Designing & Building a Domed Astronomical Observatory

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Introduction

In our roles as advice officers for telescopes, observatories, telescope accessories and telescope making in the Society for Popular Astronomy we are sometimes asked about domed observatories. Where do I get plans on how to build one? Where can I buy one, or have one made? What are the rules concerning building a domed observatory in my garden? How big should I make it and what is it likely to cost?

Surprisingly, in view of the number of practical astronomy books about both buying and making telescopes, and about ideas for different types of observatory, there is little concerning these specific issues. Which is why we have been prompted to write this book. We have been involved in both designing and building small domed observatories since the early ‘70’s, not all of them personal projects we hasten to add, but most are still standing, and so can be said to have withstood the test of time. We have also visited many domed observatories in this country, either owned by individuals or jointly by local astronomical societies. It is interesting to see how many idiosyncratic solutions there seem to be for an apparently inherently similar set of difficulties. Many of the ideas we have come across demonstrate the ingenuity of amateur astronomers.

The purpose of this book therefore is to describe how to set about designing your own domed observatory and how to go about building it. Of all the various styles of astronomical observatory the dome is in our opinion the optimum. It affords a permanent shelter from the elements, protects the telescope, equipment and observer from wind and stray light whilst allowing access to a wide area of the heavens. It also provides a home for all the accoutrements of practical astronomy that otherwise clutter the home.

We want to introduce you, the reader, who may not be an engineer or a builder by profession, to the relevant design principles and the fundamental guide lines that will enable you to design and build your own domed observatory tailored to your specific circumstances and means. If you heed these guide lines you will save yourself a lot of grief and wasted effort.

Designing and building a domed observatory can be a protracted, difficult and arduous business. not to be entertained on a whim. But it can also be thee most rewarding aspect of practical amateur astronomy, and a defining moment. If you are to succeed you will have to commit yourself to several month’s (if not years) hard work. Good luck.

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Chapter 1 - Design Principles

Prior to considering observatory design in any detail we want to review the various types of domed observatories. This will illustrate the advantages of the dome and point you towards the design that best meets your needs.

By definition of course a dome is a hemisphere. But an observatory “dome” doesn’t necessarily have to be a true hemisphere. Providing the “dome” will protect your telescope from adverse weather conditions, any practical shape will do. Some styles however are more aesthetically pleasing than others!

The simplest class of domes to construct are the facetted, or pyramidal. This is because all the panels are flat and all the joints are straight. Styles range from the drum to the conical. Next come the pseudo-hemispherical styles. These use either flat panels, or panels curved only is single plane, and either straight or curved joints. Finally there is the true hemispherical style which calls for panels curved in two planes, and curved joints. The true and pseudo-hemispherical styles can have their construction “pole” at the apex, or on the skirt. The dome can also be more than half a sphere. Some styles have no wall section, and resemble a ball with a flat bottom.

Whatever style of dome is chosen, the dome must be free to rotate through 360º in either direction, and it must have a slit wide enough to point the telescope through towards any part of the sky. The shutter covering the slit needs to be weather proof and must be able to withstand high winds when closed, and wind loads when open. The shutter is the most difficult design issue for the domed observatory. One of the problems when attempting to simplify the fabrication of a dome by opting for either a drum or conical shape is the difficulty in providing a slit opening past the apex, so the telescope will have access to the zenith. It is also difficult to make the shutters themselves. Some styles of dome require multiple shutters with overlapping joints, or a flexible shutter, or shutters which take the form of hinged doors. Problems arise with weatherproofing, cost and operation in strong winds, and in exposed situations - ice.

Generally speaking, corners and edges in a roof introduce areas of weakness, potential leaks, and awkward construction problems, and whilst odd shapes may be appropriate for specialized observing, such as the Sun which is confined to the ecliptic, the typical amateur will want to direct his telescope in all directions. A dome without overhead obstructions or shutter joints across the slit is obviously more desirable.

The Hemispherical Dome

Although a true hemisphere is awkward to fabricate it does lend itself to a simple shutter design and it is more aesthetically pleasing than most of the other forms. Aesthetic considerations are important, if only because your neighbours will be looking at your observatory for a long time. Furthermore, a hemispherical dome is better able to withstand gale force winds, and with a wide shutter opening, a wide sky coverage.

The Pseudo-hemispherical dome:

Fabricating the panels (or “gores” as they are called) of a hemispherical dome necessitates forming them into a surface curved in two directions, so that when they are pieced together the dome is uniformly curved in both the vertical and horizontal plane. This is not an easy task.

A pseudo-hemispherical dome is fabricated from trapezoidal shaped plates, which when pieced together, resemble a hemispherical dome. Domes of this type are sometimes called “facetted” domes. The more facets they have the more closely they approximate to a true hemisphere. The facetted dome is simpler to fabricate, whilst retaining all the advantages of the hemispherical dome.

Chapter 2 - Planning Consent & Building Regulations Approval

Before establishing the design of your observatory there are a few things that need to be said apropos planning permission and building regulations. The Town & Country Planning Act 1990 requires that all proposed permanent buildings erected by the owner of a private dwelling, or on his behalf, be subject to prior notification and where necessary, planning consent. The procedure is neither costly nor difficult and it is in your interests to observe these legal requirements.

If your house is not a listed building, and your land is not designated as either an area of outstanding natural beauty, an SSSI, or subject to a district bylaw, order or regulation other than section 57 of the 1990 Act, all you need to do initially is advise the district council's planning department of the building you intend erecting, apply for an exemption certificate, and provide a rough sketch showing its proposed location relative to the house and boundaries (SCALE: 1:2500 OR 1:1250) and its separation from the rear elevation of the house, boundaries and road frontage (SCALE: 1:100 or 1:250).

If the overall height exceeds 3 meters it will require full planning consent because under the new interpretation of the building regulations any structure having a roof 3m or taller (as measured from the road frontage), that is other than flat, falls within the definition of the 1990 Act. (Formerly a domed roof was classed as other than pitched and could be 4m tall before full consent was required). However unless your observatory is to have a floor area over 30 sq. meters, it will be exempt from building regulations approval.

You will need to prepare architectural drawings suitable for your planning application. These drawings and plans should be in metric, and comprise:

a] Site Plans: scale 1:2500 or 1:1250 (use Ordnance Survey charts or site plan obtained from land registry), clearly showing the site and its boundaries, edged in red. Any adjoining land owned or controlled by the applicant should be edged in blue.

b] Layout Plans: scale 1:500, showing existing land boundaries, and the existing and proposed layout; the position of all existing roads &c and the proposed observatory. Any existing trees or natural features, distinguishing those to be preserved, removed, planted &c. The proposed use of the observatory, and existing buildings and land not built on. The position and width of any access roads or paths &c, indicating any alterations to those existing.

c] Building Plans: scale not less than 1:100 (we recommend either 1:10 or 1:25) showing the materials to be used; the colour of the external walls and dome; floor plan and front and side elevation; the level of the observing floor relative to the level of the adjoining road frontage; the o'all height, width, and floor area, all in metric.

Your application procedure can take several months. If you live in a village or rural location the District Council will advise the Parish Council of your proposals. The plans of your proposed observatory will be circulated to your immediate neighbours for comments and/or objections. You should not be too concerned about any possible objections because, even though all manner of objections might be expressed, only those on specific grounds can be considered. The most immediate are the prominence of the observatory from your neighbour's purview, and its appearance and colour.

Do not be tempted to proceed without planning consent because it is unlikely that retrospective permission will be granted without either a summons and/or fine, and/or an order to modify or remove the structure.

Once you have obtained permission you will be obliged to observe any conditions imposed and commence work within a specified period (typically 5 years), but it does give you certain rights, e.g. freedom from interference with your sky access, and from intrusive or objectionable domestic or security lighting &c.

We recommend that once the application has been submitted you contact a senior councillor on your Parish or District Council, and keep abreast of developments and preempt objections by submitting modified plans that meet them, in part, and any suggestions made by the planning department in response, These actions will impose no additional costs and will help you get the District Planning Officer on side. Bear in mind that your objective is a domed observatory with as much sky access as is feasible, and a dome finished in a heat reflective material (either titanium oxide or leafing aluminum - rather than green!)

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Chapter 3 - Designing the Observatory

When you have received planning consent it is appropriate to proceed to the detailed designs. The o'all height is determined by the maximum height of the telescope above the observing floor, the height of the observing floor above the local ground datum (as distinct from the level of the road frontage used in your planning application), and the diameter of the dome.

Begin by taking the height of the observing floor above the local ground datum. To this add the height of the pivot point of the telescope mounting (the intersection of the RA/DEC or ALT/AZ axes), above the floor. This should be equal to the height of the dome rail above the floor plus the radius of the telescope tube, so when the telescope is horizontal it just clears the dome rail.

You must then decide on the diameter of the dome. It should clear the front of the tube by at least 250mm, preferably 300mm and in the case of a German or English equatorial, allow for the offset of the tube from the centre. To aid you in this decision, draw the outlines of the telescope and mounting and locate the pivot point on the dome's centre line, and then draw a radius from the pivot point through the end of the tube when directed to the zenith and the horizon. Ensure the mouth of the tube just clears the rail, and add 250mm to 300mm radial clearance. This defines the dome diameter. The rail, if located on the wall, should be placed about 100mm within the dome skin. Add a 200mm skirt to the dome and make sure it clears the wall, or roof, as well as the rail.

Once you have the size of dome needed to clear your telescope in all altitudes, you need to decide on what sort of building to place it. The dome may be placed on walls assembled from matching rings placed on a foundation. However space in such observatories is at a premium. Many amateurs choose to place their dome on some other type of small building. This can be as simple as a four sided "box" constructed with low walls with a "duck under" door entrance, less than a person's height. Such a structure would often be built on a concrete pad.

The walls which support an observatory must provide a circular, flat, level surface for mounting the base ring. The wall must be strong enough to resist wind forces, and should be mounted on a foundation that resists other weather forces such as frost and ground heave.

The wall of the observatory may be circular, square or rectangular, hexagonal, octagonal, or any other number of sides that takes your fancy. It may match the dome size or be somewhat bigger.

For ease of construction most amateurs construct square or rectangular buildings. They provide substantially additional space within the observatory, an important benefit, especially when the dome is 3m or less. For example a 3m dome on a circular wall will have a floor area of 7 sq. meters. On a 3m square wall the floor area is 9 sq. meters, a 20% increase. Place the 3m dome on a 4m square wall and the floor area more than doubles.

The height of the wall, or more precisely the height of the dome rail above the observing floor has already been dealt with. The o'all wall height depends on the type of telescope and mounting, and the height of the observing floor above the ground datum. A meter or so high wall is about right for a small Schmidt-Cassegrain or Newtonian. A refractor is usually placed on a much taller pier, so the walls need to be about 2m high.

