TOWLINES

by

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Introduction

A tow line is the essential link between tug and ship. This applies to tugs operating alongside a vessel in the push-pull mode as well as to towing tugs fastened with a tow line to the bow or stern of a ship, also called ‘tugs towing on a line’.

Towlines should be handled in such a way and be of such a type, strength and flexibility, that longevity is assured and tug assistance can be carried in a safe and effective way. Much information about towlines can be obtained from rope manufacturers and/or can be found on the internet. Other important aspects, normally not published on the internet, will be discussed hereafter. The following will be considered:

- Basic requirements for tow lines.
- Towline handling and maintenance.
- Towline strength reduction.
- Safe and effective tow line lengths.
- Safety factor.

Basic towline requirements

A towline must fulfil two basic functions, firstly to function as the load-carrying link between tug and ship and secondly to cope with the dynamic loads resulting from the relative motion between tug and ship. This leads to the following basic requirements for towlines for harbour tugs:

- **Strength**
  The towline should be of sufficient strength to cope with the forces that can be experienced during ship handling operations.

- **Stretch**
  Dynamic loads should be well compensated by the towline and/or load reducing system on the winch to avoid excessive loads in the towline and attachment points.

- **Weight/Diameter**
  The towline should be manageable on board the tug as well as on board the ship. When no towing winch is used the towline should be flexible enough for easy handling.

- **Life**
  When in use the towline should suffer a minimum of wear, distortion and loss of strength providing a the longest possible useful life.
As tug power increases, in particular when steel towlines are used, towlines become more difficult to handle. Fibre towlines and in particular the towlines made of the newest fibres have a much lower weight, but such modern towlines are still only used on a limited, although increasing, number of tugs. In the near future a gradual change in the use of towlines is to be expected.

On board ships the number of crew is still gradually decreasing, evidently without sufficient appreciation of the workload and manpower requirements associated with arrival/departure activities such as towline and mooring line handling. For the few remaining crew members it becomes a hard job to fasten and release towlines within an acceptable time. In particular the reduction in crew size is an incentive for the development of alternative systems for attending the towlines of harbour tugs. There are ships where boatmen are engaged, who board the vessel together with the pilot, to assist the crew in attending the tug's towlines and when mooring. For escort tugs different systems are in use to reduce the time for making fast. For instance Foss Maritime has developed a special towline connection link for that purpose.

Some important rules for towline handling will now be reviewed.

**Safe handling of towlines on board ships**

Most of the following rules for safe handling of towlines *on board ships* are mentioned in the OCIMF booklet 'Effective Mooring':

- A sufficient number of heaving lines of proper length and strength should be ready in time at the mooring stations for hauling the tug towlines aboard. The end of the heaving line should have a proper knot or something similar. The end of the tow line never be weighted with inappropriate objects such as metal bolts, which may injure the crew of the tug.
- The condition of the tug's towlines is unknown, and the crew on mooring stations will not normally be aware when the tug is actually towing or what load is applied to the line. It is therefore important to stay well clear of the towline at all times.
- When the tug is being secured or let go, the person in charge of the mooring should monitor the operation closely to ensure that no load comes on to the line before it is properly secured, or whilst it is being cast off.
- Never let a tug go until instructed to do so from the bridge; do not respond to directions from the tug's crew, but give them a clear signal when you are about to let go.
- If the towline is provided with an eye, heave this past the bitts so that there is sufficient slack line to work with, stopper off the line, then put the eye on the bitts. Do not try to manhandle a line on to a bitt if there is insufficient slack line. If the line has no eye and is to be turned up on the bitts then it should always be stoppered off before handling.
- The eye or shackle by which the messenger line is fastened to the towline should be removed from between the bollard and tow line in order to prevent damaging the towline and/or the eye or shackle of the messenger line.
- It is important to have the towline at the lowest position on the bollard in order to avoid excessive forces on the top of the bollard when powerful tugs are used.
- Do not try to hold a line in position by standing on it just because it is slack - if the tug moves away so will the person standing on the line.
- When letting go do not simply throw the line off the bits and let it run out; always
slack it back to the fairlead, using a messenger line, and lower it as far as possible in a controlled way on the tug's deck.

