MAORY Main Structure design: general overview

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ABSTRACT

MAORY (Multi Conjugate Adaptive Optics RelaY) is one of the four instruments for the ELT (Extremely Large Telescope) approved for construction. It is an adaptive optics module able to compensate the wavefront disturbances affecting the scientific observations, achieving high strehl ratio and high sky coverage. MAORY will be installed on the straight-through port of the telescope Nasmyth platform and shall re-image the telescope focal plane to MICADO (the first light imager of the ELT) and in a future second instrument port.

A general overview of the present status of the mechanical design of the Main structure is given in this paper.

Keywords: ELT (Extremely Large Telescope), Multi-conjugate Adaptive Optics, Astronomy with AO.

1. INTRODUCTION

The Multi-Conjugate Adaptive Optics Relay (MAORY) is a post-focal adaptive optics module foreseen to be located on the ELT Nasmyth platform A - Cerro Armazones (Chile). The instrument is conceived to provide a corrected field-of-view to its client instrument MICADO (a near-infrared camera and spectrograph) and a second port for a future instrument [1][2][3].

The opto-mechanical architecture of MAORY includes three main sub-systems [4][5][6][14]:

- MAORY system module, that includes the Main Structure and the Post-Focal Relay Optics.
- LGS WFS module.
- NGS WFS module, that includes the LOR WFS and the SCAO WFS.

Both the NGS WFS and SCAO WFS modules are hosted in the same structure; this structure, called Green Doughnut, will be mounted onboard of MICADO instrument. In February 2020 the MAORY Consortium carried out a trade-off study comparing two optical different designs: the alternative optical design called MAORY Mirror Configuration (MMC) and the 2019 MOC design (proposed by the MAORY Consortium) based on a Modified Offner Configuration (called MOC) [7]. The first configuration was selected as a new baseline, and its design study for the PDR is presently ongoing. This paper describes the mechanical design of the Main Structure of MAORY for the MMS optical configuration.

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Adaptive Optics Systems VII, edited by Laura Schreiber, Dirk Schmidt, Elise Vernet, Proc. of SPIE Vol. 11448, 1144832 · · CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2562124

2. MAORY MAIN STRUCTURE - OVERALL DESIGN OVERVIEW

MAORY, that is not a scientific instrument in itself (as it does not produce scientific data on its own), is designed to support two different instruments, both with the same optical quality and with a gravity invariant port.

The "MAORY Main Structure" is a part of the whole MAORY module that includes in the current baseline configuration:

- MAORY Main Support Structure (MAORY_MSS)
- Thermal Enclosure – MAORY side [8].
- Support Structure between MAORY & MICADO for the thermal duct.
- Thermal duct between MAORY & MICADO.
- Support Structure for MICADO Thermal Enclosure.
- Thermal Enclosure – MICADO side.
- CU Selector for MAORY Folding Mirror (FM_CU) and MICADO Calibration Assembly (MCA).

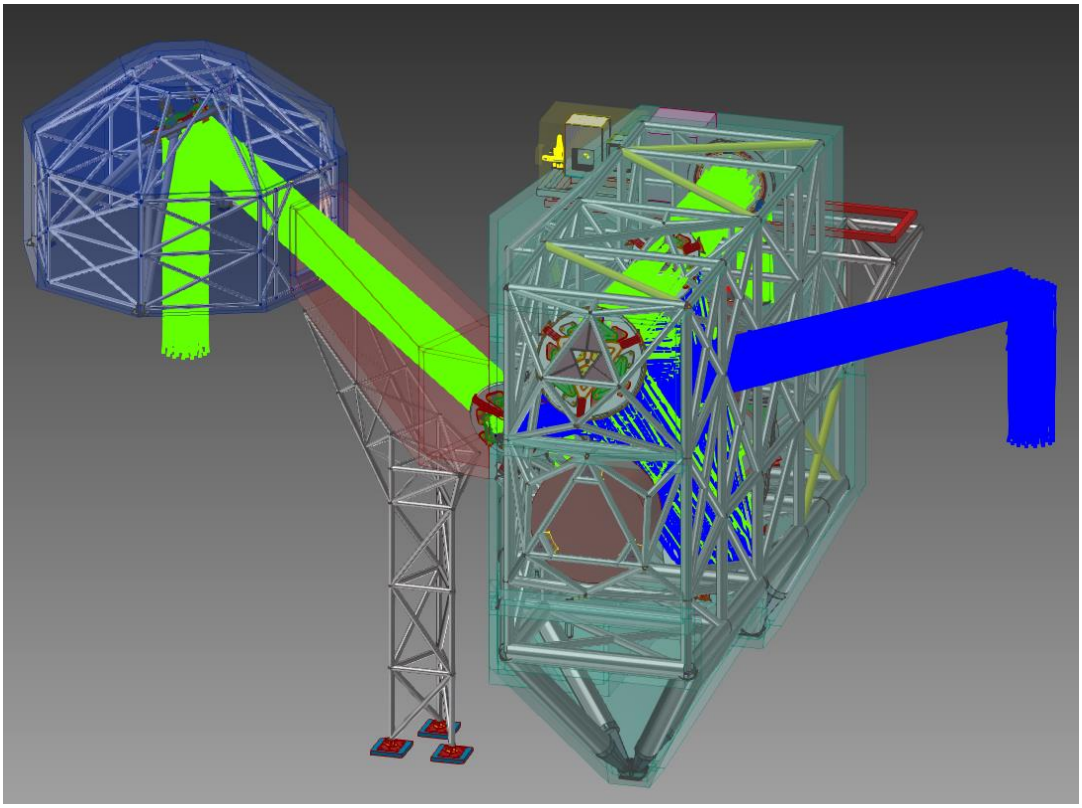


Figure 1. Preliminary CAD model for FEA of MAORY_MSS_Type_4.

