**GMT site, enclosure, and facilities design and development overview and update**

Jose Terana, William S. Burgettb, Eric Grigelb, Bruce C. Bigelowb, Eduardo Donosob, Francisco Figueroab

a M3 Engineering & Technology Corp. 2051 W. Sunset Rd. Tucson, AZ 85704 USA  
bGMTO Corporation, 465 N. Halstead, Suite 250, Pasadena, CA 91107 USA

**ABSTRACT**

The Giant Magellan Telescope (GMT) will have a 25.4-meter diameter effective aperture, and is one of the three currently planned next generation extremely large telescopes (ELTs). The GMT will be located at the summit of Cerro Campanas at the Las Campanas Observatory (LCO) in Chile, one of the world’s best observing sites. This paper provides an overview of the site master plan comprising site infrastructure, enclosure, and facilities, and outlines the analysis of alternative trade studies that will lead to the final design. Also presented is an update of the site infrastructure development and pre-construction activities currently underway that will be completed prior to the beginning of enclosure construction near the end of 2016.

**Keywords:** GMT, observatory, enclosure, shutters, wind screen, moon screen

1. **INTRODUCTION**

The GMT staff, along with M3 Engineering & Technology Corporation (M3), have been working diligently since the 2014 SPIE Proceedings, resulting in advanced design progress and the start of site construction work. Multiple design trade studies have been undertaken to advance specific aspects of the enclosure and facilities design, with the intent of providing the project with the best possible solutions. The GMT has also broken ground and begun construction work on site infrastructure, rough grading, and site improvements. This paper will provide an overview of the current status of the GMT project, along with discussing the multiple design trade studies and current site work under construction.

2. **CIVIL WORK AND INFRASTRUCTURE**

2.1 Design Evolution since the 2014 SPIE Proceedings

The GMT masterplan is defined by two areas; the summit site and the support sites. The layout of the GMT masterplan has evolved since the 2014 SPIE proceedings, with a desire to reduce building area and personnel related functions on the summit site. Reference “GMT site: facilities and enclosure design overview,” Proc. SPIE 9145-91 (2014) for further information on the 2014 design. This departure from the previous design is intended to limit personnel functions on the summit site due to the harsh environmental conditions associated with the summit site proper, provide additional space for construction related activities and staging, and provide additional real-estate for future astronomical projects. The following is a list of top-level design features of both the 2014 and 2016 masterplan layouts, also reference Figures 1 and 2.

**GMT Site Masterplan Design 2014**

- Summit Site – Enclosure & Summit Support Building  
- Support Site – Utilities Building & Warehouse  
- Lodge – Lodging, kitchen, and recreation buildings

**GMT Site Masterplan Design 2016**

- Summit Site – Enclosure & Summit Utility Building. Elimination of the Summit Support Building (functions previously within this buildings have been dispersed to other locations at the summit site and support sites).  
- Support Site No. 1 – Utilities / Shop Building & Warehouse / M1 Factory / M2 Metrology Building  
- Support Site No. 2 (Contractors Camp / Lodge) – Lodging, kitchen, and recreation buildings
Figure 1. Giant Magellan Telescope Site Masterplan - 2014 Layout

Figure 2. Giant Magellan Telescope Site Masterplan - 2016 Layout
2.2 Construction Activities

The GMT summit site, at Las Campanas Peak, was initially leveled in 2012. Site construction work has since resumed starting in early 2015, and includes site infrastructure and rough grading. Site infrastructure work complete comprises of the installation of the permanent power and communications lines, setting of electrical transformers, installation of summit meteorological towers, and an upgrade of the existing water well pumping system that supplies water to the GMT summit. Rough grading work complete comprises of the main access road, loop access road, Support Site No. 1 pads, and Support Site No. 2 pads.

Work set to commence in the near future includes site improvements, such as vehicular guardrails and signage, to enhance safety on the site during construction activities. Additional work to begin in the near future includes infrastructure and utilities work, including sanitary waste infrastructure and domestic and fire water supply to support the construction camp and future ramped-up construction efforts.

