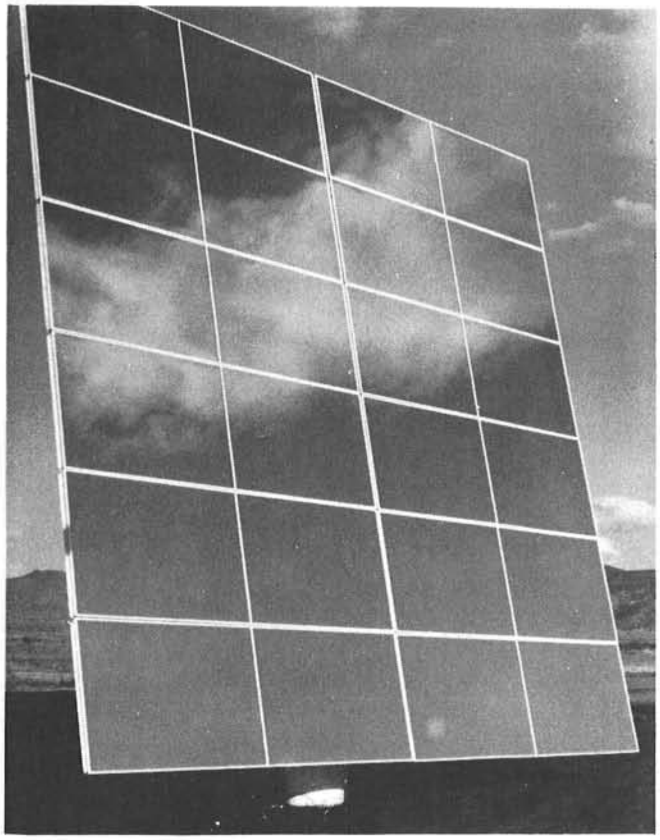
MARCH 1981

SAND 81-8178
SANDIA CONTRACT
83-2729E

SECOND GENERATION HELIOSTAT DEVELOPMENT
FOR
SOLAR CENTRAL RECEIVER SYSTEMS



FINAL REPORT

VOLUME II

SECTIONS 4.0-8.0

MANUFACTURING
TRANSPORTATION
FIELD ASSEMBLY
INSTALLATION
MAINTENANCE
COST ESTIMATES

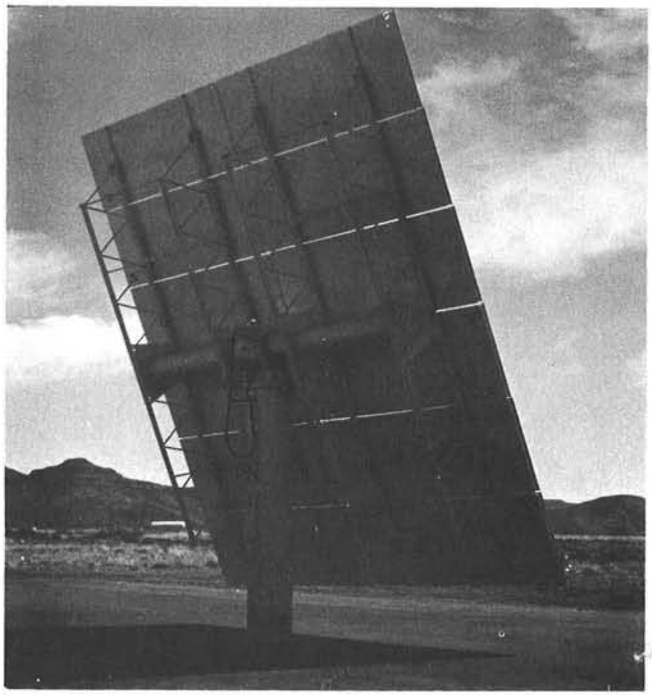
PREPARED BY

NORTHRUP, INCORPORATED

A SUBSIDIARY OF
ATLANTIC RICHFIELD CO.

AND

BECHTEL NATIONAL, INC. AND **BOOZ-ALLEN AND HAMILTON, INC.**



SECOND GENERATION HELIOSTAT DEVELOPMENT

FINAL REPORT

Volume II

Sections 4.0 - 8.0

Sandia Contract No. 83-2729E
Sandia Requestor - C. L. Mavis/8451
Contracting Representative - R. C. Christman

Work performed during the period
July 16, 1979 through March 31, 1981

by

Northrup, Incorporated
302 Nichols Drive
Hutchins, Tx. 75141

and Subcontractors:

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This report is presented in 4 Volumes. The content of these volumes is as follows:

Volume I - Sections 1.0 - 3.0
    1.0 Introduction
    2.0 Summary of Results
    3.0 Northrup Heliostat Description

This volume

Volume II - Sections 4.0 - 8.0
    4.0 Manufacturing
    5.0 Transportation
    6.0 Field Assembly and Installation
    7.0 Maintenance
    8.0 Cost Estimates

Volume III - Appendices A - E
    A. Bill of Materials
    B. Part Drawings (Subassemblies)
    C. Assembly Drawings
    D. Trade Studies
    E. System Studies

Volume IV - Appendices F - J
    F. Control Software
    G. Test Results
    H. Manufacturing
    I. Specification S-101
    J. Specification S-102

SECTION 4.0
MANUFACTURING

4.1 INTRODUCTION

The manufacturing studies completed included site selection and a detailed plan for a manufacturing plant capable of producing 50,000 heliostats per year. These studies identified a 680,000 square foot plant located in the vicinity of Albuquerque, New Mexico as the desired facility.

A description of the site selection analysis and the manufacturing facility are included in this section.

4.2 SITE SELECTION

The selection of the manufacturing facility site was limited to the region generally defined by California, Nevada, Utah, Colorado, Arizona, New Mexico, Texas and Oklahoma. It was further defined to include only cities of population greater than 50,000 bounded by Las Vegas to the west, Denver to the north, Amarillo to the east, and Albuquerque to the south. Final site selection was to be based on the best economics, and the best availability of essential resources.

4.2.1 Identification of Site Dependent Costs and Resources

The first step in analyzing sites for facility location was the identification of economic and resource parameters that will be important for site selection. Only those costs and resources that are site dependent were to be included in the analysis. The economic factors were classified into the following categories:

- Production Labor
- Material Transportation
- Building
- Utilities

- Land
- Taxes

Production labor is the most important cost item for which wage rates are sensitive to site location. Both direct and indirect labor cost information was acquired for the analysis.

Transportation cost for factory incoming material is another large cost item that is sensitive to site location. The two largest heliostat material items on a tonnage basis were estimated to be steel and glass. Steel is predominately produced in the eastern half of the country at tonnage levels required for this study. However, sufficient steel production is available in California, which provides a transportation cost advantage for supplying the cities under consideration. Glass transportation costs were based on the assumption of production in the Pittsburgh area, and steel transportation costs were based on an assumed California origin.

Utility, building and land costs are also sensitive to location. Charge rates for electricity, water and natural gas were chosen as the basis for utility costs. Building and land costs were standardized for the construction of the same basic industrial structure on equivalent land acreage at each site. State and local property taxes and state taxes on capital equipment were also included in the site selection analysis.

The most difficult activity in site selection is the gathering and interpretation of information on human and natural resources. Human resource estimates such as population, approximate size of labor force and unemployment levels are readily available. However, accurate information on the availability and distribution of work force skills is difficult to obtain.

A company must also be confident that vital natural resources such as water, electricity, and natural gas will continue to be available over the projected life time of the plant. Thus, reasonable assurance of a continuing and uninterrupted supply of critical natural resources was an important consideration in the selection of site location.

4.2.2 Preliminary Site Evaluation Criteria

Estimates of plant size, land requirements, work force and utility usage were required to develop cost information for the preliminary site evaluation. Although mass production costs from operating heliostat manufacturing facilities are not available, manufacturing profiles of operating facilities with some product and process similarities were employed as input for a preliminary site evaluation. These profile projections are summarized in the following list:

- o Total labor force of 1,500 employees.
- o Labor distribution of 65% direct, 15% indirect and 20% salaried.
- o Plant floor area of 1 million square feet.
- o Land area of 100 acres.
- o Water utilization of 20 million gallons per year.
- o Natural gas utilization of 140 billion BTU per year.
- o Electricity usage at an average of 20 megawatts.

The preliminary site analysis requires several major assumptions to standardize the estimating procedure. These assumptions are not site dependent, but were required to calculate values for site dependent costs. The assumptions include the following items:

- o Two daily operating shifts and a third shift support crew.
- o Average direct production labor rates based on values for machine and punch press operators, assemblers and welders.

TABLE 4-1

PRELIMINARY SITE EVALUATION

(Dollars are in 10^6\$)

	Denver	Colorado Springs	Pueblo	Albuquerque	Santa Fe	Amarillo	Las Vegas	Phoenix
Production Labor	$180	$131	$162	$143	$164	$154	$218	$223
Transportation	$129	$129	$129	$130	$130	$151	$116	$125
Building	$ 37.3	$ 28.3	$ 17.0	$ 24.9	$ 24.9	$ 24.0	$ 31.7	$ 34.3
Utility	$ 16.1	$ 21.8	$ 19.1	$ 25.3	$ 25.3	$ 22.4	$ 23.4	$ 26.1
Land	$ 2.3	$ 1.7	$ 2.2	$ 1.7	$ 1.0	$ 0.7	$ 2.8	$ 2.4
Taxes	$ 10.3	$ 7.7	$ 5.7	$ 6.8	$ 4.0	$ 7.3	$ 6.6	$ 9.7
Population	1,650,000	230,000	111,000	295,000	52,530	156,000	380,000	1,400,000
Labor Force	814,000	120,000	50,000	204,000	28,000	86,000	178,000	570,000
Unemployment	3%	4.5%	5.4%	6%	6.6%	4.1%	5.9%	4.8%

- Average indirect production labor rates based on values for shipping clerks, maintenance mechanics and general laborers.
- Equivalent salaried employee costs for all sites.
- Labor costs in 1980 dollars.
- Material transportation costs based on commercial rates.

4.2.3 Data Acquisition

The eight southwestern cities chosen for evaluation were Albuquerque, Amarillo, Colorado Springs, Denver, Las Vegas, Phoenix, Pueblo and Santa Fe. Telephone interviews were conducted with the public utilities, planning commissions and Chambers of Commerce for each city. Additional interviews were conducted with local builders, land developers and other key sources as required. Data obtained through these interviews were supplemented and cross checked by comparisons with data provided by publications. Trade organizations and in-house files provided additional information.

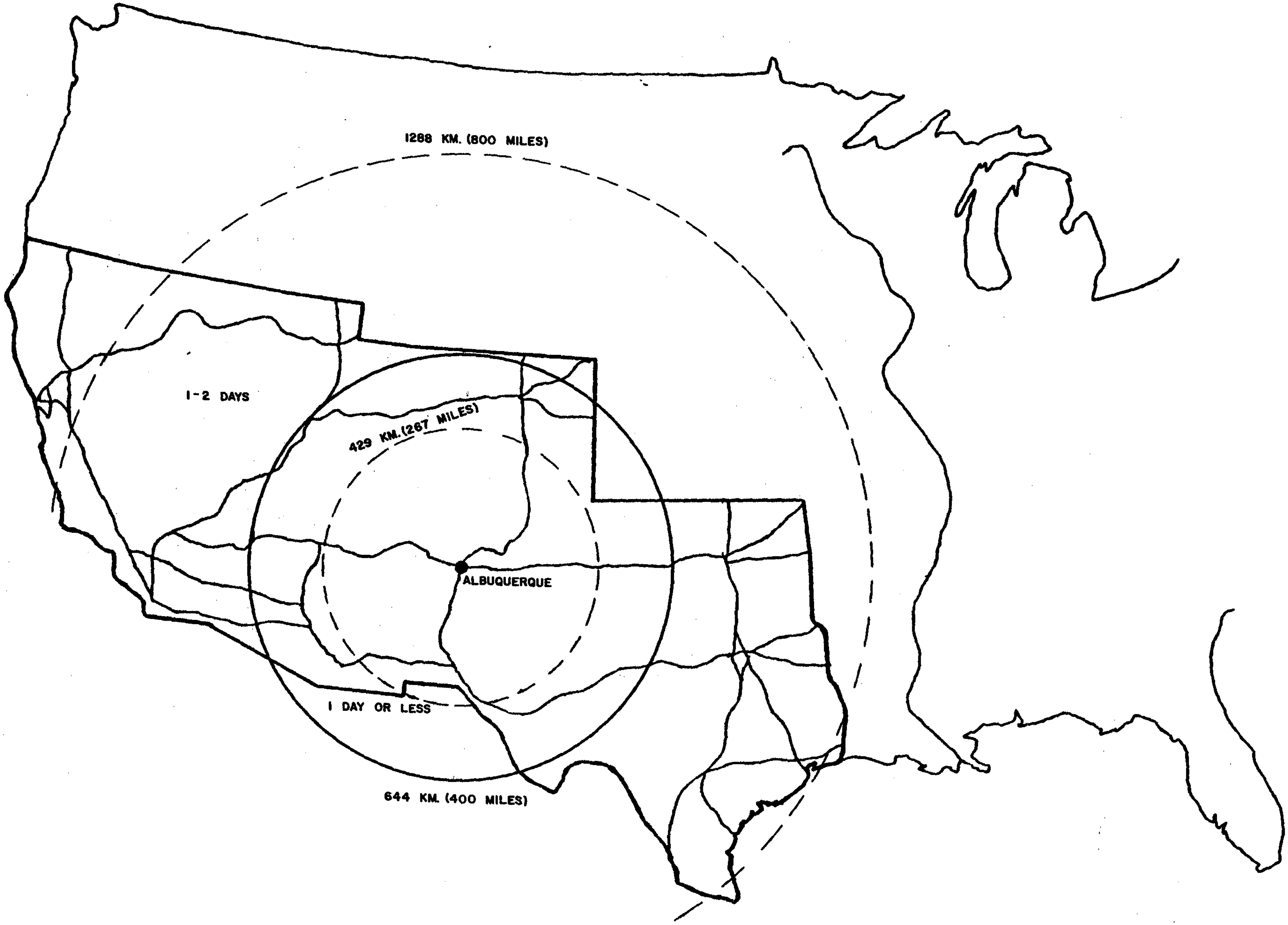
4.2.4 Site Selection Analysis

Site dependent cost information for each city was analyzed for the total planned production of 520,000 heliostat units over the time period from 1981 to 1995. All capital and annual costs were converted to 1980 dollars. The total costs were distributed over 520,000 units to establish the impact of site selection on a unit basis.

Preliminary site cost estimates and natural resource evaluations are presented in Table 4-1. The costs in this table are in 10^6\$ and represents the total cost for 520,000 units. The cost estimates indicate that labor costs are the single most important cost item for site evaluation. The highest wage rates of Phoenix are approximately 70 per cent greater than the lowest rates of Colorado Springs. Colorado Springs has the most favorable site dependent total costs, and the total costs for Phoenix are the least favorable.

The two cities of Pueblo and Santa Fe have limited human resources,

FIGURE 4-1
MANUFACTURING SITE LOCATION



and the work force profile for Amarillo is marginal. The cities of Denver, Colorado Springs, Pueblo and Phoenix have potentially severe restrictions on the availability of natural resources. Upper limits for gas usage are in effect throughout most of Colorado, and delays of many months or years are not uncommon for receiving permission to connect lines to new industries. Colorado Springs has had a 7,500 cfh gas usage limit in effect since 1973. Water shortages have occurred in Phoenix in past years, and will probably become more severe in the future.

Albuquerque has the second most favorable costs, and apparently no serious resource limitations. A tight water supply could develop. However, deep underground sources are expected to provide unlimited quantity as needed. Based on the low costs and favorable resources, Albuquerque was chosen as the manufacturing site for detailed analysis.

One of the study assumptions is that the plant would serve a market area of 400 mile radius from the manufacturing plant. Figure 4-1 shows that the Albuquerque location is central to the eight state region most likely to have central receiver installations in the near term. Most of Utah, Arizona, Colorado, New Mexico and the western parts of Texas and Oklahoma are within a 400 mile radius of that city. It also is a hub for the interstate highway system in that area. All other parts of the eight state region are within a two-day shipping radius.

An important question that should be addressed for site location relates to the importance of site related costs to overall costs of production. The site dependent costs for each city are compared on a production unit basis in Table 4-2. Albuquerque was chosen as the city for the baseline costs, and the values shown in the table are the differential costs for the other cities.

Site dependent costs per heliostat unit for the worst case, Phoenix,

TABLE 4-2

SITE DEPENDENT UNIT COST COMPARISON

	Denver	Colorado Springs	Pueblo	Albuquerque	Santa Fe	Amarillo	Las Vegas	Phoenix
Production Labor	7.15	(23.08)	36.54	---	40.38	21.15	144.23	153.84
Transportation	(1.92)	(1.92)	(1.92)	---	---	40.39	(26.92)	(9.61)
Building	23.85	6.54	(15.19)	---	---	(1.73)	13.08	18.08
Utility	(17.69)	(6.73)	(11.92)	---	---	(5.57)	(3.65)	1.54
Land	1.15	---	.96	---	(1.35)	(1.93)	2.11	1.34
Taxes	6.73	1.73	(2.12)	---	(5.39)	.96	(.39)	5.58
Total	83.27	(23.46)	6.35	---	33.64	53.27	128.46	170.77

Cost estimates are presented in dollars per unit increases or (decreases) relative to the Albuquerque estimates.

are estimated to be $171 greater than the costs for Albuquerque. This represents a small percentage of the total heliostat unit cost, and indicates that the noneconomic considerations for heliostat manufacturing sites may be more critical than the results of any economic analysis.

4.3 MANUFACTURING REQUIREMENTS

The installation plan calls for heliostat <u>components</u> to be shipped to field installation sites. The manufacturing facility, therefore, produces <u>components</u> and not completed heliostats. A complete list of these components is listed in Table 4-3. Note that there are nine items to produce and ship and ten small hardware items to purchase and include with the other shipments.

The items which require factory processing are:

Item	Minutes Per Unit Produced
Mirror Module Assembly	0.33 (20 seconds)
Drive and Motor Assembly	4
Cable Assembly	4
Control Assembly	4
Pile Assembly	4
Torque Tube Assembly	2
Truss Assembly	1
Truss Cross Brace	0.50 (30 seconds)
Truss Lower Brace	1

All these items require relatively high volume production facilities.

These assemblies and parts are distributed into five distinctive production areas. The areas are:

- Mirror
- Mirror Module
- Drive Unit
- Controls
- Structural

TABLE 4-3

Heliostat Components Shipped by Factory

		Quantity		Factory Processing Required	Production Rates		Minutes Per Unit Produced
CBS	Item	Per Heliostat	Per Year		Per Day*	Per Hour**	
4410	Mirror Module Assy	12	600,000	Yes	2400	180	0.33
	Stud	36	1,800,000	No			
	Flat washer	72	3,600,000	No			
	Jam Nut	36	1,800,000	No			
	Spherical Nut-Washer	72	3,600,000	No			
4420	Drive & Motor Assy	1	50,000	Yes	200	15	4
	Lockwashers	12	600,000	No			
	Nut, Hex	12	600,000	No			
	Cable Assy	1	50,000	Yes	200	15	4
4430	Control Assy	1	50,000	Yes	200	15	4
	Bolt	16	800,000	No			
	Lockwasher	16	800,000	No			
4440	Pile Assy	1	50,000	Yes	200	15	4
4450	Torque Tube Assy	2	100,000	Yes	400	30	2
	Truss Assy	4	200,000	Yes	800	60	1
	Truss Cross Brace	8	400,000	Yes	1600	120	0.5
	Truss Lower Brace	4	200,000	Yes	800	60	1
	Rivet	4	200,000	No			
	Rivet	32	1,600,000	No			

* Based on 250 production days/year

** Based on 13.3 productive hours/day

TABLE 4-4

Manufacturing Functions Required

Production Area	Items Produced	Major Production Function Performed
Mirror	o Mirror facets	Receive glass Trim glass Mirror glass Transfer mirrors to module area
Mirror Module	o Mirror modules	Receive pre-painted steel Fabricate steel parts Assemble (Adhesives, grease) Ship
Drive Unit	o Drive & Motor Assembly	Receive castings and bar stack Machine parts Receive purchased hardware items Assemble Paint Test Ship
Control	o Cable Assembly o Control Assembly	Receive electrical components Assemble PC Boards Assemble electrical devices Assemble cables Test Ship
Structural	o Control Housings o Pile Assembly o Torque Tube Assembly o Truss Assembly o Truss Cross Brace o Truss Lower Brace	Receive steel Fabricate steel parts Weld Paint Transfer control housing to control area Ship other items

The items produced in each area and the major production functions performed in each area are listed in Table 4-4.

4.4 PLANT LAYOUT

The plant required to produce these components covers 600,000 ft^2 of ground floor production area. In addition there are paint line penthouses on the roof of 60,000 ft^2 and an office area of 20,000 ft^2. The floor space is allocated to the production areas as follows:

Production Area	Ground Floor Area - Ft^2	Penthouse Area - Ft^2
Mirrors	50,000	-----
Mirror Modules	150,000	-----
Drive Unit	230,000	10,000
Controls	20,000	-----
Structural	150,000	50,000
Total	600,000	60,000

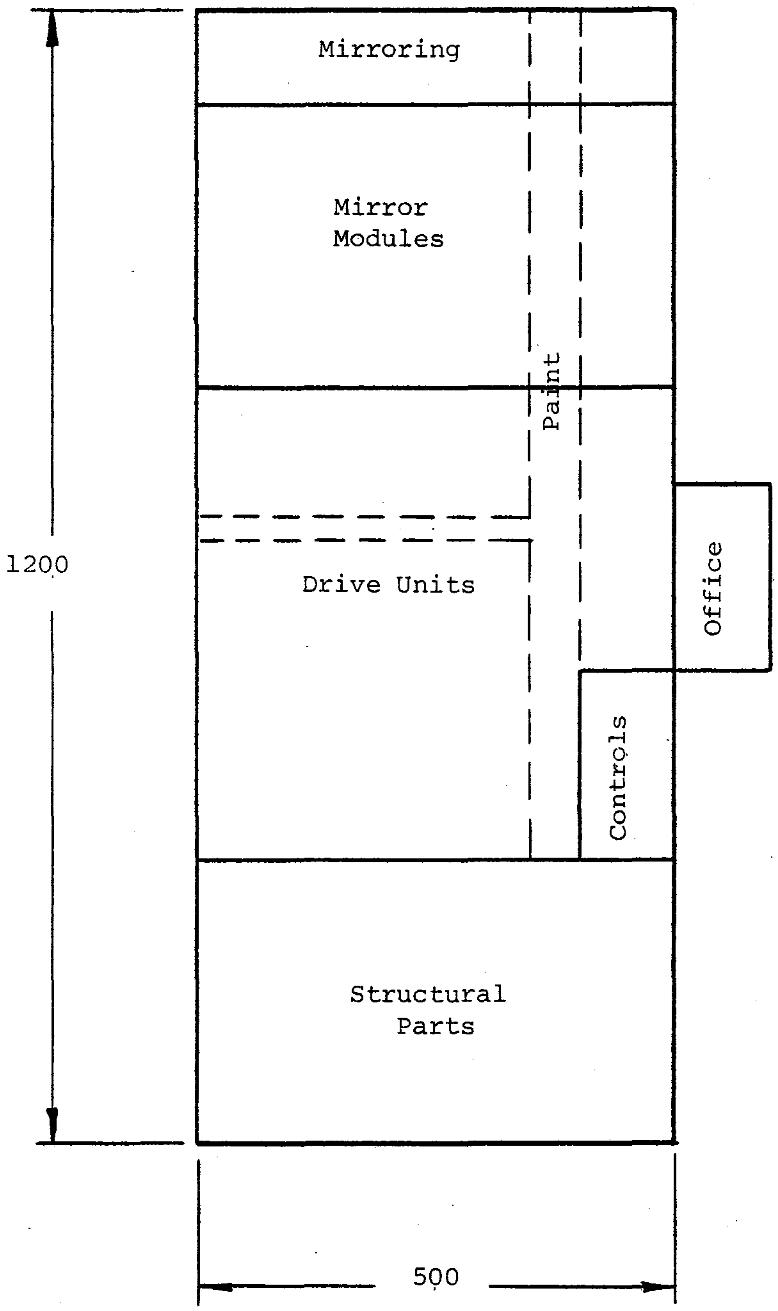
A layout of the plant is shown in Figure 4-2 and an architectural sketch is shown in Figure 4-3. The production building is a structure which is 1200 feet long and 500 wide. Each production area operates somewhat independently of the others with the only major interactions being the transfer of mirrors from the Mirror area to the Mirror Module area and the transfer of control housings from the Structural area to the Control area.

4.5 PLANT OPERATION

Since each production area is somewhat independent of the others the operating schedules do not have to be consistent. Normal operating hours to produce 50,000 units a year are as follows:

FIGURE 4-2

PLANT LAYOUT



	FT^2	
Mirroring	50,000	
Modules	150,000	
Drive Units	230,000	
Controls	20,000	
Structural	150,000	
Production		600,000
Paint-Str.	50,000	
Paint-Dr.	10,000	
Penthouse		60,000
Office		20,000

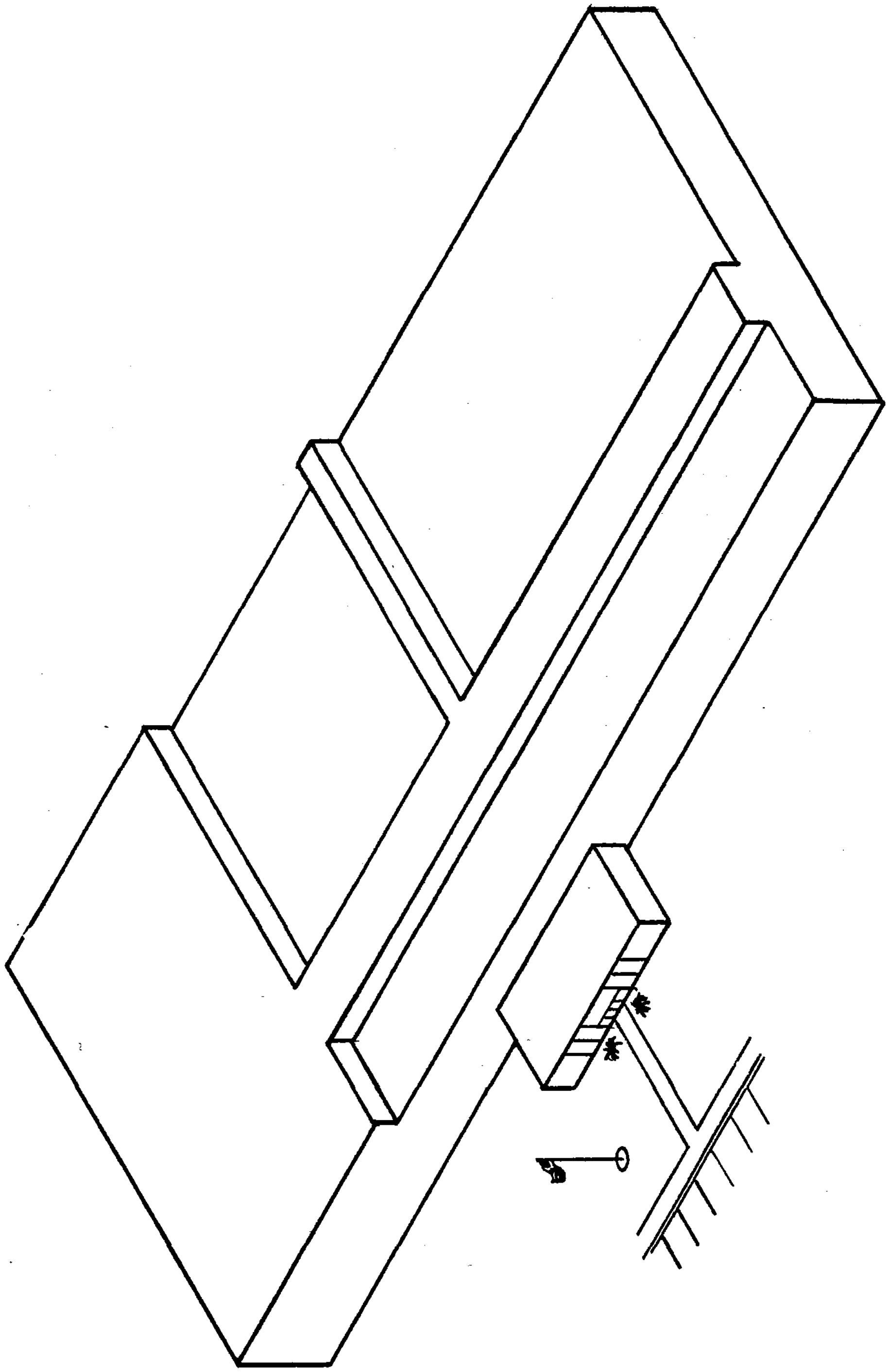


FIGURE 4-3

HELIOSTAT PLANT

50,000 Heliostats per year

Production Area	Sub Area	Shift 1	Shift 2	Shift 3
Mirror		full production	full production	---
Mirror Module		full production	full production	---
Drive Unit	Machining	full production	full production	partial production
	Assembly	full production	full production	---
Controls		full production	----	---
Structural	Fabrication	full production	----	---
	Weld & Paint	full production	full production	---

Some machining of drive unit parts spills over into a third shift operation. Due to the high capital investment for machine tools it is not economic to provide the quantity of machining equipment needed to satisfy production needs on a two-shift basis. Once the plant is in place, learning curve improvements will decrease the dependence on third-shift operations.

Control assembly is not capital intensive so the full daily requirement is planned to be met on a one-shift basis.

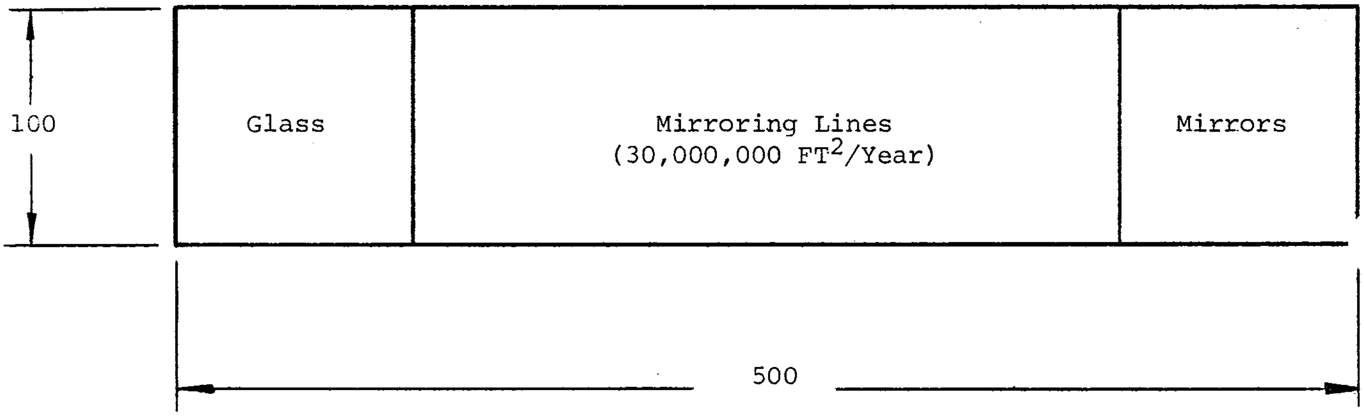
In the structural area all component parts can be fabricated on a one-shift basis with welding of parts into assemblies and painting requiring two shifts.

4.6 MIRROR PRODUCTION

The 50,000 heliostats per year production rate requires that 1,200,000 mirror facets of 4 feet by 6 feet dimension be produced a year. That totals to about 30,000,000 ft^2 of annual production. The production

FIGURE 4-4

MIRROR PRODUCTION LAYOUT



50,000 FT^2

plans call for the purchase of 0.094 inch thick low-iron float glass cut to approximate size. The glass is edged, cleaned, silvered, coated and painted to produce the finished mirror. This production is accomplished in a 50,000 ft^2 area with space allocation as follows:

Glass Receiving	10,000 ft^2
Mirroring Line	30,000 ft^2
Mirror Storage	10,000 ft^2
Total	50,000 ft^2

The floor space is laid out as shown in Figure 4-4. Each 4 x 6 glass lite weighs 30 pounds so the annual requirement for glass is 18,000 tons per year or 72 tons per day. At 20 tons per truck load about 4 truckloads of glass must be received daily. The glass is stored at the head of the mirroring lines. After processing the mirrors are stored in an area adjacent to the mirror module production area.

4.6.1 Production Process

To produce the reflective system using a float glass medium requires mechanical manipulating, washing, scrubbing, edging, coating and oven drying. The process flow is illustrated in Figure 4-5.

