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Best Practice Recommendations for Ocean Towing of MODUs

Bartley Eckhardt, PE (speaker/author), Robson Forensic, US
Capt Eric Johansson (speaker/author), Maritime College, State University of New York, US

SYNOPSIS

In late December 2012, the Mobile Offshore Drilling Unit (MODU) *Kulluk* was being towed during heavy weather by the anchor handling towing vessel ***Aiviq***. For numerous reasons, *Kulluk* became separated from ***Aiviq***, and despite multiple attempts to regain control of *Kulluk*, it grounded on a remote island. There was no loss of life or environmental damage, but the incident was a near miss of spectacular proportions.

Following investigations by the United States Coast Guard (USCG) and the National Transportation Safety Board (NTSB), the USCG tasked the Towing Safety Advisory Committee (TSAC) to review the relevant investigation reports and develop best practice recommendations for ocean towing of MODUs.

This paper presents and analyses the more seminal recommendations of TSAC's report, including:

1. Defining Critical Tows according to risk
2. Criteria for voyage plans and tow procedures
3. Criteria for proper technical analyses of Critical Tows
4. Criteria for the monitoring and logging of gear
5. Requirements for emergency tow gear
6. Competencies and responsibilities of the tug master and tow master
7. Roles and responsibilities of the marine warranty surveyor

Although the reports and recommendations of TSAC apply first and foremost to the ocean towing of MODUs, many of the recommendations could apply to any ocean towing evolution. The full TSAC Task 14-01 MODU Kulluk ROI Final Report is now available online[1].

INTRODUCTION

On June 2014, the Towing Safety Advisory Committee (TSAC) was tasked to review and provide recommendations based on the *Report of Investigation Into the Grounding of the Mobile Offshore Drilling Unit (MODU) Kulluk*.

Eric Johansson was nominated as chairman for TASK 14-01. A plan of action was developed, and subgroups were identified to include:

- tow plans, voyage plans, towing configurations
- tow gear – identification, selection, testing, utilisation, monitoring and logging
- tug master and tow master competencies, roles, responsibilities, authorities and conduct
- competencies and conduct of marine warranty surveyor work.

Subgroups began meeting immediately, preparing preliminary reports for discussion at full committee meetings, and the process continued over a two-year period. During this period, subgroups continued working, full committee meetings were held several times, and progress reports were presented at four TSAC meetings for comments. During full committee meetings, private presentations from organisations closely associated with the incident provided greater insight to the causal factors leading to the incident. The full committee team was comprised of subject matter experts, including seasoned mariners experienced in the Arctic and/or high-latitude towing of MODUs.

On 21 December 2012, the MODU *Kulluk* departed Captain's Bay, Alaska, under tow for a 1,700nm voyage to Seattle, Washington, via the Gulf of Alaska. ***Aiviq*** had towed *Kulluk* many times in the past – they were, in fact, 'mated' vessels. The tow encountered heavy weather

along the relatively shallow coastwise route taken. This route severely limited the tow's sea room, and the relatively shallow conditions severely limited payout (render) of the towline by the automatic towing winch, and prevented sufficient catenary in the main towline.

Consequently, extreme fluctuations in the towline tension caused repeated 'snatching' and cyclic overload of the towing gear, notably the main shackle. The main shackle failed and was lost, either because the single-nutted shackle pin backed out and/or the shackle failed in overload/fatigue.

Towline loading was exacerbated by the unusual shape of *Kulluk* and its superstructure, its poor directional stability, its tendency to 'slingshot', and its tendency to 'plough in' when pitching extremely.

TSAC addressed its assignment not as a fault-finding exercise. Rather, the incident was reconstructed, and then each main element of this difficult towing evolution was analysed and best practices developed for each main element. Furthermore, TSAC considered the interaction of each main element in the context of the entire towing evolution.

Several causal factors were identified during the study in the appraisal and planning for the tow, ultimately contributing to the single point of failure.

SINGLE POINTS OF FAILURE AND CAUSAL FACTORS

The following is a summary of the significant events of the *Kulluk* voyage:

- The plan called for a coastal route across the Gulf of Alaska.
- The tow departed 21 December 2012 from Captain's Bay, Alaska.
- ***Kulluk*** was being towed by a single towing vessel, ***Aiviq***, using the configuration in *Figure 1*.
- Initially, the towing winch was on 'automatic'.
- ***Aiviq*** had a rated bollard pull of 208 tons (189 tonnes); its towing winch was rated at 300 tons (272 tonnes) with a brake hold of 500 tons (454 tonnes) and 3½in (89mm) diameter main hawser rated at 391 tons (355 tonnes) breaking strength. The towing winch was set to high tension alarm at tensions exceeding 300 tons.
- At approximately 1600hrs on 22 December, ***Aiviq*** increased the length of the main hawser to approximately 1,700ft (518m). By then, the weather was worsening.
- In the morning of 27 December, out of concern for sections of shallow water, real or perceived, the towing winch was locked down 'on the dog' with 1,795ft (547m) of towline out.

