# Is the Sheet Bend Still Worth Tying?

The sheet bend (Fig. 1)* is so simple to tie, and so versatile in natural-fibre materials, that one imagines it was invented in the mists of time like the thumb knot, the reef knot and the granny knot. There is physical evidence that the sheet-bend structure was used in prehistoric times from the Arctic Circle to Egypt, and in medieval Europe sailors already used double sheet bends for greater security in rigging (Turner & van de Griend 1996, pp. 40, 49, 57, 117, 138). Archaeologists sometimes know it as the mesh knot (used in nets ancient and modern) or as the Russian knot. In Swedish, Norwegian, Danish, German and Dutch it is 'schootsteek' or similar (Öhrvall 1916), by derivation meaning lap hitch or (more likely) sailing-rope knot. The English name sheet bend derives from the lines (called sheates, sheats or sheets) which were sometimes thereby attached (bent) to the clews of sails (Manwayring 1624; Smith 1627; Steel 1794).

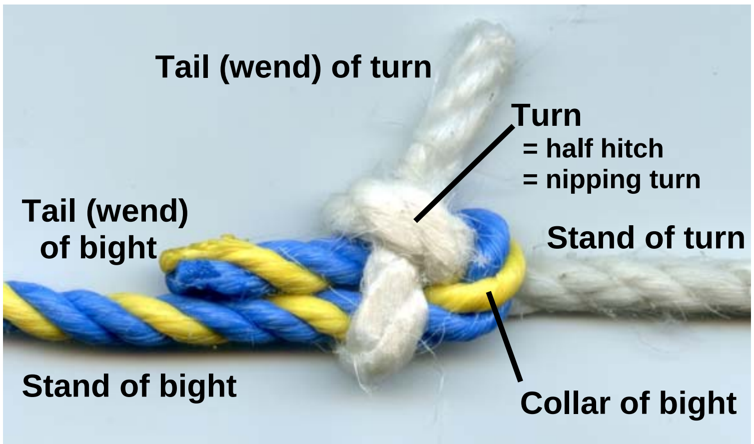

**Fig. 1.** Single sheet bend with direct tails and S-chirality turn in Z-laid rope.

* See the boxed note at the end of the article about tail lengths in all illustrations; and about how to determine chirality. Most terms are defined in the glossary on the IGKT web site.

The sheet bend – sometimes called the common, hawser, simple, single, swab, or weaver's bend – appeared in all of the early English-published works illustrating nautical knots (eg Steel 1794 – copied from Lescallier; Moore 1801 – copied from Steel; Lever 1808; Burney 1815 – copied from Lever; Brady 1841 – with an error; Dana 1841 – with a different error; Alston 1860 – with Brady's error; Nares 1862 – single and double becket versions; Luce 1863 – like Nares and Lever; Bowling 1866 – direct ends, copied from Émy; Burnley 1871; Burgess 1884 – oblique ends; Haslope 1891 – single and double; Patterson 1891 – direct and oblique). It was shown earlier, eg as "nodo alla Bufolara o della Rete" (doubled and slippery forms, in Tabula II) in Zabaglia's *Castelli e Ponti* of 1743 (see *KM* 139, 40-43); "nœud du tisserand" (Tisserand Planche VII), "nœud à l' ongle" (Soierie Planche CXVIII), and a secured form (*ABOK* #1449) in Diderot's *L' Encyclopédie* of 1751-1772; "another, mashing or barber's knot" in Emerson's *Principles of Mechanics* of 1758; and "nœud d' écoute" in Lescallier's *Vocabulaire des Termes de Marine* of 1777. It is *ABOK* #1, #2, and at least forty other entries in Ashley (1944).

Like many knots that stood the test of time in natural-fibre cordage, the sheet bend must be modified and used with caution, or abandoned in favour of more complex entanglements like the zeppelin bend and blood, barrel or multi-turn fisherman's knots, to achieve security in some modern synthetic-fibre cordage.

## Basic Design Features

The basic sheet bend consists of an interlocking turn and bight. The turn can be cast with S or Z chirality (Fig. 2). This may be relevant in chiral (laid) rope, and it is expected to be irrelevant in achiral or amphichiral rope. Svensson (1940, pp. 21-27, 52 et seqq.) preferred S-chirality turns in Z-laid ropes. Ashley (1944, pp. 16-17) was equivocal about the interaction between rope and turn chirality. About 40% of the sheet-bend diagrams in his book use S chirality turns. Day (1947, p. 15) claimed no effect of turn chirality on strength or stability of direct sheet bends tied in Z-laid manila yacht rope. Chisnall (1995, *KM* 51, 41) reported that the S form (≡ “Z/S [T]”) tended to be more secure than the Z form in oblique sheet bends tied in “Z lay thread and cord”. Brown (2000, *KM* 66, 35-39) reported that turn chirality opposite to the cord slipped less with oblique sheet bends in 1 mm diameter nylon, but with direct sheet bends no consistent effect was apparent (S turns slipped less in S cord). Mears (1950) made the data-free assertion that chirality of knots had no effect in laid mountaineering ropes, in apparent contradiction of the report cited in support (Dent et al. 1892). Nobody has presented replicated data; but with a single turn, any effect is likely to be small. Most people just learn to tie one way and stick with it. Illustrations that use unfamiliar chirality can be confusing. The illustrations in this article reflect my preference for S-chirality turns in Z-laid ropes (and direct tails discussed below).

The sheet bend is ‘designed’ to be loaded on the stands (not the wends) of the turn and the bight; but see the slippery Lapp bend in Fig. 2 for a different approach. Sheet bends can be tied with tails direct (on the same side) or oblique (on opposite sides) (Fig. 2). Which tail orientation is preferable has been debated, without compelling data[†]. Under load, the tail of the bight moves across the front of its stand in the direct but not the oblique sheet bend. Among direct double sheet bends (Fig. 4), this movement is more evident in *ABOK* #488 than in #1434 or #1435, reflecting differences in the way nip from the turn is exerted on the bight. Furthermore, this movement can be either encouraged or prevented by locks of different chirality (Figs. 5, 6).

