*The 56,000-ton bulk carrier* Sophia D *was severely damaged when it ran aground off the coast of Brazil.*

# A Most Challenging Project: Repair of the *Sophia D*

BY UWE W. ASCHEMEIER AND KEVIN S. PETERS

When most North Americans think of Curacao, they think of it as a tropical island oasis, a place where they get away from the everyday stress at work. But for 130 days, a group of dedicated commercial divers, welders, inspectors, and engineers called it their workplace. It was the site for a job that demanded they work seven days a week, 12 to 14 hours per day, with one day off during the entire job; a job so challenging that part of it was filmed for the television show "The World's Toughest Fixes," which aired on the National Geographic Channel.

## The Ship's Accident

On January 21, 2009, the 56,000-ton bulk carrier *Sophia D* was en route to China, loaded with thousands of tons of iron ore. Off the coast of Brazil, the ship ran aground, damaging the rudder so severely that the vessel was dead in the water, unable to be steered, stranding the 22-member crew for several weeks. At the time of the accident, the 623-ft-long freighter was less than a year old.

Miami Diver, Inc., President Kevin Peters was asked to develop a repair procedure for the damaged components. The vessel's owner and the insurer accepted the company's proposal to perform the repair of the rudder, the rudder horn, and

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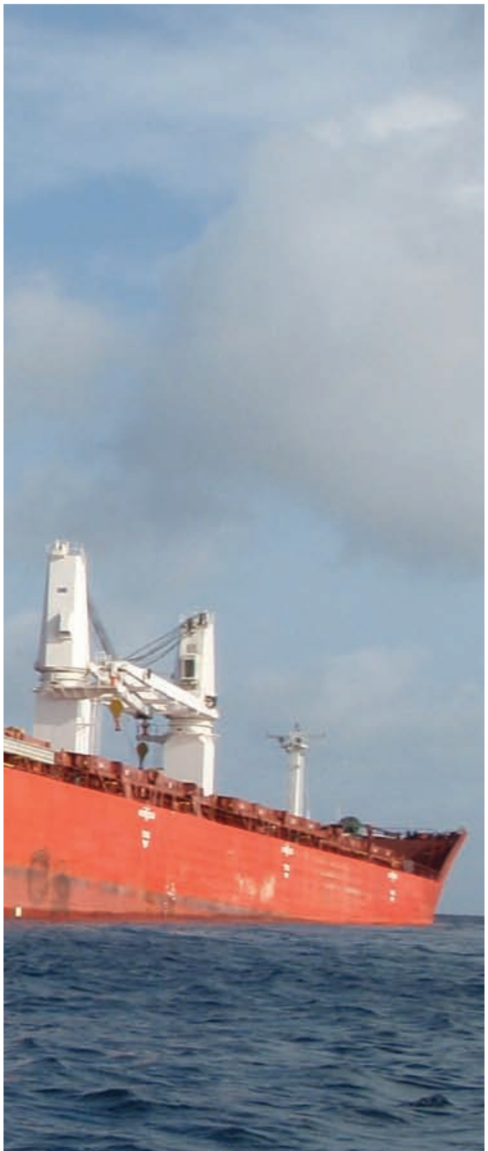

*When a cargo ship ran aground, damaging its massive rudder, a crew of commercial divers, welders, inspectors, and engineers got to work on this tough repair*

other affected components afloat. The proposal specified the repair would take place in Curacao, where Miami Diver has a fully equipped facility.

Repairs could not be performed where the vessel was stranded because of the location, which was several miles offshore, as well as poor weather conditions. In fact, the extent of the damage done to the vessel when it ran aground could not be determined on site.

The vessel was towed (Fig. 1) to Curacao, Netherlands Antilles, in the Caribbean Sea, just off the coast of Venezuela. It took 28 days to tow the vessel the 1000 miles from Brazil to Curacao.

