Loss of Stability

Lessons Learned

from Casualty Investigations

A ship capsizes while loading cargo.

by Captain Brendan Saburn
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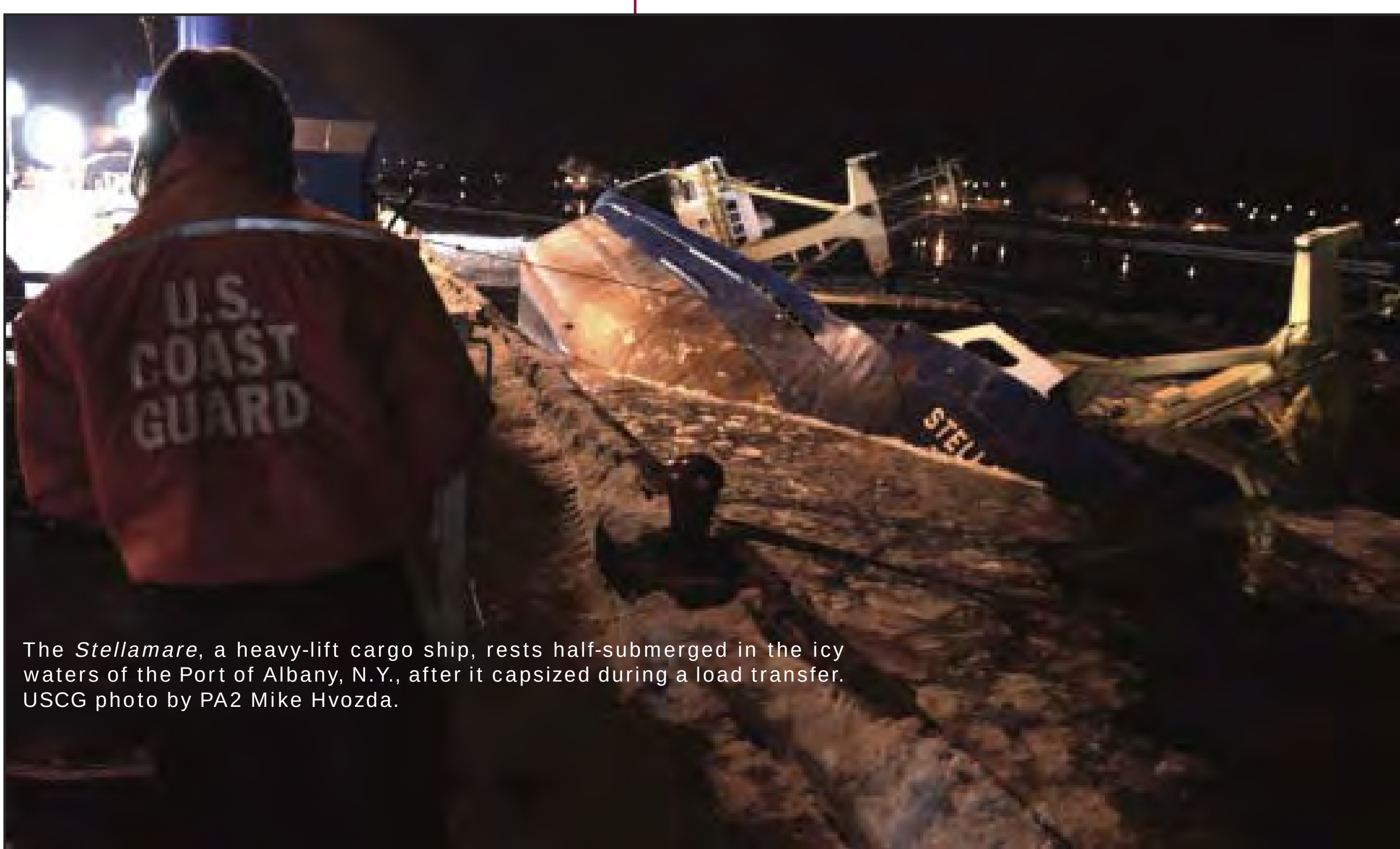
On December 9, 2003, the 289-foot heavy-lift freighter *Stellamare* capsized and sank in Albany, N.Y., while loading a 308-metric-ton generator[1] for a power plant. This major marine casualty was caused by improper ballasting and the speed of cargo handling during the loading operation. In other words, human error caused this incident, which resulted in the deaths of three of the ship's crew. Additionally, five other crewmen were injured in this incident. Drug and/or alcohol consumption was not a factor.

