CCAT Enclosure

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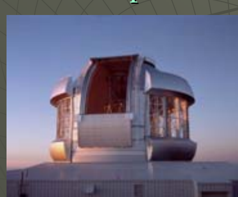
AMEC Corporate Profile

- AMEC Dynamic Structures Ltd:
  - Located in Vancouver, Canada
  - Design/build steel fabricating firm
  - Specialize in astronomy and entertainment industries





Scope

- Scope of enclosure: everything above the fixed facility building
- Scope of feasibility study:
  - Structural design
    - Structural shell design and analysis
    - Fabrication/construction considerations
  - Mechanical design
    - Calotte mechanical system
    - Azimuth mechanical system
    - Shutter
    - Crane

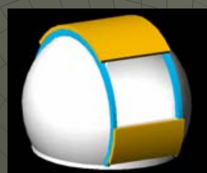
Requirements for Subsystem

- CCAT Enclosure Requirements
  - Dome diameter: 50m
  - Aperture diameter: 30m
  - Aperture zenith range: 0 – 75 degrees
  - Azimuth rotation: unlimited
  - Calotte rotation: 200 degrees
  - Key environmental loads:
    - Wind (survival): 65m/s
    - Snow Load: 100kg/m^2
    - Ice Load: 25kg/m^2
    - Seismic: 0.4g ground acceleration
  - General: simplify on-site construction due to the extreme altitude
    - Trial assembly at the manufacturer's site
    - Shipping via standard containers
    - Construction procedures that minimize field labor

Enclosure Type

- Various enclosure types considered
  - Formal trade studies carried out for TMT, VLOT, GSMT

Dome-Shutter



Carousel

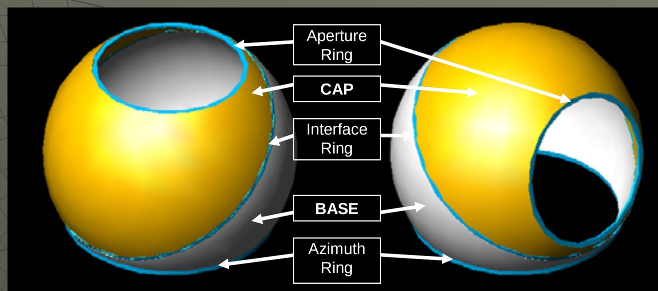
Calotte

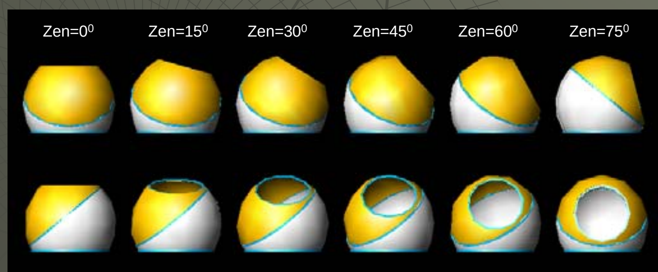
- "Calotte" selected as baseline design:
  - Continuous spherical form
    - Lighter structure = lower cost (structural, mechanical, construction)
    - Avoids concentrated loads on mechanical systems at arch girders
    - Reduces snow and ice accumulation
    - Reduces wind load on enclosure and turbulence
  - Requires minimum number of moving components (no windscreens/light screens)
  - Minimum aperture opening gives maximum wind protection

Enclosure Type

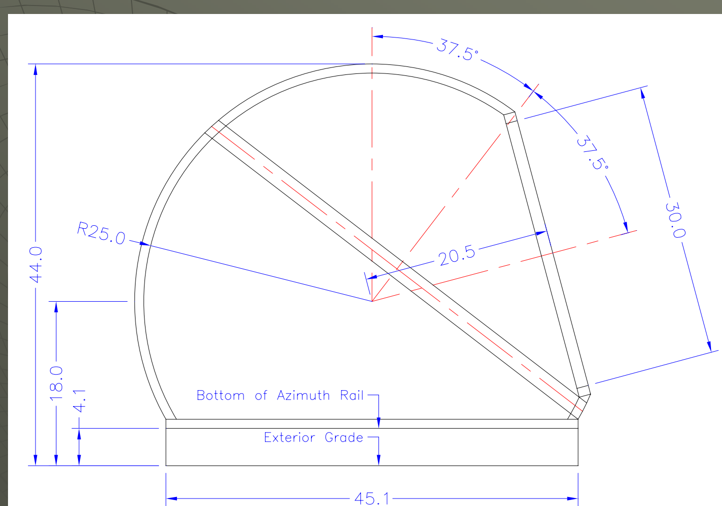
- Key aspects of TMT enclosure comparisons
  - Enclosure mass
    - Calotte: 2300 T
    - Dome-shutter: 2500 T
    - Carousel: 3600 T
  - Enclosure cost estimates
    - Dome-shutter: 20% higher than Calotte
    - Carousel: 45% higher than Calotte
  - Peak power requirements
    - Calotte: 400 kW
    - Dome-Shutter: 2600 kW
    - Carousel: 1000 kW
- Major drawback of Calotte for TMT was the possible venting limitations
  - Not an issue for CCAT

