TROUBLESPOT MACHINERY SPACE

THE *NORWAY* BOILER EXPLOSION

At 0637 on May 25th, 2003, the passenger vessel Norway (formerly France), suffered a boiler rupture in the aft boiler room about an hour after the vessel had moored in Miami, Florida, at the end of a seven-day Caribbean cruise. Eight crewmembers sustained fatal injuries, 10 suffered serious injuries, and seven received minor injuries. No passengers were injured

The formal investigation into the accident by the US National Transport Safety Board (NTSB) has now been produced and we publish here extracts from the report. Overall, the NTSB determined that the probable cause of the boiler rupture was deficient boiler operation, maintenance, and inspection practices of NCL (the owner), which allowed material deterioration and fatigue cracking to weaken the boiler, while inadequate surveys by classification society Bureau Veritas (BV) contributed to the cause.

History

Between 1974 and 1979, the *France* was laid-up during which the eight boilers in the forward and aft boiler rooms were preserved as stipulated by BV. During the vessel's 1979 overhaul, four boilers in the forward engine room and two of the propellers were removed.

About the same time, NCL contracted with Harris Pye Marine, Ltd., a leading specialist in repairing marine boilers and associated steam systems, to assess the Norway's boiler equipment. The contractor reported: 'Although these boilers are around 40 years old and are currently suffering from ongoing tube failures, there is no report of the main components - ie headers or drums - having any Conditions of Class18 put on them. It is known that various defects have been noted in and attended to in the past, but we would not suggest that this precludes these components from many more useful years work, once the deteriorating tubes have been addressed.'

In November 1997, the port engineer at the time wrote to NCL: 'The boilers on the *Norway* have reached a state where a decision must be made.' He recommended a number of options including, but not limited to, replacing the old boilers, completely re-tubing the old boilers with new economizers, and installing new automation.

Major overhauls of the boilers began in November 1998 with re-tubing of the upper and lower economisers. In May 1999, the tube bank in the furnace area was re-tubed, as was the secondary super heater in 2002.

Company reports and classification society surveys documented cracking, corrosion, pitting, and tube failures throughout the history of the ship's boilers. As early as December 1970, cracks were observed in the longitudinal welds of the waterwall headers, water drums, and steam drums of all four boilers. The documents also indicate that the longitudinal welds on the header of boiler No. 23 (the boiler that ruptured) were last weld repaired in 1990.

The boiler drums were periodically monitored by visual and non-destructive testing methods, and detected cracks were removed by grinding. When cracks extended below the minimum allowable wall thickness, they were ground off, and weld repairs built the walls back up.

No documents were found indicating that cracks were found or repaired after 1996.

Operating procedures

During start-up (light-off) and shutdown of a steam boiler, pressure and temperature changes cause bending and alternating stresses in the various boiler components, such as drums and headers. All marine boilers are designed to accommodate thermal and mechanical stresses. In the *Norway* the waterwall header, the water drum, and the inboard side of each boiler had structural supports at the front and the rear.

In addition, each boiler was supported by a 'sliding foot' that allowed it to expand as it heated up during light-off and to contract when cooling off during shutdown. However, maintenance records indicate that the boilers had experienced problems with the condition of the sliding feet on at least two occasions before the accident.

The machinery operation and maintenance guide specified proper procedures for starting up and shutting down the boilers. During light-off, the manufacturer's manual indicated that one or more of the unit's burners should be fired at intervals until the pressure reached 8bar (116psi), after which continuous firing was allowed until the boiler reached a pressure of 60bar (870psi).

The manual states that reaching the recommended operating pressure requires 'about 3h' and that it is 'advisable not to accelerate the procedure, and to allow the temperature to rise gradually.' The manual's specified procedures for boiler shut down that the superheater should not be filled with water until 'the boiler has cooled down, about 48h after extinction [of fires].'

The boiler monitoring system had several strip chart recorders that recorded various boiler operating parameters, including steam pressure. The data indicate that the boilers went from zero to full pressure of 60 to 62bar (870 to 900psi) in 1.5 to 5.5h; the average was 3.4h. They showed that the boilers were fired at 10min intervals and shut down for 10min until the boilers reached pressure.

The charted shutdown profiles showed a steadily decreasing curve, representative of a falling pressure rate over time - in most cases, a reduction from full pressure to zero in about 3h. The rate of pressure drop varied between 45min and 4h, with an average of 2.8h.

Concerns expressed

Between the late 1990s and 2002, several port engineers and chief engineers expressed concern about the effects on the

The Norway in Miami in May 2001, two years before the fatal explosion

boilers of the frequent lightoffs and shutdowns required by the vessel's operational schedule and route.

