# Sinking of the landing craft/barge “1473” with the loss of one life between Barbuda and Antigua on 26th February, 2015.

Figure 1: “1473” Loading Cargo in Barbuda Photo: Owner

The sole objective of the investigation into this accident is for the prevention of future accidents through the ascertainment of its causes and circumstances. It is not the purpose of the investigation to determine liability nor, except so far as is necessary to achieve its objective to apportion blame. This report is not written with litigation in mind and shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

The timings are approximate and local (UTC +4).

This casualty investigation was conducted by the Antigua and Barbuda Defense Force Coastguard and the Antigua and Barbuda Department of Marine Services and Merchant Shipping (ADOMS).

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# GLOSSARY OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| CoC | Certificate of Competency |
| GM | Metacentric Height |
| GZ | Heel righting lever in metres |
| hrs | Hours |
| IMO | International Maritime Organization |
| kg | Kilogram |
| kW | Kilowatt |
| l | Litre |
| LOA | Length overall |
| m | Metre |
| MLC | Maritime Labour Convention (2006) |
| nm | Nautical miles |
| PFD | Personal Flotation Device |
| SAR | Search and Rescue |
| SCV | Small Commercial Vessel |
| Spud Leg | Vertical leg/pile for anchoring and supporting a barge |
| STCW95 | The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (as revised 1995) |
| t | Tonne |
| USCG | United States Coast Guard |
| UTC | Universal Co-ordinated Time |
| VHF | Very High Frequency |

## SYNOPSIS

The tug Janika with a crew of 5 persons departed Barbuda for Antigua on Thursday, 26th February, 2015, at approximately 10:00 hrs. with a barge (ex-landing craft "1473") laden with sand and an empty tank container and one person on board. Approximately four (4) hours into the journey at around 14:15 hrs. barge "1473" capsized and subsequently sank. The person on board the landing craft was lost.

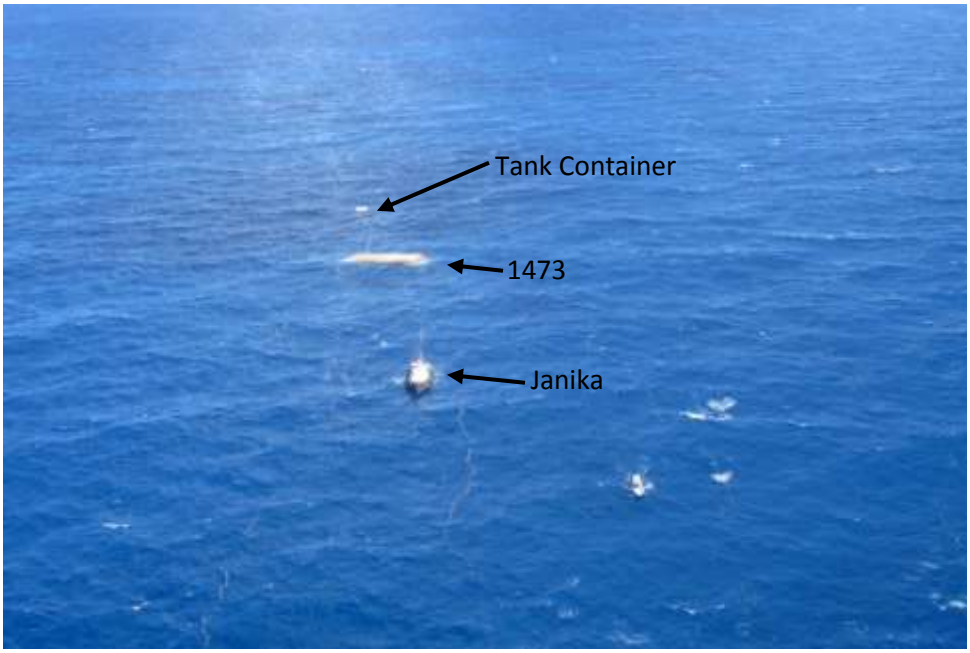



Figure 2: Janika towing Capsized "1473" and Empty Fuel Tank Container
Photo: Greg Scott – Caribben Helicopters

# SECTION 1 - FACTUAL INFORMATION

## 1.1 Particulars of the vessels involved

| | **Landing Craft (Casualty)** | **Tug** |
|---|---|---|
| Name: | 1473 | Janika |
| IMO: | None | None |
| Flag: | None | Antigua and Barbuda |
| Ship Type: | Non self-propelled barge | Tug |
| Classification Society: | None | None |
| Gross Tonnage: | estimated 277 | 179.85 |
| Length overall: | 35.08 m | 26.21 m |
| Beam: | 10.4 m | 7.4 m |
| Year Built: | 1953 | 1961 |
| Owner: | Knackbill Nedd | Knackbill Nedd |
| Manager: | Knackbill Nedd | Knackbill Nedd |

## 1.2 Voyage Particulars

| | |
|---|---|
| Port of departure: | Codrington, Barbuda |
| Port of arrival (intended): | Parham Harbour, Antigua |
| Cargo Information: | Sand (approximately 272t) |
| | Empty tank container on trailer (approximately 7t) |

## 1.3 Marine Casualty Information

| | |
|---|---|
| Date: | 26th February, 2015 |
| Type of marine casualty or incident: | Very Serious Marine Casualty |
| Location of incident: | $17^0$20.9' North $061^0$50.0 West |
| Injuries/fatalities: | One (1) fatality. |
| Damage/environmental impact: | Vessel capsized and sank. The "new" wheelhouse structure became detached with some damage to surrounding structure.<br>Vessel lost. No harm to the environment. |
| Ship operation: | On passage under tow. |
| Voyage segment: | Mid-water. |
| External & internal environment: | Wind: Easterly at 15-20 knots<br>Seas: Moderate to Rough 1.8-2.4 m / 6-8ft<br>Daylight with good visibility<br>Negligible Tidal height.<br>Tidal stream/current; Westerly approximately. 0.5 knots. |
| Persons on board: | One (1) |


Figure 3: Overview of the area of the incident – Google Earth

## 1.4 Background

1.4.1 There is regular trade of sand between Barbuda and Antigua usually carried by a flat topped barge towed by whichever tug is available, often this was Janika. The flat topped barge was undergoing maintenance so as a substitute the landing craft "1473" was utilized as a barge because it was undergoing restoration towards planned utilization as a landing craft type vessel to service the domestic trade between Antigua and Barbuda but its propulsion system was inoperative.

1.4.2 The landing craft was not registered or insured and thus had not recently undergone any official inspections.

1.4.3 Since its construction in 1953, it had undergone various modifications which in general had not been documented or overseen by external bodies.

1.4.4 Unfortunately, it has not been possible to trace any up-to-date drawings of the vessel or any stability information.

1.4.5 These vessels operate what is effectively a regular domestic service between Antigua and Barbuda.

## 1.5 Narrative

1.5.1. At the end of the previous voyage when deliberately beached in Antigua for cargo discharge the landing craft had suffered damage to the hull causing a leak and necessitating repairs which were conducted at the Crabbs Marina boat lift on the afternoon of 25th February, 2015. These repairs were conducted by an experienced welder who inserted a small plate into the vessels bottom towards the bow.

