Pier Design Fundamentals
Igloo Observatory  Hampshire, IL USA
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**Abstract:**
Telescope piers can be designed and built to meet predetermined specifications.  This paper treats the specification of pier deflection.  The importance of a large diameter to afford maximum rigidity is emphasized.  A table of pier heights and diameters accompanies the paper to aid the astronomer in designing his pier using concrete and steel pipe.

**Introduction:**
Most serious observers and imagers eventually turn to a permanent pier to mount their scope. This allows one to quickly begin observing without any tedious and time-consuming setup time.  Most commercially available piers are designed to bolt to an existing surface and therefore do not solve the problem of choosing the appropriate concrete base.  I will describe the process of specifying the concrete base and embedded pier column. I will also discuss the bolt-on pier column. You can decide if you want to tackle the job yourself or hire a contractor. Either way, you will have the benefit of specifications to help you build a solid pier.

**Specifying the Pier: How big do I need?**
Commercially available piers are generally specified in terms of their weight capacity. This is, unfortunately, a frankly useless specification. Almost any pier will support a massive weight. What we want to know is how much the pier moves with our mount and scope attached.

Pier movement is predominantly sway.  The pier acts like an inverted pendulum, hinged at the base, and sways from side to side.  The engineering term is a cantilevered beam. It is constrained at one end with the other end free to sway in the breeze.

Some astronomers concern themselves with vibrations, damping time and ringing. If you design your pier using my guidelines you can forget about these considerations completely.  You will not worry about the period of oscillation (damping time) because your pier will not deflect enough to disturb imaging or observing, whatever the fundamental frequency may be.  Similarly, your steel pier will ring with a crisp high C bell tone if you strike it forcefully with a hammer. Just don't do that while you are imaging or observing and the ringing will be of no consequence. There are no natural forces that can excite the ringing mode as long as you keep your hammer away.

The singular most important specification is pier deflection.  We can specify it in terms of movement in thousands of an inch displacement from vertical at the top when we push on the pier. But this is too coarse a specification!  We can't tolerate even a thousandth of an inch. So we specify pier deflection in terms of angular deflection – arc seconds.  This is a term we are all familiar with. We have split double stars that are a few arc seconds apart and have a feel for what a deflection of a few arc seconds would do to our imaging or observing.

I recommend a 0.5 arc second displacement for a 5 pound-force push exerted at the top of the pier. If a star is centered in your scope's FOV and you push on the pier (not the scope) with a 5-pound force, the star will move 0.5 arc second. This will meet the needs of 90% of the amateur astronomer community. It is a realistic specification accounting for wind loading on a large scope. Wind is a factor even in roll-off and dome observatories.

If you will be imaging DSOs at 4000 mm focal length from Pickering 8 skies you may want to tighten the spec. If you will never do any serious, long focal length imaging and are purely a visual observer, you can loosen the spec. But please note that it costs very little more build the pier to 0.5 arc second deflection than to 5.0 arc second deflection. The possible exception is a second-story installation with a ten-foot or higher pier. Such a pier is beyond the scope of this paper, although the specification methodology can still be applied.

**Pier Deflection Specification:** The pier shall deflect less than 0.5 arc second when a lateral force of 5 pounds is applied to the top of the pier.

**Pier Design: Diameter is your Friend!**

The equation for angular pier deflection (given in the appendix) yields a very important relationship regarding the diameter of the pier. The angular deflection is proportional to the inverse (one-over) forth power of the diameter, that is, 1/(D^4). Let's put that into practical table of numbers.

Below we consider a pier that is 6 inches in OD. This purely imaginary pier is constructed of material like PVC pipe – it is not the steel which I recommend. Let's assume that it deflects 10 arc seconds for our 5 pound push – not a very good pier! What happens if we increase the diameter of the steel pipe while maintaining nearly constant wall thickness?

| Diameter | Deflection arc seconds |
|---|---|
| 6 | 10.0 |
| 8 | 3.2 |
| 10 | 1.3 |
| 12 | 0.6 |

Table 1: Deflection vs. Diameter

We see from Table 1 above that doubling the outside diameter of our pier reduces the deflection angle by a factor 10/0.6 = 16.7. Diameter is our friend!

