National Transportation Safety Board

Office of Marine Safety
Washington, D.C. 20594

Group Chairman's Factual Report

Engineering Group

SS *El Faro*
DCA16MM001

1. Accident Information

Vessel:	SS *El Faro*
Accident Number:	DCA16MM001
Date:	October 1, 2015
Time:	0739 eastern daylight time (EDT)
Location:	North Atlantic Ocean, 40 nautical miles northeast of Acklins and Crooked Islands, Bahamas 23.3925˚ N, 73.9029˚ W
Accident type:	Sinking
Complement:	27 crew, 6 supernumeraries

2. Engineering Group

Chairman	Brian Young Office of Marine Safety National Transportation Safety Board Washington, DC 20594
Party member—US Coast Guard	[redacted] Marine Inspector, Office of Traveling Inspectors
Party member—TOTE Services, Inc.	Jim Fisker-Andersen Director of Ship Management - Commercial
Party member—American Bureau of Shipping	Louis O'Donnell Assistant Chief Surveyor

3. Accident Summary

On Thursday, October 1, 2015, about 0715 EDT, the US Coast Guard received distress alerts from the 790-foot roll-on/roll-off container (Ro/Con) ship *El Faro*. The US-flagged ship, owned by TOTE Maritime Puerto Rico (formerly Sea Star Line, LLC[1]) and operated by TOTE Services, Inc. (TOTE), was

[1] On September 17, 2015, the parent company, TOTE, Inc., announced that Sea Star Line had been renamed TOTE Maritime Puerto Rico.

40 nautical miles northeast of Acklins and Crooked Islands, Bahamas, and close to the eye of Hurricane Joaquin. The ship was en route from Jacksonville, Florida, to San Juan, Puerto Rico, with a cargo of containers and vehicles. Just minutes before the distress alerts were received, the *El Faro* master had called TOTE's designated person ashore and reported that a scuttle had popped open on deck two and that there was free communication of water into the No. 3 hold. He said the crew had controlled the ingress of water but that the ship was listing 15° and had lost propulsion. The Coast Guard and TOTE were unable to reestablish communication with the ship. Twenty-eight US crewmembers, including an off-duty engineering officer sailing as a supernumerary, and five Polish workers were on board. The vessel sank in 15,400 feet of water.

The Coast Guard, US Navy, and US Air Force dispatched multiple assets to the ship's last known position, but the search was hampered by hurricane-force conditions on scene. On Sunday, October 4, a damaged lifeboat and two damaged liferafts were located. The same day, the Coast Guard found a deceased crewmember wearing an immersion suit. A Coast Guard rescue swimmer tagged the body in the immersion suit and left to investigate reported signs of life elsewhere but then could not relocate the tagged suit. No signs of life were found, and on Monday, October 5, a debris field and oil slick were discovered. The Coast Guard determined that *El Faro* was lost and declared the event a major marine casualty. The Coast Guard suspended the unsuccessful search for survivors at sundown on Wednesday, October 7.

4. Investigation

The National Transportation Safety Board (NTSB) learned of the accident from the Coast Guard on the afternoon of October 1, 2015. A team of five investigators, a board member, and support staff launched from NTSB headquarters on October 6 and arrived on scene in Jacksonville later the same day.

The investigation was led by the NTSB. Parties to the investigation were the Coast Guard, TOTE, the American Bureau of Shipping (ABS), and the National Weather Service. Company officials, off-duty crewmembers, Coast Guard inspectors, ABS surveyors, and witnesses were interviewed. The on-scene part of the investigation was completed on October 15.

After the initial launch, the fact-gathering phase of the engineering investigation included interviews in Maine (Rockland, Castine, and Portland) during November and December 2015 of family members and of cadets from the Maine Maritime Academy. Coast Guard officers were interviewed in Washington, DC, in the spring of 2016. The Coast Guard convened Marine Board of Investigation (MBI) hearings in Jacksonville in February and May 2016. The NTSB participated in the hearings. Vessel documents and maintenance records were collected from TOTE. Project books and vessel pictures were provided by Maine Maritime Academy cadets who had sailed aboard *El Faro* in the summer of 2015. Investigators visited *El Yunque*, a sister ship to *El Faro*, on several occasions.

5. Vessel

5.1. Description and History

El Faro, hull No. 670, was built in 1975 as the SS *Puerto Rico* at Sun Shipbuilding in Chester, Pennsylvania. It was one of Sun's *Ponce*-class vessels designed specifically for the Puerto Rican trade. Operated by the Navieras de Puerto Rico Steamship Company, the *Puerto Rico* hauled cargo to and from the US East Coast for 15 years. In 1993, the ship was purchased by Totem Ocean Trailer Express and renamed *Northern Lights*. The vessel sailed frequently between Tacoma, Washington, and Anchorage, Alaska. In 1993, the vessel was lengthened by 90 feet at Alabama Shipyard, Inc., during a major conversion.[2] After servicing the Alaska trade, the vessel was chartered by the US government from 2000 to 2003 to carry military cargo for Operation Iraqi Freedom.[3]

In 2006, the ship was converted from a Ro/Ro cargo ship to a Ro/Con vessel and renamed *El Faro*. A Ro/Ro vessel is an oceangoing cargo ship that uses a dockside ramp to roll on or roll off wheeled cargo such as containers, trailers, trucks, cars, and heavy construction equipment. A Ro/Con vessel is a hybrid that has ramps serving vehicle decks as well as cargo decks accessible to cranes.

At the time of the accident, *El Faro* was owned by TOTE Maritime and operated by TOTE Services. From 2006 to 2008, the vessel had been variously under charter, running from the US East Coast to the Middle East. Between 2008 and 2011, *El Faro* was laid up except for brief activations, including a run between Philadelphia, Jacksonville, and San Juan. Beginning in 2011, the vessel was laid up in Baltimore and out of service for about 2 years (until December 6, 2013).[4] In May 2014, *El Faro* was placed into the Jones Act liner service in the Caribbean trade between Jacksonville and San Juan, replacing *El Morro* when that vessel was scrapped.[5] TOTE had plans to convert *El Faro* back to Ro/Ro service for the Alaska trade in early 2016.[6] The vessel's history can be summarized as follows:

- Initial construction: 1975, Sun Shipbuilding, Chester, Pennsylvania.
- Lengthening: 1993, Mobile, Alabama—major conversion.

[2] According to Title 46 *United States Code* (USC) 2101 (14a), a "major conversion" means a vessel conversion that (a) substantially changes the dimensions or carrying capacity of the vessel; (b) changes the type of the vessel; (c) substantially prolongs the life of the vessel; or (d) otherwise so changes the vessel that it is essentially a new vessel.

[3] MBI: TOTE vice president marine operations.

[4] Interview: port engineer, tech review comments TOTE director of operations.

[5] Tech review comments: TOTE director of operations.

[6] MBI: TOTE vice president marine operations.

- Modification from Ro/Ro to Ro/Con configuration: 2006, Mobile—not considered a major conversion by Coast Guard.
- Layup period: Baltimore, Maryland, 2013, approximately 2 years.
- Post-layup shipyard/drydocking: Bahamas, December 2013.

Vessel particulars were as follows:

Vessel Name	**SS *El Faro***
Owner/Operator	TOTE Maritime Puerto Rico/TOTE Services
Port of Registry	San Juan, Puerto Rico
Flag	United States
Type	Cargo—Ro/Con
Built	1975
Official number	561732
Classification society	American Bureau of Shipping
Construction	Steel, reduced scantlings
Draft	30 feet (9.1 meters)
Length	790 feet (240.8 meters)
Beam	105 feet (32.0 meters)
Gross/net tonnage	31,515/21,473
Engine power and type	Steam turbine, 30,000 shaft horsepower, single screw
Service speed	20 knots
Cargo	Containers and rolling cargo
Fuel capacity	11,552 barrels
Fresh water capacity	410 long tons[7]
Ballast water capacity	4,623 long tons
Persons on board	33
Fatalities	33
Damage cost	Estimated $36 million[8]

[7] One long ton = 2,240 pounds.

[8] Email from TOTE director of operations.

5.2. Machinery

The engine room of *El Faro* contained two boilers, a high-pressure turbine, a low-pressure turbine, a reduction gear set, a main condenser, two turbogenerators, three feed pumps, two forced-draft fans, and other associated equipment to produce power and propulsion for the ship. Also located in the engine room were fuel and lube oil service and transfer pumps as well as bilge, cargo, ballast, and fire pumps. Auxiliary equipment such as evaporators, air compressors, a sewage treatment plant, HVAC equipment, and heaters and coolers were located in the space as well.

The machinery installed in the engine room was located on several decks. The propeller shaft, reduction gear, main condenser, boiler foundations, and most pumps were located in the lower engine room on the tanktop deck, called the "lower level." The operating platform, main turbines, turbogenerators, boiler controls, and switchboards were on the third deck. Several fans, storage tanks, and heaters were located above these decks in the "engine casing." Outside the engine room was an emergency fire pump in the No. 3 cargo hold on the starboard side of the tanktop level, a steering gear system at the stern, and an emergency generator on the cabin deck. The cargo spaces contained ventilation fans, winches, and hydraulically operated watertight cargo doors.

5.3. Main Engine

El Faro was propelled by a 30,000-horsepower (hp), General Electric cross-compound, geared steam turbine set connected to a single, fixed-pitched, five-bladed propeller by a set of General Electric reduction gears. The propulsion turbines were installed side by side and connected by a steam crossunder pipe. The turbine rotors were connected to the pinions of the double-reduction gear, thereby reducing the speed of the turbines to propeller speed.[9] According to the 1973 ABS rules for building and classing steel vessels, the lubricating oil system of the main engine was to be "so arranged that it would function satisfactorily when the vessel is permanently inclined to an angle of 15˚ athwartship and 5˚ fore and aft." The vessel was subject to 1973 ABS rules because the construction contract was signed in 1973.[10]

Figure 1. Propeller, rudder, and shaft of *El Faro* while in drydock (TOTE photo**)**.

[9] Main engine manual.

[10] ABS rules for building and classing steel vessels 1973, section 36.65.1, p. 468.

The high-pressure (HP) turbine casing had two halves, upper and lower. The journal bearings and thrust bearings could be accessed without removing the upper case. The steam chest, which contained the ahead steam control valves, was integral with the upper half of the casing.[11]

The low-pressure (LP) turbine had an ahead steam inlet located in the aft end of the lower half of the casing. The inlet was connected to the exhaust of the HP turbine by a crossunder pipe. The astern steam inlet allowed steam to flow to the steam ring of the reversing element.[12]

The turbines were equipped with speed-limiting devices that held the turbine speed at a governing point if an overspeed condition occurred. An overspeed governor pump was located in the forward bearing bracket of each turbine. During an overspeed condition, the output of the governor pump would increase and operate an overspeed relay. The action of the relay would cause the steam control valves to move in the closing direction and limit the speed of the turbine.[13]

[11] Main engine manual.

[12] Main engine manual.

[13] Main engine manual.

Figure 2. Main propulsion turbines seen from aft end of engine room (photo from *El Yunque*).

The rated steam inlet pressure to the HP turbine was 845 psig (pounds per square inch gauge), and the maximum speed of the turbine at rated horsepower was 6,700 revolutions per minute (rpm). The maximum speed of the LP turbine was rated at 3,418 rpm. The maximum allowable propeller speed was 132 rpm.[14]

Connecting the turbine set to the propeller were General Electric double-reduction, double-helical, articulated-type reduction gears, type MD-92-1. The major rotating elements of the gear set consisted of two first-reduction pinions, two first-reduction gears, two second-reduction pinions, and one main gear,

[14] Main engine manual.

connected to the main propeller shaft. The speed of these elements at maximum horsepower was as follows: [15]

First-reduction pinion HP....	6,700 rpm
First-reduction pinion LP.....	3,418 rpm
Intermediate HP................	887 rpm
Intermediate LP.................	887 rpm
Propeller............................	128 rpm

El Faro was equipped with a torque tube between the main engine and the propeller. It was essentially an intermediate shaft, constructed of rolled steel, that connected the stern tube shaft to the propeller shaft. According to *El Faro*'s off-duty chief engineer and the company's director of marine operations, there was a casting at each end about 3 feet in diameter. Another *Ponce*-class vessel, the *Matsonia*, had experienced a failure of the torque tube.[16] It appeared to be an isolated incident and brought to light that the speed-limiting governor needed cleaning to ensure proper response.[17]

[15] Main engine manual.

[16] Interviews: off-duty chief engineer, TOTE director of marine services.

[17] Interview: off-duty first assistant engineer. TOTE director of marine services.

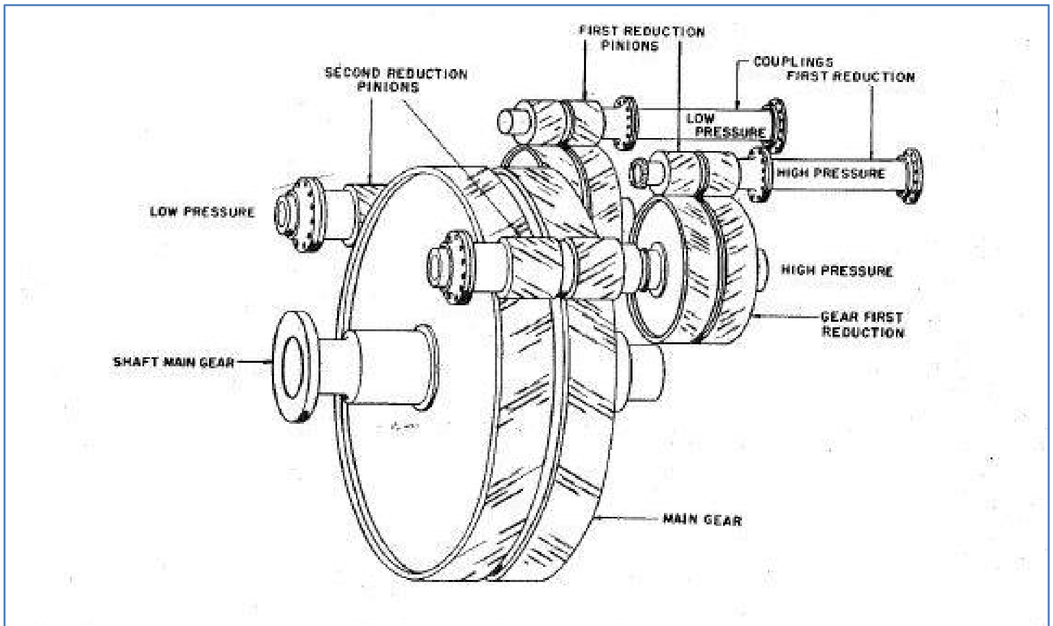

Fig. G–A Gear arrangement diagram

Figure 3. Gear arrangement diagram showing reduction gear set (General Electric manual).

