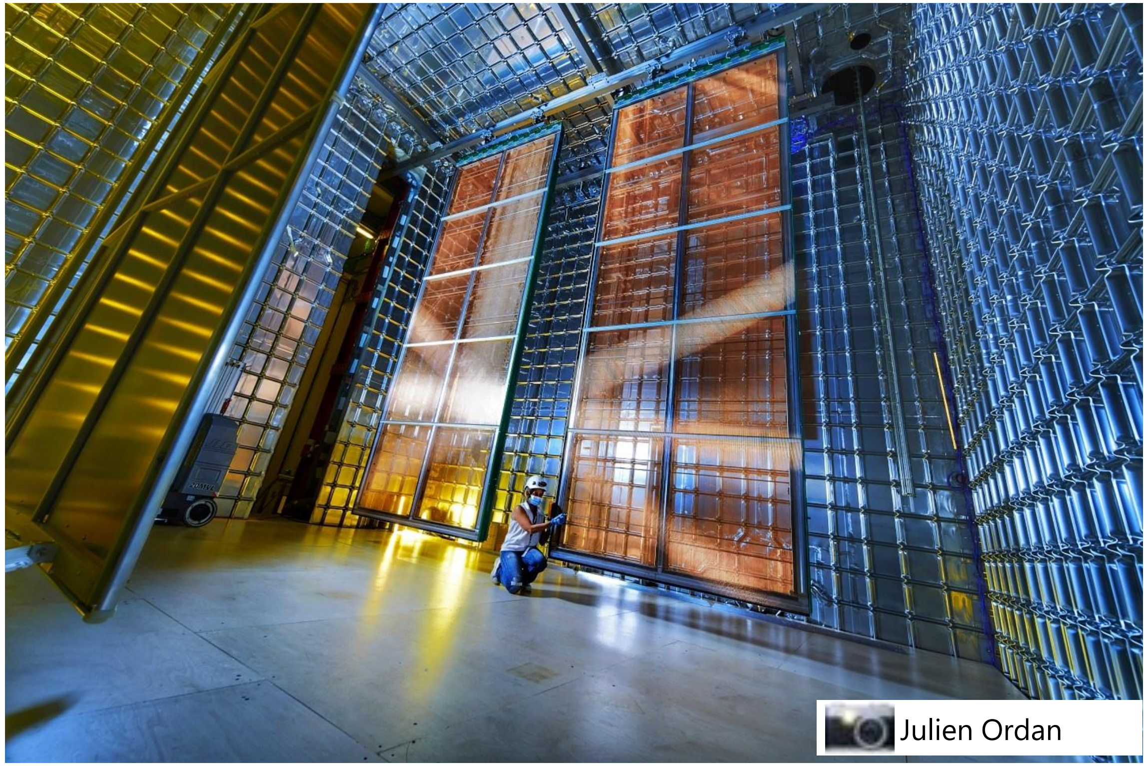
Prototyping and testing of the transportation strategy for a high energy physics detector

Forum on Tracking Detector Mechanics 2023
31st May – 2nd June 2023
Eberhard Karls Universität Tübingen



Mariana Zimbru (CERN) on behalf of:

O. Beltramello, J. Evans, J-L Grenard, J. Hrivnak, G. Buccino, B. Lacarelle, E. Seletskaia, M. Guinchard and CERN EN-MME team.

Fermilab   CERN   Sanford Underground Research Facility   U.S. DEPARTMENT OF ENERGY | Office of Science

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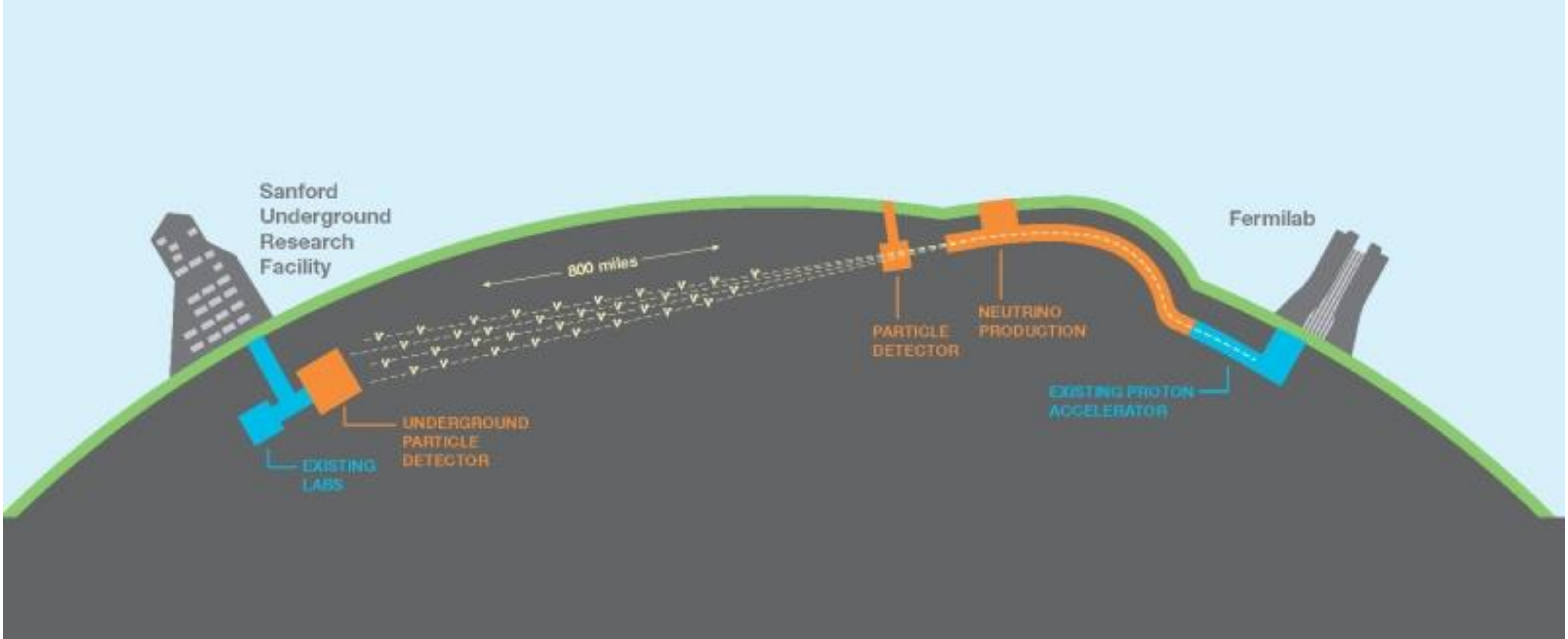
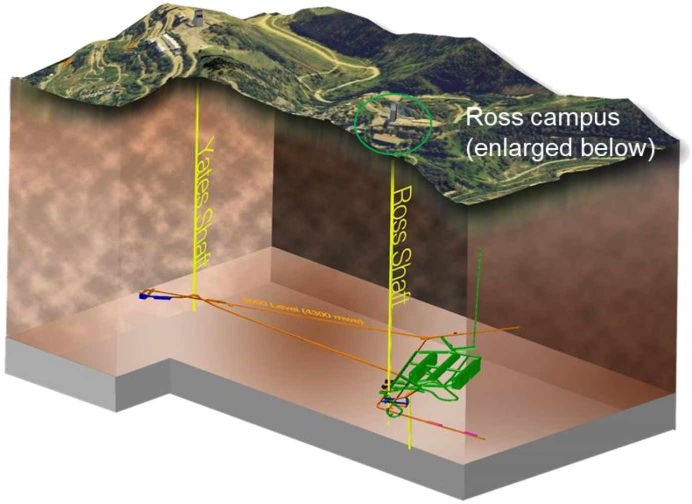
The DUNE Project

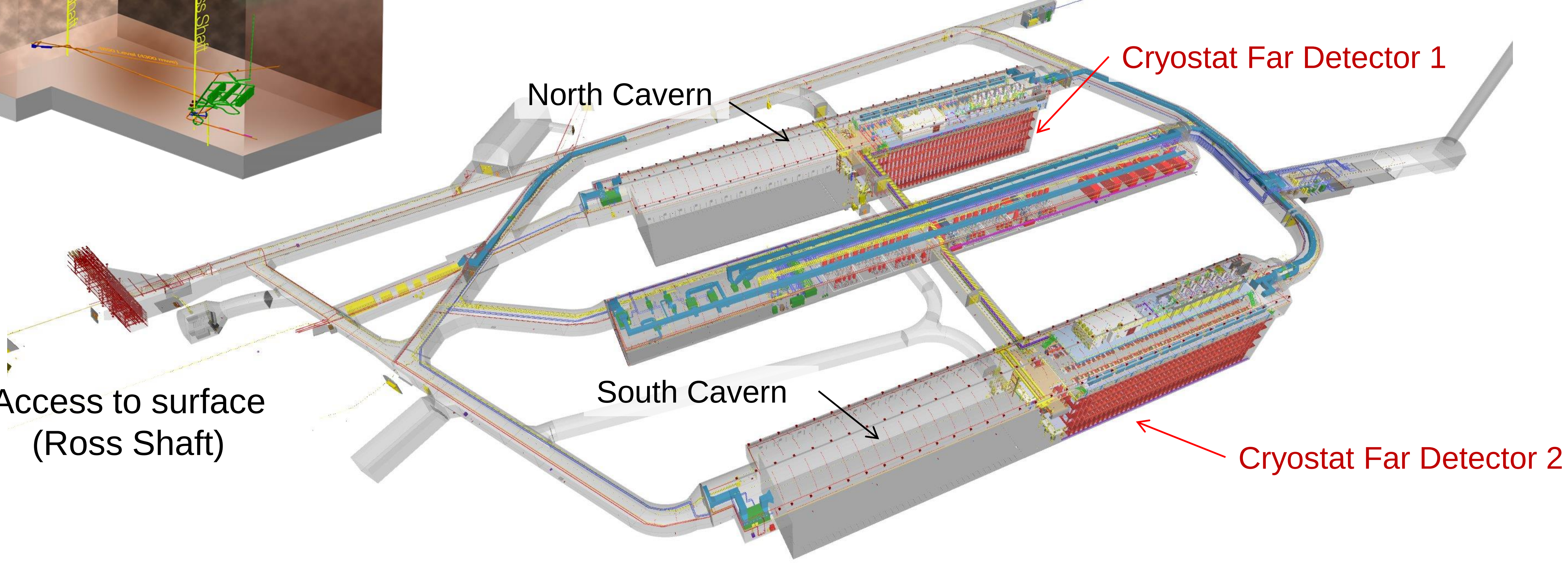


DUNE at LBNF (fnal.gov)

The DUNE Project – Far site detector

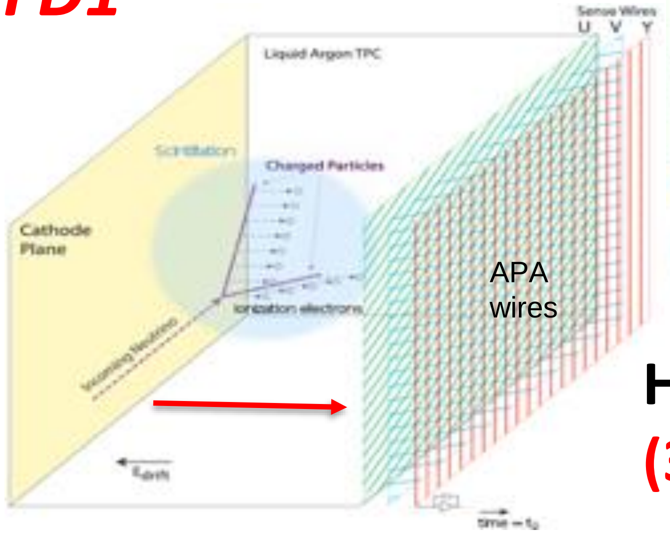


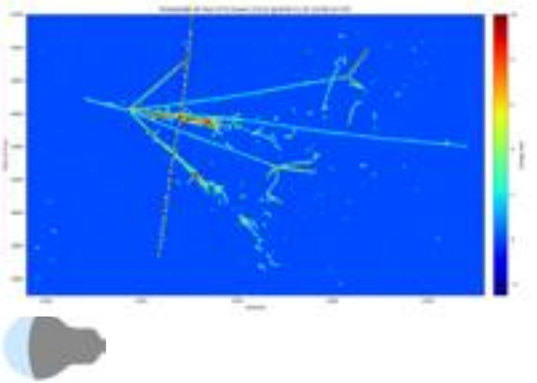
Sanford Underground Research Facility layout