Note that we don't worry about wall thickness. In a steel pipe pier, the thinnest schedule wall thickness is the most cost effective specification. Let's look at another example: Which is better?
Case i) Six foot high pier of 10-inch schedule 5s pipe with wall thickness 0.156 inch; weight 60 pounds; cost about $90 (scrap)
Case ii) Six foot high pier of solid 6-inch diameter steel cylindrical stock; weight 384 pounds; cost $576 (scrap, if you can find it)

The deflection for case i) is 0.6 arc seconds. The deflection for case ii) is 1.4 arc seconds. So we see the larger diameter, thinner wall, is both cheaper and stiffer.

The foregoing example illustrates why filling a wobbly pier pipe with concrete or sand doesn't fix the problem. The difference in deflection between a solid rod and a hollow rod is surprisingly small. The way to reduce the deflection is by increasing the diameter.

In the case of a concrete pier, the pier is of course solid. But again diameter is our friend. A concrete pier is generally cheaper for the same deflection specification as a steel pipe pier. I do not discuss aluminum because it is prohibitively expensive and offers no advantages whatsoever for a permanent pier.

I do not know how to account for rebars in a concrete pier, so unfortunately I must omit concrete pier design from my paper. Perhaps a friendly Civil Engineer will someday contribute a section on concrete piers.

**Table 2: Pipe Selection for Schedule 5s Steel Pipe**

| Height inches | OD inches | ID Inches | Deflection arc seconds | Deflection mils (1/1000 inch) | I inches^4 | E PSI |
|---|---|---|---|---|---|---|
| 12 | 6.625 | 6.407 | 0.2 | 0.0 | 12 | 3.0E+07 |
| 24 | 6.625 | 6.407 | 0.8 | 0.1 | 12 | 3.0E+07 |
| 36 | 6.625 | 6.407 | 1.9 | 0.2 | 12 | 3.0E+07 |
| 48 | 6.625 | 6.407 | 3.3 | 0.5 | 12 | 3.0E+07 |
| 60 | 6.625 | 6.407 | 5.2 | 1.0 | 12 | 3.0E+07 |
| 72 | 6.625 | 6.407 | 7.5 | 1.8 | 12 | 3.0E+07 |
| | | | | | | |
| 12 | 8.625 | 8.407 | 0.1 | 0.0 | 26 | 3.0E+07 |
| 24 | 8.625 | 8.407 | 0.4 | 0.0 | 26 | 3.0E+07 |
| 36 | 8.625 | 8.407 | 0.8 | 0.1 | 26 | 3.0E+07 |
| 48 | 8.625 | 8.407 | 1.5 | 0.2 | 26 | 3.0E+07 |
| 60 | 8.625 | 8.407 | 2.3 | 0.5 | 26 | 3.0E+07 |
| 72 | 8.625 | 8.407 | 3.4 | 0.8 | 26 | 3.0E+07 |
| | | | | | | |
| 12 | 10.75 | 10.482 | 0.0 | 0.0 | 63 | 3.0E+07 |
| 24 | 10.75 | 10.482 | 0.2 | 0.0 | 63 | 3.0E+07 |
| 36 | 10.75 | 10.482 | 0.4 | 0.0 | 63 | 3.0E+07 |
| 48 | 10.75 | 10.482 | 0.6 | 0.1 | 63 | 3.0E+07 |
| 60 | 10.75 | 10.482 | 1.0 | 0.2 | 63 | 3.0E+07 |
| 72 | 10.75 | 10.482 | 1.4 | 0.3 | 63 | 3.0E+07 |
| | | | | | | |
| 12 | 12.75 | 12.438 | 0.0 | 0.0 | 1297 | 3.0E+07 |
| 24 | 12.75 | 12.438 | 0.0 | 0.0 | 1297 | 3.0E+07 |
| 36 | 12.75 | 12.438 | 0.0 | 0.0 | 1297 | 3.0E+07 |
| 48 | 12.75 | 12.438 | 0.0 | 0.0 | 1297 | 3.0E+07 |
| 60 | 12.75 | 12.438 | 0.0 | 0.0 | 1297 | 3.0E+07 |
| 72 | 12.75 | 12.438 | 0.1 | 0.0 | 1297 | 3.0E+07 |
| 84 | 12.75 | 12.438 | 0.1 | 0.0 | 1297 | 3.0E+07 |

Note: I show deflection values for 12.75 inch diameter pipe with pier heights ending at 84 inches because higher piers will require plug loading considerations that are beyond the scope of this paper. Two-story piers, in particular, require a more detailed engineering analysis.

