MARINE SAFETY INVESTIGATION REPORT

Safety investigation into the cargo deck crane failure on board the Maltese registered bulk carrier

TRAPEZITZA

in the port of Damietta, Egypt

on 22 January 2017

201701/020

MARINE SAFETY INVESTIGATION REPORT NO. 02/2018

FINAL

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The objective of this safety investigation report is precautionary and seeks to avoid a repeat occurrence through an understanding of the events of 22 January 2017. Its sole purpose is confined to the promulgation of safety lessons and therefore may be misleading if used for other purposes.

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Malta
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Crew members and managers MV Trapezitza

DNV-GL Survey Statements

High Technology Park, Technical University, Varna

MacGregor Inspection and Service Information Manual
GLOSSARY OF TERMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS</td>
<td>Continuous machinery service</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>Gt</td>
<td>Grosse tonnage</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatts</td>
</tr>
<tr>
<td>LT</td>
<td>Local time</td>
</tr>
<tr>
<td>m</td>
<td>metres</td>
</tr>
<tr>
<td>mm</td>
<td>millimetres</td>
</tr>
<tr>
<td>MSIU</td>
<td>Marine Safety Investigation Unit</td>
</tr>
<tr>
<td>mt</td>
<td>Metric tonnes</td>
</tr>
<tr>
<td>MV</td>
<td>Motor vessel</td>
</tr>
<tr>
<td>Na</td>
<td>Sodium</td>
</tr>
<tr>
<td>nm</td>
<td>Nautical miles</td>
</tr>
<tr>
<td>No.</td>
<td>Number</td>
</tr>
<tr>
<td>PMS</td>
<td>Planned maintenance system</td>
</tr>
<tr>
<td>ppm</td>
<td>Parts per million</td>
</tr>
<tr>
<td>PQ</td>
<td>Particle quantifier</td>
</tr>
<tr>
<td>rpm</td>
<td>Revolutions per minute</td>
</tr>
<tr>
<td>Si</td>
<td>Silicone</td>
</tr>
<tr>
<td>SMS</td>
<td>Safety management system</td>
</tr>
</tbody>
</table>
SUMMARY

On 22 January 2017, at about 0010, cargo deck crane no. 1, fitted on board the Maltese registered bulk carrier *Trapezitza*, experienced a catastrophic failure during cargo operations in the port of Damietta, Egypt.

Consequently, the cargo deck crane’s combined unit and jib parted from the pedestal base and fell on the jetty, coming in contact with the cargo hold hatch cover and main deck railings.

Discharging operations were suspended and the managers arranged for the cargo to be discharged by shore cranes. The remaining cranes on board were also thoroughly inspected.

The safety investigation concluded that the immediate cause of the accident was the failure of the slewing ring bearing, as a result of excessive wear and tear in the outer ring. This led to spalling of the ball bearings and raceways, which was augmented by metal particle contaminated grease.

Taking into consideration the safety actions taken by the Company, no safety recommendations have been issued by the Marine Safety Investigation Unit.
1 FACTUAL INFORMATION

1.1 Vessel, Voyage and Marine Casualty Particulars

<table>
<thead>
<tr>
<th>Name</th>
<th>TREPEZITZA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flag</td>
<td>Malta</td>
</tr>
<tr>
<td>Classification Society</td>
<td>DNV GL</td>
</tr>
<tr>
<td>IMO Number</td>
<td>9145231</td>
</tr>
<tr>
<td>Type</td>
<td>Bulk Carrier</td>
</tr>
<tr>
<td>Registered Owner</td>
<td>TRAPEZITZA Maritime Ltd.</td>
</tr>
<tr>
<td>Managers</td>
<td>Navigation Maritime Bulgare</td>
</tr>
<tr>
<td>Construction</td>
<td>Steel</td>
</tr>
<tr>
<td>Length overall</td>
<td>168.58 m</td>
</tr>
<tr>
<td>Registered Length</td>
<td>159.72 m</td>
</tr>
<tr>
<td>Gross Tonnage</td>
<td>13965</td>
</tr>
<tr>
<td>Minimum Safe Manning</td>
<td>13</td>
</tr>
<tr>
<td>Authorised Cargo</td>
<td>Solid Bulk</td>
</tr>
<tr>
<td>Port of Departure</td>
<td>Berdyansk, Ukraine</td>
</tr>
<tr>
<td>Port of Arrival</td>
<td>Damietta, Egypt</td>
</tr>
<tr>
<td>Type of Voyage</td>
<td>International</td>
</tr>
<tr>
<td>Cargo Information</td>
<td>Sea salt (1,836 mt)</td>
</tr>
<tr>
<td>Manning</td>
<td>19</td>
</tr>
</tbody>
</table>

