ALICE
LS2 Engineering Evaluation of Spaceframe

Engineering Note

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ALICE A Large Ion Collider Experiment
CERN European Organisation for Nuclear Research

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1 Aims of the Analysis

A new Spaceframe model has been developed with AutoCAD Robot Structural Analysis with the idea of complementing the evaluation conducted during the original design studies [1,2] and providing a means to re-assess the ever-changing nature of the loading conditions to which the structure is subjected.

This report presents the model and describes the preliminary results of the structural response of the Spacerame under different combinations of normal and accidental operating conditions while evaluating it in accordance with applicable CERN Safety Rules. It should pave the ground for further in-depth analyses and more complex load combinations resulting, for example, from the loading and un-loading of TRD modules or the action of seismic excitations.

2 Components Details and Background

The Space Frame is the metallic structure made of austenitic stainless steel profiles supporting the detecting devices of Alice experiment. The Space Frame consists of two main elements: the frame and the rails. The frame is a cylindrical structure with an overall diameter and height of approximately 8.5 m and 7.0 m respectively. The frame slides on two rails to go from the assembly and maintenance position to the working position into the experiment magnet. The weight of the frame is 10.1 tones. The total weight of the detectors attached in various points of the frame is about 77 tones. Therefore, a total weight of 87.1 tones has to slide smoothly on the two 12.3-m-long rails.

Several models were developed during the original design and fabrication phases [3], as well as latter on, to assess the impact of construction non-conformities or load cases resulting from the different detector loading strategies [4,5]. Particular attention was drawn for instance to the TPC insertion procedure or the installation sequence of TOF and TRD detectors. Some of these questions have been revisited in the framework of LS2 upgrade, and highlighted the need to develop an up-to-date model that will inform these type of assessments in the future. The new model is presented in this report and used to evaluate the Spaceframe structure under the nominal loading conditions foreseen after LS2.

2.1 Spaceframe geometry

As already mentioned before, the frame is a metallic cylindrical structure approximately 7.0 m high and with a diameter of 8.5 m. The frame is assembled starting from 16 standard radial sub-frames and two special sub-frames including the so-called TPC rails. Each standard sub-frame is made using a longitudinal inner beam, a longitudinal outer beam and ten web beams. The two special sub-frames are assembled in correspondence of the frame horizontal mid-plane and they are made using the TPC rails instead of the longitudinal inner beams. The sub-frames are connected in the tangential direction by the internal front ring beams, the internal inner ring beams and the external ring beams. The welds connecting the beams are all full penetration. More details concerning the geometry and/or profiles definition can be found in the technical specification and/or drawing numbers ALIP2A__0007, ALIP2A__0008 and ALIP2A__0009.

