

# Space Shuttle Endeavour Exhibit Support Structure

## Samuel Oschin Air and Space Center

### Los Angeles, CA

The Samuel Oschin Air and Space Center will be the 200,000 sq-ft expansion of California Science Center adding a collection aerospace artifacts integrated with new hands-on exhibits. The Space Shuttle Endeavour sitting on a base-isolated podium designed by Arup will be on display in the Science Center at a launch-ready configuration making it the only authentic vertical space shuttle stack in the world.

**Structural Engineer:** Arup  
**Owner:** California Science Center Foundation  
**General Contractor:** MATT Construction  
**Year of completion:** January 2024



## The mission

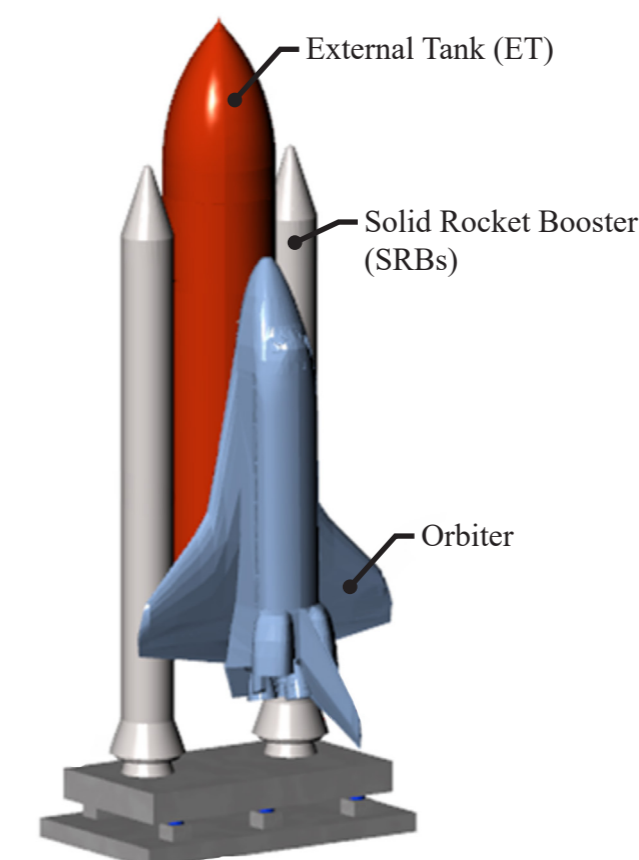
The Science Center will host the 122' long Space Shuttle Endeavour in launch-ready position. Arup designed the the support structure for the Space Shuttle Exhibit (Stack); comprised of the Orbiter Endeavour (ORB), an External Tank (ET), two Solid Rocket Boosters (SRBs), and connection hardware/elements (CHE) that the Science Center has acquired; using performance-based design procedures and utilizing seismic isolation.

The base isolation reduces the impact of earthquake hazard by achieving significant reduction in the accelerations, displacements and overturning moments at the base when compared to the fixed Stack model, making the decision to implement seismic isolation an obvious choice.

