Design of Rescue Anchorages through the 10:1 Static System Safety Factor

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International Commission for Alpine Rescue

STANDARD RESCUE LOAD (SRL) DEFFINITION

1. SRL definition
2. SSSF definition
3. Anchoring points
4. Link element
5. Connectors
6. Analysis conclusion
7. Anchor types

Description	Mass [kg]	Weight [kN]	Represents
Single Rescuer	100	1	Rescuer+ Gear
Standard rescue load	200	2	Victim+ Rescuer+ Gear

Source: *ASTM F2266-03*
N. P. S. Department of the Interior, NPS Technical Rescue Handbook, 11 th. Department of the Interior, National Park Service, 2014

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STATIC SYSTEM SAFETY FACTOR (SSSF) DEFINITION

"The safety factor, the factor of our ignorance!"

- Quick field calculations
- Dimensioning anchorages to withstand shock loads
- *Static Safety Factor (SSF) assigned to each element*

$$SSF = \frac{Element\ failure\ load}{Estimated\ static\ load}$$

- *Static System Safety Factor (SSSF) assigned to system*

$$SSSF = \min(SSF)$$

- *Example for calculating the SSF for EN 1891 A rope loaded with SRL*

$$SSF = \frac{22\ kN}{SRL} = \frac{22\ kN}{2\ kN} = 11\ or\ 11{:}1$$

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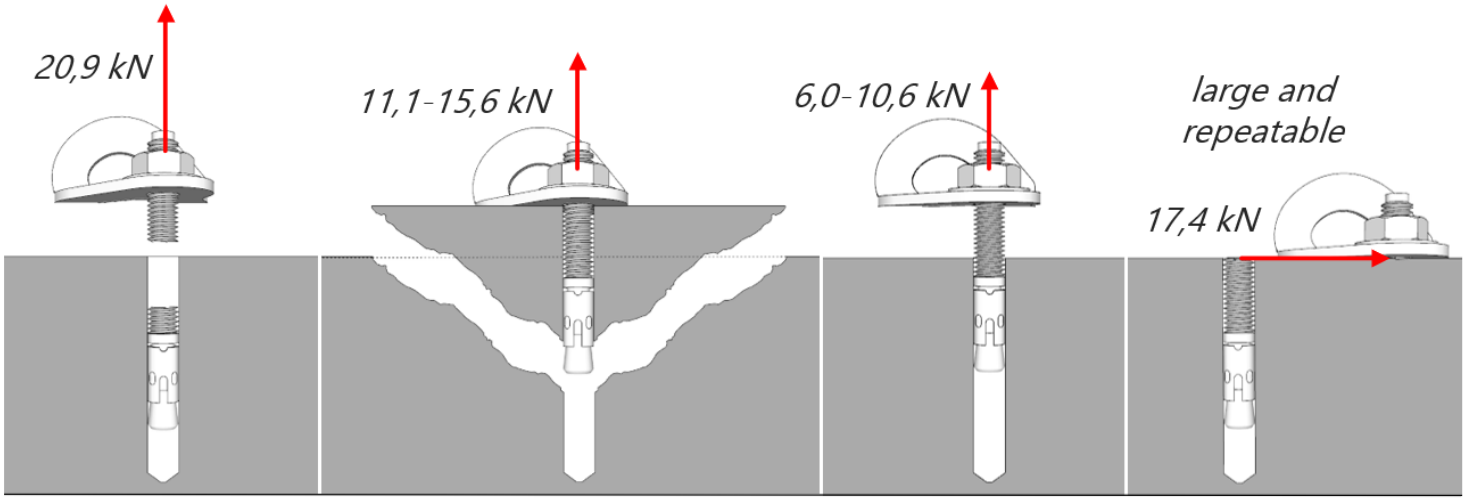
PITONS

- Pitons EN 569
  - type S (25 kN)
  - type P (12,5 kN)
- *Steel type*
  - *Soft steel pitons HRC < 22*
  - *Hard steel pitons HRC > 38*
- *Failure loads:*
  - *Varies between 6 and 18 kN*
  - *In average 11 kN (soft pitons), 10,5 kN (hard pitons)*

Source: A. *Manes and F. Cadini Assessment of the Ultimate Actual Strength of Rock-Climbing Protection Devices: Extraction Tests in the Field and the Human Capability to Predict the Ultimate Strength*

ANCHOR BOLTS

- Preferred use for mountain rescue operations
- Determining bolt location visually, aurally and tactilely
- Drill with 4 cutting edges, brushing and blowing the drill hole



Source: INDEX, "MT Mechanical anchors Technical Guide," Spain, 2022.
Wikipedia, "Concrete cone failure, "https://en.wikipedia.org/wiki/Concrete_cone_failure

