REPORT

EXAMINATION OF THE MAIN ENGINE AND OTHER PRINCIPAL ITEMS RECOVERED FROM THE SUNKEN FISHING VESSEL UTVIK SENIOR

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1. INTRODUCTION AND BACKGROUND INFORMATION

The Investigation Commission appointed to re-examine the loss of the deep-sea fishing vessel UTVIK SENIOR had recovered the vessel's main engine and other principal items from the wreck site during August 2002. The loss of the vessel, we understand, had occurred in the late 1970's and that the surviving items now available for examination had been recovered from a sea depth of approximately 34/35 metres.

The subject vessel was a deep-sea fishing trawler of 82' 7" by 22' 0" beam, with a draft of 9' 0". The vessel was constructed on a wooden keel from laminated wooden frames and deck beams, with wood infill between the frames. The keel was strengthened and protected by external steel plating of approximately 12mm thickness, which extended aft of the vessel's stern to house the lower rudder bearing pin.

The vessel had been re-engined in the autumn of 1974, and at the time of the casualty was powered by a turbocharged medium speed 540 HP in-line six cylinder four stroke RSP-6 Normo diesel engine. The engine had a fixed anti-clockwise rotation of 425 r.p.m. and a weight of approximately 15 tonnes. The engine turbocharger and charge air cooler (intercooler) were mounted on the aft upper engine casing, and both were of Brown Bovery manufacture.

The vessel's propeller was of three-blade variable pitch type, and was driven at the engine crankshaft rotational speed and anti-clockwise rotation via a direct coupling. Forward and aft thrusting of the propeller was effected by adjustment of the blade's pitch, which was in turn effected via a remotely operated hydraulic actuator and push rod arrangement.

The commission reported that UTVIK SENIOR was not operated as a deep-sea fishing trawler, but was used to service offshore nets permanently deployed to catch migratory cod. Furthermore, the commission reported that the vessel was inbound to its home port at the time of the casualty.

The wreck site seabed was confirmed by the commission to comprise sand and pebbles (rounded rocks). Since the casualty, the wreck site was reported to have been subjected to two periods of heavy storms, which it was thought could possibly have moved some of the smaller items of wreckage. It was, however, thought that the main engine, which was found laying on its starboard side, and other large items, had resided on the seabed in their relative landing positions and orientations.

The salvaged items were inspected at the kaarboverkstedet shipyard in Harstad during 29 and 30 April 2003. Items and features of interest to the commission had been cleaned to facilitate earlier examinations by others, and some had also been disassembled. Inspections of the main engine were completed with the engine in its upright position, as shown in figure 1. The shipyard inspections, subsequent laboratory examinations and reporting were all completed by Mr David Ellin of the Test House (Cambridge) Ltd. The directions of forces assigned to all engine damage are reported with respect to the engine's current (as installed) upright position.

2. SHIPYARD INSPECTIONS AND REMOVAL OF SAMPLE MATERIAL FOR LABORATORY EXAMINATION

Items and features of current interest to the commission were visually inspected in situ. To facilitate the inspections, items were re-cleaned by a combination of mechanical chipping, wire and fibre brushing, and in the case of fracture surfaces multiple applications of adhesive tape.

Initial inspections of the engine confirmed that with exception to salvage related outward bending of a number of steel plates just aft of the engine port side (figure 1), all significant damage and features were located at the engines starboard side. Inspections of the main engine and other principal items were completed as follows.

2.1 Item (1b) Main Engine Forward Starboard Side Power Take Off (PTO) Unit

The unrecovered PTO unit had been bolted to the lower forward starboard corner of the engine casing. Access to the chain drive was facilitated via a bolted steel cover plate of approximately 6mm thickness, which was located on the engine casing immediately above, and to the port side of the PTO unit bolting face (figures 2, 3 and 4).

Damage at this location comprised brittle fractures at both the engine casing and PTO unit sides of the bolted joint, upward ductile bending of the top cover plate, and generally downward bending of the joints four retained (forward) jointing studs. Collectively, it was not possible to account for all the damage at this location having occurred in a single event.

The engine casing and PTO unit mounting flange damage appeared contemporary and consistent with brittle overload fracture in response to an upward bending of the PTO unit cantilever. The prevailing fractographic evidence was also consistent with both fractured parts having been produced from grey flake graphite type cast iron. Ductile bending of the steel cover plate also appeared contemporary with fracture of the bolted PTO unit joint, and had similarly resulted from an upwardly directed force. The ductile downward bending of the four studs at the retained forward end of the PTO unit mounting and associated stripping of the nuts, was not judged to be contemporary with the fracture event. Rather, the stud damage was thought to have resulted from a later secondary event involving a generally downward acting force. The damage apparent at this engine location is, therefore, thought to have occurred in two separate events. In the first event the PTO unit mounting and engine casing (both grey cast iron) suffered brittle fractures in response to an upwardly directed bending moment, which had also resulted in upward bending of the top cover plate. The downward bending of the joints four retained studs and associated stripping of the nuts then occurred in a later event.