A two shift operation and two lines are needed to satisfy the expected yearly volume. Edging lines are required since the glass received from the glass factory has irregular edges which create potential handling problems in subsequent operations. The process lines would start with these glass edging stations to edge both the narrow and wide sides of the low iron float glass. Several diamond grinding wheels would be employed for this operation. The wheels are specified to process .094 thick glass over a range

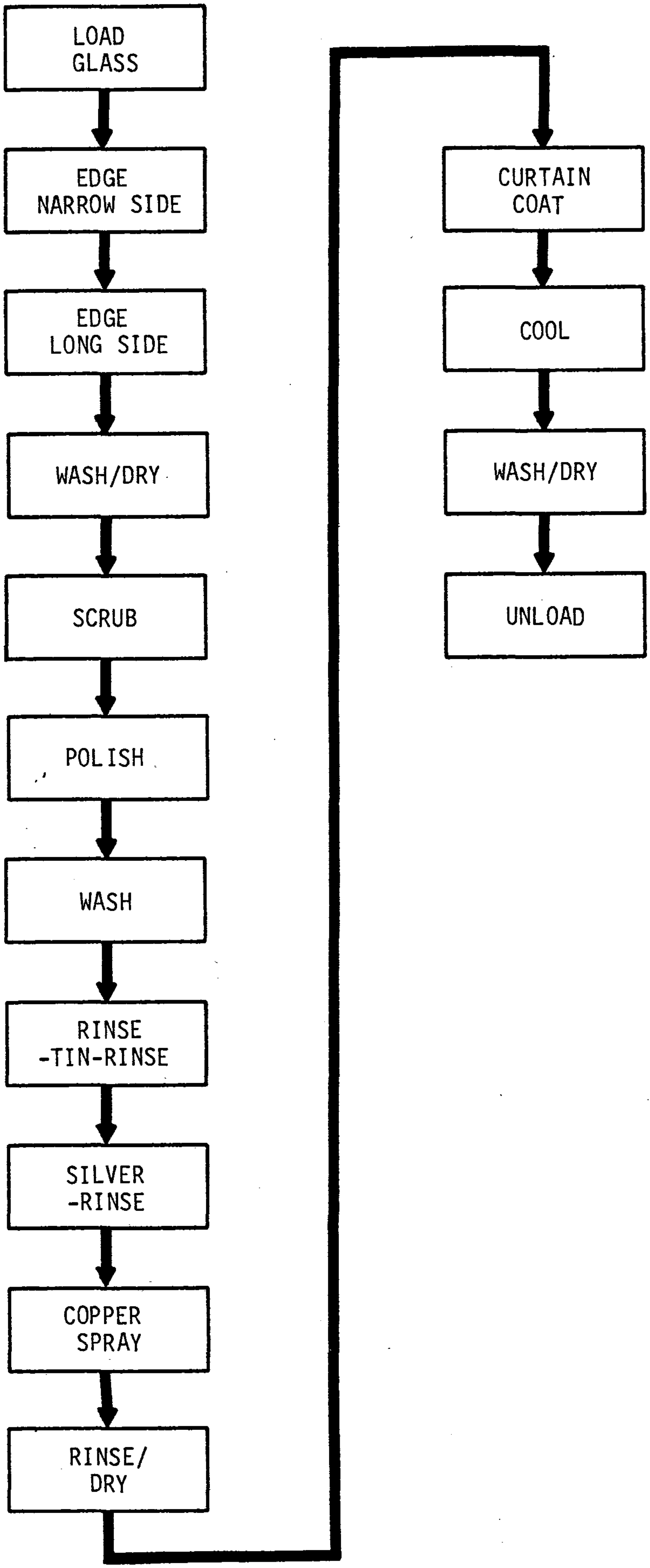


FIGURE 4-5. **Mirror Coating Process Flow**

of lineal speeds from 7 ft./min. to 15 ft./min. The line rate was determined to be 8.5 ft./min. based on the longest processing time and annual volume. Additional equipment needed in the edging line is a flat glass washer/dryer to remove particulate matter after edging and several accumulation/accelerator transfer systems. The transfer system after washing serves to accumulate two glass lites prior to entering the silvering operation. This allows the lites to travel in pairs for processing. If glass can be obtained from the glass supplier with proper control of dimensions and edge treatment these edging operations can be omitted at the mirroring facility.

The silvering line is comprised of eleven separate operations to transform the plain glass lite to a reflective glass surface. Approximately 250 feet of line length is necessary to contain the required number of processing stations at the estimated lineal velocity with some allowance for excess capacity. In addition to the silvering lines, there is a water treatment facility capable of handling 250,000 to 300,000 gallons of water per day for the various cleaning and rinsing operations. This equipment is installed in a location remote to mirror silvering and is supplied to the processing line by a piping network.

Producing the mirror facets requires the following processes:

- The float glass is positioned in front of the unloader in a vertical glass rack. A hydraulically operated arm cluster using suction cups contacts the glass surface where a vacuum is applied. The float glass is then moved from the vertical to a horizontal position and placed on the conveyor. It is then accelerated, with the glass oriented in the narrow dimension as the direction of motion, to the edge seaming operation.
- The glass enters the seaming area to be processed along the narrow direction. Seaming is performed with diamond wheels

mounted on heavy duty spindles and arms in both the wide section and narrow section. Then it is transferred 90° and seamed along the long dimension.

- The seamed float glass is conveyed through a washing and drying machine. This removes the particulate matter from storage and the previous operation, and reduces the chance of material entrapment in the silvering operation.
- Two glass lites are accumulated and then transferred to a 90° transfer conveyor. They shall travel in pairs, narrow side as the direction of motion toward the first mirror silvering operation station.
- The first operation is scrubbing the pair of glass lites. Scrubbing will be achieved by six rows of nylon brushes, each 6 inches in diameter, using an oscillatory motion. During the scrubbing operation the glass will be supported by a table and transferred by grip belts to the polishing section.
- Polishing will be done by feeding rouge compound into a continuous circulating system automatically from a central supply tank, agitator and pump. Slurry will be applied by a distribution manifold and drip pipes.
- The wash section includes a brushing action which contains and then removes the slurry. After the brushing operation there will be a city water spray header where the spent rinse water will flow into the scrub section tank.
- The rinse-tin-rinse operation will involve an initial rinse with de-ionized water by a traversing spray unit at an elevated water temperature of 135°F. Then tin will be sprayed by a

twin hydrostatic spray system using special nozzles. The tin will be pumped by a high pressure rotary pump. Tin concentrate will be injected at a controlled rate from a special panel. Following the tin spray, there will be a second de-ionized traversing water spray header to conduct the rinse.

- In the silver spray and rinse section, the silver spraying will be administered by nine pair of hydrostatic spray nozzles mounted on a carrier manifold and separate traversing units. A series of rinse headers will be attached to the same manifold. All silver and reducer solutions shall be accurately proportioned and injected into the high pressure de-ionized water stream.

- The protective copper coating solution will be sprayed by five hydrostatic spray guns fed by two pumps, supplied by two 100 gallon tanks. Rinsing will be by means of two spray headers mounted on the available manifolds, carried by a separate traverse. The copper spray area shall have an exhaust area to meet environmental requirements.

- Initial drying employs a high pressure blower feeding four air knife manifolds. Following the air knives will be 40 kw infra-red quartz heaters located beneath the glass. Above the glass will be an aluminum enclosure to reflect and retain the heat. The heat will be controlled by percentage type input controllers. The glass shall be carried through the drying tunnel by power driven rubber covered rollers.

- Glass lites shall be transported through a special curtain coater paint section incorporating a weir type of overflow controlled through an adjustable gate. A viscosimeter is provided for maintenance of proper paint flow and film thickness. The system shall contain a two speed conveyor with a photo cell control to suit various length batches and a speed range of 10 to 200 fpm.

- The curtain coated lites shall be carried through the curing section by means of mesh belt conveyor. Within the infra-red oven will be several quartz heaters controlled by two thermo couple units. Temperature of the glass will be sensed and indicated by optical pyrometers. All entrapped solvents will be exhausted from the oven by a fan and duct arrangement.

- The cooling conveyor shall be an extension of the curing oven, requiring glass to be carried on neoprene rubber covered rollers. Cooling is done by free air convection with sufficient conveyor length to allow the glass to cool.

- The face cleaning section is a face up operation and consists of a wet cooling conveyor to rapidly lower the glass temperature to ambient conditions. After this the mirror will enter a special cleaning chamber, where six rolls will work against the glass to remove any residue from previous operations. Chemicals will be fed from a central supply tank and pumped into throughs beneath the rolls which will be constantly submerged in solution. After leaving the chemicals section, the glass will enter a rinse chamber where both top and bottom shall be washed free of chemical and rinsed clean. Drying will be accomplished by a twin air wipe where the glass will be delivered clean and dry. Glass shall be carried through this section by means of rubber covered driven rollers and transferred to the unloading section.

- The unloading section will use live rubber covered rollers for transferring the glass to the hydraulically operated arm cluster. Finished glass lites shall be transferred from the horizontal conveyor to a vertical storage rack by means of vacuum cups located on the arm. The full racks are then ready to moved to mirror storage.

4.7 MIRROR MODULE PRODUCTION

The mirror module production area must produce 600,000 mirror modules a year. The manufacturing processes include receiving steel, fabricating steel parts, the assembly of the steel substrate (adhesive), the module assembly of the mirror to the mirror backing sheet (grease) and mirror backing sheet to the substrate (adhesive), the mounting of mirror edge molding and finally the shipping of the modules.

This production is accomplished in a 150,000 ft^2 facility which operates on a two-shift basis. The layout of this facility is shown in Figure 4-6. The general flow is from left to right. Pre-finished steel material is received and moves through the steel fabricating area. From there the parts flow across three major assembly lines:

- o Substrate assembly
- o Module assembly
- o Final assembly

and then into a finished goods area for loading for shipment.

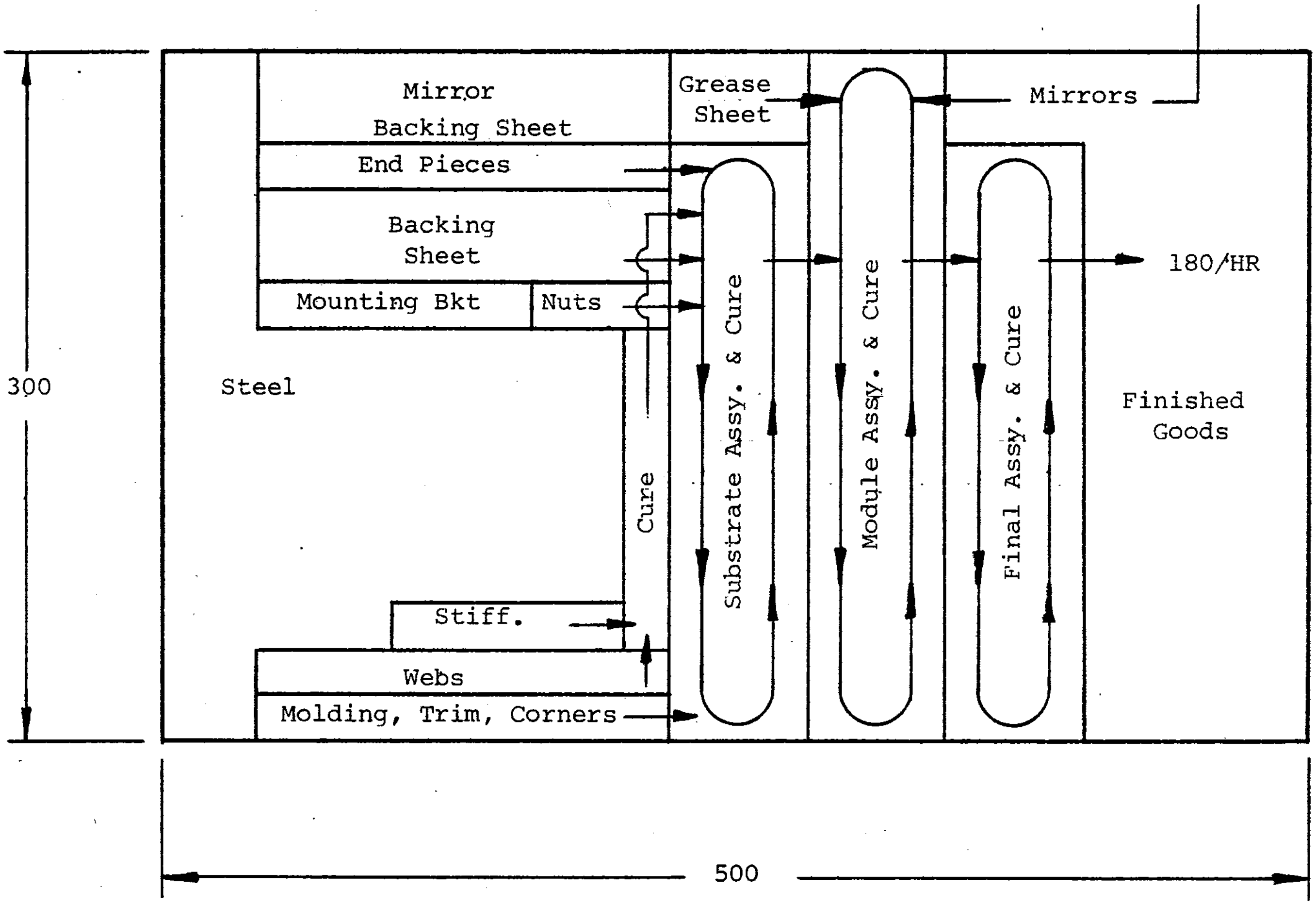
4.7.1 Fabricated Steel Parts

The module structure is fabricated from galvannealed steel which is also prepainted white on one side. The only exception is the mirror backing sheet which does not have the pre-painted finish.

The parts fabricated include:

FIGURE 4-6

MIRROR MODULE PRODUCTION LAYOUT



150,000 FT^2

Part	Paint Finish	Coil Width	Thickness	Pounds Per Module	Tons Per Day	Tons Per Year
Mirror Backing Sheet	none	48	.022	43.5	52	13,050
End Pieces	one side	4	.022	2.4	3	720
Backing Sheet	one side	48	.022	43.5	52	13,050
Mounting Bracket	one side	7	.078	15.0	18	4,500
Stiffeners	one side	2	.078	1.4	2	420
Webs	one side	4	.022	25.2	30	7,560
Edge Molding	one side	0.75	.022	1.8	2	540
Center Trim	one side	0.75	.022	.24	0.3	72
Corners	one side	0.75	.022	.04	0.1	12
					159.4	39,924
				+ 1% scrap allowance	1.6	399
					161.0	40,323

An average of 161 tons of steel must be received per day. At 20 tons per truckload that amounts to 8 truckloads of steel per day. The coiled stock will arrive from the coating supplier in the appropriate widths ready for feeding directly into the fabricating equipment.

The <u>mirror backing sheet</u> is fabricated by dereeling 48" wide coil stock, passing it over some leveling rolls and shearing to the desired length.

<u>End pieces</u> are processed from coil stock through automatic progressive dies.

<u>Backing sheets</u> are sheared in the same manner as the mirror backing sheet.

<u>Mounting brackets</u> are processed from coil stock through automatic progressive dies.

<u>Stiffeners</u> are processed from coil stock through an automatic press.

Webs are notched, roll formed, and cut to size.

Edge molding is roll formed and cut to size.

Center trim is notched and sheared on an automatic press.

Corners are processed through a set of progressive dies.

4.7.2 Module Assembly

The first part of the assembly operation is to add two stiffeners to each web. Adhesive is used for this bond and a staple or rivet may be used to maintain proper orientation until the adhesive cures. A conveyor run-out table is used for curing and transporting the stiffened webs to the substrate assembly line. The substrate assembly line is a flattened merry-go-round line with about 80 progressive assembly stations. End pieces and stiffened webs are mounted in a fixture in a vacated station, adhesive is applied to the upper facing flanges and a backing sheet is dropped into place. Mounting brackets are adhered to the backing sheet in the same manner. The assembly is then clamped and proceeds around the merry-go-round, curing the adhesive as it progresses. As it nears the end of the cycle it is transferred to the module assembly line. If the module assembly line is unable to accept the completed substrate it continues for another orbit.

The module assembly line is also of the merry-go-round type with about the same number of progressive assembly stations. Mirror facets are positioned face down on flat surfaces with the proper angle of cant between the two facets. The mirror backing sheet is passed through a series of greasing rollers which greases the under side of the sheet which is then placed on top of the two mirror facets and the sandwich is rolled to remove any excess air. Adhesive is automatically applied to the mirror backing sheet in the appropriate places and the sub-assembly is completed with the addition of a substrate which is transferred from the substrate subassembly line. The subassembly proceeds through a curing orbit. When curing is complete the module is transferred to the final assembly merry-go-round. Edge molding is added and after appropriate cure the finished mirror module is off-loaded and is ready to be shipped.

The three independent assembly lines provide flexibility in line storage, adjusting assembly stations, and compensating for temporarily unbalanced line conditions. Buffer stock can be carried in both the substrate line and module line to help assure steady input to the final assembly line.

4.7.3 Shipping of Mirror Modules

The mirror modules come off the final assembly line at a rate of 180 per hour. They are shipped 120 per truck so this means a trailer load is manufactured every 40 minutes. The finished goods area is sized so that a buffer stock of finished goods can be stored to assure a steady stream of shipments which average 15 truckloads per day.

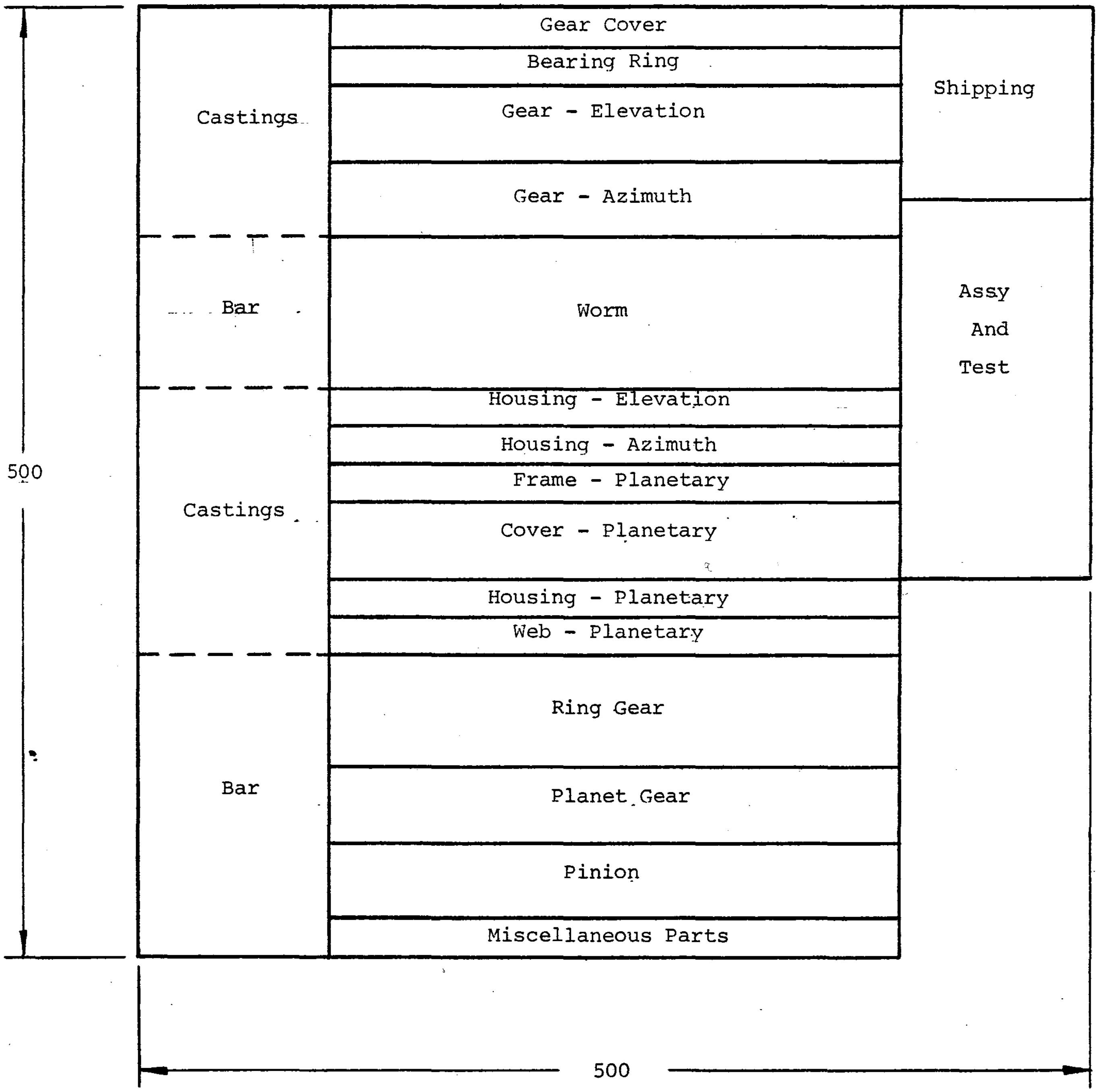
4.8 DRIVE UNIT PRODUCTION

The drive units are produced in 230,000 ft^2 of space plus a 10,000 ft^2 penthouse for painting. The general layout of the facility is shown in Figure 4-7. Flow is generally from left to right. 50,000 ft^2 is allocated to receiving steel bar stock and castings, 150,000 ft^2 is dedicated to machine tools which machine the 14 major parts of the drive along with a group of miscellaneous small parts. 30,000 ft^2 is used for assembly, test, and shipping.

The tonnage of bar stock and castings which must be handled in the receiving area is as follows:

FIGURE 4-7

DRIVE UNIT PRODUCTION LAYOUT



230,000 FT^2

	Wt. In Lbs.	Per Drive Unit	Tons			
			Per Day		Per Year	
Part			Bar	Castings	Bar	Castings
Cover, Gear	48	1		4.8		1200
Bearing Ring	45	1		4.5		1125
Gear - Elev.	217	1		21.7		5425
Gear - Azi.	176	1		17.8		4440
Worm	83	2	16.6		4150	
Housing-Elev.	229	1		22.9		5725
Housing-Azi.	297	1		29.7		7425
Frame	9.8	2		2.0		490
Cover	17.0	2		3.4		850
Housing	13.0	2		2.6		650
Web	7.0	2		1.4		350
Ring Gear	8.9	4	3.6		890	
Planet Gear	2.5	4	1.0		250	
Pinion	1.5	2	0.3		75	
			21.5	110.8	5365	27680
	+ 4% scrap allowance		.9	4.4	215	1107
			22.4	115.2	5580	28787

Approximately 1 truckload of bar stock and 6 truckloads of castings must be received to handle each day of production. The appropriate material is received and stored at the head of each machining line so material transport is kept to a minimum.

A summary of the machine tools required is tabulated in Table 4-5. Integrated transfer lines are used for large elevation and azimuth housings, but all other parts are produced on general purpose chuckers, drills, bar machines, hobbers, grinders, mills, hones and broaches. After machining the parts are cleaned and moved directly into the assembly area. The machining of the heavy parts are located adjacent to the assembly line to further minimize logistic problems.

Azimuth and elevation drives are assembled on separate but similar lines. The two drives are painted as separate assemblies in a roof top penthouse which provides low cost floor space for this activity. After paint the azimuth and elevation drives are mated and oil, drive motors, limit switches and wiring are added to complete the assembly.

TABLE 4.5

DRIVE UNIT MACHINING EQUIPMENT

			Production Rates		Equipment Type										($000)			
Part	Stock	Wt. in #'s	Per Heliostat	Per Hour	Chucker	Drill	Bar Machine	Hobber	Grinder	Thr. Grinder	Mill	Hone	Broach	Ht. Treat	Equip.	Install	Transp	Total
Cover, Gear	Casting	48	1	10	2				1					1	860	33	8	901
Bearing Ring	Casting	45	1	10	5				1					1	1260	63	14	1337
Gear-Elevation	Casting	217	1	10	5	1		18	1					1	5970	248	52	6270
Gear-Azimuth	Casting	176	1	10	5	1		18	1					1	5970	248	52	6270
Worm	Bar	83	2	20	3		5		12	30				1	9232	505	102	9839
Housing-Elev.	Casting	229	1	10		INTEGRATED TRANSFER LINE									5000	200	50	5250
Housing-Azi.	Casting	297	1	10		INTEGRATED TRANSFER LINE									5000	200	50	5250
Frame	Casting	9.8	2	20	5	1					3				1270	45	18	1333
Cover	Casting	17.0	2	20	12	3									2370	135	30	2535
Housing	Casting	13.0	2	20	5	1									970	30	12	1012
Web	Casting	7.0	2	20	6	2							1		1370	45	18	1433
Ring Gear	Bar	8.9	4	40	5	2	5	16							5970	270	56	6296
Planet Gear	Bar	2.5	4	40			5	7	1		3	1			1915	82	33	2030
Pinion	Bar	1.5	2	20	2		5	4	2				1		2135	70	28	2233
Miscellaneous																		
Worm Support	Bar	1.3	2	20	2	1					1				530	20	8	558
Pin, Journal	Bar	0.3	4	40			1		1						240	10	4	254
Clamping Disc	Bar	1.3	2	20	3										540	15	6	561
Totals					60	12	21	63	20	30	7	1	2	5	50602	2219	541	53362

4.8.1 Shipping of Drive Units

Drive unit assemblies are shipped 36 to a truckload. Based on an output of 15 units per hour a truck is loaded about every 2-1/2 hours. Each day, 5 to 6 truckloads of drive units are dispatched from the factory.

4.9 CONTROLS

Controls are assembled in a 20,000 ft^2 area. (See Figure 4-8) This activity includes receiving electrical components, assembly PC boards and other electrical hardware, cable assembly, testing and shipping. The structure used to contain the controls are obtained from the structural part of the heliostat factory. Since the facilities required for this activity represent a relatively low investment, the plan is to accomplish the full day's requirements on one shift. The output required is 30 sets of controls per hour.

Controls designed for volume production differ significantly from the prototype hardware so no attempt has been made to provide detailed planning of this activity. The processes would follow the general plans as outlined in this section.

4.9.1 Production Processes

The electronics production flow diagram is shown in Figure 4-9. The production process includes fabrication of the heliostat controls required power supply and all cables.

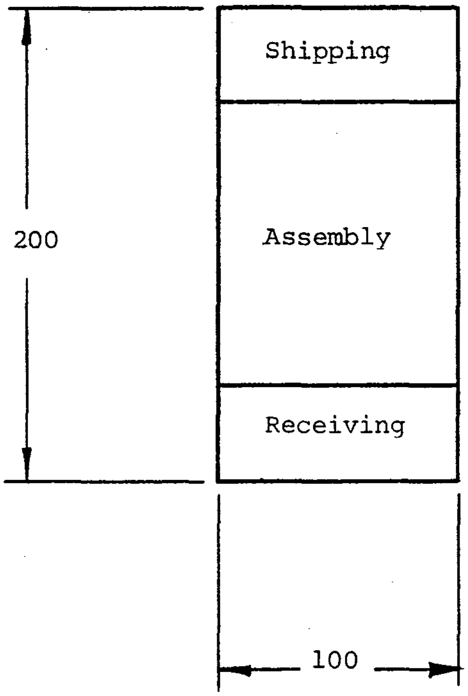
Automatic insertion of IC's up to 16 pins is employed. Hand assembly is utilized for the remaining components. The number of machine insertable axial leaded components is too small to justify purchasing a sequencer and insertion machine for automatic insertion of these components.

The electronics production flow follows:

- o Receive, inspect and inventory electronic components (IC's, resistors, capacitors, transistors, diodes, etc.), connectors, wire, printed wiring boards, and mechanical hardware

FIGURE 4-8

CONTROLS PRODUCTION LAYOUT



20,000 FT^2

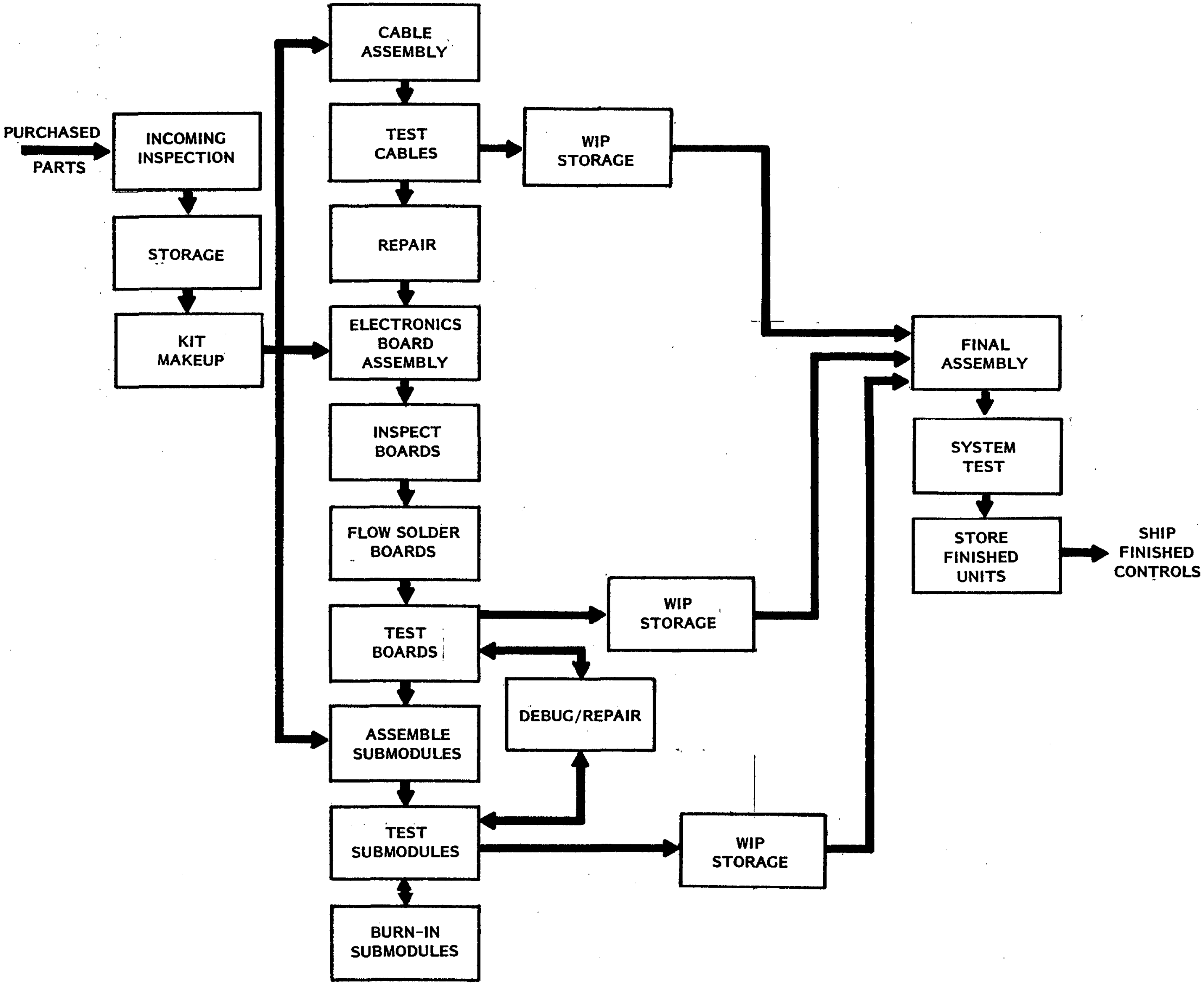


FIGURE 4-9. Electronic Controls Process Flow

(enclosure, heat sinks, screws, nuts, etc.).

- Place components into storage.

- Issue components to board assembly area, submodule assembly area and cable assembly areas.

- Board assembly.
  - Receive components from storage area.
  - Manually insert axial and radial lead components to microprocessor, motor translator and power supply boards.
  - Manually insert sockets for microprocessor and memory.
  - Place IC component tubes into automatic insertion machine.
  - Automatically insert IC's (up to 16 pin).
  - Visually inspect boards for proper components and orientation.
  - Automatically flow solder, clean and dry PWB's.
  - Visually inspect boards for bridging and voids.
  - Rework defective units.
  - Store boards until needed in the submodule assembly area.

- Submodule assembly.
  - Receive components from storage.
  - Manually assemble components onto motor controller chassis/heatsink and power supply chassis/heatsink.
  - Assemble motor translator PWB and power supply PWB to their respective chassis/heatsink.
  - Functionally test the motor translator and power supply submodules.
  - Debug/repair failed units.
  - Load the microprocessor board and the motor translator and power supply submodules into racks and burn-in with power-on for 24 hours at 60°C.
  - Functionally test the submodules.
  - Debug/repair failed units.

- Store finished submodules until needed in the final assembly area.

- Cable assembly.
  - Receive components for cables from storage area.
  - Route wire and form harnesses.
  - Automatically terminate PWB connectors onto harnesses.
  - Perform continuity test on cable harnesses.
  - Rework failed units.
  - Store tested cables until required in final assembly area.

- Final assembly.
  - Assemble microprocessor, motor controller and power supply submodules into control box.
  - Assemble power, signal and motordrive connectors to control box wall.
  - Perform system test to control box.
  - Store tested heliostat controllers until required to be shipped.