Final design and site preparation for the construction camp buildings (lodging, kitchen, and recreation) at Support Site No. 2 and temporary summit site construction offices is also progressing. This design will accommodate 280 people, including GMT, construction contractors and laborers, and additional construction support personnel.

![Figure 3. Giant Magellan Telescope Construction Activities](image)

2.3 Lessons Learned from Construction Activities

During the Civil Package rough grading construction activities, GMT and M3 gained valuable insight into the characteristics of the site and its geotechnical composition. Although the initial geotechnical investigation provided information detailing the summit site proper, minimal information was known about the broader site area where the support facilities will be located. During rough grading activities, there was a significant quantity of competent bedrock discovered just below grade. Where bedrock was not encountered, looser silts and clayey sands were encountered. The discovery of this type of soil composition was unfortunate since it did not provide the well-graded soil classifications that are highly desired for grading cut and fill activities. This led the design team to rethink pad and road elevations and to make every effort to minimize grading activities on the site. This will also inform future design decisions as to where buildings, and specific functions within buildings, are located at the GMT support sites.
3. ENCLOSURE

3.1 Overview
The primary purpose of the telescope enclosure is to protect the telescope from a wide range of extreme environmental conditions. It must also minimize the effects of thermal and wind flow conditions that impact telescope performance during science operations. Some primary design drivers of the enclosure include the following:

- Independently rotating cylindrical (carousel type) enclosure
- Enclosure centered on the telescope azimuth
- Enclosure height and width determined by the telescope swept volume
- Shutter size based upon the telescope viewing angle and aperture width
- Enclosure wind screen and moon screen are required

The enclosure consists of the upper enclosure (rotating), the lower enclosure (fixed), and the telescope pier. The upper enclosure is an independently rotating structure, allowing free movement of the telescope, without restriction, within the enclosure. Some advantages of the current upper enclosure design include: efficient use of structural materials and insulated panels, use of standard and universal construction techniques, ease of implementing shutter and ventilation door concepts, ease of implementing wind screen and moon screen concepts, and the ability to accommodate an overhead traveling bridge crane. The lower enclosure is the fixed structure that provides support for the upper (rotating) enclosure. It also provides access to the telescope pier and provides for thermal and wind protection of the pier, along with accommodating multiple personnel and telescope maintenance functions. The telescope pier is the solid support on which the telescope and its instruments are supported.

3.2 Design Evolution since the 2014 SPIE Proceedings
The design of the enclosure has considerably evolved since the 2014 SPIE proceedings. This is due to the many factors including: requirements development, design trade studies, and responses to review committee recommendations. Reference Section 4 of this paper for a detailed description of the design trade studies prepared for the enclosure. The following is a highlighted list of top-level design features of both the 2014 enclosure design and current 2016 enclosure design. Reference Figure 4 and Figure 5 for images of the two enclosures in their open and closed positions.

GMT Enclosure Design 2014
- Open steel lower enclosure structure w/ limited functions (referred to as the “Open Soffit” design option)
- Horizontal translating upper shutters and azimuthally-translating lower shutters
- Horizontal translating upper shutters act as a moon screen
- Articulated (folding) accordion-type wind screen
- Rotation system uses single rail, fixed bogies with a moving track

GMT Enclosure Design 2016
- Closed concrete lower enclosure w/ multiple mirror, instrument, and personnel functions located within this space (referred to as the “Closed Soffit” design option). This design option is still under review by the project team. Reference section 4.2 of this paper for further discussion.
- Right-angle bi-parting shutter design
- Stacking lightweight steel moon screen
- Two-part rolling clad wind screen
- Rotation system uses single rail, moving bogies with a fixed track
Figure 4. Giant Magellan Telescope Enclosure Design 2014

Figure 5. Giant Magellan Telescope Enclosure Design 2016
3.3 Enclosure Structural Design & Materials