If you are surrounded by tall trees it is a good idea to build upwards and gain extra sky room. A taller wall gives more internal space, but usually requires a taller pier, and possibly the use of an observing ladder, platform or raised floor. When the dome is higher than 2m above the floor motorisation of both dome and shutter becomes a necessity.

The height of the walls also affects the style of entry. If the wall is low (less than a meter or so) you can install two or three steps and enter the observatory through the dome slit. If entry is to be through a door in the wall, a taller wall allows a taller door, and less stooping over to enter. Alternatively the entrance can be a combination of a low door (such as the lower half of a stable door) and the slit opening in the dome. In this instance provision must be made for removing a section of the dome rail &/or wall lintel, and replacing it once you are inside.

Finally, if you want to also use your observatory as a den in the daytime, consider including one or more windows. They will increase your pleasure and make working inside much more pleasant.

Wall Construction Techniques

There are many factors to be considered when deciding on how to construct the wall. The various choices all have their pros & cons. The most substantial and durable wall is either of brick or concrete block. However bricks absorb heat when the sun shines on them and then radiate it away rather slowly after sunset. It is however possible to design a brick wall and choose types of brick that either loose their heat rapidly, or absorb very little in the first place. What you don't want is a cavity wall, especially an insulated one. It is important to maintain an even temperature inside, matching as closely as possible the ambient external air temperature. Denser engineering bricks, with lightning holes are better suited. Alternatively, the wall can be made double thickness, with the outside course of grade B engineering brick, and the inside course of selected regrades or commons. If the wall is made of blocks, these may be painted with a white stone paint that effectively reflects heat.

Timber construction is perhaps more straightforward. The framework can be made from 3" x 3" tannalised posts, and the wall panels fastened in between using sills, studs and headers. A typical sill separation would be 16" (1/2m). The panels can be made from shiplap pine boards, or marine ply, or either zintec or aluminum siding. Onto the inside of the panels you could fasten either a dry liner, or Daler board, onto which maps and posters can be pinned. The posts can be either bolted to a concrete pad, or pilings, using a Met-Post bolt down, or driven into a heavy clay soil directly using a Met-Post spike. You can use nails or construction glue to fasten the siding, or dry wall screws with an electric screwdriver. The door can be constructed on site, or made to suit in joiner's shop. Sometimes you can buy a full size door and frame, cut it down, and use the remainder for a low door. Be sure to install power points, phone wires, and other in wall services before you fit your internal liner to the wall cladding.

One of the difficulties in fitting a round dome to a flat square roof, is making it weather proof. Unless you support the dome’s base ring adequately the roof will sag under its weight and rain water will collect around the skirt, and either leak or blow in. The corners of the roof need to be braced with diagonal headers,of say 6” x 2” tannalised timber, and the roof raked with a 1 in 10 fall off to the barge boards. There needs to be an upstand within the dome skirt so that rain or snow cannot blow inside. The roof should be skinned with 1/2” or even 3/4” shuttering ply, and sealed with a rubberoid mastic to prevent it delaminating, before being covered in mineralised roofing felt. Flashing can be used to seal the dome’s base ring to the felt underlay, and bonded with a colour matching latex elastomer.

Because of the problems that arise in putting your dome on a square of rectangular building, some amateurs decide to put their dome on a round or polygonal wall.

Transition from Square to Round

Once again a circular wall can be built on a concrete slab or a ring shaped foundation. Building a brick or block wall that is truly circular is not as difficult as one might think. The bricks are positioned using a central vertical post driven into the ground onto which is fitted a radial arm, free to rotate and move up and down. This is used to position each brick. Don’t worry about the bricks not being arcs perfectly made to suit the diameter of your wall. The departure from a true circle will be too trivial to notice.

A circular timber wall can be constructed by cladding a circular sill and header frame with tongue and groove pine boards. The difficulty here of course is in making the round sill and header. This usually entails cutting arcs from either thick boards or plywood sheet and screwing and gluing it together in sections. If you do the work yourself it isn’t necessarily expensive, but it is tedious and time consuming. It can also be a tricky job, and for this reason many amateurs opt for a polygonal wall.

Because of the problems in making a flat roof on which the dome sits completely weatherproof, it is always worth considering making the dome deliberately bigger than the wall, with a skirt that hangs down below the base ring outside the wall so the drip line misses the wall altogether. Observatories built along this line of thinking avoid the rain and snow problem completely, they side step it. But when one problem goes out the door another come in the window! If the wall isn’t circular, then what about the gaps between all those corners?

The next simplest structure to build, up from a square wall, is either a six or eight sided wall (hexagonal or octagonal). But you can go one better by opting for a twelve sided wall (a duodecagon). The twelve sided wall has the advantage that those gaps between the corners are smaller, much smaller; in fact so much smaller they are barely noticeable. However building a twelve sided wall out of brisk isn’t easy, particularly if it is a double brick bond.

If you opt for a twelve sided wall it is easier to make it out of either timber or steel. Posts or stanchions at each corner can be bolted to either a slab or a foundation, and then clad and lined, and it is always possible to fit either a twelve sided header or the circular dome rail on top. When the dome diameter is 4m or bigger, a twelve sided wall will also readily accommodate a standard width door and frame between a pair of the corner stanchions. Additionally, the small gap between the dome skirt and the wall panels in between the stanchions provides ventilation, and helps keep the air temperatures inside and out, in equilibrium.

If you decide to build a circular wall, slightly smaller than the dome, ensure the skirt is not a snug fit. If the skirt hangs down past the top of the wall by about 9”, then rain water or snow will not get blown inside. Effectively sealing the dome to the wall with a snug fitting flexible skirt cuts off all circulation of air within the building, creating major problems with the seeing, and prolonging the acclimation time, and also damp.

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Chapter 4 - Designing the Dome

Designing a dome appears easy because it is a simple shape, based on the most primitive solid, the sphere. All is not what it appears though, and there are several challenges in the design of a hemispherical dome.

There are two fundamental weaknesses in a dome’s structural integrity, the shutter slit, and the base ring. Most amateurs are not aware that a circle is the weakest structural shape, and whereas it can withstand a uniformly applied radial load, it is very easy to distort when non-uniform loads are applied. The base ring of a hemispherical dome shares this property. If not made sufficiently rigid, it will deform and cause “crabbing” when you apply a tangential force in order to push the dome round. To obtain a properly rigid dome the base ring, and the arcs that support the shutter track, must be adequately reinforced. This rigidity is provided by internal flanges.

Designing a Dome that turns easily

The fundamental design challenge for a rotating roof observatory is to assure easy turning of the dome, particularly if it is going to be pushed round manually. The base ring is a circle and is easily deformed under a non-uniform load. The force applied to turn the dome deforms it and causes crabbing. As you push tangentially on the inside of the dome some of the load is translated to a radial force which if the base ring is not sufficiently rigid can cause the circular ring to distort into an ellipse, increasing drag on the rollers. As you push harder to overcome the increased resistance the base ring distorts more and drag increases, making the dome difficult to turn.

Ways to ensure the Dome will turn easily

A dome intended to be pushed around manually must offer little resistance, so it should be as light as practicable. But it must be wind proof; the shutter musn’t pop out of its track and since it can be as wide as three times the telescope’s aperture, the dome needs to be rigid enough not to flex when it has a wide slit cut out of it, past its apex.

These are conflicting requirements. If we try to add sufficient strength to the dome structure to prevent it distorting when it has a wide shutter opening, it could end up so heavy it will be a real struggle to push round anyway.

The choice of material is crucial to the overall rigidity and weight of the finished dome. The choice is quite wide ranging however, and all the suitable materials have their inherent advantages and disadvantages.

Choice of Dome material and fabrication method

The most common form of dome design entails a rigid base ring usually made by rolling steel or aluminum angle, and either welding or fastening it together in sections. Onto this are laid a pair of arches which will support, or in some instances form, the shutter track. A framework of equi-spaced ribs are then run up from the base ring to the arches, and a skin of thin sheet gores or facets, fastened to the ribs. The framework may also be constructed using timber, but this is much more labour intensive and tends to lead to a much heavier dome.

Another commonly used material is glass reinforced plastic or GRP, more commonly referred to by one of its trade names, “fibreglass”. GRP is suitable for not only the skin, but the support ribs and arches. Another alternative panel material is resin coated polyeurethane sheet. The skin maybe fabricated from galvanised steel or half hard aluminum or duralamin sheet, and either bolted or riveted to the ribbed framework. Finally there is marine ply, more commonly used by boat builders.

Marine ply and GRP are easy to work with, but they lack rigidity and require a heavier support structure. Also when made thick enough for the skin panels themselves to be adequately stiff, they become surprisingly heavy. They also need regular maintenance. Marine ply needs periodic revarnishing using yacht varnish, which is not cheap. The external gel coat to GRP panels, intended to reflect UV rays that cause the fibreglass infil to become brittle, “starshells” after a while;e, and needs labour intensive local replacement.

Galvanised steel sheet is relatively inexpensive and has a high strength to weight ratio, but it is heavy and tends to rust around rivet or bolt holes and unprotected edges. Corrosion resistant steels are very expensive and can be difficult to work. Aluminum is light, corrosion resistant and readily formed, but it lacks rigidity. ON the other hand there are aluminum alloys (duralamin) that are readily formed and have a higher strength to weight ratio than steel. Moreover they are to all intents and purposes maintenance free and also highly heat reflective.

The material you opt for will to a large extent depend on either your DIY skills, or your purse. If you can afford t have an engineering shop fabricate the framework and panels, metal is the preferred option. All things considered the “ideal” material; is half hard aluminum, which is a solution treated dural alloy. Weight for weight it is about the same price as bright mild steel sheet. It is slightly cheaper than galvanized steel sheet.

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Chapter 5 - Dome Manufacturing Techniques

Marine ply or GRP clad timber framework

Because of the necessarily heavy timber base ring, the dome rail can be incorporated into it. This makes future attempts to motorize the dome’s rotation simpler, because the motor can be fixed to the wall, under the dome rail.

There are basically two ways to form the curved timber sections; saw out the pieces from either thick plywood boards or lumber, or soak the timbers in a swimming pool and then bend them and allow them to dry out whilst restrained to the desired curvature. Both these techniques are standard practice in the boat building trade. The rough sawn sections must be spliced and glued together and finished with a spoke shave.

The arches and ribs can be fastened to the base ring/dome rail using cleats and screws or bolts. If you opt for an up and over shutter the track can be incorporated into the arches by routing out a slot on the outside faces, or rails can be fastened to them.