**The Concrete Base or Plug**

The pier ideally is anchored to a plug that extends below ground. The purpose of the plug is to anchor the pier/plug assembly to mother Earth. My recommendations apply to Midwest soil conditions – farmland with deep, soft soil. Pier builders in areas like Arizona with underlying rock will need to consult a contractor for advice.

Like the pier, the plug must not move very much. Some slight settling is normal, and can be compensated by the mount's polar alignment mechanism. The plug specification concerns both diameter and depth.

I recommend a minimum 36 inch diameter plug. It can, of course, be 36 inches square, but most contractors have access to a 3-foot auger which reduces the hole digging operation to about a 15 minute job.

The plug depth must be down to, or deeper than, the frost line, or three feet deep, which ever is greater. Failure to adhere to this requirement will result in not just minor settling, but listing of the pier by 10 degrees or more from frost heaving! The frost line in your area is well known to local contractors and is a firm requirement in building codes. Look it up and make your plug deeper.

I am not knowledgeable in the areas of proper soil compaction, gravel base layers, and rebar usage. Please consult a DIY concrete book or other outside sources for information regarding these specifications.

**Concrete Plug Specification:** The plug shall extend to or below the frost line, or three feet below ground level, whichever is greater. The plug shall be at least 36 inches in diameter if dug with an auger, or 36 inches on a side if square. Good concrete practices regarding gravel base, compaction and rebar installation shall be followed.

**Pier-to-Plug Encapsulation**

The steel pier is embedded into the concrete plug at the time the plug is poured. The pier should be embedded no less than two feet into the plug.

The cheapest combination is a cast concrete pier, as opposed to an embedded pipe. It is also the most difficult for the hobbyist doing the job himself. I hired a contractor to do the work for my Igloo Observatory. I gave him plans, discussed the project, and followed his advice. He installed the rebar, braces and Sonotube so he could pour plug and pier at the same time. He poured the slab (isolated from the pier by a 3/16 inch gap) the second day.

My concrete pier is 12 inches in diameter and two feet high. I have a 14 inch tall pier extension of 12-inch diameter schedule 5s steel pipe added to the pier so I can change the overall pier height in the future if I change scopes or mounts.

**Piers Bolted to Plug**

The DIY builder often chooses to bolt a steel pier to the plug at ground level. This makes for an easier (though more expensive) installation. The design specifications remain the same, but I offer a caution: The base of the bolt-on pier must have a large diameter, thick plate with generous gussets welded to pipe and pier. In almost all cases of home-made and commercially available piers, the major deflection occurs at the base plate. I do not know how to analyze this geometry and cannot offer any design specifications except to say that one must be very generous in the use of thick components in beefing up this end of the pier.

**Appendix**

Reference: Machinery's Handbook 24th Edition p 220 Strength of Materials
Reference: "Formulas for Stress and Strain", Raymond J. Roark, Table III. – Shear, Moment and Deflection Formulas for Beams.

Case 11: Beam with one end fixed, load at the other end
Maximum deflection at end

| | | |
|---|---|---|
| d = (Wl^3)/(3EI) | | deflection in inches |
| W= | load in pounds | |
| l= | length in inches | |
| E= | modulus of elasticity of material | |
| I= | moment of inertia of the cross section of the beam (cylinder) | |
| I= | [π(D^4 - d^4)]/64 | |
| E= | 3.00E+07 | PSI for carbon steel pipe |
| E= | 3.60E+04 | PSI for concrete (w/o rebars) |
| theta= | (Wl^2)/(2EI) deflection angle in radians | |

**Revision History**

Rev 2 Oct. 10, 2005 Added cautionary note regarding clearance with piers with OD's exceeding 8 inches.

Rev 3 Dec 10, 2005 Corrected errors in Table 2 with regard to 8.625 inch OD pier deflections.