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TECHNICAL COMMITTEE NOTE TCN 18/01

BELAY DEVICE EFFECTIVENESS

SUMMARY

This report is a summary of work carried out by W.J. Stronge and various students at Cambridge University and published in Ref. 1.

The report introduces the concept of an amplification factor for belay devices, i.e. the ratio between the force in the part of the rope going to the falling climber (the 'live' end) to the grip force produced by the belayer's hand (the 'tail' end). Measurements of these forces have been made for various different belay devices and different ropes. In addition, some measurements of individual's hand forces have been recorded.

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Approved by the Technical Committee:	MPNoa

INTRODUCTION

The principle function of a belay device is to increase or amplify the belayer's hand force. The amplification factor is the ratio of tension on the "live" side of the belay device that goes to the climber to the hand force provided by the belayer. Measurements of the amplification factor provided by various belay devices have been measured at rather small rates of pull of rope through the device (0.075 m/s). Preliminary indications are that the amplification factor decreases slightly with rate of pull of rope through the device.

RESULTS

Amplification Factor for Belay Devices used with 3 Different Diameter Ropes

(a) Apollo 11mm; (b) Booster 9.7mm and (c) Ice Line 8.1 mm

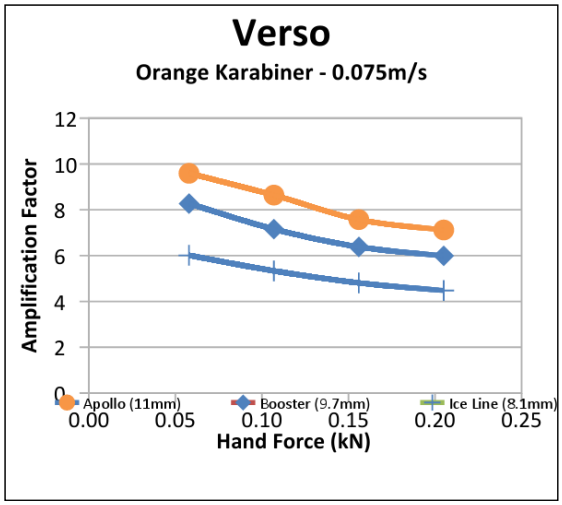


Fig 6a: Verso amplification for 3 rope diameters:

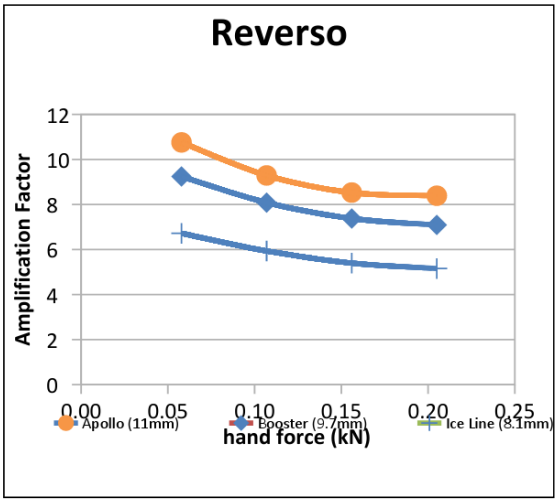


Fig 6b: Reverso amplification for 3 rope diameters

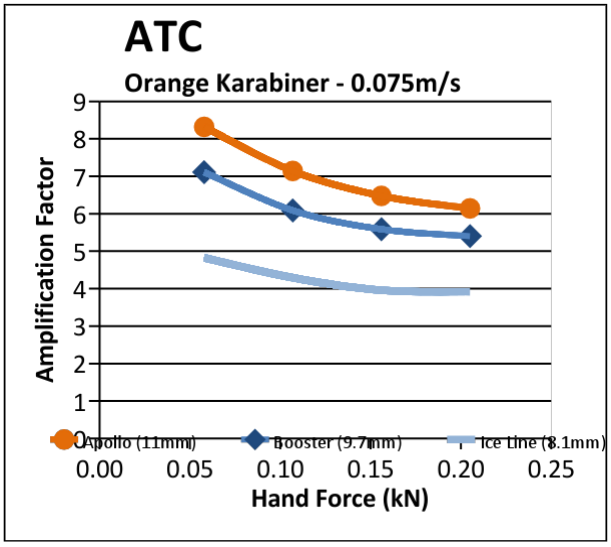


Fig 6c: ATC amplification for 3 rope diameters

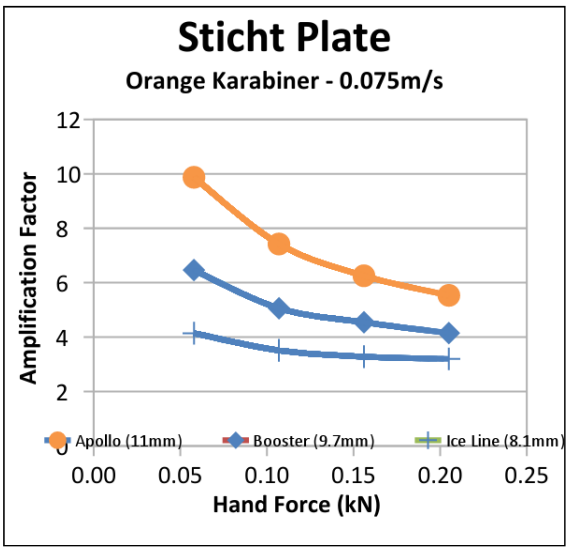


Fig 6d: Sticht Plate amplification for 3 rope diameters

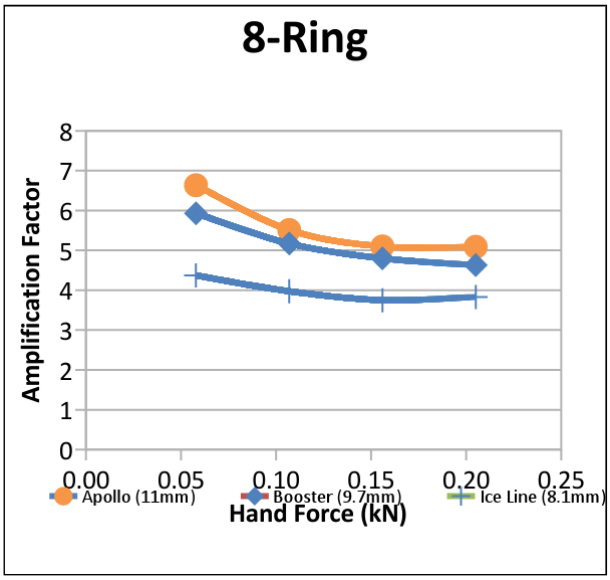
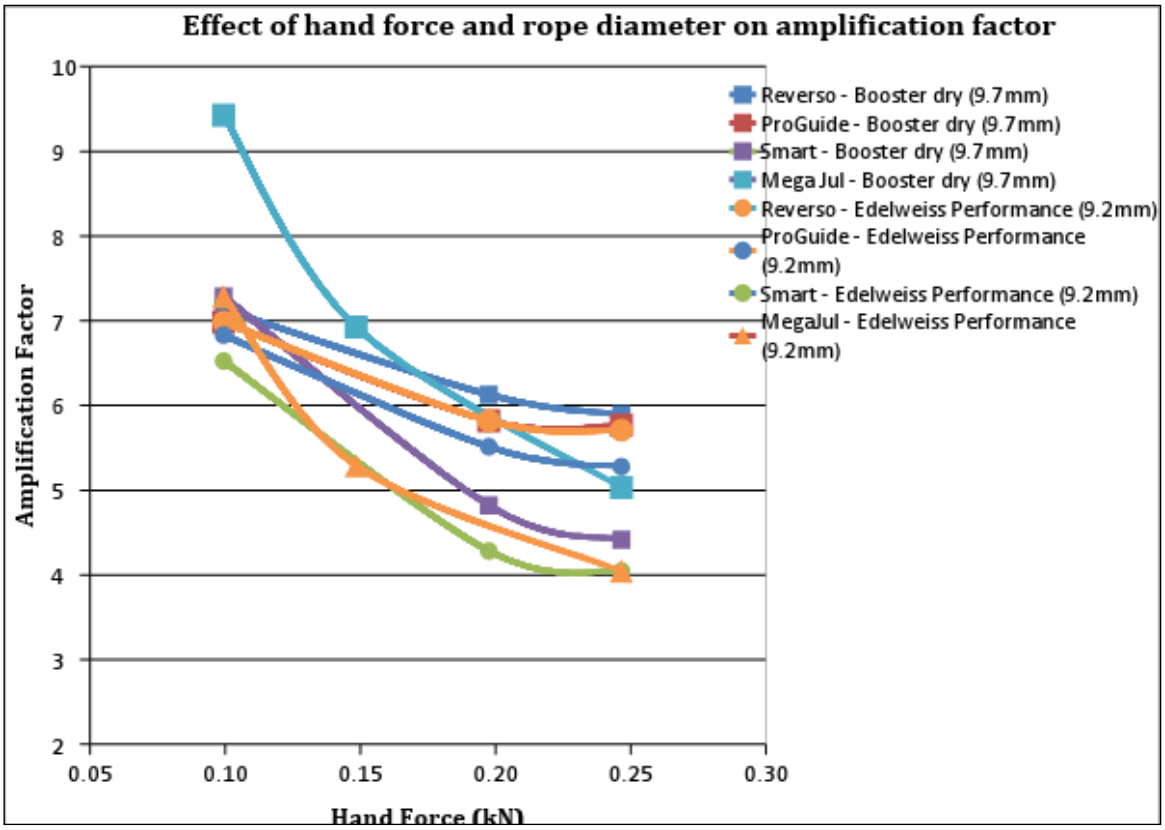


