NSS Vertical Section

Vertical Events

Beam Anchors

Gene Harrison
Chair
NSS Vertical Section
bats@starpower.net
C-703-585-4565

Version 1.0
15 June 2020

Vertical Events Overview

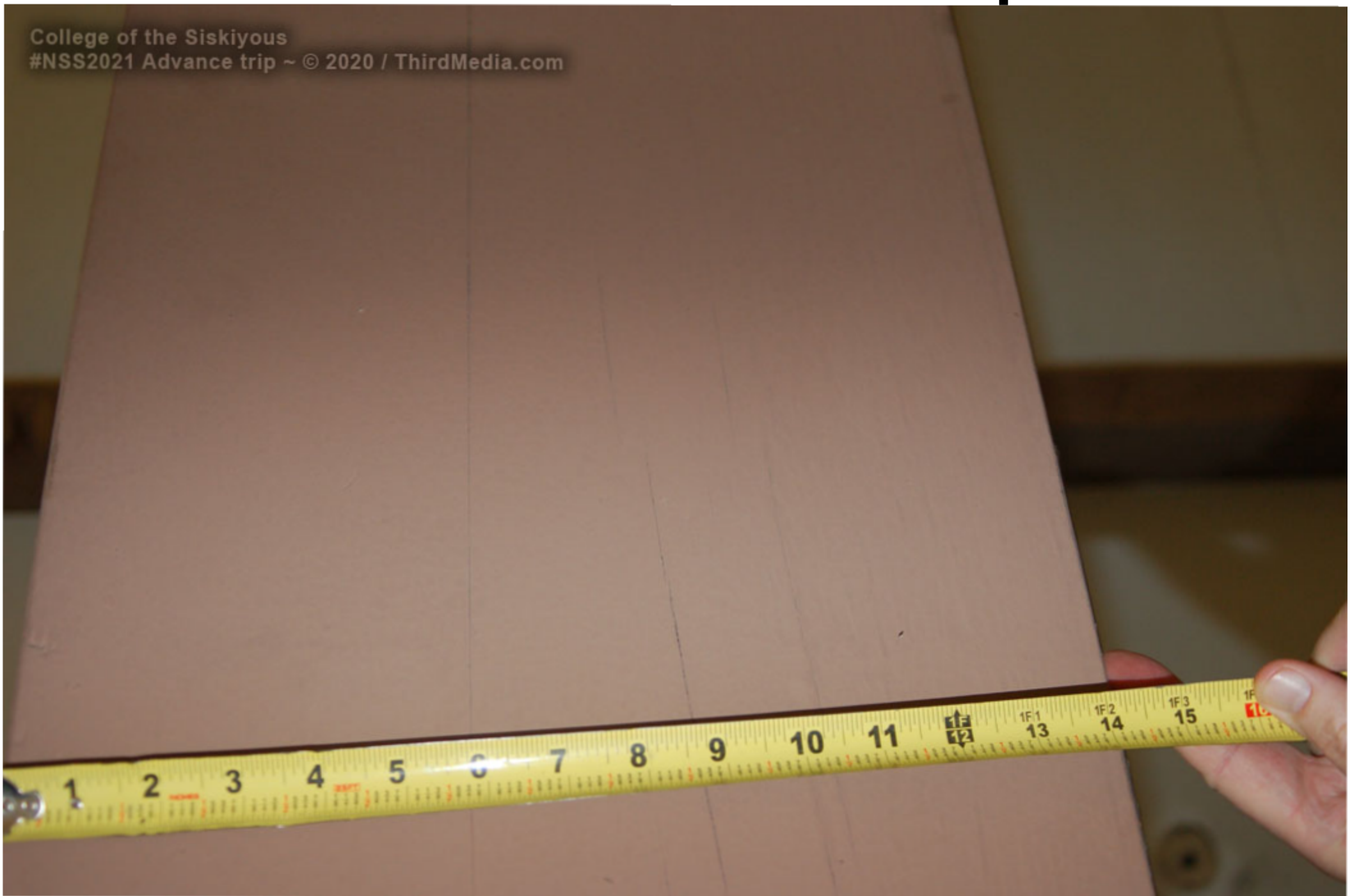
- BACKGROUND: The Vertical Section (VS) Vertical Events at each Annual NSS Convention include the Vertical Climbing Contests, the Rebelay Course and the Vertical Techniques Orientation Workshop.
- The VS Vertical Climbing Contests are one of the most popular and exciting events at each annual NSS Convention, and they attract both National and International participation. They are called the "Rope Climbing Olympics!"
- Also, additional ropes and anchors are employed for Vertical Skills practice & training, but they involve significantly less loading.
- ISSUES: The VS creates a simulated vertical cave environment and employs caving ropes and rigging for the event. This includes the necessary requirement for both high (ceiling trusses...) and low (bleachers, etc...) anchor points.
- In this case, we address solid beams, which do not provide the familiary simple mechanical elements for rigging attachments. This also supports the NSS2021 in Weed, CA, plus future needs.