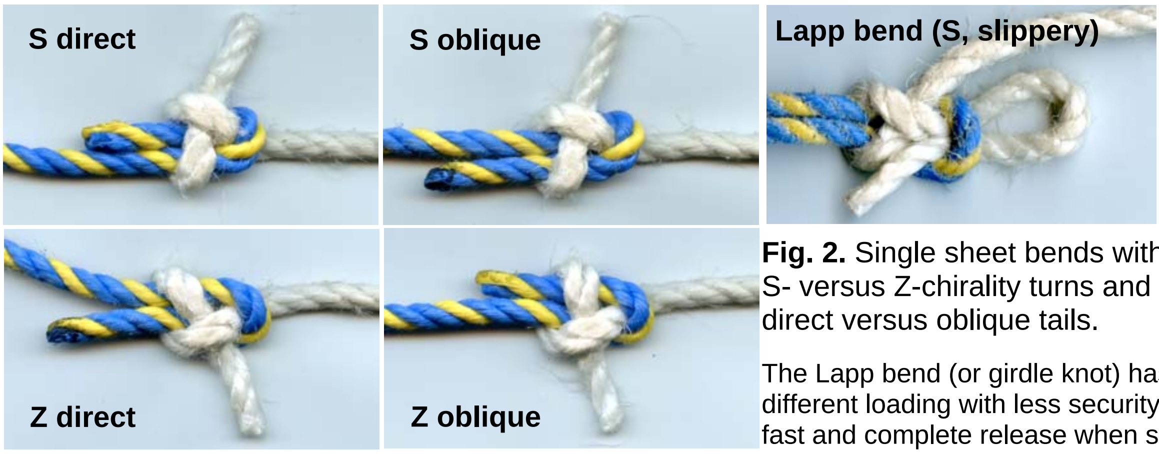

**Fig. 2.** Single sheet bends with S- versus Z-chirality turns and direct versus oblique tails.

The Lapp bend (or girdle knot) has a different loading with less security, but fast and complete release when spilled.

Tail orientation was used by Macfarlan (1947, pp. 45-47) to distinguish the (oblique) sheet bend from the (direct) weaver’s knot, but others did not make this distinction. Day (1947, p.48) explained why weavers may prefer oblique tails. In contrast, Dana and Pearl (1921) showed a Lapp bend (non-slippery version) as the weaver’s knot, used because “when pulled tight, both ends point backward, and do not catch when pulled thru the loom” (see also *ABOK* #489-493).

Most authors favour direct tails in the sheet bend (and the Lapp bend), for more nip from the turn on the wend of the bight (Ashley 1944, pp. 16-17, 273). Distribution of nip may affect slippage of the bight under load, but any advantage seems to depend on the cordage or test method. In sheet bends, Day (1947, p. 15) reported that oblique tails were less secure in laid manila yacht rope. Brown (2000, loc. sit.) concurred in 1 mm diameter laid nylon cord. Chisnall (1992, *KM* 38, 5) reported that oblique tails were more secure in some braided and kernmantle ropes. Patil et al. (2020) modelled that oblique Lapp and sheet bends have more “topological friction” than direct forms; but their model excluded rope material properties and contact geometry, and they presented no experimental data on security of either Lapp or sheet bends.

The sheet bend can be used to join lines of moderately different diameters. The usual advice is to form the bight / collar in the larger or stiffer line; or in the bunched fabric when attaching a line to a tarpaulin or sail without a corner grommet or clew (Fig. 3); but this has been challenged in tucked versions (NautiKnots 2018, https://igkt.net/sm/index.php?topic=6100).

The sheet bend can be used to join a line (or multiple lines) to an eye, commonly formed using an eye splice, a seizing, or a fixed-eye knot (Fig. 3). When formed on an eye, the sheet bend is known as a becket bend (or sometimes as a becket hitch, which reminds us that the knot can also been made on a rigid becket). Note that in the becket bend, the load is divided between the legs of the bight (eye), so the distinction between direct and oblique orientations does not apply. Also, the lead of the bight is improved in relation to snagging (see below).

Toggled and slippery versions of the sheet bend are easily made for quick release at the expense of security (Fig. 3). Or a toggle can be placed between the turn and the collar to increase jam resistance without quick release (*ABOK* #1522). Check security under high load before use of any toggled or slippery version, and only consider them for uses with sustained tension.

**Fig. 3.** Single sheet bends used: as a becket bend on an eye splice (top left); in a toggled form (top right); to attach a sheet of fabric to a cord (bottom left); and in slippery form (bottom right).

When spilled, a slippery sheet bend leaves a line through the bight, and a pulled toggle can leave a half hitch on a flared becket, whereas a Lapp bend (Fig. 2) spills cleanly (Compton 2013).

The sheet bend can be tied with one line under a load, provided a bight can be formed in that line. It is one of the few knots that can be tightened without prior dressing and packing, though that is not advisable in synthetic ropes where slippage during rapid tightening can generate heat that weakens the fibres. In all rope compositions, the double sheet bend requires careful dressing to obtain the desired conformation of turns, and packing to remove any slack in the turns before full tension is applied. In basic form it is a compact knot. The larger the knot, the greater the chance of wear through rubbing, and the greater the range of crevice sizes that might cause snagging, under some conditions of use.

The sheet-bend structure is the most important asymmetric formation used in knotting (Warner 1992, p. 156). It is used in a great variety of knots; eg the nub of an inside-tail bowline *ABOK* #1010 resembles a direct sheet bend, whereas an outside-tail bowline *ABOK* #1034½ is oblique. But the bowline has a single stand and tail, and loading in typical use is different. Therefore some, but not necessarily all, considerations about the sheet bend apply as well to the bowline. Beware that some sheet bends have sometimes been known as bowlines (Day 1947, p. 66).