Date and Time: 22 January 2017 at 00:10
Type of Marine Casualty: Less Serious Marine Casualty
Place on Board: Freeboard deck
Injuries/Fatalities: None
Damage/Environmental Impact: None
Ship Operation: Alongside Moored / Loading
Voyage Segment: Arrival
External & Internal Environment: Night-time, visibility 8 nm. Northerly light air and air and sea temperatures of 16 °C
Persons on Board: 19
1.2 Description of Vessel

1.2.1 MV Trapezitza

*Trapezitza* is a 13,695 gt, handy size bulk carrier owned by Trapezitza Maritime Ltd. and managed by Navigation Maritime Bulgare, Bulgaria. The vessel was built by Bulyard Shipbuilding Industry, Varna Yard, Bulgaria in 2004, and is classed with DNV-GL.

The vessel has a length overall of 168.58 m, a moulded breadth of 25.0 m and a moulded depth of 11.5 m. The vessel has a summer draught of 8.52 m, corresponding to a summer deadweight of 21,454 tonnes. *Trapezitza* has five cargo holds and is equipped with three cargo deck cranes.

Propulsive power is provided by an 8-cylinder BMZ-B&W 8L42MC, single acting, two stroke, slow speed diesel engine, producing 5,884 kW at 154 rpm. This drives a fixed pitch propeller to give a service speed of about 14.0 knots.

1.3 Crew

The Minimum Safe Manning Certificate issued by the flag State Administration stipulated a crew of 13 persons, including six officers. At the time of the accident, the vessel was manned in excess of the minimum safe manning requirements.

All crew members were Bulgarian nationals and the working language was Bulgarian.

1.4 Environment

According to the deck log book entries, there was a Northerly light wind. Weather was clear and visibility was good. The outside air and sea temperatures were 16 ºC.
1.5 Maintenance and Testing

1.5.1 The slewing ring bearing

The slewing ring bearing is a key component on cargo deck cranes. The main function of the slewing ring bearing is to provide a rotational attachment point to secure the rotating cargo deck crane to the fixed pedestal mount. There are various types of slewing ring bearings, designed by different manufacturers. Figure 1 shows a cross-section of the slewing ring bearing fitted on Trapezitza’s cargo deck cranes, manufactured by MacGregor.

The two main parts are the inner ring and the outer ring. The inner gear ring is fixed to the crane pedestal, while the outer ring is fixed to the upper post which rotates by means of a pinion system mounted on the upper deck which in turn acts on the inner ring’s teeth.

![Slewing ring bearing cross sectional view](image_url)

1= Outer ring, fixed to upper post
2= Inner ring, fixed to crane pedestal
3= Ball Bearing
4= Seals
5= Pedestal Plate
6= Grease Nipples

Figure 1: Slewing ring bearing cross sectional view
### 1.5.2 Maintenance schedule and regime

The specific maintenance item and the time interval are tabulated in Table 1.

