Critical Design Report

TELESCOPIO SAN PEDRO MÁRTIR Enclosure and Facilities at Parque Nacional de Sierra de San Pedro Mártir

Baja California, México

El Instituto de Astronomía de la Universidad Nacional Autónoma de México

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1 SCOPE OF WORK

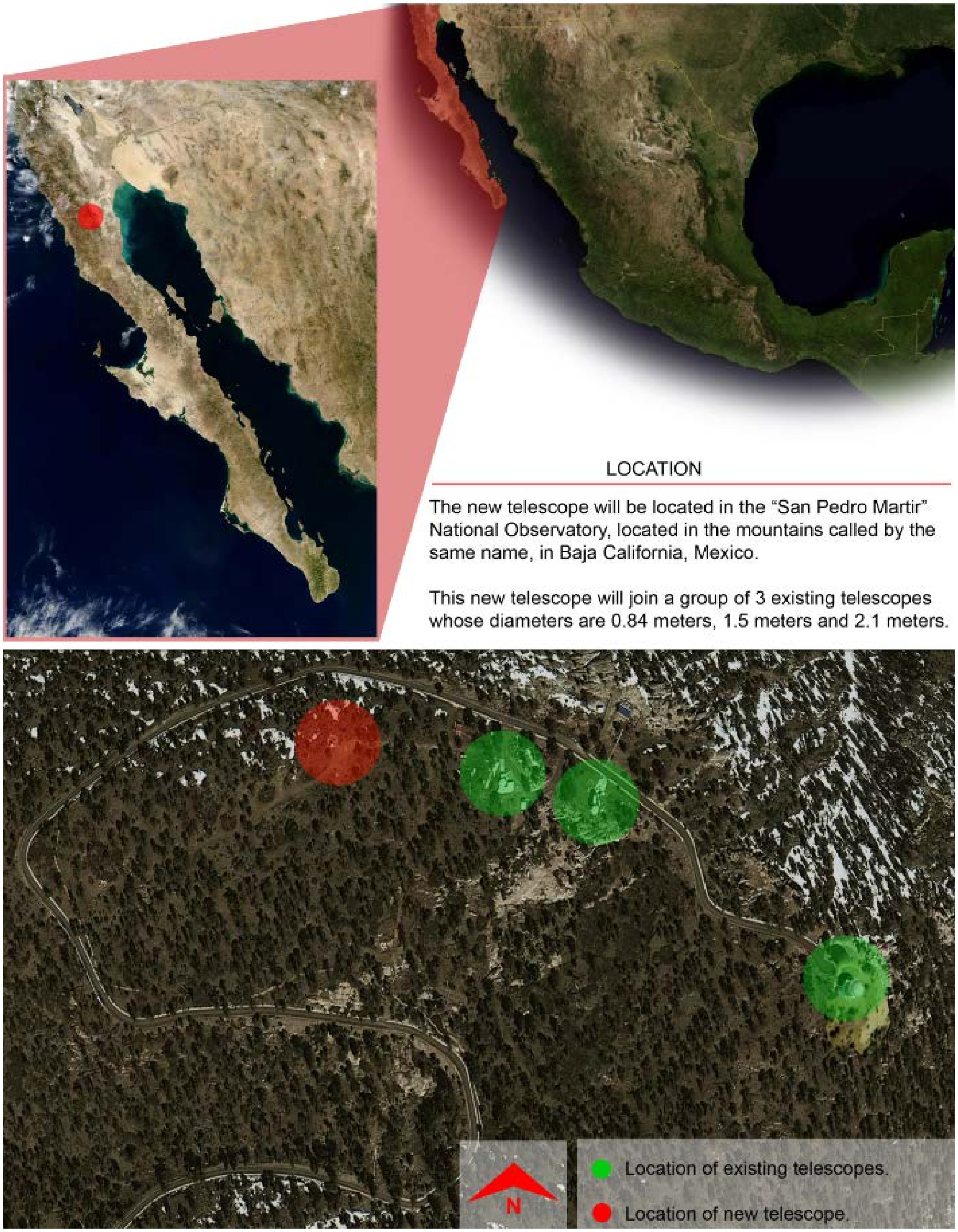
The Institute of Astronomy of the Universidad Nacional Autónoma de México, in partnership with the Mexican astronomical community, led by the Instituto Nacional de Astronomía, Óptica y Electrónica (INAOE) and in collaboration with the University of Arizona and the Smithsonian Astrophysical Observatory, will be constructing a 6.5m diameter telescope to be located at the National Astronomical Observatory of San Pedro Martir, Baja California within the Sierra de San Pedro Martir National Park. The telescope and facilities will be similar to the Magellan Observatory located at Las Campanas, Chile. Based on the Magellan Observatory, and other project specific functional requirements, M3 Engineering and Technology Corporation (M3) has provided a Preliminary Design study for the Telescopio San Pedro Martir (TSPM).

2 TELESCOPIO SAN PEDRO MARTIR OVERVIEW

2.1 LOCATION

The TSPM will be located at the Sierra de San Pedro Martir National Park in Baja California, Mexico, in the geographic coordinates of latitude 31° 02’ 43.15” North, Longitude 115° 28’ 10.16” West. It has an average elevation on site of 2,830 m. above sea level, at around 65 km west to the Pacific Ocean and at 55km East of the Sea of Cortes (Gulf of California). The ground rises gently from North, West, and South, with a peak that rises higher than 2,000 m. from the desert to the East. The highest point of the area, and actually in Baja California, is Picacho del Diablo (3,095 m), located approximately at 6 km south-west of such observatory. The area is located within the interior of a pine tree forest. Most of the area comes with a strong number of rainfall events with clear intervals between. The closest location is Ensenada (300,000 inhabitants) at a 4 hour drive and at 140km in a straight line. The closest commercial airports are located in Tijuana (at 220 km) and San Diego (250km). There is a paved road leading to the observatory, at 20km approximately from the National Park’s entrance.

Shown on Figure 2.1.1 is the proposed location for the development of the TSPM, as well as the associated infrastructure of the currently operating telescopes in the area.



LOCATION

The new telescope will be located in the “San Pedro Martir” National Observatory, located in the mountains called by the same name, in Baja California, Mexico.

This new telescope will join a group of 3 existing telescopes whose diameters are 0.84 meters, 1.5 meters and 2.1 meters.

Figure 2.1.1 Location

2.2 SITE CONDITIONS

San Pedro Mártir shows the following geotechnical and environmental characteristics. Furthermore, some data is expressed in survival conditions terms and/or operational conditions, given that regardless of the environmental condition (of survival) on site, it is needed to design based on the most stringent condition:

Environmental Conditions for the TSPM	
Elevation	2830m
Latitude; Longitude	31º 02’ 43.15” N; 115º 28’ 10.16” W
Mean Temperature	~8°C
Atmospheric Pressure	730 mbar (mean); 710-740 mbar
Relative Humidity	54% (mean); <5% to 100%
Mean Wind Speed	13 km/h
Dominant Wind Direction	Southwest to Northeast
Maximum Temperature Range	-25°C to 35°C
Day-Night Gradient	<6°C
Operating Temperature Range	-2°C to +18°C (goal -5ºC to 18ºC)
Operating Temperature Range with degraded performance	-18°C to +30°C
Operating Relative Humidity	<90%, or at condensation point
Operating Wind Speed	50 km/h (98% of the time); 60 km/h (max)
Operating Gusts	70 km/h (95% of the time); 80 km/h (max)
Maximum Recorded Wind Speed	120 km/h
Survival Wind Speed	177 km/h
Snow Load	400 kg/m^2
Ice Load	91.7 kg/m^2
Maximum Rain Precipitation	300 mm in 24 hours and 120 mm in 1 hour
Earthquake Accelerations	Seismic Design Category D
	S_S = 0.855g
	S_{DS} = 0.57g
	S_1 = 0.495g
	S_{D1} = 0.33g
	Soil Site Class B
Dust	Sporadic Suspended Dust
Electric Storms	Occasional

2.3 BUILDING CODES

The San Pedro Mártir Telescope (Baja California, México) shall consider on its design, the applicable guidelines of the following national and international references:

- International Building Code, 2006 Edition

- Occupational Safety and Health Administration (OSHA)
- International Plumbing Code, 2006 Edition
- International Mechanical Code, 2006 Edition
- National Fire Protection Association Codes and standards
- International Energy Conservation Code, 2006 Edition
- National Electrical Code, 2008 Edition
- Normas Oficiales Mexicanas (NOM)
- Ley de Edificaciones del Estado de Baja California
- Instituto Mexicano del Seguro Social (IMSS)
- Secretaría del Trabajo y Previsión Social (STPS)
- Comisión Federal de Electricidad

3 CRITICAL DESIGN

3.1 DRIVING DESIGN REQUIREMENTS

The following requirements drive the overall design of the TSPM.

Telescope and Enclosure	
Elevation Axis	12.0m above grade
Observing Level Elevation	6.5m above grade
Telescope Swept Radius	8.8m
Telescope Swept Radius (with clearance)	9.8m (1.0m clearance)
Telescope Swept Aperture	6.5m
Telescope Swept Aperture (with clearance)	8.0m (0.75m clearance each side)
Telescope Primary Mirror Diameter	6.5m
Telescope Viewing Angles	18.0 deg to zenith
Telescope Rotation within Enclosure	Independently rotating telescope
Telescope Rotating Mass	194.6 tons
Telescope Pier	
Outer Pier Height	4.66m above grade
Inner Pier Height	5.2m above grade
Outer Pier Diameter	10.4m
Inner Pier Diameter	4.3m
Outer and Inner Pier Thickness	0.9m

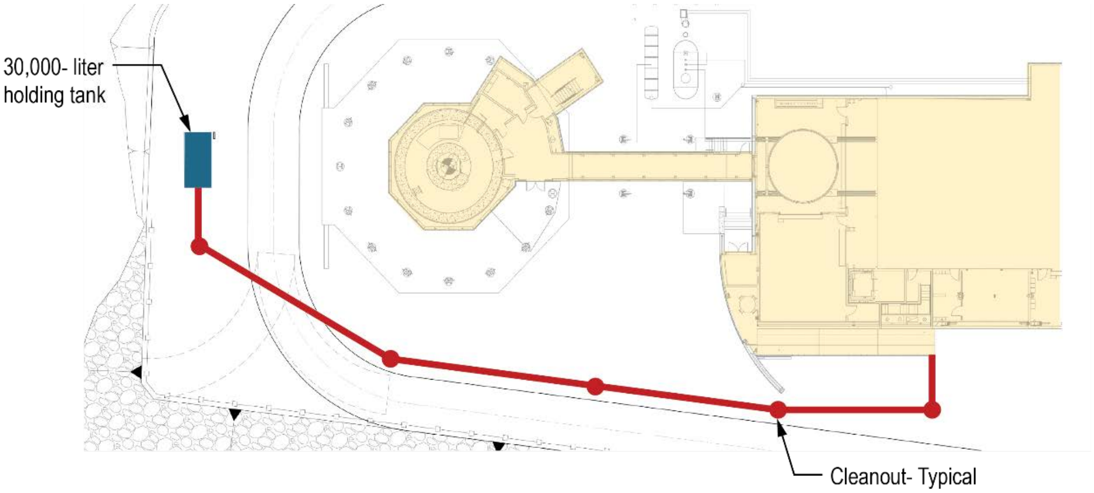
3.2 Figure Site Plan

3.3 CIVIL

The civil design for the TSPM project site includes earthwork, access road and drainage improvements as necessary for the development of the telescope site. The project has been surveyed and is based on ITRF-08 EPOCA 2010.0, UTM ZONE 11 datum. The finish floor elevation (FFE) for the Telescope enclosure is set at an elevation of 2794.0 meters. The Summit Support Building, lower level, is set at an FFE of 2795.0 meters and the Summit Support Building, upper level is set at an FFE of 2800.5 meters. These elevations result in earthworks mostly in cut. The telescope pier will be located on a cut section of the pad. The Summit Support Building, lower level, will be located entirely on cut to provide construction access between buildings. The Summit Support Building, upper level, will be located on cut and fill with the entire east side of the building in fill. A minimum slope of 5% is recommended away from all structures to provide positive drainage. Earthwork estimates are based on 1.5H:1V slope for cut and 2H:1V slope which meet or exceed geotechnical recommendations. Earthwork quantities for the telescope site include a cut estimate of 14,336 cubic meters, fill of 10,580 cubic meters for a total net export of 3,756 cubic meters. Structural-engineered fill is required in any locations where fill is necessary. This fill shall be compacted to 95% maximum modified dry density. Native angular rock rip rap will be added to all fill slopes to control erosion. A earthworks stockpile site will be determined at a later point in the design and will be utilized as required. A drainage study was conducted to analyse the on-site runoff created by the 100-year design storms during the post-development condition. The on-site watersheds were analysed using the methods outlined in the NOM M-PRY-CAR-1-06-003-00 and M-PRY-CAR-06-004-00 documents found on the Secretaria de Comunicaciones y Transportes (SCT) website. The NOMs listed utilize the Rational Method which is the method employed to design the required drainage swales for the project. A new access road will be required to reach the project site. The new access road will connect to the existing road location. A perpendicular intersection will be constructed to provide a safe intersection for access. Guard rails and reflectors shall be installed as deemed necessary. The proposed road will be paved for the first portion of roadway but will transition to gravel near the support building pad. The roadway will be a five meter wide one way access road to provide safe travel for the largest expected vehicles. The road design will also include positive drainage away from the road. The turning radii used will accommodate a WB-40 semi-truck and a 100-metric tonne crane.

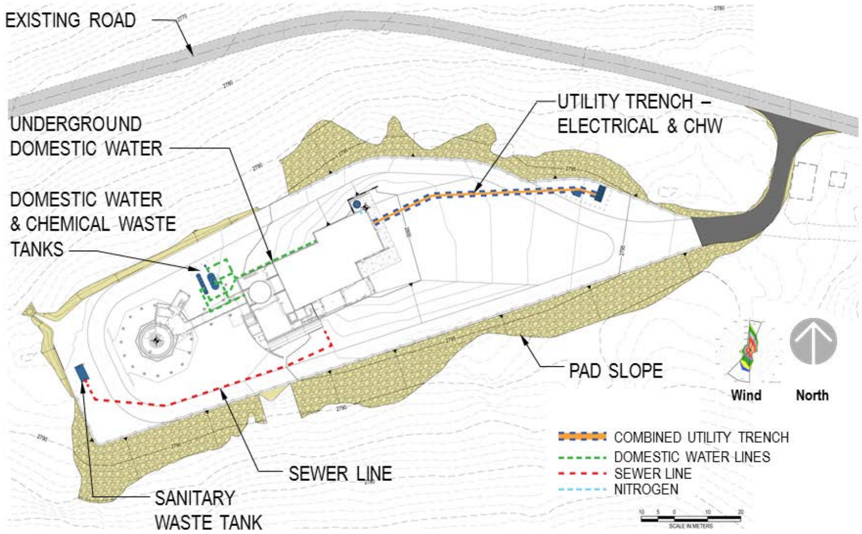
3.3.1 SEWER

The TSPM Base Camp site has access to a sewage pump truck. Therefore, current plans for the TSPM site include a sanitary waste holding tank to be pumped out by the Base Operations Support Contractor.

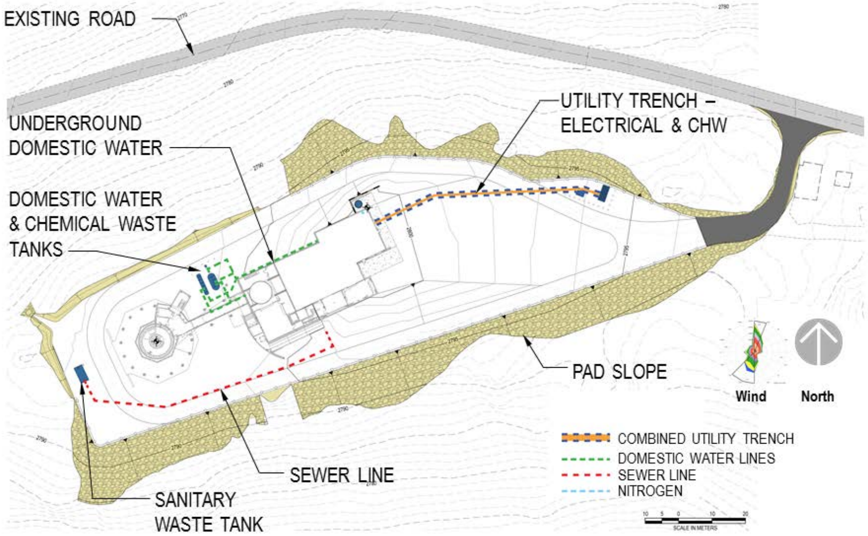


3.3.2 SITE UTILITIES

The site utilities have been coordinated to have a common trench from the remote transformer and chiller area to the support building. The chemical waste and domestic water tank have also been set adjacent to each other to allow for a common trench to simplify excavation.

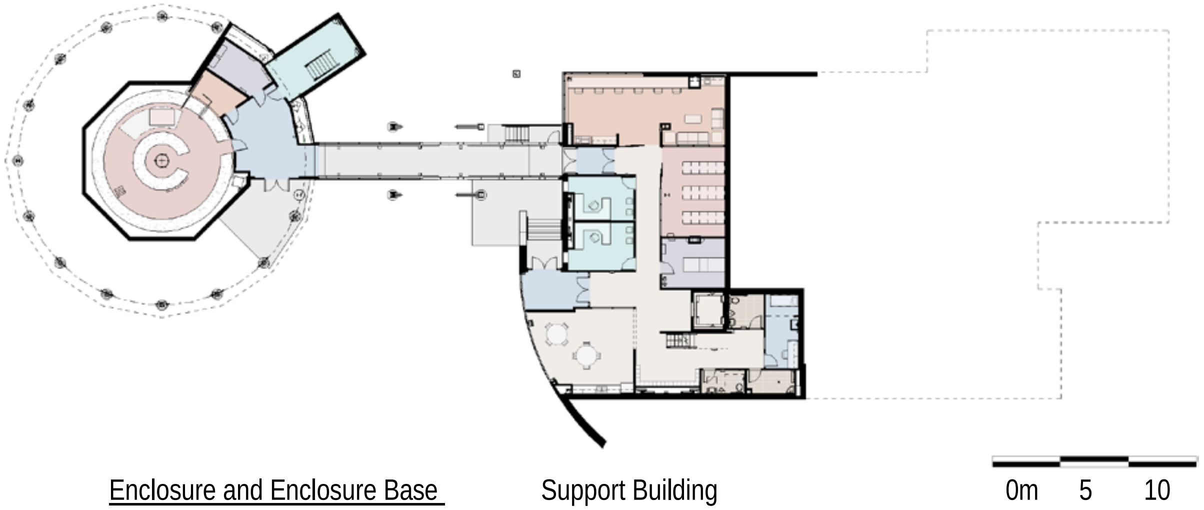


3.3.3 SITE PLAN



3.4 BUILDING LAYOUT

The Telescopio San Pedro Mártir Observatory is integrated by two distinguishable building volumes: Enclosure Building and Support Building. The Enclosure Building houses the telescope, telescope pier and Spectrograph room, while the Support building caters to telescope related activities, utilities infrastructure and personnel related functions. The two buildings are connected by a bridge that allows for mirror handling, and by an enclosed corridor for both personnel access and utilities.



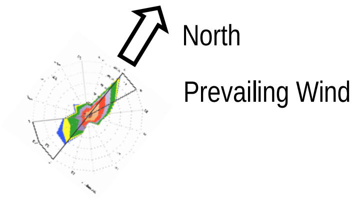


Figure 3.4.1 - Overall Floor Plan – Lower Level

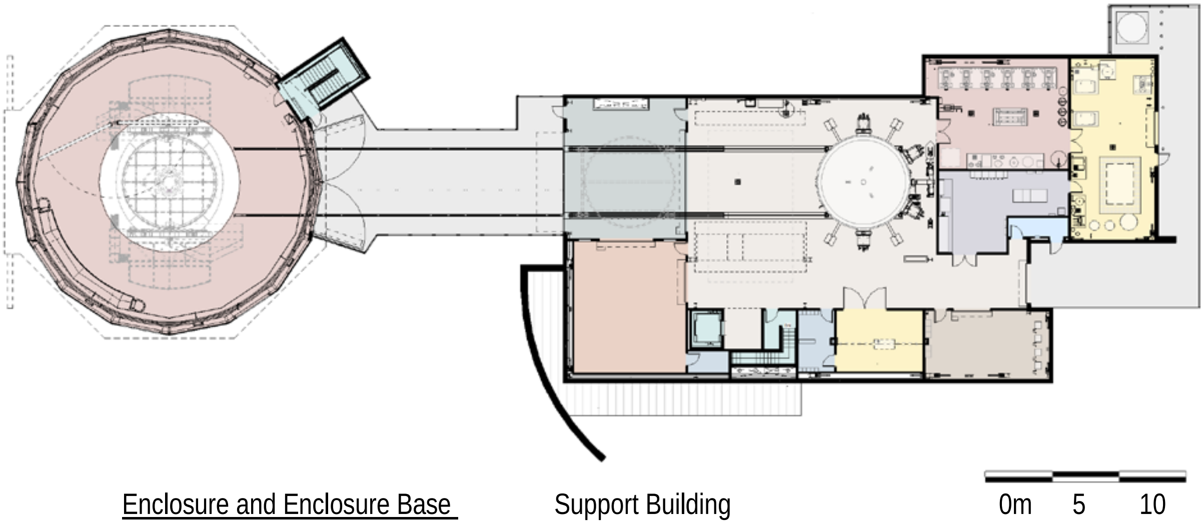


Figure 3.4.2 - Overall Floor Plan – Upper Level

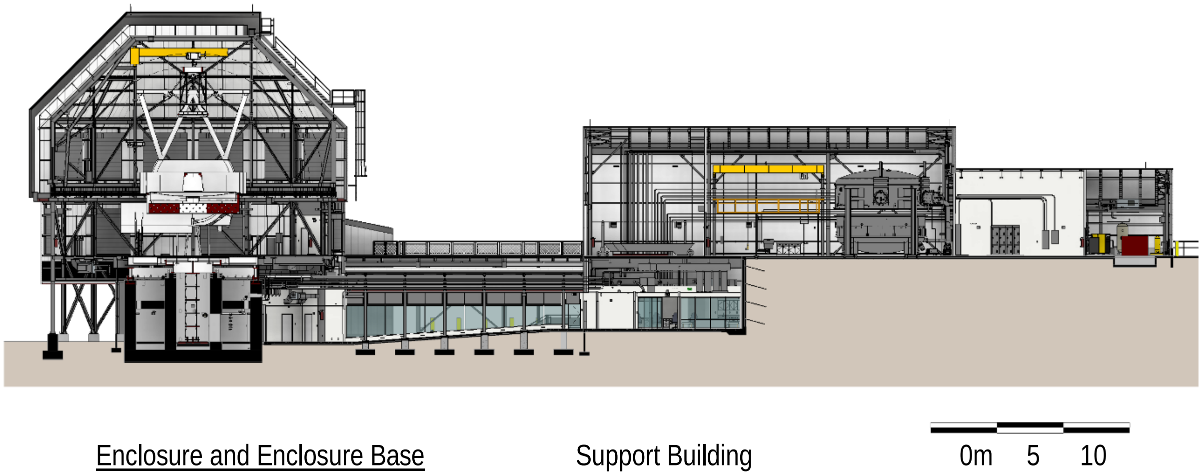


Figure 3.4.3 - Overall Building Section

3.4.1 ENCLOSURE AND ENCLOSURE BASE

The Enclosure houses the 6.5 meter TSPM telescope. In the closed position, the Enclosure protects the telescope and its instruments against adverse weather conditions. In the open position, the Enclosure allows the telescope a free field view by means of a large slit in the Enclosure. Also in this position, the Enclosure provides wind protection, ventilation, and air circulation to create optimum observing conditions for nighttime astronomical observations. The Enclosure is connected to the Support Building through the use of embedded floor rails on the observing floor. These rails allow the mirror to be transported to the Support Building for washing and aluminizing. Between these rails the floor structure is designed to allow instruments with a maximum total weight of 9 metric tonnes to be transported to and from the Support Building.

Equipment at the Enclosure includes a jib crane, framing to support a 1 ton hoist, and a secondary mirror access platform. The 5-metric tonne jib crane is located near the top of the Enclosure and is utilized to lift heavy equipment onto the observing floor or the telescope. See figures 3.4.9 and 3.4.10 for jib crane access limits. See figure 3.4.11 for 1 ton hoist coverage.

The Enclosure Base serves as a foundation and stationary floor for the rotating Enclosure. Along with providing a stationary floor at the observing level, multiple functions are provided at grade level. These functions include a Storage Room, Entrance Lobby, Electrical, and vertical circulation. M3 has provided space for future Spectrograph room. The future Spectrograph Room space has been planned to accommodate future large instruments, which are currently modeled as Hectospec and Hectochelle. There will also be a future fan coil to support this space.

Materials used for the construction of the TSPM have been chosen for their performance as well as their availability in Mexico. The Enclosure and Enclosure Base are clad with insulated metal wall panels which provide thermal performance and moisture control. The panels consist of a galvanized steel face with polyisocyanurate foam-insulated core. The rotating portion of the Enclosure is faced with adhesive aluminum foil tape, which allows for the optimization of the thermal characteristics of the Enclosure, and minimizes emissivity.

Architectural seals are provided between stationary and moving building components. The main function of seals is to protect the interior environment from a wide range of environmental conditions such as water, air, light, and dust. Seals are positioned for ease of adjustment, maintenance, and replacement. Two layers of seals will be provided. The first seal stops high wind, light and most precipitation from entering the building. The second seal keeps out moisture.

Utility coordination at Telescope Pier area and Support building demostrates the overall systems coordination which includes compressed air, hydrostatic bearing oil (by others), helium, supply and return water lines, electrical, communications, and mechanical ductwork. Refer to figure 3.4.12 and 3.4.13 at Pier and figures 3.4.14 and 3.4.15 for Enclosure Access Corridor and Support Building coordination.

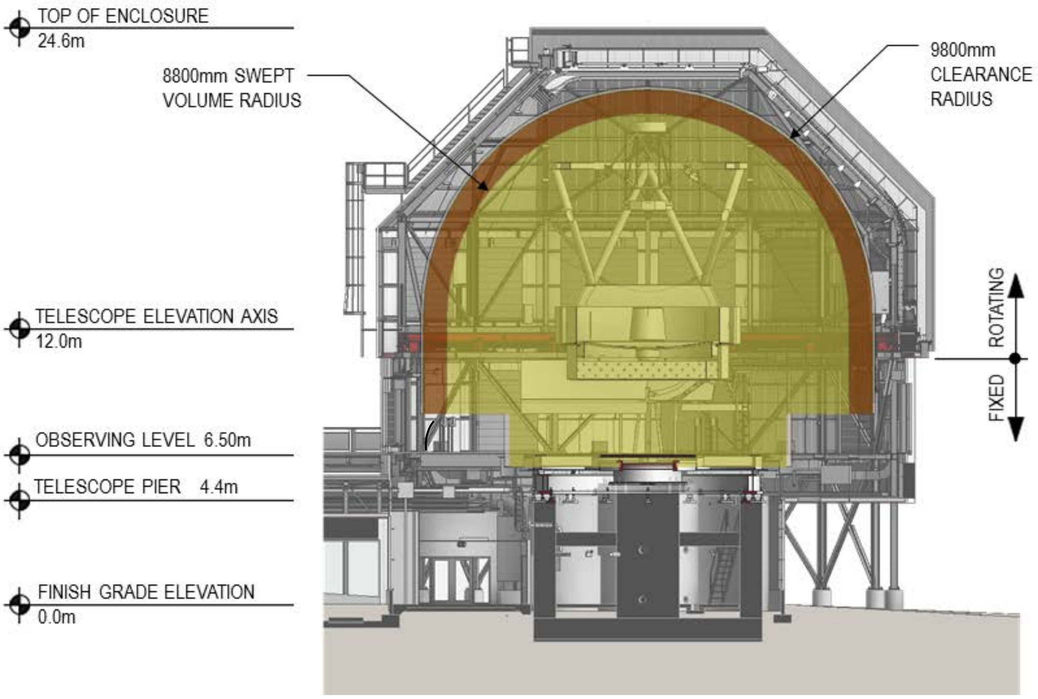


Figure 3.4.4 - Enclosure and Enclosure Base Section (1)

0m 2.5 5

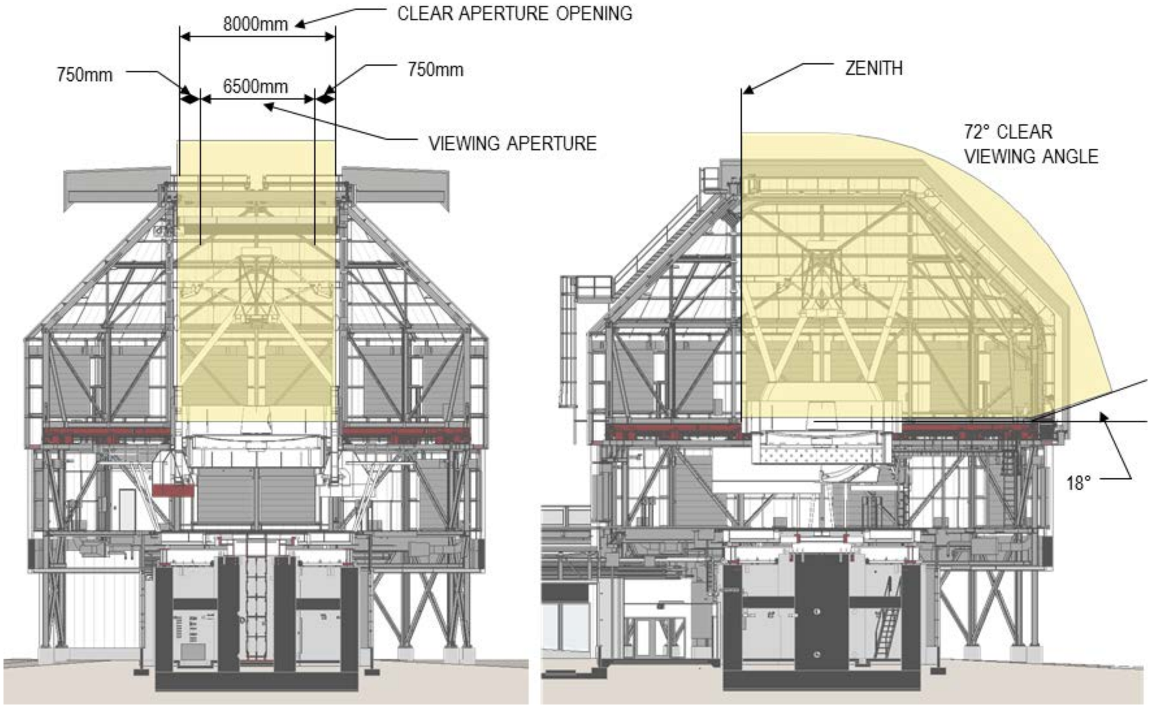


Figure 3.4.5 - Enclosure and Enclosure Base Section (2)