## Virtues

The virtues of the sheet bend are that it is simple to tie and visually check, it is easy to open after a moderate load, it is effective in lines (or even bunched fabrics) of similar or moderately different diameters, it is compact, it consumes little cord length, and (to some) it is beautiful in its simple but effective combination of an interlocking turn and bight.

## Limitations

The limitations of the sheet bend include (i) a tendency to slip in synthetic-fibre cordage (which tends to be more stiff and/or slick than natural-fibre cordage); (ii) potential in some uses to snag the tail of the bight, which can lead to straightening of the bight and slippage of the tail through the nub of the knot; and (iii) insecurity under cyclic loading (such as wind flapping in an unloaded line). Strength is discussed more later, but in most applications security is a more serious limitation.

## Slippage and Cyclic Loading

Limitation (i) has been well documented by Richards (2004) who found that the common sheet bend slipped apart before it reached breaking strain in some synthetic cordage. This is not observed under all test conditions or in all synthetic cordage (Beeson 2015, www.yachtingmonthly.com/sailing-skills/strongest-sailing-knot-30247). Approaches to overcome slippage include all of the methods to increase friction: (a) doubling the turn; (b) securing the tails to the stands by means of half hitches, thumb (overhand or underhand) knots or seizing; and (c) tucking the tail(s) back through the nub in various ways. The same approaches are used against cyclic loading.

Few knots combine jam resistance with high security and efficiency in extremely slippery ropes such as unsheathed UHMW-PE braids (estarzinger 2013, forums.sailinganarchy.com/index.php?/topic/154025-ropeknotsplice-load-testing/&). In jacketed UHMW-PE, the jacket breaks and the core pulls through the bend at a low fraction of the unknotted rope strength (Beeson 2015, loc. sit.). The manufacturers intend customised splices to be used in such ropes (Hartter 2004). In contrast, splicing is not recommended in kernmantle climbing or rescue rope (Padgett & Smith 1987).

### Doubling

There are three common ways to double the turn, and two ways to dress the most commonly tied form (Fig. 4). Although *ABOK* #1434 is the most common dressing, there is some evidence that *ABOK* #488 may be more secure, at least in double-braid yacht lines (Seaworthy 2014, https://igkt.net/sm/index.php?topic=4937). Doubling the turn hardly diminishes the above-stated virtues of the sheet bend. It should always be employed if the lines to be joined by the bend are of different diameters and/or made of synthetic fibres. Weavers use many doubled versions (ABOK #485-494); one doubled only around the wend of the bight is known as a sansome bend (Compton 2013). Doubling may reduce jamming after a heavy load, but it adds little to strength. Used alone, it may not be enough to achieve security. Even double sheet bends (type unstated) slipped apart before breaking strain was reached in some synthetic cordage (Richards 2004).

**Fig. 4.** Various double sheet bends. From left to right they are ABOK #1435 (called by Warner the rivermans bend); ABOK #1434 (the common double sheet bend) and its dressing variant ABOK #488; ABOK #1436 and its opposite-chirality form ABOK #1438.

The ‘enhanced sheet bend’ involves making an extra twist (which becomes an extra turn) in the bight. It is trickier to tie than the usual double sheet bends, and it increases both bight security and tendency to jam under load (Warner 1992, #422).

## Locks

Tying locks in the form of knots using the tails can certainly achieve security, as discussed by Warner (1992) around his #410, the "secured sheetbend". Even thumb knots in the free tails can be effective (cf *ABOK* #228, #1403). Warner (1992, p. 52) calls these stopped knots, as distinct from secured knots with complications around the stands. Stopped tails are less reliable than secured knots (Warner 1996a). They are also more likely to jam under load and they add more bulk than other locks. If used, they should be made close to the nub of the underlying knot, to reduce the risk of snagging a knotted tail in something like a rock crevice.

Locking of the tails around the stands can provide greater security than doubling, but it has more negative impact on several virtues of the sheet bend. With lines of similar diameter, it may be preferred to start with a reef knot (eg Warner 1992, #169, *ABOK* #1404). Some riggers routinely use a secured reef knot as a bend (edt71 2014, https://igkt.net/sm/index.php?topic=5075). Versions are also used by some climbers and rescue workers to obtain security comparable to a double fisherman's knot, with less tendency to jam (eg Green 2018, www.thoughtco.com/knots-for-rappelling-755662). One advantage of double thumb-knot locks around the stands is that they ensure fairly long tails on the core knot, without increasing the risk of tail snagging.

If the lines are of different sizes or very slippery, the core knot can be a simple simon, double simon, vice versa or double sheet bend (Asher 1989; Budworth 2015) (Figs. 5, 6). In many synthetic ropes these core knots provide enough friction through extra turns to achieve short-term security without locks on the tails. They may vary in ultimate breaking strength and tendency to jam after a high load, which need to be tested under the conditions of intended use.

Under demanding conditions such as cyclic loading and rubbing on rocks, overhand locks hold longer than half hitches, and grapevine locks around the stands are most recommended (eg Training Division 2009; Phillips 2014, pp. 86, 88).

**Fig. 5.** At top is a double sheet bend (*ABOK* #488) with a tuck of the turn wend through the bight. This is similar to a double version of Asher's simple simon under, but with oblique tails. The effect of tail orientation on strength or stability of 'simons' has never been reported. Oblique tails do favour thumb-knot locks of the same chirality.

At bottom is a double sheet bend (*ABOK* #1434) with a simon-like tuck of the turn wend through the bight, locked using a thumb knot on the bight and a double (grapevine form) thumb knot on the turn. There are endless variations, the simplest of which is in Fig. 6.

