Explanation of rope characteristics & impact force or What do the numbers mean on rope instructions?

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CEO Beal Ropes

Topics

- Mass per metre
- Diameter
- Length
- Sheath slippage
- Static elongation
- Dynamic characteristics
- Impact force

Mass per metre

- Apply a load of 10 kg to the rope
- Measure a length 1 metre and mark the rope
- Cut the measured length and weigh it
- Express the result in g/m

Rope Diameter

- This looks simple, but there is:
  - **nominal** diameter
    - a kind of ‘marketing diameter’
    - part of the name of the rope
  - **effective** diameter

- For example at Beal we have:

  Top Gun 10.5 mm & Booster 9.7 mm.

Rope Diameter

Obtain **effective** diameter by :

- Applying a load of - 10 kg to single ropes
  - 6 kg to half ropes
- Measure the diameter in 2 opposite directions, turning 90° around the rope, at 3 different points
- Express the diameter as the arithmetic mean of the 6 measurements.

Rope Diameter

Effective diameter

There are problems with this measurement:

- Different operators will give different results
- EN 892 demands the effective diameter on the User Instructions
- Some manufacturers repeat the **nominal** diameter

Rope Diameter

- **Nominal** diameter is part of the rope name
- The name is decided by the manufacturer

For example	
Rope name	**Effective diameter**
Apollo 11 mm	11 mm
Top Gun 10.5 mm	10.4 mm

EN 892	PERFORMANCES PERFORMANCE	UIAA NORM EURO NORM
FORCE DE CHOC / IMPACT FORCE / FANGSTOß / FUERZA DE CHOQUE / FORZA DI ARRESTO / FORÇA DE CHOQUE / IMPACT WAARDE	7.70 kN	≤ 12 kN
DIAMETRE / DIAMETER / DURCHMESSER / DIÁMETRO / DIAMETRO / DIÂMETRO / DIAMETER	11 mm	
NOMBRE DE CHUTES UIAA / NUMBER OF UIAA FALLS / UIAA-STURZAHL / NÚMERO DE CAIDAS UIAA / NUMERO DE CADUTE UIAA / NÚMERO DE QUEDAS UIAA / AANTAL UIAA VALLEN	16	≥ 5
ALLONGEMENT DYNAMIQUE / DYNAMIC ELONGATION / DYNAMISCHE DEHNUNG / ALARGAMIENTO DINÁMICO / ALLUNGAMENTO DINAMICO / ALONGAMENTO DINÂMICO / DYNAMISCH REKPERCENTAGE	35 %	≤40 %
GLISSEMENT DE LA GAINE / SHEATH SLIPPAGE / MANTELVERSCHIEBUNG / DESLIZAMIENTO DE LA FUNDA / SCORRIMENTO DELLA CALZA / DESLIZAMENTO DA CAMISA / MANTEL VERSCHUIVING	0 mm +/- 5 mm / 2m	≤ 20 mm / 2m
POIDS AU METRE / WEIGHT PER METRE / METERGEWICHT / PESO POR METRO / PESO AL METRO / PESO POR METRO / GEWICHT PER METER	75 g	
MATIERE / MATERIAL / MATERIAL / MATERIAL / MATERIALE / MATERIAL / MATERIE	Polyamid (PA)	
ALLONGEMENT 80 kg / ELONGATION 80 kg / DEHNUNG UNTER 80 kg / ALARGAMIENTO 80 kg / ALLUNGAMENTO 80 kg / REKPERCENTAGE 80 kg / ALONGAMENTO 80 kg	9,5 %	≤ 10 %

NUMÉRO DE LOT / BATCH NUMBER
SERIENNUMMER / NUMERO DE LOTE
NUMERO DI LOTTO / SERIENUMMER
NUMERO DO LOTE
B01K099606

Date de première mise en service
Date that it was first used
Datum der ersten benutzung
Fecha de priméra Utilisación
Data di prima utilizzazione
Data da 1ª utilização
Datum van eerste in gebruik stelling

BEAL - 2, rue Rabelais - 38200 Vienne - FRANCE
www.beal-planet.com

THE DYNAMIC COMPANY

Apollo II 11 mm

CORDE À SIMPLE (1) SINGLE ROPE

L= 50 m

	BEAL GUARANTY	LAB. RESULTS
Force de choc Impact force	7.70 kN	7.50-7.60 kN
Poids au metre Weight per metre	75 g	75 g
Nombre de chutes UIAA Number of UIAA falls	16	16-17

- [x] Dry Cover
- [ ] Golden Dry
- [x] Edge Resistant
- [x] Black Limit
- [x] Compact process