1.5.2 The vessel was relaunched and upon finding a small leak was re-hoisted to repair this which lead to delay in completion of the work meaning that departure for Barbuda was between 22:00hrs. and 23:00hrs with arrival in Barbuda between 03:00hrs. and 04:00hrs.

1.5.3 The usual five (5) persons were on the tug and one (1) on the barge, whose primary purpose was to ensure any water accumulating on board was removed utilizing the on board pumps as well as to raise and lower the bow ramp when in port.

1.5.4 Following arrival at Codrington, the barge attendant went to lodgings for a rest. It is reasonable to estimate that he and the tug's crew would only have got an estimated four (4) to six (6) hours of sleep that night. Had some rest been taken on passage it is unlikely that the total would exceed eight (8) hours for that night.

1.5.5 No records were maintained of rest hours. Normal procedure of a round trip every day allows for a good night's rest in Barbuda as the vessels normally arrive in the evening.

1.5.6 The requirements for working hours are contained in the Caribbean SCV Code (2014) Chapter IX part B paragraph 13 and are considered to be slightly more stringent than the requirements of either STCW or MLC.

1.5.7 Similarly there were no formal employment records available however all involved had been performing similar duties for several months minimum and could be considered adequately experienced for work on local vessels. However, the barge attendant had not undergone formal safety training, but he had been given basic instruction and was overseen by the tugs crew.

1.5.8 On the morning of 26th February, 2015 loading commenced shortly after 08:00hrs. with approximately 272 tonnes of sand being loaded at the aft end of the cargo

deck and the empty tank on trailer of approximately 7 tonnes at the forward end which was secured by a piece of 2 inch link chain on each side.

1.5.9 The vessels sailed at approximately 10:30hrs. As usual communication between tug and “1473” was maintained by hand held VHF radio whenever the need to communicate was felt. There was no fixed communication time table. Mobile phones were used for the tug captain to communicate any necessary information to shore.

1.5.10: The approximate timeline for events was as follows;

| | |
|---|---|
| 14:00hrs | “1473” was observed to be listing to port and some sand falling off however a report from the barge attendant stated that things seemed OK for a slightly rough passage. |
| 14:10hrs | There was a report from “1473” that water was coming in, the man on board was instructed to put on his lifejacket and prepare to jump overboard for Janika to come and pick him up. On board the tug, attempts were made to release the tow line from the pin arrangement and make it up on the towing bitts so that it could be easily released should the barge sink. Janika also starts to maneuver towards “1473” with the intention of recovering the man. |
| 14:15hrs | 1473” capsizes. It is not known if the man on board had already jumped overboard, was thrown overboard or was trapped when the vessel capsized. |
| 14:17hrs | Master of Janika contacted Coastguard via VHF channel 16 and reported capsized barge plus missing man. |
| 14:40hrs | Coastguard boat “D7” departed Coastguard base in St John’s. |
| 15:02hrs | Coastguard requested assistance from MRCC with air asset to search for missing man. |
| 15:07hrs | “D7” arrives at scene. |
| 15:41hrs | Local helicopter spots a pallet and gas cylinder half a mile east of scene. |
| 16:16hrs | Second coastguard boat “D8” arrives on scene. |
| 16:45hrs | Tug “Cindy” arrives at scene to help with search. |
| 16:44hrs | French SAR helicopter arrives on scene to assist with search and also puts divers into water and onto “1473”. |
| 17:53hrs | French SAR helicopter unsuccessful in search so returns to base. |

| | |
|---|---|
| 17:59hrs | Tug Cindy takes gasoline storage tank in tow to Janika. |
| 18:30hrs | Search suspended due to nightfall. |
| 18:45hrs | Tug Janika proceeding towards High point with “1473” and tank in tow. |
| 20:10hrs | “1473” sinks. Janika and tank proceed to port. |
| 22:54hrs | Janika moored. |

1.5.11 The following day sea conditions were deemed too rough to resume the search.

# SECTION 2 - ANALYSIS

## 2.1 Summary

### 2.1.1 "1473"Vessel design and construction

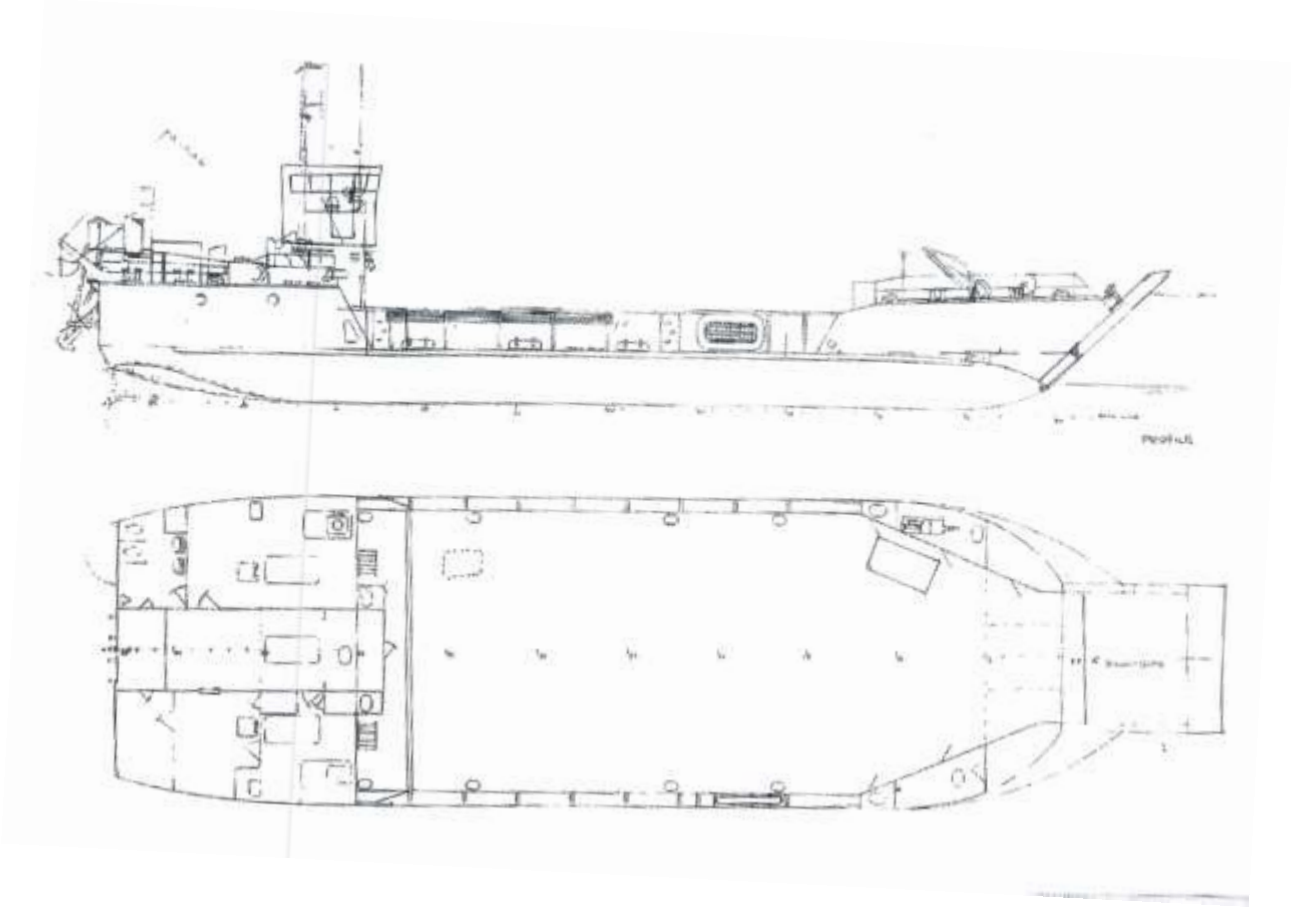


Figure 4 General arrangement plan of this type of landing craft

2.1.1.1 The vessel was originally designed as a landing craft for carrying wheeled and tracked vehicles with triple engine propulsion. The vessel is believed to have been built as LCU 1473 by the Island Dockyard for the United States Navy and delivered in 1953. It was one of the LCU -1466 Class

2.1.1.2 The wheelhouse had been modified at some stage and the military equipment removed. Annex 1 shows pictures of a similar vessel. The bow ramp arrangement had been modified to raise the effective threshold and this had created an additional void space under the cargo deck forward .The

centre engine had been removed so in general these modifications will have led to a decrease in the trim in lightship condition.