## Tucks

There are many ways to tuck sheet bend tails back through the nub. Some simple tucks are more effective than others at increasing security. Some are downright dangerous, though this may not be apparent at a glance. In general, tests of sheet bend security have not documented whether slippage occurred on the turn, the bight, or both. In climbing rope, the bight was more susceptible, but both tails slipped (Richards 2004). Therefore, to enhance security under both sustained and intermittent loading, it seems desirable to reinforce both the turn and the bight.

The simplest way to reinforce the turn (apart from doubling, with which it may be combined) is probably to wrap and tuck its tail as in Asher's simple simon under (Fig. 5). Note that while this approach involves an extra wrap that may improve bight security, it does not directly complicate the bight tail, so a further lock may be required to prevent slippage there.

The tail of the bight may be woven or tucked in various ways intended to improve its lead and/or resistance to slippage. Equivalent measures exist to secure the tail of the bight in the structurally equivalent nub of the bowline. Many methods have been described to tuck the tail (eg Alston 1860, *ABOK* #1015; Saunders 1984, *KM* 7, 19; Smith 1987, *KM* 19, 2-3; Warner 1992, pp. 161-164; Asher 1994, *KM* 45, 20-22; Nuttall 2013, *KM* 118, 26-27; Nautiknots 2018, https://igkt.net/sm/index.php?topic=6100), but only some of them are effective. Notable for simplicity among these are methods that tuck the tail of the bight back through the bight itself.

Simply folding the tail back through the bight may increase friction, but it is not sufficient to prevent bight-straightening under some conditions of adverse and cyclic loading. For this, the tuck must form a thumb knot or figure eight around the stand of the bight (RGB 2018, https://igkt.net/sm/index.php?topic=6207). Even then, a further lock is needed in some (stiff) ropes and conditions of usage. Some tucks can compromise the nub, especially if wrongly dressed or packed. The flaw is not always obvious at first, as experienced with the "Yosemite" finish (Prohaska 1988; www.ukclimbing.com/forums/rocktalk/yosemite_bowline_not_safe_for_climbing-513200).

The methods to tie effective tucks on a sheet bend are sufficiently complicated, and therefore error-prone, that one wonders: "Why not just use a secured sheet bend, or a zeppelin bend?"

## Tail Snagging and Bight Straightening

Limitation (ii) has been graphically illustrated by Toss (2016, Figure 3-30) in context of yachting. Snagging of sheet bends in rigging is likely because of the lead of the stand and wend of the bight. Simon-like knots are liable to snag in rigging when hauled in either direction. This may be dangerous, or no more than an inconvenience, depending on circumstances. Hauling to free a snagged sheet bend may cause bight-straightening, especially in stiff rope. In any use, if the bight tail becomes snagged and pulled there is danger of bight-straightening and slippage to spill the knot (especially if the bight is made in a line that is substantially thicker or stiffer than the line used in the turn). Under conditions where the knot might pass over a crevice, this risk becomes higher with long tails used to insure against other forms of slippage.

The same problem explains why the bowline has long been regarded as less secure when tied with the tail outside the eye, despite reduced susceptibility to ring loading (Ashley 1944, *ABOK* #2549, #2551; Padgett & Smith 1987, p. 37; van de Griend 1992, *KM* 39, 23-27; Chisnall 2006, *KM* 90, 14-20). It is sometimes addressed by: (a) securing the tail of the bight to its stand by means of half hitches, thumb knots or a seizing; or (b) tucking the tail of the bight to alter the lead, so that the tail is less likely to snag in the intended use. Locks and tucks are discussed above. While knots with an acute angle between a tail and stand are most liable to snag in rigging, they are also most amenable to fastening the tails to the stands, to avoid this problem. Electrical tape may be more rope-friendly than duct tape, but either adhesive can weaken rope over time. Zip ties and heatshrink have also been used (Merchant 2007, pp. 34, 142, 197). The safest fast option may be to carry a few lengths of twine suitable for constrictor knot 'seizings'.

Note that opening through bight slippage can not arise with the becket bend, so long as the eye remains intact. But there are circumstances where an eye is liable to snag on a sharp projection.

## Knot Strength and Breakage

No compelling account has been found of the break point in sheet bends. In Manila rope, bowlines were reported to break at the turn. Others claim that knots cause rope breakage outside of the nub (Warner, 1996b). Such results are highly dependent on rope properties and test methodology (Uehara et al. 2007). One theory is that ropes break when the forces from curvature, rotation, tension and compression exceed the level for rupture of the rope fibres. But the levels of these forces within practical knots under static or dynamic tension, and the levels required for rupture in real ropes, are undocumented. The development of strain-sensing material provides opportunities (Patil et al. 2020), but the challenge remains to apply this in practical ropes. Nevertheless, some ideas to improve knots aim to reduce or spread such forces.

Sheet bends are generally regarded as weaker than figure eight or double overhand bends. For example, Richards (2004) reported that (secured) sheet bends reduced the strength of new 12.5 mm static rescue rope by 45-49%, compared with 22% reduction from a double overhand bend. This difference in strength is not an issue if ropes are used within their safe working loads, which more than allow for loss of rope strength at these knots and other low-radius curves in rigging. Multiple knots do not reduce rope strength more than single knots. On the other hand, use of tools to open any jammed knot will almost certainly reduce subsequent rope strength.