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ANCHOR POINT LOAD ANALYSIS

- Triangle of forces
- Assumption: the force is distributed evenly over both anchor arms
- Curve proportion of the load force on anchor arms
- **Max anchor point load @ SRL 58% · 2 kN = 1,16 kN**

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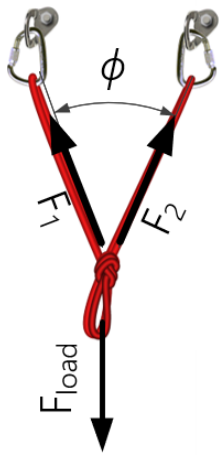

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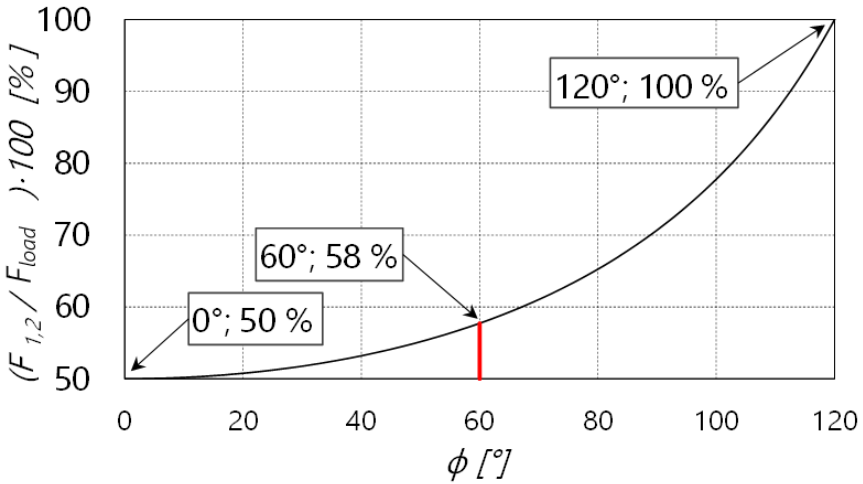

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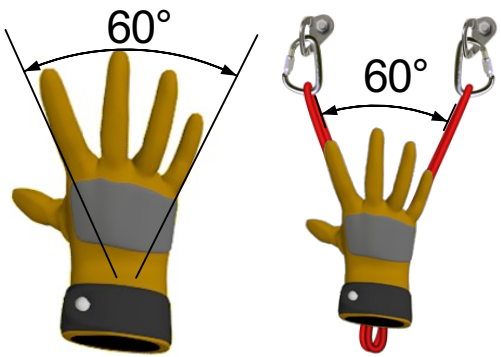

c)

ANCHOR POINT SSF ANALYSIS

Element	Piton Transversely	Bolt Axially	Bolt Transversely
Failure load [kN]	11	8,30	17,40
SSF @ 1,16 kN (2 anc. points)	9,48	7,16	15,00
SSF @ 2kN/3=0,67 kN (3 anc. points)	16,41	12,39	/

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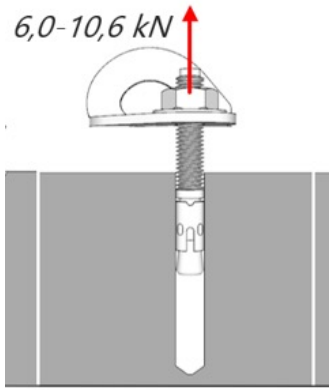
$$SSF_{piton} = \frac{Failure\ load}{58\% \cdot SRL} = \frac{11\ kN}{1{,}16\ kN} = 9{,}48\ or\ 9{,}48{:}\,1$$

- Rescue anchors construction findings:
  - Three arms with EN 569 S pitons.
  - Three arms with three axially loaded anchor bolts.
  - Two arms with two transversely loaded anchor bolts.
- Add one more anchor point if in doubt!



Pull-Out Failure

$$SSF_{piton} = \frac{Failure\ load_{min}}{SRL/4} = \frac{6\ kN}{2/4\ kN} = 12\ or\ 12{:}\,1$$

LINK ELEMENT

- Links individual anchor points to a master point
- Suitable elements:
  - Semi-static rope EN 1891 A (22 kN in general ≈30 kN)
  - PA (nylon) slings EN 566 (22 kN)
  - Single- dynamic EN 892
  - Accessory cords EN 564 Φ 7 mm (9,8 kN), Φ 8 mm (12,8 kN)
- Load capacity of the link element increases with the multiple of the number of loops.