Fracture of the PTO mounting at the forward side, would suggest that the four forward securing nuts were still present and performing their role of securing the bolted joint at the time of the fracture. This, in turn, suggests that the loss of the four forward securing nuts and downward bending of the studs occurred after fracture of the bolted joint. Though the apparent collective damage at this location results from forces acting in two different directions it may still have occurred concurrently by, for example, an initial collision with the sea bed detaching the PTO unit followed by continued grounding motion of the engine against the sea bed.

The bending force associated with the first and principal fracture event at this location is estimated in Appendix 1.

2.2 Item (1d) Camshaft Drive Chain – (Timing Chain)

A length of camshaft drive chain, less than the engines full compliment, had been recovered from the engine during earlier shipyard inspections completed by others. The length of chain available for inspection at the shipyard is shown in figure 5.

Inspection confirmed that though a number of chain plates had become detached, no pin fractures were evident. It was also observed that the detached plates were in areas of the chain that had suffered the most severe post casualty corrosion damage (figures 6, 7 and 8).

It was concluded that no pin fractures were apparent in the recovered chain length, and that plate detachment and damage in the recovered sample had probably resulted from a combination of post casualty corrosion of the pins riveted ends and removal damage.

Photographic and documentary evidence provided by others, confirmed that the recovered chain length was found detached from the drive wheel and that the drive wheel had also suffered tooth loss damage over part of its drive circumference. Having not had the opportunity to see the chain wheel in-situ, our ability to offer an opinion in respect of the likely cause of the collective damage is limited. It does, however, appear likely that damage to the chain wheel and chain breakage result from a common event. Considering the knock-on damage to the engine units that would result from a broken camshaft drive chain, it appears likely that the chain breakage and drive wheel damage occurred relatively late in the casualty sequence; a view possibly supported by an absence of readily obvious connecting rod damage with the engine units.

2.3 Item (1g) Starboard Side Engine Block

The upper starboard side engine block included a fabricated rectangular shaped steel charge air distributor to which an inlet duct had originally been bolted. The inlet pipework connection from the turbocharger and inlet duct were both absent from the engine block. The charge air duct mounting face had suffered inward bending of the lower aft longitudinal bolting face (figures 9 and 10) and inwardly bending of the aft three vertical stiffeners (figures 9 and 10). The aft most stiffener had also experienced an overload fracture of the top attachment fillet weld in response to the bending stress (figure 10).

The charge air duct had been secured to the mounting face by bolts of approximately 8mm diameter, and all were seen to have fractured close to the bolting face in response to a shear force acting generally downwards. The number 4 cylinder crank case doorframe had similarly suffered mild inwardly directed ductile bending damage (figure 11).

The turbocharger and charge air cooler (intercooler) had both been mounted on the aft end engine casing, both items and their connecting pipe and ductwork were absent from the engine. The engine had two exhaust gas manifolds, each of which terminated at a bolting flange located aft of the engines port side, no connecting pipework was evident beyond the two flanges (figure 12). Connection of the turbocharger inlet hoses to the exhaust manifold had been secured by six bolts of approximately 8mm diameter in each of the two flanges. At the time of inspection one outwardly protruding bolt was retained in the top flange, and two backwardly inclined bolts remained in the lower flange (figures 13 and 14). The joint had clearly failed by stripping of the nuts in response to a force which, based on the positions of the retained studs, probably acted in a downward starboard to port direction.

Upper damage to the starboard side engine block comprised ductile downward bending of the lower mounting face of the charge air distributor, associated fracturing of one welded stiffener, and loss of the charge air duct. The crank case doorframe of cylinder number 4 had similarly suffered ductile bending damage. Collectively the damage appeared consistent with a force or forces acting generally normal to the engine blocks starboard side. The forces, where it was possible to perform estimates, could be accounted for by a seabed grounding impact of the engines starboard side. In the case of the absent turbocharger, intercooler and associated pipe and duct work, far less indicative evidence was available. It was, however, possible to conclude that failure of the bolted turbocharger connections to the exhaust gas manifold had resulted from stripping of the nuts, and that the associated force probably acted downward from the starboard side. Insufficient indicative evidence was available to establish how the charge air cooler had been mounted to the engines aft end, and consequently it was not possible to either form or offer an opinion in respect of the detachment mechanism for this item.

The bending and fracture forces associated with principal items of damage described in this section are estimated in Appendix 2. Collectively the damage to the engine blocks starboard side and associated attachments was judged to be consistent with seabed grounding damage.

2.4 Top of Main Engine – Valves and Rocker Gear

Two panels of gauges had been mounted at the top aft starboard corner of the engine, all of which were absent at the time of performing the inspection (figure 15). The bending of retained bolting in this area was consistent with a damaging force having acted in the starboard to port direction.

The engines rocker covers and rocker gear was also absent from the top of the engine at the time of inspection (figure 16). It was also apparent that the engines aft protruding valve stems had suffered varying degrees of bending in a starboard to port direction (figure 17). Damage to the engines top end had also resulted in loss of other items mounted at the top starboard side, including fuel pump assemblies and charge air bend mountings, all of which was judged to be consistent with seabed grounding damage.