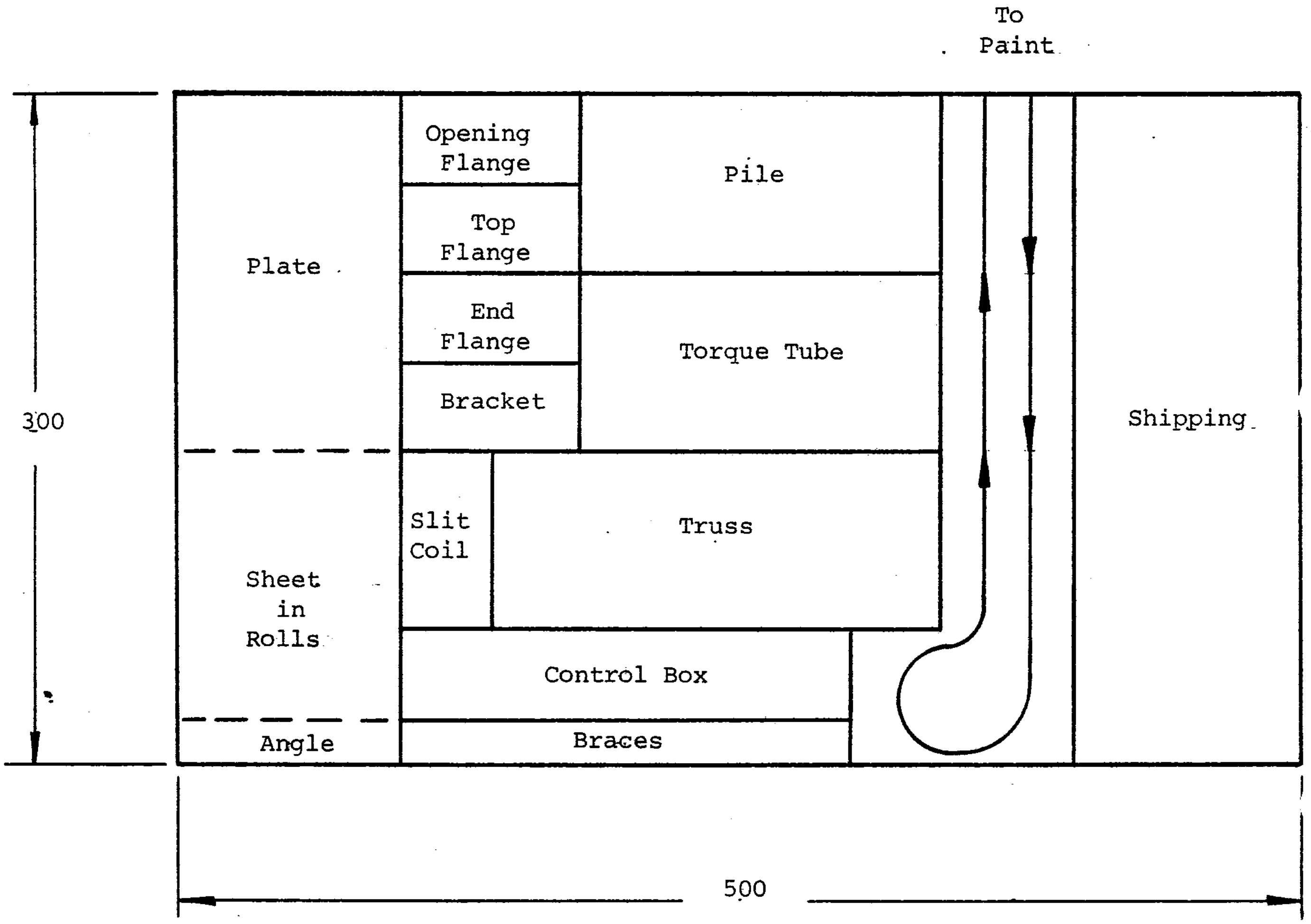
4.10 STRUCTURAL PARTS PRODUCTION

All structural parts of the heliostat are processed through one area. The manufacturing processes included in this operation include receiving of steel and the fabrication of component parts which includes tube forming, roll forming, blanking, forming and welding. After fabrication all parts are painted on a conveyorized paint system. They are off-loaded from the conveyor into a shipping area for truck loading.

The production of these parts is accomplished in a 150,000 ft^2 facility which operates on a two-shift basis in welding and paint and a one-shift basis in most part fabrication areas. The layout of this operation is shown in Figure 4-10. Material flows in from the left where all steel is received. It is processed through

FIGURE 4-10

STRUCTURAL PARTS PRODUCTION LAYOUT



150,000 FT^2

fabrication and welding and then on to a paint system which includes a 900 ft. long by 56 ft. wide tunnel which is added to the building as a penthouse. After paint the parts are removed and accumulated in the shipping area.

The major components processed through this area are shown in Table 4-6.

Note that the heavy gauge steel parts are received as plate which is blanked to size. This reduces the cost of offal removal. Material for the trusses and control box is received in rolls and slit to the needed width. Brace material arrives as cut-to-length angle.

The 235 tons of steel consumption per day represents about twelve truckloads of raw material which must be processed through the receiving area.

4.10.1 Pile Fabrication

The pile is made up of three parts--a cylindrical pipe, a top flange, and an opening flange. These three parts are welded into an assembly.

4.10.1.1 Top Flange and Opening Flange

The flanges which are located at the top of the pile and on the opening for the control box are formed from the same round steel blank. The blank is sized for the top flange and the slug removed in the center is of adequate size to become a blank for the control box opening flange. Blanks are fed through a series of dies which blank, form, and pierce the required flanges. With a required output of 200 sets of parts per day, one set of tools and equipment is adequate to do the job on a one-shift basis.

TABLE 4-6

Steel for Structural Parts

Part	Quantity Per Heliostat	Weight In Lbs.	Material Thickness	Form	Tons Per Day	Tons Per Year
Pile pipe	1	850	.125	Plate	85.0	21,250
Pile top flange	1	91	.500	Round Blank	9.1	2,275
Pile opening flange	1					
Torque Tube	2	310	.250	Plate	62.0	15,500
Torque Tube Bracket	4	17	.090	Trapezoidal Blank	6.8	1,700
Torque tube flange	2	42	.750	Round Blank	8.4	2,100
Truss top chord	4	45	.078	Roll	18.0	4,500
Truss bottom chord	4	37	.078	Roll	14.8	3,700
Truss web	4	32	.078	Roll	12.8	3,200
Cross brace	8	11	.250	Angle	8.8	2,200
Lower brace	4	11	.250	Angle	4.4	1,100
Control box	1	30	.078	Roll	3.0	750
					233.1	58,275
			+ 1% scrap allowance		2.3	583
					235.4	58,858

4.10.1.2 Pile Fabrication

After punching the control box opening in the steel plate blank the part moves to the tube forming lines. Two processing lines will be required which consist of the following equipment:

- o Two - stacker-feeders
- o Two - bending rolls
- o Two - longitudinal seam welders.

These lines are shown in Figure 4-11.

The plate stock is placed in an automatic feeder-stacker machine which feeds the plate into the bending rolls to form the support tube. The tube is then removed from the bending rolls onto a transfer conveyor by an overhead gantry hoist. The tubes are loaded with a powered roller conveyor into the seam welding operation.

4.10.1.3 Pile Assembly

The pile and the two flanges are then mounted in a fixture and automatic welders are used to complete the assembly. The pile assembly is now ready for painting.

4.10.2 Torque Tube Assembly

The torque tube assembly consists of four parts--a cylindrical pipe, a flange, and two trapezoidal-shaped brackets. These parts are welded as an assembly. The process flow chart is shown on Figure 4-12.

4.10.2.1 Flange and Brackets

The flange is fabricated from a purchased round steel blank in much the same manner as the pedestal flange. The trapezoidal support brackets are pierced and notched from purchased trapezoidal blanks. The daily requirement of 400 flanges and 800 brackets can be accomplished in one 8-hour shift.

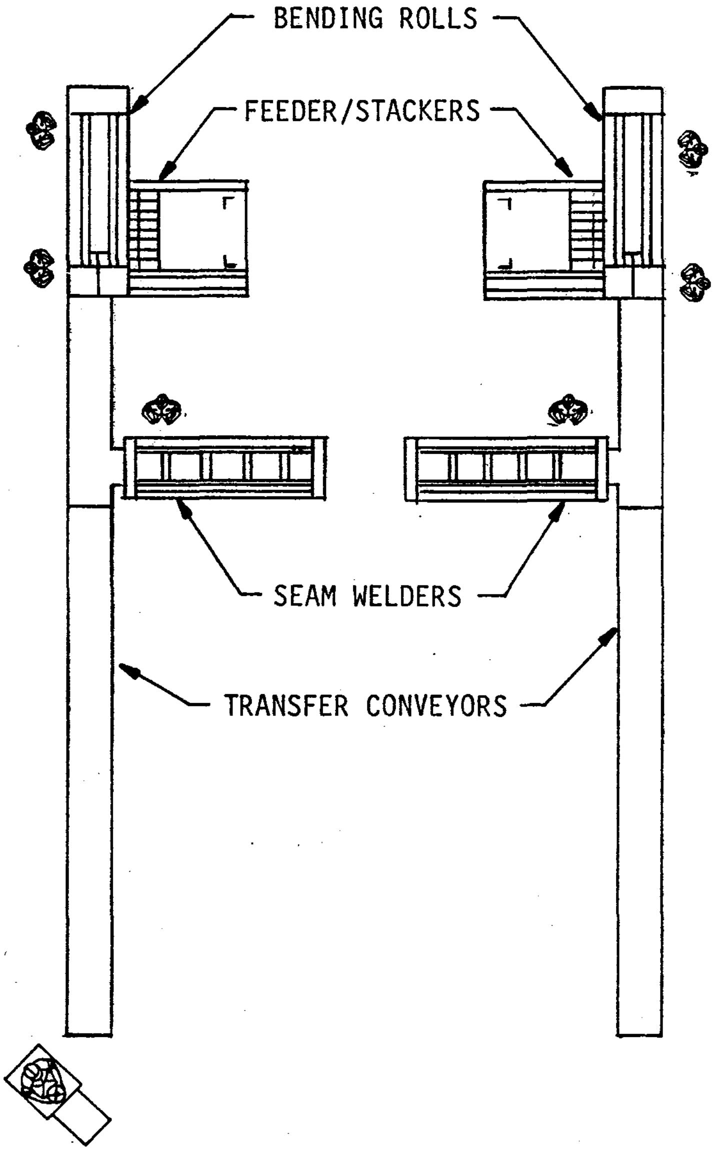


FIGURE 4-11 - Pile Assembly Area

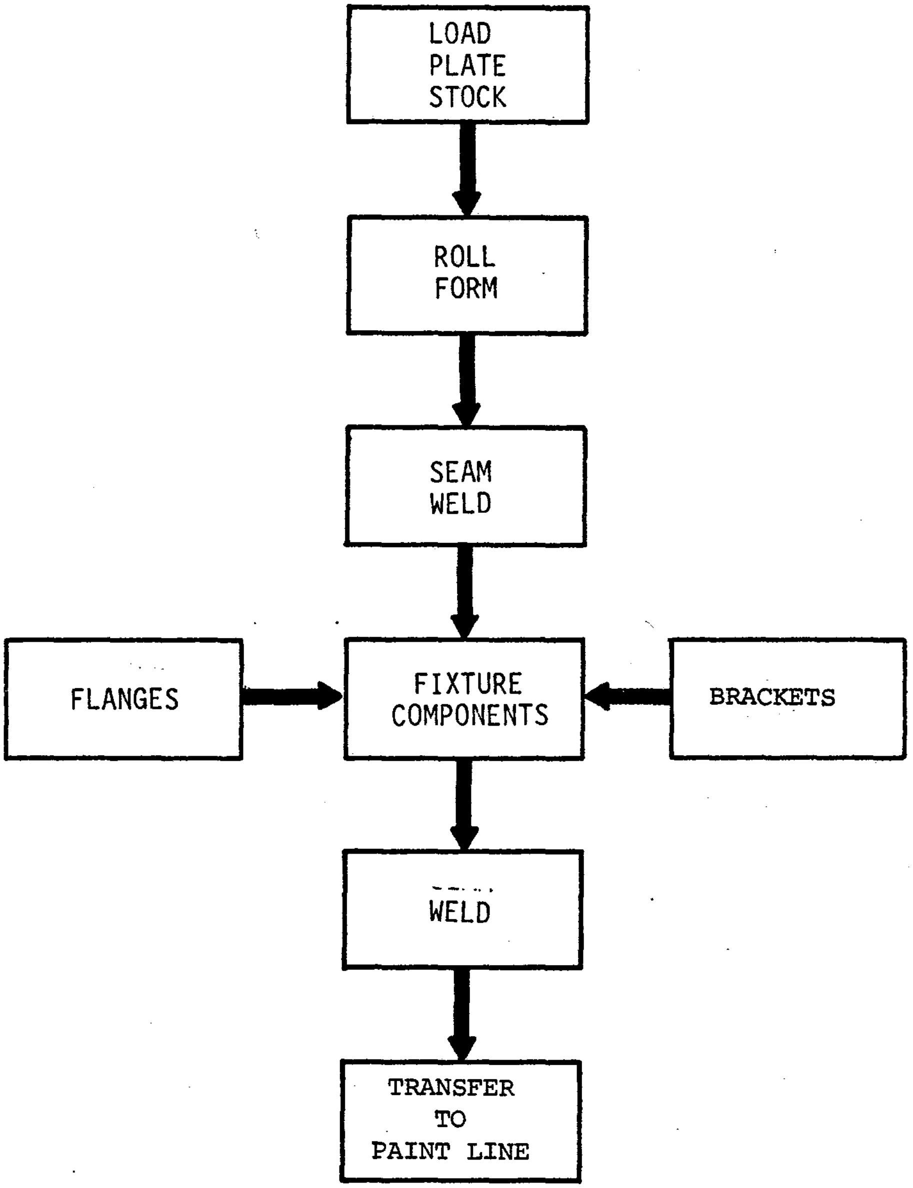


FIGURE 4-12. Torque Tube Process Flow

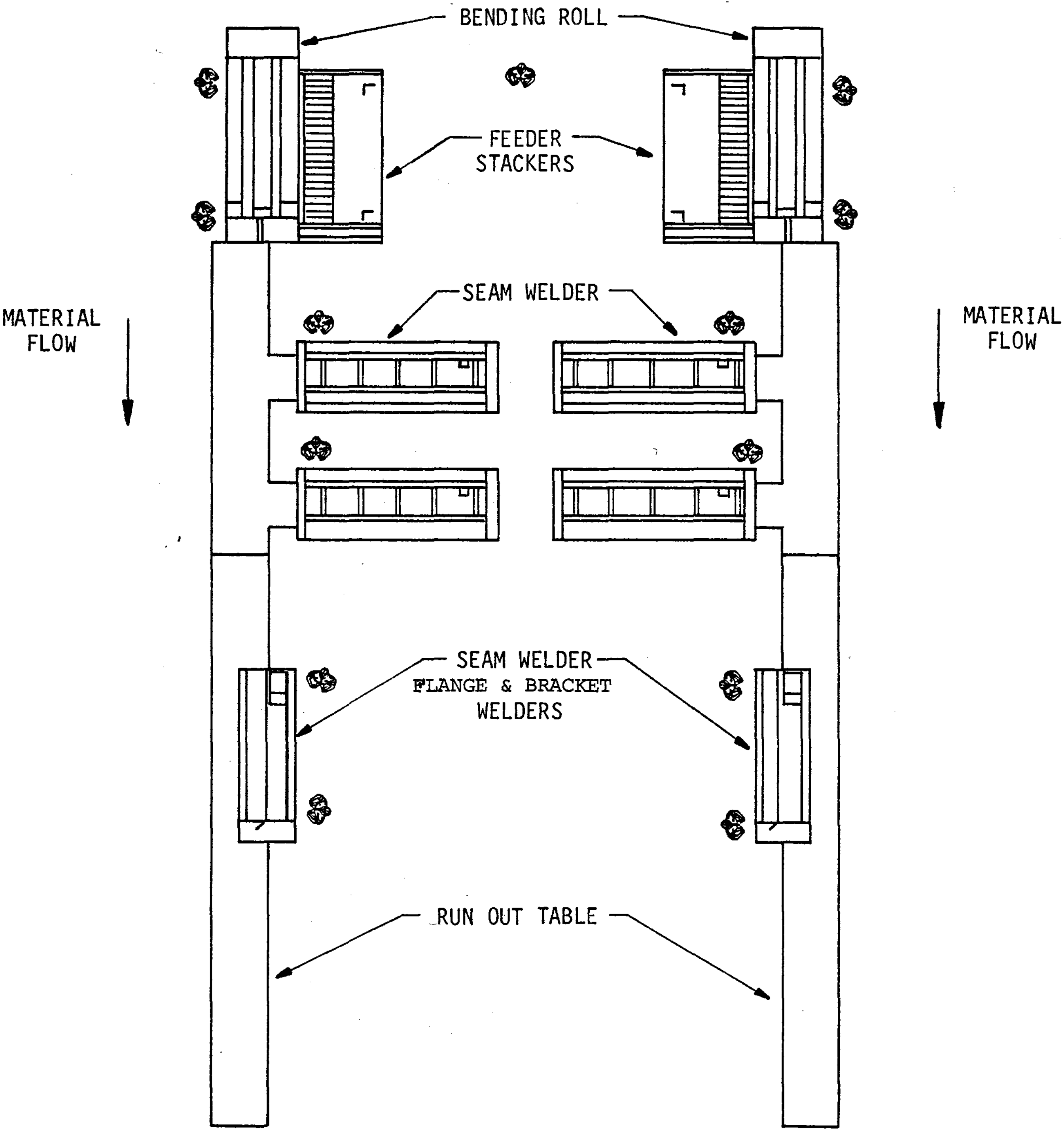


FIGURE 4-13. Torque Tube Fabrication Line

4.10.2.2 Torque Tube Fabrication

Pallets of plate stock are transferred from the raw material storage area to the torque tube line by an overhead crane. The plate stock is placed in an automatic feeder-stacker machine which feeds the plate into the bending rolls to form the basic tube. The tube is then removed from the bending rolls onto a transfer conveyor by an overhead gantry hoist.

The tubes are loaded with a powered roller conveyor into the seam welding operation. The welded tube is then transferred to an assembly jig by a powered roller conveyor.

In the assembly jig the end flange and two brackets are automatically welded to form the torque tube assembly. Proper alignment of the flange and the brackets is maintained in the assembly jig during the welding operation.

Following welding the torque tube assembly is hung on the paint line conveyor.

Two processing lines are required as illustrated in Figure 4-13. The equipment required for processing the torque tubes is as follows:

- o Two - automatic stacker-feeders
- o Two - bending rolls
- o Four - longitudinal seam welders
- o Two - automatic welders for assembling flanges and brackets.

4.10.3 Truss Fabrication

The truss manufacturing line operates on a two-shift basis. The truss assembly operation is supported by continuous roll forming lines which form the basic truss components. These lines are the tube forming and flange forming lines. The operation is supported by a coil slitting line. The coil

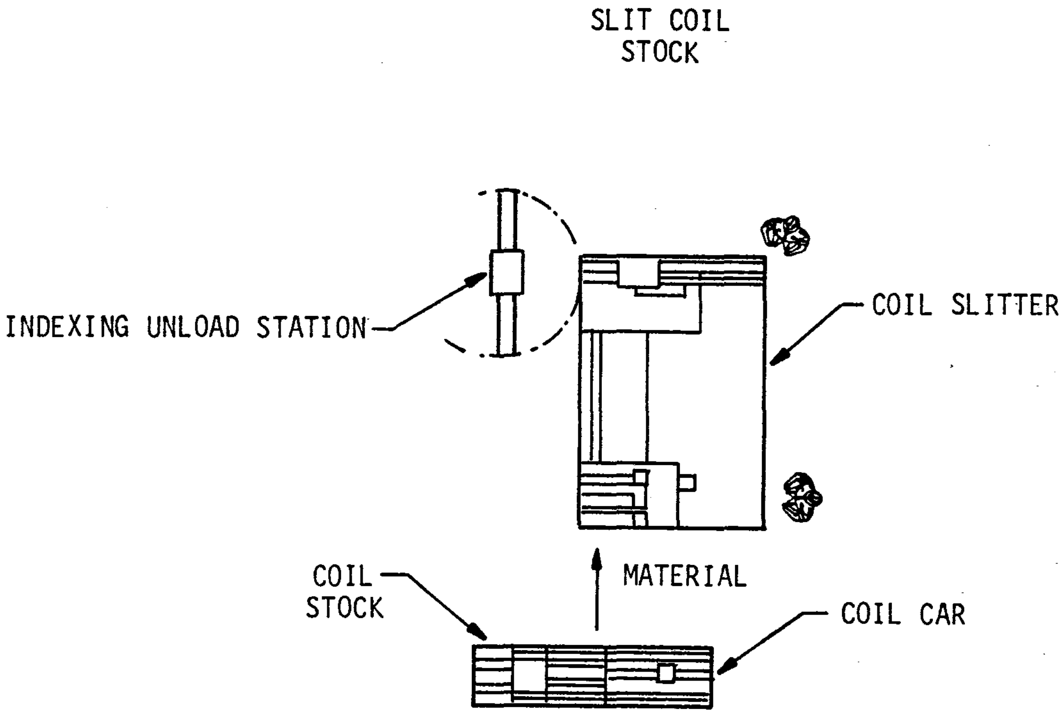


FIGURE 4-14. Heliostat Coil Slitting Area

slitting operation requires the following pieces of equipment: payoff reel, coil car, slitting machine, scrap regrinder, and a two arm turnstile. These machines are located as shown in Figure 4-14.

The tube forming and flange forming lines are shown in Figure 4-15. The tube forming line requires the following pieces of equipment: coil holder, leveling machine, coil end joiner, stock accumulator, roll former, seam welder, straighten, cut off machine and a runout table.

The roll forming lines feed continuously into the truss assembly area where the parts are welded into a finished truss. The truss assembly operation consists of the following equipment: web bender, assembly jig for web and flanges, and automatic jig welder.

4.10.3.1 Coil Slitting Process

The coil stock is sized for the manufacture of the tube and flanges to form the truss and the cross members of the support structure. The sized coils are stored in the raw material storage area adjacent to the next process lines.

4.10.3.2 Tube Forming Process

The coil stock is transferred from raw material storage to the tube forming line by a fork lift truck. The tube forming operation is a continuous rolling mill which forms the tube from coil stock and automatically seam welds the tube in line. The tube is straightened and cut to length automatically at speeds ranging up to 120 feet per minute. The finished tube is transferred onto a runout table for storage and transfer into the web bending operation where the tube is bent into the zig-zag pattern.

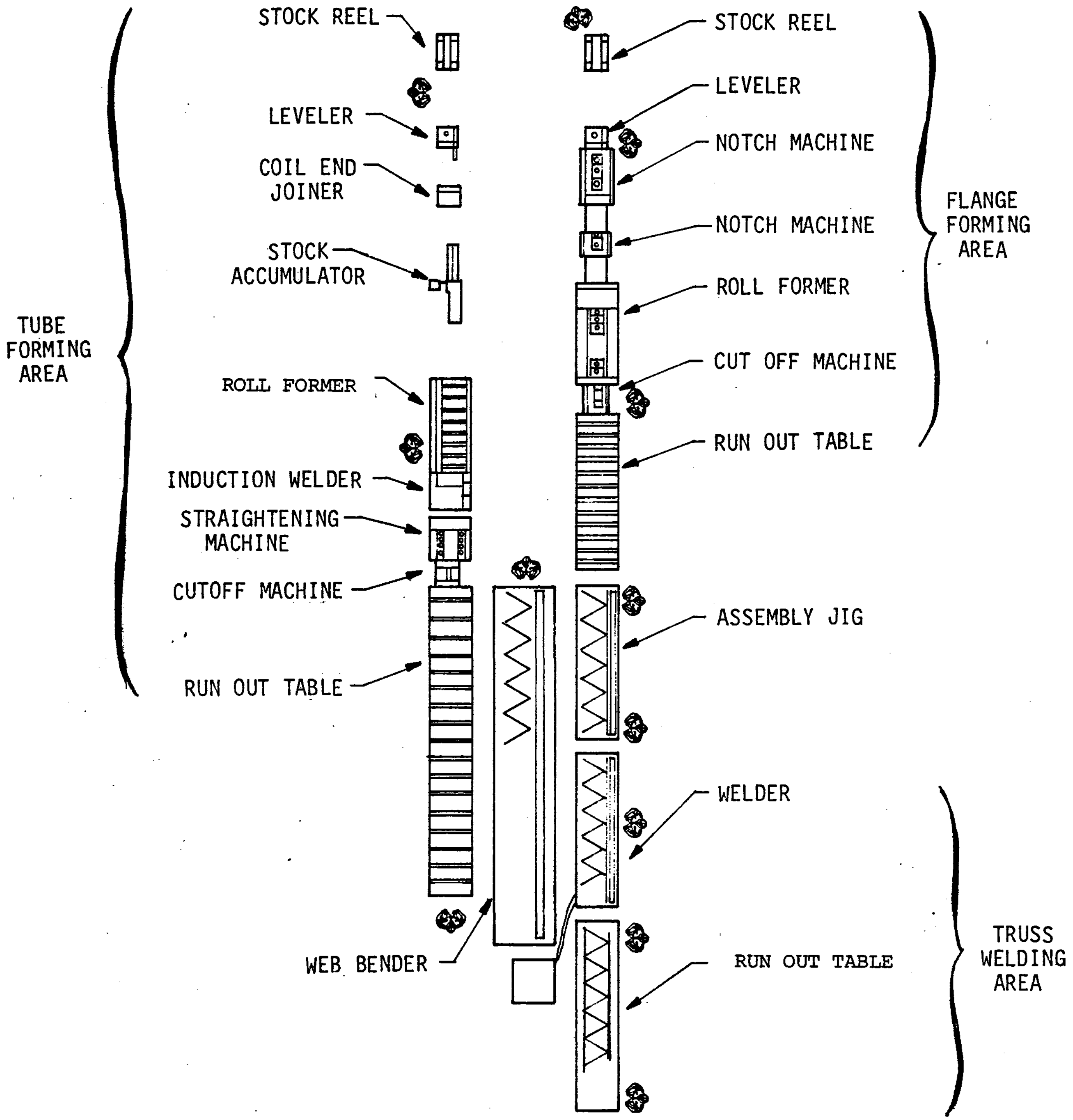


FIGURE 4-15. Truss Component Forming/Assembly Area

4.10.3.3 Flange Forming Process

The sized coil stock is transferred from the raw material storage to the flange forming line by a fork lift truck. The flange line operation is a continuous roll forming operation which forms the top and bottom flange sections of the truss. After the section is roll-formed it is automatically cut to length and transferred to the truss assembly jig. Length control of the flange sections is accomplished with a dial controlled electronic controller for tripping the cutoff presses.

4.10.3.4 Truss Assembly

The truss assembly operation is a continuous process line which receives the three truss components (the web, the top flange and the bottom flange) and forms the truss. The truss components are assembled in an assembly jig and then are transferred to an automatic resistance welding machine which welds the flanges and web into a single unit.

4.10.4 Brace Fabrication

The cross braces and lower braces are fabricated from angle iron which is received cut-to-length. Factory processing is limited to simple notching and punching and minor end forming. This is done on conventional presses.

4.10.5 Control Box Manufacture

The production design of the control box cannot be finalized until the volume production controls are developed. This area of the production will consist of conventional metal working equipment which is geared to produce 50,000 sets per year of boxes, doors, and mounting hardware. This will include shears, presses and spot welders.

4.10.6 Paint

All structural parts receive surface finishing which includes a rinse, dry, prime coat, cure, paint coat, cure cycle. This is accomplished on a conveyorized paint system which is located on the roof of the factory. The paint system is planned to be operated on a two-shift basis.

The parts to be painted include:

	Part Length In Ft.	Quantity Per Heliostat	Paint Line Length Per Heliostat in FT
Pile Assembly	22	1	22
Torque Tube Assembly	10	2	20
Truss	21	4	21 (Stacked)
Brace, cross	8	4	8 (Stacked)
Brace, lower	8	8	
Control Box	2	1	2
			73 Ft.

The right-hand column indicates the linear feet of conveyor required to hang a set of parts for one heliostat. Some paint conveyor parameters are as follows:

Conveyor speed	18.3 ft/min
Conveyor length	2200 ft.
Cycle time	2.0 hours
Carrying capacity	30 heliostats (at 73 ft/heliostat)
Required output	15 heliostats/hour

4.10.7 Shipping

After painting the structural parts are immediately staged for shipping. The paint conveyor passes adjacent to the shipping area. Control boxes are conveniently transferred to the adjoining Control Department. Pedestals, torque tubes, trusses are loaded on trailers as follows:

	Quantity Per Truck	Daily Production (200 heliostats)	Truckloads Per Day
Pedestals	26	200	7.7
Torque Tubes	80	400	5.0
Trusses	144	800	5.6
Total			18.3

Cross and lower braces can be end-loaded with the torque tubes. About 18 trucks a day must clear the loading dock.

4.11 DIRECT LABOR REQUIREMENTS

Direct labor employees required to produce the heliostat components are as follows:

Output as percent of planned capacity	Operators			
	Shift			
	1	2	3	Total
50	337	58	0	395
100	389	281	117	787
135	389	340	221	950

Note that as output increases there is a greater need for second and third shift workers. To achieve the 135% level of output requires that 12% of the hours worked be on an overtime basis. A more complete summary by production area is shown in Table 4-7 which in turn is backed up by detailed planning reported in the Appendix.

4.12 ALTERNATIVE PRODUCTION SCENARIO

In this section we have described a production facility in which all the components of a heliostat can be produced under one roof. It was noted earlier that the five production areas within the plant have little interaction so an alternative production scenario could include dispersed facilities and operation of these elements under different managements. This provides a high level of flexibility in approaching volume

TABLE 4-7

Direct Labor Summary

Output As Percent of Planned Capacity	Area	Operators Shift 1	2	3	Total
50%	Mirror	22	0	0	22
	Mirror Module	25	0	0	25
	Drive Unit	190	58	0	248
	Controls	38	0	0	38
	Structure	62	0	0	62
		337	58	0	395
		(85)	(15)	(0)	(100)
100%	Mirror	22	22	0	44
	Mirror Module	27	22	0	49
	Drive Unit	190	189	117	496
	Controls	75	0	0	75
	Structure	75	48	0	123
		389	281	117	787
		(49)	(36)	(15)	(100)
135%	Mirror	22	22	15	59
	Mirror Module	27	27	12	66
	Drive Unit*	190	190	178	558
	Control	75	26	0	101
	Structure	75	75	16	166
		389	340	221	950
	Equivalent*	427	378	257	1062
		(40)	(36)	(24)	(100)

*Based on drive unit area working a 6-day week. 12% of total hours are on overtime.

manufacturing levels. For example, at lower production volumes mirrors could be sourced from an existing mirror supplier. As production demands outstrip the supplier's capacity he may opt to build a mirroring plant in the near vicinity of the heliostat factory. It could be in the same city, in the same industrial complex or even in the same building. The ultimate integration of the mirroring operation into a factory managed by one corporation may very likely not occur. It could prove to be a more sound approach to use the base load created by the demands for heliostat mirrors to establish a qualified mirror manufacture in a new region of the country.

The same approach could apply to the drive unit area. An experienced drive unit manufacturer may provide a more optimum path to volume production by locating a production facility in the region, once again using the heliostat business as a base load.

A conveniently located pipe producer may be able to provide, at competitive costs, the cylindrical steel members required by the torque tube and the pedestal.

Building truss suppliers are already capable of supplying the truss-like structural members.

The control assemblies are of a routine nature which could be performed by dozens of control hardware specialists.

So this alternative scenario envisions a consortium of the following specialists:

- mirror manufacturer
- drive unit manufacturer
- pipe manufacturer
- truss manufacturer
- controls manufacturer

working in conjunction with the firm which designs the heliostat and performs some manufacturing of the more heliostat-specific components. The heliostat "manufacturer" may become directly involved only with the manufacture of the mirror modules, the torque tube assembly, the pile assembly and the control box. In this way, the experts in each field can maintain a competitive state-of-the-art position. The heliostat requirements provide a base load which establishes an economically sized factory for each specialist. This puts them in a position to serve other customers in the same region with products in their fields of expertise. The building of volume in other areas could lead to lower costs for the heliostat customer.

As long as the heliostat designer can associate with speciality suppliers who are interested in sharing the risks and rewards of a burgeoning industry he will find it unnecessary to venture into the manufacture of component parts which may be better performed by specialists.

SECTION 5.0

TRANSPORTATION

This section covers the transporting of heliostat components from the factory to the installation site. According to guidelines established for this study the output of the factory will be installed at sites within a 400 mile radius of the factory. The factory is located in or adjacent to a major city - the power plant sites will most likely be remotely located so truck transportation becomes the only reasonable alternative.

