CHARA TECHNICAL REPORT

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Preliminary Considerations and Cost Estimate for Telescope Enclosures

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1. INTRODUCTION TO THE CHARA ARRAY PROJECT

The Center for High Angular Resolution Astronomy (CHARA) of Georgia State University will build a facility for optical/infrared multi-telescope interferometry, called the CHARA Array. This array will consist of initially five (with a goal of seven) telescopes distributed over an area approximately 350 m across. The light beams from the individual telescopes will be transported through evacuated pipes to a central laboratory, which will contain optical delay lines, beam combination optics, and detection systems. The facility will consist of these components plus the associated buildings and support equipment, and will be located at the Mount Wilson Observatory in southern California. The CHARA Array is funded by Georgia State University and the National Science Foundation.

2. GENERAL OVERVIEW OF THE TELESCOPE ENCLOSURE DESIGN

The proposed CHARA telescope enclosure is a building, with an interior space of 15-16 feet. The vertical walls are 16-18 feet high. The walls and "floor" of the enclosure are raised off the ground, supported on columns, to allow air to circulate underneath.

The figures show a round building concept, but square or polygonal would be possible.

The walls must support the dome. A typical commercial dome (Ash Domes, Inc.) will weigh approximately 1600 pounds, and require 28 0.5" diameter anchor bolts on a 15'6" diameter.

A substantial snow load is possible, 4-5 feet on the ground.

Note that most of the interior space is occupied by the telescope and telescope pier. Both floors are connected to the enclosure and do not connect to the telescope pier. No railing is required at the inner edge of the floors, as the telescope pier and structure will fill this space.

It should be possible to insulate the walls and the lower level floor.

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For access we assume external stairways to both first and second level doors.

We may decide to install a variety of air conditioning and ventilation options. To allow for this, we would like to fabricate the enclosure with locations (knockouts) where louvered windows can be installed on both the first and second levels (although if the walls are easily pierced for retrofitting, knockouts are not needed).

There is a hatchway in both floors to allow removal of telescope components.

The enclosure will be operated remotely. No personnel will normally enter the enclosure except for installation, maintenance or repair of equipment.

Additional information on the telescope enclosure requirements is included in CHARA Technical Report No. 10, *Telescope Enclosure Specifications.*

3. COMMENTS ON INITIAL CRITERIA

3.1. Loads

- **Snow Load** will not be critical if the pre-manufactured dome covers the entire enclosure. Consideration should be given to freezing conditions and potential ice buildup on dome.
- **Earthquake Loads** will almost certainly be a major factor in designing connections and sizing structural elements. It is not feasible to do a comprehensive lateral load analysis at this preliminary stage. We will assume an approximate 33% increase in loads and resultant structural member size, over similar structures on Kitt Peak. Considering the lateral loads imposed by wind at Kitt Peak, this should be a conservative assumption. (Mt. Wilson is in U.B.C. seismic zone 4; Kitt Peak is 2A.)
- **Live Load** on floors is assumed to be 100 p.s.f.
- **Wind Load** is assumed to be not a major factor due to the surrounding vegetation and the predominance of seismic loads in lateral force analysis. Wind load will be a consideration in uplift anchorage of the dome, flashing and siding fastening, etc.

4. BASIC SHAPE CONSIDERATIONS

- The simplest and probably cheapest design would be the usual cylinder, sized to fit just within the dome skirt flashing. This is the most straightforward design and results in a predictable and dependable interface with the dome. It also is a very stable and symmetrical shape which is naturally resistant to wind and earthquake loads. The drawbacks are the need to have some curved structural elements, the complication of floor connection details, and some material waste inherent in round shapes.
- The other option that could be explored is a square tower topped by the round dome. It would result in a simpler building below the dome and slightly more usable space inside. The connection to the dome, however, would require a fairly complex curb and flashing assembly, as well as some kind of pitched roof sections over the corners to prevent snow and ice buildup.
- Other polygonal shapes would have most of the drawbacks of both the options described above with no perceived additional advantages.