CE 0120
Made in France

UIAA

UPC/A code

P R I C E

Apollo II 11 mm 50 m Dry Cover
ALL

EAN code

3 700288 202215


EN 892
PERFORMANCES
PERFORMANCE
UIAA NORM
EURO NORM
7.40 kN
≤ 12 kN
10,4 mm
11
≥ 5
37 %
≤40 %
0 mm
+/- 5 mm / 2m
≤ 20 mm / 2m
68 g
Polyamid (PA)
9,5 %
≤ 10 %
NUMÉRO DE LOT / BATCH NUMBER
SERIENNUMMER / NUMERO DE LOTE
NUMERO DI LOTTO / SERIENUMMER
NUMERO DO LOTE
B00Q276606
BEAL
BEAL - 2, rue Rabelais - 38200 Vienne - FRANCE
www.beal-planet.com
BEAL
THE DYNAMIC COMPANY
Top gun II 10,5 mm
CORDE À SIMPLE 1 SINGLE ROPE
L= 50 m
BEAL GUARANTY
LAB. RESULTS
Force de choc
Impact force
7.40 kN
7.35-7.40 kN
Poids au mètre
68 g
68 g
Nombre
de chutes UIAA
Number
of UIAA falls
11
13-14
Dry Cover
Golden Dry
Edge Resistant
Program System
Safe Control
Black Limit
Compact process
CE 0120
Made in France
UIAA
P R I C E
Top Gun II 10,5 mm 50 m Dry Cover
3 700288 201744

Length

- EN 892 no specification for measurement
- Generally will be at least the stated length
- Rope may be, not definite, 0.5 m to 2 m longer
- Measured
  - At rest
  - At the factory
  - On the new rope

Length

- Rope shrinks in storage
  - Maybe several metres
  - Affected by storage conditions
- Measurement by the User
  - Apply firm manual pre-tension
  - Measure the rope

Sheath slippage

- Core & sheath are independent components, they can slide
- “Sock effect”
  - – Caused by the action of descenders
  - – Sheath deforms & bunches
    - Gives slack zone around the core
    - Bulges appear

Sheath slippage

Evaluation of sheath slippage

- Friction force applied to the sheath
  - Applied over a length of 2 m
  - Draw rope through an apparatus 4 times
- Value expressed in mm for 2 m of rope

Sheath slippage

- Maximum permitted sheath slippage is

  20 mm for 2 mm of rope

- This can be extrapolated for all rope lengths
  - 600 mm of slippage at the end of 60 m rope
  - This is within the standard

Sheath slippage

- Zero sheath slippage in the characteristics
  - No guarantee that slippage will never occur
  - Intensive top roping (climbing walls) usually gives slippage
  - Wet conditions increase risk of slippage
  - Brand new ropes more sensitive to slippage
  - Solve problem:
    - cut the extra sheath from the end of the rope

Static elongation

- Load the rope with 5 kg
- Increase load to 80 kg
- Measure increase in length
- Calculate the result:

$$\frac{(\text{Increased length} - \text{Original length}) \times 100}{\text{Original length}} \%$$

Dynamic characteristics

Measured on a drop test rig

The principle

- Rope is attached to a fixed point
- Rope passes through orifice plate
  - Imitates 10 mm diameter karabiner
  - Has perfect surface

Dynamic characteristics

- Attach rope to steel mass (figure-of-eight knot)
  - 80 kg for single rope
  - 55 kg for half rope
- Rope length from orifice plate to attachment on steel mass is 2.5 m
- Raise mass to 2.3 m above orifice plate
- Now ready to release mass & obtain dynamic characteristics

Dynamic characteristics

Number of falls

- Release mass for first drop test
- Raise mass to original point
- Release mass for second drop test
- Repeat (at 5 minute intervals) until rope breaks
- Tests carried out on total of 3 samples
- Guaranteed number of falls is the poorest of the 3 samples