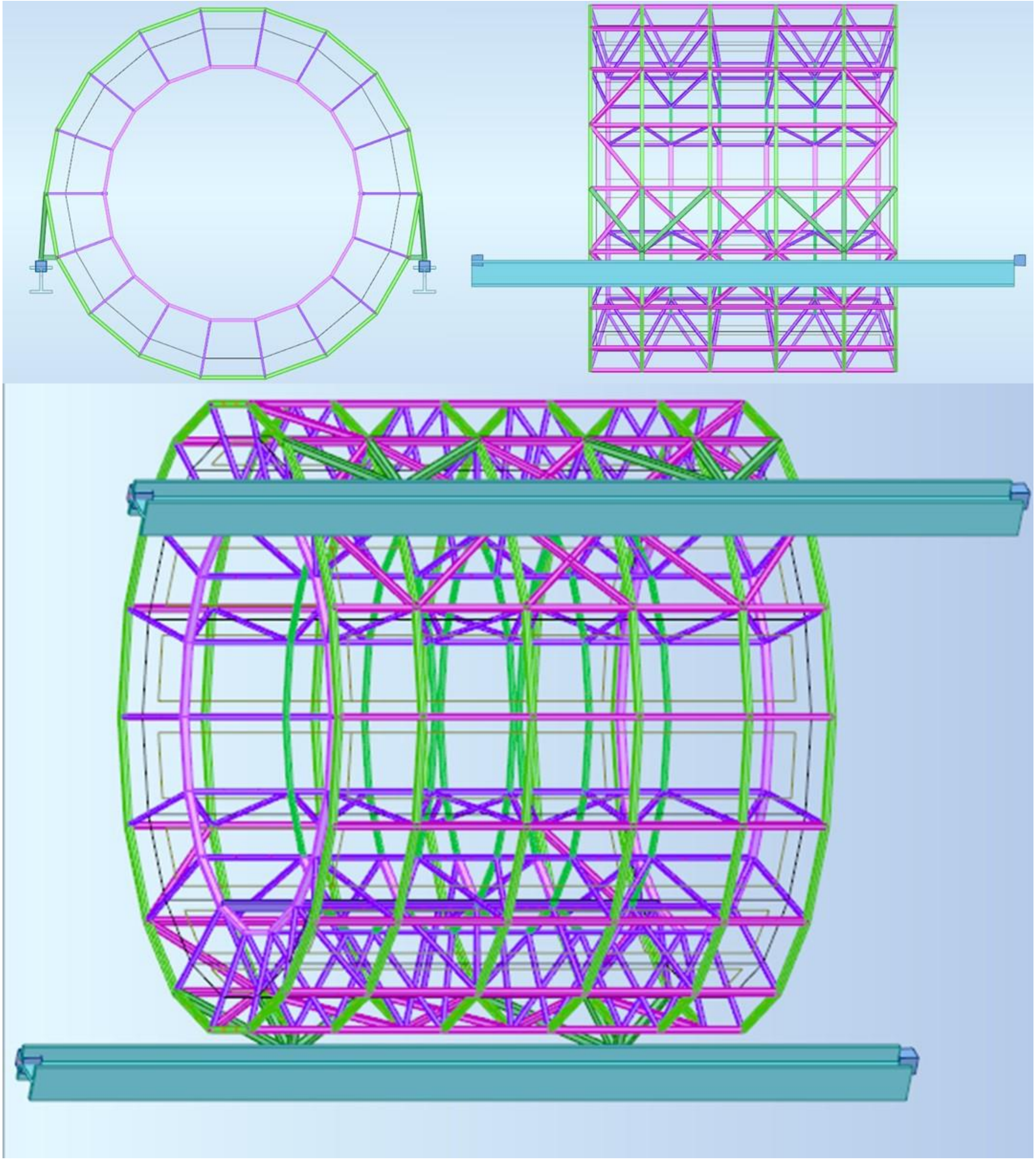


Figure 1: Geometry

2.2 Load cases

The nominal load case evaluated includes the self-weight of the structure plus those of the TPC, HPMID, TOF and TRD modules. Assumptions are consistent with those described here [REF]. For the sake of completeness, they are summarized here:

TOF detectors: The mass of each sector (from among 18) compound of 5 TOFs is assumed about **1550 kg.** It is applies as distributed load along each of the 19 external longitudinal beams.

TRD detectors: The mass of each sector (from among 18) compound of 5×6 TRDs is assumed about 1.190 kg plus 5% margin, which gives approximately **1250 kg.** It is applied as a superficial distributed load to the surface defined by nodes located at 2/3rd of the web frame width with respect to the inner ring.

HMPID: The mass of HMPIDs is estimated at **4200 kg** including their cradle. Vertical reactions are estimated by equilibrium of forces and moments from the center of gravity of the structure. In the upper support is applied a distributed load along the corresponding external longitudinal beam whereas at the lower one is captured as a couple of nodal forces at the location of the two sliders.