Enclosure Concept – “Calotte”





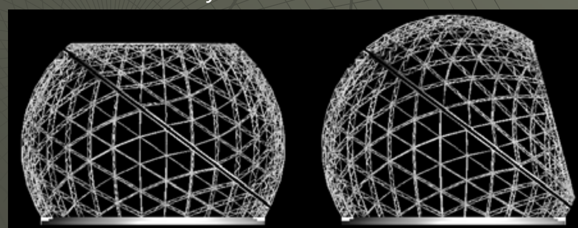
Enclosure Dimensions



Structural Design

- Structural design trades
  - Triangulation geometry (geodesic, rib & tie)
  - Beam vs. truss elements
  - Aluminum vs. steel
- Selected design for feasibility study
  - Steel triangulated truss structure, nominally 1.0m deep
  - Stiffened ring sections at mechanical interfaces
  - Shares similar components to existing enclosures (i.e. Keck I & II)

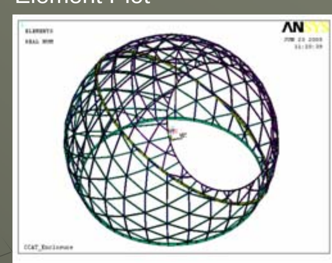
Geometry of rib & tie shell structure



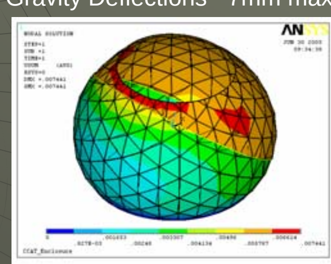
Structural Analysis

- Structural Analysis
  - Preliminary FEA of enclosure structure
  - Members optimized under survival load combinations (gravity, wind, snow, ice)
  - Mechanical elements modeled with equivalent spring elements

Element Plot

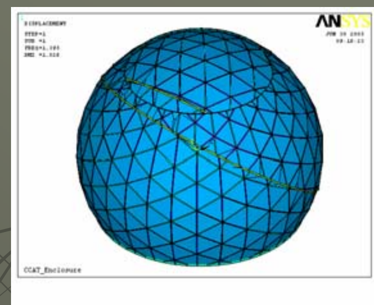


Gravity Deflections ~7mm max

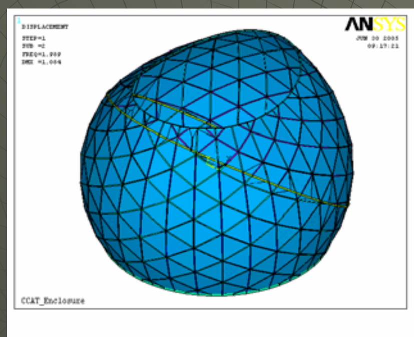


Mode Shapes

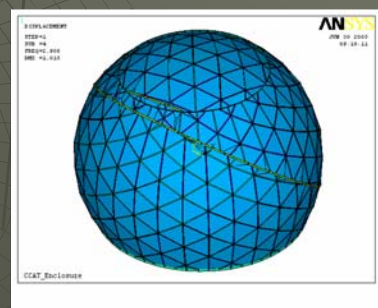
Mode 1: 1.4Hz



Mode 2: 2.0Hz (Mode 3 similar)