5.1 AVERAGE ROUND TRIP

The round trip from the factory to the installation site could vary from a few miles up to as much as 800 miles. Our costing has been based on an average value which assumes that power plant sites are equally distributed in the area served by the manufacturing plant. The average distance was determined by dividing total distance traveled to serve all power plant sites by the number of power plant sites.

$$\text{Number of power plant sites} = n \int_0^{400} 2\pi\, r dr \qquad (1)$$

where n = power plant sites/square mile

$$\text{Total round trip distance to plant sites} = n \int_0^{400} 2r \cdot 2\pi r dr \qquad (2)$$

Dividing (2) by (1) gives average round trip distance.

$$\text{Average round trip} = \frac{\int_0^{400} 2r^2 dr}{\int_0^{400} r dr} = \frac{2r^3/3}{r^2/2}\Bigg]_0^{400} = \frac{4r}{3}\Bigg]_0^{400} = 533 \text{ miles}$$

An average round trip of 533 miles was used for transportation costing purposes.

5.2 EQUIPMENT

Standard open flat bed trailers for use with cab-over-engine tractors will be used to transport the heliostat components from the factory to the installation sites. Open trailers are used to facilitate loading and unloading with overhead material handling equipment. Since all major components are designed for outdoor environments, weather protection is not required enroute to the installation sites.

These trailers have dimensions which permit loading to a volume which is nominally 96" wide by 108" high and 600" long. They can be loaded with a maximum weight of about 45,000 pounds.

The tractors are conventional double axle - 400 HP equipment. With proper maintenance tractors have a useful life of about 600,000 miles which represent 1126 average round trips per tractor. At three trips per week, the tractor fleet would be replaced every seven years.

5.3 TRAILER LOADING

The major components to be transported are as follows:

- Mirror Modules
- Trusses
- Torque Tubes
- Drive Units
- Pedestals

For volume installations trailers will be loaded with only one type of major component. This permits trailers dedicated to that component to be fitted with appropriate racks and tie down hardware.

Mirror modules will be shipped with a pair of modules facing each other to protect the mirror surface from physical damage. 10 pairs will be positioned on edge across the width of the trailer. The twelve foot module length permits four such rows and by double stacking a trailer can handle 160 modules.

The trusses are designed to nest and a trailer can be loaded in a 24 wide by 3 high by 2 long pattern for 144 per trailer.

Torque tubes have some undesirable shipping bulk as a result of the trapezoidal plates used to join the torque tubes to the truss and transmit shear loads between the upper and lower chords. A trailer can handle 80 torque tubes by a stacking arrangement which takes advantage of the trapezoidal shape of these plates. A load would consist of a stack which is 4 wide by 4 high by 5 long.

Drive units have the highest density of all the major components. Each drive unit weighs in at 1231 pounds so with a 45,000 pound loading limit a maximum of 36 drive units can be transported per truck load. In a single stack arrangement, the trailer bed area available per drive unit would be 48" x 36" which is adequate to provide suitable racking for this component.

Pedestals must precede all the other components to the installation site since it is the first component installed. The 22 foot long x

TABLE 5-1
TRANSPORTATION OUT (MAJOR COMPONENTS)

Component	Quantity Per Truck	Weight Per Unit in Pounds	Weight Per Truckload in Pounds	Quantity Per Heliostat	Truckloads Per Heliostat	Truckloads Per Day (200 Heliostats)
Mirror Modules	160	181	28960	12	.075	15.0
Trusses	144	114	16416	4	.028	5.6
Torque Tubes	80	338	27040	2	.025	5.0
Drive Units	36*	1231	44316*	1	.028	5.6
Pedestals	26	900	23400	1	.038	7.6
Total					.194	38.8

*Weight limited

24 in. dia. "pipes" would be stacked in longitudinal pattern in the trailer. The 108 inch load height limit restricts the load to 26 pedestals. They would be arranged in two tandem stacks of 13 pedestals each.

Since most of the trailer loads are not loaded to the maximum allowable weight, miscellaneous parts can be top or end loaded on shipments of major components. This includes cross braces, bolts, nuts, rivets, electrical controls, etc.

5.4 SHIPPING SUMMARY

A summary of the shipping requirements is listed in Table 5-1. The analysis shows that 0.194 truckloads are required per heliostat or conversely about 5 heliostats per truckload. A factory manufacturing at the 50,000 unit/year level would be dispatching about 40 trucks per day to installation sites. The average round trip per driver would be about 2 days so a fleet of 80 tractors would be required. The number of trailers required is as follows:

Available for loading and storing finished goods at the factory	80
Enroute	80
Available for unloading and buffer stock at installation sites	80
Total trailers required	240

All this equipment would be standard with the trailers being fitted with customized racking and tie down provisions for the components being hauled. The racks eliminate the need for crating which avoids the cost of packaging materials and the ultimate disposal of these materials at the installation site.

Section 6.0

FIELD ASSEMBLY AND INSTALLATION

Field assembly and installation is defined here to include:

- Installation of the heliostat foundations
- Field assembly and alignment of the heliostats
- Installation of the heliostats on their foundations
- Installation and hookup of heliostat controls

The designs, methods, and procedures involving the above activities are discussed below in considerable detail. Other field activities such as site preparation, and the installation of field wiring, not discussed in this section, are included in the cost estimates presented in Section 8.

6.1 HELIOSTAT FOUNDATION

6.1.1 Requirements

The heliostat foundation must satisfy the requirements of the Collector Subsystem Requirements Specification A10772. This specification limits the foundation tilt and torsional rotation at grade to 1.5 mrad when operating at the worst orientation relative to a 12 m/sec (27 mph) wind. This allowed deflection includes the foundation elastic response and up to 0.45 mrad of plastic deformation permitted as a result of previous exposure to 22 m/sec (50 mph) wind loads.

The foundation must be capable of surviving 40 m/sec (90 mph) wind loads with the heliostat in the horizontal stowed position.

The heliostat foundation is designed to withstand the above operational and survival wind loads using the soil properties of the A10772 specification. These properties are based on soil tests conducted at the Central Receiver Test Facility (CRTF) site near the intended location of the second generation heliostat foundation.

6.1.2 Assessment of Foundation Concepts

Candidate Concepts

The candidate heliostat foundation concepts described below are illustrated in Figures 6-1 and 6-2. In the discussion which follows the foundation extends to the drive assembly interface; that is, it includes the pedestal.

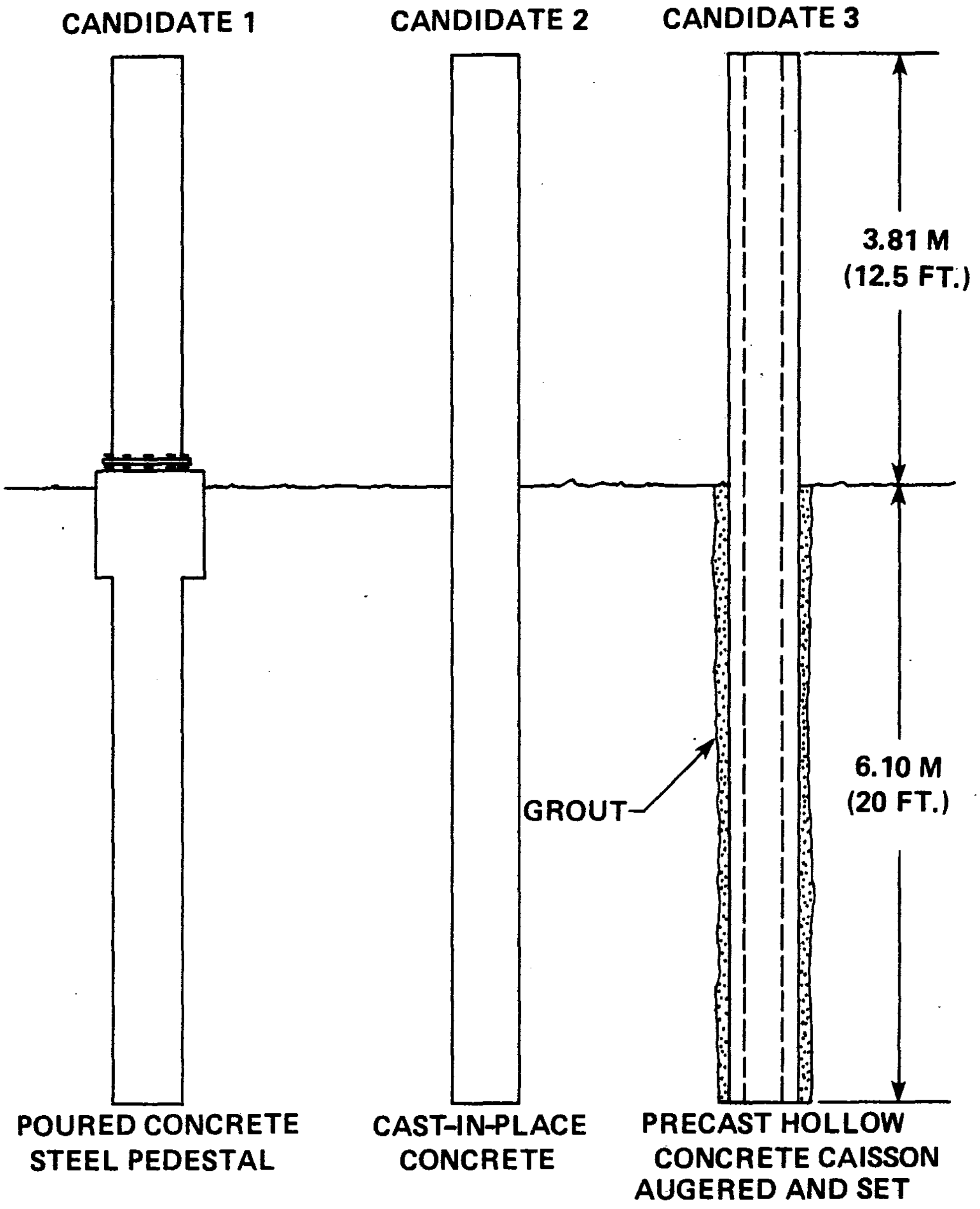


Figure 6-1 CANDIDATE FOUNDATIONS —CONCRETE

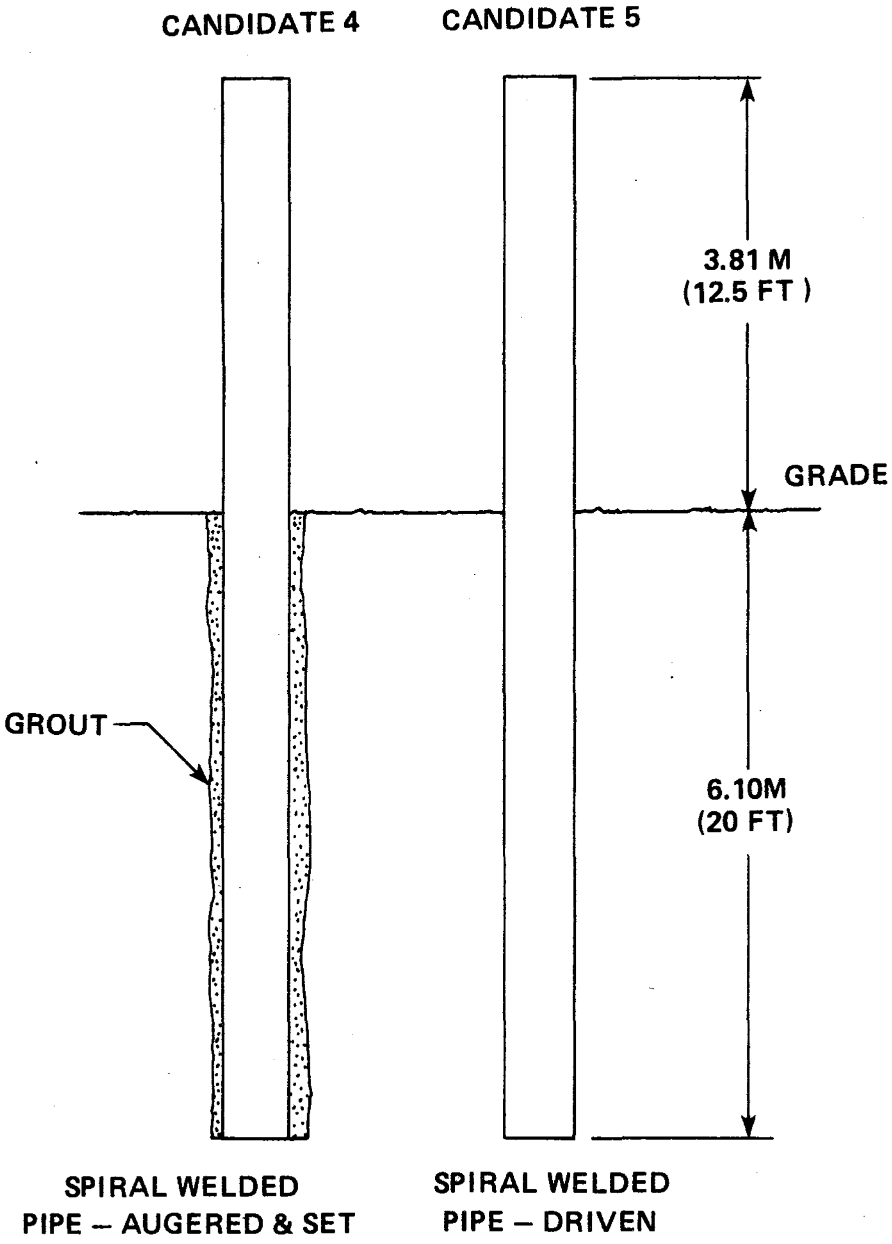


Figure 6-2 CANDIDATE FOUNDATIONS – STEEL PIPE

- Candidate 1 - Poured Concrete Foundation with Steel Pipe Pedestal. This is the baseline foundation concept that has been selected for previous heliostat design studies and installation, i.e., CRTF and Barstow.

- Candidate 2 - Cast-in-Place Concrete Foundation and Pedestal. This concept offers structural continuity between the foundation and pedestal. The concrete foundation extends above grade to the drive assembly interface. Integration of the foundation and pedestal eliminates need for a joint between the foundation and pedestal. It also requires the construction and placement of above-grade concrete forms.

- Candidate 3 - Pre-Cast Concrete Caisson - Foundation and Pedestal. A pre-cast hollow concrete caisson extends above grade to serve as a foundation and pedestal. It is placed in an augered hole and set in concrete. Pre-casting tends to reduce the required field labor but does entail a transportation charge.

- Candidate 4 - Steel Pipe Caisson - Augered and Set in Place. The pipe extends above grade to serve as a foundation and pedestal. It is installed quickly with a relatively small requirement for field labor. Use of spiral welded pipe minimized caisson cost. Conventional seam welded steel pipe may become equally inexpensive when manufactured in a dedicated facility as part of a heliostat factory.

- Candidate 5 - Steel Pipe Pile - Driven with Vibratory Hammer. Spiral welded steel pipe serves as an integral foundation and pedestal. Vibratory hammers drive low displacement piles, such as this, extremely rapidly into silty sand and gravel soils such as those encountered at the Barstow and CRTF sites.

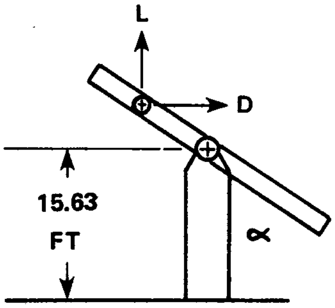
Sizing of Candidate Foundations

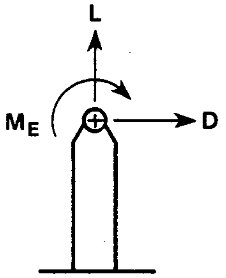
The assessment of candidate foundation concepts preceded completion of the production heliostat design. The initial screening of candidate foundation concepts was therefore based on the wind loads of the baseline heliostat design discussed in the proposal. These wind loads, presented in Tables 6-1 through 6-3, were used with the specified CRTF soil properties

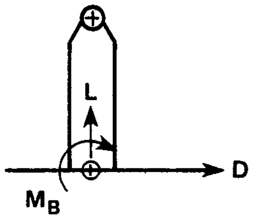
Table 6-1

BASELINE HELIOSTAT DESIGN

12 m/sec (27 mph) Wind Operational Loads







α	L		D		M_E		M_B	
DEG	N	LB	N	LB	N M	FT LB	N M	FT LB
0	200	45	4,283	963	0	0	24,408	15,052
10	867	195	4,194	943	1,106	816	21,090	15,555
20	1,521	342	4,034	907	1,818	1,341	21,040	15,518
30	2,171	488	3,763	846	2,358	1,739	20,286	14,962
40	2,776	624	3,385	761	2,640	1,947	18,766	13,841
50	3,274	736	2,896	651	3,010	2,220	16,805	12,395
60	3,416	768	2,255	507	3,589	2,647	14,334	10,572
70	3,056	687	1,041	234	4,363	3,218	9,321	6,875
80	1,374	309	409	92	2,907	2,144	4,857	3,582
90	0	0	0	0	0	0	0	0

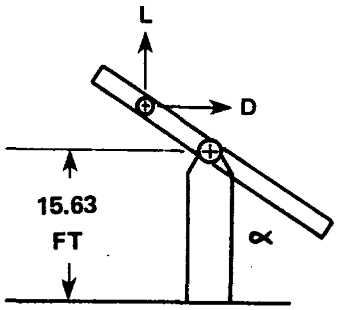
Maximum Torsion	3,116 N M (2,298 ft. lb.)
Gravity Load	19,126 N (4,300 lb.), excluding pedestal

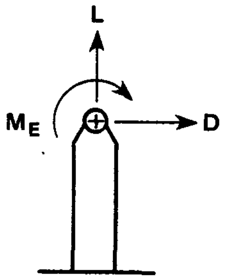
1.5 mrad Maximum Tilt & Twist (including up to .45 mrad plastic deformation from previous 22 m/sec (50 mph) exposure).

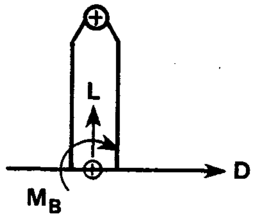
Table 6-2

BASELINE HELIOSTAT DESIGN

22 m/sec (50 mph) Wind Loads







α	L		D		M_E		M_B	
DEG	N	LB	N	LB	N M	FT LB	N M	FT LB
0	694	156	14,696	3,304	0	0	70,017	51,642
10	2,976	669	14,398	3,237	3,798	2,801	72,395	53,396
20	5,222	1,174	13,891	3,114	6,241	4,603	72,188	53,243
30	7,455	1,676	12,908	2,902	6,087	5,965	69,598	51,333
40	9,528	2,142	11,618	2,612	9,056	6,679	64,384	47,487
50	11,227	2,524	9,932	2,233	10,327	7,617	57,660	42,528
60	11,720	2,635	7,740	1,740	12,315	9,083	49,178	36,272
70	10,479	2,356	3,576	804	14,968	11,040	31,982	23,589
80	4,710	1,059	1,397	314	9,976	7,358	16,664	12,291
90	0	0	0	0	0	0	0	0

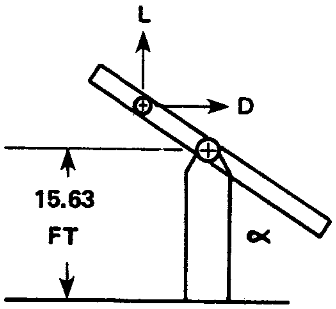
Maximum Torsion	10,687 N M (7,882 ft. lb.)
Gravity Load	19,126 N (4,300 lb.), excluding pedestal

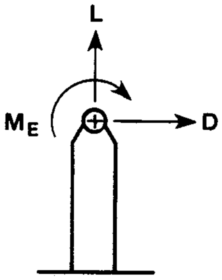
Up to .45 mrad permitted due to plastic deformation of earth.

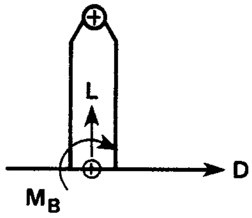
Table 6-3

BASELINE HELIOSTAT DESIGN

40 m/sec (90 mph) Wind Survival Loads







α	L		D		M_E		M_B	
DEG	N	LB	N	LB	N M	FT LB	N M	FT LB
0	2,242	504	47,616	10,705	0	0	226,854	167,319
10	9,642	2,168	46,642	10,486	12,301	9,073	234,517	172,971
20	16,916	3,803	44,867	10,087	20,225	14,917	233,870	172,494
30	24,148	5,429	41,825	9,403	26,201	19,325	225,485	166,309
40	30,869	6,940	37,634	8,461	29,336	21,637	208,589	153,847
50	36,367	8,176	32,181	7,235	33,458	24,677	186,805	137,780
60	37,973	8,537	25,078	5,638	39,899	29,428	159,325	117,512
70	33,956	7,634	11,587	2,605	48,496	35,769	103,617	76,424
80	15,266	3,432	4,524	1,017	32,319	23,837	53,987	39,819
90	0	0	0	0	0	0	0	0

Maximum Torsion	34,625 N M (25,538 ft. lb.)
Gravity Load	19,126 N (4,300 lb.), excluding pedestal.

and the method of Kocsis (Ref. 6-1) to determine the required diameter and approximate foundation depth for each candidate.

The results, shown in Table 6-4, reveal that the selection of a 0.61 meter (24 inch) diameter for each candidate foundation results in tilt values at grade which are within the 1.05 mrad elastic rotation allowance (1.50 mrad total minus 0.45 mrad allowance for plastic deformation). The pile lengths calculated by the method of Kocsis fall between 4.6 m (15 ft.) and 6.1 m (20 ft.). They are only approximate values and are normally increased by 10 to 20 percent. For the purpose of screening the relative cost of the candidates, it was assumed that each foundation extends 6.1 m (20 ft.) below grade.

Candidate Foundation Costs

The estimated cost of the candidate foundations was based on Bechtel historical data on work task time requirements, a direct field labor charge representative of the Albuquerque area and information solicited from private contractors. Some of the cost criteria are listed below. All costs are expressed in first quarter 1980 dollars.

• field labor	$20 per hour
• augering	$8.53 per meter ($2.60 per foot)
• rebar	$425 per ton
• concrete	$58.81 per cubic meter ($45 per cubic yard)
• driving steel pipe pile	$85 each
• steel pipe pile .609 meter x 6.3 mm (24 inch x .25 inch)	$68.90 per meter ($21 per foot) (mean of 5 quotes)
• transport	$60 per ton
• distributables	80% of direct field labor
• engineering	12% of field cost
• contingency	15%

Table 6-4

FOUNDATION SIZES BASED ON THE METHOD OF KOCSIS

CANDIDATE	DIAMETER		LENGTH* BELOW GRADE		TILT AT GRADE	TILT AT DRIVE ASSEMBLY
	m	in	m	ft	mrad	mrad
1. Poured Concrete Steel Pedestal	.91/.61	36/24	5.33	17.5	.70	.96
2. Cast-in-Place Concrete	.61	24	5.33	17.5	.70	1.18
3. Pre-Cast Concrete Caisson	.61	24	5.33	17.5	.70	1.18
4. Steel Pipe-Augered	.61	24	5.09	16.7	.85	1.11
5. Steel Pipe-Driven	.61	24	5.09	16.7	.85	1.11

*These values are usually increased by 10 to 20 percent to be conservative.

The resulting foundation costs, presented in Table 6-5, show that the least expensive heliostat foundation is Candidate 5, a spiral welded steel pipe pile driven by a vibratory hammer. The same pile augered and set in place (Candidate 4) is only slightly more expensive. The remaining foundations are significantly more expensive due chiefly to the greater field labor requirements and the larger indirect charges associated with the field labor. The breakdown of costs show that the concrete foundation costs are largely field labor and labor related indirect costs. The predominant cost for the steel foundations is the material cost of the pile.

While the relative costs of Table 6-5 are valid, the absolute values are somewhat higher than is reported herein for the production heliostat foundations. This is due to the fact that the baseline heliostat wind loads, used for the survey of candidate foundations, are larger than those which apply to the production heliostat design. Hence the foundations are slightly over designed. Furthermore, the use of the method of Kocsis gives a somewhat conservative estimate of required foundation depth which resulted in correspondingly conservative estimates of candidate foundation costs. The design of the selected foundation, discussed later, is based on the calculated wind loads for the production heliostat configuration and on a detailed computer simulation of the foundation and soil mechanics.

Concept Selection

Based on the assessment presented above, the foundation concept selected for the second generation heliostat design of this study is Candidate 5, the steel pipe pile driven with a vibratory hammer. The estimated driving rate of over 2.5 centimeters per second (1 inch per second) permits the installation of approximately 40 piles per day by a 7 man crew. Over half of the foundation cost is for the pile. Labor required for pile installation is relatively small.

Candidate 4, the steel pipe pile set in an augered hole, is selected as an alternate foundation for use in soils that are hard enough to refuse a vibratory hammer driven pile. The Candidates 4 and 5 piles are identical; only the installation method differs. Using the preferred vibratory hammer installation method, an augering rig can be kept on hand to accommodate any foundation locations that refuse the vibratory hammer.

6.1.3 Foundation Design

This section addresses the detailed design of the foundation concept selected above. Two foundations of this design were

Table 6-5

RELATIVE COST OF CANDIDATE FOUNDATIONS

DOLLARS

CANDIDATE	PILE	TRANSPORT	PEDESTAL	SUB-CONTRACT	LABOR	MISC	DIRECT	INDIRECT	DIRECT & INDIRECT
1. Poured Concrete Steel Pedestal	230	24	351	67	280	63	1015	580	1595
2. Cast-in-Place Concrete	388	-	-	52	520	-	960	810	1770
3. Pre-Cast Concrete Caisson	520	280	-	52	220	98	1170	560	1730
4. Steel Pipe-Augered	675	65	-	52	100	108	1000	390	1390
5. Steel Pipe-Driven	675	65	-	85	40	85	950	310	1260

installed at CRTF to support the two Northrup Second Generation Heliostat that are undergoing evaluation tests that will be completed in early 1981. This foundation design provides the basis for projected foundation costs for large heliostat fields.

The foundation design criteria includes the deflection requirements discussed previously in Section 6.1.1, which simply require that:

- total tilt and torsional rotation of the foundation at grade, due to forces imposed by a 12 m/sec (27 mph) wind with the heliostat in the worst orientation, shall not exceed 1.5 mrad, and
- the 1.5 mrad total deflection includes up to 0.45 mrad permanent set that can be permitted as a result of previous exposure to 22 m/sec (50 mph) winds.

The heliostat must operate in winds up to 12 m/sec (27 mph) with deflections within those specified. Operation, with larger deflections permitted, can continue at wind speeds up to 16 m/sec (35 mph). Stowing of heliostats begins at 16 m/sec (35 mph). Wind velocities of up to 22 m/sec (50 mph) can be attained by the time heliostats are in the horizontal stowed position. The survival wind loads occur with the horizontally oriented heliostat in a 40 m/sec (90 mph) wind.

Forces and moments applied at the heliostat elevation axis and at the pedestal base as a result of 12 m/sec (27 mph), 22 m/sec (50 mph) and 40 m/sec (90 mph) winds, are shown in Tables 6-6 through 6-8. The respective moment axes are shown in Figure 6-3. Wind load information such as this provided the basis for the pile design loads presented in Tables 6-9 and 6-10.

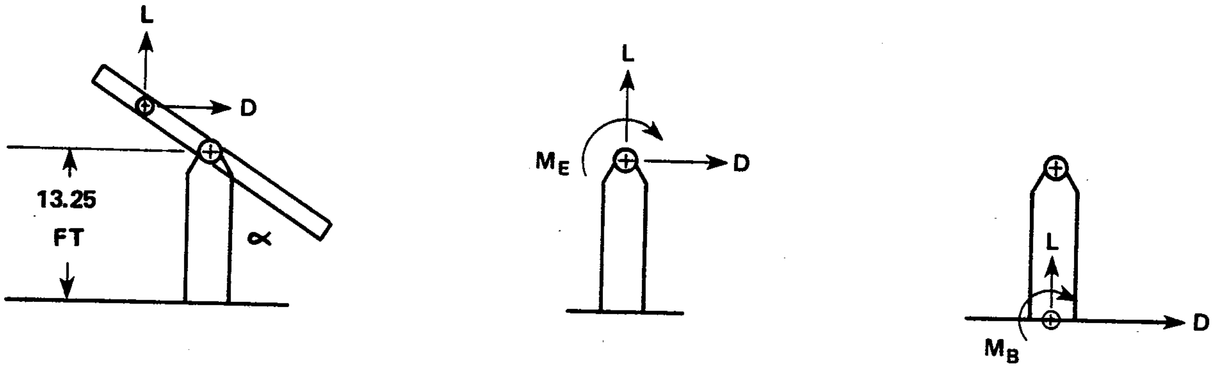
The maximum loads imposed on the foundation during the stowing operation are conservatively estimated to occur with the heliostat oriented vertically and normal to a 22 m/sec (50 mph) wind.

The design of the foundations for the two CRTF heliostats is based upon the use of a multipurpose finite element structural computer program called STRUDL, and the soil properties of the Collector Subsystem Requirements (Specification A10772, Revision D). The pile diameter and depth are selected to restrain pile deflections below 1.05 mrad (1.5 mrad total minus .45 mrad

Table 6-6

PRODUCTION HELIOSTAT DESIGN

12 m/sec (27 mph) Wind Operational Loads



α	L		D		M_E		M_B	
DEG	N	LB	N	LB	N M	FT LB	N M	FT LB
0	200	45	4,248	955	0	0	17,156	12,654
10	858	193	4,163	936	952	702	17,766	13,104
20	1,508	339	4,003	900	1,566	1,155	17,734	13,080
30	2,153	484	3,732	839	2,028	1,496	17,100	12,613
40	2,753	619	3,358	755	2,270	1,674	15,833	11,678
50	3,243	729	2,869	645	2,588	1,909	14,175	10,455
60	3,389	762	2,237	503	3,090	2,279	12,126	8,944
70	3,029	681	1,032	232	3,753	2,768	7,920	5,842
80	1,361	306	405	91	2,499	1,843	4,134	3,049
90	0	0	0	0	0	0	0	0

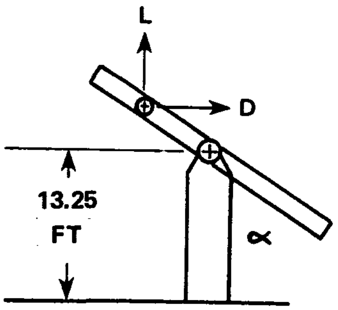
Maximum Torsion	3,752 N M (2,768 ft. lb.)
Gravity Load	17,792 N (4,000 lb.), excluding pedestal.

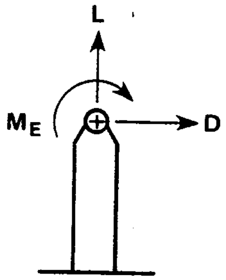
1.5 mrad Maximum Tilt & Twist (including up to .45 mrad plastic deformation from previous 22 m/sec (50 mph) exposure).

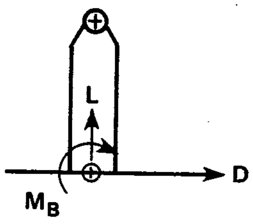
Table 6-7

PRODUCTION HELIOSTAT DESIGN

22 m/sec (50 mph) Maximum Stowing Wind Loads







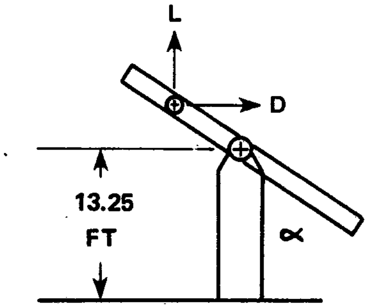
α	L		D		M_E		M_B	
DEG	N	LB	N	LB	N M	FT LB	N M	FT LB
0	685	154	14,567	3,275	0	0	58,835	43,394
10	2,949	663	14,269	3,208	3,263	2,407	60,894	44,913
20	5,173	1,163	13,727	3,086	5,370	3,961	60,810	44,851
30	7,389	1,661	12,797	2,877	6,955	5,130	58,640	43,250
40	9,443	2,123	11,516	2,589	7,782	5,740	54,293	40,044
50	11,124	2,501	9,843	2,213	8,875	6,546	48,631	35,868
60	11,618	2,612	7,673	1,725	10,586	7,808	41,575	30,664
70	10,391	2,336	3,541	796	12,876	9,497	27,176	20,044
80	4,670	1,050	1,383	311	8,569	6,320	14,156	10,441
90	0	0	0	0	0	0	0	0

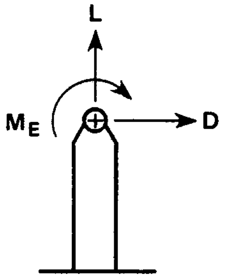
Maximum Torsion 12,876 N M (9,497 ft. lb.).
Gravity Load 17,792 N (4,000 lb.), excluding pedestal
Up to .45 mrad permitted due to plastic deformation of earth.