0m 2.5 5

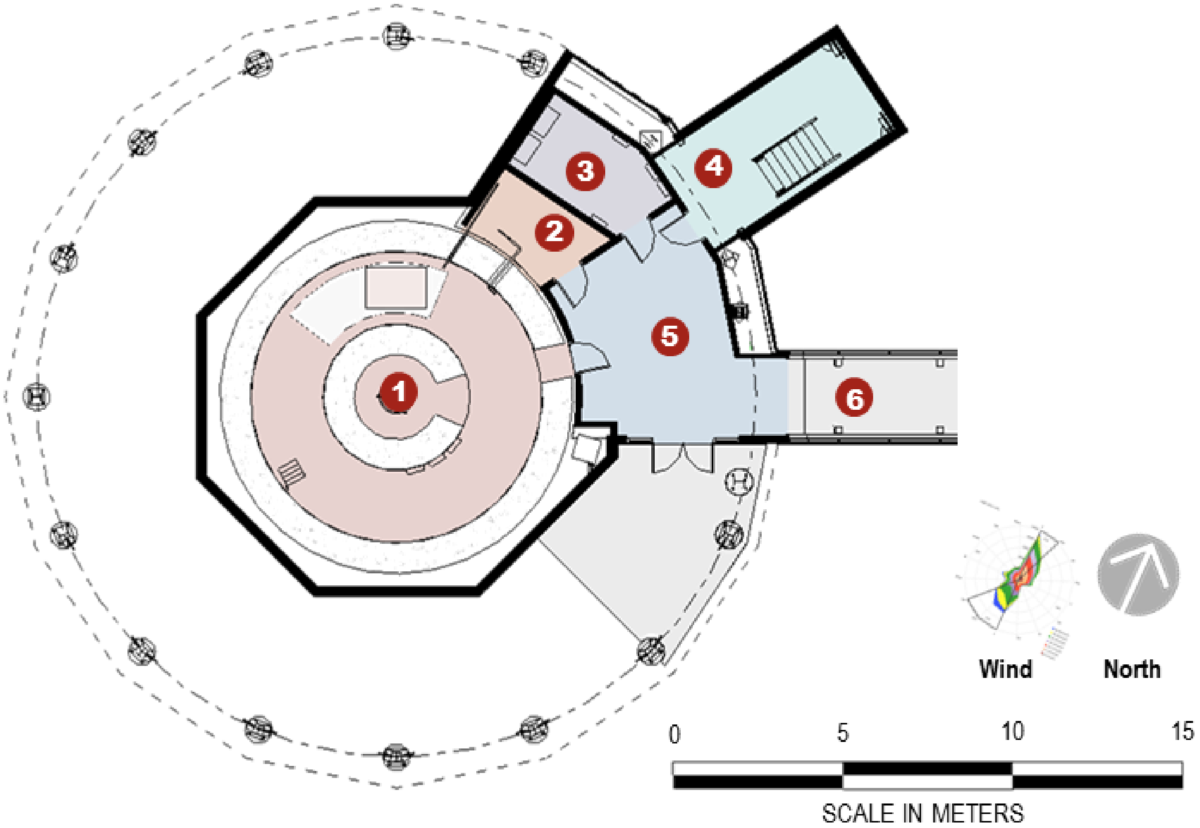


Figure 3.4.6 - Enclosure Floor Plan – Ground Level

1	Pier	5	Entrance Lobby
2	Storage	6	Enclosure Access Corridor
3	Electrical		
4	Stairs		

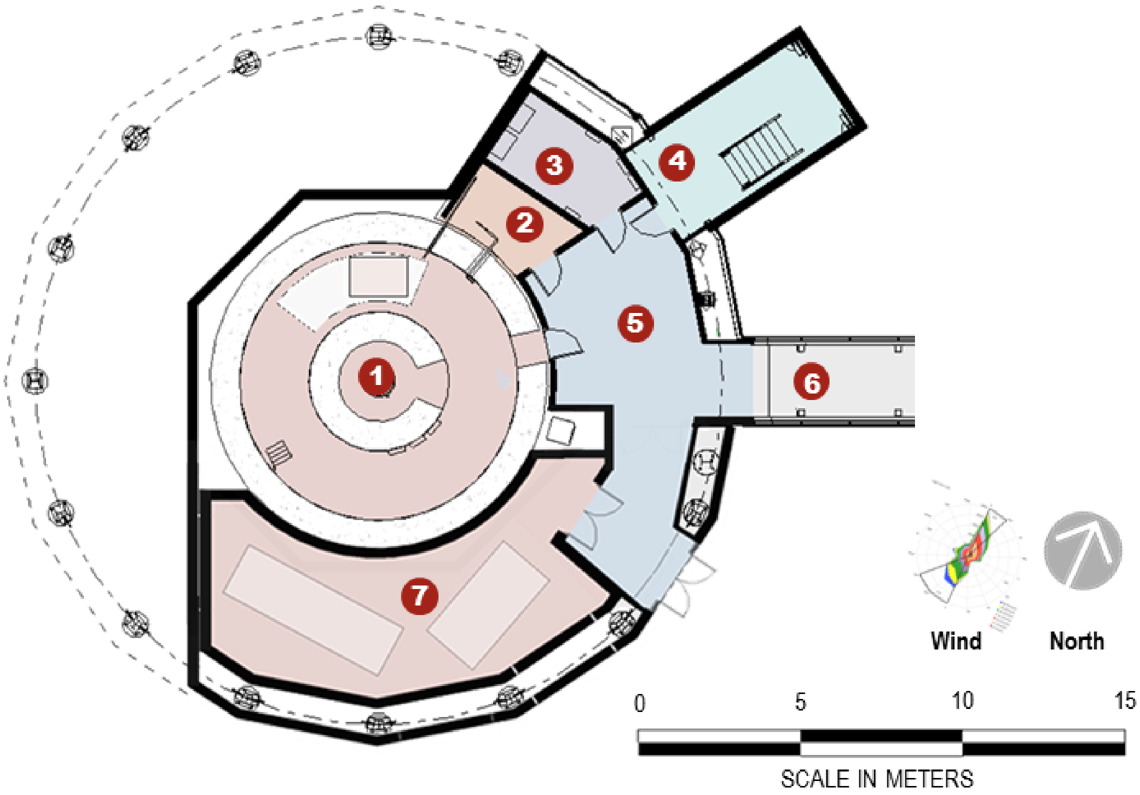
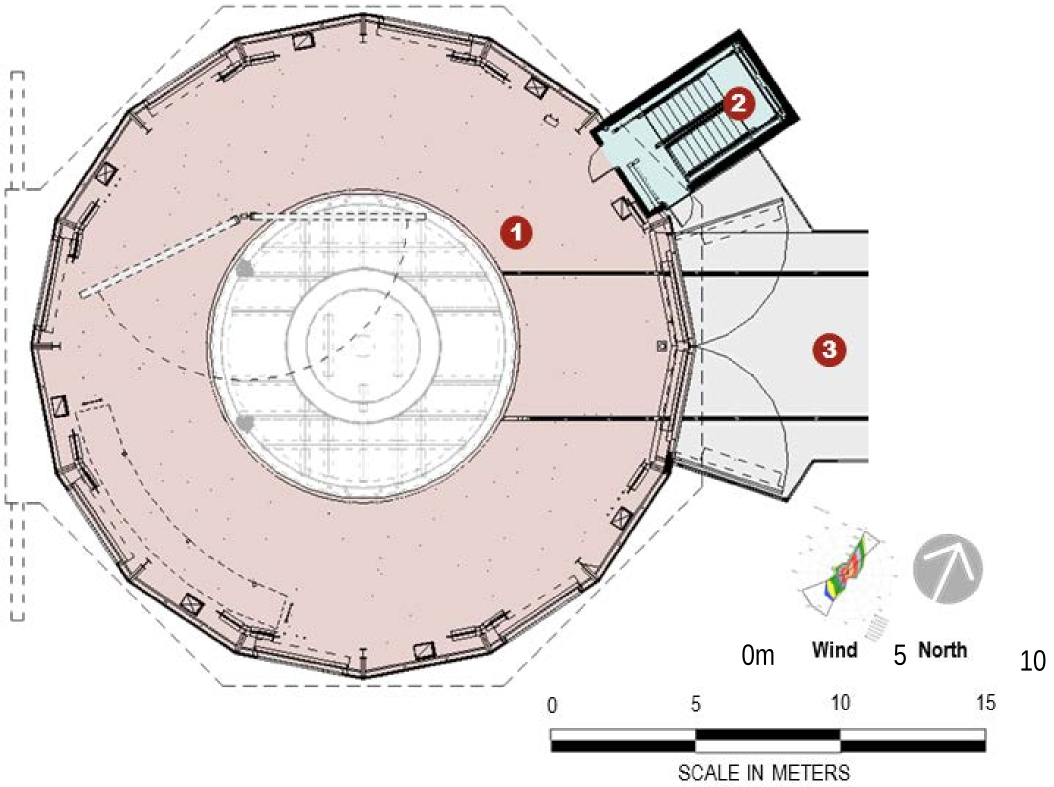


Figure 3.4.7 - Enclosure Floor Plan – Ground Level (with Future Spectrograph Room Buildout)

1	Pier	5	Entrance Lobby
2	Storage	6	Enclosure Access Corridor
3	Electrical	7	Future Spectrograph Room
4	Stairs		



1	Stationary Observing Level Floor		
2	Stairs		
3	Mirror Cart Bridge		

Figure 3.4.8 - Enclosure Floor Plan – Observing Level

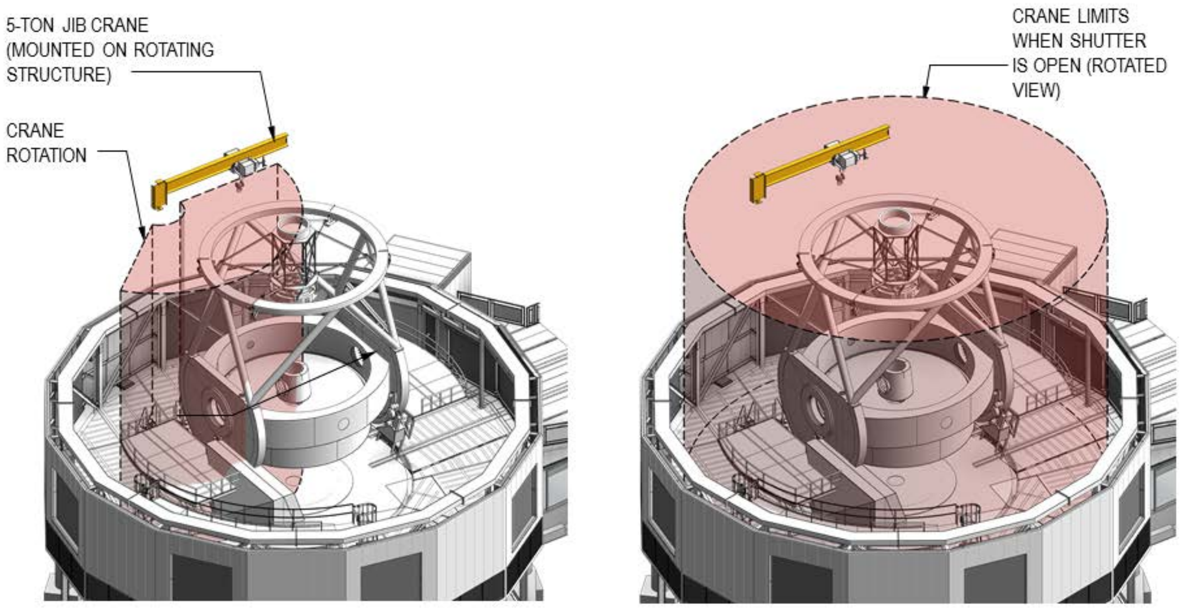


Figure 3.4.9 – 5 metric tonne jib crane at Enclosure (Shutter Open)

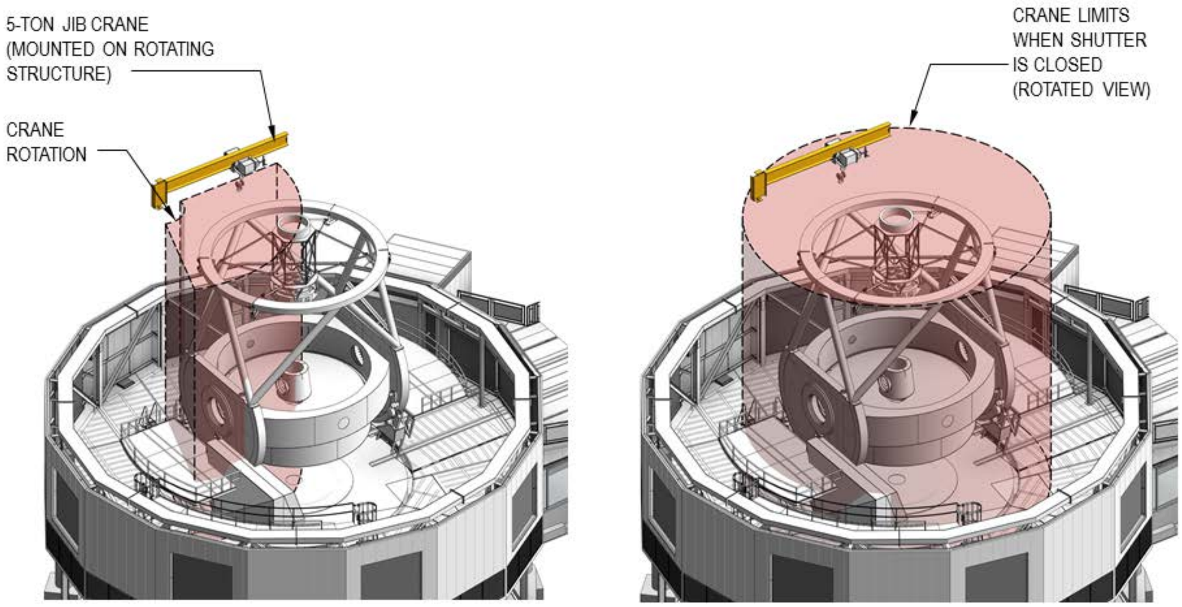


Figure 3.4.10 – 5 metric tonne jib crane at Enclosure (Shutter Closed)

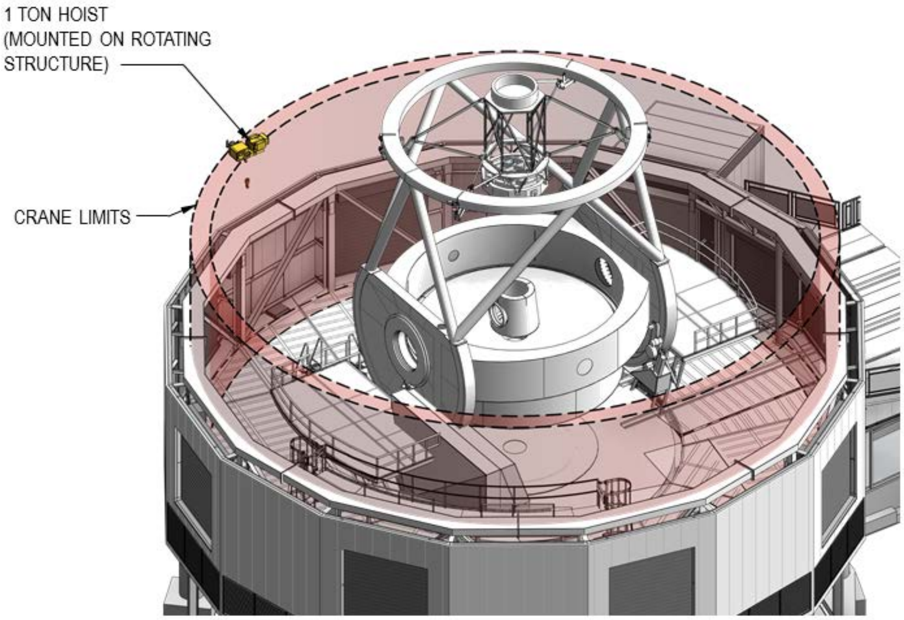


Figure 3.4.11 – 5 metric tonne jib crane at Enclosure (Shutter Closed)

Crane Summary

Location	Crane Requirement	Actual Equipment Provided	Vendor Basis of Design
Enclosure	5 metric tonne jib crane	6 US ton (5.44 metric tonne)	Konecranes
Support Building	27 metric tonne bridge crane	29.8 US ton (27.03 metric tonne)	Konecranes
Location	4 metric tonne monorail	5 US ton (4.53 metric tonne)	Konecranes

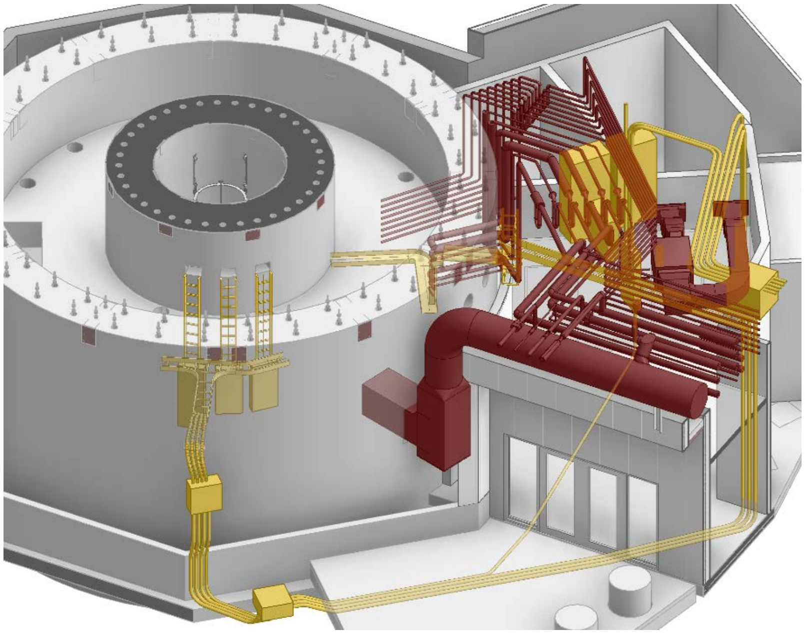


Figure 3.4.12 – Pier Utilities Coordination Isometric

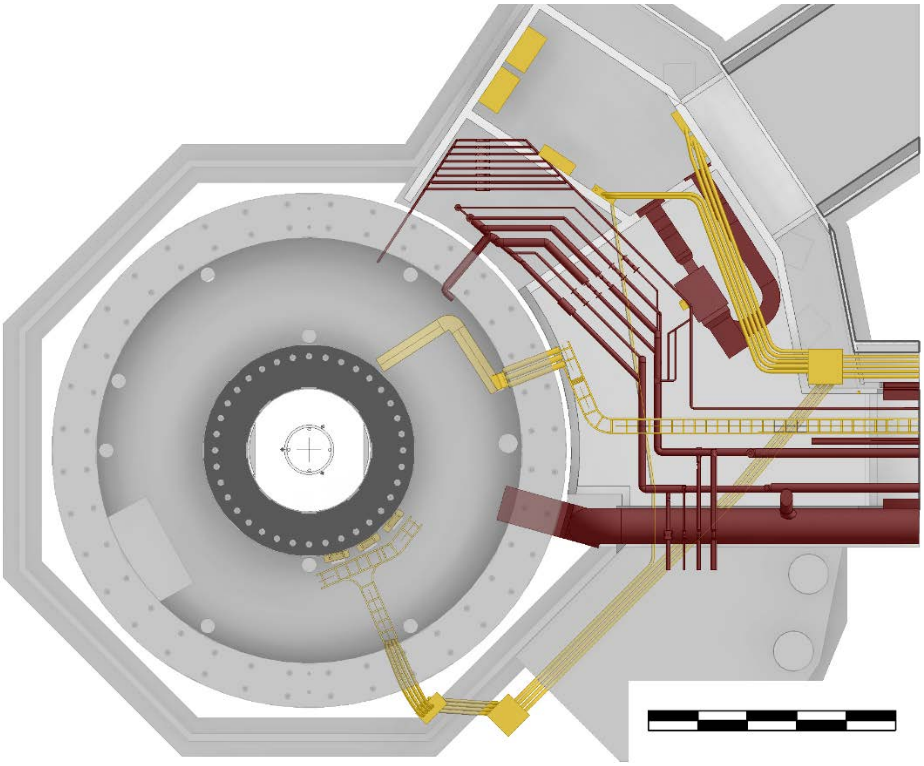


Figure 3.4.13 – Pier Utilities Coordination Plan

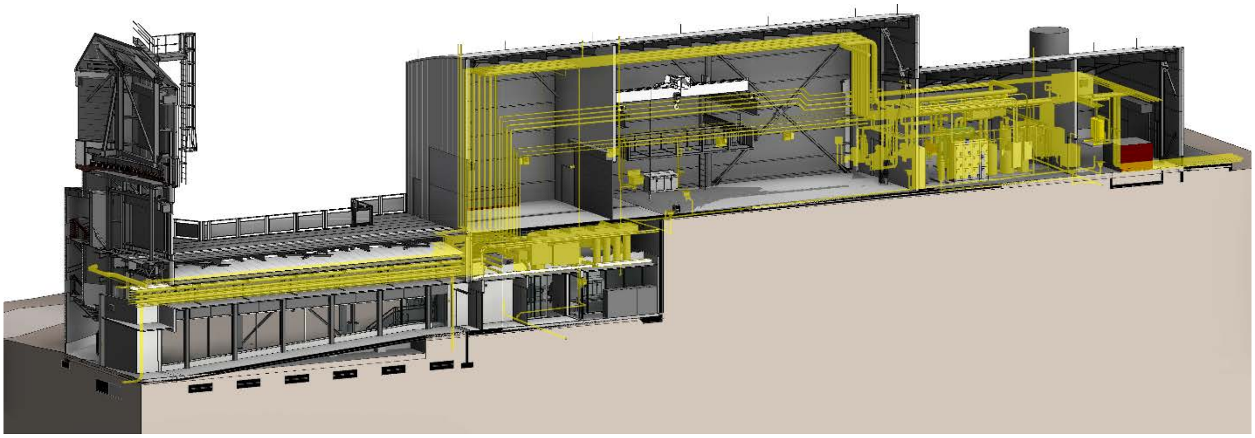


Figure 3.4.14 – Utilities Coordination Isometric- Enclosure to Support Building

Figure 3.4.15 – Utilities at Enclosure Access Corridor

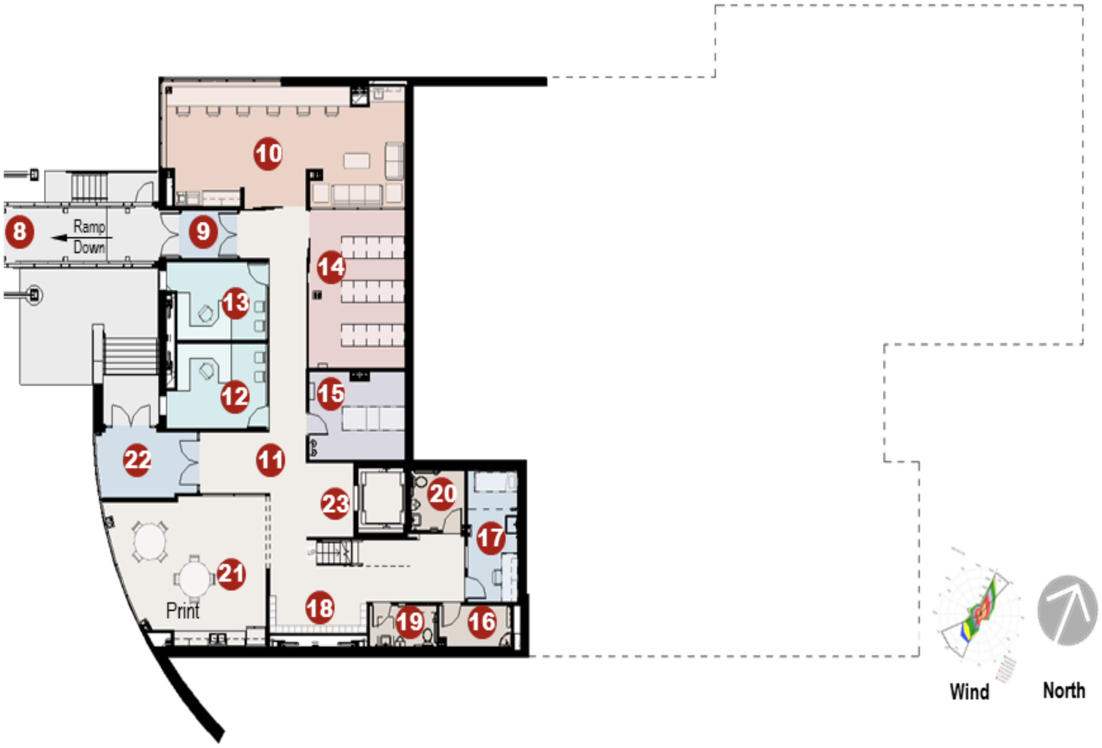
3.4.2 SUPPORT BUILDING

The support building houses telescope related activities, utilities infrastructure, and personnel related functions and is located adjacent to, and crosswind from, the enclosure. Telescope related activities and the utilities infrastructure are located on the upper level, while personnel spaces are located on the lower level. The support building is connected to the enclosure via the utilization of a bridge with floor rails for the transportation of mirror as well as instruments up to 9 metric tonnes at the upper level. An enclosed walkway, below the bridge, is also provided for the movement of personnel on the lower level. The support building can be divided into three categories to better understand the functional and space requirements. The three categories are as follows: (1) Telescope Related Activities, (2) Utilities Infrastructure, and (3) Personnel Related Functions.

Telescope related activities are housed on the upper level of the support building. This level shares the same elevation as the enclosure observing level. This facilitates the movement of mirror cells and instruments between the two buildings via a pair of embedded floor rails. Three large bays are provided for mirror related purposes: vestibule, mirror washing, mirror coating. An instrument storage designated space is also provided. The first bay is a vestibule for the mirror. The second bay is for mirror washing, and will provide space for a traveling wash platform above. A third bay is for mirror coating, and provides for the permanent placement of a high vacuum sputtering system. The coating chamber shall be used for all mirrors including primary, secondaries, and tertiary. This system is used to deposit high-reflectance aluminum films on the primary and secondary mirrors. An adjacent room to the mirror vestibule provides a space for instrument storage. A clean room, with vestibule, is also provided adjacent to this bay. To support the washing and coating activities, a dedicated room is provided to house equipment and controls for these activities.

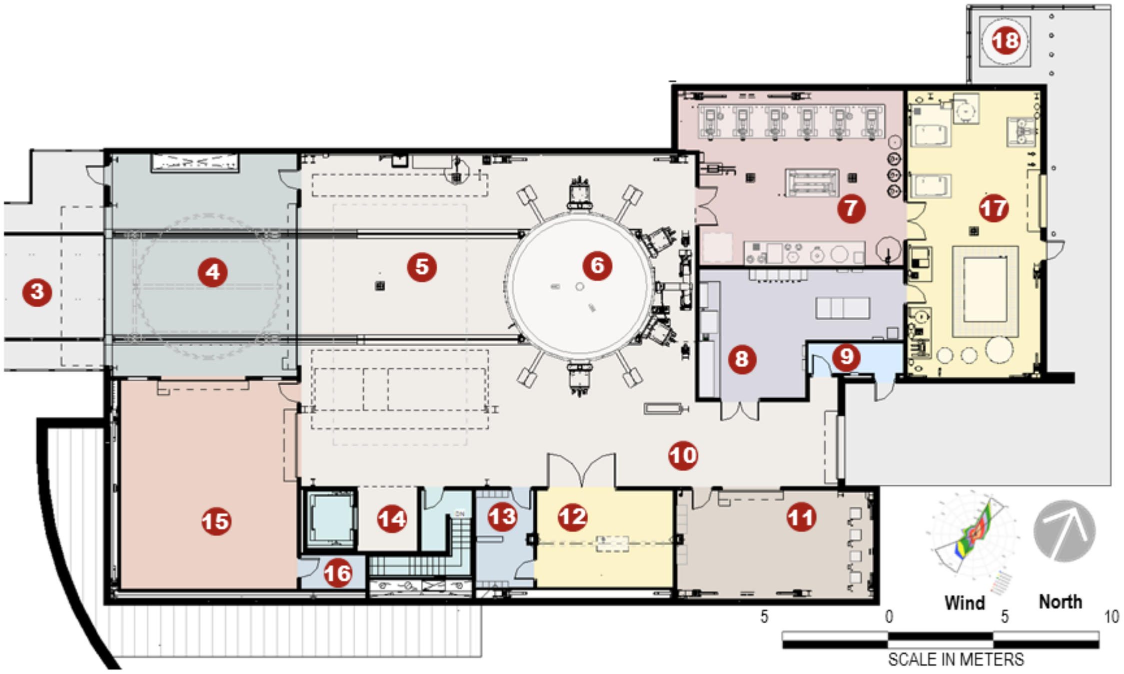
The utilities infrastructure for the entire site is located on the upper level of the support building. Dedicated rooms are provided for telescope and Owner furnished equipment, mechanical equipment, and electrical equipment. These spaces are located as far as possible from the Enclosure to reduce heat and vibration that would be detrimental to telescope operations. Ancillary space is also provided for tool storage, and miscellaneous storage. Exterior to the utility spaces, and further downwind, is the exterior mechanical and electrical equipment yard. This includes the utility transformer (by owner), and the chiller.

Personnel related functions are housed on the lower level of the support building. These spaces are those frequently occupied by TSPM staff and astronomers. A control room with countertop space is provided near the entrance to the facility, and provides windows for views directly to the enclosure and an observer's lounge. Supporting the control room is the computer room. The computer room will store the astronomers' data and will host all control system server equipment. The computer room will be provided with an independent cooling system specifically designed to promote air movement around the computer racks. The space will be designed with maximum flexibility to allow ease of expansion and future modifications. Observers will also have a dedicated break room with a small kitchenette and tables for eating and/or conference functions. Two private offices will be provided along with other ancillary spaces such as a first aid room, toilets, IT room, and a janitor's closet. Vertical circulation to the upper level of the support building is provided via stairs and an elevator. Access to the enclosure is provided through an enclosed walkway that provides personnel with a protected space to move between the two buildings in the event of a storm or detrimental weather conditions.



8	Enclosure Connecting Corridor	16	Janitor
9	Vestibule	17	First Aid Room
10	Control Room	18	Lockers
11	Hall	19	Toilet
12	Office	20	Toilet
13	Office	21	Break Room
14	Computer Room	22	Vestibule
15	IT Room	23	Stairs/ Elevator

Figure - Support Building Enlarged Floor Plan – Lower Level



3	Mirror Cart Bridge	11	TSPM Equipment Room
4	Vestibule	12	Clean Room
5	Mirror Washing	13	Clean Room Vestibule
6	Mirror Coating	14	Elevator Vestibule
7	Mechanical / Coating Equipment	15	Instrument Storage
8	Electrical	16	Storage
9	Vestibule	17	HSB Chamber Room
10	Corridor	18	Nitrogen Tank

Figure - Support Building Enlarged Floor Plan – Upper Level

3.4.2.1 Support Building Area Tabulations

Telescope Related Activities	
Mirror Washing	113 m^2
Mirror Coating	116 m^2
Mirror Vestibule	93 m^2
Instrument Storage	83 m^2
Clean Room and Vestibule	42 m^2
Washing and Coating Equipment (combined with mechanical room in Utilities infrastructure below)	83 m^2
HSB Chamber Room	86 m^2
Total Net Area	*616 m^2*

Utilities Infrastructure	
TSPM Equipment Room	47 m^2
Mechanical Room (combined with Washing and Coating Equipment room)	83 m^2
Electrical Room	46 m^2
Tool Storage	5 m^2
Total Net Area	*181 m^2*

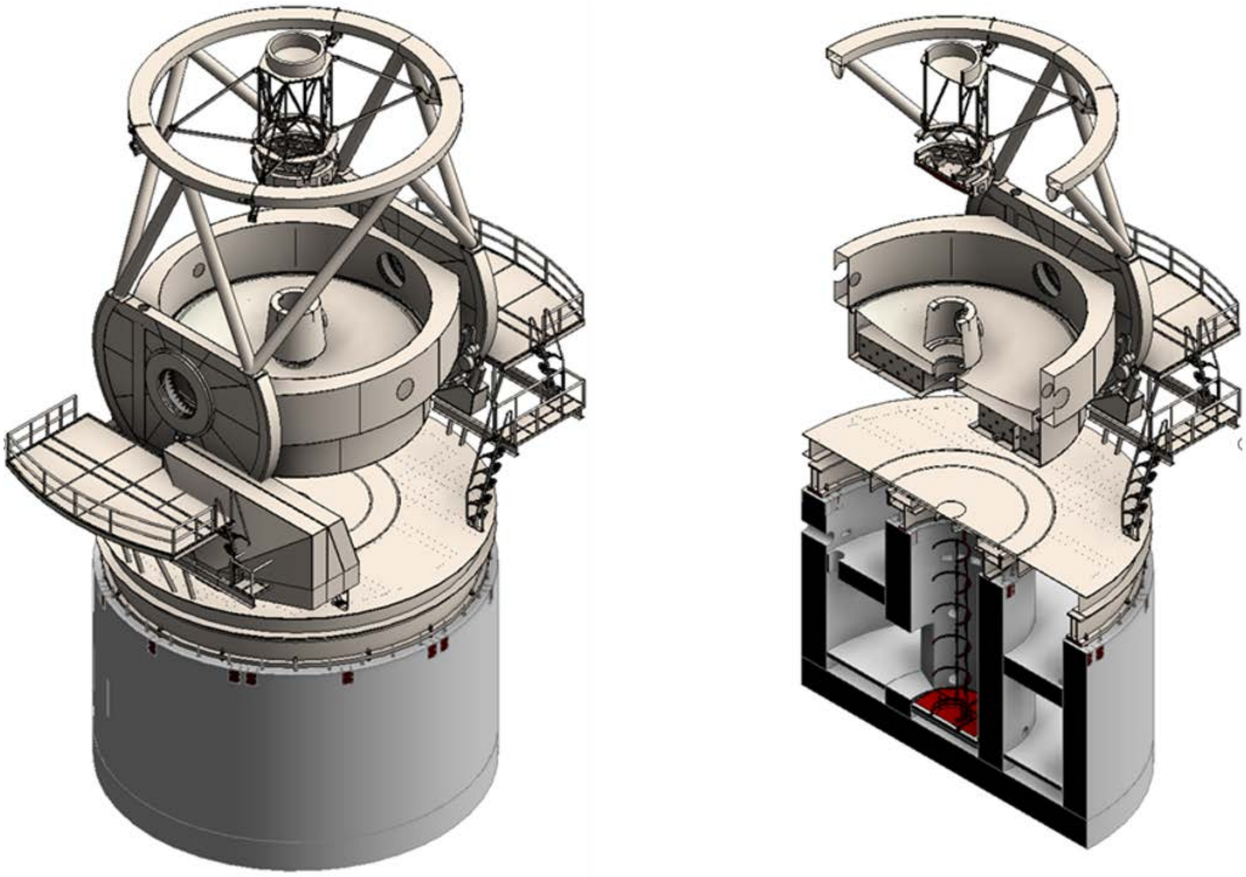
Personnel Related Functions	
Control Room w/ Observer's Lounge	55 m^2
Computer Room	31 m^2
Personnel Offices (2)	31 m^2
Lockers	7 m^2
First Aid Room	13 m^2
Toilets (2)	12 m^2
Janitor's Closet	6 m^2
Break Room	41 m^2
UPS / I.T. Room	17 m^2
Vestibule (from Grade)	13 m^2
Total Net Area	*226 m^2*

Support Building Total Area Calculations	
Total Net Area of Building	*1,003 m^2*
Total Gross Area of Building	1,263 m^2

3.5 TELESCOPE PIER

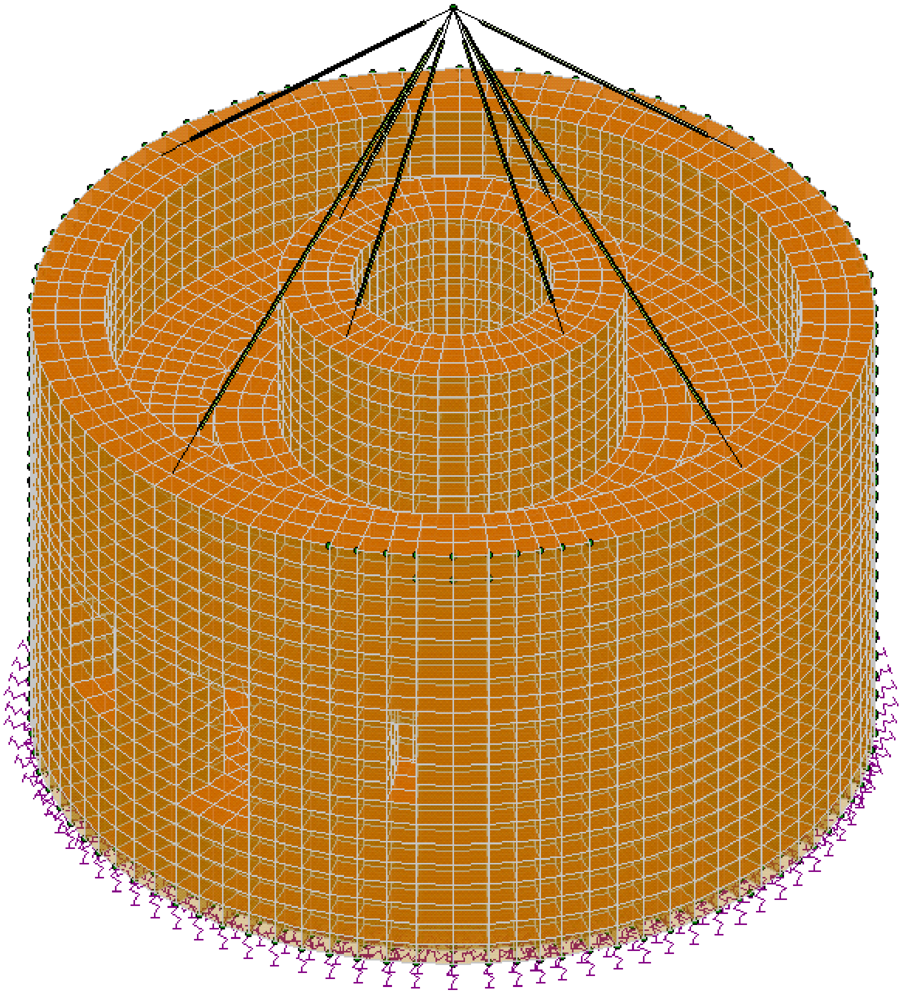
The Telescope Pier is a cylindrical concrete structure that supports the Telescope vertically and laterally. The Telescope Pier is composed of two concentric walls, a horizontal elevated slab, mat foundation and a slab on grade to define the finished floor. The exterior wall provides support for the vertical reactions from the Telescope through the Azimuth Track and, the interior wall provides lateral support of the Telescope against Seismic forces. In addition, the Telescope Pier provides access to the Telescope bearings as well as instrumentation and is a vital part in the maintenance operations' access.

The current model of the Telescope Pier has been derived using the model used for the Magellan Observatories as a genesis of design, with variations to accommodate a revised elevation and Telescope plan dimensions according to the requirements of TSPM. See Figure 3.4.1 for a rendered representation of the Telescope Pier.