TPC: It is assumed that the TPC is in its final position in the centre of the space frame. The load coming onto the structure from the TPC consists of two parts: the TPC field cage together with ITS with mass of **8000 kg** (6230 kg before) and service wheels, heat screens and ITS services with mass estimated for **12000 kg** (11200 kg before). Each of the values is distributed in four points along the TPC rail. The first point is located about 0.6 m from the front ring (loaded with one fourth of the services), whereas the second one is placed 0.25 m towards the inside (loaded with one fourth of the field cage and ITS). Then, the pattern is symmetrically repeated on both of the TPC rails.

A notional horizontal load equal to 1/200 of all the vertical loads is conservatively applied to account for global imperfections. Second order effects can be neglected from the evaluation of αcr.

As per Eurocode 3, the partial safety factor applied to permanent loads such as the structure dead weight was 1.35x, whereas the one for live loads like those of detectors was 1.5x .

2.3 Failure criteria

All cases were assessed against Eurocode 3 and evaluated with Autodesk® Robot™ for the real weight plus the weight of the detectors. Section and member stability checks were proved. Joints are not assessed give the nature of all full penetration welds.

3 Model details

3.1 Software, Codes & Standards

Operating System: Microsoft Windows 10 Enterprise, x64 Edition, Version 2009, SP1
Autodesk® Robot™ 2017
Units used in the analysis are SI (mm, kg, s, °C, V, A)

3.1 Assumptions

The following assumptions and approximations have been made in modelling the structure:

- An elastic static structural analysis has been carried out
- The evaluation of αcr higher than 10 justifies neglecting second order effects
- Notional horizontal loads equal to 1/200 of all the vertical loads are conservatively applied to account for global imperfections
- Stiffening effect of detectors on the structure can be neglected
- Joints between beam elements are assumed rigid

- Image below summarizes the main parameters used the beam type definition used throughout the model