## The Proposed Repair

The proposal for performing the repairs included the following:

- Divers removing the rudder blade underwater.
- Transferring the weight of the rudder from air chain hoists to lift bags and using two of the ship's 35-ton cranes to load the rudder blade onto the barge.
- Building and installing a cofferdam around the rudder horn in order to perform the repairs in the dry.
- Moving the cargo from the aft to the forward holds, which would allow the cofferdam to be trimmed 3 ft above the waterline.
- Dewatering the cofferdam to enable the evaluation of the damage to the rudder horn and the aft peak tank. At the same time, the rudder was to be transported by barge to the shipyard in Curacao for evaluation of the damage.
- Qualifying and certifying the welding procedures and welders to be able to weld on 1.75-in.-thick, high-tensile-strength steel. The repairs to the rudder horn and other damaged components could not be performed until the qualifications were completed.
- Cutting the rudder horn free from the hull and intalling an 8-in. insert plate to remove the "dog leg" so that the pintle bushing could be realigned with the upper neck bushing.
- Cutting out and replacing the damaged shell plating on the ship hull, as well as damaged frames and the longitudinal in the aft peak tank.
- Cutting out and renewing the external rudder plating as well as replacing internal frames that were bent. After finalizing the repair to the internal frames and the skin plate, the upper and lower casting for the rudder stock and pintle had to be line bored.
- Removing the cofferdam after the repairs to the rudder horn and shell plating were complete, then reinstalling the rudder and rudder stock.
- Renewing the steering motor foundation and remounting the steering gear to the rudder stock
- Conducting sea trials.

*Diver-welders prepare to weld.*

## Removal of the Rudder Blade

The first step was to remove the 50-ton, 30-ft-tall rudder underwater.

Divers from Miami Diver, Parker Diving, All Sea Enterprises, and Trident Diving welded 1-in.-thick, 25-ton rigging pad eyes with ¾-in. fillet welds to connect the air hoists underwater onto the rudder and above the waterline to the ship's hull. All underwater wet welding was performed with the shielded metal arc welding (SMAW) process, using Hydroweld FS electrodes, by diver-welders qualified to the requirements of AWS D3.6M:1999, *Specification for Underwater Welding*. The divers installed four 25-ton air hoists — Fig. 2.


*Fig. 1 — The* **Sophia D** *after it was towed into the Caracas Bay in Curacao for repairs.*