3.5.1 Figure – Telescope Pier Model Isometric.

The Telescope Pier model has been analyzed on a volumetric finite element model to determine the frequencies and dynamic modes, including a set of springs to represent the soil-structure boundary condition and a set of eight highly-rigid and mass-less bars to represent the link between Telescope and Pier. The four bars connecting to the inner wall have been released in the axial direction, thus transferring lateral forces only and in turn making the outer four bars to take the vertical forces to be taken by the outer wall. Furthermore, the set of springs at the base have included the most recent geotechnical information. See Figure 3.4.2 for a pictorial of the Finite Element Model used.



3.5.2 Figure – Telescope Pier Model Finite Element Model Isometric.

Based on the current geotechnical report, the dynamic modulus of elasticity at different strata under the pier location have been combined using a harmonic average and using an upper and lower bound approach. The upper bound value is that obtained directly from the values reported whereas the lower bound value considers that there will be a 20% degradation in the dynamic modulus of elasticity due to site preparations operations. The frequencies obtained from the dynamic analysis are presented on Tables 3.4.1 and 3.4.2. These values are much higher than those reported during the PDR phase, given that the dynamic moduli values have improved considerably as well as the introduction of a mat slab foundation that increases the pier bottom stiffness. At this point, the difference between lower and upper bound moduli values seem to have little effect on the frequencies obtained (see Tables 3.4.1 and 3.4.2). Nonetheless, the frequencies reported below are considered optimistic as there are several factors that can change these values, such as 1) the actual stiffness of the telescope structure (currently the telescope is modeled as infinitely rigid massless bars with a lumped mass at CG), 2) any modifications that the telescope design might experience and, 3) the actual dynamic modulus of the rock after excavation operations are performed. Finally, it is important to highlight that the current pier design has incorporated the latest telescope reactions and anchorage design provided by the telescope designer to coordinate the telescope-pier interface.

Table 3.4.1 Frequencies for case with Modulus of Subgrade Reaction based on 13.44 GPa

DYNAMIC MODULUS: E13.4 GPa / BEARING DEPTH: 1.5M / TELESCOPE MASS: ZENITH / MASS = 246 t					
Mode	Frequency (Hz)	Period (Sec)	SX Participation	SY Participation	SZ Participation
1	15.12	0.07	49.24		6.51
2	15.27	0.07	6.84		48.12
3	36.91	0.03		57.98	0.05
4	43.40	0.02	7.60		0.04
5	44.76	0.02	13.14	0.02	9.52
6	45.26	0.02	6.84	0.02	19.76
7	73.81	0.01		38.30	
8	80.83	0.01	3.51		0.03
9	81.33	0.01	4.72		0.23
10	82.61	0.01	0.02		10.13
11	86.49	0.01		0.14	0.10
12	92.81	0.01			0.09
13	102.21	0.01	6.04		
14	104.68	0.01		0.02	3.30
15	112.04	0.01	0.08		0.08
16	112.74	0.01	0.03		0.10
17	115.65	0.01	0.01	0.04	
18	120.81	0.01	0.41	0.02	0.02
19	123.32	0.01			0.01
20	127.50	0.01		0.50	0.13
Totals:			98.51	97.05	98.23

Notes:
Based on 13.44 GPa dynamic modulus of elasticity (E) and considering outer pier supports axial (vertical) forces, while inner pier supports radial (horizontal) forces. Bottom of Pier is considered to be 1.5m below grade.

Table 3.4.2 Frequencies for case with Modulus of Subgrade Reaction based on 16.8 Pa

DYNAMIC MODULUS: E16.8 GPa / BEARING DEPTH: 1.5M / TELESCOPE MASS: ZENITH / MASS = 246 t					
Mode	Frequency (Hz)	Period (Sec)	SX Participation	SY Participation	SZ Participation
1	15.79	0.06	47.21		7.20
2	15.96	0.06	7.60		46.00
3	37.71	0.03		53.80	0.04
4	45.24	0.02	21.43		0.50
5	46.53	0.02	0.04	0.03	28.05
6	47.72	0.02	5.91		0.72
7	77.95	0.01		41.18	
8	81.72	0.01			
9	86.37	0.01	6.99		
10	88.14	0.01			9.29
11	90.35	0.01		0.12	0.34
12	93.36	0.01			0.17
13	106.20	0.01	7.13		0.07
14	107.18	0.01	0.30	0.04	4.13
15	113.00	0.01	0.17		0.43
16	114.25	0.01			
17	115.84	0.01	0.03	0.05	
18	122.27	0.01	0.79	0.02	0.05
19	126.06	0.01	0.01		
20	128.22	0.01		0.62	0.19
Totals:			97.64	95.88	97.21

Notes:
Based on 16.8 GPa modulus of elasticity (E) and considering outer pier supports axial (vertical) forces, while inner pier supports radial (horizontal) forces. Bottom of Pier is considered to be 1.5m below grade.

Currently, the ratio of the Telescope Pier mass to the Telescope mass is 3.0 to 1 which tells us that the Pier has the recommended mass ratio to the mass of the telescope. At this stage of design, pier geometry refinement has been finalized and only minor modifications are expected to satisfy any minor changes from telescope to pier interface.

3.6 ENCLOSURE STEEL DESIGN

The Enclosure and Enclosure Base are design using a steel structure, following the same principles used for the Magellan Observatories with variations to accommodate a revised elevation, Telescope plan dimensions according to the requirements of TSPM and, the local steel shapes available for the project. See Figure 3.5.1 for a rendered representation of the structural analysis model of the Enclosure and Enclosure Base. In addition, the structure has been updated to incorporate the design requirements from the TSPM site as well as the current building code requirements, which are more stringent for this structure than those placed upon the Magellan design. See Figure 3.5.2 for a representation of the loads on the floor of the structural analysis model of the Enclosure and Enclosure Base

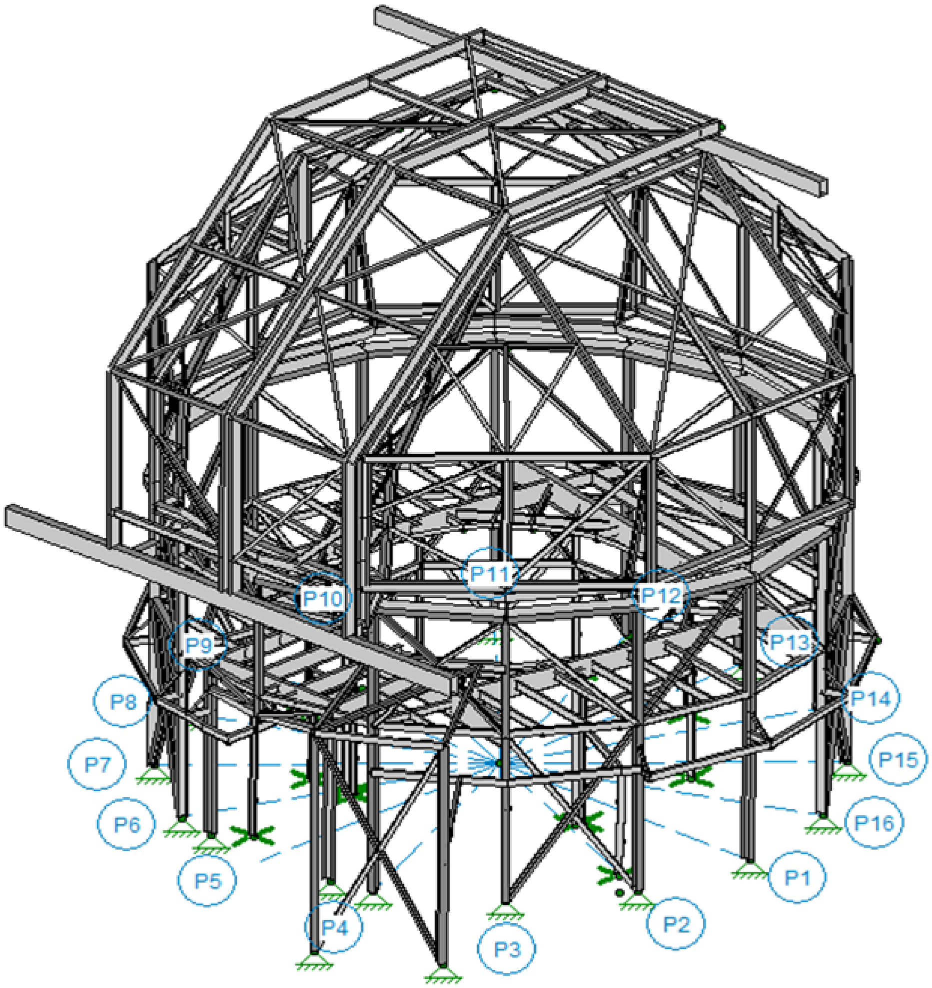


Figure 3.5.1 – Enclosure and Enclosure Base Structural Analysis Model Isometric.

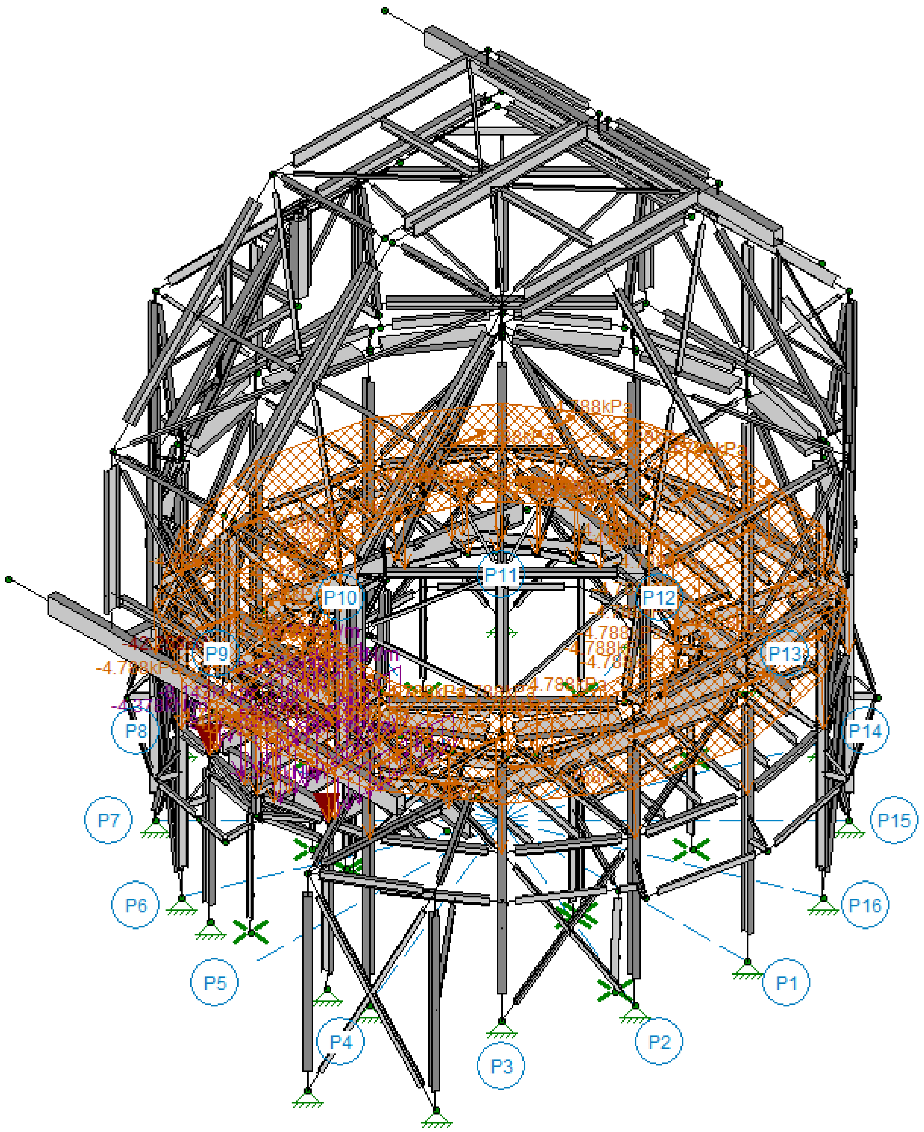


Figure 3.5.2 – Enclosure and Enclosure Base Structural Analysis Model Isometric, showing loads on the Observing Floor (including rail and special instrument cart loads)

The Enclosure and Enclosure Base model has been analyzed using a tridimensional structural model that incorporates all gravity as well as the lateral loads derived from the site conditions described under section 2.2. Using this model, deformations as well as maximum stresses have been compared to those allowed by the building codes that govern this project. See Figures 3.5.3 and 3.5.4

The Enclosure Base incorporates the use of Ordinary Concentric Braced Frames, with a seismic response modification factor R of 1.5 per ASCE 7-05. The Enclosure follows a similar detailing philosophy to resist the lateral loads imposed by wind and seismic conditions. This lateral force resisting system is considered appropriate for this project and, has been coordinated to take into account the seismic response that the azimuth bogies will exert into the system.

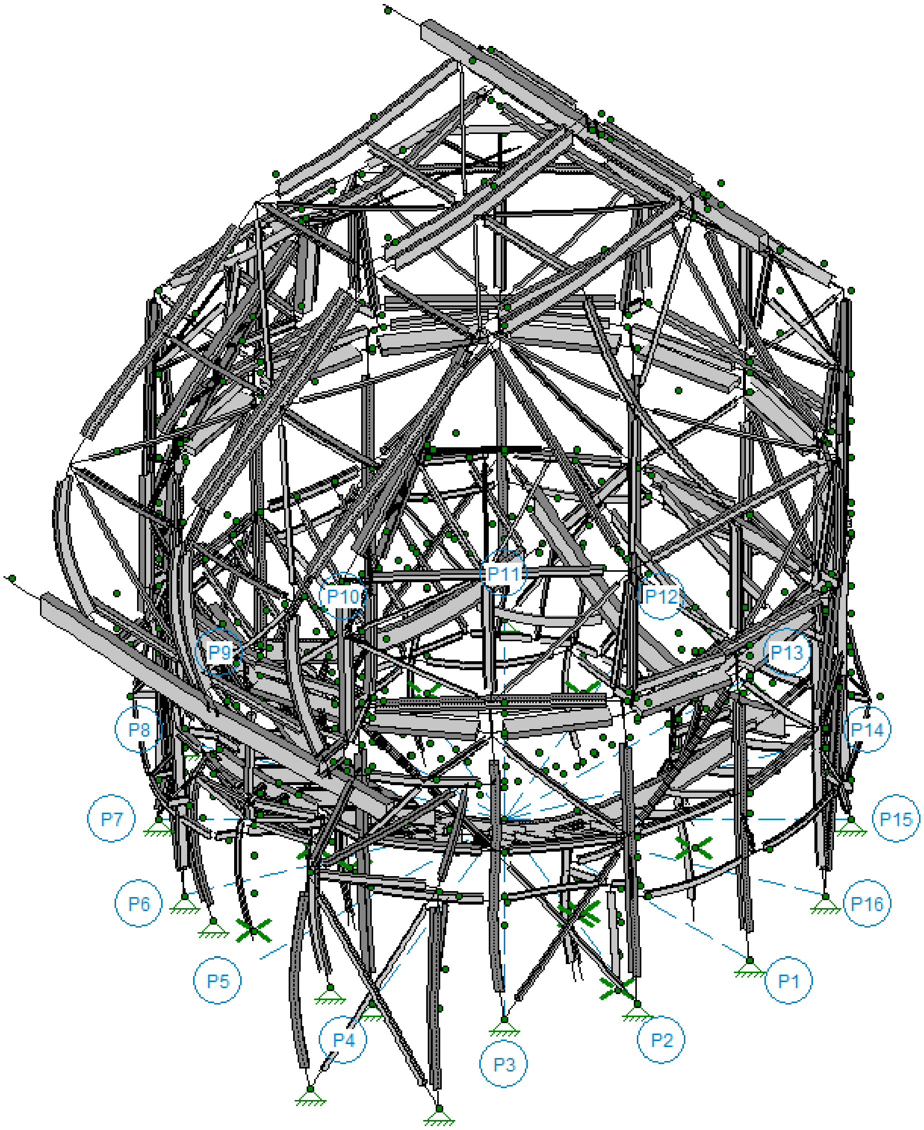


Figure 3.5.3 – Enclosure and Enclosure Base Model, Deformation under “Dead+.75Wind+.75Live+.75Snow” Load Combination. (Magnified a factor of 40, the green dots shown represent the structural joints in the undeformed state as a benchmark to graphically identify deformations)

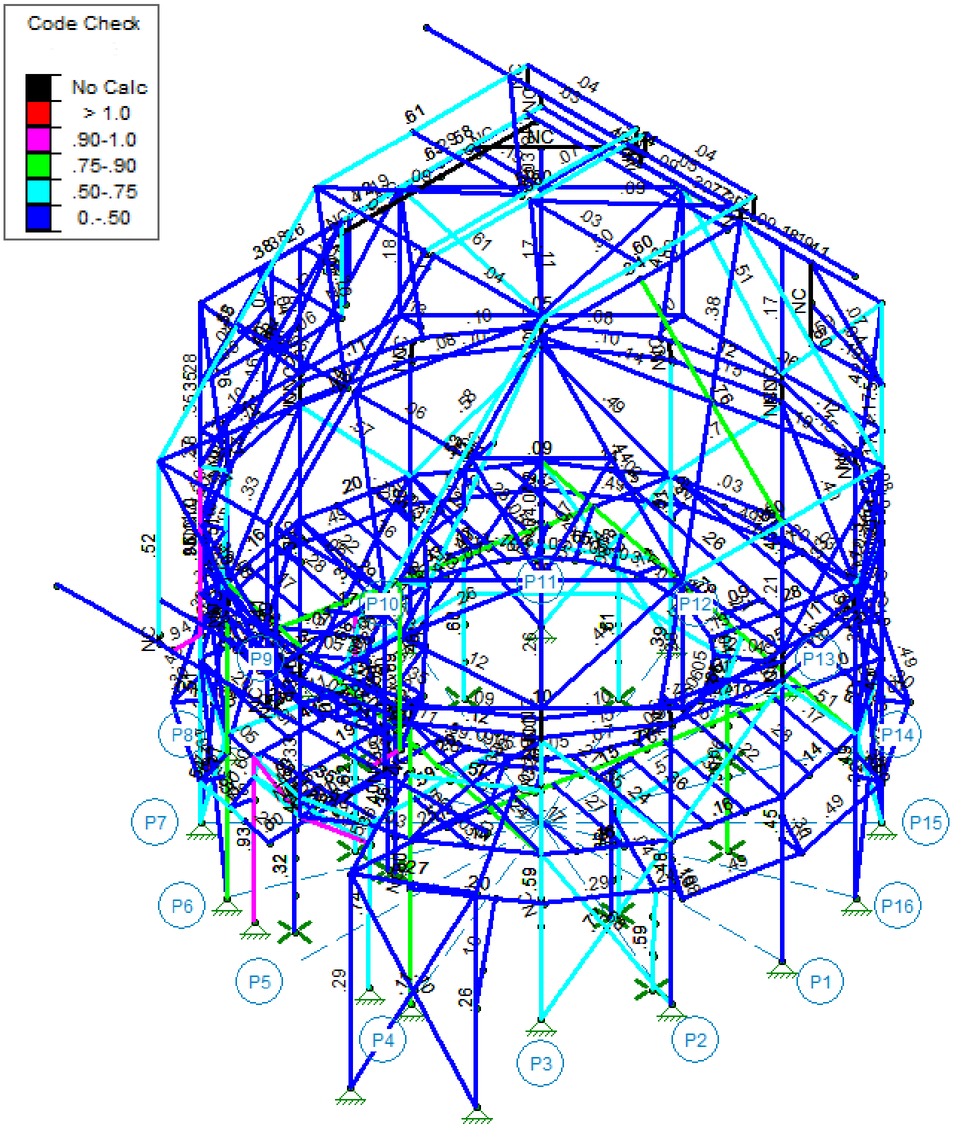


Figure 3.5.4 – Enclosure and Enclosure Base Model, Envelope of the Bending Stress Ratios on members. (Color code on bars represent the Design Unity Ratio of the member capacity)

Structural design has incorporated the interaction with the mechanisms behavior, taking careful consideration of several aspects such as: Stiffness of bogies, construction tolerance, stiffness of fixed and rotating ring girder, maximum deceleration during emergency stopping, shutter deformations and loads on enclosure, amongst other. To highlight just one of these items, the stiffness that the large overhang doors opening will have in the behavior of the bogie above has been studied and tuned to reduce the reaction envelope that this creates on the bogies. For this reason, a removable column has been incorporated as well as a steel floor truss under the observing level have been incorporated. See Figure 3.5.5.

During normal observatory operations, the removable column located at Gridline P5 provides a direct, axial load path from the bogie, through the fixed ring girder, to the beam below. The column is located inboard of two large operable doors which provide access to the observing level floor. In the open position, the doors provide a combined clear opening dimension equal to 7.0 meters wide by 3.2 meters tall. For mirror re-coating operations, the column must be removed in order to provide unobstructed egress for the mirror handling cart.

In the absence of the removable column, the fixed ring girder does not possess adequate flexural stiffness to support reactions from the azimuth bogie located at the mid-span of the ring girder. With this in mind, a structural steel space frame has been detailed to provide additional stiffness and carry gravity loads to each adjacent column. Though this is true, it is important to note that the observatory cannot be operated with the column removed. If Enclosure maintenance is to be planned during mirror coating downtime, the removable column shall be reinstalled for this purpose.

The removable column is detailed with bolted top and bottom connections which allow for its removal and reinstallation. The column removal procedure consists of the following operational steps:

- Locate the Rotating Enclosure in its stowed parked position
- Provide temporary shoring support on either side of the column by means of hydraulic or mechanical jacks
- Loosen and remove bolts at the top and bottom of the column
- Utilize Enclosure Crane and come-along devices or a stationary, portable jib crane for column handling and removal
- Remove floor plate covers at mirror cart rail
- Begin mirror handling operations

The procedure to reinstall the column shall be the same procedure mentioned above, executed in reverse order.

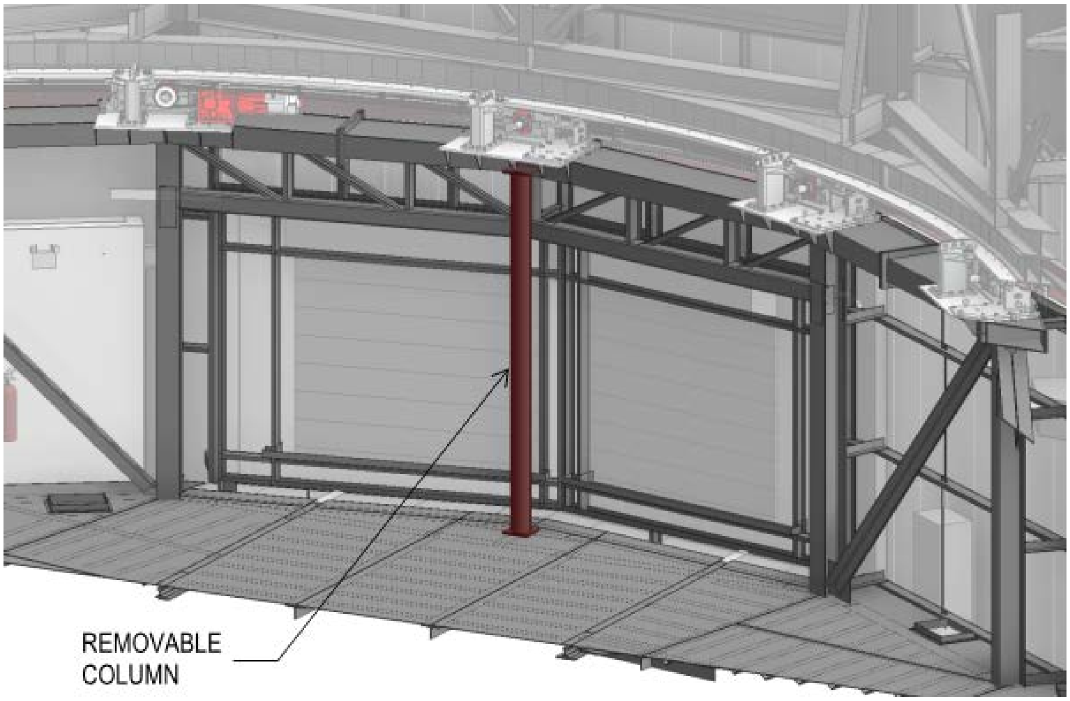


Figure 3.5.5 – Removable column at Fixed Enclosure

At this stage, all major structural steel has been identified and is awaiting final detailing. Critical interface detailing and definition of top level design objectives (such as seismic requirements for the project) are largely complete. Multidisciplinary coordination efforts using BIM technology are ongoing and will provide for a streamlined transition into final design.

4 MECHANISMS

4.1 Design Philosophy for Mechanisms

The baseline designs for the Telescopio San Pedro Martir (TSPM) mechanisms are those utilized in the Magellan 6.5 Meter Telescope Project (Magellan). The Magellan designs are, by and large, successful precedents with simple arrangements incorporating industry standard construction details.

Modifications to the original Magellan designs have been made only in the following instances:

- Where analysis evinces load path inadequacies for the survival-level environmental loads unique to the TSPM site.
- Where analysis and operational experience of the Magellans indicate lower-than-desired reliability, accessibility, maintainability, or safety (RAMS), with an economical means of remediation.
- Where obsolescence of parts requires new part selection.

To this end, detailing of TSPM mechanisms has its basis in two sources of input. First, a trip to the Magellans was taken in which the operational characteristics of the mechanisms were observed and in which the maintenance staff provided input as to the experiential reliability, accessibility, maintainability, and safety of the baseline design. Second, a detailed set of calculations was performed in which all mechanisms were rigorously studied under the influence of anticipated loads. The mechanisms section of this report summarizes the key findings from both data sources, as well as the project-specific design requirements, on a system-by-system basis.

4.2 Azimuth Rotation

Design Requirements

The azimuth rotation mechanisms shall comply with the following specifications:

- Maximum rotation speed of 3 degree per second (3°/sec)
- Minimum rotation speed of 0.03 degree per second (0.03°/sec), which will require stepping of the azimuth drives
- Rotation stop in less than 5 seconds in case of emergency
- Acceleration rate of 0.4 degrees per second per second ($0.4°/sec^2$)
- Positional accuracy of 0.1 degrees.
- Wind speeds
  - Maximum operational wind speed of 50 kilometer per hour (31 mph)
  - Maximum operational gust wind speed of 70 kilometer per hour (44 mph)
  - Survival wind speed of 170 kilometer per hour (106 mph)

The azimuth rotation mechanisms shall also comply with the following requirements:

- Sustain all imposed vertical loads
    - Dome structure, equipment, and shutter weight for normal operations
    - Dome structure, equipment, shutter, snow, and ice weight for survival conditions
    - Dome structure, equipment, and shutter weight under vertical seismic accelerations for survival conditions
    - Self-straining loads due to construction tolerances and other self-straining effects, including creep forces
- Sustain all imposed horizontal loads
    - Maximum operational wind speeds for normal operations
    - Survival wind gust speed for survival conditions
    - Lateral seismic loads for survival conditions
    - Self-straining loads due to construction tolerances and self-straining effects, including creep forces
- Unlimited rotation in any rotation direction
- Provide easy alignment and adjustment of mechanism during erection and maintenance
- Provide for maintenance access
- Provide protection of all parts against corrosion

Azimuth Rotation Mechanisms General Layout

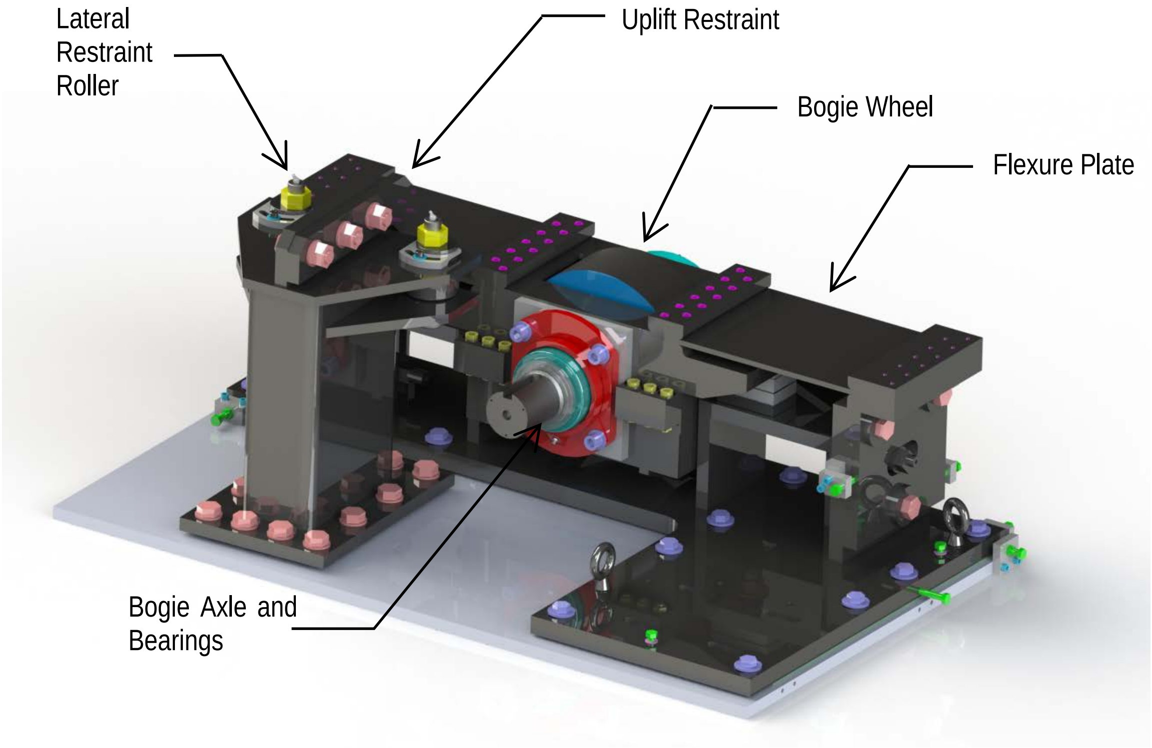
The azimuth rotation mechanisms consist of 16 equidistantly spaced bogie assemblies mounted to the fixed structure of the dome enclosure at each of the 16 column locations. Every fourth bogie is equipped with a drive, for a total of 4 equidistantly spaced drive bogies. Every bogie assembly is accompanied by a secondary restraint assembly consisting of a stanchion, 2 lateral guide rollers, and 1 uplift clip, for a total of 32 lateral guide rollers and 16 uplift clips.

Bogie Assemblies

Other than the addition of drive components to the 4 drive bogies, components are identical for all 16 bogie assemblies. This is convenient from a maintenance standpoint since it allows any bogie assembly be placed in any location within the general layout, an approach that was utilized in the TSPM design following feedback from the Magellan maintenance staff that this would have simplified their servicing operations.

Each bogie assembly consists of a welded, machined, and bolted wheelbox that holds the bogie wheel, shaft, and a pair of bearings. This wheelbox is connected to a secondary weldment with two semi-flexible elements: a pair of Fabreeka spring blocks, which provide a compliant path for vertical loads, and a steel flexure plate, which provides a stiff load path for lateral loads while allowing for tilt to accommodate rail twist. Adjustment blocks and jack screws are provided on the bogie base weldments for precise alignment and positioning of bogie wheels, drive units, and restraints to required tolerances.

Details of the bogie assembly can be seen in the following figure, where “idler bogie” indicates a bogie assembly not equipped with drive components.



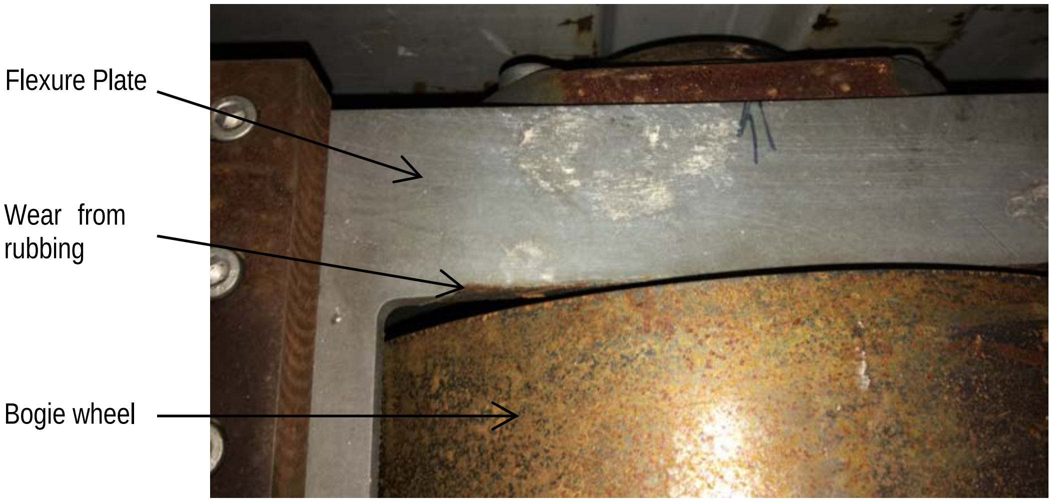
Idler Bogie Assembly - TSPM

Idler Bogie Assembly - Magellan

In general, the reliability, accessibility, maintainability, and safety of the Magellan azimuth bogie assemblies have all been fairly good, with a few minor exceptions. On the positive side, the following characteristics were observed: 1) A reasonable level of vertical compliance was provided in the design, creating a favorable level of load sharing between all bogie assemblies; 2) Well-designed adjustment features were incorporated, facilitating alignment following bogie swapping for maintenance activities; 3) There is open access to all bogies, with a baseplate adequately sized to extract the bogie from beneath the rail before hoisting; and 4) The flexure plate provides a stiff path for lateral loads near to the wheel-rail interface while largely releasing the bogie torsionally, which accommodates consistent wheel-rail contact with a non-crowned wheel. This last feature, in particular, has led to excellent wheel-rail wear characteristics, with roughly 0.1mm of wear measured on the track after nearly two decades of use (see next figure).

Magellan Track Plate Wear Measurement with Feeler Gauge

On the negative side, the greatest shortcoming of the Magellan bogie is an inadequate load path from the wheel to the wheelbox for lateral loads, which are an inevitable result of rolling contact due to creep forces that arise from steering misalignments between the wheel and the rail. This has led to two deleterious consequences: 1) Premature failure of the spherical bearings, leading to an increased level of maintenance (as much as once per year per rotating enclosure), and 2) Slippage of the wheel on the shaft and/or slippage of the shaft in the bearings such that the wheel begins rubbing and grinding against the edge of the flexure plate.