#### Table 1: Cargo deck cranes routine maintenance and time intervals

<table>
<thead>
<tr>
<th>Interval</th>
<th>Crane Part</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily or before taking crane into operation</td>
<td>Slewing gearbox</td>
<td>Oil level check</td>
</tr>
<tr>
<td>Every 200 operating hours or every two months</td>
<td>Slewing ring bearing screws</td>
<td>A visual inspection of the slewing ring bearing screws from the deck and inside pedestal. If any screws show the tendency to slacken, these should be tightened with a torque wrench or hydraulic tensioner as per manual.</td>
</tr>
<tr>
<td>After 200 operating hours</td>
<td>Slewing gearbox</td>
<td>First oil change</td>
</tr>
<tr>
<td>Every 500 operating hours or every 6 months</td>
<td>Crane house, foundation and jib welding joints</td>
<td>Inspection for any signs of cracks</td>
</tr>
<tr>
<td></td>
<td>Parking support and jib structure resting parking support</td>
<td>Inspection for wear or any signs of cracks</td>
</tr>
<tr>
<td></td>
<td>Hydraulic System</td>
<td>Check and adjust pressure as necessary for:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Feed pressure inlet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Control pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pressure cut-off (overload) valve/valves</td>
</tr>
<tr>
<td></td>
<td>Slewing gear and pinion</td>
<td>Backlash and seals check</td>
</tr>
<tr>
<td>Every 200 operating hours or every two years</td>
<td>Slewing gear set</td>
<td>Check for any leaks</td>
</tr>
<tr>
<td>Every 1000 operating hours or at least every year 3 months</td>
<td>Slewing gearbox</td>
<td>Oil change</td>
</tr>
<tr>
<td>6 months</td>
<td>Lubrication points</td>
<td>Greasing</td>
</tr>
<tr>
<td>6 months</td>
<td>Rocking test</td>
<td>Testing</td>
</tr>
<tr>
<td>12 months</td>
<td>Crane annual thorough examination</td>
<td>CMS</td>
</tr>
<tr>
<td>48 months</td>
<td>Slewing ring bearing studs/ screws</td>
<td>• All studs or screws should be tightened with a hydraulic screw tensioner or a torque wrench</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• If any studs or screws need replacement, MacGregor Cranes should be consulted</td>
</tr>
<tr>
<td>60 months</td>
<td>Hydraulic hoses inside crane house</td>
<td>Check for any damages</td>
</tr>
<tr>
<td>60 months</td>
<td>Crane five yearly thorough examination</td>
<td>CMS</td>
</tr>
<tr>
<td>60 months</td>
<td>Crane five yearly load test</td>
<td>CMS</td>
</tr>
<tr>
<td>Every 10 years</td>
<td>Hydraulic hoses</td>
<td>Renew all hoses</td>
</tr>
</tbody>
</table>
The cargo deck cranes’ maintenance schedule regime was stipulated by the manufacturers and incorporated in the vessel’s Planned Maintenance System (PMS).

1.5.3 Testing procedures
In addition to the planned maintenance jobs, the maintenance manual also provided testing instructions.

1.5.3.1 Grease test
One of the criteria to evaluate a slewing ring bearing’s condition is the analysis of grease samples. The applicable procedure consists of the following steps:

- slew the crane until the jib is in the main working area;
- clean up the seal and the surrounding areas from where the sample will be taken. When cleaning the area of the seal, it is important to prevent the cleaner either from coming in contact with the seals or from entering the raceway system; and
- push new grease into the grease nipples / bearing without rotation and collect the first used grease, which will come out at the seal. Samples should be taken at the inner or outer seal of the bearing; one sample from the front part of the crane and one from the aft part of the crane (Figure 2).

Figure 2: Grease sampling areas at the inner and outer seals
As part of the testing procedure, the following information is required:

- type of grease used at lubrication (manufacturer and type);
- lubrication intervals;
- crane running hours;
- information where the samples are taken; and
- date of slewing ring bearing replacement and article number (if applicable).

Once the grease sample is collected, the grease analysis is done either on board or in a laboratory for more detailed results.

The simplified grease analysis, which can be done on board, requires the grease sample to be spread into a very thin layer on a white paper. Under good artificial light, the sample is inspected for steel particles.

The laboratory grease analysis will normally take longer but should give scientific results, showing Fe, Si, Na, PQ and water content.

