Unique Roll-Off Roof for Housing 1.3 m Telescope at Devasthal, Nainital

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Abstract Aryabhata Research Institute of Observational Sciences (ARIES) had set up a 1.3 m telescope at Devasthal, Nainital, India in the year 2010. Country's largest roll-off roof was indigenously designed, fabricated and installed on top of a building (17×8 m) for housing 1.3 m telescope. Telescope was supplied by M/s DFM Engineering Inc., USA to ARIES and was installed in the building with unique roll-off roof to protect it from external environment. Roll-off roof was designed and fabricated considering various parameters and available manpower and resources at ARIES. This paper presents mechanical development work, simple but distinct design approach and innovative selection of materials to economically manufacture roll-off roof of large size ($8 \times 8 \times 4$ m) at hilly remote site of Devasthal situated in Central Himalayan region. All operations in the roof viz. opening of shutters and rolling of roof were motorized to facilitate observers during night observations.

Keywords Devasthal · Roll-off roof · Structure · Telescope

Introduction

Installation of ground based small and moderate size optical telescopes is quite advantageous over large and giant ones in the areas of efficiency, availability, flexibility, serendipitous and speculative observations [1]. In this

direction a 1.3 m optical telescope had been installed by Aryabhata Research Institute of Observational Sciences (ARIES), an autonomous institution of Department of Science and Technology, Government of India at its Devasthal site [2]. Devasthal ($29^{\circ}21'40''\text{N}$, $79^{\circ}41'04''\text{E}$) situated in Central Himalayas was selected after extensive site characterisation and is located at an altitude of about 2.5 km above mean sea level with unique geographical location [3, 4]. Devasthal is comparable to best observing sites in the world [5]. Site was selected on hilltop with nearly unobstructed view on all sides and with reasonably dark sky. The 1.3 m telescope was designed, manufactured and then installed at site by M/s DFM Engineering Inc., USA. Telescope has equatorial fork mount with primary mirror of 1.3 m aperture. Its optical tube has open truss design and secondary mirror is provided with computer controlled five axis housing mechanism [6]. Telescope is useful in study of variable stars, asteroseismology, sky patrolling for supernova events, gamma-ray bursts, stellar evolution and dark matter in galaxies [7, 8].

Telescope was to be protected from dust, rain, snow, wind, stray light and dew formation etc. so it was necessary to build an enclosure to protect it from external environment. Selection of the type of enclosure for a telescope depends on several factors such as scientific goals, site constraints, budget, observer skills etc. Dome and roll-off roof were two main types of enclosures that could be used for housing the 1.3 m telescope. Both dome and roll-off roof have their distinct advantages. However, their selection depends upon observing requirements such as all sky view, protection from environment and site conditions. Domes are usually expensive to build, provide limited sky accessibility through their slit and need synchronization with telescope to achieve proper view during telescope tracking. The open air environment is more favorable to

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optimum telescope operation than nominally stable and controlled environment inside a classical dome [9]. Roll-off roof protects telescope from dust, winds and various severe weather conditions in the closed condition and provides nearly full sky access in open condition. In open condition telescope cools down fast to ambient temperature, facilitating high-quality observations. Roll-off roof are quite economical to make compared to dome but require extra area besides building for the rolling of roof. Many types of roll-off roof designs are prevalent but usually they are designed to roll-off in two halves in opposite directions which require two separate gantries and two sets of tracks. However, it requires more workmanship in constructing and aligning the two gantries [10].

Considering various parameters, available space, site conditions and availability of technical manpower and resources at ARIES, it was decided to build an in-house roll-off roof for housing the 1.3 m telescope on top of two floor building. Roof was to be constructed at remote and difficult site situated near the hill top with accessibility constraints. For selection of roll-off roof, several parameters such as structural strength and stability of structure in severe rains, snow and wind were considered. Manufacturing and assembly time of structure, ventilation, operational and maintenance costs etc. were also taken into account. Roll-off roof also circumvented dome setting and dome tracking and provided full sky view for night observations.

Building Layout

Devasthal site is surrounded by magnificent forest area. A building (17×8 m) with roll-off roof was designed to house the 1.3 m telescope and its related infrastructure. An aerial view of 1.3 m telescope building with roll-off roof in open position, open south side shutter and west side entry from attached metallic stairs for lab-cum-office area on first floor is shown in Fig. 1.