5.4. Boilers

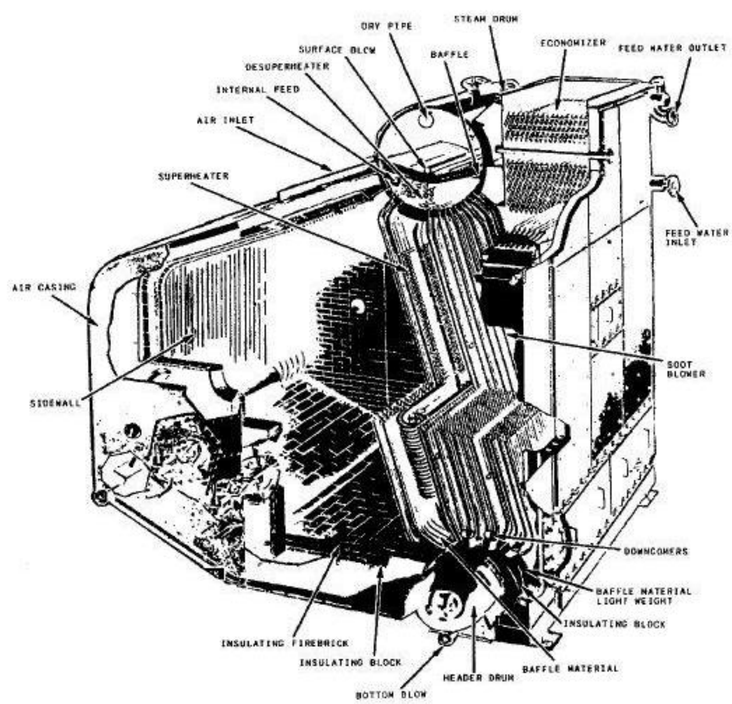

Figure 4-1.—Cutaway view of a D-type boiler.

Figure 4. Cutaway view of main propulsion boiler (Babcock and Wilcox manual).

The two Babcock and Wilcox boilers installed aboard *El Faro* had a design steam pressure of 1,070 psi, but they were being operated at about 860 psi at 900˚ F before the accident.[18] The boilers, rated for 110,000 pounds of steam per hour, had a heating surface of 7,900 square feet. The boilers were designed so that “all components to be supplied for shipyard use . . . permit satisfactory operation under the following conditions unless stated in customer’s specifications: momentary roll–30˚; permanent list–15˚; permanent trim–5˚.”[19]

[18] Interview: off-duty second assistant engineer, engine logbooks.

[19] Email from Babcock and Wilcox district service manager, July 6, 2016.

Each boiler was a two-drum, front-fired unit that included a 60-inch steam drum with hemispherical heads and a 27-inch water drum with elliptical heads. The drums were connected by a generating tube bank of 21 rows of 1-1/4-inch (outside diameter [OD]) in-line tubes staggered at their entrance to the steam drum and bent at the ends so they entered the drums around the circumference of the drum, allowing them to expand or bell.

The generating tube bank was arranged so the furnace gases made a single pass over it before entering the economizer. Two rows of 2-inch OD tubes between the furnace and the superheater screened the superheater from the direct radiation of the furnace gases. One row of 2-inch OD tubes between the superheater and the 1-1/4-inch OD bank tubes supported the superheater guides. One of the screen rows was also used to support the superheater guides.[20]

Superheater. The vertical superheater was made up of 177 U-bent tubes (1-1/4-inch OD) arranged in three loops and connected to two horizontal headers supported at the front and rear of the boiler. Panels in the casing at the bottom of the boiler allowed access to the superheater headers and also to the steam side of the tubes through handholes in the headers. The superheater was arranged so that all produced steam made four passes through it. The U-tubes extended 8 feet 9 inches, measured centerline to centerline on the tubes. Spacer castings were attached to each guide tube. Superheater tubes and guide castings could be replaced without removing the superheater guide screen or other boiler tubes. The superheater tubes in all passes were welded to headers.[21]

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[20] Boiler manual.

[21] Boiler manual.

The furnace was composed of three walls, a roof, and a floor. The front, side, and rear walls were water-cooled with boiler tubes. The sidewall tubes were bent up toward the steam drum and formed the furnace roof. The floor tubes were covered by about 5 inches of refractory (heat-resistant material). Three Saratoga-type oil burners were installed in the burner double front. They consisted of radial door air registers and 12-inch impellers and were equipped with Babcock and Wilcox steam atomizers having automatic shutoff valves.[22]

The superheater cavity for each boiler contained two horizontal IK 525-A soot blowers. The soot blowers entered through the front of the boiler and extended approximately the full length of the superheater.[23]

Economizer. Economizers perform a key function in providing high overall thermal efficiency by recovering low-temperature energy from the flue gas before it is exhausted to the atmosphere, and by transferring the energy to the incoming feedwater.[24] The economizers on *El Faro* were of the extended-surface, continuous-loop, flared type arranged in the uptake after the last row of boiler generating tubes. Each economizer was 16 rows wide and consisted of 1-1/2-inch OD studded tubes. The inlet and outlet headers were seamless forged steel fitted with one handhole in the end of the header for inspection. The tubes were seal-welded externally to the headers.[25]

[22] Boiler manual.

[23] Boiler manual.

[24] Babcock and Wilcox website.

[25] Boiler manual.

Steam Drum Internals. The steam drum had three safety valves on the top centerline of the steam drum. Two of the valves were 2-inch spring-loaded units; the third had a 1-1/2-inch spring-loaded pilot valve. The manufacturer recommended setting the 1-1/2-inch pilot safety valve at 1,030 psig and the 2-inch valves at 1,050 and 1,070 psig.[26]

Internal Feed Line. A 5-inch internal feedline in the steam drum extended about 90 percent of the drum length. Its horizontal centerline was 12 inches below the normal water level and was connected to the feed supply nozzle. The feed pipe had one row of 1/2-inch-diameter holes along the top to introduce feedwater into the drum evenly throughout the length. The normal water level was at the horizontal centerline of the steam drum.[27]

Dry Pipe. A 6-inch dry pipe was suspended along the top centerline inside the steam drum. It was perforated along its upper surface with seven rows of 3/8-inch-diameter holes. Drain holes were drilled in the bottom of the pipe at each end.[28] Steam entered the dry pipe through the upper perforated area and exited the pipe through the connection from the top of the drum to the superheater. The dry pipe had the dual function of reducing moisture carryover and allowing an even withdrawal of steam from the water surface.[29]

Surface Blow Pipe. A surface blow pipe was used to remove grease, scum, and light solids from the boiler water through the surface blow line connection. The horizontal centerline of the surface blow

[26] Boiler manual.
[27] Boiler manual.
[28] Boiler manual.
[29] Boiler manual.

line was 2 inches below the normal water level. The 3/4-inch-diameter pipe was perforated along the top centerline by four 3/8-inch holes.[30]

Chemical Feed Pipe. A 3/4-inch chemical feed pipe was used to inject boiler chemicals into the steam drum while the boiler was operating. It also served as a sampling pipe for testing the boiler water. It extended almost the entire length of the drum. Its horizontal centerline was 6 inches below the normal water level and had a row of 33 1/8-inch-diameter holes drilled along it. The pipe was connected to the chemical feed piping nozzle at the end of the drum.[31]

Swash Plates. Vertical swash plates were located in the lower half of the steam drum at the approximate center point. The purpose of the plates was to reduce excessive surging of water in the drum from one end of the steam drum to the other when the ship was pitching.[32]

Control System. Burner management, steam pressure, and boiler water level in the boilers were monitored and controlled by a system designed and installed by a company called Nortech. Off-duty engineering officers told investigators that boiler automation was tested annually by the ship's crew, in accordance with the periodic safety test procedure retained aboard the vessel. Investigators requested the vessel-specific document from the operating company, but it could not be provided because it had been kept aboard *El Faro*.

[30] Boiler manual.

[31] Boiler manual.

[32] Boiler manual.

Figure 5. *El Faro* boiler control console (photo by Maine Maritime Academy cadet).

Investigators received the periodic safety test procedure from *El Faro*'s sister ship *El Yunque*, which used the Technical Marine Service boiler automation system, a similar test procedure to *El Faro*'s. The procedure listed 16 test items:

- Lamp test
- Manual boiler trip
- Drum level high/low alarms
- Low-low drum level alarm and trip
- Forced draft fan fail alarm and trip
- Low air flow alarm
- Last-flame-out alarm and trip
- Boiler control power
- Burner safety trip control
- Trial for ignition
- Purge cycle

- Boiler in bypass indication
- Power failure alarms
- Atomizing steam low-pressure alarm
- Fuel oil low-pressure alarm
- Process controller operation[33]

According to interviews with off-duty *El Faro* engineers, the periodic safety test procedure was completed during the off-duty second assistant engineer's last trip, which ended about 9 weeks before the accident. He signed off the vessel on August 10, 2015.[34]

5.5. Electrical Generation and Distribution System

El Faro had two steam turbogenerators manufactured by Terry Steam Turbine Company. Two General Electric marine alternating-current generators that operated at 1,800 rpm, powered by 900 psi of superheated steam, were coupled to steam turbines by a set of reduction gears. Each generator had a capacity of 2,000 kilowatts of three-phase power at 450 volts and 60 hertz. The main 450-volt switchboard was energized by the two turbogenerators. The emergency bus, in the emergency generator room, was fed from the main bus through an electrical bus tie.

The vessel was constructed according to the 1973 ABS rules for building and classing steel vessels, which required the generators to "be located with their shafts in a fore-and-aft direction on the vessel and must lubricate and operate satisfactorily when permanently inclined to an angle of 15˚ athwartship and 5˚ fore and aft; the bearings are to be arranged that they will not spill oil under a

[33] Interview: off-duty chief engineer.

[34] Interview: off-duty second assistant engineer.

momentary roll of 22.5°."[35] Each turbogenerator was outfitted with a lubricating system consisting of an oil pump, main sump, cooler, and strainer. The sump, an integral part of the subbase structure, contained baffles to allow for the vessel's pitching and rolling at sea. The turbogenerators were initially designed with positive-displacement, gear-type lube oil pumps that were submerged into the sump to ensure flooding of oil. The pump was driven from the free end of the low-speed shaft through a right-angle gear and vertical extension shaft. According to TOTE, the original right-angle, gear-driven pump was replaced with a pump mounted on the end of the gear case and directly driven by the low-speed gear shaft. A 40-gallon-per-minute (gpm), 50-psi auxiliary motor-driven pump was also piped into the system, as well as an oscillating hand pump for priming or starting the generator without electrical power.[36]

The turbogenerators were equipped with protective devices incorporated into the lubrication system: a low-oil-pressure shutdown in the governor, a low-oil-pressure alarm switch, a low-oil-pressure trip mechanism, and an overspeed trip dump valve.

[35] ABS rules for building and classing steel vessels 1973, section 35.29, p. 380.

[36] Tech review comments: TOTE:

Figure 6. *El Faro*'s main 450-volt electrical switchboard (photo by Maine Maritime Academy cadet).

The emergency diesel generator (EDG) consisted of a Detroit model 7163-7005-16V71 diesel engine driving an electrical generator. The two-stroke, 16-cylinder engine had a bore of 4-1/2 inches and a stroke of 5 inches.[37] The 450-volt, three-phase, 350-kilowatt alternating-current generator could automatically start using battery power and provide electrical power if power to the main bus was lost.[38]

[37] Detroit diesel manual.

[38] Interview: off-duty chief engineer.

According to the 1973 ABS rules for building and classing steel vessels, the emergency generator was required to function when the ship was inclined at 22.5˚ and when the trim of the ship was 10˚.[39]

The EDG fuel supply tank was located outside the emergency generator room on the port side of the cabin deck, just aft of the EDG room. It had a capacity of 5,000 gallons. The tank had last been filled on July 8, 2015, with 1,800 gallons of diesel fuel. According to logbook entries, the tank contained 4,800 gallons on September 1, 2015.[40]

To power the main switchboard from the emergency generator switchboard, the main switchboard had to be stripped of all nonessential loads so the smaller emergency generator could power up vital circuits. This process was called "backfeeding" the main bus from the emergency bus. It was necessary when "lighting off the plant" (firing up the boilers) from a "dead ship condition" (main propulsion plant, boilers, and auxiliaries not operating due to absence of power).[41] On August 25, 2015, the engine department used the backfeed function of the emergency generator to power the main bus while performing maintenance during a scheduled plant shutdown.[42] According to entries made in the preventive maintenance system, the emergency generator was operated monthly with an electrical load for a two-hour period, testing the auto-start function.[43]

[39] ABS rules for building and classing steel vessels 1973, section 35.19.3, p. 377.

[40] Engine logbooks for July 2015 and September 2015.

[41] Interview: off-duty chief engineer.

[42] AMOS maintenance history.

[43] AMOS maintenance history.

5.6. Fuel Oil System

El Faro had a capacity of 11,552 barrels (bbl) of fuel.[44] Fuel consumption was approximately 2.0 bbl per nautical mile.[45] The double-bottom (DB) storage tanks on the *El Faro* were located as follows:

- No. 2A DB inboard port and starboard (approximately 2,202 bbl each)
- No. 3 DB inboard port and starboard (approximately 2,673 bbl each)[46]

At the time of the accident, the vessel burned heavy fuel oil RMK500. Samples of fuel from each bunkering operation were kept on board as well as with the supplier for testing, if necessary. The specifications of the fuel oil received in May 2015 were as follows:[47]

- Viscosity at 50°centigrade (C): 460
- API[48] gravity at 60° F: 10.2
- Density at 13° C: 998
- Temperature (° F): 136
- Flash point (° F): 198
- Pour point (° F): 27
- Water (% volume): 0.05
- Sulphur (% m/m[49]): 3.38

[44] *El Faro* Vessel Information Booklet Rev-1.
[45] MBI *El Yunque* captain testimony.
[46] *El Faro* Vessel Information Booklet Rev-1.
[47] Specifications from records retained by Maine Maritime Academy cadet.
[48] API = American Petroleum Institute.
[49] Percent by mass (measure of concentration).