**Handling and maintenance of fibre ropes, including towlines**

Consider first the danger of ‘snap-back’ of fibre lines. Snap-back is common to all lines.

- Even long wire lines under tension can stretch enough to snap back with considerable energy. Synthetic lines are much more elastic (except for Aramide and Dyneema/Spectra lines) which increases the danger of snap-back. They will strike anything in their path with tremendous force. Synthetic lines normally break suddenly and without warning. One should keep away from synthetic lines under tension and when approaching these lines it should be done with care.
- Twisted ropes can be harmed by kinking, which may form into hockles if not properly removed. When a kink forms, the load must be removed and the kink gently worked out.
- Ropes must be kept clear of chemicals, chemical vapours or other harmful substances. They should not be stored near paint or where they may be exposed to paint or thinner vapours. The susceptibility of the rope depends on the chemical structure and the fibre. Nylon, for instance, is attacked by acids and bleaching agents. Polyester is attacked by some alkalis.
- Excessive heat can damage synthetic lines, especially polypropylene. Polypropylene and Aramide are vulnerable to ultraviolet rays.
- Care should be taken when dragging synthetic lines along the deck. Avoid sharp edges, rough surfaces or surfaces with a small bending diameter.
- When dirt, grit or rust particles are allowed to cling to or penetrate into synthetic ropes, internal abrasion will result. The rope should be cleaned before storing.
- To distribute wear equally along all parts of the towline, ends should be reversed periodically. A further reason is that braided ropes, which are torque-free, develop twists when constantly used on a winch by the direction of turn of the winch, or by rolling on the winch drum due to uneven layers. A braided rope can also get twisted through repeated handling on a capstan. Twists make rope handling more difficult and reduce rope strength when not removed. If a twist develops, it should be removed by rotating the rope in the opposite direction when it is relaxed.
- Fairleads, warping drums, roller heads, etc. should be in a good condition and damage to fibre lines by rust and grooves should be avoided.
- It is recommended to use a pennant particularly for fibre towlines to minimise damage at the ship’s end of the main towline.
- Towline, stretcher and pennant (if used), must be inspected at regular intervals and these inspections should include, as far as possible, inspection of inner strands, eyes and splices.
- To minimize abrasion, towlines and/or towline pennants made of Spectra or Dyneema should be protected against chafing: fairleads should be free from rust, sharp edges and grooves. On tugs it is increasingly common to fit fairleads of stainless steel, but these also require regular polishing to ensure no rough or sharp surfaces develop.
- Finally, although all aspects mentioned above for proper rope handling and maintenance are important, it is equally important to ensure the tug is properly handled to minimise the shock loads in the towline as much as possible.
**Maintenance of steel wires**

- Steel wires should be properly maintained and regularly inspected. Visual inspection is vital, particularly around eyes, but also where wires are shackled to stretchers, as the shackle tends to increase wear on the wire at this point.
- Inspection should focus on such aspects as: broken wires in strands, corrosion and rope deformation (kinks, flattened areas, misplaced outer wires, etc.).
- One should keep away from tow lines under tension and when approaching these lines it should be done with care.

**Damage to towlines**

The experience of several towing companies is that most damage to fibre towlines is a result of problems on the ships being towed, such as corroded and deeply grooved fairleads, sharp edges between fairlead and bollards and a lack of protection or ‘rounding’ over the sterns of ships.

It should, however, be noted that the cause of grooved fairleads and bollards does not in all cases lies on board the ship. Many ships have fibre mooring lines. Grooves in the fairleads, bollards, etc. may be caused in ports where tugs are using steel wire towlines, or fibre rope towlines with steel wire pennants, which then cause problems for tugs in other ports using fibre rope towlines.