The enclosure main steel structure can be broken down into three equally important subsystems, consisting of the super columns, lateral bracing system and the rotating ring girder. The super columns (x4) are the primary gravity and lateral load carrying elements, thus forming the backbone of the enclosure. They are located at each end of the enclosure. The super columns support both the upper portion of the bi-parting shutters and the story deep truss which in turn supports the roof system and enclosure overhead traveling crane. The lateral bracing system consists of a set of diagonal structural elements located along the periphery of the enclosure which resist lateral forces (either from wind or seismic) and transfer these loads to the rotating ring girder. The rotating ring girder is an open steel box girder fabricated from hot-rolled shapes forming a tapered rectangular cross-section which supports all of the upper enclosure loads.

Materials used in the construction of the GMT enclosure building were chosen for their performance as well as their availability in the local region. Concrete and steel fabrication and erection are both commonly available in Chile, with an abundance of skilled labor in these trades. The enclosure building walls are clad primarily with insulated metal wall panels. The metal wall panels have an off-set double tongue-and-groove joint providing a full thermal break. Steel girts provide the structural support for the metal wall panels. The roof system consists of standing seam roof panels over rigid insulation over a metal deck. The metal deck is in turn supported by steel girts. Both the roof and wall panel systems are readily available in Chile. Reference Figure 6 for a section of the enclosure building.

Figure 6. Giant Magellan Telescope Enclosure Section
3.4 Lower Enclosure

The lower enclosure is the fixed structure that provides support for the upper rotating enclosure. The current layout of the lower enclosure consists of an inner and outer concrete wall, in which the walls support the upper enclosure and the observing level floor. The inner concrete wall is close to, but structurally isolated from, the concrete telescope pier. The outer concrete wall is centered on the azimuth bogie rail and supports the enclosure azimuth bogies which allow for rotation of the upper enclosure. This wall arrangement affords the GMT significant real estate for mirror, instrument, and personnel functions within the lower enclosure.

Utilizing the closed soffit as the current baseline for the lower enclosure affords the GMT significant interior climatized space for necessary telescope and instrument related functions. In the 2014 design, these functions were accommodated in a separate building on the summit site. The inclusion of these functions reduces risk in that optical and instrument components do not have to travel outside the enclosure for maintenance and servicing purposes. The utilization of a “closed soffit” concrete lower enclosure design option is still under review by the project team.

The two primary telescope related items that will be accommodated in the lower enclosure include the primary mirrors and the telescope instruments. The primary mirrors will have dedicated space for servicing (x2 bays), washing and stripping (x1 bay), and coating (x1 bay). Infrastructure required for these operations, along with adequate space to accommodate the movement of such large optics, will be thoroughly reviewed. The telescope instruments will have dedicated bays (x2 bays) for maintenance, repair, and storage. Along with these dedicated bays, a clean room and detector lab will be provided.

Personnel space is also provided in the lower enclosure. This includes a dedicated entrance, break room, electronics room, operations room, storage, and restrooms. Vertical circulation will be accommodated via stairs and elevator. Reference Figure 7 for a floor plan of the lower enclosure at both grade level and the control level.

![Figure 7. Giant Magellan Telescope Lower Enclosure Floor Plans](http://proceedings.spiedigitallibrary.org/)
3.5 Telescope Pier

The Telescope Pier is the fixed cylindrical concrete structure at the center of the enclosure that supports the telescope. It is physically detached from all other structures to maintain mechanical vibration isolation from the rest of the enclosure building. The telescope pier consists of a reinforced concrete structure with interior steel platforms that allow access to telescope equipment and utilities. A concrete slab diaphragm at the top level is also provided for access to the base of the telescope. The telescope rests on the azimuth track which in turn attaches to the top of the telescope pier wall. The telescope pier has several openings though its perimeter wall for personnel, equipment and utilities access. A large pier portal opening is provided for the movement of telescope instruments in and out of the telescope pier. Reference Figure 8 for an image of the telescope pier.