The fuel was usually burned at sea from the No. 3 DB storage tanks, three port and three starboard. Twice a day, the second engineer on the 4-to-8 watch transferred the fuel from the No. 3 DB tanks to a single fuel oil settler, whose capacity was 1,800 bbl (273 tons). The fuel was heated by steam coils inside the settler to about 130˚ F and pumped through two sets of strainers before being heated again by another set of heaters to 230˚ F, atomized by 150-psi steam, and burned in the boilers.[50] While it was in liner service between Jacksonville and Puerto Rico, the vessel bunkered weekly. It burned about 800 to 900 bbl a day at full sea speed.[51]

The fuel oil settler had a high suction and low suction piping arrangement. The low suction was usually used unless the system contained debris. The engineering crew normally changed both sets of fuel oil strainers before every departure.[52] In interviews, off-duty engineers could not recall any issues with the quality of fuel aboard *El Faro*.[53]

5.7. Lube Oil System

The lubricating oil system for the main engine consisted of two IMO Series TKC422BS-337 positive-displacement vertical rotary screw-type pumps, rated at 450 gpm, manufactured by DeLaval Turbine, Inc. The pumps were driven by 40-hp electric motors.[54] According to the electrical power distribution diagram (1252-938-1), lube oil service pump No. 1 was powered by the main 450-volt switchboard and protected by a 100-amp breaker. Lube oil service pump No. 2 was powered by the

[50] Engine logbook.

[51] Interviews: off-duty chief engineer and off-duty second assistant engineer.

[52] Interviews: off-duty chief engineer and off-duty second assistant engineer.

[53] Interviews: off-duty chief engineer and off-duty second assistant engineer.

[54] DeLaval lube oil service pump instruction manual.

emergency 450-volt switchboard and also protected by a 100-amp breaker.[55] The manufacturer recommended that a priming connection be piped to the suction side of the pump, and that a vent connection be made to the discharge side of the pump. The lube oil pump manual states that "running the pump without oil will cause rapid wear of housings, rotors, and other internal parts."[56] The pumps were equipped with mechanical seals. The purpose of a mechanical seal is to contain the pressurized fluid inside the pump housing where the rotating shaft passes through a stationary housing. A mechanical seal is a device that consists of a stationary component and a rotating assembly, held against each other with spring pressure, and typically lubricated by a fluid film created by the fluid being pumped. The lube oil system normally operated with one service pump running, with the second service pump in standby mode. This configuration would allow the standby pump to automatically start if a pressure switch sensed a 10-psi pressure drop in the lube oil supply line to the bearings.[57] Discharge oil pressure could be low for several reasons, including loss of pump prime, leaks in suction piping, obstructions (such as debris) in suction piping, leaking seals, low oil level, air in system, or clogged strainers.[58] According to "Control and comm, upper machinery space" drawing 1252-930-1, *El Faro* had communication points to advise watchstanders about lube oil issues such as: lube oil gravity tank, low lube oil pressure to main unit, lube oil cooler temperature, seven main unit lube oil temperature sensors, main unit lube oil sump. While aboard *El Yunque*, investigators noted the following alarms for the lube oil system on the main control panel: lube oil gravity tank level low, lube oil pump power failure, standby lube oil pump running, lube oil sump level

[55] Electrical power distribution diagram, 1252-938-1,

[56] DeLaval lube oil service pump instruction manual.

[57] Interviews: off-duty chief engineer, off-duty first assistant engineer. TOTE's arrangement of machinery material list.

[58] DeLaval lube oil service pump instruction manual.

high, lube oil sump level low, lube oil service pump discharge pressure low, lube oil cooler temperature low, lube oil cooler temperature high.[59]

Figure 7. Lube oil pumps and associated piping (photo from *El Yunque*).

The pumps discharged lube oil to the main engine bearings through an orifice in the supply line, as well as to a 3,200-gallon gravity tank in the upper engine room. The orifice was sized and adjusted during original construction to provide a pressure of 12 psig at the lube oil inlet header to the unit, with

[59] Control and comm, upper machinery space" drawing 1252-930-1,

oil at 115˚ and a Saybolt viscosity of 279.[60] The gravity tank was designed to overflow when at the proper level, and to supply lube oil to the bearings of the main turbines and reduction gears through a 5-inch pipe if pump pressure was lost. The gravity tank, which was 9 feet high, was located on the main deck level, about 35 feet above the operating platform. During normal operation, the level in the gravity tank would be maintained above an internal overflow line located 8 feet 2 inches above the bottom of the tank. The overflowing oil could be observed and monitored on the operating level of the engine room through an illuminated port ("bull's-eye") in the oil supply line as the oil returned to the bottom of the main sump. In the event of pressure loss, about 8 minutes of reserve oil for the main engine bearings was available in the gravity tank. The reserve oil would flow down through the supply pipe, through the orifice, and into the bearings as protection while the engine was coming to a stop. [61]

[60] Diagrammatic arrangement of the lubricating system, drawing 663-904-100.

[61] Interviews: off-duty chief engineer, off-duty first and second assistant engineers. Main engine manual.

Figure 8. “Bulls-eye” for monitoring lube oil flow to main engine (photo from *El Yunque*).

The lube oil service pumps took suction from the reduction gear sump through an 8-inch pipe, a check valve, and a set of duplex magnetic suction strainers. According to the chief engineer’s turnover notes from August 2015, both lube oil service pumps would have required maintenance during the upcoming shipyard repair period. The forward pump required replacement of the mechanical seal, and the after pump required the pump to be rebuilt or replaced because it was “running 3 psi lower than the forward pump.” These items were identified in a worklist for the shipyard. [62]

[62] Chief engineer’s turnover notes and shipyard worklist August 2015.

Figure 9. Lube oil service suction strainers (photo from *El Yunque*).

The lube oil sump was located at the bottom of the reduction gear and extended below the tanktop level. According to the diagrammatic arrangement of the lubricating system, the suction pipe was 10 inches above the bottom of the sump, about 22 inches to starboard of centerline, and about 24 inches from the after bulkhead of the sump. The sump was accessed by two manholes in the forward end of the sump.[63] A measurement taken aboard *El Yunque* in October 2016 indicated that the pump suction was located 73 inches above the tanktop. Using the diagrammatic arrangement of the lubricating system, investigators

[63] Diagrammatic arrangement of the lubricating system, drawing 663-904-100.

estimated a height of 90 inches between the bell mouth to the tanktop inside the lube oil sump. Further measurements were to be made aboard *El Yunque* at the next opportunity.[64]

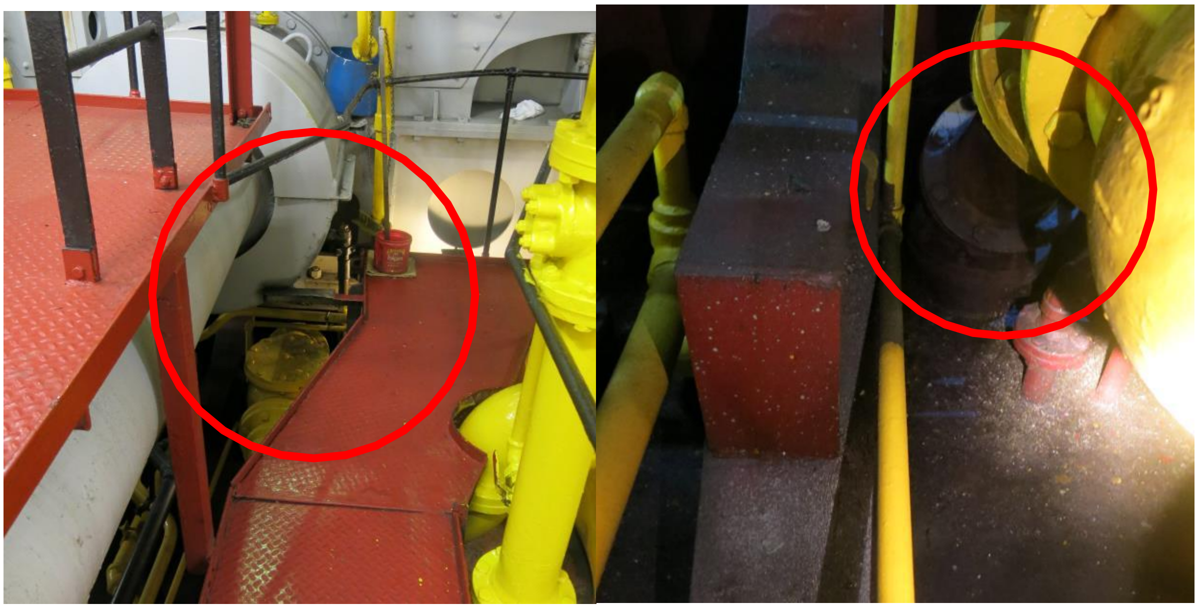

Figure 10. *Left*: Lube oil check valve above sump suction below main shaft. *Right*: Lube oil suction pipe at tanktop. (Photos from *El Yunque*)

According to logbook entries from September 2015, when the main engine was operating at about 120 rpm, the normal operating lube oil suction pressure was about 8 psig, and discharge pressure was about 58 psig. The lube oil typically entered the coolers at about 134˚ F. The temperature of the lube oil was about 20˚ lower after being cooled by the single-pass seawater coolers, which were rated for 450 gpm.[65]

The pressure relief valve on the discharge side of the lube oil pumps was set at 85 psig. The pump manufacturer stated that the relief valve discharge should not be piped to the pump inlet line; but if it was

[64] Connections on lube oil sump, drawing 663-904-04.

[65] Diagrammatic arrangement of the lubricating system, drawing 663-904-100, main engine logbooks.

necessary to be piped in this manner, it should be made as remote from the pump as possible. A set of 5-inch magnetic duplex strainers was located on the discharge side of the pumps, as well as an orifice that was installed to maintain 55 psi of pressure to the turbine governor system.[66] Also part of the lube oil system were two coolers—heat exchangers that used seawater to remove heat generated by the main engine from the oil. Two Alfa-Laval purifiers were piped into the system to remove water and contaminants from the lubricating oil for the propulsion turbine/reduction gear and the ship's service turbogenerators.[67]

The main engine lube oil sump had a design capacity of 2,870 gallons. The high-level capacity was 2,020 gallons, the operating capacity was 1,426 gallons, and the low level was 724 gallons. According to logbook entries, the lube oil level was maintained at about 26 inches.[68] According to the alteration section of the diagrammatic arrangement of the lubricating system for hulls 662, 663, and 664, changes were made to the original design specifications for the operating levels of the lube oil sump in 1972 before the keel of *El Faro* was laid. The operating capacity was increased from 900 gallons to 1,426 gallons, the low-level capacity was decreased from 750 to 724, and the sump design capacity was decreased from 4,250 gallons to 2,870 gallons.[69]

The sounding table for the quantity of main engine sump lube oil obtained from *El Yunque* indicated that a sounding of 26 inches corresponded to a quantity of 1,345.67 gallons in the sump.[70] The

[66] Diagrammatic arrangement of the lubricating system, drawing 663-904-100.

[67] AMOS component list.

[68] Main engine logbooks.

[69] Diagrammatic arrangement of lubricating system, drawing 663-904-100.

[70] Diagrammatic arrangement of lubricating system, drawing 663-904-100.

sump was equipped with a manual sounding tube, as well as a remote level transmitter that displayed the sump level at the operating console.[71]

El Faro had two tanks for the storage of additional lube oil. A 4,465-gallon, rectangular storage tank was located on the starboard side of the operating level at frames 195-199, and a 4,608-gallon, rectangular settling tank was located on the port side of the operating level at frames 195-199.[72] Lube oil could be added to the main engine sump via the lube oil purifier through a 2-inch pipe.

A low-bearing-oil-pressure switch was installed in the oil feed line to the main engine bearings. The switch was electrically connected to a normally deenergized solenoid dump valve. The pressure switch was designed so that if it sensed a pressure drop at the most remote bearing to a point where the bearings could be damaged, it would energize and release lube oil pressure from the ahead operating cylinder, thereby closing the ahead steam control valves by action of the springs on the valve levers. The valve was set to close at 4 psig and open at 8 psig of oil pressure.[73] If the lubricating system pressure fell below 4 psig at the pressure switch, the throttles would close and stop the flow of steam to the turbines.

[71] Diagrammatic arrangement of lubricating system, drawing 663-904-100.

[72] Diagrammatic arrangement of lubricating system, drawing 663-904-100.

[73] Diagrammatic arrangement of lubricating system, drawing 663-904-100.

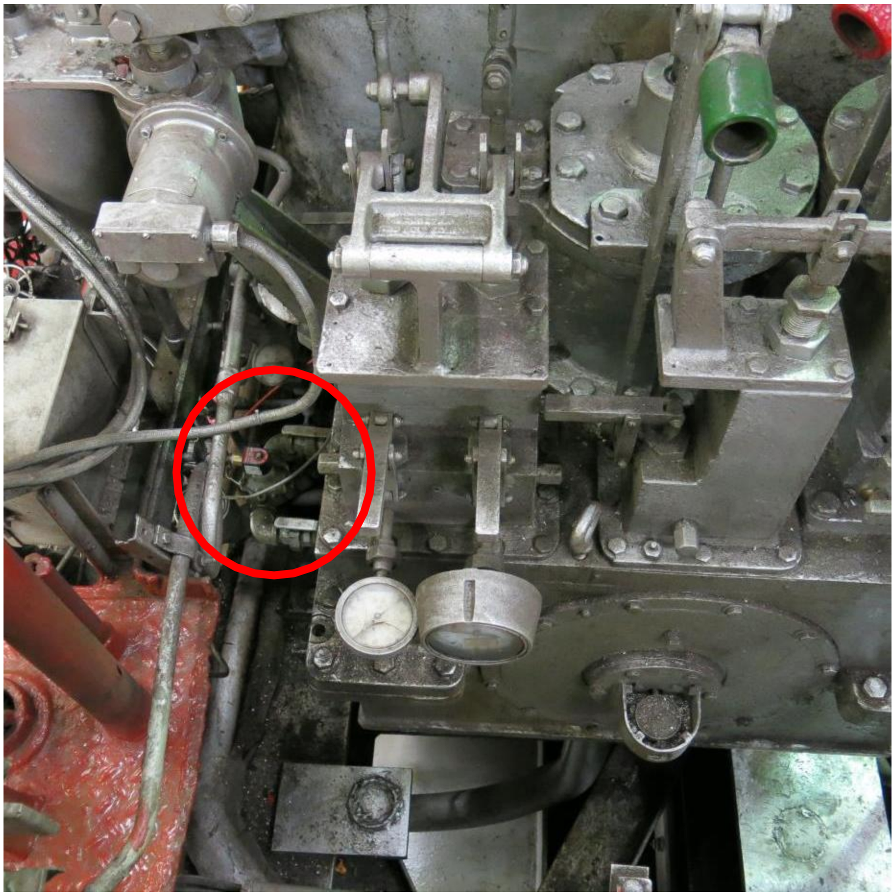

Figure 11. Low-lube-oil pressure switch, circled (photo from *El Yunque*).