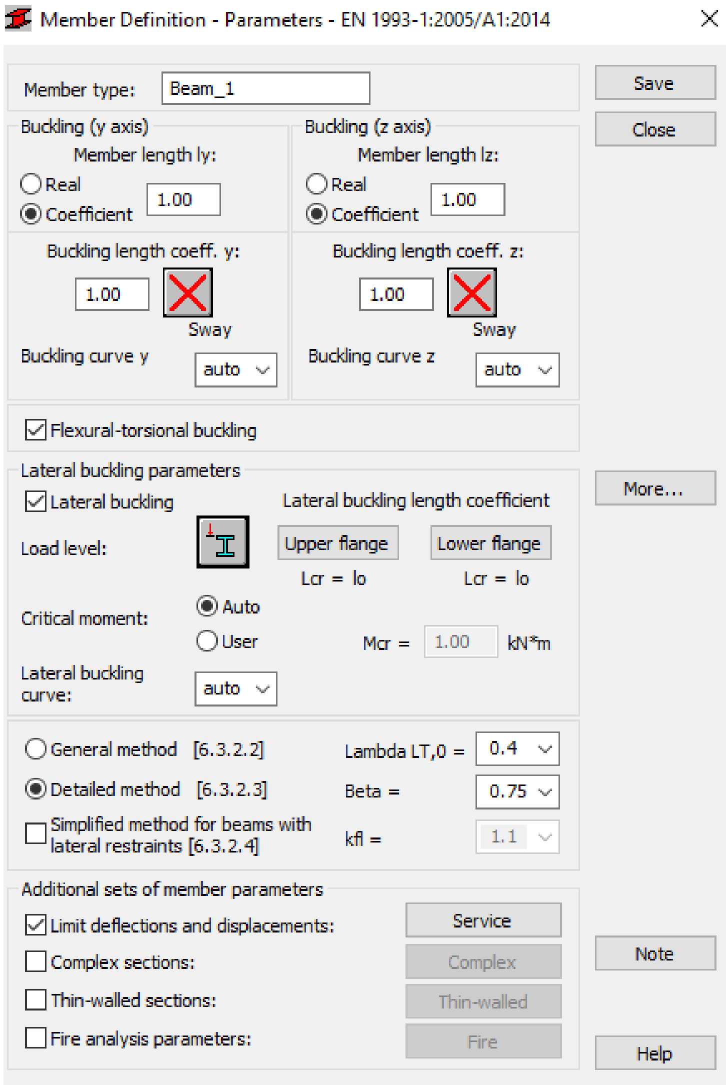


Figure 2: Main parameters for the beam definition

3.2 Materials

The structure is assumed to be made from Stainless Steel 304LN with a yield point of 210MPa and an ultimate strength of 564MPa. Linear elastic material models with properties at room temperature were used for the baseline model (200GPa Young modulus and Poisson Ratio 0.3).

3.3 Boundaries and Load Conditions

Fixed boundary conditions with both displacement and rotational degrees of freedom constrained have been imposed at the four extremities of the beams on which the spaceframe rests. As described above the joints between all beam elements are assumed to be rigid by default.

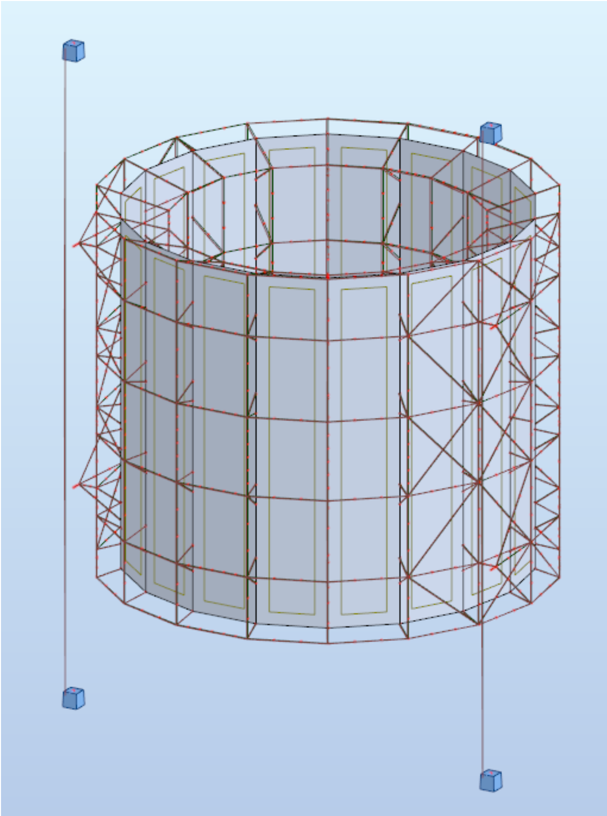


Figure 3: Fixed boundary conditions

The images below illustrates the definition of the different loads described in section 2.2.

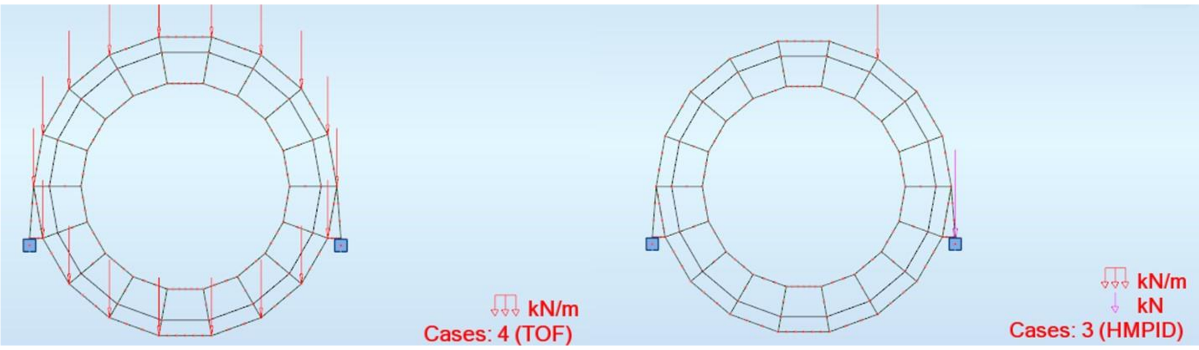


Figure 4: TOF and HPMID load definition

TOF weight and upper reaction of HPMID cradle are applied as distributed loads along the external longitudinal rails. Conversely the lower HPMID reaction is captured as two nodal forces at the slider locations.