Dynamic characteristics

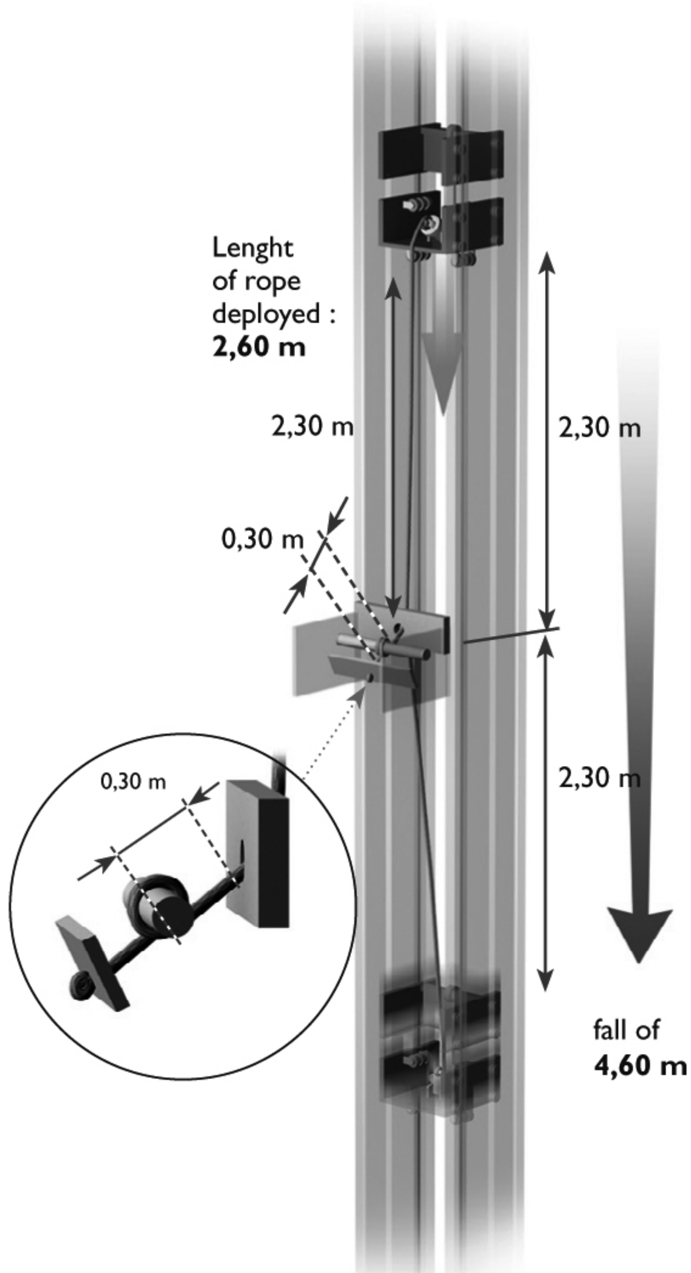
Dynamic elongation

- Maximum stretch of the rope measured after the first drop test

Dynamic characteristics

Impact force

- The force transmitted to the climber at the moment the fall is arrested
- Impact force (on User Instructions) can be called maximum impact force
  - Force transmitted to the falling mass on first drop test



$$f = \frac{4,60\ m}{2,60\ m} = 1,77$$

Dynamic characteristics

Impact force

- Value in the characteristics must be guaranteed by the manufacturer
  - Must be less than the maximum value from the 3 drop tests

Impact force

Laboratory test or UIAA impact force

- Test has extreme conditions
  - High Fall Factor
  - Fixed anchor with rope locked
  - Metal test mass
  - All energy is absorbed by the rope
    - None by friction, harness, human body deformation, belayer movement……
- We shall call this the “UIAA Impact Force”

Impact force

What happens in the drop test?

- Rope stretches & absorbs the fall energy
- First fall
  - rope just under tension at 2.3 m above orifice plate
  - Rope stretches irreversibly
    - approximately 300 mm

Impact force

What happens in the drop test?

- Subsequent falls
  - Test mass put back to first test position
  - Rope now has slack (approximately 300 mm)
  - Capacity to stretch diminishes with each drop
  - Consequently impact force increases with each test

Impact force

Theoretical Fall Factor (f_{th})