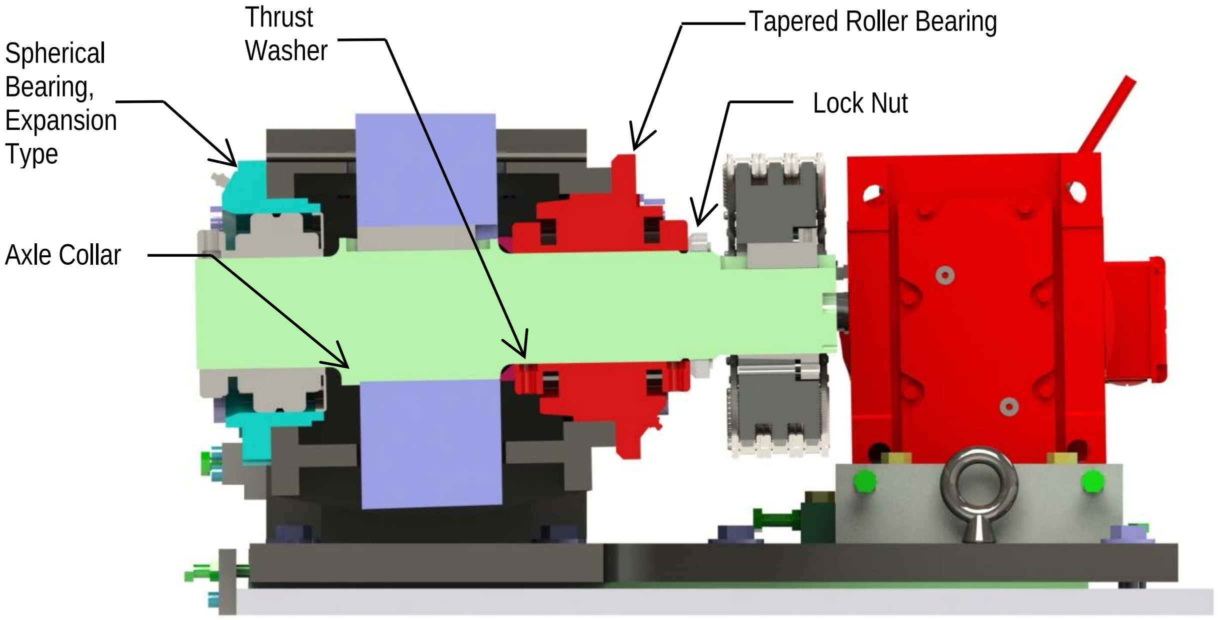


Magellan Flexure Plate Wear from Wheel/Axle Slippage

The vulnerability of the Magellan bogie to these failure modes was corroborated by analysis, in which three specific weaknesses were diagnosed: 1) The spherical bearings selected for the Magellan bogies have poor thrust capacity, with a safety factor under 1.0 for the combination of vertical and thrust loads anticipated when lateral creep forces are taken into account; 2) The holding strength of the set screw between the bearings and the wheel axle is significantly less than the anticipated lateral loads; and 3) The holding strength of the shrink fit between wheel and the axle appears marginal for transferring design-level lateral loads. These calculation results are consistent with the feedback from the Magellan maintenance staff that slippage had been observed at both interfaces.

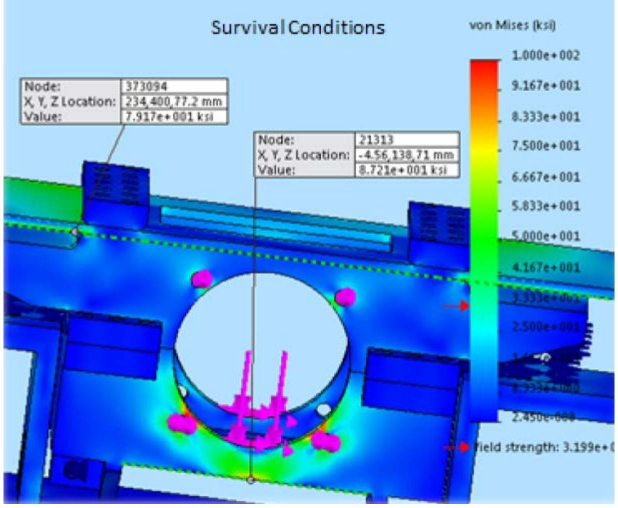
To remedy these shortcomings, the TSPM axle and bearings include several modifications to the baseline design. First, one of the spherical bearings has been replaced by a tapered roller bearing capable of absorbing lateral loads. Second, direct load paths have been created between the wheel and the tapered roller bearing through the utilization of 1) a thrust washer for a direct compressive load path on one side of the wheel, and 2) a shaft collar on the opposite side of the wheel coupled with a bearing locknut on the outboard side of the tapered roller bearing. Third, an expansion-type spherical bearing is used to further ensure that thrust loads transfer through the tapered roller bearing instead of the spherical bearing. These details can all be seen in the following cross-section of an azimuth drive bogie.

These changes were incorporated without a change in the wheel size, axle diameter, or wheelbox size. The tapered roller bearing and expansion-type spherical bearing are identical in cost to the original spherical bearings and remain standard purchased parts. The primary tradeoffs are 1) Additional cost to the axle for the added features, and 2) An offset to the location of the gearbox (due to the need for a longer axle) that slightly increases the overall space claim of the azimuth bogie assemblies. However, these were deemed worthwhile given the reduction in maintenance activities that is anticipated due to the reduction in bearing and wheel failures.



TSPM Axle and Bearing Arrangement

In addition to the modifications to the bearing arrangement, some more minor updates were made to the azimuth bogie weldments. First, plate thicknesses were changed from metric to imperial to streamline procurement and production of the mechanisms. Second, the side plates of the bogie were extended downwards by 25 mm to account for vertical survival-level environmental loads that are higher for TSPM than for the Magellans (due to high snow and ice load requirements). The stress plot shown to the right shows a calculated stress of 87 ksi (600MPa) in the lower edge of this plate prior to its modification, well above the material yield strength of 50 ksi (345 MPa)

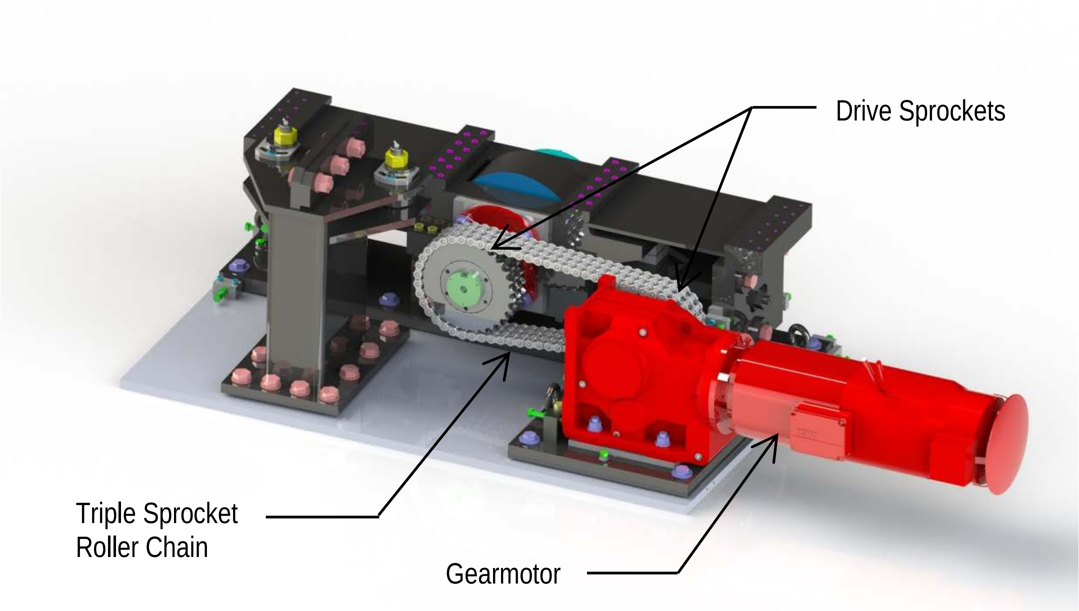


Drive Bogies

The four drive bogie assemblies include all components in the idler bogies and are further equipped with gearmotor units, chains, and sprocket assemblies to power azimuth rotation via tractive effort at the wheel-rail interface.

The four drive bogie assemblies include 5.6 kW (7.5 hp) helical-bevel gearmotor units, each driven by their own VFD. These gearmotors are largely identical to those specified for the Magellans, which the maintenance staff has claim can allow for azimuth rotation even with 2 of the 4 drive units entirely removed for maintenance.

Each gearmotor unit is provided with a fail-safe brake to arrest dome rotation; these brakes engage automatically in case of power failure. As the original Magellan brake size and settings were not known at the time of review, the TSPM brakes were sized to balance E-stop considerations (with a 3.2 s maximum stopping time under maximum tailwind conditions) with acceleration loads imparted to the building enclosure (3.2 °/s^2 under maximum headwind conditions). The figure and photo below show details of the drive assembly.



Drive Bogie Assembly - TSPM

Drive Bogie Assembly - Magellan

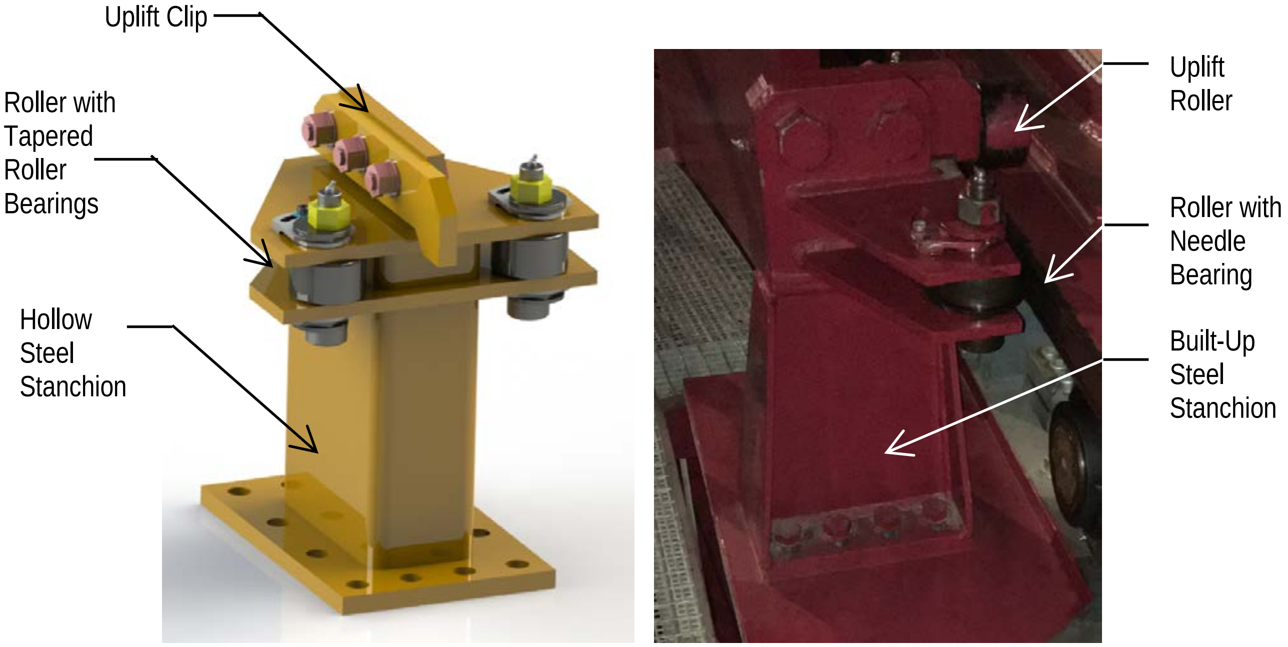
Uplift and Lateral Restraints

A stanchion weldment bolted adjacent to each bogie provides mounting locations for an uplift clip and a pair of lateral restraint rollers. Due to differences in environmental loading and feedback from the Magellan maintenance staff regarding reliability, several changes have been incorporated into the TSPM design while preserving the overall arrangement.

First, on account of increased survival-level lateral loads, arising from high seismic requirements for the TSPM site, the stanchion weldment was increased in capacity. A rectangular hollow steel section was selected that maintained a similar size to the original built-up steel I-beam.

Second, on account of a reduction in survival-level uplift loads (to the point that no uplift is expected even under worst-case wind conditions) the uplift roller was replaced with a simple steel clip. This would lead to steel-on-steel contact in the unexpected event of uplift but removes a mechanical component from the assembly.

Third, on account of semi-regular failure of lateral guide rollers, the yoke-style cam follower has been respecified from a needle bearing, which has very little thrust capacity, to a tapered roller bearing, which comes with a defined load path for the thrust loads that inevitably arise from lateral creep forces and from scrubbing that occurs during vertical travel of the track (due to bogie suspension compression). This may not eliminate roller bearing failures, as analysis evinced that suboptimal load sharing is still to be expected, but it should nonetheless offer a meaningful improvement without any increase to the roller size or price.



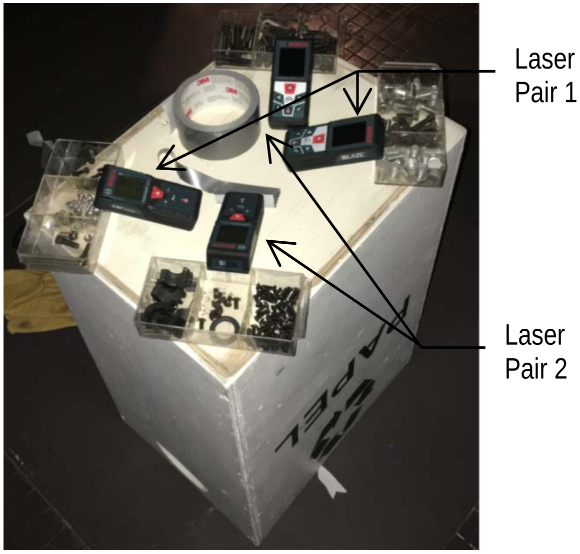
Lateral and Uplift Restraints – TSPM (Left) and Magellan (Right)

Azimuth Track Plate

As mentioned previously, the Magellan azimuth track plate has performed well over time and likely remains suitable for the TSPM track plate. It remains an area of ongoing study whether there will be cost-effective advantages – such as ease of fabrication or long-term performance of the lateral guide rollers – to switching to a track plate with a hardness that exceeds that of the 690 MPa (100 ksi) T1 plate specified for the Magellans.

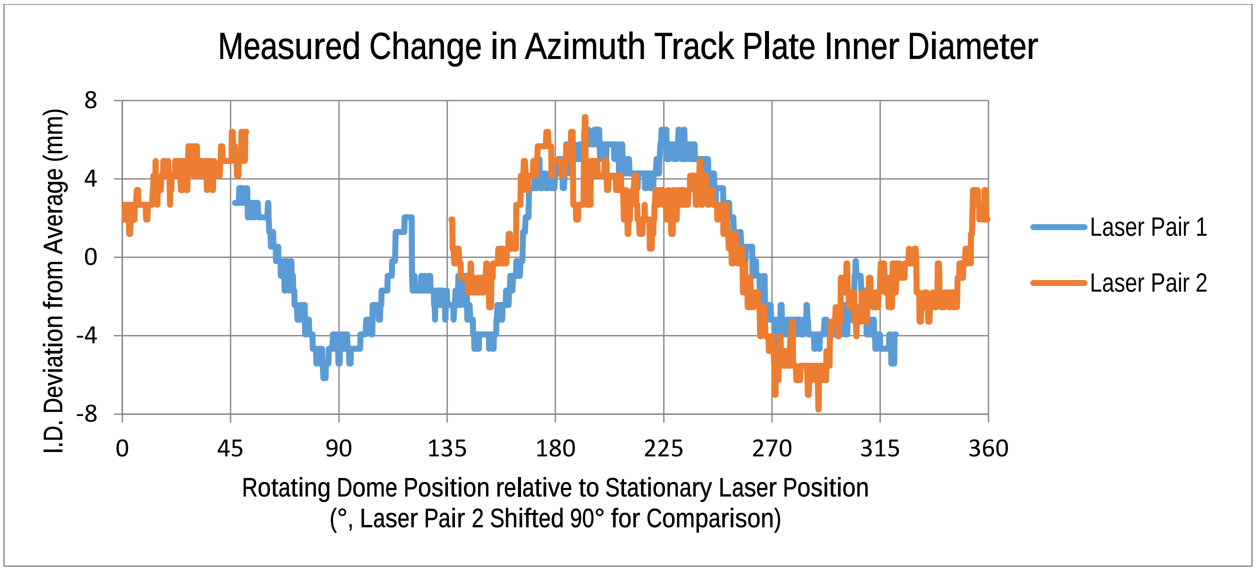
Of particular relevance to lateral guide roller performance is the circularity of the inner diameter of the azimuth track plate, as this has a significant impact on load sharing. To ensure that the Magellan baseline design serves as a reasonable guidepost to the expected performance of the TSPM lateral guide rollers, circularity measurements were performed to benchmark track plate circularity against the prescribed Magellan installation tolerances (which are intended to be reused as the TSPM installation tolerances).

To this end, track circularity was measured for the Clay observatory azimuth track plate. Four laser distance measurerers were placed approximately 90 degrees from each other on a box on the observatory floor under the center of the telescope. The lasers were angled upwards so that the beams were incident upon the interior face of the track plate. The enclosure was then rotated and the measurements were recorded by video. The laser distance measurers displayed distances in increments of 0.8 mm (1/32”). This setup can be seen in the photo to the right.



The graph on the following page plots the sums of the diametrically opposed pairs of distance measurers, shifted vertically so that they are centered about their average and shifted horizontally so that the two sets of data are aligned based on the relative position of the stationary laser pair to the rotating dome. The plots have been trigonometrically adjusted to account for the fact that the measurers were pointed at an upwards angle towards the track, effectively projecting the measurements onto a plane horizontal with the track plate.

Two primary observations are made from this data. First, the as-built condition of the Clay azimuth track shows high fidelity with the originally prescribed tolerances, which were ±4 mm on the radius; this validates operational performance of the Magellan lateral restraints as a reasonable precedent for the TSPM lateral restraints, provided that similar construction tolerances are maintained. Second, the track does not appear to change shape as it rotates round the base; this implies that the lateral guide rollers are not over-constraining the track, since it is anticipated that high levels of contact between the rollers and the track would tend to impose the “shape” of the lateral guide rollers onto the comparatively flexible rotating ring girder. This is the desired condition for TSPM as well.



Azimuth Bogie Steering Angle Alignment

A significant contributor to the success of telescope enclosure azimuth rotation systems is the steering angle alignment of the bogies. Even misalignments of a fraction of a degree can lead to substantially amplified wear rates and lateral creep forces, which in turn punish the lateral guide rollers.

The approach taken at the Magellans is simply to align the bogies “by ear.” That is, when a bogie is realigned following maintenance procedures, the enclosure is rotated while listening for the popping noises associated with stick-slip behavior. If such noises are heard, the bogie is readjusted and the procedure repeated until the audible clues for misalignment cease. This approach has evidently worked reasonably well, as wear rates are low and lateral guide roller failures are manageable, particularly given the lack of lateral compliance.

While this approach is serviceable, a more intentional alignment methodology may be preferred for the TSPM bogies – and, in fact, it appears that a more intentional alignment methodology for the Magellan bogies was originally intended as well (see image on the following page). Shaft alignment features similar to those found in the Magellan shop drawings are being proposed anew for TSPM, with the following alignment procedure suggested for further review:

1) During enclosure installation, match-drilled alignment pin holes would be used to precisely locate the azimuth bogies circumferentially. All subsequent maintenance activities would reuse these holes to ensure repeatable circumferential positions of the bogies.

2) A target would be placed on the telescope mount (either a permanent target or a removable target with a repeatable calibration technique), and the azimuthal accuracy of the telescope mount would be relied upon to place this target directly in line with the center of a given bogie wheel and the true center of the enclosure.

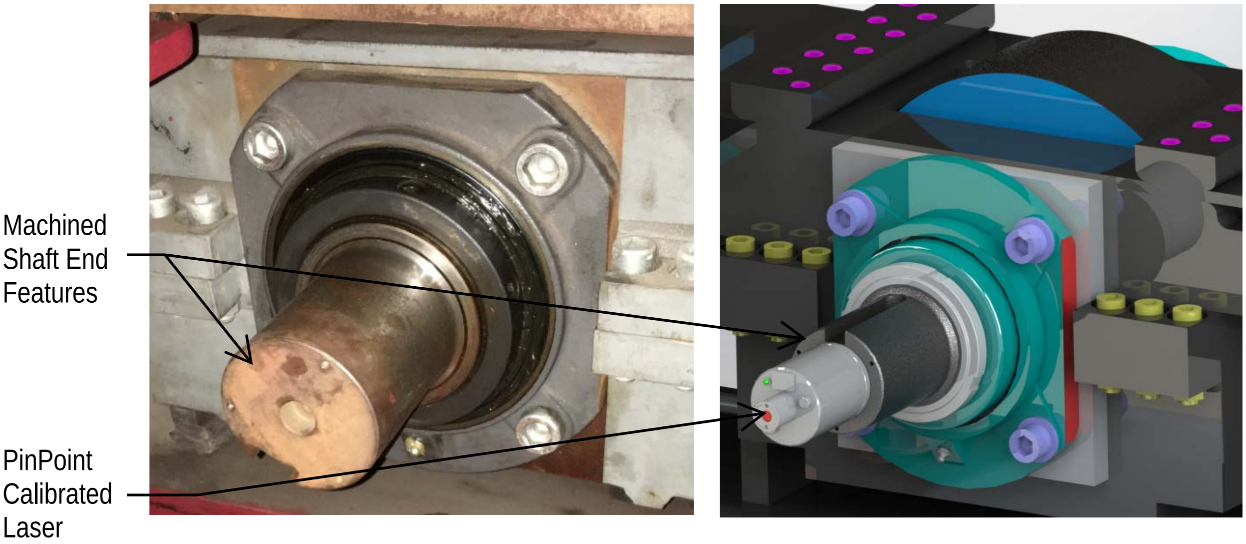
3) A calibrated visible-light laser would be mounted to the end of the bogie shaft in a manner that creates a high-fidelity extension of the shaft centerline both in concentricity and in angularity. Such a laser can be purchased from PinPoint Laser Systems with a laser-to-body accuracy of 2

arcseconds and a back face that is perpendicular and flat to within 25 µm (0.001”) over a diameter of 76.2 mm (3.0”). Coupled with a shaft whose end face is perpendicular and flat to a similar degree, this would result in a measurement error of less than 0.05°, exclusive of the accuracy of the target, which is roughly what would be required to meet the steering angle tolerance objective of ±0.10°.

4) As an additional diagnostic measure, the enclosure could be rotated with the measurement device engaged on the shaft to measure the twist tolerance of the track plate.

Note that a direct measurement of the shaft alignment is preferred to a measurement of the wheel face, since this removes wheel tolerances from the measurement.

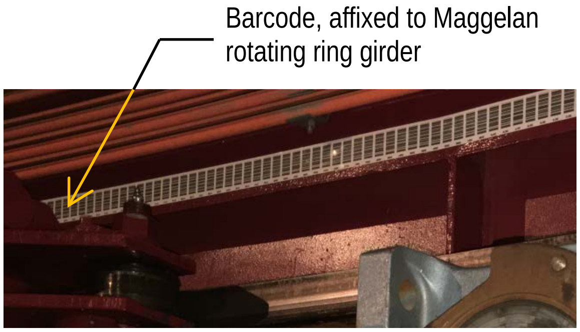
The above procedure would be contingent upon use of the telescope mount as an alignment aid, with a circumferential accuracy of roughly ±1.5 mm (1/16”) required for a target located at the O.D. of the telescope mount. Further coordination will be required to confirm that this is a feasible and preferred alignment approach.



Bogie Steering Angle Alignment Features – Magellan (Left) and TSPM (Right)

Azimuth Positioning

Azimuth position sensing will be achieved with a barcode reader, as is done for the Magellans (see image to the right). The Pepperl-Fuchs PCV Matrix Positioning Sensing system being considered uses a 2D code band that provides reliable position detection to within ±0.1 mm. If applied directly to the rotating ring girder, this translates into an angular position accuracy on the order of 0.001°, well within the required accuracy of 0.1°.



4.3 WINDSCREEN

Design Requirements

The windscreen shall comply with the following specifications:

- Travel speed of 0.36 degree per second (0.36°/sec) relative to the project origin (which translates to a linear travel speed of 76 mm/s [15 ft/min], the specified speed of the Magellan windscreen)
- Height of deployment of 9.6 m above the elevation axis
- Positional accuracy of 0.1°
- Wind speeds
    - Maximum operational wind speed of 50 kilometer per hour (31 mph)
    - Maximum operational gust wind speed of 70 kilometer per hour (44 mph)

The windscreen mechanisms shall also comply with the following requirements:

- Sustain all imposed vertical loads, including vertical seismic accelerations
- Sustain all horizontal loads, including operational winds and survival seismic accelerations
- The windscreen shall be solid.
- The windscreen shall avoid vibrations.
- The windscreen shall avoid whip.

General Layout

The windscreen protects the telescope from winds that could lead to telescope jitter during observations. The windscreen consists of 20 folding aluminium panels adjoined by steel hinges. Rollers at either end of every panel follow the paths of two parallel steel tracks, the layout of which largely matches the piecewise linear path of the enclosure arch girders. The relative offset between the two parallel tracks forces the panels to assume a rigid zig-zag pattern once deployed.

Lift chains along each side attach to the lead panel and drive the unit between the stowed and deployed positions. The chains are connected to a common jackshaft that is driven by a single gearmotor. Chain tensioners keep consistent tension on the chains during operation. An absolute encoder provides position information, and inductive limit switches provide homing feedback for the end of travel in both the stowed and fully-deployed positions

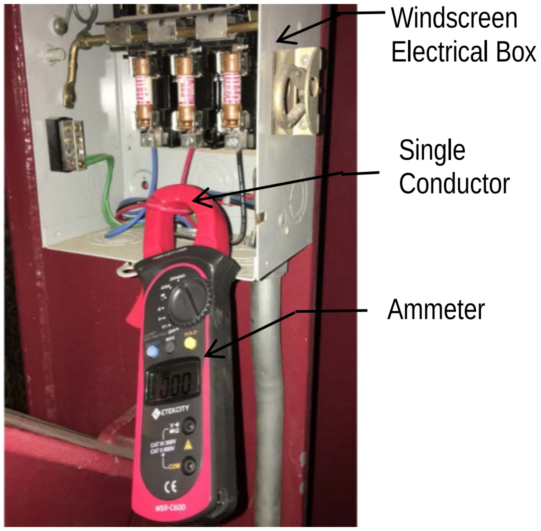
When stowed, the panels fold into a stack at the base of the rotating enclosure, located between the azimuth bogie assemblies and the lower portion of the shutter doors. When fully deployed, the panels extend to an elevation 9.6 m above the elevation axis. See the following two figures for images of the windscreen in the stowed and deployed positions.

Windscreen – Stowed (Left) and Deployed (Right)

<u>Vibration and Performance Concerns</u>

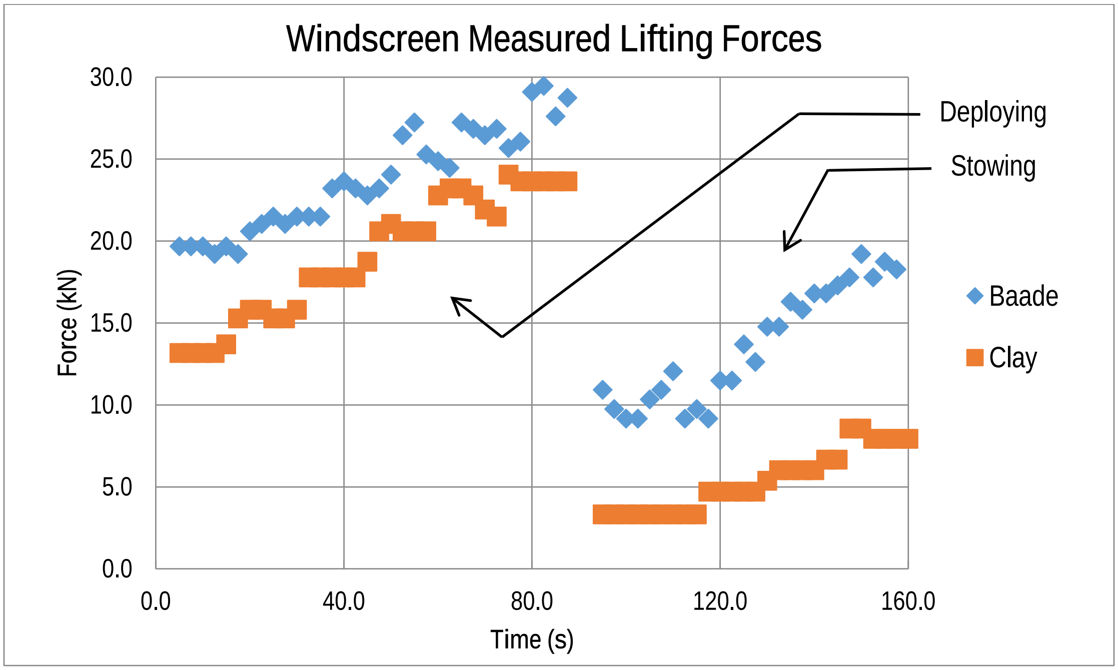
Unlike the other Magellan mechanisms, the windscreen has had a checkered history of performance; the Clay observatory windscreen has proven relatively reliable, whereas the Baade observatory windscreen has exhibited such severe vibration problems during operation that it has gone relatively unused during the lifetime of the project.

As such, the windscreen has received the highest level of scrutiny during the design and development of the TSPM mechanisms, both during the site visit to the Magellans and during the analysis phase. In particular, a focus of study has been whether the performance disparity resulted from differences in construction between the two Magellan windscreens (the Clay dome windscreen incorporated non-porous honeycomb panels with continuous piano hinges, whereas the Baade dome windscreen utilized hollow and porous aluminum panels with intermittent piano hinges), or whether other factors were contributing in unanticipated ways.



As a first diagnostic step, an ammeter was used during the Magellan site visit to measure amperages as each windscreen was deployed to roughly half height and then returned to a fully stowed position. The basic setup can be seen in the above image.

Results from these measurements were converted from amperages to torques using SEW product data and then from torques to effective lifting forces based on the gearbox specification and sprocket geometry. Lifting force is plotted against time in the following graph, where both the deploying and stowing results have been merged onto a single plot.



There is some uncertainty associated with these results due to limitations in the torque/amperage relationship product data; however, several observations can nonetheless be made: 1) The average "step" in drive forces, which occurs every time a pair of panels is picked up, is reasonably close to the 2.2 kN (500 lbf) weight of two panels referenced in the Magellan windscreen specification (adding confidence to the measured results); 2) The measured lifting force for the Baade windscreen is consistently around 8 kN (1800 lbf) higher than the lifting force for the Clay windscreen, indicating a much higher amount of drive resistance; and 3) For both the Baade windscreen and Clay windscreen, the lifting force *increases* during the stowing process, indicating that drive resistance due to binding and friction exceeds the self-weight of the panels. This last point was further confirmed by observations that the slack side of the chain alternated between deploying and stowing, implying that the panels had to be *pulled down* in order to stow.

In addition, observing the behavior of the chain and sprockets – both on site and in subsequent analysis of videos – has led to the conclusion that the deleterious vibrations during operation are dominated by stick-slip behavior, likely due to binding and friction forces. In support of this hypothesis is the observation that all dynamic behavior, including vertical oscillations of the panels and jerky motion of the sprockets, occurs at a frequency of roughly 3.1 Hz, which coincides with the frequency at which the roller chain engages with the sprocket teeth; such coupling of stick-slip behavior with sprocket tooth engagement is not uncommon in slow-moving chain applications. Although the vibrations were noticeably more violent during operation of the Baade windscreen, this same behavior (with a 3.1 Hz dominant frequency) was observed during operation of both the Baade and the Clay windscreens.

This consistent behavior is true in spite of the differing construction methodology between the Baade and Clay windscreen panels. Furthermore, both site measurements and structural analysis have confirmed that the lowest structural resonances of both windscreen panel types are comfortably outside of the cogging frequency, with a fundamental mode of around 5 Hz for the leading Baade panel and of 8 Hz for the leading Clay panel.

TSPM Windscreen Design Philosophy

In light of these observations, particularly the fact that both the Baade and Clay windscreens suffer from similar root problems (albeit to different extents), the TSPM windscreen was reengineered with the following approach:

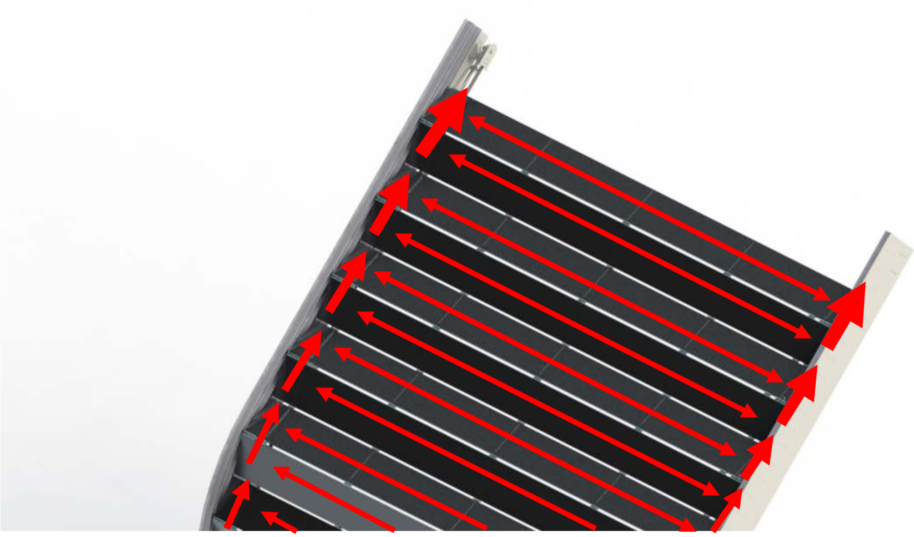
- The baseline architectural layout was preserved without modification, including hinge points, roller offsets and diameters, track locations, and deployment path.
- Where economically viable, all potential sources of binding and drive resistance were aggressively mitigated.
- The structural load path was redefined intentionally and deterministically such that all remaining sources of binding and drive resistance could be analyzed and quantified with a higher degree of certainty. In particular, heightened attention was given to the lateral load path necessary to transfer global creep forces, which appear to be unaccounted for in the baseline Magellan design.
- Consideration to constructability, including allowance for reasonable fabrication tolerances and their effects, was included explicitly in the analysis approach.

The detailing in the ensuing sections of this report illustrates this philosophy on a component-by-component basis.

Consideration for Load Path

Of fundamental importance to component detailing is the establishment of an intentional load path for both vertical (gravity dominated) and lateral (creep-force dominated) loads.

With regards to vertical loads, all panels tend to deflect in tandem like independent simply-supported beams, meaning that their self-weight load travels outwards towards the tracks before consolidating with the loads collected from the panels below them – and, in turn, traveling upwards towards the chain link arms. As a consequence, the interior hinges and mid-span panel structure carries consistently low loads across all panels, whereas the panel end-framing and end hinges carries linearly increasing load from the bottom of the windscreen to the top of the windscreen. See the following image for a pictorial representation of this load path.