For the application of TRD modules weight, a cladding surface has been created at each sector. A cladding is a surface that lets you distribute planar loads on bars while not participating in the load capacity of a structure. In other words a finite element mesh is not generated on a cladding; it is an auxiliary object for defining loads that considerably facilitates generating loads at the approximate location where the modules rest. In our case at 2/3rd of the web frame width with respect to the inner ring.

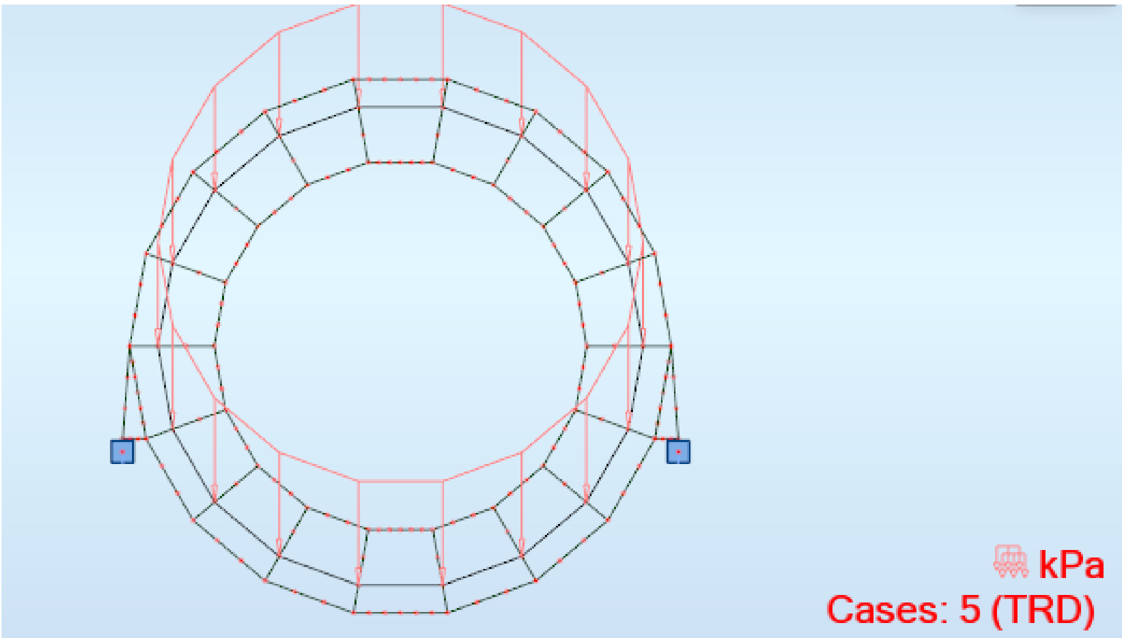


Figure 5: TRD module load definition

Finally TPC weight is applied as described in Section 2.3 to the inner rails as illustrated in the image below