Beam Anchors Overview

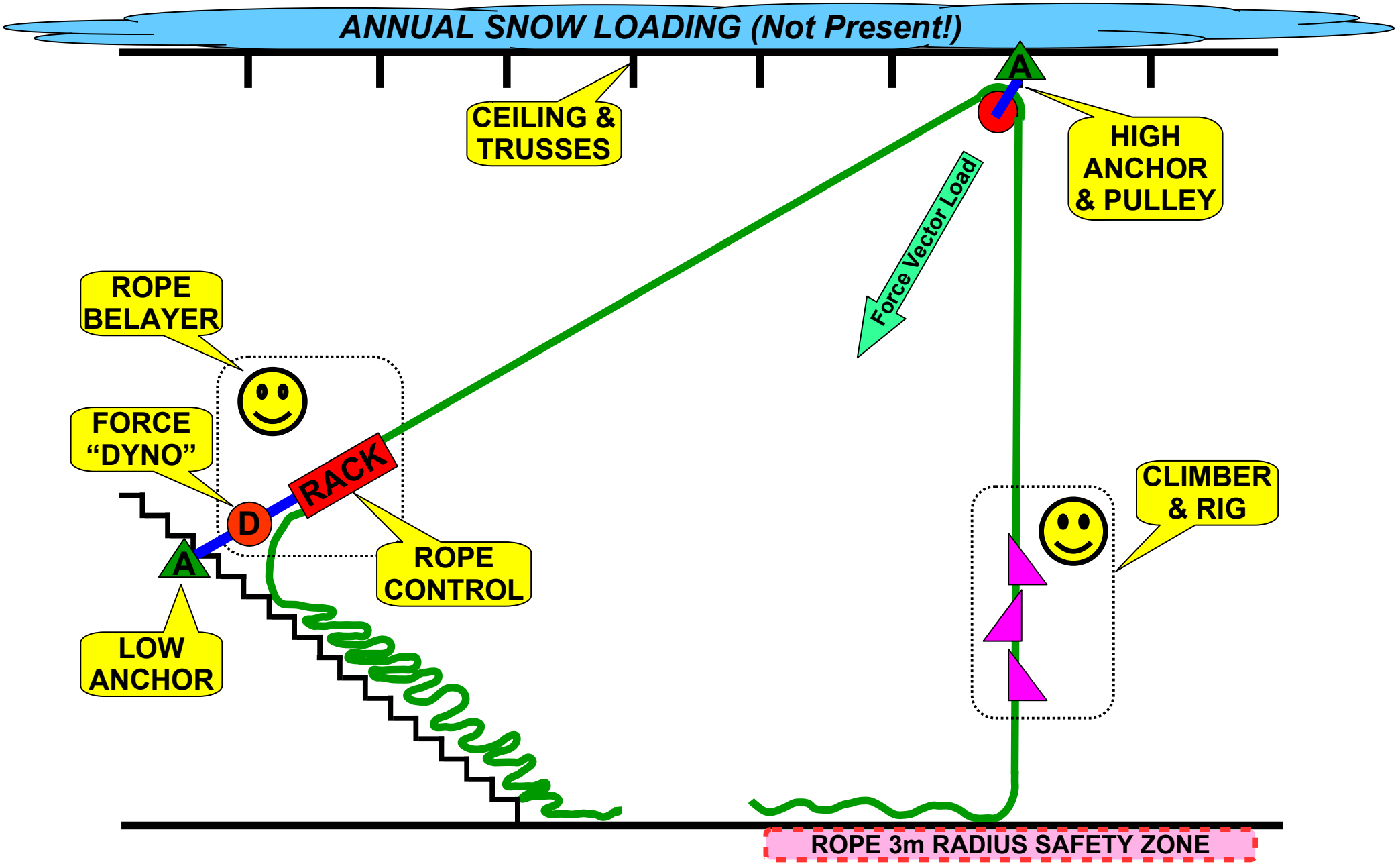
- PURPOSE: These analyses provide definitive technical design requirements for the construction of the high (ceiling) anchors, based on scientific tests, direct empirical measurements, and good engineering practices. A candidate implementation for beams is also provided for consideration.
- Essential Prerequisite Document: Please read the NSS Vertical Section Climbing Contest Load Analyses *First!*
- For these analyses, we have initially considered large engineered wood beams, and it is expected that concrete, steel, or other materials would offer equivalent or better performance, with reasonably similar anchors.
- CONCLUSIONS: *Climbing Contest, and other Vertical Events, operational stresses to the ceiling anchors are relatively not a significant factor*. And from these analyses, safe and reliable ceiling anchors in typical beams are easily constructed using readily available materials and methods. Also, they provide a beneficial residual upgrade in facility capability. Furthermore, VS rigging practices are well proven and carefully implemented, and traditionally are temporary, passive, and leave no traces. (Details follow)
- Should Users or Facilities desire more definitive assessments of such issues, we encourage them to engage a Local Licensed PE Structural Engineer.

