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Cohesive Methodology in Construction of Enclosure for 3.6m Devasthal Optical Telescope

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Abstract

Building telescope enclosures is vital for setting up any optical observatory. An enclosure was constructed in remote hilly terrain to provide shelter to India's largest 3.6 m Devasthal Optical Telescope (DOT). Primarily, the enclosure was built to protect the telescope from tough weather conditions and provide optimum space for performing various telescope related operational and maintenance activities. Other elements that were considered in the building enclosure were low thermal mass, sustainability, seismic and acoustic considerations. A steel building designed with mostly bolted connections, suitably selected materials, and mechanical systems for facilitating construction activities on site has been built for the telescope at the Devasthal site of ARIES. The enclosure construction was quite a challenging task with various project complexities. Multidisciplinary works of civil, mechanical and electrical systems in enclosure required efforts on various fronts in parallel to achieve the targets. Limitations of resources, manpower, and site conditions were managed to keep flexibility and economics in construction. Numerous challenges faced during the making of enclosures have been discussed in the paper. Insights into the construction of enclosures will provide a basic framework and learning opportunities for managing such typical construction projects in adverse weather conditions at mountainous sites.

Keywords: Construction Technology; Devasthal; DOT; Structure; Telescope Enclosure.

1. Introduction

Ground-based astronomy has played a major role in the physical sciences and the understanding of the mysteries of the universe. Telescopes installed all over the world are providing vital observations at various wavelengths, ranging from optical to radio, x-ray, etc., and supplementing human knowledge in astrophysics and related fields. With the increase in size and complexity of telescopes containing sophisticated electronics, optics, and mechanical systems, suitable enclosures have been designed to meet their requirements. A telescope contains expensive components that need protection from humidity and dust. The design of the enclosure is carried out to protect the telescope from the environment and provide an unobstructed full sky view and good seeing conditions [1]. The enclosure protects delicate optics and electronics components from the environment, including wind-induced vibrations that may degrade image quality [2]. Telescopes require associated equipment and infrastructure, such as a mirror aluminizing unit, technical room, control room, overhead cranes, and so on, which are also housed in their enclosure. The enclosure provides room for various material handling operations for telescopes, instruments, and their associated maintenance activities. In the present era, steel buildings for telescope enclosures with a minimum size of dome and auxiliary building have gained importance to reduce thermal mass and improve seeing conditions. They also meet quality requirements and cost

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efficiency during construction and operations. Control of dome air temperature through proper insulation and attention to ventilation systems are given due consideration in the design of telescope enclosures for reducing local dome seeing [3]. Forced ventilation provided by exhaust fans in windows and natural ventilation provided by doors and vents in the dome significantly reduce the heat accumulated inside the dome during the day. Removal of temperature gradients prevents distortion of the image during night observations.

Modern large-sized optical telescopes are built with structural systems containing steel structures and related mechanical components that support the optical elements and play a major role in the overall planning and construction costs [4]. Optical telescopes are generally built at remote sites at high altitudes to avoid light pollution, reduce atmospheric turbulence, and get an unobstructed view around the telescope. The type of construction and selection of building materials depends upon the functional requirements of enclosure. The planning and design of buildings in hills is challenging due to difficult terrain, steep gradients, adverse climatic conditions, natural hazards, etc. [5]. The design of high-altitude specialized steel buildings as telescope enclosures in the hills necessitates careful site selection and detailed planning of various building constituents. The design of such buildings may require retaining work and the use of different construction materials and techniques to meet project requirements. The Aryabhatta Research Institute of Observational Sciences (ARIES), an autonomous institute under the Department of Science and Technology, the Government of India, has set up a 3.6m optical telescope inside a steel enclosure at its Devasthal site in Uttarakhand.

The major science programs from the telescope include studies of variable stars and astero-seismology, supernovae, gamma ray bursts, low mass star formation, faint galaxies, AGNs, quasars, etc. The enclosure was designed as a steel building in consultation with M/s Precision Precast Solutions (PPS) Pvt. Ltd., Pune. Structural steel elements consisting of beams, girders, trusses, frames, etc., joined through plates, fasteners, welding, etc., were designed for enclosure [6]. Steel enclosures provided flexibility and cost-effectiveness owing to the availability of steel in various dimensions, a good strength-to-weight ratio, and reliability against seismic loads. The enclosure also employed various specialized mechanical systems to meet observational and maintenance requirements. The enclosure's construction was monitored from the fabrication of components in the workshop to their final erection and commissioning on site. The making of the 3.6m telescope enclosure at the site required efficient and effective teams from various disciplines, contractors, and consultants to work together to ensure project schedules with individual and collective responsibilities. A construction methodology involving the distribution and execution of work in different stages was adopted for the progress of the project. In-house expertise in the construction of such large steel buildings was not available at ARIES, so construction expertise was hired from external sources during the execution of various phases of the project. Practical implications involving day-to-day management, periodic tracking, revisions in schedules, and the preparation of functional strategies formed an important aspect of the construction methodology. Site limitations and weather constraints presented several challenges in planning, construction, synchronization of work with diverse teams, and development of project schedules for different tasks. The enclosure has been supporting telescope observations successfully since its activation in 2016.

2. Constituents of DOT Enclosure

Selection of a site is an important criteria in setting up a telescope for research work. After doing survey measurements over a few prospective sites [7], the Devasthal site for the 3.6mtelescope was selected. The site has no light pollution and offers dark sky conditions. Construction of a road of about 3 km was undertaken to the telescope site by branching off through the nearest main road from a place called Jadapani. A 1.3 m telescope was initially established by ARIES at the Devasthal site [8] with an indigenous roll-off roof [9].

