Star Light

Engineering simulation will save $5 million in construction costs for a massive telescope that will allow astronomers to peer back into the formation of galaxies.

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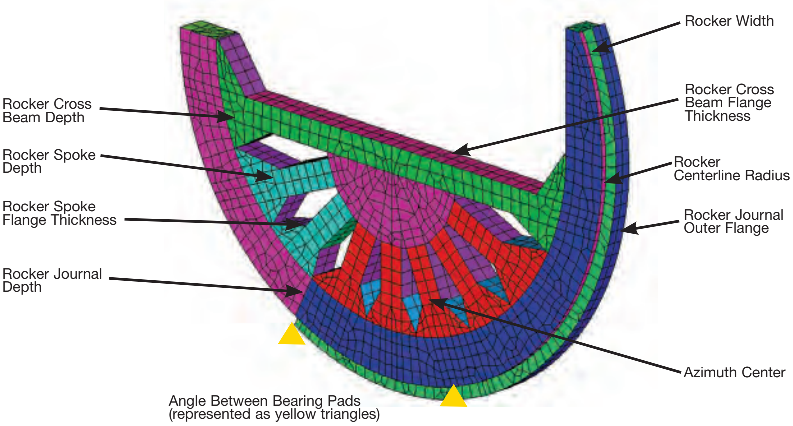
When completed in 2018, the Thirty Meter Telescope (TMT) will be the most powerful optical telescope on Earth. This massive structure will allow astronomers to identify and study light from galaxies forming at the very edge of the observable universe as well as to view objects in our solar system and stars throughout the Milky Way. The structure of the TMT will be 56 meters in diameter and 47 meters tall, and it will weigh about 1,900 tons. Designing the enormous moving mass of the telescope created a number of structural challenges. For example, the 30-meter-diameter primary mirror on the TMT has 492 mirror segments that need to be supported very rigidly because deflection causes the mirror segments to move out of alignment with each other. Actuators on each mirror segment can move the mirrors to compensate partially, but not completely, for deflection. As a result, the $100 million supporting structure, which points the telescope at different areas in the sky, needs to provide tremendous stiffness at an affordable cost.

Dynamic Structures, based in British Columbia, Canada, is designing and building the telescope's support structure and enclosure. Working together with the TMT project in conjunction with the Herzberg Institute of Astrophysics, the company has developed an innovative method to optimize the structural design directly with optical performance. In three months, the Dynamic Structures team was able to reduce the mass of the structure by about 10 percent, saving approximately $5 million in construction costs while improving optical performance.

The telescope has a spherical calotte enclosure design with a rotating base, cap cover and circular aperture. The dome rotates around a vertical axis while the 45-degree offset cap cover swivels to allow the telescope to incline. Both axes move in unison to allow the TMT to track any part of the sky beyond approximately 25 degrees above horizon. The support structure provides mounting for the telescope optics and associated astronomical instruments along with precise motion control for pointing, tracking and guiding.

TMT has an image quality error budget, which is the allowable difference between a perfect image and what is seen by the telescope. The budget is parceled out among a number of contributing factors. The primary mirror segments are supported on three actuators that control the height of the mirror and tilt in two planes. Three other axes of motion cannot be controlled. These include decentering, which describes two axes of motion moving in a plane parallel to the mirror surface, along with

Concept image of the Thirty Meter Telescope



Parametric studies were performed on the elevation journals, which are major load-carrying elements in the telescope structure. This figure shows the kinds of parameters that were modeled.

rotation in that same plane. As a result, deflections in the structure that affect these axes cause optical aberrations and must be minimized. In general, the residual errors after correction are proportional to the total range of actuator stroke required for correction, so it is important to minimize the actuator stroke.

