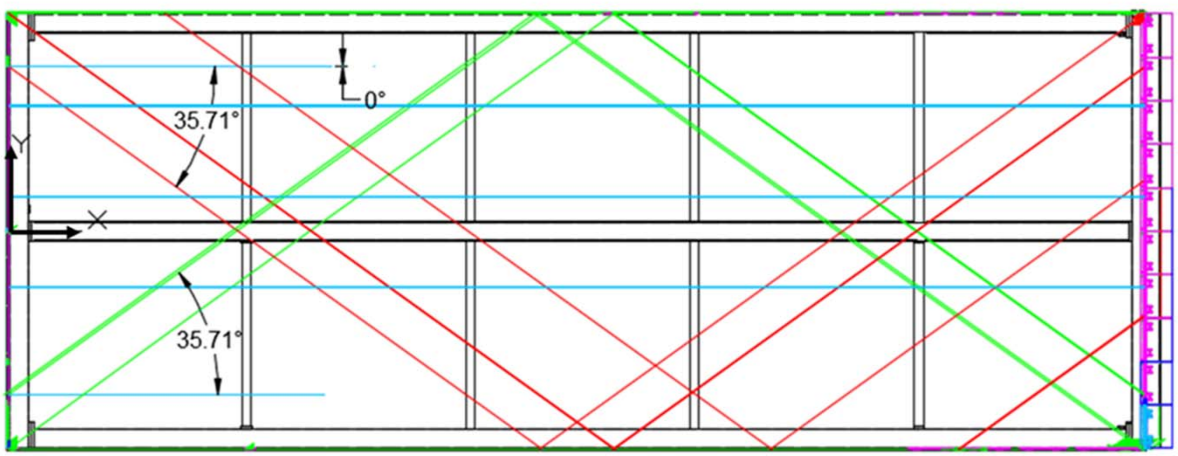
Considerations on the APA frame

- The effect on wire tension due to APA frame distortions during transport and handling.
- Strength of M20 adaptor connection
- Stress in the APA frame due to higher g-loads
- Installing the conduits
- Lessons learned from protoDUNE transport box

Effect on wire tension during transport and handling

- Each APA is wrapped with 23.4km of 152 micron wire.
- It is important to not to break wires during transportation and handling.
- Note: Some wires are sloped down at 35.71, some up and some are horizontal.



Approach

- The APA is supported in it's shipping frame on isolators, but will still be subjected to forces that distort the APA and stretch some of its wires.
- Frame displacement data was extracted from the 3 transportation cases that will have the largest effect on wire tension.
  - Quasi-static sea transport (analyzed by Jake Nesbit)
  - Road transportation with vibration (analyzed by Ang Lee)
  - Road transportation with shock (analyzed by Ang Lee)
- The effects on wires for both "in-plane" and "out-of-plane" distortions were considered.

Frame "displacements" from FEA

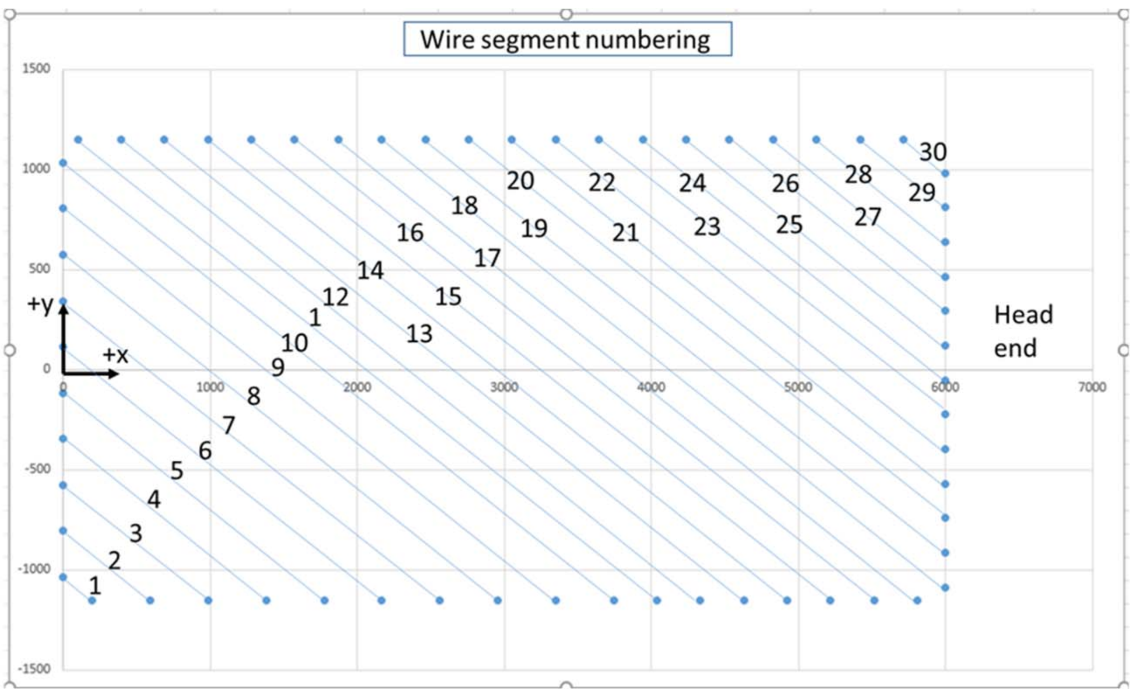
Displacements as defined by the difference between the maximum and minimum displacements (See image on page 2 for coordinate system.)