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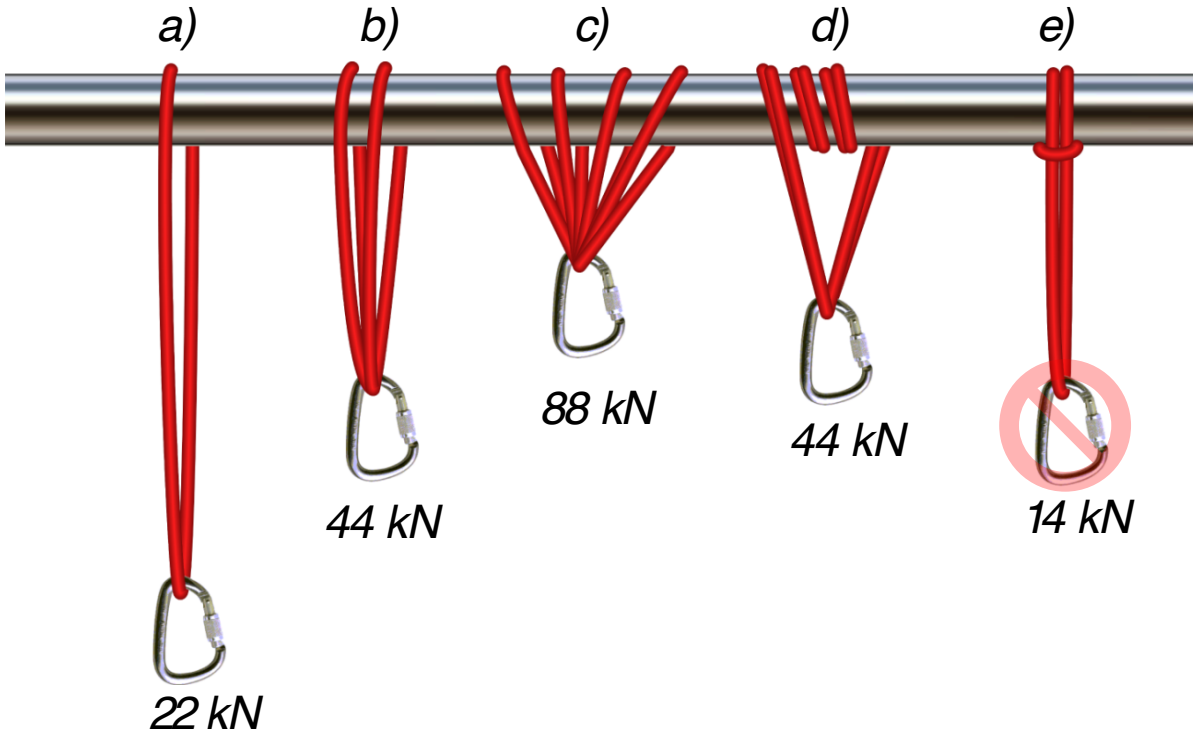
ENHANCING LINK ELEMENT LOAD CAPACITY



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FAILURE LOADS OF LINK ELEMENT WITH KNOTS

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Knot	Failure loads in knot [% nominal breakage strength]
Overhand knot as master point	65
Double bowline as master point	65
Figure 8 as master point	65
Figure 9 as master point	85
Overhand knot for connecting ropes	45
Figure 8 for connecting ropes	40

Failure load in Figure 8 knot using EN 566 sling: 22 kN · 40 % = 8,8 kN.

Source: Darko. Bakšić, U. Ilič, Dejan. Žugelj, and Maks. Merela, Vozli v jamarstvu in pri reševanju iz jam priročnik. Jamarska zveza Slovenije, Jamarska reševalna služba, 2013.

EN 566 SLING SSF ANALYSIS

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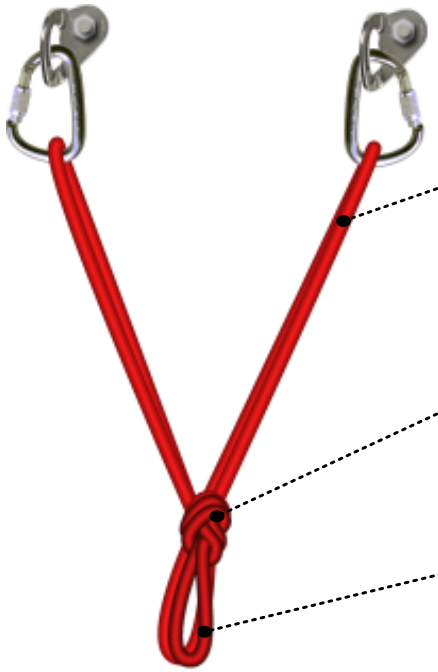

$$SSF = \frac{22\ \text{kN}}{58\ \% \cdot \text{SRL}} = \frac{22\ \text{kN}}{1{,}16\ \text{kN}} = 18{,}97$$

$$SSF = \frac{65\ \% \cdot 2 \cdot 22\ \text{kN}}{\text{SRL}} = \frac{28{,}6\ \text{kN}}{2\ \text{kN}} = 14{,}30$$

$$SSF = \frac{22\ \text{kN}}{\text{SRL} / 2} = \frac{22\ \text{kN}}{1\ \text{kN}} = 22{,}00$$