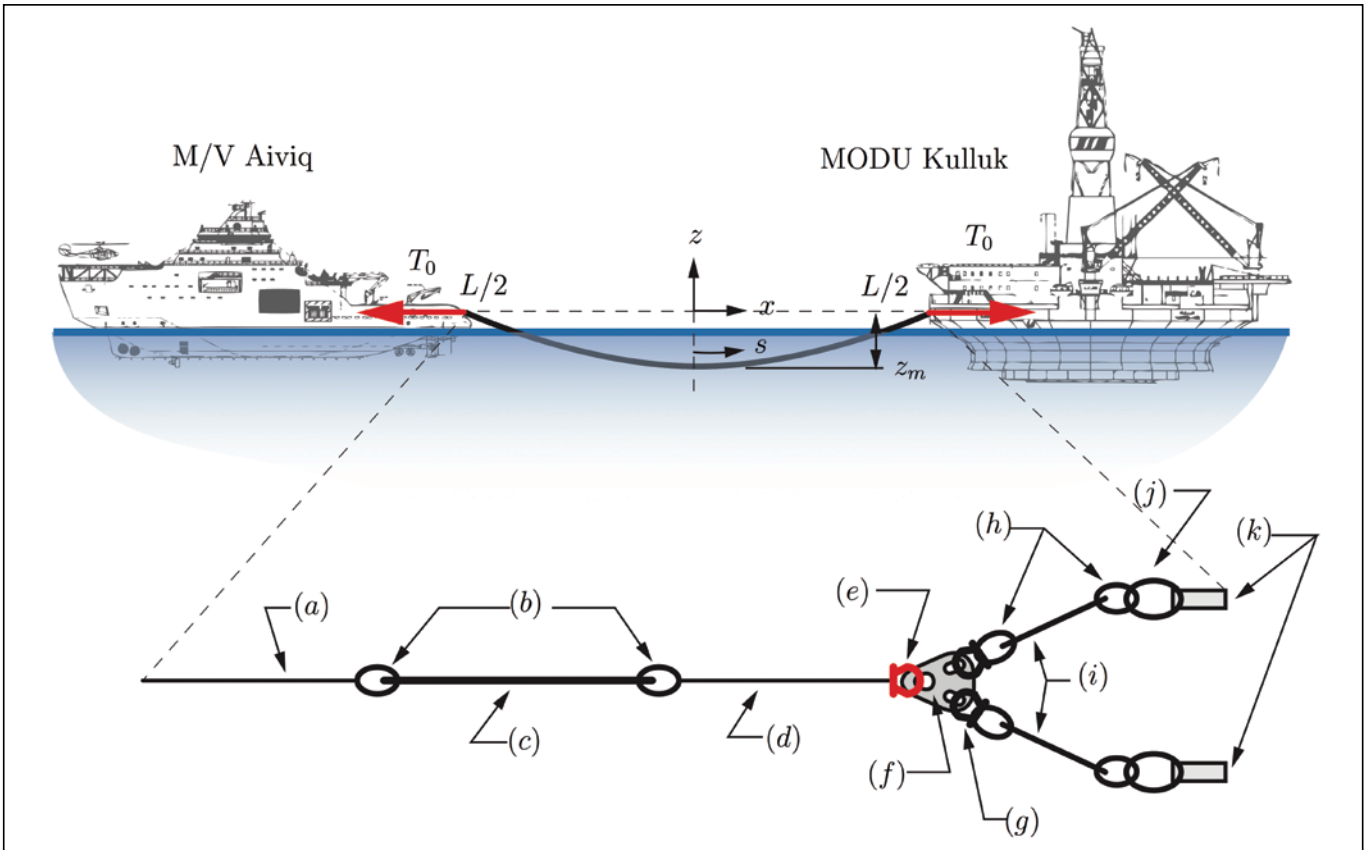


Figure 1: Towline configuration between the Aiviq and Kulluk showing positions of components (a) 3-1/2" towing wire, (b) 76 mm Kenter links, (c) 90 ft 3" Surge Chain, (d) 100 ft 3" Pennant Wire, (e) 120 T Van Beest (apex) Shackle, (f) Tow Plate, (g) 120 T Van Beest Shackles, (h) 76 mm Kenter Links, (i) 90 ft 76 mm Chain Bridle, (j) Master Link, and (k) SMIT Brackets.

Figure 1: Configuration of tow

- Later in the morning of 27 December, ***Aiviq***'s towing winch generated numerous (38) high tension alarms. At 0600hrs, the winds were E and SE at 20-25 knots, seas 20ft (8m), pitch 8-10 degrees, roll 8-10 degrees and speed of advance 3.8 knots.
- The towing evolution relied on the following towing curves *(Figure 2)*:
- At 1135hrs on 27 December, the main 120-ton (109-tonne) shackle *(shown as* (e) *in Figure 1)* failed and was lost. *Kulluk* was adrift. Other vessels were dispatched to assist, none of which had nearly the bollard pull of ***Aiviq***.
- At 1430hrs, *Kulluk* was placed under tow by ***Aiviq*** using a synthetic emergency towline.
- Around midnight into 28 December, ***Aiviq*** lost its plant, attributed to fuel contamination with water through tank vents due to the sea conditions coupled with a design flaw. ***Aiviq*** was now being pulled by *Kulluk*.
- At 0000hrs on 28 December, the winds were SW at 25-30 knots, the seas 14-17ft (5m), and pitching 8-10 degrees.
- During 28 December, various attempts by assist vessels to help were unsuccessful. Weather and sea conditions were worsening.
- From 1538hrs on 28 December until 0510hrs on 29 December, *Kulluk* was under limited tow by one of the assist vessels.
- At approximately 2300hrs on 28 December, air rescue attempts by USCG to evacuate *Kulluk* were thwarted by the conditions. *Kulluk* was reported to be rising and falling approximately 50ft (15m). Winds were SE at 35-45 knots, surface seas were 4-6ft (2m), with a confused underlying swell up to 20ft (6m) from the SE and S.