5. BASIC MATERIAL CONSIDERATIONS FOR THE ENCLOSURE

- For the small structure required, the most obvious logical choices are steel and wood. Masonry and concrete are more costly, harder to insulate/ventilate, and require extensive reinforcement for lateral loads.
- Steel is probably the best alternative for all the major structural elements (except footings and pier) due to its durability, dimensional stability, wide variety of shapes available, and relatively simple and efficient detailing of connections. The disadvantages are a slightly higher cost than wood and the involvement of a specialized construction trade.
- Wooden structural elements could be used, but would require fairly complicated connection details, especially for curved shapes. Quality control of studs, joists, and beams could be a problem. Wood structure for walls, floors, beams, and supports could, however, be explored as a way to achieve some minimal cost reduction. In any case, it is logical to use some wood elements, primarily plywood, for example at the base of the dome and for floor sheathing.
- Poured in place concrete is the assumed material for footings. It is assumed that the telescope pier will be poured in place as well, so the enclosure footings can be done at the same time and by the same crew.
- Metal siding is the logical choice for the exterior skin, and there are a wide variety of types available. The cheapest is probably a light gauge corrugated type, but lateral load design will likely require the use of a heavier structural grade.

6. COORDINATION OF CONTRACTING AND "IN-HOUSE" WORK

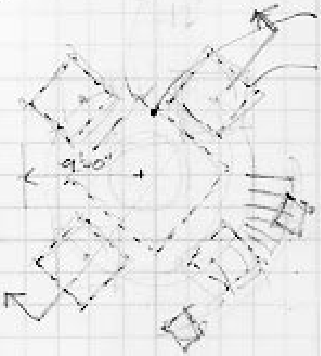
- Steel fabrication and erection will probably be most efficient and problem-free if done completely by a single sub-contractor. Steel contractors are very efficient at fabricating the largest possible pieces and designing them for field assembly by their own erectors. If we impose specific prefabrication modules or do our own erection, the overall cost and trouble will probably increase.
- It is logical to separate out for in-house work or another contractor: site preparation and excavation, concrete footings and anchor bolts, installation of siding, flooring, insulation, doors, interior work, and all specialized trades such as electrical and HVAC.
- The stairs will probably have to be custom-designed and fabricated and should probably be included with the main structural steel work. We have checked with several steel tank manufacturers, and they know of no stock/modular stairs for circular tanks (ladders are almost exclusively used instead). This could be explored further with other sources. In any case, the stairs will almost certainly have to be outside the enclosure to allow functional access space inside.
- All "general contracting" can be effectively accomplished in-house as long as the responsibility for project coordination and supervision is clearly defined.

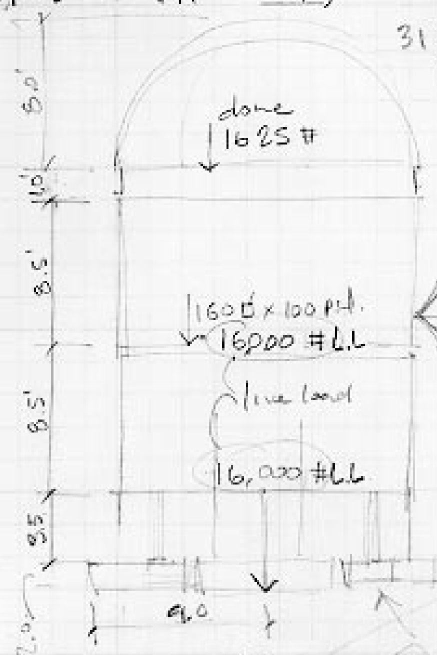
Preliminary Partial Structural Analysis

$P = C_e C_q q_s I$
$= (1.5)(.8)25.6(1)$
$= 31$ psf.