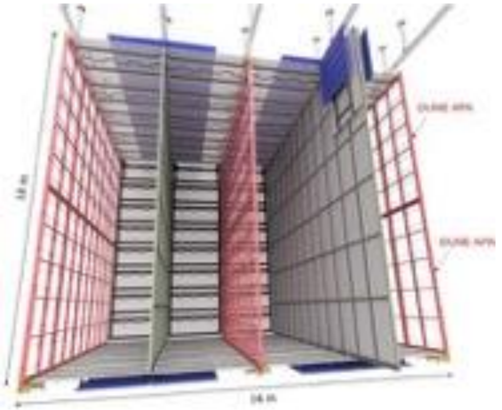
The DUNE Project – Far site detector

FD1



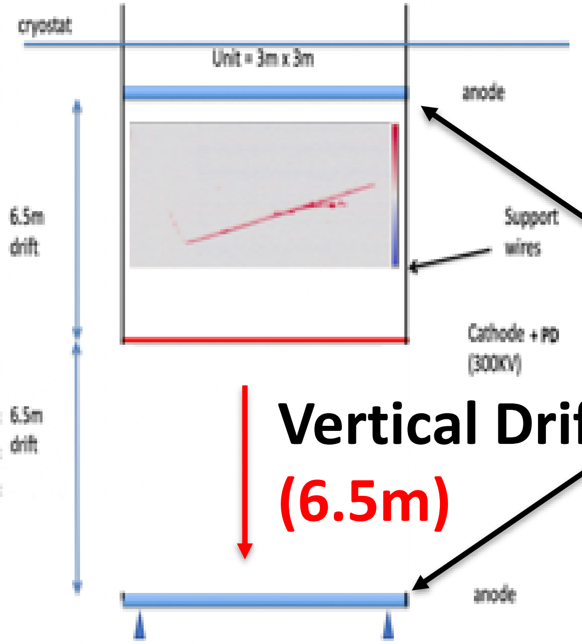


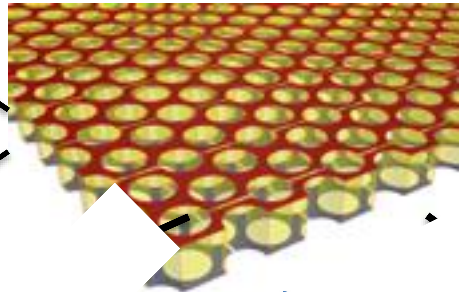
Horizontal Drift
(3.6m)

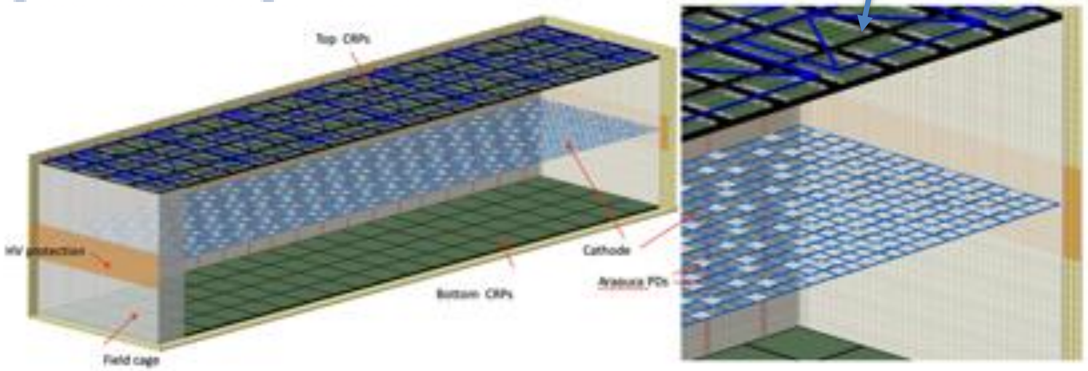


FD2

PCB perforated strips with pitch similar to that of APA wires

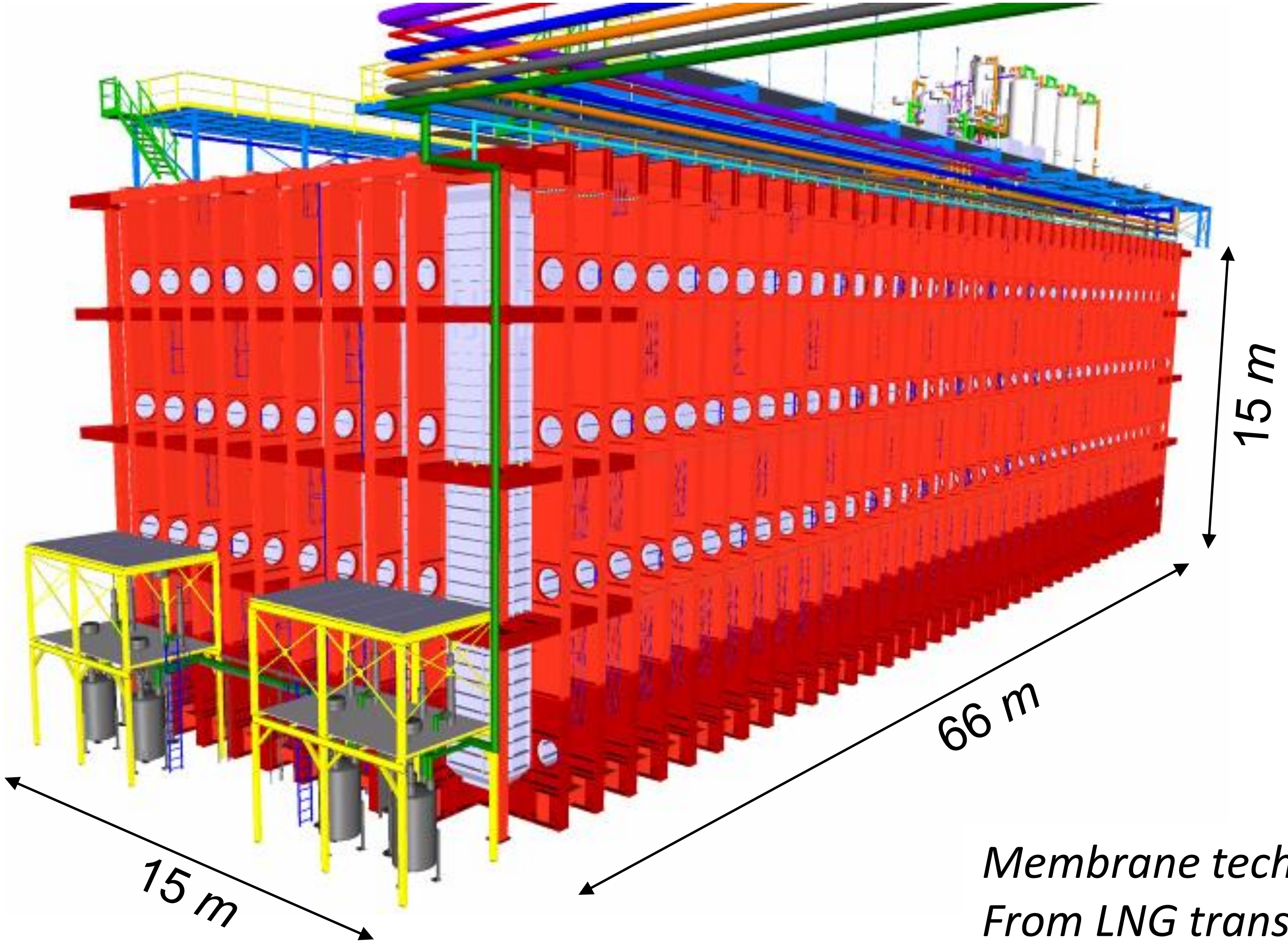




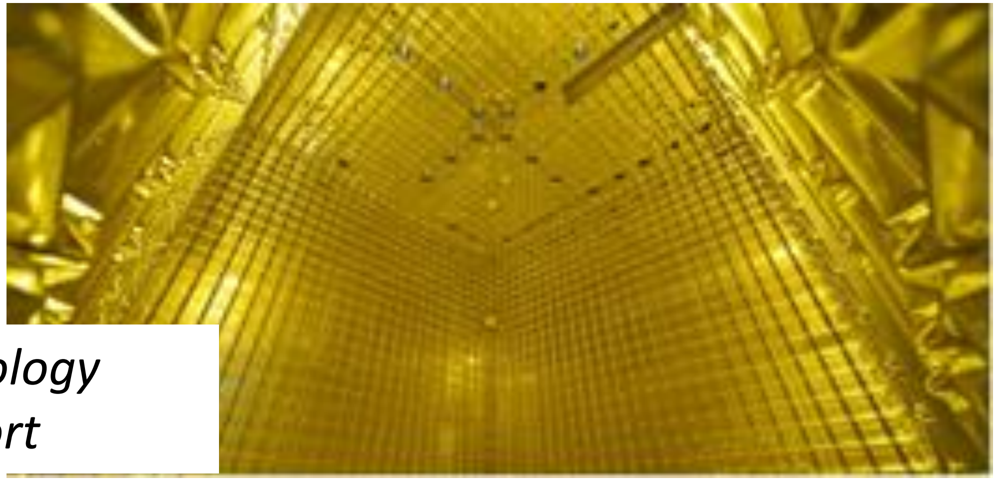


The DUNE Project

DUNE Far Site cryostats

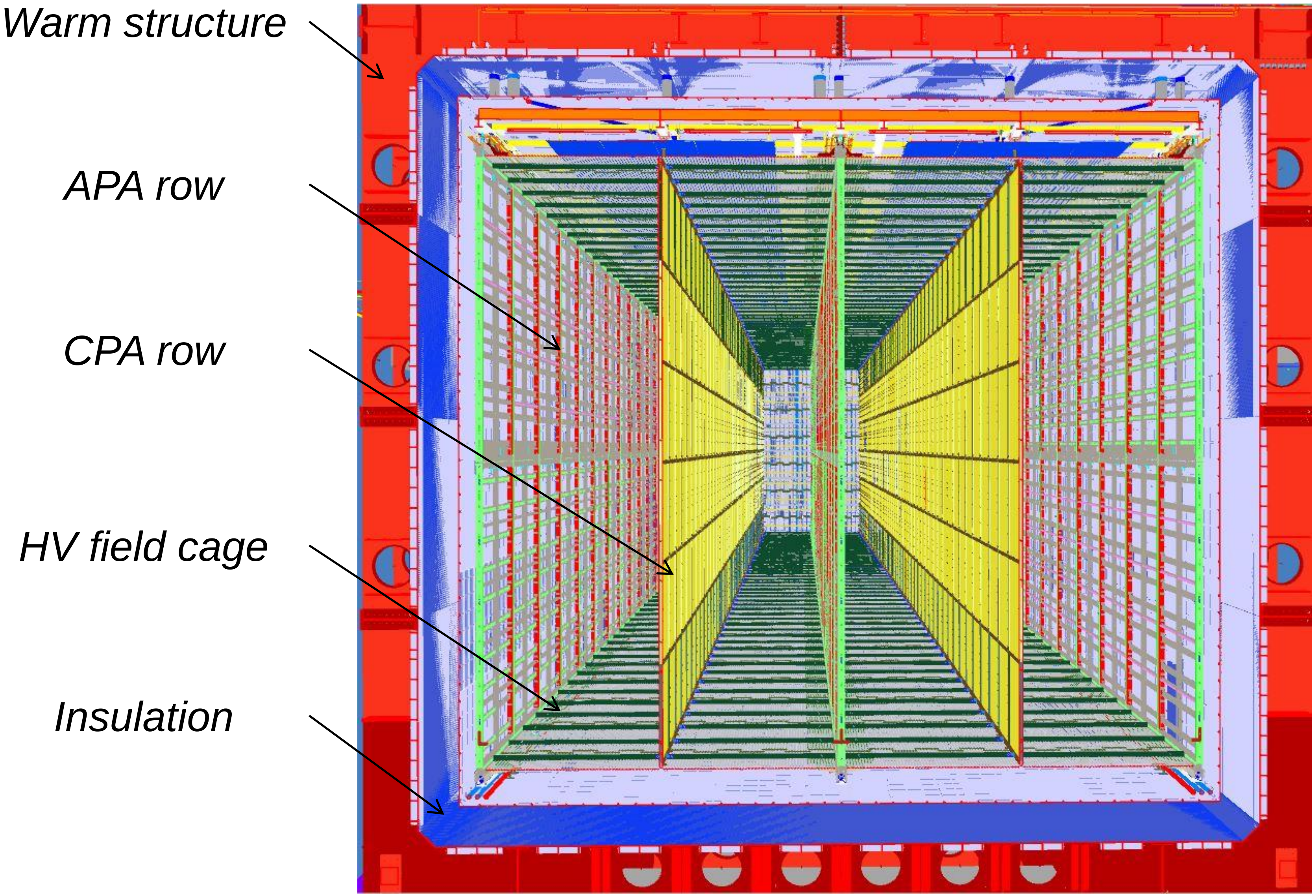


ProtoDUNE (NP04 CERN)



Membrane technology
From LNG transport

The DUNE Project



The Anode Plane Assembly (APA)

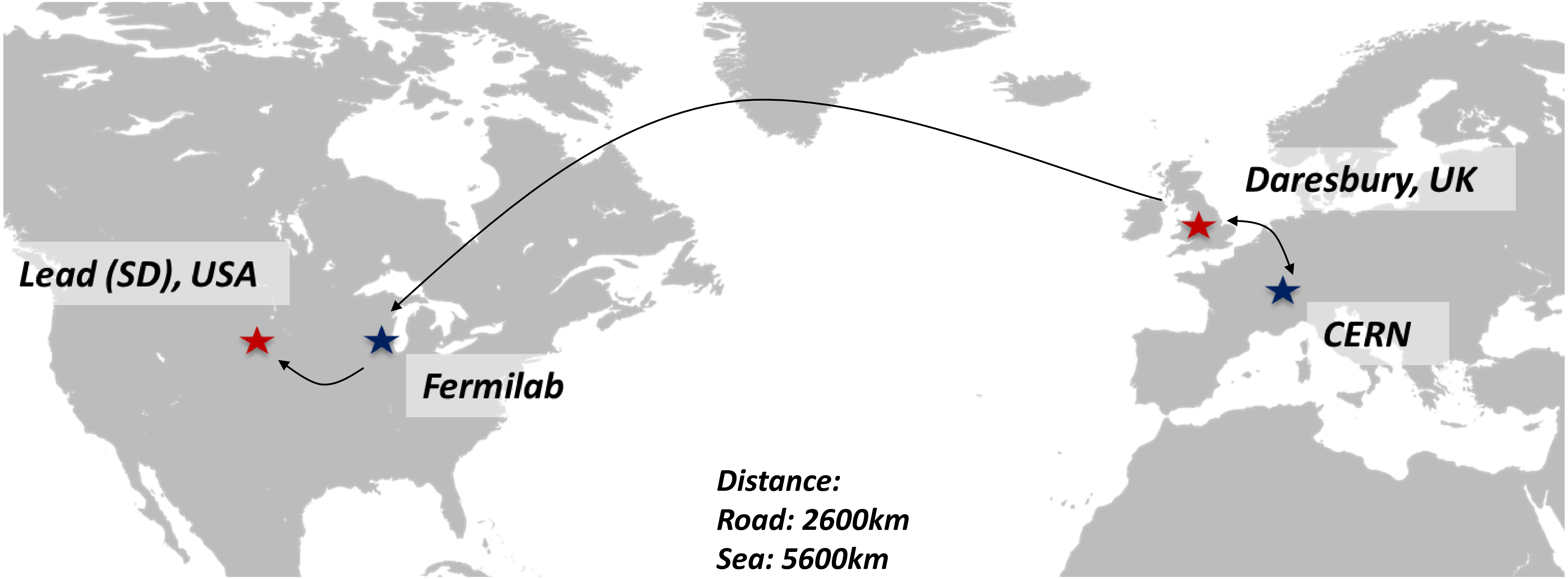
APA installed inside ProtoDUNE

Julien Ordan

Some numbers:

- APA Dimensions: 6m x 2.3m
- DUNE APA are assembled as a vertically stacked pair
- 3,520 prestressed copper-beryllium wires of 150 µm diameter wound in 4 layers (per APA)
- Flatness of the frame must be within millimetres

APA Transportation challenges and limitations



APA Transportation challenges and limitations

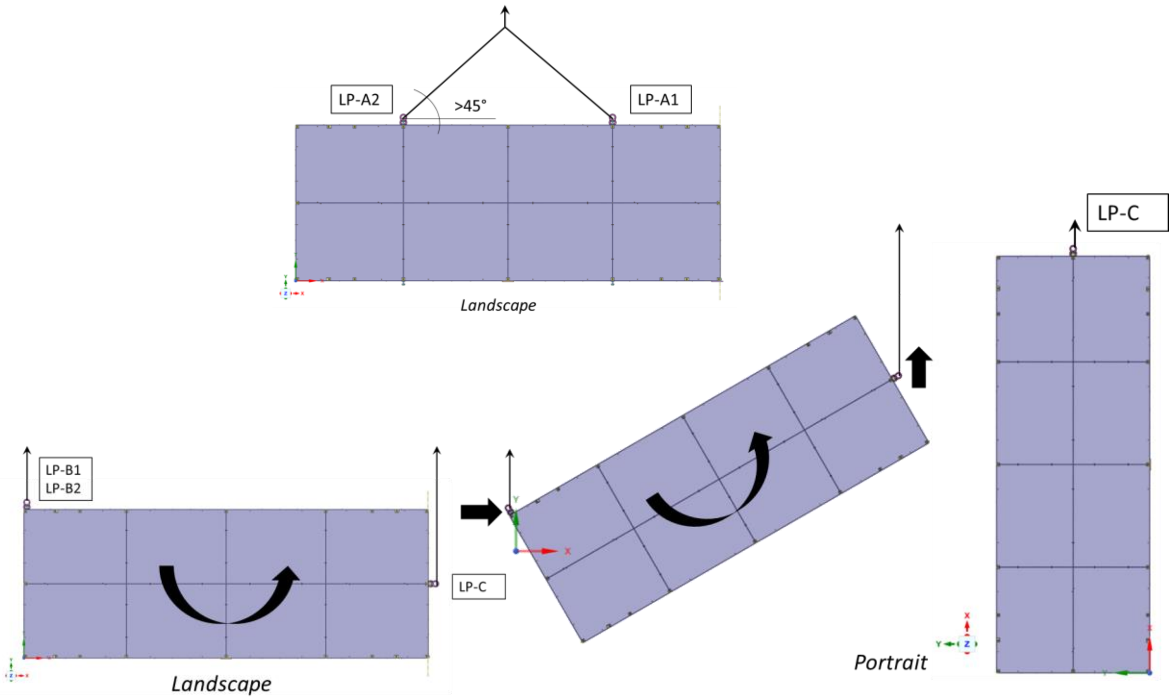
A support and transportation structure designed considering the following:

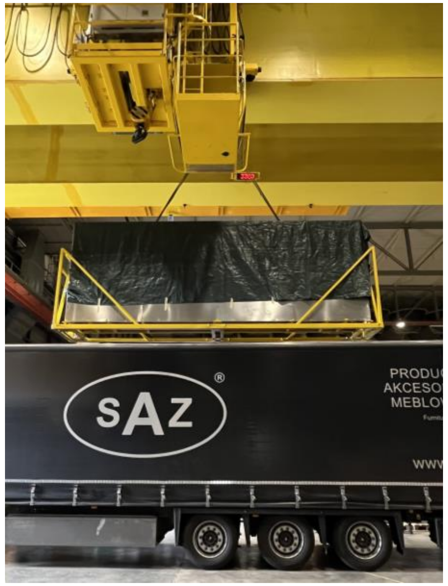
- APAs are large (6.0m x 2.3m)
- Must be transported in landscape orientation
- APAs must be transported over a long distance (>6000km)
- Limited number of support points available on the APA frame
- Transfer of vibrations and shocks must be limited
- Shipping frame must allow for APA insertion in landscape orientation
- Shipping frame must allow for APA extraction in portrait orientation
- Shipping frame must allow for manipulations and 180deg rotations
- Shipping frame must allow for PD installation at predetermined locations
- Manipulations must be done in a controlled and supervised manner
- Cost of APAs and of transport

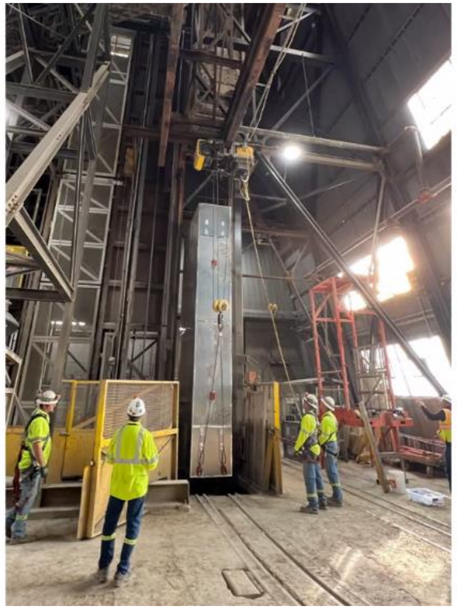
APA Shipping Frame (ASF) Design

Manipulations:

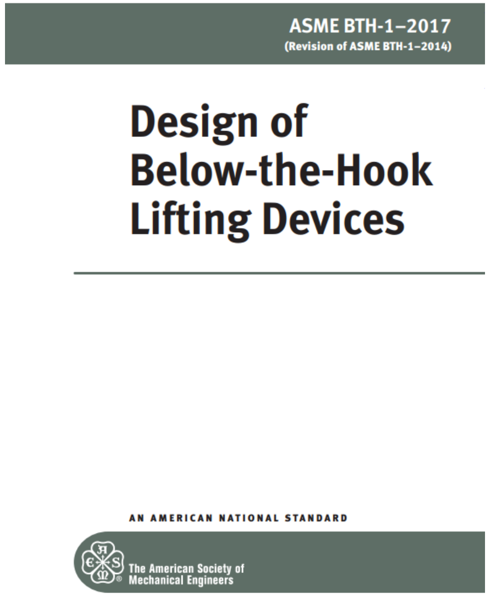
1. Lifting into/out of truck/trailer/boat/airplane
2. Lifting and rotation into and out of the Ross shaft
3. Rotation to vertical for APA extraction







APA Shipping Frame (ASF) Design



ASME BTH-1–2017
(Revision of ASME BTH-1–2014)

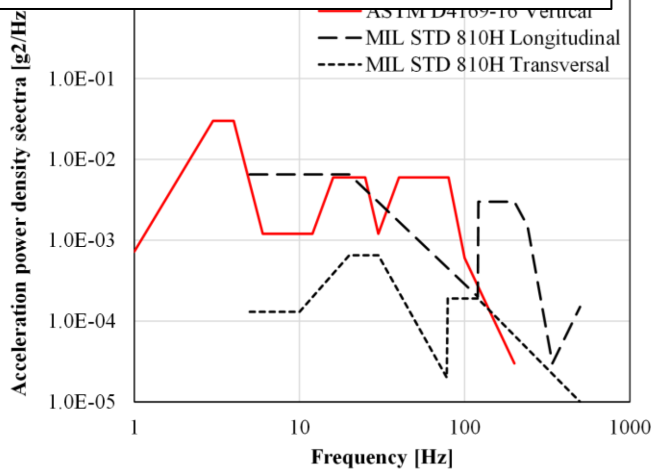
Design of Below-the-Hook Lifting Devices

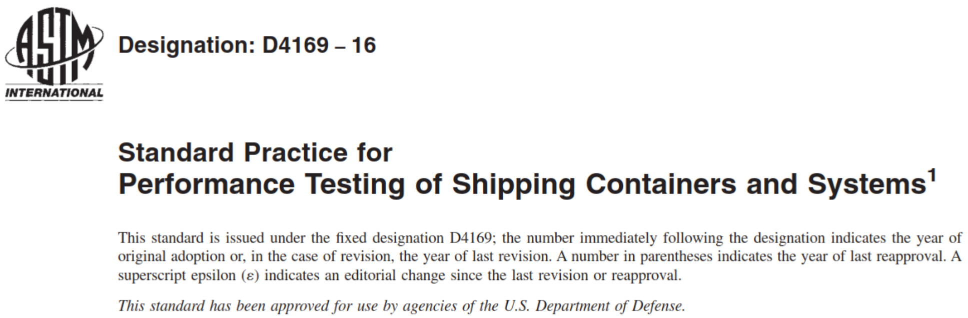
AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

Design requirements:	Impact:
1. Lifting code (ASME B30.20 and BTH-1) →	Load factor > 2
2. Transportation codes (below) →	Dynamic loading
3. Damping of vibrations and shocks →	Wire rope absorbers (WRAs)
4. Critical lift →	Oversight of manipulations

Road Vibration spectra (PSD)



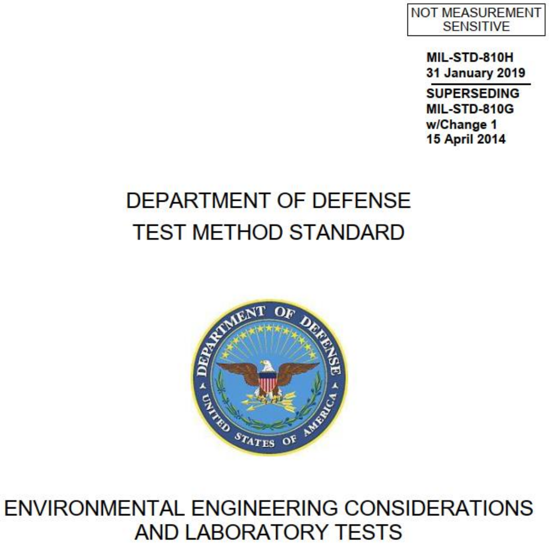


Designation: D4169 – 16

Standard Practice for Performance Testing of Shipping Containers and Systems[1]

This standard is issued under the fixed designation D4169; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.