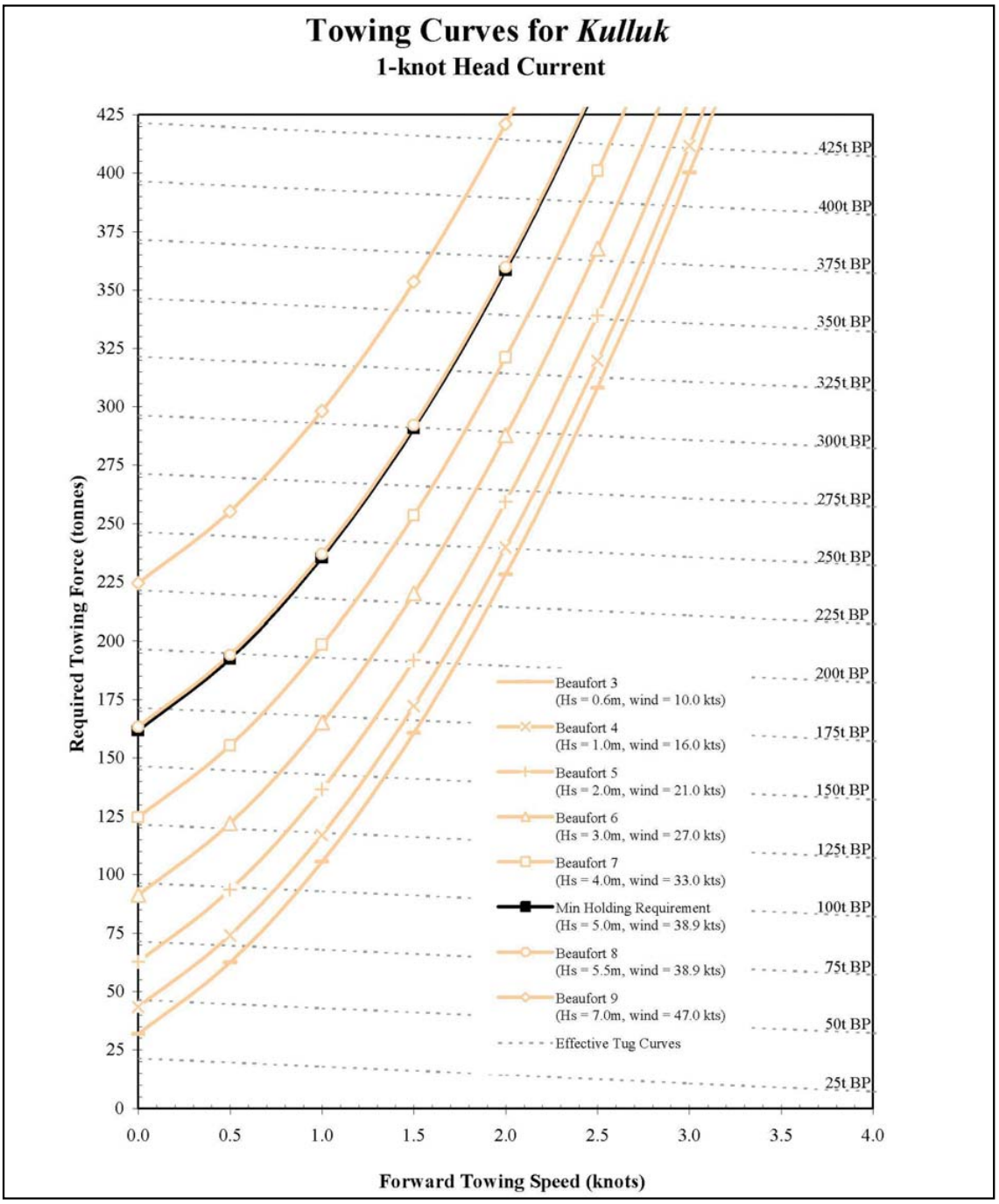


Figure 2: Towing curves for Kulluk*, created by Global Maritime*

- On 29 December ***Aiviq*** regained partial power, utilising parts airlifted by USCG. *Kulluk* was taken under tow by ***Aiviq*** with the synthetic emergency towline and by another vessel utilising its main hawser connected to a mooring wire on *Kulluk*.
- At 1335hrs on 29 December, all *Kulluk* personnel were safely air evacuated by USCG.
- By late morning on 30 December, the main towline of the assistance vessel parted and the emergency towline connected to ***Aiviq*** parted. *Kulluk* was adrift, and the winds were SSW at 40-50 knots and seas 20-25ft (8m).
- On 31 December, *Kulluk* was again under tow by ***Aiviq***, connected by ***Aiviq***'s main tow pennant to one of *Kulluk*'s mooring wires. A different vessel also assisted.
- On 31 December, and under worsening conditions, ***Aiviq***'s pennant parted and the underpowered assist vessel was directed to let go of *Kulluk*. Winds were SE at 40-50 knots, seas 20-25ft (8m) and building.
- At approximately 2055hrs on 31 December 2012 *Kulluk* grounded on a remote island.
- There was no loss of life or significant environmental damage.

The USCG's investigation cited numerous causal effects, including but not limited to: the weather, personnel, planning, route and an undersized main shackle. It determined that the 'initiating event' was the failure of the 120-ton main shackle that occurred on the morning of 27 December, where an 'initiating event' is defined as "the first unwanted outcome in a series of occurrences".[2] The NTSB concluded that "no single error or mechanical failure led to this accident".

TSAC's analysis confirmed the findings of the USCG and NTSB. TSAC's analysis also revealed that not only was the weather the most significant influencing factor, but that:

- Planning and execution of an ocean tow must contemplate weather conditions that could reasonably be encountered, not just weather conditions that are predicted.
- The first points of vulnerability to weather are 'single points of failure', where a 'single point of failure' is defined as "...a failure of a component or subsystem that results in failure of the entire system". Single point failures must be avoided if a failure of the system can produce dangerous conditions.
- Some potential consequences of heavy weather are obvious, but in the case of ocean tows, especially of unusually shaped tows including MODUs, only a detailed and proper technical analysis can predict the less obvious but critically important consequences. Conventional, often 'over the thumb' methods of determining bollard pull requirements are likely to be insufficient in dealing with the rigours of ocean towing, especially of MODUs (for more detail, see the technical analysis section of this paper, below).

Single point failure

The incident tow configuration is depicted in *Figure 1*, and is reasonably typical. TSAC contributors who are expert veterans of ocean towing were critical of the 90ft (27m) surge chain as being too short to be properly effective. Components (a), (b), (c), (d), (e), (f), shown in *Figure 1*, as well as the single towing vessel, the automatic towing winch, and – when utilised – the synthetic towline, all constitute potential single points of failure. The automatic towing winch has failsafe modes of applying the brake or locking up 'on the dog', which do not result in the loss of tow.