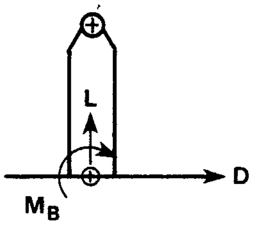
Table 6-8

PRODUCTION HELIOSTAT DESIGN

40 m/sec (90 mph) Wind Survival Loads







α	L		D		M_E		M_B	
DEG	N	LB	N	LB	N M	FT LB	N M	FT LB
0	2,200	499	47,197	10,611	0	0	190,623	140,596
10	9,559	2,149	46,233	10,394	10,574	7,799	197,299	145,520
20	16,765	3,769	44,471	9,998	17,398	12,832	197,008	145,305
30	23,935	5,381	41,455	9,320	22,534	16,620	189,964	140,110
40	30,598	5,879	37,305	8,387	25,216	18,598	175,885	129,726
50	36,047	8,104	31,897	7,171	28,756	21,209	157,580	116,225
60	37,639	8,462	24,855	5,588	34,298	25,297	134,685	99,338
70	33,658	7,567	11,485	2,582	41,694	30,752	88,080	64,964
80	15,132	3,402	4,484	1,008	27,762	20,476	45,870	33,832
90	0	0	0	0	0	0	0	0

Maximum Torsion 41,694 N M (30,752 ft. lb.)

Gravity Load 17,792 N (4,000 lb.), excluding pedestal.

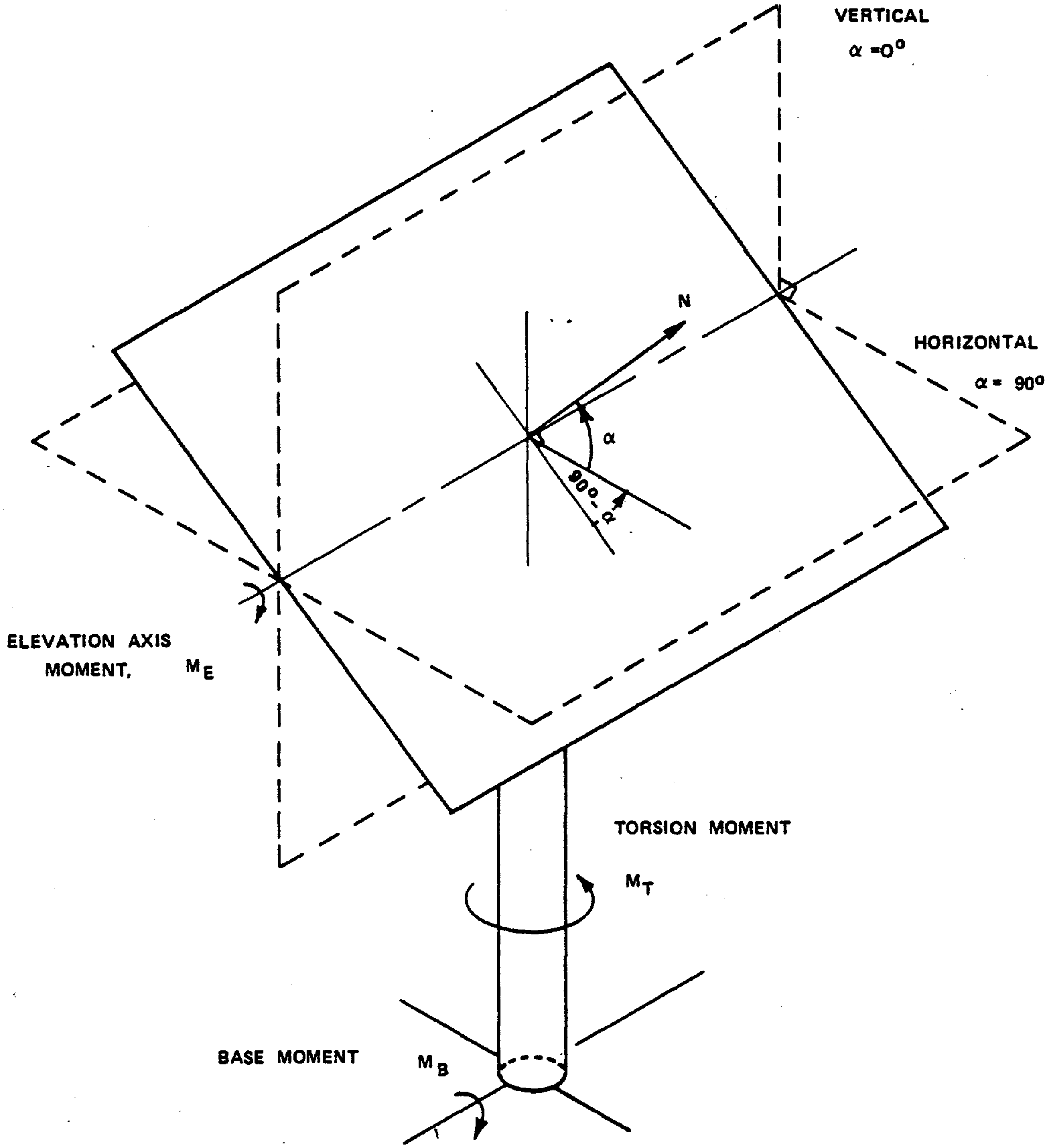


Figure 6-3 NOMENCLATURE FOR HELIOSTAT MOMENTS

Table 6-9

PILE DESIGN LOADS (METRIC)

Wind Condition	Horizontal Base Load F_B, N	Base Moment M_B N - M
Operating 12 m/sec 1.5 mR max.	4,163	17,766
Max. Stowing 22 m/sec Vertical	14,269	60,894
Survival 40 m/sec Horizontal	4,484	45,870

Table 6-10

PILE DESIGN LOADS (ENGLISH)

Wind Condition	Horizontal Base Load F_B, lb	Base Moment M_B ft - lb
Operating 27 mph 1.5 mR max.	936	13,104
Max. Stowing 50 mph Vertical	3,208	44,913
Survival 90 mph Horizontal	1,008	33,832

permanent set) in a 12 m/sec (27 mph) wind. The selected pile dimensions are also intended to prevent significant permanent set at the survival wind load conditions.

Soil Properties

Pile deflections and rotations were calculated using the laterally loaded pile option of STRUDL. This program was developed by the Massachusetts Institute of Technology. The enhanced version of STRUDL, used here for the design of the heliostat foundation, was developed by McDonnell Douglas Automation Company. Given the pile length diameter and stiffness, and the soil properties as a function of depth, STRUDL gives the pile deflection, rotation, twist and stress along its length. The soil-related input data required by STRUDL are coordinates of a family of P-Y curves (soil resistance versus deflection) as a function of depth below grade. These curves are determined by the elastic modulus of the soil and ultimate soil resistance, both of which vary with depth below grade.

Figure 6-4 shows the variation of the soil elastic modulus with depth, based on three soil modulus estimation methods. Each of the three curves is based on data from the A10772 (Revision D) Specification. The upper curve, based on seismic refraction survey data, gives the highest estimate of soil modulus. The lower curve, the calculated secant modulus of elasticity, gives a low value of soil modulus that is considered to be very conservative. An intermediate curve, based on sample hole penetration data, is considered to be the most reasonable choice of soil modulus for the present pile design calculations. Due to the increased variability of soil properties near the surface, the design curve is drawn conservatively below the modulus indicated for near-surface penetration data. The influence of additional conservatism near the surface was investigated by adding a lower branch to the design soil modulus curve.

Figure 6-5 shows the influence of soil density and angle of internal friction on the ultimate soil resistance. An appropriate range of values for these variables was selected to define the upper bound, lower bound and design curves shown in the figure. The ultimate soil resistance is the applied bearing pressure which causes unrestrained lateral movement through the soil. At such loadings the response of the soil is plastic as opposed to elastic.

Foundation Size

The soil data just discussed, provided the basis for P-Y curves,

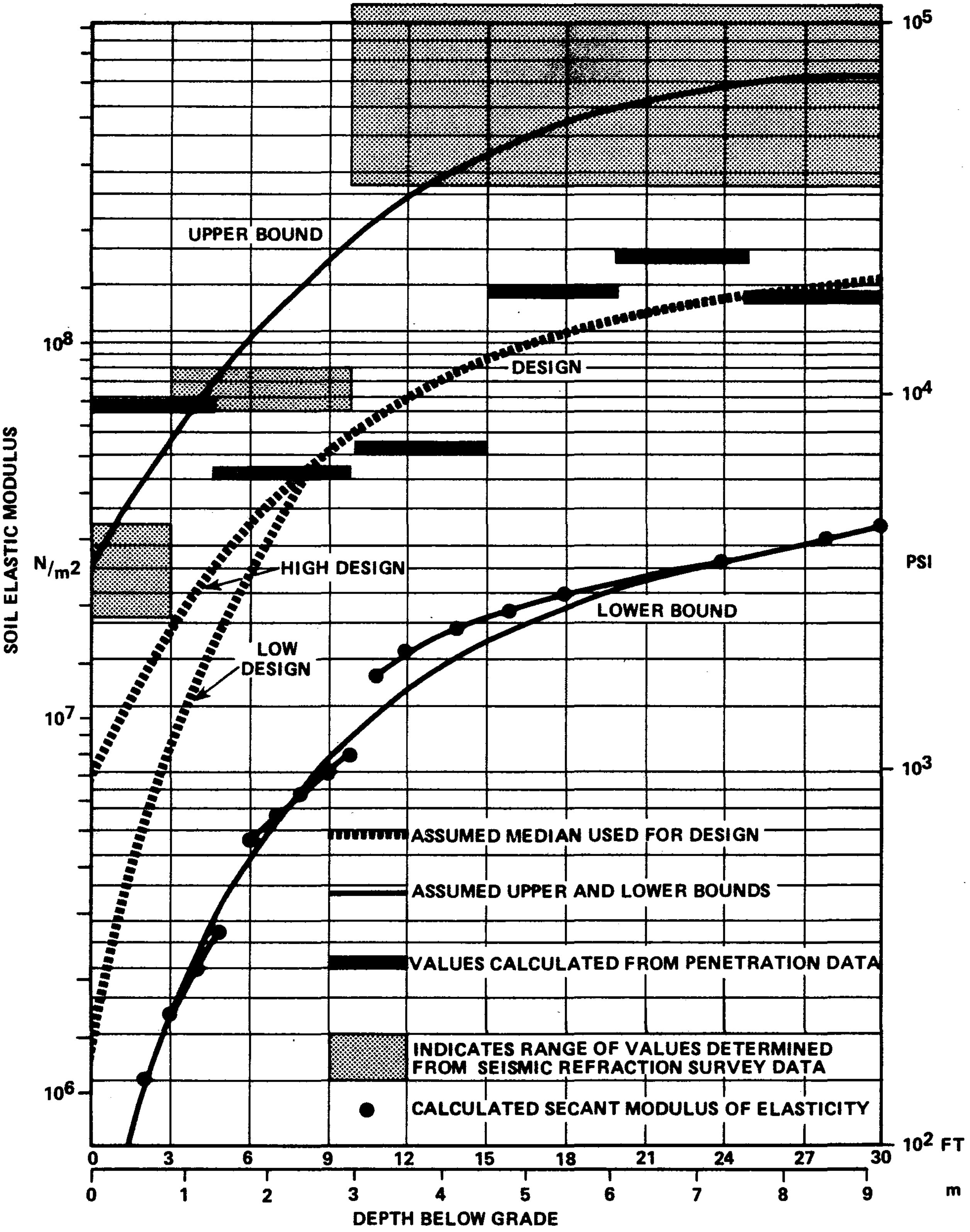


Figure 6–4 SOIL ELASTICITY

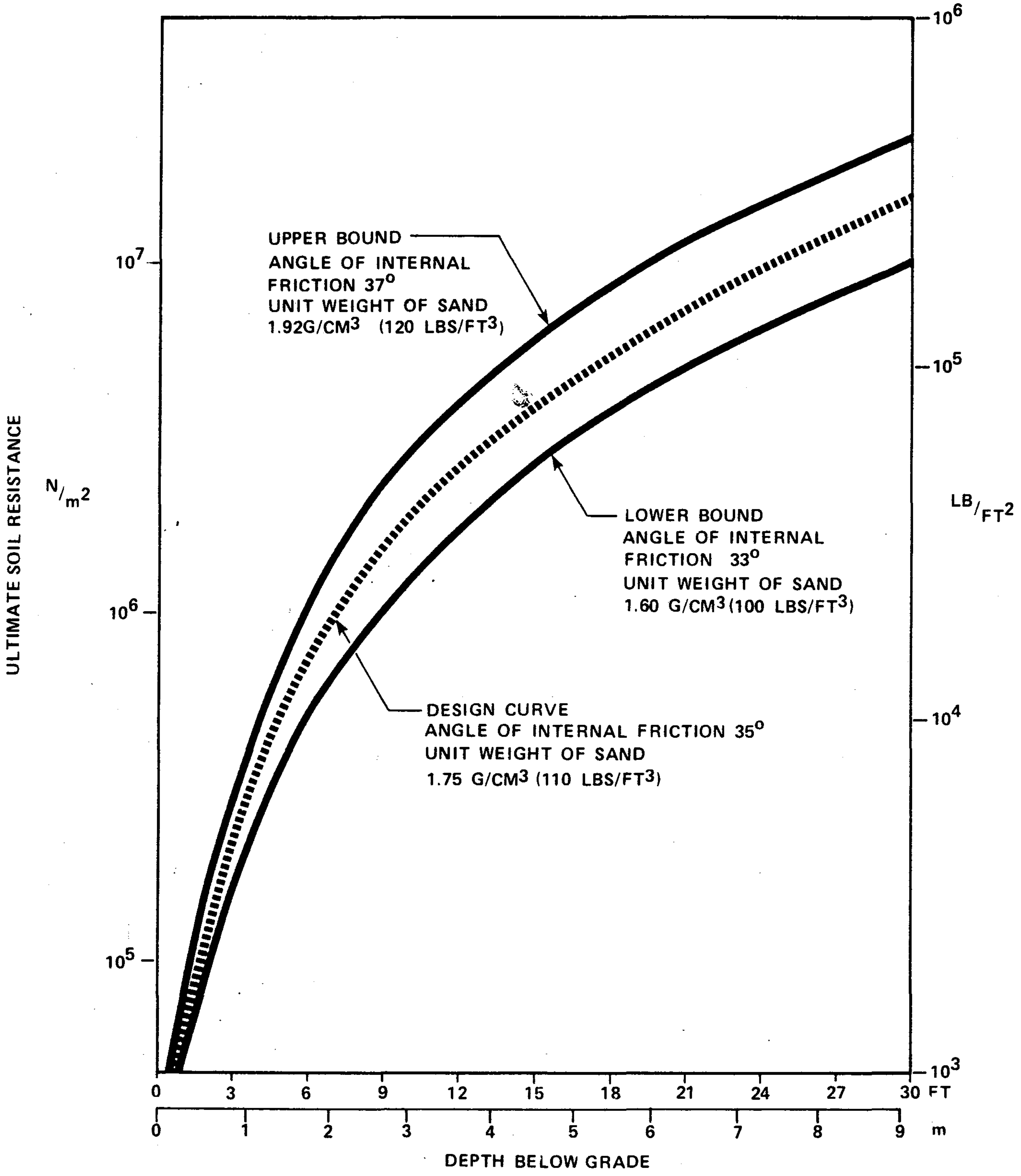


Figure 6-5 ULTIMATE SOIL RESISTANCE

such as those shown in Figures 6-6 through 6-9, which were input to the STRUDL computer program. The pile rotation for each set of soil properties was calculated as a function of pile depth for the 12 m/sec (27 mph) wind load condition. The results, shown in Figure 6-10, reveal that the wide range of possible soil properties has a large effect on the pile depth required to limit pile rotation below 1.05 mrad. The range of soil properties used here indicate that pile depths which provide sufficient restraint against rotation can range anywhere from 1.8 m (6 ft.) to 5.5 m (18 ft.) depending on the soil. Focusing our attention on the rotations of the lower design curve and lower bound curve, a choice of pile depth in the range between 3 m (10 ft.) and 5.5 m (18 ft.) must be made.

The choice is a matter of engineering judgement and the appropriate level of conservatism depends upon what is at stake. In the case of an actual heliostat field where a considerable investment and the cost of the solar energy collection is involved, more extensive soil and pile test data would be gathered in order to narrow the zone of uncertainty. In the present instance, a 4.27 m (14 ft.) pile depth has been selected for the two heliostat foundations at CRTF. This gives an expected 0.6 mrad rotation of the pile in a 12 m/sec (27 mph) wind. The prospects of experiencing the 1.4 mrad rotation, projected for the very conservative lower bound curve of Figure 6-12, are judged to be unlikely. This judgement is supported in principle by the test results that are currently being reported by EPRI (Reference 6-2, 6-3) in their laterally loaded drilled pier program. These results are purported to demonstrate that "existing state-of-the-art techniques for predicting displacement" (e.g., STRUDL) "tend to overstate measured displacements".

Soil deflections along the sub-grade portion of the pile are presented in Figures 6-11 and 6-12. The maximum wind load deflections for the Low Design P-Y curves create soil stress that range from 2 percent of ultimate soil resistance, at the bottom of the pile, to 15 percent of ultimate soil resistance, 0.6 m (1 ft.) below grade. The maximum soil stresses for the Lower Bound P-Y curves range from 4 percent of ultimate soil resistance, at the bottom of the pile, to 16 percent of ultimate soil resistance, .6 m (1 ft.) below grade. Since the deviation from elastic soil behavior tends to increase with load, the relatively small soil loading under the worst stowing conditions is an encouraging indication that permanent set due to repeated 22 m/sec (50 mph) wind loadings should be small.

