THE WRIST BAND CLOSURE UNDER LOAD

What holds when the counter-ballast pulls

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Scope: wrist lanyard, band closed correctly, load applied through the link by a counter-ballast retrieval.

1. Short answer

A correctly closed Velcro wrist band holds a counter-ballast retrieval because it is wrapped around a cylinder, not because the fastener is strong. Hook-and-loop is 40 to 90 times weaker when peeled than when sheared, and the wrap is what keeps it in shear. Geometry decides this, not the grade of Velcro.

The band is a cuff around the wrist and the link attaches at a D-ring. Under load the path runs: link, D-ring, band webbing, around the wrist, back to the D-ring. The wrist takes most of the load as hoop tension in the webbing. The closure only has to stop the cuff opening.

Two bands can use the same materials, the same Velcro and the same overlap area and still differ by a large factor in what they hold, depending on where the overlap sits relative to the D-ring and which way the tail faces. A judge cannot see either difference across a registration table.

2. Velcro is much weaker in peel than in shear

Hook-and-loop is strong when the load runs parallel to the two faces and weak when it acts perpendicular to them, starting from an edge. Shear is quoted per unit **area**, because every engaged hook resists at once. Peel is quoted per unit **width**, because the load concentrates on one row of hooks at the peel front and strips them one row at a time.

Loading	Standard grade	Premium grade
Shear (parallel, per area)	10.5 psi ≈ 7.2 N/cm²	20 psi ≈ 13.8 N/cm²
Peel (perpendicular, per width)	≈ 0.18 N/mm	≈ 0.74 N/mm

Published values for nylon hook-and-loop. Product-specific and variable; orders of magnitude, not specifications.

Applied to a typical closure of 30 mm wide by 90 mm overlap (27 cm²), against the loads from the companion document:

Case	Force	Equivalent
Closure in **shear**, standard grade	195 N	20 kg
Closure in **shear**, premium grade	372 N	38 kg
Closure in **peel**, standard grade	**5 N**	**0.5 kg**
Closure in **peel**, premium grade	**22 N**	**2.2 kg**
Realistic retrieval load (1.5 m/s)	130 N	13 kg
Worst-case retrieval load (1.5 m/s, sideways)	972 N	99 kg
Peak shock load, non-elastic link	1 200–2 500 N	120–255 kg

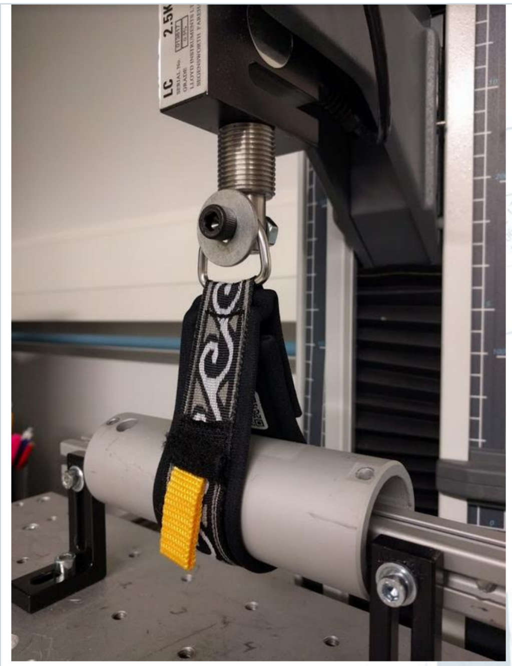
Flat lap-joint estimate. §3 explains why these are bounds rather than predictions, and §8 shows by measurement that they understate a wrapped closure by about four times. Band dimensions assumed, not measured.

Taken at face value these numbers make the closure look marginal: a premium 27 cm² overlap reaches only 372 N against a worst case of 972 N. They should not be taken at face value. Published Velcro data comes from flat coupons under a standard closing pressure, and a wrist band is a strap wrapped around a cylinder. §3 explains the difference and §8 measures it. In shear, a real wrapped band holds about four times the flat-coupon figure.

The table is still worth having. It gives a conservative floor for shear, it fixes the ratio between the two loading directions, and its peel column is the right order of magnitude, because the wrap protects shear and does nothing for peel.

3. The overlap is wrapped, not flat

A wrist band closure is not a flat lap joint. It is a strap wrapped around a cylinder, and the overlap covers a large arc of it, so part of the closure always sits on the far side of the wrist from the D-ring. This changes the mechanics in two opposite directions.