At the time of the accident, the *Norway's* itinerary was a seven-day voyage from the Port of Miami, to various port calls along the way and then returning to Miami. After Norway began that itinerary, the boilers underwent more frequent cycling than when on trans-Atlantic voyages.

The *Norway* normally sailed using two or three boilers. Typically, one or more boilers were idle for periods lasting from a day to several weeks.

For a random period (July 1997 to July 1998), the boilers had between 11 and 29 cycles, or an average of 23/year. For the 17 -month period before the accident (January 2002 through May 2003), the boilers had between 18 and 26 cycles, or an average of 15.2/year. The logbooks show that a boiler's cycle frequently lasted 1.5 days or less, and often less than 0.5 days.

The logbooks showed that between July 1997 and July 1998, the boilers were shut down for 10 or more days between two and seven times. Pressure chart data confirmed that the engineering crew typically brought a boiler's pressure down to zero shortly after shut down. Three of the four boilers each were idle for periods lasting 20 or more days.

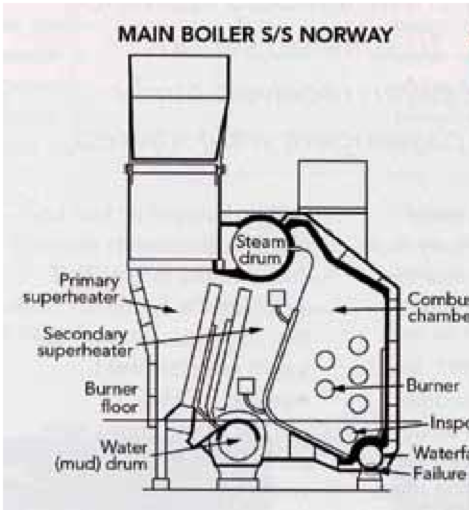
Boiler No. 23 was shut down once for more than 20 days, boiler No. 21 was shut down twice for more than 20 days, and boiler No. 24 was shut down for more than 20 days three times. The records did not show whether the boilers were in a wet or dry condition during periods of idleness or what techniques, were used to prevent oxygen corrosion during lay-up.

NCL had a chemical treatment programme that included procedures for water testing by onboard engineering personnel and a contract with Drew Marine Division of Ashland Chemical to supply test and treatment chemicals for the boiler water and to provide technical services. The Drew Marine water treatment manual recommends the level of hydrazine 33 in a boiler's water be 0.03 to 0.01 ppm for normal operations and that it be increased to 150 to 200ppm during wet lay-up. The guidance also states that a wet lay-up be used for 'all but very extended lay-up periods.' However, the manual does not define 'very extended lay-up periods.' The original operating manual from the French manufacturer recommended that if a boiler was to be 'shut down for a prolonged period (five days or more), completely fill the upper drums [with water] up to the air releases [drum vents], injecting hydrazine.'

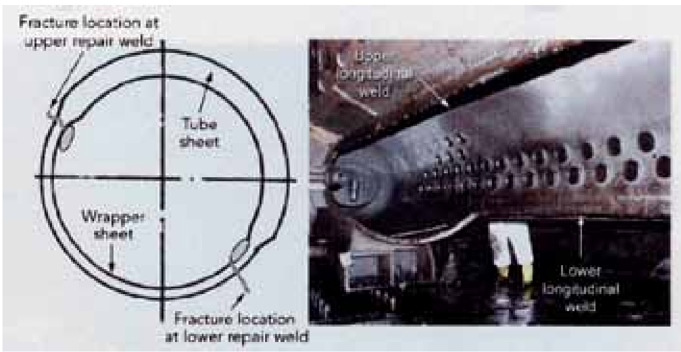
Water treatment

It was noted that entries were not logged for some boilers for veral days at a time and subsequently determined that water chemistry readings were not taken when a boiler was not steaming. Closer examination of the data for the year 2000 revealed that:

- In some cases, the levels of hydrazine were low during operation. For example, in one case levels were below the specified minimum, at approximately 0.01 ppm. - Almost every time a boiler came out of an idle period, the hydrazine level was zero or near-zero for one or more days. After reaching the specified range,levels stabilised and then kept within operational limits.
- No records indicate that after a boiler was out of service, hydrazine was increased to the level recommended for idle conditions (150 - 200 ppm).
- Boiler water chemistry readings were not taken on idle boilers in the wet condition to assess the levels of hydrazine present.