2.1.1.3 In order to carry sand most of the freeing ports at the sides of cargo deck had been covered and also a temporary bullhead had been placed across the cargo deck about 1.5 meters forward of the accommodation block, creating an area which would not have cargo in it but also appears to have very minimal drainage as modifications had also been made to deflect water off the side decks in front of the accommodation block which also obstructed the original water freeing arrangements in this area.

2.1.1.4 New accesses had been cut into the cargo deck and one of these in the aft port side area appears to have not been secured, which will have contributed to water entering the hull and also to the eventual sinking as after capsize the cover plate will have fallen off giving a good entry point for water into the hull with air probably being vented out through the original fixed bilge pumping piping system.

2.1.1.5 It is believed that the port and starboard 12V71 Detroit Diesel engines along with a fixed generator set were still in place in the engine room although all units were inoperative at the time and fuel tanks empty.

2.1.1.6 A wheeled portable generator was secured on the port side of the cargo deck towards the bow, primarily in order to provide power for the bow ramp.

2.1.1.7 It is understood that the vessels three propeller shafts had been locked but the rudders were free to move.

2.1.1.8 The vessel was designed to beach with a stern trim of about 0.76m and maximum draft of 1.6m and an even keel draft of 1.14m, the minimum freeboard to the open deck would be about 0.5m.

2.1.1.9 The cargo deck was fitted with freeing ports to allow any accumulated water on deck to quickly disperse.

2.1.1.10 The loaded displacement was approximately 352t and a cargo of 170t was envisaged or 300 troops (light displacement given as 182t). In view of the intended service the vessel was reasonably substantially constructed to cope with High Point loadings on deck and the hull scantlings were suitable for beaching in order to load and discharge a cargo of heavy military equipment of both wheeled and tracked variety as well as troops.

2.1.1.11 “1473” was also equipped with two submersible bilge pumps. In addition there was also a backup 4inch diesel pump on board.

2.1.1.12 The tow line in use on the day consisted of approximately 220 meters of wire attached to a chain bridle of some 6 meters length at the front of the vessel.

2.1.1.13 There is evidence that similar craft have been used for transporting sand in sheltered waters around the United States of America and this could have also led the owner to get the impression that the craft was suitable for this use.