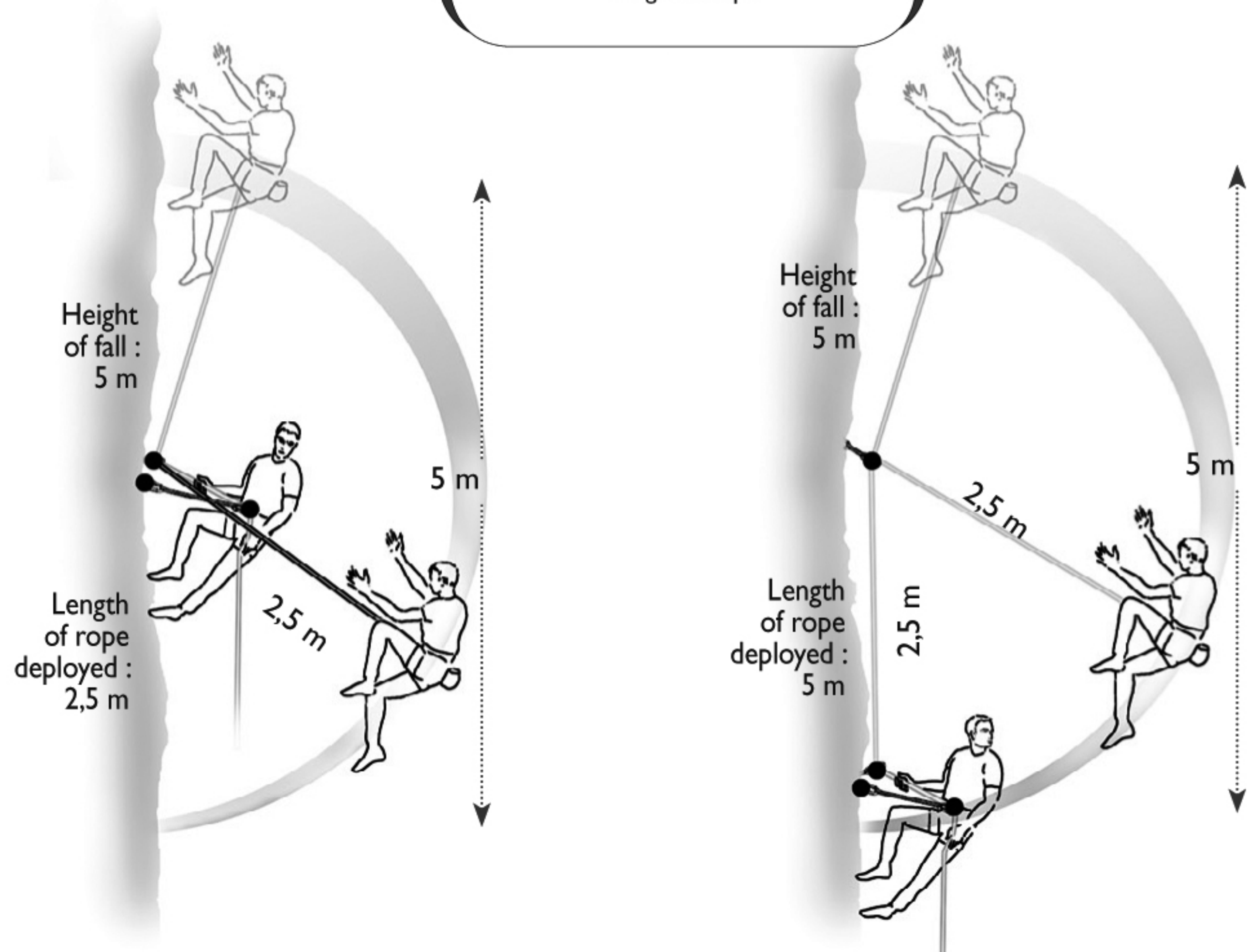
$$f_{th} = \frac{\text{Height of fall}}{\text{Length of rope}}$$

- Assumes no friction between belayer & highest runner
- Assumes all the rope in play absorbs energy equally

A LITTLE PHYSICS !

THE FALL FACTOR (f)

$$f = \frac{\text{Height of fall}}{\text{Length of rope}}$$



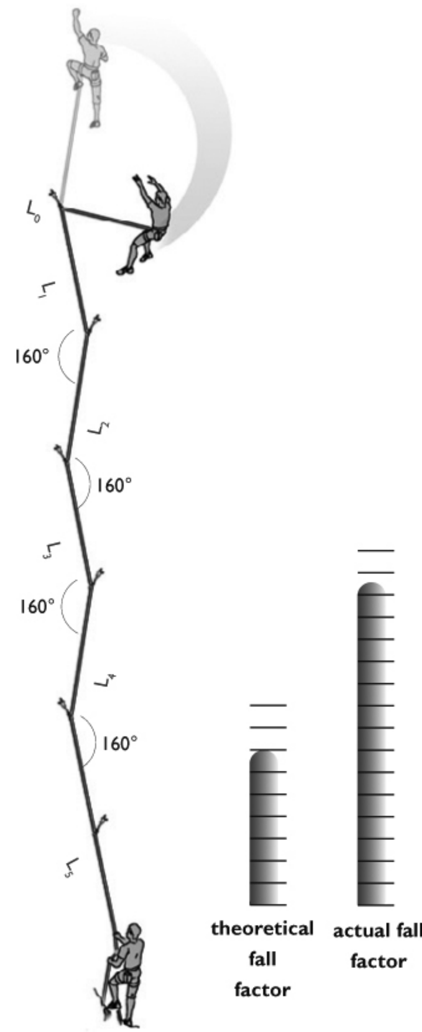
fall factor $= \frac{5{,}0 \text{ m}}{2{,}5 \text{ m}} = 2$

fall factor $= \frac{5{,}0 \text{ m}}{5{,}0 \text{ m}} = 1$

Impact force

Actual Fall Factor

- Impact force propagates along rope from the climber to the anchor
- Friction in karabiners & against rock reduces propagation of impact force
- Each rope section, between runners, will be less loaded than the previous one
- Energy absorbing capacity not fully deployed
- Actual Fall Factor much greater than theoretical Fall Factor



In the case of karabiners not far off-line, the actual fall factor becomes around:

B

$$f = \frac{H}{L_0 + 0{,}62L_1 + 0{,}59L_2 + 0{,}56L_3 + 0{,}53L_4 + 0{,}50L_5}$$