Survival site conditions and seismic parameters formed an integral part of enclosure design. The Devathal site is in the highest seismic risk zone, Zone-V, as per standard [10]. The zone factor applicable is 0.36. The wind gusts at the site are about 55 m/s and are supposed to be the highest in this region. Concrete buildings absorb heat during the daytime and then radiate it slowly after sunset, so steel buildings were chosen for the 3.6 m telescope enclosure to minimize thermal mass. Space and ventilation requirements in the building were planned precisely. The design allows the enclosure to be cooled to an ambient temperature through active cooling by ventilation fans, air duct and pier fans, etc., along with passive cooling from its structure. Mechanical systems also formed an important constituent of the DOT enclosure and were integrated at different places inside the steel enclosure during the construction phases to support telescope observations, instruments, and maintenance activities. The enclosure is made up of three main components: a dome, a dome supporting structure, and an auxiliary building (Figure 1).

The dome is an insulated cylindrical steel structure that protects the telescope from the external environment. The cylindrical dome also hinders the progression of the surface boundary layer along the enclosure and avoids degradation of observations [11]. The dome rotates around the telescope supported on a steel ring beam over wheel assemblies. A rail is fixed to the bottom side of the rotating ring beam in an inverted position to drive the dome. Large slits can weaken the dome structure and increase the wind load on the telescope. Bi-parting slit doors for domes are economical and simpler to fabricate [12].

An optimum size of slit was taken in the design of the 3.6m telescope dome for carrying out observations. The slit remains covered with bi-parting slit doors during the non-observing period and has provision for a wind screen. The Dome provides a minimum elevation angle of 15° for unobstructed telescope observations. The telescope floor is at 11m height to serve the telescope and its back-end instruments etc. It can be accessed from the ground floor by staircase as well as by passenger lift. The floor has provisions for ventilation fans and various panels for dome control, slit and overhead cranes, etc. An intermediate or mezzanine floor in an enclosure at 7.6 m height is used for storage of delicate parts of instruments and their accessories, etc. It also provides access to the hatch drive and rails for their routine maintenance and is accessible from the telescope floor at 11m through stairs. A steel structure supporting a dome over columns forms the dome supporting structure and houses the telescope pier, which is isolated from building foundations. To meet the functional requirements of the telescope, the dome support structure on the ground floor consists of a telescope control room, a technical room for telescope accessories, and an area below the hatch trolley for shifting materials to the telescope floor. Through fans provided in the basement of the building, hot air is transferred from an underground duct to the outside of the enclosure through an underground duct.

The extended part of the dome support structure is called the auxiliary building and was made primarily to house the aluminizing plant, primary mirror washing unit, mirror integration stand, and space for maintenance of telescope assemblies and instruments etc. Four customized overhead cranes, consisting of two underslung cranes in the dome and two single girder cranes in the extension building, with a 10 MT capacity each, were planned and installed in the 3.6 m DOT enclosure. Overhead cranes, along with ground trolleys, support the material handling requirements inside the enclosure and were used initially for the installation of telescope components and later for the handling of telescope sub-assemblies during aluminizing missions, the mounting/unmounting of scientific instruments from the telescope, and several upgradation and maintenance works.

Figure 1. A view of 3.6 m Telescope Enclosure

3. Construction Methodology

The project of enclosure had five broad phases involving assessment of requirements, design, construction, operation, and maintenance. The first two phases [13] and the last two phases [14] have been illustrated earlier, while the present paper discusses the third phase, viz., the construction of the enclosure. Construction of the 3.6m telescope enclosure was a very challenging task owing to the remote project site with hilly access roads and extreme weather conditions. A construction sequence was envisaged during the design process of the enclosure. The non-availability of professional construction agencies near the site required far-off agencies to take up the job within limited budget constraints but with the requisite infrastructure to support operations at a difficult site. The arrangement of materials, equipment, and technical manpower on site by the contractors required meticulous planning considering their lead times. The construction methodology for the 3.6 m telescope enclosure involved four stages, namely site development and pier construction, manufacturing at works, erection of the enclosure at site, masonry and cladding works, etc. (Figure 2).