![Telescope Pier Diagram](image)

Figure 8. Giant Magellan Telescope – Telescope Pier

Most recently, GMT and M3 have been working on the telescope azimuth track to telescope pier interface. This is a critical interface between the two systems that must sufficiently transfer the telescope loads from the telescope azimuth track through the telescope pier to grade. After a systematic review of the design inputs, which included information on anchorage quantity, location, and loads, a grouted steel shear key was proposed for the interface connection. A critical component of this interface is the ability to adjust the position during construction and operations in both the vertical and horizontal direction. M3 performed finite element analysis (FEA) modeling on the connection to verify that the deformation and stress results were acceptable. In addition to the design and modeling of this interface, M3 reviewed the constructability of the interface, which included detailing a comprehensive installation program.

The project team has also expressed an interest in pursuing seismic base isolation for the telescope, aimed at reducing large accelerations seen at various levels of the telescope. These large accelerations pose an undue risk to the optical components of the telescope. Seismic base isolation may be utilized to mitigate the deleterious effects of strong ground motion by means of seismic isolation. M3 has completed an initial study addressing this topic, with sections including the following: historical & telescope seismic isolation projects, performance requirements, standard industry practice, code requirements, seismic isolation overview, isolator types, energy dissipation systems, horizontal vs. vertical isolation systems, passive vs. active systems, potential seismic isolation locations, general arrangements and access, testing and integration, maintenance requirements, influence and impact of adjacent interfaces, constructability, cost estimation, and study findings. It is yet to be determined if seismic base isolation for the telescope will be incorporated into the project.
3.6 Pier Lift Platform

The pier lift platform is contained within the center of the telescope pier. It is used to raise telescope instruments from ground level for installation into the telescope gregorian instrument rotator (GIR). The circular design of the lift is intended to interface with the circular opening in the telescope azimuth structure. During operation of the telescope, the lift will park in this upper location to close off the telescope chamber from the large volume of air within the telescope pier below. Seals will be provided in this area to minimize air infiltration.

The pier lift platform mechanization options are still under review, but will most likely consist of a hydraulic or electromechanical system. It will be supported by 3 primary vertical steel columns / rails that originate at the base of the telescope pier. Reference Figure 9 for a preliminary image of the pier lift platform.

One primary design constraint is the lateral deformation of the pier lift platform when it is fully extended. In this position, just before the telescope instrument engages the GIR, the lift and instrument are in a vulnerable position may a survival level earthquake occur. The GMT project team and M3 will be working closely to control these deformations and provide a design that reduces risk while not over constraining the design.

The pier lift platform will have the following specifications:

- Lift Capacity: 15.0 mt
- Platform Size: 5.0 m diameter
- Vertical Travel: 15.0 m
- Speed Control: Variable raising and lowering speeds of 0.004 to 0.200 m/s

![Figure 9. Giant Magellan Telescope Pier Lift Platform](image-url)
4. ENCLOSURE DESIGN TRADE STUDIES

4.1 Overview

In order to provide the best possible enclosure design to meet the specific needs of the GMT, multiple design trade studies were conducted. These trade studies had a common theme of identifying cost efficient solutions that would increase the performance of the GMT both during the initial construction / commissioning phase and during the full operations lifespan of the project. As applicable to each trade study, the following outline was used as the basis for performing the trade studies:

- Overview with purpose of the trade study, reasons for conducting the trade study and historical precedent
- Collection and verification of design requirements and GMT design inputs
- Thorough review of applicable design options
- Summary of interfaces affected by the design option
- Discipline overview (structural, architectural, mechanisms, etc.)
- Analysis of reliability, accessibility, and maintainability (RAM)
- Identification of predominant failure modes
- Applicable risk identification and analysis
- Review of constructability, including manufacturing, fabrication, shipping, installation, and fit-up
- Rough order of magnitude cost estimations for all design options, including systems affected by designs
- Design team conclusions and recommendations

The results of the design trade studies are comprehensive reports that speak to a wide range of issues and make recommendations on specific design options.