In earlier times, knots were sometimes padded with leather or fabric to increase breaking strength (Kennedy et al. 1864). Ropes of modern manufacture have a higher strength : weight ratio, so the weakening effect of knots is generally accommodated within higher safety factors. Common "rules of thumb" are that any knot reduces current rope strength by 1/2, whereas safe (live) working loads are specified at 1/10 (Phillips 2014) or 1/15 (Padgett & Smith 1987) of current rope strength. Taking the example of a new 10.5 mm diameter low-stretch kernmantle rescue rope, the static strength typically will exceed 26 kN (Long *et al.* 2001), so knotted static strength will exceed 13 kN whereas calculated safe working load is below 3 kN. An alternative approach is to consider minimum SSSF: the smallest number obtained when the static strength at any point in a rigging system is divided by the static load force at that point (Mauthner 2014). A stronger bend may give a higher SSSF, depending on location in a rigging system. In some situations, such as traverses, the rope, anchors and knots must withstand forces far higher than the suspended load. With a 200kg (≈ 2 kN) rescue load, it is very likely that any hoisting, traverse or knot-passing will take some rigging components far above 3 kN. Rescue rigging must avoid forces approaching 13 kN on a casualty (eg a short fall of 200 kg on a low-stretch rope), as they are unlikely to be survived (Merchant 2002). 'Progress capture' devices used by rescue agencies typically slip at 4 to 7 kN on 11 mm rescue rope (Walker & McCullar 2014).

## Alternatives

Security limitations are enough for most rescue agencies to reject all use of sheet bends in life lines and at heights. Yet the speed and simplicity of tying and opening still make variations on this bend the favourites of those working on the ground, or on the water. For a quickly-tied bend, used in non-critical applications, under supervision, with sustained load, in cordage with sufficient surface friction, the single or double sheet bend remains the champion. It is unlikely to be displaced as the simplest and commonest netting knot, an application in which there are no free ends to slip through and spill the knot. For the rapid attachment of cordage to bunched corners of fabric, there is no rival other than the double simon. For ropes of substantially different diameters, the double simon (or a double sheet bend with a simon-like tuck) is hard to beat for ease of tying and untying, and it can be secured with thumb knots around the stands in slippery cordage, and/or fastening the tails to the stands to avoid snagging on rigging.

Ashley (1944) considered that securing the tails of sheet bends was "unnecessarily cumbersome" (ABOK #1404), but he did recommend seizing the tails of sheet bends in ropes of different material, and in stiff ropes (ABOK #1431, #1434). The natural-fibre ropes used in Ashley's era are rarely used today, because of other limitations including susceptibility to rotting. Higher surface lubricity of synthetic-fibre ropes, especially when wet, necessitates greater friction within the knot for security. Taping of tails can be a fast method to help avoid snagging, but used alone it does not confer sufficient security for sheet bends in many synthetic-fibre ropes. There is rarely time for traditional seizing during emergency responses.

Even in non-critical applications, the type and extent of added locks and/or tucks must be decided by the knot tier, according to the properties of the cordage employed and the expected conditions of use. Both lubricity and stiffness of synthetic ropes can change with wear. Breakage of surface fibres (fuzzing) tends to increase surface friction relevant to knotting. The need to consider these things, and the loss of other virtues of the sheet bend in making the complications, are for many knot tiers reason enough to use another bend, routinely. For example, anglers interested in knot strength and security in fine lines (and not concerned about jamming) have long preferred multi-turn blood or barrel knots (Platts 1938).

In critical applications[‡] further complication of the tails is essential for security of the sheet bend. The examples below mostly refer to rescue work. Different considerations, and different rope types, predominate in other critical applications (eg McLaren 2006; Anderson *et al.* 2015).

Secured Sheet Bends

In recent training of North American fire fighters, the secured sheet bend (Fig. 6) has been specified for utility use (NFPA 2014). Sailors may seize the tails to the stands to reduce the risk of snagging in rigging. Of the bends illustrated below, those in Fig. 6 are least likely to leave a knot in an end dropped during untying, which would increase risk of snagging in white water.

The chirality of thumb-knot locks is rarely mentioned. Sometimes the lead of the tail from the nub of the underlying knot makes one direction of tying the lock seem more natural, but effects on knot strength or security have never been established. Of the illustrations in this article, chirality of the thumb-knot locks is S in Fig. 5, Z in Fig. 6, mixed in Fig. 7, and S in Fig. 11.

**Fig. 6.** The form of the secured sheet bend specified by NFPA for joining ropes of different sizes, but not for a human load (top).

A double sheet bend and grapevine locks are used by some agencies (bottom). In lines of different size, this is hard to beat as a secure and jam-resistant bend. The bight element is the 'barrel knot' of Merchant (2002).

Figure Eight (Flemish) Bends

The rethreaded figure eight bend (also called the Flemish bend or tracer 8, Fig. 7) with thumb-knot locks around the stands is sometimes specified for rescue work, perhaps because a similar knot is taught as a harness tie-in loop (NFPA 2014). The figure eight loop (eye knot) is one of the few knots that can hold without slipping in unsheathed UHMW-PE (estarzinger 2013, loc. sit.), which is testament to its high friction and security.

**Fig. 7.** A figure eight or Flemish bend (top, *ABOK* #1411) is generally secure with ropes of similar diameter, though various structures can arise from different threading and dressing methods. With careful dressing, some users report less jamming than multiple overhand bends (Fig. 8).

For critical applications, thumb-knot locks should be added around the stands (bottom). If ropes are slippery, test grapevine locks.

The tails may be seized to the stands to reduce the risk of snagging.

Figure eight knots are specified in testing for some regulatory standards (such as EN 1891, Merchant 2002), so there may be an unintended driver to optimise rescue ropes for such knots. However, many different structures can result from rethreading a figure eight (Xarax 2010-2011, https://igkt.net/sm/index.php?topic=2198; topic=3618) and consistent dressing is somewhat finicky. There has been little analysis of relative strength or security, so the knot is perhaps less 'standard' than commonly assumed. Typically this bend is used to join identical ropes, and authorities differ (without data) regarding its suitability for ropes that are stiff or different in diameter. Figure eight bends are liable to snag on rigging and jam after a heavy load. Without locks, offset loading can cause dangerous flipping (Moyer 1999, https://user.xmission.com/~tmoyer/testing/EDK.html).

