ACCIDENT REPORT

Report on the investigation of the collapse of a crane

on board the workboat

Carol Anne

resulting in one fatality

Loch Spelve, Isle of Mull, Scotland

30 April 2015

VERY SERIOUS MARINE CASUALTY REPORT NO 11/2016 JUNE 2016

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

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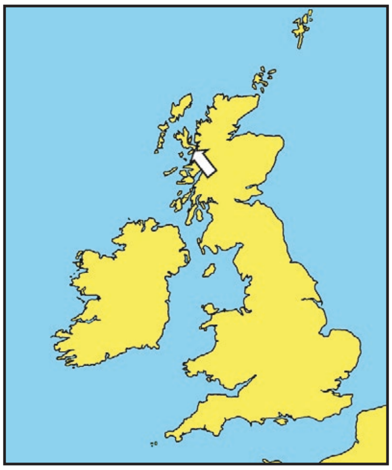
GLOSSARY OF ABBREVIATIONS, ACRONYMS AND TERMS

ALLMI	-	Association of Lorry Loader Manufacturers and Importers
BS	-	British Standard
CA	-	Certifying Authority
CE	-	Conformité Européenne
EC	-	European Community
EN	-	A European Standard ratified by one of three European Standards Organizations
EU	-	European Union
FIBC	-	Flexible Intermediate Bulk Container
HSE	-	Health and Safety Executive
HSL	-	Health and Safety Laboratory
IMS	-	Inverlussa Marine Services
ISO	-	International Standards Organization
kg	-	kilogramme
kN-m	-	kilonewton metre
LOLER	-	The Merchant Shipping and Fishing Vessels (Lifting Operations and Lifting Equipment) Regulations 2006
m	-	metre
MCA	-	Maritime and Coastguard Agency
MGN	-	Marine Guidance Note
mm	-	millimetre
MRC	-	Maritime Resource Centre
Nm	-	Newton metre
PUWER	-	Merchant Shipping and Fishing Vessels (Provision and Use of Work Equipment) Regulations 2006
SCMS	-	Society of Consulting Marine Engineers & Ship Surveyors
SI	-	Statutory Instrument

SIB	-	Stability Information Booklet
STCW	-	STCW – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended (STCW Convention)
SWL	-	Safe Working Load
t	-	tonne
UTC	-	Universal Co-ordinated Time

TIMES: all times used in this report are UTC+1 unless otherwise stated

SYNOPSIS



On 30 April 2015, an Atlas lorry loader crane fitted on the workboat *Carol Anne* collapsed while being used to offload a net at a fish farm at Balure on Loch Spelve, Scotland. The crane fell onto the workboat's skipper, who was declared deceased at the scene. The crane had been in operation since its installation 6½ weeks earlier. It was not overloaded when it failed.

A number of factors contributed to the crane's collapse. These included:

- No installation guidance was provided with the crane as none was required by the applicable regulations.
- The number and size of the lock nuts, bolts and washers supplied by Atlas (UK) to secure the crane to the vessel's deck, and the torque to which they were tightened, were not in accordance with the crane manufacturer's installation specifications.
- The lock nuts used were of inferior material grade to that indicated by their markings.
- The quality control and quality assurance procedures in place at Atlas (UK) did not prevent the use of an undersize mounting kit or the lower grade lock nuts.
- The thorough examination and testing of the crane following its installation did not identify the inadequacy of the crane's mounting arrangement.

In July 2015, a recommendation was made to Atlas (UK), the crane's supplier, to ensure the integrity of Atlas cranes installed on other workboats. In addition, in October 2015, West Yorkshire Trading Standards was informed of the misleading markings on the lock nuts.

A recommendation made in this report to Atlas Maschinen GmbH, the crane's manufacturer, is aimed at ensuring that installation information is provided with all Atlas cranes fitted in the UK. A recommendation to the Association of Lorry Loader Manufacturers and Importers is intended to improve the effectiveness of thorough examinations and testing of shipborne lorry loader cranes. Recommendations to the Maritime and Coastguard Agency and Inverlussa Marine Services, *Carol Anne*'s manager, are intended to improve adherence to, and the effectiveness of, established codes of practice with regard to the installation or replacement of shipborne cranes on workboats.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *CAROL ANNE* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Carol Anne*
Flag	United Kingdom
Classification society	Not applicable
IMO number/fishing numbers	903664
Type	Workboat
Registered owner	Inverlussa Shellfish Limited
Manager(s)	Inverlussa Marine Services
Construction	Steel
Year of build	1999
Length overall	16.26m
Beam	6.5m
Gross tonnage	32.28
Minimum safe manning	2
Authorised cargo	Not applicable
VOYAGE PARTICULARS	
Port of departure	Barcaldine, Loch Crecan
Port of arrival	Balure, Loch Spelve, Isle of Mull
Type of voyage	Coastal
Manning	2
MARINE CASUALTY INFORMATION	
Date and time	30 April 2015 at 1140
Type of marine casualty or incident	Very Serious Marine Casualty
Location of incident	Balure, Loch Spelve, Isle of Mull
Place on board	Freeboard deck/Bow ramp
Injuries/fatalities	1 fatality
Damage/environmental impact	Collapse of deck crane
Ship operation	Discharging cargo (fishing net)
Voyage segment	Moored (bow to slipway)
External & internal environment	Light breeze, rippled sea, daylight
Persons on board	2

Carol Anne

1.2 NARRATIVE

Shortly after 0500 on 30 April 2015, the workboat *Carol Anne* sailed from its base at the Maritime Resource Centre (MRC) at Barcaldine, Loch Crecan, Scotland **(Figure 1)**. The vessel was carrying a palletised cargo of plastic pipes and fittings that were to be delivered to a fish farm at Balure on Loch Spelve, Isle of Mull. On board *Carol Anne* were its skipper, Jamie Kerr, and a deckhand.

Reproduced from Admiralty Chart BA 2635 by permission of the Controller of HMSO and the UK Hydrographic Office.

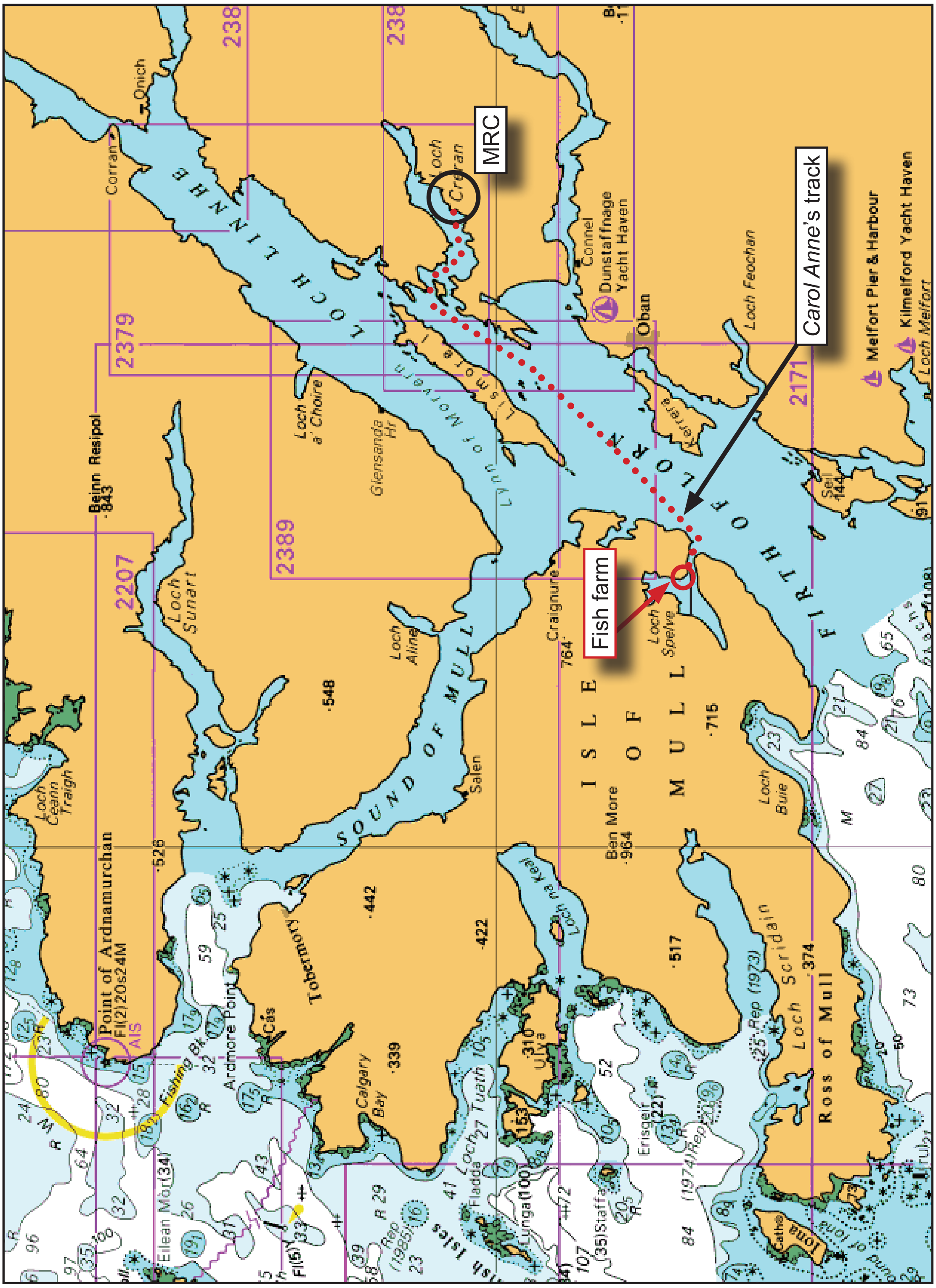


Figure 1: Extract of chart BA2635 - Scotland West Coast

Carol Anne arrived at the Balure fish farm at 0800. The palletised cargo was discharged using the workboat's crane mounted on the starboard side of the main deck. The cargo was then moved to a storage area by telehandler[1]. On completion, the fish farm's manager asked *Carol Anne*'s skipper to recover five fish cage nets from the seabed near the Loch's south shore **(Figure 2)**. The skipper agreed and then confirmed the arrangement with Inverlussa Marine Services (IMS), *Carol Anne*'s manager.

Carol Anne sailed with the fish farm's manager embarked. The workboat arrived at the nets, which were marked by buoys, at 0830. One of the nets was lifted on board with the vessel's crane. *Carol Anne* then returned to the fish farm's slipway where the net was off-loaded. The fish farm manager was satisfied with the conduct of the net recovery and disembarked.

Shortly afterwards, *Carol Anne* sailed from the slipway and returned to the area near the loch's south shore where the four remaining nets were recovered onto its deck. The workboat returned to the fish farm at approximately 1100 and its bow ramp was lowered onto the slipway. One of the nets was then landed ashore using the vessel's crane. The crane was operated by the skipper using a remote control unit. The net was lifted from the deck. The crane was then slewed in an anticlockwise direction and its boom extended in order to carry the net over the workboat's starboard side and position it over the slipway ahead of the bow ramp. The net was then lowered to the ground, unhooked and removed from the slipway using the telehandler.

To off-load the remaining nets, the deckhand operated the crane under the skipper's supervision. The skipper and the deckhand stood on the port side of the working deck opposite to the crane **(Figure 3)**. At approximately 1140, the last net was lifted and slewed over the starboard side in the same manner as the previous nets. Suddenly, there was a loud bang and the crane toppled towards the skipper and the deckhand. The deckhand ran aft towards the wheelhouse and the skipper ran forward. As the crane fell, it swivelled towards the slipway. Its boom struck the skipper and pinned him to the bow ramp.

The deckhand immediately shouted for help and ran to the skipper. One of the shore staff quickly boarded *Carol Anne* and assisted the deckhand to provide cardiopulmonary resuscitation. Another member of staff telephoned the emergency services.

On the ambulance service's advice, given over the telephone, the crane was lifted off the skipper using the telehandler. Shortly afterwards, paramedics in a fast response car and an air ambulance arrived. Efforts to resuscitate the skipper continued but he could not be revived. He was declared deceased at the scene.

Postmortem examination concluded that Jamie Kerr died as a result of injuries sustained from the collapse of *Carol Anne*'s deck crane.

[1] A self-propelled vehicle with an extending boom, capable of being used as a forklift or crane.

Reproduced from Admiralty Chart BA 2387 by permission of the Controller of HMSO and the UK Hydrographic Office.