Impact force

Actual Fall Factor

The formula if an autolock device is used becomes:-

$$f_{act} = \frac{\text{Height of fall}}{L_0 + k_1 L_1 + k_2 L_2 + k_3 L_3}$$

With k_1, k_2, k_3 between 0 & 1 and $k_1 > k_2 > k_3$

Impact force

Actual Fall Factor

- For example it could be:

$$f_{act} = \frac{\text{Height of fall}}{L_0 + 0.6L_1 + 0.5L_2 + 0.4L_3}$$

- All climbers know this formula
- During a fall with high friction along the rope
  - Force transmitted to belayer is very low
  - Last few metres of rope take little part in the energy absorption process

Impact force

Impact force in practice

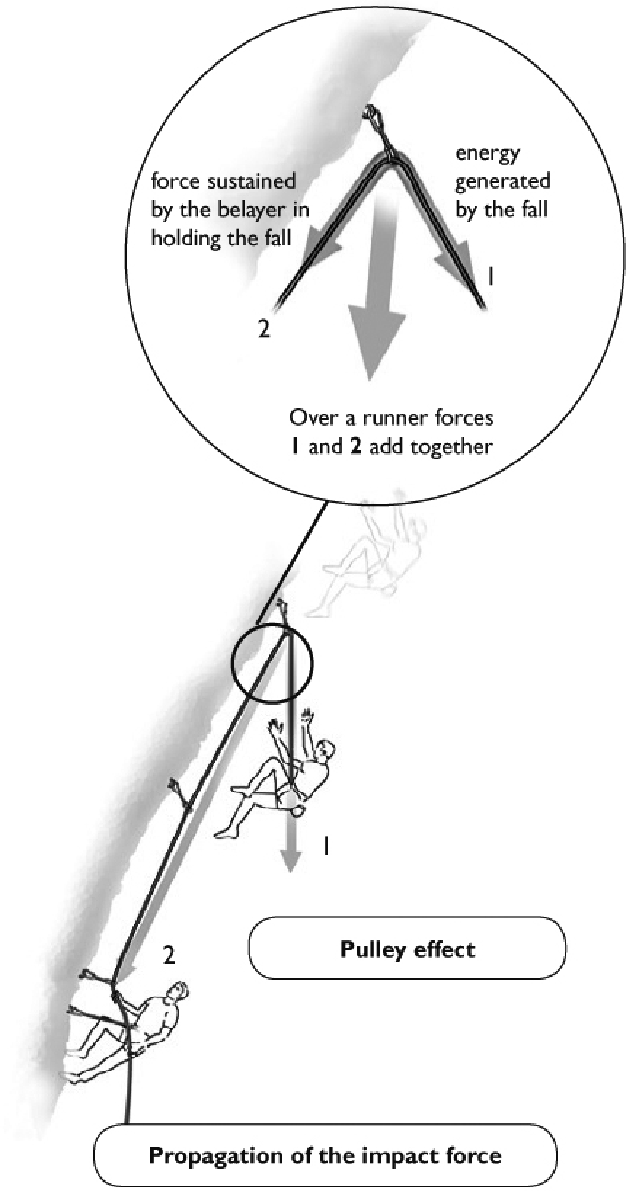
- Energy from falling climber is absorbed by belaying system – particularly the rope
- Good energy absorbing rope reduces impact on climber i.e. the impact force
- Impact force value affected by:
  - Climber’s weight
  - Capacity of rope to absorb energy

Impact force

Pulley effect on last runner

- Impact force propagates along the rope
- Highest runner takes the impact force from the climber & the force held by the belayer
- These 2 forces add together – the ‘Pulley Effect’
- Karabiner friction
  - Makes force on belayer’s side lower than that from the climber
  - Force exerted on highest runner is approx. 1.6 impact force on the climber