The bending force to initiate bending in an unsupported valve stem is estimated in Appendix 3.

2.5 Aft Starboard Side Crankshaft and Flywheel Inspection Cover

The crankshaft and flywheel cover plate had been secured with six studs (figure 18). Two studs had fractured in situ and four had been stripped from the engine casing casting. Evidence of brittle casting fracture around the top stud hole was also apparent (figure 19).

The lower retained stud exhibited extensive post fracture damage, which precluded identification of both fracture mode and force direction. The upper retained stud and fracture of the cast iron reinforcement around the top stud hole were, however, both consistent with shear type fracture in response to a force acting generally upwards and to port (see force direction arrow under sheared stud in figure 18).

An upper bound shearing force to account for the damage is estimated in Appendix 4.

A second studded mounting flange was located above and aft of the inspection cover plate (figures 18 and 20). One top stud was seen to be downwardly bent and the second upper stud had been stripped from the engine casting (figure 20).

2.6 Item (19) Turbocharger

The turbocharger had been recovered from a location remote from that of its engine installed position, and had, therefore, become detached during the casualty event sequence.

The compressor rotor and casing light metal castings were absent from the unit, and were concluded to have been consumed by long term seawater corrosion (figure 21). The exhaust gas turbine casing was thought to be a grey iron casting, as was the bolted cover plate.

Exhaust gas inlet into the turbine was via two thin convoluted flexible metal hoses. One hose had torn close to the turbocharger inlet. The second hose exhibited a plain pipe end, which is thought had earlier terminated in a bolting flange suitable for mating to the exhaust manifold (figure 21).

The exhaust turbine casing and inspection cover plates were both thought to represent grey iron castings, and both exhibited brittle fractures. Fracture of the casing was apparent at the raised compressor-mounting flange opposite the inlet (figure 22). A second brittle fracture was apparent in the rotor case cover plate (figure 23). The casting fracture at this second location was accompanied by shearing of three securing bolts (figure 23). Evidence of casting fragmentation around at least two of the bolting holes was further suggestive of shear damage (figure 23). The probe boss mounting close to the outlet appeared to have been bent towards the inspection cover.

During cleaning of the fractures in the two castings it became apparent that material was very easily removed by brushing, and graphitisation corrosion was suspected. Evidence of graphitisation would further account for what appeared to be relatively new post fracture indentation damage along the cover plate fracture edge (figure 23).

A cover plate shear fracture stress is estimated in Appendix 5.

To investigate the possibility of post casualty graphitisation corrosion, and to confirm that both the turbine casing and cover plate were grey iron castings, samples of both were removed for laboratory metallographic examination.

2.6.1 Metallographic Examination of Turbocharger Casing and Cover Plate Samples

Samples of the casing and cover plate were hot mounted and prepared to a 1-micron diamond finish by conventional metallographic techniques. The prepared specimens were examined via a metallurgical microscope in both the unetched and Nital etched conditions.

2.6.2. Turbocharger Casing Sample

This item was confirmed to be a relatively low strength pearlitic grey flake graphite cast iron (figures 24 and 25). The casting was also confirmed to be in an advanced state of graphitisation corrosion, which at the outer surface had consumed all the pearlitic matrix.

2.6.3 Turbocharger Cover Plate

This item was also confirmed to be a pearlitic grey flake cast iron, but in this case one of a higher strength grade (figures 26 and 27). Like the casing, the cover plate was in an advanced state of graphitisation corrosion.

2.7 Items (2a/2b) Front Starboard and Starboard Frame Damage

The lower front starboard side of the engine had suffered particularly heavy damage. No wooden frame timbers were present under the engine front end and the forward most engine foundation plate was absent (figure 28). The remaining starboard side engine foundation plates had all been upwardly bent around the engine sump (figures 29, 30 and 31). A large pebble measuring 355mm by 200mm was seen to be trapped behind the second upturned foundation plate (figures 29 and 30). The pebbles overall dimensions exceeded those of the opening above the first upturned foundation plate, maximum dimensions of which were 345mm by 195mm at the lower end, and 150mm by 195mm at the upper end. The engine foundation stiffener plate against which the pebble was lodged was also seen to have been bent in the aft direction (figures 29 and 30).

Aft of the starboard front-end damage, there was evidence of wooden frame timbers, which appeared to have been snapped off at their bottom ends and compressed against the upturned foundation plates at their top ends (figures 32 and 33). Evidence of some longitudinal timber infill between the frames was also apparent at the mid-engine location (figure 32). Without exception, all the starboard side engine and drive shaft foundation plates were seen to have suffered upward bending damage (figures 32, 33 and 34). The extent and severity of the bending damage appeared noticeably more severe along the side of the engine. Aft of the first deformed stiffener, shown in figure 30, foundation plates had bent in between the stiffeners (figure 35) and no significant bending of any further stiffeners was evident. The plate protrusions beyond the remaining forward three stiffeners were either bent upwards or fractured at the stiffener face. The direction of the necessary force was consistent with other damage in this area.