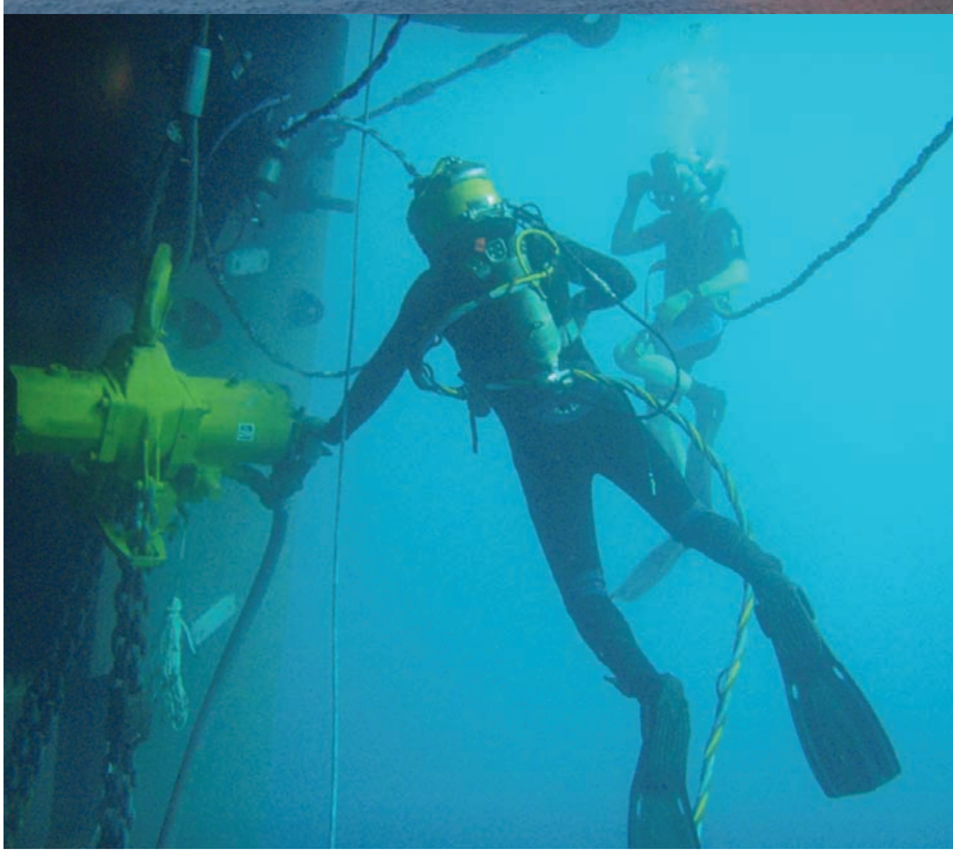

*Fig. 2 — Diver operating a 25-ton air chain hoist during removal of the rudder.*

The divers also had to remove the access plates to the rudder stock hydraulic nut. The underwater cutting was performed utilizing the hydrocarbon arc gouging process, allowing the diver to precisely remove the 1¼-in.-size weld on the access plate. The 500-lb rudder stock hydraulic nut had to be removed to allow the rudder stock to be pulled out through the main deck. However, due to the misalignment between the lower and upper bore, the rudder stock could not be moved and had to be cut apart underwater using a hydraulic diamond rope saw.

The freed rudder blade was lowered on the four air hoists and transferred aft to four 15-ton lift bags — Fig. 3. The rudder blade was towed to the backside of the ship and a preset rigging was attached to perform a two-crane pickup using two of the ship's 35-ton cargo cranes. The rudder blade was then loaded onto the barge and brought to the shipyard.

It was the underwater removal of the rudder that was featured on the National Geographic Channel television show.


*Fig. 3 — The rudder hanging from the lift bags.*

*Fig. 4 — The rudder in the shipyard.*

## Initial Evaluation

The first evaluation of the extent of the damage revealed the following:

- Pintel shaft and rudder stock were unusable.
- Upper and lower castings on the rudder blade were misaligned.
- Steering gear foundation was severely damaged.
- Rudder horn was bent 8 in. starboard, 2 in. aft.
- Ship's hull was fractured forward of the gusset plate.
- Forward gusset plate was damaged.
- Internal frames in the aft peak tank were damaged and fractured in the way of the rudder horn connections.
- The ships's shell plating, internal frames, and the longitudinal member in the aft peak tank were damaged.

## Rudder Blade Repair

The rudder repair was performed in the shipyard in Curacao — Fig. 4. An inspection of the rudder revealed severe damage, which included the following:

- The upper and lower castings on the rudder blade were misaligned.
- The 1.75-in.-thick rudder bottom plate was bent upward to an angle of 45 deg — Fig. 5.
- The skin plates on the port and starboard side as well as the top plate were buckled.
- After those skin plates were cropped

*Fig. 5 — The bent rudder bottom plate.*

*Fig. 6 — Welder Bruce Smythe at work building the 23,000-lb cofferdam.*

*Fig. 7 — Installing the cofferdam.*

*Fig. 8 — Joint preparation on the insert on the port side.*

*Fig. 9 — Ceramic heating elements and insulation are shown installed at the joint to be welded.*

out, internal plates were found to be buckled to a point that they needed to be cropped out and replaced.

The 1.75-in.-thick plate mounted to the bottom of the rudder was bent so badly (Fig. 5), it had to be trimmed approximately 1 in. overlapping the edge of the rudder skin before the rudder could be reinstalled onto the vessel. The plate helps with the steering of the vessel at slow speeds.