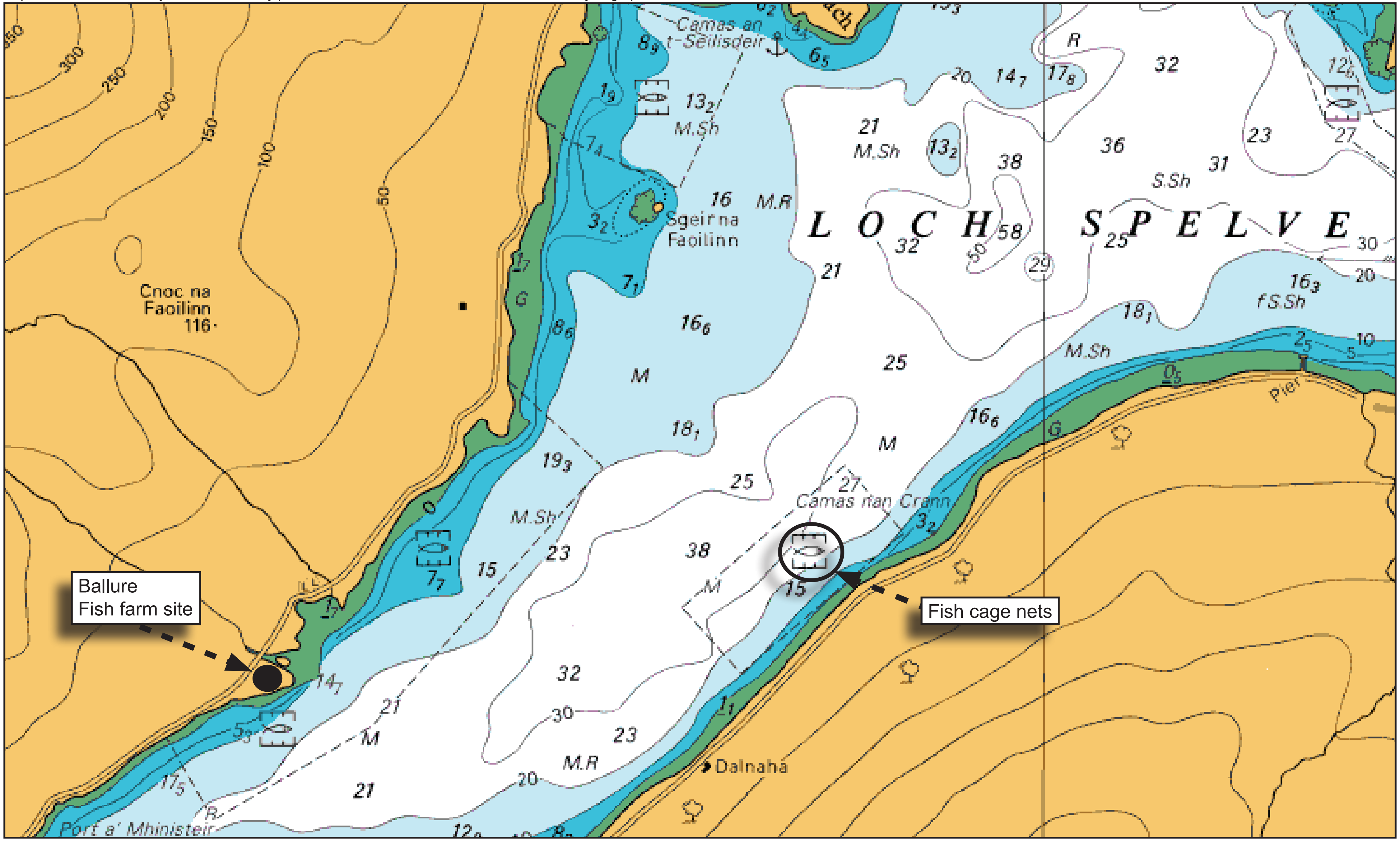


Figure 2: Extract of chart BA2387 - Firth of Lorn (Northern Part)

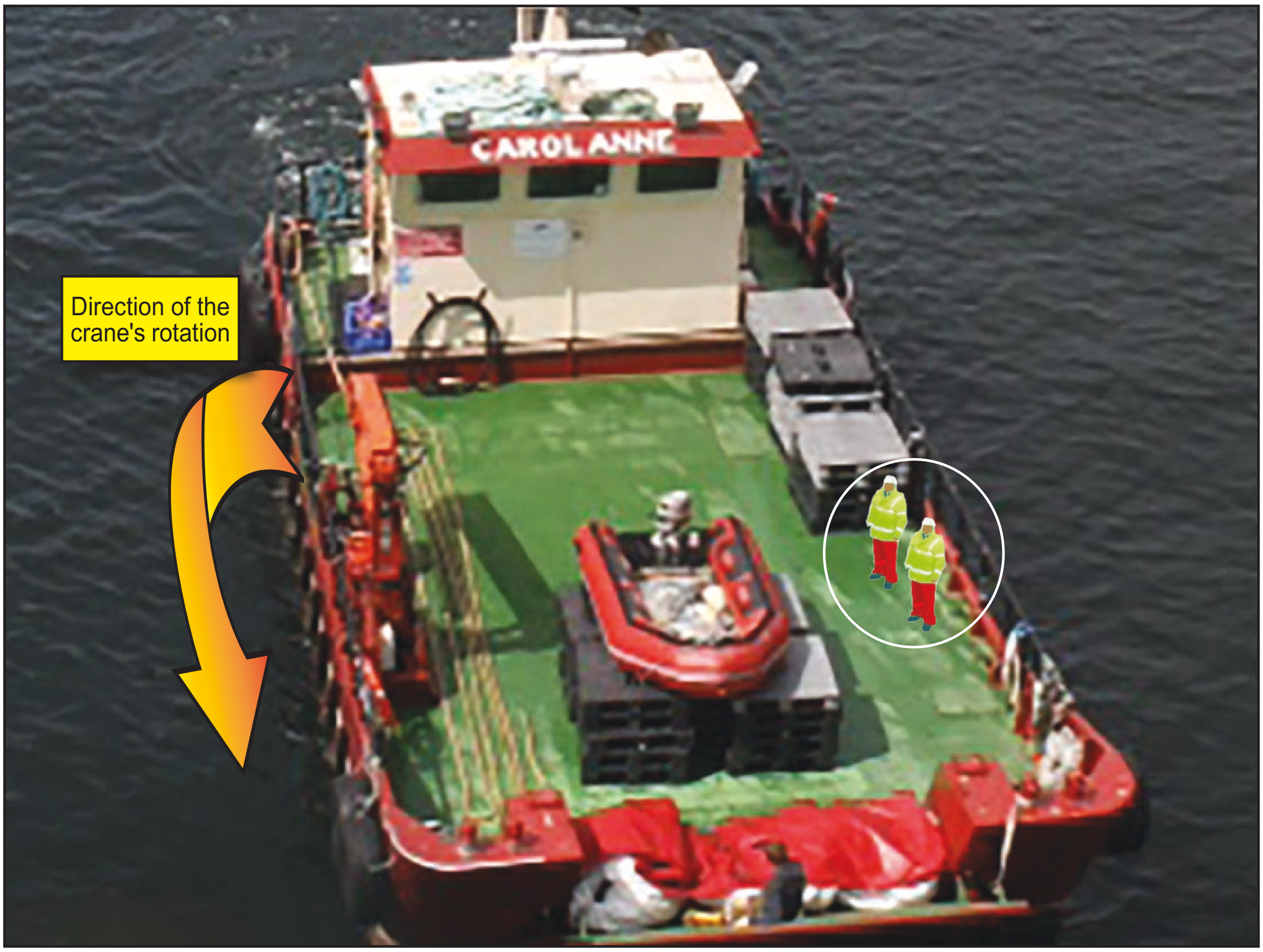


Figure 3: The positions of the skipper and deckhand

1.3 POST-ACCIDENT INSPECTION

Carol Anne's crane had fallen inboard **(Figure 4)** and was lying with its boom extended over the workboat's bow ramp. The end of the boom was 5.4m from the crane's pedestal. The net was still attached to the crane's hook and was lying on the slipway. The net weighed 2204kg **(Figure 5)**.

The nylon insert lock nuts (lock nuts) on the four tie bolts on the outboard side of the crane's pedestal had stripped **(Figure 6)** and had released from the tops of the bolts. The tie bolts remained in place **(Figures 7** and **8)**.

The four tie bolts on the inboard side of the crane's pedestal had bent in the direction of the falling crane **(Figures 7** and **9)**. One of the lock nuts had stripped and released; the other three remained in place.

Square tab washers onto which the lock nuts had been secured were deformed and showed signs of shear stress **(Figure 10)**. One of the tab washers could not be found.

The slots in the box sections of the crane's pedestal, through which the 24mm tie bolts had been secured in order to attach the crane to a base plate welded to *Carol Anne*'s deck, were 32mm wide **(Figures 7, 11** and **12)**. Neither a load radius diagram[2] nor any indication of the crane's safe working load (SWL) was found.

[2] A load radius diagram illustrates the maximum loads that can be lifted at increasing radii.

Figure 4: Collapsed crane

Figure 5: Net being weighed

Figure 6: One of the failed nylon inset lock nuts

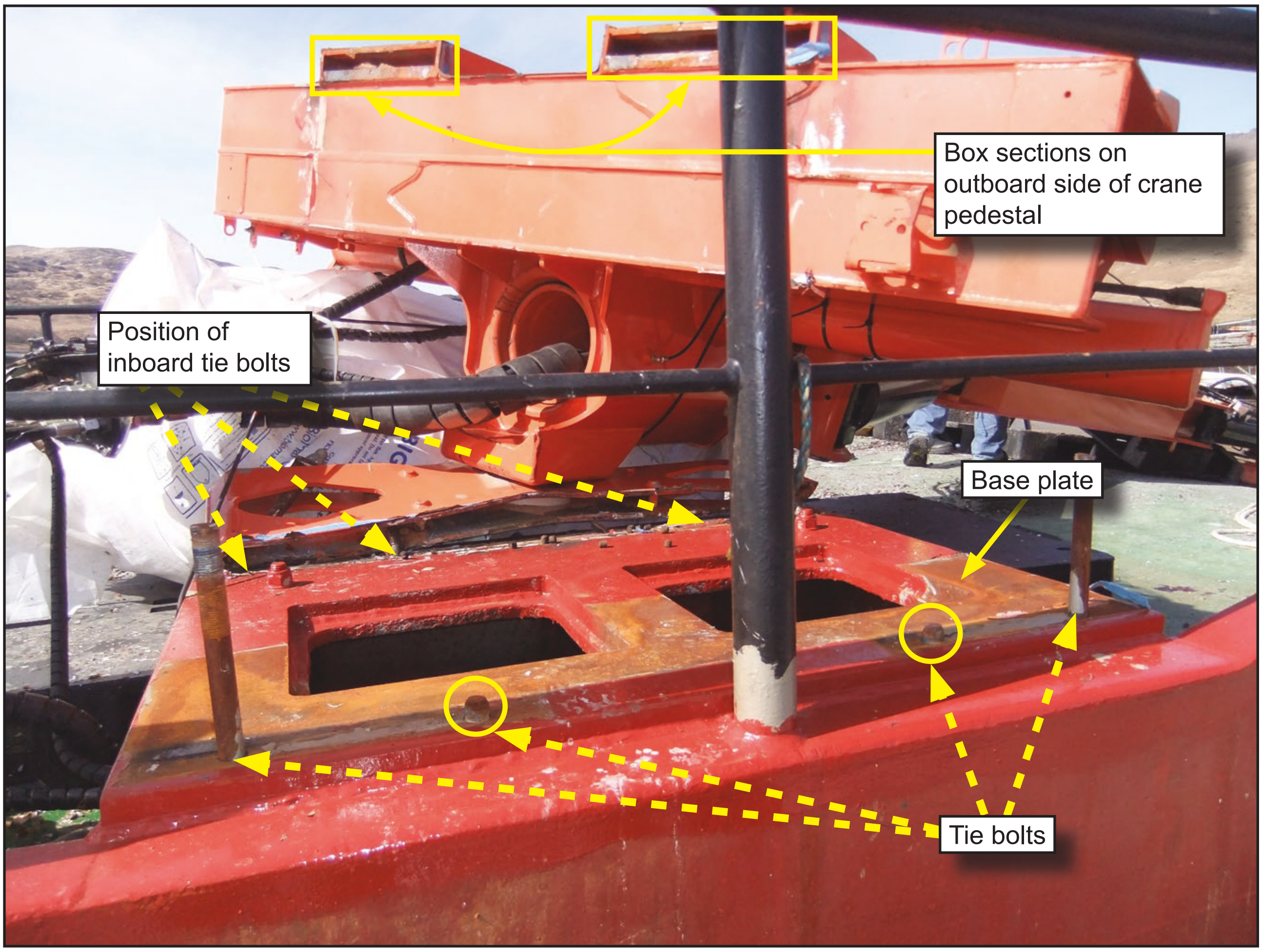


Figure 7: The positions of the tie bolts

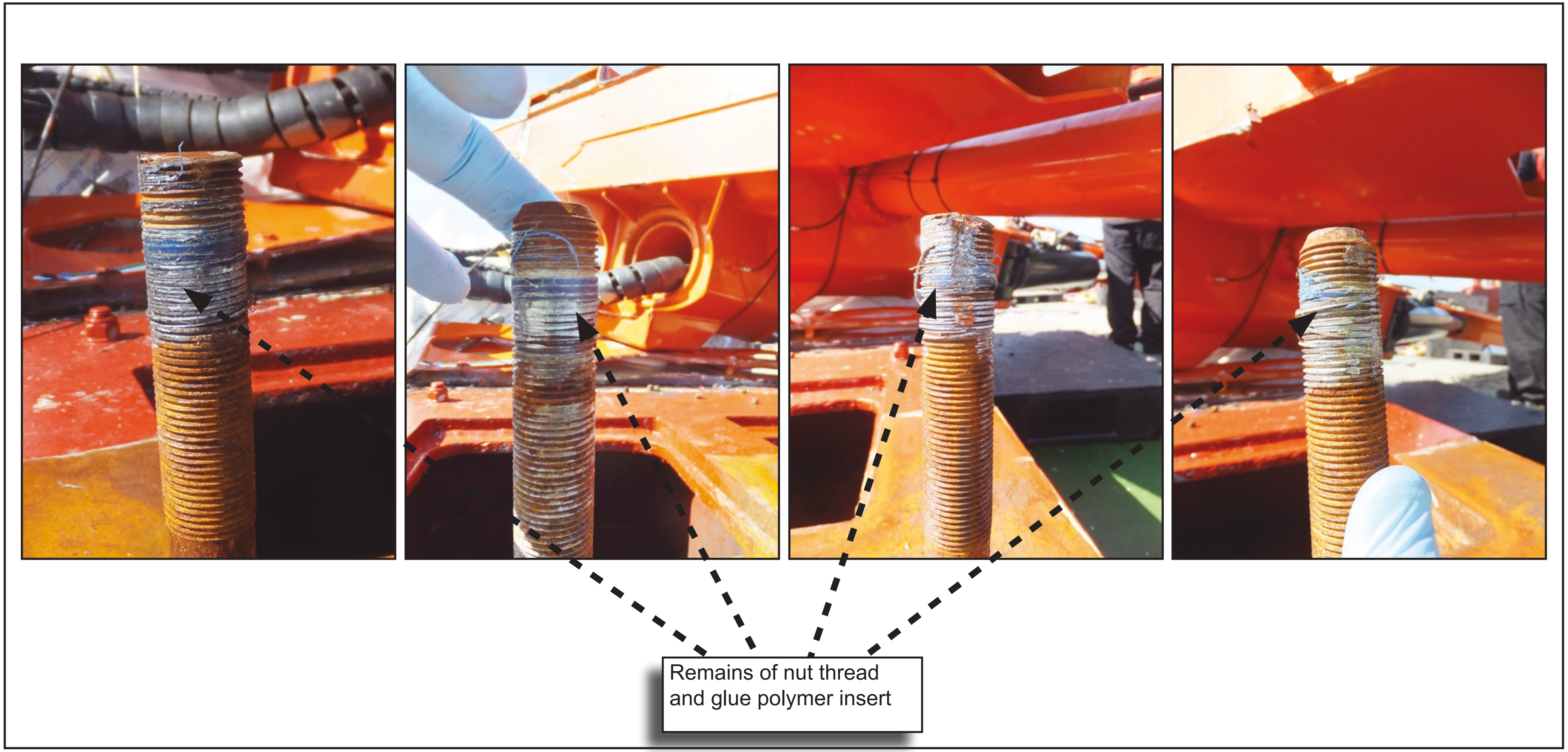


Figure 8: Tie bolts on the outboard side of the crane pedestal with the remains of the stripped lock nut threads