To best interpret the grease analysis, a sample of fresh grease should be available as a control. The maximum parts per million (ppm) shall not be exceeded and the manufacturer is to be approached in order to provide more technical guidance:

- Fe: 10,000 ppm;
- PQ: 2000 ppm;
- Si: 300 ppm;
- Na: 250 ppm; and

1.5.3.2 Rocking test

Since the slewing ring bearing is an essential part of the cargo deck crane, it must be carefully maintained. Over the years, the slewing ring bearing is subjected to fair wear and tear. A detailed record of technical results obtained by means of rocking tests, as part of the vessel’s planned maintenance regime, will ensure the availability of data for an informed technical decision to be taken on whether, for instance, the

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1 A rocking test is a simple test carried out by the ship’s engineers to determine the wear on the slewing ring bearing assembly.
slewing ring bearing needs to be renewed, or not. MacGregor recommended that rocking test measurements are taken regularly, say, every six months. As long as the readings are within the manufacturer’s recommended tolerances, the cargo deck crane may be regarded as suitable for operation.

In order to carry out a rocking test, the procedure established by the manufacturer needs to be followed. For instance, the ship shall be close to an even keel as much as practically possible. Moreover, neither loads nor cargo handling equipment should be attached to the hook at the time of the testing.

During the first initial tests, two reference points on the crane’s bottom plate should be marked. These reference points are crucial because they are then always used during all future measurements (Figure 3).

![Machined surface on crane bottom plate.](image_url)

Figure 3: Manufacturers’ instructions with respect to reference points
Accurate results necessitate that measurements are taken at four positions on the slewing ring bearing. The first position to be tested is with the crane at maximum outreach (Figure 4). At this stage, two measurements are taken at specific points labelled ‘B’ and ‘A’.

![Figure 4: Measuring points with an extended jib](image)

The jib is then operated to the next position, i.e., at the minimum horizontal reach (Figure 5), where a single reading labelled position ‘C’ is taken. The manufacturers highlight the importance of using a measuring device with an accuracy of not less than 0.1 mm.

![Figure 5: Measuring points with jib at minimum outreach](image)
The manufacturer’s manual specifies that the difference between readings taken at points ‘B’ and ‘A’ shall not exceed 7.0 mm, whereas the difference in readings between points ‘C’ and ‘B’ should not exceed 3.0 mm. It is further specified that if either of these measurements is exceeded, the deck crane shall not be operated.

The procedure of measurement in both conditions should be repeated with the crane facing the forward, aft, starboard and port sides.

Precautions, which need to be noted include:

- all the readings are always taken from the same point location to ensure accurate analysis;
- consider a wrong reading if the difference between the readings taken at points ‘B’ and ‘C’ is less than or equal to zero.

1.6 Narrative

On 29 December 2016, Trapezitza left the port of Berdyansk, Ukraine, with 1,836 mt of sea salt in all her cargo holds, drawing a mean draught of 4.46 m. The voyage was uneventful and the vessel arrived at the port of Damietta, Egypt on the 21 January 2017 at about 1515. The vessel intended to load more cargo at this port.

Cargo was delivered to the ship by trucks. A bulldozer on the quay piled up the cargo to facilitate the grabbing process carried out with a clamshell grab. The loading was carried out by three gangs in cargo holds nos. 1, 3 and 5. During the cargo operation, the master noticed that cargo deck cranes nos. 1 and 2 were operating slower than cargo deck crane no. 3. Concerned that this may affect the vessel’s trim (by the stern), the master instructed the chief mate to monitor the trim and ensure that it remains within the agreed parameters.

At 0010 (22 January), without any warning, cargo deck crane no. 1’s upper post collapsed onto the quay, making contact with the open cargo hatch cover of cargo hold no. 5 as it came down. The cargo deck crane pedestal remained intact (Figure 6).

2 Unless otherwise stated, all times in this report are local time.
No injuries were reported and immediate action was taken to ensure that no hydraulic leaks had occurred. The electrical supply to the cargo deck crane was interrupted and the driver was assisted out of the cabin. No injuries were reported and the loading operations came to a halt.