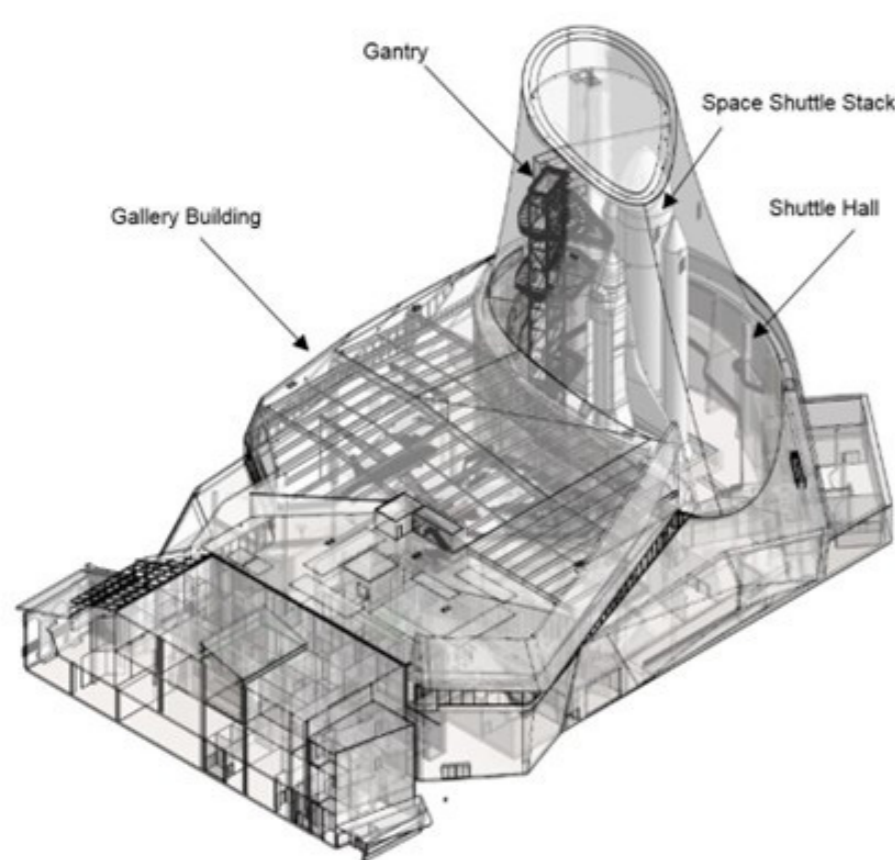
The base isolation strategy consists of using (6) triple friction pendulum (TFP) 4-sec isolators underneath a 8' deep isolated pad supporting the Stack above. TFP isolators sit on reinforced concrete columns 6'x6' on plan stemming from a 6' deep pit slab supported on piles. A moat is provided around the concrete pad to accommodate horizontal displacement during earthquakes.

The ORB is attached to the ET and is cantilevered nearly 25 feet from the center of SRB supports. The Stack is connected to the isolated concrete pad at the same 8 hold-down anchor locations in the SRBs, 4 at each SRB, used during actual launches. Due to the large eccentricity of the Orbiter's center of gravity with respect to the centroid of the SRB to concrete pad connection, the Stack experiences permanent overturning at the base of the SRBs, which amplifies with the seismic loads. This level of overturning creates significant axial tension in the SRB hold downs. The overturning demands due to seismic loads are reduced to one-third by utilizing seismic isolation.