During the incident and its attempts to recover *Kulluk*, the tow experienced failures of the main shackle (e), the pennant (d), the single towing vessel itself, and the emergency towline – each one a single point of failure and each a victim of conditions and consequences worse than anticipated or for which the voyage was planned.

DEFINING CRITICAL TOWS ACCORDING TO RISK

"The sea is selective, slow at recognition of effort and aptitude but fast in sinking the unfit."
- Captain Felix Riesenberg

While the ultimate determination of whether a vessel is unfit is made by the sea (and often specifically the weather), established principles of risk assessment can be applied to reduce risk to acceptable levels. Ocean towing occurs successfully around the world, around the clock, often in adverse conditions – how does one determine when those adverse conditions create unacceptable levels of risk?

After careful consideration, TSAC determined that the potential for a tow to encounter Beaufort 9 conditions constituted the minimum threshold beyond which detailed planning and analysis is required before a tow is under taken. This threshold and the resultant risk determination defines a Critical Tow, as described below.

Special attention is directed in the risk assessment toward single point failures. Specific ocean towing evolutions should be carefully considered, and it may be advisable to tighten the risk criteria established by TSAC, depending on circumstance. As an example, had this risk assessment been applied under the conditions of the ill-fated ***El Faro*** voyage, a tow would not have been undertaken.

TSAC defined a Critical Tow as follows, with the ratings explained in *Tables 1 and 2: It is suggested that under this sample risk assessment method, Critical Tows are those ocean tows having a Risk Factor>15, according to the following criteria: Risk = Consequence x Probability* [3]

Where the use of wire bridles or previously utilised terminal gear is contemplated, the probability of failure (POF) should be incremented by 1, and the risk recalculated. Critical tows would, by definition, carry a 4 or 5 POF rating.

5	Collision/allision/loss of tug/loss of tow resulting in fire or explosion, and/or toxic chemical release, injury to personnel or loss of life and/or damage to critical infrastructure
4	Fire, explosion, sinking affecting the vessel itself and pollution limited to that caused by the vessel itself with the potential of personnel injuries
3	Collision/allision/loss of tug/loss of tow resulting in fire and/or environmental release not immediately harmful to people and/or damage to non-critical infrastructure
2	Mechanical, thermal or chemical energy release affecting one or more of the vessel's crew and without harm to the environment
1	Failure of non-critical system affecting part of the vessel itself without harm to the crew or the environment

Table 1: Consequence rating used to calculate risk

5	Single point failure in Beaufort ≥ 9
4	Redundant failure in Beaufort ≥ 9
3	Single point failure in Beaufort 7 and 8
2	Redundant failure in Beaufort 7 and 8
1	Benign weather, Beaufort $\leq$ 6

Table 2: Probability of failure rating used to calculate risk

APPRAISAL

In this case, the route choices included Rhumb Line, Great Circle and Near Coastal. Both the Rhumb Line and Great Circle options provide sufficient sea room in the event of tow failure and/or in the event weather conditions forced speed reductions that may result in negative headway.

"A coastal route was chosen to maintain a distance less than 200 nautical miles from the shore of southern Alaska to allow easier access by search and rescue (SAR) personnel should the need arise. The 1,773-mile transit was expected to take 24.6 days at an average speed of 3 knots, 21.1 days at an average of 3.5 knots, or 18.5 days averaging 4 knots."[4]

"The plan was created to move the MODU at a time of year with a known likelihood of severe weather conditions for reasons unrelated to operational safety."[5]

Aiviq's master questioned the Coastal Route, recorded in an email sent to the tow master aboard *Kulluk* as follows:

"To be blunt I believe that this length of tow, at this time of year, in this location, with our current routing guarantees an ass kicking. In my opinion we should get to the other side just as soon as possible. It the event that our weather resources can route us 'around' an area that will jeopardise any personnel or equipment on either the *Kulluk* or the ***Aiviq*** we should strongly consider the recommendation and deal with any logistics issues as they develop."[6]

The concerns of the crew aboard *Kulluk* superseded the master of ***Aiviq***'s concerns, and therefore the route selection remained on the Coastal Route. Several days following departure on 21 December, Great Circle routing was implemented on 27 December following massive swell conditions with the shallow water of the 40-fathom bank.

There is little doubt that once the towing vessel has connected its terminal gear and is underway, the master of the towing vessel is legally responsible for the conduct during the move, which encompasses much more than the transit from one location to another. Therefore, tow master authority and responsibility must be identified within company's safety management system and chain of command.

It is also recommended that the following terms be adopted:

- *Tow master*: appointed by the owner or operator as subject matter expert for all aspects of the rig move
- *Tug master*: The master of a towing vessel

When a tow master is employed, that individual must hold appropriate licences and certifications to command the tug master, and have appropriate towing experience.

PLANNING

"Tow plans were created and approved by [redacted] for each tow of the *Kulluk*. The purpose of these documents was to support a consistent, safe method for the logistics and marine preparations and transit. Each of the towing plans addressed topics such as the roles and interfaces, departure and ocean transit operations, communications, weather and forecasting, contingency plans, routing instructions and towing equipment."[7]

Following the creation of the tow plan, meetings were held to review and comment on the tow plan to include: shipper, logistic teams, health safety and environmental team lead, emergency response specialist, tow master, rig manager, operation manager and warranty surveyor. Final tow plan approvers included other entities, with final approval resting on the Alaska venture operations manager. Absent in the creation, review, comment and final approval of the tow plan was the master of ***Aiviq***.

Tow procedures and voyage plans

'Tow procedures', when utilised, should include information not already required/identified within the vessel's voyage plan, and act as a standalone document. Along with voyage plans, tow procedures must have the full support/approval of the tug master. Tow procedures are not a substitute for voyage plans.