Image courtesy of Police Scotland

Figure 9: Bent tie bolt on the inboard side of the crane pedestal (circled)

Figure 10: Recovered tab washers

Image courtesy of Police Scotland

Figure 11: Location of crane pedestal box sections (circled)

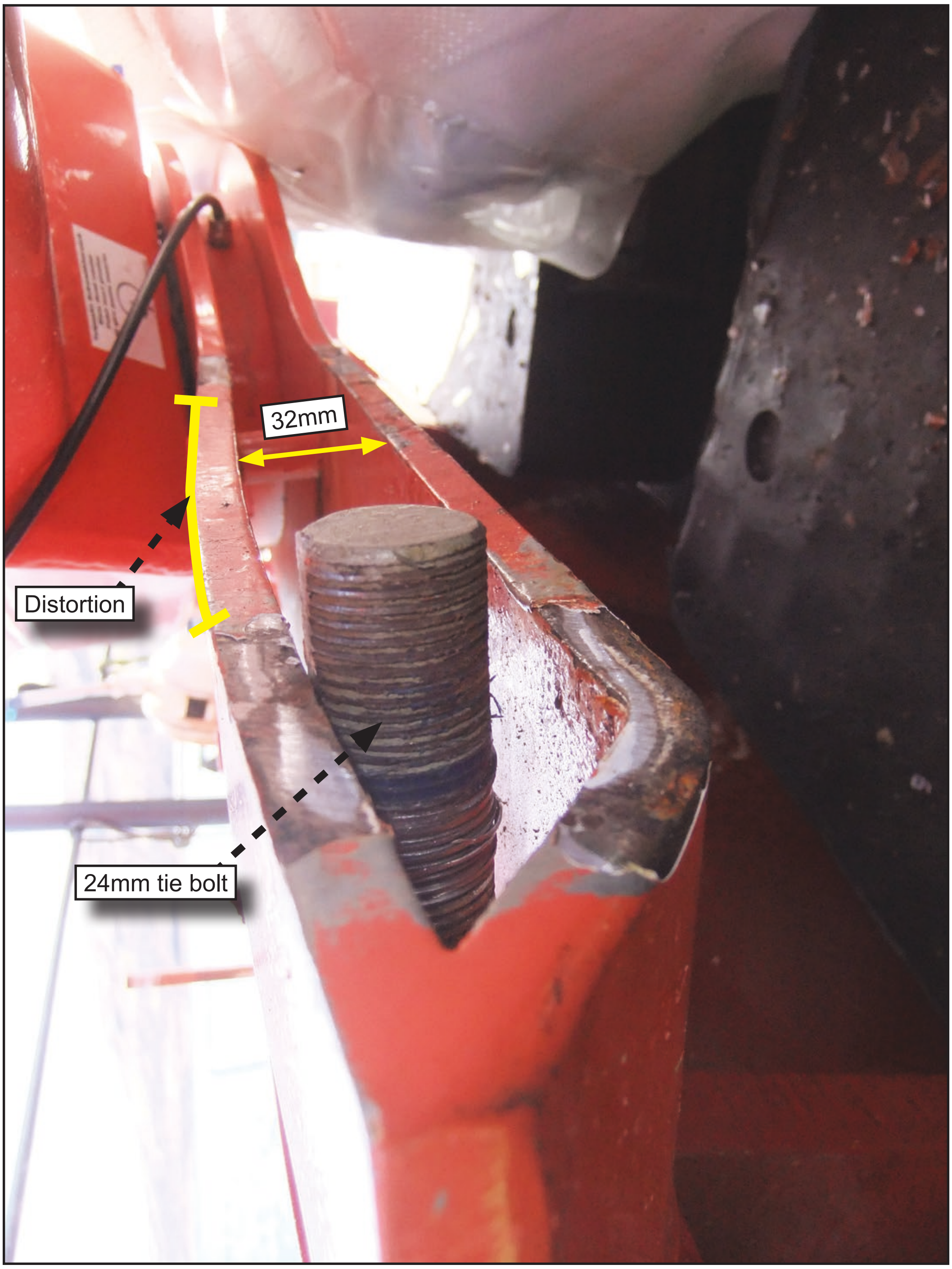


Figure 12: A 24mm tie bolt through a 32mm slot
(inboard side)

1.4 THE CREW

Carol Anne was operated from a pool of two skippers and one deckhand working a cycle of 2 weeks on duty followed by 1 week off duty. The workboat was routinely manned by either a skipper plus the deckhand or by the two skippers.

The deceased, Jamie Kerr, was 25 years old. He had worked as a fisherman since leaving school and held a Royal Yachting Association Yachtmaster Offshore certificate that had been commercially endorsed. He had also completed the mandatory basic safety training required by fishermen[3] and had been trained and certified to operate a sea crane in April 2013. Jamie joined IMS in October 2013 and was promoted to skipper and started to work on board *Carol Anne* in January 2015.

The deckhand was 20 years old and held STCW[4] qualifications in first-aid, sea survival, fire-fighting and personal safety and social responsibility. He joined IMS in February 2015 and, following a period of familiarisation, he started work as a deckhand on board *Carol Anne* at the end of March 2015.

1.5 *CAROL ANNE*

1.5.1 Operational limitations

Carol Anne was a landing craft type workboat that was built in 1999 by Alexander Nobel & Sons Ltd, Girvan. The vessel was built specifically for fish farm operations and the operating criteria and limitations listed in its Stability Information Booklet (SIB), which was approved by the Maritime and Coastguard Agency (MCA) in 2000, were:

- *Lifting nets and possibly moorings with a crane when alongside cages, for transport ashore, operating within farm limits only.*
- *Transport of up to 30 feed pallets or 30 fish bins on deck, or other equipment of equivalent weight and height of centre of gravity, when required, between shore and fish cages within the farm limits only.*
- *The vessel must always be loaded so that the loadline marks are not submerged.* [sic]

Carol Anne was operated under the Code of Practice for the Construction, Machinery, Equipment, Stability, Operation, Manning, Examination and Certification and Maintenance of Vessels of up to 24 Metres Load Line Length which are in Commercial Use for the Carriage of Cargo and/or not more than 12 Passengers or neither Cargo nor Passengers and Pilot Boats (The Brown Code). The vessel was permitted to operate up to 20 miles from a safe haven (area category 3) with a maximum weight of cargo and passengers of 28900kg and a minimum of two crew. The Certifying Authority (CA)[5] for *Carol Anne* was the Society of Consulting Marine Engineers & Ship Surveyors (SCMS); the MCA had been the workboat's CA until 21 June 2011.

1.5.2 Ownership and operation

Carol Anne had been owned and operated by IMS since 2010. IMS was a family run company, based on the Isle of Mull, that employed over 30 local staff. The company was originally focused on mussel farming, but over the last 5 years it had expanded into the marine services and fish farm sectors. IMS operated four landing craft type workboats (including *Carol Anne*) and two multipurpose support vessels.

[3] In the UK, new entry fishermen must complete basic safety courses in sea survival, elementary first-aid; fire-fighting and health and safety. Fishermen with 2 years' experience must also complete a 1-day mandatory safety awareness course run by the Sea Fish Industry Authority (Seafish).

[4] STCW – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended (STCW Convention)

[5] The Certifying Authority is either the MCA or an organisation authorised by the MCA to appoint persons for the purpose of examining vessels, signing Declarations of Examination and issuing certificates.

Carol Anne was primarily used to distribute fish food. Other tasks included fish farm development and maintenance and the treatment of fish stocks against parasites. The workboat's weekly work schedule was arranged by its crew based on the fish farms' requirements. The skipper sent the workboat's schedule to IMS in an email 1 week in advance.

1.5.3 Marine Resource Centre

The MRC **(Figure 13)** was a multi-occupancy marine industrial estate that had warehouse storage and engineering support facilities, a deep water pier and slipways. Fish food was delivered to the MRC by road in 1 tonne (t) bags (known as Flexible Intermediate Bulk Containers (FIBC)). *Carol Anne*'s crane was used to lift up to 2 x 1t FIBCs at a time from the pier onto the workboat's deck. *Carol Anne* moored alongside the MRC pier overnight.

Image courtesy of Maritime Resource Centre Limited

Figure 13: Maritime Resource Centre

1.6 CRANE REPLACEMENT IN 2010

At build, *Carol Anne* was fitted with an Atlas 100.1 A3 lorry loader crane[6]. The crane weighed 1350kg and had a capacity of 100kN-m that enabled a 1.04t load to be carried at a maximum reach of 9m[7].

Following *Carol Anne*'s change of ownership in 2010, the Atlas 100.1 A3 crane was replaced with an Atlas 165.2E A19 (Atlas 165) crane. The replacement crane weighed 1740kg and had a capacity of 165kN-m that enabled a 1.73t load to be carried at a maximum reach of 9.4m.

6 Lorry loader or truck loader cranes are cranes specifically designed to be mounted on lorries or trucks.

7 Lorry loader cranes are rated by their capacity expressed as a product of force (load) and distance from a crane's centre which is measured in kilonewton metres (kN-m). For example, a crane with a rating of 160kN-m can lift a maximum load of 2000kg at a distance from the centre of the crane of 8m (the value for gravity is taken as $10ms^{-2}$). Alternatively, a load of 8000kg can be lifted to a radius of 2m.

The replacement of the crane was recorded in *Carol Anne*'s Document of Compliance[8] in May 2011 in preparation for the transfer of CA to SCMS. However, it was not reflected in the workboat's SIB.

1.7 CRANE REPLACEMENT IN 2014

In 2014, IMS decided to replace the Atlas 165 crane on board *Carol Anne* as it was becoming increasingly unreliable. An Atlas VCS 170.2 A12 (Atlas 170) crane was ordered from Atlas Cranes UK Ltd (Atlas (UK) through HIAT (Scotland) Ltd. The quotation received from Atlas (UK) made reference to a "*special mounting kit for static applications*" and the order invoice stated that the order was for a "*full marine crane*". IMS did not notify the SCMS of its intention to replace the Atlas 165 with the Atlas 170 because it assessed that the cranes were similar.

Atlas (UK) passed the order for the Atlas 170 crane to Atlas Maschinen GmbH in Germany (Atlas (Germany). Atlas (Germany) was not requested to provide any information with respect to the crane's installation.

HIAT (Scotland) also ordered a remote control system manufactured by Scanreco[9] in Italy that was to be fitted to the Atlas 170 crane after the crane had been delivered.

1.8 ATLAS 170 VCS A12 CRANE

The Atlas VCS 170 crane was designed and built for use outside the European market. The designator "CS" indicated that the crane did not comply with European Directive 2006/42/EU (Machinery Directive). Consequently, the crane did not carry a CE mark[10]. The crane weighed 2610kg and had a capacity of 170kN-m that enabled a 1.5t load to be carried at a maximum reach of 10.8m. An engineering drawing of the crane's pedestal is at **Figure 14**.

The crane ordered by IMS was assembled by Atlas (Germany) during November 2014 at its factory in Dermenhorst, Germany. The crane was not fitted with a valve block to control its hydraulic systems, or an electronic control system. A valve block was fitted to enable the crane to be tested for functionality before it was dispatched but it was removed after the test.

On 15 December 2014, the crane and a valve block were dispatched from Atlas (Germany). No installation instructions and no mounting kit were provided. The delivery note sent by Atlas (Germany) to Atlas (UK) stated that the crane was "*without control valve*" and "*this crane is not authorised for use or operation in EU member states*".

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[8] The Document of Compliance comprised five parts: vessel details; record of compliance with design and structural requirements and fixed equipment; report on the material condition of the vessel; authorised person's declaration, and; owner/manager's declaration and record of periodic examinations. The form included a statement to the effect that *The Owner or Managing Agent must notify the Certifying Authority of any changes to the vessel details…*

[9] Scanreco is an established manufacturer of remote control systems for cranes.

[10] CE (Conformité Européenne) marking is a mandatory conformity marking for certain products sold within the European Economic Area.