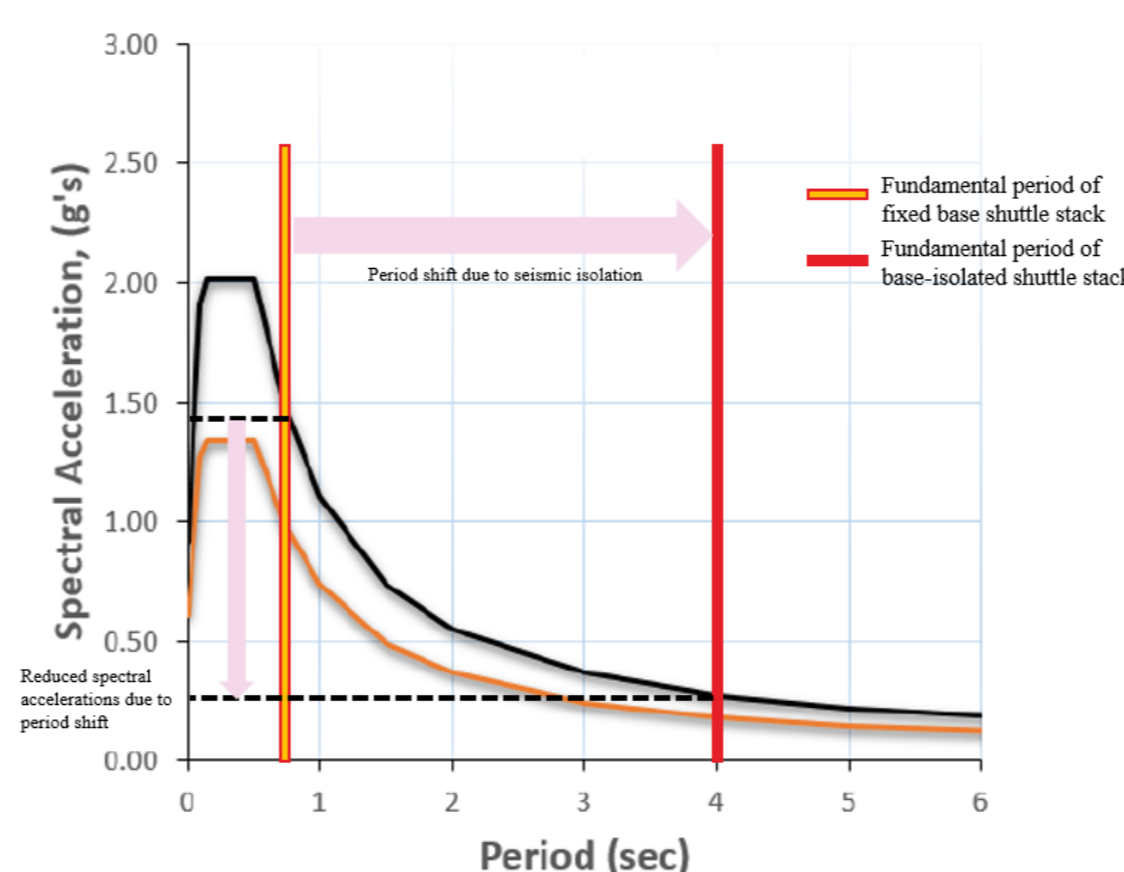
The support structure was completed in June 2023 and the Endeavour was lifted into the vertical, ready to launch configuration on January 2024 completing a 6-month, multi-phase process of stacking each space shuttle component in a 20-story vertical configuration residing within the California Science Center's future Samuel Oschin Air and Space Center.



**The Shuttle Stack in vertical display**  
 All the artifacts are real flight hardware originally designed for use in the NASA space shuttle program.



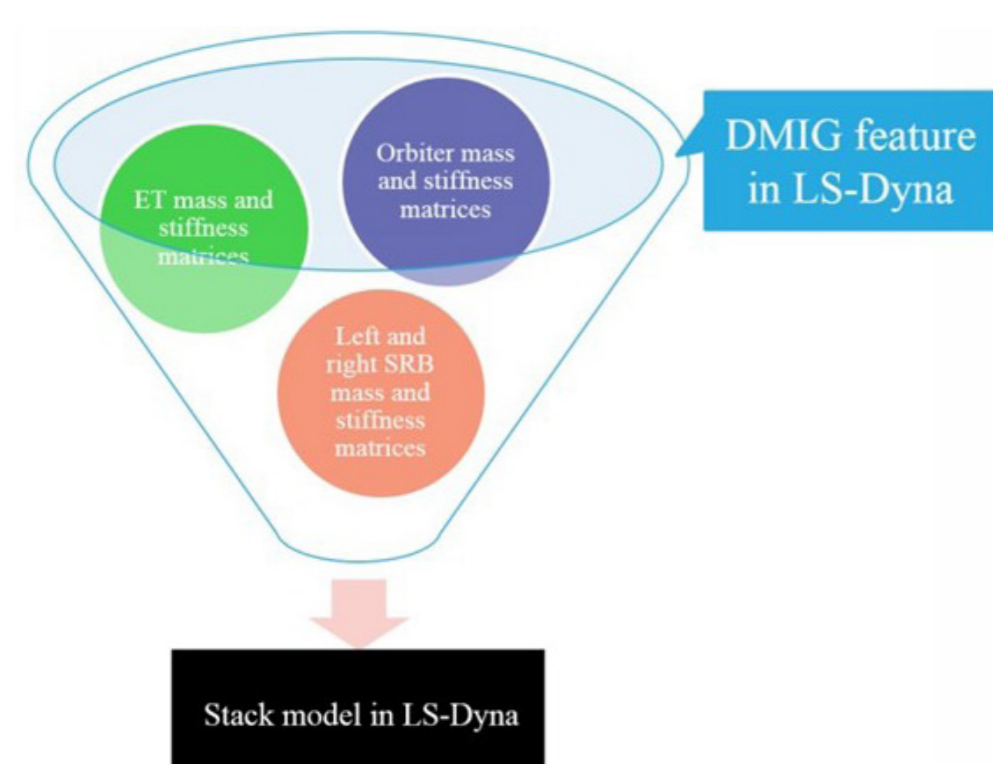
**Stack Exhibit within Samuel Oschin Air and Space Center**