**Tow line strength reduction**

Strength reduction in a towline will take place over a certain period of time and/or after a number of jobs. It is important to know the level of strength reduction and the factors that play a role, taking into account the fact that much depends on how towlines are treated on board the tugs. It is questionable whether this aspect gets sufficient attention.

Some years ago Samson Rope Technologies and DSM High Performance Fibers (producer of Dyneema HMPE fibre) carried out a study with the objective of developing retirement criteria to be used by a towing company to gauge when a rope should be removed from service (Report `Residual Strength Testing of Dyneema, Fibre Tuglines`). To that end, visual inspections and breaking tests were performed on towlines used on the escort tugs of Crowley Marine Services. The towlines were 12-strand ropes made from Dyneema SK75 fibre.

Pennants on board the Crowley tugs are generally used for one year and the main towlines for two years. After one year the main towlines are reversed, `end-for-end`. The average number of jobs carried out with the main towline was around 1200 and with the pennants around 600.

Some important conclusions of the study, based on tests with the pennants used for one year and the towlines used for two years, are:

- A strength reduction of almost 40% was found at the ends of the towline and at the pennant.
- Abrasion, compression and line twists resulted in a total strength reduction of up to 40%.
- Shock loading seems to have no effect on the residual strength of the towline, if due diligence is exercised in tug handling.
Other tests of residual strength of HMPE towlines with other towing companies show values of 50% (and higher).

Important findings are that shock loading seems to have no effect on the residual strength of the HMPE towline, provided the tug is handled in a controlled manner.

The study results show how important good towline care is. Abrasion, cutting damage and line twists should as far as possible be avoided and a twist in the line should, if possible, be removed before storing the line on the winch.

The importance of a proper safety factor is also shown by this study, bearing in mind the rather large average reduction in towline strength of 40% to 50%. DNV, for instance, requires the towline of an escort tug to have a breaking strength of at least 2.2 times “the maximum mean towing pull” as measured during active escort tests. Assuming a strength reduction of 50%, such a safety factor can be gradually degraded to 1.1, which means there is hardly any safety margin left. One should be well aware of this fact. In fact, this does not just apply to towlines of escort tugs and/or made of HMPE fibres, but to towlines of other tugs or made of other synthetic fibres as well.

There is another aspect to be taken into account, and that is what is regarded as the breaking strength of a towline. In the United States it is the practice to use spliced ropes to develop breaking strengths. Breaking strengths are reported approximately 15% higher when no spliced samples are used. The possibly lower strength of the connection between the pennant and main towline, depending on the type of connection, is a factor to be taken into account. In fact, the minimum breaking strength of the total towline should be taken into account for the required breaking strength of a tug’s towline.

Based on what has been discussed, the following aspects are important for the condition of towlines on board escort tugs, particularly those made of HMPE fibres, and for safety of towing. The aspects to be mentioned are recommended for normal harbour tugs as well.

- **Logbook**
  It is recommended to maintain a log of towline usage, noting factors such as the number of jobs performed, the results of visual inspections and any facts that may have influenced the towline’s service life.

- **A program of residual rope strength testing.**
  A program should be developed to determine the effects that influence the service life of a rope and to develop retirement criteria to gauge when a towline and pennant should be removed from service. In practice, every port is different, so data from other tugs or companies should not automatically be relied upon.

- **A realistic minimum breaking strength of the towline.**
  The minimum breaking strength of the towline should clearly be defined, stating whether the strength refers only to the rope of which the towline is made, or also including the weaker parts such as splices and, if relevant, the pennant/towline connection.

- **An appropriate towline safety factor.**
  The required towline safety factor must be based on a realistic minimum breaking strength of the towline, taking into account the reduction in rope strength during the lifetime of the rope.