The steel timber bolts along the starboard side appeared to have suffered significant bending damage, the current looseness of many bolts, however, precluded the positive charting of their casualty related bending direction. It was, however, clear that bolts had experienced a generally upwardly directed bending.

Collectively the evidence appeared consistent with bending of the engine foundation and aft drive shaft tunnel plates by a force acting in the starboard to port direction. The apparent bending to aft of the first (forward) stiffener plate would suggest that the forward starboard engine side had also been subjected to an additional force acting in the forward to aft direction. Evidence of a large pebble trapped behind the upturned foundation plate at the engines front end would also suggest that this engine location had collided directly with the sea bed, and that it had consequently been void of hull timbers before the sea bed collision.

The force associated with upward bending of the under-engine steel foundation plates and timber bolts is estimated in Appendix 6.

2.8 Item (3) Propeller

The propeller had been disassembled to facilitate earlier inspection by others, and parts from blade 1 had been removed from the shipyard for detailed laboratory examination. The blade 1 sample material that had been removed from the shipyard for detailed laboratory examination was subsequently also made available to The Test House for its examination. Propeller blade numbering used throughout this report section follows that assigned by the manufacturer.

Propeller blades 2 and 3 both exhibited local blade tip loss and bending damage (figures 36 and 37), the degree of bending damage appearing more pronounced in the case of the number 3 blade. The tip loss in both blades was considered to have largely arisen from post casualty corrosion, and no visually apparent fractures or cracks were apparent in either of the blades.

Propeller blade number 1 exhibited a series of pronounced local bends at its outer tip, which had created a corrugated edge (figure 38). A fast running brittle fracture originating from the end of the block slideway was apparent in the root of this blade (figures 39 and 40). The fracture had detached two sizeable pieces of material (weighing 5.3kg) from the drive block contact face region. The two fracture surfaces exhibited classical chevron markings typical of fast running brittle fracture (figure 40), which in this case had propagated in two different directions from an origin at the corner of the guide block slideway. A number of mechanical deformation and indentation markings were also apparent on the detached pieces. One series of markings reflected multiple loading events and one area of mechanical impact type damage clearly post-dated the fracture event.

Pitching of the three propeller blades was effected by a remotely operated hydraulic push rod acting on the blades, via pins and drive blocks located in the blade root slideways. To change pitch, the three blades rotated in split yellow metal bearings which formed an integral part of the cone casting (figure 41). There was clear evidence of heavy mechanical damage inboard and behind the cones number 1 blade bearing face (figure 42). The number 1 blade pin and drive block had also suffered damage. The drive block hole had plastically deformed and the pin was bent.

The apparent damage to the blades and cone internals would have seriously affected rotational balance of the propeller. It would, therefore, appear inconceivable that the propeller could possibly have been rotated at service speed with the extent of damage that was apparent. The current position of the hydraulically actuated push rod would suggest that the propeller had been pitched to thrust to stern. Collectively the damage and apparent thrust direction of the propeller, based on positioning of the actuator push rod, could be consistent with either of the following.

Scenario 1: With loss of hydraulic power, the current position of the actuator and push rod reflected their reaction to impact of the number 1 blade with the seabed, rather than reflecting the propellers pitch setting immediately preceding the casualty.

Scenario 2: The position of the actuator and push rod reflected the to-stern direction of propeller thrust at the time of seabed grounding.

If the hydraulic system for pitch adjustment is a closed system with no scope for hydraulic back flow, as is understood to be the case by the Commission, then scenario 2 would appear the more probable, i.e. the propeller was pitched to thrust to-stern at the time of the casualty.

Due to the complex shape of the propeller blades and inability to suitably model the geometrical stress concentration associated with the machined drive block slideway, it is not considered realistically feasible to estimate the forces responsible for the blade tip bending and brittle fracture.

2.8.1 Metallographic Examination of Propeller Blade Specimen

A metallographic specimen, removed and prepared by others, from the fracture face edge of propeller blade number 1, was examined via a metallurgical microscope in the as received etched condition.

The specimen exhibited a two-phase microstructure typical of cast Nickel-Aluminium-Manganese type bronze alloys. Though unusual in propeller castings, and not significant in this case, the microstructure exhibited a dispersion of globular features which suggests that the alloy may have been leaded.

2.9 Item (4a) Keel Plating

The vessels hull was constructed on a wooden keel which was strengthened and protected by steel plating of 12mm specified thickness. The fabricated keel plating extended aft of the vessel’s stern, to house a mounting hole for the lower rudder bearing pin.

The aft end keel underplate exhibited rounded upward bending in response to a force acting upwards and towards the port side (figure 43). The topside rudder bearing pinhole still appeared reasonably round and was generally undamaged.

At the time of salvage the engine was seen to be resting on its starboard side with the keel plating still attached and resting clear of the seabed. From the Commissions salvage video it was also apparent that the length of keel plating recovered did not extend fully to the front of the engine, and that significant bending damage was apparent at the forward-recovered end.