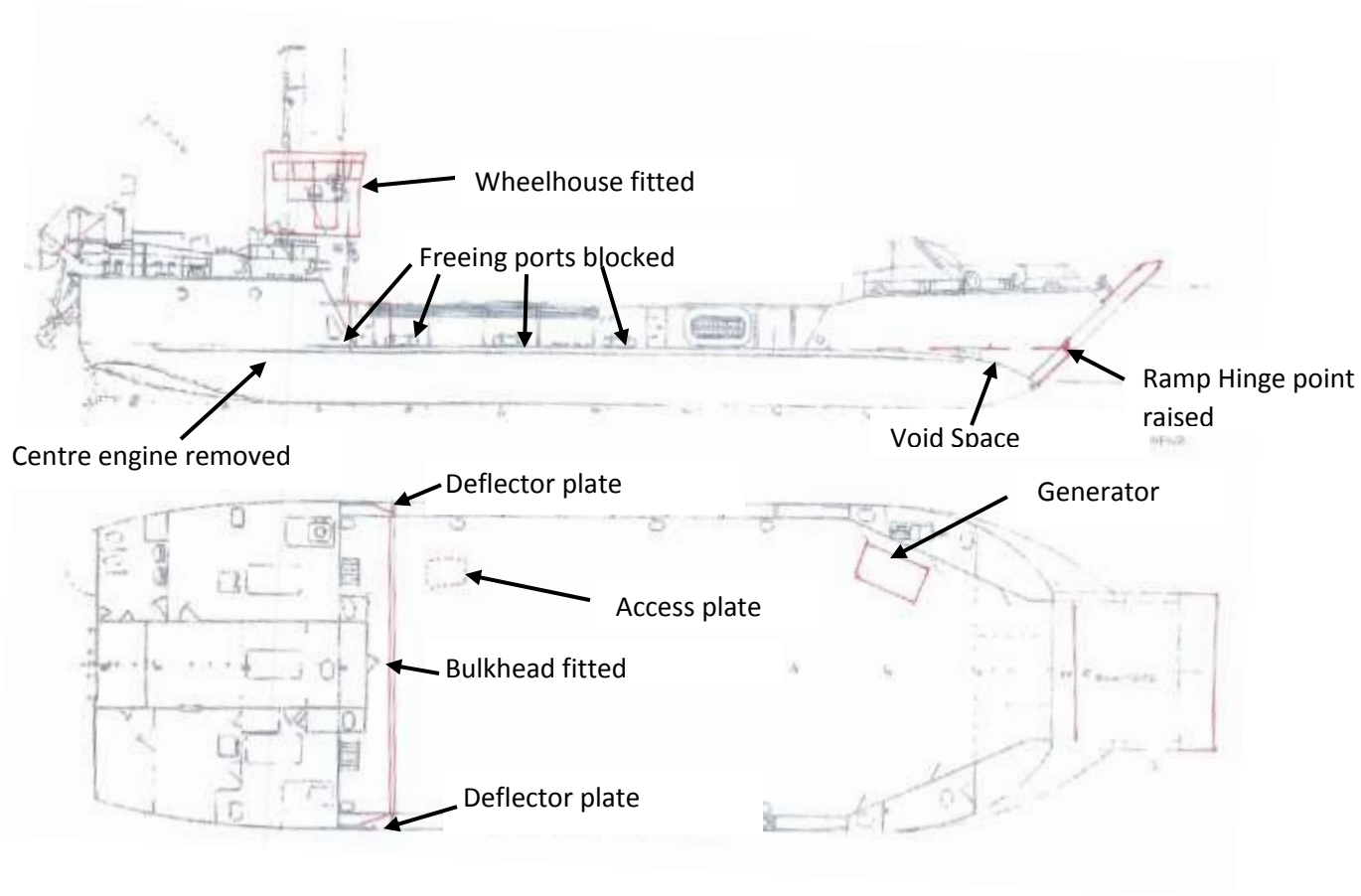



Figure 5: Main Modifications to “1473” – shown in red

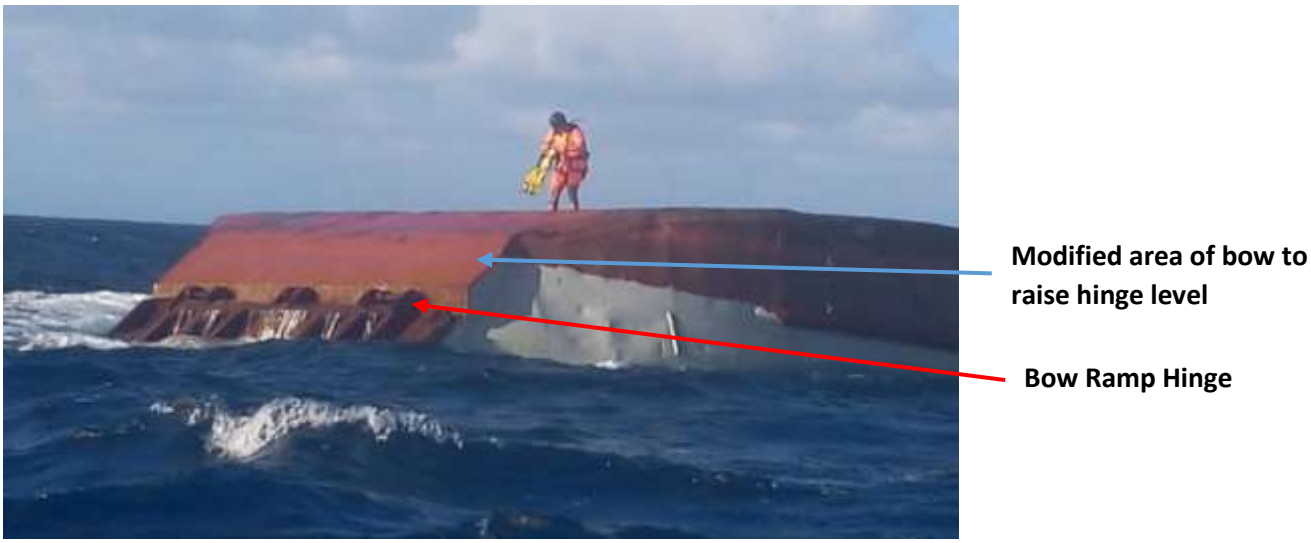



Figure 6: The bow part of “1473” clearly showing the modifications to bow ramp and also indicating that buoyancy has been retained in that portion of the vessel whilst inverted. Photo: MRCC Forte de France

Figure 7: “1473” on a previous voyage showing the bow ramp arrangement Photo: Owner

### 2.1.2 Janika - Vessel design and construction

Figure 8: Tug Janika Photo: Owner

2.1.2.1 Janika is a U.S.A. built twin screw local tug which has operated in Antigua and Barbuda since late 2010. The vessel has been appropriately certified under the Caribbean Small Commercial Vessel (SCV) Code with a certificate valid to 23rd December, 2015. The last annual inspection prior to the incident was held on 8th April, 2014.

2.1.2.2 Janika had been updated over the years but still has many original features. One modification which is of significance with respect to this casualty is that the towing arrangement had been modified to include a pin arrangement which did not have a quick release facility.

2.1.2.3 The manning levels were considered adequate for the type of voyage being undertaken and the seafarers qualified in accordance with the requirements of the SCV Code.

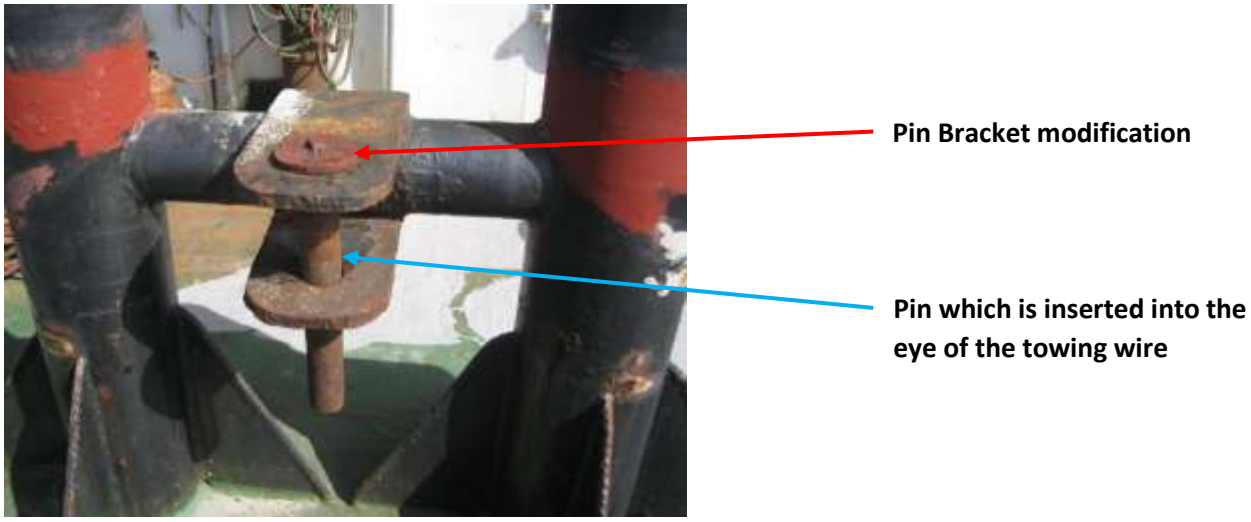



Figure 9: The towing pin mounted on the original towing bitts.
Photo: ADOMS

## 2.2 The Voyage

Figure 10: Janika and “1473” departing Codrington, Barbuda on a previous voyage. Photo: Owner

2.2.1 This voyage had been undertaken several times by this combination of vessels and type of cargo, however, the weather conditions for this voyage were considered to be amongst the worst that the passage has been attempted in.

2.2.2 The loaded freeboard was about 0.3m, whilst the vessel did not have loading marks the rubbing strake was apparently used to judge the loading condition with the vessel being judged to be fully loaded when the bottom edge of the strake touched the water. This would give a displacement of approximately 463t.

2.2.3 The sea state would have meant that once out of the lee of Barbuda, waves would have been generating spray over the vessel. Upon hitting the

windward side (port side) this would result in the windward side of the cargo becoming wet with the water absorbed by the sand and leading to an increase in weight on the port side which in turn reduces the effective freeboard and thus of course increases the amount of spray being shipped. There would also be some ingress of water onto cargo deck through the bow door opening as when raised the ramp did not completely seal this opening.

2.2.4 The initial wetting of the sand would cause the surface sand particles to bind together and thus reduce the amount being blown away from the windward side of the cargo, whilst the wind would blow some of the sand from the lee side, further contributing to a heel to windward.

2.2.4 Eventually some of the sand would be so saturated that it would start to act like a liquid with free surface effect coming into play and contributing to the ever increasing angle of heel.

2.2.5 The blocked freeing ports mean that any excess water is restricted in its ability to drain overboard and generates free surface effect. There would have been a certain amount of rolling of the vessel due to the orientation of the prevailing waves on the port bow to port beam.

2.2.6 The likely water contained in the forward void space also contributes to free surface as does any water in the main bilges and engine room bilges.

2.2.7 During the course of previous voyages there had normally been some water ingress hence the need for having a person on board to pump the bilges as necessary.