The MAORY Main Support Structure (MAORY_MSS) will require to be fixed through three main support points on the grid of Nasmyth Platform. In addition to these points, other three points will be required to fix the Support Structure for the thermal duct, between MAORY & MICADO, that connects MAORY thermal enclosure to MICADO thermal enclosure.

The thermal enclosure on MICADO will be installed on the support structure for its thermal enclosure (the mechanical structure visible in the Figure 1 on the left side). This structure itself will be mounted directly on MICADO Main Support Structure via four flanges.

3. MAORY MAIN SUPPORT STRUCTURE - DESIGN OVERVIEW

The MAORY MSS (Main Support Structure) is based on a latticework tower, made of standard structural steel truss-beam shaped with different section properties. The structure is connected to the Nasmyth platform through 10 legs that will be joint into the three mounting support points on the ESO ELT Nasmyth platform A. The overall design has been constrained to fit with the three support points concept, in order to have an ideal interface plane. This strategy eliminates the distortion induced by the Nasmyth platform displacements out of a rigid body motion. The present configuration of mechanical design for MAORY_MSS is shown below in the Figure 2.

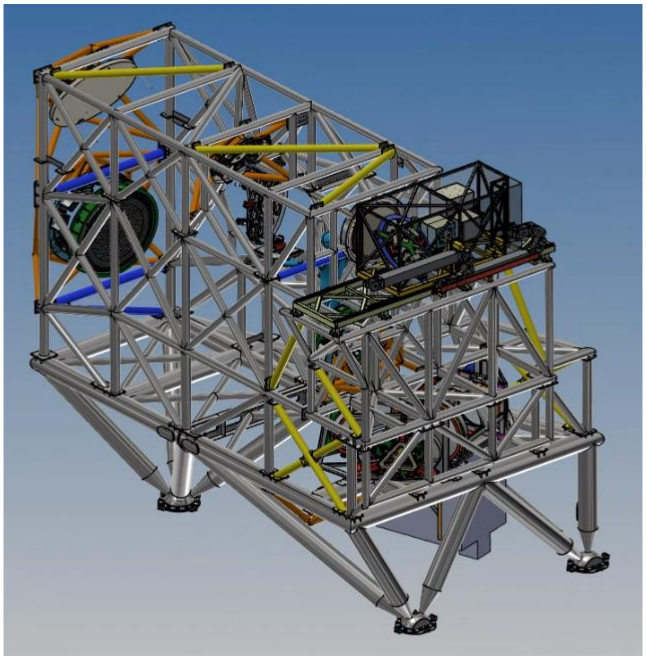


Figure 2. CAD model MAORY_MSS_Type_4.

The Main Support Structure Assembly is composed of: Main Support Structure (MSS) that holds up all optomechanical elements and their Optomechanical Support Structures themselves (see Figures below).

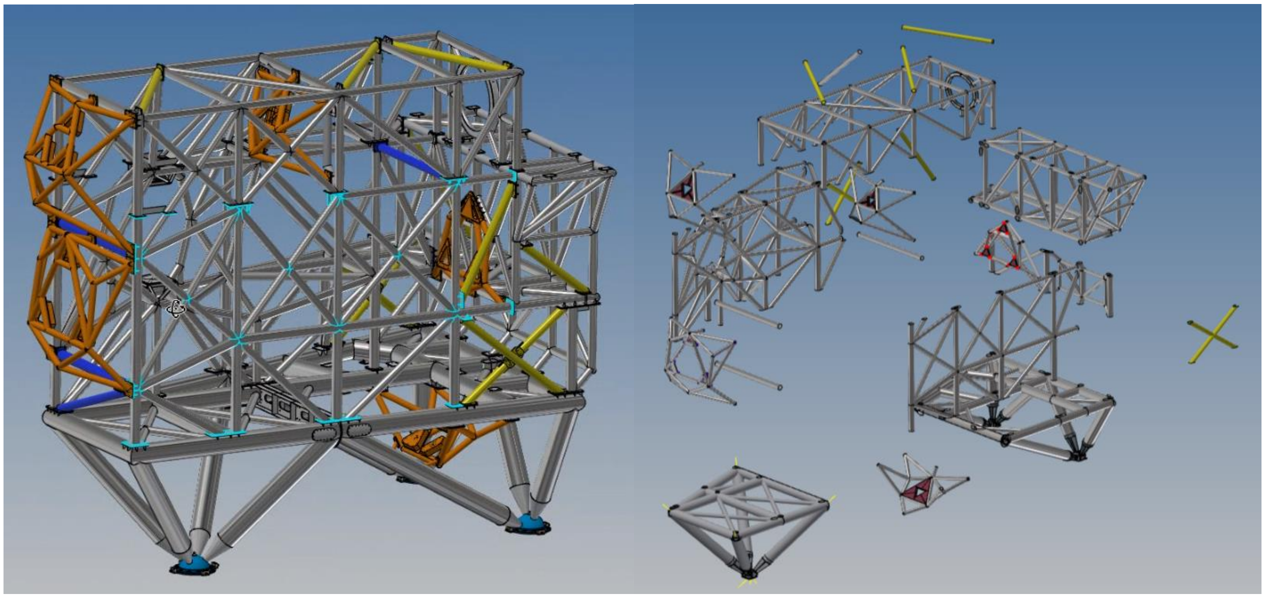


Figure 3. MAORY_MSS (left side) and splitting strategy of MSS (right side).

The main purpose of the Main Support Structure is to provide a very stable opto-mechanical reference and a support for all the opto-mechanical elements and sub-assemblies components weighing on it. This structure, shown in the Figure 3, will be split up in several (welded) parts connected to each other with bolts and using, also, reference pins in order to have an accurate mounting/dismounting for the various provisional phases (number of final parts is under evaluation).

The accessibility to all opto-mechanical components and sub-assemblies (for mounting/dismounting/maintenance operations) is ensured by the possibility of the temporary disassembly of some sub-assembly elements or beams from the MAORY_MSS (depicted in yellow in the next Figure 4). Electrical harness inside the MSS allows all maintenance operations [9][10].