4.2 Lower Enclosure Open Soffit vs. Closed Soffit

The project team has been actively evaluating the design and arrangement of the lower enclosure. Two primary design options are prevalent in the telescope observatory world, commonly referred to as the “open soffit” and “closed soffit.” The open soffit design allows wind to freely flow underneath the upper enclosure while the closed soffit walls off the lower enclosure to provide additional usable space below the upper enclosure.

Reference Figure 4 for the layout of the open soffit and Figure 5 for the layout of the closed soffit as it has been implemented on the GMT project. The closed soffit design offers the advantage of providing GMT with additional enclosed area that may be used for telescope functions that are not afforded with the open soffit design. Reference Figure 7 for a layout of the Lower Enclosure floor plans showing the additional area inherent to the closed soffit design.

On the forefront of the decision making process, is the design option that allows for the best telescope seeing. Additional design factors to be considered include; structural design, mechanism design, cost implications, and effects on the design of the ancillary facilities.

CFD modeling also provided input on this decision making process. Reference the following SPIE papers for information on CFD modeling relating to the open soffit vs. closed soffit design option:

- “Initial computational fluid dynamics modeling of the Giant Magellan Telescope site and enclosure,” Proc. SPIE 9911-41 (2016) \(^1\).
- “Site and enclosure CFD modeling and analysis for the Giant Magellan Telescope,” Proc. SPIE 9911-42 (2016) \(^2\).

The utilization of a closed soffit concrete lower enclosure design option is still under review by the project team.
4.3 Bogie Survey

GMT performed a comprehensive survey of enclosure bogies from 13 existing observatories in operations around the globe. The purpose of the survey was to provide a general review of previous enclosure bogie designs and lessons learned to be taken into account in the development of the GMT bogies systems. General features typical of the enclosure bogie systems that were surveyed include the vertical wheels, lateral guide wheels, suspension, contact stresses and fixed vs. rotating bogies.

A thorough narrative of each observatory enclosure was provided in the survey along with information learned from maintenance staff and site personnel interacting with the enclosure bogies on a daily basis. Key issues identified and recommendations resulting from the survey include, but are not limited to, wheel alignment, wheel loading, and maintainability. The information gathered from the survey resulted in actionable design measures that will prove highly valuable for the GMT project.


4.4 Azimuth Wheel-Rail Interface Wear Study

In most large telescopes, the azimuth wheel-rail interface is responsible for transferring loads of the upper, rotating enclosure to the lower, stationary base. Experience within the observatory community has shown this interface to be susceptible to significant amounts of wear, raising concerns about longevity and long term performance. Because the GMT represents a substantial and unprecedented increase in the size of ground telescopes, with a corresponding increase in loads and component sizing; understanding, predicting, and minimizing wear at the azimuth wheel-rail interface is of heightened importance. Due to this high risk design component, an exhaustive azimuth bogie wheel-rail interface wear study was performed.


4.5 Azimuth Bogie Mounting Locations

The GMT upper enclosure consists of a steel carousel which rotates on a stationary lower enclosure structure. Rotation is facilitated via a bogie wheel to azimuth track / rail interface. The bogie wheels have the option of being fixed to the lower enclosure (stationary) or attached to the upper enclosure (rotating). Multiple factors can play a role in determining the optimal location of the bogie wheels and azimuth track. The prevalent factors that influence this arrangement include the following:

- The magnitude of loads from the upper enclosure to the lower enclosure
- The concentration and degree of variability of the loads around the azimuth track
- The structure composition of the stationary lower enclosure which supports the rotating upper enclosure

This trade study summarized the key factors in determining the optimal location of the bogie wheels from a structural, mechanization, and arrangement standpoint. The four design options reviewed were as follows:

- Option 1 – Bogie wheels fixed upon a concrete lower enclosure (“closed soffit” design)
- Option 2 – Bogie wheels rotating upon a concrete lower enclosure (“closed soffit” design)
- Option 3 – Bogie wheels fixed upon a steel frame lower enclosure (“open soffit” design)
- Option 4 – Bogie wheels rotating upon a steel frame lower enclosure (“open soffit” design)