At the time of the accident, the master was in his cabin but felt the vibrations, which reportedly were also felt throughout the ship. From the port hole, he observed a number of stevedores boarding the vessel. Soon after, the third mate informed him of the accident. The master made his way quickly to the main deck to observe more closely and decide on further actions.

A restriction zone was enforced around the perimeter of cargo hold no. 1. Eventually, a mobile crane was positioned on the quay to lift the damaged cargo deck crane. The collapsed part of the cargo deck crane was repositioned on the main deck, on port side, enabling the cargo loading operations to resume.
1.7 Damage to the Vessel and Fittings
It was immediately evident that the slewing ring bearing was damaged. No damages were reported to the hull, deck plating, cargo holds closing appliances and vent heads. The only reported damage (apart from the cargo deck crane), where the deck railings where the jib fell onto the main deck and overside.

1.8 Similar Accidents on Board
Records showed that in 2011, Trapeziita had a similar accident on cargo deck crane no. 3. The Company advised that as a preventive action, more frequent rocking tests had been required.
2 ANALYSIS

2.1 Purpose

The purpose of a marine safety investigation is to determine the circumstances and safety factors of the accident as a basis for making recommendations, to prevent further marine casualties or incidents from occurring in the future.

2.2 Cause of the Accident

Evidence indicated that the immediate cause of the accident was a catastrophic failure of the slewing ring bearing. The outer and inner parts of the slewing ring bearing separated when the jib was extended to the port side while lifting the cargo from the jetty due to excessive wear and tear in the raceways Figures 7a and 7b).

Figures 7a and 7b: Photos showing excessive bearing wear

As the slewing ring bearing separated and the ball bearings fell out of the raceways, the jib and the cabin separated from the pedestal.
2.3 Cause of the Slewing Ring Bearing Failure

The safety investigation is of the view that the wear and tear on the outer slewing ring bearing may have been the initiating factor leading to its failure.

The engineering laboratory report revealed two main sources of wear present in the inner ring of the slewing ring bearing. The first source was the high amount of non-metallic oxide inclusions (Figures 8a and 8b), suggesting an increased contamination of undesired bearing elements.

Figures 8a and 8b: Non-metallic oxide inclusion found in the inner and outer rings

The other source of wear present in the slewing ring bearing was the low plasticity and impact toughness of the steel of the outer ring. These were found to be below the standard requirements (DIN EN 10083-3:2007-01) on steels for quenching and tempering. The results yielded by the analysis and comparison with the required average value have been tabulated in tables 2 and 3.
### Table 2: Outer slewing ring bearing

<table>
<thead>
<tr>
<th>No.</th>
<th>Tested probes</th>
<th>Measured values of the controlled parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Position relative to the axis of the forging</td>
</tr>
<tr>
<td>1</td>
<td>Across + 20 °C</td>
<td>0.826 x 0.993</td>
</tr>
<tr>
<td>2</td>
<td>0.821 x 0.993</td>
<td>45.1</td>
</tr>
<tr>
<td>3</td>
<td>0.822 x 0.993</td>
<td>30.4</td>
</tr>
<tr>
<td></td>
<td>Measured (average)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Across - 20 °C</td>
<td>0.820 x 0.993</td>
</tr>
<tr>
<td>5</td>
<td>0.822 x 0.993</td>
<td>16.7</td>
</tr>
<tr>
<td>6</td>
<td>0.821 x 0.996</td>
<td>27.5</td>
</tr>
<tr>
<td></td>
<td>Measured (average)</td>
<td></td>
</tr>
</tbody>
</table>

Required: steel brand 42 CrMo₄, DIN EN 100083-3:2007-01 \(\geq 35\)