Though some break-up of the forward-recovered keel plating section had occurred during the salvage operation, this did not appear to suitably account for the bending distress damage. Similarly, as the engine had come to rest on its starboard side with the keel plating clear of the bottom, seabed grounding did not appear to suitably account for either the bending damage or absence of plating at the forward end.

2.10 Item (5) Aft Lower Rudder Blade Corner

The rudder had been fabricated from sheet steel internally reinforced with stiffeners. The lower forward corner had a round hole to accommodate the bottom bearing pin. The top forward corner had a bolted flange plate connection to the flanged bottom end of the rudder stock. The rudder stock to flange plate weld had fractured and both halves of the bolted joint were retained on the rudder blade. The bottom (deformed) aft blade corner had been cut from the main blade during earlier examinations completed by others. A sub-piece removed from the deformed corner and metallographic specimen prepared by others from the sample were subsequently also made available to The Test House.

The rudder blades lower aft corner exhibited ductile bending through an angle approaching 180°, (figures 44 and 45), which was judged to be most unusual. The corner was folded on to the blades starboard side, and others had reported that a number of pebbles had been trapped on the starboard face under the fold. Though some mild abrasion damage was apparent by way of folds thick end, its location, extent and severity were wholly inconsistent with the severity and direction of bending apparent. No further evidence of mechanical deformation or deep abrasion damage was apparent.

2.10.1 Metallographic Examination of Rudder Blade Specimen Set

A set of three metallographic specimens which had been removed from the rudder blades lower deformed area were received in a common mount. The mount was re-prepared to a 1-micron diamond finish and the specimen set was subsequently examined in the Nital etched condition.

Outer bend radius surfaces were free from metallographically detectable ferritic matrix strain damage. Furthermore, there was no evidence of high strain rate induced twinning in the outer radius ferritic matrix.

The specimen set served to confirm that the rudder blade had been fabricated from a hot rolled low carbon steel, microstructure comprising small lamellar pearlite colonies in a ferritic matrix.

The bending force associated with ductile bending of the lower aft rudder blade corner is estimated in Appendix 7.

2.11 Item (6) Rudder Stock

The rudder stock and hydraulic pilot motor were found detached and remote from the rudder blade. The bar stock had originally terminated at a 30mm thick flange plate, attached by circumferential welds at each of the flange plate sides.

The stock bar exhibited bending of its bottom end, in a forward to aft direction (figure 46). Hydraulic pipe connections to the pilot motor had both been torn from fixings which were located on the forward side of the motor case (figure 47). The two welds which had attached the bottom bolting flange had both fractured (figures 48 and 49). The features apparent at the stocks bottom end connection suggested that the joint comprised a slip-on flange with relatively shallow circumferential fillet, or partial penetration butt welds, at each side of the flange plate. Though very little interpretable fractographic evidence was available, it appeared likely that both welds had failed by overload fracture through their weld throats. It was also evident that the force necessary to shear the two welds, was less than the force necessary to fracture the six bolts which joined the stock and blade flange plates.

The rudders bottom end securing pin was not recovered by the Commission. Though during our visit we did not perform a detailed examination of the rudder blades lower securing pin hole, it appears likely that absence of this item is directly related to other documented rudder and keel plate mounting hole grounding damage.

The forces associated with bending of the rudder stock and fracturing of the two stock to flange plate welds are estimated in Appendix 8.

2.12 Item (8c) Trawl Winch Services Pipe Doubler Plate

The deck doubler plate comprised a 17.5mm thick x 500mm x 270mm steel plate with two pipe branches or piercings through the plate. The plate had been secured in position by six bolts.

The plate was seen to have suffered ductile bending across the short axis (figures 50 and 51). Only one of the securing bolts had been retained, and this was seen to have been bent through approximately 90°. The two pipes had suffered extensive post casualty corrosion damage, and no other significant features or impact damage were apparent.

It appears likely that the plate had been attached to either the deck or a bulkhead, and if this were the case the necessary bending force was probably associated with break-up of the wooden deck or bulkhead.

The forces associated with bending of the steel plate are difficult to estimate without precise knowledge of the installation, an order of magnitude value is never the less estimated in Appendix 9.

2.13 Item (12) V Belt Pulley Wheel

The six V belt drive pulley with fractured mounting bracket appeared to have suffered very severe post casualty graphitisation corrosion (figure 52).

Fracture damage to the pulley groove edges appeared to post-date the casualty, and had probably resulted from recovery damage of a heavily graphitised casting. The fracture to the cast mounting bracket appeared typical of an overload fracture in grey cast iron, with an indeterminate fracture direction. To confirm the parent material type and extent of graphitisation corrosion a sample was removed from the pulley wheel for metallographic examination.

2.13.1 Metallographic Examination of Pulley Wheel Sample

The sample was hot mounted and prepared to a 1-micron diamond finish by conventional metallographic techniques. The prepared specimen was examined via a metallurgical microscope in the unetched condition only.