Conclusions from the study indicate that rotating bogie wheels are more advantageous to a concrete lower enclosure (“closed soffit” design) and fixed bogies are more advantageous to a steel frame lower enclosure (“open soffit” design). Implementation of these design options will weigh heavily upon the decisions reached regarding the lower enclosure soft design.
4.6 Enclosure Shutter Comparison Study

A critical component of the upper enclosure is the shutter system. In the open position, the shutter system is designed to provide the telescope with an unobstructed view of the sky from 30 deg. above horizon to zenith. In the closed position, the shutter system is designed to protect the telescope from a wide range of environmental conditions. M3 reviewed the following design options for the enclosure shutters:

- Design Option 1 - Horizontal-stacking / Vertical bi-parting shutter design
- Design Option 2 - Right-angle bi-parting shutter design

Reference Figure 10 for images of the shutter design options in both the open and closed positions.

In summary, the right-angle bi-parting shutter design presented in Design Option 2 significantly minimizes project risk while also offering favorable reliability, maintainability, emergency closure, open / close sequencing characteristics, and life-cycle costs. For these reasons the project team has made a decision to move forward with the right-angle bi-parting shutter design.

4.7 Enclosure Wind Screen Comparison Study

A critical component of the upper enclosure is the wind screen. The wind screen is located within the vertical aperture opening of the upper enclosure and protects the telescope from wind and stray light. The wind screen improves telescope seeing by significantly decreasing the peak magnitude of non-uniformity of the wind velocity entering the upper enclosure. This results in lower, more uniform pressure distribution, with lower thermal gradients, on the telescope structure and mirror optics. Further advantages include lower thermal gradients within the telescope optical path and reduced wind shake on the telescope structure.
M3 reviewed the following design options for the enclosure wind screen:

- Design Option 1a – Folding wind screen at 17.3m total height
- Design Option 1b – Folding wind screen at 25.3m total height
- Design Option 2a – Two-part rolling wind screen at 17.3m total height
- Design Option 2b – Two-part rolling wind screen at 25.3m total height

Reference Figure 11 for images of the wind screen design option 1b and 2b in both the stowed and deployed positions.

Figure 11. Giant Magellan Telescope – Enclosure wind screen design options

In addition to the studies performed by M3, Boeing Research & Technology noted that “the addition of the wind screen significantly increases the blockage of the incoming air mass into the enclosure, particularly with the enclosure at the head wind pointing orientation. As a result, the magnitude of the flow velocity inside the enclosure is decreased as compared to the enclosure without a wind screen. The wind screen also generally modulates the flow gradients near the primary mirror, particularly for the head wind case, resulting in lower, more uniform pressure distribution on the mirror surface.” Information provided by Boeing Research & Technology, “GMT Site and Enclosure CFD Modeling and Analysis Final Report,” (2015).

In summary, the two-part rolling wind screen, as presented in design options 2a and 2b considerably minimize project risk while also offering favorable structural, mechanism, reliability, accessibility, and life-cycle costs. For these reasons the project team has recommended moving forward with the two-parting rolling wind screen design.
### 4.8 Enclosure Location on Summit Site

Las Campanas peak, where the GMT enclosure will be located, was initially sized to allow the placement of two large telescope observatory projects. Previous conceptual designs indicated the placement of the GMT to be on the northwest corner of the summit site. This location on the summit was verified to have competent bedrock and was preferred for constructability purposes over the southeast corner of the site. As the design progressed, the design team reevaluated the potential location of the enclosure on the summit site.