	ux	uy	uz
Case 1	1.30	3.48	5.27
Case 2	0.70	6.47	1.92
Case 3	0.31	2.70	0.99

Analysis of “In-plane” effects

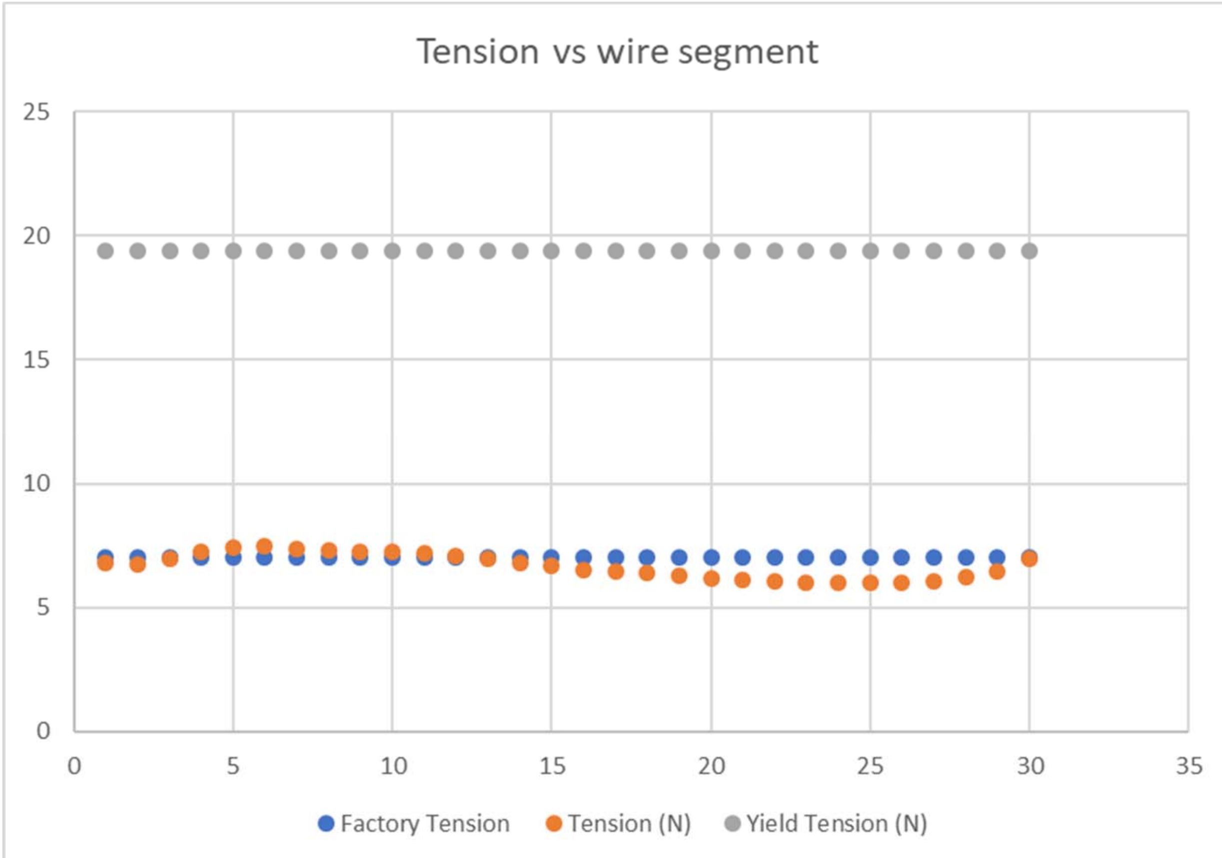
- 30 wire segments were checked on the wires sloped at -35.71 degrees
- Determined the change in length in the x-y plane between two nodes on each end of the wire.
- Wires sloped at +35.71 will see similar strains
- Wires with no slope will not see as much stress.

Foot end



Head end

Results: Case 1 “in-plane”



Max Tension increases from 7* to 7.5N

*Note: Factory tension tolerance is 6+/-1N. For purposes of this analysis, it is assumed all wires will start out at the maximum tension

Results: Case 1 “out-of-plane”

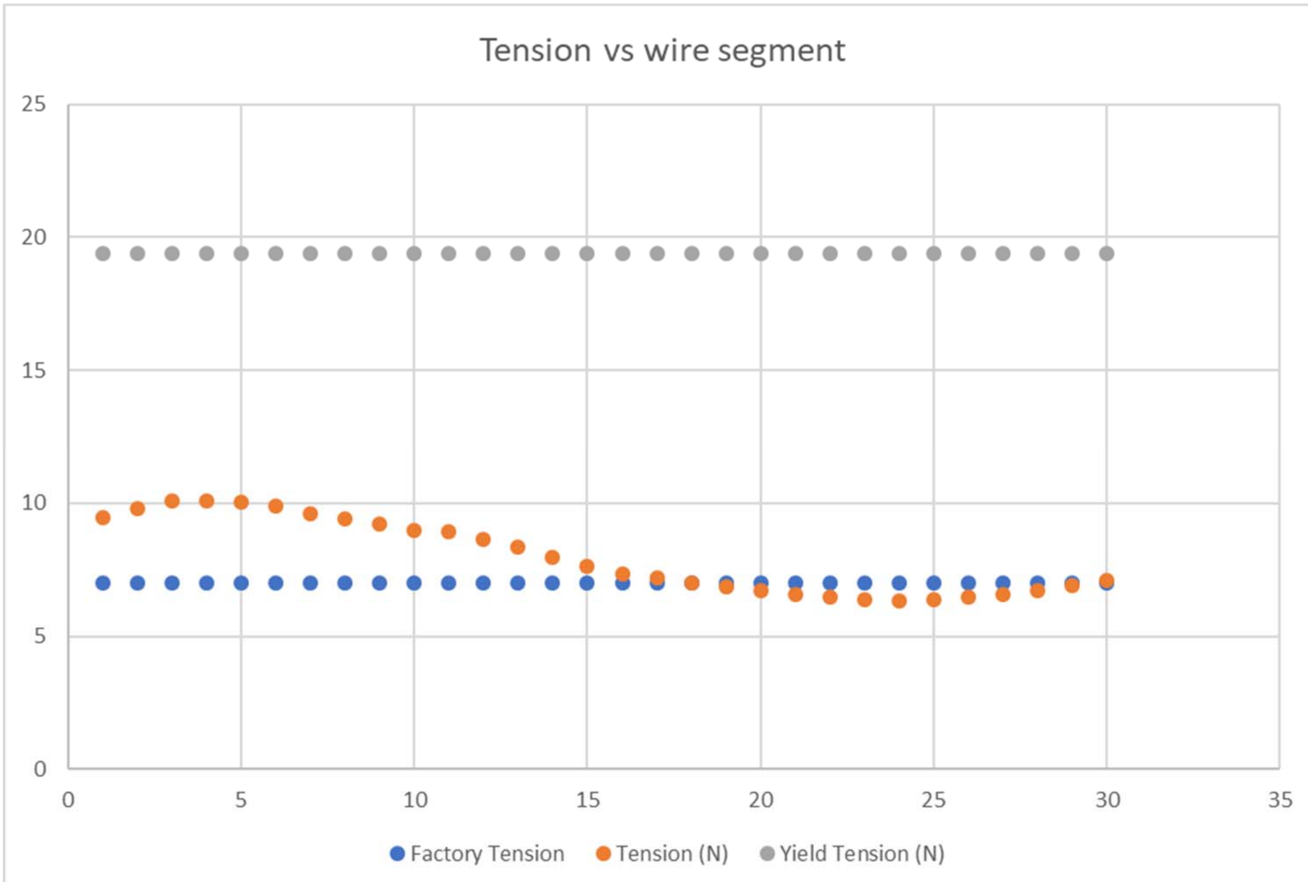
APA will bow out ~5mm > ~radius of curvature > 900m