The sample material was confirmed to have suffered 100% graphitisation corrosion (figure 53). Though the casting exhibited complete graphitisation, it was still possible to conclude that the material was a relatively low strength grey flake graphite cast iron.

2.14 Item (24) Base Plate with Mounted Chain Stopper and Bollard

This item of interest to the commission was not inspected due to time constraints.

2.15 Engine Crankcase

The engine crankcase was heavily fouled with hard seabed products and semi-cemented pebbles, which obscured a significant amount of the crankshaft and big end connections. The limited inspection completed confirmed all six connecting rods to be visually free from bending damage, and established that all were still connected to the crankshaft and their respective pistons.

The pressed steel crankcase doors had been largely consumed by post-casualty seawater corrosion. Visual evidence of door corners, retained as corrosion products, did however, suggest that the engine had not suffered a crankcase explosion either prior to or during the casualty sequence and sinking.

2.16 Item (1h) Cover for the Aft End of the Camshaft Drive

This item of interest to the Commission was not inspected during our visit and we are consequently unable to offer comments on the damage at this site.

3. SUMMARY

3.1

Casualty related damage to the engine and engine room foundation plates was confined to the starboard side, and was at its most severe at the front end of the engine.

3.2

Aft of the engine the starboard side propeller drive shaft tunnel plates had also suffered bending damage. The direction of bending was in a starboard to port direction, like that of the engine room floor foundation plates. The foundation plate damage aft of the engine was, however, significantly less severe than was the case along the engine side.

3.3

The starboard side engine damage was consistent with a force, or forces, acting generally normal to the starboard engine side. A secondary force or force component acting in a forward to aft direction was also thought to have contributed to damage at the front starboard end of the engine.

3.4

The presence of a large seabed pebble trapped between the front end starboard side engine foundation plates and the engine sump represented clear evidence of this area having collided directly with the seabed.

3.5

The forces associated with damage to the engines starboard side, cylinder head and ancillaries were all judged to be of a magnitude which could be suitably accounted for by a direct collision of the engine with the seabed.

3.6

The sub-total length of camshaft drive chain that had been recovered from the engine was seen to have suffered severe local post casualty corrosion of the riveted cross-pin ends, and beyond noting the corrosion damage little further could be concluded from the recovered chain length.

3.7

The turbocharger had suffered extensive post casualty corrosion damage, which had totally consumed the light metal compressor side and graphitised the exhaust turbine casing and cover-plate. The fractures apparent in the cast iron turbine casing and cover-plate appeared typical of brittle overload fractures in cast iron. The estimated fracture forces were again of an order of magnitude which could have been generated by impacting of the engine with the seabed.

3.8

The number 1 propeller blade had suffered extensive damage, in the form of a fast running brittle root fracture and severe tip bending damage. With the amount of damage to both the number 1 blade and cone internals, it appeared inconceivable that the propeller could possibly have been rotated under power at the service speed. It, therefore, appears more likely that the damage resulted from casualty related collision of the number 1 propeller blade with the seabed.

Based on the position of the actuator and push rod, the current pitching of the propeller was confirmed to be set to thrust aft. Two scenarios were offered to account for the apparent thrust direction. If the Commissions understanding of the actuator hydraulics is correct, then the propeller was thrusting to aft at the time of the casualty.

3.9

The rudder assembly had suffered bending of the lower aft blade corner, bending of the lower end of the rudder stock, loss of the lower mounting pin and fractures of both rudder stock to flange plate welds. The apparent areas of damage were thought to be related and contemporary. The rudder blades remote recovery position could not, however, be fully accounted for, and would suggest that either the reported post casualty storms had moved some items, or that the rudder assembly had broken-up before reaching the seabed.

The 180° bending of the aft blade corner appeared most unusual, and can only be reasonably explained by a scenario including the blade grounding and then folding over itself. The reported presence of pebbles under the fold would also tend to support a seabed grounding scenario. The estimated force necessary to effect the damage was relatively small and could conceivably have been generated by the vessels engine and steelwork mass.

3.10

Bending damage to the aft end of the keel by way of the lower rudder bearing pin hole location was also thought to have resulted from casualty related seabed grounding damage, and was thought likely to be directly associated with the rudder grounding damage. Absence of keel plating under the engines forward section and bending at forward end were not, however, judged to be consistent with grounding damage.

3.11

The precise installed location of the trawl winch services doubler plate was not known. The apparent absence of impact or collision type damage would suggest that bending of the plate and the one retained bolt had resulted from catastrophic break-up of the deck or bulkhead to which the plate had been attached.

3.12

The V belt pulley wheel and its mounting bracket were both grey iron castings. The mounting bracket had suffered brittle overload fracture, which had proceeded in an indeterminate direction. The inherent low strength and brittle nature of such materials, coupled with their insensitivity to shock, bending and tensile loadings would suggest that the fracture load was quite low, and well within the loadings which could have been generated by a collision of the engine with the seabed.