"The ***Aiviq*** Master was responsible for the safety of the tow once the tow hawser was secured to the *Kulluk* and the vessel was underway."[8]

"There are no specific roles or responsibilities contained in the Towing Plan for the ***Aiviq*** Master, Captain [redacted]. He understood that the towing plan directed him to follow the instructions of the Tow Master."[9]

It was recommended that company's voyage planning policies, containing voyage planning flowcharts, be risk-assessed during the voyage planning process, whether using the process documented in this report, or using a process delineated in the company's SMS or otherwise. Sample voyage planning guidelines can be found in Appendix 4 of the TSAC Task 1401 *Kulluk* ROI Final Report. The tug master is ultimately responsible, and therefore should have final approval of all voyage plans.

Voyage and passage planning

This includes appraisal: gathering all information relevant to the contemplated voyage or passage, detailed planning of the whole voyage or passage from berth to berth, including those areas necessitating the presence of a pilot, execution of the plan, and the monitoring of the progress of the vessel in the implementation of the plan.[10]

It is recommended that in addition to voyage plans, tow procedures must be generated for the towage of Critical Tows. Sample tow procedure guidelines are provided in Appendix 3 of the TSAC Task 1401 *Kulluk* ROI Final Report.

Tow procedure

The guidance documents that the details, steps and personnel responsibilities for the proposed operations include information regarding picking up a tow, getting underway with a tow, towing while underway and releasing a tow. In the case of MODUs, this means the removal from a location, towage, and emplacement at a new location.

CRITERIA FOR VOYAGE PLANS AND TOW PROCEDURES

During the review of the tow procedures and voyage plans, both with ***Aiviq*** and with industry professionals, it was clear that confusion regarding parameters and differentiation of voyage plans and tow procedures were common in the industry.

As a result, the following definitions were developed:

- *ALARP*. An abbreviation of the term 'as low as reasonably practical (or practicable)' when referencing a process for assessing the amount of effort and resources that should reasonably be applied to reduce risk. Reducing a risk to a level that is ALARP involves objectively determining the balance of where the effort and cost of further reduction measures become disproportionate to the additional amount of risk reduction obtained.
- *Tow master*. The on-scene manager responsible for the overall towage of the towed vessel or asset. A tug master may be designated as tow master where appropriate.
- *Tug master*. The master of a towing vessel.

The TSAC wrote:

Voyage plans

Compulsory Voyage Plans required by regulation. As a minimum standard, when done properly, Voyage Plans provide a solid foundation and may be expanded to encompass additional information or augmented with additional procedures.

At a minimum, Voyage Plans must consider the enumerated detailed requirements as outlined in 33 Code of Federal Regulation, Chapter 1, Subchapter P, Part 164, Section 80 (c) iii and are not intended to be confused with "Tow Procedures".

The voyage plan must follow company policy and its Safety Management System (SMS) and consider the following:

i. Applicable information from nautical charts and publications, including Coast Pilot, Coast Guard Light List, Marine Safety Information Bulletins (MISBs) and Coast Guard Local Notice to Mariners for the port of departure, all ports of call, and the destination;

ii. Current and forecast weather, including visibility, wind, and sea state for the port of departure, all ports of call, and the destination;

iii. Data on tides and currents for the port of departure, all ports of call, and the destination, and the river stages and forecast, if appropriate;

iv. Forward and after drafts of the barge or barges and under-keel and vertical clearances (air-gaps) for all bridges, ports, and berthing areas;

v. Pre-departure checklists;

vi. Calculated speed and estimated time of arrival at proposed waypoints;

vii. Communication contacts at any Vessel Traffic Services, bridges, and facilities, and any port-specific requirements for VHF radio;

viii. Any master's or operator's standing orders detailing closest points of approach, special conditions, and critical maneuvers; and

ix. Whether the towing vessel has sufficient power to control the tow under all foreseeable circumstances.[11]

IMO guidelines

In the *IMO Guidelines for Safe Ocean Towing*,[12] it states that all aspects of towage should be planned in advance, including as follows:

1. Maximum anticipated environmental conditions
2. Tides/currents
3. Water depths

4. Tow (size, windage, displacement, cargo storage, and draft)
5. Weather routing advice with careful consideration of the bollard pull of the towing vessel
6. Towing arrangements and procedures (with routing planned so that under all normal circumstances the water depth is at least half the length of the paid out tow line)
7. Contingency plan for Points of Refuge (a copy should also be carried aboard the barge or towed vessel if manned)
8. Manuals for routine towing operations
9. Manuals for special towage requirements

The *IMO Guidelines for Safe Ocean Towing* is largely consistent with already existing US voyage planning requirements.

TOW PROCEDURES

Voluntary tow procedures are intended to reduce risk to a level ALARP. Tow procedures should be prepared for tows considered to be a Critical Tow.

Multiple towing vessels might be used when towing in restricted or harsh environments and/or where sea room and response time for rescue and salvage assets are limited. When such tugs are deployed, additional towing vessels should be of equivalent bollard pull to the lead towing vessel and be equipped with the same terminal gear.

'Tow procedures' when utilised should include information not already required/identified within the vessel's voyage plan and act as a standalone document. Along with voyage plans, tow procedures must have the full support/approval of the tug master. Tow procedures are not a substitute for voyage plans.