A complete wrist band closed around a cylinder as it is worn, carrying 2 500 N at the D-ring. The Velcro overlap wraps the underside of the cylinder, on the far side from the pull. Photograph: Espotel Oy tension test report, 23 April 2018.

3.1 How much of the wrist the overlap covers

A 170 mm wrist in a 3 mm sleeve gives a closed cuff of about 189 mm circumference, or 60 mm equivalent diameter.

Overlap length	Arc of the wrist	Share of circumference
50 mm (typical minimum)	95°	26%
70 mm	133°	37%
90 mm	172°	48%
110 mm	210°	58%

At 90 mm the overlap wraps about half the wrist, so whatever the load direction a large part of the closure is on the opposite side of the cylinder from the pull.

Cross-section through the wrist. Green is Velcro overlap in shear, held shut by the wrap. Orange is overlap sitting where the link lifts it off the wrist. Same band, same fastener, same overlap area.

3.2 Curvature turns pull into clamping pressure

A strap wrapped around a cylinder turns its own tension into pressure against that cylinder, the same way a rope holds on a bollard. For a band of width w at radius R carrying hoop tension T, the pressure is $p = T / (R \cdot w)$. Taking the worst-case 972 N shared between the two legs of the cuff, a 30 mm band on a 60 mm wrist develops about 540 kPa between the layers.

That pressure helps twice. It holds the hooks engaged instead of letting them relax, and it makes peel much harder to start, because the layers cannot separate unless the outer one grows in circumference, which means stretching the webbing. Where the wrap is loaded, geometry alone largely prevents peel.

This is the difference in the figure. With the overlap opposite the D-ring, the radial lift at the link becomes hoop tension and arrives at the closure as in-plane load, which is shear. With the overlap at the link, the same lift acts directly on an overlap edge, which is peel.

3.3 Load is not spread evenly along the overlap

Working the other way: in any lap joint the shear stress concentrates at the two ends of the overlap and is low in the middle, because load transfers into the joint gradually from each end. Geometric area therefore overstates effective area. Doubling the overlap does not double the static strength, and past a certain length extra overlap adds very little.

> **The two corrections work against each other and neither is quantified.** Wrap pressure raises capacity above the flat-coupon figures in §2; uneven stress distribution lowers it. Published Velcro data is measured on flat coupons and captures neither. Read the §2 numbers as rough bounds, not as predictions for any particular band. This is why the closure has to be tested rather than calculated.

3.4 What overlap length buys

If a peel front does start, it has to unzip the whole overlap before the cuff opens. At 5–22 N of front force, unzipping 90 mm takes 0.5–2.0 J and 90 mm of travel, and the band is still on the wrist the whole time. On a wrapped cuff the front also has to move into the region held shut by clamping pressure, so it may stop instead of running to the end.

This is worth being precise about. On a flat coupon a peel front that starts runs to failure at a fraction of the force it took to start, so failure is sudden and total. On a long, well-placed, wrapped cuff that is not necessarily so. Overlap length buys slow failure rather than static strength, which for a backup system is worth more.

3.5 Design rules

- Overlap at least 50 mm, and longer is better, for peel travel rather than static strength.
- Place the overlap so it covers the side away from the D-ring. This is free and worth a lot, and the diver cannot influence it.
- Keep the D-ring away from an overlap edge, where radial lift acts directly as peel.
- Point the free tail so load presses it shut, never so load lifts it.
- Band width sets both the pressure on the wrist and the width of any peel front. Wider is better on both counts.

3.6 What this means for the test rig

Clamping pressure goes as 1/R, so the diameter of the test pole changes the answer. A real wrist in a 3 mm sleeve is about Ø 60 mm. A Ø 40 mm pole develops about 51% more pressure between the layers at the same tension, so a tighter radius makes the closure perform better on the bench than on a diver.

> **Test on a pole of roughly wrist diameter: Ø 55 ± 5 mm.** A much smaller pole flatters the closure. Better still, cover the pole in neoprene of the thickness athletes wear and test it both uncompressed and compressed. The same applies to the field check in the companion document: close the band on a round object of realistic wrist size, exactly as it is worn.