The most tricky problem is making the gores. If you opt for marine ply, it is possible to form the panels into true gores by either steaming or soaking, and forcing the panel onto a reference surface under pressure until the glue which holds the layers together resets. If you opt for GRP, the gores need to be layered up in a mould which can be made out of waxed wash and boil proof hardboard, painted with a release agent. The shape of the gore is important. The sides will be curved like an ellipse, and making the mould, or cutting out the plywood panels before they are formed entails some clever marking out.

The number of gores you have to make depends on how wide you decide to make the base. But the wider the gore the more difficult it is to form into a spherical segment. A good rule of thumb is to divide the base ring circumference by at least 24. Remember that if you are going to have an up and over shutter, there can be a curved panel fitted between the arches running from the base ring to the start of the dome slit.

The width of the base of the gore will be equal to the circumference of the dome divided by the number of sections. The length of the panel before you cut and profile it into a gore will be a quarter of the circumference.

To mark out the profile I recommend you divide the length of the panel into nine equal parts. The relative width of each part, taking the base width as unity, will then be cos10º; cos20º; cos30º.......cos80º; cos90º respectively. To work out the real width you simply multiply the trig ratio by the base width. For example, 4/9 of the way from the base to the apex of the gore, it will have a relative width of cos40º=0.7660.

Making true spherical gores out of galvanized steel or half hard aluminum sheet is far more difficult, and unless you have been trained in the craft of sheet metalwork or bodywork, it is best left to the expert. The technique is simple enough in principle, but very awkward in practice. The panel is first cut and profiled, and a former made onto which the finished gore can be laid. The former can be made out of series of latitudinal ribs, curved on their outside edges to the same curvature as the hemispherical surface. The panel is then rolled back and forth between two polished rollers; a two man job. Periodically the gore is placed on the former to check progress, until it is in contact all over. The edges are then trimmed to the correct profile. Aluminum being a more ductile metal, is easier to form this way than steel.

In order to avoid this difficulty it is common practice to make the gores curved in the vertical plane only. The profile is formed in the same way, but the panel is then either fastened onto the ribs progressively from base to apex, or formed to the circumference of the dome in one direction only and then forced to conform to the base ring and ribs.

Although making a gore with a curve in one plane only is far simpler. it does give rise to the obvious difficulty of the panel buckling when it is bolted or riveted to the framework. This is why the base width of the gore must be kept as short as practicable.

Now it may have occurred to many of you that the gores will not all end up meeting at the apex of the dome because of the shutter slit. In fact, if the “pole” of the dome is at its apex, the gores will end up as mirrored pairs, after they have been fitted to the ribs. IN other words, although they will have been initially cut to the same profile, and formed to the same spherical surface, they will all be different in o'all shape. This is a manufacturing nightmare, and there is a very simple and effective alternative method of construction that gets around this problem completely, and it is puzzling why it is not more commonly encountered. By placing the “poles” of the dome on the base ring, at right angles to the shutter arches, every gore profile can be identical, and if they are true gores, there can be fewer of them, say half a dozen on either side of the arches.

Monocoque & Facetted Domes

The chief difficulty in constructing a dome to the correct size, and getting it rigid enough to withstand deformation, is in fabricating the framework. Even a simple steel engle or tee section ribbed framework can be heavy and relatively expensive. A timber framework demands carpentry skills that the average DIYer does not possess. Furthermore, as we have seen, a truly hemispherical dome is an assembly of gores, an awkward shape to make. They must also be an accurate fit within the framework if it is to be watertight.

What if instead of opting for a true hemisphere we opt instead for a facetted shape that closely approximates a hemisphere, and in order to save time and expense we made the facets with straight sides, and we abandon the idea of cladding a skeleton framework and fasten the facets to one another to form a “monocoque” structure. Since the dome needs a slit past the apex, the facets do not need to meet at the apex, but a set distance down. That radial distance will correspond to half the width of the slit.

The next consideration is the thickness or gauge of the sheet metal, and determining how many sheets we will need to buy. If you do opt for half hard aluminum, and this is probably the best choice, 16SWG (1.6mm) is an easily worked thickness suitable for domes from 3m to 6m diameter. It comes in standard sheet sizes (8’x4’) and the task is to make the dome from the smallest number of sheets, making use of the most sheet area, so we have the minimum wastage. Work out the facet sizes and determine the minimum number of sheets needed to make them. Then recalculate the facet sizes to minimise the wastage. You can then work backwards to arrive at a slightly bigger dome, and round down to the nearest workable diameter. Redesign your observatory based on that revised dome diameter, making sure you keep within the o’all height specified in the planning consent.

A “pseudo-gore” can be formed from three separate trapezoidal facets. Each facet needs a joggled flange top and bottom, and an angled return fold on both sides. Because the facets are flat, and the sides straight, they can be cut out of the stock sheet using a workshop sheet metal guillotine, the joggles formed using a press tool & a brake press and the returns using a former and a bench press. The three separate facet shapes are marked out using a template. Templates will also be need for drilling the rivet holes before the returns are folded. Each of the three facets that go to make up the “pseudo-gore” are then sealed and pop rivetted together along their joggles. When each “pseudo-gore” is fastened side to side, they form a “quasi-hemisphere” with a hole at the apex whose diameter corresponds to the slit width.

To assemble all the “pseudo-gores” you need a jig. This takes the form of a vertical pole (a galvanized or aluminum scaffold pole will suffice), with a tubular wheel with spokes welded at right angles to the top. (The completed fixture resembles a Maypole with a Catherine wheel on top). Around the bottom of the pole you must locate your dome’s base ring, which will become the lower flange of the dome when all the “pseudo-gores” are rivetted in situ. This can be made from 50x50x6mm dural angle, cut and formed into a polygon. The number of sides is your choice. Just bear in mind that the more sides your “quasi-dome” has, the more closely it will approximate a true hemisphere, and also the more rigid it will become. You can make the polygon by hacksawing cuts in the lower flange of the angle and heating the outer flange with an oxy-acetylene blow torch, just sufficient to soften it so you can bend it to the correct angle, and then welding the saw cuts together once the ring is completed. You must take care not to distort the ring when heating and welding it. It must lie flat and not become twisted or buckled, and most importantly, it must be the same distance across flats all the way round. (A few millimeters leeway is tolerable but no more). You will need sufficient “pseudo-gores” to go all the way round save one or two, because of the gap you will leave for the shutter opening. I suggest you make the last “pseudo-gore” width to suit, so as to accommodate accumulated build error as you go round the fixture. If you work accurately no one will notice that one of the “psuedo-gores” is marginally wider or narrower than the rest.

Making the Shutter

Another challenge when constructing your dome is the shutter opening. The most obvious issue is how the shutter will open and close, including the ability to operate either manually or by electric motor. A less obvious problem is how to construct the opening itself so that it will have sufficient rigidity. Recall that the opening has a circular cross section with inherently little resistance to deformation from non-uniform radial loads.

When we try to design a shutter that opens past the apex, we immediately run into another challenge. Where does the opened shutter end up? After all, if the dome is a hemisphere, or a close approximation to one, a shutter opening that goes past the apex requires a shutter that is longer than the radial distance from the skirt to the apex. If made all of a piece, it will come down below the skirt on the back of the dome and foul the skirt or the wall.

There are five solutions to this problem:

1) Provide one or more shutter sections that can be lifted from the dome and stored elsewhere. This solution will function for small domes, but in larger domes the weight of the heavier shutters, and the effect of wind loads on the bigger area, can cause major handling problems.

2) Use a flexible shutter that rolls or folds (in a concertina fashion) out of the way. The difficulty is ensuring smooth operation under freezing conditions, and in obtaining a long life for the shutter, and making the shutter's edges weather proof.

3) Use bi-parting or a single lateral moving shutter. This option is employed in many large domes. It is what gives Mount Palomar Observatory for instance its distinctive appearance. Bi-parting shutters require coordinated movement of the shutter halves, but this is a comparatively simple matter of fitting a pulley and chord or cable system. A strong frame must be attached to the dome on which the shutter rollers run, top and bottom. This framework must be able to withstand high wind loads. Bi-parting shutters also have a long joint running between them when they are closed that is susceptible to water leakage. A closure strip is therefore needed, with a runoff lip, to prevent rain being blown in, and to provide a drip line off the dome and away from the wall.

The major limitation of a lateral or bi-parting shutter is that the slit is open along its entire length, which is not necessarily the case with an up & over shutter. When you are observing Venus in daylight for example, it is possible with an up & over shutter to only partially raise it, keeping the inside of the dome cooler and darker than if the shutter was fully open. Being able to limit the length of the exposed dome slit can also help in windy conditions.

4) Use a two piece non-nesting shutter. The shutter is in two pieces but cannot be stored out of the way:-

i) Option 1 - the upper shutter is moved up & over the dome, and the lower shutter is a drop down flap.

ii) Option 2 - the upper shutter alone is moved up & over the dome, allowing use of the top part of the dome slit. When it is necessary to use the lower part the lower shutter is attached to the upper shutter which can raise it part way. The major disadvantage is the inability to use the entire shutter opening, complicating the sequencing of observations at different zenith distances, and reducing the amount of visible sky.

5) Use a two piece nesting shutter, or a twin up & over shutter. In the nesting type both the front and top piece move together, with automatic disconnection and storage on the back of the dome. In the twin shutter type, there are two up & over shutters running in separate tracks, independent of each other. Both can be stored at the back of the dome to uncover the dome slit completely.

These are the alternative mechanical design options for the shutter. But in addition to how the shutter opens and closes, the width of the dome slit is also an important consideration. In general, you will benefit from as wide a dome slit as is feasible. A wider slit affords the observer greater sky access and easier orientation, and less frustration in locating objects. In addition a wide slit allows you to use the telescope on a particular object for longer periods without turning the dome. However, as you might expect, the wider the dome slit, the more inherently weak the dome structure becomes.

The shutter track and dome slit cut into the hemispherical shape. There is no physical apex to the dome, since the zenith has to be accessible, so all forces on the dome produce stresses around and at the back of the shutter opening. This necessitates the shutter tracks and their support arches be very rigid, so that neither the dome nor the shutter opening distort unduly under load.

The shutter track can be formed from “U” section, rolled to the desired radius, with the opening outwards. The roller assemblies take the form of “spiders” and you will need four assemblies per track for an up and over shutter (i.e. 16 rollers). The shutter must be made in three sections if it of type 4i, and fed into the track and rivetted together in situ. Make sure it runs freely and smoothly before you assemble it. The bottom flap can be made to fold in half outwards when you need to observe near the horizon. For most purposes you will not use it. In fact if you aren’t bothered about observing at zenith distances greater than 75º you may dispense with it altogether.

Designing & Building a Domed Astronomical Observatory

Chapter 6 - Designing and Fabricating the Rail & Roller System

When designing the dome rail and roller system, it is a simple matter to make provision for motorisation and/or automation at this stage. If considered from the outset, it need not be the insuperable problem most amateurs make it out to be.