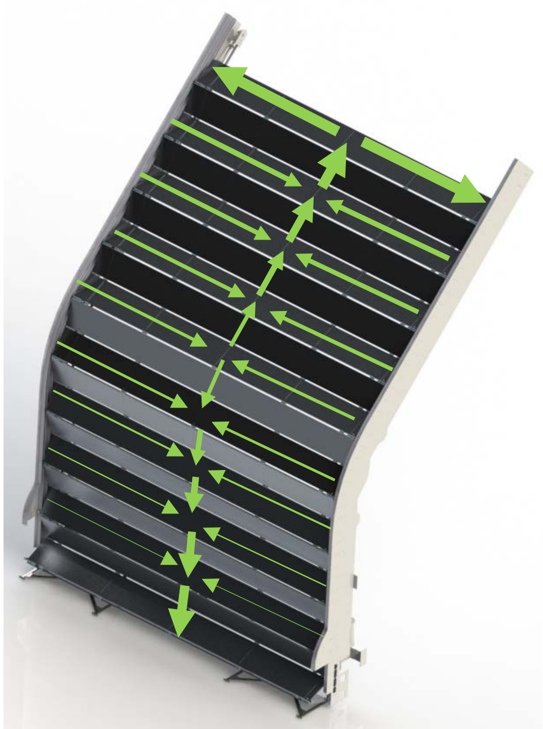
Load Path for Vertical (Gravity) Loads – Magellans and TSPM

As opposed to the vertical loads, which have a well-defined load path intrinsic to the architectural layout of the windscreen, the lateral loads due to creep forces will take whatever load path is made available to them: either from a roller to its panel and then on to an adjacent panel via thrust at hinges, or from the roller directly out to the track via compression between stud and slide pad.

In the Magellan windscreens this load path is highly indeterminate due to the use of piano hinges and a lack of anchorage for the trailing panel, making it impossible to predict the most direct load path. The TSPM windscreen, by contrast, has been designed with a specific load path: from panel-to-panel via thrust hinges – located only at panel midspans – and then either upwards towards a custom roller stud or downwards towards an anchorage point to ground. See the following image for a pictorial representation of the lateral load path.

The location of the thrust hinges at midspan is intentional, as it concentrates lateral loads in the portion of the panels with the least amount of vertical load (as well as the least amount of structural rotation of an individual panel bending under its self-weight). This leads to symmetric deflections of all panels under their individual vertical loads and further minimizes the possibility for binding forces induced by composite-action shear flow between adjacent panels.

A consequence of this arrangement is that hinges can be optimized for the loads they must bear, with the end hinges designed for high radial loads and the midspan hinges designed for low radial loads but high thrust loads. This is further described in the next section.



Load Path for Lateral Loads – TSPM

Windscreen Hinges

Piano hinges were used in the Magellan windscreens and run either continuously across the entire hinge line (Clay) or as a mix of continuous and intermittent hinge lines (Baade). See images below.

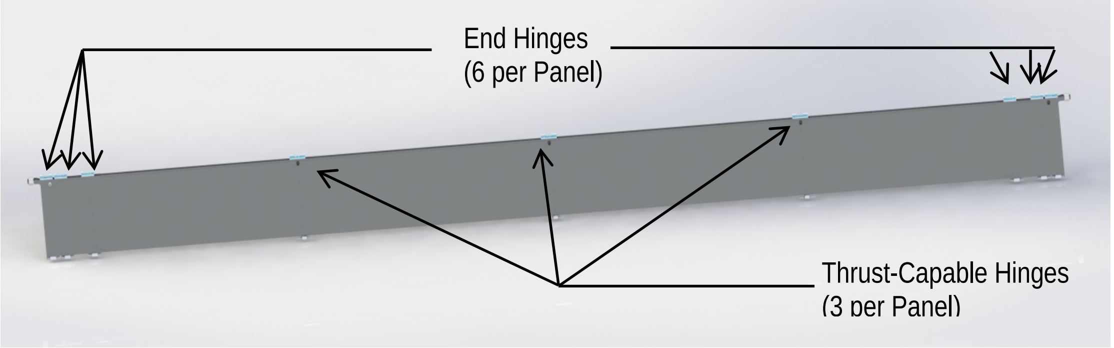
Clay Observatory Windscreen: Continuous Piano Hinges

Baade Observatory Windscreen: Intermittent Piano Hinges

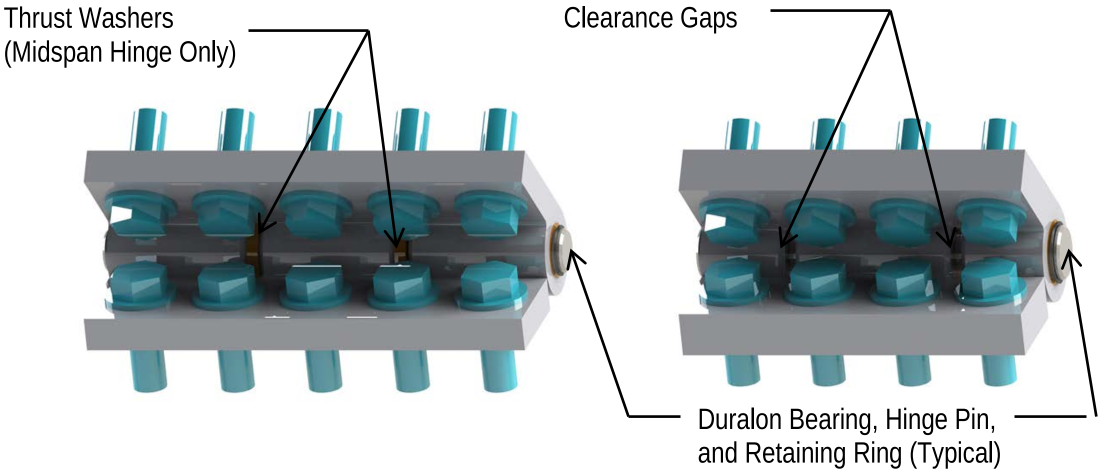
The following potential shortcomings were observed: 1) Hinge knuckles nearest the rollers are potentially undersized and over-utilized; this may lead to slippage or deformations that exacerbate binding concerns; 2) Hinge knuckles over the interior 90% of the panel are potentially oversized and under-utilized, leading to weight inefficiencies; 3) Indeterminacy for lateral loads may lead to binding and hinge-knuckle rubbing (by forcing composite action between adjacent panels as they deform under their own weight); 4) Hinge pins occasionally work their way out and must be monitored (see image to the right); and 5) The continuous nature of the hinges makes it difficult to ensure proper lubrication, with steel-on-steel rotations further adding to drive resistance.

To obviate these issues in the TSPM windscreen, multiple design modifications have been made to the hinges. First, two types of hinges have been incorporated: a stouter, stronger hinge for the panel ends, where radial loads are the highest, and a longer hinge optimized for thrust loads at the midspan and quarter points. Second, all hinges have clearance gaps between their knuckles to eliminate indeterminate loads paths that may induce binding, with the exception of the midspan hinge (into which low-friction Duralon thrust washers have been inserted). Third, all hinges incorporate Duralon sleeve bearings to create a maintenance-free, low-friction surface for rotation. Fourth, all pins have been secured with snap rings to prevent pins from working their way out. Fifth, all hinges have been designed with slip-critical connections to the aluminum panel to safeguard against movements that could lead to out-of-tolerance behavior during deployment.

These details can be seen in the following several images.



TSPM Windscreen Hinge Layout



TSPM Thrust Hinge (Left) and End Hinge (Right)

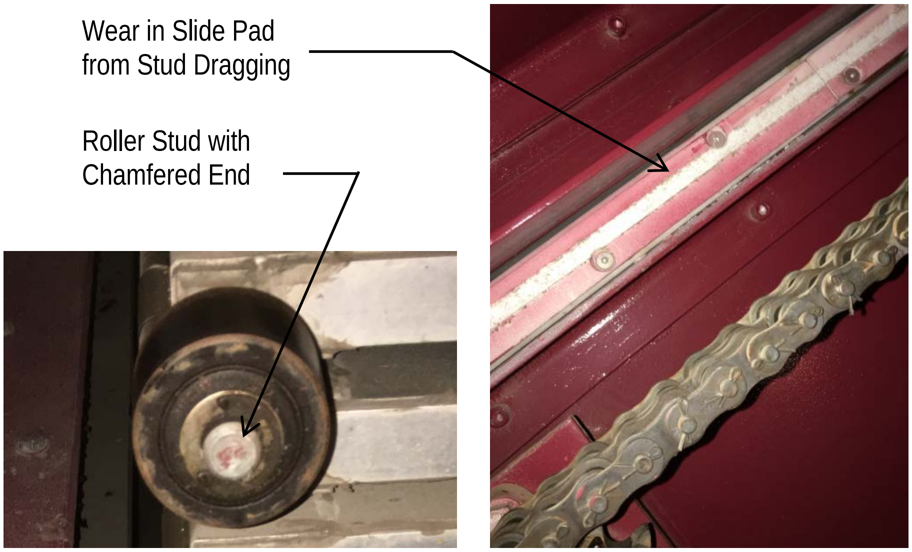
One potential advantage of the continuous piano hinge, which is lost in the transition to discrete hinges, is that it imposes forced alignment of an entire hinge line. To ensure that this does not become a shortcoming of the TSPM windscreen design, structural analysis was performed to verify that economically-achievable construction tolerances would result in manageable binding loads for the locations and spacings of the hinges as specified.

<u>Windscreen Rollers, Studs, and Slide Pads</u>

The Magellan windscreen rollers are 63.5 mm (2 ½”) diameter yoke-mount rollers with needle bearings. As with the azimuth lateral restraint rollers, the maintenance staff commented that bearing failures were somewhat common; this is unsurprising given that lateral creep forces likely produce thrust forces for which needle bearings are not designed.

Tapered roller bearings, which would be the preferred upgrade, are not available in this size and product line. However, heavy duty cylindrical bearings are available in this size for no additional cost, and they have been selected for the TSPM windscreen on account of two notable improvement. First, they offer a nominal thrust capacity of roughly 10% of the radial load, which will at the least extend the life of the rollers. Second, these units come lubricated for life, thereby reducing maintenance costs and safeguarding against premature failure due to a lack of lubrication.

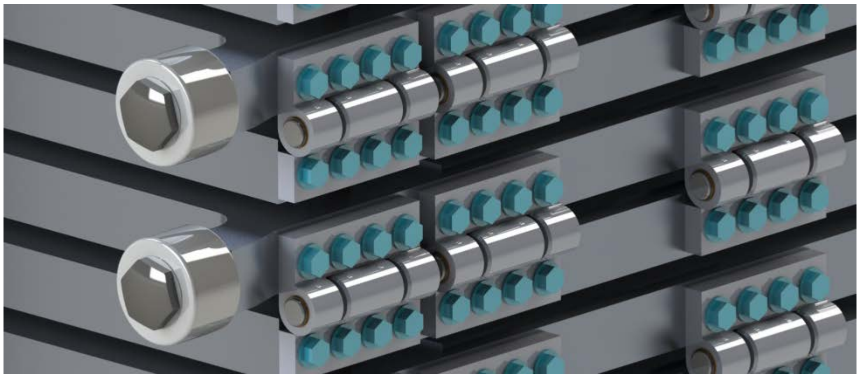
The studs to which the yoke rollers mount serve a secondary purpose of lateral guidance via bearing of the stud against a slide pad. This detail, however, has not performed well over time, as the semi-sharp chamfer of the stud had end-milled a rough trough in the slide pad over time. This behavior is shown in the images on the following page.



Magellan Roller and Stud (Left) and Slide Pad (Right)

Based on the roughness of the trough in the slide pad, it may be that stud dragging further amplifies the drive resistance and stick-slip behavior observed at both windscreens. Indeed, the wear was much more severe on the slide pads in the Baade windscreen, which may contribute to the more violent vibrations observed on site.

To ameliorate this behavior without a adjusting the space claim, a custom roller stud has been designed with a plated convex head that ensures smooth sliding of the steel stud against the slide pad. Budgetary pricing has been obtained on this element to verify that the cost increase due to the added complexity is not appreciable. See image below.



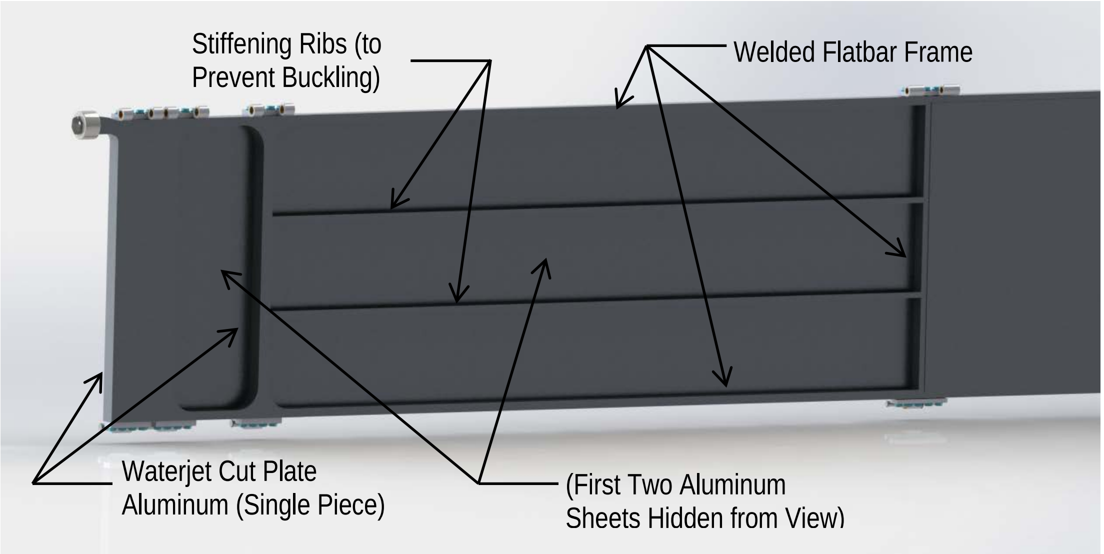
TSPM Rollers and Studs

With regards to the site RAMS analysis, one additional concern poised by the Magellan maintenance staff was the difficulty of accessing the rollers, since only isolated holes in the track allowed for access. Although difficult to produce the preferred level of accessibility with the current arrangement, the situation has been improved for the TSPM windscreen by creating an opening in the track that allows access to each and every roller in the stowed position. This was made possible by the previously described decision to anchor the lowermost panel to the substructure, which prevents the rollers from bearing against the slide pads near the stowed position and allows these elements to be removed from the design altogether without negative consequence.

Panel Design

As discussed earlier, the Clay and Baade panels utilize different construction methodology. Since analysis and site testing confirmed that honeycomb was not required for performance reasons, the aluminum panels for TSPM have been detailed as frame-and-sheet weldments for cost and ease of construction.

Specific detailing considerations are as follows: First, the panel ends (up to and through the third hinge point) have been specified to be waterjet cut from a single piece of aluminum plate, allowing for economically-obtained high tolerances for the placement of the hinges that are most sensitive to misalignments due to their proximity to each other. Second, the rest of the outer framing is comprised of welded aluminum flatbar, since hinges through the interior are less sensitive to tolerances and can accommodate industry-standard fabrication techniques. Third, relatively thin aluminum sheet has been paired with smaller longitudinal ribs in order to prevent local buckling without the need for adhered honeycomb panels. These details can be seen in the below image.



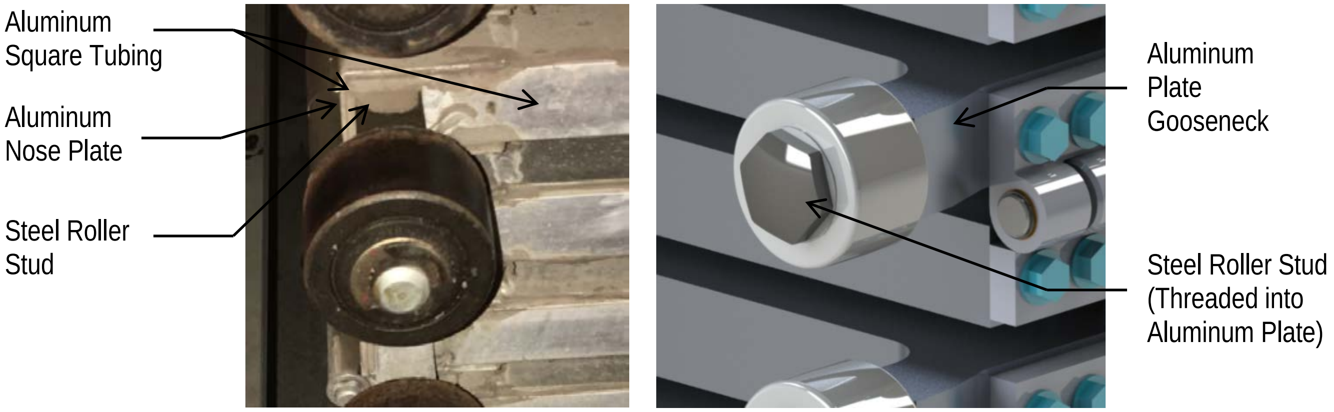
Aluminum Panel Detailing

On the leading panel, an additional stiffening angle has been added to further safeguard against wind-induced oscillations (since the leading edge is the only portion of any panel that is unstiffened by an adjacent panel or anchorage point).

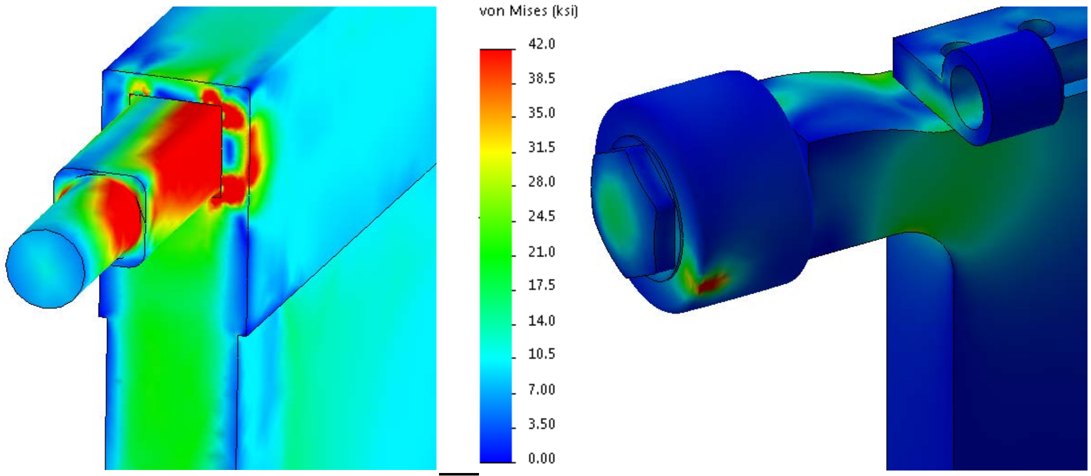
Due to consideration for localized stresses, additional detailing modifications were made to the windscreen panels at their interfaces with the roller, including the following.

First, the roller stud was shortened and switched from a sleeved-and-pinned connection to a preloaded threaded connection. This produces a more efficient load path for bending and significantly reduces the bending stresses in the roller stud. (While this removes access for lubricating the cam rollers, the TSPM rollers have been specified as lubricated-for-life heavy duty rollers.)

Second, the welded aluminum nose-plate construction was replaced with a gooseneck extension of the waterjet-cut aluminum plate. The downside to this approach is added complexity to replace panels in situ, but this is a rare (or wholly unexpected) scenario. Furthermore, this significantly reduces bearing and bending stresses in the aluminum, which in the original Magellan design likely reach or exceed the yield strength of the aluminum on the uppermost panels (for which the roller loads are the highest) when the windscreen is fully deployed. See images that follow.



Roller Mounting details – Magellan (Left) and TSPM (Right)

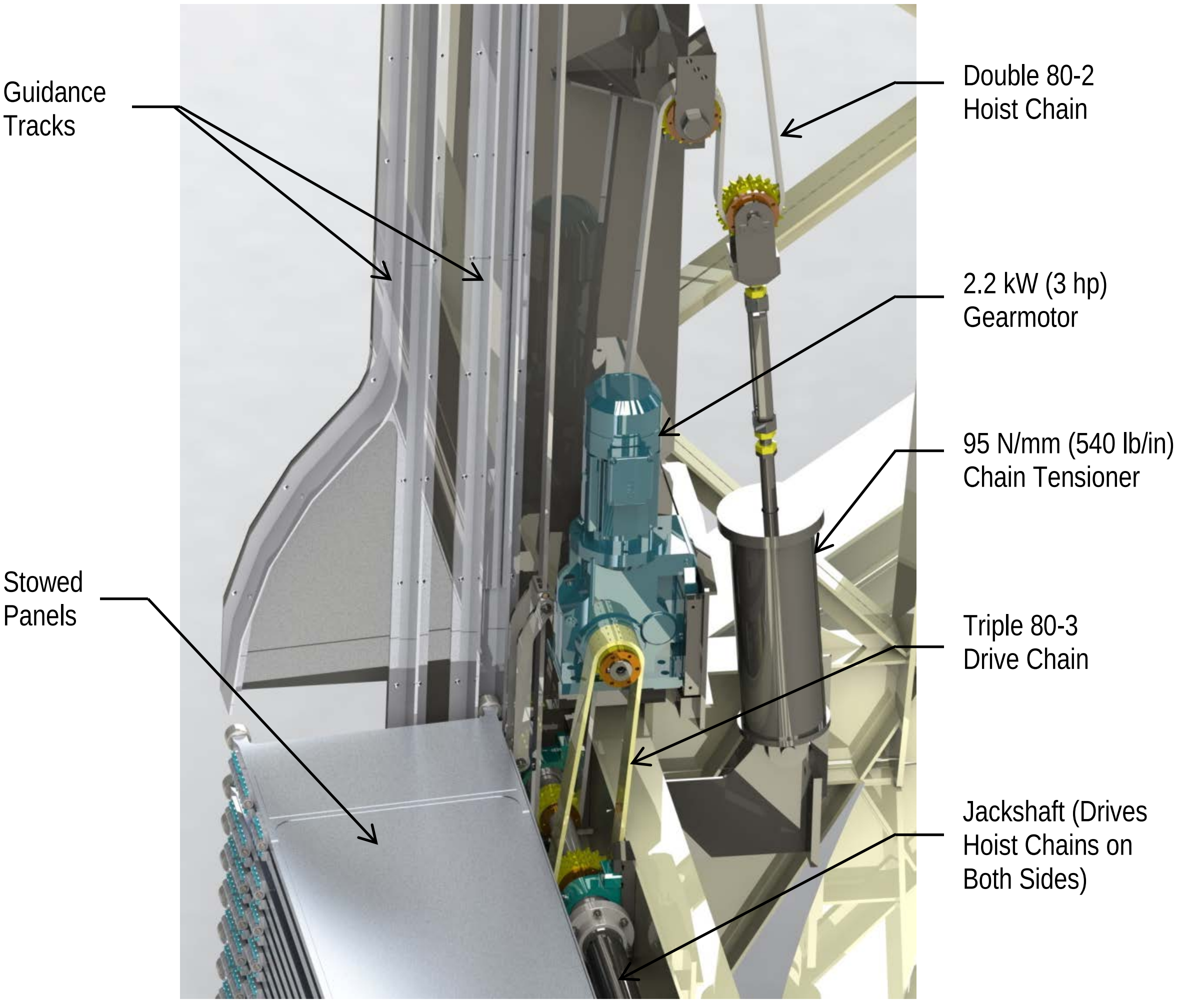


Von Mises Stress Plots for Roller Stud Connection under Max Roller Load – Magellan (Left) and TSPM (Right), Shown with Same Scale Bar (Center) [290 MPa (42 ksi) = Ultimate Strength of 6061-T6 Aluminum]

Drive and Jackshaft

The reliability, accessibility, maintainability, and safety of the gearmotor and jackshaft were both observed and reported to be adequate. In spite of higher-than-planned drive resistance, the 2.2 kW (3 hp) gearmotors have proven capable of deploying the windscreens. Calculations have further shown the motor to be adequate, albeit with little margin once binding and friction forces are taken into account. Other than modernization of part numbers, no changes to these components have been made in the TSPM design.

Additional drive system details can be seen in the below figure.

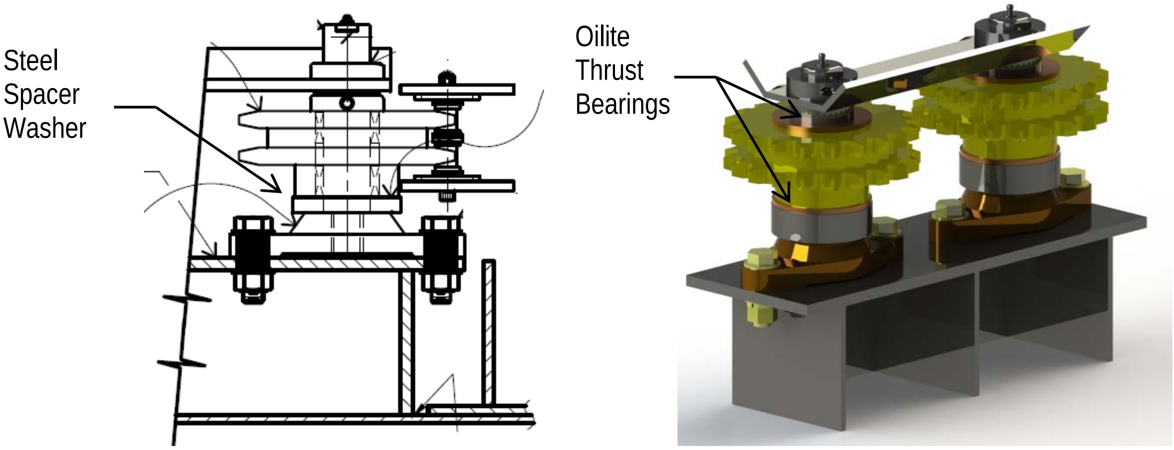


Windscreen Drive Details – TSPM

Chain and Sprocket

The windscreen chain and sprockets have performed relatively well at the Magellans and remain largely unaltered in the TSPM design, with two notable exceptions.

The first exception is the addition of thrust bearings at sprocket locations. Although not confirmed during the site visit, the Magellan shop drawings indicate that the load path for sprocket thrust loads includes steel-on-steel rubbing against spacer plates. In an effort to reduce drive resistance and stick-slip behavior to the greatest extent possible, these have been substituted with Oilite thrust bearings for the TSPM design; see images below.



Chain Sprocket Details – Magellan (Left) and TSPM (Right)

The second exception is a repositioning of the uppermost sprocket to avoid chain whip. As can be seen in the below image, the chain pulls away from the second-from-the-top sprocket as the windscreen tow arm passes over it. This behavior stems from the geometry of the three uppermost sprockets, all of which lie along a single line. Thus, as the windscreen tow arm passes over the middle of these sprockets, imparting a pull-away force due to the geometry of the tow arm, there is nothing but the self-weight of the chain available to keep the sprocket engaged with the chain.

Chain Disengagement with Sprocket

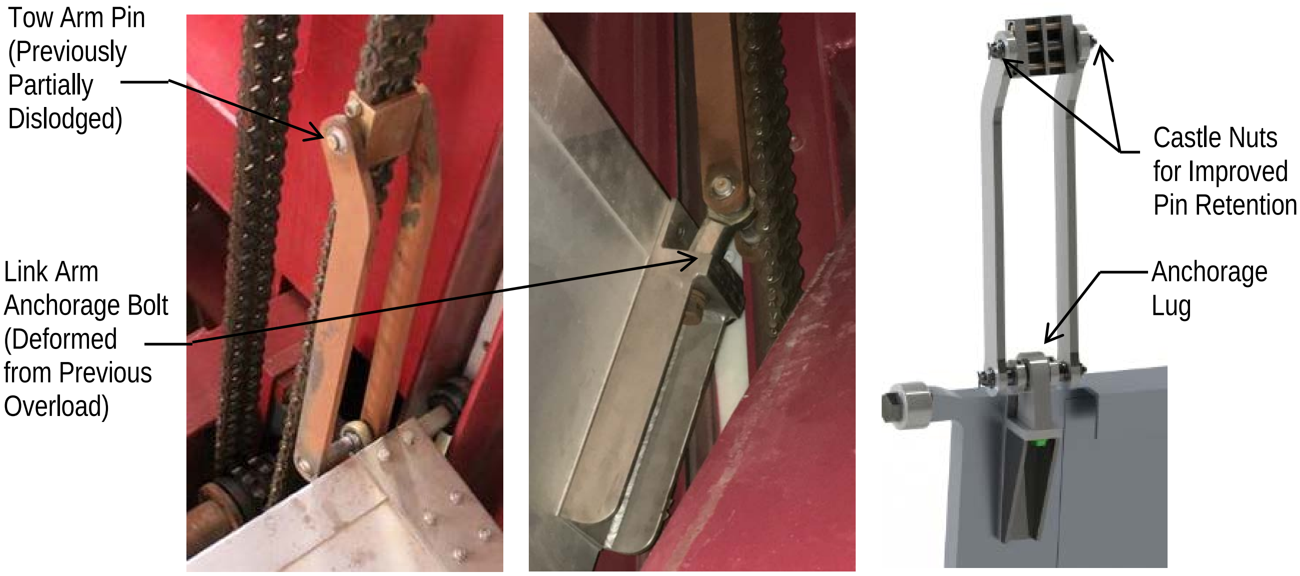
To eliminate this behavior, the uppermost sprocket has been shifted slightly downwards such that the pretension in the chain is sufficient to keep the chain engaged with the interior sprocket.

Tow Arm

The tow arm is an element of the drive train for which reliability shortcomings were expressed by the Magellan maintenance staff. The observed areas of concern were twofold.

First, the pin on the upper end had become partially dislodged and, if not noticed in time, could have led to a catastrophic collapse of the windscreen. It appeared that the retaining ring on the pin had become removed. Since this is a single-point-of-failure, this has been remedied in the TSPM design by replacing the retaining ring with a castle nut, which is more robust against failure in vibrating applications.

Second, the ¾" bolt that secures the link arm to the windscreen was visibly bent, apparently overloaded during a stowing operation due to the direction of yielding. This detail has been replaced with a staunch steel lug in the TSPM design. See the following photos and image.



Windscreen Tow Arm – Magellan (Left and Center) and TSPM (Right)

Limit Switches and Encoder

Limit switches and an absolute encoder will be used to monitor and verify the position of the windscreen, as is the case for the Magellan windscreens. For improved robustness and longevity of components, the mechanical limit switches will be replaced with inductive limit switches.

The selected encoder, which will be mounted to the output shaft of the gearmotor, provides a rotational accuracy of 0.35°. This equates to a windscreen linear position accuracy of roughly 0.5 mm, which, in turn, translates to an angular position accuracy (as measured relative to telescope origin) of approximately 0.003°. This is well within the specified positional accuracy of 0.1° and allows sufficient margin of error for structural and mechanical deflections.

4.4 Moonscreen

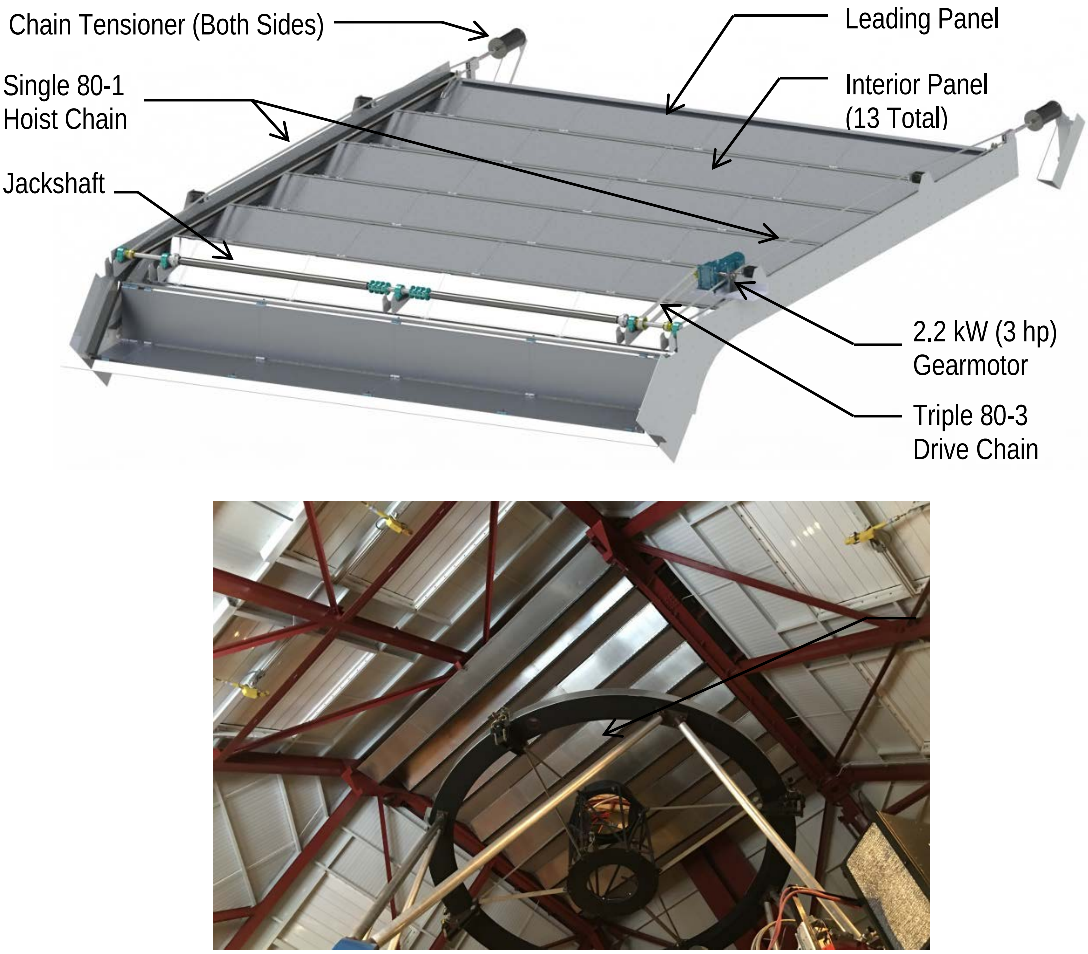
Design Requirements

The moonscreen specifications and requirements mimic those of the windscreen.