Pulley Effect



Forces in different situations

Dr Bedogni will now demonstrate:-

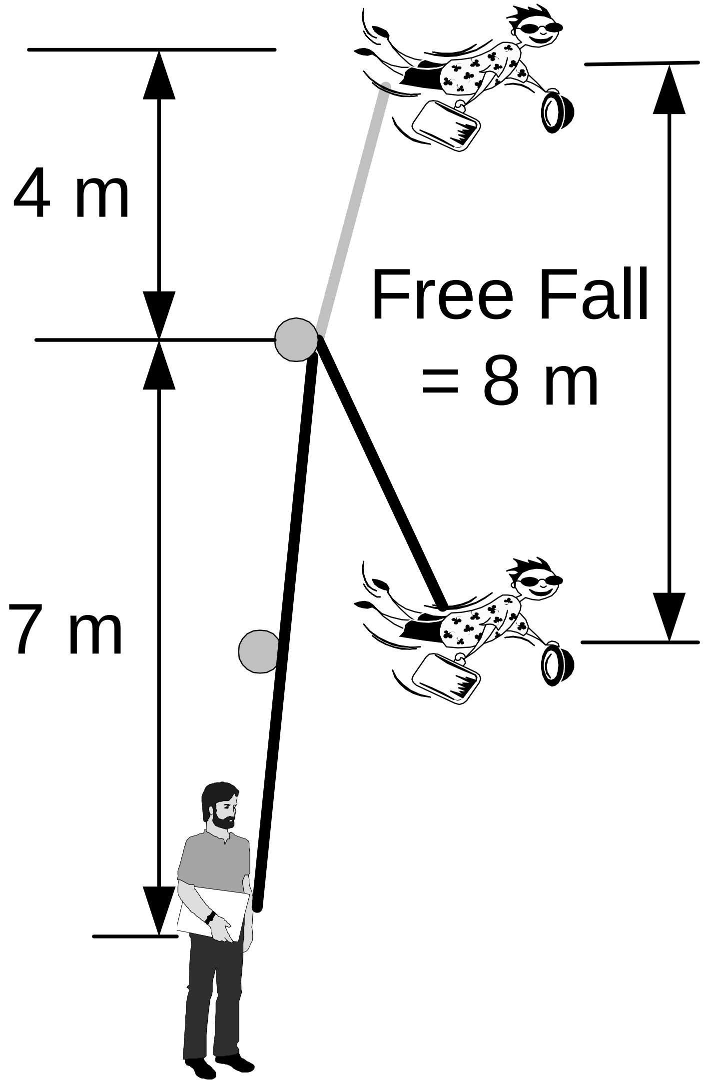
Forces in different situations

Illustrating Dr Bedogni's presentation, we have 4 different situations:-

In each situation:-

- Climber of mass 80 kg
- Fall from 4 m above last runner
- Free fall 8 m
- Compare forces at last runner & on the stance
- Using figure-of-eight or Tuba & GriGri & different UIAA impact force ropes

Forces in different situations



Example 1

No friction in the system

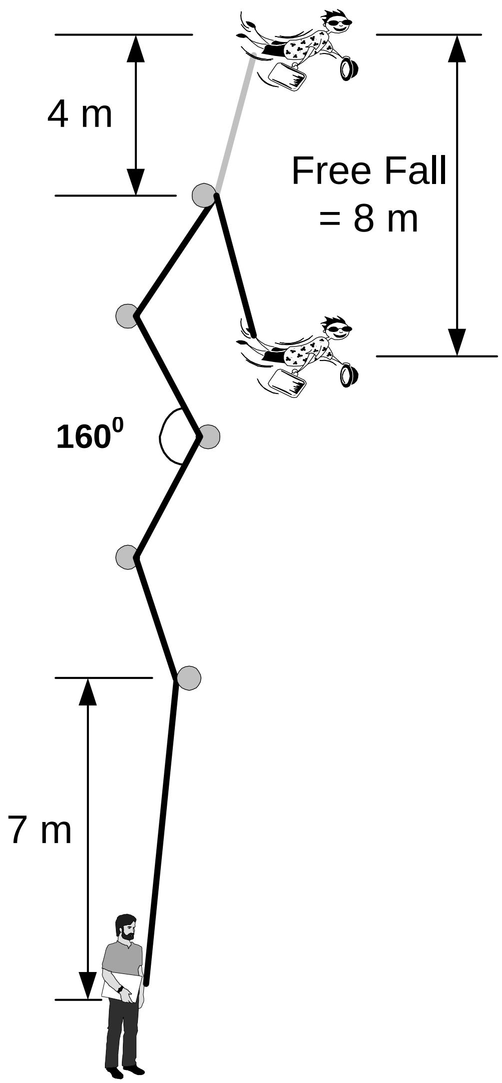
Theoretical Fall Factor 8/11 = 0.73

Actual Fall Factor for autolock belay ≈ 0.95

Forces in different situations
Example 1

	Classic belay device		Autolock belay device	
UIAA impact force of rope kN	Force on the stance kN	Force on last runner kN	Force on the stance kN	Force on the last runner kN10
12.00	**2.98**	**8.62**	**5.19**	**13.60**
10.00	**2.51**	**7.26**	**4.40**	**11.57**
9.00	**2.28**	**6.58**	**3.97**	**10.42**
7.20	**1.86**	**5.36**	**3.23**	**8.49**