If you want to be able to drive your dome with a small economical gearmotor, it must turn freely and easily. If the dome is light yet rigid, this is not difficult to achieve.

First, an elementary lesson in Newtonian dynamics. If you push the dome round from the inside it will not of its own volition move in a circle. Newton's first law of motion states that a body in motion, will continue moving on a straight path unless and external force acts upon it to change its direction. The second law states that the change of motion is proportionate to the external force; and is in the direction of that force. When you push tangentially on the dome it reacts by trying to move in the same direction as the applied load, that is sideways! The only thing that forces it to go round is the roller system.

There are two options concerning the location of the dome rail. You can locate it on the dome, either supported off the base ring, or as a part of it. Alternatively you can locate it on the wall. If the rail is located on the dome, it will add considerably to the dome's weight, and make pushing the dome round by hand more strenuous. But the rollers can then be fixed to the wall lintel, and the drive mechanism fastened to the wall also. This eliminates the problem of transferring power to a moving dome motor via a bus bar.

If the rail is supported on the wall, it can be as heavy and rigid as you choose because it will not add anything to the moving weight to be pushed round. However the rollers will have to be mounted on the dome, either off the base ring, or within it, or off the dome's framework. All the rollers will have to be kept in constant contact with the rail if the dome loads are to be uniformly distributed and deformation minimized. In addition any motor will have to be supported off the dome's framework as well, and power transferred from the building to the moving motor via a bus bar, or some other arrangement.

Up to now we have given you all the options and left the decisions to you. But at this stage we think a little guidance would save you a great deal of angst.

Now you could fasten the rail to the dome's base ring and place the rollers on the wall. Indeed, considering the only two possible alternatives, and their pros & cons, this appears the sensible option. But the rail needs to be heavy and rigid otherwise it will flex under the dome's weight, and the dome will jam. This makes the rail so necessarily heavy that the dome's weight rises to the point where a considerable effort is needed to push it round. In our opinion it is better to place the heavy rail on the wall so it is no longer a moving part, and place the rollers on the dome.

The Dome Rail Section

What section should the rail be? If it is rolled from either flat strip steel or dural, or formed from timber arcs, it flexes easily and twists and buckles, so it needs lots of side stiffeners and support cleats that interfere with the rollers.If it is rolled from steel or dural angle or tee section it is expensive and difficult to form into a true arc because the ends of the rolled lengths will always depart from the desired radius of curvature. Curved fishplates also have to be rolled to join the arcs together to form a full circle.

What we want is a section that is as stiff laterally as it is up and down, but can be easily rolled into an arc. There is only one shape that fulfills these criteria and that is the tube. Choose a rail diameter about 200mm less than the dome diameter, so as to provide clearance for the roller support bracketry and the roller standoff from the dome framework. For a 4m dome a suitable rail tube can be made out of Schedule 10 47mm steel pipe (about 4mm wall thickness). It should be rolled in four or five lengths to a template to a tolerance of ±3mm (1/8”), and plug and butt welded on site. The rail can be located on the wall using 100x100x6mm (4”x4”x1/4”) welded steel seating plates. When bolted in situ the dome rail must be round within ±6mm (1/4”) and dead level all round. It is important to brace the sections with G clamps and scaffold poles and arc weld in short radial sections, one section at a time, checking on the roundness as you proceed. If you weld one joint at a time the intense local heating around the joint expands the tube and forces it out of round, and you will never get it back round afterwards; be warned. The butt welds must be dressed flush all round. Keeper plates may be welded underneath each joint, but they must clear the path of the rollers.

The Dome Rollers

Now, what about the rollers? The dome tries to move sideways when it is pushed, so if the rollers have a flat cross section you will need both horizontal and vertical rollers to ensure the dome goes round. We have also visited domed observatories where, in order to try and accommodate an eccentric rail the vertical rollers can slide along their axle. The difficulty with this approach is that the rollers can only move along their respective axles whilst the rail is in contact. If for any reason the rail is twisted, the roller can become derailed. The trouble with both these two dimensional roller systems is that they overlook a very real problem with any rail/roller system. Because the reaction of the roller on the rail due to the weight of the dome is not inelastic, the rollers produce friction which causes rolling resistance. The accepted wisdom is that the rolling resistance is directly proportional to the load per roller, and therefore the more rollers we use, the lower the load per roller (assuming all the rollers make equal contact), and consequently the combined rolling resistance remains the same, regardless of their number. And adopting the ball race principle of the roller bearing, the more rollers the better. Nothing could be farther from the truth. Rolling resistance is caused by elastic contact between rail and roller. The flawed logic used to advocate lots of rollers assumes the contact is inelastic; that is it treats the surfaces as infinitely hard. The contact area is not directly proportional to the load, and if you double the load you do not double the contact area, it only marginally increases. In fact the fewer rollers you have the lower their combined rolling resistance. The minimum number of rollers you can possibly get away with is three. But here we must next consider another aspect of roller design, axle loads, and the rigidity of the dome’s base ring. For a given axle diameter, the more rollers the lower the rolling resistance caused by friction n the axles. But it isn’t proportional because most of the frictional losses are caused by stiction, or static friction. Once the roller is moving, the frictional losses drop off dramatically. Obviously the dome cannot be perfectly rigid. When a tangential force is applied to its side, it will deform slightly, however well made it is. This will cause the rollers to ride up on the rail, and perhaps derail altogether. Clearly more than three rollers are needed if this is to be avoided. So how many are needed?

For a dome diameter of 3m to 4m we recommend 6 rollers, and for a dome between 4m & 6m, 8 to 12 rollers. However, only half of them need to be in permanent contact. The ones in between can stand off by about 3mm (1/8”). They merely provide lateral restraint and limit the amount the dome crabs.

Next we must consider the roller cross section and size. Small rollers suffer high axle stresses, which in turn produce high frictional losses and increased rolling resistance. As a rule of thumb, make the rolling contact line diameter twice that of the rail diameter.

If the dome has a ribbed framework, fasten each roller off a square section tubular framework bolted between the ribs. If it is a monocoque dome, mount each roller off a similar framework bolted to a lower panel. Since the ribs, or the panel will be inclined, the axle of the roller will be declined which will provide a semi-kinematic advantage in our bid to encourage the dome to want to move in a circle rather than sideways. Because the rail has a circular cross section, we can also choose a roller section that runs on both the outside and the inside of the rail simultaneously, so we combine the actions of both horizontal guide rollers and vertical load bearing rollers in a single roller. This automatically halves the rolling resistance. To minimize the contact area the roller contact faces must be flat, not curved to match the rail. Such a roller is “Diablo” shaped.

Roller Material

The most obvious material is either steel or dural. But steel rusts, and it will be no use either galvanizing it or cadmium plating and passivating it, because the pressure on the contact line will just strip it off. Also both materials have a tendency to skid and slide. What is needed is a material that will grip the rail without deforming, and a material that doesn't corrode or degrade. We recommend you have your rollers turned out of Nylon 66, because it fulfills all these criteria and it will also never need lubricating. In fact it both grips the rail tube and scrubs the contact line clean in a pressure polishing action. The roller axles should be fitted with radial self aligning roller bearings and cover plates. These can be sealed for life or the cover plates made removable so the bearings can be occasionally regreased.

We might at this stage also add a note about rail restraints, to prevent the dome becoming derailed in a high wind, or heaven forbid, blown off the wall altogether.
A dome, properly designed and fabricated is a windproof structure. When the airflow over the dome is lamina, the Bernoulli effect produces a very high vertical component (lift), but there will also be a moderate horizontal component which will push the dome sideways and could derail it. The Bernoulli effect diminishes at the trans-critical flow region because of drag around the skirt. In the supercritcal region there is no lift, only the horizontal component, heavily concentrated on the windward pole of the dome. On the leeward edge there is horseshoe shaped turbulent wake which produces a modest windward horizontal component. IN a high wind the dome is subjected to a violent translational force.

The wind velocities at which lamina, trans-critical and supercritical flow occur to some extent depends on the dome's surface, and its aspect ratio. A facetted dome, or a dome with bi-parting shutters, will have structures that stick out and disrupt the sir flow. Generally though, the difference between a true hemispherical dome and a real dome with a shutter, and possibly facets is trivial. Lamina flow pertains at wind velocities in the region of 20 m/s (45mph - force 8 or a fresh gale); the trans-critical region occurs around 30 m/s (67mph - force 11 or a storm); the supercritical region occurs in excess of 40m/s (90mph - higher than force 12 or hurricane).

The loading on the dome due to aerodynamic forces are incredibly high compared to the dome's weight so it is vital that the rail restraints are designed to withstand these forces. For example a monocoque 4m dome made of 16SWG half hard aluminum sheet will weigh roughly 1.5kN (350lbsf), but the maximum lift in the subcritical flow region (lamina air flow) will be approximately 25.5kN, and the maximum horizontal force in the supercritcal region approximately 19kN.

These loads are far in excess of what most amateurs who construct their own domes intuitively anticipate, which is the main reason apocryphal tales of domes sailing away in storm force gales are so common.

If the dome rail is a tube, supported on the wall, how can the rail restraints hold the dome down? Surely the restraint brackets which need to go under the rail would foul the support plates and the wall lintel. The fact is these brackets do not have to lock beneath the rail. The dome can be easily held by a series of brackets that run around the inside edge.As the dome is buffetted on any side, the rail restraints grab on the inside edge opposite and lock the dome to the rail.

For a 4m dome a dozen restraints made from 2” wide x 1/4” thick steel strip would be appropriate, each bolted to the base ring with 6mm (1/4”) high tensile bolts.

If your observatory has a floor area larger than 30 sq. meters, (which roughly corresponds to a 6m dome on a circular wall), it will have to conform to Building Regulations. As part of obtaining a building permit, calculations will have to be submitted to show your observatory conforms to the code of practice CP3Pt.2. These calculations are described in the Appendix, and are helpful in assessing the dome wind loadings and the needed strength of the rail restraints. Although they are not needed for smaller domes, they are nevertheless helpful, and we recommend you perform them, following the example, rather than trusting to chance.

Dome & Shutter Drives

There are various methods that have been devised in the past for motorising the rotation of the dome and the opening and closing of the shutter.

With a tubular dome rail supported on the wall, and a roller system comprising six or more large nylon Diablo shaped rollers, to motorise the dome all you need to do is fasten a drive belt gear and a torque limiter/scroll clutch to one of the contact rollers and drive it with a right angle gear motor. A suitable drive rate would be one revolution every 4 minutes for a 4m dome, from which you can work out the output speed of the gear motor. We also recommend you employ a single phase 250VAC capacitor start induction gearmotor driven via an inverter and a 12VDC gas recombination powercell. All these components, when placed on a suitable support framework above the drive roller, force it down on the rail tube and cause it to maintain contact. The torque limiter on the drive belt gear prevents the motor stripping the worm drive in its gearbox in the event of an overload or power surge on starting.