31 psf × 404 □ = 12,524#
← wind pressure

12' sq × 2' thick (assumed for pier)
4' sq × 2' thick (approx. req'd)





Building & stair footings - 140 c.f. = 5.5 C.Y.

Telescope footing 12' □ × 2' deep
cylinder - 22 □ × 8' = 176 c.f.

470 c.f. = 18 C.Y.

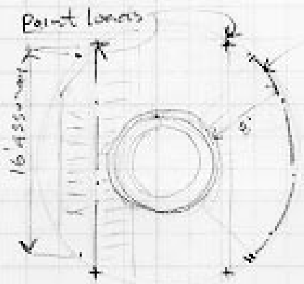
overturning moment
= 200,400 ft #

dead loads
1625# (dome)
9,000 # (enclosure)
? # (footings)
33,400

16.0

will probably determine footing size - 4' × 2' deep min

for overturning moment 33,400 lbs reqd. dead load



load on curved beams @ lower level
(approx. equivalent uniform load)

750 lbs/L.F × 2 floors = 1500 PLF Live load
+ 200 PLF Dead load
1700 PLF Total load

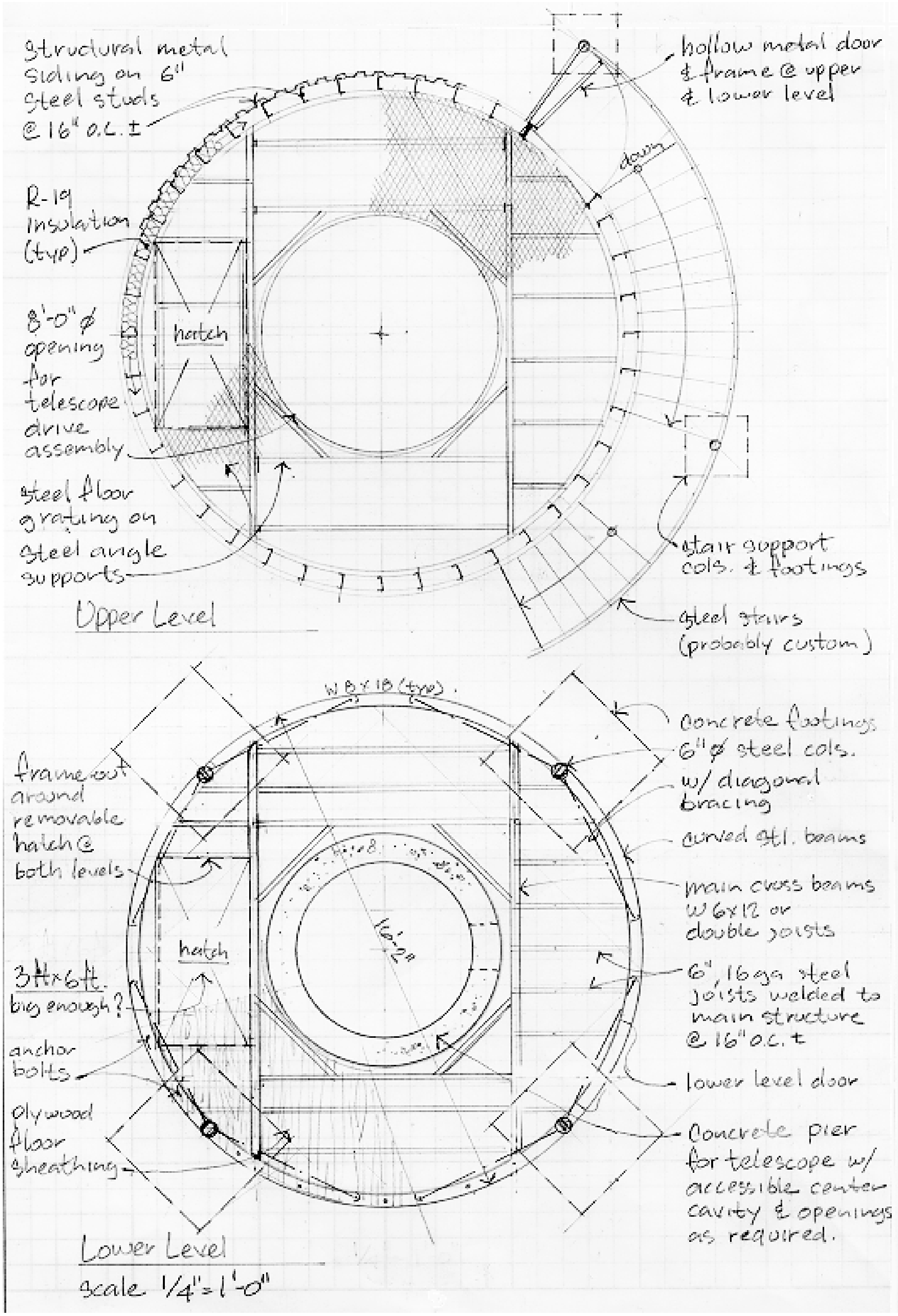
$$\text{max moment} = \frac{wl^2}{8} = \frac{(1700\ \text{PLF})(12')^2}{8} = 30.6^{k'}$$