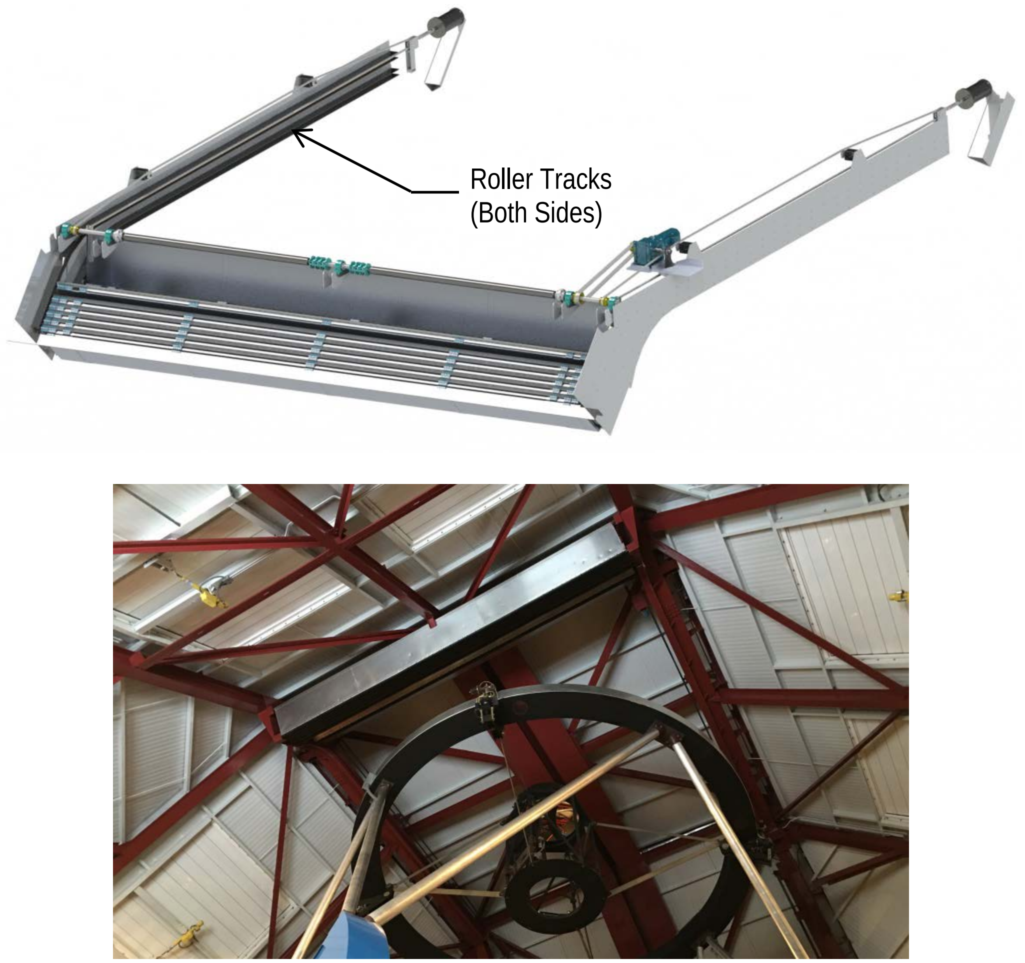
General Layout

The mooncreen protects the telescope from stray light during observations. The moonscreen is located in the roof of the enclosure structure within the observation opening. When not in use, the moonscreen folds and stows in a dedicated recess at the back of the observation opening, beneath the upper shutter beam.

The moonroof construction, form, and mechanization are all similar to those of the windscreen. However, because the moonscreen moves horizontally rather than vertically, drive loads, roller reactions, and hinge loads are all substantially reduced as compared to the windscreen. Even though demands are less, though, commonality of parts is sought where practical to minimize parts and streamline maintenance activities.



Deployed Moonscreen – TSPM (above) and Magellan (below)



Stowed Moonscreen – TSPM (above) and Magellan (below)

Magellan Performance and RAMS

As opposed to the windscreens, the Magellan moonscreens have shown a high level of reliability. Due to its location on the roof, accessibility and safety are suboptimal, although the maintenance staff has developed the habit of using the deployed moonscreen itself as a maintenance platform for the chains, sprockets, and gearmotor. It should be discussed whether the moonscreen should be analyzed and designed for this load case for TSPM.

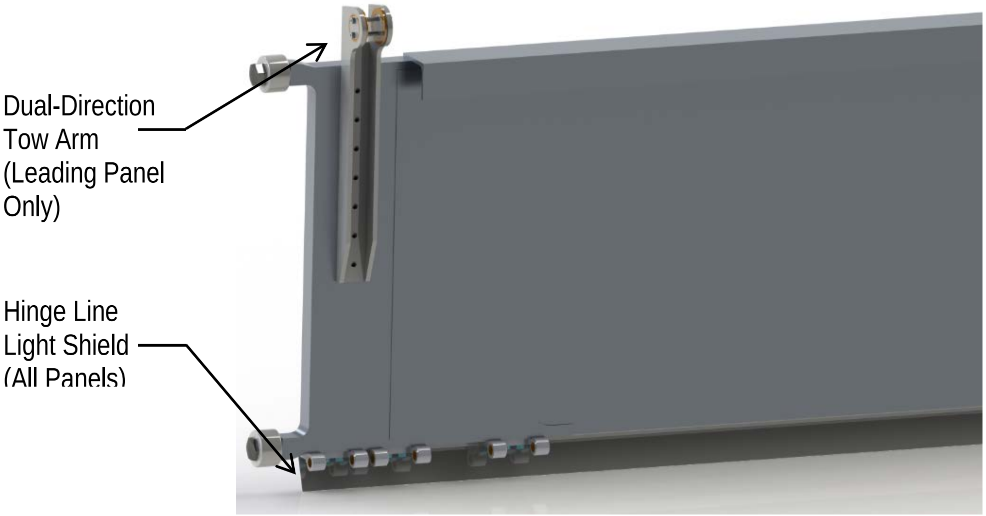
The largest shortcoming expressed by the maintenance staff is the difficulty of accessing the rollers, particularly in the stowed position. For TSPM, the same solution incorporated for access to the windscreen rollers will be implemented: cutouts will be added between the track plates, made possible by anchoring the lowermost panel laterally to prevent panel drift.

Panel Detailing

As with the Magellan baseline design, commonality of panel detailing is kept between the windscreen and the moonscreen for simplicity of design, fabrication, and spare parts. Due to performance reasons, there are two exceptions to this.

First, a light shield has been added to every hinge line to eliminate stray light that could penetrate between the discrete hinge locations (this was not necessary at the Magellans due to the use of continuous piano hinges at the hinge lines).

Second, the tow arm detail from the Magellan moonscreen was used in favor of the tow arm used on the windscreen since 1) The windscreen tow arm concept is intended to work only in tension, and 2) The Magellan moonscreen tow arm detail has proven to be a successful precedent.

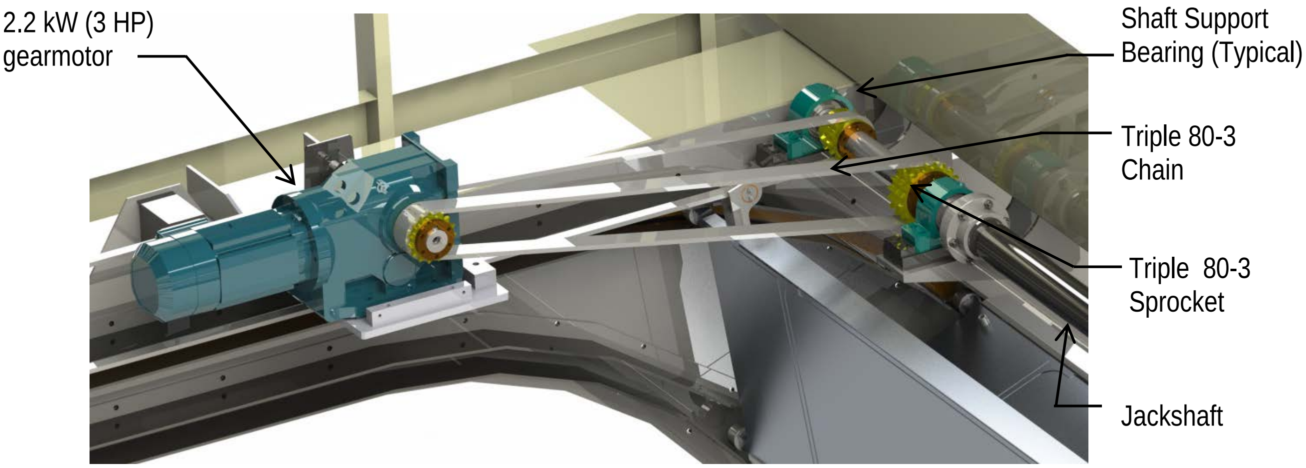


Moonscreen-Specific Panel Detailing – TSPM

Commonality of Drive Parts

The commonality of parts between the windscreen and the moonscreen for TSPM has been extended to include even more commonality than was the case for the Magellans, specifically the drive components. The jackshaft and all its components will be identical between the windscreen and the moonscreen, as will be the 2.2 kW (3 hp) gearmotor, which was originally specified as a 0.7 kW (1 hp) gearmotor for the Magellan moonscreen. The cost increase for upsizing these components is almost negligible, and it will allow for the same spare parts to service both mechanical systems. Drive train that will now be common to both systems are shown in the following figure.

In addition, the same absolute encoder as the windscreen will be used for the moonscreen. As a result, positional accuracy will be similar between the moonscreen and the windscreen, with roughly 0.003° in positional error (relative to telescope origin) resulting from the accuracy limitations of the encoder itself.



Moonscreen Drive Components Common with Windscreen – TSPM

Modification to Magellan Arrangement

Only one layout modification was made to the baseline moonscreen design: The jackshaft was shifted back, slightly nearer to the upper shutter beam, to facilitate greater telescope viewing clearances past the zenith position. Since additional panel travel and stowage room was already available, this was the only modification necessary to increase the viewing clearance.

4.5 Shutter Mechanisms

Design Requirements

The shutter mechanisms shall comply with the following specifications:

- Shutter open/close maximum time of 2 minutes
- Shutters stop in less than 5 seconds in case of emergency
- Wind speeds:
  - Maximum operational wind speed 50 kilometer per hour (31 mph)
  - Maximum operational gust wind speed 70 kilometer per hour (44 mph)
  - Survival wind speed 170 kilometer per hour (106 mph)

The shutter mechanisms shall also comply with the following requirements:

- Independent operation of each shutter
- Sustain all imposed vertical loads
  - Shutter weight for normal operations
  - Shutter, snow and ice weight for survival conditions
  - Shutter weight under vertical seismic accelerations for survival conditions
- Sustain all imposed horizontal loads
  - Maximum operational wind speeds for normal operations
  - Survival wind gust speed for survival conditions
  - Lateral seismic loads for survival conditions
  - Self-straining loads due to construction tolerances and self-straining effects, including creep forces
- Provide easy alignment and adjustment of mechanisms during erection and maintenance

- Provide for maintenance access
- Provide protection of all parts against corrosion

Shutter Mechanisms General Layout

The shutter mechanisms consist of two separate systems: restraints and drives. The shutter restraints are comprised of vertical wheel shutter bogies, lateral guide rollers, and uplift rollers, all of which serve to support and guide the shutter door during travel. The shutter drives – one system per door – consist of a gearmotor, reduction gearboxes, shafting with pillow block supports and universal joint connections, pinions, and racks, all mechanically joined such that a single motor drives each door along both the upper and lower shutter beam.

Images of the various drive and restraint components are shown following the system-by-system component descriptions.

Shutter Mechanisms RAMS Assessment

Per the Magellan maintenance staff, the shutter doors have exhibited a high degree of reliability. Although issues have previously been encountered with the universal joints, these were remedied once routine maintenance procedures were implemented to ensure proper lubrication (once every 6 months). Accessibility and safety suffer from some of the same limitations as the moonscreen, but with lifts all mechanisms are directly accessible. The largest mechanical components, the reducers, have never been replaced.

The primary concerns expressed by the maintenance staff were both related to the lateral guide rollers. First, the bearings in the lateral guide rollers had failed on multiple occasions, requiring replacement. Second, when these lateral guide rollers had to be replaced, jacking of the shutters was required to unload the rollers (the self-weight of the shutters pushes the inboard guide rollers against the shutter beam rail), and there was no convenient way to do so.

Other than addressing the concerns related to the cam rollers, no significant modifications to the layout or approach of the baseline design will be incorporated in the design for the TSPM shutter mechanisms.

Bogies

Four shutter bogies support each shutter under its self-weight, with one bogie at each upper corner and one bogie at each lower corner. Shutter bogie weldments are of welded construction and house a single crane-type wheel with internal bearings and wheel shaft. Permanent adjustment blocks and jack screws are provided on bogie weldments for alignment and positioning of bogie wheels and restraints to required tolerances. Bogies travel along structural steel beams to allow full movement of the shutters to the open position.

Shutter Uplift and Lateral Restraints

Weldments bolted onto the shutter door structure near all of the upper and lower bogies provide mounting locations for uplift and lateral restraint rollers. Uplift restraints are cam yoke roller bearings mounted on plates sized to accommodate survival uplift loads. Lateral restraints are cam yoke roller bearings mounted on plates sized to accommodate survival lateral loads.

To address the reliability concerns expressed by the maintenance staff, two modifications will be made. First, the lateral guide rollers will be switched from needle-bearing type to tapered-roller-bearing type, which will provide more robustness against thrust loads without any tradeoff in space claim or cost. Second, jacking points will be coordinated with the structural steel package such that the guide roller preload can be safely removed should a replacement still be necessary.

Drive Assemblies

Each shutter drive assembly includes a gearmotor unit that drives shafting to operate drive pinions located at the upper and lower shutter ends. This shafting follows the geometry of the enclosure arch girders through a series of bearing supports, couplings, and universal joints. A reduction gearbox is located at the end of each shaft (upper and lower) driving the pinion to operate the shutter.

Each shutter gearmotor is a 1.5 kW (2 hp) unit, unchanged from the baseline design. In the event that emergency operation is required, a manual operation hand wheel will be provided for each gearmotor for use in the absence of power.

The gearmotors are equipped with fail-safe brakes to arrest shutter movement; brakes will engage automatically in case of power failure but can be manually released if needed for emergency operation via the hand wheel. Gearmotor and reduction gearbox position adjustments are accomplished through the use of shims and slotted holes in support weldments. An absolute encoder monitors position of both the upper and lower racks via pinions dedicated to position monitoring.

Rack and Pinion

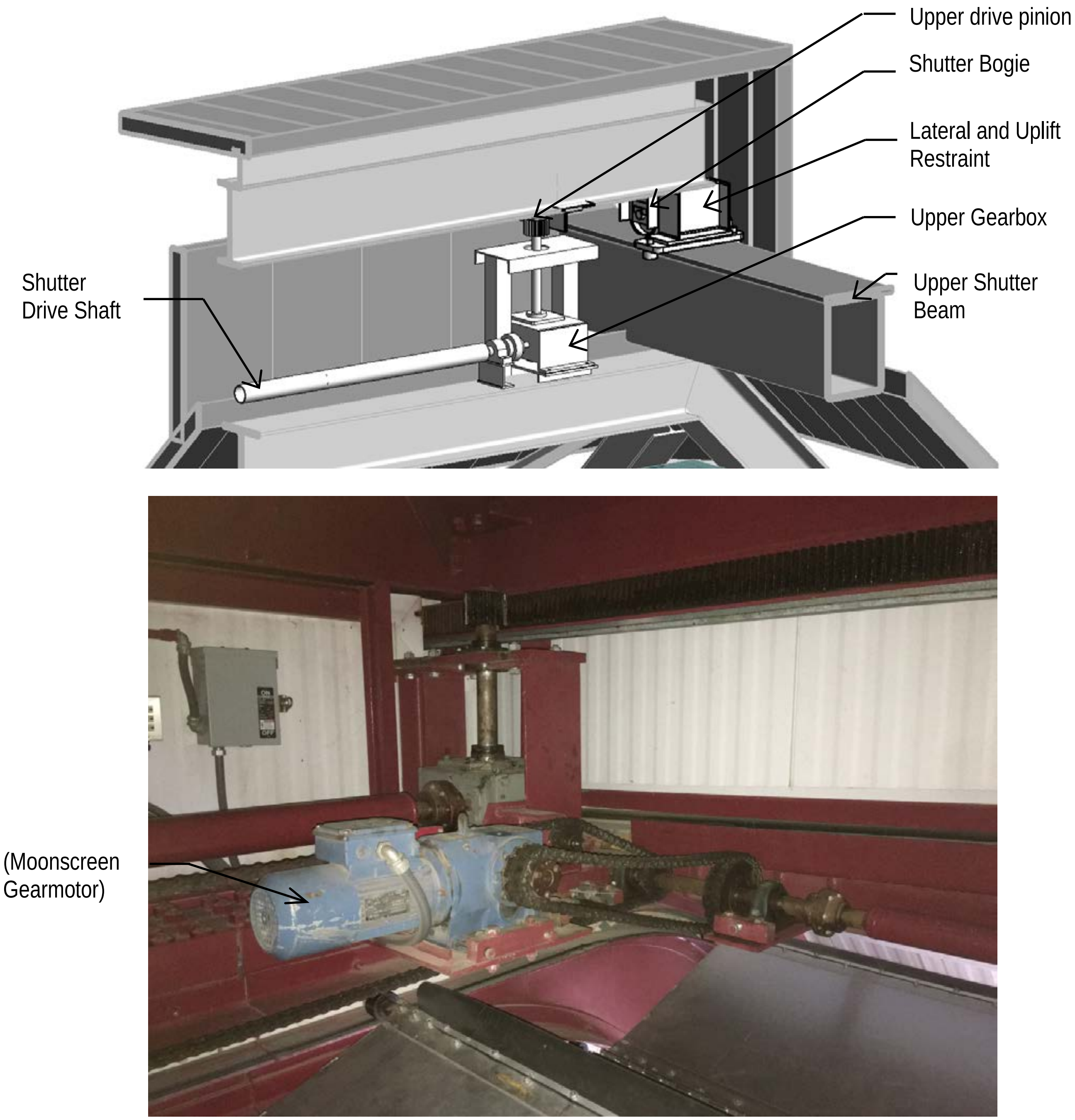
Rack gear is attached directly to the shutters on both the upper and lower extents and travels with the shutters as they open and close. The racks are mounted to steel structural angles with connections that allow fine adjustments through shimming and slotted holes. Fine-tuning of these connections will be required to ensure proper engagement between the racks and their pinion gears.

Over-Travel Stops

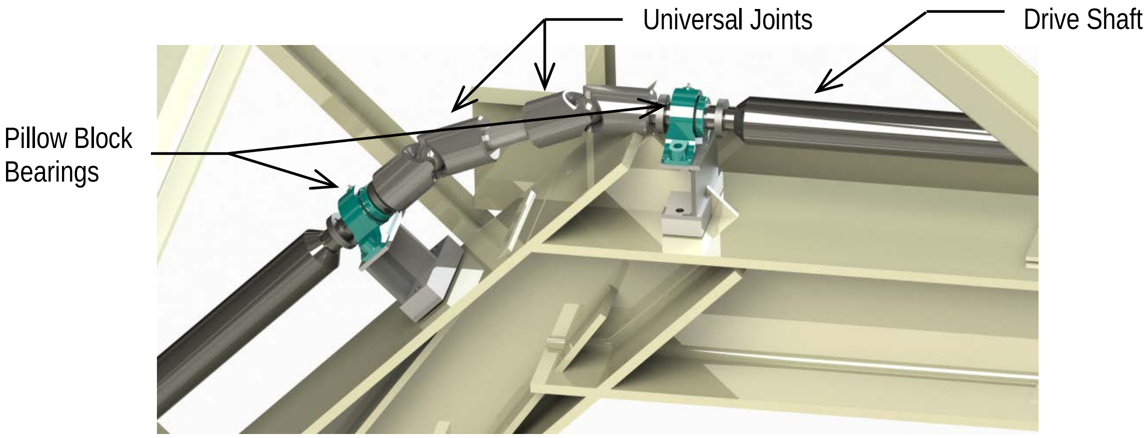
Over-travel stops are mounted to both the upper and lower shutter beams, at the extreme open and close travel limits of the shutters. A total of eight over-travel stops are needed, two at the end of each shutter beam. The over-travel stops include bumpers, stop bolts, and proximity sensors to report end-of-travel positions to the control system.

Maximum Shutter Aperture

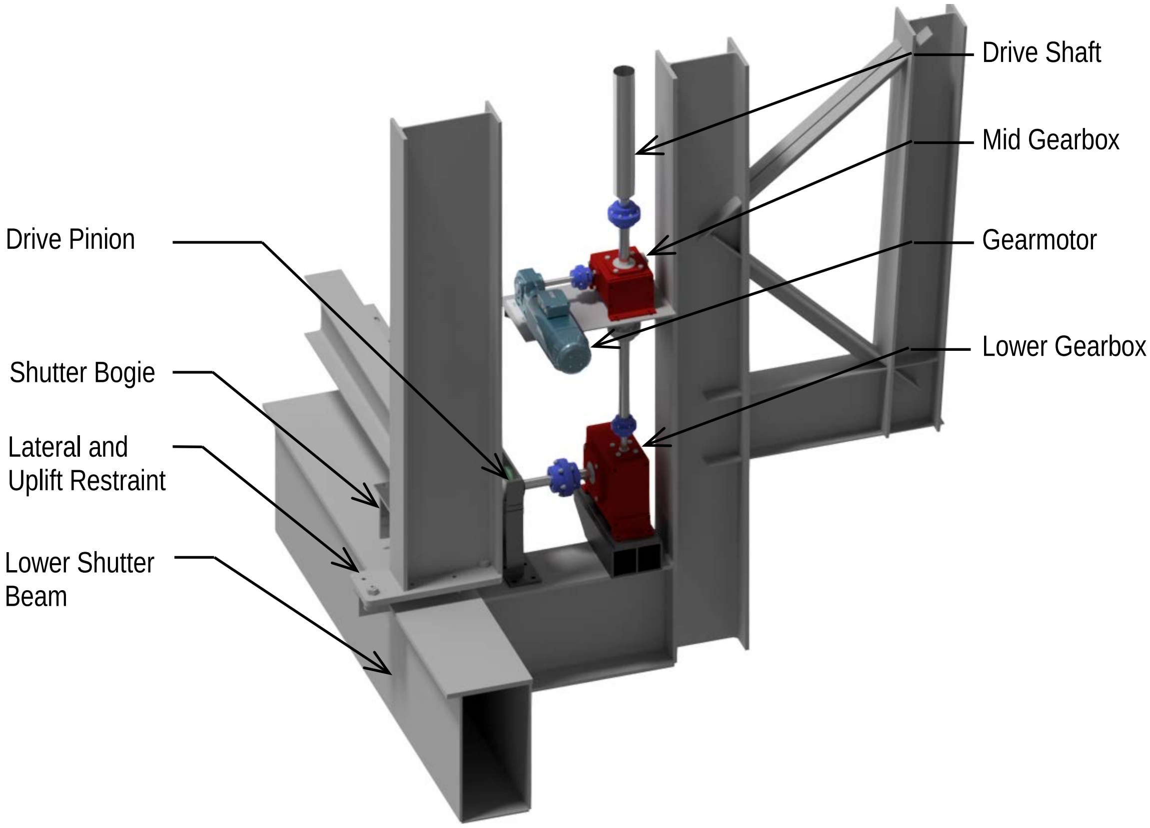
The maximum shutter aperture per design is 8 m. For construction activities, over-travel may be desirable or necessary for introducing structural parts of the telescope into the enclosure. With the shutter drive fully installed and the shutter hard stops removed, the next point of interference is between the drive pinion and the shutter steel column and occurs at a shutter aperture of 8.2 m. With the removal of several drive components – including pinions, shafts, and reducers – the shutters could be manually opened to a maximum aperture of 8.6 m; temporary stops would be required to ensure the shutters remain on the shutter beams.



Upper Shutter Drive – TSPM (above) and Magellan (below)



Shutter Drive Universal Joint (Typical, Two Places per Drive)

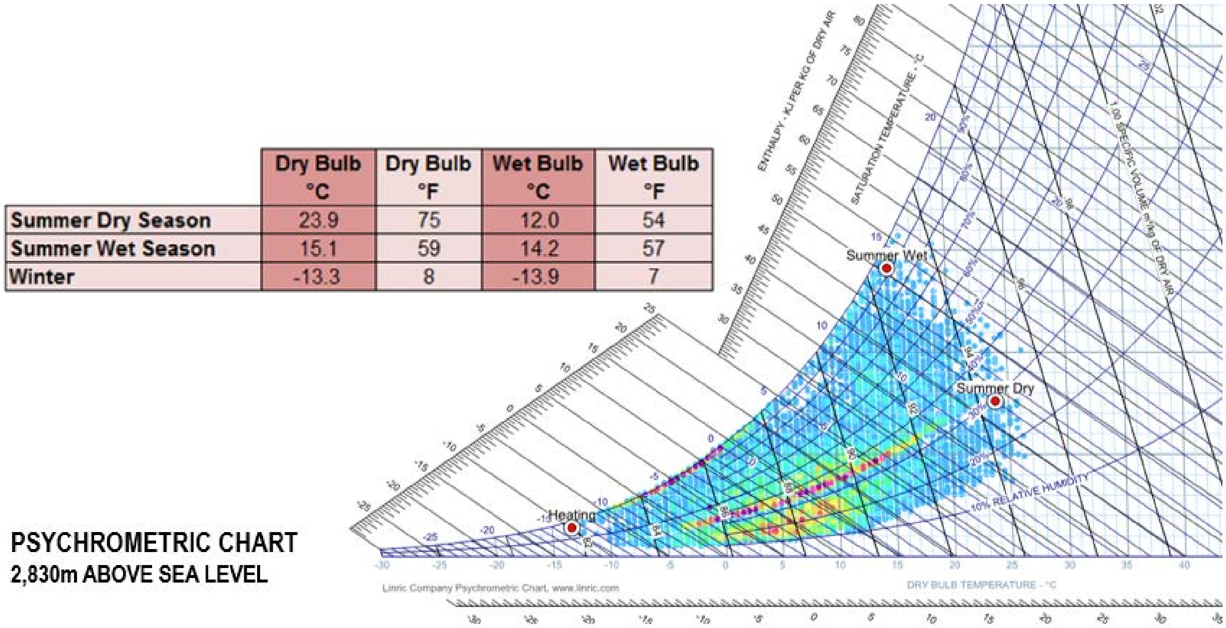


Lower Shutter Drive

5 MECHANICAL AND PLUMBING

5.1 SITE WEATHER DATA

Selecting the correct weather design conditions is essential to providing an efficient and properly sized Heating, Ventilation and Air Conditioning (HVAC) system. TSPM provided historical weather data from June 2006 to August 2014. This data was then plotted on a psychrometric chart, see Image 5.1. Three design points are noted on the chart, these points correspond to the Summer Dry, Summer Wet and Winter conditions. These are the temperatures that are used in HVAC design calculations. Two summer conditions are required as the high moisture content of the wet season air has a significant impact on the HVAC system calculations, especially spaces that have large outside air requirements.

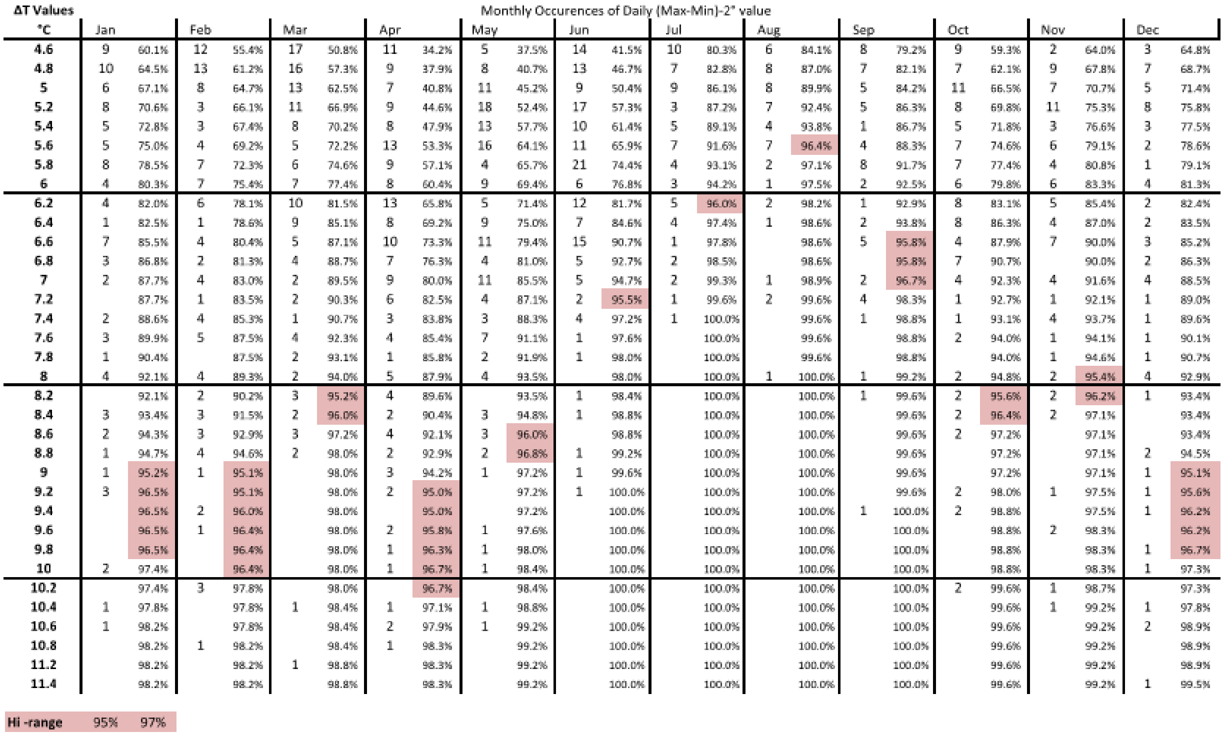


	Dry Bulb °C	Dry Bulb °F	Wet Bulb °C	Wet Bulb °F
Summer Dry Season	23.9	75	12.0	54
Summer Wet Season	15.1	59	14.2	57
Winter	-13.3	8	-13.9	7

Image 5.1 - Psychrometric Chart with HVAC Site Weather Design Points

5.2 ENCLOSURE COOLING

The Telescope Enclosure will be cooled during the daytime so that it is maintained 2 degree C above the measured previous dawn temperature. The differential between the daytime high and the morning dawn temperature plus 2°C point have been sorted by month to see how the differential changes during the year. A 10°C differential will be used for the dry season while a 7 degree C differential will be used for the wet season. By using the 7 degree C versus the 10 degree C temperature difference for the wet season calculation, the enclosure cooling loads were reduced. This temperature differential is shown on Table 5.1, the 95% to 97% points have been highlighted.



ΔT Values	Monthly Occurences of Daily (Max-Min)-2° value																							
°C	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
4.6	9	60.1%	12	55.4%	17	50.8%	11	34.2%	5	37.5%	14	41.5%	10	80.3%	6	84.1%	8	79.2%	9	59.3%	2	64.0%	3	64.8%
4.8	10	64.5%	13	61.2%	16	57.3%	9	37.9%	8	40.7%	13	46.7%	7	82.8%	8	87.0%	7	82.1%	7	62.1%	9	67.8%	7	68.7%
5	6	67.1%	8	64.7%	13	62.5%	7	40.8%	11	45.2%	9	50.4%	9	86.1%	8	89.9%	5	84.2%	11	66.5%	7	70.7%	5	71.4%
5.2	8	70.6%	3	66.1%	11	66.9%	9	44.6%	18	52.4%	17	57.3%	3	87.2%	7	92.4%	5	86.3%	8	69.8%	11	75.3%	8	75.8%
5.4	5	72.8%	3	67.4%	8	70.2%	8	47.9%	13	57.7%	10	61.4%	5	89.1%	4	93.8%	1	86.7%	5	71.8%	3	76.6%	3	77.5%
5.6	5	75.0%	4	69.2%	5	72.2%	13	53.3%	16	64.1%	11	65.9%	7	91.6%	7	96.4%	4	88.3%	7	74.6%	6	79.1%	2	78.6%
5.8	8	78.5%	7	72.3%	6	74.6%	9	57.1%	4	65.7%	21	74.4%	4	93.1%	2	97.1%	8	91.7%	7	77.4%	4	80.8%	1	79.1%
6	4	80.3%	7	75.4%	7	77.4%	8	60.4%	9	69.4%	6	76.8%	3	94.2%	1	97.5%	2	92.5%	6	79.8%	6	83.3%	4	81.3%
6.2	4	82.0%	6	78.1%	10	81.5%	13	65.8%	5	71.4%	12	81.7%	5	96.0%	2	98.2%	1	92.9%	8	83.1%	5	85.4%	2	82.4%
6.4	1	82.5%	1	78.6%	9	85.1%	8	69.2%	9	75.0%	7	84.6%	4	97.4%	1	98.6%	2	93.8%	8	86.3%	4	87.0%	2	83.5%
6.6	7	85.5%	4	80.4%	5	87.1%	10	73.3%	11	79.4%	15	90.7%	1	97.8%		98.6%	5	95.8%	4	87.9%	7	90.0%	3	85.2%
6.8	3	86.8%	2	81.3%	4	88.7%	7	76.3%	4	81.0%	5	92.7%	2	98.5%		98.6%		95.8%	7	90.7%		90.0%	2	86.3%
7	2	87.7%	4	83.0%	2	89.5%	9	80.0%	11	85.5%	5	94.7%	2	99.3%	1	98.9%	2	96.7%	4	92.3%	4	91.6%	4	88.5%
7.2		87.7%	1	83.5%	2	90.3%	6	82.5%	4	87.1%	2	95.5%	1	99.6%	2	99.6%	4	98.3%	1	92.7%	1	92.1%	1	89.0%
7.4	2	88.6%	4	85.3%	1	90.7%	3	83.8%	3	88.3%	4	97.2%	1	100.0%		99.6%	1	98.8%	1	93.1%	4	93.7%	1	89.6%
7.6	3	89.9%	5	87.5%	4	92.3%	4	85.4%	7	91.1%	1	97.6%		100.0%		99.6%		98.8%	2	94.0%	1	94.1%	1	90.1%
7.8	1	90.4%		87.5%	2	93.1%	1	85.8%	2	91.9%	1	98.0%		100.0%		99.6%		98.8%		94.0%	1	94.6%	1	90.7%
8	4	92.1%	4	89.3%	2	94.0%	5	87.9%	4	93.5%		98.0%		100.0%	1	100.0%	1	99.2%	2	94.8%	2	95.4%	4	92.9%
8.2		92.1%	2	90.2%	3	95.2%	4	89.6%		93.5%	1	98.4%		100.0%		100.0%	1	99.6%	2	95.6%	2	96.2%	1	93.4%
8.4	3	93.4%	3	91.5%	2	96.0%	2	90.4%	3	94.8%	1	98.8%		100.0%		100.0%		99.6%	2	96.4%	2	97.1%		93.4%
8.6	2	94.3%	3	92.9%	3	97.2%	4	92.1%	3	96.0%		98.8%		100.0%		100.0%		99.6%	2	97.2%		97.1%		93.4%
8.8	1	94.7%	4	94.6%	2	98.0%	2	92.9%	2	96.8%	1	99.2%		100.0%		100.0%		99.6%		97.2%		97.1%	2	94.5%
9	1	95.2%	1	95.1%		98.0%	3	94.2%	1	97.2%	1	99.6%		100.0%		100.0%		99.6%		97.2%		97.1%	1	95.1%
9.2	3	96.5%		95.1%		98.0%	2	95.0%		97.2%	1	100.0%		100.0%		100.0%		99.6%	2	98.0%	1	97.5%	1	95.6%
9.4		96.5%	2	96.0%		98.0%		95.0%		97.2%		100.0%		100.0%		100.0%	1	100.0%	2	98.8%		97.5%	1	96.2%
9.6		96.5%	1	96.4%		98.0%	2	95.8%	1	97.6%		100.0%		100.0%		100.0%		100.0%		98.8%	2	98.3%		96.2%
9.8		96.5%		96.4%		98.0%	1	96.3%	1	98.0%		100.0%		100.0%		100.0%		100.0%		98.8%		98.3%	1	96.7%
10	2	97.4%		96.4%		98.0%	1	96.7%	1	98.4%		100.0%		100.0%		100.0%		100.0%		98.8%		98.3%	1	97.3%
10.2		97.4%	3	97.8%		98.0%		96.7%		98.4%		100.0%		100.0%		100.0%		100.0%	2	99.6%	1	98.7%		97.3%
10.4	1	97.8%		97.8%	1	98.4%	1	97.1%	1	98.8%		100.0%		100.0%		100.0%		100.0%		99.6%	1	99.2%	1	97.8%
10.6	1	98.2%		97.8%		98.4%	2	97.9%	1	99.2%		100.0%		100.0%		100.0%		100.0%		99.6%		99.2%	2	98.9%
10.8		98.2%	1	98.2%		98.4%	1	98.3%		99.2%		100.0%		100.0%		100.0%		100.0%		99.6%		99.2%		98.9%
11.2		98.2%		98.2%	1	98.8%		98.3%		99.2%		100.0%		100.0%		100.0%		100.0%		99.6%		99.2%		98.9%
11.4		98.2%		98.2%		98.8%		98.3%		99.2%		100.0%		100.0%		100.0%		100.0%		99.6%		99.2%	1	99.5%

Hi -range	95%	97%

Table 5.1 – Analyzing Enclosure Maximum Temperature Differentials for Cooling Load Calculations
ΔT Values = (Day High-Day Low) - 2°C
Number under months are occurrences for ΔT values listed
Percent (%) numbers are the cumulative total of the occurrences

The Enclosure will be cooled by using (4) Fan Coil Units (FCU), see Image 5.2. The summer wet season with its high relativity humidity and the winter time's coldest days will be the most challenging for this system. During the winter months, the enclosure can cool to minus 2 degree C which is the lowest operational temperature. To cool the enclosure to this temperature will require minus 15 degree C chilled water. A water cooled low temperature chiller has been placed in the Support Building to provide the required chilled water to the FCU's. Ducts will connect the air devices located on the Observing Level, see Image 5.3, to the FCUs located below the observing floor. Each unit has been sized to cool 1/4 of the Enclosure load. Air devices on the end of the supply duct will allow the supply air to be directed to minimize space stratification.