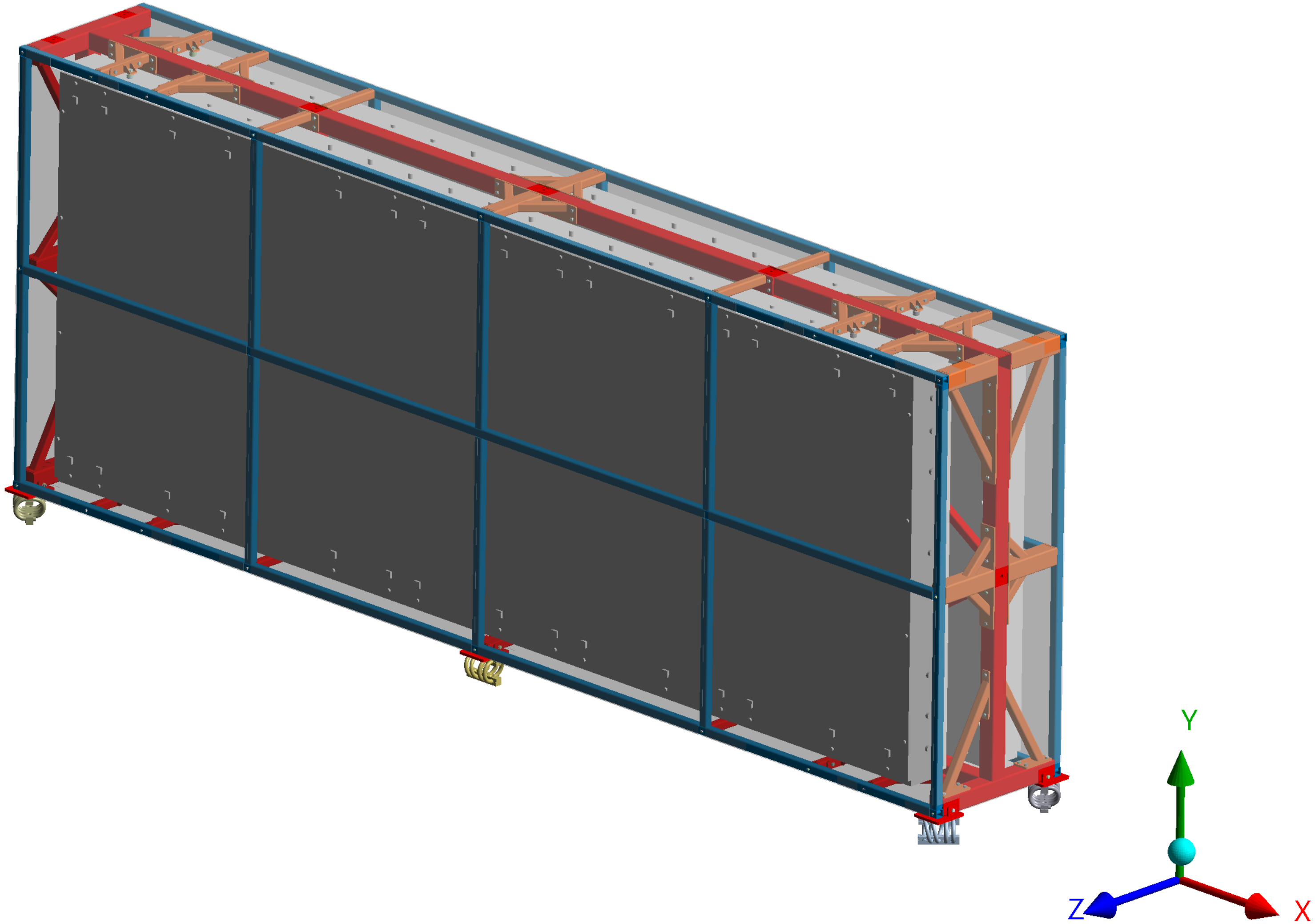
NOT MEASUREMENT SENSITIVE

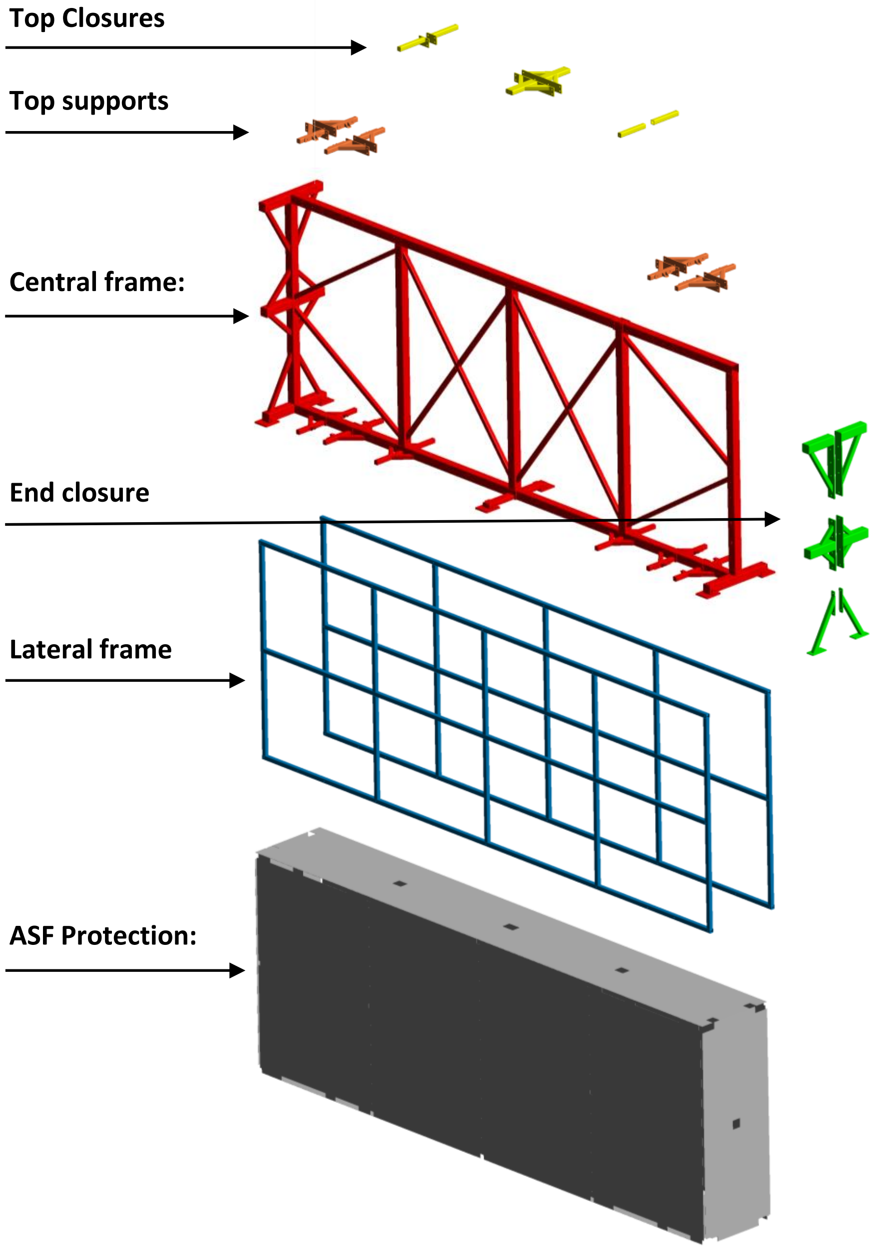
MIL-STD-810H
31 January 2019
SUPERSEDING
MIL-STD-810G
w/Change 1
15 April 2014

DEPARTMENT OF DEFENSE
TEST METHOD STANDARD

ENVIRONMENTAL ENGINEERING CONSIDERATIONS AND LABORATORY TESTS

APA shipping frame (ASF) assembly





APA shipping frame (ASF) assembly

ASF in portrait orientation

APA – ASF adapters

ASF with 2 protoDUNE APAs installed

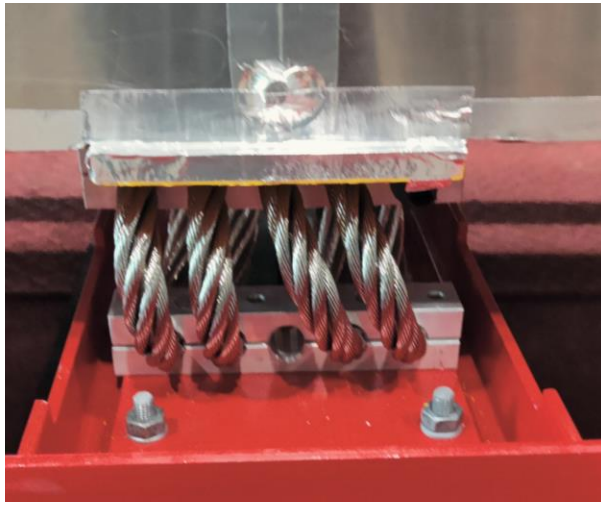
BF with the base WRAs installed

APA shipping frame (ASF) assembly

End absorber (WRA)

ASF assembly w/ protection

Base absorber (WRA)



APA Transportation Prototyping campaign

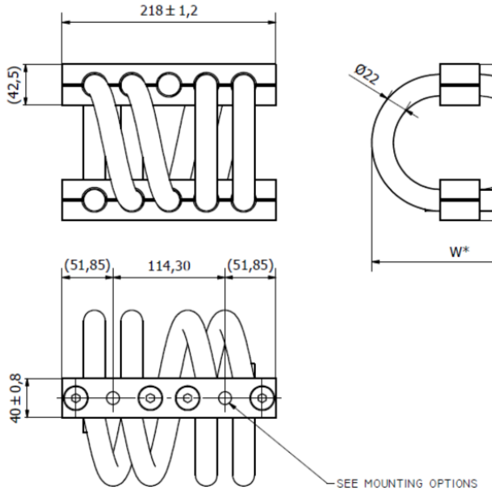
Testing at different levels:

1. ASF prototype – load tests
2. WRA tests
3. Assembling testing
4. Experimental modal analysis
5. Road vibrations testing
6. Sea inclination measures
7. Handling shocks

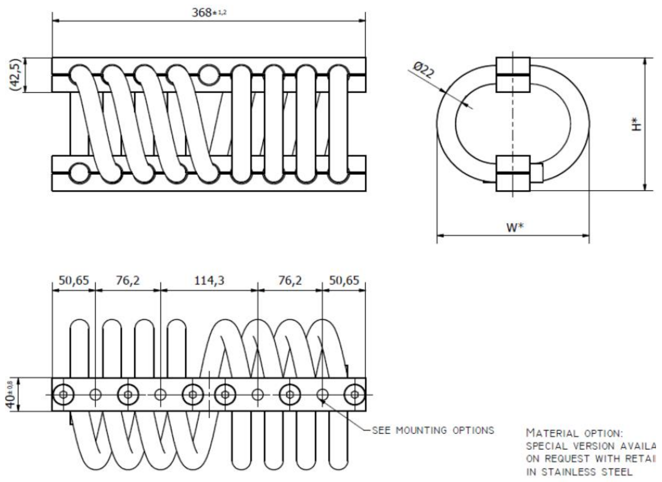
Prototype ASF – Lifting tool Testing

1. Designed for a load factor of 2
2. Load test in all lifting and rotation configurations
3. Qualified with a load test assuming a load factor of 1.5
4. CE certified

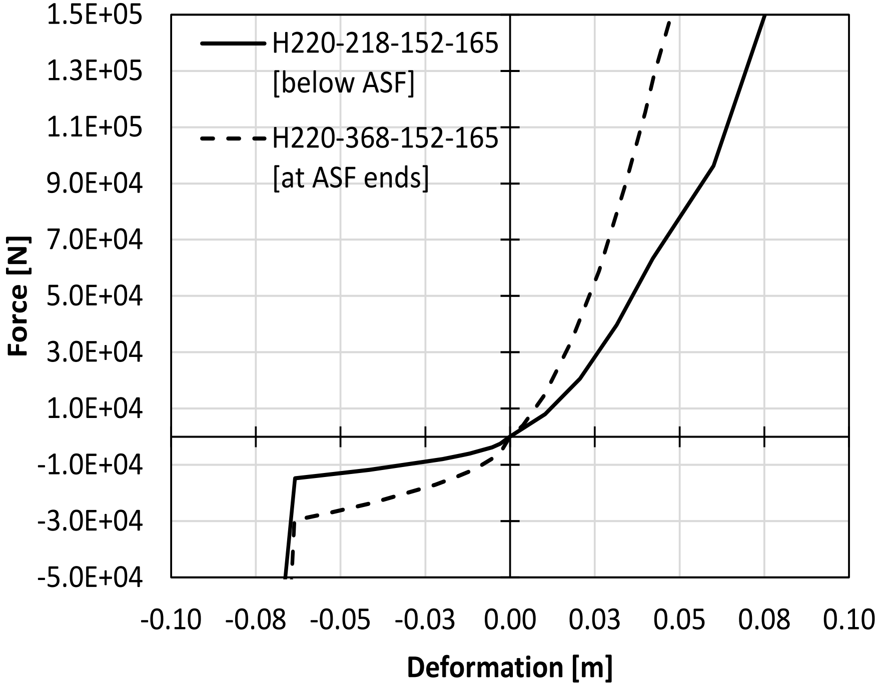
Prototype ASF – WRA Testing

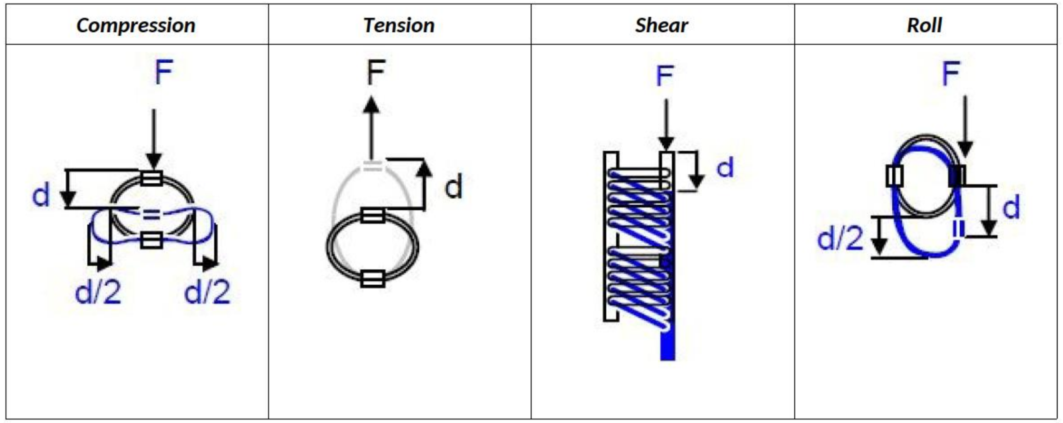


Series CAVOFLEX H220-218-H-W-4S



Series CAVOFLEX H220-368-H-W



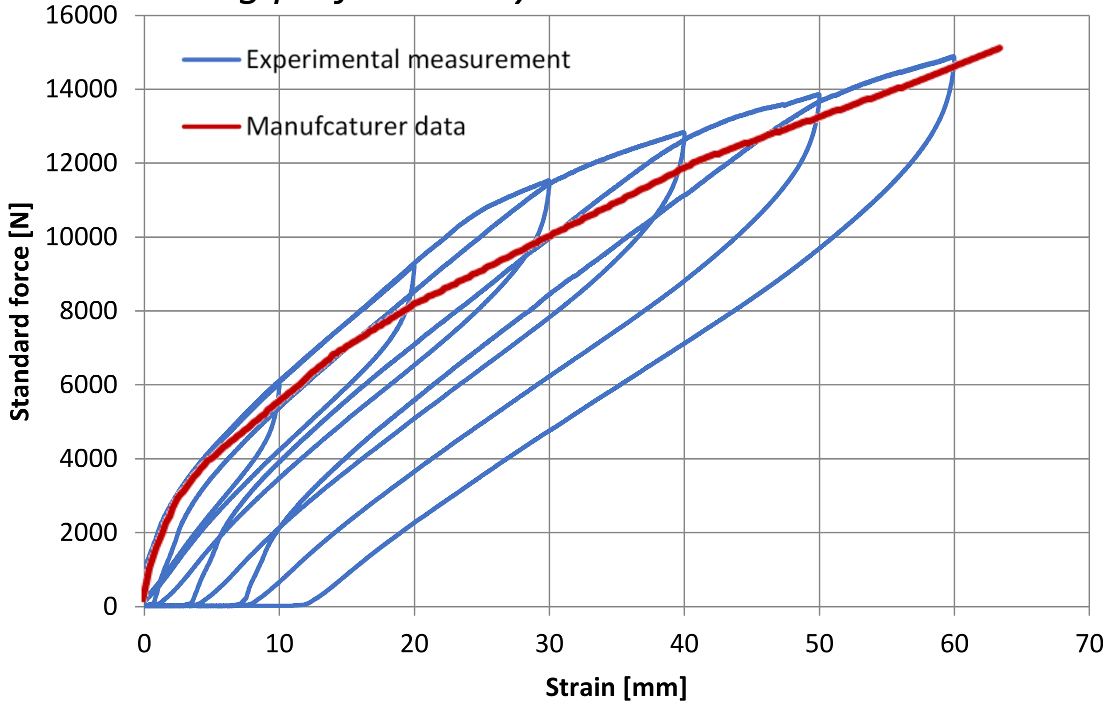


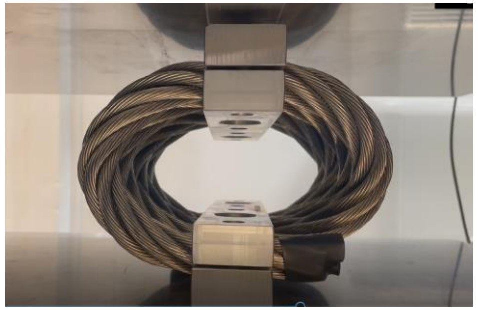
Maximum elastic deformation capacity of WRAs