Mode 4: 2.9Hz

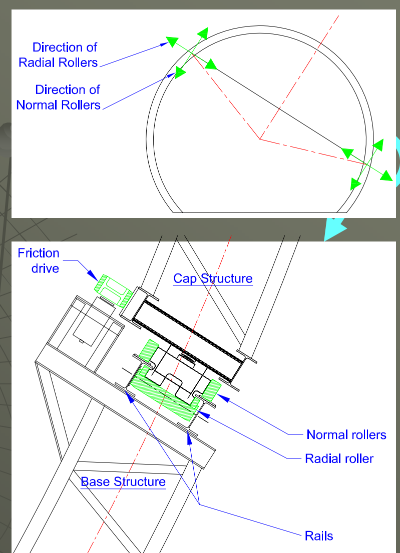


Interface Bearings/Drives

- The mechanical interface design (i.e. the bearings and drives at the inclined plane) are considered a high risk component of the Calotte enclosure design
  - Wear Issues
  - Over-constraint and Differential Thermal Expansion
- Interface design trades:
  - Continuous vs. discrete rolling elements
  - Bogie mount location (cap-mounted vs. base-mounted)
  - Bogie orientation (parallel to plane of rotation vs. parallel to structural shell)
- Several general concepts for the mechanical design have been developed; the preferred point design is presented here

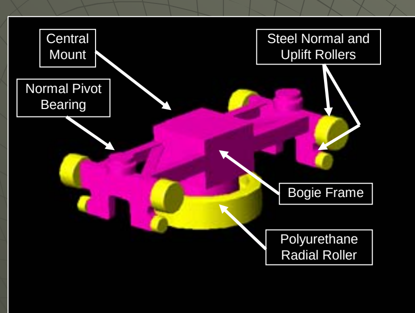
Interface Bearing Concept

- Bogies contain 2 roller sets:
  - *Normal rollers* oriented perpendicular to plane of rotation
  - *Radial rollers* oriented perpendicular to axis of rotation
- Bogies mounted to "cap", rails mounted to "base"
  - Allows bogies to be accessed from single location at lowest point of interface
- Drive assembly independent from bogie assembly
  - Several drive units mounted to base at lowest point of interface; allows redundancy and ease of access
  - 90 hp total input power required

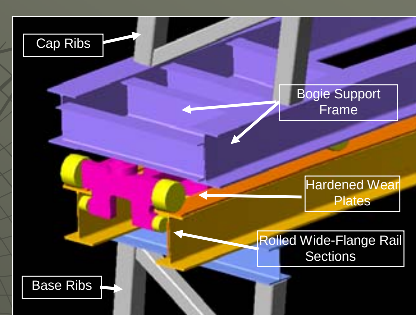


Interface Bearing Concept

Interface Bogie Assembly

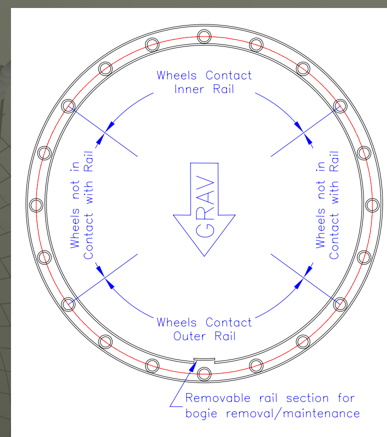


Interface Bogie/Rail Assembly



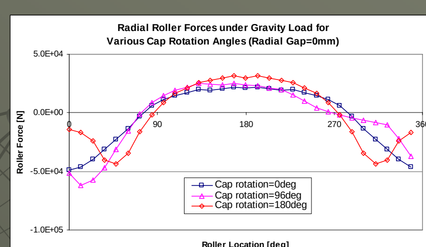
Interface Bearing Concept

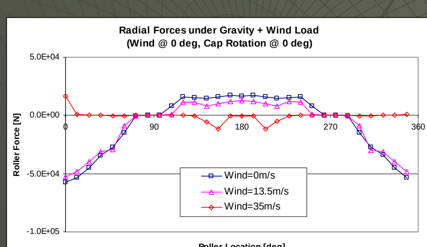
- Radial rollers contained within a double rail
  - Loading switches between inner/outer rail due to gravity load on inclined interface
- Gap between rollers and rails
  - Notionally 1” gap
  - Avoids over-constraint
  - Eases fabrication and assembly tolerances

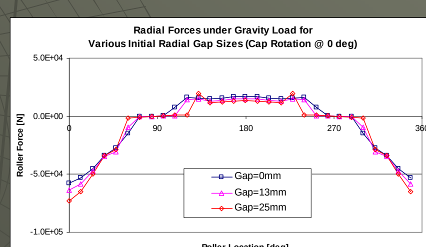


Interface Analysis

- Analysis have investigated load distribution at interface bogies
  - Analysis based on enclosure FEM
  - Load cases considered include gravity, wind, thermal, fabrication tolerances
    - Fabrication/construction tolerances found to a driving consideration
  - Sample results shown here