2.2.8 The total extra displacement caused by these factors could easily exceed 24t and the heel angle would result in deck edge immersion being reached due to the heel induced by cargo wetting on one side alone.

2.2.9 Whilst the vessel was under tow even with little trim there would have been a certain amount of stability induced by the forward motion, however once the tow was slackened this would be lost and furthermore the barge would become orientated more directly broad side on to the prevailing waves.

2.2.10 The wave conditions described by witnesses and the local forecasts were such that the likely wave profile was close to that which gives the maximum capsizing moment to a vessel of this beam, this combined with the heal induced by asymmetric wetting of the cargo and stability reducing effects of the free surface of water in the vessel as well the additional capsizing forces induced by the waves breaking on the narrow side decks and possibly over

the bulwarks would have led to the eventual capsize of the vessel. Annex 4 contains a very simplified stability diagram indicating likely reduction in the vessels stability due to these effects.

2.2.11 Because neither the original nor as modified stability information nor lines drawings could be found for the vessel it was decided to produce data based on the known current details of the vessel in order to demonstrate the likely causes. This information is contained in Annex 4.

2.2.12 Very basic model tests were also undertaken to attempt verify the likelihood of capsize in these circumstances, but even allowing for the scaling effects did demonstrate the extremely rapid capsize that could occur with these circumstances.

2.2.13 Whilst the vessels reducing stability should have been reasonably obvious to an experienced mariner it is less likely to have been obvious to the occupant of the barge with more limited experience and training. He is also believed to have had a good sense of pride in the upkeep of the vessel and may have been in denial that anything could go wrong until very shortly before its rapid capsizing.

2.2.14 When inverted the vessel maintained a reasonable “freeboard” and this indicates that there was probably not a large amount of water in the main tanks at the time of capsize. The aft section of vessel would quickly flood due to the hatches and doors being open. The dive survey showed that these were not dogged down and also revealed that there was an access hole to the main hull void which although likely to have been covered when the vessel was upright became open upon capsize and this together with air probably venting out through the original fixed bilge piping system would have led to the slow sinking of the vessel.

2.2.15 Had all spaces been properly weather tight then it is likely that the vessel could have been towed to shore inverted and then reasonably easily salvaged.

| | Wind Speed (knots) | | | | | | | | Wind Direction (Degrees) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 02hr | 05hr | 08hr | 11hr | 14hr | 17hr | 20hr | 23hr | 02hr | 05hr | 08hr | 11hr | 14hr | 17hr | 20hr | 23hr |
| Feb 25 2015 | 15 | 15 | 15 | 14 | 15 | 15 | 18 | 18 | 090 | 100 | 100 | 090 | 090 | 090 | 090 | 090 |
| Feb 26 2015 | 19 | 19 | 21 | 21 | 20 | 19 | 21 | 19 | 090 | 090 | 090 | 090 | 090 | 090 | 090 | 090 |
| Feb 27 2015 | 21 | 19 | 20 | 19 | 20 | 19 | 20 | 20 | 090 | 090 | 090 | 090 | 090 | 090 | 090 | 090 |
| | Significant Wave Height (meters) | | | | | | | | Wave Period (seconds) | | | | | | | |
| | 02hr | 05hr | 08hr | 11hr | 14hr | 17hr | 20hr | 23hr | 02hr | 05hr | 08hr | 11hr | 14hr | 17hr | 20hr | 23hr |
| Feb 25 2015 | 1.7 | 1.8 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.8 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Feb 26 2015 | 1.8 | 1.9 | 1.9 | 2 | 2 | 2 | 2.1 | 2.1 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 8 |
| Feb 27 2015 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |

Figure 11: Weather conditions from Windguru information


Figure 12: Janika and “1473” off Codrington; Barbuda on a previous voyage. Photo: Owner

### 2.3 Vessel maintenance

2.3.1 Considering the age of the vessel it appears to have been in reasonable condition, no formal survey records were available.

2.3.2 Maintenance had been undertaken and was ongoing, with the intention of restoring the vessel to being capable of self-propulsion.

2.3.3 Operational damage was repaired whenever encountered utilizing local workmen with a reasonable level of appropriate skills although in some cases without evidence of formal training and qualifications.

2.3.4 The barge attendant was said to have taken pride in his work to improve the appearance of “1473”.

## 2.4 Cargo

### 2.4.1 Dangerous goods

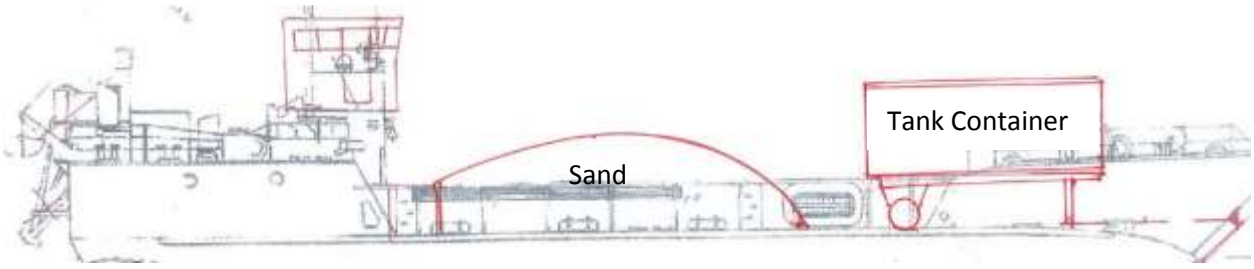
2.4.1.1 The standard twenty foot ISO tank container mounted on a trailer unit had been used for carriage of petroleum products to Barbuda and was thus class 3, flammable liquids, dangerous goods.

2.4.1.2 “1473” did not have any certification for the carriage of dangerous goods, however the tank used was suitable for this purpose.

### 2.4.2 Sand

2.4.2.1 The sand cargo is believed to have been reasonably dry with a density of approximately 1630 kg $m^{-3}$ which with maximum moisture content was found to increase to 1850 kg $m^{-3}$ which is a mass increase of some 13.5%

2.4.2.2 The IMO International Maritime Solid Bulk Cargoes Code describes sand as a group C cargo which is not liable to liquefy during transport. However it recommends that the cargo should be kept dry and trimmed reasonably level. In this case of course the sand was neither kept dry nor had it been trimmed level.



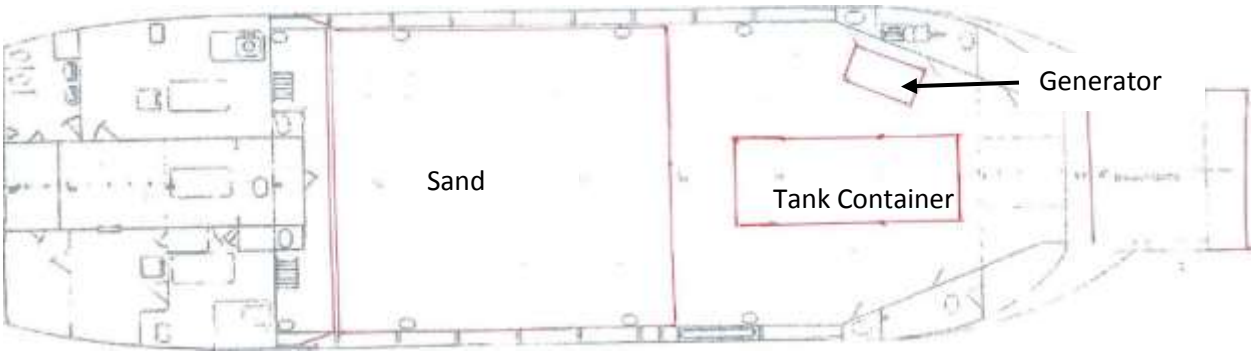



Figure 13: Approximate cargo plan

## 2.5 Training and Experience

2.5.1 There is however often a very “laid back” approach to health and safety aspects in many areas within the region which applies not just to the shipping industry.