Knot	Failure loads in knot [% nominal breakage strength]
Overhand knot as master point	65

EN 1891 A SEMI-STATIC ROPE SSF ANALYSIS

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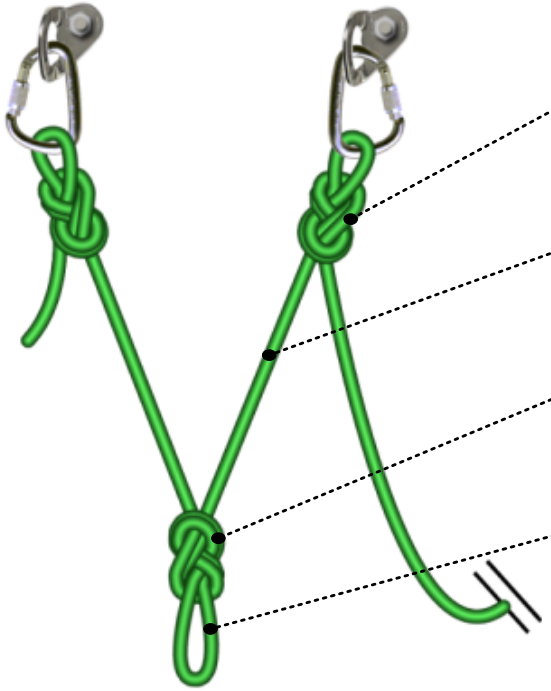

$$SSF = \frac{65\,\% \cdot 22\ \text{kN}}{58\,\% \cdot \text{SRL}} = \frac{14{,}30\ \text{kN}}{1{,}16\ \text{kN}} = 12{,}33$$

$$SSF = \frac{22\ \text{kN}}{58\,\% \cdot \text{SRL}} = \frac{22\ \text{kN}}{1{,}16\ \text{kN}} = 18{,}97$$

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$$SSF = \frac{22\ \text{kN}}{\text{SRL} / 2} = \frac{22\ \text{kN}}{1\ \text{kN}} = 22{,}00$$

- dynamic EN 892 single ropes

EN 564 ACCESSORY CORDS SSF ANALYSIS

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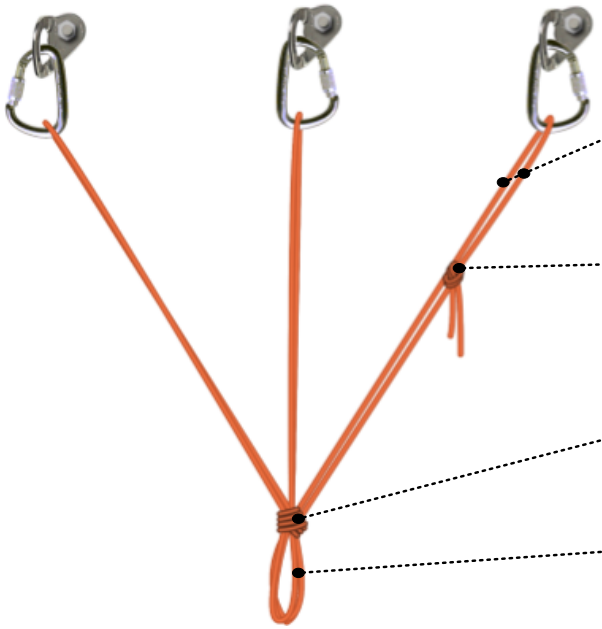


Both strands of the accessory cord

$$SSF = \frac{45\,\% \cdot 9{,}8\ \text{kN} + 9{,}8\ \text{kN}}{SRL/3} = \frac{14{,}21\ \text{kN}}{0{,}67\ \text{kN}} = 21{,}21$$

Overhand knot – rope connection

$$SSF = \frac{45\,\% \cdot 9{,}8\ \text{kN}}{\text{SRL}/6} = \frac{4{,}41\ \text{kN}}{0{,}33\ \text{kN}} = 13{,}36$$

$$SSF = \frac{65\,\% \cdot 6 \cdot 9{,}8\ \text{kN}}{\text{SRL}} = \frac{38{,}22\ \text{kN}}{2\ \text{kN}} = 19{,}11$$

$$SSF = \frac{3 \cdot 9{,}8\ \text{kN}}{\text{SRL}/2} = \frac{29{,}40\ \text{kN}}{1\ \text{kN}} = 29{,}40$$

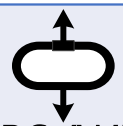
$SSF_{\varphi 6\text{-}3\ points}$= (45% · 7,2 kN) / (0,67 kN/2)= 9,67