Direction	WRA Base	WRA End
Compression	64mm	64mm
Tension	43mm	43mm
Shear/Roll	64mm	64mm

Prototype ASF – WRA Testing

Testing performed by the CERN EN-MME team

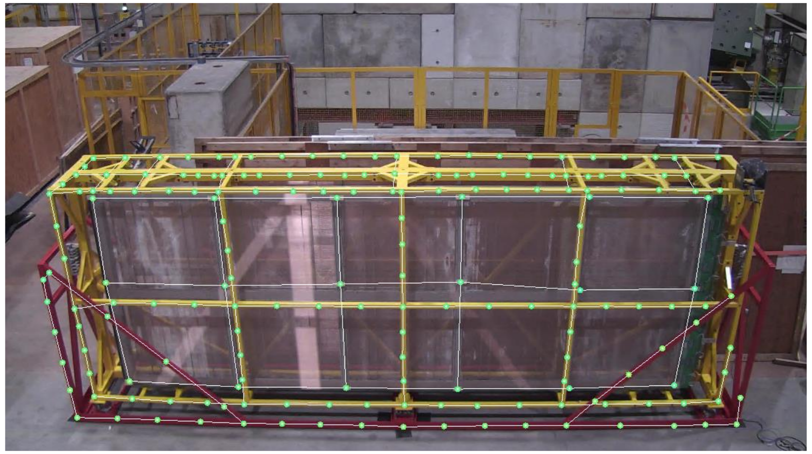




1. Manufacturer provides the force-displacement curve in the three orthogonal direction
2. Monotonic and cyclic tests were performed on one WRA in compression to verify the behaviour
3. The manufacturer data was confirmed for large displacements

Prototype ASF – Experimental Modal Analysis (EMA)



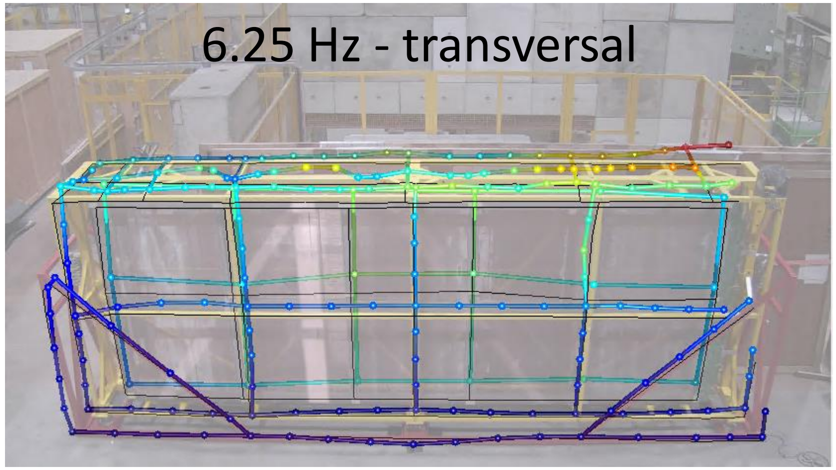


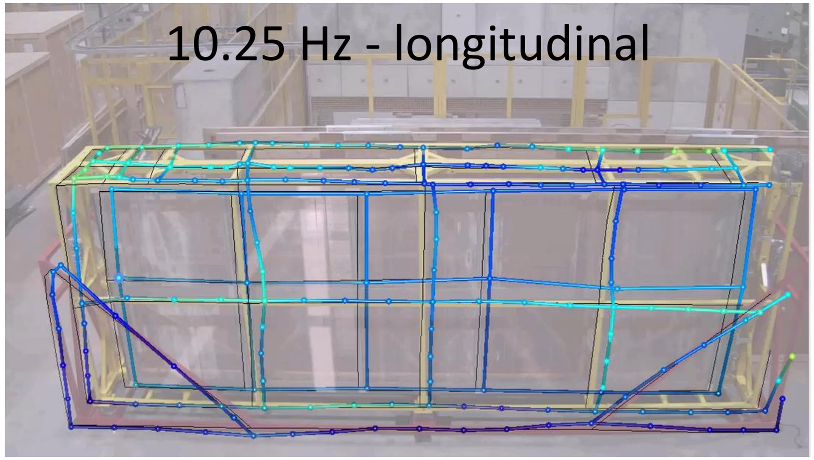

Testing performed by the CERN EN-MME team

Results Source	Transversal [z]		Longitudinal [x]		Vertical [y]	
	Freq. [Hz]	*Eff. Mass[kgs]*	*Freq. [Hz]*	*Eff. Mass[kgs]*	*Freq. [Hz]*	*Eff. Mass[kgs]*
Experimental Modal Analysis	6.25 19.25	n/a n/a	10.25	n/a	16.75	n/a
FE Modal Analysis UNCALIBRATED	3.43 6.49	1459.7 638	6.52	2132.8	7.83	2074.8
FE Modal Analysis CALIBRATED	6.10 11.04	1650 620	10.28	2442	12.9	2037

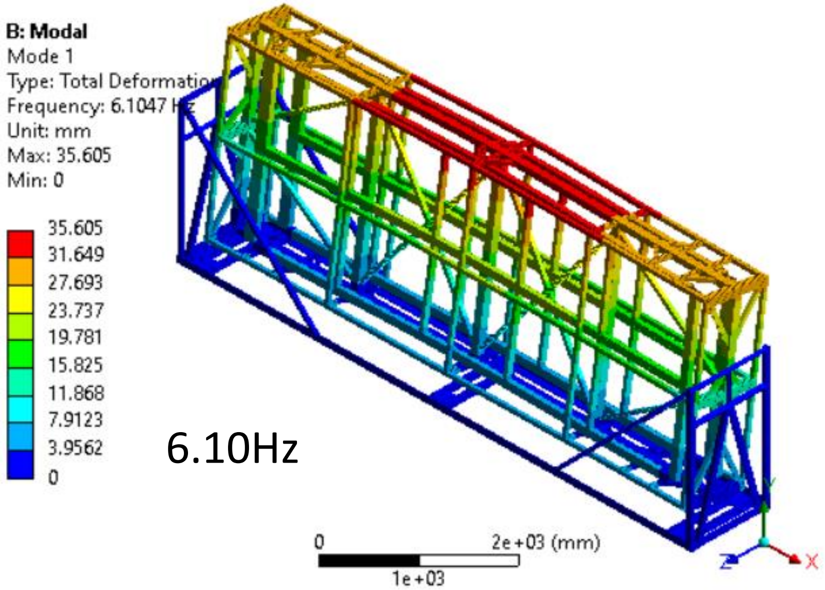
Prototype ASF – Experimental Modal Analysis (EMA)