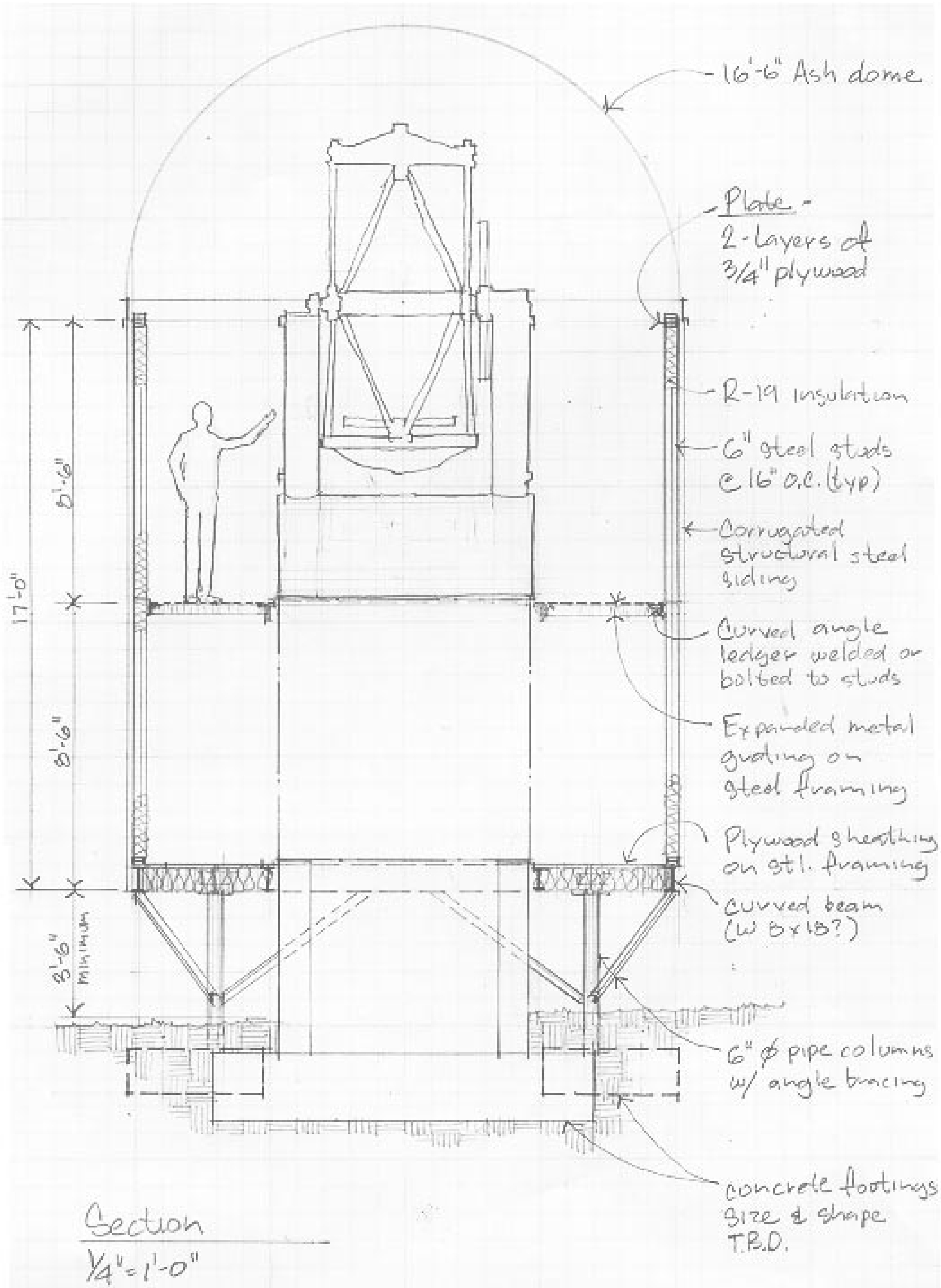
$$f_b = \frac{M}{S} = \frac{(30.6) \times (12''/')}{15.2\ \text{in}^3} = 24.2\ \text{ksi}$$