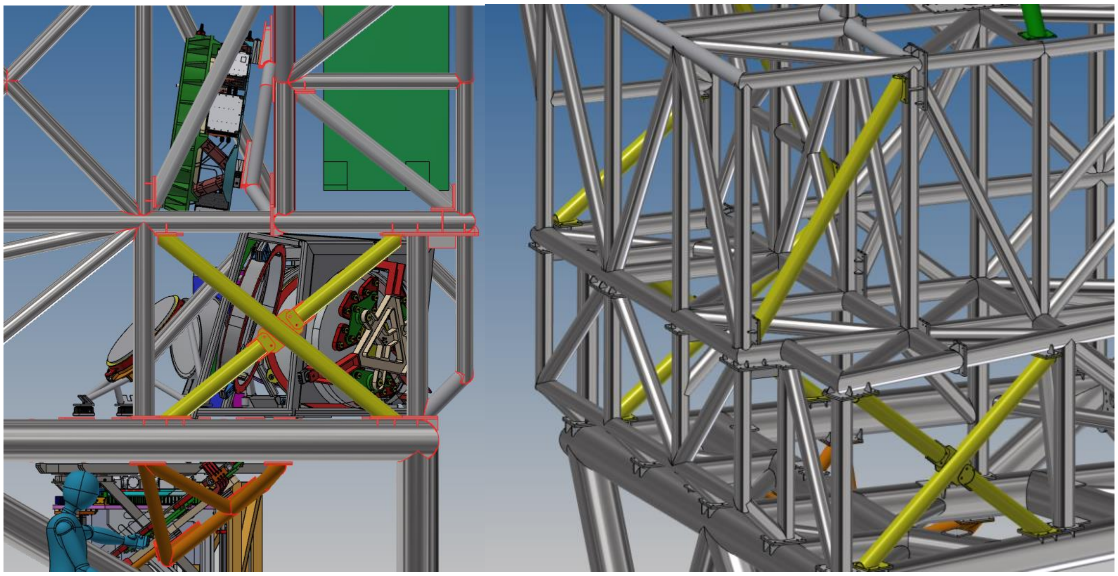


Figure 4. MAORY_MSS_Type_4: disassembly items.

3.1 Optomechanical Support Structure

The Optomechanical Support Structures (OSS) are the orange structures highlighted in the Figure 3. These structures will be used in order to accommodate accurately the optical and optomechanical elements [11] installed on the MAORY module. The optical elements hosted are: SP, M6, M7, M8, M9/DM1, M10/DM2. The structure of these sub-assemblies are made of structural steel pipes and interface steel plates with the cinematic supports for the Optomechs. The optomechanical support structures of M8 (left side) and M7 (right side) are shown below in the Figure 5.

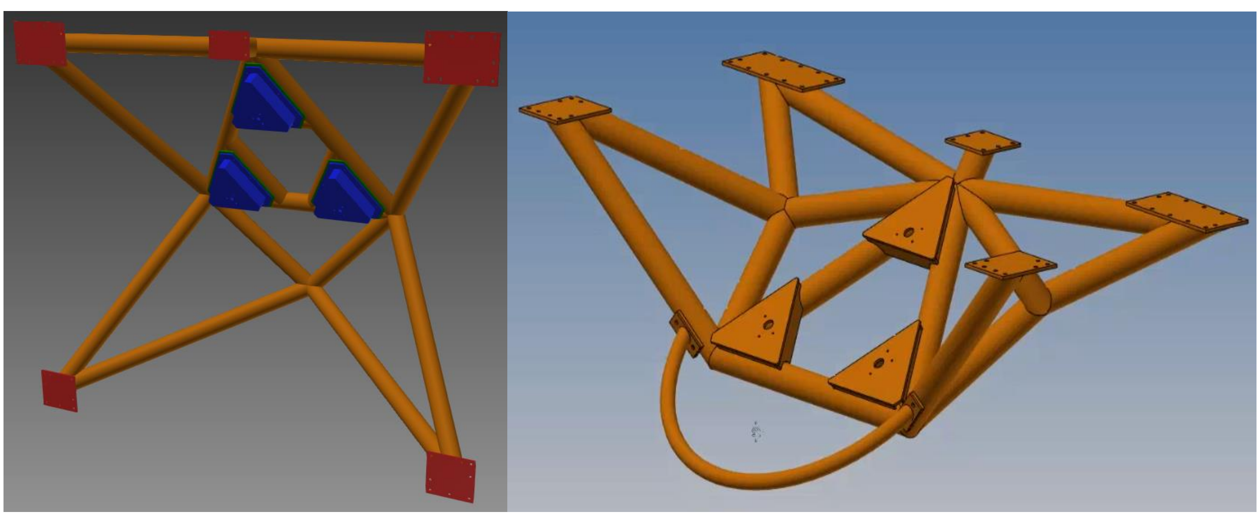


Figure 5. Optomechanical Support Structures of M8 (left side) and M7 (right side).

3.2 CU Selector for MAORY FM_CU and MCA

The calibration selector is a linear stage that deploys the MAORY FM_CU (Folding Mirror for MAORY Calibration Unit) and the MCA (MICADO Calibration Assembly), or clears the path for the light coming from the telescope. More details and information on the current design of MAORY Calibration Unit are included in the relative papers presented in this Conference [12].