### Multi-overhand Bends

The double overhand bend (also called the double fisherman's knot, double English knot, or grapevine knot; Fig. 8), or the triple version used in slippery cordage, is strong and secure in ropes of similar diameters, but liable to jam after a heavy load. This bend is widely used by cavers and climbers to form, in accessory cord, a sling which will not be untied but kept available for use in Prusik hitches. The bend can gradually slip under cyclic load, so a typical practice is to require tails longer than 40 mm for a sling to be considered serviceable (Holton 2009). In other uses, a multi-overhand bend in stiff rope (especially with tails taped or seized to the stands) might be coaxed through an aperture that would stop a zeppelin bend (Merchant 2002), and the slight give during tightening under a heavy load might reduce the force of a fall to a survivable level (Long *et al.* 2001). If the polymers in synthetic ropes are unknown, beware sliding versions of these knots that might heat and soften fibres.

**Fig. 8.** Double overhand bend (grapevine, double English, or double fisherman's knot, *ABOK* #1415) viewed from the front and rear. Stronger but more prone to jam than a Flemish bend (Fig. 7).

In Z-laid rope, this bend is reputed to be stronger with S-chirality thumb knots, as illustrated (see Warner 1996b).

If ropes differ in diameter (up to 20%), use the triple version. The tails may be seized to the stands to reduce the risk of snagging.

Multi-overhand bends are widely used by rescue agencies (eg Merchant 2002; Holton 2009; Training Division 2009; Phillips 2014), possibly because their strong but simple structure based on multiple thumb knots is easy to teach and check, and not prone to mistakes that yield a similar-looking product with compromised security. In rescue situations, these considerations may outweigh subsequent ease of opening.

## Zeppelin Bends

The zeppelin bend (Fig. 9) is perhaps the best for combination of strength, security, jam-resistance, compactness, tails perpendicular to the stands, and applicability to ropes of moderately different diameters. It is more complicated to tie than a sheet bend or simon, and it requires more careful dressing and packing. With practice, the zeppelin bend (zep) requires about the same time as locked versions of a sheet bend or simon. Once tightened, it resists loosening by slack shaking. It also seems to tolerate loading of the tails, though this has been questioned (Merchant 2007, Patil et al. 2020) and the breaking-strain or jam-resistance may be lower than the usual mode of loading the stands. More testing is needed. Unlike a sheet bend: it cannot be toggled or slipped readily for quick release; it is difficult to tie with a load on either line or in bunched fabric; and it can not take advantage of an existing eye, clew or becket. Two rope ends are needed to tie the usual version.

**Fig. 9.** Zeppelin bends (not in *ABOK*) made using ropes of similar diameters have a similar and symmetrical appearance from front or back. This is a very secure and jam-resistant bend.

There is a variant with the wends crossed rather than parallel in the nub. Differences in behaviour are not recorded.

When attempting to tie a zep, there is the possibility for an inexperienced or flustered person to tie one of the similar-looking structures based on interlocking thumb knots, some of which are insecure (Roo 2010, https://notableknotindex.webs.com/butterflybend.html). The best way to avoid this problem is probably to teach one reliable tying method, such as the '69' or 'underhand and overhand loop' method (Roo 2002, https://notableknotindex.webs.com/Zeppelin.html; Grogono 2012, www.animatedknots.com/zeppelin-bend-knot), and what can go wrong if this is varied. Then practise until the tying is fast and reliable, and refresh the practice frequently so that the correct bend will always be formed in an emergency. The zep combines turns of S and Z chirality, which may contribute to its function or (for some) its visual appeal (Fig. 10).

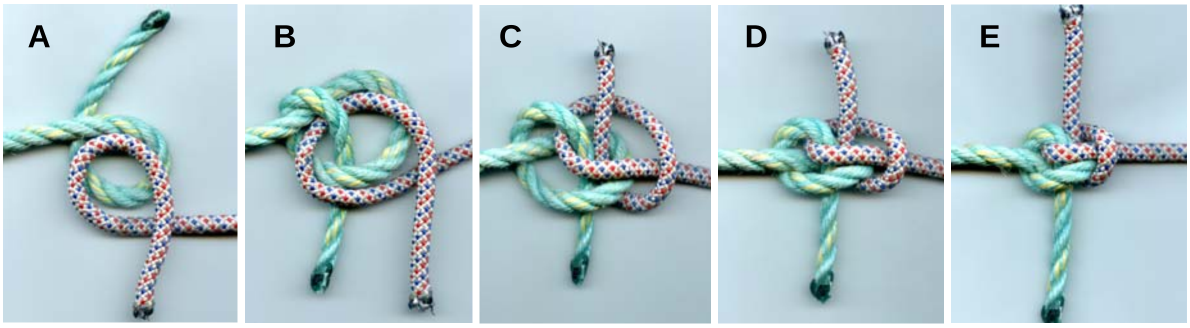

**Fig. 10.** Stages in tying, dressing and packing a zeppelin bend (zep).

Tying a zep:

1. Make a clockwise underhand loop in one rope end, and on top make a clockwise overhand loop in the other rope end. This is the '69' or 'bq' (Fig. 10A). If you prefer, you can make both loops counter-clockwise, but the wends must lie on the outside of the loops.
2. Put a finger through both loops from behind and turn them to a vertical position (the finger will be horizontal, pointing towards you). Use your other fingers and thumb to keep the '69' loops in shape. With practice you can simplify or skip this step, but it helps when learning.
3. Bring the rear wend forward, outside the loops and across both ropes, then pass it back through both loops (Fig. 10B). Withdraw your digit from the loops. Take the front wend backward, outside the loops and across both ropes, then pass it forward through both loops (this is the reverse of what you did with the rear wend). You have made two thumb knots, interlocked in a particular way (Fig. 10C).
4. Looking from above you should now see the characteristic form of the zep, albeit loose. Dress and pack it carefully by pulling on the four ends sequentially or in pairs. Several rounds may be needed to set the knot (Fig. 10C-E).