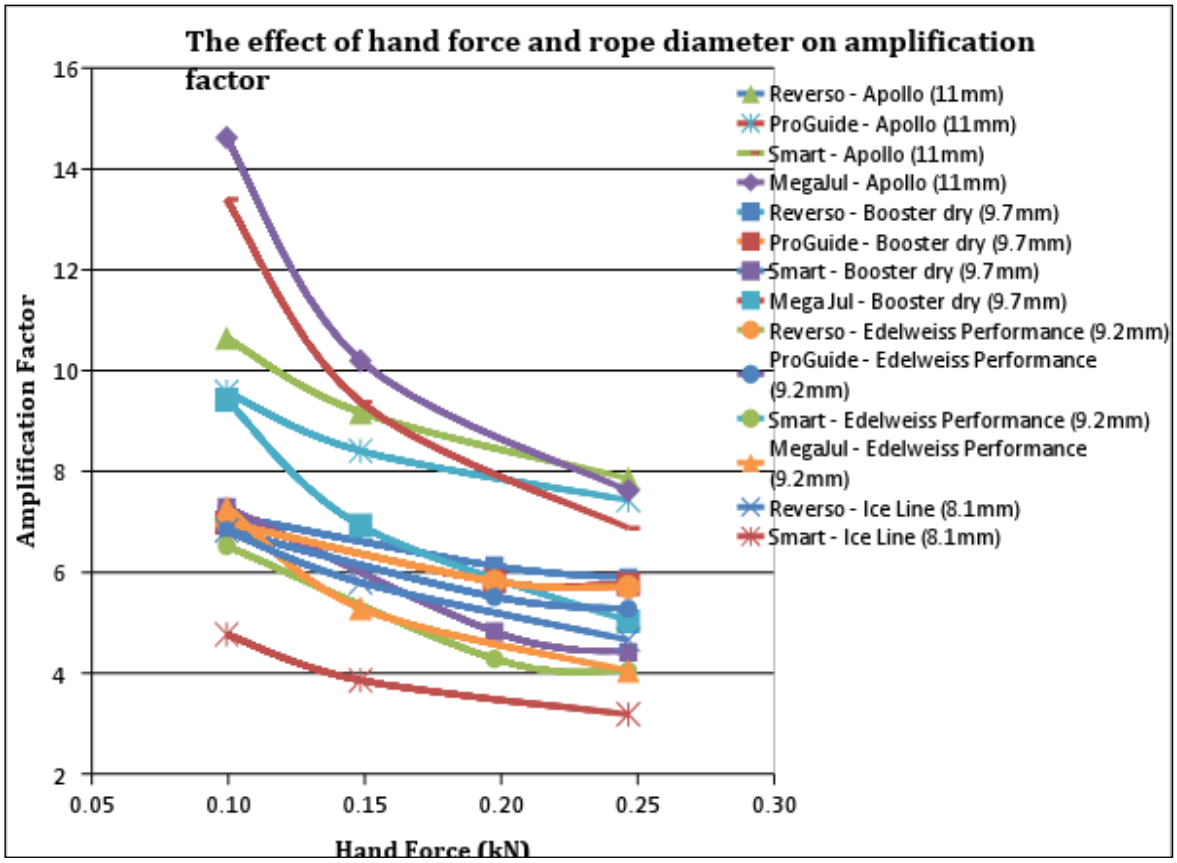
Fig 6e: Figure 8 amplification for 3 rope diameters