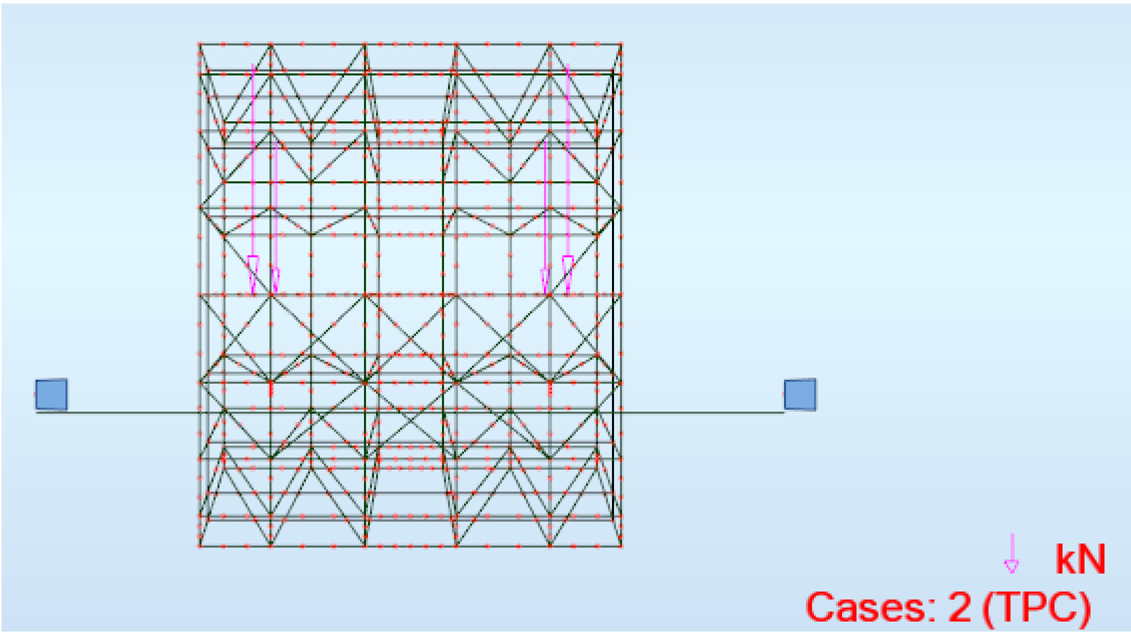


Figure 6: TPC module load definition

Notional loads to account for global imperfections are applied in the most unfavourable way on the side of the HPMID cradle