- **A retirement program for towline and pennant.**

- **Proper rope care, which includes proper tug handling, as has been mentioned earlier.**
Finally
As already mentioned, there is a large variety of rope types, rope composites and construction methods, and consequently of rope characteristics and applications. Therefore, when selecting a rope for a towline or for a stretcher, a careful consultation with rope manufacturers and/or suppliers is needed regarding the most suitable rope type and recommended use, taking into account the tug’s capabilities, working methods and conditions.
The manufacture and marketing of ropes is a very competitive business, and the reputable suppliers generally offer excellent after-sales service and advice. Users should be prepared to take advantage of these services, and should consider benchmarking against other reputable tug companies to ensure they are being given the best possible service, and the most appropriate towline for their needs.

Note:
Most basic aspects have been addressed, but this article does not cover all the aspects necessary to get a complete insight into the properties of all the different towlines on the market or what would be needed for a specific tug or for specific towing operations.


Safe and effective towline lengths

The towline length of tugs towing on a line is now considered. However, it will be shown that conclusions are often also be applicable to other tug operation methods.

When towing on a line a tug captain determines the length of the towline on the basis of his insight and experience. This applies to tugs with towing winches and tugs using ship lines as towline. On tugs without a towing winch and using their own towlines the available length is usually limited to a preset towline length.

The towline length used while towing on a line depends on factors such as type and length of tug, size and deck height of ship to be assisted, environmental conditions and available manoeuvring space for the tug. Ship’s speed is also important. These factors may result in longer towline lengths in one port than in another and may also differ depending on the tug captain's experience. The towline length will also influence ship's manoeuvres, as will be explained.

Tow line length in relation to ship's response times and path width

To show how towline length affects ship's manoeuvres, the example of a forward tug towing on a line is considered. From the figure below it is clear that when required to change from pulling direction 1 to pulling direction 2 tug A needs more time in comparison to tug B owing to the longer distance to be covered. Tug B, with the shortest towline, can react much faster when required, for instance to stop a sudden sheer of the assisted ship.

So, with a short towline faster tug reactions are possible than with a longer towline. This applies to tugs towing on a line as well as for tugs operating in the push-pull mode at the ship’s side. When the length of the towline is doubled the reaction time will also approximately double.
The manoeuvring space required by a ship is smaller when tugs react quickly. A ship passing through a harbour basin with the assistance of tugs, for example, needs a manoeuvring lane of a certain width. This path width is smaller when tugs work on short towlines, because the ship does not have much time to sheer or drift. As soon as sheer or drift is noticed, the tugs can react very quickly.

The total required manoeuvring lane width for the combination of ship and tugs is also narrower, because tugs towing on short lines require less space. So, it works to double effect.

Working on a short towline therefore has three important advantages:

- Faster reaction time of tugs.
- Reduced ship's path width.
- Less manoeuvring space required for the combination of ship and assisting tugs.

These aspects are of particular importance when manoeuvring space is limited as is the case in most port areas. This all sounds very logical, but the experience of some ship's captains is that in a number of ports long towlines are used too often. It then takes too long before a tug can exert towing forces in the required direction. In the meantime the ship is drifting or swinging in the wrong direction.

**A steep towline and the effectiveness of the tug**

Irrespective of assisting method, the vertical towline angle can be quite large when short towlines are used. There has been a lot of discussion whether the effectiveness of a tug is affected when the towline is shortened, apart from the negative effect of the tug’s propeller wash hitting the ship’s hull.

For an explanation that no loss in effectiveness will occur when the towline is shortened, see figure 1 below.

Both tugs are exactly the same and are both pulling ahead with equal full power P. This gives a force T in the towline. This towline force has a vertical component, which lifts the tug a little out of the water, but is compensated for by the tug’s increased apparent weight L. Force L together with the towline force T gives the resultant force R, equal to the pulling force P of the tug in a state of equilibrium.

The towline force T = T\(^1\) on the ship. This force T\(^1\) can be resolved in a vertical force L\(^1\) and in a horizontal force P\(^1\). The forces P\(^1\), which are the tugs' pulling effects on the ship, are equal to the towing forces P of the tugs.

It can be concluded from this, that shortening of the towline does not affect tug's effectiveness.
However, there is an important aspect to be taken into account and that is force $L^1$. This is the friction force. Figure 1 shows that when using a short towline this friction force is very large, which results in high temperatures and considerable wear, imperilling the towline’s life.