$SSF_{\varphi 7\text{-}2\ points}$= (45% · 9,8 kN) / (1,16 kN/2)= 7,60

$SVF_{\varphi 8\text{-}2\ points}$= (45% · 12,8 kN) / (1,16 kN/2)= 9,93

CONNECTORS

- Minimum Breaking Strength (MBS)
- Working Load Limit (WLL) unless explicitly stated 25 % MBS = MBS/4

Connector	 MBS (WLL)	 MBS (WLL)	 MBS (WLL)
Petzl William	27 kN (6,75 kN)	8 kN (2 kN)	8 kN (2 kN)
Petzl OK	25 kN (6,25 kN)	7 kN (1,75 kN)	8 kN (2 kN)
Petzl Am'D	25 kN (6,25 kN)	7 kN (1,75 kN)	8 kN (2 kN)

- When loaded in long axis direction with doors closed WLL exceed the SRL values > 3 x

Source: R. Delaney, "Physics for Roping Technicians 2022," 2022.
PETZL, "PETZL Verticality lighting 2022 professional catalog," 2022.

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SSSF ANALYSIS CONCLUSION

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1. Transverse Loading of Anchor Bolt: Use a two-arm anchorage.
2. Axial Loading of Anchor Bolt: Use a three-arm anchorage.
3. Using Pitons: Minimum three-arm anchorage is required.
4. EN 1891 A Semi-static Ropes and EN 566 Slings: Minimum two-arm anchorage shall be constructed.
5. Rescue Anchorages: Can be constructed with Φ 7 mm and Φ 8 mm accessory cords, whereas minimum three-arm anchorage shall be constructed.
6. EN 892 Single Dynamic Ropes: Minimum three-arm anchorage shall be constructed.

EN 566 SLING ANCHOR TYPES: 2 POINTS

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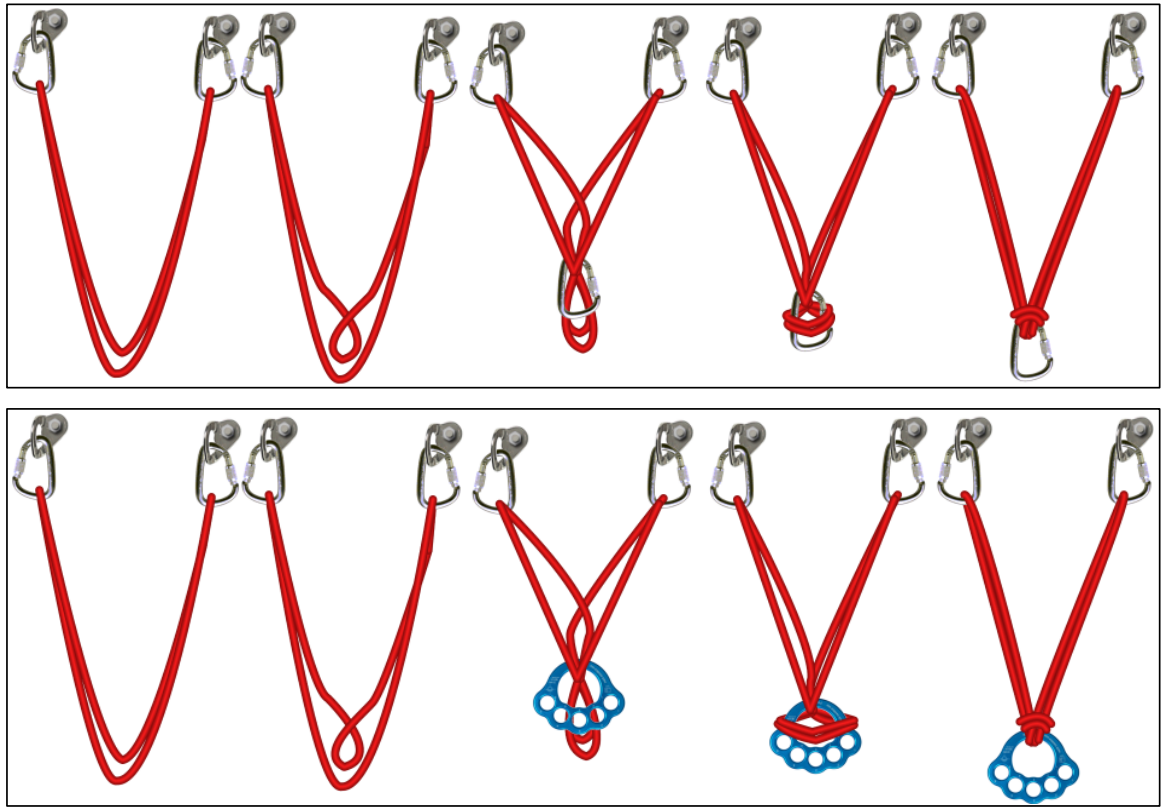