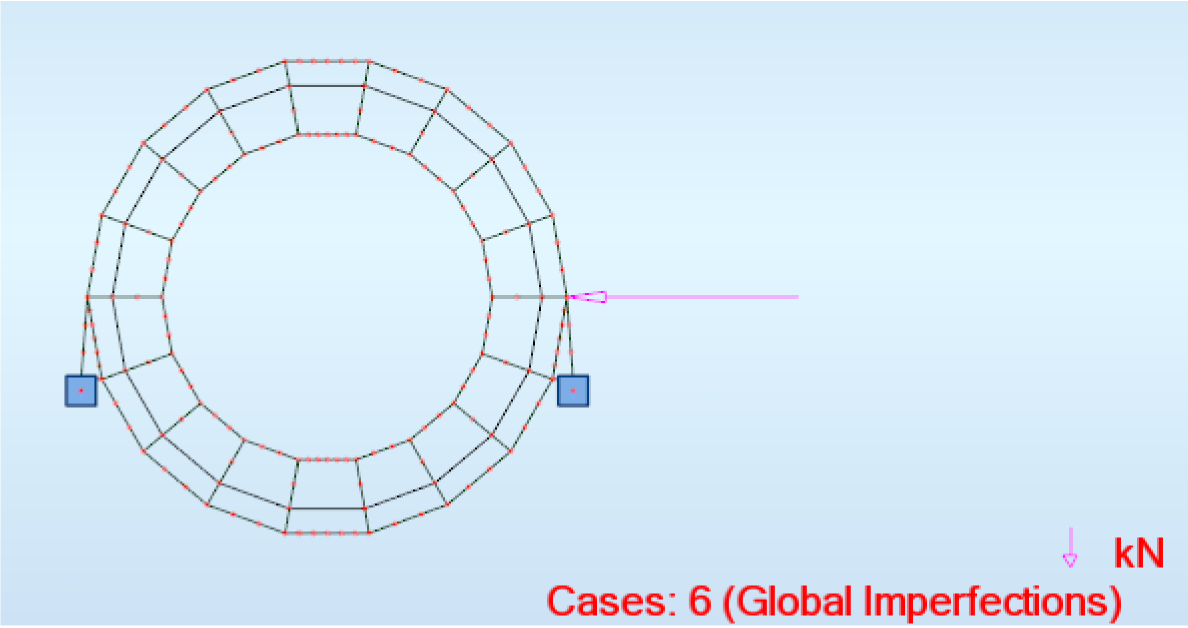


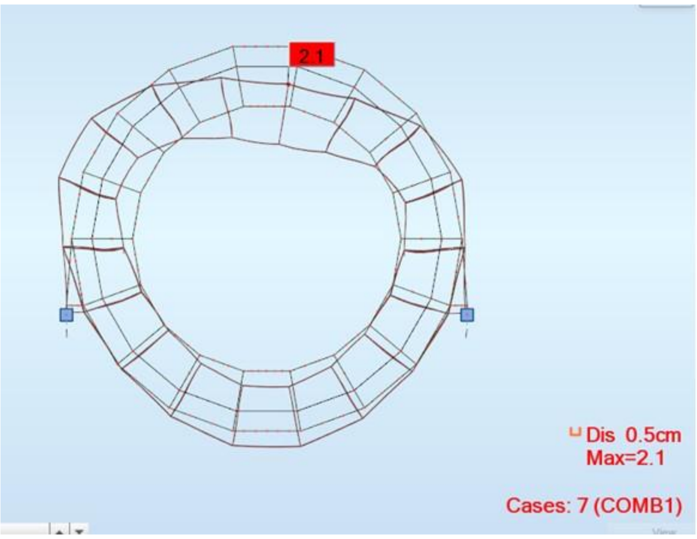
Figure 7: Notional loads for global imperfections

4 Results

4.1 Nominal Load Case

This load case checks section, member stability and deflections for a combination of all loads mentioned above. It includes the earth gravity acting on the frame plus the dead weight of the TPC, HPMID, TOF and TRD modules. Scaling factors on all actions are included as per Eurocode 3, namely 1.35x for death weight and 1.5x for all the rest except the notional loads.

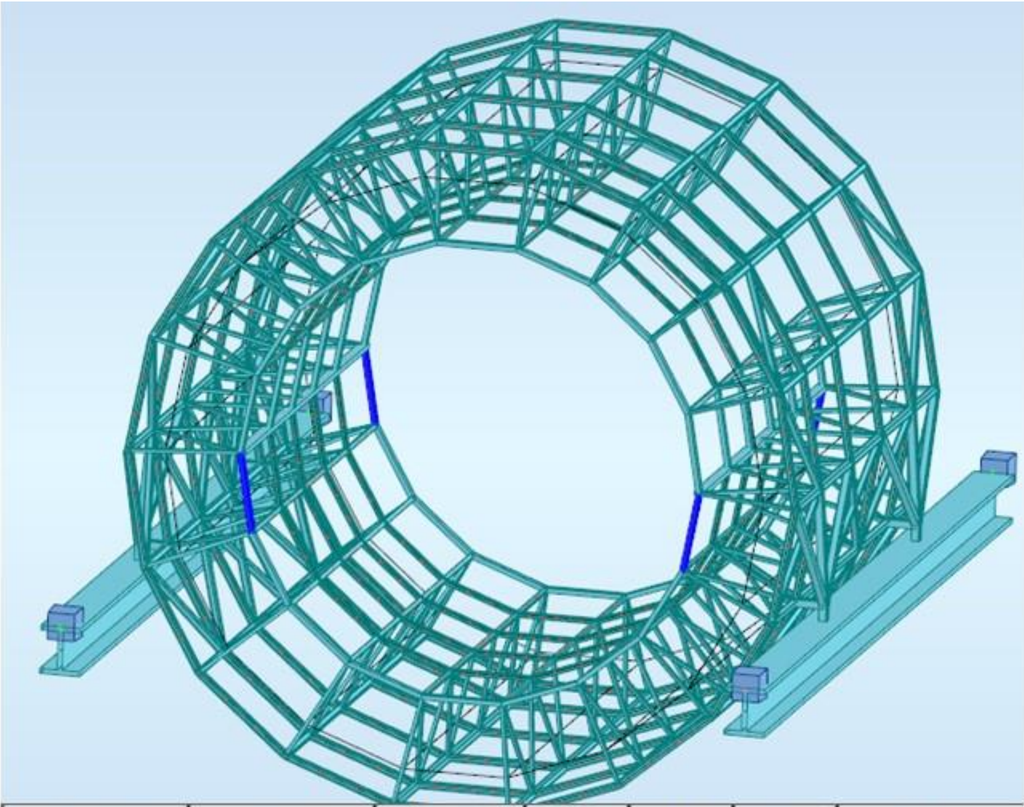
The figure below illustrates the maximum displacements under the nominal load case along with the sum of reactions for all sub-cases for verification purposes