To set the scene, Albany is located 126 miles above the Statue of Liberty and the tip of Manhattan. Only a small ship like this heavy-lift vessel can travel that far upstream, due to low bridge clearances and the depth of the Hudson River. Additionally, the operation of a small heavy-lift ship is highly specialized. This is a ship less than 300 feet in length, with cargo gear capable of lifting a total of 360 tons, which is on the order of 10 loaded eighteen-wheeler trucks. This particular ship was fitted with two heavy-lift derricks. Each of these was officially rated by a classification society[2] for a safe working load of 180 metric tons, so a combined load of 360 tons was permissible. This ship's deadweight tonnage[3] was only 2,760 metric-tons, so one heavy-lift load of 360 tons was approximately one-eighth of its total carrying capacity.



The *Stellamare*, a heavy-lift cargo ship, rests half-submerged in the icy waters of the Port of Albany, N.Y., after it capsized during a load transfer. USCG photo by PA2 Mike Hvozda.

Two generators were to be loaded aboard this ship that day. One weighed 308 metric tons, the other one weighed 234 metric tons. Both generators were destined for European ports, one to Italy and the other to Romania. One was for use in a nuclear power plant, where it would be driven by a steam turbine and reduction gear assembly—the same type of turbine and gear assembly used with boilers in a power plant or on an old steamship. The other was intended to be attached to a pair of what's known as gas turbine engines in naval engineering—the same size and type of jet engines that a large modern aircraft has for propulsion, which are the same type of engines that turn the propeller shafts of modern Coast Guard cutters and Navy combat ships.

During operations on December 9, the smaller generator was loaded as planned. It was loaded first, onto what had been an empty ship, to make the ship more stable in preparation for the heavier generator.

Stability: An Illustration

It's important to understand what is meant by "stability." There are three states of stability: stable, neutral, and unstable. To imagine this, think of a small child in a rocking chair. The chair rocking forward and backward is analogous to a ship rolling to starboard and port. If the child is sitting, the chair is very stable and nothing is going to go wrong. The chair can be rocked back and forth, but won't topple over forward or backward, because the center of gravity of the child and chair combination is down low, where it should be.

But what if the child decides to kneel? Then the chair will be in "neutral" equilibrium. If the child leans forward, there is neither a tendency for the chair to return to the upright position nor a tendency for the chair to topple. The chair will stay where the child positions himself while kneeling.

If the child stands up in the chair, the center of gravity of the child and chair combination is now too high. In other words, we now have the condition of unstable equilibrium. If the standing child moves the least bit too far forward or backwards, the chair can topple.

Let's continue our example. How can we make the chair more stable so the child can't upset it by standing in it? One way would be to fasten bricks to the underside of the chair, which would add weight below the desired center of gravity. In other words, we could "ballast" the rocking chair. We could also lengthen the chair's rockers, which would be analogous to making a ship wider.

Stability in Action

Any student of stability also needs to consider the vertical location of the weight of a heavy piece of cargo. The weight is either in the hold, where it's being stowed for the sea passage (a few feet above or below the ship's center of gravity), or the weight is "acting from" a point (such as the head of the cargo boom) that can be 100 feet above where it would be when the piece is down in the cargo hold. In the rocking chair example, if you hung a weight of 10 or 15 pounds from the horizontal top piece of the chair, then moved that weight onto the seat of the chair, the center of gravity would have shifted during this operation.

A stability pontoon is a floating vessel that makes a 300-ton lift and load possible. For a ship this size, the pontoon is approximately 50 meters in length and floats alongside the outboard side of the ship. From its stowed position on deck, it's picked up by one of the booms and carefully lowered down over the side through a track that serves as the attachment bracket. The pontoon increases the ship's "effective breadth;" the wider a vessel, the more stable it is. The two-di-

mensional area of the ship's waterplane[4] has been increased in the width dimension, making the ship a lot more stable. This ship used a stability pontoon on the outboard side that day.

The center of gravity of a ship this small, with a weight of 300 tons suspended from a point approximately 20 meters above its keel, is approximately one or one-and-a-half meters above where it would be if the weight were stowed in the hold, provided the stability pontoon is properly deployed. The ship would have only a small measure of stability while the weight is suspended, but it wouldn't be considered a problem if everything else is all right. The first generator loaded on that day weighed 234 tons (approximately 250 tons with its lifting hardware) and the ship was quite stable while the load was suspended.