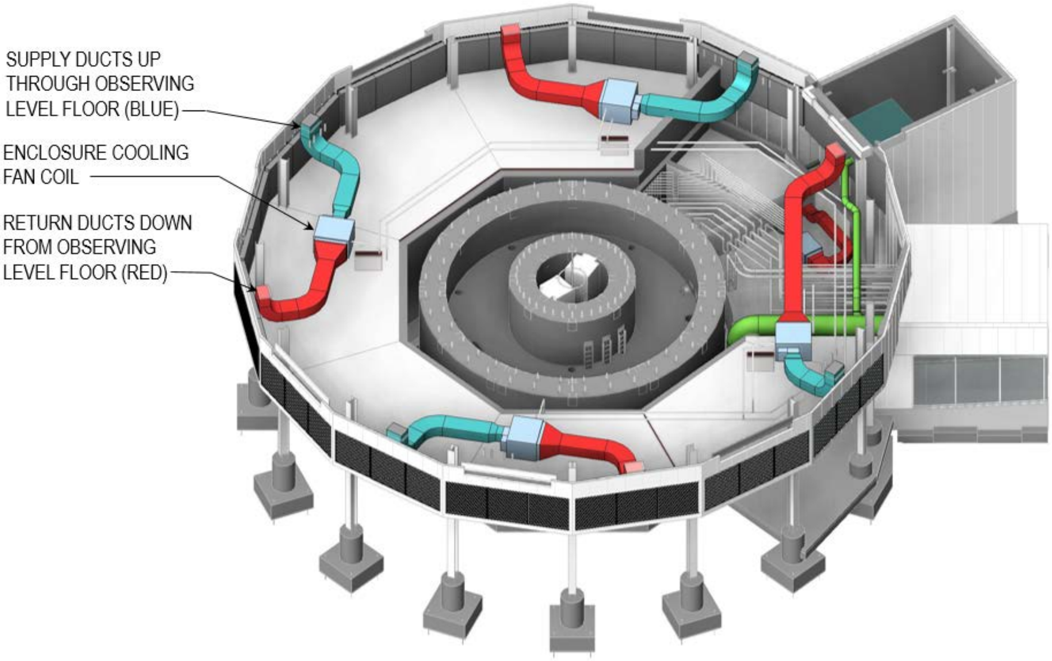


Image 5.2 - Enclosure Fan Coil Units Below Observing Floor

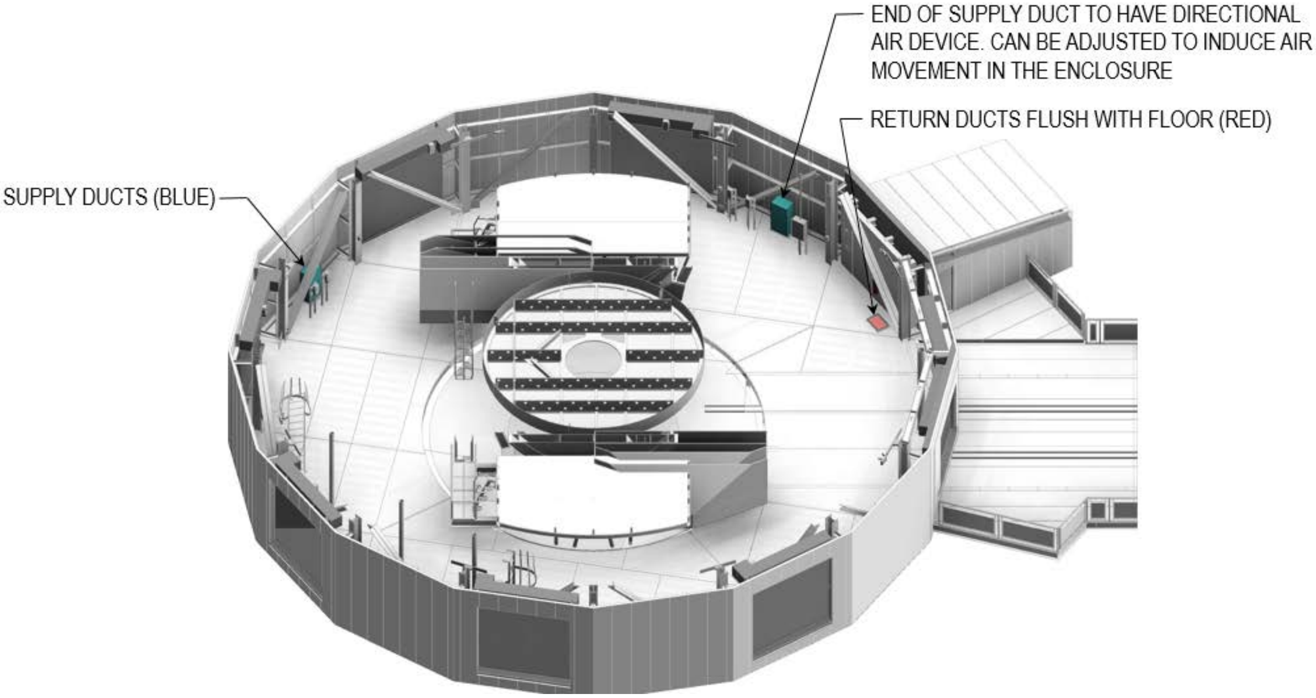


Image 5.3 - Enclosure Observing Floor Supply and Return Ducts

5.3 SUPPORT BUILDING HVAC

The Support Building has multiple spaces that all require different heating and cooling requirements and in some cases humidity control. Water cooled fan coil units with electric heat or electric unit heaters will be used to maintain space temperatures. In spaces that have a maximum humidity level the cooling coil will have sufficient capacity to dehumidify the air. In spaces that have a minimum humidity requirement an electric humidifier will be used. All supply and return air is circulated by a system of rigid metal and flexible duct with air devices positioned in each conditioned space. All occupied spaces will be provided outside air in accordance with ASHRAE 62.1.

All toilets, workshop areas and similar areas will be exhausted as required by ASHRAE 62.1. Rooms with UPS batteries will be exhausted by a dedicated fan. These systems will discharge on the Support Buildings eastern wall via weatherproof louvers.

The proposed temperatures have been identified for each space, see Image 5.4, 5.5, and 5.6.

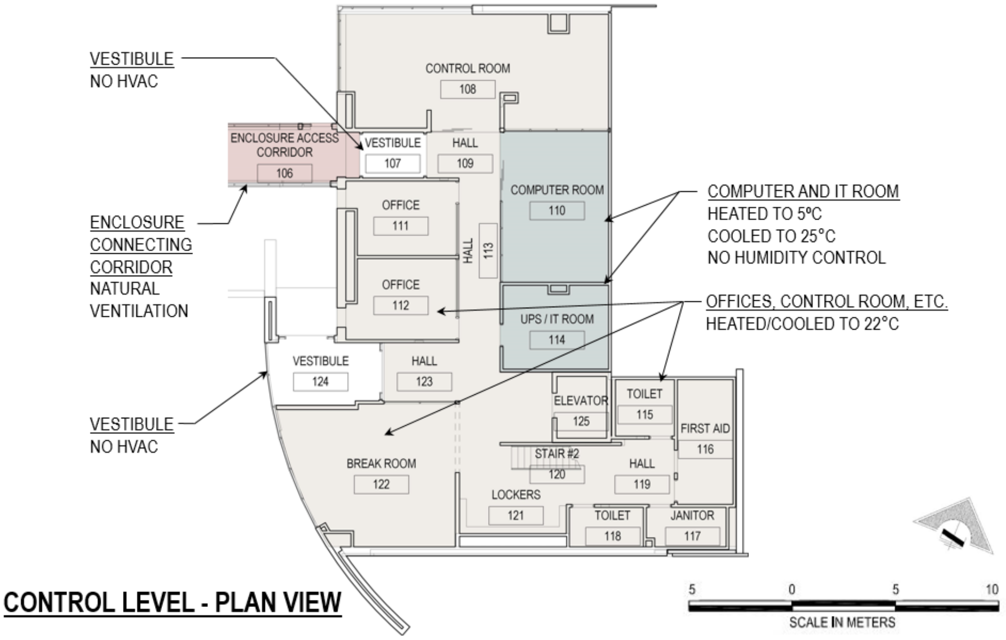


Image 5.4 – Space Cooling and Heating Temperatures – Control Level

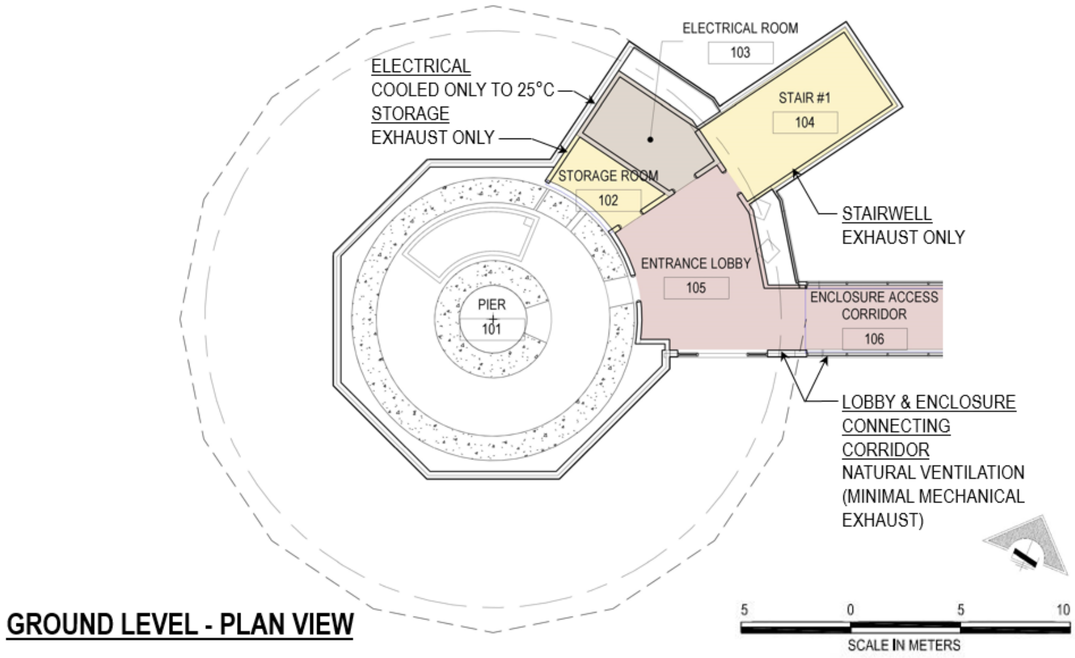


Image 5.5 – Space Cooling and Heating Temperatures – Fixed Enclosure

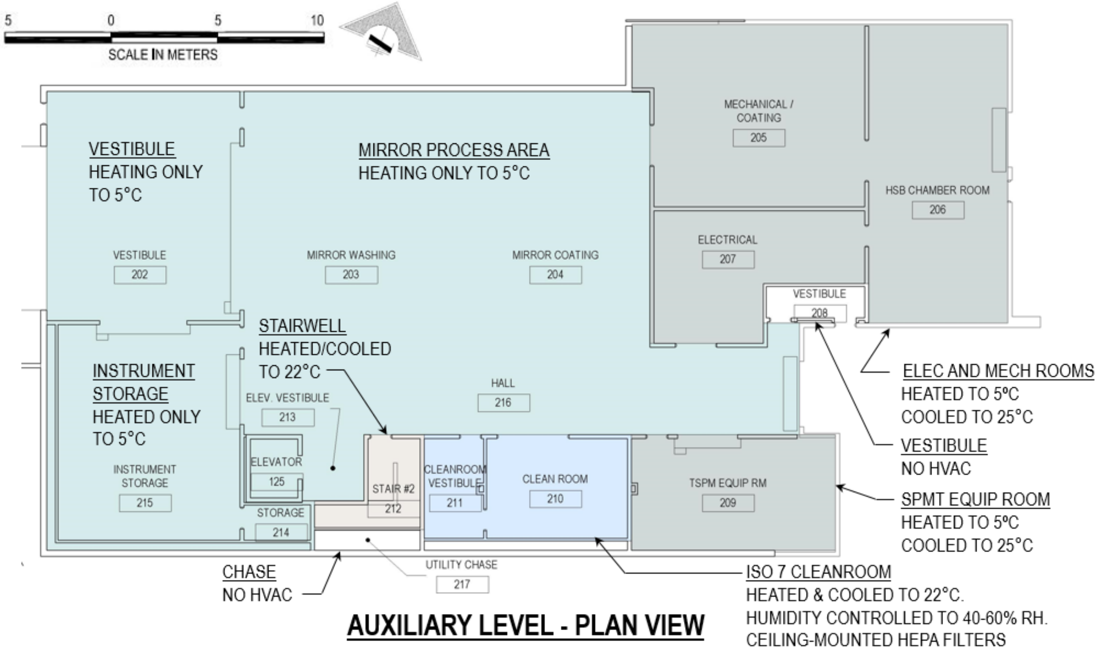


Image 5.6 – Space Cooling and Heating Temperatures – Auxiliary Level

5.4 PIER AND LOBBY VENTILATION

Project requirements require the pier to be exhausted while the telescope is operational, see Image 5.7. The storage room, stairwell, and lobby will be ventilated at night to help remove any stray heat plumes. These three areas will use a common system and the air will be exhausted out the Support Buildings east wall. A centrifugal exhaust fan suspended on spring isolators will be located in the Support Building.

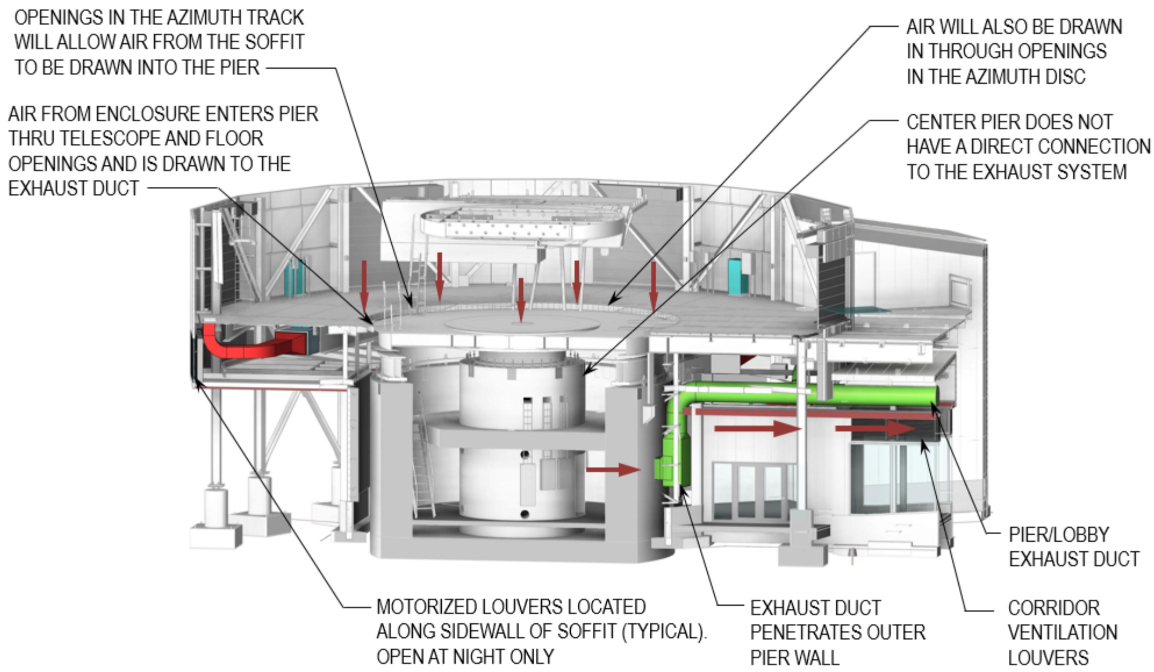


Image 5.7 – Pier and Lobby Ventilation

Louvers have been placed around the Lower Enclosure to allow the plenum space to be ventilated at night. These louvers will be controlled through the Building Management System (BMS). The connecting corridor has louvers on each side. A manual switch located in the corridor will allow the owner to open/close the louvers as required, see Image 5.8 for Enclosure and Corridor louvers.

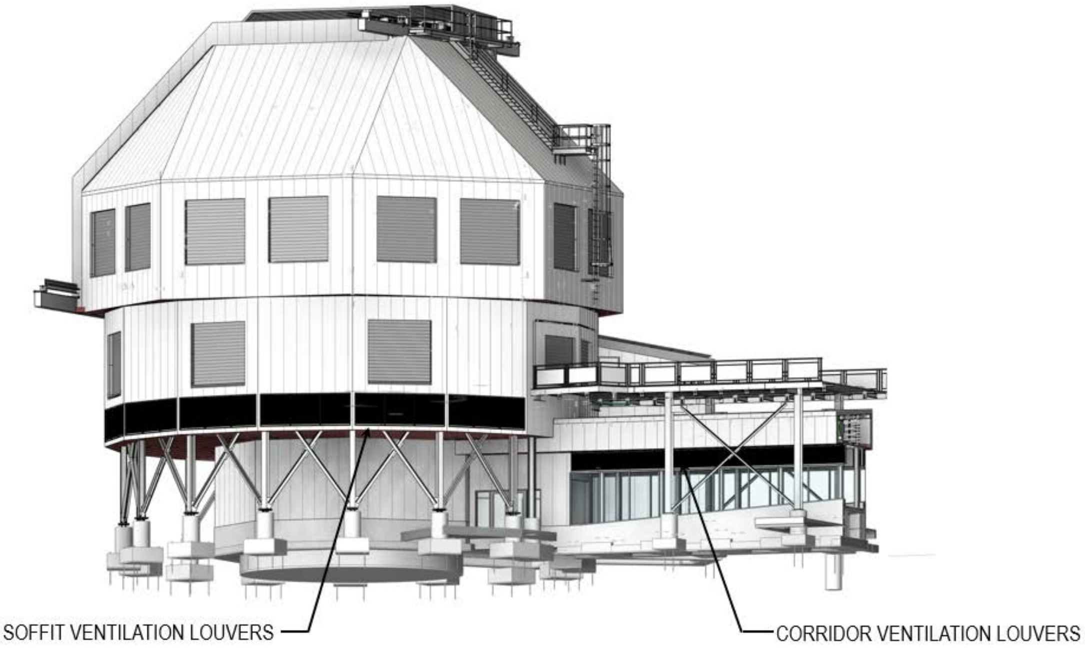


Image 5.8 – Enclosure and Corridor Louvers

5.5 CHILLED WATER

The facility will have an air cooled chiller located outdoors away from the Support Building. This will be the point of heat rejection for all water cooled equipment. It will provide chilled water to the low temp chiller, and FCU's, except the Enclosure FCU's. The discharge temperature of this chiller is set to 7 degree C to help with space dehumidification. See Image 5.9 for chilled water schematic and Table 5.2 for chiller load summary.

A water cooled low temperature chiller located in the Mechanical room will provide chilled water down to minus 15 degree C so that the Enclosure can also be cooled during the winter months. It also provides chilled water to the Hydrostatic Bearing System and the VTCW heat exchanger. The condenser water heat is rejected to the 7 degree chiller.

Variable Temperature Chilled Water (VTCW) will cool the telescope mirror and instruments. Water from the low temp chiller will be circulated through a heat exchanger where it will be regulated to 8 degree C below the current ambient air condition.

A food grade 50% propylene glycol solution will be used on chilled water systems to protect the system from freezing, this will also limit the danger of onsite chemical spills. All chilled water systems will be provided with two pumps, a primary and backup unit. Chemical pot feeders will be used to facilitate maintaining proper water treatment in the piping systems. Chillers and pumps will be mounted on spring isolators to reduce the possibility of vibrations affecting the telescope.

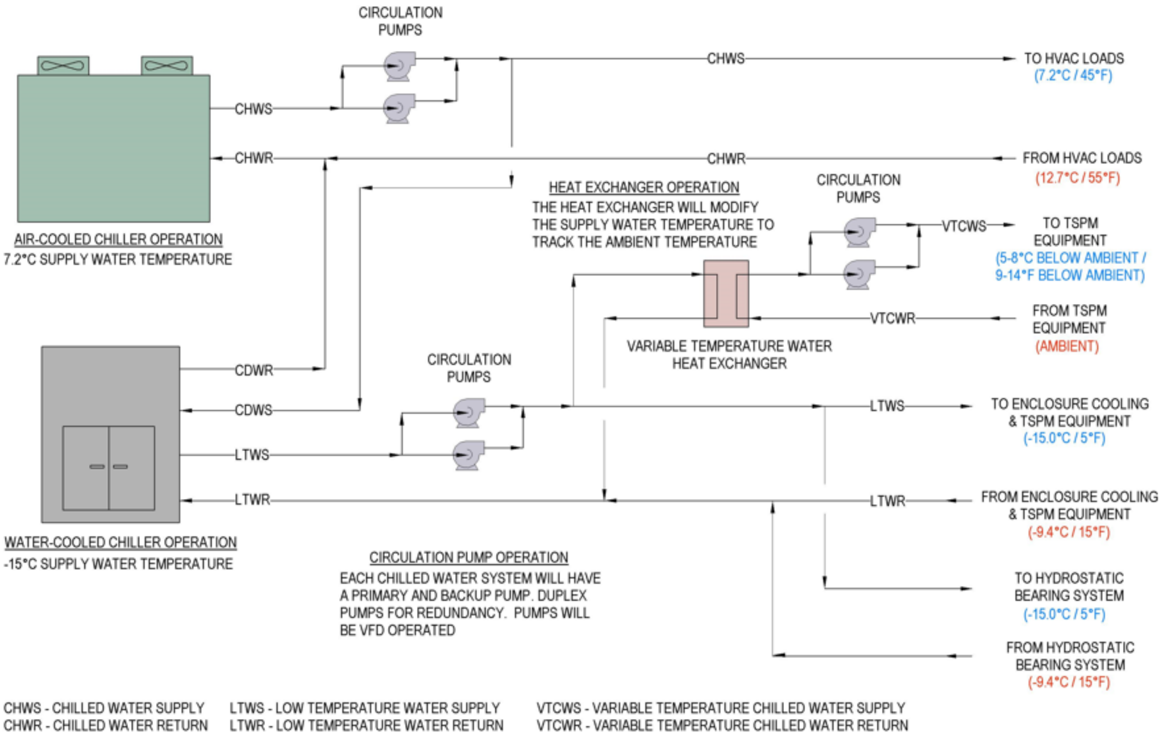
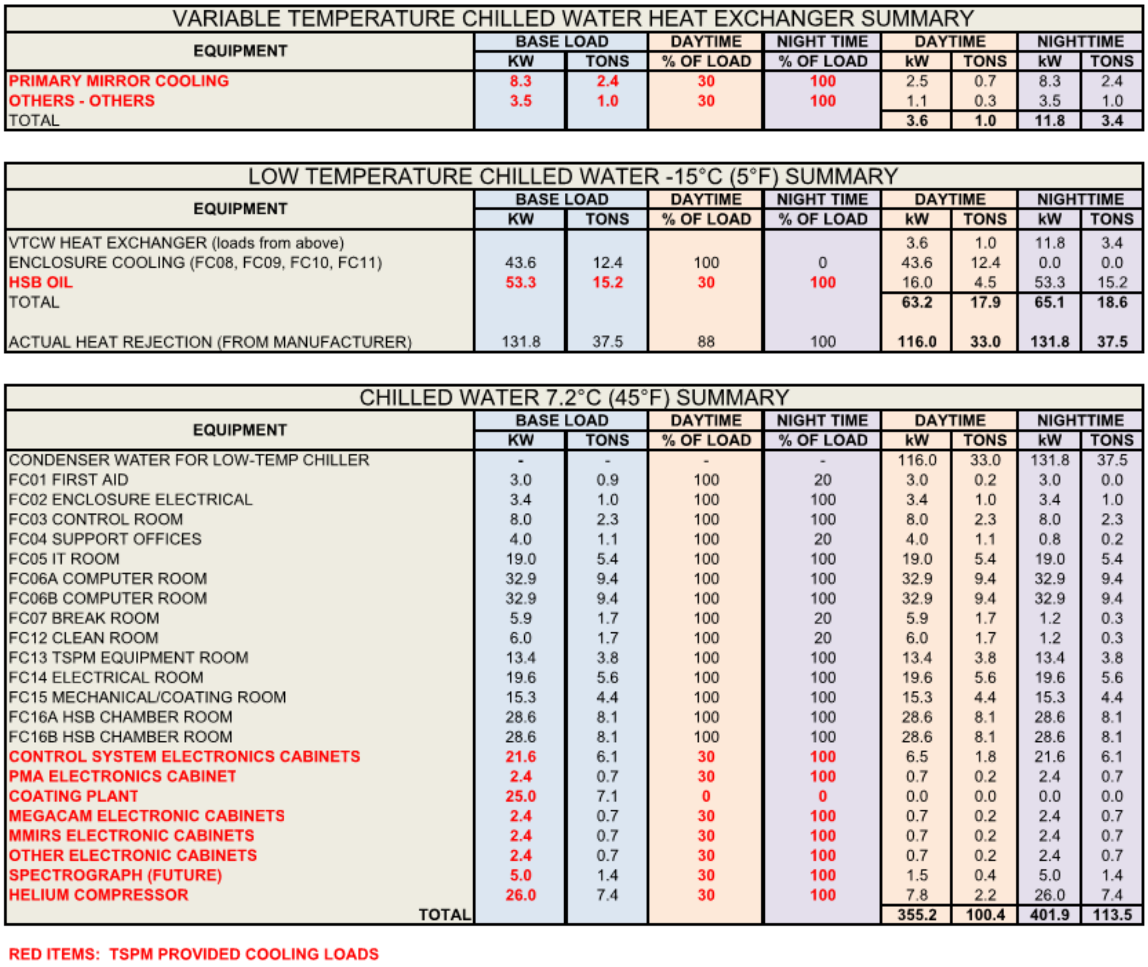


Image 5.9 – Chilled Water Schematic



VARIABLE TEMPERATURE CHILLED WATER HEAT EXCHANGER SUMMARY

EQUIPMENT	BASE LOAD		DAYTIME	NIGHT TIME	DAYTIME		NIGHTTIME	
	KW	TONS	% OF LOAD	% OF LOAD	kW	TONS	kW	TONS
PRIMARY MIRROR COOLING	**8.3**	**2.4**	**30**	**100**	2.5	0.7	8.3	2.4
OTHERS - OTHERS	**3.5**	**1.0**	**30**	**100**	1.1	0.3	3.5	1.0
TOTAL					**3.6**	**1.0**	**11.8**	**3.4**

LOW TEMPERATURE CHILLED WATER -15°C (5°F) SUMMARY

EQUIPMENT	BASE LOAD		DAYTIME	NIGHT TIME	DAYTIME		NIGHTTIME	
	KW	TONS	% OF LOAD	% OF LOAD	kW	TONS	kW	TONS
VTCW HEAT EXCHANGER (loads from above)					3.6	1.0	11.8	3.4
ENCLOSURE COOLING (FC08, FC09, FC10, FC11)	43.6	12.4	100	0	43.6	12.4	0.0	0.0
HSB OIL	**53.3**	**15.2**	**30**	**100**	16.0	4.5	53.3	15.2
TOTAL					**63.2**	**17.9**	**65.1**	**18.6**
ACTUAL HEAT REJECTION (FROM MANUFACTURER)	131.8	37.5	88	100	**116.0**	**33.0**	**131.8**	**37.5**

CHILLED WATER 7.2°C (45°F) SUMMARY

EQUIPMENT	BASE LOAD		DAYTIME	NIGHT TIME	DAYTIME		NIGHTTIME	
	KW	TONS	% OF LOAD	% OF LOAD	kW	TONS	kW	TONS
CONDENSER WATER FOR LOW-TEMP CHILLER	-	-	-	-	116.0	33.0	131.8	37.5
FC01 FIRST AID	3.0	0.9	100	20	3.0	0.2	3.0	0.0
FC02 ENCLOSURE ELECTRICAL	3.4	1.0	100	100	3.4	1.0	3.4	1.0
FC03 CONTROL ROOM	8.0	2.3	100	100	8.0	2.3	8.0	2.3
FC04 SUPPORT OFFICES	4.0	1.1	100	20	4.0	1.1	0.8	0.2
FC05 IT ROOM	19.0	5.4	100	100	19.0	5.4	19.0	5.4
FC06A COMPUTER ROOM	32.9	9.4	100	100	32.9	9.4	32.9	9.4
FC06B COMPUTER ROOM	32.9	9.4	100	100	32.9	9.4	32.9	9.4
FC07 BREAK ROOM	5.9	1.7	100	20	5.9	1.7	1.2	0.3
FC12 CLEAN ROOM	6.0	1.7	100	20	6.0	1.7	1.2	0.3
FC13 TSPM EQUIPMENT ROOM	13.4	3.8	100	100	13.4	3.8	13.4	3.8
FC14 ELECTRICAL ROOM	19.6	5.6	100	100	19.6	5.6	19.6	5.6
FC15 MECHANICAL/COATING ROOM	15.3	4.4	100	100	15.3	4.4	15.3	4.4
FC16A HSB CHAMBER ROOM	28.6	8.1	100	100	28.6	8.1	28.6	8.1
FC16B HSB CHAMBER ROOM	28.6	8.1	100	100	28.6	8.1	28.6	8.1
CONTROL SYSTEM ELECTRONICS CABINETS	**21.6**	6.1	**30**	**100**	6.5	1.8	21.6	6.1
PMA ELECTRONICS CABINET	**2.4**	0.7	**30**	**100**	0.7	0.2	2.4	0.7
COATING PLANT	**25.0**	7.1	**0**	**0**	0.0	0.0	0.0	0.0
MEGACAM ELECTRONIC CABINETS	**2.4**	0.7	**30**	**100**	0.7	0.2	2.4	0.7
MMIRS ELECTRONIC CABINETS	**2.4**	0.7	**30**	**100**	0.7	0.2	2.4	0.7
OTHER ELECTRONIC CABINETS	**2.4**	0.7	**30**	**100**	0.7	0.2	2.4	0.7
SPECTROGRAPH (FUTURE)	**5.0**	1.4	**30**	**100**	1.5	0.4	5.0	1.4
HELIUM COMPRESSOR	**26.0**	7.4	**30**	**100**	7.8	2.2	26.0	7.4
TOTAL					**355.2**	**100.4**	**401.9**	**113.5**

RED ITEMS: TSPM PROVIDED COOLING LOADS

Table 5.2 – Chiller Load Summary

5.6 BUILDING HVAC CONTROLS

A Building Management System (BMS) using BACnet protocol will be used throughout the facility to control all HVAC equipment. The system shall be accessible through the internet for viewing purposes only. Control programing and set point adjustment shall only be made through the onsite work station. Communication between this system and the owners site weather prediction software will be required to set the Enclosure cooling system set point each day.

5.7 POTABLE AND WASTE WATER

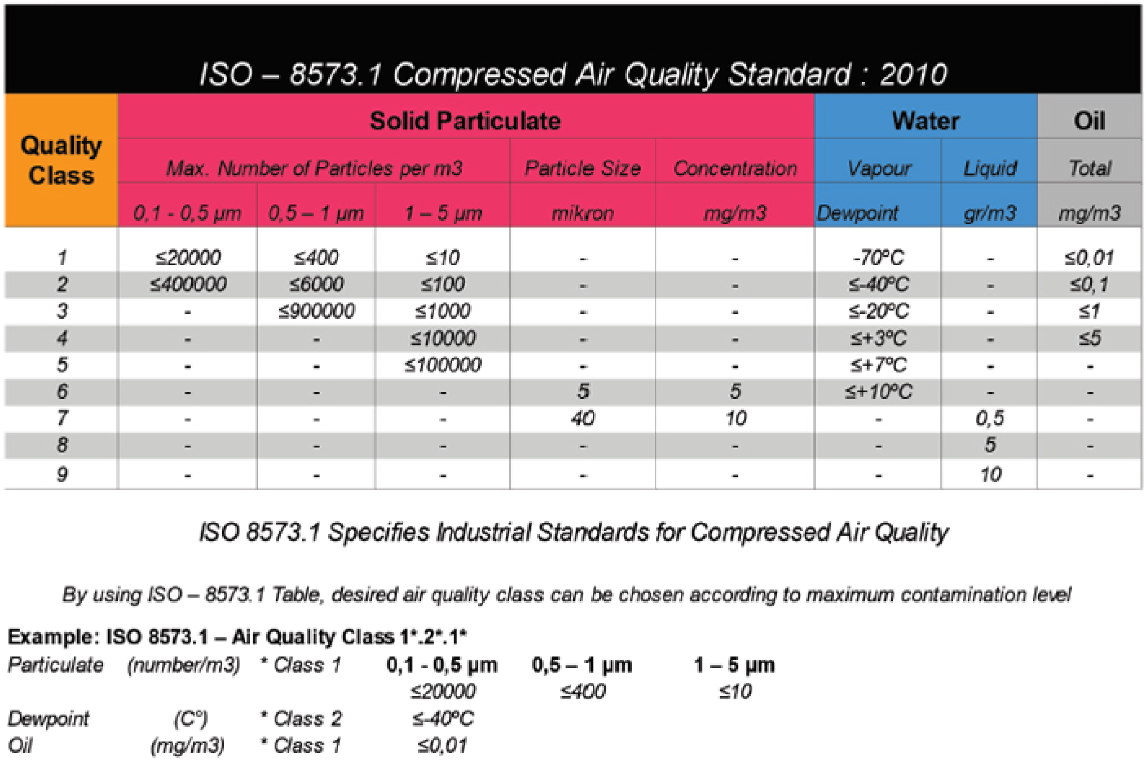
Domestic water will be trucked to the site and stored in a below grade tank located next to the Support Building. A wet well with two pumps will provide the required flow rate and pressure to operate all plumbing devices, including safety showers. A chlorine based water treatment system will circulate the water in the holding tank to maintain potable water standards. Because of the risk of chemical burns while filling the chlorine tank, a safety shower will be required at the chlorine injection system, a shower will also be provided by the mirror stripping area. Reverse Osmosis (RO) and De-Ionized (DI) water will also be provided. The RO water will be used in all humidifiers while the DI water will be used for the mirror wash process.