The primary reason for this reassessment had to do with the characteristics of the wind flow over the summit site. To investigate this in further detail, GMT enlisted the assistance of Boeing and RWDI to perform CFD studies. The CFD studies looked at both site locations, along with the incorporation of numerous design options, with the purpose of evaluating the following to assess the most advantageous design option for the GMT:

- Reduction of lower level winds / near-ground layer air with higher thermal gradients, entering the enclosure
- Reduction of high velocity air flowing over the mirrors which reduces the gradients over the mirror surfaces

The CFD results from both Boeing and RWDI indicate that relocating the GMT to the southeast corner of the site may be valuable to the project depending upon the lower enclosure design option selected as the baseline for the project. The next steps in the decision making process include the assessment of the geotechnical properties of the new location, additional on-site wind testing, and a comprehensive review of alternate access options.

### 4.9 Wind Speed Technical Note

M3 prepared a wind speed technical note discussing the survival wind speed requirements for the project. Previous reports prepared for the project predicted gust wind speeds after a 50-year return period of 65 m/s. In attempts to better understand this requirement and avoid overdesigning the building structures, M3 reviewed the following topics relating to survival wind speed requirements: Design building codes and referenced standards, wind structural systems (main wind force resisting systems and components & cladding), wind failure modes (building envelope and cladding), progressive collapse (wind failure mechanisms, risk & mitigation), applicability and implications of survival wind loads (analytical method vs. site-specific wind tunnel studies), and cost implications.

In addition to the technical note prepared by M3, RWDI performed an Extreme Climate Wind Assessment discussing the following:

- Data sources and quality control – Review of nearby observatories and historical wind data
- Design wind speed assessment – Prediction of extreme wind speeds and recommended design wind speeds

In summary, the design team believes that the project can relax the survival wind speed constraint from the current 65 m/s requirement. Further discussion is needed to determine the new design wind speed requirement.

### 4.10 Summary of Design Trade Studies

The design trade studies for the enclosure have been very productive, yielding results that will help inform the design team on how to move forward with the best solutions for the GMT project. While not all of the design options have been selected, the background information provided in the trade studies in instrumental to the decision making process.

**Table 1. Giant Magellan Telescope Design Trade Studies Summary**

<table>
<thead>
<tr>
<th>Design Trade Studies Summary</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enclosure Open vs. Closed Soffit</td>
<td>Open – Under review (Closed soffit as the baseline)</td>
</tr>
<tr>
<td>Azimuth Bogie Mounting Location</td>
<td>Closed - Dependent upon open vs. closed soffit decision</td>
</tr>
<tr>
<td>Enclosure Shutter Design Option</td>
<td>Closed – Utilize right-angle bi-parting shutter design</td>
</tr>
<tr>
<td>Enclosure Wind Screen Design Option</td>
<td>Open – Under review (Rolling wind screen as the baseline)</td>
</tr>
<tr>
<td>Enclosure Location on the GMT Summit Site</td>
<td>Open – Under review</td>
</tr>
<tr>
<td>Survival Wind Speed Requirement</td>
<td>Open – Under review</td>
</tr>
</tbody>
</table>
5. FACILITIES

5.1 Design Evolution since the 2014 SPIE Proceedings

The location, layout, and functionality of the facilities have considerably changed since the 2014 SPIE proceedings. For an image of the 2014 and 2016 site masterplan layout, refer to Figures 1 and 2. The primary shift in the location of the facilities was discussed in Section 2 of this paper.

5.2 Buildings at Support Site No. 1

Support Site No. 1 houses two buildings; the Utilities / Shop Building and the Warehouse / M1 Factory / M2 Metrology Building. The Utilities / Shop Building has the primary function of serving as the incoming utilities hub for the project site. The building also serves as a shop space for vehicle maintenance, large parts maintenance, and parts welding. The Warehouse / M1 Factory / M2 Metrology Building serves many functions, those of which will change as the project moves from construction to commissioning to operations. Initially the building will serve as a large open space for the integration of the primary mirrors into their mirror cells. During integration the building will also provide clean lab space for the M2 assembly and components. As the project moves into full operations, half of the building will be designated for general purpose warehousing, while the other half of the building will serve as a clean space for ongoing M2 testing, storage, and repair. Reference Figure 12 for a layout of Support Site No. 1 and its buildings.