The Typical "Lift" Procedure

After connecting the hardware (slings and lifting beam) to the cargo falls, the first step in lifting a weight of this magnitude is to take a slight strain (50 tons, in this case) on the falls using the winches. The strain is judged by the dynamometer gauges and the list of the ship. A ship this small takes on a list of 2.5° or so with two cranes over the wharf and a 50-ton strain on the falls.

Next, the ballast tanks on the opposite (outboard) side of the ship are filled with water. If the ship is moored starboard side to the wharf (as this ship was in Albany), the port side (outboard) ballast tanks are filled with river water to help bring the load across from starboard to port. As they're filling, tension on the falls increases. The goal is to have less wear and tear on the winches, and a smoother, safer loading operation. The ship's center of gravity rises as the falls gather more tension from the cargo's weight.

Depending on the loading plan, ballast water is either pumped from the inboard side to the outboard side, or the tanks on the outboard side are filled from the water in which the ship is floating. The idea of ballasting, by itself, lowers the ship's center of gravity. Though people have been ballasting since ships have been going to sea, this becomes a specialized ballasting operation when done in conjunction with raising a heavy-lift

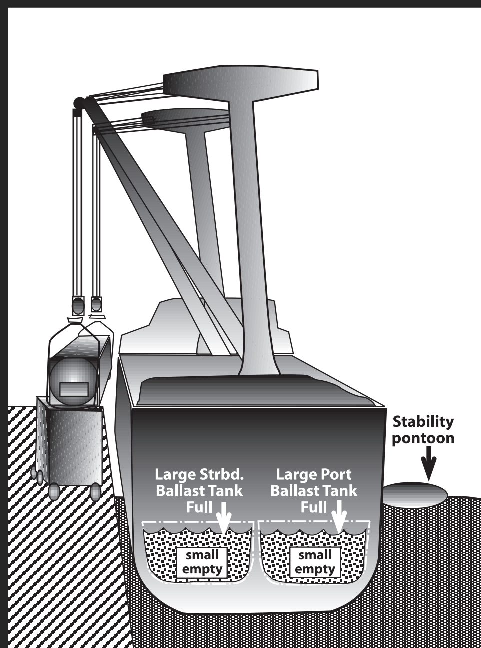
Divers approach the ship to search for missing crewmen. USCG photo by PA2 Mike Hvozda.

load. Here, the ballast water is referred to as "swing ballast" because its primary purpose is to help swing the load aboard. The applied ballast also has a tendency to lower the center of gravity a foot or two, but that helps to balance out the suspended load, which has a tendency to raise the center of gravity a few feet.

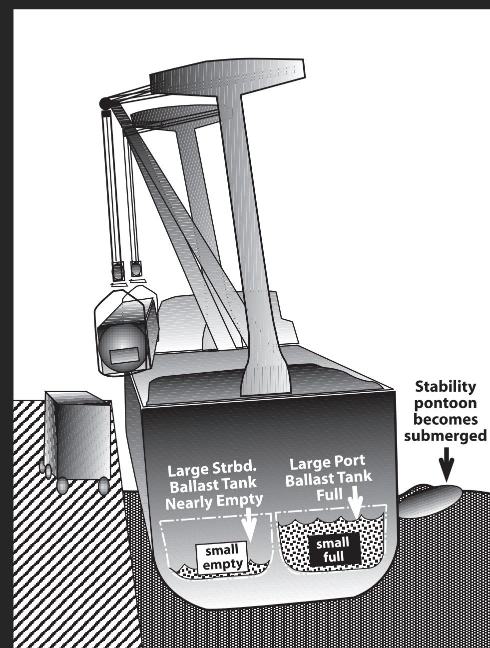
This is a very slow operation for two reasons: it takes time to fill ballast tanks, and it takes time for cargo to be lifted when using 12-power tackle for cargo runners. Both of these evolutions take place simultaneously. Although the ballast tanks on a heavy-lift ship can be filled at a rate of over 200 tons per hour,[5] the speed is determined by the time it takes to slew the cranes inboard once the load gets to a height where it will clear the bulwarks and hatch coaming. For those of us whose block and tackle seamanship is a dusty memory, the load being lifted (or lowered) by a 12-power tackle only moves up (or down) a foot for every 12 feet of cargo fall handled by the winch.