Solid Beam Example

Solid Beam Example



Rope System Design



Climbing Contest...

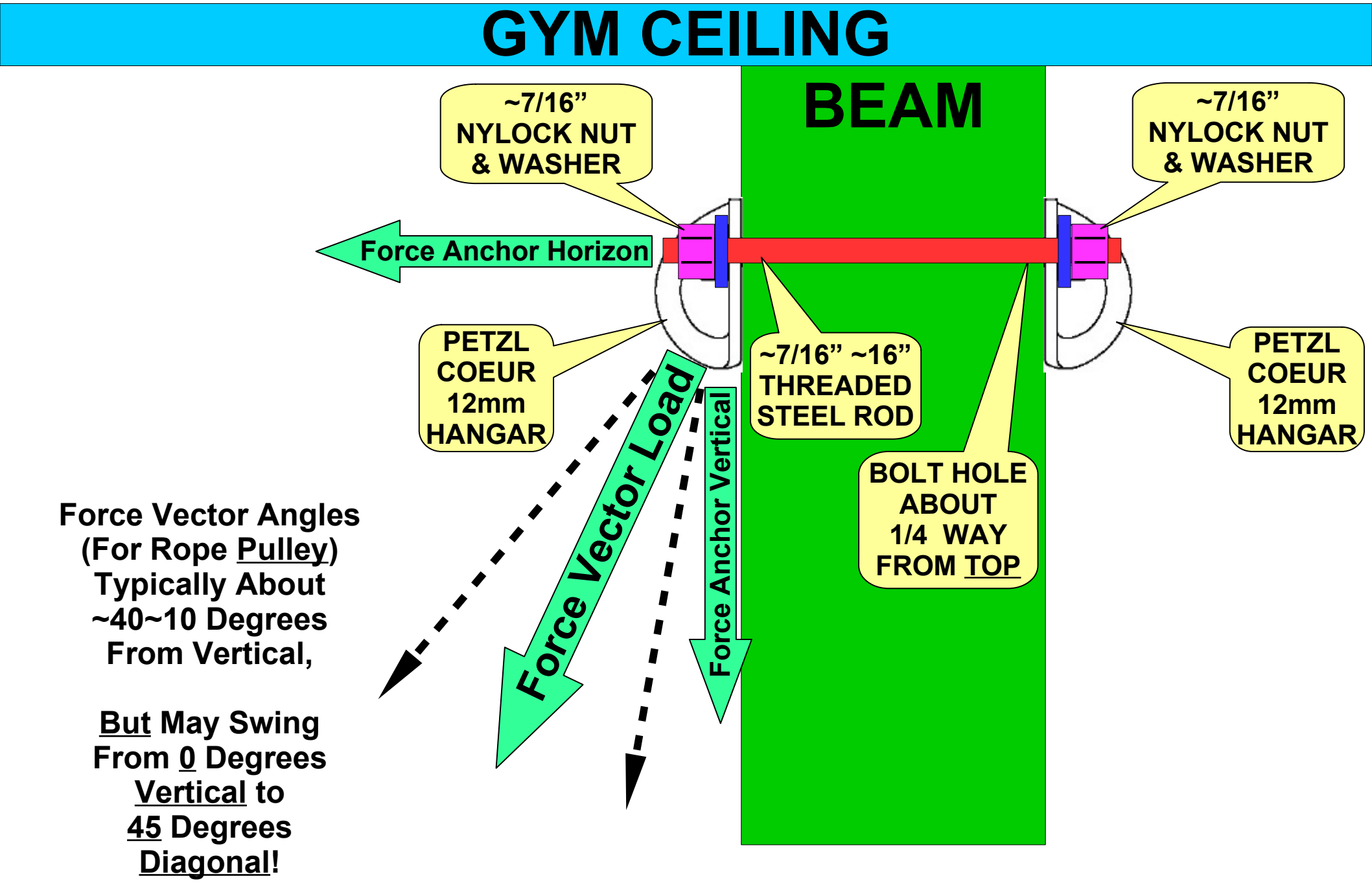
Analysis of Anchor Forces

- Please read the NSS Vertical Section Climbing Contest Load Analyses *First!*
- Actual Measurements at NSS2019 – Most Stressing Metrics
  - Most Dynamic System Peaks – Frog +34% [Rope Walker +3% max]
  - Most Dynamic Surges – Frog // 132 lbs // 176.2 lbs // +34%
  - Heaviest Climber – Frog // 209 lbs // Peak 222 lbs // +6%
  - Feed Rope Angle – 27 degrees from horizontal (very modest)
- **Empirical Maximum Anchor Loading**, Peak (pounds)
  - **Peak Vector << 400 pounds**
  - **Frog 378.91** Vector // 323.08 Vertical // 197.98 Horizontal [Climber 209 lb]
  - Truss Anchor Load Vector Angle 31.2 degrees from vertical (very modest)