Source: Karsten Delap, "Climbing Anchors: The Girth Hitch Master Point (don't do this)," https://www.youtube.com/watch?v=dgHlAlucRvc&t=300s

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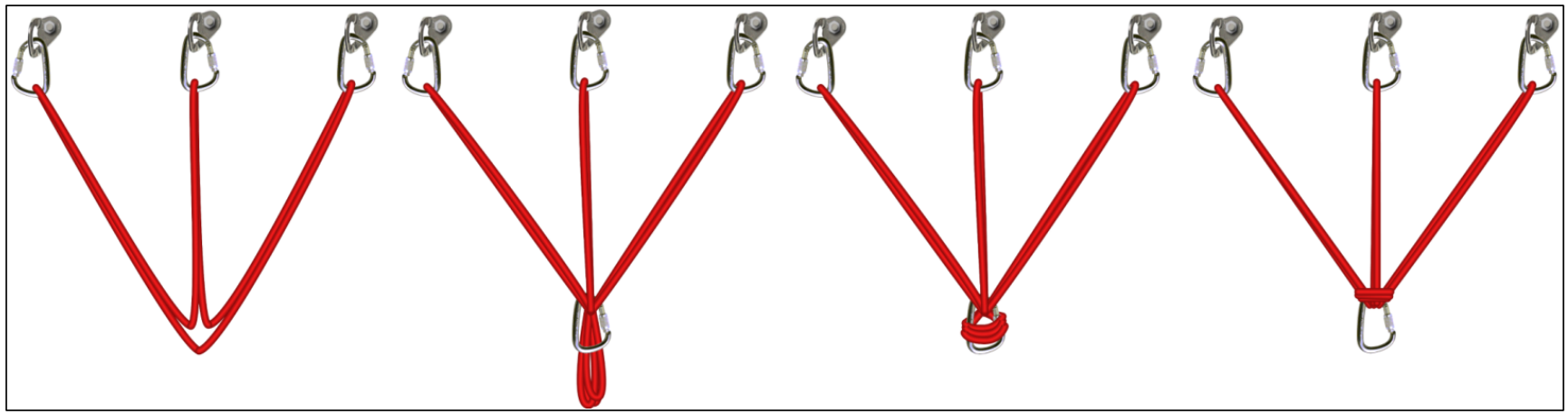
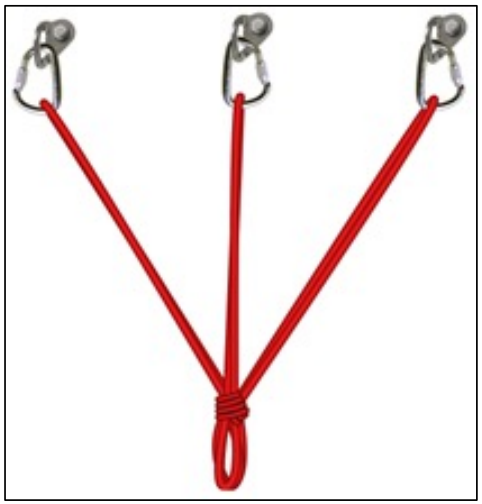
EN 566 SLING ANCHOR TYPES: 3 POINTS





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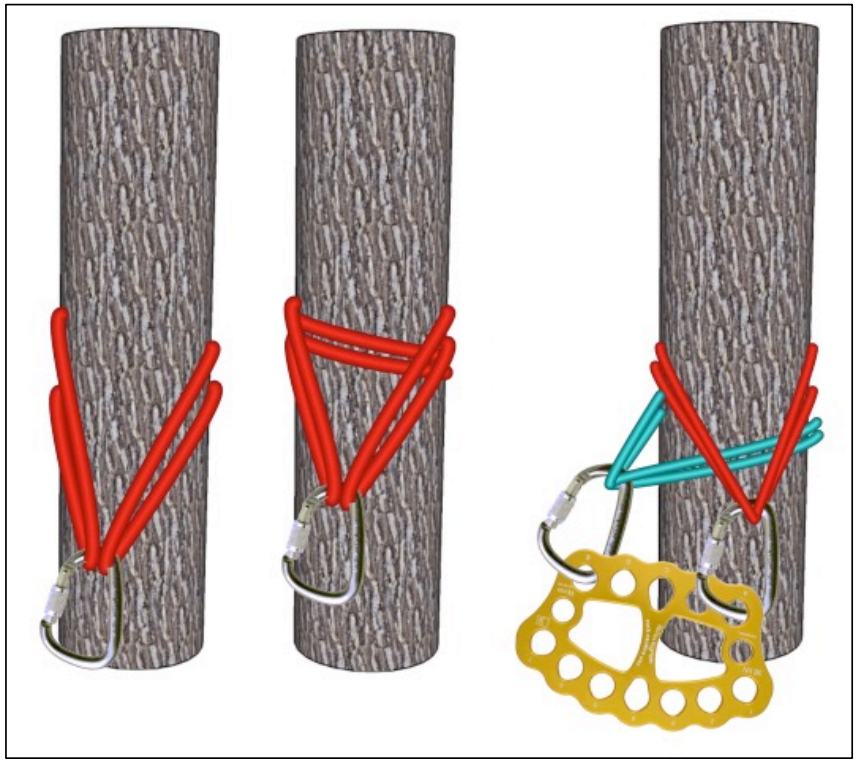
EN 566 SLING ANCHOR ON TREES