The ahead steam valves were located in the steam chest of the HP turbine. They were arranged in a “split beam” configuration that allowed the valves to lift off their seats in a specific sequence when, in response to the movement of the ahead operating cylinder piston, the beam was raised by the lift rods.

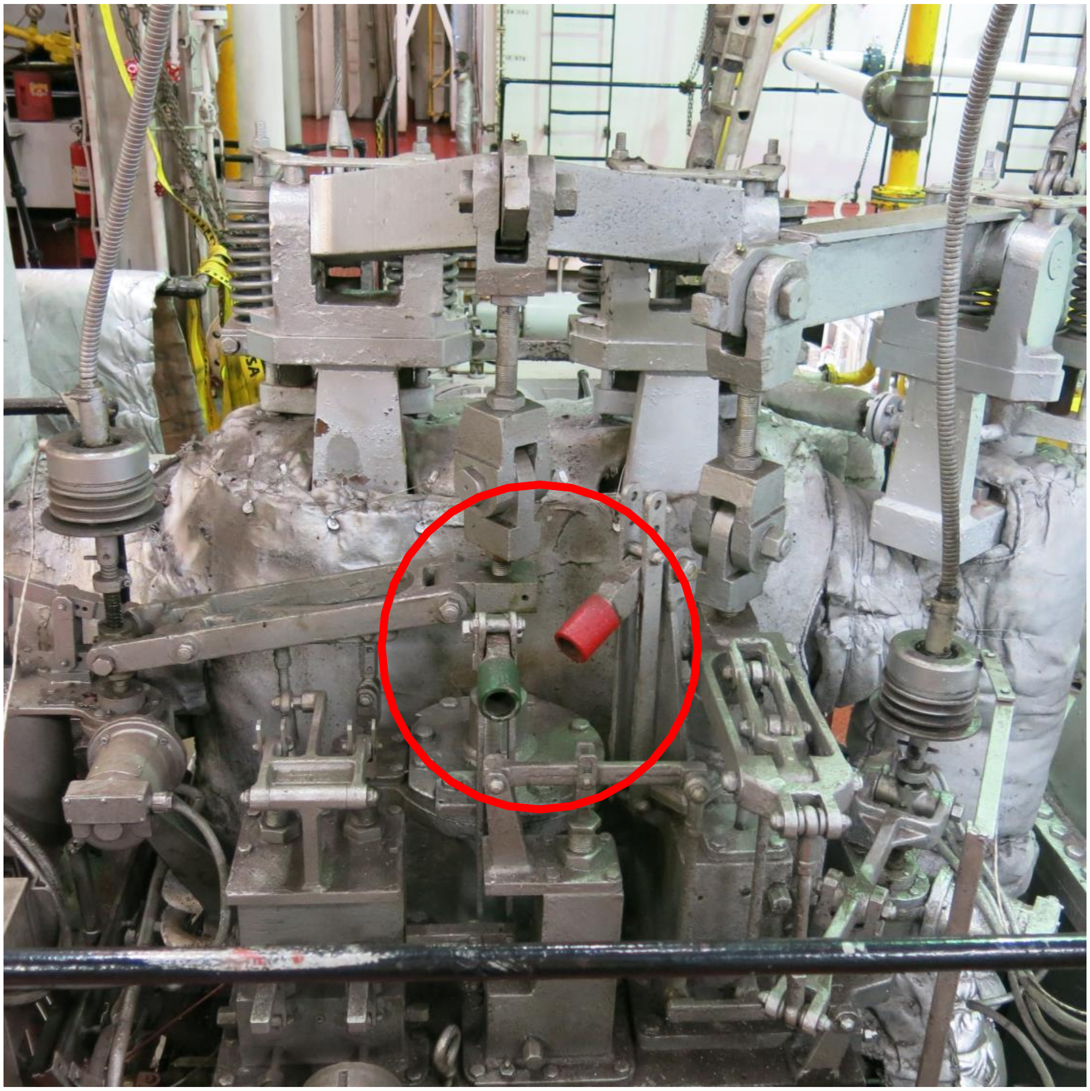

Figure 12. Main engine throttle arrangement, emergency levers circled (photo from *El Yunque*).

The ahead operating piston responded to the steam control valve on the main console, which would be manually adjusted by a member of the engine department based on orders received from the bridge via the engine-order telegraph.[74]

[74] Main engine manual.

Figure 13. Engine order telegraph on operating console of engine room (photo from *El Yunque*).

In the event of a failure of the control mechanism, including a loss of control oil pressure, the ahead and astern control valves were designed to be operated with a long-handled emergency bar or hydraulic hand pumps attached to cables in the overhead that, in an emergency, would raise the lifting beams and admit steam to the turbines.[75]

[75] Main engine manual.

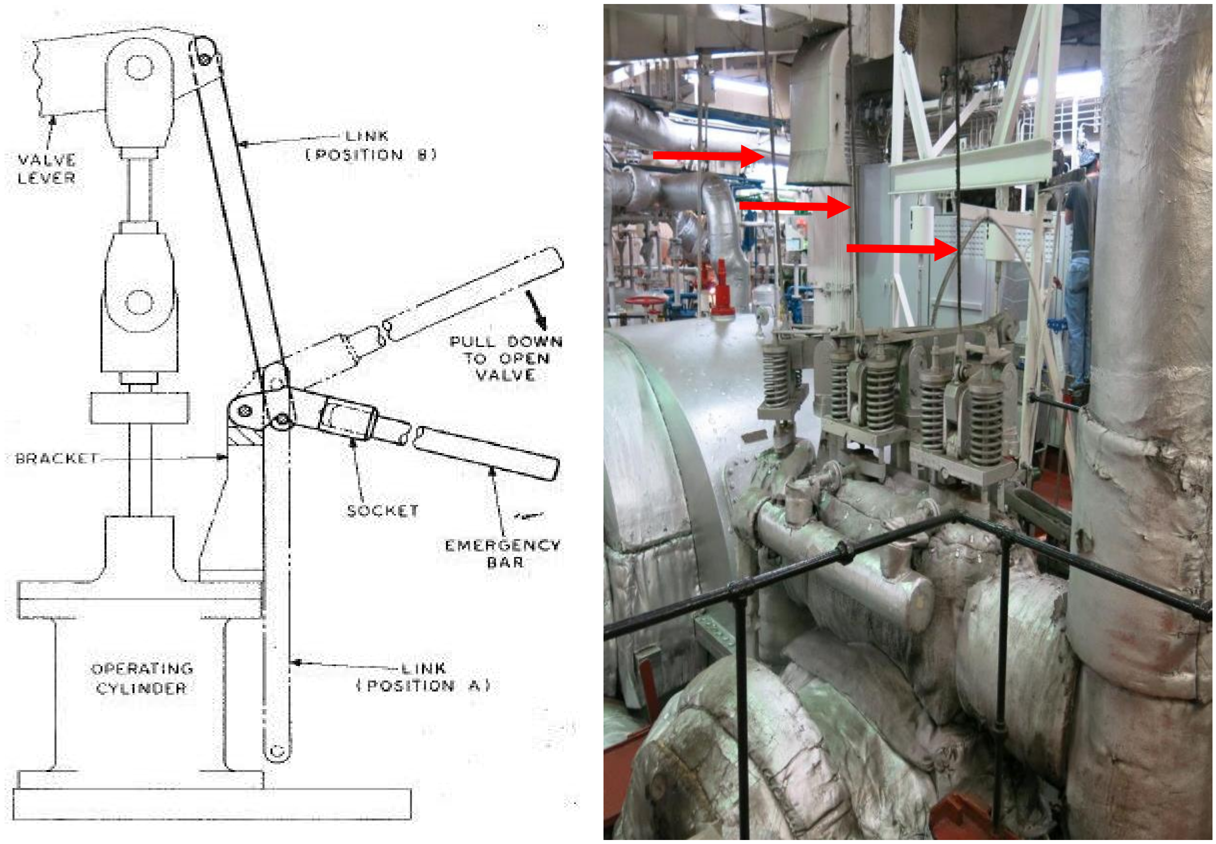

Figure 14. *Left*: Emergency bar for steam control valves (schematic from General Electric manual). *Right*: Emergency operating cables, identified by red arrows (photo from *El Yunque*).

According to the manufacturer's manual, lube oil could be lost for several reasons: plugged strainer, pump failure, stuck oil header reducing valve, low oil level, improper valve lineup, defective pressure sensor, or excessive oil leakage due to a broken oil line. The action required in such cases was to stop rotation of the shaft and restore oil pressure if possible.[76]

The lube oil system also contained overspeed governor pumps, one in each forward bearing bracket of each turbine. The pump impellers were assembled on the forward end of the turbine rotors. The oil inlets to the pumps came from the bearing headers, and the outlets from the pumps were piped to the

[76] Main engine manual.

overspeed relay. If a condition developed that would cause the turbines to overspeed, the output of the governor pumps would increase and actuate an overspeed relay. The action of the relay would cause the steam control valves to move in the closing direction and decrease the speed of the turbines by limiting the amount of steam admitted.[77]

The overspeed system was designed to be self-restoring. When the overspeed condition had been corrected and normal turbine speed was resumed, the lube oil output pressure would drop and the steam control valves would be restored to their previous opened position.[78]

[77] Main engine manual.

[78] Main engine manual.

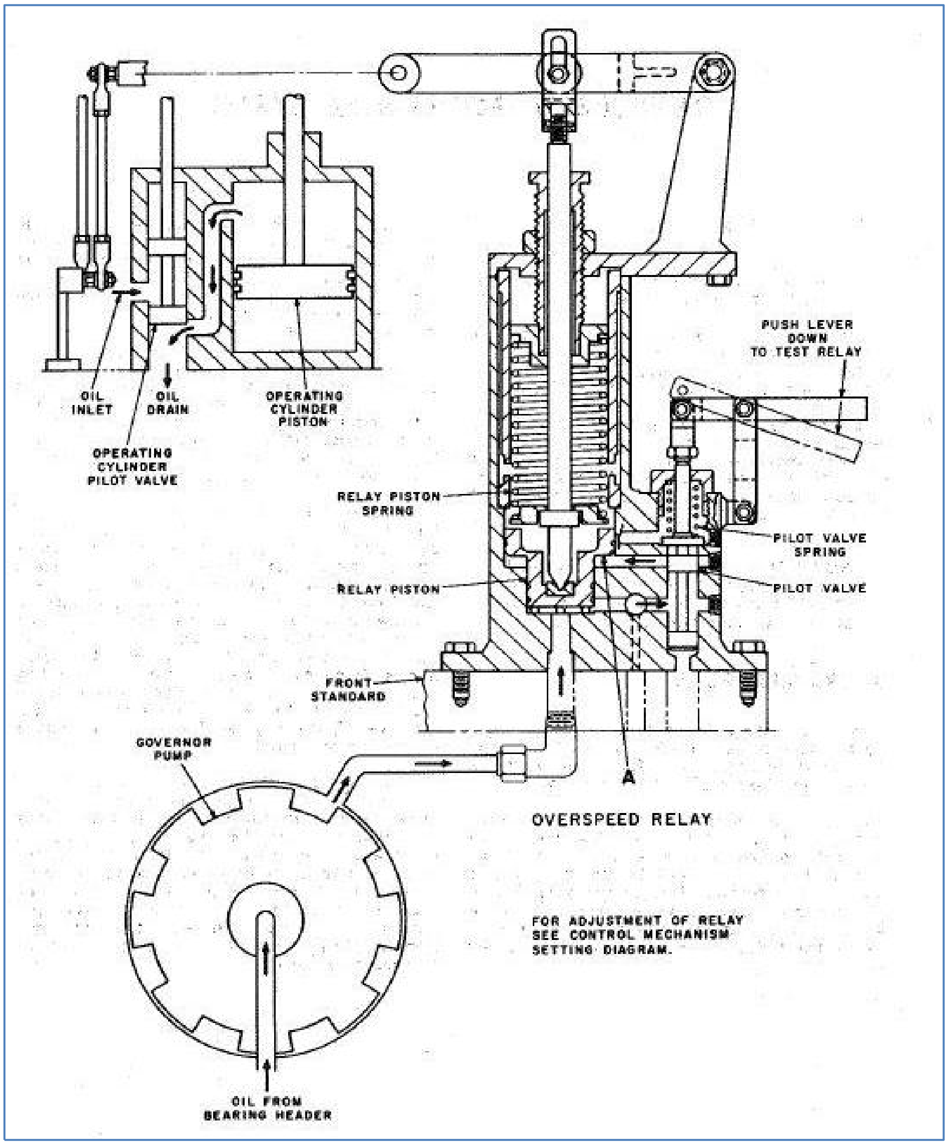

Figure 15. Overspeed relay and speed governing system (schematic from General Electric main engine manual).