Image courtesy of Atlas Cranes (UK)

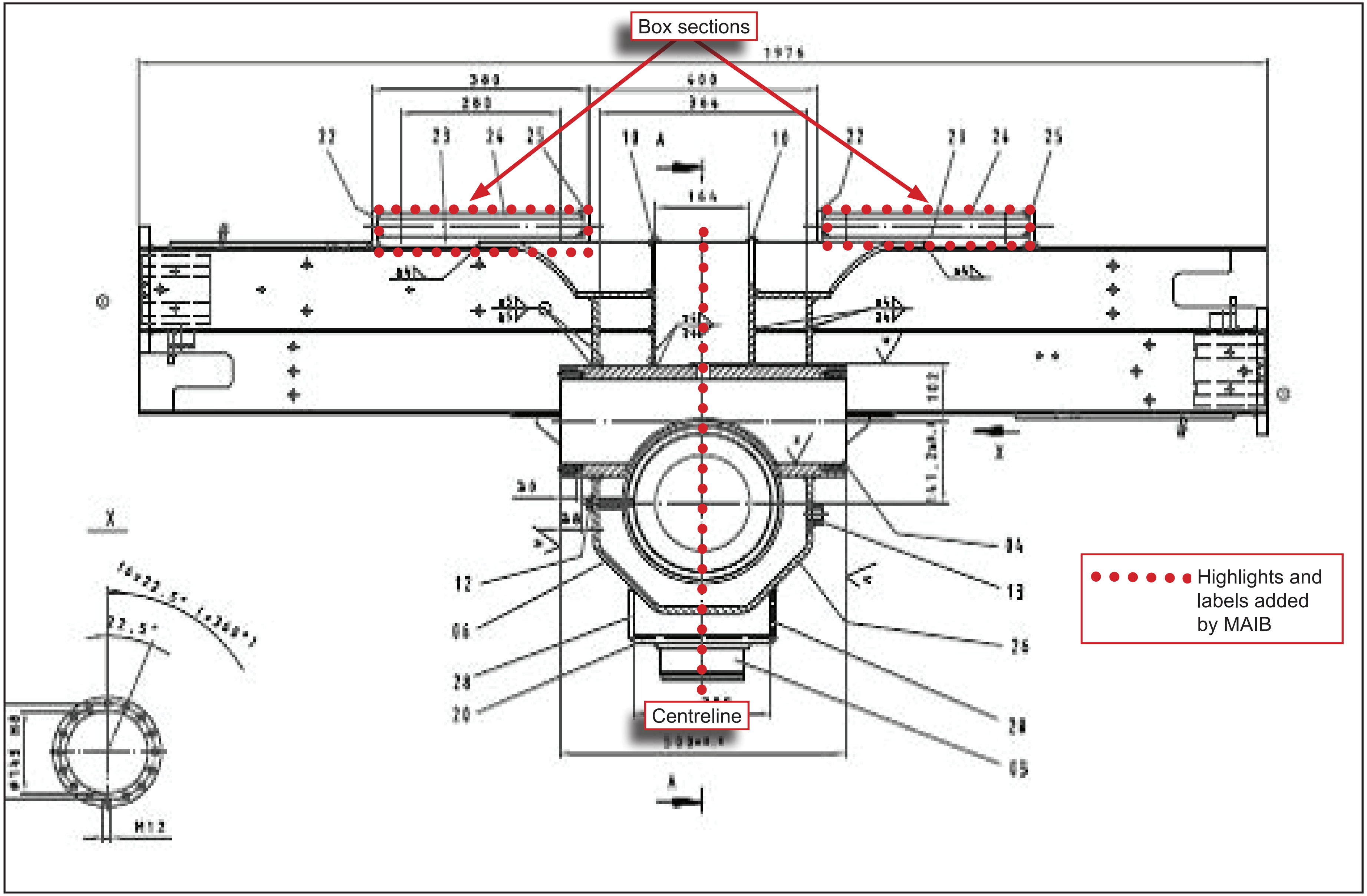

Figure 14: Drawing of the crane pedestal as fitted

1.9 CRANE MODIFICATION

The Atlas 170 crane and the valve block were delivered to R Allison Ltd, lorry loader specialists based in Lanarkshire, Scotland, on 18 December 2014. The Scanreco remote control system arrived the same day. R Allison Ltd fitted the valve block and the remote control system to the crane assembly. The valves were checked for correct sequence of operation but R Allison Ltd did not have the facilities to test the crane under load or to verify the overload or safety limits set.

1.10 CRANE INSTALLATION

1.10.1 Mounting kit

On 22 December 2014, Hiat (Scotland) Ltd sent a request by email to Atlas (UK) for a mounting kit comprising 8 x M24[11] tie bolts, eight nylon insert lock nuts, sixteen plain nuts and eight tab washers **(Figure 15)**. HIAT (Scotland) Ltd specified M24 bolts as they were the bolts most commonly used by the company when fitting Atlas cranes. The email stated that the mounting kit was for the Atlas 170 crane and it also included the serial number of the crane sent from Atlas (Germany). Atlas (UK) dispatched the mounting kit as requested and it arrived at the MRC on 24 December 2014.

Image courtesy of Atlas Cranes (UK)

Figure 15: Example of an M24 tie bolt with two plain nuts, one lock nut and a tab washer

[11] The size of the tie bolt is measured by its diameter, M24 = 24mm and M30 = 30mm.

1.10.2 Base plate

IMS contracted PMG Services Ltd to install the crane. PMG Services Ltd serviced and maintained diesel engines, and hydraulic plant and systems, including lorry loader cranes. The company was based near Oban, Scotland, and had been engaged by IMS to service and repair equipment on board its vessels.

The Atlas 170 crane for *Carol Anne* was delivered to PMG Services Ltd on 8 January 2015. PMG Services Ltd sub-contracted Mackenzie Welding Ltd to fabricate and fit a new base plate for the crane as it had a larger footprint than the Atlas 165 crane. In order to fabricate the new base plate, Mackenzie Welding Ltd required the dimensions of the Atlas 170 crane pedestal and the intended positions of the tie bolts. Holes in the base plate needed to be drilled before the plate was welded to the existing mounting on *Carol Anne*'s deck. To obtain this information, IMS contacted Atlas (UK), which then supplied an engineering drawing of a crane pedestal **(Figure 16)**.

1.10.3 Crane fitting

The Atlas 170 crane was fitted on board *Carol Anne* between 12 and 15 March 2015 while the workboat was alongside at the MRC **(Figure 17)**. PMG Services Ltd sub-contracted Turnbull Engineering Services to assist with the work. The crane was secured to the new base plate **(Figure 7)** using the mounting kit supplied by Atlas (UK) **(Figure 15)**. The slots in the pedestal's box sections **(Figures 7, 11** and **14)** did not align with the pre-drilled holes in the base plate so the position of the pedestal had to be adjusted further forward than intended. The 8 x M24 tie bolts were inserted through the 32mm slotted mounts on the crane pedestal and the pre-drilled holes in the base plate.

Four tie bolts were located on the outboard side of the pedestal and four on the inboard side. Two plain nuts were fitted to the bottom end of each tie bolt where the bolt protruded through and under the base plate. A square tab washer was placed over the upper end of each tie bolt and then positioned into slots on the mounting frame. A nylon insert lock nut was then screwed onto each tie bolt and tightened onto the tab washer.

The tie bolts were tightened to a torque[12] of 450Nm and then to 600Nm. The torque used was based on PMG Services Ltd.'s experience in fitting grade 10.9 bolts and grade 10 nuts on other makes of crane. The torque was achieved by tightening the nylon insert lock nuts with a torque wrench and socket while holding the plain nuts on the underside of the base with a spanner. No lubrication was applied to the tie bolts and nuts during their installation.

The crane's ancillary systems and controls were fitted between 14 and 15 March. Its functionality was checked on 16 March by Turnbull Engineering Services. This check did not include any verification of the crane's overload or safety settings.

[12] Torque is the turning moment of a nut which is expressed as the force exerted (newton; N) and the length of the lever arm (metre; m). The torque applied to a nut is determined by the external loads that a connection is subjected to and to the number, dimensions, thread pitch and material grade of the fastenings used.

Image courtesy of Atlas Cranes (UK)

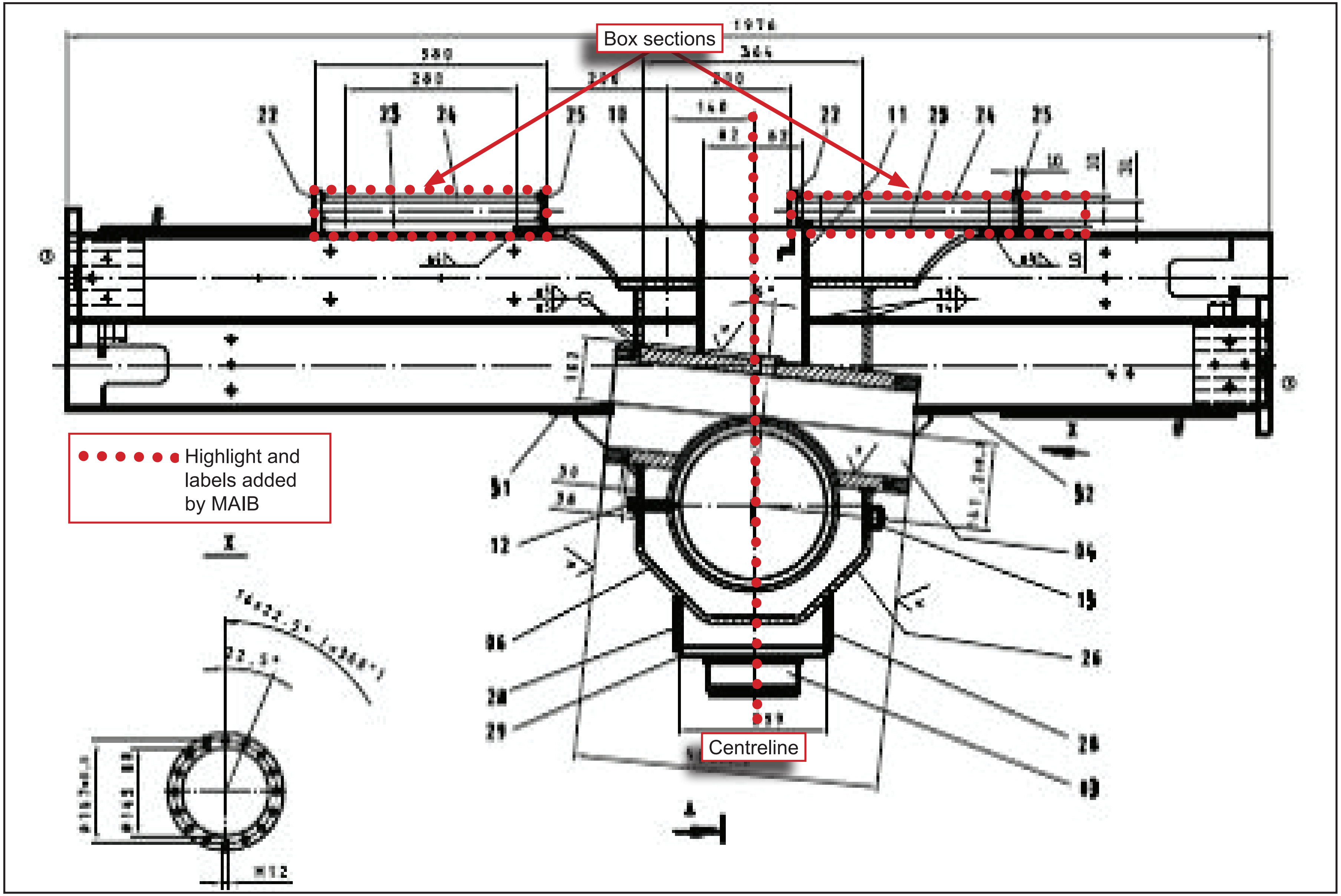

Figure 16: Crane pedestal drawing supplied by Atlas Cranes (UK)

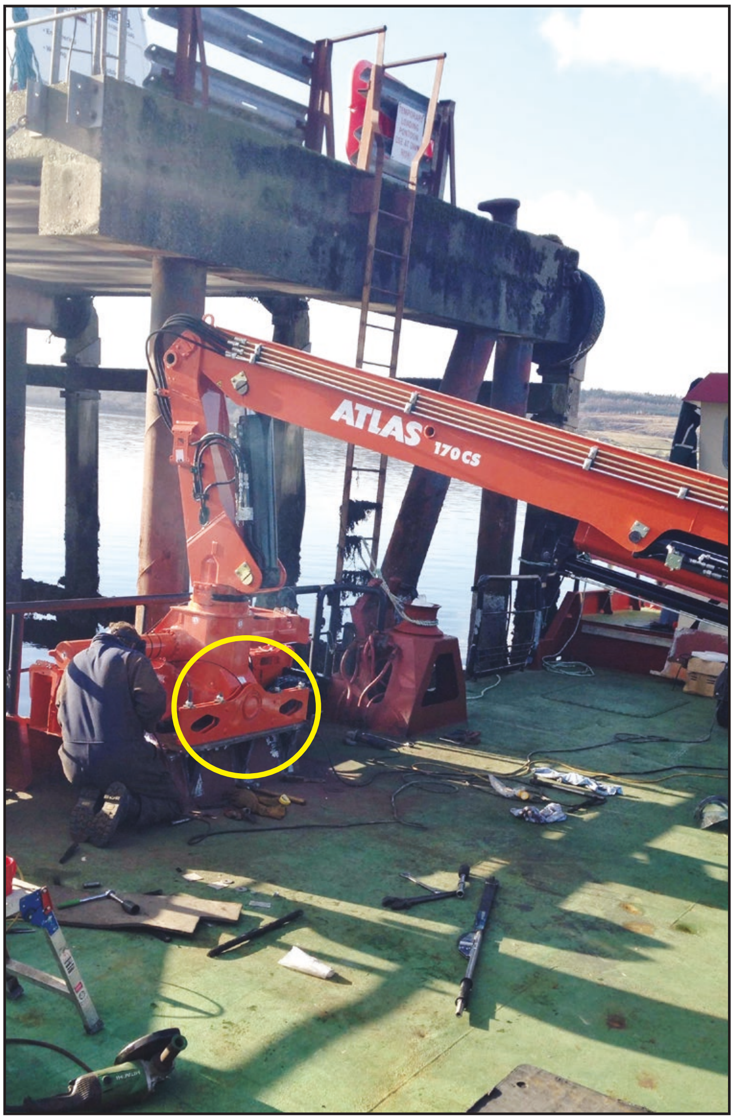

Figure 17: Crane installation showing inboard box section (circled)

1.11 CRANE USE FOLLOWING INSTALLATION

Between 16 and 23 March 2015, *Carol Anne* distributed up to 40 FIBCs at a time from the MRC to several fish farms. During this period, the newly fitted Atlas 170 crane was used to load and discharge the FIBCs, two at a time.