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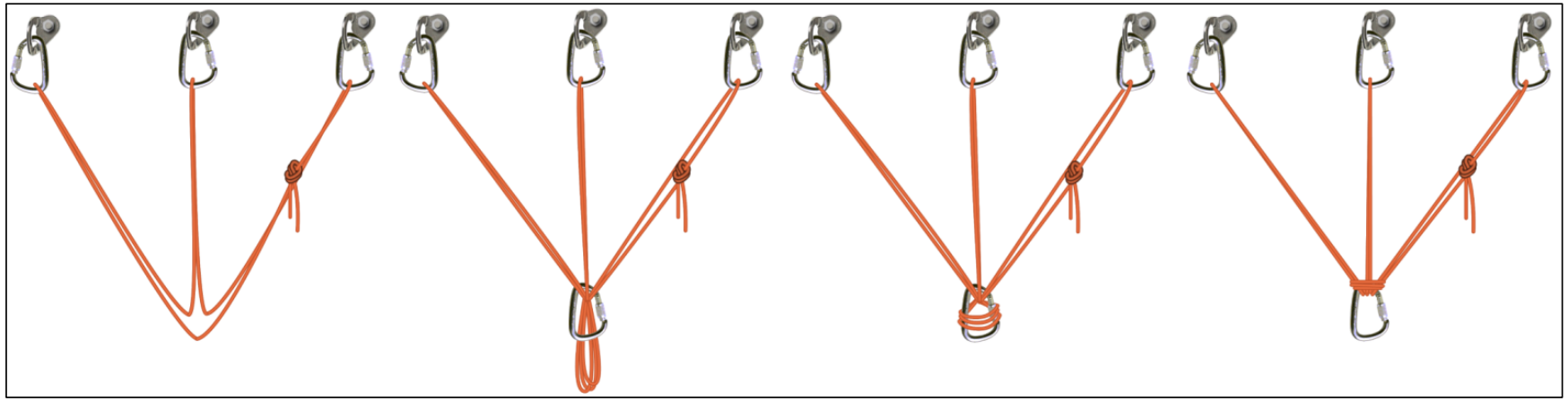
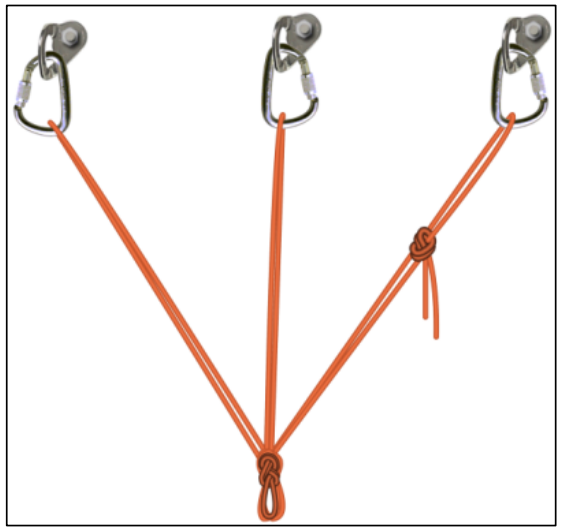
EN 564 Φ7 AND Φ8 ACCESSORY CORD: 3 POINTS