The most direct way to drive the shutter is by an endless cord system via a windlass; limit switches control the end of travel and reversal of the motor.

To prevent the dome drive roller riding outwards, a jockey roller is placed under the shutter transom so as to roll on a vertical axis around the outside of the rail tube. This means the drive roller must be positioned diametrically opposite the shutter opening, which is the most suitable location for the shutter drive windlass for an up and over shutter in any case.

Chapter 7 - Pier & Floor

The footing for the wall, or the concrete pad on which the dome and wall rest must be kept separate from the pier. Otherwise vibrations from the building due to people walking around the observing floor, or the dome being turned will be transmitted to the telescope.

The shape of the pier, and whether it is in the centre of the foundation or offset, and whether or not it needs to be aligned to the meridian depends on the type of telescope mounting. A small Newtonian on a German equatorial or a fork equatorial, and likewise a Maksutov or Schmidt-Cassegrain can be located on a vertical pipe. A yoke, or English or cross axis equatorial needs two piers, a north and a south pier accurately aligned to the meridian. An overhung German equatorial will need a rectangular pier aligned to the meridian and south of the floor centre.

The size of the pier is largely dictate by the size of the equatorial base plate. The height of the pier above ground, by the height of the mounting's pivot point above either the ground datum or the observing floor. The depth of the footing that supports the pier, or the depth to which the pipe is sunk into the ground needs to be approximately a meter, especially if the top soil is deep and sandy.

Vibration & how the Pier acts to Damp it.

Now let's consider vibration of the telescope and pier. Vibration results from an applied force. Different frequencies and modes of vibration can be induced into the pier and the telescope by cycl;ic forces. After these induced loads are removed, the vibrations will die down due to frictional losses within the structure. The speed of damping is measured by the Q (quality) factor. Roughly, the Q factor equals the number of fundamental oscillations that occur before the amplitude drops to 1/3 the starting value. A high Q means damping is small. Oscillations take many cycles to die away. Q for typical mechanical systems lie in the range 1 - 100. Q for a vehicle suspension system when fitted with a shock absorber will be in the region 1 to 3. A vibrating blade held at one end & twanged, about 30. How does all this affect telescopes? Movements of a telescope occur when the system (pier, mount, or telescope) are moved by some force. If this force is steady, continuous and uniform, no vibration will be induced. However, if a sudden force is applied, then removed, vibration(s) will occur, which will then die out according to the Q of the telescope, mounting, pier system. If the force is applied and/or released very quickly rather than slowly and gently, a wider variety of vibrations will be excited. If the exciting force is repeatedly applied in a cyclic manner and occurs at a frequency matching a natural mode of oscillation of the system, large oscillations can build up, even from small excitations. The lower the Q (the greater the damping), the more rapidly the vibration will die out after the excitation is removed.

Ideally the telescope mount and pier should have a high natural frequency (in the region 5-50Hz) and a low amplitude and low Q factor. If completely isolated form the building foundation so much the better. However even though it is feasible to isolate the pier from the observing floor, both the pier footing and the wall footing inevitably rest on the same bit of ground.

Effects of Vibration or Telescope Movement

Induced oscillations in the mounting and pier system result in movement of the telescope. Only tilting or rotational movements effect the position of the image in the field of view. Translational movements will have no effect because astronomical objects are so remote. To minimize tilting or rotational movements we must construct a pier and mount that is extremely rigid. Very stiff structures have a high fundamental mode of vibration. For a given Q factor any induced vibrations will be rapidly damped. Very stiff structures, especially ones of large mass, also tend to have smaller amplitudes of oscillation as a result of a given excitation. Rigidity is achieved by choosing inherently stiff materials and adopting mechanical designs which have Large second moments of inertia and radii of gyration, (i & k values). However mass alone is not the answer. Reducing component weight and second moments of area by keeping masses close to support points increases the system’s natural fundamental frequency. Simply adding mass in an attempt to strengthen the structure may reduce the fundamental mode whilst increasing the harmonic modes.

Construction of a very low Q pier requires that you design it to dissipate energy rapidly. This calls for as large a contact area on the footing as practicable, and perhaps filling the pier with dry, sharp sand, so that vibrational energy is rapidly lost due to friction within the sand mass. Additionally, a pier system that responds to perturbation by oscillating in a translational, as opposed to a tilting or rotational mode, will not result in any image shift. A pier with a large base area will have a tendency to move up and down rather than tilting or twisting. A long thin pipe will have a tendency to rock and twist.

The Observatory Floor

If the floor and the concrete foundation pad are one and the same, we recommend an air space under a separate suspended floor to prevent the joists rotting. You should allow at least 450mm below the joists for free air circulation, and ventilation grills or air bricks in the wall between the pad and the floor, or damp proof course and floor. We do not recommend you simply seal the concrete pad and leave that as your observing floor. Concrete floors are numbingly cold at night, especially during winter months.

The wood flooring can be either 4” t&g or “Wayrock” t&g MDF boards. However “Wayrock” is not water resistant, it cannot be permitted to get damp or it will disintegrate, so it must be sealed, at least on the upper surface. Alternatively it may be tiled with either cushioned floor tiles or carpet tiles, or hardwood floor tiles such as “Parkiflex” and varnished.

An observatory with a tall wall and an elevated observing floor provides an ideal underfloor space for the stowage of equipment that would otherwise clutter the working area. Access to the underfloor space can be provided by an access hatch.

The size, pitch and span of the floor joists and noggins is governed by the BSI building standard BS5268:Part 7:Section 7.1:1989. A typical calculation is given in the Appendix. Again, if your dome is 6m or larger and the floor area 30 sq. meters or greater, you will need to submit these calculations in order to obtain Building Regulations approval.

The Foundation Structure

Foundation structure refers to the underlying building structure that will support the dome, floor and pier. Where the dome is supported by a wall on a footing or concrete pad the only significant way for vibration to be transmitted between the pier and the pad is via the soil. Depending on the soil type, this coupling may or may not be significant. Sticky clay and chalky gault clay soils have very low coupling properties. Both bed rock or compacted sandy soils or alluvial loams have very high coupling properties; so much so that vibrations induced by passing road traffic can be a real problem.

Piers and Pads

If the observatory is to be on a pad on the ground, the classic approach is to install a pier through a hole in the middle of the pad. This type of installation is commonly used for any situation where the pier is to be supported in the ground. The pier, usually a steel pipe, 100mm (4”) to 300mm (12”) diameter, is set in a concrete footing that might extend down between a meter and a meter and a half (3’ to 5’). This footing is usually poured directly into the hole, i.e. there is no shuttering. But what exactly is the purpose of the footing, and how massive does it have to be? As you might expect, the answer is, “It all depends!”

Suppose you install a pipe directly into the soil. You dig a hole, insert the pipe, and then heavily tamp down the soil in, and around it. The result, in most soils, is a fairly rigid pier. But how deep do we go? Again, “it all depends.” One reason to go deeper is to get a good portion of the pipe below the frost line. As the soil freezes, it expands, and moves up. As the soil thaws it moves down along the pipe. A short pipe will eventually creep upwards, out of its footing. Heavy clay soils react differently. Clay expands when it gets saturated, and expands again as the water freezes. During the summer, as it dries out it shrinks and cracks. This heaving of the ground will loosen the footing. A concrete footing, at least a meter deep, and a meter in diameter will prevent this from happening.

So far we have dealt only with a steel pipe, either directly in the ground or in a concrete footing. Another option is to construct a pier and footing of concrete and blockwork, tied together with reinforcing bars. A more common approach is to pour concrete (or dry sand) into a tube or pipe made of plastic, cardboard, sheet metal, short lengths of concrete pipe, or other materials such as sonnotube used to cast concrete piles. The footing might be poured separately, with the addition of reinforcing bars or mesh, and the pier itself poured in a series of small pours to achieve the height desired.

You can also use piers made of wood. Such a pier, even when infilled with concrete, should be made from pressure treated timber. Be aware however, that because wood is relatively flexible, you will need to use large amounts to achieve a sufficiently rigid pier.

The advantages of a concrete footing for the pier are:

1) It increases the base area of the pier so that forces are spread out over more soil. Hence even weak soils will be able to resist lateral forces.

2) The relative effect of the “off balance” equatorial mount is reduced by the mass and size of the concrete footing.

3) If you touch the telescope or pier, the large mass and rigidity of the system will have a higher frequency of vibration, thus reducing the amplitude and duration of any adverse visual effects.

4) Vibrations coming through the soil cannot move the large mass of the footing to a significant degree. In effect isolating the pier from the soil.

Chapter 8 - Building Foundations

In this chapter we will consider two very different types of foundation. The basic concrete pad, on which the observatory is bolted down, and the integral tanked footing, which provides an underfloor cavity or working space.

Most of you will be unfamiliar with handling and finishing concrete, or in either brick or blockwork. We therefore think it worthwhile explaining in substantial detail the actual preparation, handling and construction techniques, including the “mystic” crafts of the trade, such as finishing a concrete raft to produce a level smooth surface.

Cement & Concrete

Concrete is a mix of cement and certain aggregates, and sand. Sand is of course finely divided stone, which in its turn is broken and pulverised quartz rock. The broken stone and the sand may be natural, or produced by crushing and grinding.

The variety of stone used is enormous, depending generally on the character of the local deposits, so that in London, as an example, use is made of the gravel deposits of the Thames valley, whilst in Lancashire, limestone is preferred as being more easily obtained and therefore cheaper.

At one time there was a good deal of prejudice against the use of rounded aggregates, but research has shown that the shape of the stones does not have much adverse effect on the strength of the concrete provided they are not thin and flat ones. The chief requirement is that they shall be dense and hard whilst being quite clean. Some ballasts contain a good deal of alluvial clay which forms a scum and prevents adhesion. When choosing aggregate take some up in the hand, rub it well and clay will betray its presence by leaving a dark brown stain. The same test can be applied to sand which is best bought under the description “washed pit.”

The ideal aggregate contains grains and pieces of all sorts of different sizes which fit nicely together to form a dense mass when the inevitable tiny spaces between them are filled with cement. Aggregates are nowadays usually sold premixed with sharp sand (quartz sand and ground flint). The type of aggregate you will need is referred to as “3/4” down”. Ballast is crushed stone, also sold by a sivved size, e.g. “3/4” down”, or “1-1/2” down”.

Stone varies in its power to absorb water, some sorts soaking it up like a sponge, and if these have been used to make the aggregate, it will need a soaking time during mixing.