Tow procedures may include (or reference), but not be limited to, the following subjects:

1. General
    a. Go/No Go departure criteria and associated decision-making process
    b. Contact details and responsibilities
    c. Reporting requirements: who to, how often and content
    d. Arrival details, contacts, field plan (scaled chart of the oil field clearly displaying the location of all surface and subsea assets), etc
    e. Contingency planning
    f. Communications schedules
2. Description of the towed asset, vessel or object.
    a. Any limiting criteria and motions (roll, pitch and period, etc) for the transport or tow, weather forecasting arrangements (two independent sources)
    b. Motions and strength – detailed supporting calculations for the motions and accelerations, longitudinal strength and strength of the seafastening and cribbing grillage
    c. Drawings to include, where applicable, cargo, general arrangement (GA) and other key drawings of vessel and cargo, stowage plan, towing arrangement, cribbing/grillage arrangement, load-out /discharge plan, seafastening arrangement, guidepost details, etc
3. Description of the towing vessel(s)
    a. Reference documents, including applicable standard operating procedures of each operator
    b. Towing vessel bollard pull calculation (if applicable)
    c. Towing vessel specification, including but not limited to, stability documentation
    d. Tow configurations and drawings
    e. Fuel system efficacy

Towing configurations

Differing towing situations and vessel configurations are unique to towing vessels requiring proper planning beforehand. Compliance with mandatory rules/ regulations and best management practices utilising guidelines and recommendations from recognised industry organisations and class societies is an essential element of risk management. Towage of any kind in all latitudes requires due care and consideration for both the forecast and potential operational environment.

It must be noted that the towage of *Kulluk* was not in Arctic waters and therefore was *not* an Arctic tow. A separate tasking for towage of all kinds, and in particular the towage of rigs and MODUs in the harsh and remote environment of Arctic waters is recommended.

TECHNICAL ANALYSIS

Critical to the sizing of the gear, risk analysis of single points of failure, sizing of the towing vessel(s), and other considerations, is the determination of extreme towline tension. Extreme towline tension is defined as "the additive accumulation of the complex dynamic responses of tug, tow and towline".[13] Under normal and reasonable ocean towing conditions, where the hydrodynamic properties of the tow are well known, and the tow is known to be well-behaved in a seaway, extreme towline tension is generally well known and proven empirically.

TSAC's *Sample Towing Gear Selection Flowchart* for sizing gear is presented in *Appendix I*, recommended to be implemented for any and all Critical Tows as previously defined. Obviously, this is a minimum threshold, and is advised to be used in general and

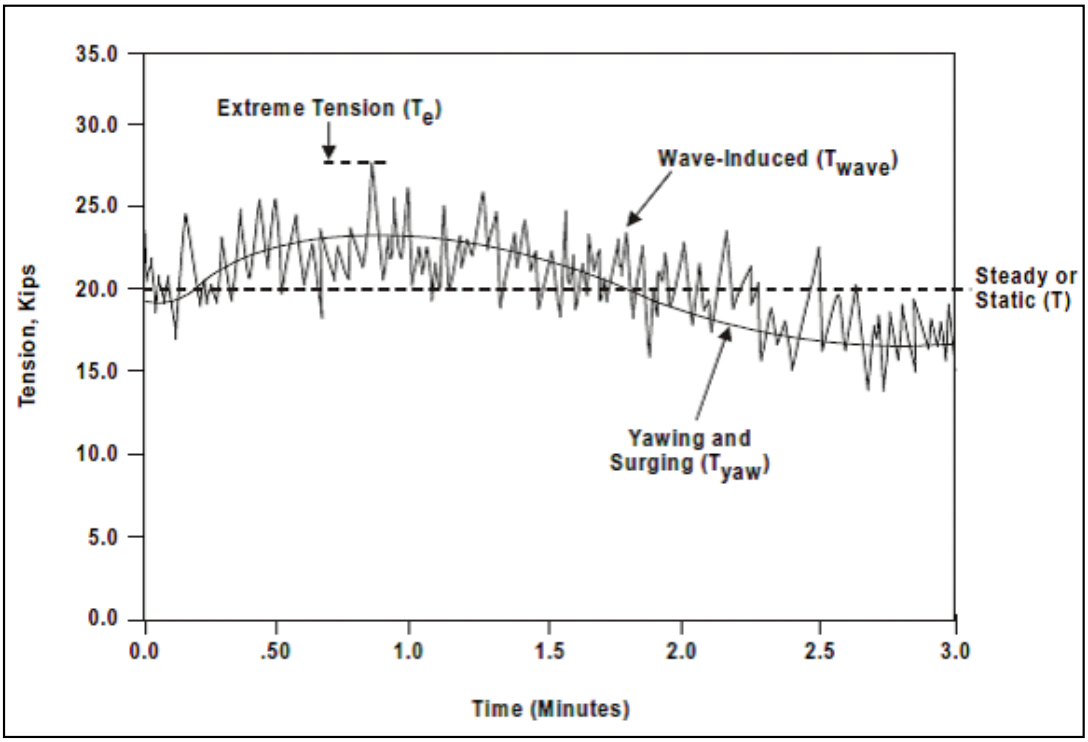


Figure 3: US Navy criteria for extreme towline tension

especially when life safety or special circumstances (eg, political and environmental) dictate. The US Navy, in its Towing Manual, sets forth the following basic formula for calculating extreme towline tension *(Figure 3)*:

Extreme towline tension occurs when yawing tension and wave induced tension are additive. The total towline tension or extreme tension (T_e), can be expressed as:

$$T_e = T + T_{yaw} + T_{wave}$$

Where:

T_e = Extreme tension
T = Steady towline tension ($R_t + R_{wire}$)
T_{yaw} = Time-varying tension due to yawing of the towed vessel
T_{wave} = Time-varying tension due to wave action on the ship and on the tow

This formula can be further developed using analytical tools, but may be incomplete in considering the extremes of ocean towing MODUs and other vessels where the full range of hydrodynamic behaviour of the tow is extreme and erratic. In addition, the formula assumes drag locking of the tow wire. The graph suggests that the towline tension is gathered empirically from known tows of known vessels in a time domain. If so, then such an empirically developed model would account for towline stiffness and catenary effects.

The general towing and motion characteristics of *Kulluk* are described in *Table 3, overleaf*.