Forces in different situations



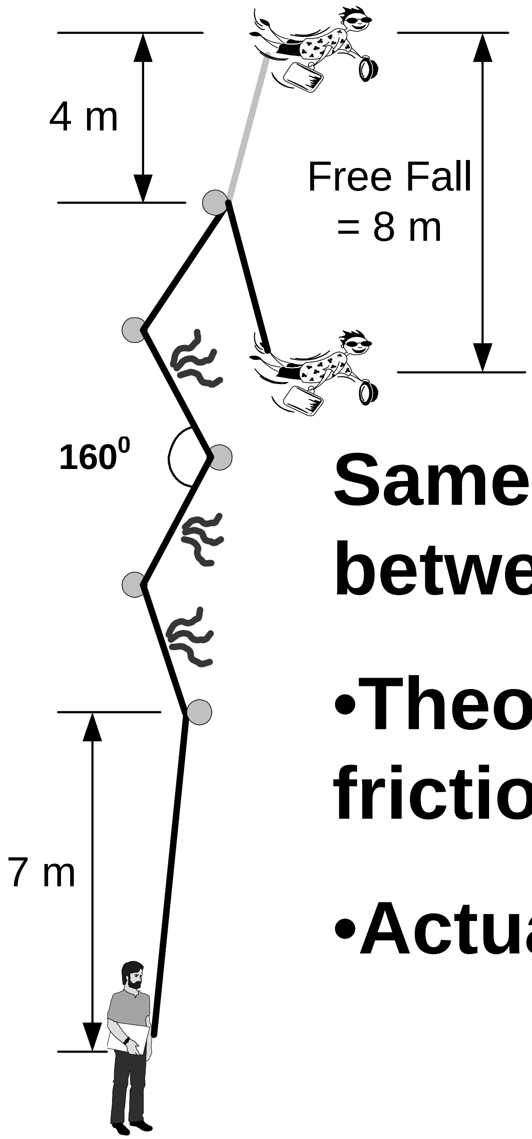
Example 2

- No rubbing on the rock
- First 7 m in line
- Then 5 runners off-line 3 m between them
- 19 m ascent to last runner
- Theoretical Fall Factor 8/23 = 0.35
- Actual Fall Factor for autolock belay ≈ 0.55

Forces in different situations Example 2

	Classic belay device		Autolock belay device	
UIAA impact force of rope kN	Force on the stance kN	Force on last runner kN	Force on the stance kN	Force on the last runner kN10
12.00	**2.06**	**7.34**	**3.35**	**10.87**
10.00	**1.75**	**6.24**	**2.84**	**9.19**
9.00	**1.59**	**5.69**	**2.57**	**8.35**
7.20	**1.32**	**4.70**	**2.11**	**7.31**

Forces in different situations
Example 3



Same as Example 2 but with hard friction between the runners

- **Theoretical Fall Factor 8/23 = 0.35 (no friction)**
- **Actual Fall Factor for autolock ≈ 0.74**

Forces in different situations Example 3

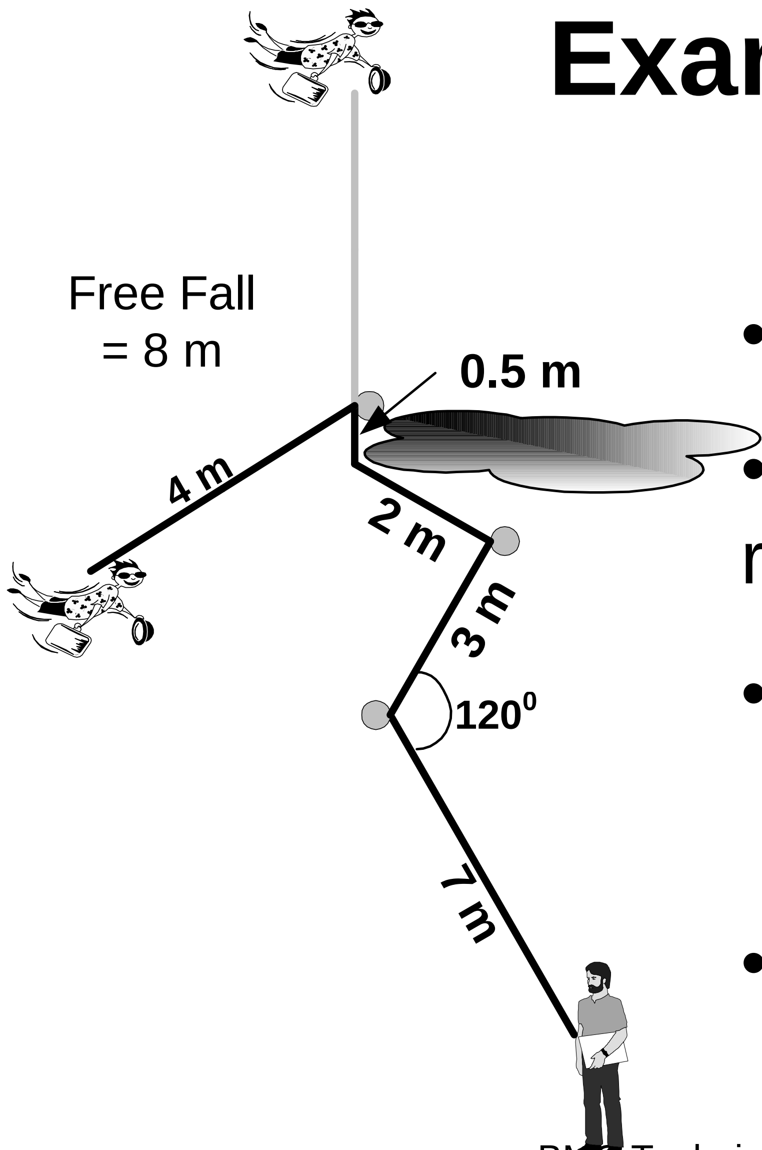
	Classic belay device		Autolock belay device	
UIAA impact force of rope kN	Force on the stance kN	Force on last runner kN	Force on the stance kN	Force on the last runner kN10
12.00	**1.19**	**10.58**	**1.54**	**12.39**
10.00	**1.01**	**8.99**	**1.29**	**11.13**
9.00	**0.92**	**8.20**	**1.17**	**9.44**
7.20	**0.76**	**6.75**	**0.95**	**8.21**