Ground Floor Layout

The main entry of the building is from east side where it is connected to road through stairs and a ramp. A double door (2.0×2.7 m) was used as main door of building for easy entry of telescope components and other accessories inside it. Telescope was installed on a Reinforced Cement Concrete (RCC) Pier (2.13×1.52 m) with a height of 3.3 m above ground till first floor of building to avoid degradation of view due to local environments. Pier was isolated from building by a gap of 0.15 m from its foundation that was loosely filled with vermiculite material. Ground floor has a telescope control room with computers and associated

Fig. 1 Roll-off roof in open position over two floor building showing 1.3 m telescope open to full sky view

hardware for telescope control and operations. This floor has two rest rooms (3.90×2.85 m) with attached toilets and a small kitchenette (2.40×1.85 m) for observers. An electrical room (3.0×2.85 m) was also provided to cater to telescope electrical maintenance requirements. Roof of ground floor has a hatch (3.30×1.75 m) which was kept for taking telescope components up to first floor during installation and further for bringing the telescope mirror down during aluminizing. Metallic stairs from inside near entrance of building were provided to access the telescope at first floor. To prevent heat flow up to the telescope floor, several windows (1.2×0.6 m) and few exhaust fans were provided on ground floor to vent out heat generated from equipments of electrical room and control room etc.

First Floor Layout

First floor houses the telescope enclosed in roll-off roof. On first floor, walls only up to height of 2.45 m were constructed with 0.40 m reinforced beam at the top over which rails were provided for moving the roll-off roof. Permanent walls are provided near all the conveniences of a domed observatory and everything under the roll-off roof rapidly falls to outside temperature as soon as the observatory is brought into operation [11]. The walls are high enough to allow the rolling roof with open shutter to completely clear the parked telescope during its movement. Walls provide a reasonable amount of privacy along with partial protection from wind and cold. The hatch area was covered with wooden planks that were fitted in steel frame to give a steady floor. The telescope observation floor (8×8 m) on first floor has a door (1.05×2.10 m) that opens into the lab cum office area (9×8 m) for performing various works associated with maintenance and up gradation of the telescope. This area has a roof of corrugated aluminium sheets with plastic sheets fitted from inside to avoid entry of thermal mass into the building.

Design of Roll-Off Roof

Roll-off roof has been conventionally designed and built at several places for various telescopes [12–14]. Important considerations while designing roll-off roof for 1.3 m telescope were to meet basic requirements, technical requirements and observer's operational requirements. Basic requirements during design were to provide protection to 1.3 m telescope from external environment and ensure telescope safety during roof operation. To withstand extreme weather conditions at remote hilly site of Devasthal, strength and durability were the principal technical requirements. Fabrication of roll-off roof was to be carried out in available space at site with available manpower, resources and cautious selection of materials requiring low maintenance. Observer's operational requirements were to carry out stellar observations during night from telescope installed in roll-off roof. Observers with in the institute and from outside were required to take observations alone during night from 1.3 m telescope through easy operation of roll-off roof. As site is prone to extreme weather conditions so observer is required to close the roof immediately to protect the telescope in case of bad weather during the night. Observer may also need to stop the rolling roof at desired distance depending upon research objective. Observers also require minimum down time of observations with very low maintenance of system.

Design of roll-off roof was accomplished considering all the technical requirements which were met successfully and are subsequently explained in various sections of the paper. Few innovations were also carried out in roll-off roof like selection of innovative materials, use of motorized wheel carriage assemblies, motorized double walled aluminium shutters and interlocks for safety of telescope. Roof design becomes complicated with increase in size and intricacies of site. Fabrication of such large structure in hilly remote area with limited resources and manpower at site was a very challenging task.

Meticulous planning during design stage was done owing to transport constraints and accessibility of site for carrying various materials and tools etc. required for fabricating roll-off roof to the site. The roof was indigenously constructed by ARIES with design support from M/s Yogendra Architects to house the 1.3 m telescope. Roof skeleton was fabricated from various mild steel sections and its skin envelope was made with light weight and rust proof corrugated aluminium sheets. Roll-off roof was designed with trusses and purlins moving on two motorized wheel carriage assemblies containing two motorized shutters with safety interlocks along with provision of a 2 ton electric hoist. This paper presents an improved, sturdy and a typical innovative design over various conventional roll-