The manufacturer recommended that the overspeed relays be tested when operating at greater than 90 percent of ahead speed to ensure that the system was in proper working condition.[79] The off-duty chief engineer stated that the overspeed limiting device was tested monthly on southbound trips because the

[79] Main engine manual.

vessel would then be running at higher rpms. The overspeed protection device was activated by stepping on a foot-pedal located forward of the HP turbine. An engineer would depress the pedal, observe the throttle closing, then release the pedal and observe the throttle opening up again. The off-duty chief engineer stated that there had not been any issues with these tests.[80]

The monthly tests were recorded in a computerized system called AMOS (see section 6.1). A review of the AMOS maintenance records for 2015 indicated that the overspeed test was completed on February 5, July 1, and September 8 of that year. No frequency was assigned to the work order in AMOS.[81]

The manufacturer recommended an oil with a Saybolt viscosity of 380-560 seconds at 100˚ F and 54-70 seconds at 210˚ F, and a minimum flash point of 360˚ F.[82] *El Faro* used Chevron GST oil (ISO grade 100) as the lubricating oil in the main engine and reduction gear set.[83] Typical test data, obtained from Chevron's website, indicate that the Saybolt viscosity of the GST oil was 520 at 100˚ F and 65.4 at 210˚ F, which met the manufacturer's specifications. The flash point was 504˚ F, which also met the specifications.[84]

The lubricating oil for the main engine system was analyzed quarterly through Chevron's LubeWatch maintenance management system. Oil samples were taken on board and sent to a LubeWatch laboratory for analysis. According to the LubeWatch website, results can be received immediately, by

[80] Interview: off-duty chief engineer.
[81] AMOS maintenance system.
[82] Main engine manual.
[83] Chevron LubeWatch oil analysis report (see text).
[84] Chevron website.

phone, fax, or email, or can be sent by mail. NTSB investigators examined quarterly LubeWatch oil analyses from 2014 and 2015 for several *El Faro* systems, including turbogenerators, emergency generator, feed pumps, main turbines, air compressors, steering gear, stern tube bearing, and strut bearing.[85] The analyses consistently reported that "wear rates were normal; abrasive and other contaminant levels are acceptable, viscosity within specified operating range for the main turbine oil system."[86]

The level of lube oil was normally maintained at 26 inches in the sump.[87] *El Faro* had a storage capacity of 51 long tons of lube oil.[88]

On March 14, 2015, the *El Faro* captain submitted a marine casualty report to the Coast Guard after an incident in which the main engine shut down soon after departing San Juan.[89] No mechanical failures were found. The company conducted an internal investigation and determined that the cause was human error: a crewmember had mistakenly closed a valve in the lube oil system to the main engine. The situation was rectified and corrective actions taken in which the crew received training and the valves were labeled and tied in the proper position.[90]

[85] LubeWatch oil analysis report.

[86] LubeWatch oil analysis report.

[87] Engine logbooks.

[88] *El Faro* ship particulars, p. 42, Maine Maritime Academy cadet sea project.

[89] Coast Guard form CG 2692.

[90] Interview: TOTE director of ship management - commercial.

5.8. Steering

El Faro's steering system was built by Kawasaki Heavy Industries, Ltd., of Kobe, Japan. It was an electrohydraulic system, type FR-280. The two Kawasaki-Bruninghaus type BV-732 variable-displacement, axial-piston hydraulic pumps were powered by a pair of 60-hp, three-phase, 60-hertz, 1,150-rpm induction motors having an output of 45 kilowatts. One of the electric motors that powered the system was fed by the main 450-volt bus, and one was fed from the 450-volt emergency bus. The system was designed to have a maximum torque of 140 ton-meters and to turn 65° in 28 seconds. The diameter of the ram was 280 millimeters.[91]

5.9. Bilge and Ballast System

The cargo bilge pumping system was powered by the 450-volt main bus. Two vertical centrifugal bilge/ballast pumps, manufactured by Worthington, were located on the lower level of the engine room. Each pump was driven by a 20-hp vertical electric motor. The pumps were rated for 950 gpm at 28.5 psi.[92]

An emergency vertical, centrifugal, submersible bilge pump was powered by the emergency power supply. The pump was located on the lower level of the engine room and could dewater the machinery space. The pump, manufactured by Prosser, was rated at 50 gpm at 30 feet of total dynamic head.[93]

[91] Steering gear manual.

[92] Arrangement of machinery material list.

[93] Arrangement of machinery material list.

According to the AMOS system, bilge alarms in the engine room and cargo spaces were required to be tested monthly. [94] A bilge alarm panel was located in the engine room.[95]

5.10. Fire Main System

The fire main system aboard *El Faro* consisted of a combination pump, called a “bilge, fire, and general service pump,” located on the starboard side of the lower engine room. The pump was a Worthington vertical, centrifugal model rated at 575 gpm at 125 psig. An emergency fire pump, rated for 635 gpm at 125 psig, was located on the starboard side of the No. 3 cargo hold, on the tanktop level. This pump, also a Worthington vertical, centrifugal model,[96] had its own sea suction directly outboard of the pump. As seen in figure 15, the fire pump was protected by a vertical guard pipe forward of the pump. According to a diagram supplied by TOTE, a platform was located above the pump and a vertical ladder was installed near the pump.[97]

[94] AMOS maintenance system.

[95] MBI transcript: chief engineer.

[96] Arrangement of machinery material list.

[97] General arrangement AutoCad drawing.

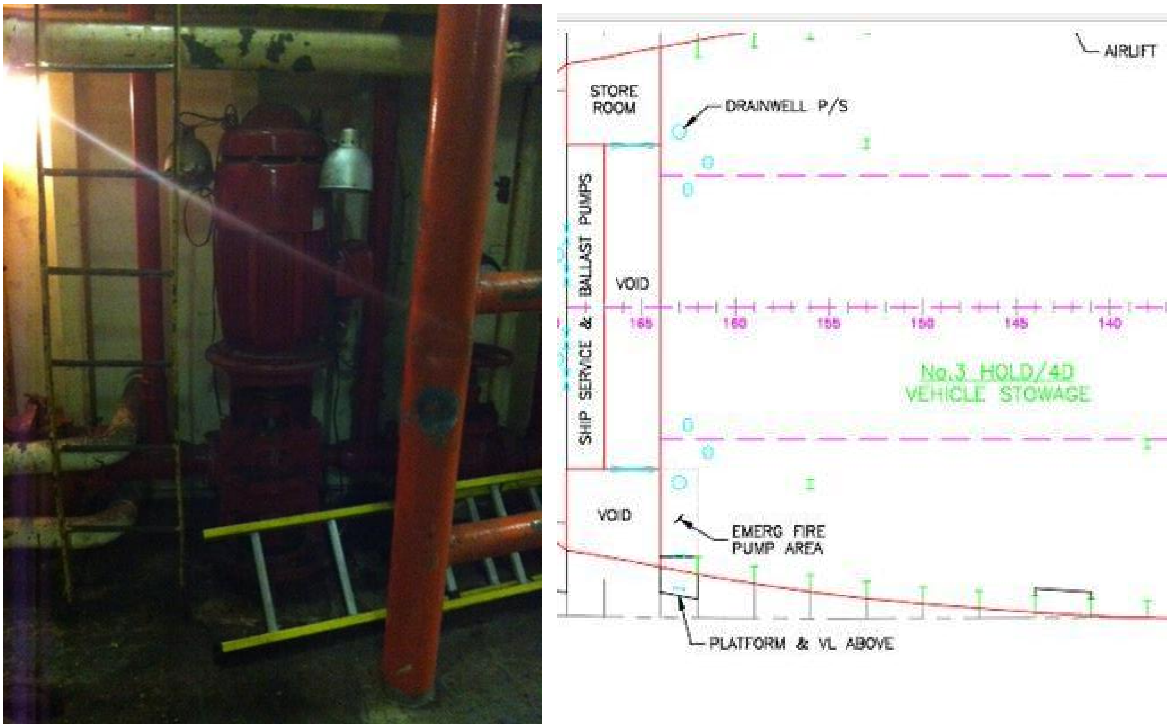

Figure 16. Left photo shows emergency fire pump in No. 3 hold (photo by Maine Maritime Academy cadet). On right, diagram of emergency fire pump location in No. 3 hold, deck four (drawing by Tote).

While aboard *El Yunque,* investigators located the emergency fire pump in the No. 3 hold on the tanktop in a similar location to that of *El Faro*'s emergency fire pump. The pump aboard *El Yunque* had vertical pipes welded to the deck and framing as protection. There was no protection around the suction pipe and valve.

Figure 17. Emergency fire pump and inlet piping in No. 3 hold of *El Yunque*.

5.11. Engine Room Ventilation System

The engine room ventilation system consisted of two supply fans and two exhaust fans. The axial-flow supply fans were rated for 70,000 cubic feet per minute each and were located in the casing of the engine room. The supply fan intakes were located on the aft and outboard sides of the ventilation trunk on the main deck. Fire damper handles were located on the aft bulkhead of the ventilation trunk on deck No. 2. The fans discharged outside air into ductwork in the engine room to distribute the air throughout the spaces. The engine room exhaust fans were rated for 43,000 cubic feet per minute each and were located in the upper casing of the engine room. The exhaust fans discharged air through ductwork leading to the aft side of the lower navigation bridge deck.[98]

6. Maintenance

6.1. AMOS

The crew of *El Faro* used a computerized preventive maintenance, spare parts, and purchase tracking system called AMOS (Asset Management Operational System). Investigators reviewed maintenance records and purchase orders for the previous 2 years, downloaded from the operating company's file server, and conducted interviews. The off-duty chief and first and second assistant engineers reported no overdue or deferred maintenance at the time of the accident.[99] The *El Faro* port engineer stated in an interview that he did not check work orders for their completion status and was unaware if there were any outstanding work orders. [100] In an interview, the director of ship management-commercial said that he did not monitor the activity in AMOS on a daily, weekly, or monthly schedule, but did so when an issue was communicated to him. The director further stated that completion of planned maintenance was verified through internal audits. The chief engineer and first assistant engineer were the

[98] Arrangement of machinery material list.

[99] Interviews: off-duty chief engineer, off-duty first assistant engineer, off-duty second assistant engineer.

[100] Interview: port engineer.

only engine department officers with access to AMOS. They would manually enter maintenance histories and order spare parts.[101]

Each piece of equipment on the vessel was assigned a “component number” in AMOS, and periodic “work orders” were assigned to these components based on weekly or monthly intervals. In 2014, 308 records were entered for various maintenance tasks by the deck and engine departments. Routine maintenance, such as inspections, oil changes, lubrication, and manufacturer’s recommended maintenance, were recorded as part of the planned maintenance program. Equipment tests and surveys were also recorded in the database. In 2015, 435 maintenance records were entered into the system up to the time of the accident. A total of 23 entries were made in 2014 and 11 in 2015, under the “Unplanned/Corrective” class of maintenance, in which machinery failures that had been corrected were identified and rectified aboard the ship.[102]

6.2. Boiler Inspection

According to AMOS entries and an email sent by the chief engineer on July 29, 2015, the crew had inspected and cleaned the port boiler on July 11, 2015. The chief engineer advised the port engineers that the brickwork was getting worse and that the front waterwall tubes were bowing out “even further.” The crew had inspected and cleaned the starboard boiler on July 25, 2015, and reported that the front wall brickwork was starting to fail and that the front waterwall tubes were bowing out.[103] As a result of the inspections, the chief engineer recommended that Walashek complete a boiler survey to determine the

[101] Interviews: off-duty chief engineer, off-duty first assistant engineer, off-duty second assistant engineer.
[102] AMOS written history.
[103] AMOS written history.

scope of work to be completed in the shipyard. He recommended that the boilers needed the front wall brickwork repaired or replaced, burner throats renewed, floor brick replaced, and all fire stops repaired. The port engineer responded to the email the following day, stating that he had contacted Walashek to set up inspections and that he wanted to start on the work as soon as logistically possible.[104]

The fire side of the starboard boiler was inspected by the Walashek boiler repair company (Jacksonville) on September 11, 2015, to identify required maintenance to be addressed during the upcoming shipyard repair period (scheduled for November 2015). The inspection report indicated that the front waterwall tubes were bowed, the refractory damaged, and the burner throats deteriorated.[105] The "highly recommended" repairs included renewing the front wall tubes, brickwork, and burner throats on both boilers. The Walashek representative did not recommend a time frame for the repairs and stated in an interview that in his professional opinion, a couple of months could have elapsed from the inspection date to the repairs.[106] Walashek also recommended restoring the furnace decks, removing the waterwall and superheater handhole plates to inspect headers and seats, opening both steam and water drums for water side inspection, and inspecting a sample of the generator and water tubes with a borescope for pitting and corrosion. Walashek reported that the port boiler economizer had seven temporary tubes (jumpers) installed, signs that the upper bank was starting to fail. Walashek recommended retubing the upper economizer bank.[107]

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[104] Chief engineer email to port engineer July 29, 2015.

[105] Walashek boiler report, September 11, 2015.

[106] MBI 1 transcript: Walashek representative.

[107] Walashek boiler report, September 11, 2015.

The port boiler was not inspected by Walashek, but it was assumed to be in the same condition as the starboard boiler, based on discussions with the *El Faro* off-duty chief and first and second assistant engineers. On September 24, 2015, Walashek prepared a repair estimate for TOTE based on the inspection. The list in the estimate did not include tube repair or replacement.[108] TOTE provided an estimated budget for the 2015 shipyard repairs that included anticipated costs for "economizer replacement/upgrade—port and starboard boilers" under the category "life extension items."[109] The Walashek representative conducting the boiler inspection had not been trained by the boiler manufacturer.[110] According to statements he made at the Coast Guard MBI, the representative did not have any certification that authorized or qualified him to conduct boiler inspections. He had worked for Walashek for 14 years, starting as a boilermaker, and had worked his way up to lead man and superintendent, doing repairs and working on multiple projects.[111] The boiler inspection was conducted while the ship was under way from San Juan to Jacksonville with the starboard boiler out of operation. The captain had notified the Coast Guard about the single-boiler operation before departure.[112]

The last water side survey of the *El Faro* propulsion boilers was conducted by ABS in December 2013. The survey checklist stated that both boilers had been surveyed, including the internal water side and fire side, boiler mountings, and safety valves, and that the vessel's maintenance history had been reviewed. The checklist indicated that a hydrostatic test had been completed on December 9, 2013, but

[108] Walashek repair estimate, September 24, 2015.

[109] Tech review comments: TOTE: TOTE00110663 shipyard estimate

[110] MBI hearing.