Azimuth Bearings/Drives

- Azimuth bearings/drives
  - Bogies are fixed to foundation, rail surface is mounted to enclosure
  - Drive system utilizes rubber-tire drive rollers, spring loaded to maintain friction force
    - Bearing and drive concept is similar to HET/SOAR concepts
    - 110 hp total input power required
  - Not considered a high-risk design issue due to experience with existing designs

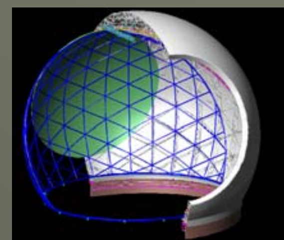
Shutter

- Shutter key design trades
  - Fixed vs. Movable
    - Movable structure required: fixed shutter blocks too much sky
  - Interior vs. Exterior
    - Interior structure preferred: minimizes wind/snow/ice loads on the shutter structure, resulting in lighter shutter structure
  - Azimuth mounted vs. interface mounted
    - Azimuth mounted preferred: minimizes load on enclosure structure, and does not require structure to be balanced about rotation axis

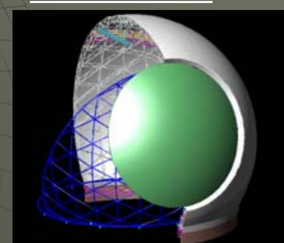
Shutter

- Selected shutter concept is movable, azimuth mounted, internal structure
  - Shutter closes w/aperture pointed to zenith=75^0
  - Shutter structure supported via bogie system on enclosure azimuth ring girder, rotates 180^0 to open/close shutter
  - Shutter structure does not require drive system:
    - In open or closed configurations, locking pins fix shutter rotation to enclosure rotation
    - In transition from open to closed configurations, locking pins or brakes fix shutter rotation to foundation, and enclosure rotates 180^0 in azimuth to open/close shutter
  - Shutter seals opening via a telescoping annulus ring and an inflatable seal

Shutter OPEN

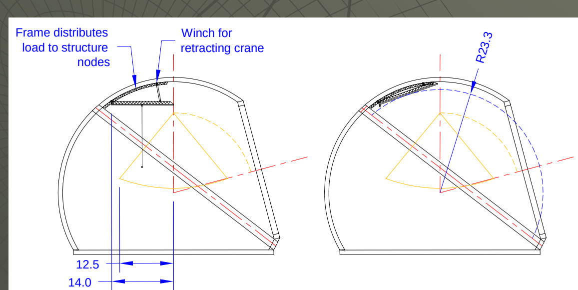


Shutter CLOSED



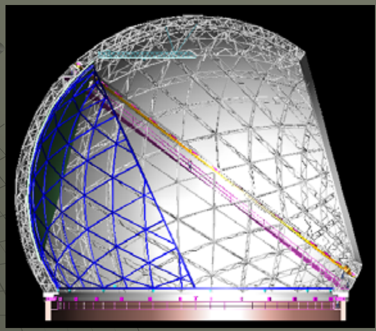
Enclosure Crane

- Enclosure requirements specify 2-tonne crane for telescope maintenance
- Alternate crane options have been considered:
  - An enclosure-mounted retractable gantry crane is currently the preferred option (see figure below)
  - Alternate concepts include vehicle-mounted jib cranes; access to telescope is either from interior of enclosure or from exterior through open aperture



Mass Estimate

Component	Mass [Tons]
Structural - Ribs	54
Structural - Ties	101
Structural - Azimuth Ring	21
Structural - Interface Ring-Base	24
Structural - Interface Ring-Cap	24
Structural - Aperture Ring	12
Structural - Shutter	50
Structural - Cladding/Insulation	81
Mechanical – Azimuth	76
Mechanical - Interface	38
Mechanical - Shutter	15
TOTAL	**496 tons**



Note: Gemini Dome: 36m Diameter 360 tons, Scaled to 52m=1100 tons

Keck Dome: 36 m Diameter 650 tons, Scaled to 52m=2000 tons

Critical Risk Assessment

- Critical issues identified:
  - Interface
    - Further detailed of design/analysis required; no potential showstoppers indicated in analysis to date
    - Development of fabrication and installation procedures
  - Structural mass
    - Structure fabrication/construction a large cost driver, potential to further optimize structure due to efficient structural form
    - Opportunity to utilize subcontractors specializing in manufactured domes