off roofs with wood constructions, corrugated galvanized iron or plastic sheets etc. Roof is constructed over a building instead of conventional roll-off roofs which are constructed on ground with low walls. Low walls need guided movement and are even peril for visitors. Conventionally pulleys system is used for rolling the roof manually with rope tied to roof. Some use a pair of winches in which one pulls the roof open while the other unwinds it. For heavy roofs and ease of working roofs are pulled by ropes through pulleys by using gearbox and motor mounted on ground at a distance from the roof that require additional space. Also the ropes keep getting damaged and loose with usage. Present design used motorized wheel carriage assemblies eliminating the use of ropes and pulleys. It proved quite useful and provided trouble free and low maintenance system for rolling the roof. The design has scope for expansion to accommodate new instruments and related infrastructure and has stood to the test of time. Unusual large size moving structure, simple design approach and careful selection of materials make this roof quite unique at the remote site. Structure was made sturdy with simple design and proved to be fairly economical and durable. Roll-off roof was designed to give sufficient space to allow full instrument swing and room for observer and visitors. Fabrication, installation and commissioning of roll-off roof were completed by early 2010 and the same is in use since then.

Track and Motorized Wheel Carriage Assemblies

After casting of concrete beam on the first floor of building, the next step was to lay a track on which roll-off roof can move. Several types of tracks were considered for using as rails for the roll-off roof that could be easily made available and transported to site. To prepare track for movement of wheel carriage assemblies an innovative and economical design of rails was made on the site itself by using mild steel square bars. Two rows of bolts (M20 $\times$ 300 mm) were grouted in the RCC beam during its casting (Fig. 2). Mild steel flats (300 $\times$ 150 $\times$ 12 mm) were tightened on the grouted bolts over which ISMB 200 was welded. A 50 $\times$ 50 mm square bar was welded over ISMB 200 and used as track for movement of motorized wheel carriage assemblies (Fig. 3). Open position of roll-off roof obtained by moving roof towards north end provides clear line of sight through the optical axis of telescope at 29° above horizon corresponding to the site latitude (Fig. 4). Limit switches and mechanical stoppers were also provided at the ends of tracks so that roll-off roof cannot move beyond them.

Roll-off roof size (8 $\times$ 8 $\times$ 4 m) for housing the telescope was coming relatively big as compared to conventional ones usually found at other places due to large

Fig. 2 Two rows of bolts grouted in RCC beam during its casting

Fig. 3 Mild steel flats tightened on grouted bolts over which ISMB 200 was welded. Square bar welded over ISMB to use as track for movement of motorized wheel carriage assemblies

building size on which roll-off roof had to be constructed. Normally it is not advised to make rolling roofs larger as it increase its weight and load on the track requiring extra casters and more force to move it on and off [10]. Due to requirement of unusual large roof at the site, it was necessary to choose motorized wheel carriage assemblies in such a way that the drive system and wheels should move smoothly over track with proper weight distribution during its movement as they form heart of the system. Two wheel carriage assemblies of 10 MT capacities were customized, one on each track for driving the roll-off roof (Fig. 5). Two heavy duty wheels of 0.30 m diameter and 0.10 m width were provided in each wheel carriage assembly at a distance of 6.5 m. Each wheel carriage assembly consists of one driver wheel and one idler wheel. The driver wheels were placed diagonally opposite to each other and each driver wheel was designed to move the roof independently

even in case of fault in any one of them. Each driver wheel was connected to foot mounted motor with a gearbox using flexible geared coupling (Fig. 6). Wheels were provided with spherical roller bearings for smooth rotation. An Electro Hydraulic Thruster (EHT) brake with brake drum was provided to stop the roof at desired locations when power is switched off and also to prevent roof movement over rails when it is not operational. Power to wheel carriage assemblies was provided with shrouded bus bars arranged inside the building. The wheel carriages move the roof at the speed of about 10 m/min so that telescope can be quickly protected during bad weather conditions of rain and high speed winds etc. within a minute by closing the roll-off roof. A weather station was installed outside the building which gives the weather information to the observer during observations for deciding on the closing of roof during bad weather conditions.

Roof Skeleton

Trusses were designed and fabricated to make skeleton of roll-off roof. Pratt truss design was adopted for trusses. Four trusses of 125 kg each at equal distances were fabricated to take load of structural elements and roof sheeting along with snow and wind loads. A gantry girder for 2 ton electric hoist with load distribution over four trusses was also planned. The design of roll-off roof in which roof slides northwards and perpendicular to the apex do a better job of clearing useful horizon [11]. Trusses were specifically put along east–west direction instead of north–south direction of building due to space constraint in the north

Fig. 4 Close and open positions of roll-off roof showing clear line of sight through the optical axis of telescope at 29° corresponding to site latitude

Fig. 5 Two wheel carriage assemblies of 10 MT capacities one on each track for driving the roll-off roof

direction so that once roof is moved near its maximum limit it can provide a clear sky view to telescope in north direction up to 29° above horizon.