5.3 Buildings at Support Site No. 2

Support Site No. 2 houses the activities associated with personnel, such as sleeping quarters, dining / kitchen, and recreational facilities. During construction, this site will host multiple buildings for contractors and personnel associated with construction activities of the GMT. This includes; dormitories, kitchen, dining, lounge and recreation buildings. During operations, the size of the facility may be reduced to accommodate the personnel required for operations of the GMT. The site will serve similar functions, but for different personnel. This site is located away from the other GMT facilities, including the main access road, to reduce noise levels and provide increased privacy. The location of the buildings will afford the personnel unobstructed views of the neighboring mountaintops along with distant panoramas of the Atacama Desert.
6. FACILITATING CONSTRUCTION

6.1 Managing Design and Construction Simultaneously

Large construction projects characteristically commence initial building activities before final design work is complete. This enables construction to begin as funds become available and as critical design decisions are being reviewed. To accommodate this design and construction overlap, the project team must give consideration to, and anticipate, how the project design requirements will be fulfilled to the furthest extent possible. This will reduce the risks associated with starting construction before design is fully complete.

Accommodation of this delivery method is typically done by breaking up the design into multiple construction packages. The GMT has taken this approach and divided the enclosure, facilities, and site work into the following construction packages listed in Table 2.

Table 2. Giant Magellan Telescope Construction Packages

<table>
<thead>
<tr>
<th>Construction Package</th>
<th>Status</th>
<th>Estimated Construction Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Civil Package (Rough Grading Package)</td>
<td>Under Construction</td>
<td>Q3 of 2016</td>
</tr>
<tr>
<td>2 - Sanitary Waste Infrastructure Distribution Package</td>
<td>In Final Design Phase</td>
<td>Q4 of 2016</td>
</tr>
<tr>
<td>3 - Utility Infrastructure Distribution Package No. 1</td>
<td>In Design Development Phase</td>
<td>Q4 of 2016</td>
</tr>
<tr>
<td>4 - Improvements Package No. 1</td>
<td>Design Complete &amp; Out for Bids</td>
<td>Q4 of 2016</td>
</tr>
<tr>
<td>5 – Utility Infrastructure Distribution Package No. 2</td>
<td>In Conceptual Design Phase</td>
<td>Q4 of 2016</td>
</tr>
<tr>
<td>6 – Concrete Package (All Inclusive)</td>
<td>In Preliminary Design Phase</td>
<td>Q4 of 2017</td>
</tr>
<tr>
<td>7 – Support Site No. 1 &amp; Utilities Package</td>
<td>In Preliminary Design Phase</td>
<td>Q2 of 2018</td>
</tr>
<tr>
<td>8 – Summit Shell Package</td>
<td>In Preliminary Design Phase</td>
<td>Q1 of 2020</td>
</tr>
<tr>
<td>9 – Summit Completion Package</td>
<td>In Conceptual Design Phase</td>
<td>Q4 of 2020</td>
</tr>
<tr>
<td>10 – Improvements Package No. 2</td>
<td>In Conceptual Design Phase</td>
<td>Q1 of 2021</td>
</tr>
</tbody>
</table>

7. CLOSING REMARKS

Over the last two years, the diligent work of the project team has yielded results that will not only provide for an improved design of the GMT, but will benefit the operations and maintenance staff for the lifetime of the project. The information delivered within the multiple design trade studies have been reviewed by a wide array of team members who provided input to reach conclusions of value and substance. Moving forward, GMT is confident that the design decisions being made have been judiciously selected as the best possible solutions to meet the extraordinary demands required for a project the caliber of the GMT.

ACKNOWLEDGEMENTS

This work has been supported by the GMTO Corporation, a non-profit organization operated on behalf of an international consortium of universities and institutions: Astronomy Australia Ltd, the Australian National University, the Carnegie Institution for Science, Harvard University, the Korea Astronomy and Space Science Institute, the São Paulo Research Foundation, the Smithsonian Institution, the University of Texas at Austin, Texas A&M University, the University of Arizona, and the University of Chicago.
REFERENCES