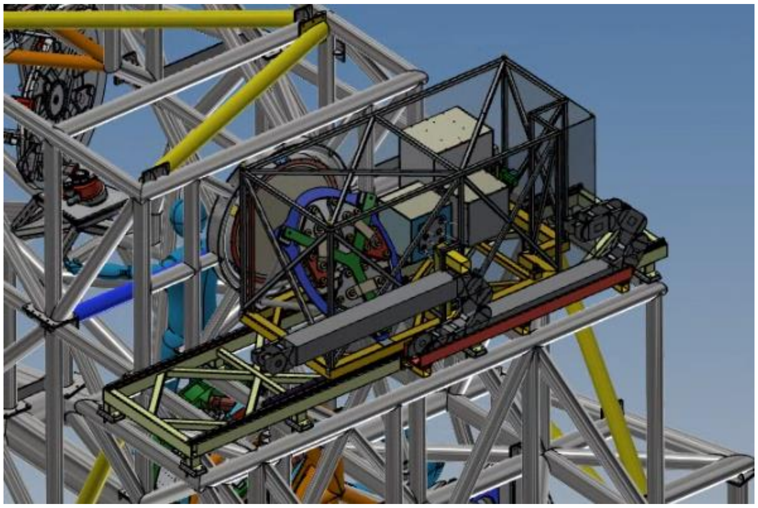


Figure 6. CAD model CU Selector.

3.3 Support Structure between MAORY & MICADO

The Support Structure between MAORY & MICADO is the mechanical structure shown below in the Figure 7. On the top part of this support structure the thermal duct (red tube on the right in the Figure 7) between MAORY and MICADO enclosures will be installed [13]. The installation of this support structure will be possible using the three additional support points on the grid of the Nasmyth platform.

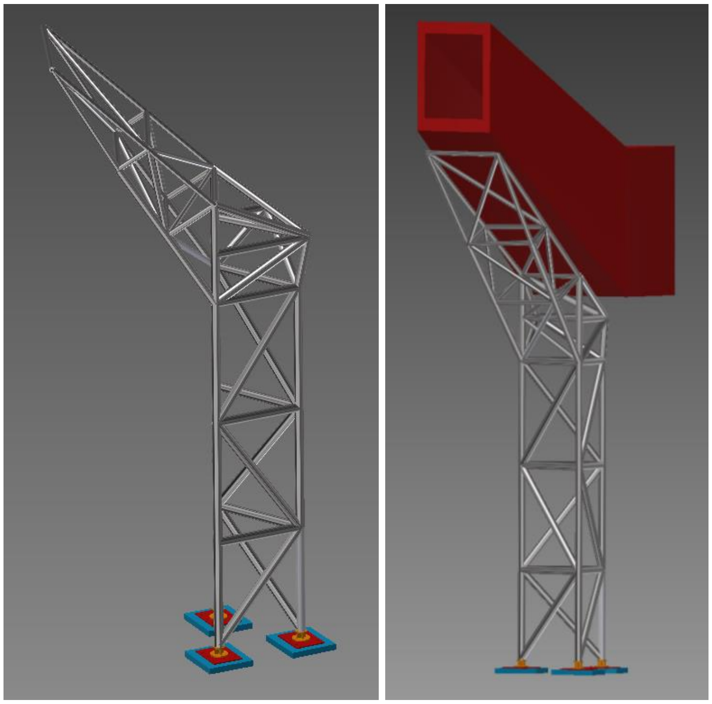


Figure 7. CAD model Support Structure between MAORY & MICADO.

3.4 Support Structure for MICADO Thermal Enclosure

In this paragraph the mechanical solution for the Support Structure for MICADO thermal Enclosure is presented. The preliminary mechanical design is shown in the next Figure 8 (right side). This support structure holds up the thermal enclosure of MICADO and is installed directly on this instrument. The four interface flanges on MICADO top bench are shown below in the Figure 8 (left side) and are highlighted with yellow circles.

This structure is made with standard structural aluminum pipes. The details and the structural verifications are reported in the next chapter concerning the FEM analyses.

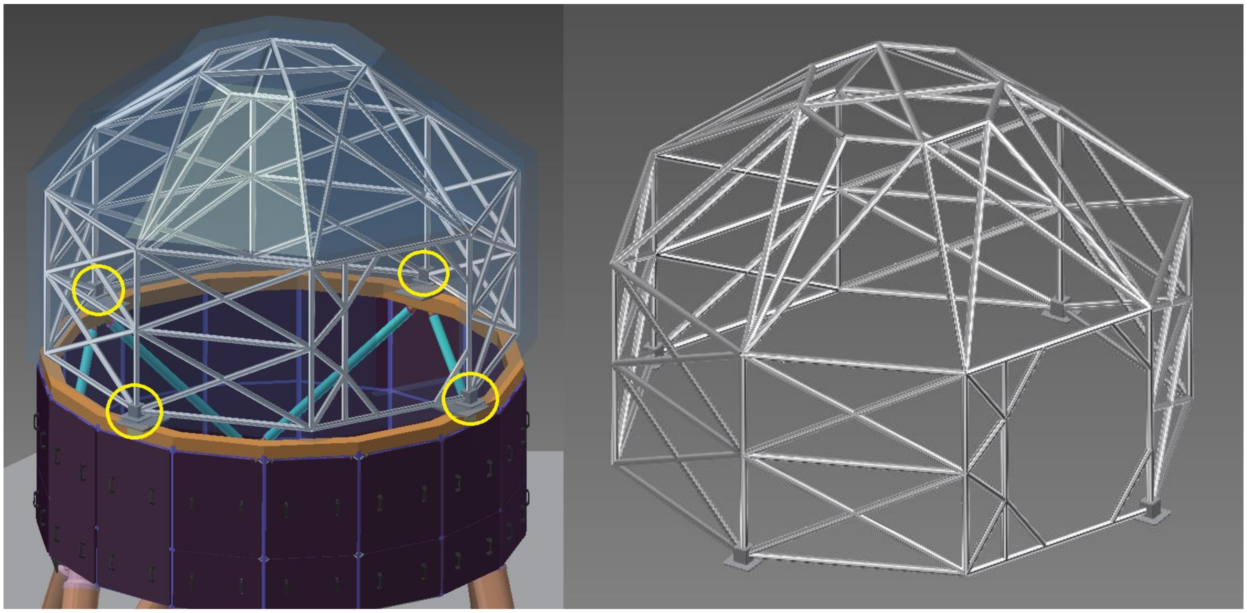


Figure 8. CAD model Support Structure for MICADO thermal Enclosure.