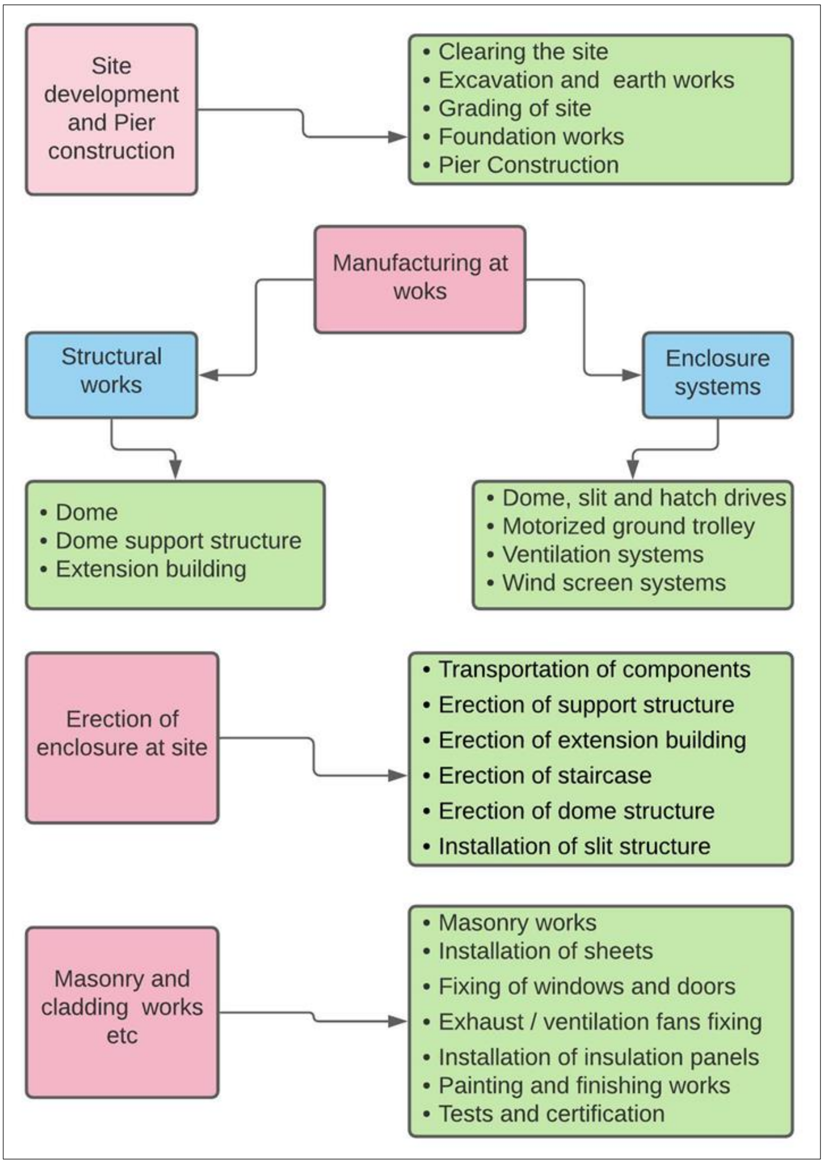

Figure 2. Four stages in construction methodology for 3.6 m telescope enclosure

3.1. Site Development and Pier Construction

Site development for major construction in remote hilly terrain is generally quite a tedious and demanding process. The 3.6m enclosure location at Devasthal was quite tough to work on owing to limited space at the hill top, big boulders in the ground, steep valley on the south side and a difficult approach road. Mobilization of manpower and machinery to the site was also quite challenging due to incremental weather and tough working conditions. The civil works for site development were planned in several sequential steps. Site development involved clearing the site by the cutting of bushes and shifting of a few trees. Substantial cutting and filling of earthworks was required for site preparation. Machines were extensively used, apart from a manual work force, to prepare the site (Figure 3). The hard rock cutting work on some column foundations and piers was very tedious and time-consuming. Hammer drill machines were employed to break the big boulders found during the foundation work. Grading of the site was carried out and the top of the mountain was prepared to the desired level and slope for the layout of the building. The building civil work comprised of building foundations, flooring, masonry walls, the construction of a concrete pier and two rooms in the basement.

Templates with holes were specifically prepared for the positioning and setting of foundation bolts for the steel columns of the building. The layout of bolts at different locations of the building was carried out and markings prepared for their grouting. The slope on the south side of the designated site was about 70 degrees due to the fact that there was no space on that side for construction activities. Construction of retaining walls on the south side was quite unique, which included rock anchoring for retaining wall stability and resisting superimposed building pressure on the retaining walls. A stepped reinforced cement concrete retaining wall was built towards the valley on the south side. With advancement in retaining works, excavations and construction of building foundations and pier were initiated (Figure 4). Once foundations were in place, the construction of the basement floor was taken up. Steel binding and shuttering work at the site were meticulously planned and executed. Arranging water for construction and curing activities at the site requires constant dependence on outsourcing of water from nearby sources. A wall up to 3m high using masonry was constructed to support doors and windows coming into the ground floor of the building. The base wall in masonry was also quite useful in supporting various dome and extension structure activities. Construction of the building floor was accomplished.

Figure 3. Preparation of site using machinery

Figure 4. Construction of building and pier in progress

The telescope was required to be placed at such a height on the pier so that it was free from the effect of ground turbulence. Devasthal site studies indicated that if a telescope is located at a height of about 13m above the ground, one can achieve sub-arcsec angular resolution for a significant fraction of the observing time [15]. The combined natural frequency and bare pier frequency of the pier were vital in the design of the pier. They were fixed at around 15 and 25 Hz, respectively, based on the natural frequency of the telescope system, which is 7.4 Hz, to keep offset and avoid any kind of resonance. The analysis was carried out in different 3D analysis packages such as SAP2000 and STAAD Pro and was vetted by using manual calculations. Natural frequency was calculated by the Rayleigh method and by modal analysis for different modes. Figures 5(a) and 5(b) show analysis models for a bare pier and a pier with a telescope as rigid links. The pier design was checked for the load distribution of about 150 MT provided by the telescope manufacturer, and its analysis was carried out in STAAD Pro V8i.

The range of relative deflections was found to be from 0 to 32 microns in its various pockets. The global deflection on top of pier wall locations was found to be uniform at all points and averaged out to be 2.411mm. The pier location was made eccentric by 1.85m inside the dome building to maximise the available space towards the east side of the dome for handling of telescope components through the hatch opening. The construction of the pier was done to meet telescope installation requirements and its anchoring with concrete. A hollow cylindrical concrete pier of 7m outer diameter and 5m inner diameter, maintaining a one-meter wall thickness, was constructed at the site (Figure 6). The pier and the building foundation were isolated from each other with a gap of 150 mm around the circumference to avoid vibration transfer. Special care was taken to avoid falling construction materials into the gap during various lifts of the pier. A 630 MT pier was built to a height of 8.26 m in eight lifts of about 1 m each using M25 grade concrete. Due attention was given during the construction of the pier as it was vital for achieving the desired frequency, strength and durability. The top slab thickness of the pier was 1m and a mechanical template was prepared for the top surface grouting works with a special grouting material called conbextra GP2. The construction of roads, drains, and paved areas around the building marked the completion of civil works.

