected to encounter more severe rotational and pounding forces with the given (computed) wavelength of 512-631 feet. The crew's accounts of "surfing" and difficulty holding a heading are certainly consistent with these conditions.

Shiphandling tactics in heavy weather are varied, and in selecting course and speed for the easiest riding, it is usually necessary to experiment before a completely satisfactory combination is found. Running slowly before the wind is usually the most gentle method of riding out a severe storm. An almost-universal rule: all other things being equal, the lower the speed at which the ship is run, the easier the ship will ride, and the less pounding will be a factor.

The speed of the SANTA CLARA I was somewhat troublesome in the analysis of this case. Given the beating the ship was taking in heavy seas, a speed of between 9.5-13 knots (for a ship with a maximum loaded speed of 16 knots) was certainly suspect. The Master repeatedly testified that he tried to slow down further, but found the ship fell to starboard rapidly below 18 pitch, equivalent to just under 11 knots in calm water, and he effectively lost steerinq control.

In view of the compound effects from the waves, the Board could not rule out the Master's explanation or his perceptions of loss of control, however it was noted that a further reduction below the 11-knot threshold was apparently not attempted. It may well have improved the overall handling of the ship, even lessening the synchronism with the incident waves.

However, a substantial speed reduction by itself would also increase the effective set of the ship into the shoal waters within a couple miles to starboard. Clearly the ship's position in relation to shallow water was a factor. A speed reduction in combination with a course change to port might be better, and would probably serve to further attenuate the synchronous rolling, but would also increase pitching and head the ship (albeit slowly) toward the storm center. The issue leaves the Board with some uncertainty; however, the fact that several of these options remained untested suggests some weakness in shiphandling.

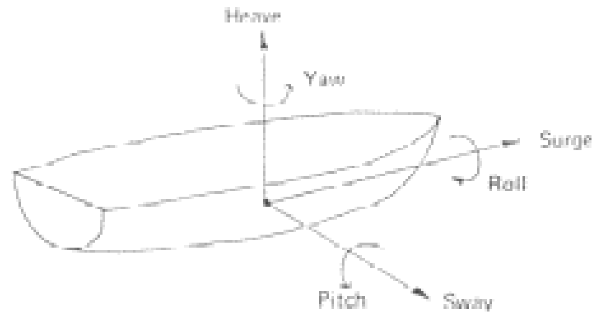
Given the violent behavior of the ship in heavy weather, the Master was asked (later) if he had considered turning back. He said that he felt it was too dangerous and he couldn't - any turn to starboard would put the ship into shoal waters; a turn to port would put him, at least for a short time, squarely into the trough where he risked losing the entire ship. Given the conditions, especially in view of the synchronous rolling, this may have been true by about midnight, or within a couple hours before the containers were lost over the side. But there certainly was a previous point in the journey when such preventive action could have been taken safely.

Finally, the Master was asked if he considered not leaving port - waiting in Port Elizabeth for better weather. His reply: "We are sailors - we go to sea." Significantly, this disposition was echoed by other respected, professional mariners. Once at sea, a reasonable, explainable delay would be acceptable to protect the ship and cargo. But the prevailing expectation is that a commercial ship will get underway.

Up-front, the critical action for the Master is to track the storm and take sufficiently early action to position the ship where he can be free to reduce speed once the center of the storm is near him. Clearly, the position of the SANTA CLARA I by the time heavy weather was upon it left more limited options. The Master didn't use all the tools available to him for tracking the storm, and apparently didn't recognize the point at which he needed to take decisive action. And once the ship began reacting severely in the weather, his shiphandling was inadequate.

In the Board's judgment, the Master's inexperience aboard this particular ship played a role. He overestimated his ability to react to increasingly severe conditions, and probably misunderstood some of the interactions between this ship and the seas, particularly synchronous rolling and the control of ship's speed.

The pressures to meet the schedule in Baltimore may have biased navigational decisions, particularly at the earlier stages of the voyage.



Basic motions of a ship in a seaway

Forces Affecting Ship and Cargo

Given a fairly severe response of the ship in heavy weather, an important question arises: Did the forces exceed design conditions?

The general subject has been exhaustively studied over the past 20 years, as the design of restraint systems requires a coherent picture of these forces as a starting point. Classification societies began to publish rules as early as 1973 (Germanischer-Lloyd), however the SANTA CLARA I (built in 1974 and classed by LLoyd's Register) has not been surveyed or certified for its container restraint system. (Certification has always been optional.)

The problem is also complex, requiring a large number of assumptions and approximations for each individual ship. A variety of methods have evolved. In a 1983 study for the Maritime Administration, C.R. Cushing identified and compared six analytically different methods used by various classification societies and IMO, and found a range of results for any given ship.

A ship in a seaway is subjected to six basic motions - both linear and rotational in each of three dimensions.

Deck-stowed cargo is affected by both static and dynamic forces associated with these motions. It is affected first by gravity, which acts both normal to and across the deck as the ship is inclined in any direction; and second by inertial acceleration from the motion itself. As a practical matter, the gravity component is significantly larger than the acceleration component, although both effects add together at the point of maximum pitch or roll. The force of the wind is added where applicable. Deck-stowed cargo, especially the furthest outboard and nearest the ends of the ship, is most vulnerable.

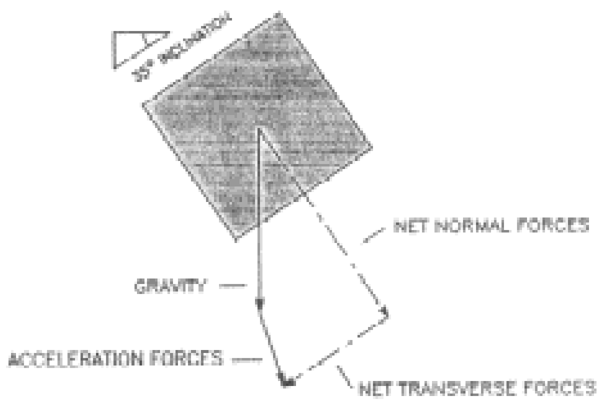
The forces acting on a unit of cargo at any given moment equal the 3-dimensional vector sum of all the static and dynamic forces combined.

The variations in ship characteristics, loading conditions, weather, and shiphandling preclude any exact projection of maximum forces for design use. The variety of calculation methods used by different classification societies reflects this to some extent. However, some common threads do exist. Design typically aims at winds up to 80 knots, and wave height with an encounter probability of 1:100 million (once every 20 years of continuous operation in the N. Atlantic). These clearly were not approached in this case.

Calculations also generally assume the usual loading conditions which would produce the largest forces; and target the container which would be subject to the most severe of those forces. Most methods further assume a maximum roll angle of 30°. The casualty conditions for the SANTA CLARA I span the range in some of these factors. GM and maximum roll angle may have exceeded the values for the design condition.

For comparative purposes, the Board reconstructed the design and casualty conditions using Lloyd's Register rules (1984). Both conditions targeted the containers on the #2 hatch, the forwardmost hatch fitted for the carriage of containers.

In the design condition, the projected maximum transverse (across-the-deck) force was 25.1 metric tons for a fully loaded (30-ton) container on top of the outboard stack. Normal-to-deck forces ranged from about 12 tons (at the top of a roll) to a just over 48 tons (at the bottom).



Forces shown as vectors

The same formula with inputs from the casualty condition generates a maximum transverse force of 21.1 tons, and normal forces ranging from almost 10 tons to a little over 38 tons. In this case, the critical container was one loaded to 24.3 tons - situated on top of the stack second from outboard on the port side.

	Design Condition	Casualty Condition
Transverse	25.1	21.1
Normal (top of roll)	12.1	9.6
Normal (bottom of roll)	48.7	38.5

Comparison of force computations

While certain design factors such as roll angle and GM may have been exceeded in the casualty condition, substantially lower values for other factors (such as container weight and wind speed) are offsetting. The net result is that all force values in the departure condition were within the bounds of the design condition.

Similar comparative results (though varying in magnitude) were obtained with several other methods from other classification societies.