### Table 3: Inner slewing ring bearing

<table>
<thead>
<tr>
<th>No.</th>
<th>Tested Probes</th>
<th>Measured values of the controlled parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Position relative to the axis of the forging</td>
</tr>
<tr>
<td>1</td>
<td>Across + 20 °C</td>
<td>0.825 x 0.994</td>
</tr>
<tr>
<td>2</td>
<td>0.821 x 0.990</td>
<td>62.8</td>
</tr>
<tr>
<td>3</td>
<td>0.825 x 0.992</td>
<td>83.4</td>
</tr>
<tr>
<td></td>
<td>Measured (average)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Across - 20 °C</td>
<td>0.823 x 0.994</td>
</tr>
<tr>
<td>5</td>
<td>0.824 x 0.993</td>
<td>34.3</td>
</tr>
<tr>
<td>6</td>
<td>0.823 x 0.993</td>
<td>45.1</td>
</tr>
<tr>
<td></td>
<td>Measured (average)</td>
<td></td>
</tr>
</tbody>
</table>

Required: steel brand 42 CrMo₄, DIN EN 100083-3:2007-01 \(\geq 35\)
Analysis of the inner and outer slewing ring bearing at the engineering laboratory showed that both rings had a deformed toroid groove (Figure 9). It was also revealed that the deformation in the outer ring was not complete but only present round half of the ring, whereas for the inner ring, the crown gear remained non-deformed.

![Cross-sectional view of inner and outer bearing showing toroidal wear](image)

**Figure 9: Cross-sectional view of inner and outer bearing showing toroidal wear**

Even more, the laboratory analysis of the fracture on the surface of the toroid groove on both rings indicated that the ball bearings’ contact with the rings was not centred due to the presence of unacceptable deformation of the bearings (Figure 10).
The ball bearings were worn out mainly through a toroidal strip round one axis (Figure 11) due to lack of normal rolling. This may have been caused by the wear in the slewing bearing rings. It has been therefore concluded that the wear of the balls was due to the sliding and blocking against the grooves over time (Figure 11).

Spalling of the outer slewing ring bearing would have created excessive amounts of debris in the bearing grease. The contaminated grease would have then migrated throughout the bearing assembly as a result of the general rotation during cargo operations. It has therefore been concluded that operation of the ball bearings over the contaminated lubrication accelerated the spalling observed on either side of the soft zone in the outer bearing radial housing.
2.4 Slewing Bearing Design and Testing

2.4.1 Interpretation of the rocking test results
The last two rocking tests prior to the accident were carried out on 26 February 2016 and 31 August 2016. Results from these two tests are tabulated in Table 4.

Table 4: Readings taken during the latest two rocking tests prior to the accident
<table>
<thead>
<tr>
<th>Test date</th>
<th>‘B’ – ‘A’ (mm)</th>
<th>‘B’ – ‘C’ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. diff = 0.7 mm</td>
<td>Max. play = 3.0 mm</td>
</tr>
<tr>
<td>26 February 2016</td>
<td>2.30</td>
<td>3.00</td>
</tr>
<tr>
<td>31 August 2016</td>
<td>2.50</td>
<td>2.30</td>
</tr>
</tbody>
</table>

The ‘B’ – ‘A’ reading showed an (expected) increase due to fair wear and tear. However, the ‘B’ – ‘C’ value decreased\(^3\) by 0.7 mm (Table 4). This decrease suggested that the slewing ring bearing was worn out such that the top part of the cargo deck crane was not only leaning but also sliding slightly, thus reducing the difference in values ‘C’ and ‘B’. This sliding phenomenon was due to the toroidal wear present in the slewing ring bearing edges and the ball bearings (Figure 12). This resulted in a condition where, apart from tilting, the cargo deck crane would also slide slightly sideways due to the gap produced by the wear.

Figure 12: Toroidal wear on bearing raceways and ball bearings

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\(^3\) One would have expected that the value would have actually increased due to wear and tear.
As illustrated in Figure 13, although the centre of tilting would have moved laterally, when considering the measurements to calculate the difference in the level test (‘B’ – ‘A’), the tilting angle would remain the same since the variation in either point would have been compensated by the other point (i.e. if ‘A₁’ is smaller than ‘A’, ‘B₁’ is larger than ‘B’, due to the sliding effect).  