Analysis of Anchor Forces

- Theoretical Worst Case Scenario – Most Stressing Metrics
  - Consider a Mythical Super Vertical Caver, very Heavy 250 lb, Strong & Fast, for Max Loading!
  - Plus consider rigging variants for Worst Case Feed Rope Angles, Vertical or Horizontal
    - 0 to 90 degrees from horizontal
  - Plus consider the Most Dynamic System Peaks – Frog +50% (far more than actually experienced!)
- **Theoretical Worst Case Anchor Loading**, Peak (pounds)
  - **Worst Case:: Heavy Climber – Frog // 250 lbs // Peak 375 lbs // +50%!! (that rare gorilla caver!)**
  - **Frog // 750 lb Vector // 750 lb Vertical // 375 lb Horizontal [Climber 250 lb]**
  - **Peak Truss Anchor Load Vector << 800 pounds**
  - **Truss Anchor Load Vector 0-45 degrees from vertical (Worst Case Limits)**
- Should Users or Facilities desire more definitive assessments of such issues, we encourage them to engage a Local Licensed PE Structural Engineer.

Beam Anchor Design



Petzl Coeur Hangar

PETZL Part Number
P36AA-12 ~$40 / 20

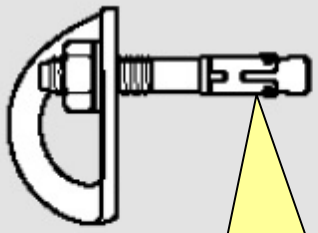
Petzl Hangar Strength

Strength Resistance

PETZL NOTES THAT STRENGTHS ARE TYPICALLY LIMITED BY THE PLACEMENT AND MATERIAL (ROCK OR CONCRETE) VS THE HANGAR OR THE ANCHOR BOLT

	STEEL		STAINLESS		HCR
	∅ 10	∅ 12	∅ 10	∅ 12	∅ 12
50 Mpa	23 kN	25 kN	25 kN	25 kN	25 kN
	SHEAR	***5620***	***LBS***		
50 Mpa	15 kN	18 kN	15 kN	18 kN	18 kN
	TENSION	***4047***	***LBS***		

CŒUR BOLT



DID WE MENTION THAT WE ARE NOT USING THIS ROCK ANCHOR?