Aggregates and sand are sold by the cubic meter or metric tonne (although most builders we meet still work in yards and tons!) For those of you who prefer to calculate their requirements instead of merely guestimating, some equivalent weights and measures are listed below:

1 tonne of River Sand	contains 1.9 cubic meters
1 tonne of Pit Sand	contains 2.0 cubic meters
1 tonne of Ballast	contains 2.0 cubic meters
1 tonne of Course Sand	contains 2.1 cubic meters
1 tonne of Shingle	contains 2.2 cubic meters

Dry sand will weigh between 1.1 and 1.2 tonnes per cubic meter, but moist sand only 0.9 to 1.1 tonnes per cubic meter. Thereby hangs a tale. Why should wet sand weigh less than dry?

If we pick up a largeish grain of sand we see that it looks hard and shiny. Not much hope of water penetrating very far into a material like that, but all the same it will take up water, and in a peculiar way; by holding it as a thin film all over its surface.

The convenient way to order sands, aggregate and ballast is in “big bags”, which can be delivered on site and the empties returned to the builder’s merchant. A good merchant will give you “long measure”, that is, the volume you order and a bit extra. It pays to shop around and compare prices and delivery charges.

The next point to consider about concrete aggregates is that though a heap of the stuff looks fairly solid it is actually full of voids. To illustrate this pour some 3/4” down into a big jar to the brim, and then see how much water you can pour into the apparently full jar without any overflowing. If the jar holds a litre, you will be able to pour in about 1/2l of water. The water is, of course, used up in filling all those voids.

When we make concrete we add sand for the purpose of filling up the voids with something which costs far less than rather expensive cement. Sand looks dense enough but it, too, has voids and like the average course aggregate may have as much as 50%. This seems a lot, but the fact remains, and explains the purpose of cement which, being very finely ground, can get into the minute spaces between the grains of sand almost as easily as water.

The above fact explain why when we mix concrete we must not expect to get a cubic meter of it from a cubic meter of mixed aggregate and sharp sand.

The general basis for calculation is that the quality of wet concrete will be seven-tenths that of the dry material. This is best illustrated by working out an actual example in which we wish to make a cubic meter of wet concrete.

Well, it will have to be made to some sort of recipe, generally known as the mix. Common mixes are 1:2:4; 1:2-1/2:5; 1:3:6; & so on, but for our present purpose we will imagine that we want a 1:1-1/2:3 mix.

This will need for each cubic meter of concrete, fifteen 25kg bags of Portland cement, 1/3 cubic meter of sand and 2/3 cubic meter of ballast. As a 25kg bag of Portland cement contains about 1/20 cubic meter, the total dry materials will be 1-3/4 cubic meters, and multiplying by 7/10, we end up with just under 1-1/4 cubic meters, which is just over the cubic meter we were aiming at. In the Appendix the reader will find lists of various mixes with the quantities of materials required and will therefore be saved a certain amount of arithmetic.

Mixing the Concrete The strongest concretes have a water:cement ratio of about one half. Although it will be found that fine aggregates absorb more water. Because there is a tendency to make the mix too wet, it is best to use an electric mixer and mix dry before adding the water. MIxing concrete is an arduous task, and a mixer takes a lot of the labour out of the job. A small mixer on wheels with handles like a wheel barrow is handy because it can be positioned where the pour is needed.

To the mixer shovel in the aggregate and sand and allow to mix thoroughly. Then add the cement gradually, allowing the blinded (dry) mix to stir until it is a uniform grey. Then proceed to add the water from a hose pipe. The correct amount may be gauged by the action of the mix as it falls over on itself as the mixer turns. There should be little or no free water running before the mix as it folds over. If there is add a little more sand until the mix has a uniform texture of thick paste.

Concrete sets by a process involving the dehydration of lime. It is a chemical process and does not entail the concrete “drying out” as is commonly imagined. When you pour your footings or base pad, care should be taken to ensure the concrete does not dry out too rapidly, otherwise it will become dusty.

Modern concrete specifications are controlled by a standard, BS5328. Details are provided in the Appendix.

Pier in a Pad

A concrete pad will usually include ducts for power and signal cables and an opening for the pier. The minimum size of pad is that needed to support the dome and a wall of a slightly smaller diameter. The pad should not extend more than a few inches beyond the wall, to prevent splash back above the damp proof course, it if is a brick wall, or onto the timber or metal wall.

The depth of the foundations should be at least 225mm (9”), but this includes a layer of hardcore onto which a damp proof membrane is placed, typically 1000g polythene, before the shuttering is installed, the services ducts fitted, and the pad poured. If you intend using a pipe for the pier, it is a good idea to fit a sleeve first, and fill this with concrete just before your slide the pier into position.

For a 3m pad, a concrete thickness of 100mm to 150mm is appropriate, for which about 1 to 1-1/2 cubic meters is needed. If it reinforced so much the better,

Establishing the Meridian

If the building &/or the pier needs to be aligned to the meridian you will first of all need to peg out the site carefully. This will involve establishing a true north-south and east-west line intersecting immediately beneath the pivot point of the telescope.

The north-south or meridian line is the first objective. We have witnessed all manner of oddball methods, ranging from a compass and Ordnance Survey map corrected for magnetic deviation, to sighting Polaris at upper or lower culmination. They are all a ridiculous nonesense. The method I am about to describe will suffice, and prove the least troublesome and the most accurate. All you need is a large sheet of thick brown paper and some paper weights, a tripod and a plumb line and bob, a black felt marker pen, a watch set to UT, an Astronomical Almanac, a meter rule, and pegs and string. You must also have your longitude to the nearest arc minute which may be obtained from the 20 000 series Ordnance Survey.

Having leveled the site, lay the sheet of brown paper as close to the north-south line as you can estimate, and hold it down with the weights. Place the tripod across the south end and suspend the plumb bob from the head so it can swing freely with the bob just clearing the paper. Mark the bob point when it has settled.

Calculate the time of local noon from the Almanac. To do this look up the time of solar transit at Greenwich. Correct for your longitude. Remember if you are east of Greenwich local noon occurs earlier, and if you are west of Greenwich it occurs later. Convert your longitude from arc to time (based on 1º = 4mins & 1’ = 4secs) and add it to Greenwich time of solar transit if west or subtract it if east. This is the time the Sun will be exactly due south at your site. Set your watch by the speaking clock or the MSF time signals and correct for BST if necessary. (remember if you do this in summer the clocks are set an hour ahead of Greenwich). It is imperative you make this calculation without any mistakes, especially the longitude correction. We have seen professional observatories with equatorials skewed on their piers due to stupid mistakes made by so called experts. Take care, and get someone to check your sums.

About an hour before local noon begin marking off the end of the plumb line’s shadow on the brown paper using the felt marker pen and noting the time. Do this at regular intervals (say 12 mins), and mark local noon as well if the Sun isn’t clouded over at that precise moment. If it is, carry on until about an hour after local noon, and then interpolate the shadow marks. The best way of doing this is by drawing a straight line from the first to the last mark and measuring the intervals of each shadow mark along the line from the first, and listing the distance against the time interval.

Once you have established the noon shadow mark, draw a line from the bob point to the noon mark and extend it across the paper, both north and south. Then peg out a long line so the string runs contiguous with the line on the paper, several meters beyond each end. This is your local meridian. Do not move it - it is sacrosanct!

Set out a similar length of line at right angles to your meridian line, intersecting the meridian line at the bob point. To make certain it is a true right angle, make a line of 12 equal knotted lengths, and peg it out as a 3,4,5 triangle, and use the 4 knot length as a reference base line. As a final check strike off equal offsets along the meridian and east-west lines from the bob point, and then measure their separations. They should be equal within about ±10mm (3/8”).

Having established the meridian you can then peg out the foundations for the wall and the pier.

Installing the Shuttering

There are several methods of preparing the form for a pad and then smoothing (finishing) the concrete. The easiest, of course, is to get a friend who has done concrete work to do the job. But if you don’t move in such exalted circles, you will have to learn something of the craft for yourself.

The simplest method is to install a braced form, using 12mm (1/2”) shuttering ply and stakes made by sawing up lengths of 2”x2” carcassing and prepping the ends with a hand axe.

The site is first cleared of turf and leveled and then excavated to a depth of 225mm (9”), where the pad is going to be poured, and about 1 to 1.5m (3’-5’) where the pier pipe is going to go. The ground can be made easier to work on by covering it with dry aggregate to a depth of 50mm (2”). Cable ducts should be laid on top between the perimeter and the centre.

Shuttering forms are then assembled with braces spaced about 300mm (a foot) or so apart if the pad is circular, or at the corners if it is polygonal, with perhaps a brace along either each side. The forms are made by nailing 225mm (9”) wide sheets to the stakes and hammering them in place, ensuring the top of the stakes are flush with the forms and level.

Once this has been done a damp proof membrane is cut and placed across the site so it comes up the inside of the form and under the service ducts, and the first batch of concrete mixed and poured over it. You then need to cut out the reinforcing mesh with heavy duty bolt croppers and drop it into the concrete. Do this after each batch has been poured until you get within 100mm (4”) of the top of the form. A further 50mm (2”) is poured without reinforcing and tamped down with a wide rake, deliberately leaving the surface with a wavy pattern of indentations to provide a mechanical key to the screed which is going to be applied as the finishing surface.

The recommended batch mix for a 225mm (9”) pad is BS5328 C20P or C25P. You can make this by weight batching in the ratio 1:2:4, cement, aggregate, ballast. As a rough guide, 25kg of cement should be mixed with 65 litres of ballast and 40 litres of aggregate. For example a cubic meter batch will require 300kg cement, 490kg aggregate and 800kg ballast. When calculating the total volume of concrete required for your pad, please bear in mind that the cement does not add to the batch volume of the mix.

The rough concrete surface should be covered with a tarpaulin or plastic sheet and allowed to cure over about a week, without being allowed to dry out. The surface should then be painted with a rubberoid mastic such as “Synthaprufe” and after a day or so, another coat applied and lightly dusted with sharp sand.

You then need to mix up your screed. This is a simple 1:3 cement, sharp sand mix with a dash of a plasticiser such as ”Feb mix”, worked up to a blinded paste (i.e. moist bordering or the dry side). We find it easier to mix screed on a mixing platform or banker, by hand, than in a cement mixer.

Shovel the screed onto the mastic and rake it flat. Keep doing this until you are up to the top of the shuttering form. Get an assistant and a long length of straight carcassing and run it slowly across the top, tamping the screed up and down as you proceed. Scrape up the excess with the carcassing as you go and run it off over the form when clear the edge.

You will then need some scaffold planks. Make a running bridge to support your weight above the pad, and taking a brick layer’s float, or a home made Darby, float off the surface of the screed, bringing the water to the surface in wide sweeps. There is a technique to this. The lower surface of the float should be almost flat on the screed, but angled just sufficiently to prevent it digging in. Go over the screed several times from different directions, smoothing off the remaining ridges and blow holes.