The APA will bow and the bending stresses and strains at the midplane of the APA will be zero. The wires are offest from this nuetral axis and will be stretched. This strain can be conservatively approximated as the ratio of the offset from the neutral plane to the wires.

$v := 65 \cdot mm$	Offset from the neutral plane of the APA to the wires
$\varepsilon := \frac{v}{r} = 7.222 \cdot 10^{-5}$	Additional wire strain seen by wires aligned to the APA long axis. Strain will be less for angled wires.
$T := \varepsilon \cdot A \cdot E = 0.168\ N$	Conservative estimate of additional Tension due to "bowing".

Tension < 7.5N+.17N < 7.67N

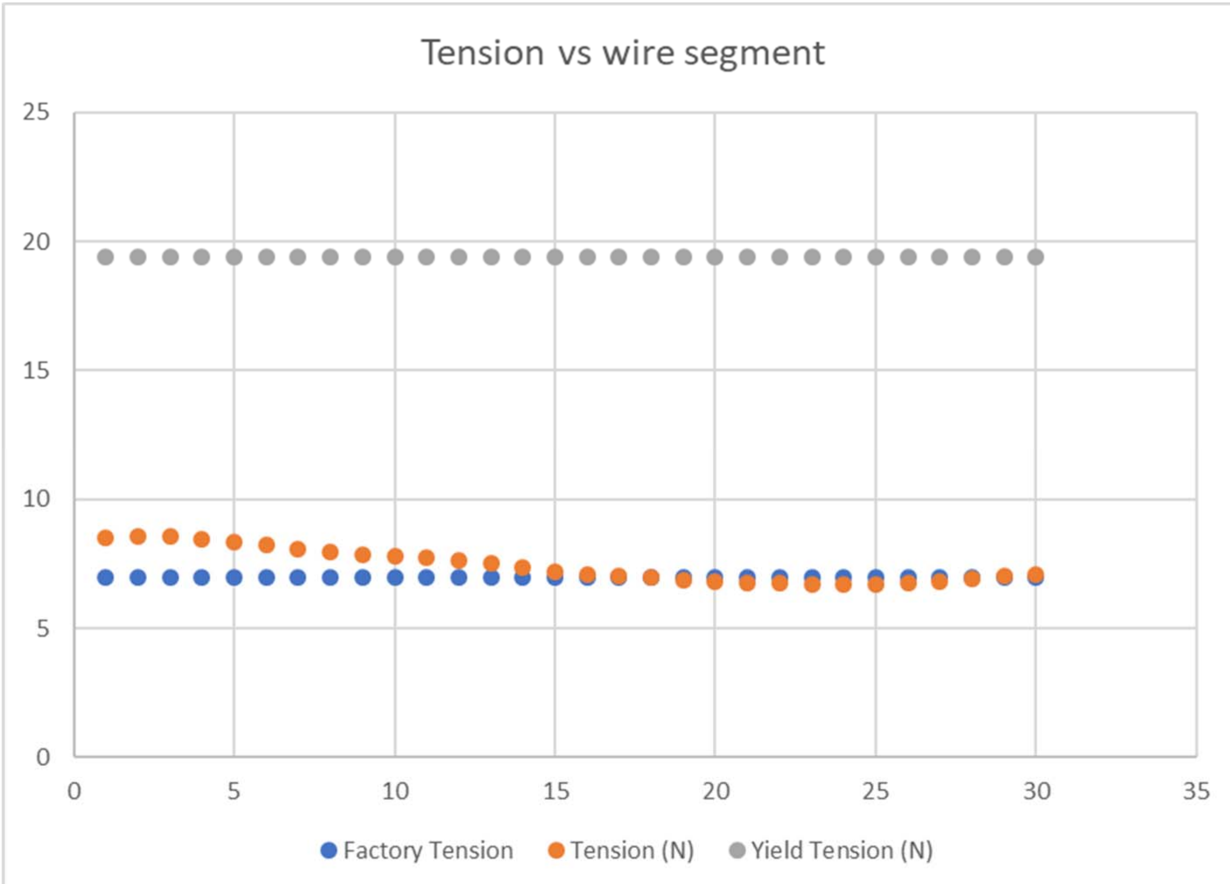
Results: Case 2 “ in plane”



Tension increases from 7 to 10.1N.