Assessing Petzl Hangar

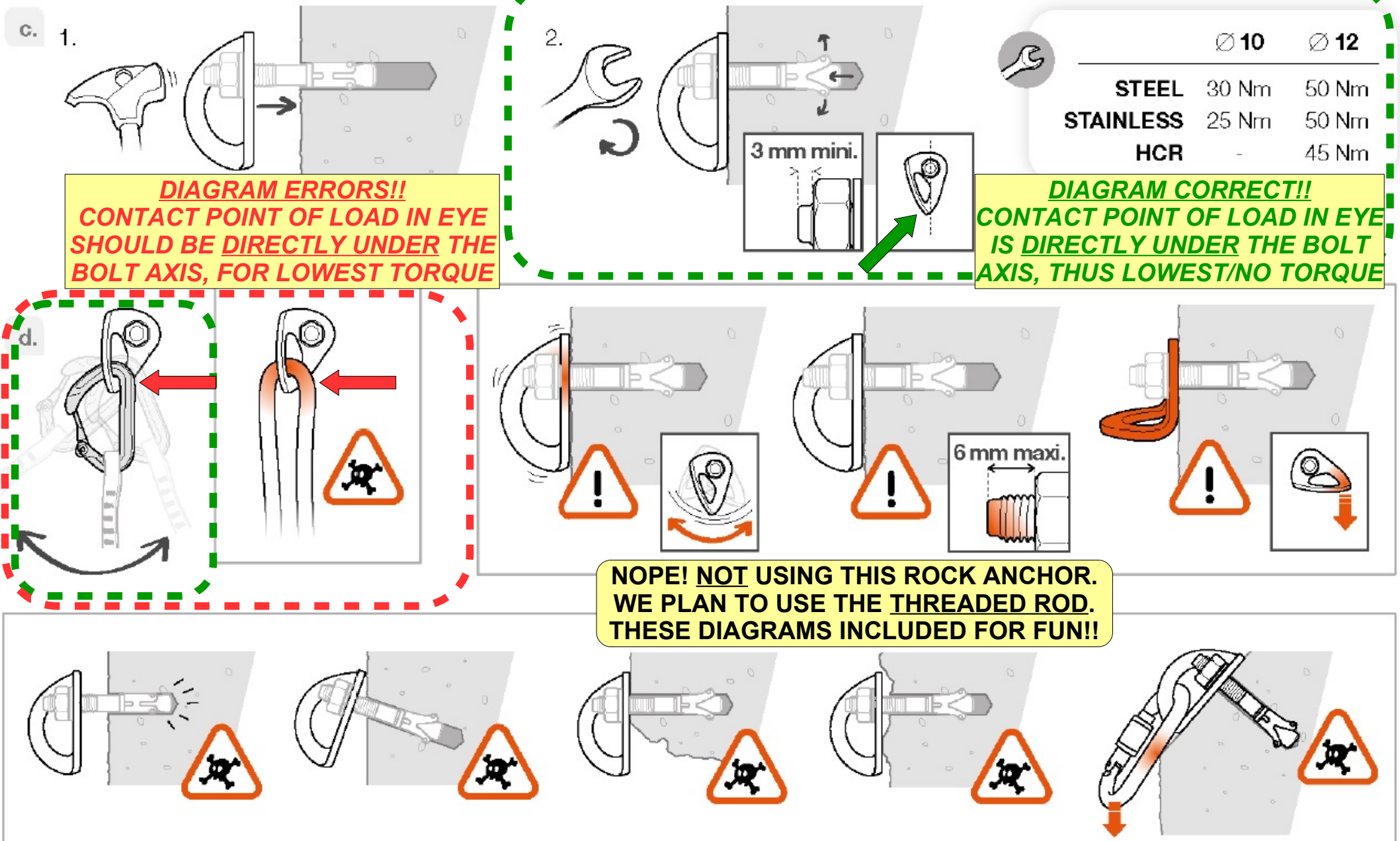
- Need to Provide Significant Safety Margin Beyond Presented Loading
- Petzl Hangar Performance Characteristics::
- Theoretical Worst Case Anchor Loading Analyses::
  - (Please see attached data and analyses)
  - Peak Vector << 800 pounds
  - 750 lbs Vector // 750 lbs Vertical // 375 lbs Horizontal
  - Truss Anchor Load Vector 0-45 degrees from vertical (Worst Case Limits)
- Petzl Hangar Performance Characteristics::
  - Vertical (Shear) >= 5620 lbs (25 kN)
  - Horizontal (Tension) >= 4047 lbs (18 kN)

Assessing Petzl Hangar

	WORST CASE LOADING	HANGAR RATINGS	RATIOS	SAFETY MARGINS
Units	Pounds	Pounds (kiloNewtons)	percent	Multiples
VERTICAL (Shear)	750	5620 (25)	13.3 %	*7.5 X*
HORIZONTAL (Tension)	375	4047 (18)	9.3 %	*10.8 X*

CONCLUSIONS:: THE PETZL 12mm COEUR HANGAR PROVIDES AN EXCELLENT MARGIN OF SAFETY FOR THIS ANCHOR PLACEMENT

Petzl Hangar Guidance



Petzl Hangar Issues

4. Compatibility

Verify that this product is compatible with the other elements of the system in your application (compatible = good functional interaction).
The carabiner used with the hanger must meet current standards in your country (e.g. EN 362 or EN 12275 connector depending on the type of application).
Use a bolt diameter that is appropriate for the hanger (e.g. 10 mm diameter bolt for 10 mm diameter hanger).
Warning: do not combine bolts, nuts, washers or hangers of dissimilar metals.
To use a COEUR hanger with any anchor device other than the BOLT bolt, be sure that the anchor system is strong enough, and compatible with the chosen hanger.

Suitable environment:

COEUR STEEL: indoor use, climbing gyms.
COEUR STAINLESS: outdoor environment, not aggressive enough to cause stress corrosion cracking (SCC).
COEUR HCR: aggressive SCC environment.
For anchor installations on a sea cliff, or in any other highly corrosive environment, the lifetime of the anchor is significantly reduced. It is preferable to use a material with good corrosion resistance so that the lifetime of the installation is satisfactorily long.

Petzl Hangar Install

5. Installing the anchor

Before installation, verify that the hanger and its means of attachment to the supporting medium (e.g. the bolt) are made of the same material.
Example of installation with an expansion bolt:
Check the quality of the supporting medium around the anchor. Make sure the rock is solid and uniform.
a. After cleaning the drilling area of any friable rock, drill a hole of the appropriate diameter and depth.
b. Clean the hole with a brush, then with a blower.
c. Push the bolt with the hanger into the hole and tighten the nut to the recommended torque.
d. After each installation, verify that the quickdraw moves freely in the hanger. Warning: if the bolt protrudes too much, it can hinder free movement of the quickdraw in the bolt hanger.
Hanger removal:
Unscrew the nut and remove the hanger. Before reusing the hanger, carry out a detailed inspection of it.