1.12 INSTALLATION INSPECTION AND TEST

Atlas (UK) arranged for one of its service engineers to inspect and test the Atlas 170 crane fitted on board *Carol Anne*. The service engineer met *Carol Anne* at 1320 on 23 March 2015 as the workboat returned to the MRC after it had completed deliveries of fish food. He quickly determined that *Carol Anne*'s crane could not be fully extended through its entire slewing range (410°) due to the proximity of an adjacent pier **(Figure 18)**. He also saw that there was no load radius diagram for the crane or any information regarding its installation or operation, which he required to complete the inspection and test.

Figure 18: *Carol Anne* alongside during the thorough examination

The engineer contacted Hiat (Scotland) Ltd, which then passed him sufficient information, including SWL data, over the telephone to enable an overload test (see paragraphs 1.17.1 and 1.18.1) to be completed. The engineer visually inspected the crane installation. He also checked the tie bolts by tapping them with a small hammer. The engineer assessed that the bolts and nuts were adequate.

In preparation for an overload test, the engineer set the crane's hydraulic pressure regulating valves so that the crane was able to lift a test weight of 2.08 tonnes with its boom fully extended to 10.8m. The engineer used two 1t FIBCs **(Figure 19)** as the test weight. A load cell[13] was used to check that the weight of the two FIBCs was 2t. During the test, the crane lifted the FIBCs and was then slewed with the boom, at its maximum extension. However, the crane could not be slewed outboard on *Carol Anne*'s starboard side due to the adjacent pier.

The service engineer then conducted a dynamic test that required the crane to be fully extended and operated over as wide a range of movements as possible with a test weight of 1.8t. The two 1t FIBCs were again used as the test weight. To compensate for the additional weight, the engineer reduced the extension of the crane's boom, but the crane's operation over the starboard side was still hampered by the pier.

[13] An electronic device which when used in conjunction with a load slung on a crane hook will indicate the weight of the load.

Figure 19: 1 tonne Flexible Intermediate Bulk Containers (FIBC)

The service engineer assessed that the crane had passed the overload and dynamic tests. He adjusted the crane's hydraulic control valves to set its operating limits and overload protection system. The engineer then locked and sealed the valve adjusters and carried out a function test of the crane. The engineer had a calibrated torque wrench, but he did not check the torque of the tie bolts. The engineer issued a "*Report of Thorough Examination of Loader Crane*" **(Annex A)**. The report noted that a load plate/radius diagram was not fitted to the crane.

1.13 POST-ACCIDENT TESTS

1.13.1 Health and Safety Laboratory

The tie bolts, nuts and tab washers used to secure the Atlas 170 crane fitted on board *Carol Anne* were removed and sent to the Health and Safety Laboratory (HSL)[14] at Buxton, UK for metallurgical testing. The torque wrench used in the installation of the crane was also tested for calibration. The results of the examinations and tests included:

<u>Tie Bolts</u>

When the tie bolts were removed from the accident site, it was found that two of the four inboard bolts had fractured during the incident. The other two inboard bolts had bent and were removed by flame cutting.

[14] HSL is an agency of the Health and Safety Executive (HSE).

The tie bolts were marked with '10.9' at one end **(Figure 20)**, which indicated the grade of steel. The mechanical and chemical properties of the M24 tie bolts met the requirements of BS EN ISO 898 Part 1: 2013[15] for a 10.9 grade bolt. Each tie bolt was 450mm long with a threaded section at each end. One threaded section was 204mm long and the other 57mm long. The centre section of each tie bolt had been machined to give a plain diameter of 22.5mm. The threads had been machined to give a diameter of 23.9mm and a pitch of 2.0mm, which is a fine pitch thread.

Figure 20: Grade marking on the M24 tie bolt

Tab washers

Seven of the eight tab washers **(Figure 10)** were recovered. All showed evidence of plastic deformation with imprints of the nut on the upper surface and the sub-frame on the lower surface. The missing tab washer would have been located on the rear-most outboard position.

The tab washers were manufactured from rolled 10.1mm thick black steel bar and were nominally 50mm square. Two opposite sides had been sawn and the other two sides were bowed from the rolling process. Each tab washer had a 26mm diameter hole punched centrally between the sawn edges but was slightly off centre between the rolled edges to allow the welding of a tab on the underside of the washer. The tab was located centrally between the two sawn edges and was 20mm long x 8.3mm wide and 8.1mm thick. The tensile strength of the steel used in the tab washer was 460N/mm^2.

[15] BS EN ISO 898 provides the mechanical properties of fasteners made of carbon steel and alloy steel. Part 1 details the mechanical and physical properties of bolts, screws and studs with specified property classes. Part 2 covers similar information for coarse and fine pitch nuts. The standard describes the testing method to be used to determine the physical properties of nuts and bolts and how they are to be marked.

Lock nuts

The four outboard lock nuts and one of the inboard lock nuts had failed by thread stripping. The remaining three inboard nuts had not failed. One of the failed nuts was not recovered.

The pitch of the M24 nylon insert lock nuts matched that of the tie bolts. Each nut was 22.9mm high and 35.1mm across the flats with a threaded bore diameter of 21.9mm. A blue polymer insert was fitted at one end. The nuts were marked with the symbol |8| **(Figure 21)** to indicate their grade**,** and were galvanised.

The mechanical properties of the M24 nylon insert lock nuts did not meet the requirements of BS EN 898- Part 2:2012 for a grade 8, M24 nut with a fine pitch thread; the nuts had a hardness of 211 HV10 whereas the standard requires a hardness of between 233 and 253 HV10.

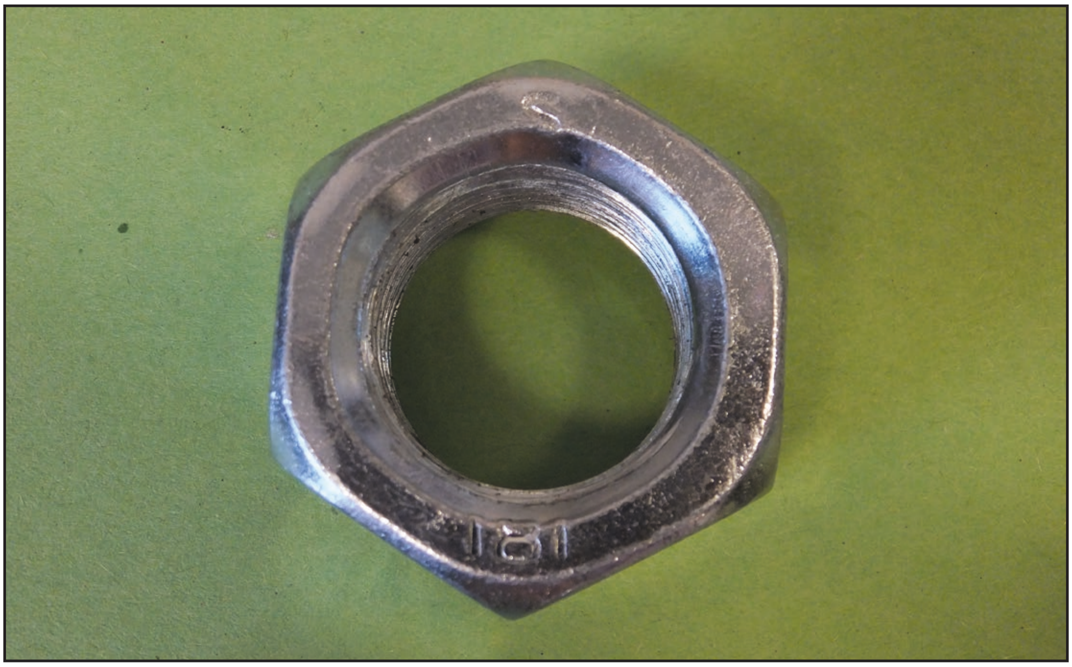

Figure 21: Grade marking on the M24 nylon insert lock nut

Torque wrench

The torque achieved on the torque wrench with 600Nm set was 586Nm. The accuracy of the wrench was within the limits detailed in BS ENO 6789:2003.

Finite element analysis

HSL conducted a finite element analysis to compare the strength of the M24 mounting kit to the strength of an M30 mounting kit also used by Atlas (UK). The results of the analysis indicated that the M24 mounting kit was 53% weaker than the M30 mounting kit. It also indicated that the plastic strain at the centre of the tab washer was 0.2% for the M30 kit and 10% for the M24 kit. One of the conclusions of the analysis was that:

The use of the M24 mounting kit significantly reduced the ability of the mounting kit to securely attach the crane to the boat base plate. The reduction in strength was due to two factors; the smaller size of the mounting kit and the difference arising from the washer being clamped (M30) and subjected to bending and shear (M24). [sic]

<u>Main Findings</u>

The main findings of HSL's test report included:

The studs were compliant with BS EN ISO 898 Part 1: 2013 grade 10.9. The incident nuts were marked as grade |8| and were found to be compliant, in so far as tested, with BS 3692: 2014 grade |8|. BS EN 898 Part 2: 2012 grade 8 nuts have a higher specified hardness and therefore strength than grade |8| nuts to BS3692: 2014.

The use of a grade 8 nut with a grade 10.9 stud is not recommended by BS 3692: 2014 because the nut is significantly weaker than the stud. The Standard recommends a grade 10 nut with a grade 10.9 stud.

The four outboard bolted connections failed by thread stripping of the nut. Of the four inboard bolted connections, one failed by thread stripping of the nut. Two of the four connections had fractured at the stud thread root by ductile overload in bending as the threaded regions protruded above the mounting plinth in the area in which bending occurred. The fourth connection did not fail, but the tab washer deformed allowing the sub-frame to pass over the washer.

The use of the smaller diameter (M24) studs, tab washers and nuts in a slot designed to use a larger M30 kit, resulted in a poor fit of the tab washers and a larger than expected freedom of movement of the stud in the slot before tightening. This resulted in misalignment of some of the studs and placed some of the tab washers in shear loading rather than compression. The M24 tab washers were 30 % thinner than the specified M30 tab washers and were therefore much weaker.

The crane mounted on the MV Carol Anne was of the type typically used as a truck loader. When used on a truck, stabilisers fitted through the sub-frame would provide the main load path for resisting load moments. As fitted to the MV Carol Anne, no stabilisers were fitted, forcing the mounting studs to take the full load moments. Also, as the inboard section of the sub-frame could pivot about the crane column, only the outboard studs could resist load moments about the transverse axis (with the boom forward or aft on the MV Carol Anne).

In summary, the failure was a result of three main factors:

- *no adjustment was made to the mounting arrangement to take account of the static mounting without stabilisers;*
- *the use of an undersize mounting kit with smaller diameter studs, nuts and washers; and*
- *the use of lower strength nuts on high strength studs. [sic]*

The report also concluded that based on measurements and photographs taken at the accident site, the crane was working with the load at a radius of approximately 3.6m. It assessed that this was well within the envelope of acceptable working positions, assuming a load of 2.3 tonnes being carried at the time of the incident. Therefore, it was unlikely that the crane was overloaded at the time of the incident.

1.13.2 Caparo Testing Technologies

A representative sample of the lock nuts supplied by Atlas (UK) was submitted to Caparo Testing Technologies at Willenhall, UK, which assessed them against recognised standards.

The findings of the tests on the M24 zinc plated lock nuts included:

- The markings on the nuts indicated they were grade 8 (style 1).
- The nuts were a thin nut (style 0).
- Thin nuts (style 0) have a reduced loadability compared to regular nuts (style 1) and are not designed to provide resistance to thread stripping. The proof load[16] of an M24, grade 8 (style 1) nut is 395.5kN compared to 307kN for a grade 8 (style 0).
- The nut threads stripped at a force of 301.21kN.
- The nuts had not been heat treated and displayed the characteristics of a grade 6 (style 0) with a proof load of 230kN.

Caparo's test report **(Annex B)** also highlighted that, in accordance with BS EN ISO 898-2:2012 Table 2, a grade 10 regular nut (style 1) should be used with a grade 10.9 tie bolt.

1.13.3 Bolt Science Ltd

A copy of the Caparo test report was sent to Bolt Science Ltd in Chorley, UK for analysis. The calculations and research undertaken by Bolt Science Ltd indicated that:

- The calculated thread stripping load for the lock nuts was 254kN.
- The anticipated preload[17] range with a tightening torque of 600Nm was between 139kN and 231kN.
- The anticipated preload range with a tightening torque of 350Nm was between 48kN and 133kN.

[16] Proof load is the maximum safe load that can be applied without causing permanent deformation. Typically, fasteners (bolts/studs/nuts) can be "torqued" up to 90% of the designated proof load. Proof loads for each size, type and grade of nut and bolt are detailed in BS EN ISO 898.

[17] Preload is the tension placed on a connection by the tightening of the nut on a bolt to a known torque and varies with the coefficient of friction used. The range of 139kN to 231kN is based on coefficients of friction of 0.14 and 0.08 respectively.