Forces in different situations Example 3

Compare with Example 2

- Same configuration
- More friction
- Forces at last runner significantly increased
- Rope close to Belayer partly loaded, absorbs little energy

Forces in different situations Example 4



- No friction until the roof lip
- Last runner 0.5 m above roof lip
- Theoretical Fall Factor

  8/16.5 = 0.48 (no friction)

- Actual Fall Factor

  autolock **≈ 1.26**

Forces in different situations
Example 4

	Classic belay device		Autolock belay device	
UIAA impact force of rope kN	Force on the stance kN	Force on last runner kN	Force on the stance kN	Force on the last runner kN
12.00	**1.17**	**13.97**	**1.45**	**15.73**
10.00	**0.99**	**11.81**	**1.21**	**13.16**
9.00	**0.90**	**10.72**	**1.09**	**11.87**
7.20	**0.73**	**8.75**	**0.88**	**9.57**

Forces in different situations

Comments

- Forces shown are for the last runner
- Divide this by 1.6 to get force on climber
- First example
  - Fall after 11 m climbing, no friction
- Second example
  - Fall after 23 m climbing, some karabiner friction
- Third example
  - Fall after 23 m climbing, friction on karabiner & rock
- Fourth example
  - Hard friction on roof lip & karabiners due to the angles

Forces in different situations

Fall Factor – Autolock belaying

- Actual Fall Factor is very different to theoretical Fall Factor
  - Example 3 more than double
  - Example 4 almost triple
- Considering theoretical Fall Factor (with no allowance for friction)
  - Will lead to wrong analysis

	Example 1	Example 2	Example 3	Example 4
f_{th}	0.73	0.35	0.35	0.48
f_{act} Autolock	≈ 0.95	≈ 0.55	≈ 0.74	≈ 1.26

Forces in different situations

Classic belay versus Autolock belay

- Force on the last runner increases with Autolock
  - Very large increase with low friction, examples 1 & 2
  - Small increase with hard friction examples 3 & 4
- Autolock can easily give >12 kN on the last runner
  - you must have safe protection

Forces in different situations

Classic belay versus Autolock belay

	Classic kN	Autolock kN	Increase
Ex 1 Rope 10 kN	7.26	11.57	50 to 60%
Ex 1 Rope 7.2 kN	5.36	8.49	
Ex 2 Rope 10 kN	6.24	9.19	
Ex 2 Rope 7.2 kN	4.70	7.31	

Forces in different situations

Classic belay versus Autolock belay

	Classic kN	Autolock kN	Increase
Ex 3 Rope 10 kN	8.99	11.13	10 to 25%
Ex 3 Rope 7.2 kN	6.75	8.21	
Ex 4 Rope 10 kN	11.81	13.16	
Ex 4 Rope 7.2 kN	8.75	9.57	

Forces in different situations

Forces on the stance

- Friction between the rock & the rope absorbs energy
  - The belayer needs very little effort to stop the fall

Forces in different situations

		Rope 7.2 kN	Rope 10 kN	Increase %
Classic belay device	EX 1	5.36	7.26	35
	Ex 2	4.70	6.24	33
	Ex 3	6.75	8.99	33
	Ex 4	8.75	11.81	35
Autolock belay device	Ex 1	8.49	11.57	36
	Ex 2	7.31	9.19	26
	Ex 3	8.21	11.13	36
	Ex 4	9.57	13.16	37

Forces in different situations

UIAA impact force of the rope

- Look at forces on the last runner
  - 10 kN UIAA rope & 7.2 kN UIAA rope
  - 10 kN UIAA rope
    - Impact force is 35% higher than with 7.2 kN UIAA rope
    - Increase is independent of belay device type
- Remember
  - UIAA impact force of rope has big influence on forces at the runners when dynamic belaying

Forces in different situations

Conclusion

- To evaluate forces from a fall
  - Consider the actual Fall Factor
  - Do not consider the theoretical Fall Factor
- Remember to increase theoretical Fall Factor
  - No friction increase by 30%
  - Light friction increase by 60%
  - High friction increase by 200%

Forces in different situations

Which rope to choose?

- No rope available which is best in all situations
- Depending on your rope use
  - Look for high number of falls
  - Low weight
  - Colour…..
  - Uncertain protection? Go for low impact force

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