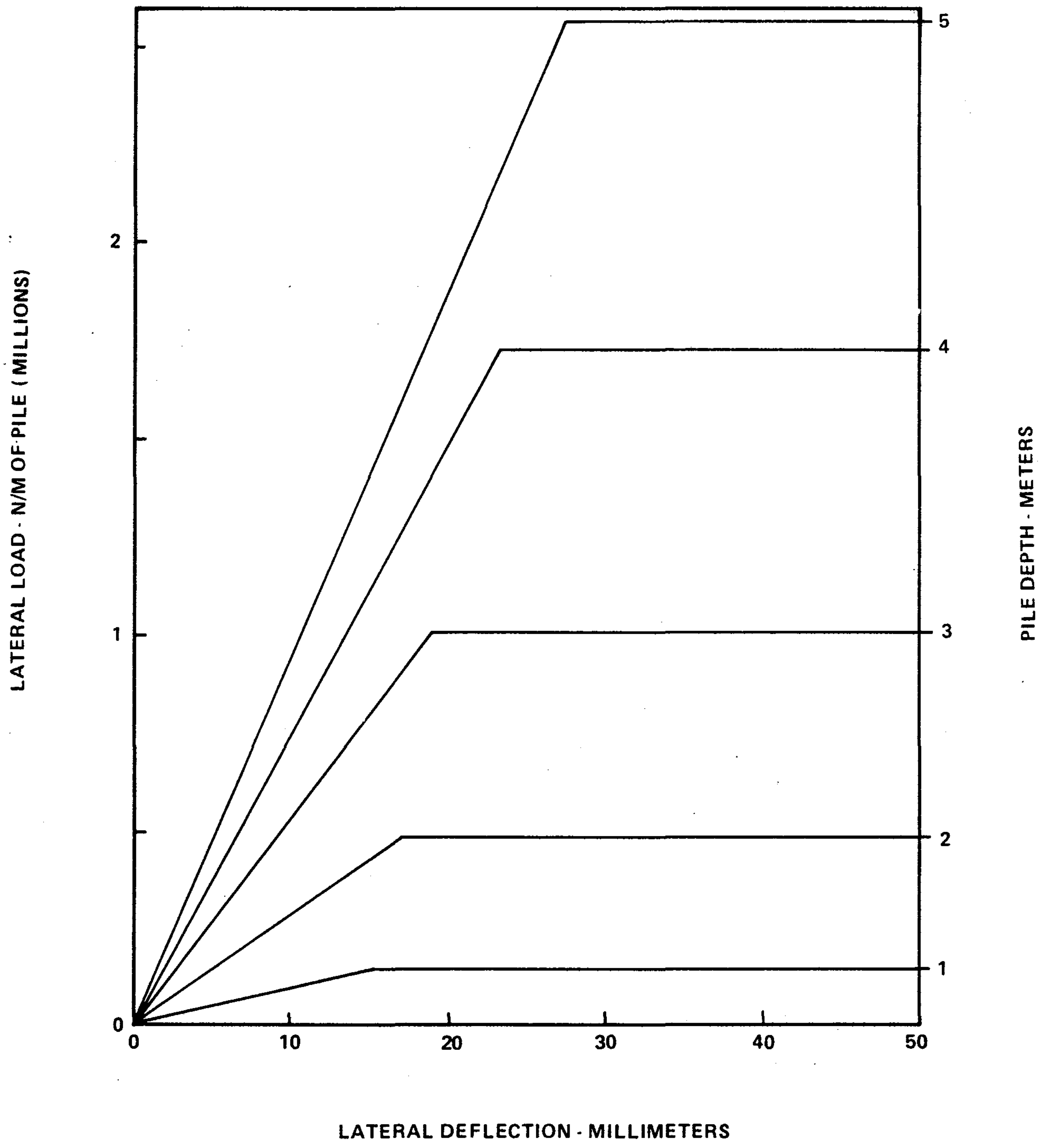


Figure 6 - 6 LOW DESIGN P - Y CURVES - METRIC UNITS

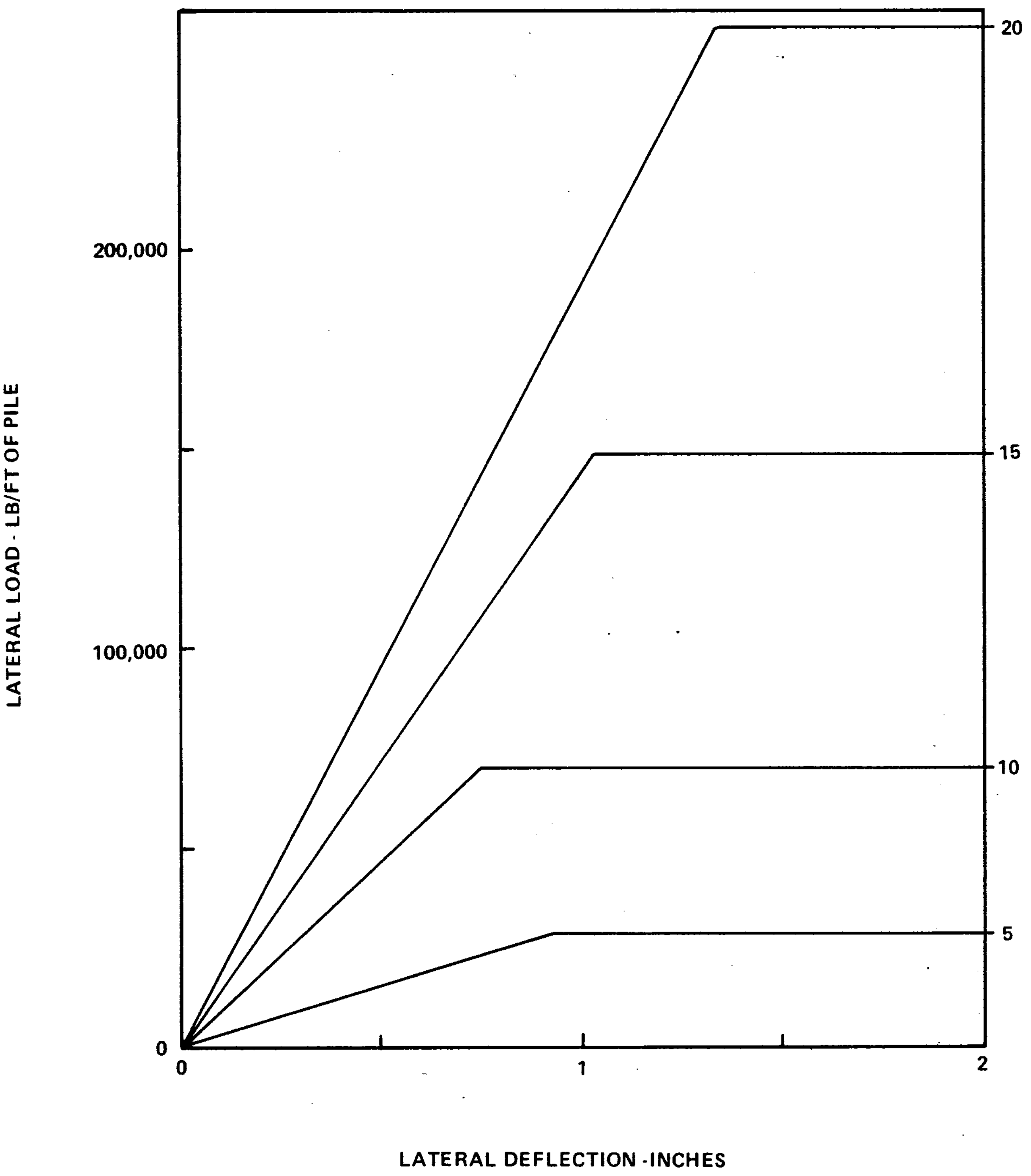


Figure 6 - 7 LOW DESIGN P- Y CURVES - ENGLISH UNITS

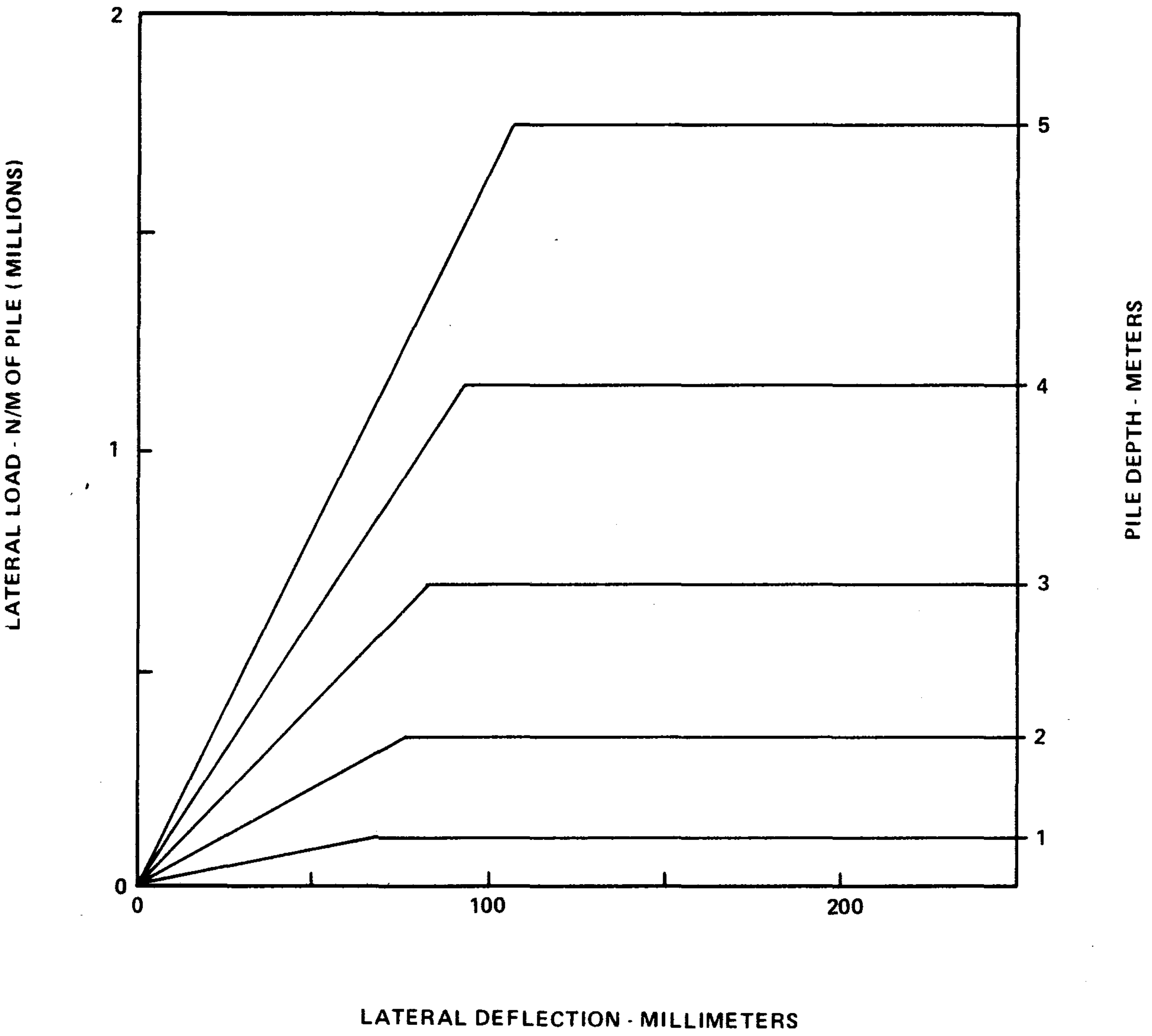


Figure 6 - 8 LOWER BOUND P - Y CURVES - METRIC UNITS

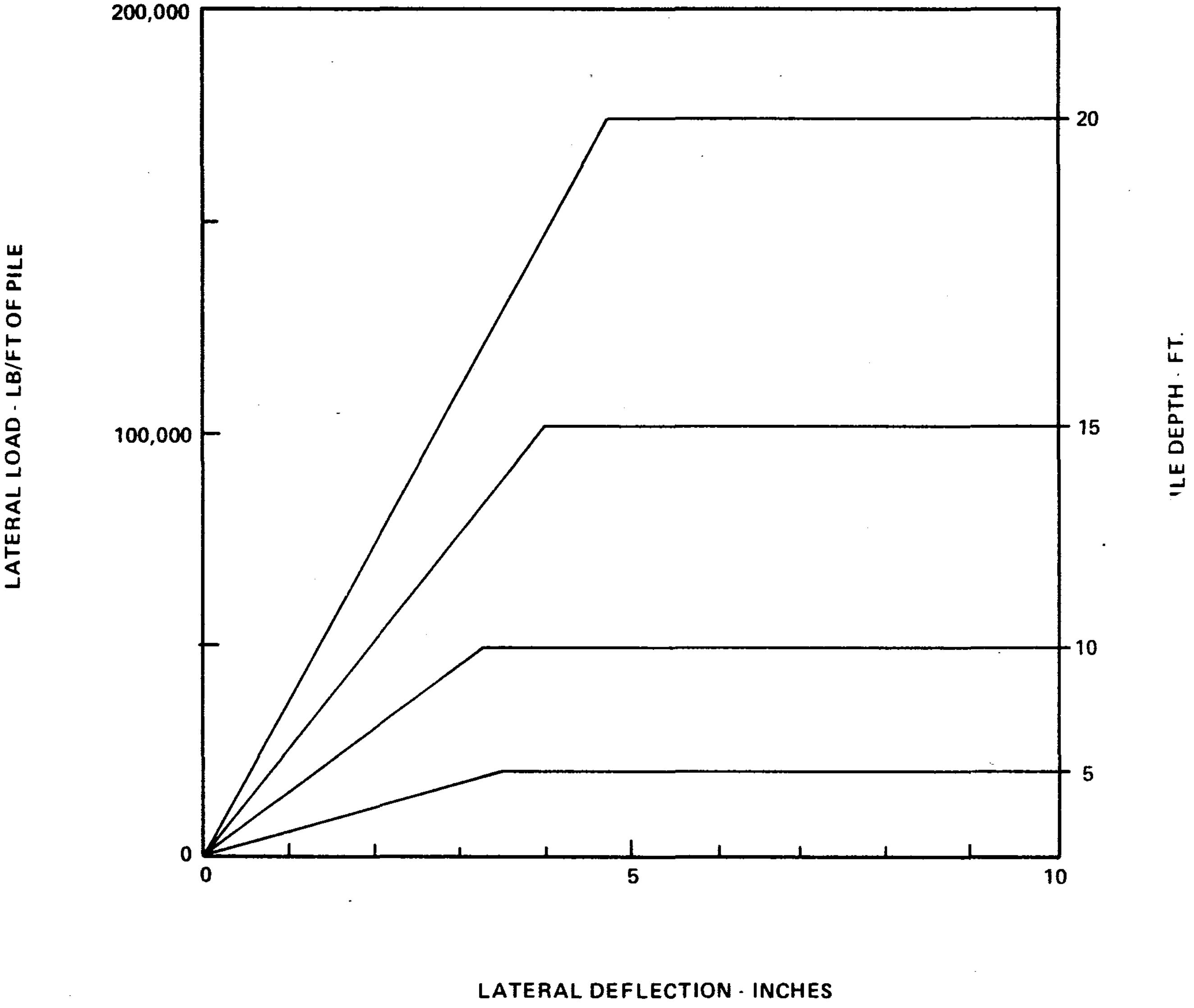


Figure 6 - 9 LOWER BOUND P - Y CURVES -ENGLISH UNITS

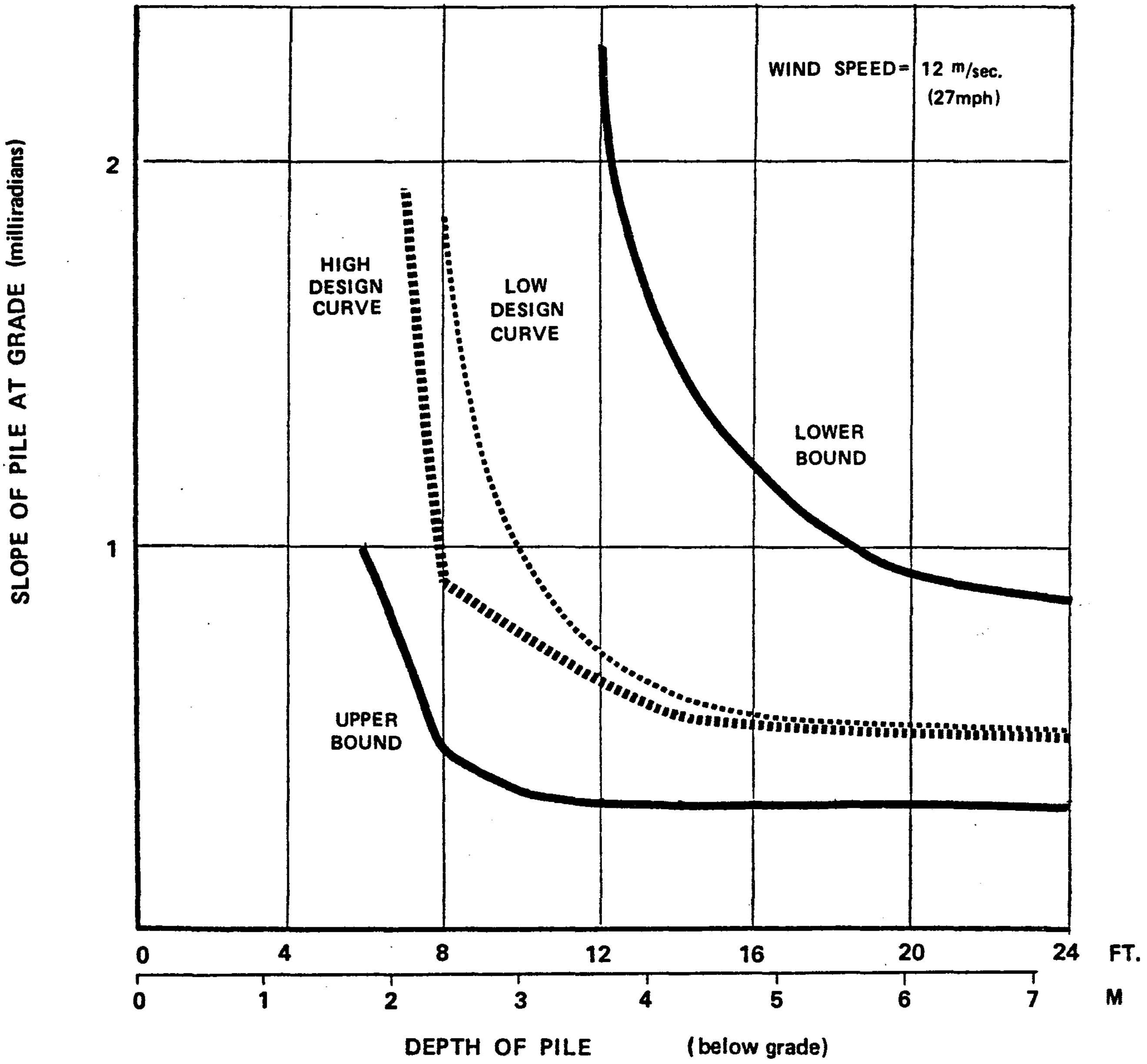


Figure 6 - 10 INFLUENCE OF SOIL PROPERTIES ON PILE ROTATION

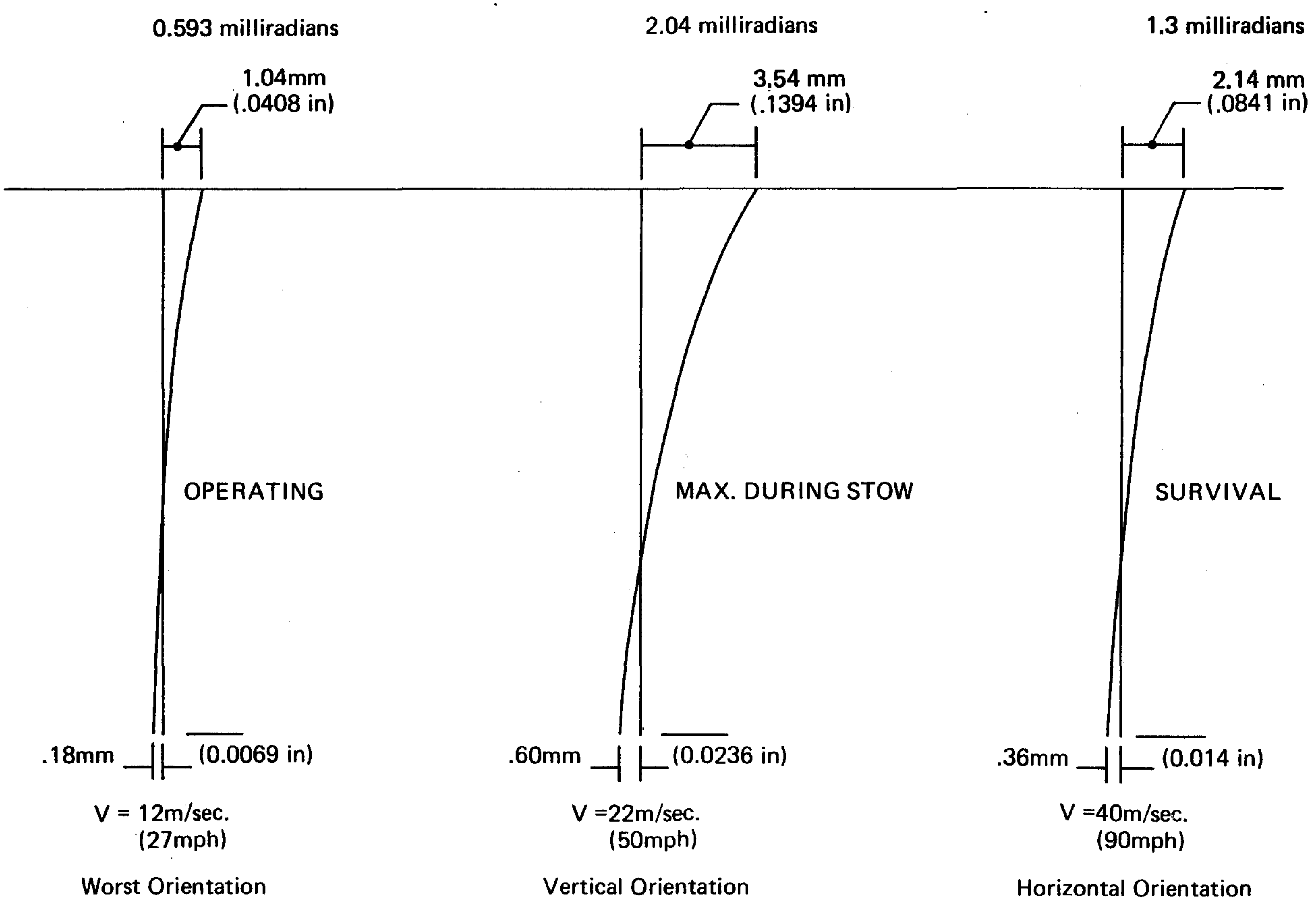


Figure 6-11 PILE DEFLECTIONS FOR 0.61m (2 FT) DIAMETER STEEL PIPE PILE DRIVEN 4.27m (14 FT) BELOW GRADE – LOW DESIGN P-Y CURVES

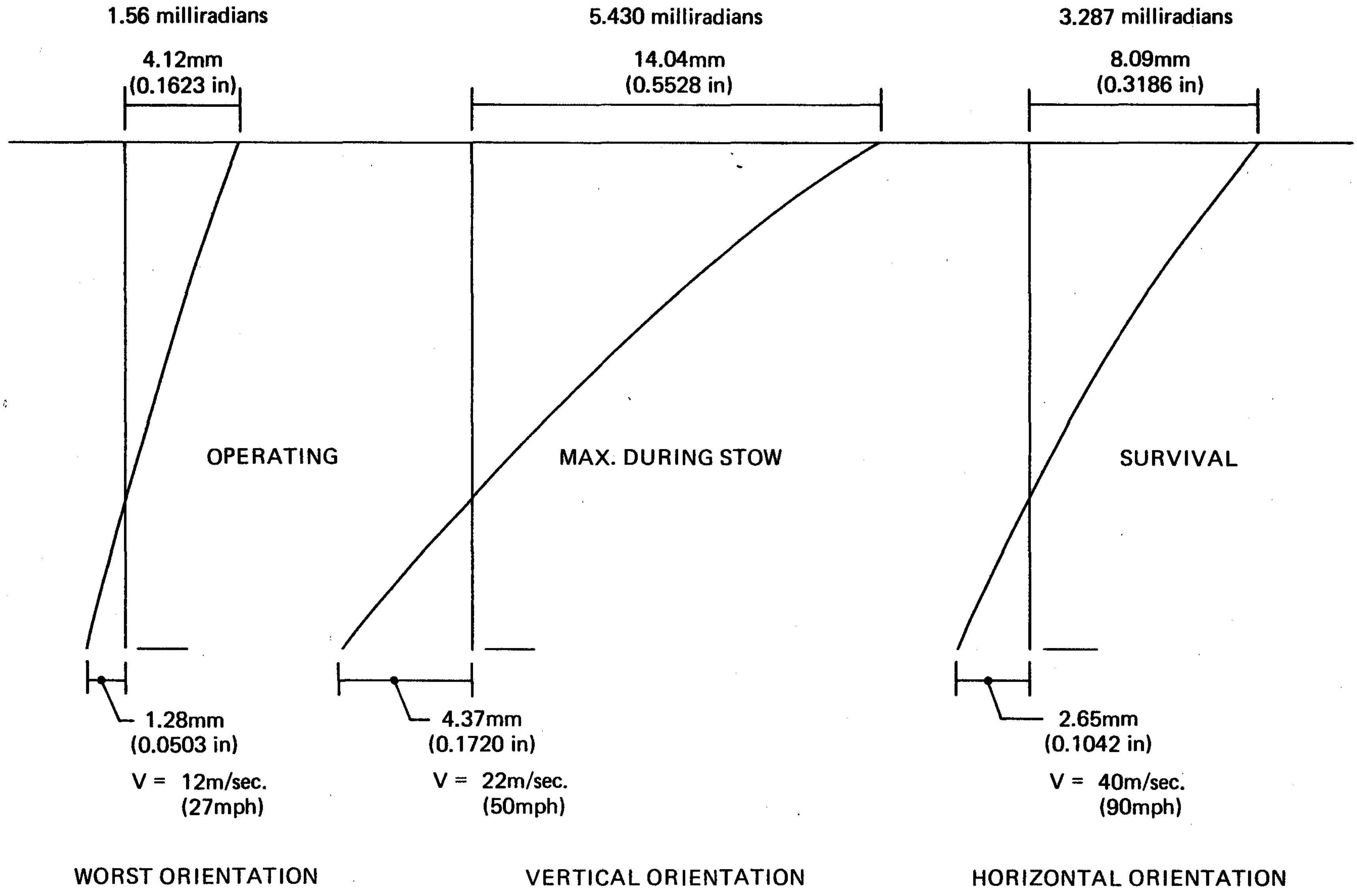


Figure 6-12 PILE DEFLECTIONS FOR 0.61m (2 FT) DIAMETER STEEL PIPE PILE DRIVEN 4.27m (14 FT) BELOW GRADE – LOWER BOUND P-Y CURVES

Foundation Details

The pile design selected for installation at the Central Receiver Test Facility (CRTF) is a .61 m (24 in.) diameter spiral welded steel pipe pile, 7.32 m (25 ft.) long with a 6.35 mm (0.25 in.) wall. It has a flange at one end, for mounting of the drive assembly; and a reinforced opening for housing of the electronic controls. The portions of the pile which are above grade are provided with a protective coating for corrosion prevention. This coating is applied, at the factory, to the exterior and interior surfaces of the pile per the instructions of Specification S-102 (Appendix J). Steel piles driven into undisturbed soil do not require corrosion protection below grade (Reference 6-4).

These and other pile design details are shown in the Figure 6-13 pile drawing.

Figure 6-14 is the pile installation drawing. It specifies required plumbness and driving depth. It also specifies instructions for installation of the Figure 6-15 tapered leveling shims which are attached to the pile flange to compensate for the out of plumbness of the driven pile.

Required pile driving attachments, Figure 6-16, includes a reinforcing cover for the electronic package opening that is in place when the pile is driven. A special driving attachment that will be required for the two CRTF piles is also defined in the Figure 6-16 drawing. Need for this driving attachment will be avoided in larger heliostat field installations through use of a custom vibratory hammer driving head.

Figures 6-17 and 6-18 are interface drawings for the electronic package flange and the pile flange.

Foundation Specification

The specification for installation of the open end pipe piles is presented in Appendix I.

6.1.4 Foundation Installation

Site Preparation

Site preparation consists chiefly of clear and grub operations, rough grading and a survey for the placement of foundation markers.

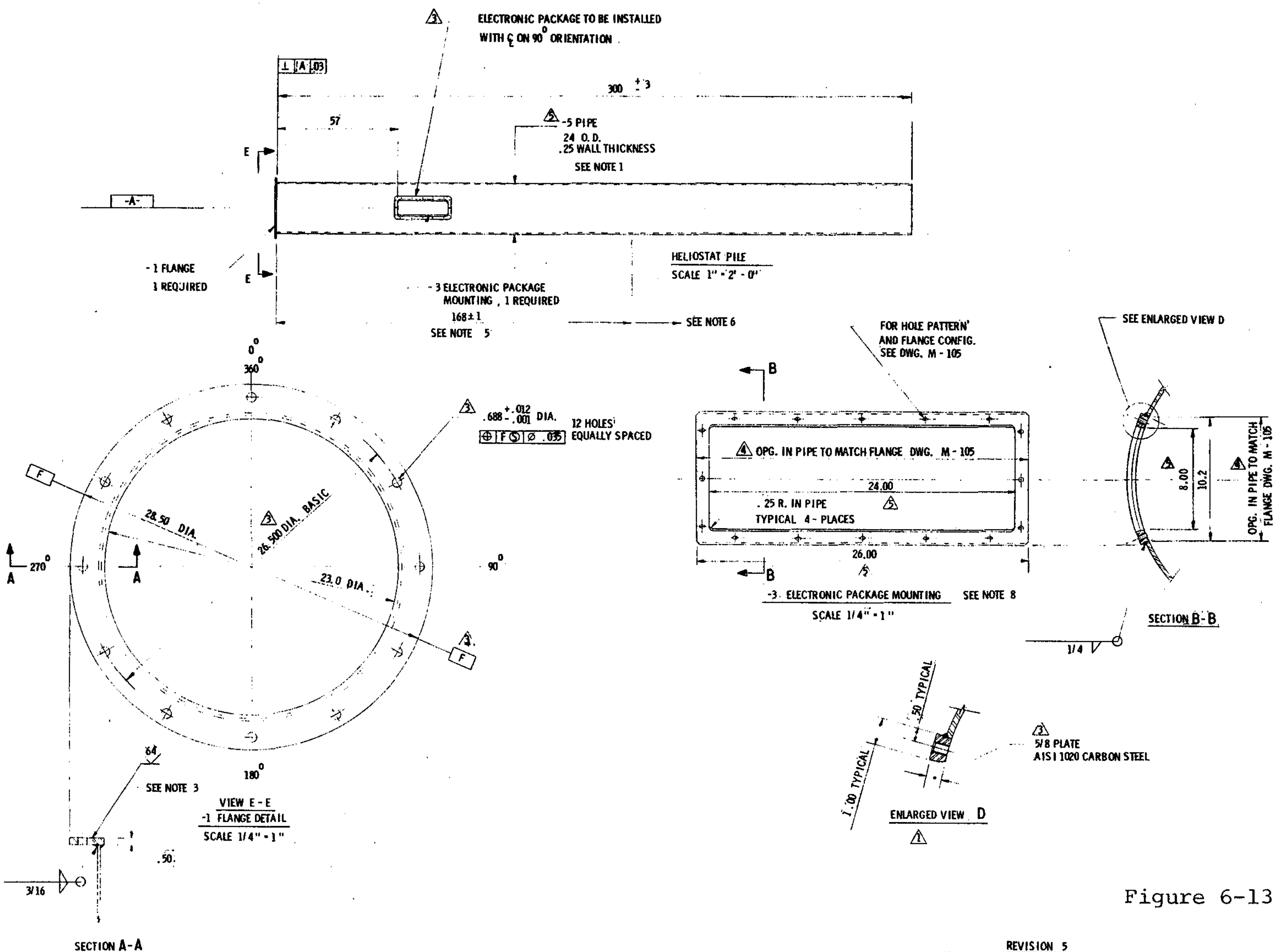


Figure 6-13

NOTES :

1. WELDED PIPE PER ASTM A 252, GRADE 2.
WITHIN 6 INCHES OF THE FLANGE END THE FOLLOWING SHALL APPLY :-
OUTER CIRCUMFERENCE EQUALS 75.4 ± 0.2 INCHES
OUT OF ROUNDNESS (MAX. DIA. - AVERAGE DIA.) NOT TO EXCEED .0625 INCHES. AVERAGE DIAMETER BASED UPON MEASURED OUTER CIRCUMFERENCE.

2. DIMENSIONAL TOLERANCES : .XXX ± .010
.XX ± .03

3. THIS SURFACE SHALL BE FLAT WITHIN .001

4. DIMENSIONS ARE IN INCHES

5. COAT INNER AND OUTER SURFACES PER SPECIFICATION S-102 FOR THIS PORTION OF PILE. APPLY NO COATING TO FLANGE FACE

6. NO COATING REQUIRED BEYOND THIS POINT. INADVERTANT RUNOUT PERMITTED

7. WELD PER AWS D1.1 STRUCTURAL WELDING CODE

8. THIS ARRANGEMENT IS IN CONFORMITY WITH NORTHRUP INC. DESIGN FOR ELECTRONIC PACKAGE MOUNTING

9. COAT FLANGE FACE WITH GREASE AND ATTACH M - 104 - 3 FLANGE COVER

REVISION 3

ELECTRONIC PACKAGE MOUNTING FLANGE WAS 3/8 THICK AND ORIENTATION ADDED
1 FLANGE HOLE PATTERN DIMENSIONS ADDED

REVISION 1

ELECTRONIC PACKAGE MOUNTING FLANGE WAS FLAT
SECTION C - C REMOVED NOTES 8 & 9 ADDED
HOLDS REMOVED VIEW D ADDED

REVISION 5

ADD:
a. -5 PIPE TO HELIOSTAT PILE.
b. 26.00 & 24.00 DIMENSIONS TO ELECTRONIC PACKAGE MOUNTING.
c. 8.00 AND 10.2 DIMENSIONS TO SECTION B-P

CHANGE:
NOTE 1. WELDED PIPE.... TO NOTE 1. WELDED PIPE....

6	12/10/80	REVISIONS NOTED				HAF	RL	
4	[illegible]	OPG. IN PIPE WAS 24.00 x 8.00				HAF	RL	
3	6/4/80	REVISIONS NOTED				HAF	RL	
2	5/15/80	NOTE 1 REVISED				HAF	RL	
1	4/9/80	REVISIONS NOTED				HAF	RL	
0	3/24/80	ISSUED FOR FABRICATION				HAF	RL	
No.	DATE	REVISIONS	BY	CHKD				APPR

SCALE NOTED
DESIGNED
DRAWN CRD

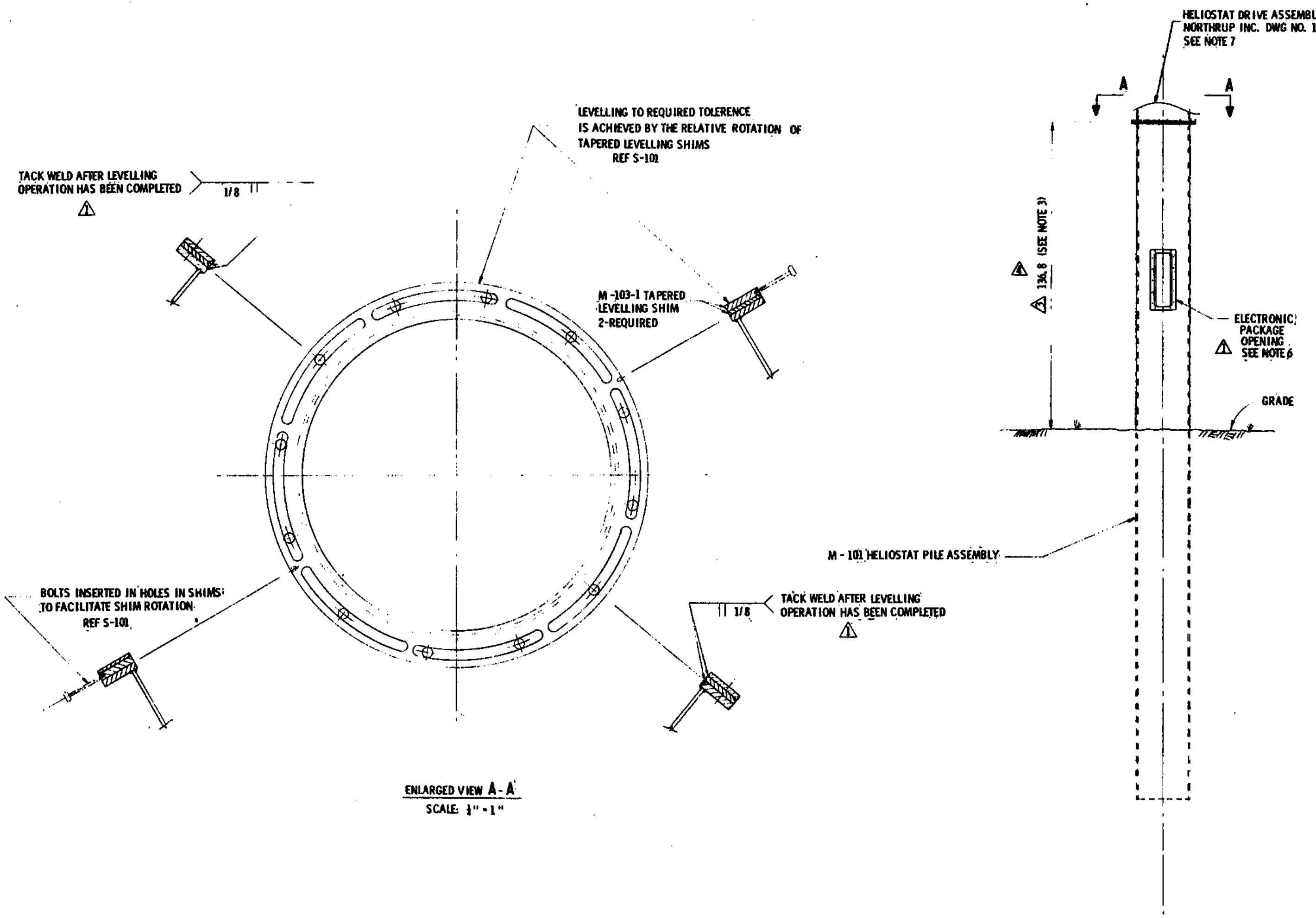
BECHTEL
SAN FRANCISCO

SECOND GENERATION HELIOSTAT DEVELOPMENT

HELIOSTAT PILE ASSEMBLY AND DETAILS

JOB No.	DRAWING No.	REV.
13353	M - 101	5

22 x 34 "D" SIZE



INSTALLED PILE
SCALE: 1"=2'-0"

NOTES :

1. LEVEL SHIMS PER INSTRUCTIONS IN PILE DRIVING SPECIFICATION S-101
2. PILE MUST BE PLUMB WITHIN 2% (2.73" IN 136.5")
3. ELEVATION OF FLANGE SHALL NOT DEVIATE FROM DIMENSION SHOWN BY MORE THAN 2"
4. ELECTRONIC PACKAGE OPENING SHALL BE ORIENTED TO FACE AWAY FROM TOWER
5. PILE SHALL BE DRIVEN PER PILE DRIVING SPECIFICATION S-101
6. ELECTRONIC PACKAGE COVER DWG. M-104-5 SHALL BE INSTALLED WITH ALL BOLTS TIGHTENED WHEN PILE IS DRIVEN
7. HELIOSTAT DRIVE ASSEMBLY FLANGE TO BE SECURED WITH 12, 5/8-11 UNC CL2 SELF LOCKING NUTS AND FLAT WASHERS, SUBSEQUENT TO PILE PLACEMENT. ELECTRONIC PACKAGE (NORTHRUP INC. DWG. NO. 12-400) SHALL BE INSTALLED WITH 16, 5/16-24 UNF x 1" CL2B BOLTS WITH FLAT WASHERS SUBSEQUENT TO DRIVING PILE.

9. DIMENSIONS ARE IN INCHES
10. WELD PER AWS D1.1 STRUCTURAL WELDING CODE
11. REMOVE M-104-3 PLYWOOD FLANGE COVER AND ATTACH M-104-1 DRIVING STUB PRIOR TO DRIVING PILE.

HOLDS REMOVED
TACK WELDS WERE ON O.D. OF SHIMS

REVISION 4

CHANGED: (a) NOTE 2. ...2% (2.58" IN 129") TO (2.73" IN 136.5")
(b) NOTE 7. ...FLAT WASHER. TO ...FLAT WASHER SUBSEQUENT TO DRIVING PILE.
(c) PILE HEIGHT FROM 135 TO 136.8
DELETED: NOTE 8. (TOLERANCE. X-.100)
ADDED: NOTE 11.

Figure 6-14

4	12/9/8	REVISIONS NOTED				HAF	RL	
3	9/19/80	PILE HEIGHT WAS 129				HAF	RL	
2	4/6/80	24 UNF x 1 WAS 18 UNC x 1½				HAF	RL	
1	4/1/80	REVISIONS NOTED				HAF	RL	
0	3/21/80	ISSUED FOR FABRICATION				HAF	RL	

NOTED
CD

BECHTEL
SAN FRANCISCO

SECOND GENERATION HELIOSTAT DEVELOPMENT

HELIOSTAT PILE INSTALLATION

JOB No.	DRAWING No.	REV.
13353	M - 102	4

SIZE B 11 X 17

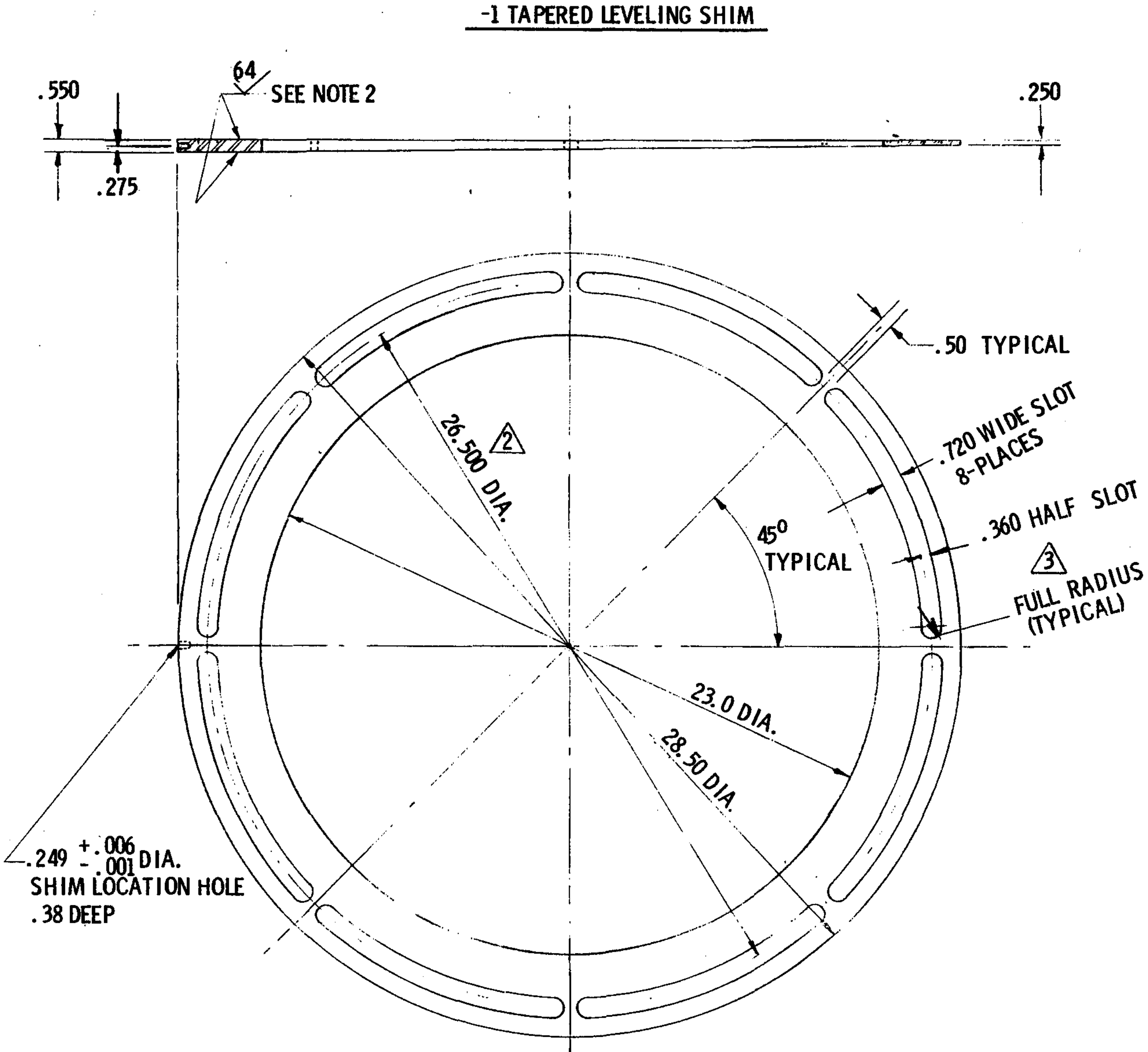


Figure 6-15

NOTES :

1. TOLERENCES .XXX ± .010
   .XX ± .030
   X° ± 2°
2. THESE SURFACES MUST BE FLAT WITHIN 0.001
3. FABRICATE OF AISI 1020 CARBON STEEL THAT HAS BEEN NORMALIZED AT 1100°F (MIN.) FOR 1 HOUR (MIN.) FOR DIMENSIONAL STABILITY
4. DIMENSIONS ARE IN INCHES
5. △1 COAT O.D. PER. SPECIFICATION S - 101
6. △1 AFTER FABRICATION, COAT MACHINED SURFACES WITH GREASE AND WRAP IN HEAVY WAX PAPER

No.	DATE	REVISIONS	BY	CH'K	DSGN SUPV.	ENG'R	PROJ. ENGR.	CLIENT
△3	12/4/80	FULL RADIUS FOR SLOTS	SH	E	L	HAF	RL	
△2	6/4/80	26.500 DIA ADDED	CBY	E	E	HAF	RL	
△1	4/10/80	NOTES 5 & 6 ADDED	CBY	E	E	RL	RL	
△0	3/24/80	ISSUED FOR FABRICATION	MJ	E	E	RL	RL	