The Bolt Science Ltd report **(Annex C)** also included:

> *Since the applied force from lifting is significantly lower than the anticipated thread stripping load, then either one or more of the points below applies:*
>
> *1. One or more of the nut threads had been partially stripped (sheared) by the tightening process, the applied loading subsequently sustained being sufficient to completely shear the threads.*
>
> *2. The thread tolerances are not as assumed in the analysis, that is, the thread dimensions were outside normal practice.*
>
> *3. The deformation of the washers resulted in the force needed to strip the threads being reduced.*
>
> *4. The fasteners were not evenly loaded due to the orientation of the applied load or due to some fasteners being only partially tight.* [sic]

It also highlighted that:

> *It is good practice for the nuts to be as strong, or stronger, than the bolts to avoid the risk of thread stripping if the nuts are over-tightened. That is, considering that property class 10.9 bolts had used in this application, full height property class 10 nuts should have been used.* [sic][18]

1.14 ATLAS MASCHINEN GMBH

1.14.1 Overview

Atlas (Germany) was established in 2010. The company designed and manufactured lorry loader cranes for use on lorries and trucks and also for 'static' installations such as shipborne cranes. Atlas cranes were sold through a worldwide network of dealers. When supplying lorry loader cranes for marine installations in Germany, the design, manufacture and mounting of the Atlas crane was usually overseen by vessels' classification societies.

1.14.2 Technical information and guidance

Atlas (Germany) maintained an online database that was accessible to its dealers and contained technical details and service information. The manufacturer also provided guidance to vehicle manufacturers and lorry loader installers in its "*Assembly guidelines for TEREX loading cranes*"[19]. The guidelines mainly concerned lorry-mounted cranes, but they noted that cranes mounted on ships, railroad vehicles and concrete bases were subjected to greater forces than lorry installations.

Atlas (Germany) expected to be contacted by its dealers to discuss the mounting arrangements for static crane installations. During the MAIB investigation, the manufacturer stated that it would have been appropriate for the Atlas 170 crane to be fitted on board *Carol Anne* with 12 x M30 tie bolts in order to take account of static applications being less resilient to shock loading. It also stated that the 32mm

[18] MAIB note: Bolt grades are designated by number and decimal whereas nuts are designated by number only. A grade 10.9 bolt and a grade 10 nut are considered to be suitably matched.

[19] Atlas (Germany) was previously owned by Terex

wide slots in the box sections of cranes' pedestals were designed to be fitted with M30 tie bolts; M24 tie bolts were intended for use in slots with an internal width of 26mm.

1.15 ATLAS CRANES UK LTD

1.15.1 Overview

Atlas (UK) was based in Bradford, UK and was a wholly owned subsidiary of Atlas (Germany). The company supplied Atlas lorry loader cranes and maintained a network of service engineers within the UK. It did not install cranes but provided advice and guidance to installers if requested. Atlas (UK) was a member of the Association of Lorry Loader Manufacturers and Importers (ALLMI).

Since 2013, Atlas (UK) had supplied 18 lorry loader cranes for shipborne use. Of these, three were Atlas 170 VCS cranes. The company considered that each shipborne installation needed to be assessed on an individual basis and did not offer installation guidance. It was not aware of the assessment of Atlas (Germany) that static installations of the Atlas 170 required 12 x M30 tie bolts.

Until the collapse of the crane on board *Carol Anne*, Atlas (UK) had not been made aware of structural failures to any of the lorry-mounted or shipborne cranes that it had supplied.

1.15.2 Installation manual

Atlas (UK) provided an installation manual for the fitting of Atlas lorry loader cranes to lorries and trucks. The extant edition of the manual at the time the Atlas 170 crane was installed on board *Carol Anne* (4th edition) did not contain any references to static installations.

A table in the manual showed the tie bolt sizes, material grade and the torque to be used for 39 different models of Atlas cranes. Of these, the Atlas 170 crane was one of eight crane models to be secured with 8 x M30 tie bolts of grade 8.8 steel (used with grade 8, style 1 lock nuts) torqued to 550Nm. Twenty of the remaining crane models were secured with 8 x M24, grade 10.9 tie bolts (used with grade 8, style 1 lock nuts) torqued to 350Nm. The manual also indicated that each tie bolt should be secured with a lock nut at its bottom end and two plain nuts and a tab washer at its top.

1.15.3 Nuts and tie bolts

Atlas (UK) obtained the various sizes and grades of tie bolts, nuts and tab washers required for the different models of Atlas cranes from several suppliers. The fastenings were supplied in batches and stored by type and size in bins. The batches were not stored separately.

In 2013, Atlas (UK)'s purchasing department placed orders with John Sylvester (Fasteners & Plastics) Ltd, (John Sylvester) Bradford for plain nuts and lock nuts. The order for the plain nuts was for *M24 x 2 fine thread, DIN 934, grade 8.8*. The order for the lock nuts was for *M24 "Nyloc" fine pitch*.

John Sylvester Ltd sourced the M24 lock nuts from Harrison & Clough Ltd, Bradford, which imported the lock nuts from Linkwell Industry Co. Ltd. in Taiwan. The imported M24 lock nuts were described as *M24 x 2.00P DIN 985, Type T Nyloc nut class 6, zinc plated bulk packed*. The nuts were supplied to John Sylvester Ltd as a class 6 lock nut despite being stamped as grade 8 (see Section 1.13.12). The delivery invoices supplied with the lock nuts to Atlas (UK) described the nuts as *M24 metric nylon insert nuts, type T, fine pitch, zinc, 2mm pitch.*

1.15.4 The service engineer

The service engineer who inspected and tested *Carol Anne*'s crane on 23 March 2014 had worked for Atlas (UK) for over 20 years. He was one of three company service engineers based in Scotland. The engineer was trained and certified by the ALLMI for operating, examining and testing of lorry loader cranes. He had successfully completed the ALLMI training scheme and competency assessment for the Thorough Examination and Testing of Lorry Loader Cranes. He had last revalidated his certification in this respect on 25 February 2015.

The service engineer's role included the routine servicing of lorry loader cranes and rectifying crane breakdowns. It also included the testing and examination of lorry loader cranes fitted to vehicles. The service engineer had examined and tested shipborne cranes, but this occurred no more than once a year. The service engineer had never installed lorry loader cranes.

1.16 ASSOCIATION OF LORRY LOADER MANUFACTURERS AND IMPORTERS

The ALLMI was founded in 1978 at the request of the HSE and was the UK's only trade association devoted exclusively to the lorry loader industry. Its members comprised manufacturers, importers, service agents, ancillary equipment manufacturers / suppliers, fleet owners and site operators.

The ALLMI's core aims were:

- *To promote the safe use of lorry loaders.*
- *To ensure that the Association is involved in the formulation of any legislation which affects the industry's interests.*
- *To promote compliance with training requirements embodied in current legislation.*

The ALLMI provided training and certification in all aspects of the lorry loader industry, including the training and certification of engineers carrying out thorough examinations of lorry loader cranes required by the Lifting Operations and Lifting Equipment Regulations 1998 (LOLER)[20].

The syllabus for the ALLMI's Training Scheme and Competency Assessment for the *Thorough Examination and Testing of Lorry Loaders* included: documentation, visual inspection, function check, overload test, dynamic test, post-test inspection and signing off.

[20] Regulations dealing with the lifting equipment in use every day in workplaces: factories, offices, shops, hospitals, construction sites, warehouses, farms – wherever lifting equipment is used at work.

On successful completion of the training, an examiners' manual was issued to participants for reference. The manual contained details of the checks to be conducted during a thorough examination including documentation, the specifications of the lifting equipment, mounting requirements, the integrity of structural connections and the torque of the tie bolts. The manual did not contain guidance on static installations such as shipborne cranes. It also did not refer to the Merchant Shipping and Fishing Vessels (Lifting operations and lifting equipment) Regulations 2006 (see paragraph 1.17.2).

1.17 REGULATORY REQUIREMENTS

1.17.1 The Brown Code

Section 11.6 of The Brown Code focuses on the stability requirements of workboats fitted with a deck crane. It requires that information and instructions to skippers using a deck crane are included in a workboat's SIB and should include:

1. *the maximum permitted load and outreach which satisfy the requirements of 11.4.2, or the Safe Working Load (SWL), whichever is the lesser (operating performance data for a crane or other lifting device of variable load-radius type should be included as appropriate.);*

2. *details of all openings leading below deck which should be secured weathertight; and*

3. *the need for all personnel to be above deck before lifting operations commence.*

Section 25.4 of the Code requires that load tests are conducted to verify a crane's safe operation to the satisfaction of the CA. Reference is made to BS 7121: Part 2:1991 - Code of practice for the safe use of cranes: inspection, maintenance and thorough examination – Loader cranes.

Section 27.7 of the Code concerns the requirement for workboats to be maintained, equipped and operated in accordance with documented arrangements. It states:

> *The validity of a certificate issued under the Code is dependent upon a vessel being maintained, equipped and operated in accordance with the documented arrangements contained in the appropriate report form(s). Proposals to change any of the arrangements should therefore be agreed in writing with the Certifying Authority before a change is implemented.*

Similar requirements were included in Marine Guidance Note (MGN) 280(M) Small Vessels in Commercial Use for Sport or Pleasure, Workboats and Pilot Boats – Alternative Construction Standards, that was published in 2003. MGN 280 was an equivalent and harmonised standard to the workboat code and three other existing codes of practice applicable to small boats.

1.17.2 The Merchant Shipping and Fishing Vessels (Lifting Operations and Lifting Equipment) Regulations 2006

The Merchant Shipping and Fishing Vessels (Lifting Operations and Lifting Equipment) Regulations 2006 - SI 2006 No.2184 (LOLER 2006) apply to all UK registered ships and are the maritime equivalent of LOLER 1998.

Regulation 11 (1) includes:

The employer shall ensure that no lifting equipment, accessory for lifting or loose gear is used:

(a) after manufacture or installation, or

(b) after any repair or modification which is likely to alter the safe working load or affect the strength or stability of the equipment,

without being first suitably tested by a competent person.

Regulation 12 (1) states:

The employer shall ensure that, where the safety of lifting equipment depends on the installation conditions, it is inspected by a competent person-

(a) after installation and before being put into service for the first time; or

b) after assembly at a new site or in a new location,

to ensure that it has been installed correctly, in accordance with any manufacturer's instructions, and is both safe to operate and capable of operating safely.

A competent person is defined as "*a person possessing the knowledge or experience necessary for the performance of the duties under these regulations*". [sic]

MGN *332* - The Merchant Shipping and Fishing Vessels (Lifting Operations and Lifting Equipment) Regulations 2006 provides guidance on the interpretation of LOLER 2006. With regard to thorough examination and inspection, the MGN states:

"Thorough Examination" as defined in regulation 2 means a detailed visual examination by a competent person, supplemented if necessary by other suitable means or measures in order to arrive at a reliable conclusion as to the safety of the lifting equipment or accessory for lifting examined. Additionally it is recommended, following any overload test or dismantling of gear, that a function test with a nominal load is also carried out before any lifting equipment is put into service. Similarly "Inspection" means a visual inspection by a "competent person" to establish that no defects or deterioration is present in the equipment and that it remains safe to use.

1.17.3 European Machinery Directive

The European Machinery Directive (Directive 2006/42/EC) aims to ensure a common safety level in machinery placed on the market or put in service in all European member states and to ensure freedom of movement within the EU. It applies to all machinery sold, used or imported into the EU. Machinery complying with the provisions of the Directive bear a CE mark and are accompanied by an EC declaration of conformity. Compliant machinery is also required to be accompanied with assembly, installation and connection instructions as appropriate.

Article 1 of the Directive details the products outside its scope, which includes:

"*seagoing vessels and mobile offshore units and machinery installed on board such vessels and/or units*".

1.17.4 The Supply of Machinery (Safety) Regulations 2008

The Supply of Machinery (Safety) Regulations 2008 (SI 2008 No. 1597) transpose EU Directive 2006/42/EC in to UK law. Schedule 3 of the Regulations excludes machinery installed on seagoing vessels from the scope of the Regulations.

1.17.5 Merchant Shipping and Fishing Vessels (Provision and Use of Work Equipment) Regulations 2006

The Provision and Use of Work Equipment Regulations 2006 (SI 2006 No.2183) (PUWER) aims to prevent injuries to crew from their use of work equipment. The Regulations are detailed in MGN 331 (M+F) which also provides guidance on their application. With regard to Regulation 12, the MGN states:

All work equipment should conform to the appropriate European product standards, apart from equipment which pre-dates any relevant standards. The Schedule to the Regulations details the UK instruments which give effect to the relevant EC directives. Work equipment which carries a CE marking is considered to comply with the provisions of a Community directive, provided that the CE marking is relevant for the purpose for which the equipment is to be used. In this context "CE marking" means a marking signifying compliance with the basic requirements of design and manufacture of, and the specifications and test methods applicable to, a piece of work equipment which have been adopted by the appropriate authorities in the European Economic Area. Reference to a CE marking also includes the marking for an alternative Standard which provides, in use, equivalent levels of safety, suitability and fitness for purpose.

One of the instruments included in the Schedule to the Regulations is the Supply of Machinery (Safety) Regulations, as amended.

1.18 STANDARDS

1.18.1 BS 7121 - Code of practice for the safe use of cranes

BS 7121 covers all aspects of the operation of all types of cranes. Part 2 of the standard covers the pre-use checking, in service inspection, thorough examination and testing of cranes. In all cases, the standard refers to thorough visual examinations being carried out to check for signs of distortion or damage both before and after testing.

The standard also specifies that the testing is to include a dynamic functional test and an overload test. For the dynamic test, a test load of 1.1 times a crane's rated capacity is slung at the maximum radius attainable. For the overload test, a load 1.25 times a crane's rated capacity plus 1.1 times the boom mass is slewed through the maximum slewing angle. The purpose of the overload test is to ensure that a sufficient margin exists against structural failure.

1.18.2 BS EN 12999:2011 Loader Cranes

BS EN 12999:2011 is a harmonised standard to enable loader cranes to comply with the requirements of the Machinery Directive 2006/42/EC. It covers all the requirements of the Directive including installation information to be provided to the installer and requirements for the installation test. A reference is made to static installations in respect of the strength of the foundations on which the crane is mounted. BS 12999 does not apply to loader cranes used on board ships or floating structures.