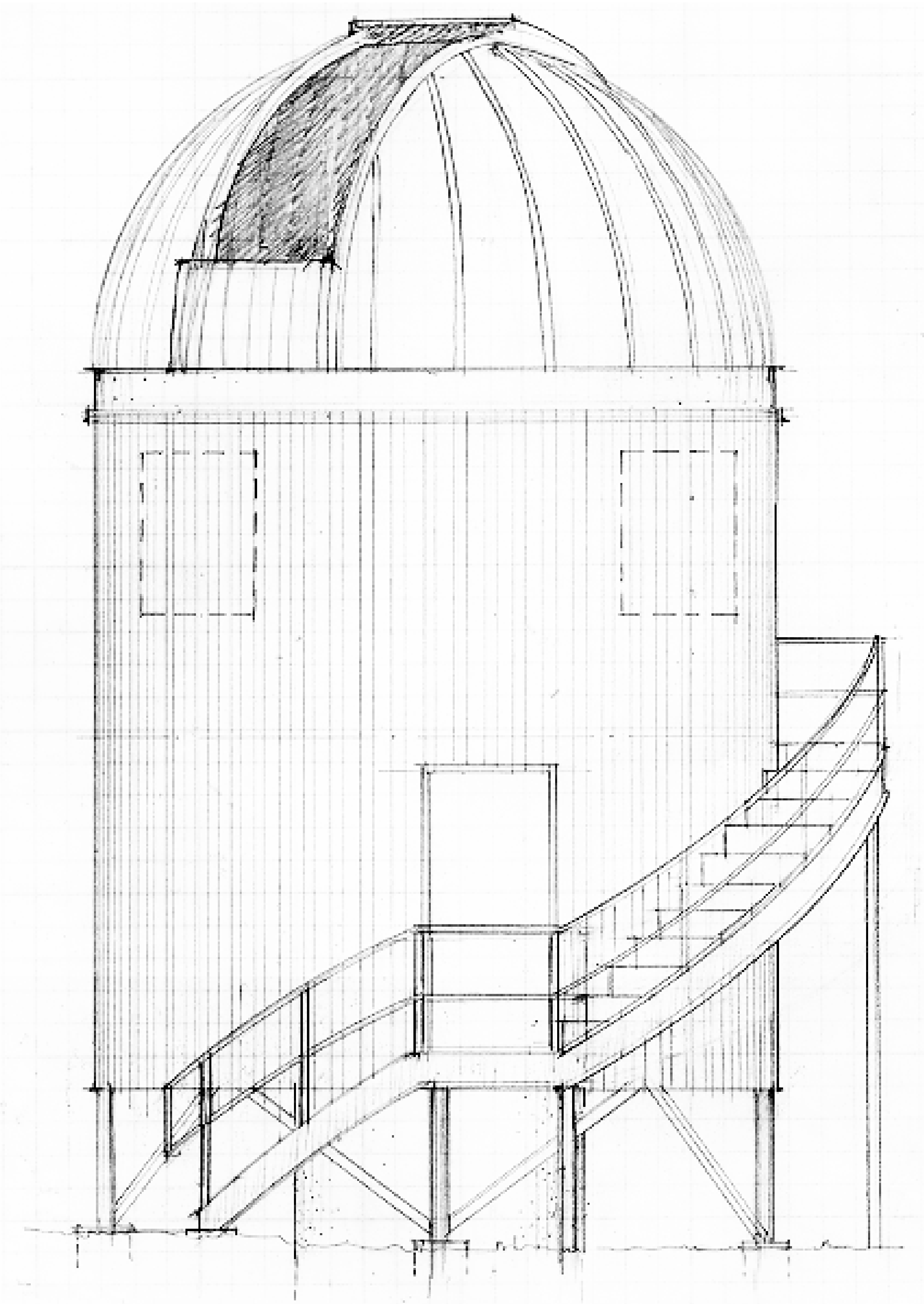
W 8×18 (36 KSI stl.) seems o.k. w/ some reserve factor for lateral loads, point loads, etc.