![Figure 13: Offset displacement for difference in level values](image)

The error in value manifests itself when testing for play values. Figure 14 shows the displacement due to tilting when measuring values ‘C’ and ‘B’. The centre of gravity of the crane moves due to the jib being fully open or closed, but so does the centre of rotation due to the sliding motion phenomena. This lateral motion causes an almost elliptical displacement of the tilting point which is illustrated in figure 14 by the dashed line. ‘B’ and ‘C’ are the readings which would have been taken on 26 February 2016, where the wear on the bearing would have not been extensive enough for the sliding effect to happen.

![Figure 14: Offset displacement and sliding path for play test values](image)

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4 Measurements ‘A’, ‘B’ and ‘C’ are the values obtained without considering sliding. ‘A₁’, ‘B₁’ and ‘C₁’ are the values obtained after considering the sliding.
‘B₁’ and ‘C₁’ represent the possible measured values, which would have been taken on 31 August 2016. In this case, the sliding motion would have been more pronounced. Although ‘B’ – ‘C’ is larger than ‘B₁’ – ‘C₁’, in reality the wear in the play would have increased.

### 2.4.2 Measurement taking during rocking test

As mentioned in section 1.5.3.2, the rocking test is normally done using a Vernier calliper and the dimensions are measured from pre-designated locations. Considering the environment where the measurement is being taken, this method may be subject to numerous flaws. Of most concern is the fact that the measuring points are located in a confined space of not more than two meters in diameter and without any natural light (Figure 15).

![Figure 15: Location of rocking test measuring points inside the crane pedestal (lighting provided by camera flash)](image)

These conditions may result in either the crew member positioning the measuring instrument improperly while taking measurements, or read the dimensions incorrectly because of inadequate artificial lighting⁵.

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⁵ A more specialised tool, incorporating pre-designated mounting points (which could be covered during the measurement would prevent dirt and dust from altering dimensions) would have been more ideal. Moreover, this would ease the measuring process as the jig would be simply mounted into place, thereby eliminating the possibility of incorrect measurement.
2.4.3 Grease test
On 02 December 2016, greasing of the slewing ring bearing was done by the crew members. Since the rocking test results were within acceptable parameters (Table 4), it was not deemed necessary to perform grease sampling for particle consistency. Visually, the crane showed no signs of any wear in the mechanism. An analysis of the quality of grease in the slewing ring bearing would have probably detected abnormal wear from particle containment in grease due to the excessive wear.

Gard-Loss Prevention Circular No. 11-08, explains that analysis of grease quality can prevent premature failure of machinery and bearings and that such analysis does not have to necessarily be a laboratory analysis.

2.4.4 Metallurgical quality of bearing steel
The metallurgical quality of bearing steel is related to both its harmful purity in sulfides, nitride inclusions, and especially hard-to-deform globular oxide inclusions. The work of bearings is characterized by high local loads and hence, stringent purity requirements for non-metallic inclusions. In cases where the slewing ring bearing has a high content of oxide inclusions, a decrease in the fatigue fracture resistance and the life-time threshold of the bearing will be experienced. The lifetime of the bearing depends on a number of factors, including, the size of non-metallic inclusions; the larger the inclusion size, the shorter the lifetime.

2.5 Missing Cues
As indicated elsewhere, the safety investigation believes that there were at least three instances which may have provided potential cues on the condition of the slewing ring bearing, but which were missed. These were:

1. metal fragments in the grease sample;
2. the February and August rocking tests results; and
3. the slower operating speed of deck crane no. 1.

This compromised the risk identification and its management.
The MSIU believes that there were a number of reasons as to why these cues had been missed. It would appear that the results of the rocking tests (which fell within the maximum play limit established by the manufactures), had misled the crew members in believing that the deck crane remained safe to operate. The (apparent) reduction in slewing ring bearing play did not cause any concern to the crew member, whose main criterion was that the play did not exceed 3.0 mm.

Then, in the absence of any mishap, the crew members had no reason to delve deeper into the issue – actually, there was no reason to believe that there was an issue at all. It was clear that the grease test was not considered to be necessary because the results of the rocking tests were deemed to be a good enough indication that the slewing ring bearing was operating within the maximum limits established by the manufacturer.