Four beams of ISMB 200 mm were erected on four corners of carriage of wheel assemblies and a framed structure from ISA 50 × 50 × 6 mm, 65 × 65 × 6 mm, 75 × 75 × 8 mm, ISMB 100 and ISMC 100 etc. was fabricated with trusses on top of the structure (Fig. 7).

Purlins were provided over trusses for stiffening the entire roof structure and to support roofing sheets. Straight portion of roof (up to 2.5 m height) comes on rails above which slopping roof up to 1.5 m height of trusses was fabricated. Total load on wheel carriage assemblies consisted of dead load of structure, snow, and wind load etc. which is about 8 tons. Further, the roof was provided with an inclination of 25° to drain off rain water and snow.

Fig. 6 View of wheel carriage assembly over fabricated track driven by gear box and motor arrangement with EHT brake provision

Fig. 7 Framed structure of roll-off roof with trusses and purlins

Roof Skin Envelope

Large size of roll-off roof opened the search for efficient sheeting materials for its roof and sides. Light weight durable material was required that could be transported to hilly difficult site and could be easily fixed on to the roof. Also material should be corrosion resistant, withstand extreme climatic conditions and possess enough strength to withstand wind and snow loads at Devasthal site for its long life. Material for sheeting was required to be good conductor of heat with high reflectivity for radiant heat and light so as to keep the telescope inside it cooler in summer, while its low emission rate should also be able to cut heat loss in winter. Several materials were searched and studied to achieve maximum blend of required properties along with the economics to work with and it was concluded to use circular corrugated aluminum sheets of 1.5 mm thickness and size 2438 × 1219 mm in roof and as side cladding sheets as they met almost all the requirements. Aluminium sheets provided high thermal conductivity and long life to avoid rusting at the mountainous site

which is prone to heavy rains, hail stones and snow. Aluminium sheets do not shatter when hit by hailstones and provide waterproofing as well. Aluminium sheets being light in weight allowed installation of long lengths on site and due to high strength to weight ratio, made them ideal for use over large area of roof. Normally galvanized iron corrugated sheets are used for roofs in hilly areas with extreme climatic condition which start corroding in couple of years and require frequent maintenance. Selection of aluminium sheets not only provided corrosion-resistance but also gave roof long life and good looks along with high reflection of heat from its surface. Thus, even after its use for more than 6 years the sheets are well maintained. Also aluminium is stain proof and doesn't discolour or rot for several years.

Due to light weight of Aluminium sheets there was no problem in transporting them to the site and also in lifting them to top of the structure. Sheets were fastened on to the structure using J bolts, cup and bitumen washers to avoid any leakage from roof. Aluminium sheet's high reflectivity for radiant heat and light (75–80 % when new, 60 % after several years) has been useful to keep the interiors of building from 5 to 8 °C cooler in summer, while its low emission rate cuts heat loss in winter thus granting excellent thermal properties. Sheets are quite easy to maintain and wash. Metal structure cools fast to ambient temperature after Sunset and wooden ply was provided from inside that served as an efficient insulator during the day time. Aluminium skin envelop not only provided pleasing aesthetics, superior weatherproofing solution and saved painting costs but also offered structural integrity. As site is in forest and hilly area which is prone to fire so aluminium sheeting being non-combustible and non-flammable was chosen to protect the expensive telescope. The site being at high altitude is also prone to frequent lightening during monsoon for which the roof was earthed properly. As aluminium also has high electrical conductivity, so it offered best protection from electrical storm during lightening periods. Overhang of corrugated sheets to about 0.25 m on sides of roof was provided to prevent the entry of water with wind.

Rolling Shutters

Two motorised rolling shutters (4.5 × 3.0 m) were provided in the rolling roof. Instead of single walled conventional shutters, double-walled aluminum shutters were specifically custom manufactured and outsourced to avoid leakage of water and entry of fog during rainy season. Shutters were installed according to the specific design requirement in north and south side of roof. They proved to be very useful in preventing entry of water on the telescope floor. Shutters were manufactured from aluminium strips

with aluminium side guides and bottom angles. A motor mounted at top from inside of shutter drives the shutter and was specifically provided with provision of manual chain override in case of power failure so that shutter can be closed to protect the telescope and its components in case of any emergency. Shutter in south direction must be opened before roof starts moving towards north to clear the telescope during its motion. Shutter in north side was provided to give homogeneity to the rolling structure for unobstructed flow of wind.