Note: Transverse deflection is less than 2mm and can be ignored

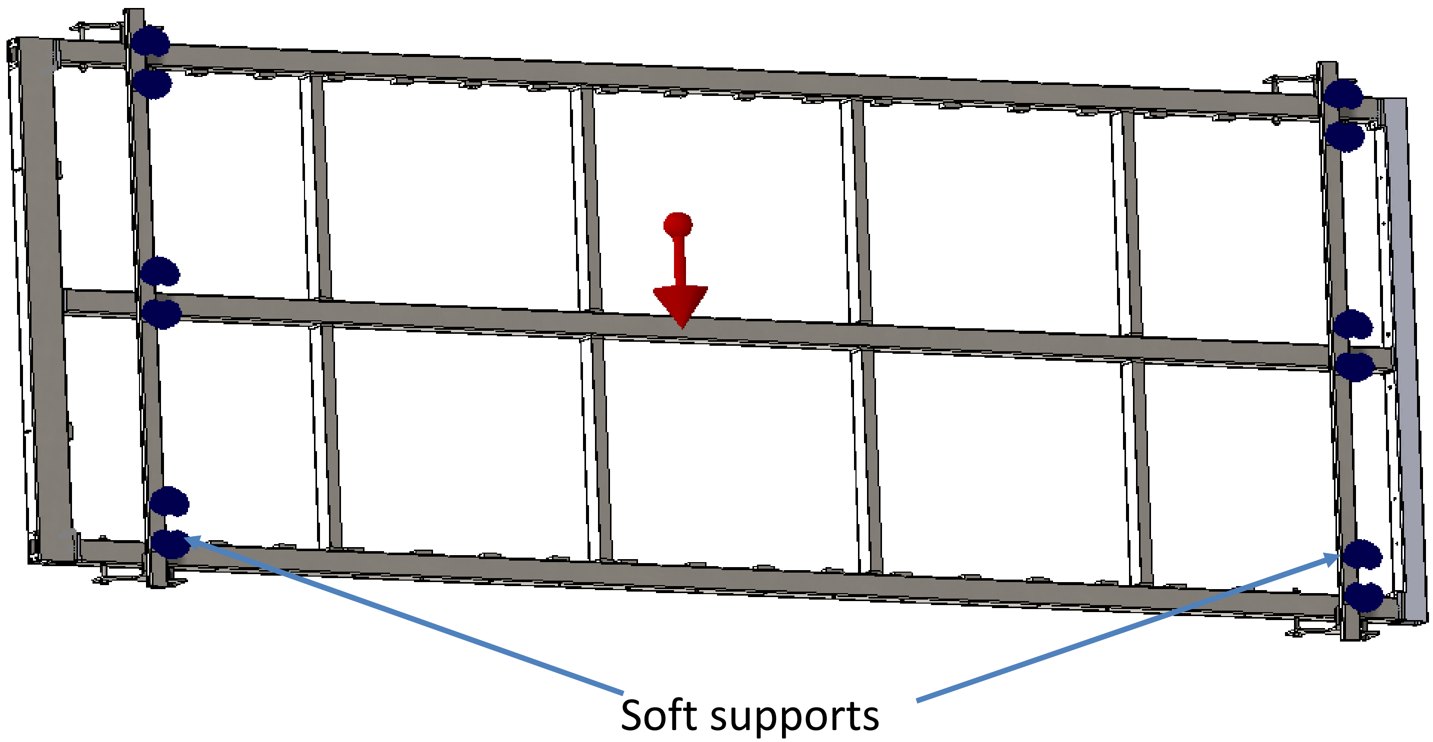
Results: Case 3 “ in plane”



Tension increases from 7 to 8.59N.
Note: Transverse deflection is less than 1mm and can be ignored.

Strength of M20 adaptor connection - Constraints

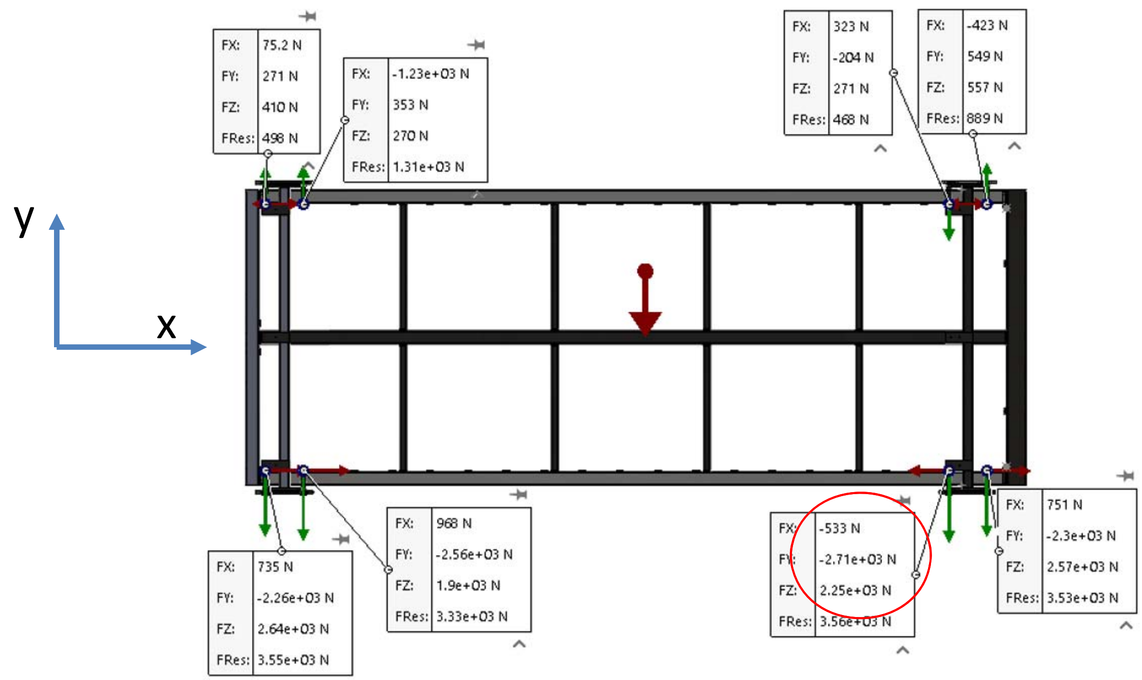
- Frame and support bracket included in the model
- The frame and bracket assembly are constrained in FEA model using soft supports with spring constants approximating the vibration isolators



Strength of M20 bolt and threads - inputs

Inputs Mass of APA with protection, contingency and a 1.4 load factor is 868kg
loads –determined by FEA