When everyone is in position and ready, the winch operator takes a strain. The captain simultaneously gives the order to begin filling ballast tanks on the outboard side before the list gets to a point that the pontoon comes out of position and loses its effectiveness. If it does, the ship could capsize to starboard onto the wharf. Reaching the point of full tension on the falls, the booms will get slewed inboard. Everyone exercises caution to ensure the cargo load doesn't get ahead of the swing ballast. From time to time the cargo movement stops and the brakes are set to allow the ballast to catch up to the load. The idea is to do as much as possible with swing ballast to ease the operation of the booms.

The Incident



Booms are positioned over the wharf to begin lifting the second generator. At this point, large port and starboard ballast tanks are full. As strain is taken, the stability pontoon becomes misaligned.

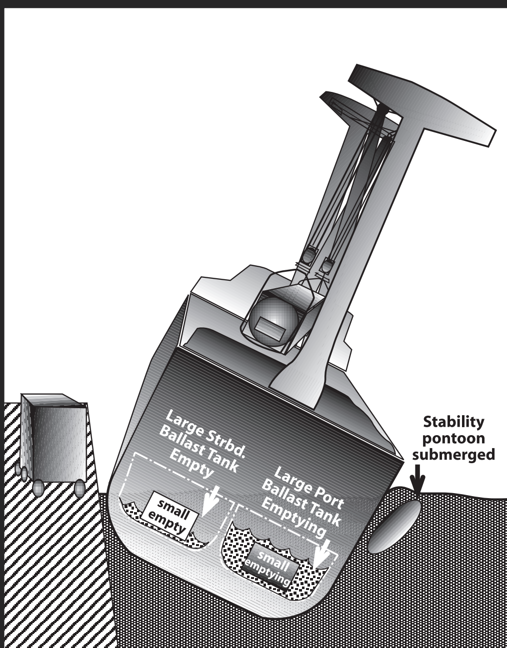


As the generator is lifted, ballast is discharged from the large starboard tanks. Smaller port-side ballast tanks are filling. Pontoon begins to become submerged.

The First Lift

These factors explain why it took three hours to load the first generator on that day in December. This first load went very smoothly. First the cranes were slewed out and positioned over the railcar on the wharf and swing ballast was loaded into tanks on the inboard side. The combined effect of the weight of the booms and the ballast listed the ship slightly inboard (toward the wharf), as desired. At this point in the evolution, someone would have checked on the stability pontoon on the outboard side, since the pontoon would be effective only if the list did not exceed 2.5° to either side. While someone checked on the pontoon, people on the wharf hooked the generator to the cargo falls, which took a good few minutes because of the size and weight of the lifting hardware.

When everyone was in position and ready, the winch operator took a strain. The captain also gave the order to begin filling ballast tanks on the outboard side before the list could get to a point that the pontoon could come out of position and lose its effectiveness. If it had come out of position, the ship might have capsized (to starboard) onto the wharf. Reaching the point of full tension on the falls, the crew started to slew the booms inboard. Caution was exercised to ensure that the cargo load didn't get ahead of the swing ballast so that they didn't lose control of the list. From time to time, the movement of the cargo was stopped and the brakes set to allow the swing ballast to catch up to the cargo.



Ship lists to port and discharge of port-side ballast begins. Ship remains listing to port as discharge of port-side ballast begins. The stability pontoon no longer provides additional waterplane area. Additionally, with so much weight (300 tons) suspended from above, and not enough weight (ballast) below, ship is dangerously unstable and capsizes to port.

Eventually, the two large port-side ballast tanks were filled and the generator was properly positioned over the hatch, three meters to port of the ship's centerline. From here it took a few more minutes to lower it down into the hold. Twelve feet of cargo fall had to be paid out for every foot that it descended. Four crewmen down in the hold unhooked it and immediately began securing it for sea. Unfortunately, these crewmen were still in the hold during the second lift.

The Second Lift

The idea of doing as much as possible with swing ballast to ease the operation of the booms was a success during the first lift. As mentioned, the smaller generator was loaded first, onto what had been an empty ship, to make the ship more stable in preparation for the heavier generator. The second lift began the same way, except for how the ship was ballasted. The swing ballast from the first lift remained in the large tanks on the port side. Using that setup, the captain could plan on discharging (overboard) the starboard side swing ballast while the load was slewed aboard.