The waste water from the mirror stripping process will be stored in a below grade double contained waste water storage tank, next to the support building. The waste piping connected to this tank will also be double contained. General sanitary waste will also be stored in a below grade waste storage tank. Controls will be included with each waste tank and alert site personal when they need to be emptied. The disposal trucks should come with their own pumps. To reduce the amount of sanitary waste needing to be trucked off site all clear water wastes (condensate, humidifier blow down and RO reject water) will be disposed using surface drainage.

5.8 COMPRESSED AIR

Compressed air for the facility will be supplied by two separate systems. One system will supply the compressed air needs of the telescope. This system will be called the M1 compressed air system. The M1 system will have two rotary screw compressors with one compressor acting as the primary and one compressor acting as the backup in an n+1 configuration for redundancy. The system will provide 37 L/s of air at 862 kPa. There will be a 908 liter air receiver that is capable of providing 1 minute of reserve capacity upon loss of power. There will also be one dryer and multiple filters in the system that will treat the air to an ISO 8573.1 Class 1.2.1, see Table 5.3 for ISO classification.

The second system will supply the compressed air needs of the facility. This system will be called the Facility Compressed Air (FCA) system. This system will have one rotary screw compressor and will provide 15 L/s of air at 690 kPa. There will be a 454 liter receiver in this system. There will also be one dryer and multiple filters in the system that will treat the air to an ISO 8573.1 Class 2.2.3.



ISO – 8573.1 Compressed Air Quality Standard : 2010

Quality Class	Solid Particulate					Water		Oil
	Max. Number of Particles per m3			Particle Size	Concentration	Vapour	Liquid	Total
	0,1 - 0,5 µm	0,5 – 1 µm	1 – 5 µm	mikron	mg/m3	Dewpoint	gr/m3	mg/m3
1	≤20000	≤400	≤10	-	-	-70°C	-	≤0,01
2	≤400000	≤6000	≤100	-	-	≤-40°C	-	≤0,1
3	-	≤900000	≤1000	-	-	≤-20°C	-	≤1
4	-	-	≤10000	-	-	≤+3°C	-	≤5
5	-	-	≤100000	-	-	≤+7°C	-	-
6	-	-	-	5	5	≤+10°C	-	-
7	-	-	-	40	10	-	0,5	-
8	-	-	-	-	-	-	5	-
9	-	-	-	-	-	-	10	-

ISO 8573.1 Specifies Industrial Standards for Compressed Air Quality

By using ISO – 8573.1 Table, desired air quality class can be chosen according to maximum contamination level

Example: ISO 8573.1 – Air Quality Class 1*.2*.1*

Particulate	*(number/m3)*	** Class 1*	**0,1 - 0,5 µm** *≤20000*	**0,5 – 1 µm** *≤400*	**1 – 5 µm** *≤10*
Dewpoint	*(C°)*	** Class 2*	*≤-40°C*		
Oil	*(mg/m3)*	** Class 1*	*≤0,01*		

Table 5.3 – ISO 8573.1 Classification

6 ELECTRICAL

6.1 PRIMARY DISTRIBUTION

The primary feed and the medium voltage transformer will be provided by TSPM. TSPM is to coordinate the proposed power line capacity and routing.

6.2 SECONDARY DISTRIBUTION

From the TSPM provided medium voltage service transformer, secondary cables are provided to the TSPM main building service entrance switchboard “SB-SB01” located inside room E206 of the Support Building. “SB-SB01” is rated at 2000 amps at 480Y/277V, 3 phase, 4 wire, 60 Hz with main circuit breaker (MCB) and ground fault circuit interrupter.

From the “SB-SB01” distribution section, 480Y/277V power is distributed within the Support and the Fixed base feeding panelboards through-out, mirror coating system, elevator, heat exchanger ‘HX01’, chiller No.1, bridge crane, and two UPS’s which serve the helium compressors, computer room racks, telescope control system, and rotating enclosure loads.

A 300 kVA step down transformer shall be provided to serve a distribution switchboard “SB-SB02” located inside Room E207 of the Support Building. “SB-SB02” is rated at 1000 amps at 220Y/127V, 3 phase, 4 wire, 60 Hz with main circuit breaker (MCB). "SB-SB02" is to serve all 220Y/127V, 3 phase, 4 wire panelboards through-out the Support, and Fixed Base.

The Enclosure azimuth drives will be served by VFD's which will be fed from a 480Y/277V, 3 phase, 4 wire, 60 Hz panel "FB-PH01" which is located in Elec Room 103 of the Ground Level Enclosure. "FB-PH01" will be served by Main Switchboard "SB-SB01".

In accordance with the NEC the maximum permissible voltage drop between the point of supply and any point of the electrical installation shall be 5%.

6.3 ELECTRICAL LOAD

The electrical load for this facility will be calculated per Article 220.40 of the NEC. The calculated load for 60% CDR is 1,700 amps. The final calculated electrical load is to be determined

6.4 TEMPORARY POWER

It is the contractor's responsibility to determine and provide temporary construction power requirements. The TSPM provided electrical primary feed to the site may be used to energize the temporary power transformer. Temporary diesel power generation may be required, if no other power source is available at the start of construction. Design Objectives

6.5 DESIGN OBJECTIVES

The objectives of the electrical design are as follows:

- Provide reliable electrical systems for TSPM
- Provide electrical system compliance with the respective installation codes, regulations and standards
- Provide required power and controls for enclosure drive systems
- Low voltage systems including switchboards, power feeder and branch circuit distribution
- Internal and external lighting, including emergency exit lighting, lighting controls
- Earthing and lightning protection systems

6.6 SITE MAIN SWITCHBOARDS (SMS)

Main switchboard shall be provided with forms of internal separation. These measures shall improve the reliability of the installation by reducing the likelihood of the initiation of an internal arcing fault. Switchboards shall be configured for top/bottom cable entry and outgoing feeds and front access only.

The SMS switchboard shall be based on the following design criteria:

- Metering shall be supplied to provide detailed information about power consumption for the Facility

- The intelligent meters shall be minimum Class 1 accuracy to interface with to the BMS to monitor the minimum parameters set out below;
    - Volts phase to neutral for LV with selector switch
    - Amps each phase 3 off
    - Average power factor each phase 3 off
    - Watts, kVA, kWh

6.7 DISTRIBUTION PANELBOARDS

Distribution panel boards for light and power within buildings shall be provided with internal separation as described in NEMA, UL and applicable standards.

Distribution panel boards shall be wall mounted, sheet steel type, insulated busbar chassis, suitable for accommodation in the cupboards or spaces provided or surface wall mounted or recessed in walls as shown on the drawings.

6.8 BRANCH CIRCUITS

Minimum conductor size for power and lighting circuits shall be No. 12 AWG, unless shown otherwise on the drawings. Minimum conductor size for control and signal circuits shall be No. 14 AWG, unless shown otherwise on the drawings.

All conductors No. 8 AWG and larger shall be stranded. All conductors No. 10 AWG and smaller shall be solid.

All conductors located in dry locations shall be type THHN/THWN unless specifically designated otherwise. All conductors located in outdoor or wet locations shall be type XHHW-2.

Conductors shall be color coded as follows:

277/480V, 3 phase, 4 wire......................	Brown, Orange, Yellow and Gray
120/208V, 3 phase, 4 wire......................	Black, Red, Blue and White
Control circuits.......................................	Other than above

Wiring systems installed in locations where is a risk of mechanical damage shall be adequately protected in accordance with the NEC.

6.9 LABELLING

Label equipment to facilitate operation and maintenance. Function labels shall be direct engraved on switches, major electrical equipment and similar items. Labels shall be 3 layer laminated plastic (traffolyte) generally, White/Black/White, with special or UPS equipment labelled in other colours e.g. Orange/White/Orange for main switches.

Control wiring shall be identified at terminations with engraved; interlocking ferrule type labels and corresponds with associated wiring diagrams.

Switchboards shall be provided with typewritten circuit schedule cards. The cards are to be suitably sized showing:

- Sub main/sub circuit designation/description and area supplied

- Cable size and type
- Rating of the sub main/sub circuit protective device

Labels shall be provided on all switchboards and panelboards. The label shall be securely fixed in a prominent location on the front door or external cover of the switchboard assembly. The label shall be an engraved two colour laminated traffolyte or similar.

The minimum letter height for switchboard designations shall be 25mm for Main Switchboards (MSB) and 15mm for all other switchboards. All other engraving shall be minimum 6mm height.

6.10 SWITCHBOARD AND PANELBOARD DESIGNATION

The switchboard and panelboard designation shall be as shown on drawings.

6.11 UNINTERRUPTIBLE POWER SUPPLY UNITS

The UPS systems identified at this stage of the design are as follows:

1) One (1) 100 kVA, 480V, 3 phase, 3 wire UPS located in Elec Room 207 of the Support Building to serve the helium compressors.
2) One (1) 160 kVA, 480V, 3 phase, 3 wire UPS with internal step down transformer with integral distribution panelboard with voltage of 220Y/127V, 3 phase, 4 wire located in UPS/IT Room 114 on the Control Level of the Support Building. This UPS will feed the following loads:
    - Telescope control system
    - M1 thermal control system
    - 15 Computer Room Racks
    - Ventilation doors control system
    - Shutter drives control system
    - Moon and Wind screen drives control system

The current design indicates to provide battery time of 10 minutes at full UPS load for both UPS's.

6.12 GROUNDING

The grounding system is to provide electrical safety for personnel and equipment. The system needs to provide a solution which addresses the following:

- Electrical protection of the electrical HV and LV distributions systems
- Protection to electrical circuits feeding equipment
- Grounding system for the communications system
- Equipotential earth bonding of all metallic components

The electrical room shall have a ground bus mounted on the wall which connects to the perimeter earth electrode conductor.

The MEN link will be located within the Main Switchboard section. Main incoming underground metallic pipes services shall be bonded to earth directly on the Main Switch room earth bar.

All other ancillary metallic components shall be bonded to earth as required by the NEC via the local switchboard or the Main Switch room earth bar. Typically this will include:

Cable trays and ladders

Ceiling support systems

Adjacent structural steel

The Communications Equipment Room shall be provided with a Telecommunications main ground bus (TMGB) that will be a wall mounted copper earth bar. Each CET shall be directly bonded to the perimeter earth electrode conductor. Any communications system equipment will be connected as radial connections back to the TMGB.

6.13 LIGHTNING PROTECTION

The design will be in accordance with NFPA 780 and shall comprise with the following:

- Bonding of metal work at roof level
- Bonding of metal work through to footings
- Down conductors and/or bonding of structural and concrete reinforcement as required;
- Test links
- Earth terminations

Surge/over-voltage protection will be provided in the main switchboard and in the panels located in the rotating base.

Generally the following materials will be used for the lightning protection system:

- Air terminals: Aluminum, not less than 12.7 mm diameter, with rounded tip points.
- Down conductors – Structural steel columns or steel reinforcement in concrete columns
- Earth electrode – copper rods using the delta ground rod method with grounding enhancement material and copper ring electrode

The design shall avoid connection and contact between metals and other materials which may cause electrolytic corrosion of one or other material.

When the lightning protection systems have been installed, have the systems inspected by a UL representative. Obtain and install a UL numbered master label "C" for each of the lightning protection systems at the location directed by the UL representative and the Owner.

7 TELESCOPE/ENCLOSURE CONTROL SYSTEMS AND INSTRUMENTATION

7.1 DESIGN INFORMATION - HARDWARE

7.1.1 Programmable Logic Controller (PLC) 1 – Stationary

There are two Rockwell CompactLogix PLCs used on this project. The PLC Panel 1- Stationary PLC (1 1PLC) controls the Azimuth Variable Frequency Drives (VFDs). The drives power the motors that rotate the enclosure.

This PLC shall be made up of the following components:

- CompactLogix Processor with Serial and Ethernet ports
- Ethernet control module(s)
- Processor power supply

- 24VDC Discrete input module, 32 input
- 24VDC Discrete output module, 32 output
- CompactLogix high speed counter module

The PLC will connect to the azimuth drives using the Ethernet/IP protocol.

The PLC will connect to the Rotational PLC (2 1PLC) using an industrial wireless Ethernet network.

The PLC will transmit and receive a “heartbeat” signal via network connection at a rate no less than 1 Hertz.

7.1.2 Programmable Logic Controller (PLC) 2 – Rotational

The PLC Panel 2 – Rotational PLC (2 1PLC) controls the Bi-Parting Door Variable Frequency Drives (VFDs). The drives power the motors that open and close the doors. The PLC also controls the ventilation doors. This panel is mounted on the rotating enclosure.

This PLC shall be made up of the following components:

- CompactLogix Processor with Serial and Ethernet ports
- Ethernet control module(s)
- Processor power supply
- 24VDC Discrete input module, 32 input
- 24VDC Discrete output module, 32 Output
- CompactLogix high speed counter module

The PLC will connect to the Bi-Parting door drives using Ethernet/IP protocol.

The PLC will connect to the PLC 1 – Stationary PLC (1 1PLC) using an industrial wireless Ethernet network.

The PLC will transmit and receive a “heartbeat” signal via network connection at a rate no less than 1 Hertz.

7.1.3 Operator Interface Unit

The Operator Interface Unit (Human Machine Interface – HMI) is mounted on the front of the PLC panel 1-Stationary PLC. The operator interface is used to control items connected to both of the PLCs.

The Operator Interface Unit will be a Rockwell PanelView Plus 1000 unit. The unit will be a 250mm color touchscreen device and designated as 1 1HMI.

Warning: In the event of an emergency, the operator must use an Emergency Stop Push button to stop equipment motion. There are 4 Emergency Stop Pushbuttons for the Azimuth Rotation Motors. (One of the pushbuttons should be mounted near the Operator Interface Unit (1 1HMI)).

Warning: The panel with the Operator Interface Unit (1 1HMI) does not contain an Emergency Stop Pushbutton.

Warning: In the event of a hardware failure, motion may occur when the Emergency Stop Pushbuttons are reset.

The Operator Interface Unit (1 1HMI) is used to control the system locally.

The Operator Interface Units will have the following types of screens:

- A Directory Screen. This screen will identify the process and allow access to most of the other screens. This screen will appear when the system is first started. If size permits, it may include the integrator information.
- A Status Screen. This screen will provide status information about the current state of the system. (This may require more than one page.)
- A Control Mode Screen. This screen will allow the operator to change the mode of operation.
- NORM Normal Mode (Either)
- LOC Local (Operator Interface Units)
- REM Remote (Control Room Link)
- LOC ONLY Local Only (locks out Control Room)
- MAINT Maintenance (Allows forcing Outputs at PanelView – Locks out Control Room
- An Azimuth-Manual Screen which will allow the operator to move the enclosure at a constant speed and to set up the home switch. The operator will be able to set the Speed and Acceleration Parameters. There will be momentary pushbuttons to start, stop and perform the home sequence. The operator will be able to input the home position reference only when the enclosure is at home position. (This value is used to set 0 encoder counts to the due North.)
- An Azimuth-Move to Position Screen which will allow the operator to move the enclosure to a specific location expressed as arc-deg. min. The operator will be able to set the Speed and Acceleration Parameters. There will be momentary pushbuttons to start, move and stop.
- An Azimuth-Automatic Screen which will allow the operator to set the number and frequency (expressed as period – in minutes) of minimum length moves. (The length of the minimum move will be determined during start-up.) There will be momentary pushbuttons to start, move and stop.
- A Bi-Parting Door – Manual Screen (Left and Right have separate screens) which allow the operator to move the door at a constant speed and to set the encoder for the closed position. The operator will be able to set which VFD is to be used and the Speed and Acceleration Parameters. There will be momentary pushbuttons to open, close and stop. The operator will be able to input the Close Position Reference only when the door is at the closed position. (This value is used to set 0 encoder counts when the door is closed.)
- A Bi-Parting Door Automatic Screen which will allow the operator to open the doors. The operator will be able to set which VFD is to be used first. (If this VFD fails, the other VFD will be used automatically.) There will be momentary pushbuttons to open, close and stop.
- The Ventilation Door Control Screens will allow the control of the Ventilation Doors. There will be momentary pushbuttons to open, close and stop each door and a set of pushbuttons to operate all of the doors at the same time.

- The Lighting Control Screen will allow control of the lights. There will be momentary pushbuttons to turn the lights on and turn the lights off.
- The Maintenance Screens will allow the operator to monitor the digital inputs and outputs. In Maintenance mode the operator can individually force each of the digital outputs on or off.
- The Active Alarm Screen will show all of the active and unacknowledged alarms. This screen will have an Acknowledge Pushbutton.
- Alarm Banner. This will "pop-up" over the bottom of the active screen. This will occur whenever an alarm occurs. The Acknowledge pushbutton is included in this "pop-up".

Control Room remote system control

The Control Room system will have all of the capabilities of the local PanelView.

The Control Room system is not in the scope of this contract/document.

7.2 SOFTWARE

7.2.1 Control Modes

The operator can set the following control modes. The modes apply to all items controlled by the PLCs.

- Normal Mode will allow control from the Operator Interface unit (1 1HMI) or from any remote location over the network. This is the mode that will normally be used.
- Local Mode will allow changes only to be made from the Operator Interface Unit (1 1HMI). Remote locations will be able to monitor but not control or change parameters.
- Maintenance can only be set at the Local Station (1 1HMI) and will allow changes only to be made from the Local Station (1 1HMI). Remote locations will not be able to change the control mode. In Maintenance mode the operator can individually force digital outputs on and off. (All outputs will be returned to "auto" (not forced) when the mode is changed to any other mode.

Warning: Energizing or De-Energizing outputs while the system components are operating may cause equipment damage. This mode should be used by authorized trained personnel only.

Warning: The operator should switch the system mode out of "Local" or "Maintenance" modes before leaving the facility. These modes can only be changed at the Local Operator Interface (1 1HMI).

7.2.2 Enclosure Control

The Enclosure Azimuth location is controlled by 4 Variable Frequency Drives (VFDs). These drives are controlled by the Stationary PLC (1 1PLC). The PLC will send speed signals to each of the drives.

When the Enclosure is not moving the mechanical brakes will be activated holding the enclosure in a fixed position.

Warning: When any of the Enclosure Azimuth Emergency Stop Pushbuttons are depressed or any Power outage, the drives will be disabled and the mechanical brakes automatically set.

Each VFD/motor is provided with a Disconnect Means and a Brake Bypass Switch. All of the disconnect switches must be turned on for the system to operate, unless the associated Brake Bypass Switch is set to “Bypass”.

If associated Brake Bypass Switch is in “Bypass” the VFD/motor will not be used. The remaining VFD/motors will be used to rotate the enclosure.

Warning: The drive wheels must be physically released from the Enclosure whenever the Brake Bypass Switch is set to “Bypass”. Failure to do so may result in equipment damage.

If all of the Disconnect Switches are on (or the associated Brake Bypass Switches are set to “Bypass”) then controlled motion is possible.

When motion is commanded by the PLC a timer will start. If at the end of the time limit (to be established during start-up) the Brake Released input is not activated then an alarm will occur and controlled motion will stop.

When motion is commanded by the PLC a timer will start. If at the end of the time limit (to be established at start-up) both absolute encoders have not changed then an alarm will occur and controlled motion will stop.

Warning: The system does not utilize a warning horn before motion occurs. Motors may start operating at any time.

Azimuth – Manual

- When the “START” pushbutton for the Azimuth – Manual control is pressed the Enclosure will start moving using the parameters set for direction, speed and acceleration. (The minimum and maximum parameters will be determined at start-up.)
- When the “STOP ENCLOSURE” pushbutton for the Azimuth control is pressed the enclosure will stop moving using the parameters set for acceleration. (The acceleration parameter will also be used for deceleration.)
- When the “HOME SEQUENCE” pushbutton for the Azimuth control is pressed, the enclosure will start moving clockwise using the parameters set for speed and acceleration. This will continue until the Home Switch input is energized and then de-energized. The enclosure will then stop and start moving at low speed in the counter- clockwise direction until the Home switch is energized. The enclosure will stop quickly. This is the home position. The operator can then set the encoder counts so that 0 represents due North. (This value will be determined at start-up.)

Azimuth – Move to Position

- When the “START MOVE” pushbutton for the Azimuth – Move to Position control is pressed the enclosure will start moving using the parameters set for direction, speed and acceleration. (The minimum and maximum parameters will be determined at start-up). The operator can also set the direction to clockwise, counter-clockwise, or auto. In auto the system will determine the shortest direction to move. The motion will stop so that the desired location is reached. (This executes a symmetrical trapezoidal move.)

- When the setpoint is changed over the SCADA link and the "START MOVE" signal for Azimuth – Move to Position signal is left energized, the motion will start whenever the setpoint and the actual position are different by a minimum move size. (To be determined during start-up).
- When the "STOP ENCLOSURE" pushbutton for Azimuth control is pressed the enclosure will stop moving using the parameters set for acceleration. (The acceleration parameter is also used for deceleration.)

Azimuth – Automatic

- There are two parameters that the operator can set. The number and frequency (expressed as period – in minutes) of minimum length moves. (The acceleration, minimum move length and minimum move speed parameter used will be determined during start-up.) The period parameter includes the time required to make the move.
- The following values will be calculated as follows:
    - Total Time = Period (in minutes) x Number of moves
    - Total Distance = Minimum Distance x Number of moves

Note: The minimum move parameters and maximum continuous speed must be coordinated so that all possible time/distance combinations are accommodated. (This will be determined at start-up)

- When the "START MOVE" pushbutton for Azimuth – Automatic is pressed the enclosure will start moving using the method as outlined above. This will continue until the final location is reached.
- When the "STOP MOVE" pushbutton for Azimuth – Automatic is pressed the enclosure will stop moving using the parameters set for acceleration. (The acceleration parameter is also used for deceleration.)

7.2.3 Bi-Parting Door Control

The Bi-Parting Doors are controlled by 2 Variable Frequency Drives (VFDs). One VFD is used on each side.

Warning: **In the event of an emergency, the operator must use tan Emergency Stop Pushbutton to stop the system components.**

When the door is not moving the mechanical motor brake will be activated. However, when the doors have stopped moving the clutches will be dis-engaged so the brake will not hold the doors in place.

Warning: **When any Power Outage occurs, the drives will be disabled and the mechanical motor brakes automatically set disengaged. The drives clutches will be dis-engaged which will allow operation with the manual handwheel.**

Each VFD/motor is provided with a Disconnect Switch. The Disconnect Switch must be closed for the respective door to operate.

Each Bi-Parting Door is provided with a "Handwheel Engaged" input to the PLC. The associated VFD/motor will not operate if this input indicates that the handwheel is in the manual position. The Bi-Parting door latch mechanism will have an actuator, which has two limit switches. The latch disengaged limit switch should be in closed position in order to operate the shutters.

Bi-Parting Doors – Manual

- When the "OPEN" pushbutton for the Left or Right Bi-Parting Door Manual Control is pressed, a signal will be sent to the latching mechanism which will be disengaged. When the latch mechanism disengaged signal is provided, the selected motor brake will be deactivated and the door will start moving using the VFD and parameters set for speed and acceleration. (The minimum and maximum parameters will be determined during start-up.) Travel will continue until the door is fully open. Five seconds after motion travel is complete, the selected motor brake will be activated.
- When the "CLOSE" pushbutton for the Left or Right Bi-Parting Door Manual Control is pressed, the selected motor brake will be deactivated and the door will start moving using the VFD and parameters set for speed and acceleration. (The minimum and maximum parameters will be determined during start-up.) Travel will continue until the door is fully closed. Five seconds after travel is complete, the selected motor brake will be activated and the latch mechanism will be set.
- When the "LEFT DOOR STOP" or "RIGHT DOOR STOP" pushbutton for the Bi-Parting Door control is pressed, the respective door will stop moving using the parameters set for acceleration (The acceleration parameter will also be used for deceleration) and the brake will be activated.
- Bi-Parting Doors – Automatic
- When travel is commanded by the PLC a timer will start. If at the end of the time limit (to be established during start-up) the absolute encoder values have not changed then an alarm will occur and controlled travel will stop. The selected motor brake will be activated.
- If while moving the values from the absolute encoders are different by more than 25mm (encoder count value to be determined during start-up) then an alarm will occur and travel will stop and the selected motor brake will be activated.
- When the "OPEN" pushbutton for Bi-Parting Doors Automatic Control is pressed, a signal will be sent to the latching mechanism which will be disengaged. When the latching mechanism disengaged signal is provided, the selected motor brake will be deactivated and the door will start moving using the VFD and parameters set for speed and acceleration (The minimum and maximum parameters will be determined at start-up.) Travel will continue until the door is fully open. Thirty seconds after travel is complete, the selected motor brake will be activated.
- When the "CLOSE" pushbutton for Bi-Parting Doors Automatic Control is pressed, the selected motor brake will be deactivated and the doors will start moving using the VFD parameters set for speed and acceleration. (The minimum and maximum parameters will be determined at start-up.) Travel will continue until the door is fully closed (This executes a symmetrical trapezoidal move and then a slow move.) Thirty seconds after travel is complete, the selected motor brake will be activated.
- When the "STOP" pushbutton for the Bi-Parting Door control is pressed, the doors will stop moving using the parameters set for acceleration. (The acceleration parameter will also be used for deceleration.)

7.2.4 Ventilation Door Control

The 21 Ventilation Doors are controlled by open and close signals. When the open signal is sent to the ventilation door controller, the door will open until the signal is removed or the open limit switch is reached.

Warning: There is no way of individually Emergency stopping the ventilation doors. All motion on the Enclosure and Telescope will stop upon activation of an E-Stop pushbutton.

When the close signal is sent to the ventilation door controller, the door will close until the signal is removed or the close limit switch is reached.

When motion is commanded by the PLC a timer will start. If at the end of the time limit (to be established during start-up) either the open limit switch or the close limit switch have not been reached then an alarm will occur and controlled motion will stop.

Ventilation Doors – Automatic

- When the “OPEN” pushbutton for all ventilation doors is pressed, all of the ventilation doors will open until the opened limit switch is reached.
- When the “CLOSE” pushbutton for all ventilation doors is pressed, all of the ventilation doors will close until the closed limit switch is reached.
- When the “STOP” pushbutton for all ventilation doors is pressed, all of the ventilation doors will stop moving.
- When the “OPEN” pushbutton for ventilation door (1-21) is pressed, the associated ventilation door will open until the opened limit switch is reached.
- When the “CLOSE” pushbutton for ventilation door (1-21) is pressed, the associated ventilation door will open until the closed limit switch is reached.
- When the “STOP” pushbutton for ventilation door (1-21) is pressed, the associated ventilation door will stop moving.

The approximate percent open of the ventilation doors is determined solely by running time and is only an approximation. It is reported in 10% increments and is reset whenever the open and closed limit switches are reached.

7.2.5 Windscreen/Moonroof

Warning: The windscreen/Moonroof must stop when any Emergency Stop Pushbutton is pressed.

The windscreen is operated by two motors controlled by VFDs.

Each side of the windscreen includes an absolute position encoder. If the encoder feedback is ever unmatched by more than 25mm (configurable at start-up), an alarm will annunciate on the HMI and the windscreen movement will cease.

Each VFD/motor pair is included in the Emergency Stop Pushbutton input circuit. The associated VFD/motor will not operate if this input indicates that any Emergency Stop Pushbutton is depressed. (Any Emergency Stop Pushbutton must stop every VFD.)

The windscreen will be controlled from a “Windscreen Control” screen on the HMI.

Move to Position

- The operator will enter the desired position for the windscreen on the “Windscreen Control” screen. When the “START MOVE” pushbutton is pressed the windscreen will start moving using the parameters entered. (The minimum and maximum parameters will be determined at start-up. The motion will stop so that the desired location, according to the absolute position encoders, is reached. When the setpoint is changed over the SCADA link and the “START MOVE” signal for Position is left energized, the motion will start whenever the setpoint and the actual position are different by a minimum move size. (To be determined during start-up).
- If the “STOP MOVE” pushbutton for Azimuth control is pressed the windscreen will stop moving, regardless of whether it has reached the desired position, using the parameters set for acceleration. (The acceleration parameter is also used for deceleration.)

The following information will be available at the HMI. Each will annunciate an alarm if it is out of predetermined limits.

– Door panel skew

– Over torque

– Over Speed

7.2.6 Lighting

The enclosure lighting at the observing level, rotating enclosure lighting, entrance lobby, and enclosure access corridor lighting will be controlled via an addressable low-voltage lighting control system which will be provided with a software that will be controlled at the control room.

Each fixture located at the rotating enclosure and observing level will have the ability of being controlled indivually from the control room.

Warning: Emergency and egress lighting must not be connected to the system.

7.2.7 Alarms

The following alarms are included in the system:

- Disconnect Means Open – Azimuth VFD 1-4
- Azimuth VFD Fault 1-4
- Brake Bypass Switch set to Bypass – Azimuth 1-4
- Brake Failed to Release – Azimuth 1-4
- Azimuth Failed to Move
- Disconnect Switch Open – Left Bi-Parting Door Panel
- Disconnect Switch Open – Right Bi-Parting Door Panel
- Right Bi-Parting Door VFD Fault
- Left Bi-Parting Door VFD Fault

- Right Bi-Parting Door Failed to Move
- Left Bi-Parting Door Failed to Move
- Lighting Contactor Failure
- PLC Communications Link Failure
- Widow/orphan
- Ventilation Motor Failed to Reach Limits (1-21)
- Windscreen Door panel skew
- Windscreen Over torque
- Windscreen Over Speed

8 COMMUNICATIONS

This section details the Design Criteria for the Communications works for the Project.

8.1 PERFORMANCE REQUIREMENTS

Two 4" conduits will be routed underground from the IT Room 115 to outside to a TSPM designated location. TSPM will then intercept the conduit and route their communication line through the conduit.

Tele/Data will consist of 4" square back box with a single gang mud ring and a minimum of ¾" EMT conduit stubbed into ceiling space and routed to nearest cable tray. All telephone/data cabling is by TSPM.

9 FIRE ALARM

The design of the fire alarm system will consist of an addressable type system installed in accordance with NFPA 72.

Notification devices will be provided through-out the facility.

The fire alarm system will interface with the BACnet building automation system (BAS) to provide a notification of any event. This notification will be accessible to any remote clients. The BAS will also provide this notification to the enclosure control system using either Ethernet I/P communication or a discrete I/O point.

Smoke detectors will be provided in electrical rooms, mechanical rooms, ups/IT rooms and similar spaces.

The wiring system shall be a class 'A' system. All outgoing and return conductors, exiting and returning to the FACP, shall be in separate conduits, wiring shall be per the requirements of NFPA 72.

A 6' separation between supply and return loops shall be provided

10 CONSTRUCTION SCHEDULE BY PACKAGES

Work packages are delivered in phases so that construction begins while the design is finalized. Total design needs to be at a 50% completion minimum before packages can be separated and issued. Work packages also allow the design team to focus on completing drawings per on-site construction activities, adapting priorities to the construction schedule and logistics. For TSPM, there will be four construction packages:

1. CIVIL: Site Earthwork and Improvements
2. CONCRETE: Underground Utilities, Concrete and Miscellaneous Steel
3. SHELL: Structural Steel, Building Envelope and Mechanisms
4. COMPLETION: Architectural, HVAC and Plumbing, Fire Protection and Electrical

11 CONSTRUCTION LOGISTICS

11.1 CONSTRUCTION AT SAN PEDRO MARTIR

The proposed site for the Telescopio San Pedro Martir is considered remote and will require all material and construction personnel to be transported to site. Personnel are anticipated to work extended hour days and a six-day workweek. Since adjacent facilities will not be adequate for construction personnel, a temporary construction camp will be required. The temporary construction camp will be comprised of dorms, cafeteria, and recreation hall constructed on site. The existing vehicular access road is assumed to be adequate for construction traffic.

The logistics of material and equipment transportation, available laydown area near the site, and distance to the nearest port are all factors in the total cost of the facility. Construction laborers typically receive an additional stipend when working at remote sites and are reimbursed for all travel expenses to and from the construction site.

There are several general contractors and subcontractors available in Mexico capable of building this facility. The goal of the Telescopio San Pedro Martir is to have typical building construction methods and tolerances. Where tighter tolerances such as machined parts are required, shop assembly and fit-up is required prior to shipment to the project site.

During the pre-bid process, it is important to pre-qualify potential general contractors and subcontractors. This is typical in the industry, and the process provides an understanding of potential contractor’s interest in the project. This process also provides information on the contractor’s experience in similar projects types and their experience working on remote sites.

11.2 CRITICAL RISK ASSESSMENT

The design objective of the TSPM is to provide an observatory that is low risk with proven solutions. The TSPM design is based upon the Magellan Observatory, which has been in operation for over a decade. There have been many “Lesson Learned” over the past decade, which the TSPM will be able to improve upon.

The TSPM will be designed to reduce the risks of design and construction through the following methods:

- Reduce on-site labor by fabricating components off-site.
- Utilize locally available materials that are familiar to the local labor force.
- Specify products and equipment that are readily available and easily maintained.

These methods will directly impact the willingness of a contractor to bid the work, and will lay the groundwork for a competitive bid environment. A competitive bid environment is favorable for both cost and schedule.

11.3 PRE-CONSTRUCTION PHASE

The success of a construction project is highly dependent on how well a contractor plans during the pre-construction phase. The goal of this phase is to minimize 'on-site' time during construction and avoid potential conflicts that can affect the project budget and schedule. The general contractor will prepare a critical path schedule and cost analysis report to include material and personnel logistics, transportation, and subcontractor utilization. During this phase, the quality control agencies and surveyors will be sourced and contracted. Their availability to travel to the project site on an 'as-needed' basis will also be confirmed.

As part of the pre-construction phase, the steel subcontractor will fabricate and preassemble the rotating box girder in the shop. Prior to installation of the rotating box girder top plate, an independent quality control agency will inspect all welds, member sizes, and connections. Once completed, the box girder is assembled with the machined steel track and inspected for fit-up tolerances.

Pre-assembly of the dome, other than the rotating box girder and bogie track, is not required for this structure. The steel structure drawings created with a 3D software package provides the steel fabrication drawings. The electronic file of each steel piece is loaded to automated fabrication equipment and assembled based on the information provided in the electronic file. The accuracy and quality of this system, and approach to fabricating steel, provides enough confidence that the expense of pre-assembling the entire steel structure is unwarranted. This method has been proven with success in similar size projects, making the pre-assembly of the entire dome not a requirement.

All azimuth rotation and shutter door mechanisms need to be pre-assembled and operated in the shop prior to sending to the site. The anchor bolt template for the azimuth drives and bogies provided to the structural steel fabricator will ensure proper fit up.

11.4 CONSTRUCTION PHASE

Construction equipment required to build the Telescopio San Pedro Martir is readily available in Mexico from many equipment rental companies located throughout the country. A 100-ton mobile crane for lifting all steel equipment into place is common, and utilized throughout Mexico on large scale industrial projects and mining facilities. Other construction ancillary equipment such as backhoes, man lifts, excavators, and other earthwork equipment is readily available.

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