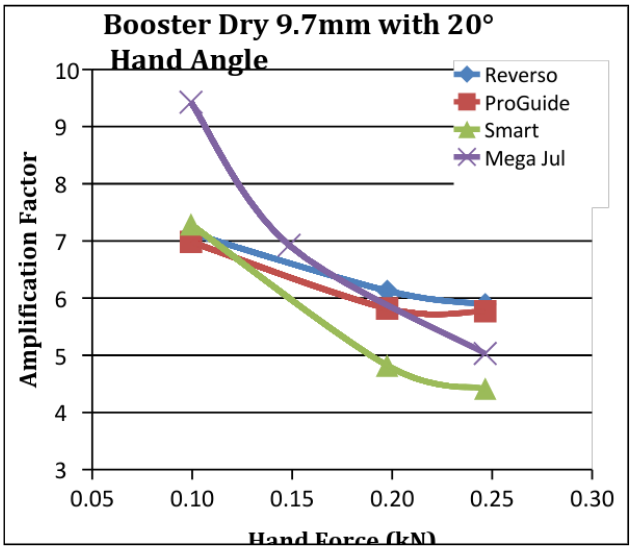
Amplification factor for ropes with 0.2 kN, (0.25 kN) hand force

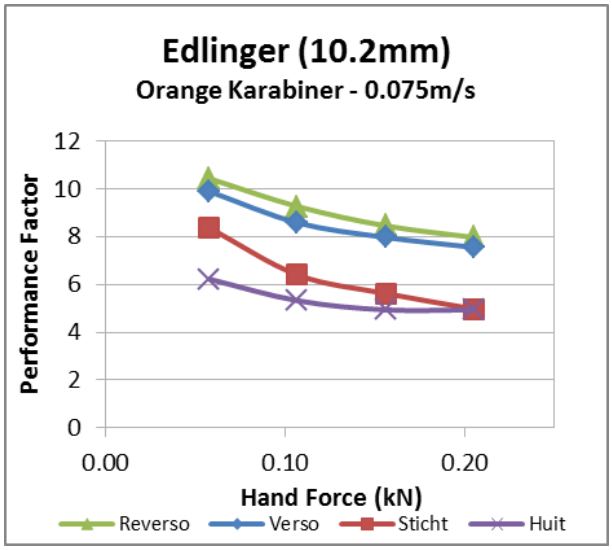
9.7 mm Booster			**11 mm Apollo**	
Device	**Amp. Factor**		**Device**	**Amp. Factor**
Sticht Plate	4.1		Sticht Plate	5.7
8-Ring	4.7		8-Ring	5.2
SMART	4.7 (4.5)		SMART	7.7 (7.0)
ATC	5.4		ATC	6.0
MegaJul	5.8 (5.0)		MegaJul	8.5 (7.6)
ProGuide	5.8 (5.8)		ProGuide	7.7 (7.5)
Verso	6.0		Verso	7.2
Reverso 3	6.3 (5.9)		Reverso 3	8.4 (7.9)

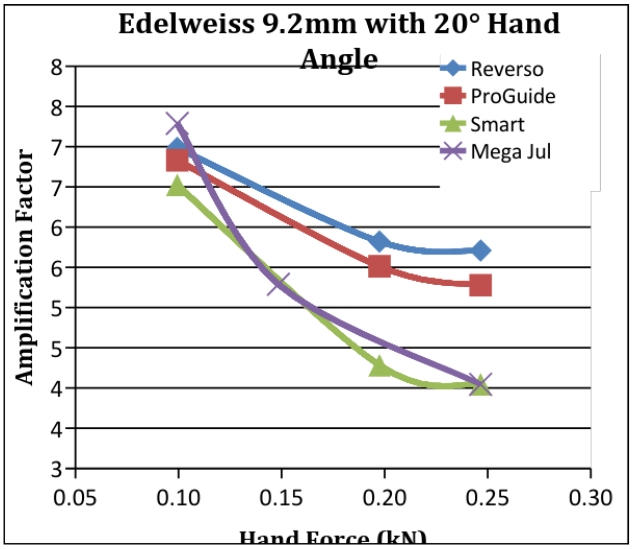
Measurements taken with hand force angle of 20º