This engineer author, along with technical colleagues Dr Richard Burke and Dr Daniel Fridline, PE, turned attention to *DNV Recommended Practice DNV-RP-H103 Modelling and Analysis of Marine Operations*, which describes methods for determining extreme towline tension. TSAC ultimately recommended that extreme towline tension for Critical Tows of MODUs can, and should, be thoroughly and properly done by executing a 12 degree (2 x 6 degree) freedom of motion analysis of tug and tow, with due consideration of towline characteristics.

Such analysis can be undertaken using finite element modelling in a time domain, or deterministic methods in a frequency domain. Time domain modelling would require solid empirical data for the range of conditions that could be encountered, otherwise inputs to the model would be highly suspect. Under all circumstances, extreme towline tension should be determined for weather conditions that *could* be experienced, not just those predicted. While automatic towing winches, in proper condition, properly sized and appropriately operated can reliably ease the towline tension, there are legitimate circumstances of breakdown, sea room, depth, etc, as well as deployment of synthetic emergency towlines that would dictate 'lock up' of the towing winch. Therefore, TSAC recommended that all gear, including the towing vessel(s) and the emergency towline, be sized based on extreme towline tension with an automatic winch in 'lock up'.

There was insufficient data available to TSAC to execute either frequency or time domain modelling of the *Kulluk* incident. However, of particular relevance is the following formula presented in DNV-RP-H103 (April 2011) to estimate Extreme Towline Tension:

$$T_{max} = T_0 + \eta_{max} K_E$$

T_0 is the mean towing force, K_E is the elastic stiffness of the towline itself, and η (in metres) is a factor taking into account hydrodynamic properties of the tow and

Sea state/wind	Sea direction	Result
6m (18ft) and below		Waves tend to slap vessel, resulting in minor accelerations in any direction
7m and over		Can experience rapid accelerations in any direction
	Seas from abaft of beam to 60 degrees	Increased rolling motion and 'slamming', that result in accelerations and slow tow
	60 degrees to dead on bow	Greater rolling motion and 'slamming', resulting in considerable changes in acceleration
10m seas (~33ft)		Pitching over 20 degrees which can result in violent synchronous pitching motion. It can then 'slingshot' forward, resulting in rapid accelerations and stopping once the hull becomes buried in seas
Wind		In higher winds, ***Kulluk*** would act like 'balloon on a string', and would not follow behind the towing vessel well in wind from the beam

Table 3: Towing and motion characteristics of Kulluk[14]

interaction between towing vessel and towed vessel. For reference purposes, $\eta = 2.1$ for typical barge shapes.

It is important to note that η is determined, according to DNV, via transfer function(s) in a domain of spectral frequency. As demonstrated in the *Kulluk* tow, the tension fluctuation in the towline was so extreme that it would be difficult, if not impossible, to determine a reliable Steady or Static T_0. It appears that the DNV methodology does not consider the changing catenary of the towline that occurs under extreme conditions, and its effect on the interaction between the vessel tow and towed vessel. The changing catenary would affect the overall system stiffness.

It is also noted that under certain conditions of pitch, and as can be seen in videos of the *Kulluk* voyage, the leading edge of *Kulluk* 'digs in'. This condition would cause seriously extreme tensions, and may have been the condition that caused towline tensions to repeatedly exceed 300 tons (272 tonnes) prior to the failure of the main shackle.

TSAC noted that when such proper technical analysis is undertaken, the results may indicate that there are certain limits of weather beyond which a tow should not be undertaken. Results will certainly determine limits and sizing of gear, and may inform the use of multiple towing vessels.

Main shackle failure

The main shackle was rated and stamped for 125 tons, with a proof (yield) strength of approximately twice rated, or 250 tons (227 tonnes). Breaking (ultimate) strength would have been approximately five times rated, or 625 tons (576 tonnes). The 300-ton (272 tonnes) high tension limit was exceeded some 38 times during the incident tow, which means the main shackle was loaded in excess of its proof strength and was therefore overloaded into its plastic range. The wave period was determined by TSAC to have been approximately seven seconds, subjecting the main shackle to cyclic loading approximately 500 cycles per hour, and therefore in the range for low cycle fatigue.

While a material defect in the shackle, or backing out of the pin, cannot be ruled out, it is the opinion of the author that the nature, extent and frequency of loading point to an overload/fatigue failure of the main shackle. This supports the conclusion that the main shackle was therefore undersized for the conditions experienced. Stress analysis by TSAC showed that stress concentrations are greatest at the bow of the shackle and at the pin. Subjected to overload into its plastic range, the pin would likely have deformed and therefore been unable to back out.

ROLES AND RESPONSIBILITIES OF THE MARINE WARRANTY SURVEYOR

TSAC confirmed the roles and responsibilities of the marine warranty surveyor as follows:

In the planning of a rig tow, a marine warranty surveyor's purpose is to use their education, experience and training to provide advice in a risk management role. Normally, a marine warranty surveyor (MWS) is hired by insurers of one or more parties to the planned towage with the goal to protect the insurers.

At the conclusion of a successful marine warranty survey, the MWS will typically write a report of findings and recommendations as well as issuing a Warranty Certificate of Approval.

One area that remains to be fully developed is a consistent method of identifying, training, testing and certification of marine warranty surveyors worldwide.

Many companies that provide marine warranty surveyors have an internal training and vetting programme. The International Institute of Marine Surveyors and Lloyds Maritime Academy among others offer coursework in marine warranty surveying. In April of 2013, the International Association of Marine Warranty Surveyors (IAMWS) was founded. The stated goal of the IAMWS is to provide acceptable knowledge, experience and performance standards, a code of ethics and certification of individuals as a certified marine warranty surveyor.

CONCLUSION

Many owners of vessels for towing, as well as MODUs, have asked when to start planning for such a move. The answer lies in the amount of data that is needed or already known concerning the specific move and the vessel being towed. Each voyage is different and requires understanding of all of the above information. Keeping records of the plans made and lessons learned during any voyage, whether successful or with incident, will provide the opportunity to prevent incidents during future voyages.