4. CONCLUSIONS AND DISCUSSION

The fishing vessel UTVIK SENIOR was a wooden hull vessel with aluminium superstructure. The items recovered from the wreck site, however, comprised largely only metal items that had not been consumed by post casualty long term seawater corrosion.

Inspection of the recovered items identified no damage to directly suggest that UTVIK SENIOR had been in collision with another surface or sub-surface vessel. A collision with another vessel could not, however, be completely ruled out, as any ensuing collision damage may have been sustained in areas of the vessel remote from the recovered items.

Evidence at the engines forward starboard side did, however, suggest that UTVIK SENIOR had suffered a catastrophic incident prior to, or during the casualty sequence, and that the engine subsequently collided directly with the seabed. The forces necessary to account for the engine and foundation plate damage are similarly only suitably accounted for in a scenario which involves at least starboard side break-up of the vessel prior to seabed grounding. The apparent absence of keel plating under the forward engine section and bending damage at the forward end also suggested that the vessel's forward section had suffered pre-grounding damage.

Without a catastrophic event leading to break-up of at least the vessels starboard side, it becomes impossible to account for the damaging forces. It is, therefore, concluded that UTVIK SENIOR had suffered a catastrophic event that culminated in at least partial break-up of the hull. The front starboard side of the engine then collided directly with the seabed and the engine and aft steelwork subsequently rolled over onto the starboard side.

Damage to the propeller and rudder was similarly attributed to casualty related seabed grounding. The current pitching direction of the propeller, based on the position of the push rod and hydraulic actuator, was in the aft thrust direction.

Estimating of the forces necessary to account for the apparent damage were completed via a combination of simple elastic and plastic bending and shear force solids mechanics computations. The seabed was assumed to be of sufficient rigidity to largely react the available collision force, an assumption supported by the lower forward starboard foundation plate damage, some of which had clearly resulted from seabed grounding. The force estimates rely on the sinking engine mass as the sole principal source of the grounding force.

Taking individual areas of damage in isolation and accepting that the engines starboard side was exposed at the time of seabed grounding, it appears conceivable that the sinking engine mass could react the necessary force. Looked at collectively we are becoming increasingly less sure that a seabed collision force of sufficient magnitude was available.

To resolve the issue of damage and the available force, we feel that the Commission should investigate this aspect further by an energy balance approach. We would suggest that damage should be assessed in terms of strain and fracture energy, and that this then be compared with the available kinetic energy assigned to the sinking mass. Though we have expended a significant effort in attempting to evaluate the damage via the energy accounting route we reluctantly conclude that such an approach is beyond the scope of our experience and ability.

Report prepared and authorised by:

D Ellin
Director and Head of Laboratory

T30642: APPENDIX 1

Item (1b) PTO Housing

Upward bending force to fracture housing joint

$$I = \frac{1}{12}\left(b_1 d_1^{\,3} - b_2 d_2^{\,3}\right)$$

$$\frac{M}{I} = \frac{\sigma}{d_1/2}$$ σ ~ 230 N/mm^2

$$I = \frac{1}{12}\left(300x350^3 - 275x325^3\right)$$

= 285 x 10^{6}mm

$$M = \frac{285x10^6 x230x2}{350} \quad \text{Nmm}$$

= 375 x 10^{3}Nm or 37.5 kNm

and for ½ lever 75 kNm

T30642: APPENDIX 2

Item (1G) Exhaust Connections and Charge Air Duct Damage

Broken Bolted Connections – Exhaust Manifold Flanges – Stud Stripping Force

6 bolts per flange (8mm, 6.5mm core diameter) assume property class 5.6 (σ_{ut} 500 N/mm^2)

$$\text{Bolt cross section area } = \pi\left(\frac{6.5}{2}\right)^2 = 33mm^2$$

Fracture force = stress x area
= 500 x 33
=16500N or 16.5 kN

6 bolts per flange – 6 x 16.5 = 99kN per flange

Shear Fracture of Charge Air Duct Bolting Studs

8mm diameter (6.5mm core diameter) studs – assume 28 property class 5.6 (500 N/mm^2 UTS) studs used to secure duct to engine bolting face

28 Stud of cross section area = 33mm^2 and tensile fracture force per stud = 16.5 kN. Assume double shear fracture stress to be 0.5 x tensile stress then

28 studs x 16.5 x 0.5 = 231 kN absolute shear force

N.B. The above absolute shear force take no account of the potential cantilever effect created by the ducts outward protrusion from the engine bolting face. The potential cantilever effect would be to reduce the necessary detachment force to a value below that of the estimated absolute shear force.

T30642: APPENDIX 2 (continuation)

Fractured Stiffener Fillet Weld

Assume shear strength of 250 N/mm^2 for weld metal and weld of 5mm throat and 100mm length

Weld shear area = 5 x 100

= 500mm^2

then shear force to fracture weld = 500 x 250

= 125 kN absolute

and assuming shear force had been generated by bending of the stiffener, the resultant damaging force would be reduced by the reaction length. Bending of adjacent stiffeners would suggest that deformation had occurred at a level of force less than that of the absolute fillet weld shear strength.