There are, of course, a number of other variables which may impose additional forces acting on the containers - from structural weaknesses of the containers themselves, loose cargo inside the containers, additive force from adjacent containers inadequately lashed, pretensioning in the lashings, and shock loads from slack in the lashings. None of these factors are addressed specifically in any of the methods for calculating forces, but all of the methods apply a design safety factor to account generally for such unanticipated forces as well as for various possible weaknesses in the restraint system. In particular, Lloyd's uses a safety factor of 3 for wire lashings.

A higher level of uncertainty is introduced with the force of green water on deck - a powerful and highly variable factor. Lloyd's rules account for this to some extent by applying a 20% multiplier for the forces on deck-stowed cargo in the forward ¼-length; but it's widely recognized that boarding seas can cause major cargo damage.

Given the departure drafts and trim of the SANTA CLARA I, the top edge of the #2 hatch would be submerged in calm water at a roll angle of just over 40°. In seas, the angle would vary with the wave profile along the side of the ship. Given the moderate seas, the elevation of the containers above the top of the bulwark, the questionable roll angles experienced, and the poor visibility, the influence of green water on the deck-stowed cargo in this case is uncertain, but probably small.

Overall, the forces affecting the deck stowed cargo were probably very high, even closely approaching the extremes of the design conditions. The principal contributor to these high forces was GM both directly (increasing acceleration forces) and indirectly (increasing roll angle in resonance with the seas). In fact, the excess GM may have accounted for up to 23% of the forces acting on the cargo.

The variability of results across different force calculation methods cannot be fully resolved. Without following each completely through to a calculation of lashing requirements (a substantial effort), the Board was unable to assess the real net differences. Furthermore, there is some inherent guesswork in any of the methods which will inevitably pose a challenge to comparative evaluations.

The simple absence of any analysis and documentation for the SANTA CLARA I is more to the point. Over the years, several IMO guidelines have addressed the issue. As recently as November 1991, IMO Resolution A.714(17) consolidated and codified the recommendations that container-carrying ships have a Cargo Securing Manual - to include, among other things, an analysis of force factors used in the design of the container restraint system. By carrying such a manual aboard, key assumptions (like GM) are made available for use by the Master and crew, helping to avoid outlying conditions under which the restraint system may not hold.

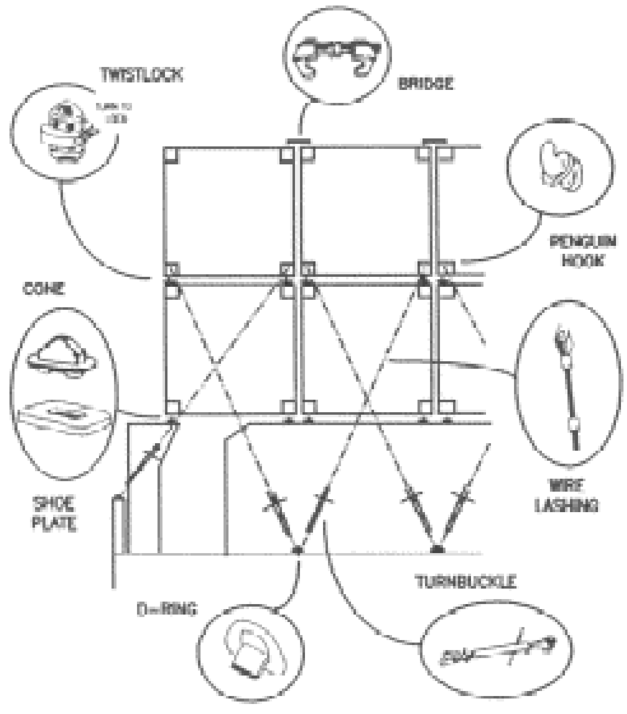
Without defined boundaries for operation, the SANTA CLARA I was inevitably exposed to increased risk.

Container Securing

On the SANTA CLARA I, containers are supported on the hatch covers and outboard on elevated deck pedestals. Each hatch is arranged to accommodate eight stacks of 40-foot containers and another eight stacks of 20-foot containers, all stowed longitudinally.

Extra deck fittings are provided to stow two 20-foot containers in place of any 40-foot container. Although designed for stacks up to three-high, the ship never carries more than two-high.

The ship is fitted with a basic stack-lash system, dating to initial construction of the ship and extended with the retrofit of deck pedestals.



Stack-lash restraint system
SANTA CLARA I

Components of the securing system include:

* *Flat shoe-plates* are fitted on the hatch covers and pedestals

* *Cones* are set in place in the recess of the shoe plates

* *The bottom tier of containers* is placed on the cones, which fit up into the corner fittings of the container

* *Twistlocks* are fitted between the bottom and second tier

* *Bridges* are fitted athwartships at the tops of adjacent container stacks

* *Penguin hooks* are fitted into the bottom corner fittings of the top container, or (in the case of a 1-high stack) the top corner of a single container

* *Wire Lashings,* with press-fitted stoppers every few feet and eyes at either end, are fitted over the penguin hooks and run diagonally down toward the deck

* *Turnbuckles* tie the lashings to *D-rings* on deck (or on the hatch covers or pedestals), providing tension control for the lashings

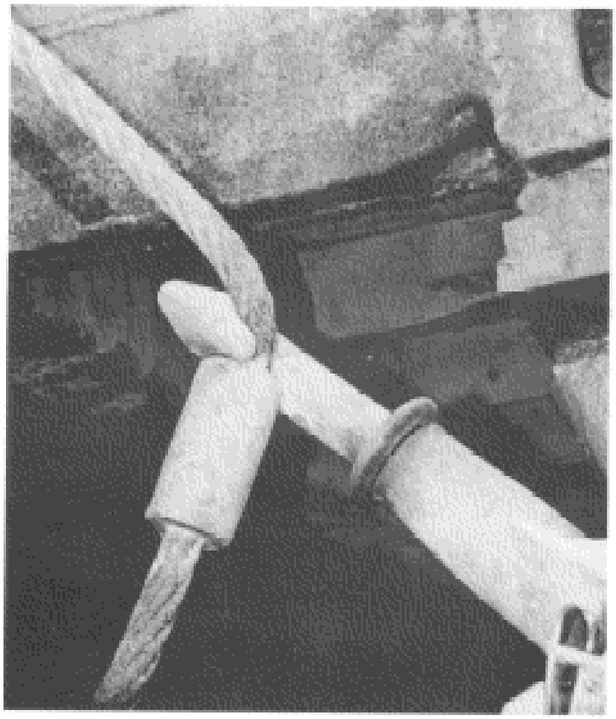
The parts of the restraint system acting together work to transmit the forces on the cargo into the ship's structure. Achieving that aim depends on a variety of factors, including the strength and elasticity of the components (and the containers), fit tolerances, and proper installation. Without benefit of shipboard documentation or detailed analysis, the system components were evaluated in context of Lloyd's recommendations and general industry design standards. Overall, most components appeared to represent standard and sturdy construction, with ample load capacities under tension and shear.

The system breaks down in the onboard application by the crew. Without a Cargo Securing Manual, stowage and securing were done based on crew experience; none had ever had any specific formal training in the subject. Despite an apparently well-designed system dating from the ship's initial construction in 1973, the installed system in 1992 reflected an increasing mismatch between parts and improvised installation.

The most obvious irregularity was a mismatch between turnbuckles and the wire lashings. The press-fitted lashings are designed for use with cylindrical claw fittings on the turnbuckles, which take a straight, even strain on the wire; about half of the turnbuckles onboard were this type. But an approximately equal number of turnbuckles were fitted with a rigid hook at the working end. Installed on the lashings, they result in a severe bend of about 75 degrees and a seriously unbalanced strain on the wire, effectively reducing its cross-section. The bearing surface is also significantly reduced, presenting the potential for a slackened wire to jump out of the hook. The Board observed both types of turnbuckles in use on the #3 hatch, and photos showed similar installation on the #4 hatch in Baltimore shortly after the casualty.