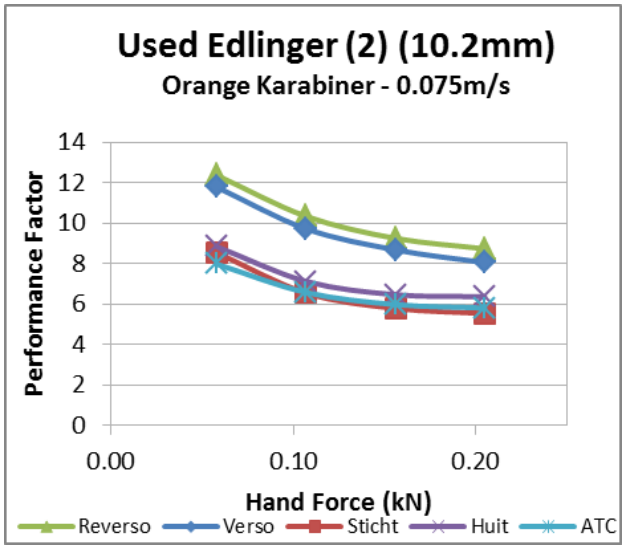

Effect of hand force and rope diameter on amplification factor
Amplification Factor
Hand Force (kN)
10
9
8
7
6
5
4
3
2
0.05
0.10
0.15
0.20
0.25
0.30
Reverso - Booster dry (9.7mm)
ProGuide - Booster dry (9.7mm)
Smart - Booster dry (9.7mm)
Mega Jul - Booster dry (9.7mm)
Reverso - Edelweiss Performance (9.2mm)
ProGuide - Edelweiss Performance (9.2mm)
Smart - Edelweiss Performance (9.2mm)
MegaJul - Edelweiss Performance (9.2mm)

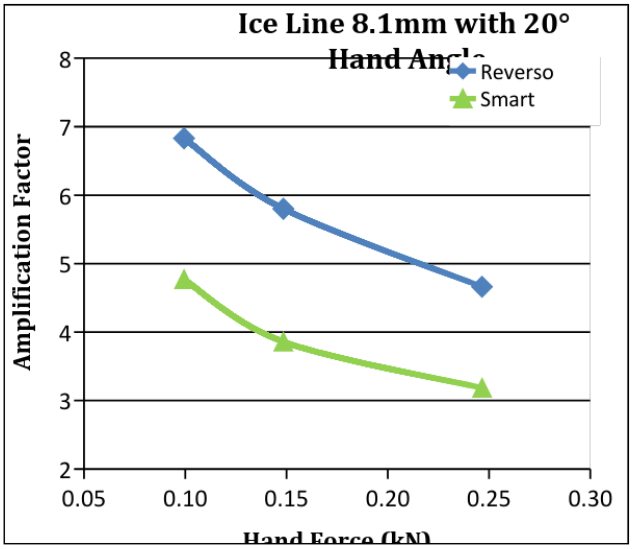

The effect of hand force and rope diameter on amplification factor
Amplification Factor
Hand Force (kN)
16
14
12
10
8
6
4
2
0.05
0.10
0.15
0.20
0.25
0.30
Reverso - Apollo (11mm)
ProGuide - Apollo (11mm)
Smart - Apollo (11mm)
MegaJul - Apollo (11mm)
Reverso - Booster dry (9.7mm)
ProGuide - Booster dry (9.7mm)
Smart - Booster dry (9.7mm)
Mega Jul - Booster dry (9.7mm)
Reverso - Edelweiss Performance (9.2mm)
ProGuide - Edelweiss Performance (9.2mm)
Smart - Edelweiss Performance (9.2mm)
MegaJul - Edelweiss Performance (9.2mm)
Reverso - Ice Line (8.1mm)
Smart - Ice Line (8.1mm)