load on main cross beams
approx. equiv. uniform load = 400 lbs/L.F. Live load
+ 50 lbs./L.F Dead load
450 PLF → Max Moment = $14.4^{k'}$ → $f_b = 22.1$ KSI ∴ o.k.
(assuming W 8×10)

- Assumed size of beams etc. is approximately right
- Load on 6" steel studs @ 16" o.c. imposed by upper floors & dome assumed o.k.
- Shear characteristics of struc. steel deck on steel studs assumed o.k.
- 6" ⌀ stl. columns assumed ok for 4' height (w/ bracing as req'd.)


structural metal siding on 6" steel studs @ 16" o.c. ±
R-19 insulation (typ)
8'-0" ϕ opening for telescope drive assembly
hatch
steel floor grating on steel angle supports
Upper Level
hollow metal door & frame @ upper & lower level
down
stair support cols. & footings
steel stairs (probably custom)
W 8 x 18 (typ)
frame out around removable hatch @ both levels
hatch
3ft x 6ft big enough?
anchor bolts
plywood floor sheathing
16'-2"
concrete footings
6" ϕ steel cols. w/ diagonal bracing
curved stl. beams
main cross beams W 6x12 or double joists
6", 16 ga steel joists welded to main structure @ 16" o.c. ±
lower level door
Concrete pier for telescope w/ accessible center cavity & openings as required.
Lower Level
scale 1/4" = 1'-0"


16'-6" Ash dome
Plate - 2-Layers of 3/4" plywood
R-19 insulation
6" steel studs @ 16" o.c. (typ)
Corrugated structural steel siding
Curved angle ledger welded or bolted to studs
Expanded metal grating on steel framing
Plywood sheathing on stl. framing
Curved beam (W 8x18?)
6" ø pipe columns w/ angle bracing
concrete footings size & shape T.B.D.
17'-0"
8'-6"
8'-6"
3'-6" MINIMUM
Section
1/4" = 1'-0"



Elevation
1/4" = 1'-0"

7. COST ESTIMATES FOR ENCLOSURES

The following table collects the available information and estimates. Question marks indicate that no detailed estimate was attempted. However, estimates for these areas are included in the final Summary Sheet as Unrefined Guesses.