Two types of turnbuckles onboard SANTA CLARA I
(cylindrical claw on left; rigid hook on right)

Both types in use

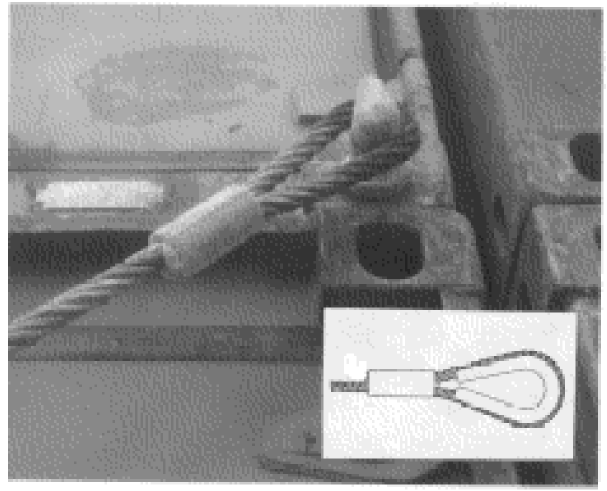


Hook-type turnbuckle with strain on lashing

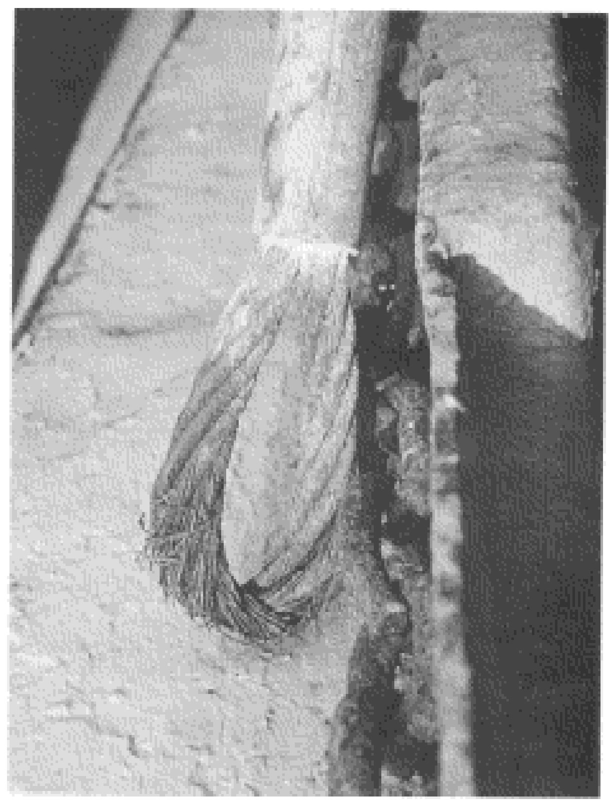
The strength reduction resulting from the mismatch is compounded by the actual damage already evident in the lashings. The lashing in the photo, for example, was corroded in way of the bend, with broken strands on the outside of the bend, the point of greatest load.

Indiscriminate installation methods extended to the orientation of the lashings as well, about half of which (apparently at random) were found inverted. While fitted with eyes at both ends, only one end incorporated a rope thimble (standard marine practice to maintain rope strength and reduce wear). Where the “soft eyes” (those without thimbles) were fitted over the penguin hooks, the wire was pulled to a tight radius of about one inch. Connection efficiency would be expected to be reduced by as much as 10% as the rope flattens under load.

Actual damage was again evident, as the Board found several loose lashings on deck showing permanent deformation and broken strands at the unreinforced eye.



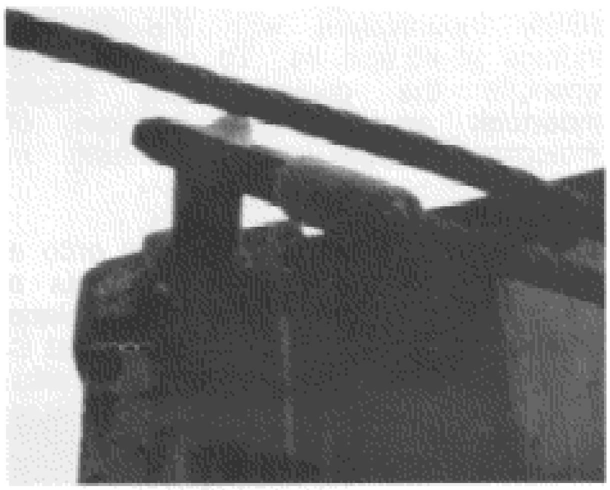
Unreinforced eye over penguin hook
(Inset - with thimble)



Damaged eye

Another potential failure point was found in the pairing of penguin hooks with wire lashings. Although this was the standard configuration aboard the SANTA CLARA I, penguin hooks are more commonly seen with rod-type lashings. The mismatch is subtle, but again evident in the actual onboard installation.

By design, penguin hooks are fitted into the container corner castings simply by turning them in place. The degree of turn is part of the problem; the flexibility of the lashings is the other part. As installed aboard the SANTA CLARA 1, some hooks were observed to be turned at a substantial angle to the axis of the lashing, and in at least one case the lashing was also partially twisted, riding up on the projected hook and taking a bite a little above the elbow of the hook. With cyclic tensioning and slackening of the lashing, it's easy to conceive that it might either incrementally turn the penguin hooks or just fall off.

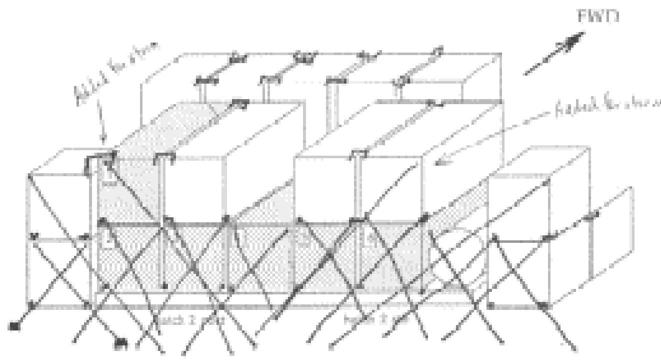


Twisted eye/hook connection

The possibility is lent support from photos of the #2 hatch shortly after the ship arrived in Baltimore. Several turnbuckles and lashings remained attached to the ship; four of the lashings were visible along their length and still threaded through the turnbuckles; all showed intact eyes. Given that the lashings were probably the weakest link (lowest breaking strength) in the system, the connection at the penguin hook emerges as the more likely failure point.

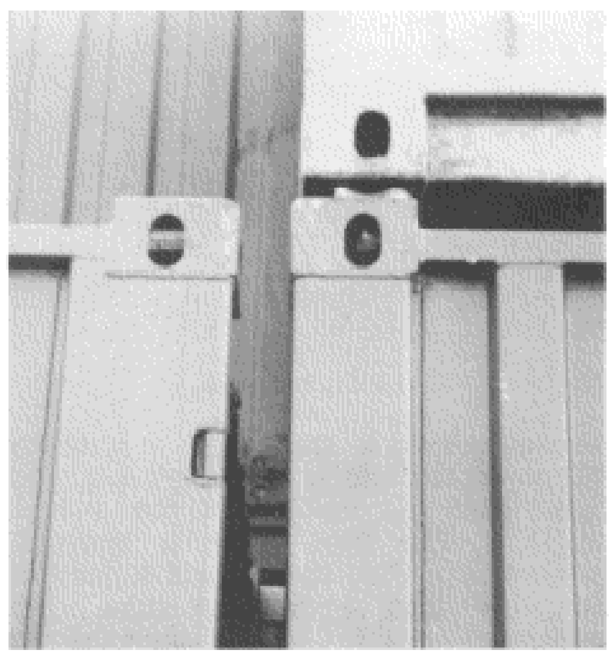
Apart from weaknesses associated with individual components, an examination of the overall lashing at the #2 hatch revealed stowage errors, a misunderstanding of securing mechanics, and a disquieting pattern of incomplete lashing.