Node/Case	FX (kN)	FY (kN)	FZ (kN)
Case 1	DL1		
Sum of val.	-0.00	270.84	0.00
Case 2	TPC		
Sum of val.	-0.00	200.00	-0.00
Case 3	HMPID		
Sum of val.	0.00	43.83	0.00
Case 4	TOF		
Sum of val.	-0.00	284.00	0.00
Case 5	TRD		
Sum of val.	-0.00	224.86	0.00
Case 6	Global Imperfections		
Sum of val.	4.00	0.00	-0.00
Case 7 (C)	COMB1		
Sum of val.	4.00	1494.67	0.00

Figure 8: Maximum displacements under the nominal load case

Utilization factor for most loaded bars remains in all cases under 1 as seen below. A detailed results report for bar 1945 can be found as an example here rd_res.rtf , evidencing lateral flexural buckling as main failure mode.



Member		Section	Material	Lay	Laz	Ratio	Case
1945	OK	60x100x5	Stainless Stee	27.68	41.75	0.68	7 COMB1
1939	OK	60x100x5	Stainless Stee	27.68	41.75	0.68	7 COMB1
1927	OK	60x100x5	Stainless Stee	27.68	41.75	0.68	7 COMB1
1933	OK	60x100x5	Stainless Stee	27.68	41.75	0.68	7 COMB1
1003	OK	60x40x5	Stainless Stee	68.71	96.29	0.61	7 COMB1
1141	OK	60x40x5	Stainless Stee	68.71	96.29	0.61	7 COMB1
1192	OK	60x40x5	Stainless Stee	62.29	87.29	0.57	7 COMB1
1054	OK	60x40x5	Stainless Stee	62.29	87.29	0.57	7 COMB1
1465	OK	60x40x5	Stainless Stee	62.29	87.29	0.55	7 COMB1
1327	OK	60x40x5	Stainless Stee	62.29	87.29	0.55	7 COMB1

Figure 9: Utilization factor for most loaded bars

5 Conclusions and recommendations

This report presents the newly developed Autodesk Robot Spaceframe model. Although not an extensive analysis of all possible loading scenarios it does present as well preliminary results of the structural response of the Spacerame under nominal conditions and evaluates them in accordance with applicable CERN Safety Rules. Large safety margins are observed throughout.

This new model should pprovide a means to re-assess the ever-changing nature of the loading conditions to which the structure is subjected.

References

[1] ALICE space frame design, Jan Bielski, July 2000

[2] ALICE space frame design, Jan Bielski, July 2001

[3] Changes in the ALICE space frame design, Baby space frame design, Analysis of the TPC movement, Jan Bielski, July, August 2002

[4] Data for experimental verification of displacements in the space frame, Jan Bielski, July 2003

[5] Remarks on safety issues of the space frame, Jan Bielski, February 2004

The space frame – strength revision of last changes, Jan Bielski, July-August 2004

Annex I

Autodesk Robot Model

RobotModel_v13.rtd