Division 1: General Conditions

Items to be provided by CHARA and Observatory Staff and Facilities Department (cost T.B.D.):		?
Project administration		
On-site supervision and inspection		
Temporary utilities		
Other necessary support?		
Permits and fees		?
Structural design (per enclosure)	($20,000 total)/5	$4,000
	Subtotal (div. 1)	$4,000+

Division 2: Site Work

Site clearing and grading	no information provided	?
Underground utilities	no information provided	?
Soil testing	no information provided	?
Site drainage/erosion protection	no information provided	?
Excavation for concrete footings	(by observatory staff)	?
Telescope pier footing (20 c.y.)		
Enclosure and stair footings (10 c.y.)		
Backfill and finish grading		
Other required site improvements (fencing, paving, roadways, etc.)	(extent and cost T.B.D)	?

Division 3: Concrete

Note: these costs are for concrete and reinforcements in place. Support labor not included and assumed to be in-house. Additional costs T.B.D.

Telescope pier footing	11 c.y. @ $200	$2,200
Telescope pier footing	6.5 c.y. @ $300	$1,950
Enclosure and stair footings and stems	6 c.y. @ $200	$1,200
Flatwork (pads on stairs, under hatchway, etc.)		?
	Subtotal (div. 5)	$5,350+

Division 4: Masonry

No work

Division 5: Steel

Note: These costs for steel fabrication and erection reflect increases historically experienced for remote work, small scale work, and governmental/university projects.

Anchor bolts/hold-down hardware (I.S.)		\$200
Primary Structural Steel for Enclosure: Lower level		
6″ dia. pipe cols and bracing	600 lb. @ \$3.00	\$1,800
W 8 × 18 curved beams	940 lb. @ \$5.00	4,700
W 8 × 10 main cross beams	280 lb. @ \$3.00	840
6″ steel studs (joists)	160 l.f. @ \$2.00	320
Upper level:		
4″×6″×1/4″ curved angle	420 lb. @ \$5.00	\$2,100
W 6 × 12 main cross beams	340 lb. @ \$3.00	1,020
4″ × 4″ × 1/4″ cross supports	700 lb. @ \$3.00	2,100
4 lb. expanded metal grating	200 s.f. @ \$6.00	1,200
Walls:		
16 gauge steel studs, 6″ × 16 ft.	700 l.f. @ \$2.50	\$1,750
22 gauge structural decking for exterior siding	900 l.f. @ \$3.50	2,700
Miscellaneous plates, clips, frame-outs, etc.		\$1,500
Steel stairs:		
3 ft. wide curtain steel stair	18 risers @ \$250.00	\$4500
2 landings	24 s.f. @ \$60.00	1440
Railing	26 l.f. @ \$40.00	1040
	Subtotal (div. 5)	\$26,980

Division 6: Wood

Lower level sheathing: 3/4″ exterior grade plywood	200 s.f. @ \$2.50	\$500
Plywood top and bottom plates fabricated from	materials	100
two layers of 3/4″ structural grade plywood	labor	300
Miscellaneous blocking, frameouts, etc.		200
	Subtotal (div. 6)	\$1,100

Division 7: Thermal and Moisture Protection

Insulation on walls: R-19 fiberglass batts, 15″ wide	900 s.f. @ \$0.60	\$540
Insulation on lower floor: R-22 fiberglass batts, 15″ wide	200 s.f. @ \$0.70	140
Protective sheet/moisture barrier on interior of walls and exterior of lower level floor	1100 s.f. @ \$0.20	220
Curved flashing on base of dome	52 l.f. @ \$1.50	80
Caulking and gaskets as required		50
	Subtotal (div. 7)	\$1,030

Division 8: Doors and Windows

Two $3' \times 7'$ hollow metal doors prehung w/ frame and hardware	2 @ $500.00	$1,000
Window type knock-outs for future ventilation openings. (Materials covered in div. 5) Extra cost for detailing	8 @ $50.00	400
	Subtotal (div. 8)	$1,400

Division 9: Finishes

Rubber mat flooring on lower level	160 s.f. @ $3.00	$480
Painting - structural steel, doors, etc.		500
	Subtotal (div. 9)	$980

Divisions 10, 11, and 12: Specialties, Equipment, etc.