During questioning, several of the crew sketched the lashing arrangements on #2 from memory. The sketches were remarkably consistent even in most minor details, showing a fairly standard "inside diagonal" lashing configuration, with four extra long lashings reportedly fitted for Heavy} weather



Lashing sketch by Bosun
(Arsenic trioxide containers are shaded)

An inherent weakness in this configuration is the stowage of 20-foot containers in the 40-foot spaces on both outboard sides. It leaves no room for lashing the abutting ends of the containers, which are separated by only about 3 inches. At the base they're resting on cones only. Essentially these containers are secured at one end only.



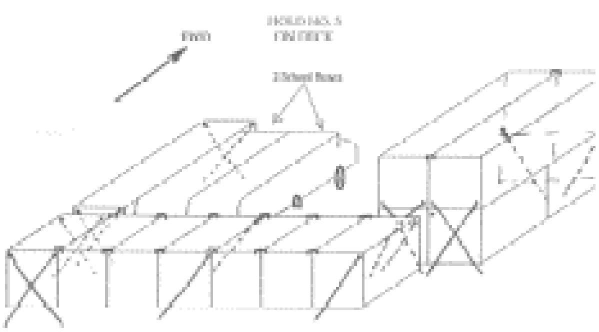
Typical spacing for 20' containers in 40' space

The longitudinal bridges as drawn between these 20-foot stacks, if they existed, would have been virtually ineffective in tying them together. In any event, the Board found no evidence that these longer-than-usual bridges were even available onboard the ship.

The long lashings drawn to the tops of the upper containers were described by the crew as "extra" for the heavy weather. However, without symmetric lashings on any given container, these long lashings (again - if actually installed) provide no support (half the time) as the ship rolled from side-to-side. They also would tend to build in an unbalanced racking tension into the containers themselves.

But strong evidence emerges that the crew most likely didn't finish the lashing at all.

A study of the lashing at the #3 hatch was most revealing. In Charleston, the containers on #3 were found fully-bridged but only partially-lashed. Photos from Baltimore show the exact same configuration, and none of the cargo had been worked or scheduled between the two ports.



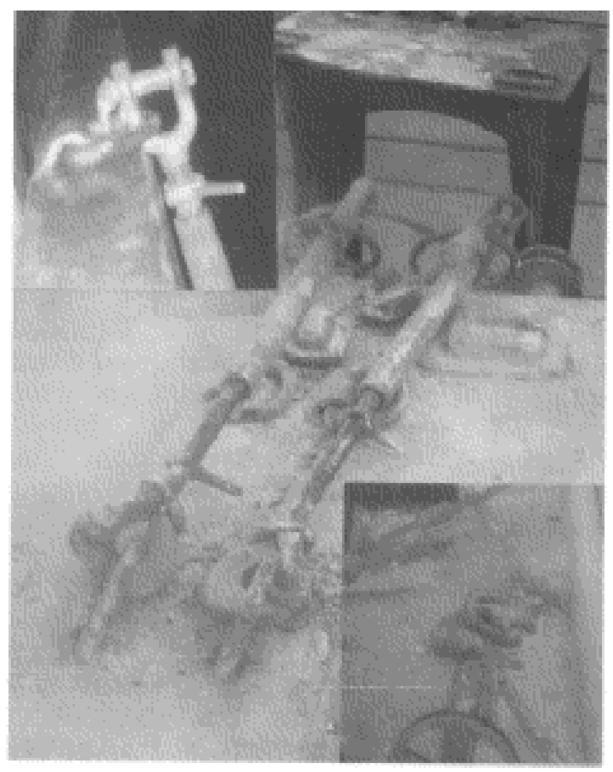
Lashings on #3 hatch

Two peculiarities stand out - a single lashing in the middle of the aft row, and more complete lashing of the 2-high stacks. But they have a common explanation: they both reflect a point of departure from a previous stow. As containers were added onboard in Baltimore, the "old" outboard lashings (in the middle of the aft row) were left in place, and the "new" outboard container (3 spaces to the right) was lashed. The lashing of the 2-high stacks simply reflected the methods of the shoreside lashing gang in Baltimore - again newly loaded cargo.

A photo of the #4 hatch in Baltimore repeats the pattern. Interior container stacks were left unlashed. Stevedores indicate the approach is not uncommon, and is generally determined - even where shoreside lashing gangs do the work - by directions of the Chief Mate.

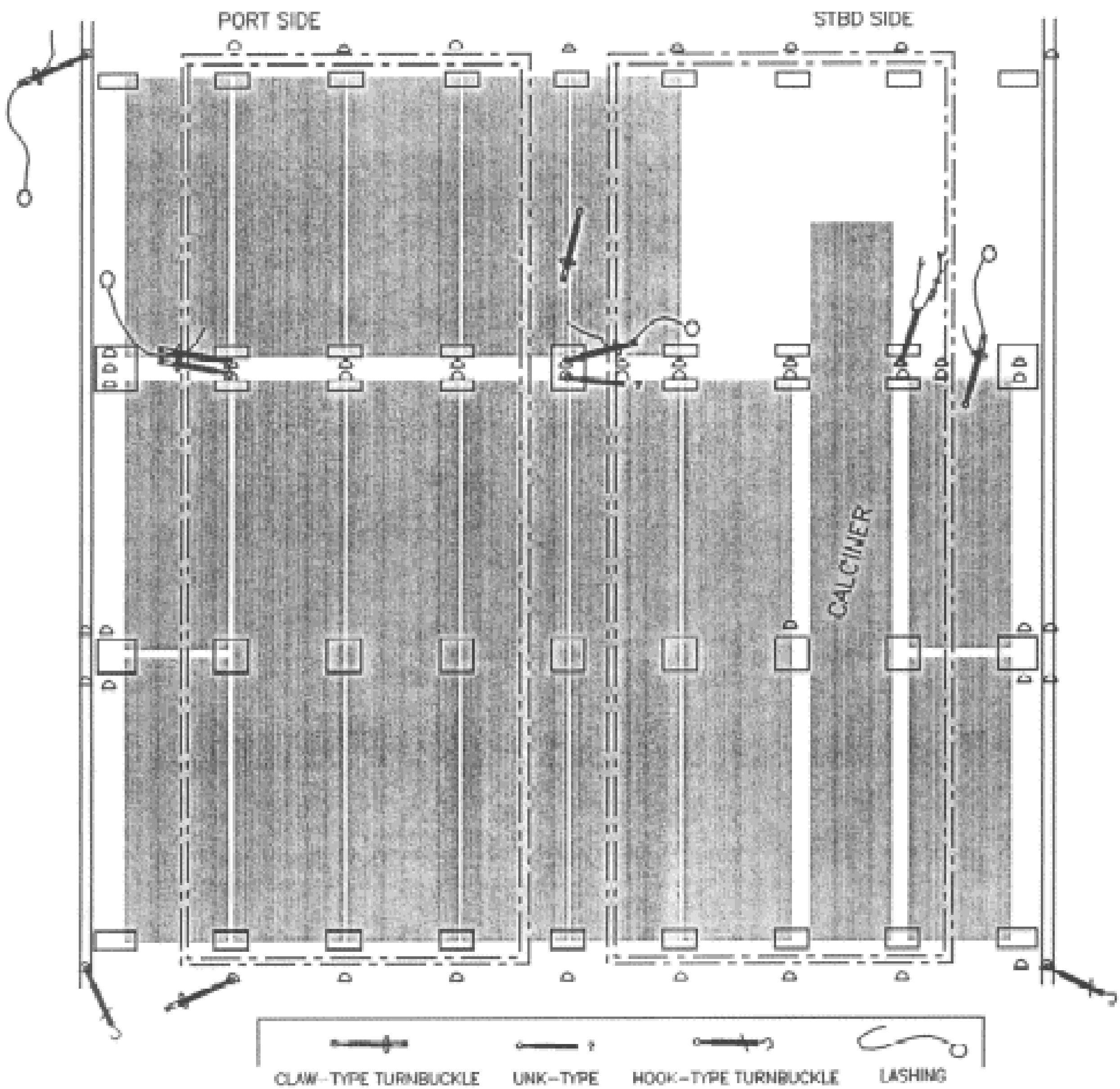
The crew's drawings of the #2 hatch were clearly inconsistent with the Board's findings at #3 and #4. To evaluate and reconcile the disparity, the Board undertook an in-depth analysis of photographs from the #2 hatch in Baltimore.