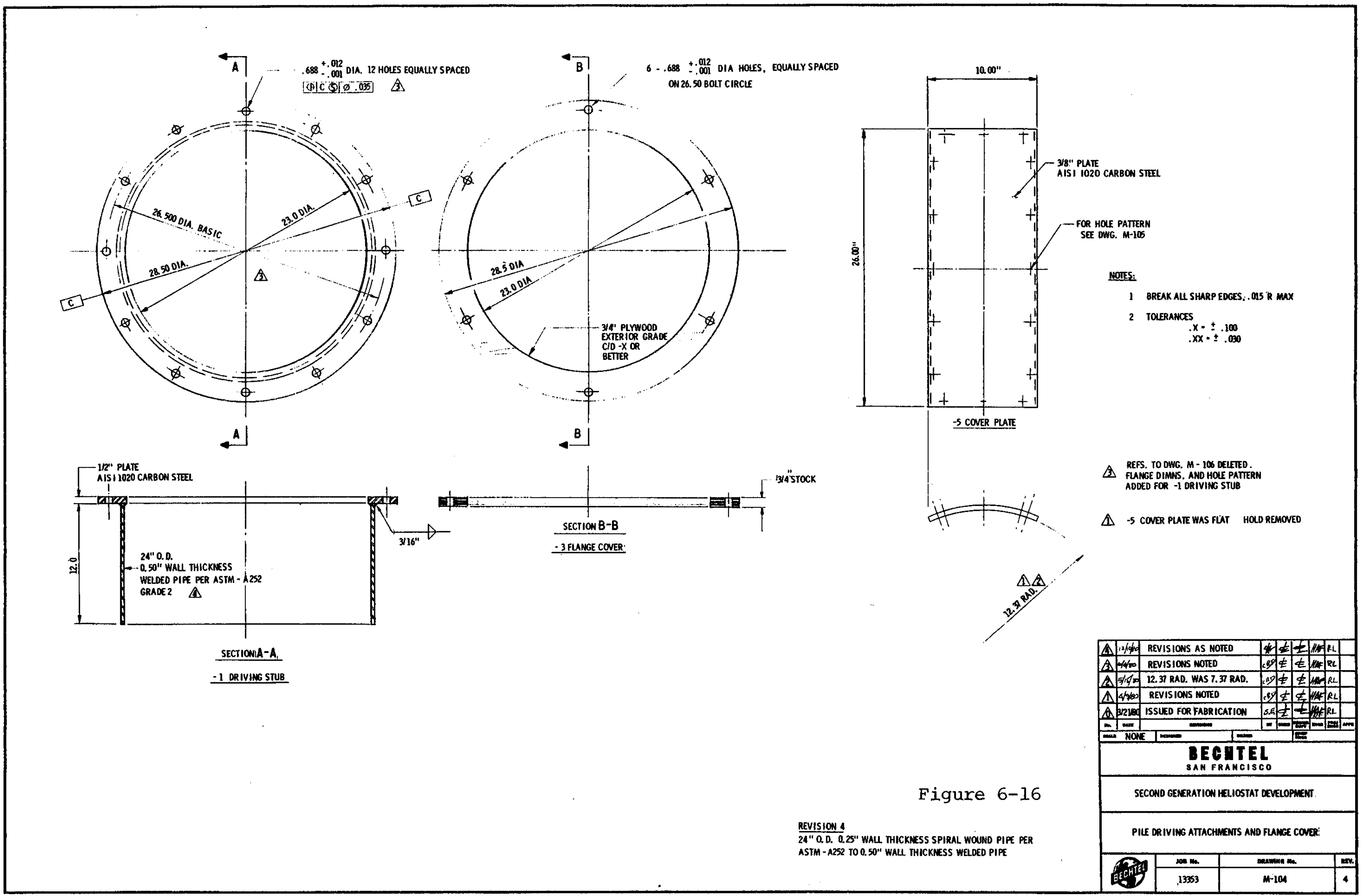
SCALE 1/4 = 1"	DESIGNED	DRAWN CD

BECHTEL
SAN FRANCISCO

SECOND GENERATION HELIOSTAT DEVELOPMENT

TAPERED LEVELLING SHIM

	JOB No.	DRAWING No.	REV.
BECHTEL	13353	M - 103	3



NOTES:

1 BREAK ALL SHARP EDGES, .015 R MAX

2 TOLERANCES
.X = ± .100
.XX = ± .030

3 REFS. TO DWG. M - 106 DELETED. FLANGE DIMNS. AND HOLE PATTERN ADDED FOR -1 DRIVING STUB

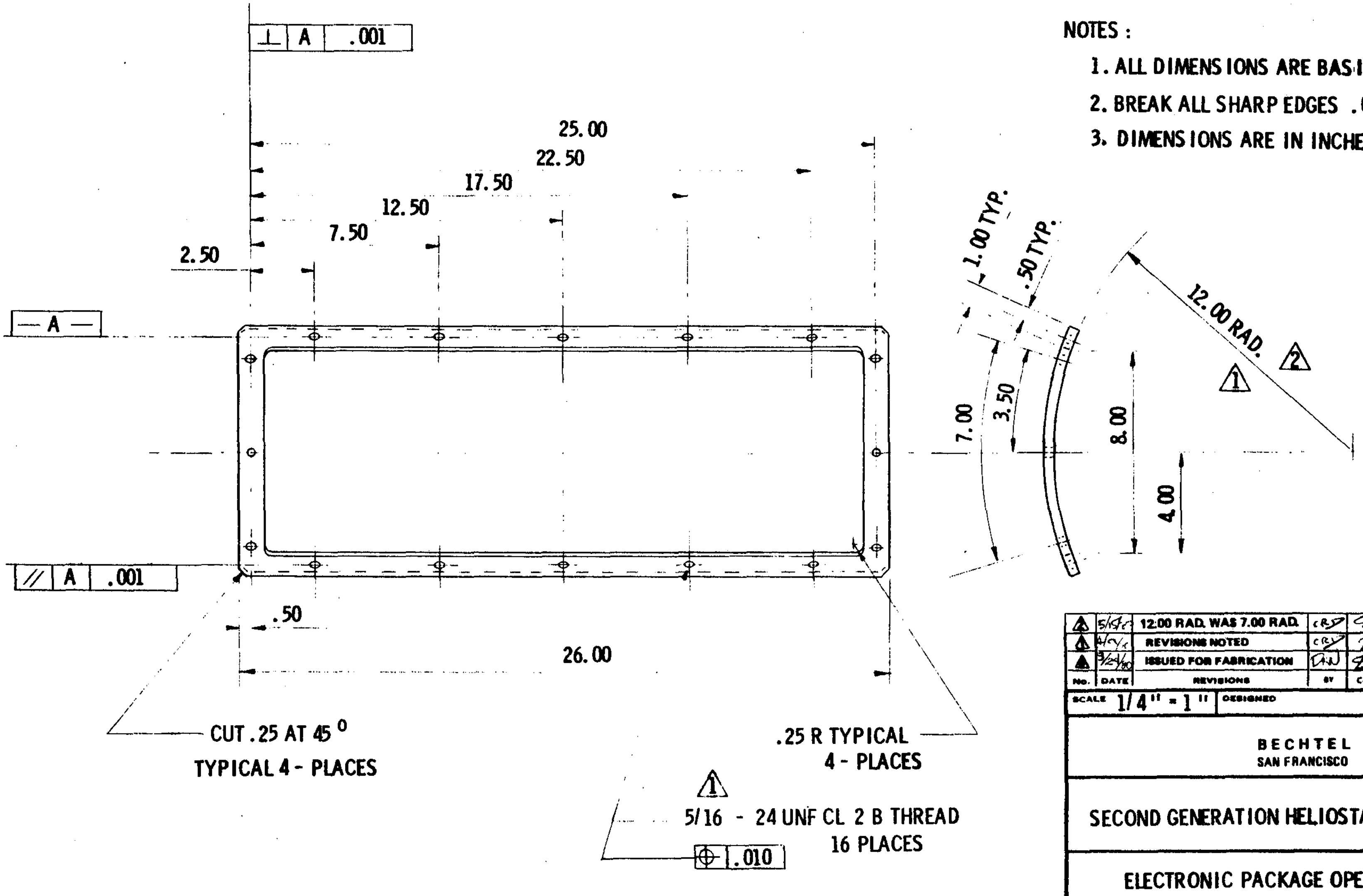
1 -5 COVER PLATE WAS FLAT HOLD REMOVED

REVISION 4
24" O.D. 0.25" WALL THICKNESS SPIRAL WOUND PIPE PER ASTM - A252 TO 0.50" WALL THICKNESS WELDED PIPE

4	12/10/80	REVISIONS AS NOTED	[illegible]	[illegible]	[illegible]	HAF	RL	
3	6/4/80	REVISIONS NOTED	[illegible]	[illegible]	[illegible]	HAF	RL	
2	5/19/80	12.37 RAD. WAS 7.37 RAD.	[illegible]	[illegible]	[illegible]	HAF	RL	
1	4/9/80	REVISIONS NOTED	[illegible]	[illegible]	[illegible]	HAF	RL	
0	3/21/80	ISSUED FOR FABRICATION	S.E.	[illegible]	[illegible]	HAF	RL	

Figure 6-16

SIZE B 11 X 17



NOTES :

1. ALL DIMENSIONS ARE BASIC
2. BREAK ALL SHARP EDGES .015 R MAX.
3. DIMENSIONS ARE IN INCHES

HOLES WERE .311 DIA.

△1 FLANGE WAS FLAT

Figure 6-17

No.	DATE	REVISIONS	BY	CH'K	DSGN SUPV.	ENG'R	PROJ. ENGR.	CLIENT
△2	5/15/80	12.00 RAD. WAS 7.00 RAD.	CRY			HAF	RL	
△1	[illegible]	REVISIONS NOTED	CRY			HAF	RL	
▲	3/24/80	ISSUED FOR FABRICATION	DAW				RL	

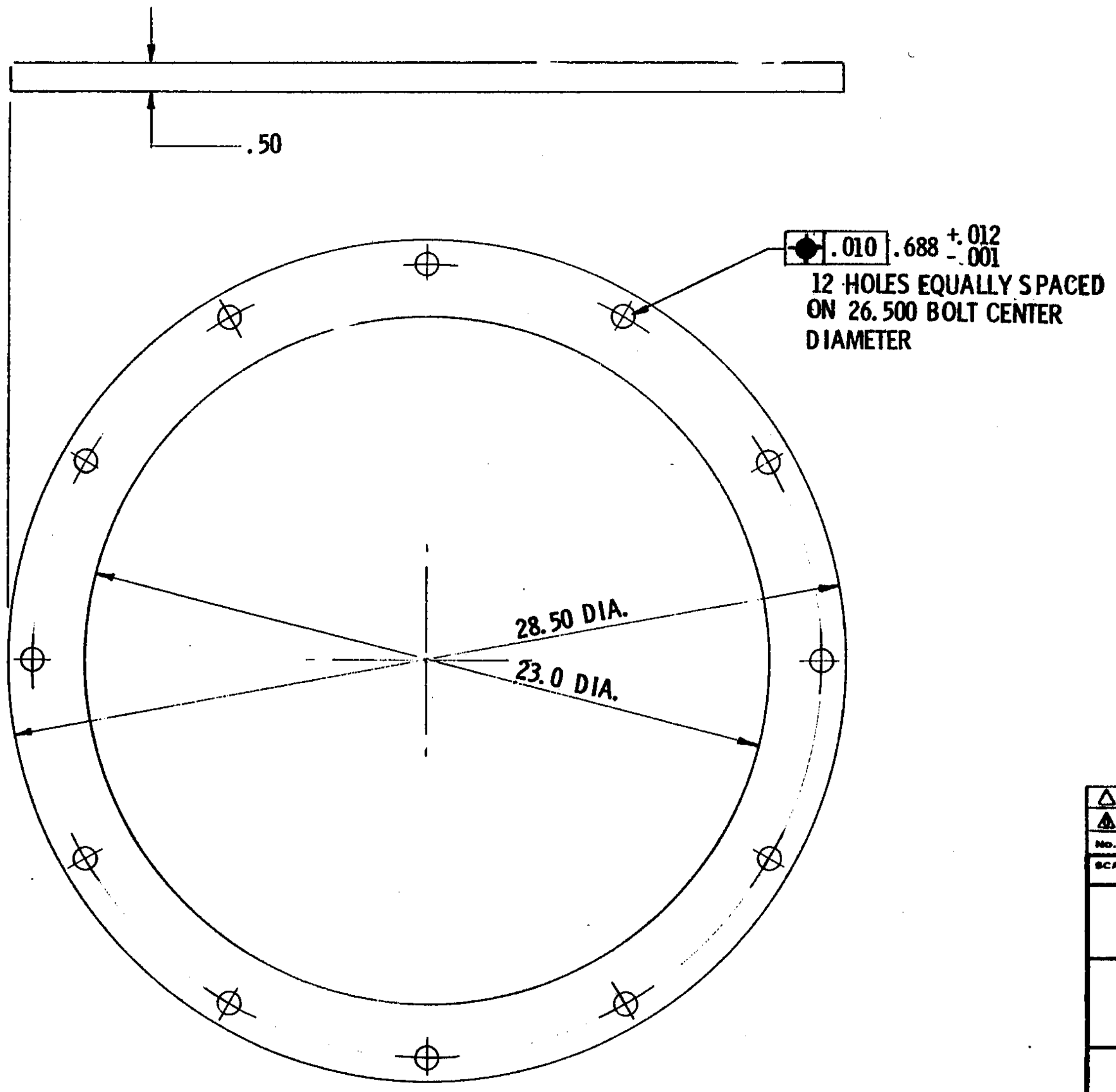
SCALE 1/4" = 1" | DESIGNED | DRAWN CD

BECHTEL
SAN FRANCISCO

SECOND GENERATION HELIOSTAT DEVELOPMENT

ELECTRONIC PACKAGE OPENING FLANGE
INTERFACE DRAWING

	JOB No.	DRAWING No.	REV.
	13353	M-105	2



NOTES:

1. ALL DIMENSIONS ARE BASIC
2. BREAK ALL SHARP EDGES .015R MAX.
3. DIMENSIONS ARE IN INCHES

Figure 6-18

No.	DATE	REVISIONS	BY	CH'K	DSGN SUPV.	ENG'R	PROJ. ENGR.	CLIENT
△								
△0	3/24/80	ISSUED FOR FABRICATION	DKW			HDF.	RL	

SCALE $\frac{1}{4}$" = 1" DESIGNED DRAWN CD

BECHTEL
SAN FRANCISCO

SECOND GENERATION HELIOSTAT DEVELOPMENT

HELIOSTAT PILE FLANGE
INTERFACE DRAWING

JOB No.	DRAWING No.	REV.
13353	M - 106	0

Pile Placement

The open end steel pipe piles are driven with a vibratory hammer. These hammers contain counter rotating weights which are operated by electric or hydraulic drives to vibrate the pile at a frequency of 10 to 20 hertz. The natural frequency of most soils fall in this range. The effect of the vibration is to fluidize the soil so as to permit the weight of the pile and the hammer to force the pile into the ground. This approach is particularly effective with low displacement piles (e.g., sheet piling and open ended pipes) in sandy soils. Very rapid pile placement is possible under these conditions. Driving rates of 2.5 to 5 cm per second (1 to 2 inches per second) or 1.5 to 3 m per minute (5 to 10 ft. per minute) are normal for soil such as that specified for CRTF. Figure 6-19 shows a forklift, outfitted with barrel-jaws, positioning the pile so the vibratory hammer can be attached to the driving stub. When the hammer jaws clamp onto the stub, the forklift is disengaged and leaves to fetch the next pile, while the vibratory hammer begins the pile driving operation.

A crew of 7 workers with a crane and forklift can install approximately 40 piles per day. Each crew is made up of:

1 Crane Operator

1 Oiler

1 Pile Driver Foreman

3 Pile Drivermen

1 Forklift Operator.

Two or three such crews are needed to install heliostat foundations for a typical 50 MWe power plant requiring approximately 6000 foundations. They are supported by a superintendent and an engineer (part-time).

The piles are driven to satisfy the requirements of the Specification S-101, "Installation of Open End Pipe Piles" (Appendix I) and the Heliostat Pile Installation Drawing (Figure 6-14). The major requirements are that the pile must be plumb within 2 percent and the pile must be driven so as to place the pile flange 3.47 m (11.40 ft.) above grade ± 51 mm (2 inches).

Flange Leveling Shim Installation

When the pile has been driven, leveling shims are installed on each pile flange to correct for pile out-of-plumbness and to provide a level surface for support of the drive assembly.

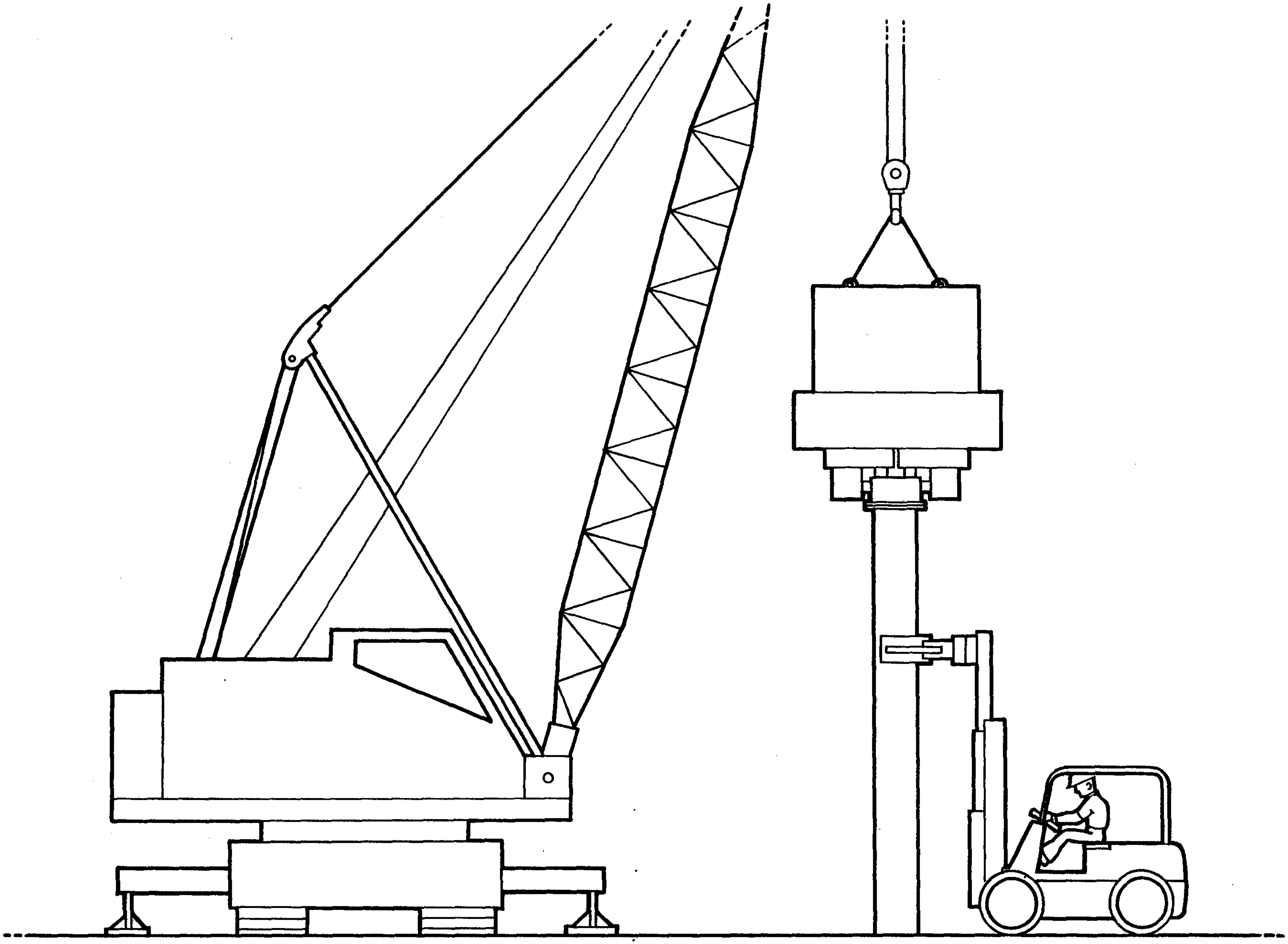


Figure 6 - 19 POSITIONING OF PILE PRIOR TO DRIVING

A pile, that is out-of-plumb by the full 2 percent allowed, has one edge of the 0.72 m (28.5 in.) diameter flange approximately 14.5 mm (0.57 in.) lower than the opposite edge. The tapered leveling shim (Figure 6-15) is designed to correct this condition. This is accomplished by installing a pair of tapered leveling shims onto each pile flange following the instructions of the Heliostat Pile Installation drawing (Figure 6-14) and the S-101 pile installation specification (Appendix I).

The leveling shims are installed by a crew consisting of 7 workers, a forklift and welding equipment. Each crew is capable of installing shims on 48 piles per day. The crew includes:

5 Millwrights

1 Forklift Operator

1 Welder

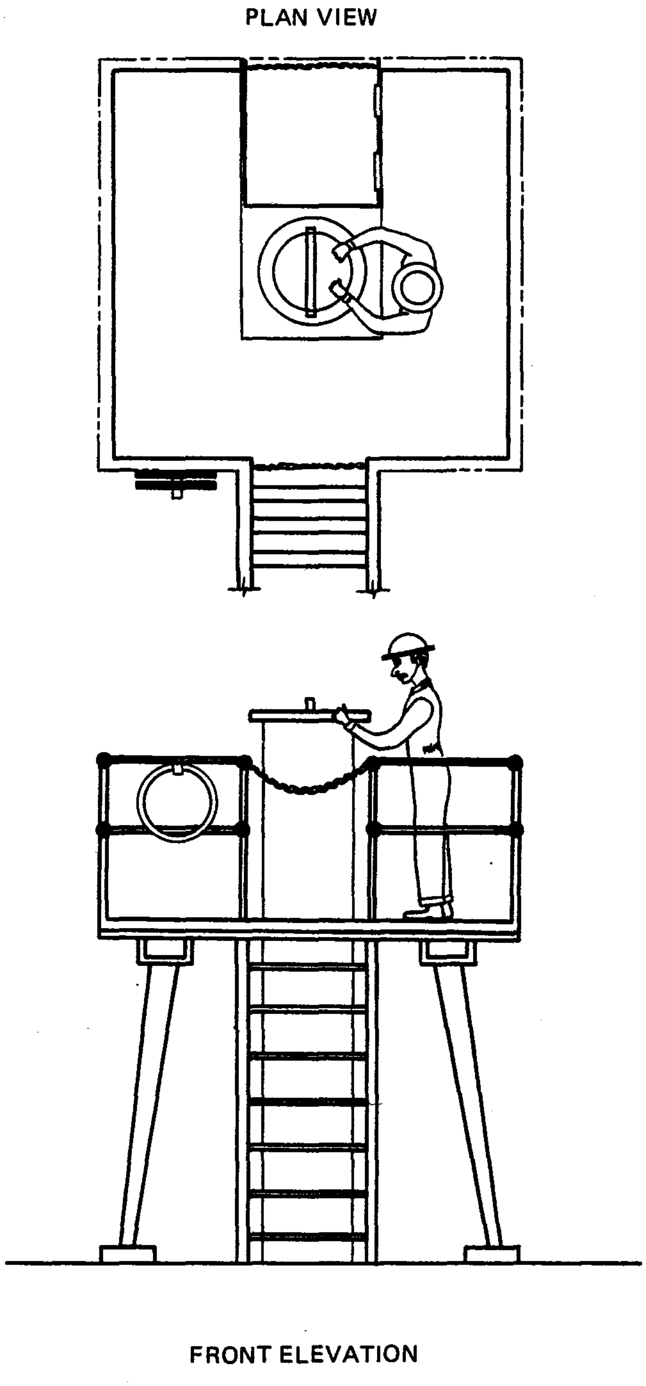
The installers work on special stands (Figure 6-20) which place them in proper proximity to the pile flange. A supply of leveling shims and leveling tools are stored on the shim installation stand platform. When the shims are installed to give the desired level surface, they are tack welded in place by the welder. The stand is left in place for subsequent use by the heliostat installation crews which are following close behind the shim installers. The heliostat installation crew uses the stand to assist riggers in placement of the heliostat upon the pedestal. Then the forklift operator moves the stand to a new pedestal for subsequent use by a shim installer.

The mounting surface, provided by the shims, is level to within 0.1 mrad. Each shim installation requires approximately 1.3 worker hours.

6.2 HELIOSTAT ASSEMBLY

In order to minimize shipping cubage, heliostat parts are assembled at the site. The following parts,

- frame truss members
- frame cross braces
- torque tubes
- drive assemblies
- mirror modules



PLAN VIEW

FRONT ELEVATION

Figure 6-20 SHIM INSTALLATION STAND

are delivered by truck to the site assembly facility. There the heliostats are assembled and the mirror modules are canted to the desired focal length.

6.2.1 Assembly Facility

A single assembly line capable of producing 48 heliostats per day is housed in a building measuring 15.2 m (50 ft.) by 45.7 m (150 ft.). This facility, illustrated in Figure 6-21, provides a work station for half-frame assembly; another station for mirror module placement and joining of drive and half-frame assemblies; and a third work station for final alignment and fastening of the mirror modules. In addition there are provisions for performing certain work tasks in the unloading areas, and for transport of frame trusses, mirror modules and drive assemblies to the work station by overhead rail hoists. The torque tubes and frame cross bracing are delivered to the work station on carts. Bulk materials such as rivets, welding rods, jam nuts, washers, etc., are located in bins at the respective work stations.

There are no provisions for warehousing of unassembled parts at the site. Heliostat parts are unloaded from trucks at docks adjacent to the work stations and fed directly into the assembly line. The truck trailers provide all on site storage of parts. Trailers containing parts are brought to the site each day and parked nearby. Empty trailers are then returned to the factory.

The assembly line day shift operation is based on a 20 minute work cycle at each work station and a 0.75 productivity factor. Therefore work advances to the next work station at approximately 27 minute intervals.

Work Station No. 1 - Half-Frame Assembly

The two heliostat half-frames are assembled at Work Station No. 1. Each half-frame requires a crew of five; one unloader, two riveters and two welders. Thus, Work Station No. 1 requires a total of ten workers.

The unloaders work cycle consists of unloading a torque tube onto a cart-mounted mandrel and moving the cart to the half-frame assembly area. Next he unloads two half-frame trusses, attaches two wheels to each truss, lifts the trusses with an overhead hoist and conveys them to the nearest half-frame assembly area.

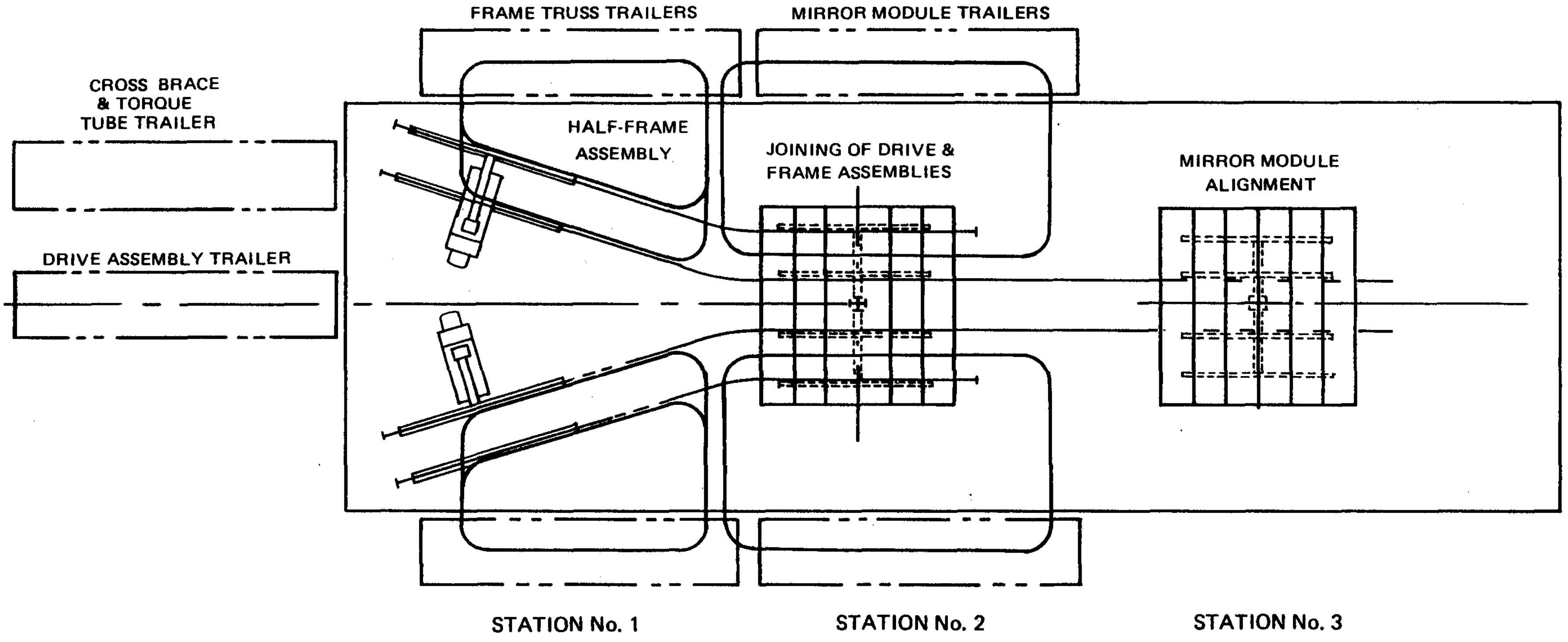


Figure 6-21 HELIOSTAT ASSEMBLY FACILITY FLOOR PLAN

The work cycle at the half-frame assembly area (see Figure 6-22) starts with the positioning of the torque tube on a vertically adjustable cradle (Figure 6-23) between the tracks. The transport cart mandrel is withdrawn from the positioned torque tube, two half-frame trusses are slid over the tube ends and positioned against the torque tube gussets. The torque tube cradle is then lowered to permit the truss wheels to engage the tracks (Figure 6-24). With the two welders holding the trusses in a vertical position, the two riveters position jigs which engage certain frame truss holes to place each truss in the required orientation relative to the other. With the trusses now positioned by the jigs, the riveters start making the 14 rivets which attach the half-frame trusses and the cross members and the welders weld the two torque tube gussets to the truss rails. Finally the welds are touched up with paint.

Work Station No. 2 - Joining of the Half-Frame and Drive Assemblies

The operations conducted at Work Station No. 2 are illustrated in Figure 6-25. This work station occupies a total of fifteen workers, three of whom are engaged in the joining of the half-frame and drive assemblies, and twelve of whom are engaged in the preparation and placement of mirror modules.

The first three workers lower the drive assembly onto a lazy susan which is sitting on an elevation jack. While one worker departs to unload the next drive assembly, the other two align the half-frame and drive assembly torque tube flanges. They next actuate mechanisms which move the rails the necessary 25 mm (1 inch) required to mate the two flange pairs. The flanges are then joined with bolts.

The six mirror modules required for each half-frame are unloaded and prepared for placement by a crew of three workers. Unloading is accomplished with the aid of an overhead hoist. Preparation for placement consists of installation of 18 mirror module mounting studs, and the installation of a jam nut and a stand-off nut on each stud. The mirror modules are then conveyed to the Work Station No. 2 assembly area. Six modules are then placed on each half-frame with a crew of three workers, one of whom operates the hoist. The other two workers guide the studs into the support holes. They then install and snug-up the additional stand-off nuts.