4. MAORY MSS - FEM ANALYSES

The preliminary FEM analyses has been carried out to check and improve the structural behavior of the MAORY Main Support Structure. The 3D CAD model was prepared using the Autodesk Inventor® and the finite element analyses were performed using ANSYS Workbench®.

4.1 Description of the model

The MAORY MSS is made of truss-beam shaped elements. We will use different profiles (in structural steel), with different thickness, in order to optimize the ratio between inertia, stiffness and global mass of the whole structure. In order to use plates and beams elements in the FE model, the CAD model developed in the pre-computational phases is made of surfaces, lines and points (see Figure 9 - left side).

The ANSYS elements used for FEA (Finite Element Analysis) are:

- SHELL181: four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes.
- BEAM188: element with two nodes and all 6 degrees of freedom for each node.
- MPC184: rigid element, used to transfer the load from mass points to nodes linked to the structure; these elements are classified as “constraint elements” (rigid link, rigid beam, etc.).
- MASS21: mass element, used in order to simulate the CoG mass of all opto-mechanical mounting and sub-assemblies.

The FE model imported and meshed in the CAE software ANSYS Workbench is shown in the Figure 9 (right side). This model is optimized in terms of computational calculation time. This FE model offers very accurate results for a global analysis approach. An example of a local structural verification is reported in the next paragraphs.

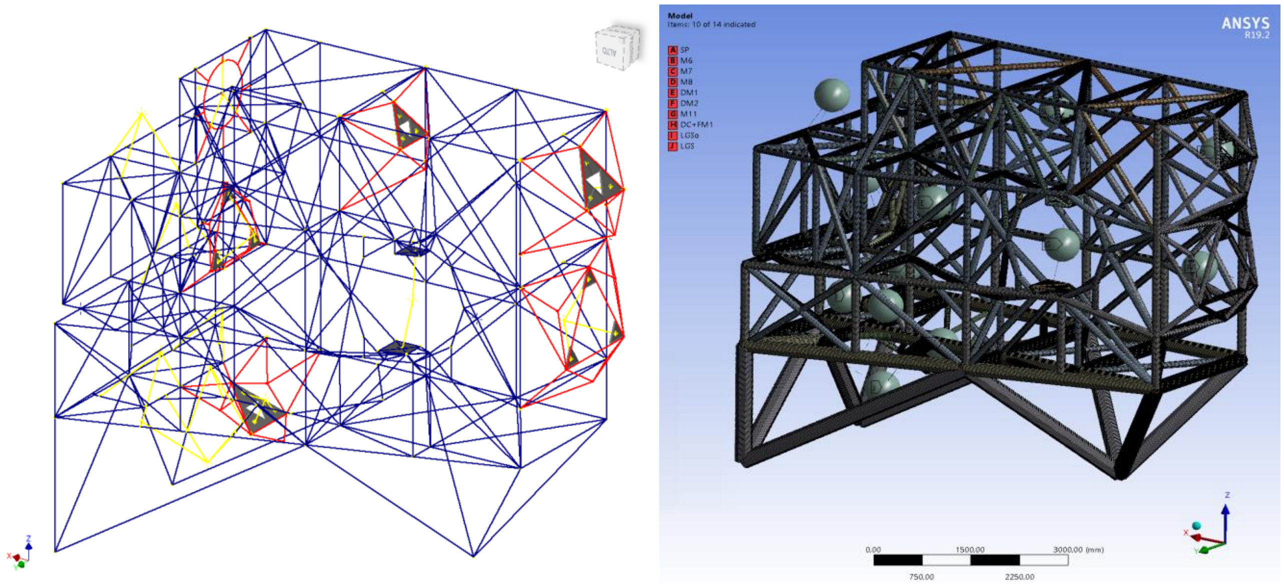


Figure 9. FE model MAORY MSS.

4.2 Model – Material

Table 1 (reported below) summarizes the properties of the material used in these FEM analyzes carried out for the MAORY MSS:

Table 1. Material properties: Steel AISI 4130.

Property	Unit	Value
Density	[kg/mm^3]	$7.85*10^{-6}$
Young's modulus	[MPa]	210000
Poisson's ratio	-	0.3
Yield strength	[MPa]	400
Tensile strength	[MPa]	700

4.3 Model - Constraints and Loads

The interfaces between the legs of the Main Support Structure and the Nasmyth platform are modelled as fixed points (three, in our case) that do not allow any rotations and displacements.

The total mass of each opto-mechanical mounting or sub-assembly has been applied, as nodal weight, in its CoG, and each CoG is connected to the Main Support Structure using rigid elements. The rigid elements tie all the degrees of freedom of the point (each CoG) to the degrees of freedom of the points located on the MSS.

In order to apply the contingency in these FEM analyses a margin of 20% is considered on all nodal weights for each optomechanical element. In the Figure 10, reported in the next page, the net and gross mass budget being considered are shown.

Name	Mass_Budget_net_27_07_2020 [Kg]			with_20%
SP		130		156
M6		178		214
M7		305		366
M8		334		401
DM1/M9		612	650	780
DM2/M10		998	1092	1310
M11		291		349
DC		166	596	715
Structure FM1-DC		200		
FM1		230		
LGSo		400		480
FM3		70		84
M12 (on MICADO)		412		494
Linear_stage		587	1000	1200
FM_CU_MAORY		213		
CU_MICADO		200		
CU_bench_part		350		420
LGS		625		720
Enclosure MAORY		2076		2491

Figure 10. Loads applied on MAORY MSS.

4.4 FEA Results - Static and modal analyses

The preliminary FEM analyses were carried out by applying the updated gross total mass of the opto-mechanical mountings, as nodal weight, in its CoG and transferring it to the MAORY structure via rigid elements.