Interior Design

There is enough space inside 1.3 m telescope building to carry out observations comfortably, perform maintenance activities and also to accommodate few visitors. After Sunset building cools fast to the surrounding air temperature so that telescope and its accessories achieve quick thermal equilibrium. Inside the structure of roll-off roof decorative wooden ply of 6 mm was fixed to insulate from outside heat and also to give good aesthetics. Electrical controls and light sockets etc. were provided in the building on walls for roof operation and lights etc. Linoleum flooring was done on floor to keep it clean and provide insulation from concrete slab.

Electric Hoist

An electric hoist of 2 ton capacity with its gantry girder supported on four trusses was installed inside the roof. It was very useful in telescope installation and various maintenance activities. It will also be used for handling of mirror cell with primary mirror of telescope for aluminization activities. Provision of slow speeds in hoisting and cross travel with variable voltage and variable frequency drive (VVVFD) for delicate handling of telescope mirror was also provided in the hoist.

Protection Systems

Safety provisions for immediately stopping the rolling roof at the desired location were incorporated. Brakes in motors of wheel carriage assemblies are normally closed type and are applied as soon as the power supply is switched off to stop the roof motion at desired location. Limit switches at the end of the track were provided to cut off power and stop the roof [15]. Apart from limit switches, for the safety of the roof, mechanical stoppers were also provided to stop the roof in case of failure of limit switches. In addition few other safety provisions were also considered due to site conditions. Anti-lift arrangement was provided in roof to prevent the lifting-off of roof during heavy winds and storms. Manual roof lock was provided to protect its

motion during storms. Also windows and doors in building were provided with sufficient latches to avoid their opening during storms. Electrical interlock in the roof motion was provided that prevents motion of roof till south shutter is opened to avoid possibility of collision of south shutter on to the telescope. The problem of leakage that might happen due to the weathering away of bitumen washers in fasteners of roof due to extreme weather conditions and vibration while rolling the roof was taken care by covering them with silicon sealants.

Variations in Development of Roll-Off Roof

Few variations were carried out in development of India's largest roll-off roof for 1.3 m telescope which are usually not carried out in making of roll-off roofs. The Roll-off roof is quite large in size of $8 \times 8 \times 4$ m. Ready made rail was not used. Instead a track made out of mild steel square bar was prepared and used for moving the roof. Aluminium sheets were used to cover skeleton of roof instead of galvanized iron or plastic sheets. Whole structure was made to move only on four wheels with two driver wheels and two idler wheels. Keeping in view all the rolling roof requirements additional features were also incorporated in roof like motorized double walled aluminium shutters and electrical interlocks for safety as explained earlier.

Conclusions

Country's largest moving roll-off roof was made operational for taking observations from 1.3 m telescope by meeting all basic, technical and observer's operational requirements. As telescope was installed at a remote hilly site so all operations in roof viz. opening of shutters and rolling of roof were motorized. Hence, observer can operate roll-off roof alone during night time without any difficulty. Roll-off roof provides ease of quickly re-pointing the telescope to a completely different part of sky. Roll-off roof was indigenously and economically fabricated in-house by ARIES mechanical workshop team by arranging required materials, tools and machines etc. and further fabricating and assembling them at the site itself in difficult weather conditions. Roof was also made operational and ready to use well before installation of telescope. Roll-off roof has served as a very efficient enclosure for 1.3 m telescope with minimal maintenance and operational costs for supporting the astronomical observations. The smooth functioning of roll-off roof has been achieved with its distinct simple design approach and cautious selection of light-weight materials, economical design of its rails, customized motorized wheel

carriage assemblies and double wall rolling aluminium shutters etc. so as to take the load of the unusual large structure. Due to its simple design approach the roll-off roof is not only unique but has also remained as the backbone of 1.3 m observatory performance till date. Sometimes minute leakages during heavy and long monsoon period had been noticed which were corrected by applying silicon sealant at required places. Even after about 6 years of operation, roll-off roof is functioning properly, and withstanding severe weather conditions at Devasthal site with pleasing aesthetics.

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