Once you have done this a few times, it is a lot quicker to tie than to read the instructions.

To open a zep, roll each collar down onto its stand, until the stands can be pulled or pushed into the nub to loosen the knot. In most ropes, this works even after heavy loading.

With substantial differences in diameter and/or stiffness of the lines, doubling the passes of the wends through the nub of the zep is recommended (Fig. 11), especially for the smaller line. It may be easier to use interlocked bowlines (Fig. 11). Doubling of zeps can make them harder to open after a heavy load (the same applies to thumb-knot locks on bowlines, and a triple overhand bend). Check security and jamming under extreme load in the lines to be used in the field.

**Fig. 11.** With lines of very different diameters or stiffness, double the passes of the wends through the nub of the zep (left). If this becomes challenging to dress, instead use interlocked bowlines (*ABOK* #1455; shown below with S turns and S thumb-knot locks).

There is no published replicated testing of strength or security of the zeppelin bend, but the experience of critical users seems uniformly positive (www.treebuzz.com/forum/threads/the-zeppelin-bend.15765/; www.treebuzz.com/forum/threads/the-zeppelin-loop-vs-the-f8-in-pulls.15928/). There are several fixed-eye versions (search the IGKT forum), and an interesting (if cumbersome) three-eye version that might be considered either TIB or PET (https://en.wikipedia.org/wiki/Zeppelin_bend).

## Carrick Bends

Those working with very large and stiff ropes, and especially those who like to use seizings, may prefer to use a carrick bend (Warner 1992, #472D, 477B) or one of its derivatives (Ashley 1944; Asher 1989). If greater friction is needed and the rope is sufficiently flexible, a carrick bend can be used with thumb-knot or grapevine locks. Unless the wends are seized tightly to their stands, a carrick bend will draw up into a bulky form less suited to pass around a capstan.

## Considerations Beyond Strength and Security

In context of cave rescues, Merchant (2002) makes the case that knots should not be added to a rescue team's repertoire without good reason. He shows no bend that can be released after a rescue load, without cutting the rope. If ropes of different diameter or composition must be joined (something avoided wherever possible in rescue work) he recommends tying each side to a karabiner (ie using two hitches or eye knots rather than one bend).

No-one has yet worked out how to obtain high and sustained security in a jam-resistant bend that will also roll over rock edges as easily as an offset overhand bend (EDK) during abseil rope retrieval (eg Cox & Fulsaas 2003, pp. 192-193). In that case, short-term security relies on careful dressing and packing, with long tails that are free of additional knots. No secure and non-toggled bend may be jam-proof after sufficient loading of stretchy cordage. No bend will easily pass a descender or progress capture device.

## Side Notes

* All of the illustrations in this article show knots with short tails, to save space and emphasise detail in the nub. In practical application, tails (and added bights in the case of slippery versions) should be much longer. Thirty rope diameters is enough to tie a double thumb-knot lock around the stand, or around the returning leg of the eye in the case of a bowline.

To determine chirality, use your hands. In any helix or spiral made of rope, the chirality matches the hand which, when grasping the helix or spiral, allows the fingers to point in the direction of progression of the rope while the thumb points in the direction of progression of the helix or spiral. Left hand = sinistral = S chirality. Right hand = Z chirality. It is the same for a bolt or screw thread. It is the same for a 'spiral-laid' rope, if the fingers follow the strands. A single loop or turn is like the first loop in a spiral. Determine the direction of progression of the spiral based on the side that the rope crosses itself to make the loop or turn. A half hitch is merely a turn arranged to confer some nip on itself, so it follows the rule as for a turn. With multiple loops, turns, or half hitches there can be different chiralities (compare a clove hitch which will be SS or ZZ to a cow or girth hitch which will be SZ or ZS). It can be tricky with thumb knots: note the side of the first loop (not the subsequent wrap or tuck). The result will match the chirality of the helix along the spine of an open thumb knot. Multiple thumb knots may be dressed in grapevine form, displaying a helix of 'crossing turns' opposite in chirality to the helix of turns along the spine of the knot in open form (see for example Warner 1992, pp. 11, 30-31, 52-54, 69).

[†] To an experimental scientist, compelling data come from a test with replication and a randomised or structured design. This should allow a valid statistical analysis to show the probability that any observed difference between the averages for different treatments (knots) has arisen by chance alone. Even better if the results have been repeated, and if they hold up under the most challenging conditions expected in practical use of the knot. All that is costly and time consuming, so there are almost no published examples in knotting (see Hartter 2004 for an example with breaking strength of splices in UHMW-PE). Experiments of this quality are a minimum for peer-reviewed publication in many areas of science. They can make a contribution to knowledge, as distinct from an interesting observation or speculation. The same applies to any quantifiable property of any knot in any specified cordage.

[‡] Critical applications include: supporting any living person, or loads that could harm any person if they fell; or securing any valuable material (such as a ship or even a mast or sail, or a tarp on a storm-damaged roof), especially for unattended use under potentially adverse conditions that may expose a knot to aberrant or cyclic loading. These applications require expert training (beyond reading) in current best practice; and careful selection of the rope type, knots and ancillary equipment best suited to the specific application. The needs and standards differ substantially for different critical applications, and best practice changes over time (eg Merchant 2002-2007; McLaren 2006; Anderson *et al.* 2015).

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Alston AH (1860) *Seamanship, and its Associated Duties in the Royal Navy.* Routledge, Warne & Routledge, London. https://books.google.com/books?id=uMFJAAAAIAAJ Fig. 156 (p. 112) copies Brady's error of illustration.

Anderson DL, Koomjian W, French B, Altenhoff SR & Luce J (2015) Review of rope-based methods for the forest canopy. *Methods Ecol Evol* 6**,** 865-872. DOI 10.1111/2014-210X.12393 http://www.researchgate.net/publication/275103303

Asher H (1989) *The Alternative Knot Book.* Adlard Coles Nautical, London. ISBN 0713659505.