The second, 308-ton generator, which was the size of a locomotive and weighed the same as eight and a half loaded 18-wheelers, came very close to the maximum lift capacity of the cargo gear. In cases like this, meticulous calculations are required to ensure the ship's stability while the load is suspended. Even the weight of the hardware between the cargo hook and the actual piece of cargo has to be accounted for. For a lift this heavy, the lifting beam and sling assembly weighs more than 20 tons.

The Incident

The heavier generator was to be loaded three meters to starboard of the centerline. Its rotor was intended to be loaded the next day and would have gone on the port side to balance the ship for sea. The derricks were slewed out so the heads of the booms were over the railcar on the wharf with the 308-ton generator. The boom heads were now 13 meters (to starboard) from the centerline. This, by itself, caused a list to starboard. Additionally, the captain had one large starboard-side ballast tank filled to cause a maximum safe list before taking a strain on the cargo runners.

The generator was hooked up with hardware (the lifting beam and its slings, hooks, and shackles) weighing over 20 tons. Meanwhile, the captain and cargo superintendent checked the stability pontoon to ensure the crewmen operating the winches and pumps were in position and ready. Additionally, there were four men down in the hold securing the smaller generator for sea, and a few others were in their staterooms or working in the galley.

As the runners took a strain, ballast was discharged from the large starboard side tanks and the empty ballast tanks on the port side were filled. All of this happened faster than it should have. One pump was available for each ballast tank worked. By the time there was full tension on the cargo runners, all port tanks were full and both of the large starboard tanks were empty.

This led to the first mistake: there was no place to put ballast (on the port side) in case there was a need for it. The port side had no "reserve ballast capacity," a phrase coined by the Coast Guard's technical advisor to the investigating officer. With full tension on the cargo runners, the captain had the idea that he could safely and easily discharge port-side ballast while slewing in the derricks to bring the generator aboard. At this point in the evolution, the idea was to prevent the ship from listing toward its port side. This would not have been a problem if everything else was all right. Specifically, this would not have been a problem if the stability pontoon had remained in position. The derricks were slewed in faster than they should have been; but the real mistake was that no crewmember was stationed to observe the pontoon for this second lift.

At some point before the port-side ballast discharge began, the pontoon became submerged and lost its effectiveness. This loss of effective waterplane area meant that the ship, with its suspended load, was unstable, but the captain didn't realize it. The heavy load was suspended on the starboard side—almost in position over the hatch—but the ship was unstable because the pontoon was submerged.

The suspended weight was hanging slightly to starboard and all the port-side ballast tanks were full. At that point, the captain realized the ship was listing to port.[6] The best course of corrective action would have been to ballast. Usually, stability teachings dictate ballasting an unstable ship first on the low side, so the ship can't flop from a port list to a starboard list and capsize (toward the wharf in this case). However, since all the port-side ballast tanks were still nearly full, the alternative should have been to ballast on the starboard side; that is, ballast anywhere possible to make the ship less unstable. When in dire straits, this could even include filling tanks that are normally used as fuel tanks. The captain should have given the orders to fill the starboard ballast tanks and top off the port tanks that he had started emptying. Unfortunately, instead, he didn't realize the condition of instability caused by the submerged pontoon and continued discharging port-side ballast in hope of alleviating the port list. At this point, the captain asked the chief engineer if ballast could be discharged any faster. The center of gravity got higher with every ton of ballast discharged, and the situation became more dangerous.

Salvage work continues. USCG photo by PA2 Mike Hvozda.

Then, the inevitable happened—the ship capsized (to its port side, away from the wharf) with unnecessary personnel aboard. In addition to the necessary loading crew—captain, cargo superintendent, chief engineer, and cargo winch and ballast pump operators—there were four crewmen down in the hold securing the previously loaded generator. A cook was at work in the galley. Some other crewmen were in their staterooms.

Everyone on deck immediately tumbled into the 30°F water of the Hudson River, with both brash and skim ice. A few seconds later, they were joined by all of the other crewmen except for three of the four who were down in the hold. Some were able to hold onto some part of the ship. Others were free-floating in the river. The wind blowing on their heads felt like 5°F with the wind chill factor. One multi-million-dollar generator was in the hold, and the other was on the bottom of the Hudson. Fuel oils and hydraulic fluids spilled into the river, as well. The fuel would continue to seep into the river until the tank vents could be plugged.