The technique in obtaining a hard, durable surface, that isn’t prone to dusting. is to begin a cycle of working the screed, and allowing it to partially cure before reworking it. Work roughly at hour intervals, all the while bringing the water to the surface. After about 3 to 4 hours it will be strong enough for you to kneel and lean on if you kneel on a board. You can then finish by floating off the remaining water.

The first time you try this the boards will probably dent the surface and you will have to smooth these off. You will soon notice that some areas of the pad are higher than others. Angle the float so that you use the flat of the float and its trailing edge to sweep the screed level. Don’t try to move the screed by scraping it up, move it in continuous smoothing sweeps of the float.

Finally, after you have floated off the water, but before the screed cures, go round the form, hammering the stakes below the pad’s surface. This will leave the lip of the pad proud of the shuttering. Go round this with either the narrow end of your float, or a Frenchman, and smooth the lip off.

This is a good time to carve your initials and the date, and maybe your families palm prints. Just make sure to keep the family pets away!

Allow the screed to cure overnight, and then remove the form. Do this carefully or you will break away the perimeter edge of the pad. If you have constructed your pad so that it proud of the surrounding lawn, or ground, it is a good idea at this stage to lay a perimeter of shouldered flettons to protect the edge from damage by pedestrian traffic or your lawnmower. You can easily do this by digging a narrow trench around the pad, pouring in a mortar mix (1:5 cement, soft sand), and laying the bricks in end face down and edge side out, against the pad, so that the tops are just below the level of the pad, say 6mm (1/4”), and then pointing the gaps.

After about two to three days the pad will be sufficiently cure to walk on, and to drill holes and fit anchor bolts &c. Be careful when working on it for the first week or so because concrete does not fully harden for several weeks.
To prevent the surface dusting you can apply a diluted PVA liquid wash with a soft

broom. This is always a good idea in any case, especially if you intend sealing the surface with an epoxy based industrial floor paint such as “Watco”.

Non-Pad Foundations

Whilst this chapter deals primarily with prepping a concrete pad, many designs of domed observatory demand something a little more sophisticated in way of a suitable foundation. If for example your observatory dome is to be supported on a brick or block wall, and have a raised floor, and perhaps an underfloor store room, then the footings will have to be a lot deeper than 225mm (9”), especially if you are on a heavy clay subsoil that suffers from ground heave. The hydraulic pressure caused by dry clay becoming saturated is enormous, easily enough to crack even a reinforced 225mm (9”) pad. Furthermore, recollect, that we wish to avoid at all costs, the foundation, or the pier footing, tilting, which can easily happen on clay subsoils where the foundation is inadequate. Finally, despite impressions, a brick wall is strong only in compression. If the ground heaves upwards and fractures the footing, the brick wall will go with it.

The two most common types of foundation, designed to support a brick or block wall, are the ring foundation and pilings. A ring foundation is a “wall” in the ground to support the observatory. The foundation will usually rest on a footing of concrete poured on the bottom of a trench. The footing spreads the load, and provides a reasonably level base for the foundation. The foundation itself may be constructed of poured reinforced concrete or concrete blocks. If poured concrete, the ring is typically about 225mm (9”) wide and a meter (3’) deep. If constructed from block work, the ring will be two blocks thick. In any case, leave holes for reinforcing rods and don’t forget the services duct.

The big advantage of the ring foundation made either way, is that it can be constructed in stages. It may also be readily made by mixing small batches of concrete, either by hand, or a DIY type portable mixer.

The observatory floor may be made of concrete poured subsequently, and the observing floor supported above, either at or slightly above ground level, or off the brickwork using joist shoes. It is also possible to dig down to the water table, and tank the foundation so you have a dry, comfortable, large, underfloor work room and storage space. accessible via a floor hatch.

Pilings are narrow supporting pillars around the perimeter of the walls. A 3m dome requires about eight or more piles. A pile might be a tannalised timber post sunk into the ground, or it might be constructed of blockwork, or poured concrete. Usually a sill of some sort is constructed that connects the tops of the piles. For example, eight wood piles might have 200mm x 50mm (8”x2”) joists bolted to the top of them to form a continuous octagonal support for the observatory wall. A wood floor could easily be built onto the sill.

Whilst pilings involve less labour, and are undoubtedly less expensive, they are unsatisfactory in a number of ways. They are inherently weak, capable of withstanding compression loads but not shear forces. Ground heave in clay subsoils places the piles in tension and can shatter them. They can settle at different rates, causing the observatory to tilt slightly and this can result in the dome rail deforming.

In our opinion the use of pilings should be avoided. They are the lazy man’s way of avoiding a bit of hard graft. A ring foundation, if properly made, will not suffer any of the problems to which pilings are prone.

Designing & Building a Domed Astronomical Observatory

Chapter 9 Constructing the Building

Attaching the Observatory to the Pad

So far, we have described how the foundation is built, but we have not talked about attaching the observatory to the foundation. The bulk of the work entailed in building a domed observatory is in the foundation. After all this work it would be a shame if the observatory were to blow away!

There are several methods used to provide anchor bolts into concrete, and each has advantages and disadvantages. One method of providing bolt attachments is to cast threaded studding into the concrete. This seems straightforward enough, but it is not so simple in practice:

1) each stud location must be accurately marked out; changes afterwards are difficult.
2) each stud must be held in a rigid, vertical position, even when concrete is pushed up against it.
3) threads must be protected from the concrete.
4) fitting the assembled base ring is awkward because it usually cocks over on the studs and jams.

Whilst these problems are very real, at least you don’t have to drill holes in the reinforced concrete at a later stage.

A second anchoring method is to cast female threaded anchors into the concrete. These anchors are available from builder’s merchants and some can even be inserted into wet concrete, although there would still remain the difficulty of locating them precisely where you want them.

A third anchoring method is to drill holes into the hardened concrete, using a power drill and a masonry bit. After the hole has been marked out you drill a smaller pilot hole to avoid the position being drawn off by the aggregate inclusions, and then the finished hole. Again, different types of anchors are available for insertion into the hole. Some types of anchors are grouted or epoxied in place. These are easy to use; however, the bond may not be effective if the concrete is damp or temperature low. Other types are designed to expand when the bolt is inserted and tightened, gripping the side of the hole.

Some anchors accept machine bolts, while others take lag bolts (large coarsely threaded bolts). Look over the selection at a hardware store or builder’s merchant, and select the anchor and bolt system that suits your needs. Use a minimum of 6mm (1/4”) machine bolts, and preferably 10mm (3/8”) with underhead washers. Anchors for 10mm (3/8”) bolts usually require holes 16mm (5/8”) to 20mm (3/4”) diameter. The anchor should go through the screed and well into the concrete, say a minimum of 75mm (3”), and preferably 100mm (4”).

After you have bolted your base ring or sill in place there will be narrow gaps underneath that need sealing. There are various ways you can do this. One is to inject expanding polyeurethane foam, and paint the exposed fillet after you have cut off the excess with a razor knife, with a latex elastomer. Alternatively you can inject a colour matched silicone sealant along both the outside and inside edge.

If the wall is fabricated on site, it can now be assembled on the sill which forms the splashback. If it has already been prefabricated in sections, these can now be fastened together on the sill with glue and screws.

Building the brick or block wall

It is at this stage you need to select and order your bricks. Before doing so we suggest you consult a good DIY(manual, and pay a visit to a builder’s merchant and discuss your project with the yard forman who will be able to help you make an appropriate choice.

There are literally hundreds of different types of brick, many of them peculiar to particular regions of the country. There would be little point in recommending a red Ibstock or Anglian buff brick if it is not available in your locality.

Bricklaying is a skill that takes considerable practice to perfect. Unless you are a competent DIYer, or a craftsman with building experience, the services of a bricklayer will save you time and trouble. However if you feel confident you can tackle the job yourself, then there are a few pointers that we feel will be of assistance.

Tools for bricklaying:-

brick trowel [300mm -(12-inch) - handed]
bolster
lump [club] hammer
striding level
torpedo level
line and pins
steel measuring tape
spot board [home made]
gauge rod [home made]
builders square [home made]
hawk
frenchman [for pointing]
straight edge [home made]

Types of mortar

Choosing the right mortar

Using lime in mortar

Mixing mortar; use of feb mix (plasticiser) or feb band &c (PVA)

Using a brick trowel

Using a club hammer and boulster

Using a line & pins (making grooved L-blocks)

Checking with a level

Pointing (types of joint - rubbed, recessed, flush &c)

Bond of lay - bonds for single and double brick walls

Built in barriers to rising damp - DPC - on brickwork - round door frame

Working from a concrete pad

Working from footings or a ring foundation

Roofing - fitting flashing - spanning openings above door and window frames

Cleaning brickwork - removing cement splashes

Building the Pier	- from a footing - brick or blockwork - infil - pier lintel - bed plate - bed plate fittings (for mount base plate &c) - provision for polar alignment

Installing the observing floor	- joists - flooring
Erecting the dome	- dome paints
Fitting out	- services & controls - the lighting system - PSU's

Designing & Building a Domed Astronomical Observatory

Chapter 10

Aligning the Equatorial

Polar alignment suited to deep sky astrophotography minimises dec. drift at certain declinations, and between certain hour angles either side of central meridian. Mountings with hour axes elevated above the true pole to reduce declination drift require initial alignment on the true pole, and an elevation correction applied to compensate for dec. drift. Alignment methods dependent upon the reduction of dec. drift are unsuited to alignment on the true pole, or for determining the direction of the hour axis.

If all you require is an approximate alignment that reduces the frequency with which RA drive corrections and DEC drift compensation need to be made, alignment by King's method is perhaps more appropriate. If however you do not specialize in deep sky long exposure astrophotography, but observe solar system objects and double stars for example, a true pole alignment method is most appropriate.

To align the hour axis to the true pole and achieve the necessary accuracy the mounting and telescope must be furnished with three essential items:

i) a filar micrometer or vernier eyepiece (for measuring dec. drift)
ii) accurate setting circles with adjustable verniers (or hi-res encoders)
iii) differential elevation & azimuth alignment bolts, or alignment wedges.

A sidereal clock will also prove useful.

The successive stages in setting up an equatorial are:

1) Collimate Optical Axis to the Tube Mechanical Axis

2) Collimate Finder

3) Square Optical Axis to Declination Axis

4) Square Dec. Axis to Hour Axis

5) Elevate Hour Axis to the True Pole & Zero Dec. Verniers

6) Adjust Hour Axis into the Meridian

7) Set HA Verniers into the Meridian by transit of an equatorial star.