Cross section through the Norway's No 23 boiler showing the site of the rupture at bottom right

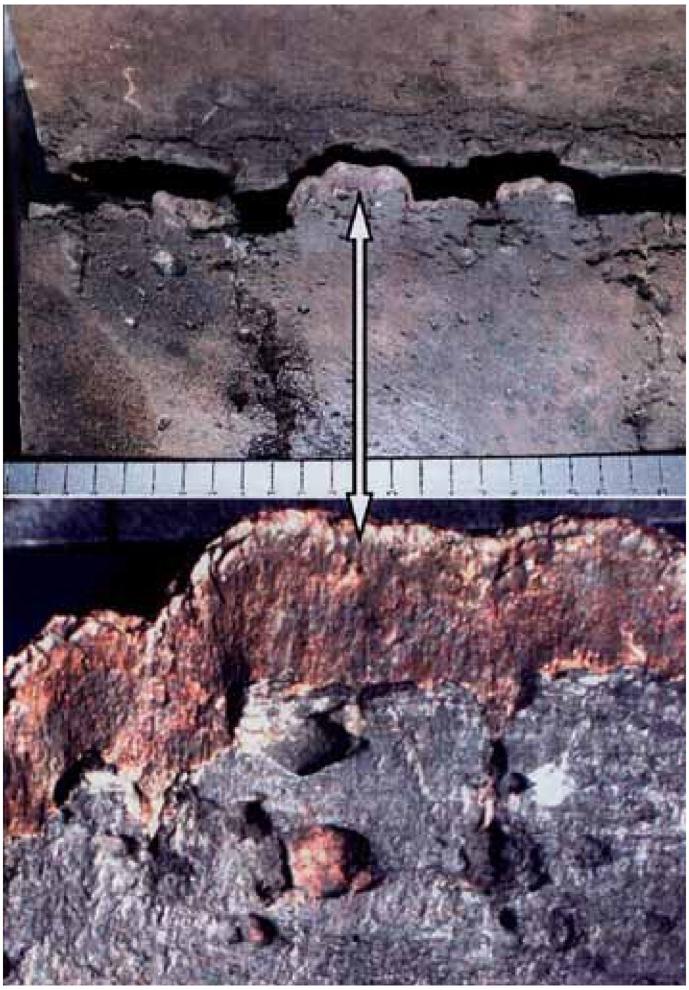


Schematic (left) showing location of fracturing along the longitudinal welds, and partial view (right) of damaged waterwall header, looking aft. The waterwall header was constructed by longitudinally welding together two half-cylinders and then welding caps (dished heads) on either end. The two half-cylinders were of different thicknesses. During the manufacture of the header, the tube sheet was tapered down to the wrapper sheet and the two were welded together at the bottom of the tapered region. The header fractured where weld repairs had been made along the original longitudinal welds joining the tube sheet and the wrapper sheet

3000h service

Statements and maintenance records for the three years preceding the accident, showed all four boilers had been cleaned and inspected about every 3000h. The maintenance tasks included cleaning the water economiser and water-washing the superheater and generating tubes. The original boiler manual stated 'if treatment of the boiler water is correct, then no significant deposit should occur within the boiler tubes.' It adds that the drums should be cleaned at every inspection by washing with fresh water to remove mud deposits that 'may have a rapid corrosive effect.'

Because of the limited access to the interiors of the waterwall headers (a manhole at each end of the 13ft long cylinders), inspection was best accomplished by the inspector actually entering the headers. However, access was difficult as the access manholes measured only about 30 by 40cm and the drum was only 29in in diameter. The second engineer in charge of boiler maintenance said that he did enter the waterwall headers to check the inside of the drums. The relief chief engineer, who was 6ft 7in tall and weighed 340lbs, said that it was impossible for him to enter them.



View of matching fracture halves (above) and enlarged image of copper nuggets (below) at the edge of the fracture. Arrow points to area of enlarged image. It appears that copper tubing may have been deliberately introduced into the boiler waterwall header during a misguided maintenance action

BV rules required a complete (internal) survey of boilers twice in five years, or about every 2 1/2 years. The BV surveyor at the time of the accident stated that BV did not require its surveyors to enter the drums and that he could not get into the steam drum, the water drum, or the waterwall header because the access manholes were too small.
The previous BV surveyor had not entered the waterwall He also stated that the BV guidelines required the surveyors to enter only the steam drum; the requirements did not stipulate that they should enter the water drum or the waterwall header.

NTSB conclusion

The NTSB determined that the following factors contributed to the boiler rupture:

- Lack of adherence to water chemistry composition limits and procedures by both the water chemistry subcontractors and NCL during wet lay-up periods, leading to pitting from oxygen corrosion
- Failure to take number of boiler cycles into account during maintenance
- Severe thermal transients from heating and cooling the boilers too quickly and from constraints created by frozen boiler support feet
- Use of questionable weld repair procedures
- Lack of appropriate non-destructive testing by the BV surveyors and NCL inspectors to determine whether cracks were present
- Inadequate survey guidance from BV to its surveyors
- Failure to repair cracks into which copper had been inappropriately introduced.

Source: MER February 2008