SECTION 2 - ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.2 FAILURE MECHANISM

When *Carol Anne*'s crane collapsed, it had been extended to a radius of 3.6m (paragraph 1.13.1) and was carrying a 2204kg net **(Figure 5)**. The resulting force generated was 79.34kN-m, which was well within the crane's rated capacity of 170kN-m. In addition, the safety limits had also been set, tested and sealed during the thorough examination. Therefore, the crane was not overloaded.

The examination and testing of the fastenings used to secure the crane to *Carol Anne*'s deck (paragraph 1.13.1) indicate that the crane collapsed because the threads of the four lock nuts securing the outboard side of the crane pedestal were stripped. The damage to the four inboard fastenings probably resulted from the crane toppling. **Figure 22** shows the distribution of the loads acting on the four outboard fastenings at varying jib slew angles. At the time of the collapse, the crane jib was slewing towards the centreline forward from the starboard side and the aft, outer fastening (No 4 in **Figure 22**) was bearing the highest load. Therefore, it was probably the first fastening to fail. However, the proportion of the load on this fastening would have instantaneously transferred to the remaining fasteners, leading to their failure.

HSL's report highlighted that one of the reasons for the crane's collapse was that the lock nuts were weaker than the tie bolts. The use of nuts of a lower steel grade than the tie bolts was also noted by Caparo and Bolt Science **(Annexes B** and **C)** as being at variance with the recognised standard and engineering best practice (paragraphs 1.13.2 and 1.13.3). BS EN ISO 898 states that the grade of a nut should be equal to or exceed the grade of its associated bolt. This is to ensure that a tie bolt will fail before the nut's threads strip if over-tightened. In this case, the tie bolts were grade 10.9 and the lock nuts were found at testing to be grade 6, which was even lower than the grade 8 as assumed by HSL. Therefore, as the stripping load of the lock nuts was probably between 254kN (paragraph 1.13.3 and **Annex C**) and 301.21kN (paragraph 1.13.2 and **Annex B**), the stripping of the nuts' threads, rather than the failure of the bolts (proof load of 319kN), was inevitable.

That the crane did not collapse earlier in its operation indicates that the integrity of its fastenings had reduced incrementally over its 6.5 weeks in service. This was primarily due to the deformation of the tab washers **(Figure 10)** which, in turn, would have resulted in uneven loading of the fasteners and reduced the load required to strip the lock nut threads.

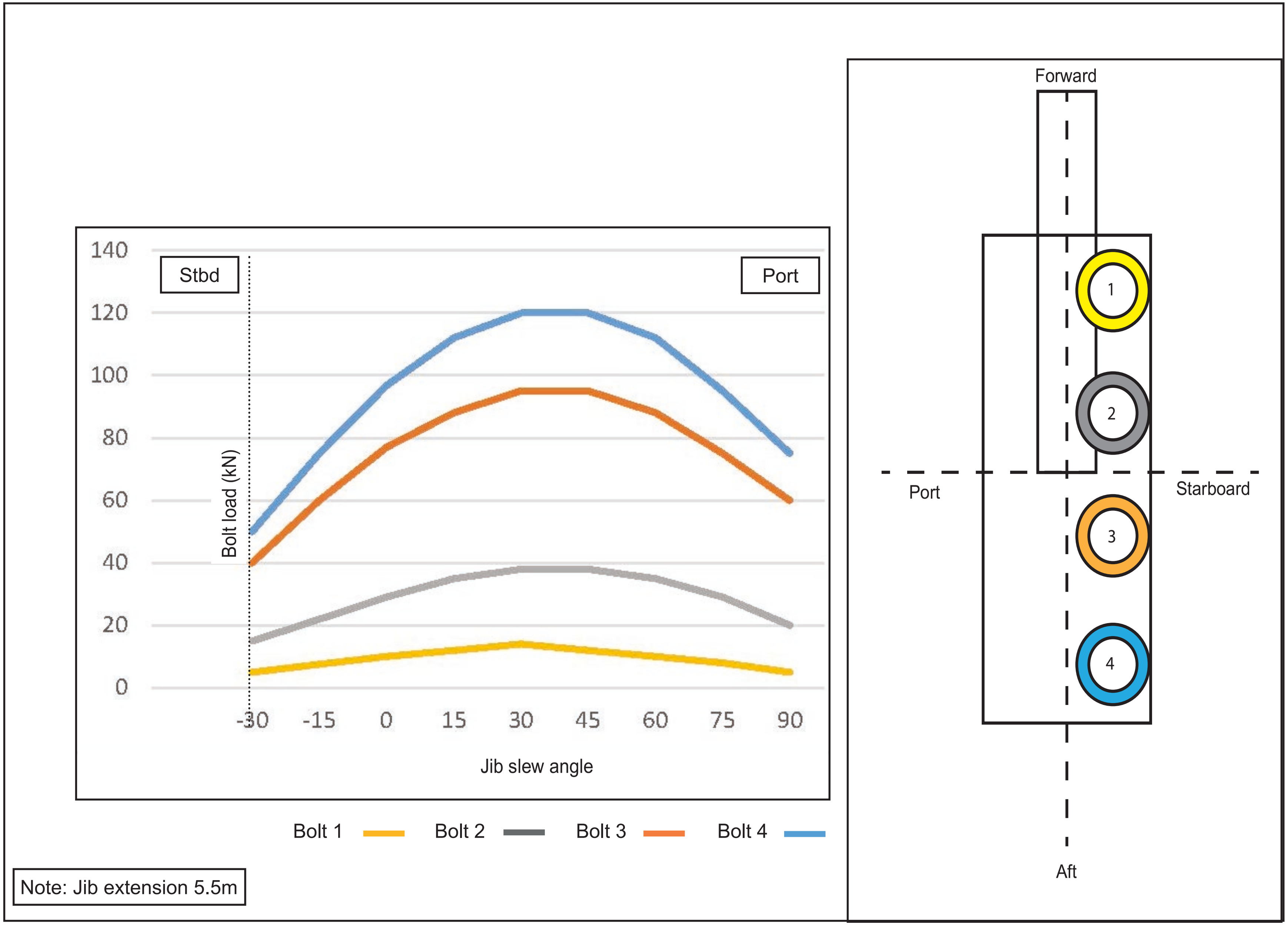

Figure 22: Graph showing outboard bolt loading at varying jib slew angles

2.3 MOUNTING ARRANGEMENT

HSL identified that another of the factors leading to the collapse of *Carol Anne*'s crane was that no adjustment had been made to the mounting arrangement to take account of its static platform (paragraph 1.13.1). However, the stabilisers referred to by HSL, fitted in conjunction with truck and lorry-mounted cranes, are intended to prevent the vehicles from becoming unstable due to load moments and shifts in the centre of gravity. As static installations such as shipborne cranes are mounted on stable platforms, the use of stabilisers is not warranted. Nonetheless, it is essential that the mounting arrangements of static crane installations are sufficiently resilient to cope with shock loading.

In this respect, following the crane failure Atlas (Germany) advised that, when used as a static installation the Atlas 170 should be secured with 12 tie bolts (paragraph 1.14.2). However, Atlas (UK) was not aware of this requirement. Furthermore, the M24 mounting kit used to fit the Atlas 170 crane on board *Carol Anne* was undersized.

The Atlas (UK) installation guide indicated that for lorry installations, the Atlas 170 should be mounted with 8 x M30 tie bolts and nuts (paragraph 1.15.2). Although *Carol Anne*'s crane was a static installation that required greater resilience to withstand shock loads than a lorry-mounted crane, tie bolts and nuts of only 24mm diameter were used. A pictorial comparison of the M24 and the M30 mounting kits is shown at **Figure 23**.

The use of the undersized mounting kit had three significant consequences:

- The proof loads of the M24 fastenings were lower than the M30 fastenings. The proof load for an M30 lock nut grade 8 (style 1) with a friction coefficient of 0.14 was 516kN, whereas the proof load of the intended M24 lock nut grade 8 (style 1) was 395.5kN. Significantly, the proof load of the grade 6 (style 0) lock nuts used on board *Carol Anne* was only 230kN.

- The tab washers used in conjunction with the M24 tie bolts and nuts were 30% thinner than the tab washers used in conjunction with the M30 tie bolts and nuts. They were therefore much weaker.

- The use of M24 tie bolts in the 32mm slots in the box mountings on the crane's pedestal, which were intended to be used with M30 tie bolts, resulted in the bolts having 8mm freedom of movement **(Figure 12)**.

The larger than intended freedom of movement of the tie bolts before tightening led to the misalignment of some of the tab washers, placing them in shear loading rather than compression. Furthermore, as the tab washers were supported only at their extremities **(Figure 24)**, and were thinner than the washers used in the M30 mounting kit, they were prone to bend downwards under load **(Figure 10)**. Such deformation, which could have occurred when the lock nuts were tightened or when the crane was under load, would have led to uneven loading on each of the lock nuts. In turn, this would have reduced the lock nuts' ability to withstand thread stripping.

Figure 23: M30 and M24 mounting kits

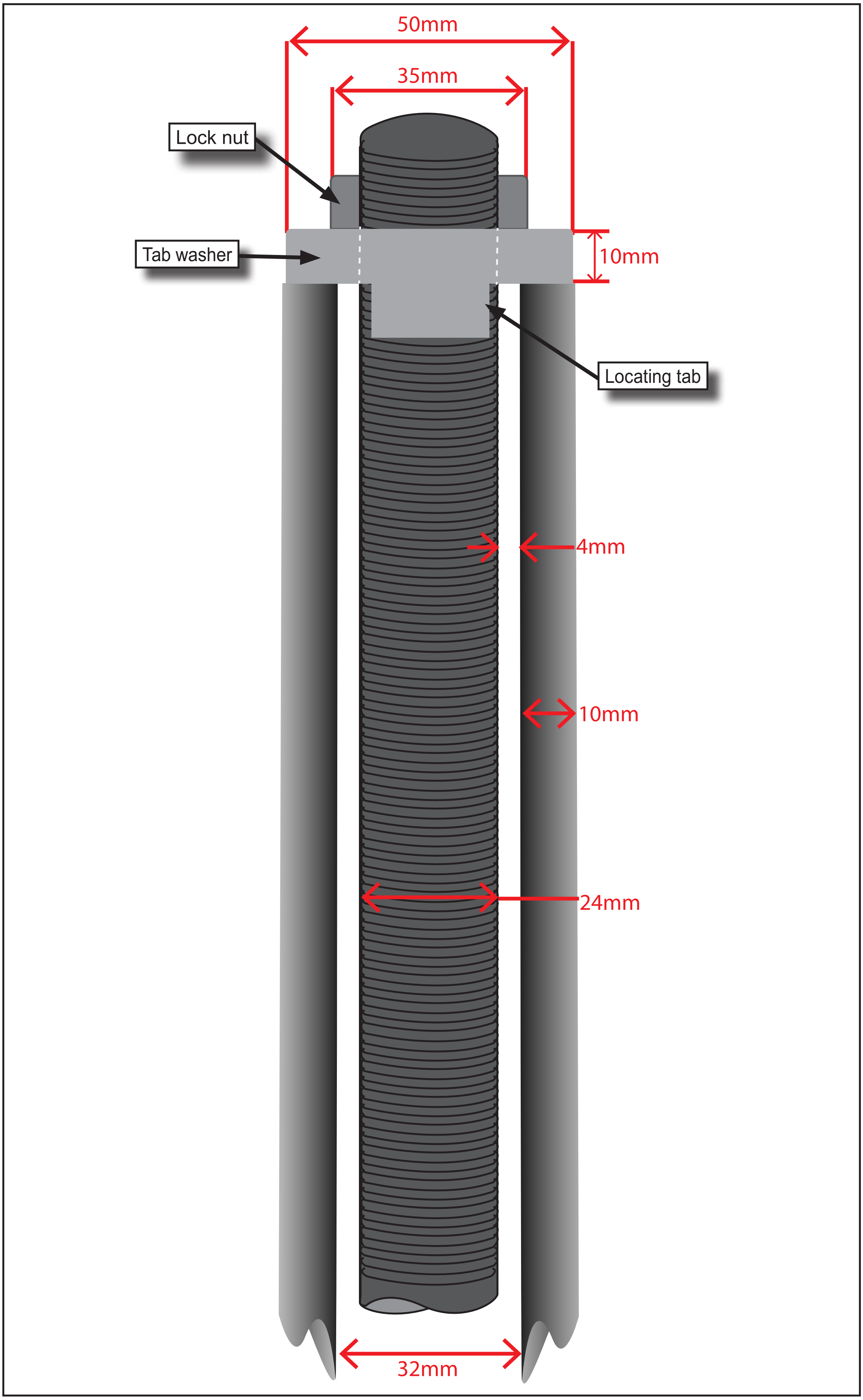

Figure 24: Diagram showing the tab washer arrangement

2.4 INSTALLATION

The positioning and the tightening of the lock nuts during the installation of the Atlas 170 crane on board *Carol Anne* were contributory to their stripping and release. The Atlas (UK) installation guide (paragraph 1.15.2), which had not been provided to PMG Services Ltd, indicated that the lock nuts should have been affixed to the bottom end of the tie bolts on the underside of the base plate. However, the lock nuts on *Carol Anne*'s crane were affixed to the top of the tie bolt and were tightened onto the tab washers. Had the lock nuts been positioned on the bottom ends of the tie bolts, as intended, they would have been evenly supported by the underside of the base plate. Although the two plain nuts at the top of the tie bolts would then have been subjected to the uneven loading resulting from the deformation of the tab washers, the strength of the two plain nuts acting together would have provided greater resistance to thread stripping than the single lock nuts.

A further consequence of the Atlas (UK) installation guide not being provided was that the lock nuts were tightened to a torque of 600kN rather than 350kN. Although the torque used was based on sound engineering principles for the grade of the tie bolts, the resulting preload was 139kN per tie bolt instead of 80kN. Not only was this likely to have deformed the tab washers to some degree, but also the risk of stripping the threads of the grade 6 M24 lock nuts was initially increased.