The results of the analyses are as follows:

- **Static analysis**: the maximum displacement is **0.47** mm (see Figure 11 – left side).
- **Modal analysis**: first natural frequency is **9.62** Hz (see Figure 11 – right side).

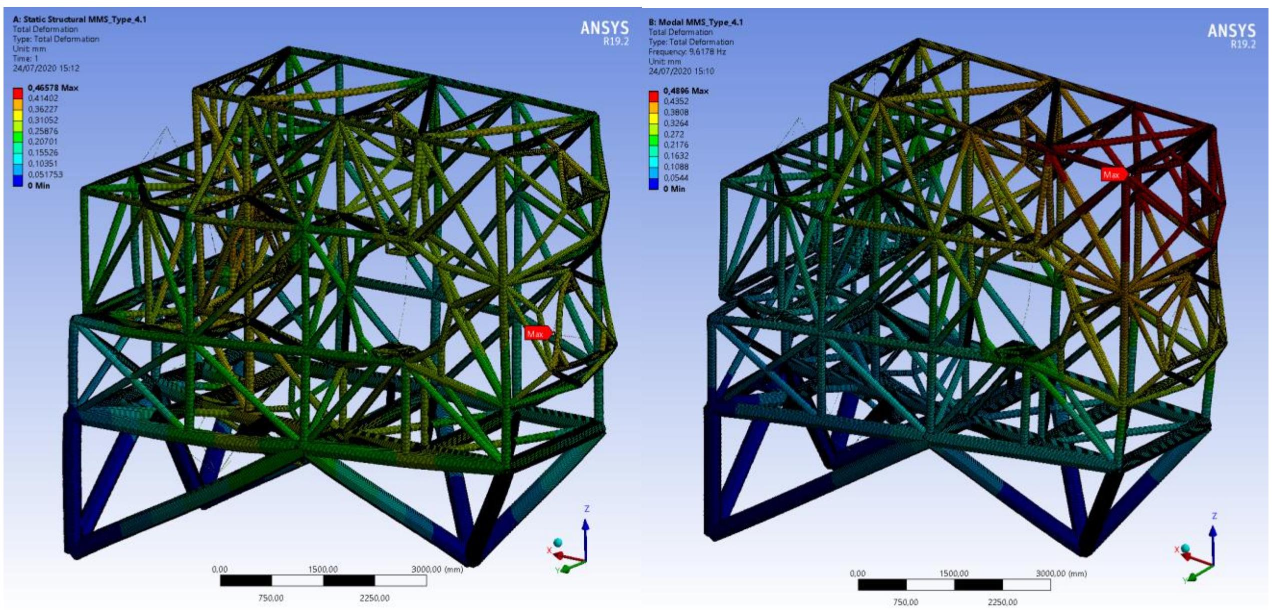


Figure 11. MAORY MSS Results - Static and modal analyses.

The mass, derived from the FE model of the configuration analyzed, is 7.6 tons (without contingency).

4.5 FEA Results - Earthquake analyses

For the earthquake analysis the case of the Simplified Seismic Analysis Method without response spectrum was considered. The quasi-static seismic acceleration to be applied to the structure in the three directions is obtained by performing a linear combination of the three equations below, obtaining a total of 24 load cases. The following equations can be found in EN 1998-1 (2004): Eurocode 8: Design of structures for earthquake resistance – Part 1.

$$\begin{aligned} A_{Ed1} &= \pm E_{dx} \pm 0.3E_{dy} \pm 0.3E_{dz} \\ A_{Ed2} &= \pm 0.3E_{dx} \pm E_{dy} \pm 0.3E_{dz} \\ A_{Ed3} &= \pm 0.3E_{dx} \pm 0.3E_{dy} \pm E_{dz} \end{aligned} \tag{1}$$

The obtained reactions on the Nasmyth flanges are shown in next Table 2.

Table 2. Reaction forces of earthquake analyses.

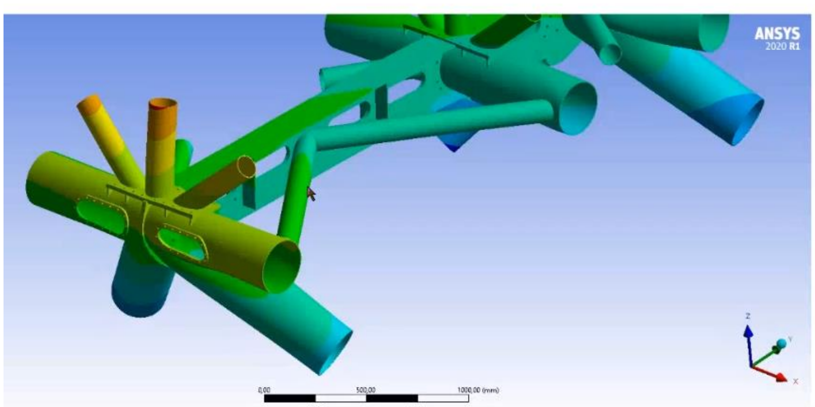
	Force Reaction X	Force Reaction Y	Force Reaction Z
MAX **[N]**	294318,9	369731,0	765712,1
MIN **[N]**	-291859,6	-350554,2	-861351,2

The model is compliant with the requirements, since the maximum values imposed by ESO are:

- **500000 N** in directions of X_{AZ} and Y_{AZ};
- **1000000 N** of traction and **1250000 N** of compression in the Z_{AZ} direction.

4.6 FEA Results – Local stress analyses

In order to verify the local stress limit (at yield, of course) in the main over-solicited joints, a local stress analysis approach is used. The strategy consists in analyzing "at local level" the global load imposed condition. For these analyses solid CAD models, imported and meshed directly in ANSYS Workbench, are used. The material is the same utilized for the previous analysis. The conditions of loads and the constrains are imposed in order to guarantee the global equilibrium of the system. The gain of this approach is essentially to have a look in the critical joints during the most significant earthquake load conditions. Only as an example, a local verification of a main joint between the two bottom parts of the MSS, during a specific earthquake load case, is shown in the Figure 12.