Signage		?
Safety equipment		?
Racks for mounting electronics, etc.		?
Other		?

Division 13: Special Construction

$16' 6''$ diameter Ash dome installed price (per S. Ridgway)		$20,000

Division 14: Conveying Equipment

Hoists or other material handling equipment		?

Division 15: Mechanical

Plumbing: none assumed		
Heating, ventilation, and air conditioning: described as remote separately housed units for environmental control and heat exhaust for all 5 telescope enclosures.	No information for estimating provided	?

Division 16: Electrical

Wiring, raceways, devices and fixtures for lighting, outlets for tools and power to dome drive	lump sum	$5,000
Specific power and wiring for telescope drives, instrumentation and electrical equipment (clean power required)		?
Site electrical (separate panel at each enclosure?)		?
	Subtotal (div. 16)	$5,000+

8. SUMMARY SHEET

Listed below are summary costs of each complete enclosure and related construction, followed by costs of cylinders with floors, doors, et cetera, for comparison with other options.

Division	Estimated Itemized Costs	Unrefined Guesses
1 : General conditioning	\$4,000+	\$1,500
2 : Site work	TBD	2,000
3 : Concrete	5,350+	2,500
4 : (No Work)		
5 : Steel	26,980	
6 : Wood	1,100	
7 : Thermal and moisture protection	1,030	
8 : Doors and knock-outs	1,400	
9 : Finishes	980	
10 – 12 : Equipment, etc.	TBD	2,000
13 : Dome	20,000	
14 : Conveying equipment	TBD	1,000
15 : HVAC	TBD	8,000
16 : Electrical	5,000+	5,000
Subtotal	\$65,840+	22,000
10% contingency		8,500
Total (±20%)		\$96,340

Steel structure and siding	\$20,230
Additional administrative costs for more complex assembly process	1,000±
Wood (floor sheeting and plates)	1,100
Doors and knock-outs	1,400
Additional in-house labor required	2,000±
Additional design required (1/3 of total)	1,330±
Total (±20%)	\$27,060

9. COMPARISON WITH OTHER PROJECTS

Comparisons are made regarding cost of enclosure, floors, et cetera, as shown on the previous page.

- **SARA:** (1993 – 1994) — 26.5′ diameter dome and enclosure similar in construction to CHARA enclosures as described.

\$155,000	contract with Kasper-Hall steel — included some subcontract work but not dome and interior work.
	Following are best guesses (no breakdown available)
− 8,000	subtract 5% for overhead on sub-contracts
−20,000	subtract for pier and other concrete work
−15,000	subtract for stairs, bridge, and other non-enclosure steel
−40,000	subtract for electrical, plumbing, etc.
\$72,000	

For comparable cost of enclosure will scale by ratio of s.f. covered:

$$\$72,000 \times \frac{214 \text{ s.f. (CHARA)}}{550 \text{ s.f. (SARA)}} \approx \$28,000$$

- **Kitt Peak Visitors Telescope:** (1994 – 1995) — elevated structural steel frame with steel siding and 20′ diameter dome. Similar to CHARA in size and materials.

\$67,855	steel subcontract (from schedule of values doc.)
− 6,800	subtract 10% for G.C. overhead
−12,000	subtract for stairs
− 5,000	subtract for steel pipe pier
\$44,055	

For comparable cost of enclosure will scale by ratio of weight of main structural steel:

$$\$44,055 \times \frac{6,800 \text{ lb. (CHARA)}}{9,700 \text{ lb. (KP)}} \approx \$30,900$$

Since both of these comparables came out higher than the \$27,060 figure as estimated, it may be advisable to adjust that figure upward to about \$29,000.00.