2.5 THOROUGH EXAMINATION

It is of concern that *Carol Anne*'s crane collapsed only 5½ weeks after it had been inspected and tested by an Atlas (UK) service engineer. The conduct of thorough examinations of lifting equipment in remote areas requires a degree of flexibility and improvisation. On this occasion, the use of the FIBCs as test weights, and the adjustment of the crane's radius to take into account the fixed weight, were pragmatic approaches. However, overall the examination and testing lacked rigour. In particular:

- No installation documentation was provided.
- The load radius diagram was not available.
- The SWL was not marked on the crane.
- The overload and dynamic tests were not conducted through the crane's entire slewing range due to the proximity of the jetty.
- The visual examination did not identify that the tie bolts and nuts were undersized or that the lock nuts were screwed to the top end of the tie bolts.
- The torque of the bolt connections was not checked after the tests were conducted.

As it is likely that some of the tab washers would also have been deformed by the time the overload and dynamic tests had been completed, if not before, it is apparent that this important change in the integrity of the bolt connections was also overlooked.

The service engineer's training, routine workload and the ALLMI examiners' manual focused on lorry or truck-mounted cranes. This is supported by the fact that his report **(Annex A)** referred to LOLER 1998 rather than LOLER 2006. However, the inspection requirements and procedures detailed in LOLER 1998, BS12999:2011 and the ALLMI examiners' manual were similar to those contained in LOLER 2006, BS 7121, The Brown Code and MGN 280 and followed similar principles. The lack of documentation, the undersize connections and the position and torque of the lock nuts on board *Carol Anne* were equally relevant to both lorry-mounted and shipborne installations. Therefore, although the engineer's competency was predominantly on 'land-based' equipment, this should not have disadvantaged him when undertaking thorough examinations of marine installations.

Nonetheless, lorry loader cranes are routinely being fitted on board UK workboats and other vessels. Competent persons conducting thorough examinations of these cranes should be aware of their differing requirement compared to lorry-mounted cranes. They should also be aware of the regulations contained in LOLER 2006 as well as LOLER 1998.

2.6 INSTALLATION INFORMATION

Other than the engineering drawing supplied to Mackenzie Welding Ltd **(Figure 16)**, no information was provided by Atlas (Germany) or Atlas (UK) concerning the installation of the Atlas 170 crane on board *Carol Anne*. As a result, PMG Services Ltd fitted the bolt connections using its experience and knowledge of lorry loader cranes; the 8 x M24 bolt connections were installed and tightened to a torque of 600kN. Furthermore, the drawing used by Mackenzie Engineering Ltd was incorrect **(Figures 14** and **16)**. Although the 'as fitted' drawing **(Figure 14)** and the drawing supplied to Mackenzie Engineering Ltd **(Figure 16)** appear to be similar, the position of the base sections relative to the crane's centreline were different, consequently, the crane pedestal did not accurately line up with the pre-drilled holes in the base plate.

Atlas (Germany)'s *Assembly Guidelines for TEREX loading cranes* acknowledged that shipborne installations were subjected to greater forces than lorry-mounted cranes, but the company expected its dealers to contact it to discuss details of specific applications. Atlas (UK) also considered that each shipborne installation needed to be assessed on a case by case basis, but it was unaware of its parent company's view that the Atlas 170 should be fitted with 12 x M30 tie bolts and nuts when fitted to a static platform. It also did not examine the specifics of *Carol Anne*'s installation or provide the relevant details of the fitting of the Atlas 170 contained in its installation manual.

Neither Atlas (Germany) nor Atlas (UK) was required to provide installation information as the crane was built for use outside of the EC and did not have to meet the requirements of the Machinery Directive. In addition, the Supply of Machinery (Safety) Regulations 2008 (cited in Regulation 12 of PUWER) and BS EN 12999:2011 were not applicable to seagoing vessels such as *Carol Anne*. Had the information available been provided, it would have been readily apparent to the installers that the crane required 12 x M30 bolt connections tightened to a torque of 550kN. The crane's mounting would have been significantly more secure and its collapse would have been avoided.

2.7 QUALITY ASSURANCE

When tested the M24 lock nuts used on board *Carol Anne* were found to be equivalent to grade 6 (style 0) and had a proof load of 230kN. They were significantly weaker and less resistant to thread stripping than the lock nuts that were intended to be used, which were grade 8 (style 1) and had a proof load of 395.5kN (paragraph 1.13.2).

The misleading marking of the nuts used, which indicated they were 'grade 8', was outside the control of Atlas (UK) and is a matter for Trading Standards. Nonetheless, that:

- the grade of material was not specified on Atlas (UK)'s order for the lock nuts (paragraph 1.15.3) or included on the nuts' delivery invoices supplied by John Silvester Ltd;

- no material test or specification data was sighted;

- and that the different batches of lock nuts were not stored separately to facilitate tracking indicates that Atlas (UK)'s control of its fastenings was not robust.

Similarly, the supply of the M24 mounting kit instead of an M30 mounting kit used to install the Atlas 170 crane on board *Carol Anne*'s also indicates that Atlas (UK)'s quality assurance procedures were flawed. In the absence of any installation information, Hiat (Scotland) Ltd requested an M24 mounting be provided based on its experience of fitting other Atlas cranes. However, although the model and serial number of the crane were included in the emailed request, the suitability of using the M24 mounting kit with the Atlas 170 was not checked by Atlas (UK) against its own installation guidance. The M24 mounting kit was despatched without question.

2.8 VESSEL MANAGEMENT

2.8.1 Crane replacement

Section 27.7 of The Brown Code required IMS and the SCMS to agree in writing to proposed changes in *Carol Anne*'s arrangements before any changes were implemented. In this case, IMS did not inform the SCMS of its intention to replace the Atlas 165 crane with the Atlas 170 crane as it assessed that it was replacing 'like for like'.

However, the Atlas 170 crane was 830kg heavier and had a longer reach than the Atlas 165. Therefore, its installation impacted on the workboat's stability to some degree. Moreover, as The Brown Code also required the load tests to be conducted to the satisfaction of the CA, and for the maximum permitted load and outreach of the crane to be detailed in *Carol Anne*'s SIB, the failure of IMS to inform the SCMS was potentially a significant omission.

2.8.2 Crane operation

It is of concern that the Atlas 170 crane was routinely used following installation before a thorough examination and test had been completed. The crane's safety limits had not been set and therefore there was potential for it to be overloaded.

Regulation 11 of LOLER 2006 clearly requires that every employer ensures that no lifting equipment is used after installation before it has been tested by a competent person. Although the crane's functionality was tested by Turnbull Engineering Services, this test did not include the verification of the crane's overload or safety settings.

2.9 ROLE OF THE CERTIFYING AUTHORITY

Lifting equipment on board seagoing vessels is excluded from key regulations such as the Machinery Directive, The Supply of Machinery (Safety) Regulations 2008 and PUWER. However, while the exclusion of seagoing vessels from these regulations impacts on aspects of product delivery such as the provision of installation information, both LOLER 2006 (paragraph 1.17.2) and The Brown Code (paragraph 1.17.1) require that shipborne cranes are inspected and tested following installation to verify their safe operation. In most cases, the successful inspection and testing by a competent person under LOLER 2006 should satisfy the obligations placed on the CAs in this respect.

The SCMS was not aware of the replacement of the crane on board *Carol Anne*. Therefore, the CA was unable to meet its responsibilities detailed in The Brown Code and it is not possible to determine what action the SCMS would have taken had it been informed of IMS' intention. However, given the circumstances of the crane's failure on board *Carol Anne* and the potential impact of lifting equipment on a workboat's stability (the Atlas 170 crane was 1.26t heavier and was able to lift a .46 heavier load at a 1.8m longer outreach than the Atlas 100.1 crane fitted to *Carol Anne* at build), it is clear that CAs have an important role to play in assessing the potential operational consequences of substantial changes that an owner might wish to make to a vessel.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. *Carol Anne*'s crane collapsed due to the load of the lifted net exceeding the residual strength of the fasteners causing the threads on the lock nuts on the outboard side of the crane pedestal to strip. [2.2]

2. The use of lock nuts of a lower material grade than their associated tie bolts was at variance with recognised standards. [2.2]

3. The grade of the lock nuts (grade 6) was lower than the grade marked on them (grade 8). [2.2]

4. Atlas (Germany) had established that 12 tie bolts were required to secure the crane's pedestal to the base, but Atlas (UK) was not aware of this requirement and supplied only eight. [2.3]

5. The Atlas (UK) installation manual indicated that M30 tie bolts should be used to secure an Atlas 170 crane, but *Carol Anne*'s crane was secured with M24 tie bolts. [2.3]

6. The excessive freedom of movement resulting from the use of M24 tie bolts in the 32mm slots in the crane's pedestal resulted in the misalignment and deformation of some of the tab washers. [2.3]

7. The tab washers supplied with the M24 mounting kit were thinner and weaker than the washers supplied with the M30 mounting kit. [2.3]

8. Deformation of the tab washers resulted in the loading on the lock nuts becoming uneven, and reduced their ability to withstand thread stripping. [2.3]

9. The tightening of the lock nuts to a torque of 600Nm rather than 350Nm, as indicated in Atlas (UK)'s installation manual, increased the preload on the crane's tie bolts from 80kN to 139kN. [2.3, 2.4]

10. The positioning of the lock nuts onto the tab washers was not in accordance with the guidance provided in Atlas (UK)'s installation manual. [2.4]

11. The thorough examination and testing of the crane following its installation lacked rigour and did not identify a number of deficiencies. [2.5]

12. Neither Atlas (Germany) nor Atlas (UK) provided any accurate installation guidance. [2.6]

13. Atlas (UK)'s control and monitoring of the provenance of its fastenings was not robust and its quality assurance procedures were flawed. [2.7]

3.2 SAFETY ISSUES NOT DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. *Carol Anne*'s managers did not notify the workboat's certifying authority of the crane's replacement. [2.8.1]

2. The use of *Carol Anne*'s crane before it had been thoroughly examined and tested was contrary to the requirements of LOLER 2006. [2.8.2]

3. Certifying Authorities have an important role to play in assessing the potential operational consequences of substantial changes that an owner might wish to make to a vessel. [2.9]

SECTION 4 - ACTION TAKEN

4.1 MAIB ACTIONS

On 13 July 2015, the Chief Inspector of Marine Accidents made a recommendation (MAIB recommendation 2015/142) to Atlas Cranes UK Ltd to take actions to ensure that:

- All Atlas 170.2 cranes supplied in the UK have been installed using fastenings of the diameter, grade and number of fastenings as promulgated by Atlas GmbH.
- The M24 nylon insert locknuts supplied are of the same grade or higher than their associated studs.
- The operators of all other Atlas crane installations in the UK, for which Atlas UK has supplied fastenings, are made aware of the potential that the nuts that have been supplied may be of an insufficient grade.

On 29 October 2015, the MAIB notified West Yorkshire Trading Standards of the accident, and highlighted that the lock nuts marked as grade 8 were found to be grade 6.

4.2 ACTIONS TAKEN BY OTHER ORGANISATIONS

Atlas Cranes UK Ltd has:

In response to MAIB recommendation 2015/142:

- Examined all Atlas cranes installed on marine craft in the UK. It has increased the number of tie bolts from 8 to 12 and replaced all nylon insert lock nuts with two plain nuts.
- Replaced nylon insert lock nuts with two plain nuts in its installation kits.
- Implemented a system to verify the material grades of the fastenings used to install Atlas cranes.

The **National Workboat Association** has:

Issued an advisory notice **(Annex D)** to workboat owners/operators reminding them of their responsibilities under the workboat code, and highlighting the requirement to notify and seek approval from the certifying authority prior to implementing any changes or modifications to vessels.

The **Maritime and Coastguard Agency** has:

- In September 2015 issued a revised Brown Code for consultation with industry stakeholders. With regard to lifting appliances, the latest draft of the revised code includes, inter alia:
    - A definition of 'modifications'

    - A requirement for the verification of the strength of vessels’ structures to withstand the maximum loads imposed by lifting appliances
    - A requirement for CAs to undertake design approval of the installations of lifting appliances
    - The provision of a load-radius diagram
    - Details of applicable over-arching regulation and the requirements for load tests
    - A requirement for ‘competent persons’ conducting tests and inspections to have experience of cranes on waterborne craft

The revised Brown Code is expected to come into effect after 2016.

- Modified the Workboat Certificate to make it clear that modifications or damage should be reported to a vessel’s CA. The MCA intends to similarly modify the certificates of vessels operating under other small commercial vessel codes.
- Stated an intention to issue a Safety Alert concerning lifting equipment on workboats.
- Stated its intention to verify the procedures adopted by CAs regarding crane installation during audit.

Inverlussa Marine Services has:

Revised its vessel safety management system procedures manual to emphasise the need to notify the CA of modifications to vessels and new equipment fitted.

SECTION 5 - RECOMMENDATIONS

Atlas Maschinen GmbH is recommended to:

2016/122 Ensure that installation information and guidance is provided with its cranes irrespective of whether they are intended as mobile or static installations or for use inside or outside the European Community.

The **Association of Lorry Loader Manufacturers and Importers** is recommended to:

2016/123 Work with the Maritime and Coastguard Agency to ensure that the maritime requirements and regulation covering the inspection and testing of shipborne lorry loader cranes is included in its training syllabi and examiners' manuals.

The **Maritime and Coastguard Agency** is recommended to:

2016/124 Instruct certifying authorities to ensure that their procedures for the agreement of the fitting or modification of lifting appliances on board workboats take into account, inter alia, the importance of assessing the suitability of installation arrangements and the impact on vessel stability.

Inverlussa Marine Services is recommended to:

2016/125 Ensure that it meets the requirements of LOLER 2006 and informs the applicable certifying authority of any intended changes or modifications to its vessels.

Safety recommendations shall in no case create a presumption of blame or liability

Marine Accident Report

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