Pin to Nut Plate Forces



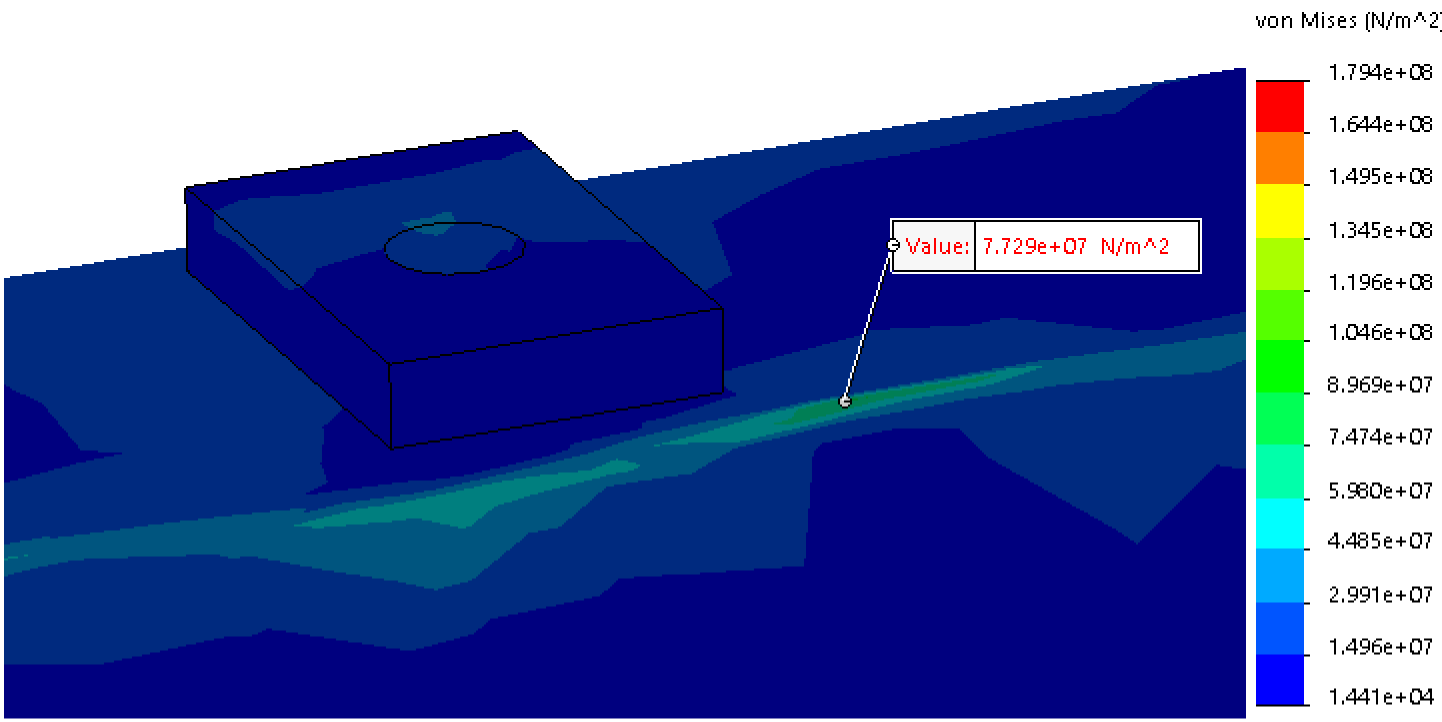
Maximum FY on pins. See note.

Slide courtesy of Jake Nesbit

Note: Polarity shown represents forces acting on the pins. The forces of the pin acting on the nut plate are equal and opposite.

Tube wall stress

Stress by nut plate with vertical load of 2710N is 72 MPA.
Available stress is 186MPa



Inputs continued

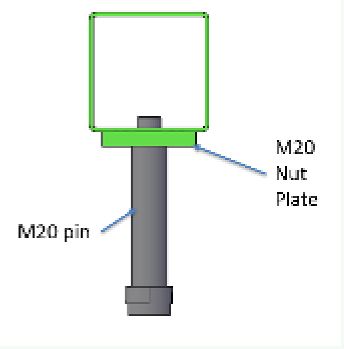


Figure 1 M20 nut plate

1 Inputs:

$mAPA\_lf := 620 \cdot kg \cdot 1.4 = 868\ kg$ — Mass of APA factored with Protection and Contingency

$F := 2710 \cdot N$ — The load from FEA

$Fb := F = (2.71 \cdot 10^3)\ N$ — Tensile force per bolt

$Fbs := \left((553 \cdot N)^2 + (2250 \cdot N)^2\right)^{.5} = (2.317 \cdot 10^3)\ N$ — Shear force per bolt

Strength of M20 bolts and threads per code

Shear and tensile strength for M20 bolts (per J3.6 page 16.1-131 of 14th ed.)

$Fu := 500 \cdot MPa$	Ultimate tensile stress of 304 SS
$Fnt := .75 \cdot Fu = 375\ MPa$	Nominal tensile stress, per table J3.2
$Fnv := .45 \cdot Fu = 225\ MPa$	Nominal shear stress, per table J3.2
$Ab := \left(\frac{\pi}{4}\right) \cdot (20 \cdot mm)^2 = 314.159\ mm^2$	Nominal unthreaded body area of bolt
$Rnt := Fnt \cdot Ab = \left(1.178 \cdot 10^5\right)\ N$	Nominal tensile strength
$Rnv := Fnv \cdot Ab = \left(7.069 \cdot 10^4\right)\ N$	Nominal shear strength
$Rdt := .75 \cdot Rnt = \left(8.836 \cdot 10^4\right)\ N$	Design tensile strength for $\phi := .75$
$Rdv1 := .75 \cdot Rnv = \left(5.301 \cdot 10^4\right)\ N$	Design shear strength for $\phi := .75$

Shear strength for female M20 threads

$D := 20 \cdot mm$	Nominal diameter of screw
$p := 2.5 \cdot mm$	Pitch of screw
$Le := 12.7 \cdot mm$	Length of thread in tube wall
$dp := (D - 0.64952 \cdot p) = 18.376\ mm$	Pitch diameter per ISO 898 Part 1
$Ass := 0.5 \cdot \pi \cdot dp \cdot Le = 366.589\ mm^2$	Shear area of threads per ISO 898 Part 1
$Fu := 500 \cdot MPa$	Ultimate tensile stress of 304 SS
$Fnv := .6 \cdot Fu = 300\ MPa$	Nominal shear stress of 304 SS 0.6 = Ratio of shear/tensile strength in table J3.2)
$Rnv := Fnv \cdot Ab = \left(9.425 \cdot 10^4\right)\ N$	Nominal design shear strength of female threads
$Rdv2 := .75 \cdot Rnv = \left(7.069 \cdot 10^4\right)\ N$	Design shear strength of female threads

Results

Verification of M20 screw and nut plate thread strength.

$Rdmin := min(Rdt, Rdv2) = (7.069 \cdot 10^4)\ \boldsymbol{N}$ Minimum design tensile strength

$Fb = (2.71 \cdot 10^3)\ \boldsymbol{N}$ <Rdmin=(70.69*10^3) N ✓ Verification of tensile strength

Fbs=(2.32*10^3) N<Rdv1=(53.01*10^3) N ✓ Verification of bolt shear strength

Note: Per User note on page 16.3-134 it is not necessary to check combined stresses because required stress is less than 30% of available stress.