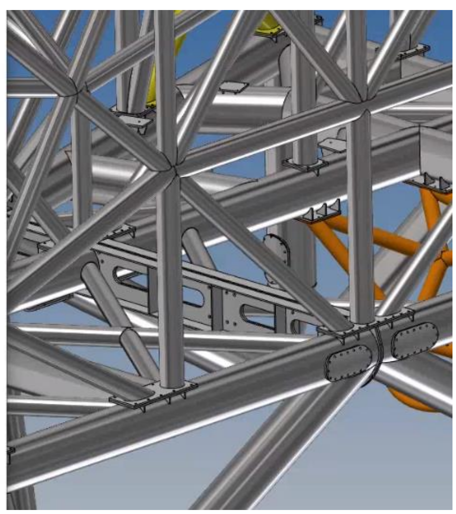


Figure 12. MAORY MSS Results - Local stress analyses.

5. OTHER SUPPORT STRUCTURES - FEM ANALYSES

In this chapter the results of the preliminary FEM analyses carried out on other two products of Main Structure are presented:

- Support Structure for thermal duct between MAORY & MICADO.
- Support structure for MICADO thermal Enclosure.

5.1 Support Structure between MAORY & MICADO

The FE model developed for this analysis is similar to previous approach utilized for the MAORY MSS. This model is composed only of beam elements, utilizing the geometry shown in Figure 7. Of course, in order to optimize the global mass, different circular pipe profiles are used.

The material used is the same of the previous one, shown in Table 2.

The loads applied are considered as 5 nodal mass points on the top plane of this structure, in order to simulate the weight of the thermal duct. The total load applied is 250 Kg.

The three constraint points on the Nasmith platform are fixed (3 rotations and 3 displacements are 0).

The results of the analyses are as follows:

- **Static analysis**: the maximum displacement is **1** mm (see Figure 13 – left side).
- **Modal analysis**: first natural frequency is **7.43** Hz (see Figure 13 – right side).

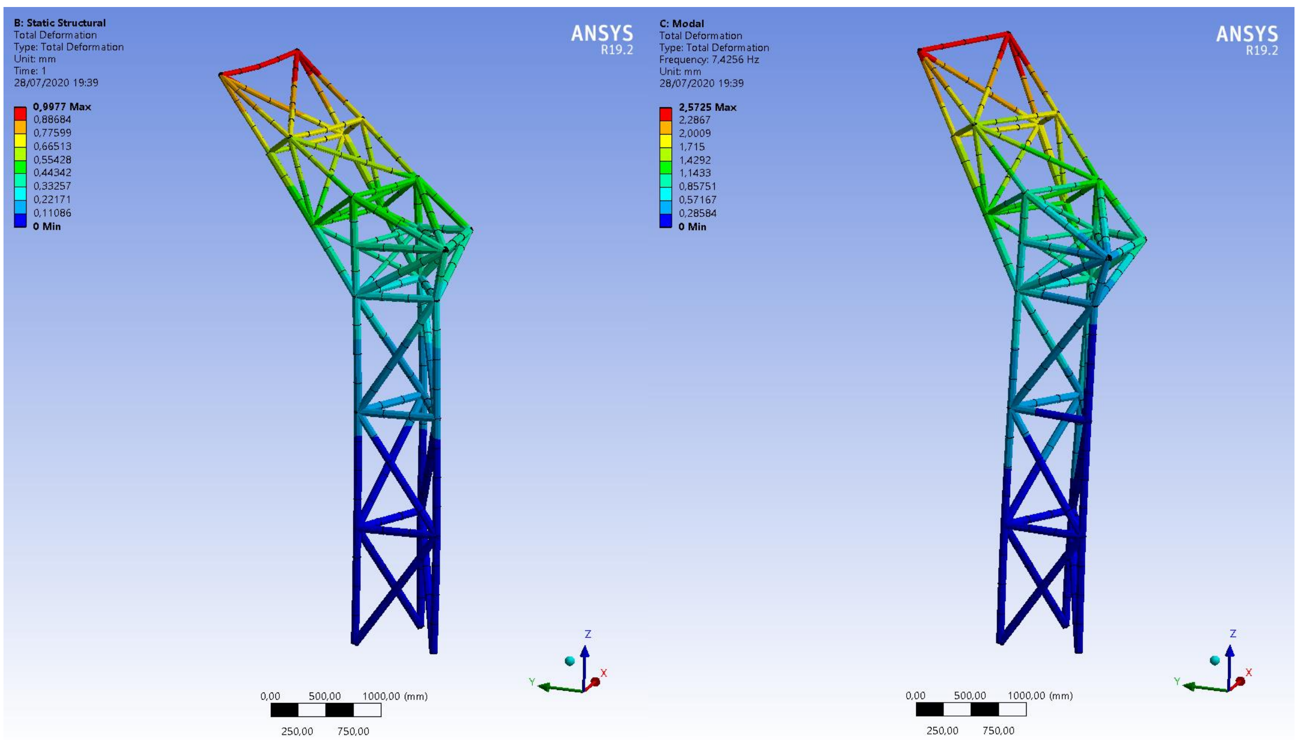


Figure 13. Support Structure between MAORY & MICADO Results - Static and modal analyses.

The mass, obtained from the FE model of the configuration analyzed, is 380 Kg (without contingency).

5.2 Support Structure for MICADO thermal Enclosure

The FE model of Support Structure for the MICADO thermal Enclosure are developed for the geometry shown in the Figure 8. This geometry imported in the CAE software, as beam elements, is meshed directly in ANSYS Workbench. As before, in order to optimize the global mass, different circular pipe profiles are used.

The material used is an Aluminum Alloy and its characteristics are shown below in Table 3.

Table 3. Material properties: Aluminum Alloy 6060 T6.