Where tugs have to work with such short and steep towlines strong pendants are recommended, if they can be used, because they can easily be replaced when damaged.

*Other important considerations regarding tug’s towline length*

**Interaction effects (1)**
A short towline has a large negative effect on the effectiveness of a pulling tug due to the tug’s propeller wash hitting the ship’s hull. This effect is larger the smaller the distance between tug and ship and the smaller the ship’s under keel clearance.

When for instance a large container vessel has to be pulled from the berth against a strong onshore wind, the tug should pull on a long towline. If this is not done, the bollard pull of the tug may theoretically be sufficient, but due to the negative effect of the tug’s propeller wash tug’s power may not be enough in practice.

**Interaction effects (2)**
A tug is pulling into port direction at the bow of a deep loaded bulk carrier, using a short towline. Due to the water flow around the bow and along the starboard side of the bow a low pressure is created at the starboard side of the bow. Although the tug is pulling with full power, the ship’s bow will move to starboard due to the Coanda effect (see figure 2).
Safety effects. A longer towline as bow tug
If a bow tug is towing on a short towline, the distance between the tug and the ship's bow is very small. Consequently, the time available for a tug captain to react is very limited. When, in addition, ship’s speed is high the tug only has a small amount of reserve engine power and as a consequence reacting quickly becomes problematic. Thus the tug captain has to constantly and closely observe the ship's course and speed changes. Similarly, pilots have to be careful with rudder and engines manoeuvres and have to keep tug captains well informed about the intended manoeuvres, because the safety of tug and tug's crew is involved. For this reason forward tug captains do not like to tow on a short towline in case of dense fog or when an attended ship has a rather high speed. They prefer to tow on a longer line and proceed slightly to the side of the ship’s path.
In addition, with increasing speed other effects such as interaction effects might come into play.

Waves
If operating on a short towline in wave conditions, the towline can easily part. Therefore, in such conditions it is better to lengthen the towline.

Finally
For tugs operating alongside a ship it might in some situations be better not to fasten towlines. Such situation can arise when tugs are on the leeside of a ship entering a harbour or harbour basin in high winds. If the vessel is drifting to leeward and tugs are not strong enough to counteract the leeway, they may get jammed between ship and shore if they cannot get away in time due to towlines that cannot be released quickly enough.

Towline safety factor
The safety factor discussed below applies to tugs towing on a line as well as to tugs operating in the push-pull mode. For an assessment of the towline safety factor a number of factors play a role.

1. Static forces in short and long towlines
A tug sometimes has to work with a steep towline angle, for instance when a ship has to enter a dry dock. Up to a vertical towline angle of 40° the influence on the force in the towline is not so large. However, when the vertical towline angle further increases, the force in the towline increases very rapidly. At a vertical towline angle of 60° the force is already twice the exerted towing force of the tug. A vertical towline angle of 45° - 50° for tugs secured at the ship's side is not too large but when towing on a line it is a large angle, although it does happen. In this case the static force in the towline is already 1,5 times as high as the towing force of the tug.

There is not always a direct relationship between the forces in a towline and the towing force exerted by the tug. Tugs operating in the indirect towing method, particularly at high speeds as is the case with escort tugs, experience very high towline loads mainly due to the high lift forces generated by the tug’s underwater body and skeg, if fitted. However, the main factors for the maximum static forces in the towline during normal harbour operations are the tug's bollard pull and the towline angle.
2. Dynamic forces in a short and long towline
In addition to static forces, dynamic forces can occur in a towline and can reach high values. They are generated by sudden accelerations of the tug, wrong tug manoeuvres, waves, swell, and so on, creating shock loads in the towline. Horizontal tug accelerations can be kept under control to some degree by careful manoeuvring, but this is not the case with vertical accelerations due to waves and swell. It is obvious that these vertical accelerations, which can even be created by waves of passing ships, have a large effect on the forces in a towline, especially in the case of short and steep towlines. The longer a towline and the higher the elasticity, the better dynamic forces can be absorbed and the lower the peak values of the towline loads will be. That is why much attention has to be paid to strength and elasticity of a towline especially when tugs have to work in wave and/or swell conditions with short towlines.