High G load analysis on APA frame - inputs

Three load cases were analyzed with extra g-load on the APA frame

- Case 8 - The APA and transport box lying flat. This case represented possible orientation in the South Dakota warehouse and this orientation is no longer foreseen. (g-load applied perpendicular to the plane of the APA)
- Case 9 - The APA and transport box in landscape mode. This is the typical orientation during transportation. (g-load aligned to minor axis of the APA)
- Case 13 - The APA vertical with the head end down. This is orientation the upside down APA will see when transported down the shaft. (g-load aligned to major axis of the APA)
- Load factor of 1.4 applied to loads on the APA frame
- Proper resistance factors applied to material and connections

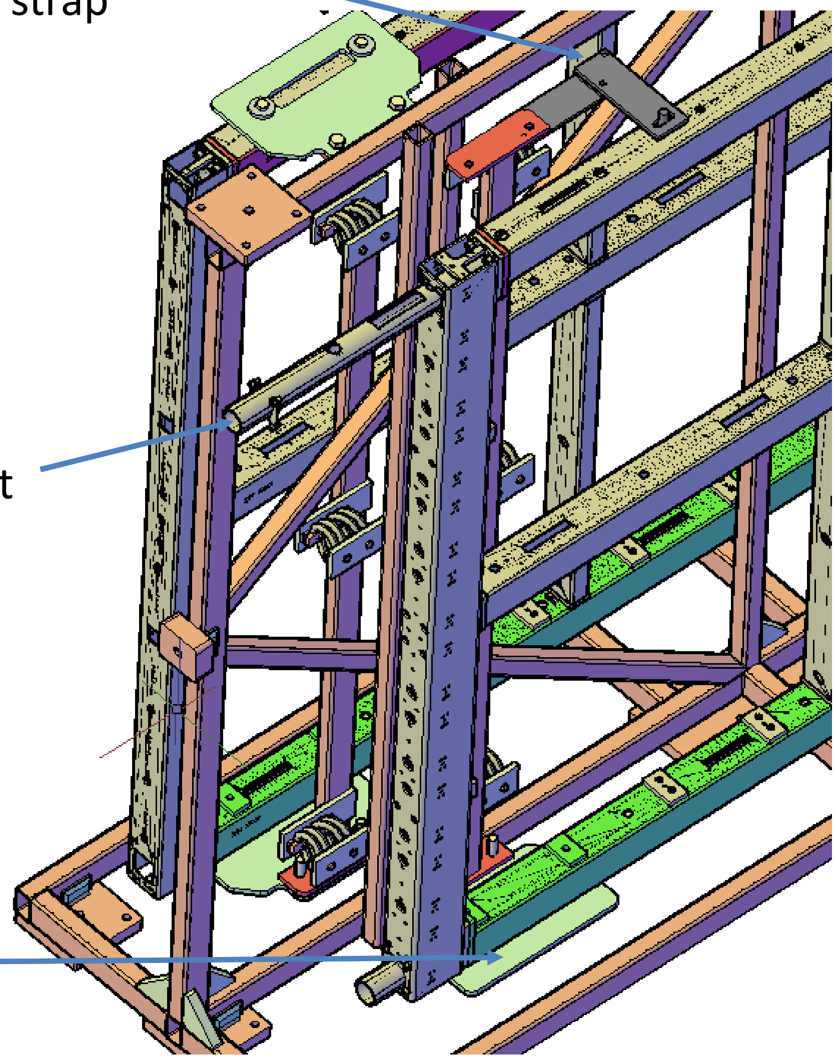
High G load analysis on APA frame - results

- G-load increased until a limiting factor was reached
  - Limiting factor > Weld strength by AISC code
  - Case 8 > 4g
  - Case 9 > 4g
  - Case 13 > 6g
- Max g-load from vibration or shock that can transferred to the APA. (Analysis was done in the vertical direction for the various orientations. The vertical direction is typically the direction of maximum g-loads.)
- Ang Lee's analysis dynamic analysis estimates g-loads much lower than 4 g's.

Conduit installation – Steps 1 to 4

- APA is transferred using the edge lift kit to the transport box. Adaptor pins are preinstalled in the bottom side tube.
- Bottom plates are mounted to the adaptor pins.
- Stabilizing straps are mounted on each end to keep APA from tipping
- Top conduit is installed (Tapered nose cone added to help guide conduit.)

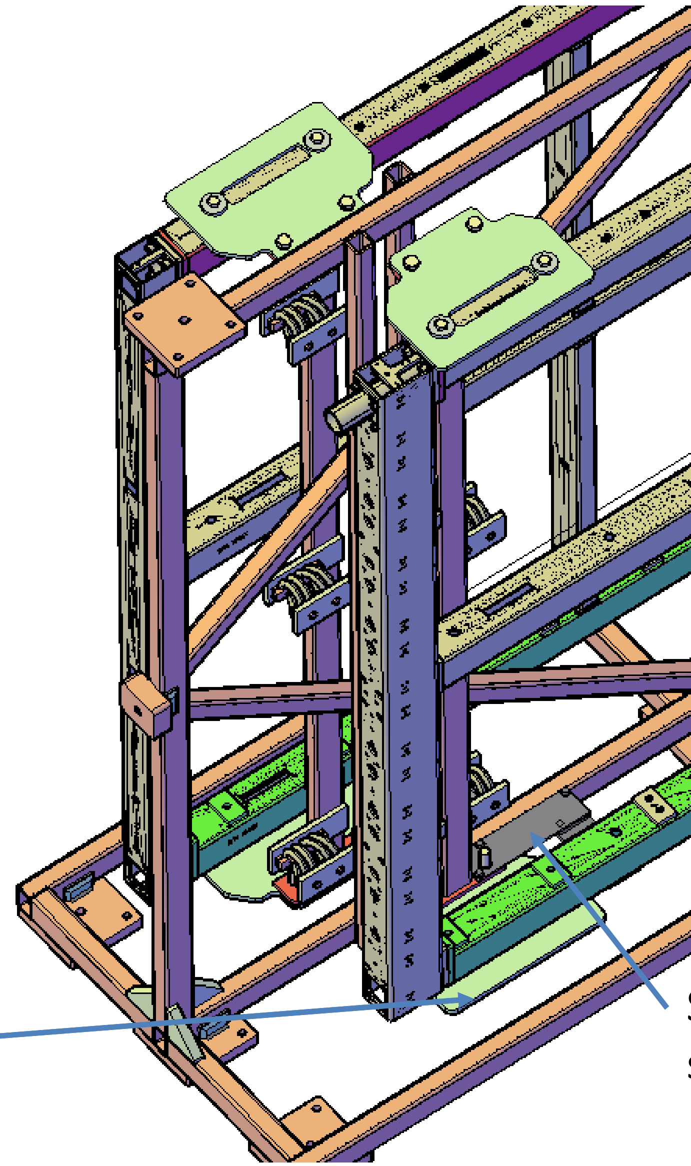
Note: Protection is not shown for clarity