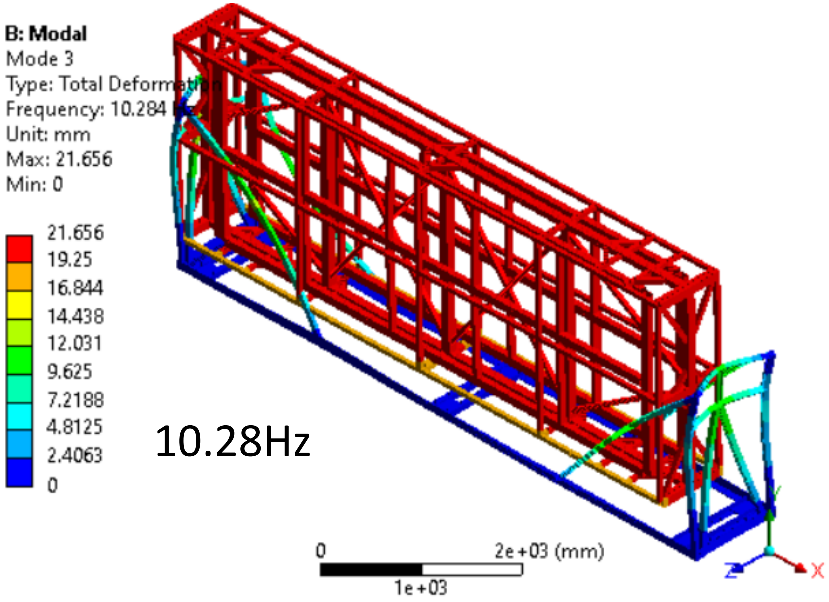
EMA





Calibrated FEA

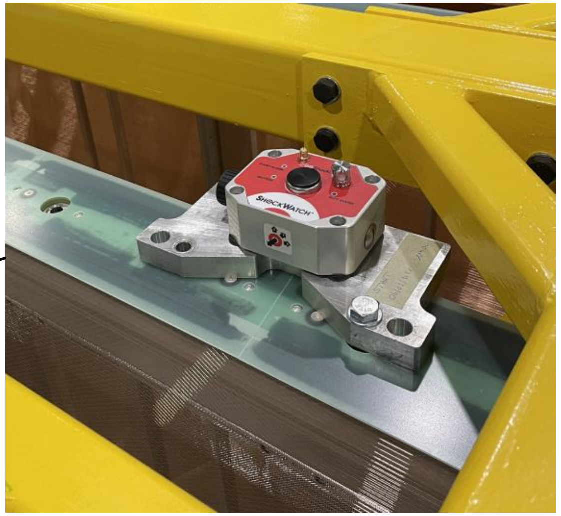




Prototype ASF – Instrumentation

Instrumentation by the CERN EN-MME team

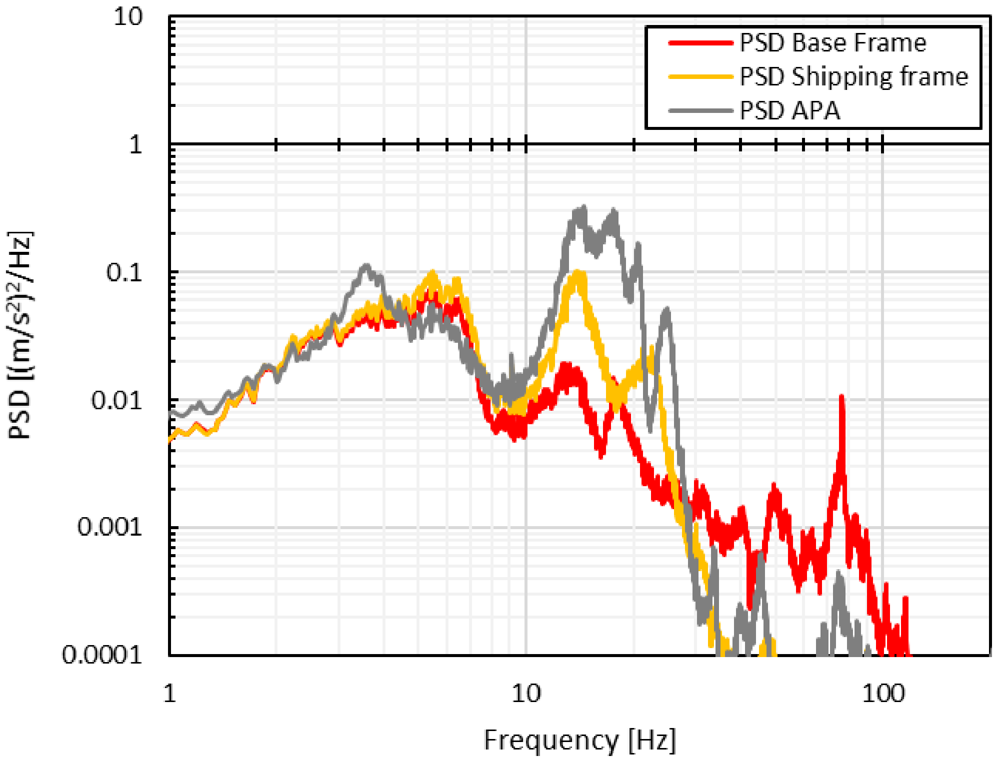
APA frame shocklog



ASF and BF accelerometer

Base frame shocklog

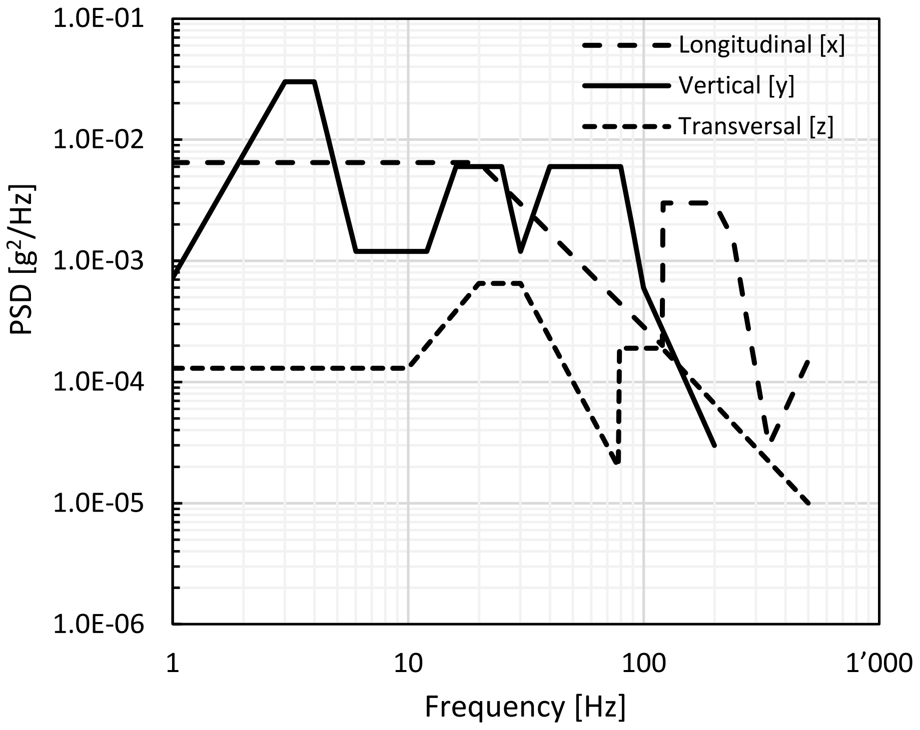
Prototype ASF – Dynamic Testing and FE model validation



Data processing by the CERN EN-MME team

Prototype ASF – Dynamic Testing and FE model validation

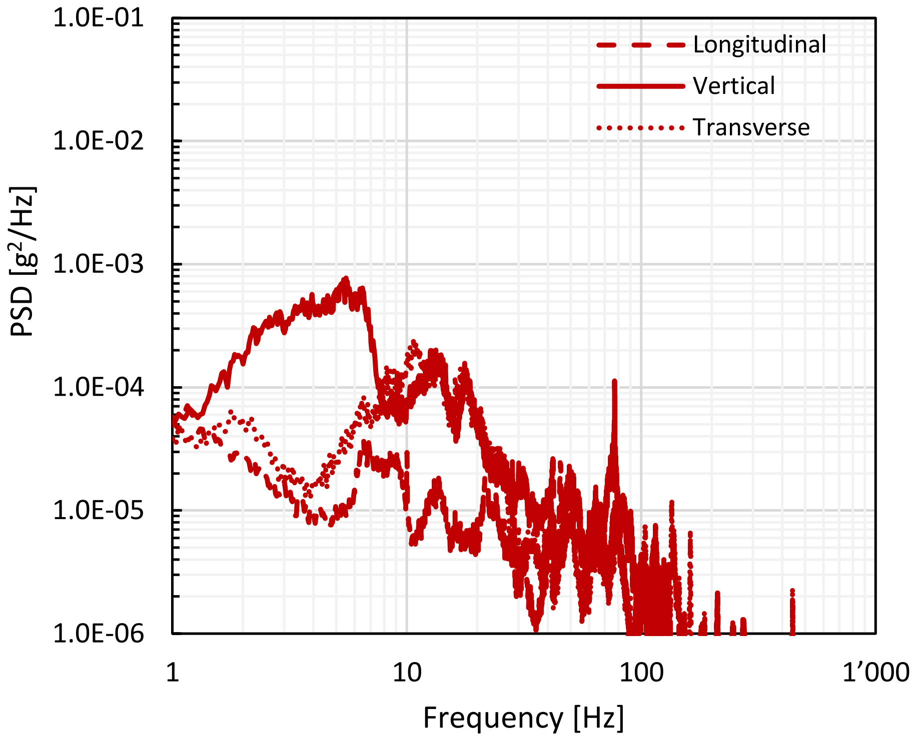
Design PSD



Design PSD are extracted from international codes providing three-dimensional random vibration spectra for road profiles

These are used as input at the base of the transportation assembly

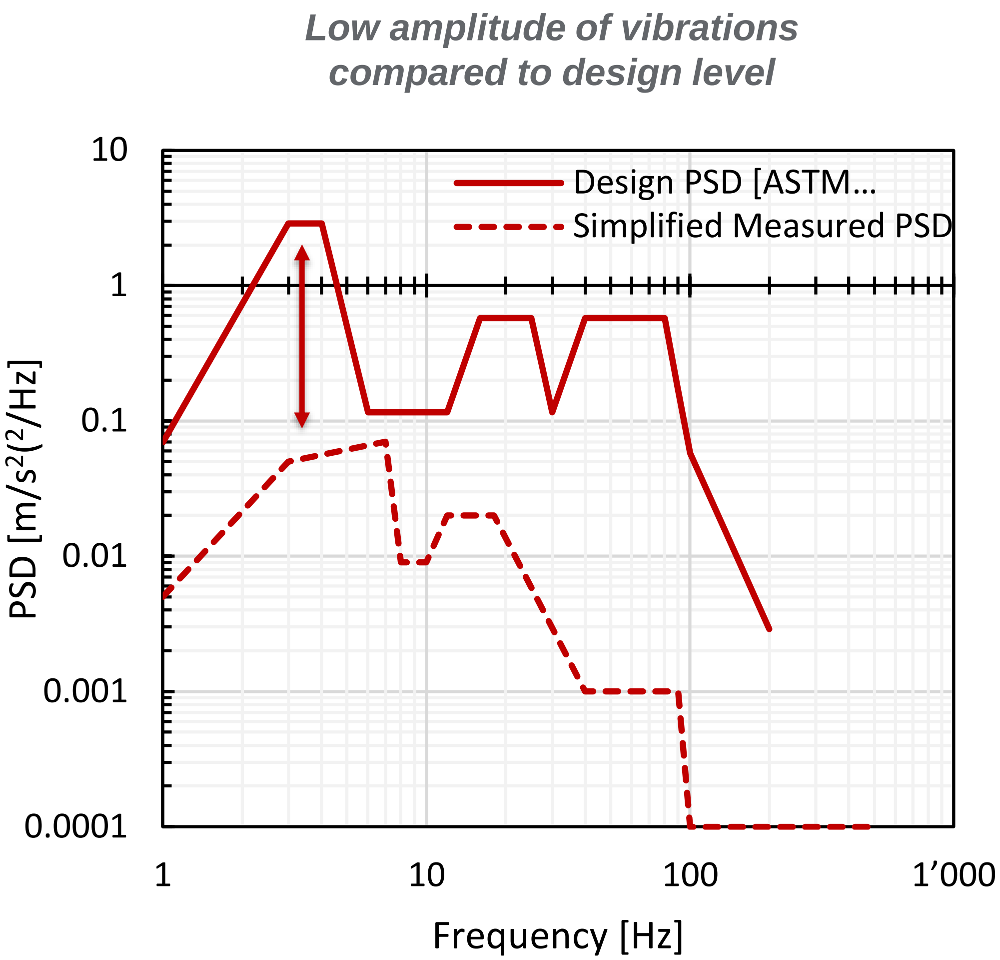
Measured PSD



Measured PSD are the result of the acceleration data post-processing.

The values valid for comparison with the design PSD are the ones recorded at the level of the base frame

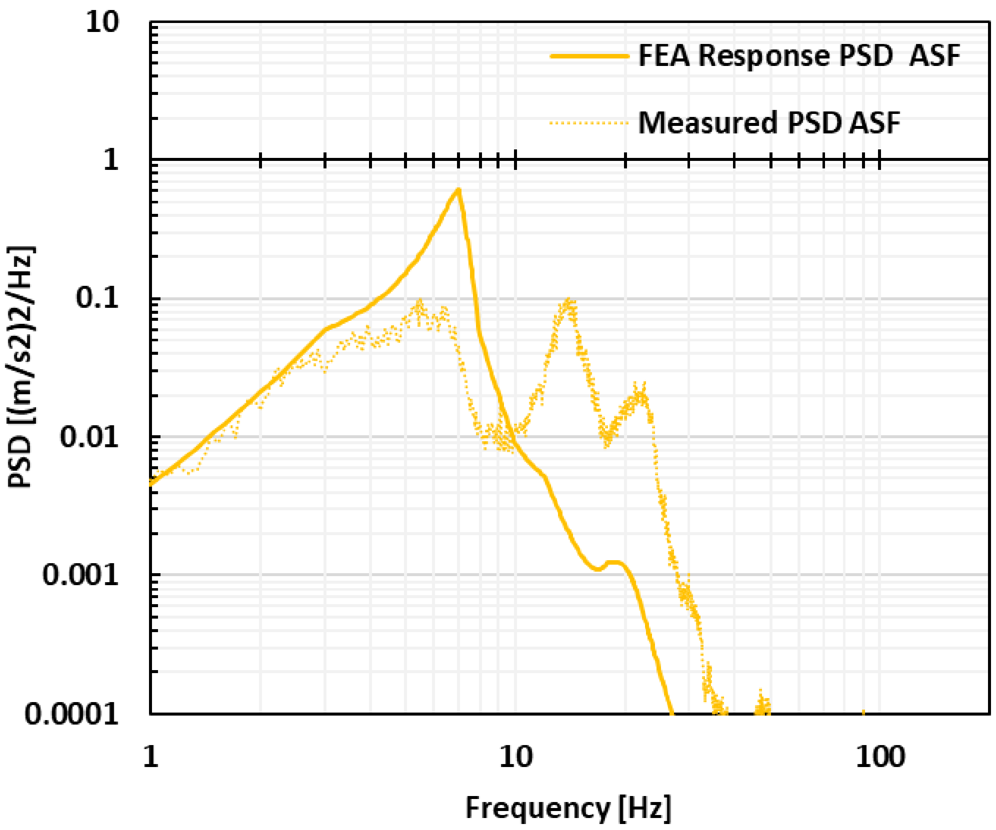
Prototype ASF – Dynamic Testing and FE model validation



1. In order to establish the accuracy of the FE model, the simplified measured PSD is used
2. To be noted that the amplitude of the measured vibrations is well below the design PSD
3. The random analysis performed using Ansys is based of a Modal analysis and thus the WRAs cannot be modeled using the nonlinear response curve. The preliminary analyses were performed considering an average and a maximum value of the stiffness.