4. Why the weakness is deliberate

§5.1.14 requires a quick release and accepts a Velcro wrist band as one. So the closure has two contradictory jobs: hold several hundred newtons during a retrieval, and open by hand instantly with cold fingers in an emergency.

Being much stronger in one direction than the other is the only way to do both, and the wrap decides which direction applies. The band is strong the way the retrieval pulls and weak the way the diver pulls to get out, peeling the tail outwards away from the wrap. That is the property that makes Velcro usable here at all. It also means the closure's safety depends on orientation, which comes from geometry and body position rather than from the material.

5. What can still turn shear into peel

5.1 Off-axis pull and rotation

The favourable geometry in §3 holds while the overlap stays opposite the load. An unconscious diver rotates freely and the cuff can rotate on the wrist, so the relative position is not fixed. If the overlap turns round to the load point, the band moves from the left-hand case in the figure to the right-hand one without anything breaking.

5.2 Slack at depth

Rotation needs slack, and depth provides it. Neoprene compresses: measurements across 33 commercial samples give an average thickness reduction of 64.3% at 200 kPa, equivalent to 20 m.

Sleeve thickness	Circumference at surface	At 20 m	Slack
3 mm	189 mm	177 mm	**12 mm (6.4%)**
5 mm	201 mm	181 mm	**20 mm (10.0%)**

Slack from neoprene compression, assuming a 170 mm bare wrist. Competition depths are well beyond 20 m, so these are lower bounds.

A band tightened properly at the surface is measurably loose at depth. Slack lets the cuff rotate before it takes load, so the band reaches load in an unknown orientation, and it also reduces the wrap pressure that was holding peel back. The closure is loosest and least predictable at exactly the depth where a blackout is most likely.

5.3 Dirt and water

Salt, sand and hair clog the loop side and reduce the number of hooks that engage. Water lubricates the band against the sleeve and reduces the friction that resists rotation. Neither effect is quantified anywhere, and both reduce capacity.

6. The load lasts longer than the test

Velcro creeps under sustained shear: hooks let go progressively rather than all at once. A retrieval from 100 m at the rule minimum of 1 m/s loads the band for about 100 seconds. The static lift test in the companion document holds for 15.

Fifteen seconds is a screen. It catches gross slip, badly oriented closures and badly placed overlaps, which is what a registration check needs. It says nothing about creep over a real retrieval. Creep rates for wet, salt-contaminated Velcro do not appear to be published, and a manufacturer testing to Tier 1 could measure them cheaply. A 120-second hold at the same load would be far more representative.

7. What reaches the wrist

If the closure holds, the load goes into the arm. Assuming it is spread over about half the wrist circumference:

Band width	Worst case (972 N)	Shock peak (2 500 N)
20 mm	572 kPa	**1 471 kPa**
30 mm	381 kPa	**980 kPa**
40 mm	286 kPa	**735 kPa**

Contact pressure on the wrist. Distribution is idealised; real pressure concentrates at the band edges, so these underestimate the local peak.

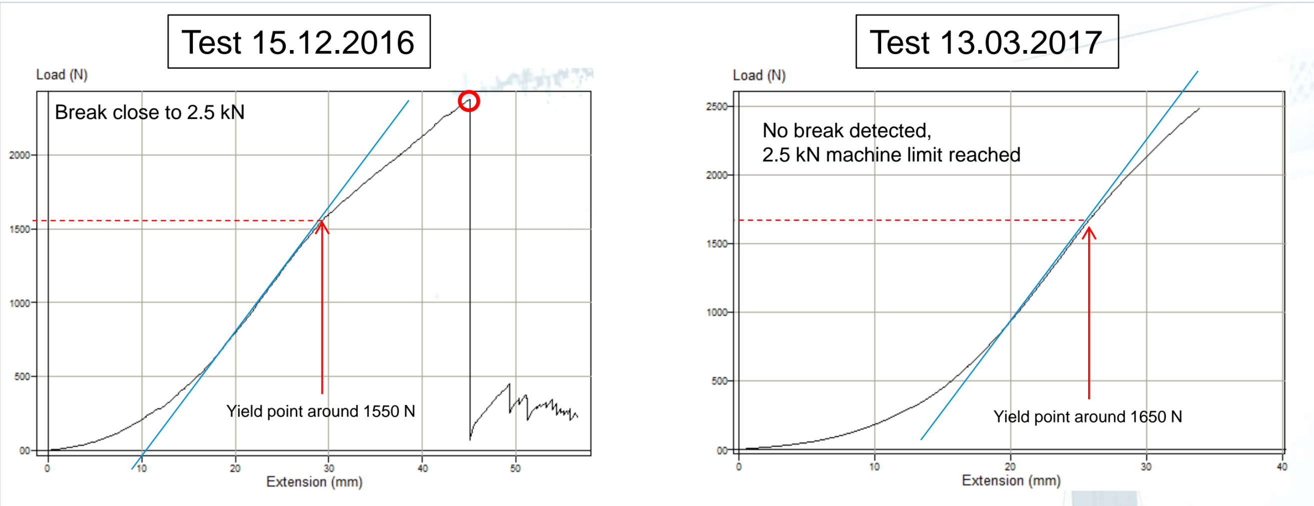
Band width is a safety parameter the rules do not mention: going from 20 mm to 40 mm halves the pressure on the wrist at no cost. The shock column is where injuries happen. Steady retrieval pressures are uncomfortable and will bruise; shock pressures are two to three times higher and arrive in milliseconds. This supports the argument in the companion document that a less stiff legal link protects the diver as well as the hardware.