Given that there are many entities that could become part of these moves results in the determination of when to start. If this is the first voyage for a given MODU, the gathering of the information above could take months before the intended voyage. Lessons that we have learned that have led to this review indicate that each voyage is different and will require sufficient time to guarantee proper operational risk management leading to the best safety management system.

REFERENCES

[1] https://homeport.uscg.mil/Lists/Content/Attachments/799/TSAC%20Task%2014-01-Final%20Report_MODU%20KULLUK.pdf

[2] Defined by the Coast Guard Marine Safety Manual Volume 5, COMDINST M160000.10

[3] American Petroleum Institute. (2009). Risk-Based Inspection: “API Recommended Practice 580”, Second Edition. Washington, D.C. API Publishing Services

[4] NTSB Marine Accident Brief: *Grounding of Mobile Offshore Drilling unit* Kulluk

[5] NTSB Marine Accident Brief: *Grounding of Mobile Offshore Drilling unit* Kulluk

[6] *USCG Report of Investigation: MODU Kulluk Marine Casualty Investigation*, p36

[7] *USCG Report of Investigation: MODU Kulluk Marine Casualty Investigation*, p19, bullet 9

[8] *USCG Report of Investigation: MODU Kulluk Marine Casualty Investigation*, Executive Summary, p1

[9] *USCG Report of Investigation: MODU Kulluk Marine Casualty Investigation*, p24

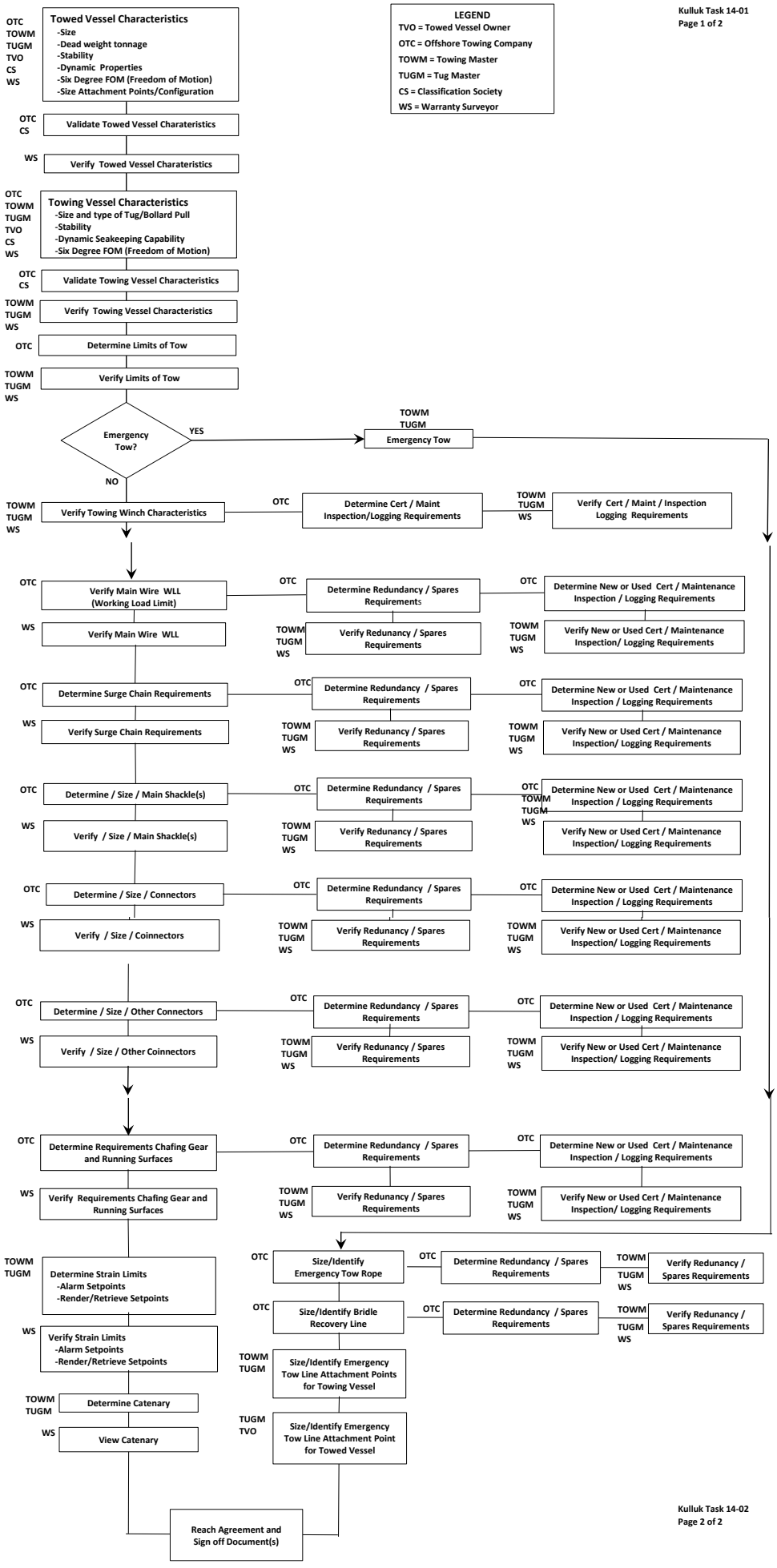
[10] IMO Resolution A.893(21)

[11] 33 CFR Chapter I, Subchapter P, Part 164, Section 80 (c) 3

[12] *IMO Guidelines for Safe Ocean Towing*, Revision 7, pp3-4

[13] *TSAC TASK 14-01: MODU Kulluk ROI Final Report and Recommendations* (definitions are listed in Appendix I of the report)

[14] General Towing and Motion Characteristics of the Kulluk from first-hand accounts of Kulluk Tow Master (USCG Analysis), *USCG Report of Investigation: MODU Kulluk Marine Casualty Investigation*

Appendix I

Enclosure (5) Sample Towing Gear Selection Flow Chart