Strength

Test results obtained in 50 MPa concrete (high quality concrete, or rock). Common concrete has a weaker compressive strength, about 25 MPa.
The anchor breaking strength values depend on the quality of the supporting medium and on the quality of the placement.
Warning: in soft rock, the anchor strength may be reduced. It might be necessary to use a longer or different type of anchor, and to conduct strength tests in the field.
Warning: anchor strength can be near zero if poorly installed.

Steel Bolt Strengths

- **Proof Load** - is the maximum tensile force that can be applied to a bolt that will not result in plastic deformation
- **Clamp load** - equals to 75% of proof load

Example for 7/16" Steel Bolts:: We initially considered a Group 5 bolt, using 120 kpsi steel, and clearly sufficient for the load. BUT a long 15-16" bolt is simply unavailable!! Thus, we next consider a long threaded rod…

US Bolts - Coarse Threads

Proof Load

PROOF LIMIT
5850 lbs (Gd2)
9050 lbs (Gd5)

Nom Bolt Size *(in)*	Grade			
	2	5	8	Lamalloy
	Proof Load *(lb_f)* (kN)			
1/4	1750	2700	3800	4600
5/16	2900	4450	6300	7600
3/8	4250	6600	9300	11250
7/16	5850	9050	12800	15400
1/2	7800	12100	17000	20600
9/16	10000	15500	21800	26400

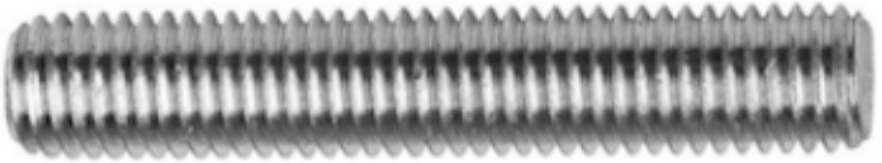
Clamp Load

CLAMP LOAD
4388 lbs (Gd2)
6788 lbs (Gd5)

Nom Bolt Size *(in)*	Grade			
	2	5	8	Lamalloy
	Clamp Load *(lb_f)* (kN)			
1/4	1313	2025	2850	3450
5/16	2175	3338	4725	5700
3/8	3188	4950	6975	8438
7/16	4388	6788	9600	11550
1/2	5850	9075	12750	15450
9/16	7500	11625	16350	19800

Steel Rod Strengths

Weight rating of threaded hanger rods



Load capacities of threaded hanger rods are indicated below:

Nominal Rod Diameter (in)	Root Area of Thread (in^2) (mm2)	Maximum Load [1]	
		lb	kg
3/8	0.07	600	270
1/2	0.13	1100	500
5/8	0.20	1800	820
3/4	0.30	2700	1220
7/8	0.42	3800	1720
1	0.55	4900	2220

7/16” 7/16 0.105

[1] The maximum loads in the table above are based on allowable tensile stress of *12 kpsi* - re *kpsi* allowable stress.

***Example* for 7/16” “Hanger” Steel Threaded Rods::**
- Method shown here, but with *12* kpsi *low* strength steel
- Expect *120* kpsi *medium* strength steel to be about *10x stronger*
- Which will be in the same range as a *Group 5* bolt.

Analysis of Steel Rod

- A 7/16” diameter bolt or rod is a very good fit for the 12mm Petzl Coeur Hangar, and is available in very long sizes to accommodate thick (14”) beams (likely cut to 15”-16”)
- For sufficient load capacity, we select B7 medium strength steel with 120 kpsi tensile strength, equivalent to the desired Grade 5 bolts
- As a good practice, we derate the strength by 25% to 90 kpsi to provide a generous margin below Proof and Maximum Loading
- The bolt cross section for 7/16” dia stock solid shank is ~0.150 sqin
- But for a threaded rod we use the thread root cross section, which is ~70% bolt area, for ~0.105 sqin
- Thus 90 kpsi x 0.105 sqin = 9475 lbs Maximum Tension
- In common practice, the perpendicular loading strength is considered to be about 60% of tensile strength, thus ~5685 lbs Maximum Shear

RESULTS for a 7/16” B7 Medium Steel Threaded Rod::
Maximum Load : ~9475 lbs (Tension), ~5685 lbs (Shear)