Mapping details from the photos onto a plan view of the #2 hatch reveals a distinguishing pattern - the left-in-place turnbuckles appear to be concentrated in way of exterior container stacks. It also



A variety of turnbuckles remaining attached reveals a conspicuous shortfall of securing gear. Of all the visible D-rings in the photos, the Board would have expected to see 28 turnbuckles (based on the Bosun's drawing), including two each on 9 of those D-rings. We found a total of eight still attached; none were doubled up. None of the D-rings were broken.

Several possibilities were considered for explaining the "missing" turnbuckles. The suggestion that they fell off just doesn't account for the predominant mix of turnbuckles fitted with bolted clevis jaws or pelican hooks with keepers at the bottom end. Equally improbable is the notion that they broke off - lashings were again more likely the weaker link even in good condition and properly installed. The one remaining explanation is the only real credible one, and the one that the Board embraces - the additional turnbuckles and lashings weren't installed in the first place.



Plan View of #2 hatch upon arrival in Baltimore
(shaded areas show original stowage of containers and calciner)

Review of container offloads and restows in Port Elizabeth even further buttresses the reasoning. Of the 52 lashings the crew said were installed at #2, the Board found 40 separate lashings which *could not* have been in place *before* leaving the pier. With a significant time constraint (less than 21/2 hours available for bridging, locking and lashing all the cargo after leaving Port Elizabeth), the dimension of the task is clear, as is the unlikelihood of completion. The Board's best estimate is that a total of 18-20 lashings were actually installed at #2, and that #2 was lashed in a pattern similar to #3 and #4.

The absence of a Cargo Securing Manual resurfaces as a key deficiency. IM0 Resolution A.714(17), as in previous guidelines, recommends providing such a manual, and IMO circulars describe the expected contents - to include details of the securing arrangements and their location, inventory of securing gear and their strengths, correct methods of application, guidance on stowage and securing nonstandard cargoes, heavy weather plan and other relevant operational factors, and an analysis of design forces.

The Board examined one such Cargo Securing Manual aboard a Greek ship of similar design, age and size of the SANTA CLARA I, and found it most comprehensive. Furthermore, the ship used it and the Master was intimately familiar and conversantwith it

The Board also reviewed a sample Cargo Securing Manual developed in 1983 by the Swedish Shipowners Association, and found it too was comprehensive and addressed standards and guidelines spanning most of the deficiencies observed aboard the SANTA CLARA I.

In contrast, the Master of the SANTA CLARA I offered only two general reference books (in English) and one construction plan of the container pedestal installation (showing the general diagonal configuration of the lashings).

He was unable to produce any securing manual specific to the ship, although both Lloyd's Register and the system-supplier routinely provide them (upon request) as part of the setup or review package.

The lack of a good cargo securing manual in this case demonstrably factored in the casualty.

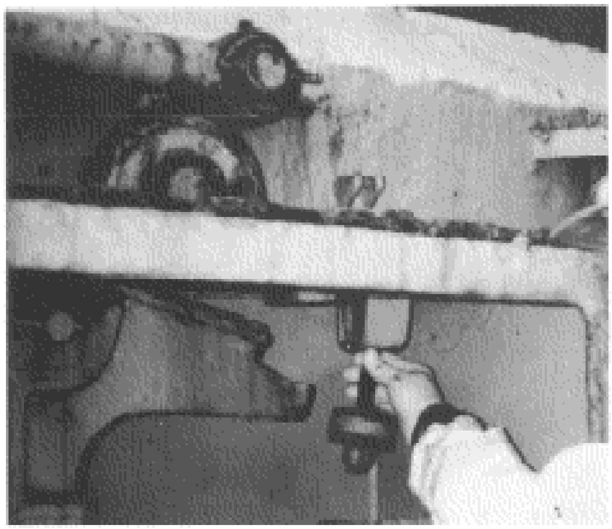
Hatch Covers

The hatch covers on the SANTA CLARA I are constructed of 8 panels each, folding open/closed by a chain-drive mechanism. The hatch covers provide most of the structural support for the containers, and an intermediate structure for transmitting the forces from the containers and lashings to the ship's hull via D-rings and shoe-plates.

Loading capacities for the hatch covers were unavailable, and the Port Captain indicated that he used only a rule-of thumb in planning the stow; but the Board noted that the vessel plans envisioned container stacks three-high. The SANTA Clara I no longer carries deck containers higher than two-high, and there is no indication the static load capacity of the hatch covers was a problem.

The resistance of the hatch covers to other-than-downward force was more suspect. Examination by the Board four weeks after the casualty showed that none of the hatch covers had been dogged down for some time - at least several months, possibly years. All of the bolt threads were badly caked with rust, and several of the bolts were bent/damaged preventing use. None were dogged at the time of observation, and all evidence indicates they were not dogged at the time of the casualty.

(Incidentally, the Board notes that it is common practice to leave hatch covers unsecured during coastwise voyages, and that classification societies don't require that hatch covers be dogged.)



Unsecured dogs on the hatch covers

While force calculations show no negative forces generated (no net lift off the deck), downward forces could be reduced at least by half of the cargo weight at the top of a roll - enough to substantially reduce the friction between the gasket and the knife-edge of the hatch, allowing the covers to move with perhaps one inch of "play."

Damages sustained during the storm bent rollers on the outboard side of the port hatch cover, preventing the hatch from opening - suggest the hatch covers probably did shift at some point, but it's uncertain to what degree the damage reflected cause or effect of loose containers on deck.

If shifting preceded the breakdown of the stow, the effect on the lashing system would be pronounced. While most of the cargo rested on the hatch covers, at least 2/3 of the lashings were secured to stationary D-rings on the deck. As the hatch covers moved, most of the lashings would be affected, some in greater tension and some with increased slack.

While arguably inconclusive, the failure to dog the hatches certainly weakened the stow, and increased the likelihood of small lateral movements/

Pedestals

The deck pedestals were the subject of much attention during the few weeks after the casualty, since two adjacent pedestals in way of the #2 hatch had failed catastrophically. Both were bent completely over the bulwark, by 100-120° from their original upright position. Several others in way of #2 showed limited signs of compression damage at the base as well.

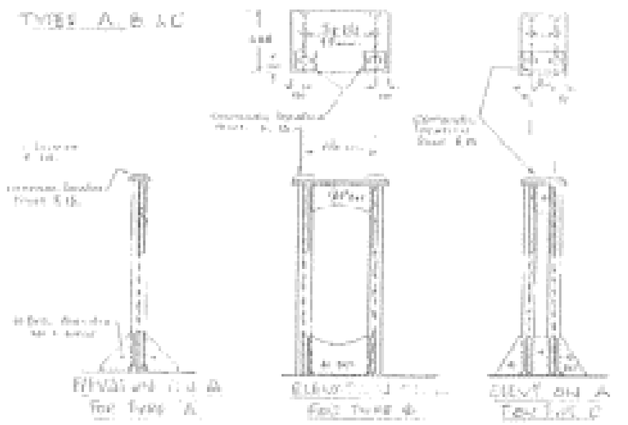
Failed deck pedestals
(starboard side looking aft)

The Board evaluated the role of the pedestals as a causal element in the casualty, and made the following observations:

1) The pedestals were bent too far to have been pulled over by the container originally spanning them. Since the container was secured to the pedestal only by its weight resting on a cone fitting, it would have broken free and fell overboard by the time the pedestal bent somewhat less than 90 degrees.

2) Only the middle two pedestals on the starboard side failed, with only a single

20-foot container spanning these. Both were double-width pedestals with double web frames. The weakest pedestal, with only a single web frame, didn't fail, yet supported a two-high stack and about twice the weight



3 basic pedestal plans

3) Normal-to-deck forces were not enough to cause such failure in compression. In fact, the total downward forces on these two pedestals were substantially less with one container than under the simple static weight of two containers for which they were designed and often carried.