2.5.2 Most of the seamanship skills possessed by the seafarers on board the vessels were obtained by learning through experience rather than a formalized training program. Thus the specific hazards associated with the carriage of this type of cargo on this type of vessel may not have been fully appreciated.

# SECTION 3 - CONCLUSIONS

3.1 The main causes of Barge “1473” capsize were that the barge was overloaded for the voyage to be undertaken.

3.2 The weather conditions were such as to make this kind of operation hazardous.

3.3 The initial heeling of the vessel to windward was caused by wetting of the windward side cargo due to spray from waves hitting the windward side hull and bulwarks causing an offset load, this heel was increased by the free surface effect of water on board the vessel, which increased as water was shipped onto the open deck.

3.4 The final capsize was due to the wave pattern encountered with the vessel laying “deadship” broadside on to the waves.

3.5 As the body of the barge attendant has not been recovered it is not possible to verify for certain that he has perished or the manner in which he has perished.

3.6 From the evidence presented it is likely that either the barge attendant was not wearing a PFD or had it on incorrectly, as what is believed to have been the PFD on board was seen floating nearby after the capsize. It is not possible to establish if this factor contributed significantly to his loss.

3.7 There is also the possibility that the barge attendant was injured during his attempt to escape which would have further reduced his chances of surviving.

3.8 Fatigue induced by the previous late running voyage, due to repairs, may well have contributed to desire of those involved to complete the fateful voyage quickly and get back home. There may also have been a certain amount of commercial pressure and pride in fulfilling obligations to the owner.

3.9 Whilst the barge attendant was aware that there was a problem immediately prior to the capsize, he may have been in a kind of denial phase believing that his pride and joy was not about to be lost and thus reluctant to leave it. It is also possible he was fearful of jumping into the sea in these circumstances.

**SECTION 4 - ACTION TAKEN**

- "1473" had not been salvaged at the time of this report and more suitable barges are being utilized for the trade between islands although many are still not subject to specific regulation.

- The Caribbean SCV Code review committee is considering including guidance for vessels and seafarers engaged in towing operations particularly with respect to quick release arrangements for tows and ensuring safety of towed vessels with a view to including such items in the 2017 version of the code.

- The Caribbean SCV Code review committee is considering including more information relating to MLC in the 2017 version of the code

**Actions taken shall in no case create a presumption of blame or liability**

## SECTION 5 - RECOMMENDATIONS

- The Government of Antigua and Barbuda is recommended to consider enacting regulations to govern the safe operation of vessels over 24 metres in length engaged in domestic voyages.
- The Government of Antigua and Barbuda is recommended to consider means by which the standards of training of seafarers serving on vessels in domestic trade can be improved especially with respect to correct loading and carriage of various cargo types, including dangerous goods and the importance of the maintenance of watertight integrity of vessels.
- The Barbuda Council is recommended to establish a means to ensure that any vessels which it encourages to trade between Barbuda and Antigua are fit for purpose with their seafarers suitably trained and qualified.
- The Owner is recommended that he only uses appropriately loaded fit for purpose vessels for conducting transportation activities at sea and reviews the towing arrangements utilized.

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

## Annex 1: Sister Vessels utilized as originally intended


http://www.navsource.org/archives/10/18/1018149101.jpg


http://www.navsource.org/archives/10/18/1018146601.jpg

## Annex 2: "1473" In use in St John's Harbour with spud legs and mobile crane on board (both since removed)


Photo: USCG

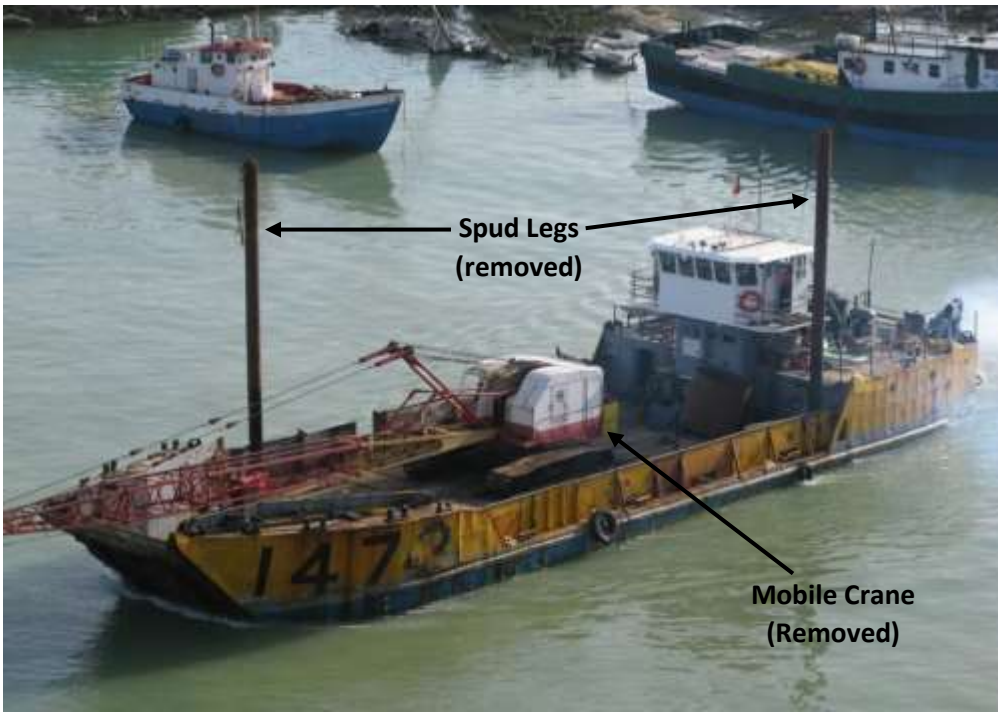
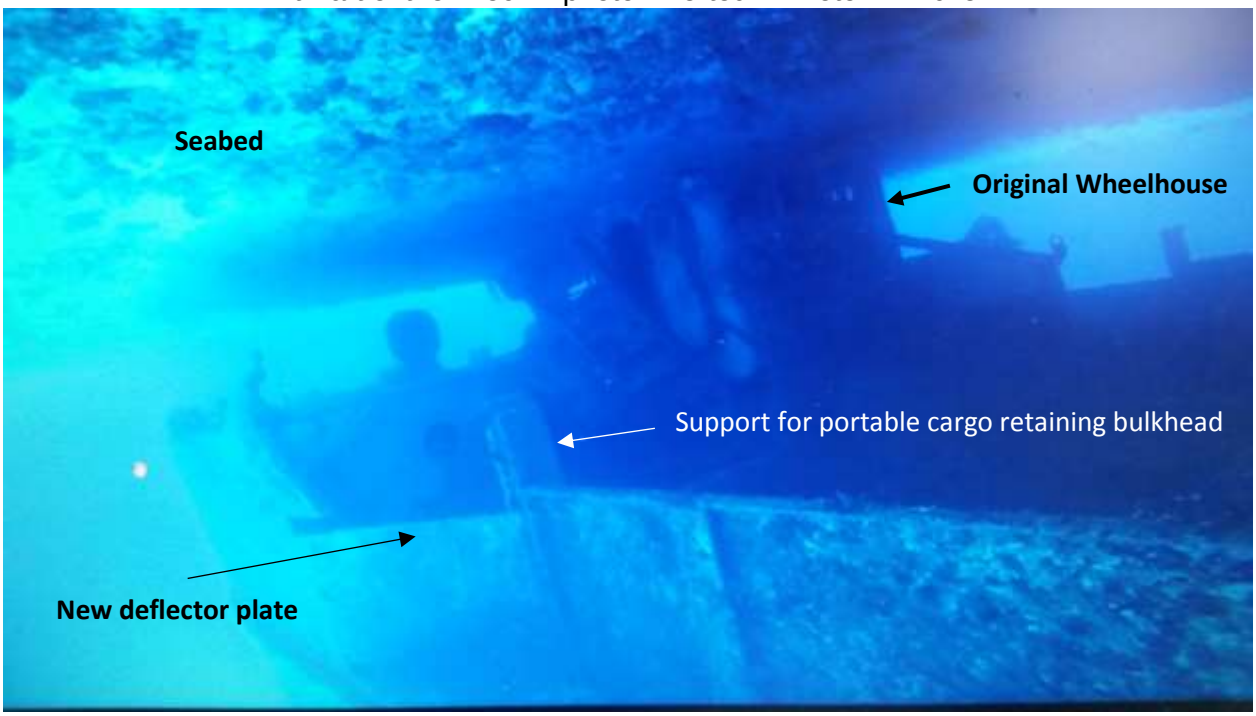