Injury thresholds for wrist and forearm compression are not established here. This is the most useful missing number in the field. Without it, no acceptable peak force or minimum band width can be set on evidence rather than judgement.

8. What a real band holds, measured

A closure of this type has been tested to destruction in the geometry described in §3. It holds about four times what published Velcro data predicts for a flat joint of the same area. Where the measurement and the estimate disagree, use the measurement.

Setup: a complete FreeXperience wrist band closed around a horizontal cylinder as it is worn, Velcro grip length set midway between its maximum and minimum, load applied vertically at the D-ring by a Lloyd Instruments testing machine at 60 mm/min.



Measured load-extension behaviour. Both curves show a toe region as the cuff beds onto the cylinder, a linear region, then a gradual departure from linearity at yield. No sudden slip. Left: broke close to 2.5 kN. Right: no failure, 2.5 kN machine limit reached. Source: Espotel Oy tension test report, 23 April 2018.

Test	Yield	Result
15 December 2016	1 550 N (158 kg)	Broke at about 2 350 N (240 kg), at ~45 mm extension.
13 March 2017	1 650 N (168 kg)	**No failure.** Reached the 2 500 N (255 kg) machine limit at ~34 mm extension, closure still holding.

Espotel Oy tension test report, 23 April 2018; tests dated 15 December 2016 and 13 March 2017.

So a correctly closed band of this construction starts to yield at 1 550–1 650 N, around 160 kg, and does not let go below 2 350 N (240 kg). In one of the two tests it survived the machine's full 2 500 N without failing.

8.1 Why catalogue figures understate a wrapped closure

Working from published Velcro values (§2) and halving the load for the wrap gives about 390 N, against 1 600 N measured. Three things compound, and §3.3 explains why none of them can be read off a data sheet:

- Published shear figures come from flat coupons under a standard closing pressure. They do not include the pressure a wrapped cuff generates from its own tension.
- Purpose-made webbing closures are not consumer-grade Velcro. The psi values in §2 describe general-purpose hook-and-loop, not the heavy-duty combinations used in load-bearing straps.
- The assumed geometry was conservative. §2 uses a 30 × 90 mm overlap; a real band is wider and the wrap is longer.

> **The direction of this gap matters more than its size.** Flat-coupon data understates a wrapped closure by four times in shear. Do not assume the same margin exists in peel. The wrap protects shear and does nothing for peel, and peel capacity of a real band has not been measured.

8.2 Against the loads that occur

Load	Force	Against the measured 1 550–1 650 N yield
Realistic retrieval, 1.5 m/s	130 N (13 kg)	Holds, 12× margin.
15 kg field check	147 N (15 kg)	Holds, 11× margin. Comfortably non-destructive.
Worst case, sideways	972 N (99 kg)	Holds, 1.6× to yield and about 2.4× to break.
Shock peak, non-elastic link	1 200–2 500 N	**Inside the failure range. A shock can reach yield and, at the top end, the breaking load.**

The closure carries even the worst steady retrieval load, with 1.6× margin. That margin exists because of the load sharing in §1 and §3: the webbing loop, the strap doubled back through the D-ring and the hand as a stop all reduce what reaches the Velcro, and the wrap clamps shut what does reach it. In steady retrieval the closure is not the weak link.