Assessing Steel Rod

- Need to Provide Significant Safety Margin Beyond Presented Loading
- Steel Rod Performance Characteristics::
- Theoretical Worst Case Rod Loading Analyses::
  - 750 lbs Vertical (Shear)
  - 375 lbs Horizontal (Tension)
- Steel Rod Performance Characteristics::
  - Vertical (Shear) ~5685 lbs (B7 ~Gd5)
  - Horizontal (Tension) ~9475 lbs (B7 ~Gd5)
  - WARNING: Safe & reliable performance is critically dependent on equivalent high quality self-locking Grade 5 nuts, and washers!!
- ***Recommendations:***
  - ***Procure B7 Medium Strength Steel Threaded Rods and***
  - ***Grade 5 Nylon Lock Nuts***
  - ***And buy only from reliable industry sources, such as McMaster-Carr, and not the local hardware store!!***

Assessing Steel Rod

	WORST CASE LOADING	ROD RATINGS	RATIOS	SAFETY MARGINS
Units	Pounds	Pounds	percent	Multiples
VERTICAL (Shear)	750	5685	13.2 %	*7.6 X*
HORIZONTAL (Tension)	375	9475	3.96 %	*25.3 X*

CONCLUSIONS:: THE 7/16" B7 THREADED STEEL ROD PROVIDES AN EXCELLENT MARGIN OF SAFETY FOR THIS ANCHOR PLACEMENT

Beam Anchor System Parts

	DESCRIPTION *For TEN High Anchor Sets*	QTY	COST EACH	COST TOTAL
1	Threaded Rod, Steel, Plated – 7/16”-14 UNC ~16” Long Each – Medium Strength B7 McMaster Part 98957A610 www.mcmaster.com/98957A610	10 (Buy & Cut <u>Five</u> 3-Foot Rods)	$5	$25
2	Lock Nut, Steel, Plated, Nylon Insert – 7/16”-14 UNC Grade 5 McMaster Part 95615A180 www.mcmaster.com/95615A180	20	$12/100	$12
3	Washer, Steel, Plated – 7/16”	20		
4	Hangar, Steel, Petzl Coeur – 12mm Part P36AA-12 - (uses 7/16” bolt)	20	$40/20	$40
5	Drill, 7/16” – Metal or Wood - > 15” Reach	1		
	TOTALS	71 items		

References

- NSS Vertical Section Documents
  - NSS Vertical Section Climbing Contest Load Analyses – G. Harrison
- Engineering Toolbox
  - www.engineeringtoolbox.com/steel-bolts-sae-grades-d_1426.html
  - www.engineeringtoolbox.com/us-bolts-tensile-proof-load-d_2066.html
  - www.engineeringtoolbox.com/loads-hanging-rods-d_1341.html
- Portland Bolt & Manufacturing
  - www.portlandbolt.com/technical/fastener-identification-markings
  - www.portlandbolt.com/technical/faqs/bolt-shear-strength-considerations
- Hardware Sources – McMaster-Carr
  - Grade B7 Medium-Strength Steel Threaded Rod
  - 7/16"-14 Thread Size, 3 Feet Long
  - Part 98957A610 ~$5 / 3ft
  - www.mcmaster.com/98957A610
  - Medium-Strength Steel Nylon-Insert Locknut
  - Grade 5, Zinc-Plated, 7/16"-14 Thread Size
  - Part 95615A180 ~$12 / 100ctt
  - www.mcmaster.com/95615A180
- Petzl Technical Data
  - Petzl Coeur Hangar 12mm Steel – Part P36AA-12 ~$40 / 20ct
  - www.petzl.com
  - www.petzl.com/US/en/Sport/Anchors/COEUR-STEEL

Analytical Data...

- Actual Test Data from Selected NSS2020 Rope Contest Climbs
  - Vertical Section Climbing Contest Load Analyses
- Examination of Significant Loading Parameters
- Creation of the Worst Case Scenario
- Analyses of Worst Case Loading

WORST CASE ANCHOR LOADING ANALYSES				DYNAMIC STATUS >>>		STATIC FEED ROPE LOAD	PEAK FEED ROPE LOAD	STATIC FEED ROPE LOAD	PEAK FEED ROPE LOAD
RECORD INDEX	DATE DAY	TIME START	CLIMBER NAME	CLIMBING SYSTEM	ROPE RUN DISTANCE	. FRL Static	. FRL Peak	. FRL Static	. FRL Peak
						.	.	P=2.2xkg	P=2.2xkg
Case	x	x		"Rig"	meters	kilograms	kilograms	pounds	pounds
1	17 June	1441	n/a	Frog	30	95.00	101.00	209.00	222.20
4	17 June	1553	n/a	Frog	120	60.00	80.10	132.00	176.22
13	18 June	1200	n/a	Rope Walker	n/a	87.00	89.20	191.40	196.24
A	HEAVY CLIMBER & FROG			Frog	n/a	95.00	101.00	209.00	222.20
B	ROPE FEED HORIZONTAL			Frog	n/a	95.00	101.00	209.00	222.20
C	ROPE FEED VERTICAL			Frog	n/a	95.00	101.00	209.00	222.20
D	HEAVY CLIMBER & FROG			Frog	n/a	95.00	127.30	209.00	280.06
E	HIGHER 1.34 SURGE			Frog	n/a	95.00	127.30	209.00	280.06
F				Frog	n/a	95.00	127.30	209.00	280.06
G	HEAVIEST CLIMBER & FROG			Frog	n/a	113.64	152.27	250.00	335.00
H	HIGHER 1.34 SURGE			Frog	n/a	113.64	152.27	250.00	335.00
J				Frog	n/a	113.64	152.27	250.00	335.00
K	HEAVIEST CLIMBER & FROG			Frog	n/a	113.64	170.45	250.00	375.00
L	HIGHEST 1.5 SURGE			Frog	n/a	113.64	170.45	250.00	375.00
M	*THE WORST CASE COMBO			Frog	n/a	113.64	170.45	250.00	375.00