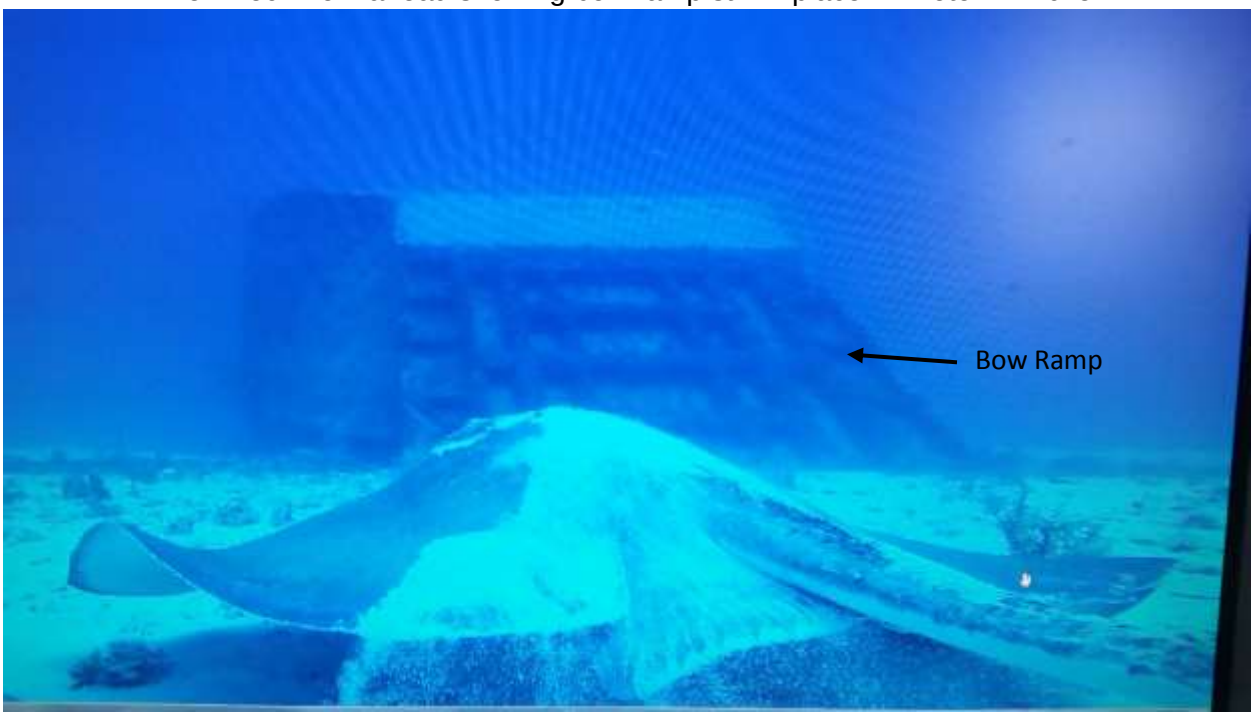

Photo: USCG

## Annex3: Photographs of “1473” Sunken

Aft Part of the wreck – photo inverted – Photo: Eli Fuller




The Wreck from ahead showing bow ramp still in place – Photo: Eli Fuller



## Annex 4: Basic stability diagrams

As no definitive plans or stability information on the vessel were available, these diagrams had to be produced by estimating the vessels design characteristics to give a reasonably representative version of the likely scenario.

The graphs are of righting lever (GZ) against angle of heel, which give the “GZ curve”. The area under the GZ curve indicates positive dynamic stability.

Whilst the effects of waves, wind and free surface are complex, the diagrams attempt to depict a simplified version of these effects. Due to the design of the vessel, the effect of waves in the conditions encountered on the fateful voyage are significantly greater than those of the wind. With a heel to windward having been induced by the asymmetric wetting of the cargo, the wind effect did not overcome this induced heel and the passing waves would have induced a sufficient capsizing moment by effectively adding up thrust to the lee side and reducing buoyancy on the windward side and thus adding to the capsizing moment imposed by the cargo to induce the capsize to windward. The dynamic stability of the vessel was already reduced by the effect of the excess of cargo loaded and the free surface effect of water movement in some spaces.

It is difficult to estimate the precise curves at larger angles of heel as some of the sand cargo will have discharged itself, effectively reducing the capsizing moment however the shift of cargo as it discharges will increase the capsizing moment with the net result being that these moments overcame the reduced dynamic stability that existed prior to taking wave effects into consideration.

**Diagram I**

Estimated GZ curve for loaded condition as 1473 was designed indicating sufficient dynamic stability fora vessel of this type.