Shock is different. Measured yield at 1.6 kN sits inside the range a non-elastic link produces in a drop. That is another reason to take the position in the companion document: peak force, not steady drag, is what threatens the hardware and the diver, and controlled stretch at the softer end of the legal range is what reduces it.

8.3 What the measurement does not settle

- **Peel.** Not tested. The argument in §2–§4 rests on published data and physics, not on this measurement.
- **Overlap position.** Both tests used a correctly built band. The penalty for putting the overlap at the D-ring is argued, not measured.
- **Condition.** New, clean, dry, at the surface. Salt, sand, sleeve compression at depth and creep over 100 seconds all reduce capacity by unknown amounts.
- **Rate.** 60 mm/min is slow. Dynamic loading stiffens the response and shifts the curve up.
- **Sample size.** Two tests, one band design, one manufacturer.

9. Conclusions

1. **A correctly built and correctly closed band holds around 160 kg before it yields and does not let go below 240 kg**, measured in the geometry it is worn in. That is 12× the realistic retrieval load of 13 kg and 1.6× the worst case of 99 kg (§8).
2. **Do not specify or assess a band from catalogue values alone.** Flat-coupon figures leave out the pressure a cuff generates from its own tension and understate a wrapped closure by about four times in shear. The margin is not symmetrical: the wrap protects shear and does nothing for peel.
3. **Geometry decides this, not the grade of Velcro.** Measured shear capacity is about 1 600 N; estimated peel capacity for the same width is 5–22 N. Even allowing generously for the estimate, that is two orders of magnitude, and peel has not been measured. It is the most useful test still missing.
4. **The closure is exposed to shock, not to steady load.** Measured yield at 1.6 kN is inside the range a non-elastic link produces in a drop. Steady retrieval is covered comfortably; a shock is not.
5. **Overlap length buys slow failure, not proportional strength.** Uneven stress distribution limits what extra area contributes statically, but a long wrapped overlap makes any peel front travel its full length against rising clamping pressure and may stop it entirely.
6. **Put the overlap away from the D-ring and point the tail so load shuts it.** Both are free at the design stage, both are worth a large factor, and neither shows up in an inspection.
7. **Test on a Ø 55 ± 5 mm pole.** A Ø 40 mm pole develops about 51% more pressure between the layers than a real wrist and flatters the closure. Better still, test over neoprene both uncompressed and compressed.
8. **The geometry cannot be calculated reliably, so the closure has to be tested as worn.** That is what the 15 kg static lift does. At 147 N it sits above the realistic 130 N retrieval load, below the shear capacity of a sound closure, and 7 to 28 times above any peel capacity, so it passes a well-built band and fails a badly oriented one straight away. Closing the band on a round pole exactly as worn is not a detail of the test.

Basis, assumptions and limits

Measured. Closure capacity in §8: Espotel Oy, Tension test for FreeXperience products, 23 April 2018 (Sami Inkilä); tests of 15 December 2016 and 13 March 2017, Lloyd Instruments testing machine, 60 mm/min, band closed around a cylinder as worn. The same report covers complete lanyards: yield around 630 N, and two samples pulled to failure at about 2 200 N, both breaking without throwing off parts.

Sourced. Velcro shear and peel figures from published nylon hook-and-loop test data (indicative, product-specific, and shown in §8.1 to understate a wrapped closure). Neoprene compression: 64.3% average thickness reduction at 200 kPa across 33 commercial samples, Rutkowska et al., Polymers 17(21):2820, 2025. Rule references from AIDA World Apnea Competition Rules & Regulations V17.8. Retrieval loads from the companion document.

Assumed. Closure of 30 × 90 mm and a 170 mm bare wrist in the §2 and §3 worked figures; load spread over half the wrist circumference; hoop tension of half the applied load per leg.

Not established. Peel capacity of a real band, which is the most useful missing measurement. Also: the penalty for putting the overlap at the D-ring; creep rates for wet or salt-contaminated Velcro under sustained load; the effect of dirt and sleeve compression on engaged area; the dynamic correction to the 60 mm/min results; injury thresholds for wrist compression.

Disclosure. FreeXperience makes and sells freediving lanyards and would be affected by any standard adopted in this area. The analysis can be reproduced from the figures and assumptions given, and corrections are welcome — freexperience.com.