[111] MBI hearing, February 25, 2016.

[112] Coast Guard-supplied emails.

the checklist sheets were not used by the surveyor to include comments or numerical data concerning the tests. As a result, pressures were not included in the documentation.[113] Investigators examined AMOS maintenance records during December 2013 for the boilers. An entry for the boiler with component No. BLR.226.02.001 (starboard) indicated that on December 20, 2013, "inspected boiler internals in shipyard looked ok." A second entry in AMOS for the boiler with component No. BLR.226.02.002 (port) stated, "inspected the boiler in the shipyard December 2013, boiler in good condition." Both entries were made by the chief engineer.[114] No values were recorded in AMOS for test results such as hydrostatic pressure.

NTSB investigators requested boiler water chemistry test results for the past 2 years from Drew Marine, the company that supplied test and treatment chemicals. Investigators received evaluative reports of the March 8, 2014, test results for the feedwater system in the following areas: evaporator air ejector drains, condensate system, reserve feed tanks, distilled tank, and atmospheric drain tank. Drew Marine's analysis found that copper was exceptionally high in the air ejector drains, condensate, reserve tanks, and distilled tank. Iron was exceptionally high in the condensate system, reserve tanks, and distilled tank. Drew recommended cleaning the reserve and distillate water tanks, followed by deaeration and oxygen scavenging.[115]

The test on March 20, 2014, found that the boiler water chemistry contained very high pH and conductivity. Drew Marine recommended that the boiler water sides be inspected for deposits or signs of corrosion. The engineering logbooks between December 2014 and September 2015 showed that the

[113] ABS boiler survey report, December 30, 2013.

[114] AMOS written history, 2013

[115] Drew Chemical report.

shipboard engineers recorded the following boiler chemistry daily: total dissolved solids, pH, chlorides, phosphates, and hydrazine.[116] Engine logbooks, AMOS, and interviews with off-duty crewmembers did not discuss any record of Drew's recommendations from March 2014 being carried out.

6.3. Economizer Repairs

Water leaks developed in the port boiler economizer in August 2015. Jacksonville Machinery and Repair, a shoreside company, repaired the economizer by installing welded jumpers around the leaking tube passes. According to the ABS surveyor, the repairs were tested to 800 psi on September 8, 2015, about a week after the repairs were done.[117] The test pressure took into account the discretion afforded by ABS rules for such testing, the fact that the vessel had made a round-trip to San Juan the previous week at operating pressure, and the working pressure on the boiler while the vessel was in port. An off-duty chief engineer was employed aboard the vessel as a supernumerary at the time of the repairs, and recalled that the chief engineer stated that the economizer had been successfully tested at 1,000 psi.[118] Investigators requested the service report, but TOTE advised that a service report had not been provided, because Jacksonville Machinery and Repair issues "invoice descriptions." Neither the engine logbook nor AMOS contained any entries regarding the repairs or testing.[119]

[116] Engine logbook.

[117] Interview: ABS surveyor.

[118] Email from off-duty chief engineer

[119] Interviews: off-duty *El Faro* chief engineer and first assistant engineer, Jackson Machinery and Repair representative.

6.4. Lube Oil Analysis

The lubricating oil in critical machinery systems was periodically sampled and sent to a Chevron LubeWatch laboratory for analysis. Investigators examined the last 2 years of results. All critical systems received acceptable results, except for the oil in the stern tube and strut bearing systems. The strut tube bearing oil was tested at the Kemel Company in Hyogo, Japan, on July 3, 2014, and rated as "normal." It was in the "alert" state in analyses dated January 3, 2015, April 14, 2015, and July 21, 2015, and in the "caution" rating on June 6, 2015.[120] The stern tube bearing was reported by Chevron LubeWatch in the "caution" range on May 19, 2010, "normal" on October 20, 2010, "severe" on January 14, 2014, and "abnormal" on May 7, 2015.[121]

6.5. Stern Tube System and Strut Bearing Analysis

In May 2015, Chevron LubeWatch results indicated that all wear rates were normal in the stern tube system. Water content was acceptable, the total acid number was above the recommended limit, and viscosity was within the specified operating range. Actions required were to sample at a reduced service interval to monitor further. In January 2014, the oil had been reported as "severe," containing elevated lead, tin, aluminum, and silicon levels.

Also in January 2014, analysis of the oil in the strut bearing system indicated a high level of wear metals as well as high levels of silicon, sodium, and potassium. The analysis report stated that the oil

[120] Kemel test results.

[121] Chevron LubeWatch UINC95A.

additives were consistent with the type of oil tested. The recommended action was to check for higher operating temperatures, change oil and filters, check filters for debris, and sample immediately.

In April 2015, a strut bearing sample was sent to the Kemel Company for analysis. The results showed that the oil contained high levels of tin, which placed the oil in the alarm state. The results were consistent with the analysis of three previous oil samples taken at 6-month intervals.

The strut bearing oil was most recently sampled in July 2015 and analyzed by Kemel. The stern tube oil was once again in the alert status, showing high levels of tin. The equipment's condition was evaluated as poor, and the recommendation was to replace the oil.

The shipyard scope of work for 2015 included optional inspection and repair of the strut shaft seal assembly. It also called for an optional flush of the strut bearing oil system, including the piping and head tank. AMOS contained no information about completed strut maintenance. Maintenance by a Kemel representative on the stern tube seal indicated that the forward strut seal had been overhauled with the tail shaft withdrawn while *El Faro* was drydocked from December 15 to December 28, 2013. The representative reported that the forward sealing ring had normal wear, but that the aft sealing ring had 4 millimeters of "blistered" condition. Kemel overhauled the aft seal rings with the tailshaft withdrawn and machined 1.0 millimeter off the liner diameter. It was reported that the liners had not been supplied by Kemel.[122]

[122] Kemel shipyard report

6.6. Riding Gang

A five-member riding gang, all pipefitters, was aboard the vessel at the time of the accident. The pipefitters, Polish nationals, had signed on as supernumeraries. They were working to refit the ship for a return to the Alaska trade by reinstalling winches, cables, and piping systems. They were under the direction of an off-duty chief engineer who was aboard the ship at the time of the accident.[123] Their scope of work consisted of the following:[124]

- Reinstall Butterworth heater.
- Reinstall saltwater piping for Butterworth heater.
- Reconnect sea chest steam-out connections.
- Install saltwater recirculation system.
- Reinstall ramp deicing.
- Verify functionality of freshwater cooling system.
- Install forward shore ramp (to be done in Tacoma).
- Install midship shore ramp (Tacoma).
- Install aft shore ramp (Tacoma).
- Install forward shore ramp (Anchorage).
- Install midship shore ramp (Anchorage).
- Remove covers over deck ramps to allow vehicle access.
- Install constant-tension winch.

[123] Interviews: port engineer, off-duty chief engineer.

[124] Scope of work for Alaska conversion (TOTE).

According to off-duty crewmembers, there was a language barrier between the ship's crew and the riding gang. The most senior member of the riding gang spoke some English and would translate to the rest of his team. The rest of the team did not speak English.[125]

According to off-duty crewmembers, the riding gang went through orientation and familiarization regarding lifeboat stations. For abandon-ship drills and procedures, the riding gang was divided between the vessel's two lifeboats.[126]

An off-duty engineer from the operating company, who held credentials as a chief engineer, supervised the riding gang. He had sailed on several of the *Ponce*-class ships since 2004 in various engineering capacities. He had also worked as a first assistant engineer aboard *El Faro* since 2014. He was employed as a supernumerary during the accident voyage, having been hired to oversee the Alaska-conversion project. He updated the port engineer regarding progress and part requests.[127]

7. Survey and Inspection

7.1. US Coast Guard

7.1.1. Alternate Compliance Program

The Alternate Compliance Program (ACP) is a voluntary process by which US vessels can obtain a Coast Guard Certificate of Inspection (COI) by complying with the standards of an authorized classification society. The program is intended to avoid redundancies in the inspection regimes of the

[125] MBI testimony by off-duty chief engineer. Interview of chief engineer.

[126] MBI testimony by off-duty chief engineer.

[127] Alaska conversion system summary list. Interviews: off-duty chief engineer, port engineer.

Coast Guard under the *Code of Federal Regulations* (CFR) and international conventions and by the classification societies under their class rules, while maintaining equivalent levels of safety for US-flagged vessels. In effect, the Coast Guard delegates to the class society the authority to conduct vessel inspections and tonnage measurements and to accept plan reviews and approvals.[128] The inspection and survey requirements for a vessel enrolled in the ACP would be governed by international conventions, class rules, and an approved US Supplement. The US Supplement was established to reconcile the different standards in the CFR and class rules for surveys, tests, or inspections.[129] The program began operating in February 1995. It was designed to enhance the competitiveness of the US maritime industry while maintaining a level of safety and environmental protection equivalent to Coast Guard regulations.[130]

The program constitutes an alternate method for owners of US-flagged vessels to fulfill the regulatory requirements for vessel design, inspection, and certification. The Coast Guard can issue a COI based on reports issued by authorized and recognized classification societies confirming that a vessel complies with applicable international conventions, classification society rules, and other requirements. ACP is an option for owners of tank vessels, passenger vessels, cargo vessels, miscellaneous vessels, and mobile offshore drilling units that engage in international voyages.[131]

At the time of the accident, the Coast Guard had entered into formal agreements with five classification societies for ACP participation, under the authority of 46 USC 3316: American Bureau of

[128] U.S. Supplement and MOU – ABS.

[129] Tech review comments: ABS.

[130] Tech review comments: ABS.

[131] USCG.mil.

Shipping, Class NK, Det Norske Veritas, Germanischer Lloyd, and Lloyd's Register. The agreements cover the delegation of certain statutory survey and certification functions for US-flagged vessels. Delegated function means a function related to Coast Guard commercial vessel inspection that has been delegated to a recognized classification society.

According to Coast Guard inspectors interviewed after the accident, the Coast Guard's oversight of an ACP vessel may include inspections which are less stringent then what would be required of a vessel not enrolled in the ACP program, since the ABS is conducting surveys on their behalf. Coast Guard inspectors are given a special inspection book for conducting ACP examinations of freight vessels (CG-840 ACP FV). Inspectors use inspection book CG-840 MI for full examinations.[132] According to the Coast Guard, inspection book CG-840 ACP FV has not been revised since January 2001, and inspectors used the CG-840 book with a 1999 revision date during the March inspection of *El Faro*.[133] Coast Guard inspectors refer to Navigation and Vessel Inspection Circular 02-95, change 2, with an issue date of May 5, 2006.[134]

Results of surveys conducted by ABS are recorded in a web-based database (eagle.org). The system is designed so that Coast Guard inspectors can access the database to review previous results before attending vessels for examinations, although there is no written requirement to do so.[135] Coast Guard

[132] Interviews: Coast Guard.

[133] Tech review comments: USCG

[134] Tech review comments: USCG

[135] Interviews: Coast Guard personnel.

inspectors and ABS surveyors typically communicate by email regarding vessel inspections and findings.[136]

According to the Coast Guard, as of September 2016, the US inspected fleet contained 228 active diesel-powered cargo vessels and 39 active steam-propulsion cargo vessels.[137]

7.1.2. *El Faro* inspections

El Faro, which was enrolled in the ACP, had successfully completed an annual survey by an ABS surveyor on February 16, 2015, in Jacksonville. The Coast Guard issued a COI on March 6, 2015, in San Juan, which stated that the vessel was "fit for route and service."[138]

The Coast Guard maintained an "ACP Targeted Vessel" list that was updated annually around October 1. The Coast Guard used an automated risk matrix to determine whether a vessel should be on the targeted list. Point values were assigned to the matrix for issues such as operational controls, port state detentions, overdue deficiencies, major non conformities in SMS audits, marine casualties, vessel service, and vessel age. Ten percent of vessels with the highest aggregate score were added to the list. According to the Coast Guard, at the time of the accident, *El Faro* had not been added to the 2016 ACP Targeted Vessel List, but was slated to be added on October 1, 2015, the day of the accident.[139]

El Faro had recently reported a medical emergency, which was scored as a "marine casualty" under Coast Guard regulations and added enough points to include the vessel on the targeted list for 2015.

[136] Interviews: Coast Guard and ABS personnel.

[137] Email from USCG.

[138] Interviews: Coast Guard inspector.

[139] Interviews: Coast Guard inspector.

Two additional casualties (one loss of propulsion as a result of crew error and an oil spill) occurred that would have added points to the vessel's total but were not scored by the automated risk matrix because the Coast Guard's data system (MISLE) was in transition at the time, which prevented timely data entry.[140] According to the Coast Guard, no operational controls were placed on *El Faro* at the time of the accident.

Vessels on the targeted list are subject to additional oversight at the 6-month mark of the examination cycle. The scope of examination can be increased if inspectors find safety issues on board. The Coast Guard had guidance stating that targeted vessels "shall be attended during drydock… activities," but that the Officer in Charge of Marine Inspection (OCMI) had the discretion to determine whether oversight attendance was necessary, considering "operational concerns, unit resources, as well as the extent and reasoning of repairs."[141]

The Coast Guard inspectors who attended the annual COI examination in March 2015 in San Juan had the following qualifications and experience:

- The lead inspector had over 22 years of experience in the Coast Guard, receiving his first inspection qualification in 1993. He was one of 21 marine inspection training officers in the Coast Guard. He had numerous qualifications at the time of the 2015 COI exam, including machinery, machinery–steam, (which is an extension of the basic machinery qualification), and drydock. He was in the process of developing updated test and training procedures for issuing qualification letters to Coast Guard inspectors. All his qualifications

[140] Tech review comments: USCG.