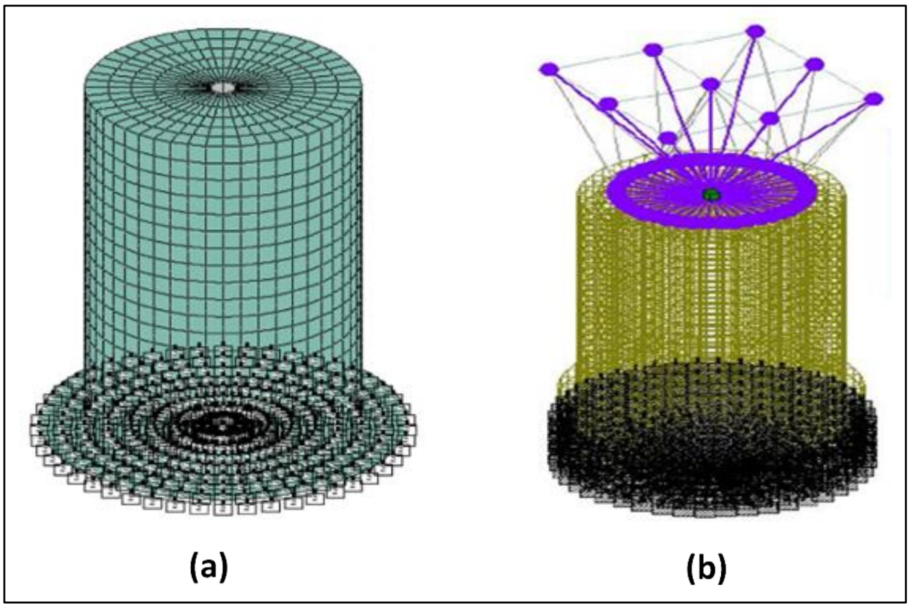

Figure 5. Analysis model for (a) Bare Pier (b) Pier with telescope as rigid links

Figure 6. Hollow cylindrical concrete pier constructed at site

Maintaining the quality of construction work along with the progress of work involves extensive scheduling, planning, and documentation for various tests and checks at different stages of construction so as to avoid rework and alterations. Cross-checks of reinforcement for piers and good curing practices at site were followed to safeguard all concreting work. Requisite tests, such as cube tests at 7 and 28 days, were performed to ensure the strength of concrete as per design requirements. A few social hurdles owing to the involvement of people due to the adjoining existing temple were also faced initially, but were sorted out. Due to the variety of issues faced at the site, time was lost in clearing bottle necks that delayed construction activities despite paramount efforts from the project team, management, and construction agencies.

3.2. Manufacturing at Works

Due to site constraints, it was planned to have a prefabricated steel structure for the telescope enclosure. The circular part of the enclosure building, with a rotating dome, posed challenges in planning and manufacturing of the components. Selection of materials was done to provide rigidity, optimum weight, and increased life to the enclosure. The work of manufacture, supply, erection, and commissioning of the 3.6m DOT enclosure structure and equipment was given to M/s Pedvak, Hyderabad. They prepared the manufacturing shop drawings based on the issued construction drawings and manufactured various components for assemblies. Manufacturing activities were broadly classified into two main categories, viz., structural work and enclosure systems.

3.2.1. Structural Works

It consisted of structural steel work for the dome, support structure, and extension building. Geometry of dome, slit doors, slit doors in closed condition over dome with supporting wheels and combination of dome building and dome were prepared (Figures 7(a) to 7(d)). Different structural members were worked out for the manufacturing enclosure. Structural components of the dome, dome support structure, and extension building consisting of portal frames, columns, wall and roof framing, crane girders and purlins, etc. were fabricated. Portal frames as framing members were fabricated from British Standard (BS) structural steel rolled into I-shapes. The circular bottom and top ring beams were also fabricated at the workshop. Dome portal frames were fixed on the top ring beam at the base. Rigid portal frames were made on both sides of the slit opening. The rigidity of the dome was maintained by reinforcing its ring beams and arcs. For its lateral stability, vertical bracings were prepared for fixing along the dome perimeter. The secondary frames and purlins for supporting the portal frames were fabricated. Steel portal frames laterally braced in vertical and roof plane were fabricated for slit doors. Frames were supported from cantilever brackets fixed on dome ring beam. The structural parts were bolted and checked for assemblies at the workshop to avoid problems at the site. Fabricated materials are galvanized. About 450 MT of enclosure materials as per design were transported to the Devasthal site in trucks for the construction of the enclosure. Materials were unloaded with mobile cranes at the site and stored in a planned manner for subsequent erection and commissioning activities.

Fabrication of the enclosure to accurate dimensions as per its design drawings was a complex task. Manufacturing components of the enclosure required qualified technicians and regular inspections at works. Material certificates, dimensional accuracy, and workmanship were inspected at different stages of fabrication. Technical problems encountered during the fabrication process require timely solutions to maintain the flow of work. Manufacturing, inspection, assembly at work, and testing were carried out following quality assurance plans to ensure the quality of components and assemblies.