Prototype ASF – Dynamic Testing and FE model validation

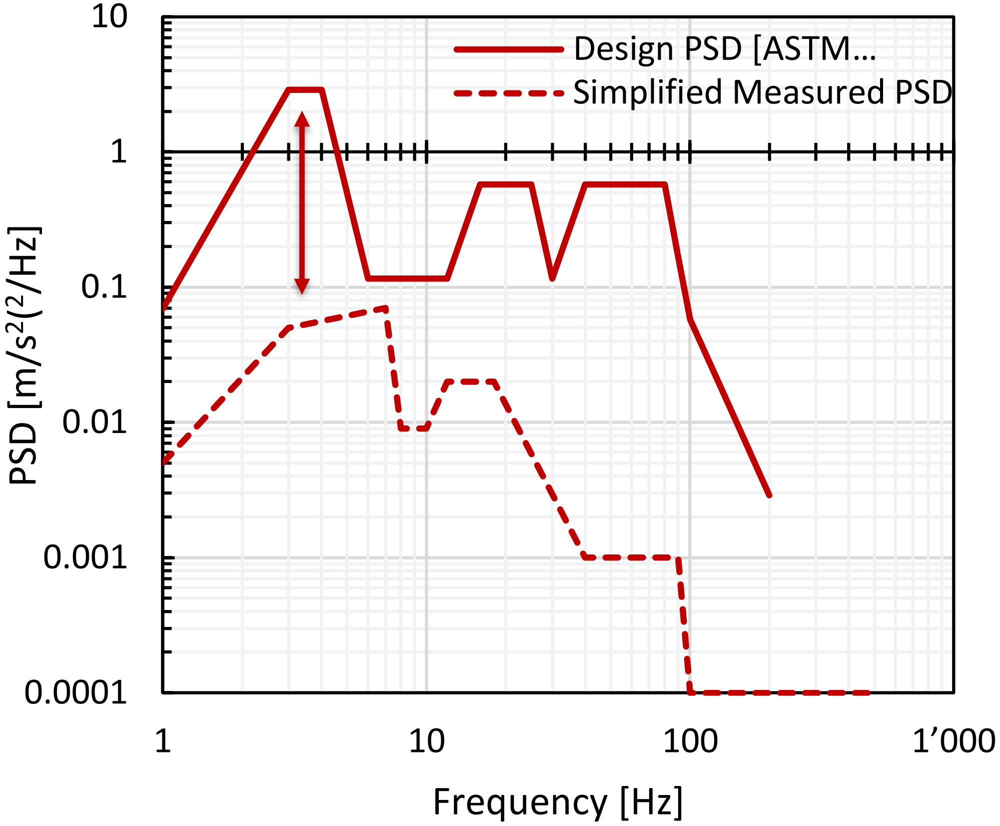
Analyses w/ uncalibrated model



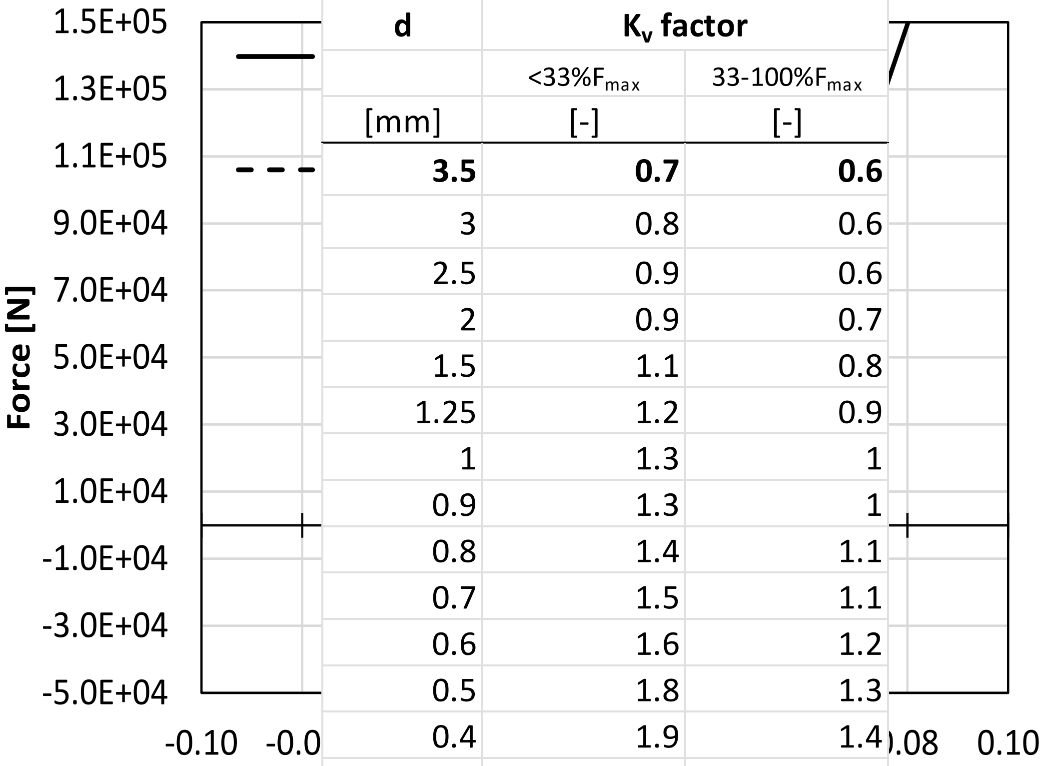
1. Using the average stiffness leads to discrepancies between the experimentally measured and numerically predicted response
2. Due to the lower amplitude of the measured vibrations, it is expected that the absorbers were working in the low-deformation and high stiffness range
3. The FE model predicts well the field measurements when the stiffness is correlated with the deformation (vibration) energy input

Prototype ASF – Dynamic Testing and FE model validation

Low amplitude of vibrations compared to design level



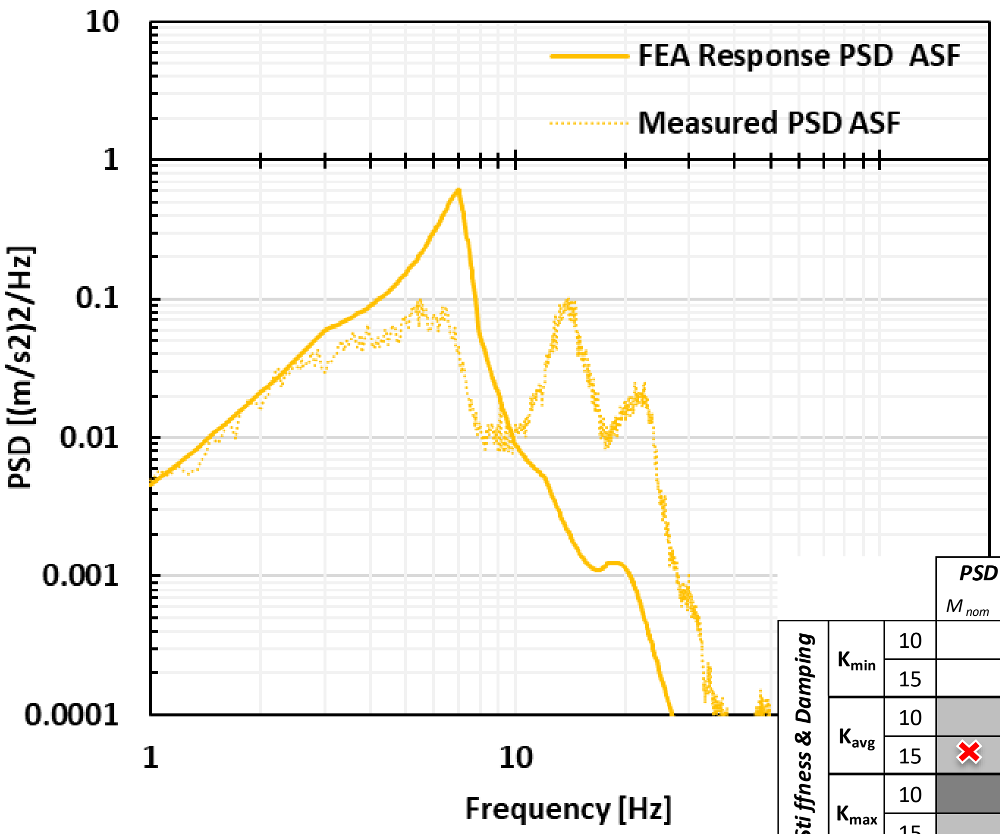
Stiffness and damping need to be corrected for low energy inputs



d [mm]	K_v factor <33%F_{max} [-]	K_v factor 33-100%F_{max} [-]
3.5	**0.7**	**0.6**
3	0.8	0.6
2.5	0.9	0.6
2	0.9	0.7
1.5	1.1	0.8
1.25	1.2	0.9
1	1.3	1
0.9	1.3	1
0.8	1.4	1.1
0.7	1.5	1.1
0.6	1.6	1.2
0.5	1.8	1.3
0.4	1.9	1.4
0.3	2.2	1.6
0.2	2.6	2
0.1	3.6	2.7
0.05	4.9	3.6

Prototype ASF – Dynamic Testing and FE model validation

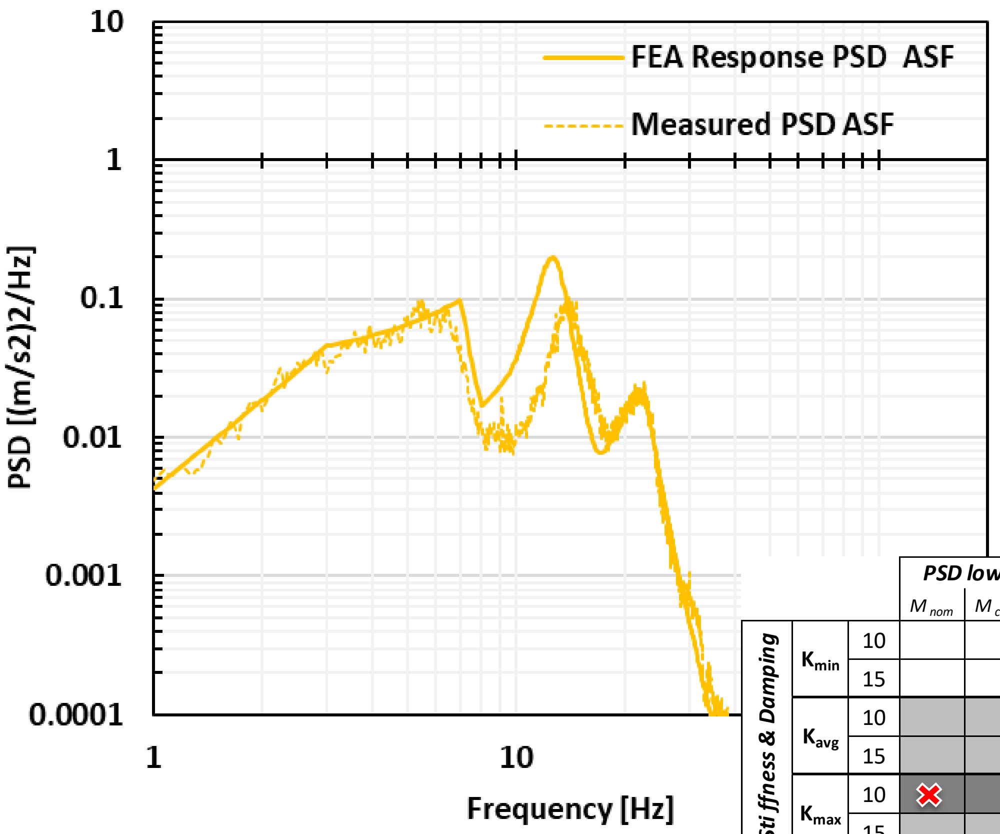
Analyses w/ uncalibrated model



			PSD low		PSD design	
			M nom	M cont	M nom	M cont
Stiffness & Damping	K_{min}	10				
		15				
	K_{avg}	10				
		15	✖			
	K_{max}	10				
		15				

Recommended
Required (Done)

Analyses w/ calibrated model

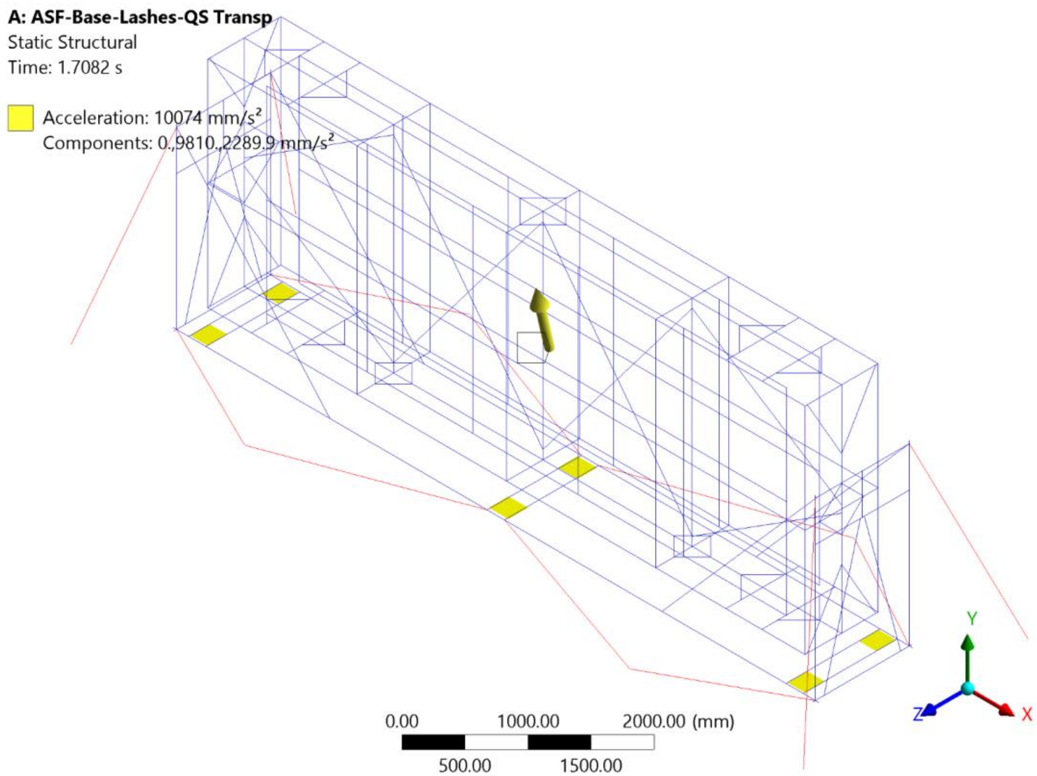


			PSD low		PSD design	
			M nom	M cont	M nom	M cont
Stiffness & Damping	K_{min}	10				
		15				
	K_{avg}	10				
		15				
	K_{max}	10	✖			
		15				

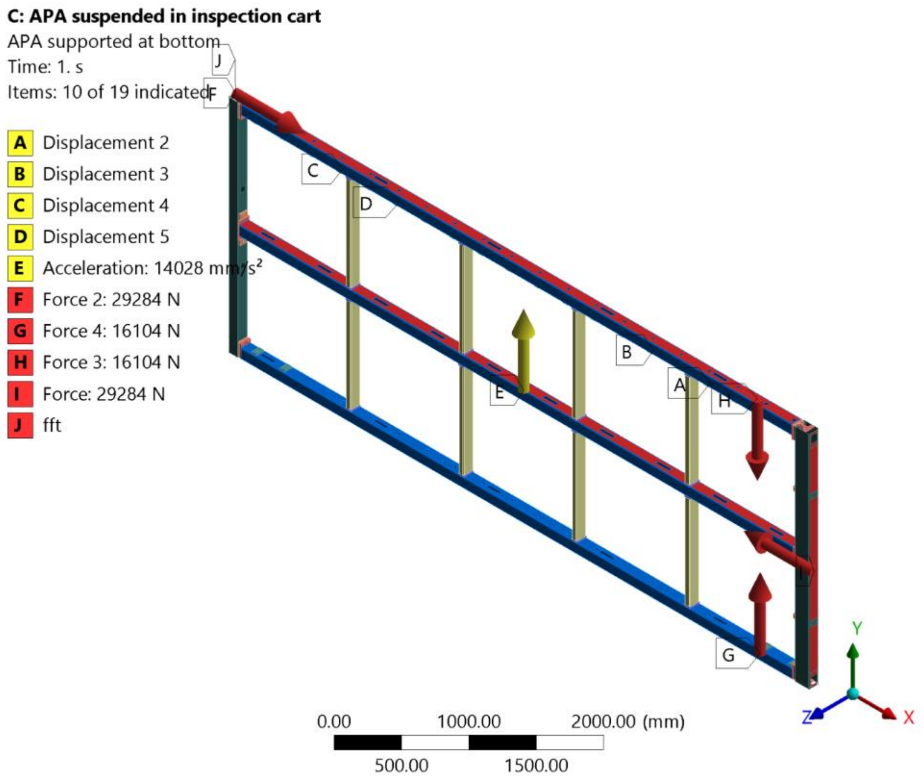
Recommended
Required (Done)