[141] Message R 221722Z from USCG.

were current at the time of the 2015 inspection.[142] The lead inspector held the title "Marine Inspection Training Officer."[143]

- Three other Coast Guard inspectors participated in the annual COI examination of *El Faro* in March 2015. The machinery inspector had 27 years of experience in the Coast Guard. According the Coast Guard, the inspector had not completed any of the requirements to receive command approval for the qualifications for his machinery steam qualification at the time of the inspection. He participated in the *El Faro* inspection to gain experience with a steam plant but had not received any official signoffs to become qualified.[144]

The Coast Guard created seven Centers of Expertise in 2009 in an effort to improve marine safety and increase competency in marine inspection and investigation. The centers offered operational support, technical expertise, and focused training to Coast Guard personnel and maritime industry representatives. The activities of the centers included consulting about design, examination, and operational situations and the development of regulations, policies, and doctrines. The centers also helped train Coast Guard inspectors.[145]

The Vintage Vessel Center of Expertise, created in 2009 and based in Duluth, Minnesota, focused on the steam propulsion systems of commercial cargo vessels or vessels with riveted hulls. According to Coast Guard inspectors, the center closed in 2013. Most of the center's work dealt with freshwater vessels in the Great Lakes. It also encompassed older vessels operating in any environment—steamers in the US

[142] Interviews: Coast Guard inspector.
[143] Interviews: Coast Guard inspector.
[144] Tech review comments: USCG
[145] USCG.mil.

Maritime Administration's National Defense Reserve Fleet, older warships and sailing vessels, and any vessels built using equipment no longer in standard production. The center's experts were expected to develop and maintain vintage-vessel inspection competencies and curricula, inspect vintage vessels, and establish merchant marine training in steam-powered and legacy-hull fleets.[146]

7.2. American Bureau of Shipping

ABS is a not-for-profit classification society founded in 1862. A classification society is a nongovernmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures. Classification societies provide classification and statutory services and assist the maritime industry and regulatory bodies with regard to maritime safety and pollution prevention based on accumulated maritime knowledge and technology. The objective of ship classification is to verify the structural strength and integrity of the essential parts of a ship's hull and its appendages, as well as the reliability and function of the propulsion and steering systems, power-generation systems, and other features that maintain essential services on board. Classification societies aim to achieve this objective through the development and application of their own rules and by verifying compliance with international or national statutory regulations on behalf of flag administrations.

A classification certificate should not be construed as a warranty of safety, fitness for purpose, or seaworthiness of a ship. It is an attestation only that the vessel is in compliance with the rules that have been developed and published by the society issuing the certificate. Further, classification societies are not guarantors of the safety of life or property as sea or the seaworthiness of a vessel because,

[146] USCG.mil.

although the classification of a vessel is based on the understanding that the vessel is loaded, operated, and maintained in a proper manner by competent and qualified personnel, the society has no control over how a vessel is operated and maintained between the periodical surveys it conducts.[147]

According to the ABS website, "The mission of ABS is to serve the public interest as well as the needs of our members by promoting the security of life and property and preserving the natural environment through the development and verification of standards for the design, construction and operational maintenance of marine-related facilities.[148]

El Faro was classified as "steel" by ABS and the vessel's status indicated "reduced scantlings" based on corrosion control. *El Faro* was designated by ABS with the notation:

✠A1, Vehicle Carrier, Ⓔ, ✠AMS

The Maltese cross symbol is assigned to "vessels and off shore units for which the hull construction and/or the manufacture of its machinery and components and any associated required testing, as applicable, is carried out under ABS survey." The Maltese cross followed by "A1" is a classification symbol that indicates "compliance with the hull requirements of the ABS Rules or their equivalent for unrestricted ocean service and survey by ABS during construction of the vessel." "Vehicle Carrier" is a notation assigned to a vessel designed and constructed to carry roll-on/roll-off cargoes, including vehicles, cargoes on pallets, etc…and forms part of the classification designation assigned to vessels built in

[147] Website of International Association of Classification Societies <iacs.org.uk>.

[148] ABS website <ww2.eagle.org>.

accordance with the ABS Rules for Building and Classing Steel Vessels." Circle E is a classification symbol that signifies that "the equipment of anchors and chain cables of the vessel is in compliance with the requirements of the ABS Rules, or with the requirements corresponding to the service limitations noted in the vessel's classification which have been specifically approved for the particular service." The Maltese cross followed by "AMS" is a classification notation that indicates that a vessel's machinery, boilers, and systems have been constructed and installed under ABS survey in accordance with the requirements of the ABS Rules."[149]

7.2.1. Qualification of Surveyors

The three ABS surveyors who had attended surveys of *El Faro* in Jacksonville and San Juan since 2014 were qualified as follows:

- The surveyor in Jacksonville held a third assistant engineer's credential and was a graduate of Massachusetts Maritime Academy. The surveyor had been with ABS for about 7-1/2 years after shipping out for a few years and working as a service technician for manufacturers of diesel engines and air compressors. The surveyor transferred to Jacksonville in March 2014 and was in charge of ABS's project to support new offshore construction (such as drilling platforms). The surveyor attended several ABS academy classes, which included classroom, field, and on-the-job training.[150.]
- The San Juan surveyor graduated from the US Merchant Marine Academy in 2004 and sailed as an assistant engineer until 2008, when the surveyor joined ABS. The surveyor

[149] ABS Notations and Symbols February 9, 2016.
[150] Interviews: ABS surveyors.

worked at ABS in Ft. Lauderdale, Florida, until November 2013, and then transferred to ABS San Juan. At the time of the *El Faro* inspections, the surveyor held a second engineer's credential for motor (unlimited) and a third engineer's credential for steam (unlimited). The surveyor attended several ABS academy classes, which included classroom, field, and on-the-job training.[151]

- The second ABS surveyor from Jacksonville graduated from Massachusetts Maritime Academy in 2007 and went to work for ABS in August of that year in the ship engineering department, as a review engineer for piping systems and equipment. In 2008, the surveyor transferred to the survey department in Tampa, and then transferred to Jacksonville in July. The surveyor attended several ABS academy classes, which included classroom, field, and on-the-job training.[152]

7.2.2. *El Faro* Surveys by ABS: 2014–2015

- On January 19, 2015, an ABS surveyor attended *El Faro* to complete the annual survey. The emergency generator was tested online, and bilge alarms, steering gear, and lube oil pumps were all tested. Paperwork for the radio equipment was verified. There were no concerns or findings.[153]
- On January 23, 2015, an ABS surveyor attended *El Faro* to conduct the annual hull survey. Examined were handrails, welding on decks, ventilation ducts, mooring cleats, cargo doors,

[151] Interviews: ABS surveyors.
[152] Interviews: ABS surveyors.
[153] Interviews: ABS surveyors.

gangway, and stability book. A drainage plug in the forward bosun's locker was found to have a small area of wastage. That finding was included in the report.[154]

- On January 27, 2015, an ABS surveyor attended *El Faro* to inspect the coating of ballast tanks No. 1 port and starboard, which had been rated in "poor condition" in the ABS hull survey.[155] The tank coating was still noted as poor after the inspection. During the inspection of the No. 1 port DB ballast tank, frames 50 and 51 were found to be detached at the outboard connection to the tank top. The fillet welds were fractured from the tank top plating between the weld access hole on the frame at the side shell to 2 feet inboard, terminating at another weld access hole (referred to as a "rat hole"). The surveyor recommended that the area be repaired, but TOTE was not required to perform any temporary repairs at that time. The welds were to be repaired at the special periodical survey due on February 26, 2016.
- On March 10, 2015, an ABS surveyor attended *El Faro* to verify repairs of the steering system to correct a problem, identified during the COI inspection, with a faulty potentiometer that caused an error of 3° to 4° when steering to starboard. The repairs were completed, and the system tested properly.[156]
- On April 14, 2015, an ABS surveyor attended *El Faro* to survey repairs completed on the overhead of the forepeak space in way of the hatch in the bosun's storeroom. The area and related hatch were not watertight spaces in that they were above both the waterline and the

[154] Interviews: ABS surveyors.
[155] Interviews: ABS surveyors.
[156] Interviews: ABS surveyors, Coast Guard inspector.

vessel's watertight deck. The area was repaired to the satisfaction of the surveyor, and no pressure tests were needed to test the sufficiency of the repair to this nonwatertight area.[157]

- On June 16, 2015, an ABS surveyor attended *El Faro* to conduct a continuous machinery survey, during which various pumps were operated, including the bilge/ballast pumps. The emergency generator was also started and tested. No deficiencies were found.[158]
- On September 8, 2015, an ABS surveyor attended *El Faro* to survey repairs completed on the port boiler, in which Jacksonville Machinery and Repair installed jumpers on seven leaking economizer tubes. The welding repair to the tubes was inspected and found to be to the satisfaction of the attending ABS surveyor. The repairs had been carried out approximately 2 weeks earlier. The vessel had made a round-trip to San Juan the previous week under normal operating pressure, with no reported problems. A hydrostatic test was performed at 800 psi, which the surveyor considered to be sufficient based on the examination of the repair, the pressure at which the boiler was operating at the time of the survey, and the discretion provided by the ABS rules and the ACP Supplement to determine the testing pressure. [159]

8. Engineering Staff

The *El Faro* engineering department consisted of 11 personnel. It had six engineering officers—one chief engineer, one first assistant engineer, one second assistant engineer, and three third assistant

[157] Interviews: ABS surveyors.

[158] Interviews: ABS surveyors.

[159] Interviews: ABS surveyors.

engineers. Five crewmembers were also aboard—three oilers and two qualified members of the engine department (QMEDs)/reefer (refrigerator) electricians. The officers were members of the American Maritime Officers (AMO) union, and the crewmembers were members of the Seafarers International Union (SIU).[160]

The engine department stood manned watches in the engine room at all times. The second and third assistant engineers would stand in 4-hour-on and 8-hour-off rotations. The second assistant engineer stood the 4-to-8 watch, and the third assistant engineers stood the 8-to-12 and 12-to-4 watches. The oilers stood watch in the engine room on a 4-hour-on and 8-hour-off schedule. The chief engineer, first assistant engineer, and QMEDs were dayworkers.[161]

8.1. Officers

All *El Faro* engineering department officers held credentials issued by the Coast Guard.[162] The third assistant engineering officers who graduated from Maine Maritime Academy had been trained on a diesel-electric ship built in 1990 rather than on the academy's training steamship, TS *State of Maine*, which it replaced in 1997.[163] The chief engineer onboard at the time of the accident, who graduated from the State University of New York (SUNY) Maritime College, had been trained on a steam training ship, the TS *Empire State VI*, as part of his college seagoing requirement. The first assistant engineer had been trained on Massachusetts Maritime Academy's steamship TS *Enterprise*. According to documents

[160] Crew list.

[161] Engine logbooks.

[162] Crew personnel records.

[163] Maine Maritime Academy website <mainemaritime.edu>.

provided by TOTE, none of the engineering officers aboard *El Faro* at the time of the accident had been selected to initially crew TOTE's new liquid natural gas-fueled container ships, the *Isla Bella* and the *Perla Del Caribe*.[164] TOTE stated that the chief engineer, first assistant engineer, and two third assistant engineers had been sent for training at the engine manufacturer's facility in preparation to rotate them onto the new ships.[165]

Investigators reviewed the personnel files for each of the engineering officers aboard *El Faro* at the time of the accident. Chief engineers were "required to complete evaluations on all licensed officers whenever an officer was detached for any reason."[166] Each officer was evaluated on eleven categories such as cooperation, leadership, attention to assigned duties, watchstanding ability, mechanical ability, knowledge of ship's equipment, knowledge of company policy and procedures, and personal conduct/appearance. The evaluation sheet used a scale of "poor, fair, good, very good, and excellent" to evaluate the officers. The sheet contained a section for remarks where the chief engineer could describe positive qualities, areas where improvement could be made, and measures taken to further improvement. Boxes could be checked to indicate whether the evaluation had been reviewed with the officer in question and if the individual was recommended for reassignment to the vessel.[167] The company's safety management system (SMS) had a policy that required the chief engineer to be evaluated periodically. The details of this requirement are discussed in section 9, "Company Safety Management System."

[164] Crewing lists for *Isla Bella* and *Perla Del Caribe*.

[165] Tech review comments: TOTE.

[166] Ship's officer evaluation/performance report.

[167] Ship's officer evaluation/performance report.

Chief Engineers. The chief engineer on *El Faro* at the time of the accident graduated from SUNY Maritime College in 2003. His most recent credential was issued on November 4, 2014, and expired on November 4, 2019. He was qualified as a chief engineer of steam, motor, and gas turbine vessels of any rating. He joined the ship on August 18, 2015.[168]

The chief engineer at the time of the accident had undergone several official shipboard evaluations throughout his career with Sea Star/TOTE as a junior officer. On July 22, 2013, while aboard *El Yunque* as first assistant engineer, he received ratings of "very good" or "excellent" in all categories. He was reported to be "intelligent, hard-working, and [having a] good attitude." He had no areas that required improvement, according to the evaluation. An evaluation as first assistant engineer while aboard *El Morro* on January 5, 2012, stated that he was a "hard working and knowledgeable first (assistant engineer) working his way to becoming a chief" and that he was "able to work through difficult times."[169]

Another evaluation was completed on April 14, 2011, while the *El Faro* chief engineer at the time of the accident was aboard *El Morro* as first assistant engineer. Ratings were in the "excellent" and "very good" range. Comments indicated that he had a "can-do attitude, great work ethic and brings a lot of steam experience to *El Morro*." The evaluation stated that "since he has not spent his whole career at Sea Star, he brings new ideas, methods, management style, and troubleshooting skills to *El Morro*. Great knowledge of steam plant operations." An evaluation completed in August 2011 as first assistant engineer stated that he was "a pleasure to sail and work with," and that he was "very self-motivated and works well with the

[168] Crew personnel records.

[169] Crew personnel records.

crew and the jobs at hand."[170] TOTE provided one draft evaluation for the chief engineer, dated October 2, 2014, in which the evaluation stated that the chief engineer was "driven to do the best job possible. The ship and crew reflect that." Ratings for each evaluation criteria were 5 out of 5, meaning "exceptional."[171]

The off-duty chief engineer who was interviewed by investigators graduated from Maine Maritime Academy in 1996 and started with TOTE in 1999. He began sailing as chief engineer in 2006 aboard the sister ship *El Morro*, and became chief engineer of *El Faro* in 2013.[172]

First Assistant Engineers. The first assistant engineer on *El Faro* at the time of the accident graduated from Massachusetts Maritime Academy in 2005. His credential was issued on May 8, 2015, and was due to expire on May 8, 2020. He was qualified as chief engineer of steam, motor, and gas turbine vessels of any rating.[173]

He joined the ship 2 months before the accident, on August 4, 2015. His first TOTE vessel was *El Morro*, which he joined as a third assistant engineer in January 2010. He had several evaluations from chief engineers as second and third assistant engineer in the fair/good/very good range. In January 2015, after his first trip as a first assistant engineer aboard *El Faro*, he was evaluated by the chief engineer. Most of the results were "fair" and "good," and the chief engineer remarked that he needed "to work on his communication skills," that he "often acted without thinking in order to complete the job," and that "his work ethic was lacking in certain areas." The evaluator also stated: "Greater attention to detail was

[170]Crew personnel records.