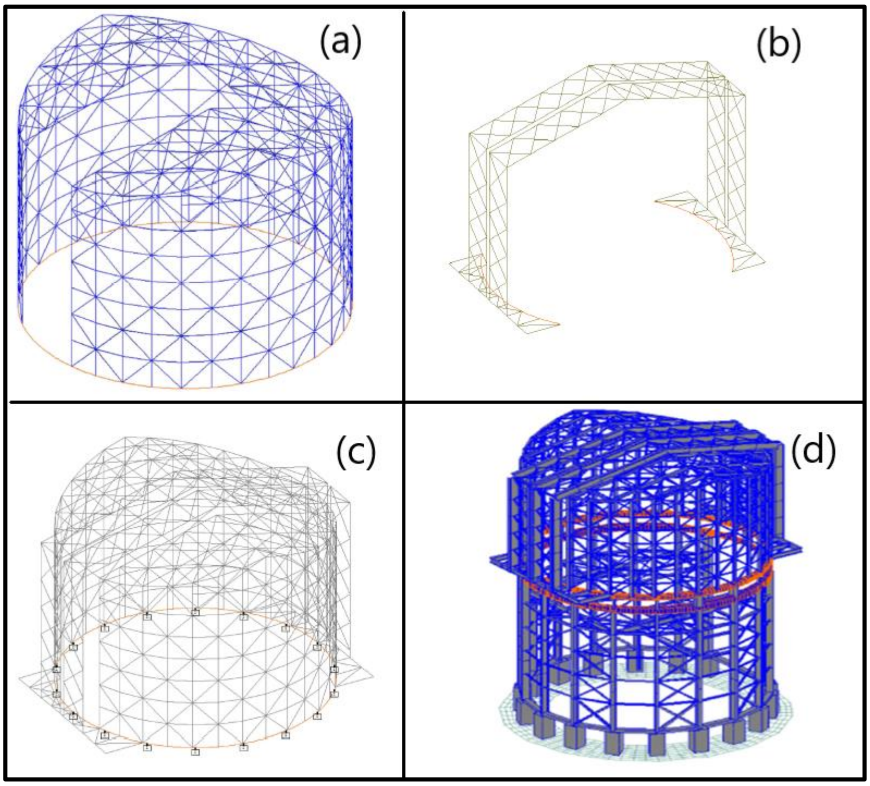

Figure 7. Geometry of (a) Dome (b) Slit doors (c) Slit doors in closed condition over dome with supporting wheels (d) Combination of dome building and dome

3.2.2. Enclosure Systems

Dome drive systems, slit drive systems, hatch cover drive systems, motorized ground trolleys, ventilation systems, and wind screen systems constitute the major electro-mechanical systems of the enclosure. Dome drive systems consist of dome ring beams and wheel assemblies. Dome top and bottom ring beams, wheel assemblies, and other components were manufactured in parts and required special attention during fabrication to avoid distortions during welding. The deviation in diameter during manufacturing of the ring beam was maintained within 10 mm and the flatness of its surfaces within 2 mm. Dome ring beams were fabricated from plates, rails, and rail clamps, etc. Wheel assemblies were manufactured and tested at work. Assembly, installation, and functional requirements of dome rotation were ensured by pre-assembly of ring beams and wheel assemblies in the workshop. Ring beams and drive assembly test setup were prepared, and testing of the rotation of the top ring beam was carried out with dummy concrete loads to check its performance from a long-run perspective and to avoid problems at the site. The assembled top ring beam was supported by 18 wheel assemblies placed on the bottom ring beam over a level platform. Six wheel assemblies were provided with geared drives, while the other twelve were idler wheel assemblies. Dome weight excluding top ring beam was about 155 MT so dummy concrete blocks weighing 1.25 times the weight of the dome, i.e., about 195 MT distributed uniformly over the ring beam, were used for trials (Figure 8). Problems related to alignment and drive systems were attended to. Multiple trials were conducted to solve the various teething problems of sound, etc. and meet the requirements during trial runs [16].

Bi-parting shutter doors were designed for the dome of a 3.6 m telescope to give synchronised motion of both the shutter halves, with motorised and idle wheel arrangement. Two drive wheels and two idler wheel assemblies were manufactured for each slit door. Drive wheel assemblies were manufactured and fitted with motors containing fail-safe electromagnetic brakes. The rail was prepared for fixing on the cantilever platform attached to the dome. Mechanical stoppers were fabricated to restrict the travel of slit doors beyond the limits. The joint between the bi-parting shutters in closed condition was made leak-proof by using an overlapping sheet strip to prevent the entry of rain drops. A provision for covering the vertical opening between open slit doors of the dome was provided in the form of a motorized wind screen. It was prepared in the form of an inverted light weight rolling shutter made from polyester with a PVC (Polyvinyl chloride) coating material and can be moved to limit the opening, especially during high wind conditions.

Figure 8. Ring beam and drive assembly test setup at works

A hatch of 5.5×5.5 m in size in the design of the telescope floor was provided for the initial telescope installation and later on for service requirements of the telescope and its instruments. Hatch covers in the form of motorized mechanical trolleys with wheels rolling over rails were manufactured for frequent opening and closing of hatches. The closed hatch provides safety, and its location on the telescope floor is used for a variety of tasks. As the hatch trolley was required to take heavy loads during installation and maintenance activities of the telescope, it was designed for a 1.0 MT/m^2 load capacity. Chequered plates have been used as the floor of the hatch trolley. The trolley was supported on extended supports provided by columns of the extension building, enabling its travel up to about 6.4 m. Drive and idler wheel assemblies were manufactured for movement of the hatch drive over rails.

A 20 MT capacity motorized ground trolley was manufactured to move on rail track provided on the ground between the extension building and the dome support structure to reach below the hatch opening for movement of telescope components, instruments, and tools, etc. through it. A trolley measuring 4.5x4.5 m was manufactured from steel beams and plates. Four wheel assemblies were manufactured for the trolley. A common shaft for two drive wheels was provided for motor drive. Electric supply to the motor was provided through the cable releaser mounted below the trolley. A cable reeling drum was used to cover the 27 m travel length over rail track.

The technical room on the ground floor of the dome support structure was prepared to accommodate the hydraulic power pack, compressed air system, chiller units, and electrical panels, etc. for the telescope operation. This equipment generates heat inside the enclosure. The heat generated inside the enclosure at various levels was planned to be removed using ventilation systems so that the temperature over the telescope floor could be maintained close to the temperature outside the enclosure during observations. Twelve large axial flow ventilation fans of 1.5 m diameter were fixed on the observation floor in its circular wall to provide forced ventilation for the observation floor. Fans were provided with louvres and fan hoods from outside of the building. The pier was ventilated by providing an opening at about 3 m height from which an exhaust fan mounted on the frame inside the technical room sucked air. Three exhaust fans were fixed in the technical room to remove heat generated inside it. Heat generated inside the technical room is also removed by an underground duct that was laid from it to the ventilation fan room located in the basement of the building. Three ventilation fans were set up in the ventilation fan room of the basement to suck hot air from the technical room into the atmosphere. Two are used at a time, and one is kept as a spare. For standard bought out equipment such as fans, panels, etc., an inspection was carried out at the supplier's end and materials were dispatched to the site and installed.