The manufacturer’s manual emphasised that rocking tests were more of an indicative result of the slewing ring bearing condition, compared to the grease sample test. However, both tests were not intended by the manufacturer to be considered as mutually exclusive. Rather, the manufacturer specified that both the rocking test and the grease sample test together would provide the best basis for evaluation of the slewing ring bearing condition.

The slower speed of deck cargo crane no. 1 was also not attributed to possible issues with the slewing ring bearing. As such, the master had observed two cranes which were operating at a low speed. Per se, that may have reinforced the belief that the low operating speed was due to one other crucial variable, i.e., the inexperienced crane operators rather than a possible mechanical issue. As much as this was the only possible cue that would have indicated a potential problem in the hours prior to the accident, it has to be clarified that that would have been a very weak cue and not strong enough to be immediately captured by any of the crew members.

In the absence of such information (because of missing the cues), the crew members had a less rich mental model of the precarious mechanical condition of the cargo deck crane and hence, had no reason to conduct a systematic analysis of the risks involved in operating it. In actual fact, on the basis of the information available (which suggested that the tolerances had not been exceeded), the crew members had no reason to express any concern. The feedback from the prevailing context indicated no
particular hazards, which would have warranted drastic measures, such as, for instance, suspending the loading operations or using a shore crane.

It was therefore clear that the decision to operate the cargo deck cranes had been immediately conditioned by the available data and what seemed to be a normal operation of the deck machinery, has actually ended in significant damages.
THE FOLLOWING CONCLUSIONS, SAFETY ACTIONS AND RECOMMENDATIONS SHALL IN NO CASE CREATE A PRESUMPTION OF BLAME OR LIABILITY. NEITHER ARE THEY BINDING NOR LISTED IN ANY ORDER OF PRIORITY.
3 CONCLUSIONS

Findings and safety factors are not listed in any order of priority.

3.1 Immediate Safety Factor

.1 The outer and inner part of the slewing ring bearing separated when the jib was extended to the port side while carrying a load, due to excessive wear and tear in the raceways.

3.2 Latent Conditions and other Safety Factors

.1 The slewing ring bearing was contaminated with high amount of non-metallic oxide inclusions;

.2 The low plasticity and impact toughness of the steel of the slewing bearing outer ring was also a source of contamination;

.3 The inner and outer slewing ring bearing had a deformed toroid groove, causing the ball bearings’ contact with the rings not being centred due to the presence of unacceptable windage and deformation of the bearings;

.4 The wear on the ball bearings contributed to wear on the slewing ring bearing;

.5 Spalling of the outer slew bearing ring would have created excessive amounts of debris in the bearing grease;

.6 Operation of the ball bearings over the contaminated lubrication accelerated the spalling observed on either side of the soft zone in the outer bearing radial housing;

.7 The rocking test results were interpreted to mean that the play in the slewing ring bearing was within maximum tolerances;

.8 No grease sample analysis had been carried out because the play in the slewing ring bearing was considered to be within the maximum tolerances;

.9 The fatigue fracture resistance and the life-time threshold of the slewing ring bearing had been compromised because of the contaminated grease;
The crew members had a less rich mental model of the precarious mechanical condition of the cargo deck crane and hence, had no reason to conduct a systematic analysis of the risks involved in operating the deck crane;

The decision to operate the cargo deck cranes had been immediately conditioned by the available data and what seemed to be a normal operation of the deck machinery, has actually ended in significant damages.

4 SAFETY ACTIONS

During the course of the safety investigation, the Company took the following safety actions:

1. Grease samples will be tested every six months and this requirement has been included in the vessel’s PMS;

2. A Technical Circular addressing rocking tests and grease sampling, has been sent to all vessels in the Fleet;

3. Enhance information in the vessel’s PMS on ship’s cranes checks, measurements and maintenance jobs;

4. Discussion of this accident during shore-held monthly seminars and pre-boarding briefings of chief engineers.