**Spectral acceleration reduction on the Stack with base isolators**

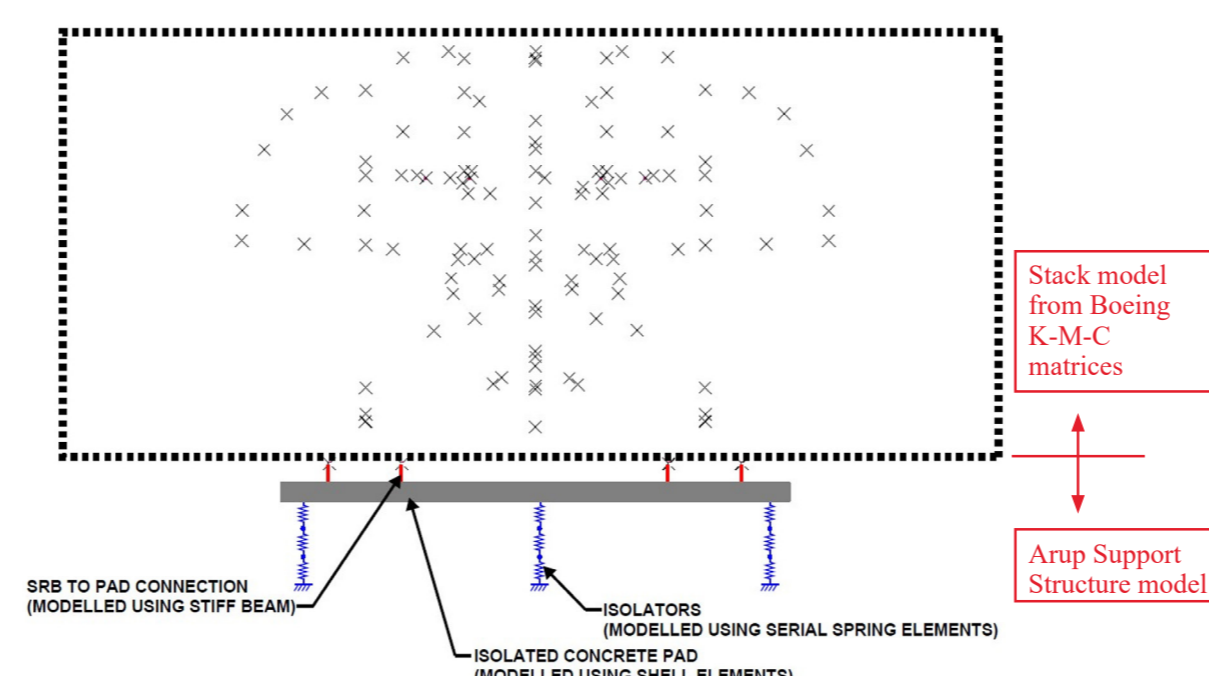


**The Endeavour being lifted into the vertical configuration**



### Modelling the Stack in LS-Dyna

The Science Center obtained and provided Arup with the mass and stiffness matrices of the four Stack components for use in representing the Stack dynamic behavior in an analysis model.



### LS-DYNA analysis model representation

Nonlinear Response History Analysis (NLRHA) procedure is used for the design of the isolator pad, substructure and the performance evaluation of the base isolated Stack. LS-Dyna was selected for the analysis based on its ability to model the triple friction pendulum isolators and its capability to work with direct matrix input.



**Reinforced concrete pit with isolators placed on site**