4) Transverse forces on these two pedestals in particular were also substantially less (over 50%) than the design condition of a two-high stack, and far less than with a three-high stack. The single 20-foot container was not tied to any inboard stack (a piece of machinery was stowed in that position, separately lashed), and therefore no additive loads were imposed.

5) Compression damage at the bottom of the various pedestals was at the outboard flange of the beam. Unless the inboard side of the container first broke free from the cones in deck sockets on the hatch cover, all of the transverse and normal forces would have been expressed in a tipping action, downward on the far *inboard* edge of the pedestal. Any compression failure would be expected on the inboard flange, not the outboard one.

Compression damage at bottom of pedestal

6) The compression damage of the two pedestals on the port side is better explained by the force of rolling and banging containers, exerting impact loads far greater than the forces acting on a secure stow. These pedestals were also spanned by only a single 20-foot container in the stow.

7)A more plausible explanation for the catastrophic failure of the two starboard pedestals centers on the piece of machinery stowed just inboard of the 20 foot container. The machinery was mounted on a heavy steel frame, with substantial open spaces to get "caught" on the tops of the pedestals as it slid or rolled over the side. The length of the machinery (about 50 feet) might easily clear the two pedestals located forward and aft of the two which failed. The location of the machinery on the ocean floor indicates it went over the starboard side.

The Board eventually discounted the pedestal failures as a causal element in the casualty.

Containers

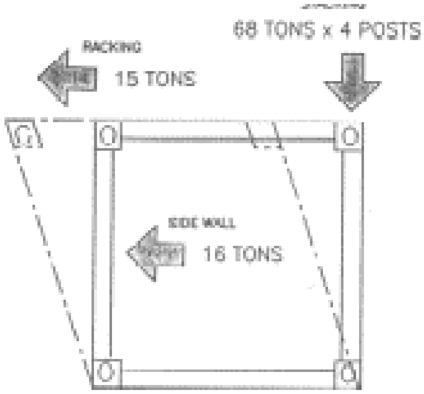
The containers themselves provide an important structural element of any restraint system.

Apart from tipping and sliding failures, probably the most important concerns for shipboard container stows are racking (the tendency to get out-of-square), corner post collapse, and local structural failures of the containers. All have been subject to a good deal of scrutiny over the years.

Standards for design, construction testing, inspection, and maintenance have been established under the International Convention for Safe Containers (CSC) and generally in 49 CFR 450-453.

Dimensional specifications have been highly standardized by commercial necessity, and there is no evidence of any deviations from these specifications with any of the containers aboard the SANTA CLARA I.

Standards for construction are performance-oriented. Regardless of materials or design, the containers must be able to withstand applied test loads of 15 tons (transversely) on the end structure for racking, 0.6 times the container's maximum payload (typically 0.6 x 27 metric tons) on the sidewalls, and 1.8 times the maximum stacking weight (typically based on 6-high container stacks) spread across the four corner posts.

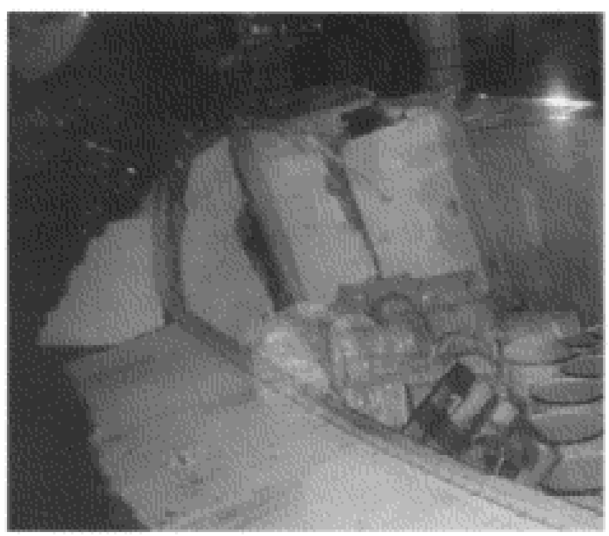


Typical test loads for 40' container

In-service inspection and maintenance are the responsibility of the container owner. Detailed repair standards have been published within the industry, and maintenance records must be available for Coast Guard examination.

All of the containers stowed on the #2 hatch were 8-foot width, 81/2-foot height, and either 20 or 40-foot length. Most were steel construction; one was fiberglass-reinforced plastic (FRP), sandwiched with plywood core panels on the sides, ends and top. All were tested in conformance with IMO standards (some grandfathered based on successful service), and were subject to regular inspection programs under 49 CFR 453. However, there is some evidence that the in-service strength for at least one container on the #2 hatch was inadequate.

The FRP container in particular drew attention to the construction and maintenance standards. One of the four containers remaining aboard at the #2 hatch, it was the only one which broke apart, splitting at the top, sides, and end walls.



FRP container destroyed during storm

The physical properties of FRP are different from steel in one key respect whereas steel under load goes through first an elastic range (where it will spring back to its original shape), then a plastic range (where it will show some permanent deformation), to its breakpoint- FRP has no plastic range. It goes from an elastic range to a break. While many of the steel containers (those left on deck and those observed underwater) showed substantial distortion and deformation, the FRP container did not.

Stowed above the FRP container was a container of cotton (the same container seen hanging over the side in Baltimore) loaded to a gross weight of 20 metric tons. While not an especially high stacking weight by itself, a total of six containers were bridged in a "block," subjecting the FRP container to cumulative racking forces in consonance with moderate crushing forces.

A lashing system can augment the container's racking resistance when properly installed. However, without lashing support throughout the stow, the combined transverse forces across bridged stacks are absorbed by only the container structure itself and whatever lashing is installed. Bridges merely average the forces. Given an estimated transverse force of over 21 tons for the one container analyzed on the SANTA CLARA I, the cumulative racking forces for the entire stow in the casualty condition could have exceeded the net racking resistance of the containers and the few installed lashings on the outermost stacks. The Board observed evidence of racking at the door ends of several containers, although it's uncertain whether the failure was cause or effect of the broken stow.

Sidewall strength in service is coupled with packing effectiveness, but generally even the maximum forces in this case were within range of test loads. Applying the previously-developed force factors to the container payloads for the SANTA CLARA I, the largest force acting against the sidewall would have been about 17 tons, just over the 16 ton test load. Blocking and bracing can transmit some of these forces to the floor or side rail of the containers.

Stacking weights were probably not an issue in this case. Containers are normally constructed and tested for 6 high stacking (at 1.8 9); containers on the #2 hatch were stacked two-high. There is no evidence that any of the corner posts failed in compression.

The Board's limited research uncovered a number of general concerns in the industry regarding FRP containers, suggesting they were "less durable" than other materials, showed more frequent problems at the fastenings to the side rails, and more easily suffered damage from dunnaging. None of these reports could be confirmed independently during the inquiry. However, the Board noted that the Coast Guard receives little feedback on maintenance histories for containers. Furthermore, an attempt to invoke Coast Guard authority to examine the maintenance history of the FRP container from the SANTA CLARA I has so far produced negative results. The owner of the container says the lessee has the records; the lessee points to the owner.

Whether the failure of the FRP container preceded the collapse of the stow is unknown. However, the FRP construction in general appears to provide degraded performance in service, raising some doubt as to its suitability for the unrestricted carriage of hazardous materials aboard ship.