8) Adjusting Elevation of Hour Axis by Measuring Dec. Drift Rates due to Refraction

1) Collimate Optical Axis to the Tube Mechanical Axis

i) This applies to both refractors and reflectors.

ii) The reflector is at a disadvantage because a tilt of the objective displaces the optical axis.

iii) The axes need not be coincident but they must be parallel.

iv) The object glass of a refractor must be squared on and this is best done by field collimation.

v) The initial collimation of a Newtonian may be done in daylight and completed by field collimation.

vi) The mirror must not move in its cell, and the tube assembly should be very stiff.

2) Collimate Finder

i) Use the filar micrometer to define the field centre.

ii) Select a star near the pole to reduce tracking errors.

3) Square Optical Axis to Declination Axis

i) Align the telescope circle following (East of Pier), upon an equatorial star at culmination and record the sidereal time and hour angle.

ii) Reverse the telescope, circle preceding (West of Pier), and repeat.

iii) If angle S is less than a right angle, the star will be seen to transit late circle following and early circle preceding, and vice versa.

iv) The HA difference, less the sidereal time interval and 12hrs., gives twice the error.

i.e.

$$\hat{S} \le 90^0 \quad t_f late / t_p early \quad t_f - t_p \le 12 hrs$$

$$\hat{S} \ge 90^0 \quad t_f early / t_p late \quad t_f - t_p \ge 12 hrs$$

$$Error = \tfrac{1}{2}\left(t_f - t_p - \delta t - 12 hrs\right)$$

v) Convert the time error to arc and apply the correction by either shimming the saddle or adjusting the compound saddle push-pull bolts if the mounting has such a feature.

vi) Repeat the procedure and note the residual error.

4) Square Dec. Axis to Hour Axis

i) Most instruments have no facility for correcting this error.

ii) Align the telescope on a polar star

(e.g. αUMi/σOCT)

iii) With the telescope circle preceding note the hour angle and sidereal time.

iv) Reverse the telescope circle following and repeat.

v) If angle H is less than a right angle, the star's hour angle west will be too great and hour angle east will be too small.

vi) The difference in HA less the sidereal time interval and 12hrs., gives twice the error.

i.e.

$$\hat{H} \le 90^0 \quad HA_W \; too\ great / HA_E \; too\ small \quad t_p - t_f - \delta t \ge 12\,hrs$$

$$\hat{H} \ge 90^0 \quad HA_W \; too\ small / HA_E \; too\ great \quad t_p - t_f - \delta t \le 12\,hrs$$

$$Error = \tfrac{1}{2}\left(t_p - t_f - \delta t - 12\,hrs\right)$$

vii) Convert the time error to arc and either record it or apply the correction by shimming the dec. axis bearings.

viii) Repeat and note the residual error.

5) Elevate Hour Axis to the True Pole & Zero Dec. Verniers

i) Select an equatorial star near culmination.

ii) With the telescope circle following read the instrumental declination and correct for astronomical refraction.

iii) With the telescope circle preceding repeat.

iv) Half the sum of the dec. readings equals the true instrument dec.

v) Apply the correction by subtracting the true instrument dec. from the apparent dec. given in the ephemeris precessed to epoch of date, and adjusting the elevation of the pole end of the hour axis in the opposite direction.

vi) Half the difference of the instrument dec. readings equals the dec. vernier error.

vii) Adjust the telescope in dec. by the error, in the opposite direction, and adjust the verniers to read the apparent dec. at epoch of date corrected for refraction.

viii) Repeat & note the elevation error & vernier errors.

6) Adjust Hour Axis into the Meridian

i) Direct telescope to a star on the 6h/18h circle, zenith distance less than 75º

ON 6h CIRCLE - DEC. READING HIGH - POLE END of HOUR AXIS EAST of MERIDIAN
ON 6h CIRCLE - DEC. READING LOW - POLE END of HOUR AXIS WEST of MERIDIAN
ON 18h CIRCLE - DEC. READING HIGH - POLE END of HOUR AXIS WEST of MERIDIAN
ON 18h CIRCLE - DEC. READING LOW - POLE END of HOUR AXIS EAST of MERIDIAN

ii) Correct readings for refraction in declination.

iii) From the apparent declination precessed to epoch of date subtract the corrected reading.

iv) This gives the azimuth error.

v) To apply the correction adjust the pole end of hour axis in the opposite direction to the azimuth error.

vi) Repeat and note residual azimuth error.

7) Set HA Verniers into the Meridian by transit of an equatorial star.

i) Align telescope on star near culmination.

ii) At time of transit as indicated by the sidereal clock, stop drive.

iii) Adjust HA verniers to 12h & 0h.

iv) Repeat & note HA vernier errors.

Refraction

$$r = 60''.4\ \tan z$$
$$\cos z = \sin\varphi.\sin\delta - \cos\varphi.\cos\delta.\cos H$$

Refraction in dec.

$$r_\delta = 60''.4\ \frac{\tan\varphi - \tan\delta.\cos H}{\cos H + \tan\varphi.\tan\delta}$$

Refraction @ HA 6h/18h

$$r_\delta = 60''.4 \cot\delta$$

z = zenith distance
φ = site latitude
δ = declination
H = hour angle

Depending upon the reading accuracy of your setting circles, the hour axis will now be adjusted close to the true pole, and the meridian error will be much smaller than the elevation error and of no consequence to the tracking rate. By definition you will possess a filar micrometer or graticule eyepiece to determine arc at the focal plane. You may now refine the elevation of the hour axis to within ±5"arc of the true pole by observing dec. drift rates due to refraction.

8) Adjusting Elevation of Hour Axis by Measuring Dec. Drift Rates due to Refraction

i) Centre a star near the meridian and set your filar micrometer to measure dec. drifts.

ii) Follow star for about 2hrs. & measure dec. drift.

iii) Compare the averaged hourly rate to the theoretical rate.

iv) The difference in hourly rate is caused by the elevation of the hour axis deviating from the true pole.

This process can be rather tedious. The determination of the elevation of the hour axis from the true pole may be simplified by preparing two plots beforehand, one of the theoretical hourly rate in declination when the hour axis is directed at the true pole; the second of the hourly rate in declination due to the departure of the hour axis from the true pole. This enables the theoretical rate in declination to be read off from the mean HA & dec. of the star. The difference between the observed & theoretical rate is read off on the second plot, yielding the error in elevation of the hour axis.

The hourly rate in declination at the true pole:

$$\frac{d\delta'}{dh} = +15''.\frac{\sin\varphi.\cos\varphi.\sin H}{(\sin\varphi.\sin\delta + \cos\varphi.\cos\delta.\cos H)^2} \quad arc\sec s / hr.$$

The hourly rate in declination due to departure from true pole:

$$\frac{d\delta_c}{dh} = \gamma \; .\sin H \quad arc\sec s / hr.$$

where γ = elevation of hour axis above true pole

As an example a pair of plots have been prepared for observatory site latitude,

$$\varphi = 52^0 : 09' : 20''.32N$$

z = zenith distance
φ = site latitude
δ = declination
H = hour angle

Method Summary

i) Measure dec. drift and determine hourly rate.

ii) Read off the theoretical rate at the mean dec. and hour angle.

iii) Subtract the observed rate.

iv) Read off the corresponding value of gamma at the mean hour angle.

IF DIFF. + AXIS BELOW TRUE POLE
IF DIFF - AXIS ABOVE TRUE POLE

v) Apply correction in opposite direction to error.

N.B. + γ ‘s REDUCE DEC. DRIFT

A refinement of this method which can accommodate azimuth misalignments is described by W.R. Vezin, 'Polar Axis Alignment of Equatorial Instruments,' J.B.A.A. 1978, 88, 3, p267.

Conclusion

It should be manifestly obvious that trial & error alignment methods intended to minimise dec. drift are both inappropriate & meaningless. It is not possible to adjust the hour axis to counteract dec. drift due to refraction at all declinations & hour angles. Any alignment that minimises dec. drift at certain decs. & HA's elevates the hour axis above the true pole.

Designing & Building a Domed Astronomical Observatory

Appendix - Codes of Practice
- Calculations for Building Regulations Approval
- Bibliography

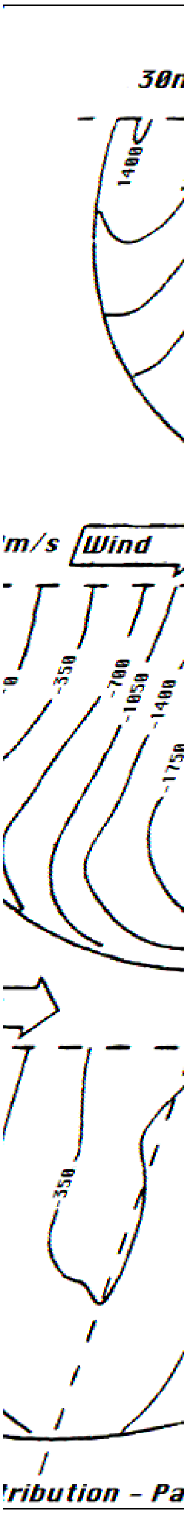
Codes of Practice

Note: these codes of practice may be consulted at any good reference library.

Assessment of wind load in accordance with BS6399:Pt.2: 1995
Reference document:
Building Research Establishment: The designer's guide to wind loading of building structures: pt.2:1995 - N.J. Cook
Butterworths Press

BS5328 Concrete batch mixing by weight or by volume
Reference document:
Concrete mixes for general purposes by Dennis Palmer - publication no:45.031 available from the Pulications Sales Unit, Cement & Concrete Assoc. Wexham Springs, Slough SL3 6PL.

BS5268:Pt.7.1:1989 Structural use of timber - Domestic floor joists.



Calculations for Building Regulations Approval

Assessment of wind load in accordance with BS6399:Pt.2:1995

effective wind speed:

$$\begin{aligned} V_e &= V_s \cdot S_b \\ &= V_b \cdot S_a \cdot S_d \cdot S_s \cdot S_p^* \cdot S_b \\ &= 23.1.035.1.0.1.0.\sqrt{1.4}.1.45 \\ \therefore V_e &= 40.8\, m/\text{sec} \end{aligned}$$

dynamic pressure:

$$q_s = 0.613 V_e^2 = 1020 Pa\,(21.3 lbsf/sq.ft.)$$

[1]gust factor: $g_t = 3.44$

dynamic augmentation (drag)

$$c_r = 0.25$$

*Annexe D (normative) - probability factor $\sqrt{1.4}$ for annual risk $Q = 5.7.10^{-4}$. This is the annual risk corresponding to the standard partial factor for loads, corresponding to a mean recurrence interval of 1754 years. Back-calculated assuming the partial factor load for ultimate limit .

1 Annexe F - gust factor ($V_s = 24 m.s^{-1}$ & $\frac{q}{V_s} = 4.8$ & $H_e = 4m$)