Ashley CW (1944) *The Ashley Book of Knots.* Corrected edition. Faber and Faber Limited, London. https://archive.org/details/TheAshleyBookOfKnots G Budworth ed. (1993). ISBN 057109659X. Hence *ABOK.*

Bowling T (1866) *The Book of Knots.* Robert Hardwicke, London. http://www.bodleian.ox.ac.uk/dbooks Figs 48-49 correctly illustrates a weaver's knot (Z direct sheet bend).

Brady WN (1841) *The Naval Apprentice's Kedge Anchor.* Taylor and Clement, New York. https://catalog.hathitrust.org/Record/100128186 Illustrates in Plate I (after p. 34) the sheet bend with error (crossed reef knot) and correct (Z) bowline. The error remained until at least the 6th edn (1852).

Burney & W Falconer W (1815) *A New Universal Dictionary of the Marine.* T. Cardell & W. Davies, London. https://books.google.com/books?id=ZjDwy8xhu-AC Plate III shows an (S) sheet bend on a becket; plate XII shows a (Z) bowline.

Budworth G (2015) *The Ultimate Encyclopedia of Knots & Ropework.* Southwater, London. ISBN 9781844768912.

Burgess JT (1884) *Knots Ties and Splices.* George Routledge and Sons, Limited, London. https://archive.org/details/cu31924014519940 The sheet bend is illustrated in Z oblique form in Fig. 66 (weaver's knot) and in S oblique form in Fig. 76 (hawser bend). All bowlines are shown with S turns (Figs 39-41).

Burnley C (1871) *The Boy's Manual of Seamanship and Gunnery.* Trübner & Co, London. https://books.google.com/books?id=1UcOAAAAQAAJ Single and double (S) sheet bends in becket form are shown on p 15. Also called a swab hitch, used for bending a rope's end to swabs when washing them overboard.

Cox SM & Fulsaas K (eds.) (2003) *Mountaineering: The Freedom of the Hills.* 7th Edition. The Mountaineers, Seattle. ISBN 0898868289.

Compton N (2013) *The Knot Bible.* Adlard Coles Nautical (Bloomsbury), London. ISBN 9781408154762.

Dana HJ & Pearl WA (1921) *The Use of Ropes and Tackle.* State College of Washington, Pullman. https:// archive.org/details/useofropestackle00danarich

Dana RH (1841) *The Seaman's Manual.* Moxon, London. https://archive.org/details/seamansmanualcon00danarich Plate V (after p. 32) shows an incorrect (carrick-like) S-turn sheet bend (corrected by 4th edn) and a correct (Z-turn) bowline.

Day CL (1947) *The Art of Knotting and Splicing.* Dodd, Mead and Co. Inc, New York. Later editions updated and published by Naval Institute Press, Annapolis. The 4th Edition (1986) is ISBN 0870210629.

Dent CT, Conway WM & Wicks JH (1892) Report of the special committee on equipment for mountaineers. *Alpine J* 16**,** Supplement (569-600). https://pahar.in/alpine-journals-1864-1921/

Emerson W (1754) *The Principles of Mechanics*. W. Innys & J. Richardson, London. (1st edn, 32 Pl, Gale 18th C collections) 2nd: https://books.google.com/books?id=Wx80AAAAQA 3rd: https://archive.org/details/principles mechan00emer (43 Pl). Knots described pp 166-167, illustrated pdf pp 202, 322, 324. Only the 3rd edn scan has complete plates.

Hartter J (2004) *Investigation of Synthetic Rope End Connectors and Terminations in Timber Harvesting Operations.* MSc Thesis, Oregon State University. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/mk61rk34p

Haslope LL (1891) Knotting, Splicing, and Working Cordage. *Work*, commencing pp. 6, 65, 137, 139, 199, 244, 309, 361, 468, 523, 535, 551, 603, 613, 676, 715, 725 and 775. Cassell & Company, London. https://archive.org/details/work1891unse The sheet bend is illustrated in (Z) becket form as Fig. 10. Fig. 36 is a seized Z sheet bend on a clew. Fig. 37 is a double sheet bend. Fig. 38 is a complicated double.

Holton M (2009) *Knots, Bends and Hitches for Emergency Service Personnel*. State Government of NSW, Sydney. http://www.pdfdrive.com/knots-bends-hitches-%E7%AD%91%E6%B3%A2%E5%A4%A7%E5%AD%A6-e37848941.html

Kennedy ES, Grove FC, Cowell JJ, George HB, Hall WE & Nichols RC (1864) Report of the special commitee on ropes, axes, and alpenstocks. *Alpine J* 1**,** 321-331. https://pahar.in/alpine-journals-1864-1921/

Lever D (1808) *The Young Sea Officer's Sheet Anchor.* Thomas Gill, Leeds. A 1930 reprint of the 1808 edition is at: https://catalog.hathitrust.org/Record/010745004 Fig. 61 (facing p. 8) correctly illustrates an S sheet bend on a becket. Figs 46 and 48 show Z bowlines.

Long A, Lyon M & Lyon G (2001) *Industrial Rope Access - Investigation into Items of Personal Protective Equipment.* HSE Books, Sudbury. UK Health and Safety Executive. ISBN 0717620913. http://www.hse.gov.uk/research/crr_htm/2001/crr01364.pdf pp. 16, 80-81 note that the DF tightens under heavy load and thus the line stretches, reducing force.

Luce SB (1863) *Seamanship: Compiled from Various Authorities.* James Atkinson, Newport. https://books.google.com/books?id=cjJFAAAAYAAJ Plate 9 correctly illustrates (S) sheet bends, including a doubled version, on beckets. Earlier plates show (Z) bowlines.

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