Assuming again a vertical towing angle of 45° - 50°, towline forces certainly reach higher values than the previously mentioned 1.5 times bollard pull, due to the dynamic forces generated. How large the dynamic forces are will depend, amongst other things, on length, type and/or composition of the towline. But towline forces in excess of two times the bollard pull of the tug are not uncommon, particularly when towlines with little stretch, such as steel wire and the modern fibre towlines, are used. It is clear that when the brake holding power of the towing winch is less than this value the brake of the winch may slip. This is, of course, only when the minimum breaking strength of the towline is sufficient to cope with the dynamic forces.

3. Safety factors regarding towline strength
The most important question is what the towline strength should be in relation to the bollard pull of a tug. This is considered starting with a steel wire towline.

The so-called "endurance limit", approximately half the minimum breaking load, is of great influence on the life of a steel wire. Tests have shown that when a steel wire cable has several times endured a load higher than the "endurance limit", its life is very short and it breaks without ever being exposed to a load up to the "elastic limit", which is approximately two thirds of the minimum breaking load. It is therefore clear, that shock loads play an important role.

Taking into account the towline force of two times the bollard pull of the tug, the minimum breaking load of a steel wire towline should then be at least four times the bollard pull of the tug in order to stay within the "elastic limit".

Peak values in towline loads due to dynamic forces will be lower in `conventional fibre’ lines than in steel wire ropes. These fibre lines have better dynamic load absorbing characteristics. According to OCIMF (Oil Companies International Marine Forum), the safety factor for synthetic mooring lines is 2.0, although depending on the type of fibre line (e.g. safety factor of nylon lines is 2.2). This means that the maximum allowable load is half the breaking strength of the line. As mentioned above, forces in the towline can be two times the bollard. This means that the same safety factor can be used in practice for both steel and fibre towlines, viz. 4 times the bollard pull.

Although only an approximation, the safety factor of at least 4 times the bollard pull corresponds reasonably well to what is applied by a number of large harbour tug companies, viz. 3.5 to four times the bollard pull. A factor of six times the bollard pull can be found in some companies, and also much smaller safety factors (as low as twice the bollard pull for instance). Such a low safety factor affects a towline's life.
For escort tugs the high towline forces that can be generated in the indirect mode are much higher than the bollard pull and therefore a more appropriate criterion for the required minimum breaking strength of the towline is needed. Det Norske Veritas, for instance, requires for escort tugs a minimum breaking strength of 2.2 times the bollard pull, provided that the towing winch of the escort tug has a load reducing system and normal escort operations are not based on use of brakes on the towing winch. The towing winch should be able to pay out towing line if the pull exceeds 50% of the breaking strength of towing line.

With respect to the first two items mentioned above, one should carefully consider what the minimum breaking strength of a tug’s towline is. A few other aspects have to be kept in mind with regard to an appropriate safety factor:

- A cow hitch connection between a fibre pennant and a fibre towline, as often used, reduces strength of the total towing connection by approximately 15%.
- Splices in a rope will decrease minimum breaking strength by 10%.
- Studies have shown that there can be a rather large average reduction in towline strength of 40% to 50% over a period of two years.

Low temperature affect the performance of ropes. A few examples:

- The strength of polyester ropes increases by about 20% at an extreme temperature of minus 35 - 40°C, although icing causes larger internal abrasion, consequently reducing the breaking strength.
- Nylon loses up to 10% strength at these cold temperatures, with an additional strength loss due internal abrasion caused by icing.
- Ropes made of modern fibres may also be affected by cold temperatures.

This article is far from complete. There is much more to know about towlines. For further information and for other practical subjects the reader is referred to the book “Tug Use in Port. A practical Guide” 2nd ed. The Nautical Institute, London, UK

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