	WORST CASE ANCHOR LOADING ANALYSES			STATIC FEED ROPE LOAD	PEAK FEED ROPE LOAD	STATIC FEED ROPE LOAD	PEAK FEED ROPE LOAD
COLOR CODES	Fixed Fields	Sequence Fields	Data Inputs	FRL Static kilograms	FRL Peak kilograms	FRL Static pounds	FRL Peak pounds
	Data Into Formulas	Formula Results	Notable Results	PEAKS 113.64	PEAKS 170.45	PEAKS 250.00	PEAKS 375.00

		PEAK	PEAK	PEAK	PEAK	PEAK	
FEED ROPE	FEED ROPE	FEED ROPE	FEED ROPE	TRUSS	TRUSS	TRUSS	TRUSS
LOAD	ELEVATION	TRUSS LOAD	TRUSS LOAD	ANCHOR LOAD	ANCHOR LOAD	ANCHOR LOAD	ANCHOR LOAD
RATIO	ANGLE	Horizontal	Vertical	Horizontal	Vertical	VECTOR	ANGLE
RatioPkSt	AngleR	FRLHoriz	FRLVert	TALHoriz	TALFRVert	TALVector	TALAngle
FRPeak/ FRStatic	.	RFLPeak * Cosine (AngleR)	RFLPeak * Sine (AngleR)	FRLHoriz	FRLVert + FRL	SqRt ((TALHoriz^2) + (TALVert^2))	ArcTan (TALFRVert / TALHoriz)
(no units)	degrees	pounds	pounds	pounds	pounds	pounds	degrees
1.06	27	197.98	100.88	197.98	**323.08**	**378.91**	58.50
1.34	27	157.01	80.00	157.01	256.22	300.50	58.50
1.03	27	174.85	89.09	174.85	**285.33**	**334.64**	58.50
1.06	27	197.98	100.88	197.98	323.08	378.91	58.50
1.06	**0**	222.20	0.00	**222.20**	222.20	314.24	45.00
1.06	**90**	0.00	222.20	0.00	**444.40**	**444.40**	90.00
1.34	27	249.54	127.14	249.54	407.20	477.58	58.50
1.34	**0**	280.06	0.00	**280.06**	280.06	396.06	45.00
1.34	**90**	0.00	280.06	0.00	**560.12**	**560.12**	90.00
1.34	27	298.49	152.09	298.49	487.09	571.27	58.50
1.34	**0**	335.00	0.00	**335.00**	335.00	473.76	45.00
1.34	**90**	0.00	335.00	0.00	**670.00**	**670.00**	90.00
1.50	27	334.13	170.25	334.13	545.25	639.48	58.50
1.50	**0**	375.00	0.00	**375.00**	375.00	530.33	45.00
1.50	**90**	0.00	375.00	0.00	**750.00**	**750.00**	90.00

		PEAK	PEAK	PEAK	PEAK	PEAK	
FEED ROPE	FEED ROPE	FEED ROPE	FEED ROPE	TRUSS	TRUSS	TRUSS	TRUSS
LOAD	ELEVATION	TRUSS LOAD	TRUSS LOAD	ANCHOR LOAD	ANCHOR LOAD	ANCHOR LOAD	ANCHOR LOAD
RATIO	ANGLE	Horizontal	Vertical	Horizontal	Vertical	VECTOR	ANGLE
RatioPkSt	AngleR	FRLHoriz	FRLVert	TALHoriz	TALFRVert	TALVector	TALAngle
(no units)	degrees	pounds	pounds	pounds	pounds	pounds	degrees
PEAKS	PEAKS	PEAKS	PEAKS	PEAKS	PEAKS	PEAKS	PEAKS
1.50	**90.00**	**375.00**	**375.00**	**375.00**	**750.00**	**750.00**	**90.00**