3.3. Erection of Enclosure at Site

After the civil works were completed, the superstructure construction activities were started on site. An assessment of the road and structures on the hilly route from Kathgodam in the foothills to the 3.6 m telescope site at Devasthal was carried out to evaluate the transportation of enclosure consignments. The road at the site facilitated the transport of materials in trucks and their handling by mobile cranes. Detailed scheduling for transportation, storage, and manpower was done regularly with the contractor to ensure the continuity of erection activities. The design of the connections of various structural members was prepared to simplify the assembly at the site. Fabrication of bolted components at work was carried out to ease assembly and erection activities at the site. Bolting of connections required less time for inspection and could be performed in bad weather conditions on site using hand tools. Erection of structural work involved lifting, positioning, aligning, and bolting together parts to make assemblies that fit inside the enclosure at the site. Getting adequate skilled manpower and then retaining it for the erection of enclosure parts in tough weather conditions involves a lot of manpower management issues. Arrangement of infrastructure such as scaffoldings, mobilization of different capacities of mobile cranes as per site requirements and other equipment’s to site for installation activities of enclosure was a cumbersome task. Rough weather conditions involving heavy rain and snowfall caused major disruptions during work. The site had severe space constraints for performing installation activities. Normally, site modifications to steel structures can be carried out quite fast and economically. However, due to limited resources and space at the site, the fit-up issues and site modifications involved several difficulties and took more time than estimated for the same.

Erection planning was carried out to maximise the assembly of components on the ground, followed by their lifting to their respective positions in the enclosure using mobile cranes and other material handling equipment. The contact surfaces of the joints were cleaned of any oil, dust, etc. before assembly. Lifting of components was carried out by cranes using appropriate slings at suitable positions. Access for erection was quite limited and involved the handling of parts in various configurations. For safety reasons and to prevent unauthorized access during crane work, the swing area of the crane was obstructed using barriers. Inspection of erected components at site over different heights with limited access involved a lot of effort and time to fulfil design requirements. Safety was a major concern during all erection activities. Safety aspects were stressed to the erection teams with regular safety meetings. Safety nets, harnesses, helmets, etc. were used exclusively by erection staff during various erection activities. Following were main stages for the superstructure installation at site:

- Transportation of fabricated components to site.
- Erection of the dome support structure.
- Erection of extension building structure.
- Erection of staircase to telescope floor.
- Erection of dome structure.
- Installation of slit structure.

The deficiencies identified during inspections at work were required to be rectified before the materials were sent to site for erection and commissioning. It required continuous follow-up and interfacing of the materials dispatched to the site. Manufactured components from the works were transported to the Devasthal site. Components of the enclosure were quite heavy and large in size, which required cranes for loading and unloading in trucks transporting them over 1700 km. Bought out equipment and components manufactured for their assembly with enclosures were also brought to the site with the progress of work. Materials received at the site were checked for quantity, inspection reports, and specifications, etc. Components at risk of damage during transportation were also examined so that problems, if any, could be rectified well in time. Storage and material movement areas were marked at the site. Received materials were required to be located in a storage area as per erection planning at the site. Stored materials were prevented from being harmed by rain water, etc., by stacking them over sloping wooden pallets and covering them with plastic sheets during bad climatic conditions. Tools and equipment for erection and assembly were engaged for the site activities.

The location and layout of the works at the site were carried out by using grid lines and elevations marked on the drawings. Horizontal and vertical control points were created and marked at appropriate points on the site. Plates for mounting columns were grouted on site after their alignment with the theodolite. Steel columns were erected for the lower steel structure, carrying vertical loads and supporting the dome and extension building. The verticality of columns was checked and corrected to reduce errors. The tie beams and vertical bracings of the fixed portion of the dome structure were installed before final alignment. Figure 9 shows how different types of mobile cranes had to be hired for different parts of the project at the construction site. The cranes had to be able to lift and connect parts to each other through bolts. The rotating portion of dome erection started after the completion of the fixed structure. The bottom ring beam, wheel assemblies, and top ring beam were also erected in parts using mobile cranes, aligned in position, and tightened. A laser was employed for final alignment and placement of wheel assemblies. Dome parts were erected on top of the ring beam. Final welding of components was completed at the site after erection, levelling, and alignment of components to the desired accuracies. Work involving welding and grinding was performed with the utmost safety to prevent fire, especially during summer and windy months at the site. Bi-parting slit doors were erected with overlapping joints and their synchronization tests were performed. The Dome was tested over the wheel assemblies and finer adjustments were carried out. Dome tests with 360º rotation in both clock-wise and anti-clockwise directions were performed. Strict control on dimensional tolerances and load trials at work facilitated erection activities and the acceptance of the dome in trial runs at the site. At the junction of the fixed and rotating structures, a bell-shaped outer sheet hanging down from the dome was fixed to prevent the entry of water inside the dome.

Figure 9. Erection of enclosure components using mobile crane

Two customized underslung cranes in a dome and two single girder cranes in an extension building of 10 MT capacity each were commissioned in the enclosure [17, 18]. A trench was prepared from the extension building to the dome support structure along rails for the cable laying of the ground trolley. A 20 MT ground trolley manufactured at the works was installed on the rails and tested with load for transferring components between the extension building and the dome support structure.