Property	Unit	Value
Density	[kg/mm^3]	$2.77*10^{-6}$
Young's modulus	[MPa]	71000
Poisson's ratio	-	0.33
Yield strength	[MPa]	280
Tensile strength	[MPa]	320

The load applied, as 31 nodal weights on this structure, in order to simulate the weight of the thermal enclosure, is 350 Kg. The four constraint points on the MICADO interface plates are fixed (3 rotations and 3 displacements are locked).

In the next Figure 14 the meshed configuration and the load condition applied on this support structure are shown.

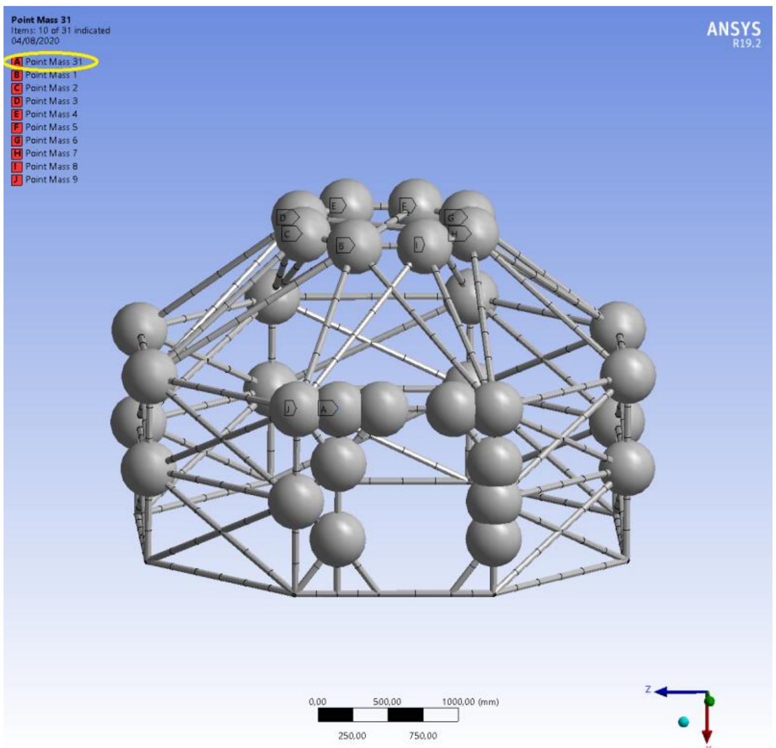


Figure 14. Support Structure for MICADO Enclosure - Load condition.

The results of the analyses are:

- **Static analysis**: the maximum displacement is **0.26** mm (see Figure 15 – left side).
- **Modal analysis**: first natural frequency is **23.2** Hz (see Figure 15 – right side).

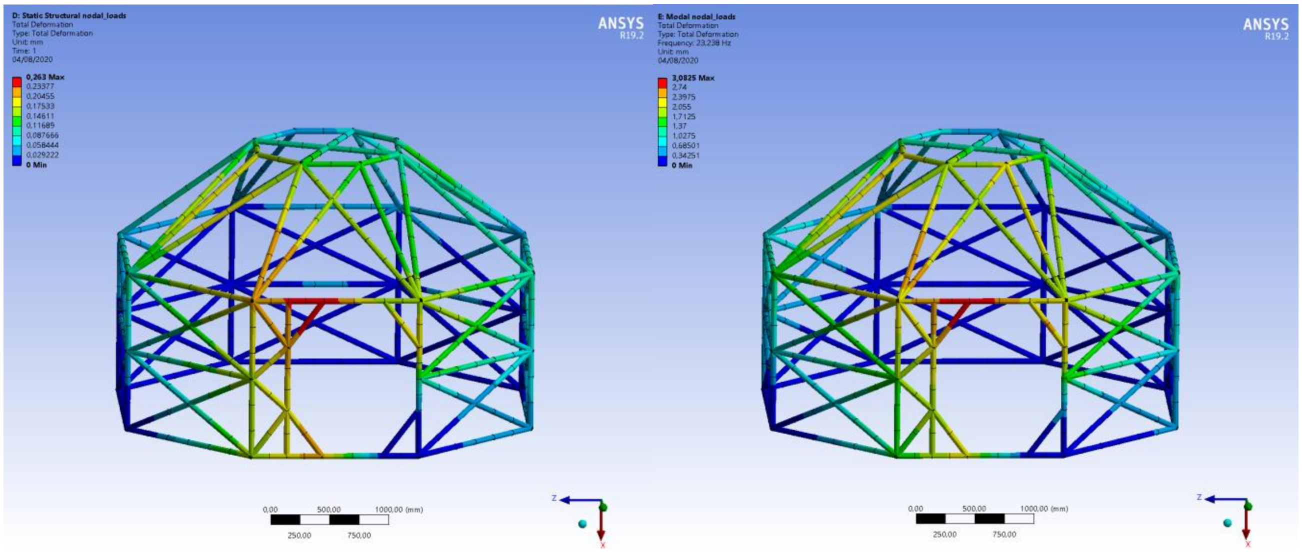


Figure 15. Support Structure for MICADO Enclosure Results - Static and modal analyses

The mass, derived from the FE model, is 250 Kg. (without contingency).

6. CONCLUSIONS

The last baseline mechanical design of the MAORY Main Support Structure has been presented in this paper. Significant changes of requirements and instrument design have been made since the MAORY project phase A.
The different set of preliminary analyses done, prove that the present mechanical model is compliant with the requirements imposed by ESO for ELT instrumentation.

7. ACKNOWLEDGEMENTS

The MAORY instrument is developed in the framework of the Agreement No. 65221/ESO/15/67001/JSC between the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) and the Istituto Nazionale diAstrofisica (INAF) on behalf of the Consortium consisting of INAF, Institut National des Sciences de I'Univers du Centre National de la Recherche Scientifique (INSU/CNRS) acting on behalf of the Institut de Planetologie et d'Astrophysique de Grenoble (IPAG) and of School of Physics at the National University of Ireland Galway (NUIG).

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