## Building and Installing the Cofferdam

A marine engineer specifically designed a cofferdam for this job that would displace 130 cubic yards of water. The cofferdam was installed around the rudder horn after the rudder was removed. The approximately 15-ft-long, 13-ft-wide, and 14-ft-tall cofferdam was built out of ¼-in.-thick ASTM A36 steel, reinforced with 4 × 4 × ⅜-in. angles at the bottom and the sidewalls — Fig. 6.

The 23,000-lb cofferdam was built at Miami Diver's facilities in Curacao while the vessel was being towed from Brazil.

After the cofferdam was finished, it was transported to the vessel, lowered into the water, lifted up, and welded to the ship's hull — Fig. 7. Once installed, 30 tons of cargo had to be moved to the forward compartments allowing the ship to trim the cofferdam 3 ft above the waterline. The cofferdam was dewatered to enable evaluation of the damage to the rudder horn and the aft peak tank.

## Qualifying the Procedures and the Welders

Before any welding could be performed on the vessel, the welders had to be qualified and the welding procedure approved by Det Norske Veritas (DNV).

The tests were performed at Miami Diver's facility in Miami, Fla. The welding engineer wrote the necessary Performance Qualification Records (PQRs). After the PQRs were qualified, five more welders were tested in Curacao, with the local DNV surveyor as witness.

In Miami, two welders welded identical procedure qualification plates, which were 1 in. thick, and 14 in. long per DNV specifications. One welder welded qualification plates according to AWS D1.1, *Structural Welding Code — Steel*, on 1-in.-thick material, in the 3G and 4G positions.

Time and passing the tests were crucial, since the welding procedure was the foundation for the weld repair. Preparations and test runs were performed on Sundays.

The welding procedure qualification plates were welded in the 2G (horizontal) position. The root, filler passes, and cover passes were welded, and then the root was backgouged and rewelded from the backside. The welding process was SMAW with DNV-approved ESAB Atom Arc ⅛-in. 7018 electrodes.

The rudder horn material was AH 36

*Fig. 10 — Two welders working simultaneously on the portside joint.*

*Fig. 11 — Inspector Mark Thury performing an ultrasonic inspection of a complete-joint-penetration weld.*

DNV high-strength steel; the procedure qualification was performed on high-strength, low-alloy (HSLA) material, comparable to ASTM A572 Grade 50 HSLA steel.

Preheat and interpass temperatures were calculated from the chemical composition provided by mill certificates and based on ISO/TR 17844:2004, *Welding — Comparison of Standardized Methods for the Avoidance of Cold Cracks*.

The preheat temperature was calculated to 225°F, with a maximum interpass temperature of 400°F. Temperatures during the tests were verified with heat-indicating crayons.

The DNV surveyor witnessed the welding of the qualification tests. The welds passed the visual inspection and were brought to a local metallurgical lab, accredited by the classification societies.

The following laboratory tests were performed:

- Radiography
- Round tensile test (weld metal)
- Tensile test (flat specimen transverse to the weld)
- Charpy V-notch tests at –20°C with the notch location in weld metal, weld interface, HAZ + 2 mm, and HAZ + 5 mm
- Transverse side bend tests
- Hardness measurements (Rockwell A)
- Macro section test.

Test results were available one week after the plates were delivered to the lab. The results were positive.

## Material

All materials, including the electrodes and the steel, had to be certified. The steel had to meet certain criteria, and had to be approved and stamped by DNV. Det Norske Veritas approved and stamped plate proved difficult to find on short notice in the United States, so DNV agreed to use material approved and stamped by the American Bureau of Shipping, another classification society. Riverfront Steel, Cincinnati, Ohio, was able to locate the material needed in Houston, Tex. The plates were transported by truck to Miami, then flown to Curacao.