3.4. Masonry, and Cladding Works, etc.

The enclosure up to 3 m in height from ground level has masonry work to cater to windows and doors for their easy management at lower level. Buildings above 3 m in height were cladded with profiled galvalume sheets. For natural lighting in the extension building, fixed windows at higher levels were fixed. The dome was covered with 3 mm plates from the outside and with insulation panels from the inside. Insulation prevents the transfer of outside heat into the dome during the day. Sandwich panels of phenotherm were used for insulation inside the dome. Panels, being light in weight, were quickly installed to provide thermal insulation along with durability and long life. Rainstorms, snowfall, and severe wind conditions caused several disruptions in the welding of sheets on the dome structure and fixing of sheets on the building. Welding of 3 mm sheets was a tedious task, but it was adopted considering the dynamic forces during rotation and to ensure leak-proof joints from rain and snowfall. Special attention was paid at interfaces to maintain leak-proof joints. To ensure proper fit-up during welding, sheets were accurately positioned and held securely at various locations in the dome. Welding of sheets requires good weather conditions at the site along with proper access for welding and its inspection tests etc. Scaffoldings and temporary platforms at different heights were prepared for cladding work and tied with support structures to withstand windy conditions at the site.

Circular bus bars were fixed in the dome inner circle over a fixed ring beam to give power to various drives and control panels. Dome motion assisted in performing various erection and testing activities. The installation of cable trays, underground trenches, sheet metal channels, and ducts, among other things, completed the electrical work. Routing for power and data cables, etc., was accomplished. Fixing of doors, windows, exhaust fans, ventilation fans, etc. was completed. The external surface of the dome was cleaned thoroughly and painted with two coats of primer followed by coats of aluminium paint as per standards. Inspection of the steel structure and performance tests of various sub-systems of the enclosure were carried out from time to time. Active communication with contractors and consultants during commissioning activities of various enclosure systems facilitated the timely rectification of problems. Documentation of the project, involving drawings, reports, and tests, etc. was prepared at different stages of the project. Certification of enclosure works was undertaken by consultants from M/s PPS.

3.5. Enclosure Maintenance

After the construction of the enclosure was completed, it was put through routine preventive maintenance to enhance its life. Heavy monsoons with strong winds, snow, and low temperatures can occasionally cause damage to enclosures. Taking appropriate precautions in bad weather conditions can help to avoid or reduce damage to the enclosure. Heavy snow cover over the roof during the winter months and water seepage in the monsoon are avoided by using appropriate measures at the site. Maintenance activities in the enclosure are mostly managed in-house by ARIES staff without disturbing telescope observing schedules. Repairs in enclosures mainly involved welding, bolting, and replacement of a few components, etc., that maintained their strength and aesthetics. To prevent corrosion, leaks are fixed and routine painting of the structure is carried out. Inspection of fasteners and welding are performed on a regular basis to prioritize replacement and refurbishment work to prevent further propagation of damage caused by extreme weather conditions. Maintaining a clean pitched roof on the dome and extension building allowed snow and rain water to drain smoothly. Drain pipes in buildings are regularly checked and cleaned to prevent blockage, as it may lead to seepage of water inside the building and cause rusting of components. Thus, preventive maintenance of the building with little expenditure of time and money has helped in the trouble-free operation of the enclosure.

4. Discussions and Conclusions

The construction methodology adopted for the 3.6 m telescope enclosure facilitated and synchronized construction activities at different stages of the project. Over the last decade, the 3.6 m DOT enclosure's painstaking design, construction, operation, maintenance, and upgrades have yielded results and provided a safe home for the 3.6 m telescope, its instruments, and the aluminizing facility, among other things. It also supported telescope erection activities, aluminizing missions, telescope repair missions, and maintenance activities of instruments and telescope sub-systems. Steel enclosures ensured durability, minimal ageing, and low refurbishment work as compared to conventional buildings. Steel buildings required fewer foundations and, consequently, less wastage of materials, which reduced their effect on the environment. A telescope is important in setting up any observatory, but its enclosure also plays a significant role in taking good observations. Though the cost of enclosure is substantially less when compared to the telescope, it needs to be kept in mind that anything bad in enclosure quality will affect the overall performance of the telescope and also the finances of the project. Engaging qualified and experienced manpower was very important for achieving quality and economical construction work. The erection of prefabricated steel structures at the site was nearly dust free and produced much less noise, which helped in maintaining the flora and fauna of the region. Selection of reliable contractors and having experience in the hills should be preferred for specialized building work such as enclosures to get quality results.

Problems are encountered during the execution of most construction projects, and they need to be addressed with the best possible solutions to prevent their recurrence. Numerous challenges were faced in the construction of the enclosure at the difficult site of Devasthal. Solutions to every problem encountered improved work procedures and contributed to making new strategies that contributed to the success of the enclosure project. Unanimity among different parties involved in the project, despite frequent difficulties, was valuable in driving the project. Completion of the project was carried out by integrating all aspects of construction through multidisciplinary teams. Resource and time management were crucial in driving the project. Both successes and disappointments during work serve as great learning lessons for future endeavours. Lessons learned during the making and operation of the 3.6 m DOT enclosure will encourage repetition of required outcomes and decrease potential problems and risks in future projects. The construction challenges in the making of the 3.6 m DOT enclosure at Devasthal will also provide useful information for the teams taking up similar projects at similar sites involving specialized building work. Project based knowledge involving structural analysis, different types of materials, and mechanical systems resulted in the construction of an economical telescope building.

Planning for the construction of the telescope enclosure at a hilly site required detailing of requirements, arrangement of finances, manpower, and allocation of resources to meet desired outcomes. Meticulous planning was carried out for major construction work in difficult hilly terrain, with built-in flexibility to suit the site's weather conditions. Achieving the required quality and safety during work was the essence of the project. Digital documentation was resorted to keep all the project documents handy for quick decision-making. Experience and knowledge gained in the project will be used in the execution of major projects at ARIES and will be disseminated to the wider community involved in construction projects of distinct structures. Developments, upgrades, and maintenance activities have been carried out during the last five years since the regular operation of the enclosure to improve the sub-systems and increase its operational efficiency. Improvements in the designs of some subsystems, automation, rainwater harvesting, and beautification around the enclosure will further provide value addition to the enclosure. Improvements to the telescope enclosure will also benefit the operation and maintenance teams involved with it on a day-to-day basis.