Conduit installation – Step 5-8

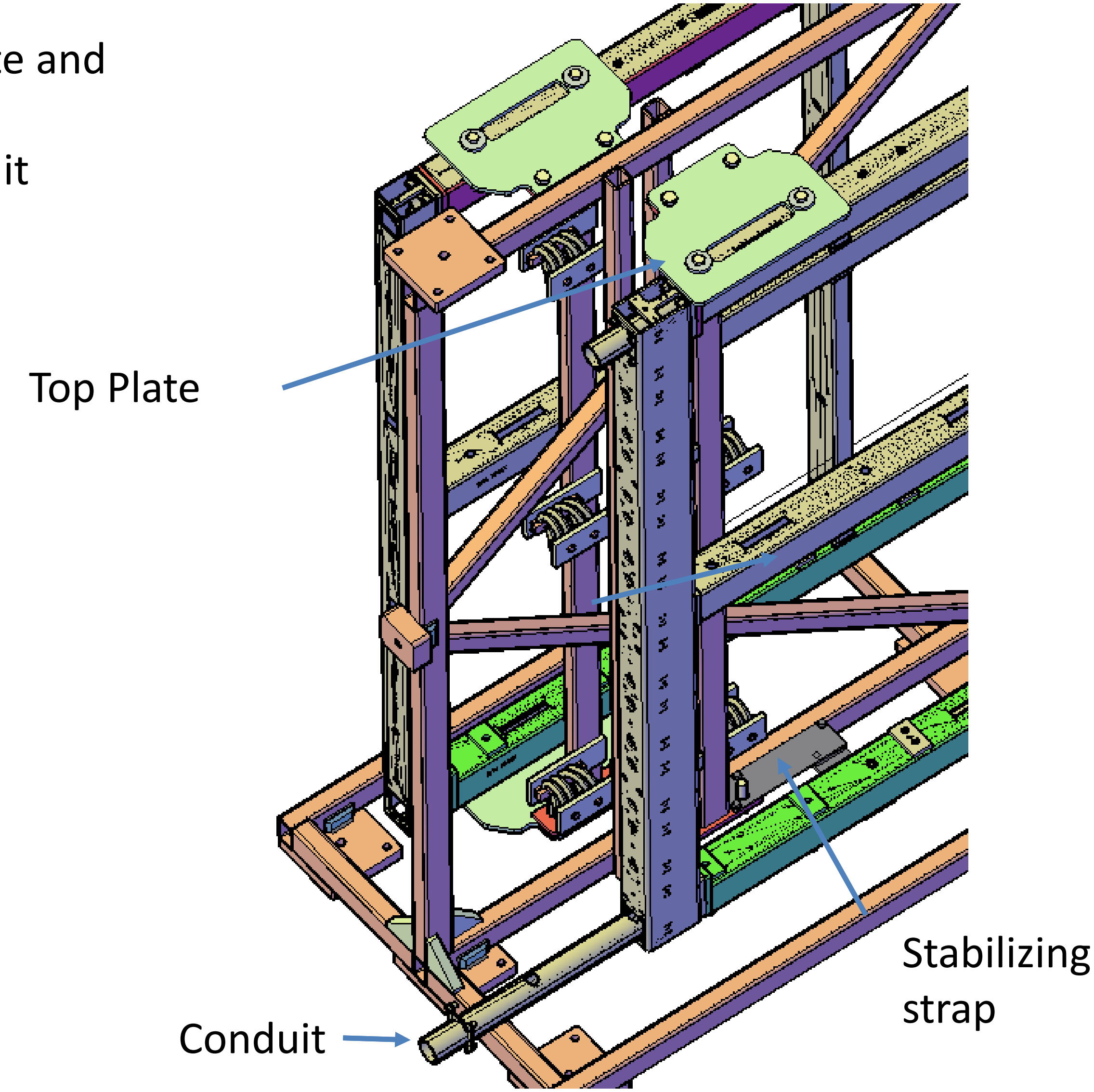
- Install adaptor pins in the top side tube
- Mount the top support plates
- Remove the top stabilizing strap
- Add the bottom stabilizing strap