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EN 1891 A SEMI-STATIC ROPE

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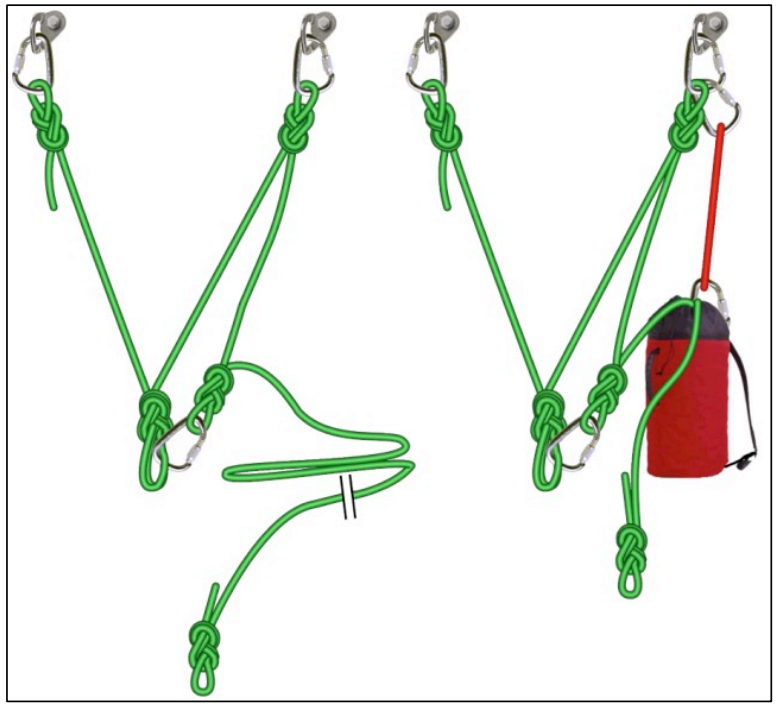
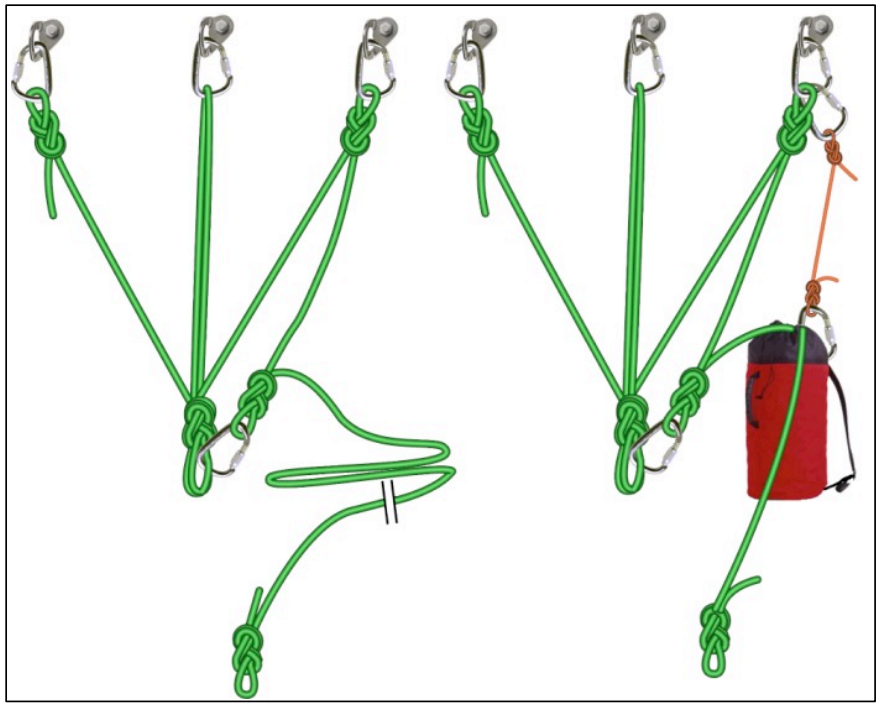
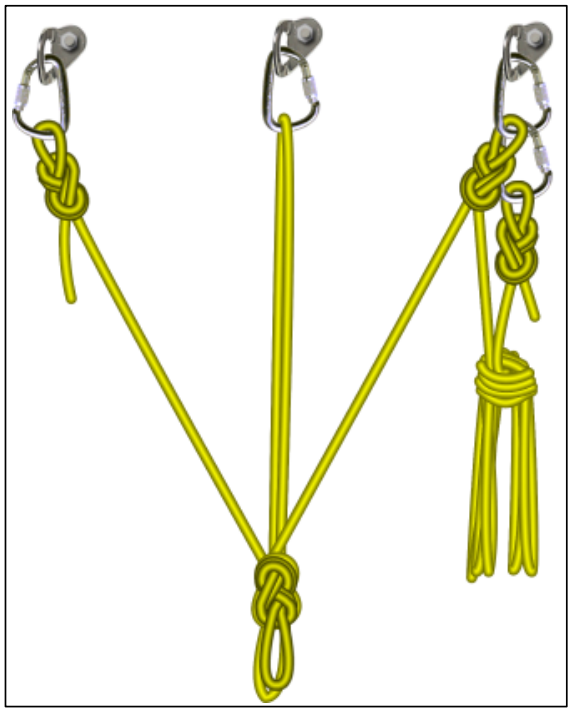




EN 892 DYNAMIC SINGLE ROPE



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