The Response

The captain of a dredge working just downriver picked up his VHF and made the distress call on behalf of the

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POST-INCIDENT OIL REMOVAL

Nine thousand gallons (1,200 cubic feet[1]) of the ship's fuel oil discharged out through the tank vents before the ship could be refloated. Fuel seeped through the port-side tank vents because the ship was submerged on its port side (on the bottom) after capsizing. The simple float balls that act as check valves[2] in the goose-neck tank vents can't function effectively unless the sunken ship is upright. Immediately after capsizing, river water entered the fuel tanks and fuel oil exited through the port-side goose-necks as the vents were submerged to the bottom of the river.

Slowly, there was free communication[3] of water into the tanks and oil and water out of the tanks. After a few hours, the remainder of the fuel in the port-side tanks was floating on the water that had entered the tanks. Contractors had the vents plugged by the following day. The situation was different on the starboard side. Here, the saving grace was that the goose-necks were above surface of the river, where nothing could flow in or out.

This oil spill was cleaned up by contracted personnel working their way through both brash and skim ice in the Hudson River. Three different contractors were hired and all environmental concerns related to the spill were alleviated quickly.

Generator fuel is much lighter than main engine fuel on any merchant ship. On this ship, there was a difference of 10% in their specific gravities, which is typical. The heavy, main engine fuel had a specific gravity of 0.95 and the generator fuel (#2 diesel fuel) had a specific gravity of 0.85.[4] Depending on the sizes of its tanks, a ship will have its main engine fuel in four to six tanks and its generator fuel in two to four tanks. Each generator fuel tank also has a goose-neck vent that allowed free communication in this instance.

The effect of the low temperatures of the air (below 20°F) and water (approximately 30°F) made the pollution situation out of the ordinary. Had this happened on a hot summer day, evaporation would have made a big difference. But, because of these low temperatures, the diesel fuel actually floated on a thick film of the heavy fuel and was evaporating very slowly, allowing time for the contractors to remove it. The heavy fuel was so viscous at this low temperature that it resisted flowing out through its goose-neck vents. This mitigated the amount of heavy oil spillage. Almost all of the 9,000 gallons spilled was diesel fuel, a product that is easily recovered and recycled at the refinery after cleanup.

Additionally, all cargo ships have pollution potential from the hydraulic fluid that's used for the cargo derricks, hatch covers, and other deck machinery. The hydraulic machinery for the derricks required a fluid, which, in essence, is the same as automatic transmission fluid. The cherry-red-colored fluid was conspicuous next to the diesel fuel on the water, even though only a couple hundred gallons were spilled.

Endnotes:

1. For simple visualization, the total spillage of 1,200 cubic feet of oil amounts to one foot of oil on the floor of a 1,200-square-foot house. A typical (250-gallon) home heating oil tank for a small house is only 33 cubic feet (7.5 gallons in a cubic foot). If a full household tank leaks its entire content onto the basement floor, the flooding will only be five-sixteenths of an inch (8 millimeters) deep.
2. The function of a tank vent is to prevent pressure and vacuum from developing in the tank. The check valve (in the goose-neck vent) will prevent water from entering the tank provided that the ship sinks upright.
3. "Free communication" is a term usually used in the context of a ship with a hole or crack in a tank. Here, the communication (of water in and oil and water out of the tank) is somewhat restricted by the presence of the dysfunctional ball in the gooseneck.
4. Small tug boats and other work boats use the same (diesel) fuel in both the propulsion and generator engines.

ship and its people in the water. All hands on the wharf grabbed their cell phones. In addition to the Coast Guard, the Marine Unit of Albany Fire and Rescue, and a Good Samaritan vessel, a tug that had been moored less than a quarter mile downriver, responded quickly. Meanwhile, workers on the wharf used a shoreside crane to pull people out of the water.

Tragically, all three of the men stuck in the cargo hold either drowned or died of hypothermia. Everyone else was pulled out of the water alive. Five of these people had to be treated for injuries. One real lesson learned was that there was no need for anyone to have been in the hold. Crewmen who weren't directly engaged in the loading operation should not have been on the ship, especially considering that the crew had all night to secure the cargo for sea. The ship would have been in port the next morning to load the rotor for the heavier generator.