T30642: APPENDIX 3

Engine Valve Stem Bending Force

Stem diameter 20mm, unsupported height 200mm
Stress $\sigma_y \sim 900$ N/mm^2

$$Mp = \frac{900x4}{3}x10^3 = 1200 \text{ kNmm}$$

$$\text{then bending force} = \frac{1200}{200}$$

= <u>6 kN</u>

T30642: APPENDIX 4

Item (1h) Camshaft Drive Cover Plate

Shear fracture force for 6 M12 property class 5.8 (500 N/mm^2 UTS) securing studs
Shear force ~ 0.5 x UTS

Stud core diameter = 9.8mm then cross section area = $75.43mm^2$

Stud shear force = 500 x 0.5 x 75.43 x 6

<u>113 kN</u>

T30642: APPENDIX 5

Item (19) Fractured Turbocharger Cover Plate

Assume shear fracture acting across the short axis of one plate end – assume fracture of plate to be equal to or less than shearing fracture force of 3 bolts. Bolts assumed to be of property class 5.6 (500 N/mm^2 UTS)

Bolt core diameter = 6.5mm and cross sectional area = 33.18mm^2

Then shear force = 33.18 x 500 x 0.5 = 8.3 kN

And for three studs = 8.3 x 3

= <u>24.9 kN</u>

T30642: APPENDIX 6

Item (2a) Bent Engine Foundation Plates and Timber Bolting

Foundation Plates

12.7mm thick plate of assumed Lloyds grade A, B, D or E (235 N/mm^2 min yield stress)

$$Mp = \frac{235x280}{4}x\left(12.7^2\right)$$

= 2653 kNmm

Assume moment = bending from half unsupported length

$$\text{Then force bending} = \frac{2653}{(650x0.5)}$$

= 8.16 kN per plate

Timber bolting

25mm bolts bent from a height of 150mm and assumed yield stress of ~ 900 N/mm^2

$$Mp = \frac{900x4x12.5^3}{3}$$

= 2344 kNmm

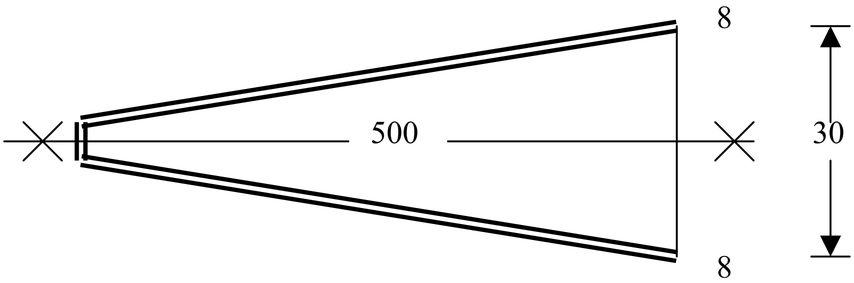
$$\text{and force} = \frac{2344}{150}$$

= 15.6 kN

T30642: APPENDIX 7

Item (5) Bending of Bottom Aft Corner of Rudder Blade

Assumed Lloyds grade A, B, D or E plate (235 N/mm^2 σ_y)



$$I_{xx} = \frac{1}{48} db^3$$

$$= \frac{1}{48} x500\left(46^3 - 30^3\right)$$

$$= 732.7 \text{ x } 10^3$$

$$\frac{M}{I} = \frac{\sigma}{y}$$

$$\text{then } M = \frac{732.7x10^3}{23} x235$$

$= 7.5 \text{ x } 10^6$ Nmm or $7.5 \text{ x } 10^3$ Nm

then for ½ lever force = <u>15.2 kN</u>

T30642: APPENDIX 8

Item (6) Bending of Rudder Stock and Shear Fracture of Flange Welds

Bending of rudder stock (Assume $\sigma_y = 235$ N/mm^2)

$$Mp = \frac{235x4x54^3}{3}$$

= 49339 kNmm

Taking movent to equal the height from the bottom of the blade to the stock bend site, then

$$\text{Force bending} = \frac{49339}{673 + 1650}$$

= 21.2 kN

Fracture of welds in shear – assume shear strength of 250 N/mm^{2}for weld metal and weld throat of 2 x 3mm

Weld shear area = π x 108 x 2 x 3

= 2036 mm^2

then shear force to fracture both weld = 2036 x 250

= 509 kN absolute

and assuming that this shear force had been generated by bending of the blade and stock the force would be reduced by the forces reaction length

T30642: APPENDIX 9

Item (8c) Doubler Plate

Assume plate fixed at one end and of Lloyds grade A, B, D or E $\sigma_y \sim 235$ N/mm^2. Assume no positive or negative contribution to stiffeners from pipes, then

$$Mp = \frac{235x17.5x270^2}{4}$$

= 74950 kNmm

Assuming movement acting over half plate length from end loading

$$\text{then force} = \frac{74950}{(500x0.5)}$$

= <u>300 kN</u>