Prototype ASF – Impact on the APA assessment for transport

Typical ASF assembly model

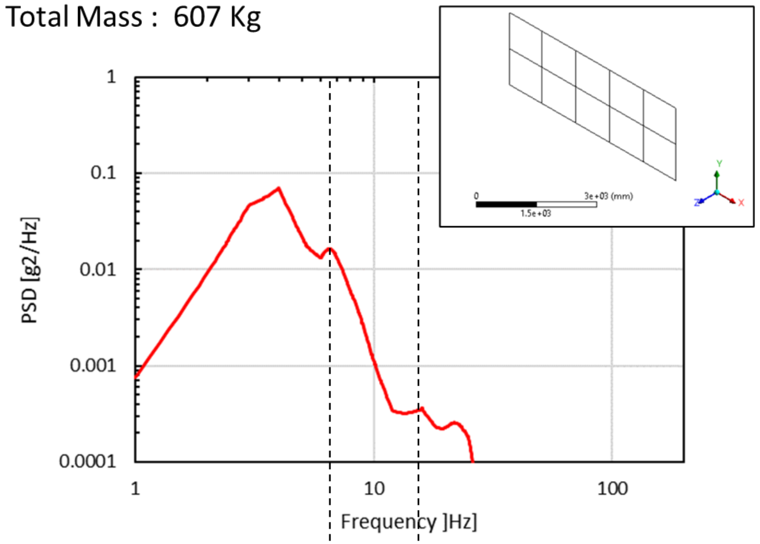


Typical APA model (individual)



Prototype ASF – Impact on the APA assessment for transport

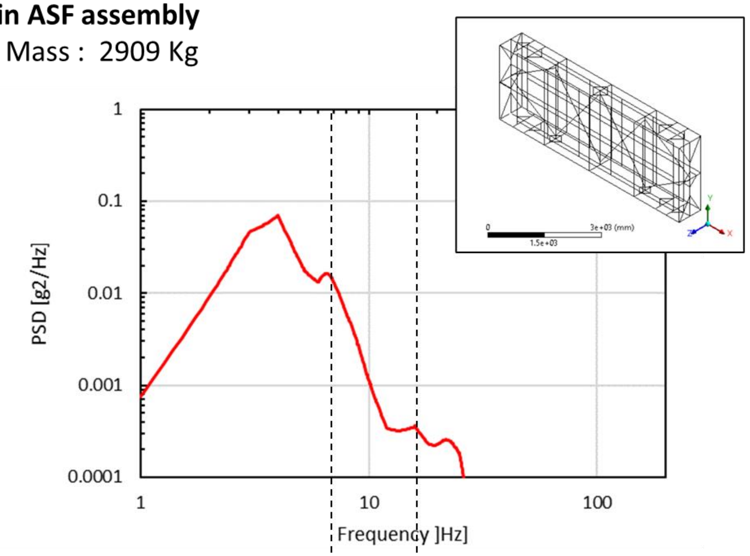
Individual APA model
Total Mass : 607 Kg



ASF vertical mode
– 0% Mass
(not modelled)

APA Vertical mode
> 90% Mass
Majority of APA mass participates to the APA vertical mode -> significant stresses/deformations

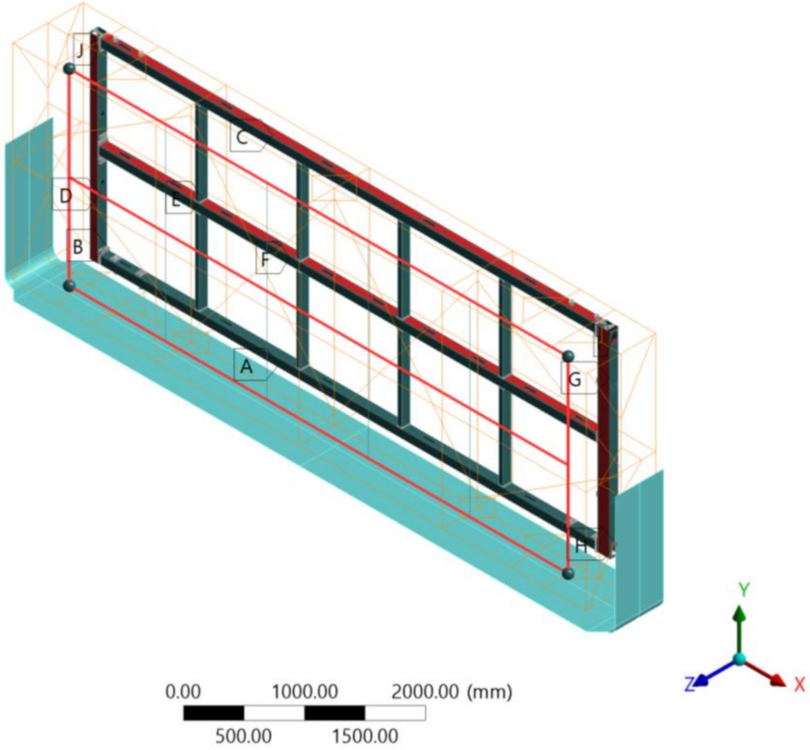
APA in ASF assembly
Total Mass : 2909 Kg



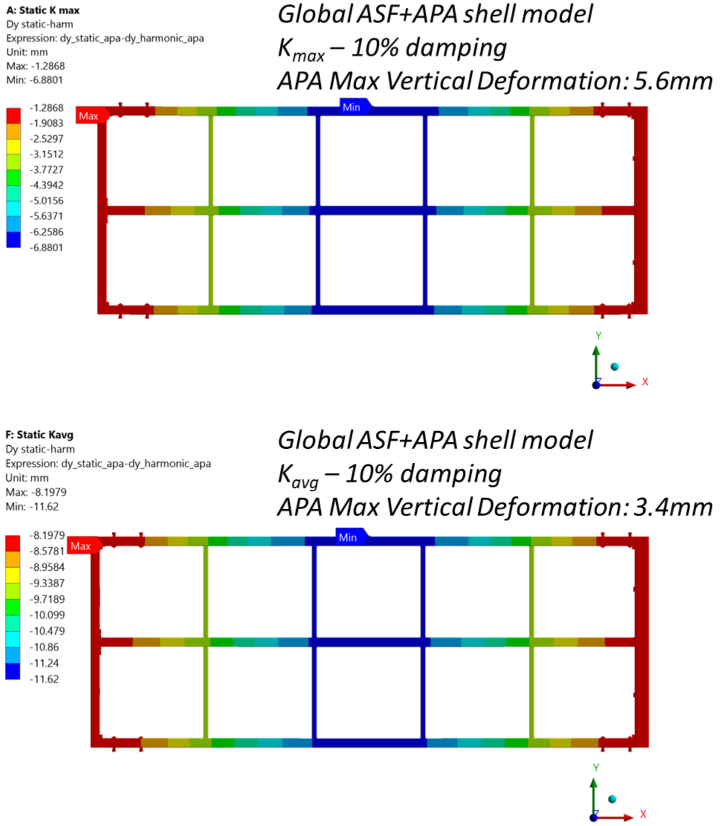
ASF assembly Vertical mode
- 90% Mass
APA is accelerated as a mass, therefore less deformation/stress is observed

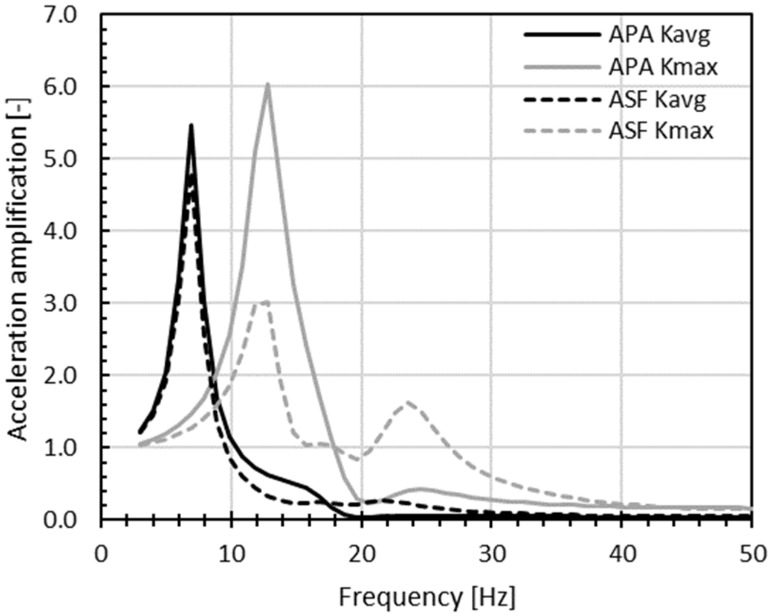
APA Vertical mode.
<0.5% Mass
Small mass participation for the APA mode -> lower magnitude of forces/stresses/deformations

Prototype ASF – impact on the APA assessment for transport

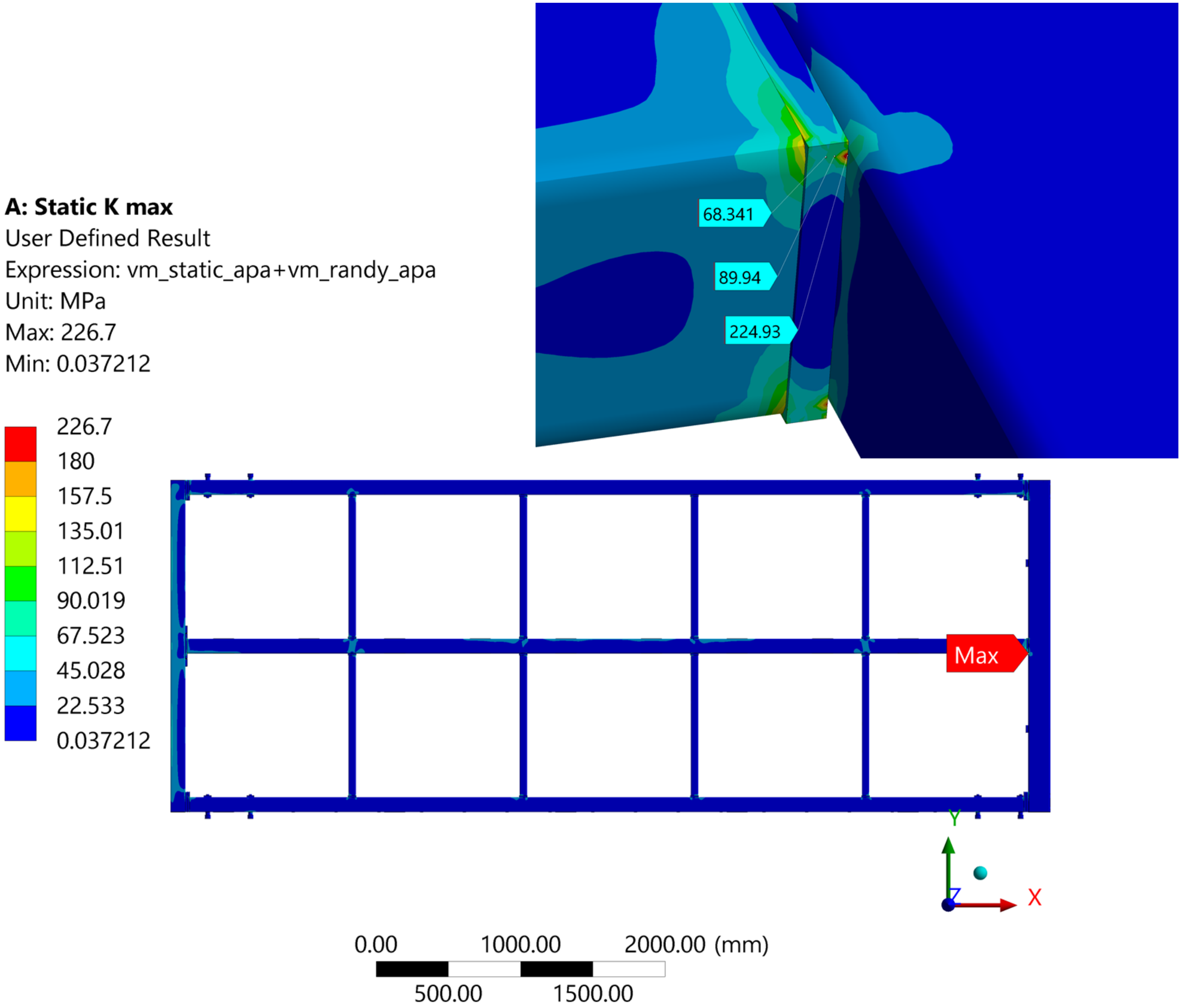


Global ASF-shell APA assembly model





Prototype ASF – impact on the APA assessment for transport



Summary and Main Outcomes

- The FE model was calibrated and the initial discrepancies between measurements and FE results were understood.
- High confidence level in the numerical model owing to the experimental validation
- Better understanding of the transportation conditions in comparison with the design values of the transportation loads
- Road vibration levels are well below the design assumption
- Shocks can be limited when handling is done in a controlled manner. The recommendation for supervised manipulations at all stages was reinforced.

Thank you for your kind attention!

Questions?