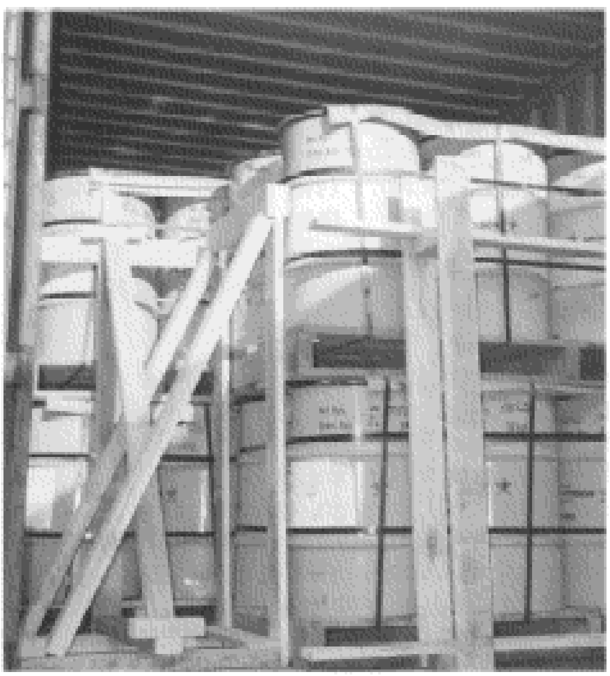
Container Packing

In Charleston, an interior inspection of Arsenic Trioxide containers which were stowed below deck revealed upset contents in two of the nine sampled; blocking and bracing was broken and adrift.

Given the greater forces affecting above deck cargo, it's reasonable to expect that the Arsenic drums in at least some of those containers on the hatch covers were similarly upset.

Regulations in 49 CFR 176.76 provide basic performance standards for container packing. IMO, National Cargo Bureau (NCB), and Maritime Administration, among others, offer additional guidance, but objective standards for blocking and bracing arrangements do not exist. The packing or "stuffing" of cargo in intermodal containers remains more an art than a science.

Review of the container packing certificates (which are recommended by the IMDG Code as prerequisite for accepting the containers for shipment, and which were available in this case), revealed no specific procedural problems in packing; the end-result, however, plainly argues the weakness of the overall blocking and bracing scheme used.



Inside and belowdeck stowed arsenic container

A few possible shortcomings were identified. First, palletizing the drums often results in too much void space across the container floor, making a tight stow more difficult. While palletizing cargo is generally more economical in terms of handling costs, drums in particular are more easily stowed in a tight, balanced arrangement individually.

Given the palletized configuration, the dunnaging materials and arrangement appeared inadequate. The triangular braces in particular provided an inadequate angle and tie-in to the container side rails for resisting heavy transverse loads. No tomming was installed between the tops of the drums and the ceiling of the container. The dimensions and seasoning of the lumber could not be readily determined. And in the case of the FRP container, the sides have no corrugations to permit effective "wedging" of the dunnaging materials.

Once broken loose inside the container, shifting cargo can exert impact loads much greater than the forces associated with the ship's motions. The impact on the securing system is naturally compounded.

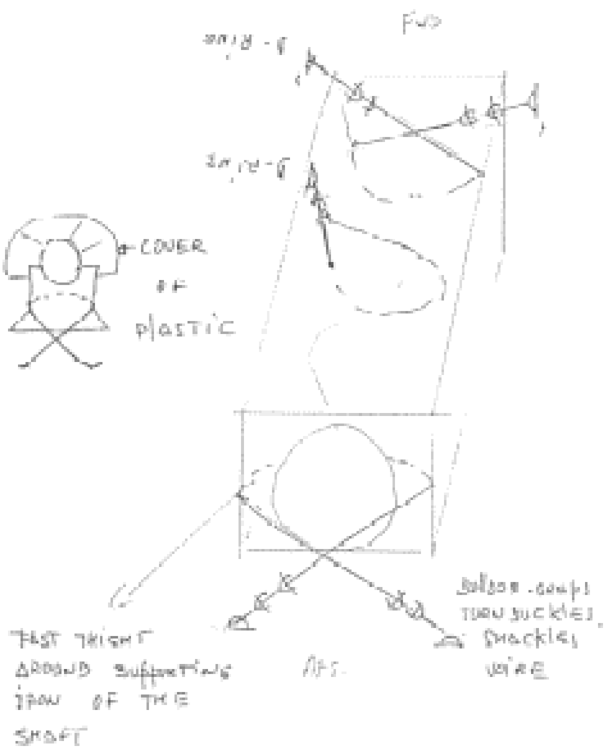
Regulatory oversight of container packing is currently limited. The regulations are probably adequate, but the emphasis and enforcement lag behind. Any renewed effort toward a container inspection program should account for the availability and expertise of third party organizations, which already offer their services to shipping companies upon request.

Machinery Stowage and Securing

An unusual aspect of the stow on the #2 hatch was an odd-shaped piece of machinery - a calciner, used as a drier in the mining industry - stowed adjacent to the outboard stack of containers on the starboard side. This type of cargo (a heavy item) has been highlighted by IMO as one which has "proved to be a potential source of danger."

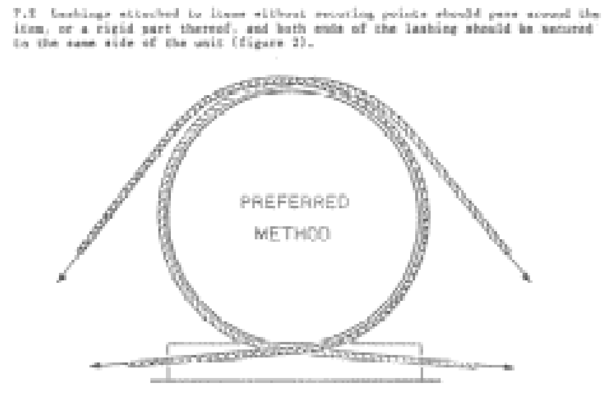
Weighing about 21 tons, the calciner was fitted on a steel frame, secured to a wooden skid and wrapped in a tarp for shipping. Finished dimensions of the unit were 49.2 feet long, 6.9 feet high, and 5.25 feet wide - about 2.75 feet less in width than the space in which it was stowed.

The skid was constructed of 4x6” timbers sandwiched between solid hardwood flooring. The skid, in turn, rested on the hatch cover - or more specifically, on at most 8 flat shoe-plates on the hatch cover. Transverse movement was restrained only by friction, and by the lashing around the calciner itself. There were no fittings for the use of cones or twistlocks. The calcirner was lashed at three points as indicated on a drawing by the Chief Mate, with each wire lashing at the ends running diagonally underneath the calciner, up around the top, then back down diagonally across to the other side.



Lashing of calciner as drawn by Chief Mate

The weakness of this configuration is fairly evident. IMO guidelines for lashing this type of cargo unit (MSC Circular 530) specify that effective lashings are to be brought around the unit and both ends secured *at the same side,* to prevent transverse movement. The lashings depicted in the Chief Mate’s drawing, in contrast, develop a sort of “rolling eye” in the wire as the cargo is permitted to shift short distances easily.



IMO guideline for securing heavy items

The number of wire clips used to secure the lashings may have presented another weak link. Standard marine practice requires a minimum of 2 clips for wire of ½-inch diameter, or 3 clips for wire 5/8 inch diameter or greater. Judging only from photographs of the broken wire remaining on deck in Baltimore, the lashings were at least 1 /2-inch, more likely 5/8-inch. The drawing shows 2 clips per wire; the photo shows one remaining. Notably, the crew used only a single clip per wire in lashing the buses stowed at the #3 hatch.

One of the calciner lashings (at the forward end) clearly parted - as seen in the photos from Baltimore. The middle lashing as drawn by the Chief Mate was gone when the ship arrived in Baltimore, as was any turnbuckle which was used at that point; more likely, this lashing was not installed in the first place. The after lashing was not visible in the photos, and the securing points were obscured from view. While the parted wire suggests that the rope failed before the clips, the inferences are certainly inconclusive.

More importantly, the lashing configuration and the relative width of the unit in an 8-foot wide space gave too much room for sliding. The small frictional surface area afforded by the flat shoeplates further minimized the resistance. And despite the extensive irregularities in securing containers on the #2 hatch, securing of the calciner probably represented the greater deficiency.

As with the containers, the crew lashed the calciner after departing Port Elizabeth.

Failure & Collapse of the Stow

A principal objective of a restraint system is to keep the cargo from moving "just a little." When subjected to loads, small movements will begin to work the lashings, which progressively loosen, leading to the ultimate collapse of the stow. The scenario is common and recognizable to many in the industry. It also broadly reflects the most likely situation aboard the SANTA CLARA I on the morning of January 4. 1992.