5. Declarations

5.1. Author Contributions

Conceptualization, R.R.; methodology, T.B.; writing—original draft preparation, T.B. and R.R.; writing—review and editing, T.B. and R.R. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.5. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. References

[1] Neill, D. R., DeVries, J., Hileman, E., Sebag, J., Gressler, W., Wiecha, O., Andrew, J., & Schoening, W. (2014). Baseline design and requirements for the LSST rotating enclosure (dome). Ground-Based and Airborne Telescopes V, 91454O, 1636-1652. doi:10.1117/12.2056521.

[2] Sutherland, W., Emerson, J., Dalton, G., Atad-Ettedgui, E., Beard, S., Bennett, R., Bezawada, N., Born, A., Caldwell, M., Clark, P., Craig, S., Henry, D., Jeffers, P., Little, B., McPherson, A., Murray, J., Stewart, M., Stobie, B., Terrett, D., … Woodhouse, G. (2015). The Visible and Infrared Survey Telescope for Astronomy (VISTA): Design, technical overview, and performance. Astronomy and Astrophysics, 575(A25), 1–27. doi:10.1051/0004-6361/201424973.

[3] Harding, G. A., Mack, B., Smith, F. G., & Stokoe, J. R. (1979). On the avoidance of bad seeing conditions within telescope domes. Monthly Notices of the Royal Astronomical Society, 188(2), 241–247. doi:10.1093/mnras/188.2.241.

[4] Kärcher, H. J. (2009). Telescope structures worldwide. Steel Construction, 2(3), 149–160. doi:10.1002/stco.200910019.

[5] Chawhan, V., & Arif Kamal, M. (2021). A Study of Planning, Design and Construction of Buildings in Hilly Regions of India. American Journal of Civil Engineering and Architecture, 9(1), 13–22. doi:10.12691/ajcea-9-1-3.

[6] Chen, W. F., & Liew, J. R. (2003). The civil engineering handbook. CRC Press, Florida, United States.

[7] Sagar, R., Stalin, C. S., Pandey, A. K., Uddin, W., Mohan, V., Sanwal, B. B., Gupta, S. K., Yadav, R. K. S., Durgapal, A. K., Joshi, S., Kumar, B., Gupta, A. C., Joshi, Y. C., Srivastava, J. B., Chaubey, U. S., Singh, M., Pant, P., & Gupta, K. G. (2000). Evaluation of devasthal site for optical astronomical observations. Astronomy and Astrophysics Supplement Series, 144(2), 349–362. doi:10.1051/aas:2000213.

[8] Sagar, R., Omar, A., Kumar, B., Gopinathan, M., Pandey, S. B., Bangia, T., Pant, J., Shukla, V., & Yadava, S. (2011). The new 130-cm optical telescope at Devasthal, Nainital. Current Science, 101(8), 1020–1023.

[9] Bangia, T. (2017). Unique Roll-Off Roof for Housing 1.3 m Telescope at Devasthal, Nainital. Journal of the Institution of Engineers (India): Series C, 98(3), 359–366. doi:10.1007/s40032-016-0242-0.

[10] Indian Standard: 1893 (2002). "Criteria for Earthquake Resistant Design of Structures", Part 1: General provisions and buildings, 5th revision, Bureau of Indian standards, 1-39, New Delhi, India.

[11] Yamauchi, H., & Kawahara, S. Enclosure of SUBARU Telescope. Symposium on Astronomical Telescopes and Instrumentation for the 21st Century, Proceedings of SPIE Advanced Technology Optical Telescopes V in Kailua, 2199, 430–441.

[12] Bely, P. Y. (2003). The Design and Construction of Large Optical Telescopes with 327 Illustrations. Springer-Verlag New York, Inc, USA. doi:10.1007/b97612.

[13] Pandey, A. K., Shukla, V., Bangia, T., Raskar, R. D., Kulkarni, R. R., & Ghanti, A. S. (2012). Enclosure design for the ARIES 3.6m optical telescope. Ground-Based and Airborne Telescopes IV, 8444, 844441. doi:10.1117/12.926001.

[14] Bangia, T., & Uddin, W. (2020). Sustaining mechanical systems of 3.6m optical telescope at Devasthal, India. Ground-Based and Airborne Telescopes VIII 2020 Proceedings in SPIE Astronomical Telescopes, Instrumentation Online Conference, 11445, 32. doi:10.1117/12.2561220.

[15] Pant, P., Stalin, C. S., & Sagar, R. (1999). Microthermal measurements of surface layer seeing at Devasthal site. In Astronomy and Astrophysics Supplement Series, 136(1), 19–25. doi:10.1051/aas:1999195.

[16] Bangia, T., Raskar, R., & Ghanti, A. S. Acoustics and Functional Space Design of 3.6m Devasthal Optical Telescope Building. Technologies for a Quieter India 2013 Proceedings in Acoustics in New Delhi, India, 201–207.

[17] Bangia, T., Yadava, S., Kumar, B., Ghanti, A. S., & Hardikar, P. M. (2016). Customized overhead cranes for installation of India's largest 3.6m optical telescope at Devasthal, Nainital, India. Ground-Based and Airborne Telescopes VI, 9906, 990620. doi:10.1117/12.2232127.

[18] Ermis, K., Caliskan, M., & Tanriverdi, M. (2021). Design Optimization of Moveable Moment Stabilization System for Access Crane Platforms. Acta Polytechnica, 61(1), 219–229. doi:10.14311/ap.2021.61.0219.