Note: Protection is not shown for clarity



Conduit installation – Step 9-10

- Remove the bottom plate and adaptor pins.
- Insert the bottom conduit

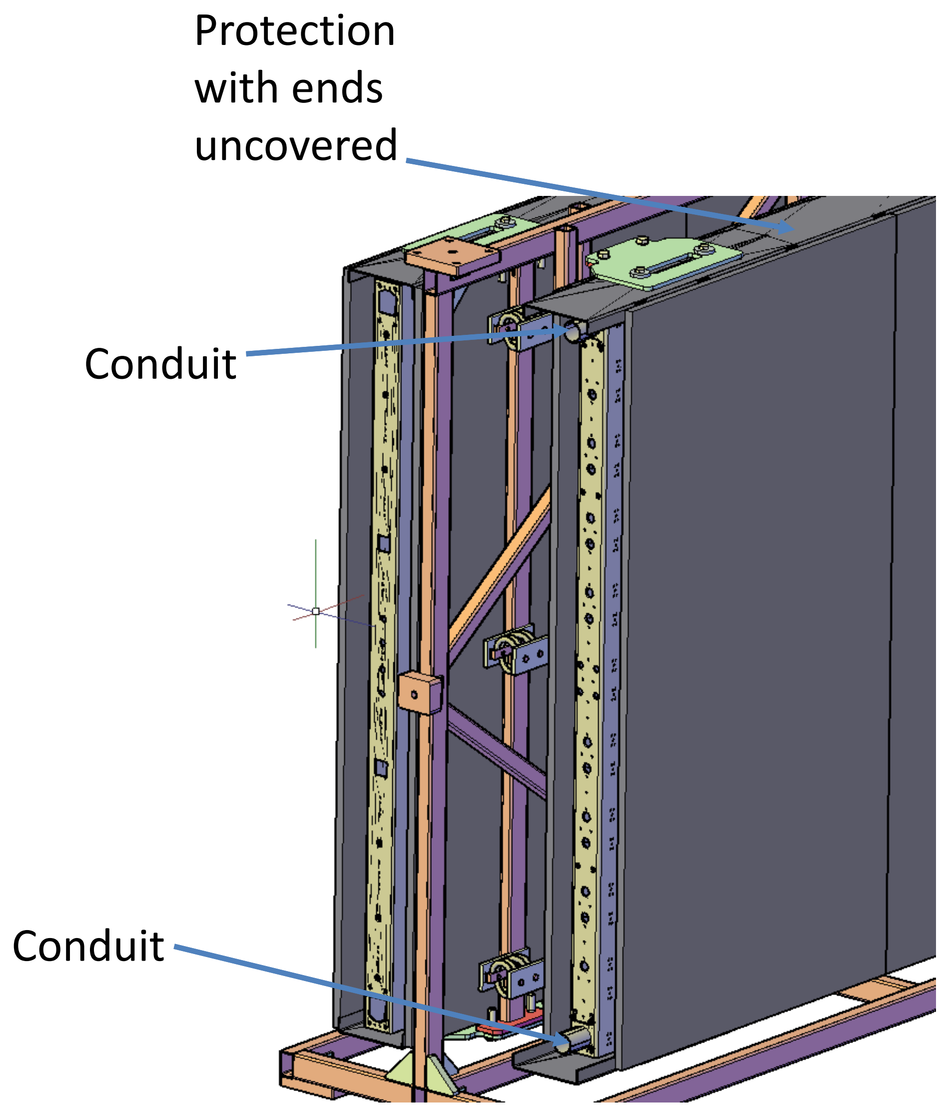


Note: Protection is not shown for clarity

Conduit installation – Step 10-12

- Reinstall the adaptor pins and remount the bottom plates
- Remove the bottom stabilizing straps.

- Note: An alternative is to set up a special single APA station that simulates the Transport frame support brackets, but without the springs. The APA could then be moved to the transport frame with the edge lift kit. Additional holes would be required in the conduit for the edge lift kit.



Lessons learned from protoDUNE transport box

- The protoDUNE transport box was used for truck, air, and sea transport, but did not have nearly as many requirements imposed upon it.
- For DUNE, the transport box must handle being lowered down the shaft and rotated to “ upside down” landscape. This drove significant design changes.

APA is suspended from above

ProtoDUNE APA being loaded into transport box

Suspension system

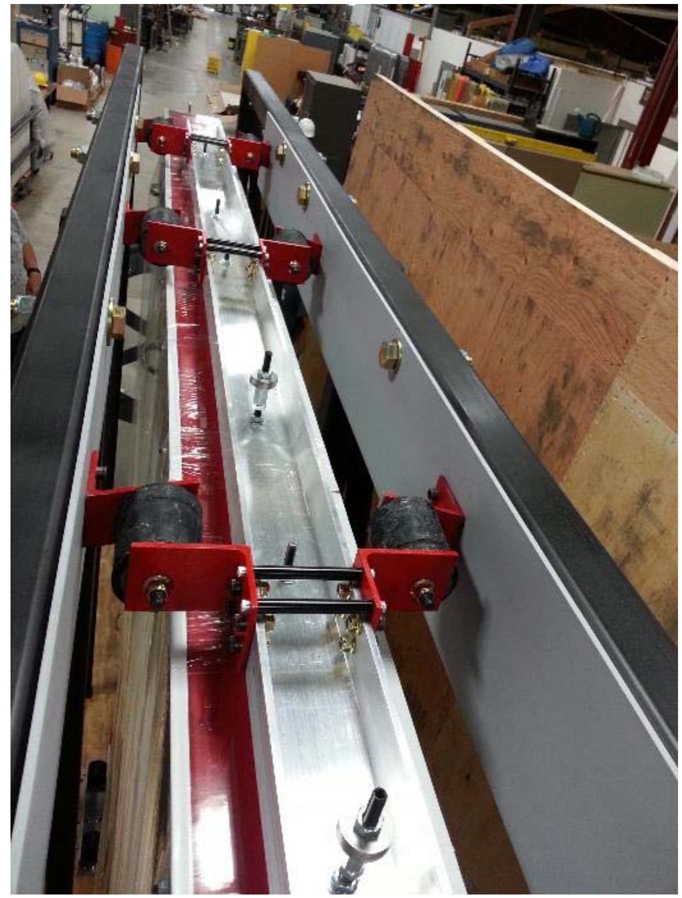
Lessons learned from protoDUNE transport box

- Lessons learned still be applicable to the transport frame from "LessonsLearned by Systems.xlsx" (docDB 8255):
  - Took a long time to connect the lifting fixture, yoke and trolleys. > protoDUNE lifting fixture was mounted with the APA in landscape mode. It was difficult to install the connecting bars because they cantilevered into the side tubes and because they bound on the pins (Equivalent to the M16 to M20 adaptors). The new design will be connected with the Transport box vertical and connections will be more compliant. See APA removal talk.

Lessons learned from protoDUNE transport box

- Time consuming to remove suspension system. Many fasteners with Allen heads. > 48 bolts replaced with 8 M16 bolts and 8 M16 to M20 adapters.

Six suspensions assemblies with 8 bolts each



View of three suspension assemblies

Lessons learned from protoDUNE transport box

- Working platforms were either to tall or too short. > Working with the installation team to ensure adequate access for operations.
- Unpacking check list and tool list was useful > Goal is to do the same for DUNE.
- Some fasteners came loose. (This may be a fastener retention issue or may have been a vibration isolation issue.) > Close attention is being paid to vibration isolation in the DUNE APA transport frame design. Also, methods of fastener retention will be implemented.
- Rivnuts bolts (threaded rod) had Loctite and where difficult to remove on APA #6. > Will be considered when specifying retention methods.

M10 threaded rod.