Given the pervasive carelessness and improper application of equipment, an observation by the C.R. Cushing report in 1983 is especially poignant:

> *"If the lashing gear is improperly used, no attempts to over-design by incorporation of safety factors will protect the integrity of a securing system and eliminate hazard to the ship, Hs cargo and, above all, its personnel. "*

Development of force calculations, safety factors, and strength criteria for components is a systems approach which presupposes a certain degree of faithful application. They are discussed here for illustrative purposes, but by no means does the failure of the stow point to some single, numeric threshold which was exceeded. The failure modes were diverse. Seven separately-secured blocks or units of cargo all failed.

Some of the pieces in the puzzle were found at the bottom of the ocean. Of the 21 containers lost overboard, fifteen as well as the calciner were located in an elongated debris field roughly following the ship's trackline from about 0150 0210. Interestingly, the cargo was generally clustered by stowage location from the #2 hatch. The calciner, in particular, was found near three other containers from the starboard side.

An inspection on deck in Charleston showed a wide arc scraped across the starboard side hatch cover, coincidental with the stowage location of the calciner.

In the course of the inquiry, the Board developed a number of working theories, often discarded as quickly as they were conceived. But in the end, a fairly likely scenario emerged. The sequence is not of any special significance:

> *Cargo and securing gear first began working in heavy weather. The securing gradually developed increasing slack, which was not taken up by re-tightening due to the adverse conditions out on deck.*
>
> *Small lateral movements of the hatch covers and slack in the lashings began to introduce shock loads*
>
> *Shifting winds/seas introduced synchronous rolling, which further increased the transverse forces acting on the stow. Cargo inside the containers began to shift as the dunnaging gave way under load.*
>
> *The calciner began sliding, first within a small range from the lashing configuration, then somewhat more as the lashings loosened in the wire clips. At some point, the calciner began to impact adjacent containers.*
>
> *Continued racking of container stacks alternately strained and slackened the lashings as well as the bridges. Some of the lashings jumped out of the turnbuckle hooks and/or slipped off penguin hooks; some simply parted. Failure in one area of the restraint system put increased loads on other parts, leading to collapse of the stow like a "house of cards", with cargo adrift on deck.*

Cargo on the starboard side went overboard first, at just about 0150.

The calciner swept the deck in an arc, with the forward lashing the last to part. As the calciner slid overboard, it wiped out the two middle pedestals on the starboard side

Containers on the port side began to go overboard very shortly after the first few from the starboard side. By about 0210, most of the stow was gone. One or two containers may have hung up on the pedestals, but by the time the ship entered Delaware Bay just four containers remained aboard at the #2 hatch

CONCLUSIONS

1. The proximate cause of the cargo loss was the failure to adequately secure containers and cargo on deck.

2. Mechanical weaknesses in the cargo securing system which may have contributed directly to the loss of deck cargo include:

   a. inadequate number of wire lashings to overcome static and dynamic loads on the container stow:

   b. mismatched/improvised lashing gear, especially the use of an incorrect type of turnbuckle for the wire lashing and the unconventional use of penguin hooks with wire rope lashings;

   c. improper (inverted) installation of wire lashings, putting an unreinforced eye over the pelican hooks;

   d. pairing of penguin hooks with wire lashings, possibly weakening the connection to the corner fitting of the container;

   e. use of already-damaged lashing gear;

   f. weak stowage configuration of outboard 20-foot containers in a 40-foot space, leaving one end of each container stack unsecured;

   9. deficient lashing configuration for the machinery on deck, minimizing the restraint against transverse sliding;

   h. insufficient number of clips on the machinery lashing; and

   i. unsecured hatch covers, permitting small lateral movements of the entire stow and slackening of the securing system.

3. Operational weaknesses which may have contributed to the casualty include:

   a. failure to follow recommended international standards for providing stowing/securing instructions (a Cargo Securing Manual) aboard ship;

   b. lashing under time pressure underway into heavy weather, reducing the standard of care by the crew, and reducing the extent of actual lashing and securing;

   c. maintaining an inventory of too many varieties of securing gear onboard, complicating the job for lashing gangs or crew;

   d. excessive GM, causing increased dynamic forces acting on the cargo, greater likelihood of synchronized rolling with the seas, and therefore greater likelihood of large roll angles and green water on deck. The Master's unfamiliarity with the ship may have misled him in evaluating the stability conditions:

   e. failure to properly assess the storm, its movement and relative winds;

f. failure to take early action in deteriorating weather to avoid putting the ship in a dangerous situation with limited safe alternatives remaining. The Master should have navigated to put the ship in a position where he could effectively reduce speed, better control his heading in relation to the weather, and avoid heavy rolling and green water on deck. His unfamiliarity with the ship may have caused him to overestimate the capabilities of the ship in heavy weather; and

9. failure to effectively counteract synchronous rolling, pounding and the attendant violent motions of the ship, by reducing speed and/or changing course.

4. Other factors which may have contributed to the loss of cargo:

a. An apparent structural weakness inherent in the material of FRP containers, strained with the carriage of heavy, dense cargo; and compounded by stowage of the FRP container below another heavy container.

b. Inadequate blocking and bracing of the contents of the containers, a condition which was exacerbated by palletizing the drums for container shipment.

5. Regulatory controls and oversight programs leave significant gaps in safety for the carriage of containerized dangerous cargo in U.S. waters. IMO and Classification Society rules and guidelines systematically outline the development of a good cargo securing system; however, neither the U.S. nor Panama has implemented the IMO guidelines by regulation. If the vessel operator had carefully applied these guidelines, the casualty may have been prevented.

6. Stowage of marine pollutants such as Arsenic Trioxide on deck in lieu of under deck may present an unacceptable risk. In some conditions, such as the introduction of green water on deck, the forces may be of such magnitude that damages to deck-stowed cargo is unavoidable. The variables may be too many. However, the alternatives may present equally compelling safety problems associated with stowage in confined and inaccessible spaces (such as in the event of a shipboard fire), and very substantial economic costs to the industry. The trade-offs require more deliberate study.

7. Failure by the ship's crew and owner representatives to report and mitigate a known spillage of Magnesium Phosphide (and other hazardous cargoes) in Baltimore resulted in exposure of the crew and shoreside personnel to a substantial health threat, and left unchecked a safety hazard affecting the ports of Baltimore and Charleston

RECOMMENDATIONS

1. Develop, in coordination with RSPA, a regulatory package to implement IMO Resolution A.714(17), Code of Safe Practice for Cargo Stowage and Securing, for all vessels transiting U.S. waters with dangerous cargo.

2. Propose that IMO improve Res. A.714(17) in view of the detailed findings of this inquiry, and recommend that it be made mandatory under the SOLAS Convention for ships carrying cargoes addressed by the IMDG Code.

3. Develop a compliance inspection program for securing gear and securing arrangements, addressing the need for complete securing before a ship leaves the dock or enters pilot waters inbound.

   a. Propose to the International Association of Classification Societies that they make the design, construction and maintenance of container securing systems a condition of class for all container-carrying vessels.

   b. Consider use of the National Cargo Bureau to assist in operational inspections, to take advantage of existing expertise.

4. Examine the failure and repair history for FRP containers to determine their suitability for continued, unrestricted use.

5. Develop a container inspection program for assessing the adequacy of blocking and bracing inside containers, and enforcing the existing regulations on packing.

6. Initiate a quantitative risk analysis regarding on-deck stowage of Marine Pollutants, in coordination with the IMO Subcommittee on the Carriage of Dangerous Goods.

7. Refer the case to the Department of Justice for pursuit of any available criminal and civil penalties, regarding the owner's failure to notify the Coast Guard of spilled hazardous materials below deck in Baltimore.

8. Forward a copy of this report to the government of Panama, IMO, IACS, National Cargo Bureau, and Lloyds Register of Shipping, for information.

Dated: May 8, 1992

J. F. McGOWAN
Captain, U.S. Coast Guard
Chairman

R. B. PEOPLES
Commander, U.S. Coast Guard
Member

R. KOWALEWSKI
Lt. Commander, U.S. Coast Guard
Member and Recorder


tex


CAT