Booster Dry 9.7mm with 20° Hand Angle
Amplification Factor
10
9
8
7
6
5
4
3
0.05
0.10
0.15
0.20
0.25
0.30
Hand Force (kN)
Reverso
ProGuide
Smart
Mega Jul


Edlinger (10.2mm)
Orange Karabiner - 0.075m/s
Performance Factor
12
10
8
6
4
2
0
0.00
0.10
0.20
Hand Force (kN)
Reverso
Verso
Sticht
Huit


Edelweiss 9.2mm with 20° Hand Angle
Amplification Factor
8
8
7
7
6
6
5
5
4
4
3
0.05
0.10
0.15
0.20
0.25
0.30
Hand Force (kN)
Reverso
ProGuide
Smart
Mega Jul





HAND FORCE MEASUREMENTS

When catching a fall, we assume that the belayer applies maximum hand force (grip strength) to resist flow of the rope through the belay station and thereby, limit the length of the fall. Previously measurements of hand force have been presented for a group of climbers either with or without gloves. (While the glove protected the belayer's hand, it had negligible effect on the maximum hand force.) These measurements, however, were for rope tension pulling downward; i.e. an upper belay. To be more representative of a leader fall scenario, the present measurements in Fig. A1 have considered also the rope tension pulling upward. The grip strength for an upward pull is somewhat larger than that for a downward pull. For a 10.2mm diameter rope, this set of climbers had an average hand force of 0.36 and 0.24 kN for upward and downward tension, respectively.

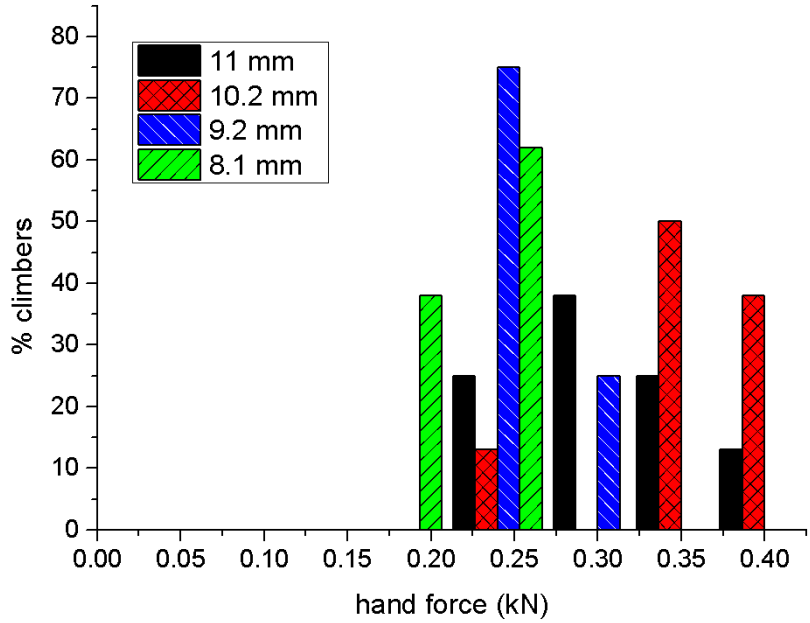


Fig. A1 Measured max. hand force for sample of recreational rock climbers: upward rope tension (triceps)

Ropes were 11mm Beal Apollo, 10.2mm Beal Edlinger, 9.2mm Sterling Nano and 8.1mm Beal Iceline. Ropes were almost new except for the Edlinger which was well used (furred sheath). For all subjects, average hand forces for an upward pull (triceps) using the 4 ropes were 0.30, 0.36, 0.26 & 0.23 kN while average hand forces for a downward pull (biceps) were 0.25, 0.24, 0.22 and 0.20 kN, respectively. In all cases the arm was in locked off position to maximize hand force.

Additionally it was shown that a well-used rope showing signs of wear and wet ropes both increase the hand force by 10-20%.

REFERENCES

1. Effectiveness of mountaineering manual belay/abseil devices. W.J.Stronge, Mathonwy Thomas. International Sports Engineering Association 2013.