## Rudder Horn

Since the rudder horn was bent 8 in. starboard and 2 in. aft, it was cut from the vessel at approximately 12 in. below the hull penetration. An approximately 8-in.-tall section was removed. During the cutting operation, the lower, 25-ton portion of the horn was supported vertically by six 15-ton load-rated turnbuckles. For side alignment, four 10-ton chain hoists were placed forward and aft at the port and starboard sides between the hull plating and the lower casting at an approximately 30-deg angle.

The rough cut was ground smooth, and a 45-deg bevel was prepared at the upper part of the rudder horn plating. For the lower part of the joint, the 8-in.-tall plate insert needed to be prepared with a 45-deg bevel.

An 8-in.-tall plate insert was installed to remove the "dog leg" so that the pintle bushing could be realigned with the upper neck bushing.

The rudder horn nose plate was found to be cracked and had to be cropped out and replaced. The thickness of the steel for the rudder horn plating and the nose plate was 1.75 in.

## Joint Preparation

The 8-in.-tall plate insert on the port and starboard sides, as well as the nose insert plate, were tacked in place and strongbacks were welded onto the backside of the joint — Fig. 8. Run-off plates were welded at the ends of the welding joints.

Joint preparation was a single bevel groove weld with a 45-deg opening angle on top. This allowed the lower part of the joint to be used as a shelf. The root opening was held at approximately ± ⅛ in.

After alignment of the inserts was confirmed, ceramic heating elements and insulation pads were installed to maintain the preheat temperature and to reduce the cooling rate of the finished welds — Fig. 9. After approximately two hours the 225°F preheat temperature was achieved and the root could be welded. Preheat and minimum interpass temperatures were maintained during the welding operation for a distance not less than 3 in. in all directions from the point of welding.

The two upper joints on the port and starboard side were welded first. The root passes on the upper weld joints were welded simultaneously by two welders, each working on one side. They worked in a predetermined welding sequence, staring from the center to the outside. Four welders working at the same time, two on each side (Fig. 10), welded the fill and cover passes. Welding was accomplished in two 12-h shifts.

The welders started in the center of the joint, moving outward. The challenge was to convince the welders they weren't in a race, and each welder had to weld at the same speed. It took 35 passes and approximately 24 hours to fill each of the 12-ft-long joints.

After welding the outsides of the insert plates and the front section, the rudder horn nose and the root sides of the welds needed to be gouged out and rewelded from the inside. This posed a burden on the welders, since they had to sit inside the rudder horn, with preheat temperatures still applied. After welding the root from the inside of the rudder horn,

*Fig. 12 — The rudder on the barge deck awaiting reinstallation.*

the internal girder and the plates needed to be installed.

After welding was completed, the temperature was increased to 350°F, held for 2 h, then decreased 50°F every 2 h until ambient temperature was achieved.

Other welding repairs performed with regard to the rudder horn connections were internal frames in the aft peak tank, hull plate, and gusset plate forward of the rudder horn. The steering gear foundation was reconstructed and the main deck plate, which had had to be cut out to remove and reinstall the rudder stock and steering gear foundation, needed to be re-installed.

## Weld Inspection

Mark Thury of Intnerational Inspections, Inc., a third-party inspection agency based in California, performed all the inspections, including weld inspection.

Det Norske Veritas required 100% visual inspection of all welds, magnetic particle testing on root passes of all welds on insert plates, and ultrasonic inspection of all complete-joint-penetration welds — Fig. 11. In addition, leak testing had to be performed on all watertight compartments. After Thury passed the inspected items, the DNV surveyor performed a verification inspection.

## Removal of the Cofferdam

With the completion of all repairs, divers removed the cofferdam. The rudder also had to be reinstalled (Fig. 12), as well as the rudder stock and the steering gear foundation.

After 130 days in Curacao, the *Sophia D* passed the sea trials and was on her way to China.♦