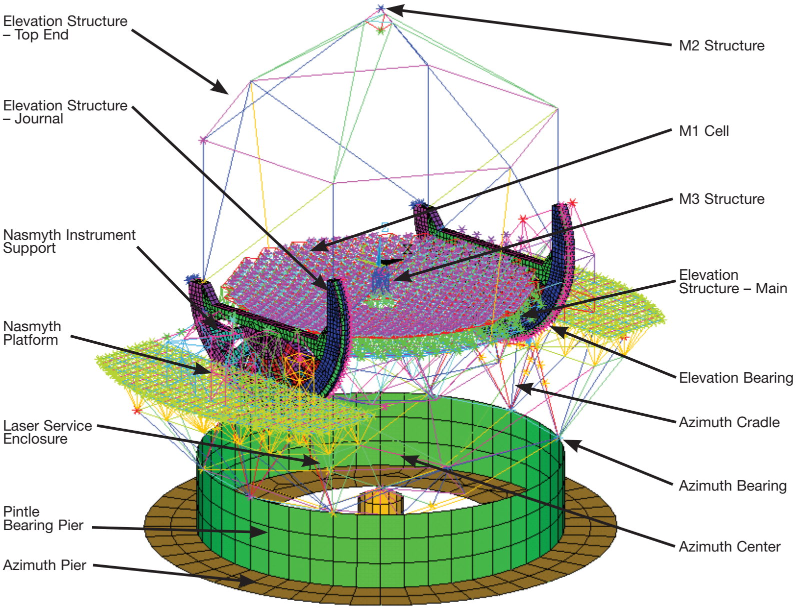
In the traditional approach for telescope structural design, optical engineers provide frequency and displacement constraints based on required tolerance parameters related to desired optical performance. Then finite element analysis is used to predict the response of the structure to wind, gravity, temperature and actuator motion. The process of analyzing each proposed design against the optical criteria is complex and often must be repeated many times until an acceptable design is found. The methodology developed by the design team for the TMT allows the structural performance to be optimized directly against the optical requirements. Dynamic Structures engineers developed parametric models to generate the geometry for each design iteration of the telescope structure. Using ANSYS Mechanical software's APDL interface made it easy for the engineers to quickly generate a large series of runs by changing various design parameters. For each design iteration, the engineering team used ANSYS technology to determine the structural performance along with a merit function routine (MFR) to assess the actuator stroke requirements and motions of the optics. Lengthening the actuator stroke sacrifices accuracy. The optics motions are critical to optical performance, particularly those degrees of freedom that are not compensated by actuator motion.

The core MFR routine is implemented in MATLAB® and is called from ANSYS Mechanical software. An MFR calculation is initiated by applying a load to the ANSYS model, extracting nodal displacements and calling MATLAB. The MATLAB code reads the displacement file, then calculates and saves the MFR parameters to a results file. These parameters are read back to ANSYS software as scalar parameters. Engineers can read these parameters through the APDL interface into their spreadsheet to evaluate results and to drive future iterations.

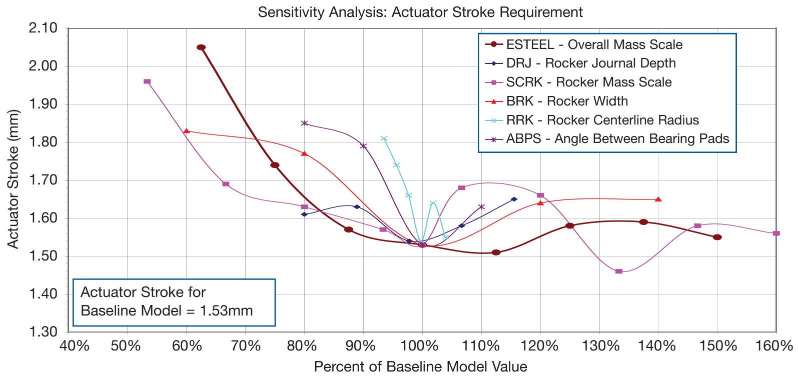
ANSYS technology was used to perform elastic quasistatic analysis and modal analysis. The displacements of optical interface nodes in the model were used by the MFR to evaluate absolute and relative motions. Smaller quasistatic displacements are indicative of higher stiffness and natural frequency. The MFR takes the positions of all optical interface nodes from the ANSYS Mechanical model as input and generates a set of optical performance measures and positioning system requirements.

Evaluating the seismic performance of the telescope was another critical design consideration. Computationally efficient spectrum analysis could not be used because it applies only to linear systems, and this telescope uses a nonlinear base isolation system. Instead, Dynamic Structures engineers performed transient analysis with technology from ANSYS using a series of loading functions to evaluate various seismic scenarios.