[171] TOTE evaluation of chief engineer, October 2014.

[172] Crew personnel records.

[173] Crew personnel records.

needed." The first assistant engineer received one "very good" result in the "knowledge of TSI (TOTE Services Inc.) policy and procedures" category. A previous evaluation in January of 2015 as second assistant engineer from the same evaluator showed "excellent" results in each category, and in the remarks section, it was stated that the first assistant engineer "has shown he is ready and capable to sail at a higher position and take on more responsibility."[174]

The off-duty first assistant engineer who was interviewed by investigators graduated from Maine Maritime Academy in 1995. He worked aboard several ships before working ashore for 4 years. In 2004, he returned to shipping and worked on *El Faro* when it was named the *Northern Lights*, shipped on *El Morro*, and returned to *El Faro* when *El Morro* was scrapped.[175]

Second Assistant Engineers. The credential of the second assistant engineer on *El Faro* at the time of the accident was issued on March 30, 2012, and expired on March 30, 2017. He was qualified as a second engineer of steam, motor, and gas turbine vessels of any horsepower. He received several evaluations. The most recent stated that he was "one of the most dependable" and "hardest working men" the chief engineer had ever worked with. He joined the ship on August 11, 2015.[176]

The off-duty second assistant engineer who was interviewed by investigators graduated from Massachusetts Maritime Academy in 2012 and came to TOTE after one trip on a tanker. He worked on *El Morro*, and when it was scrapped, joined *El Faro*.[177]

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[174] Crew personnel records.

[175] Crew personnel records.

[176] Crew personnel records.

[177] Crew personnel records.

Third Assistant Engineers. One of the third assistant engineers on *El Faro* at the time of the accident graduated from Maine Maritime Academy in 2012. His credential was issued on September 11, 2013, and expired on September 11, 2018. He was qualified as a third engineer of steam and motor vessels of any rating. He had a recent evaluation in January 2015. Remarks stated that he was an "excellent engineer and a valuable asset to the vessel." He had made five 70-day trips aboard *El Faro* before the accident.[178] He joined the ship before the accident voyage on September 22, 2015, in Jacksonville.[179]

Another third assistant engineer at the time of the accident graduated from Maine Maritime Academy in 2012. His credential was issued on July 9, 2012, and expired on July 9, 2017. He was qualified as a third engineer of steam, motor, or gas turbine vessels of any horsepower. In an evaluation in November 2014, the evaluator remarked that he "shows up on time" and "has done everything I asked him to do." Also, the evaluator stated that he needed to "pay attention to detail" and "become more familiar with ship's equipment and automation." In a previous evaluation dated November 14, 2014, after he had served aboard *El Yunque* as a third assistant engineer, the evaluation indicated that he had done a "very good job as 3rd (assistant engineer)" and he was a "good shipmate and learned the job quickly." The evaluator stated that he needed to "take on more responsibility and start thinking on his own" and "be more proactive in his job." He had made two trips aboard *El Yunque* and one trip aboard *El Faro* before the accident. He joined *El Faro* on September 15, 2015, in Jacksonville, 2 weeks before the accident. [180]

[178] Crew personnel records.

[179] Crew personnel records.

[180] Crew personnel records.

The newest third assistant engineer onboard at the time of the accident graduated from Maine Maritime Academy in 2014. His credential was issued on May 3, 2014, and expired on May 3, 2019. He was qualified as a third engineer of steam and motor vessels of any rating. *El Faro* was his first ship. He signed on in Jacksonville the evening *El Faro* departed on the accident voyage.[181]

Riding Gang Supervisor. The off-duty chief engineer who was sailing as a supernumerary and supervising the Polish riding gang graduated from Massachusetts Maritime Academy in 1996. His credential was due to expire on October 28, 2016. He was qualified as chief engineer of steam, motor, and gas turbine vessels of any rating. He joined the ship on August 4, 2015, about 2 months before the accident. He had previously worked aboard *El Yunque* and received positive remarks about his work ethic and safety consciousness.[182]

8.2. Port Engineer

TOTE assigned one port engineer to *El Faro* to assist with maintenance, spare parts, supplies, monitoring inspections and surveys, monitoring vessel certificates, arranging for vendors to facilitate repairs, and shore support. According to TOTE, a backup port engineer was assigned in case the primary port engineer was unavailable.[183]

As stated in the company-supplied job description, the port engineer was "responsible for the management and supervision of every aspect of assigned commercial vessels while they are in port, at sea,

[181] Crew personnel records.
[182] Crew personnel records.
[183] MBI: port engineer testimony.

and in dry dock, including providing direction to all shipyard and repair vendor personnel engaged in vessel repairs. Oversees installation and repair of marine power plants, propulsion systems, heating and ventilation systems, and other mechanical and electrical equipment in ships and marine facilities."[184] The port engineer position consisted of several essential duties such as:

- Prepare budgets and work plans for vessels.
- Coordinate with captain to ensure proper cargo and other mission-related logistics.
- Make final judgment regarding mechanical issues in coordination with chief engineer.
- Review, approve, and process material and spare requisitions submitted by the vessels.
- Coordinate with captains and chief engineers to manage vessel repairs, maintenance, and requisitioning for spares, goods, and services.
- Manage repair contractors, regulatory inspection, and crewing activities.
- Attend vessels to evaluate and observe overall condition and performance.
- Maintain the maintenance and repair software program.
- Oversee repairs to equipment such as boilers, turbines, and auxiliary systems.[185]

The port engineer for the *El Faro* held an unlimited chief engineer's credential for steam and motor vessels. He graduated from California Maritime Academy in 1976 and had sailed for 28 years on both steam and diesel ships. He started with TOTE as a port engineer in November 2013.[186] He said that he

[184] Port engineer job description.
[185] Port engineer job description.
[186] Interview: port engineer.

boarded *El Faro* every week when the ship was in Jacksonville and occasionally visited the ship in San Juan.[187]

The port engineer reported to TOTE's director of ship management-commercial, who was responsible for "ensuring all commercial vessels are in compliance with all regulatory requirements. Designs and oversees installation and repair of marine power plants, propulsion systems, heating and ventilation systems, and other mechanical and electrical equipment in ships, dock, and marine facilities." Other responsibilities included supervising vessel engineering staff, training employees, evaluating performance of employees, developing annual business plans for vessels, coordinating day-to-day activities between office and vessels, distributing pertinent vessel information to involved employees, and overseeing repairs to equipment. The director of ship management-commercial reported to TOTE's vice president of marine operations–commercial.[188]

9. Company Safety Management System

As required by the International Safety Management (ISM) Code and US law, *El Faro* operated under a formal SMS established by the company.[189] TOTE's SMS procedures were compiled in two manuals, one covering vessel operations (OMV) and another covering emergency preparedness aboard vessels (EPMV). The SMS also included a binder referred to as OPSMEMO that acted as a supplement to the OMV and EPMV manuals acting as interim policy statements for policies that were to be incorporated into the policy manuals or canceled.

[187] Port engineer interview, MBI testimony.

[188] Job description: TOTE director of ship management-commercial.

[189] The ISM Code is incorporated into US law at 46 USC 32. Coast Guard regulations for SMSs are found at 33 CFR 96.

The operations manual (OMV section 3.2.1.2) stated: "all newly joining officers and crewmembers, family members, contractors, and owners authorized to sail with the vessel must be indoctrinated into the vessel's organization and more especially to their duties and responsibilities." Some crewmembers said that they were given a familiarization tour when joining the vessel. A familiarization booklet was referred to by crewmembers.[190] NTSB investigators requested the booklet and received a generic guide for contractors.

The company's SMS addressed adverse weather in the navigation section of the operations manual (OMV 10.8.1-4). It stated that "the master was responsible for the monitoring and analysis of the weather along the vessel's intended track." During adverse weather, the captain was instructed to "ensure that the vessel was properly handled" and to "take proper precautions to safely stow and secure all the vessel's equipment to prevent any damage to the equipment or vessel." The captain was to "advise the HQ Office of speed reductions and/or course changes due to adverse weather" and "should consider taking on additional ballast in adverse weather conditions."[191] TOTE reported that there was "no heavy weather guidance provided specifically to engineers in the OMV."[192] The company's SMS detailed a policy (OMV 3.4.1, "Responsibility for: Contractors, Riding Gangs & Surveyors") regarding contractors and riding gangs while aboard the ship. The system required oversight by a chief engineer or a chief mate of "hot work," use of personal protective equipment, and job hazard analysis. The SMS policy specifically stated that all members of a riding gang "shall be given an indoctrination tour of the vessel before or soon after

[190] Interviews: crewmembers.

[191] SMS manual, section 10.8.2.

[192] Email from TOTE director of ship management-commercial.

sailing as possible" (OMV 3.4.1). NTSB investigators received records of completed indoctrinations up to May 19, 2015, but records for the Polish riding gang could not be obtained because they were kept on the vessel.[193]

The SMS manual (OMV 3.2.1.1, "Officer Turnover Notes") stated that "all licensed officers shall leave a written turnover report for their relief when departing the vessel" and a "signed copy of the turnover notes shall be given to the Master or Chief Engineer for review and retention, prior to payoff." Off-duty crewmembers stated in interviews that they submitted turnover notes after each rotation. The operating company provided turnover notes from the chief engineer, submitted on August 26, 2014, August 11, 2015, and August 18, 2015.[194]

According to the SMS manual (OMV 12.6.7.1), evaluations of the captains and chief engineers were to be initiated by the marine crewing department in September of each year. In addition, a completed original evaluation was required to be forwarded to the personnel department for entry into the individual's personal file.[195] Investigators requested evaluations of the chief engineer that had been completed by the company. One evaluation of the chief engineer was provided, but it was not complete. Several shipboard evaluations were received.[196]

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[193] Cadet onboard training indoctrination logs.

[194] Chief engineer turnover notes, chief engineer interview, port engineer interview.

[195] OMV 12.6.7.1

[196] Crew personnel records.

An internal audit required by the ISM Code was held on March 6, 2014, after *El Faro*'s layup in Baltimore. No corrective action requests or nonconformities were issued, but the audit included six observations:

- A master's review needed to be done before the ABS external audit.
- The semiannual audit of the oily water separator and the annual vessel inspection by the port engineer were due.
- The chief engineer had inserted all of the updates and changes in the ISM system at the time of the audit.
- The vessel antenna diagram needed updating.
- Several of the container walkway gratings on the main deck needed repair.
- The oil record book and related information binder were missing an update. TOTE was to provide.[197]

An ISM internal audit was conducted on March 3, 2015, by TOTE's designated person ashore. The audit yielded no corrective action requests or nonconformities, but it included four observations:

- Recent copy of OPSMEMOS and other communications from the office were not received on *El Faro* due to an incorrect email address.
- Ship-specific critical equipment list was required to be put in place.
- Possibility of an online MSDS [material safety data sheet] library and management contract was discussed.

[197] ISM internal audit report, March 6, 2014.

- Previous corrective action reports lacked verification due to *El Faro*'s layup status.[198]

10. Postaccident NTSB Actions

10.1. Analysis of Fuel Oil Samples

After the accident, NTSB investigators contacted the supplier and obtained fuel oil samples from *El Faro*'s last three bunkering operations before the accident voyage (on September 8, September 14, and September 21, 2015). The samples were sent for testing to an independent facility, Core Laboratories, in Deer Park, Texas. The fuel was tested for flash point, kinematic viscosity, sediment by extraction, and water. The fuel was found to be within ASTM specifications. The table below shows results and standards, as reported by Core Laboratories:

Sample Date	Flash Point (° F) Min 140	Kinematic Viscosity (cSt @ 100° C) Min 15, Max 50	Sediment by Extraction (Wt%) Max 0.5	Water (LV%) Max 1	Water (Wt%) Max 2
9/8/2015	196	38.45	0.02	0.05	0.07
9/14/2015	196	38.45	0.01	0.05	0.06
9/21/2015	194	36.57	0.01	0.10	0.11

cSt = centistokes. Wt% = weight percent. LV% = liquid volume percent.

10.2. Voyage Data Recorder Search and Recovery

Shortly after the sinking, the NTSB contracted with the Navy to locate the *El Faro* wreckage. The Navy ship *Apache* departed Little Creek, Virginia, on October 19, 2015, fitted with underwater detection

[198] ISM internal audit report, March 3, 2015.

equipment. The ship's sonar located the *El Faro* hull on October 31, at a depth of about 15,400 feet. A remotely operated vehicle (ROV) confirmed the finding on November 1.

Video from the ROV documented that the navigation bridge and the deck below it had separated from the hull. The top of the engine room casing was open to the sea, all containers had fallen off the cargo areas, and the ship's mast and voyage data recorder (VDR) were missing from the wreckage area. The search was completed on November 15.

In April 2016, the National Science Foundation and the Woods Hole Oceanographic Institution jointly sent the research vessel *Atlantis* to the wreckage area to search for *El Faro*'s VDR. *Atlantis* arrived on scene on April 22 and deployed an autonomous underwater vehicle (*Sentry*) to comb the debris field. *Sentry* located the VDR capsule on April 25, but the investigative team determined that it could not be recovered due to its proximity to the mast and other obstructions.

Sentry surveyed the wreckage of the hull with a high-definition camera. Mooring lines could be seen rising from the hull, including one from the stern that showed signs of having parted.

Ten months after the accident, in August 2016, a third mission was launched, aimed at recovering *El Faro*'s VDR. The Navy ship *Apache* departed Little Creek on August 5 and arrived at the accident site on August 8. At 1950 that evening, an ROV retrieved the VDR capsule from a depth of 15,410 feet. The VDR was submerged in a bath of distilled water while the *Apache* traveled to Mayport, Florida. After the ship reached port on August 12, the VDR capsule was transported to NTSB headquarters in Washington, DC, where it was opened by recorder specialists in the presence of the manufacturer's representatives. Over 26 hours of parametric data and audio files were accessed from the VDR's memory module.