The Aftermath

The refloating operation took three weeks for the ship to float upright. The salvage company needed two barges with a large crane on each. In spite of the ship's small size, this operation was not without grave difficulty. With the exception of the house and engine room, this little ship was all cargo hold, and all of it was full of water, since the ship was on its port side on the bottom.

The group planned to get the hatch covers back on as quickly as possible so the hold could be dewatered. The hatch covers were the type put on in sections, using the ship's derricks. This created greater difficulty, as the hatch-cover sections were hollow and had a tendency to float while the salvage crew worked to install them in the miserably cold weather conditions. With cutting torches, the salvage crew burned holes in the sections so they could fill with water and sink as they were manhandled into place by people and machines. Fortunately, the pumps discharged at a faster rate than the inflow of river water, and the dewatering operation was a success.

With divers in the water, boats were able to get wire slings around both of the derricks' masts and the two cranes (aboard the barges) took a strain. Imagine a ship being picked up like a boat that sank in a marina, except that these were big cranes. The ship maintained a severe 20° list through the remainder of the dewatering operation. Finally, the ship floated upright and it was safe enough for the representatives of the insurance underwriters to go aboard. There was a coating of oil everywhere and people had to be extremely cautious with every step.[7] The two generators, one in the hold, the other on the bottom of the Hudson River, were recovered, and the barge cranes were able to get them onto the wharf. The owner was paid an appropriate settlement for the damage to the ship, and the remaining fuel was sold locally.

In May of 2004, the Albany Maritime Ministry held a memorial service for the three men who perished. A ceremonial gravestone with their names and the name of their ship was placed in a park adjacent to the Port of Albany.

About the author:

Captain Brendan Saburn has held the rank of captain in the Navy Reserve since 2006. In civilian employment, he's an analyst of maritime safety data in the Office of Investigations & Analysis at Coast Guard headquarters. Prior to this position, he spent five years at the Coast Guard's National Maritime Center, where he was a recognized subject matter expert, specializing in the material used on exams for prospective merchant marine deck officers and other vessel operators. Formerly, and for a number of years, he was an instructor of celestial navigation and other nautical sciences. The Coast Guard issued him the merchant marine license "master of vessels of any gross tons upon oceans" in 1999.

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Endnotes:

1. Technically, this was the main body assembly of the generator—the (stationary) stator and its solid framework. Its rotor would not be included since it would be loaded separately, later in the operation.
2. The International Maritime Organization is the bureaucratic maker and overseer of stability requirements for ships via Safety of Life at Sea Regulations: SOLAS Chapter II-1. Governmental regulation enforcement agencies [i.e., the U.S. Coast Guard and its counterparts in other nations and their cooperative classification societies in seapower nations, such as the American Bureau of Shipping (U.S.), Bureau Veritas (France), Det Norske Veritas (Norway), Lloyds (U.K.)] are the on-site overseers to ensure that ships are built and equipped as required.
3. "Deadweight tonnage" (dwt) is the measure of the ship's cargo-carrying capacity in terms of weight. This tonnage is the weight that will immerse the ship to its maximum permissible draft, and includes the weight of the ship's fuel, water, and stores. This ship's dwt was only 2,760 tons.
4. A ship's waterplane is the two-dimensional area of the horizontal plane formed by the ship at the surface of the water in which the ship is floating. It is simply the outline of the hull at the water's surface, as viewed from above. The overall waterplane, in this case, includes the pontoon's waterplane.
5. This ship had three 150-ton-per-hour ballast pumps. If all three are discharging to the same tank, 2,000 gallons per minute is theoretically pumped. This can only be done in theory, due to the physical constraint of the pipes and valves. Realistically, the flow rate is more like 200 to 250 tons per hour with two of the three pumps online. It's imperative that the swing ballast doesn't get ahead of the load, so that the ship doesn't start to return to its upright position too quickly, which could result in the ship suddenly listing to its outboard side. This could be something of a moot point due to the inherent constraints of the piping system.
6. An unstable ship can list either way regardless of which side of the ship has more weight, and there is no physical tendency for the ship to return to the upright position. A ship in such a state is said to be listing at an angle of loll.
7. A merchant ship's cargo is insured separately from the ship itself. Therefore, there are two concerned underwriter parties. The owner has hull and machinery insurance on the ship; analogous to comprehensive insurance on a motor vehicle. Protection and indemnity insurance on cargo is usually purchased by the party to whom it's being delivered, unless other arrangements are made.