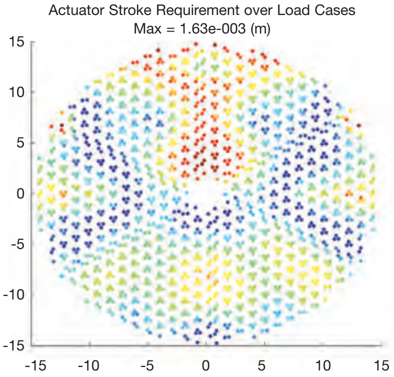
Dynamic Structures engineers also used the ANSYS Mechanical interface to write a program that computes strain energy distribution throughout the structure. Groups of elements with



Finite element model component groups, which show the division of telescope structural and mechanical elements into component groups used to optimize different parts of the structure



Parameter studies investigated the sensitivity of M1 actuator stroke to various geometric parameters defining the telescope structure. For example, the radius of the elevation journals (rockers) was used as a parameter.



Plot of M1 mirror actuator stroke requirements, generated by merit function routines

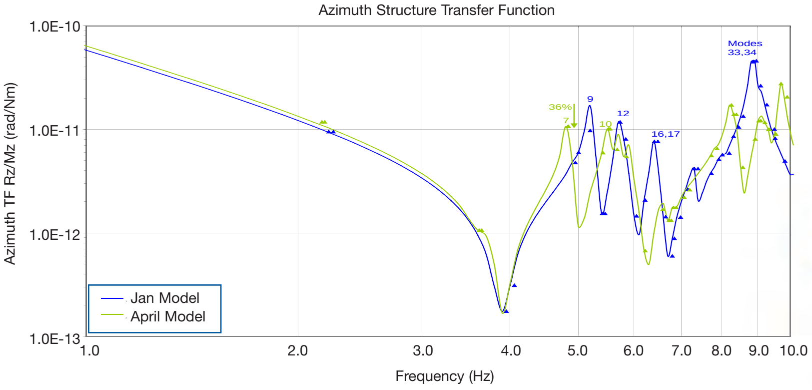
the highest strain energies are candidates for stiffening. Mass reduction is often possible with the rest of the elements. This process of redistributing mass among element groups maintains optimal dynamic performance while reducing mass.

Parametric studies and sensitivity analyses were conducted throughout the conceptual and early preliminary design stages. At the conceptual stage, the impact of major geometric parameters was studied. For example, the spacing and dimensions of the two large elevation journals (load-carrying elements) were investigated using a coarse-level model with a simplified support structure. Subsystem-level models were then used to gain understanding of the structural behavior on a local level and to maximize the stiffness of individual components. Finally, more detailed models of the support structure were developed to validate the overall performance. Parameters used to optimize the performance of the elevation journal include detailed quantities such as the dimensions and thickness of plate elements that make up the journals.

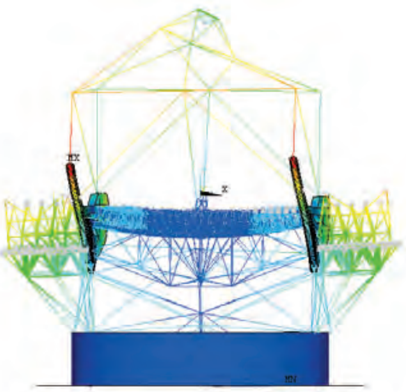
Maximizing the bandwidth of the control system is important in minimizing the response of the structure to wind shake caused by unsteady turbulence inside the enclosure. Bandwidth is a measure of how quickly the control system can respond to deflection. Dynamic Structures' approach was to link the output of the structural analysis to an APDL routine that computed the drive control system transfer function. Using the transfer function output, the most problematic modes could be directly identified. This made it possible to evaluate the impact of structural design alternatives directly on the metric of interest, resulting in a more efficient design process than the traditional method and a more economical design.

Analysis results showed that strain energies were concentrated in a few key components of the elevation structure: the hexagonal ring on the top of the structure, secondary columns that support the ring, elevator journals and the Nasmyth platform that holds the instruments. Strengthening these components and reducing the masses of the rest of the components reduced the mass of the overall structure while improving dynamic performance.

The optimized model is 183 tons lighter, yet it performs better dynamically, as demonstrated by its lower response amplitude and higher frequency at mode 10. The static performance of the optimized model design under gravity was evaluated using the MFR to ensure that the lighter design meets active optics requirements. The 10 percent mass reduction saved roughly 5 percent of the costs of building the structural support system, or about $5 million.



Azimuth structure transfer function comparison before and after optimization. Mode 10 limits the control bandwidth of the elevation axis. Response at critical 5Hz peak has decreased by almost 40 percent, leading to improved control bandwidth.



Shape of critical 5Hz mode