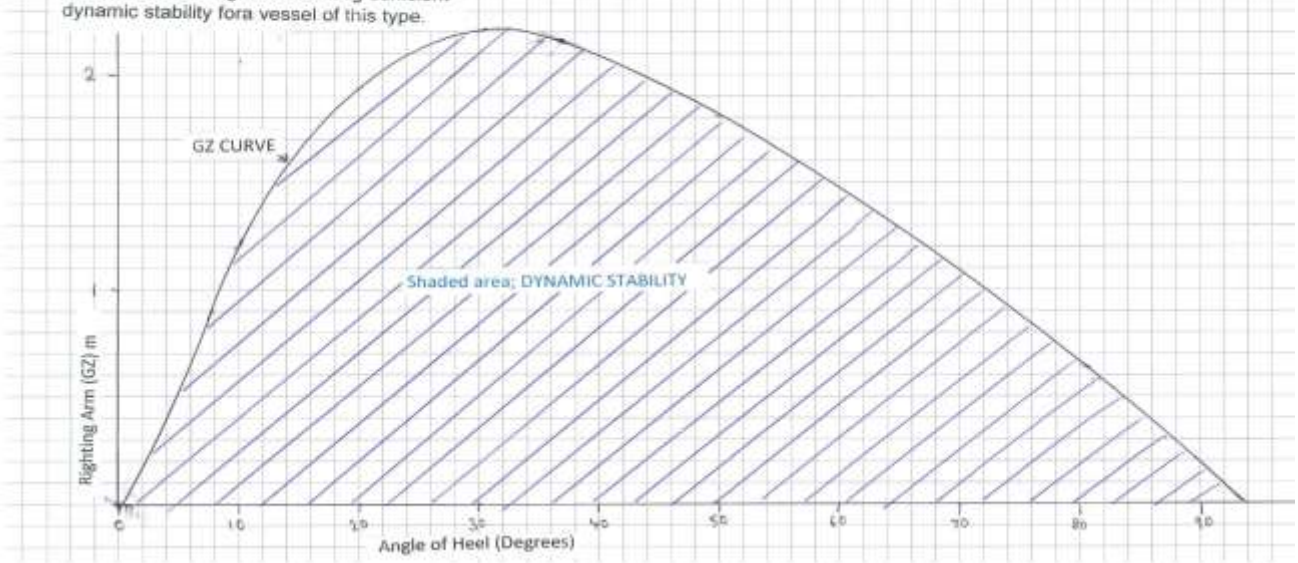



**Diagram 2**

Estimated as designed GZ curve for loaded condition showing maximum heeling lever caused by wind/waves and resultant residual dynamic stability

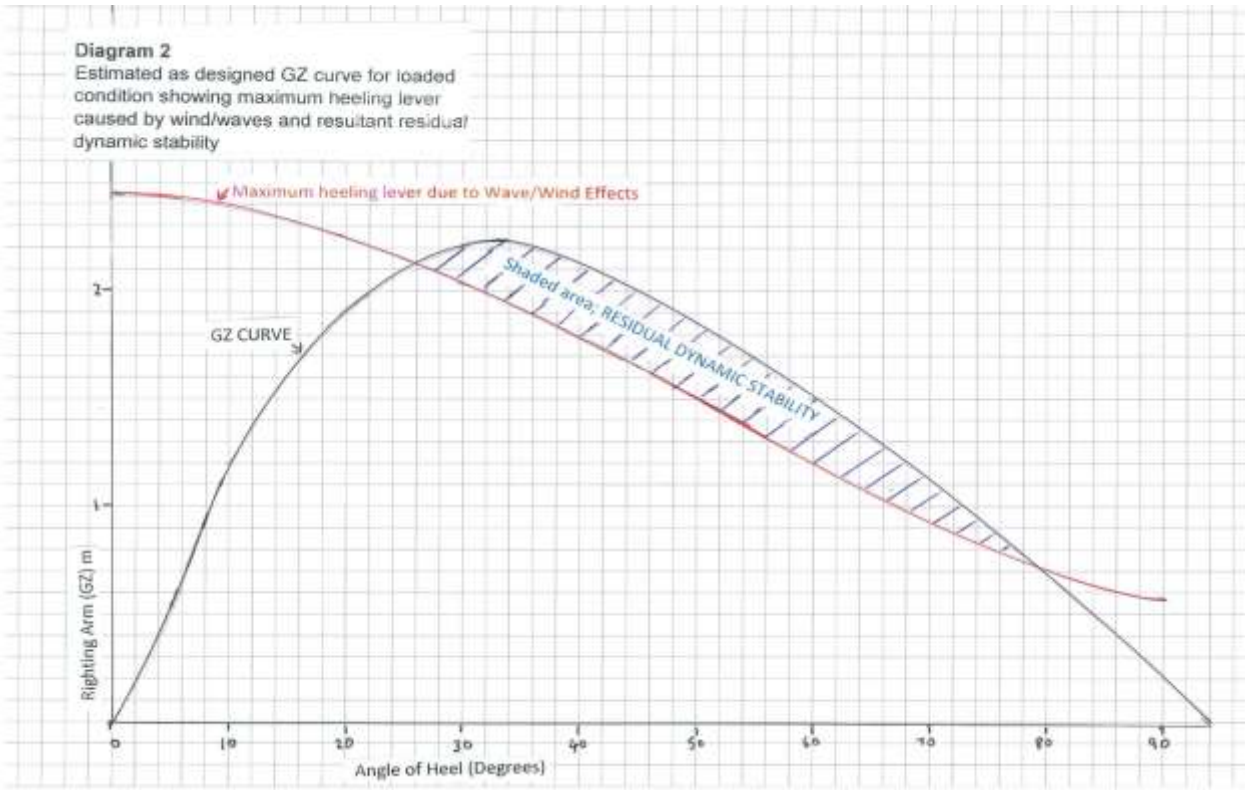


**Diagram 3**
Estimated as loaded GZ curve for condition at time of capsize showing reduced GZ caused by free surface effect and also the offset load effect which led to the vessel heeling and further reduced effective GZ and reserve of dynamic stability

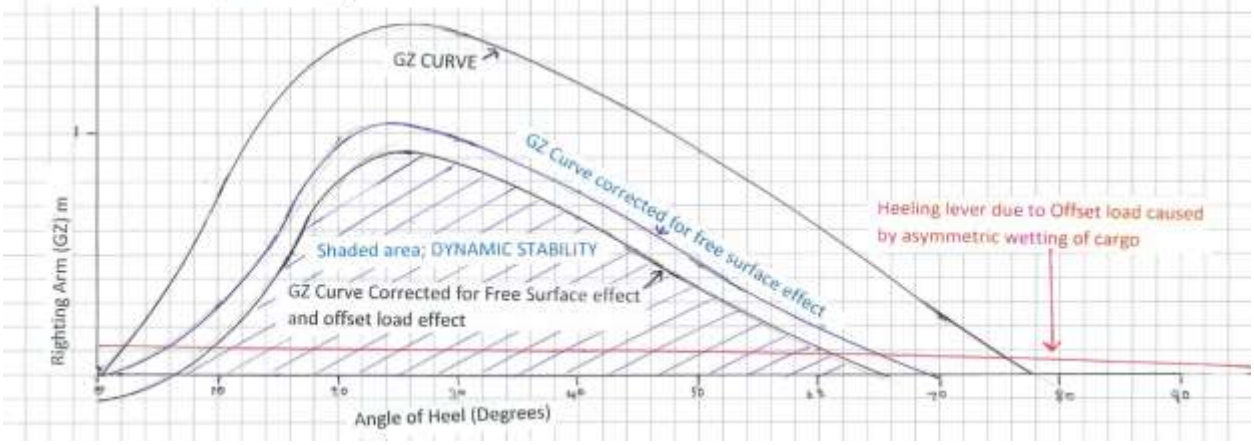



**Diagram 4**
Estimated as loaded GZ curve for condition at time of capsize showing maximum lever of 2m high waves significantly exceeds righting lever and thus removes reserve of dynamic stability.