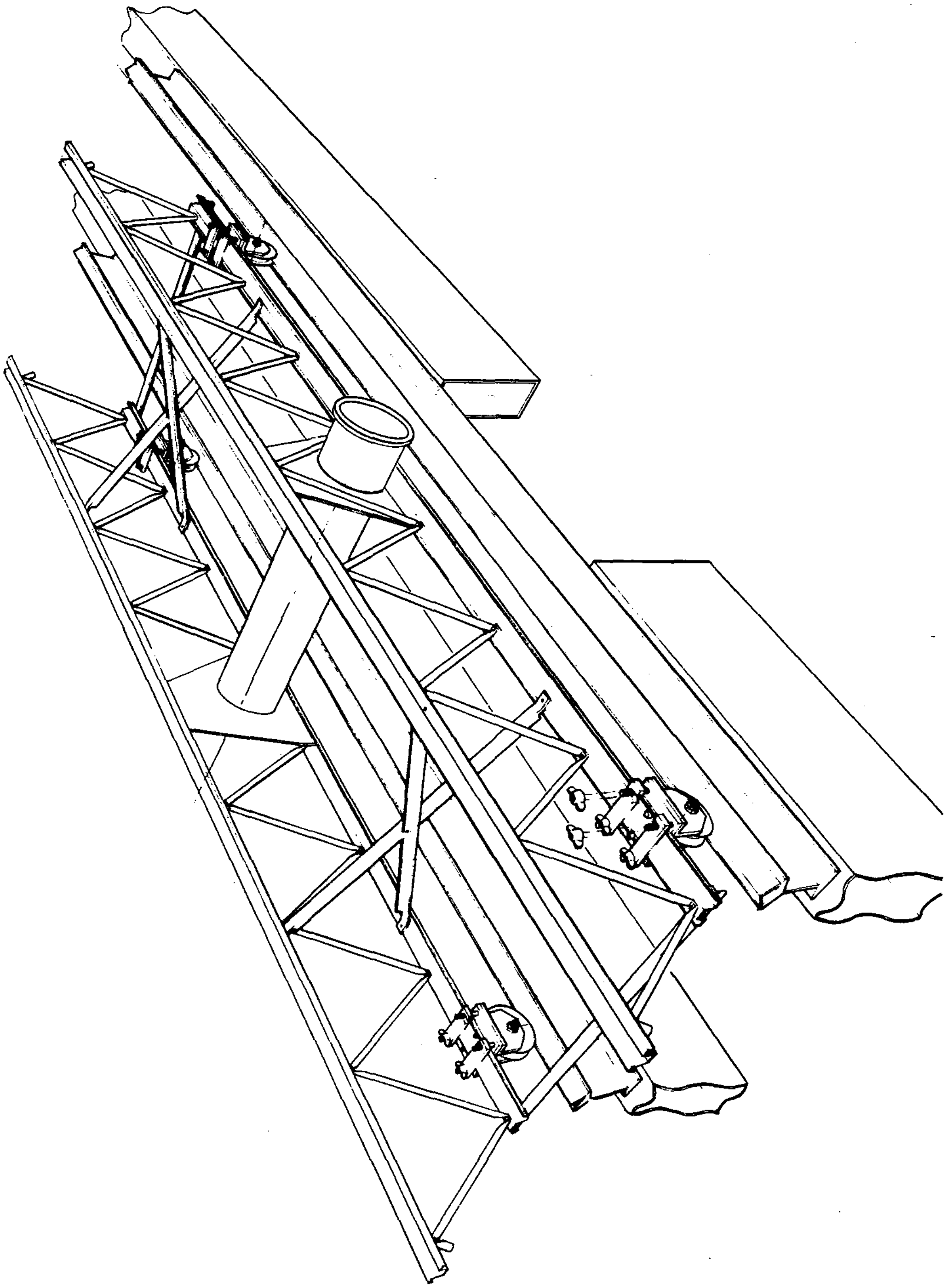


Figure 6-22 STATION NO. 1 — HELIOSTAT HALF - FRAME ASSEMBLY

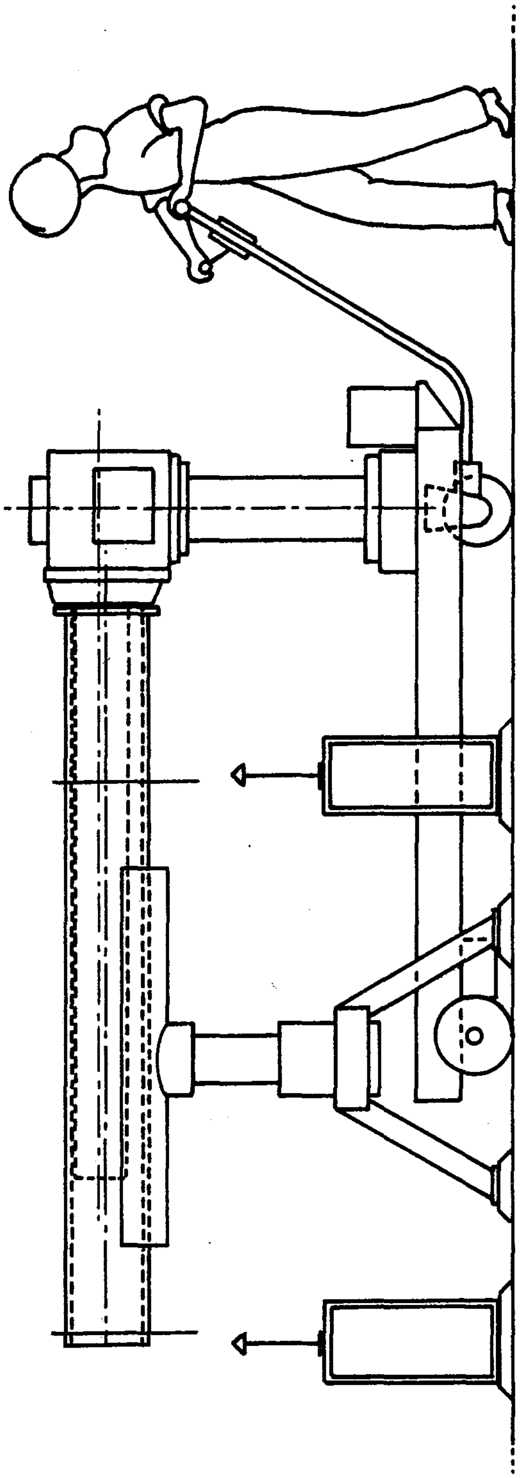


Figure 6 - 23 TORQUE TUBE PLACEMENT ON CRADLE

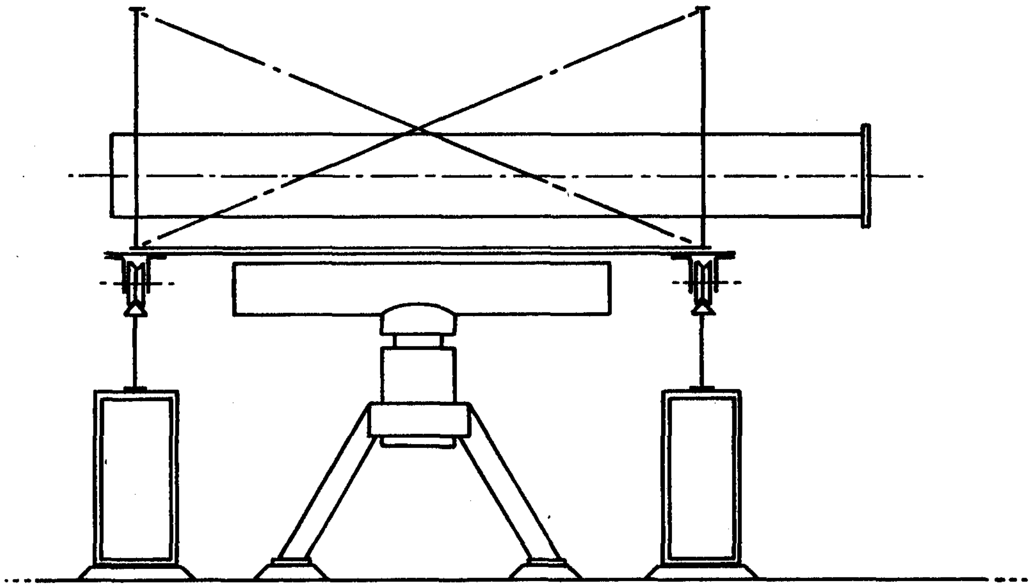


Figure 6 - 24 ASSEMBLY OF HALF-FRAME AT STATION No.1

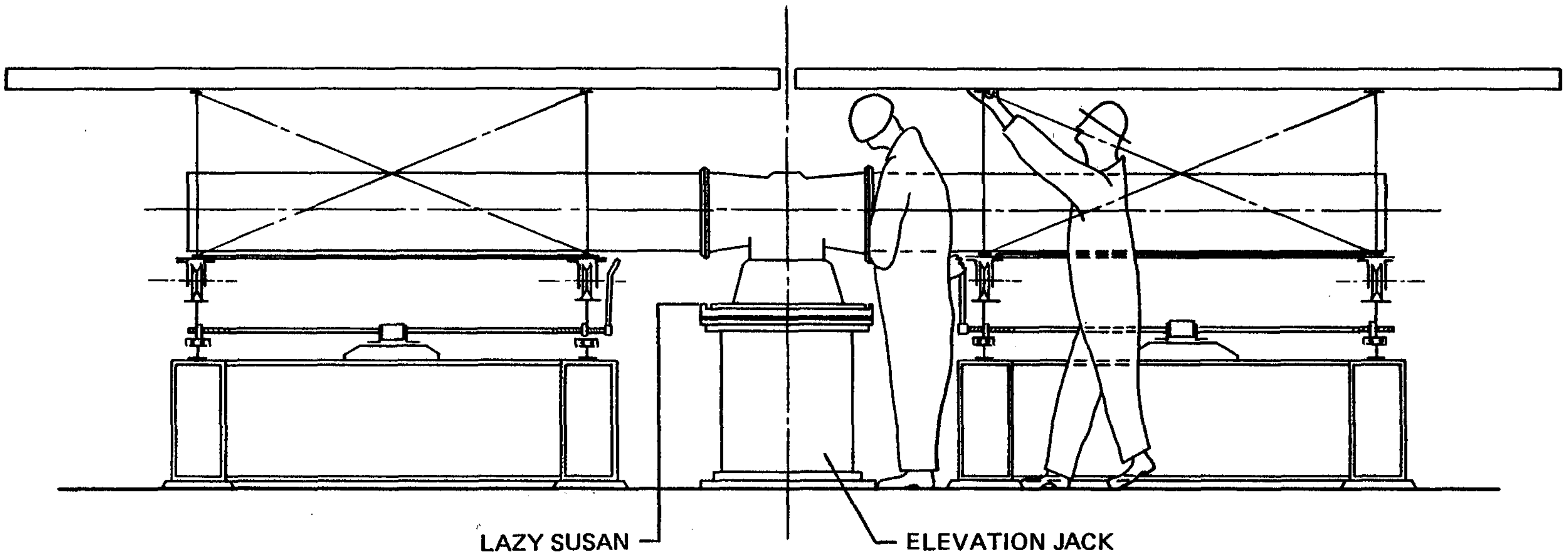


Figure 6-25 STATION NO. 2 — JOINING OF HALF - FRAME AND DRIVE ASSEMBLIES

Work Station No. 3 - Mirror Module Alignment

The mirror modules are aligned at this work station by a crew of eight workers.

The heliostat assembly is rolled to this work station (Figure 6-26). and the drive assembly flange is positioned over a hydraulic hoist flange and attached with three toggle clamps. The hoist lifts the assembly from the rails and the wheels are removed from the frame. With the mirrors facing upward and with the heliostat supported only by the drive assembly flange, all deflections are those normally imposed by gravity.

Canting is accomplished through use of preadjusted levels which, when placed on the surface of the upward facing mirror modules, give level bubble readings when the mirror module surfaces are properly canted. Two levels are placed on each mirror module - with one level oriented parallel to each of the two mirror module edges.

Four pairs of workers perform the mirror module alignment. Each pair is responsible for alignment of one quadrant of the heliostat which consists of three mirror modules. With one worker checking the level bubble readings and the other adjusting and locking down the stand-off nuts the desired canting is attained.

Support Personnel

The following support personnel are required to maintain assembly line operation:

1 Foreman

1 Inspector/Warehouseman

2 Fill-in Workers

2 Support Workers

The shift foreman directs the entire assembly operation. The inspector signs for all deliveries and, with the help of the support workers, inspects parts for shipping damage as they are unloaded and fed into the assembly stream. The fill-in workers assist as required to keep progress at the work stations synchronized. They also relieve other workers

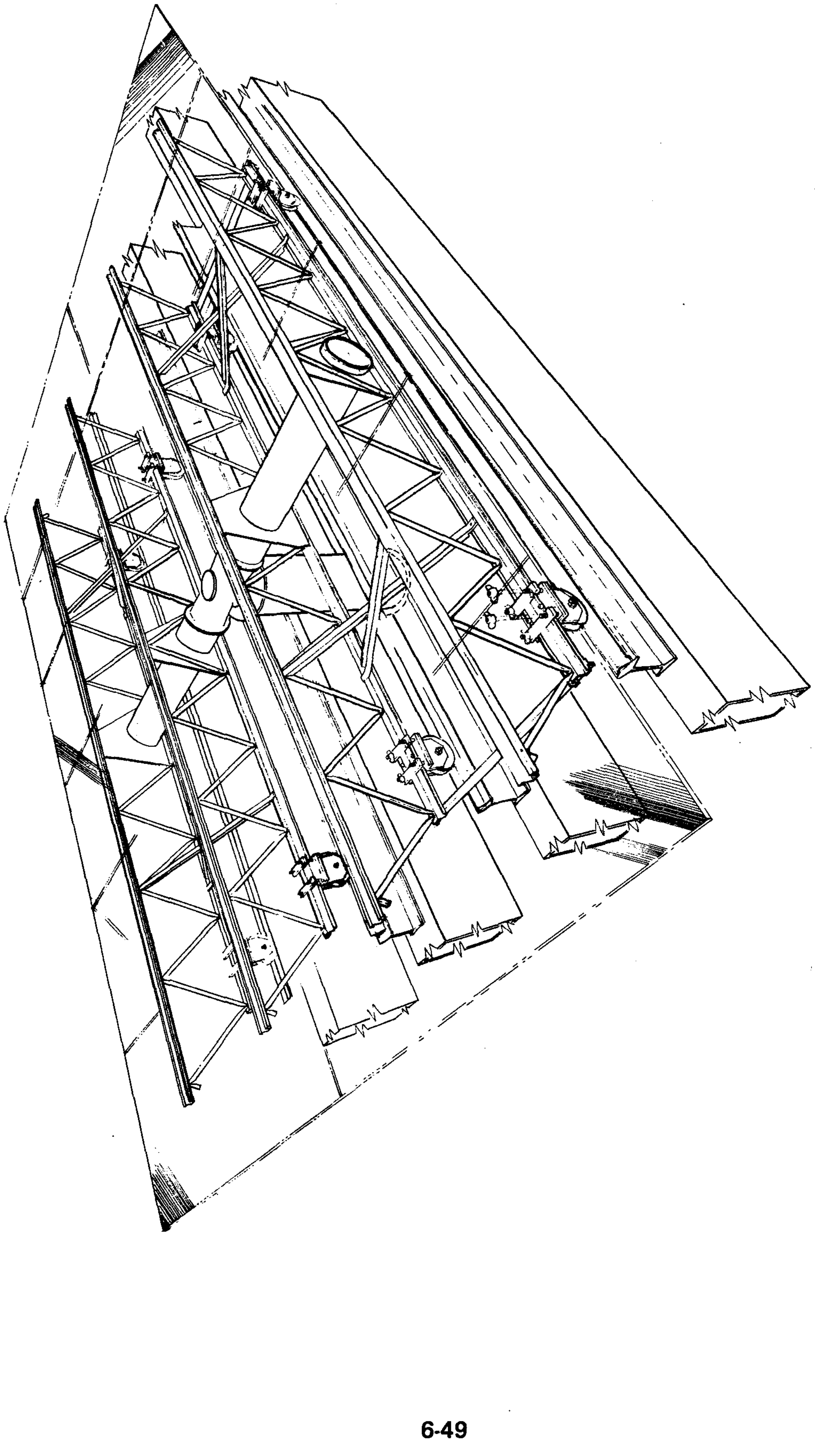


Figure 6-26 STATION NO. 3 — MIRROR MODULE ALIGNMENT

for brief periods as required. The support workers assist the inspector, do maintenance and replacement of assembly line equipment, deliver bulk supplies to the work station storage bins and remove defective parts discovered during inspection.

6.2.2 Assembly Time-Line

Work Station No. 1

Supply Workers - 2 Required	Time-Minutes
Unload torque tube onto cart	7
Transport cart to Station No. 1	4
Unload two frame trusses	5
Attach wheels to frame	11
	27

Half-Frame Crews - 2 Required (2 Riveters - 2 Welders per crew)	
Position torque tube, trusses & place frame jigs	10
Install first cross brace	5
Finish riveting - complete torque tube gusset welds	10
Touch up welds with paint	2
	27

Work Station No. 2

Drive-Frame Joining Crew - 1 Required (2 Assemblers)	Time-Minutes
Position drive assembly on elevation jack	9
Mate two torque tube flange joints	9
Secure two flanges with bolts	9
	27

Drive Assembly Supplier - 1 Required

	Time-Minutes
Help position drive on elevation jack	9
Unload next drive assembly & transport to work station	18
	27

Mirror Module Supply Crews - 2 Required

(3 workers per crew)

Unload six mirror modules	8
Install mounting studs	12
Install lock nuts & stand-off nuts	7
	27

Mirror Module Placement Crews - 2 Required

(2 Assemblers - 1 Vacuum Lift Operator per crew)

Position six mirror modules	9
Tighten stud base lock nuts	18
	27

Work Station No. 3

Mirror Alignment Crews - 4 Required

(2 Aligners per crew)

Fasten drive flange to hoist flange	2
Raise lift & remove wheels	4
Align mirror modules with level system	21
	27

6.2.3 Heliostat Assembly Labor Requirements

Labor required to operate the assembly line is:

	Workers
Work Station No. 1	10
Work Station No. 2	15
Work Station No. 3	8
Support Personnel	6
	39 Workers per shift

Worker-hours per day for 3 shift operation are:

3 X 39 X 8 = 936 worker hours/day.

6.2.4 Heliostat Assembly Rate

Production by the first shift, based on a 20 minute work cycle and a .75 productivity factor, is:

$$\frac{(8 \text{ X } 60) \text{ (minutes/shift) X .75 productivity}}{20 \text{ minutes/heliostat}}$$

or 18 heliostats per shift.

Lower productivity is assumed for each succeeding shift as follows:

1st shift	18 heliostats
2nd shift	16 heliostats
3rd shift	14 heliostats
Daily Total	48 heliostats

It follows that the assembly work hours per heliostat are:

$$\frac{936 \text{ (workhours/day)}}{48 \text{ (heliostats/day)}} = 19.5 \text{ workhours/heliostat}$$

6.3 HELIOSTAT INSTALLATION

The heliostat installation operations include,

- marshalling of heliostats as they come off the assembly line,
- loading of heliostats onto trucks,
- transport of heliostats to the pedestals,
- unloading of heliostats and placement upon the pedestals,
- installation of control electronics and the electrical hook up.

6.3.1 Heliostat Storage

Heliostats are assembled on all three shifts while heliostat installation is restricted to the first shift. Therefore provision for storage of the heliostats assembled on the second and third shifts is required. The approximately thirty heliostats assembled on these shifts are temporarily stored in the marshalling yard, illustrated in Figure 6-27, for subsequent field installation during the following day.

When alignment of the heliostat mirror modules is completed at the final work station of the assembly line, the hydraulic lift is lowered to place the heliostat on a cart. When the heliostat is secured to the cart, a yard tractor pulls the cart and heliostat to the marshalling yard (during the second and third shifts) or to the dispatching pad (during the first shift). Storing of assembly line output occupies one worker on second and third shifts. Two yard tractor operators are required on the day shift for transport of heliostats and carts from the assembly line and the marshalling yard to the dispatching pad.

6.3.2 Loading and Transport

Two loading cranes are located at the dispatching pad. They lift the heliostats, in the manner illustrated in Figure 6-28, from the carts and onto trailer beds. The C-frame lift remains with the crane, serving as a fixture for engaging the heliostat. The mounting of the heliostat on the trailer bed is shown in Figure 6-29.

Each crane crew consists of a crane operator and three riggers.

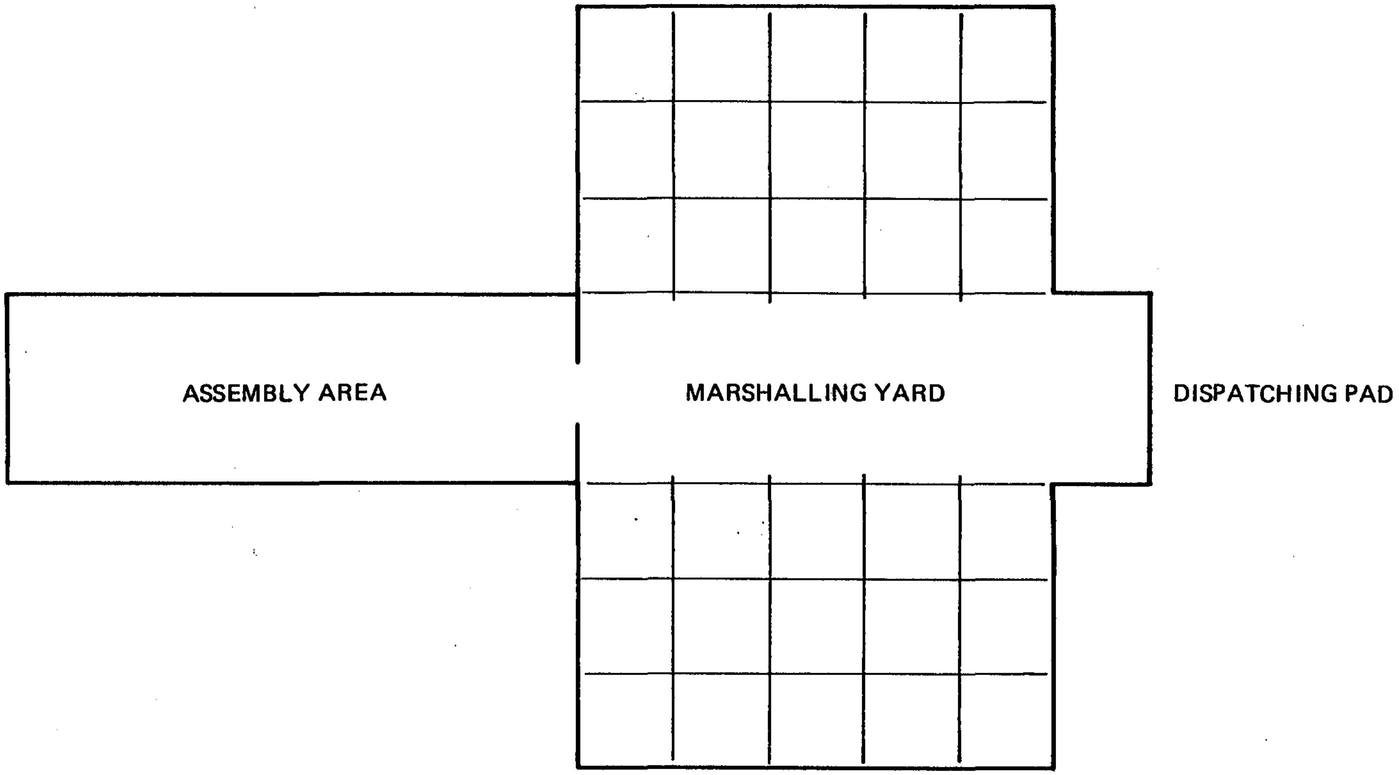


Figure 6-27 HELIOSTAT MARSHALLING AND LOADING AREA

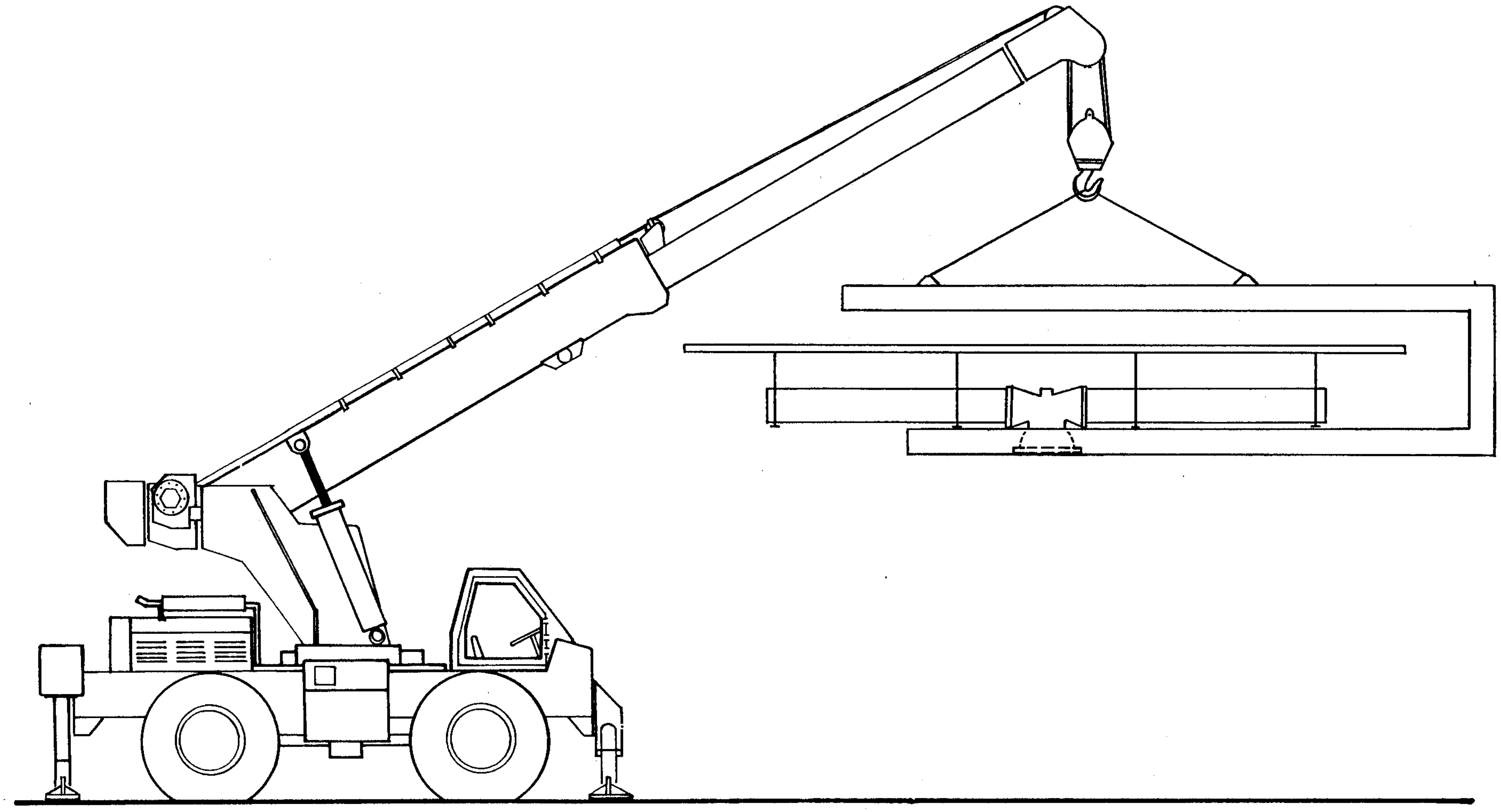


Figure 6-28, ROUGH TERRAIN CRANE & HELIOSTAT ASSEMBLY

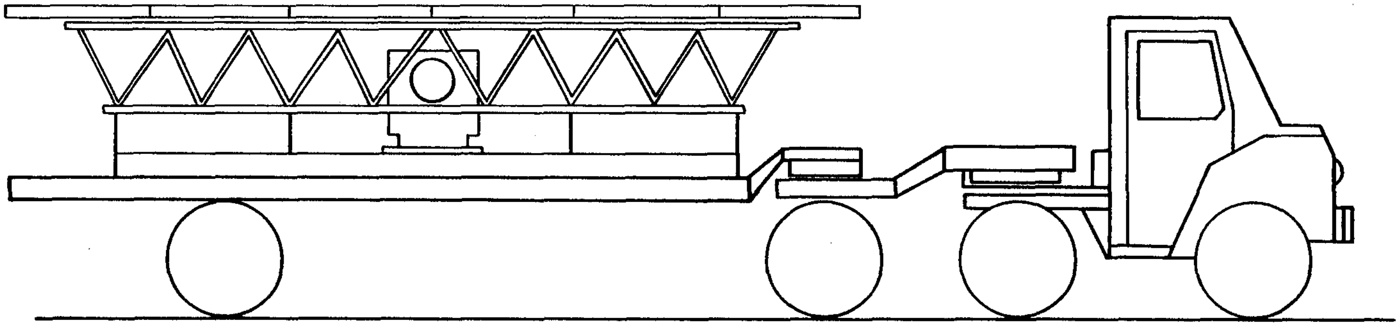


Figure 6-29 HELIOSTAT TRANSPORT TRAILER & TRACTOR

Truck drivers, arriving from the field, place the empty trailer on one side of the crane, disengage the tractor from the empty trailer and subsequently engage the loaded trailer on the other side of the crane. Three truck drivers are occupied in continuously transporting heliostats from the dispatching pad to the three installation crews that are installing the heliostats in the field. In the field the driver places the loaded trailer next to the intended pedestal and disengages the tractor. He subsequently engages the previously delivered trailer, now empty, and returns to the dispatching pad.

6.3.3 Unloading and Installation

Each heliostat installation crew requires four workers and a crane. The workers are a crane operator and three riggers. A pedestal stand, used previously for shim installation (see Figure 6-20), is already at the pedestal. The riggers position themselves on this stand when the heliostat is lowered onto the pedestal and the drive assembly flange and the pile flange are joined. The crane and C-frame lift fixtures used in the field are identical to those used at the dispatching pad. Each installation crew is capable of installing sixteen heliostats per day. Three such crews are required.

A total of 5.2 worker hours per heliostat are required for the marshalling yard, dispatching pad, transport and installation operations described above.

6.3.4 Installation and Hook-up of Heliostat Controls

The Control Electronics Assemblies are installed in the pedestals and hooked up at the rate of 48 per day using a crew of 12 workers with one forklift and one medium truck. The workers include 10 electricians, one forklift operator and one truck driver/parts dispenser.

The electricians work in pairs. They are supported by a truck driver who dispenses parts onto pallets that are placed at each pedestal by the forklift operator. The electricians install the control electronic assembly in the pedestal and make the hook-up of power and control wiring between the installed assembly and the terminal box near the base of each heliostat. They finally attach the drive assembly power and data bus plugs to the receptacles on the control box assembly.

A total of 2.2 worker hours per heliostat is required for installation and hook-up of the heliostat controls.

6.3.5 Alternate Installation Equipment and Procedures

An alternate approach to heliostat installation based on the use of less conventional equipment was considered. It was rejected for the present, although the method has merits that may warrant reconsideration in the future.

The approach in question is based on the modification of a "travel lift", sometimes called a "straddle hoist" or a "sling crane", to transport heliostats from the marshalling yard to the heliostat pedestals. This type of vehicle is used in stevadoring operations to transport containerized cargo. It is also used in marine yards, to transport boats, and in lumber yards. Figures 6-30 and 6-31 show this vehicle, as modified to serve as a heliostat installation vehicle.

The vehicle structure is essentially a cube shaped framework supported on four wheels and completely open on one end to permit maneuvering over a heliostat pedestal. The vehicle supports the heliostat assembly from underneath. Two of the four wheels can be turned ± 90 degrees to give excellent maneuverability.

Installation of the heliostats with the travel lift is accomplished as follows.

The heliostats from the assembly line are transported, with carts and yard tractors, to the marshalling yard (2nd and 3rd shift) or to the dispatching pad (1st shift), as discussed earlier.

During the day shift heliostat carts are delivered to the dispatching pad. There the heliostats are lifted off the carts by hydraulic hoists and raised high enough to permit the travel lift to be driven underneath. The heliostat is then lowered onto the travel lift and secured. Crews of two men per loading station operate the hydraulic lift and secure the heliostat to the travel lift. Two such crews are required at the dispatching pad.

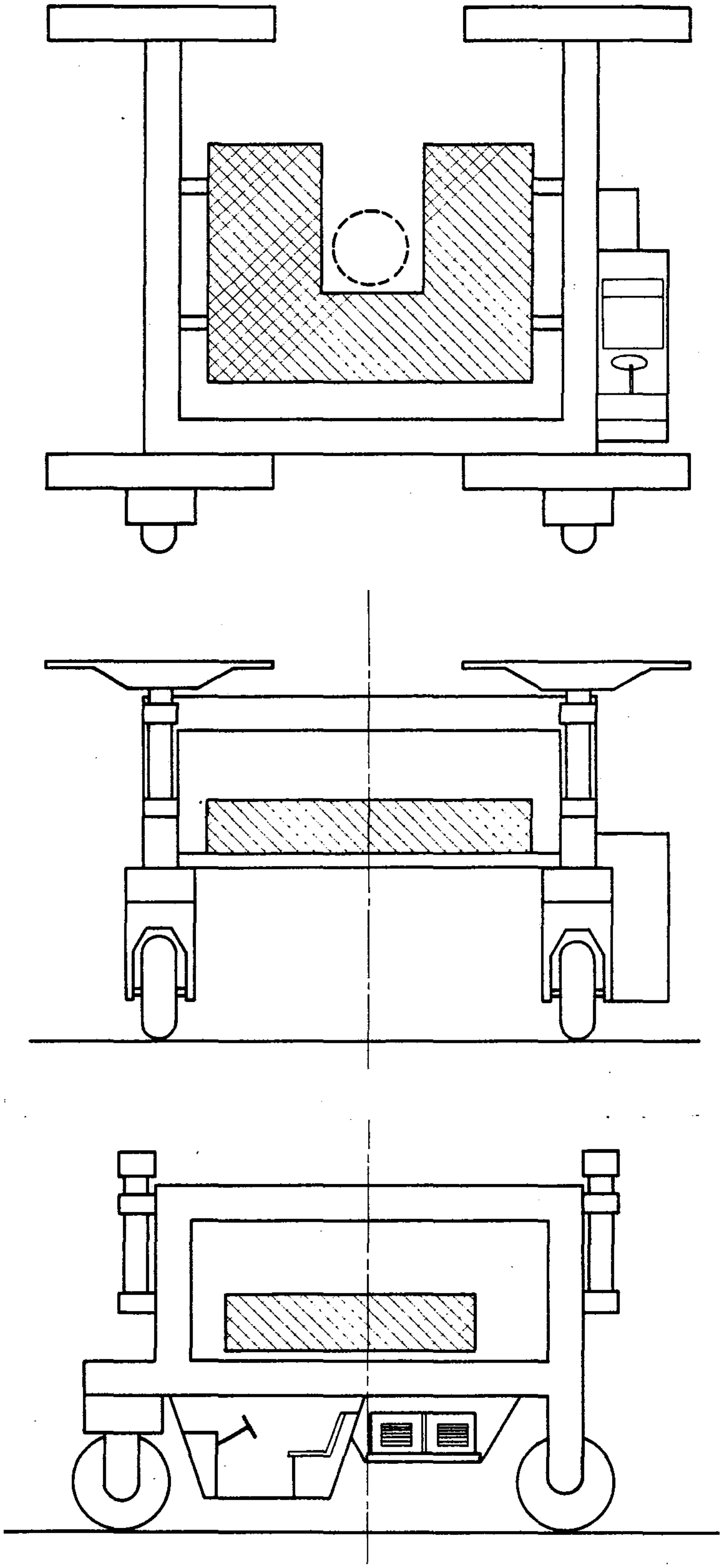


Figure 6-30 TRAVEL LIFT VEHICLE

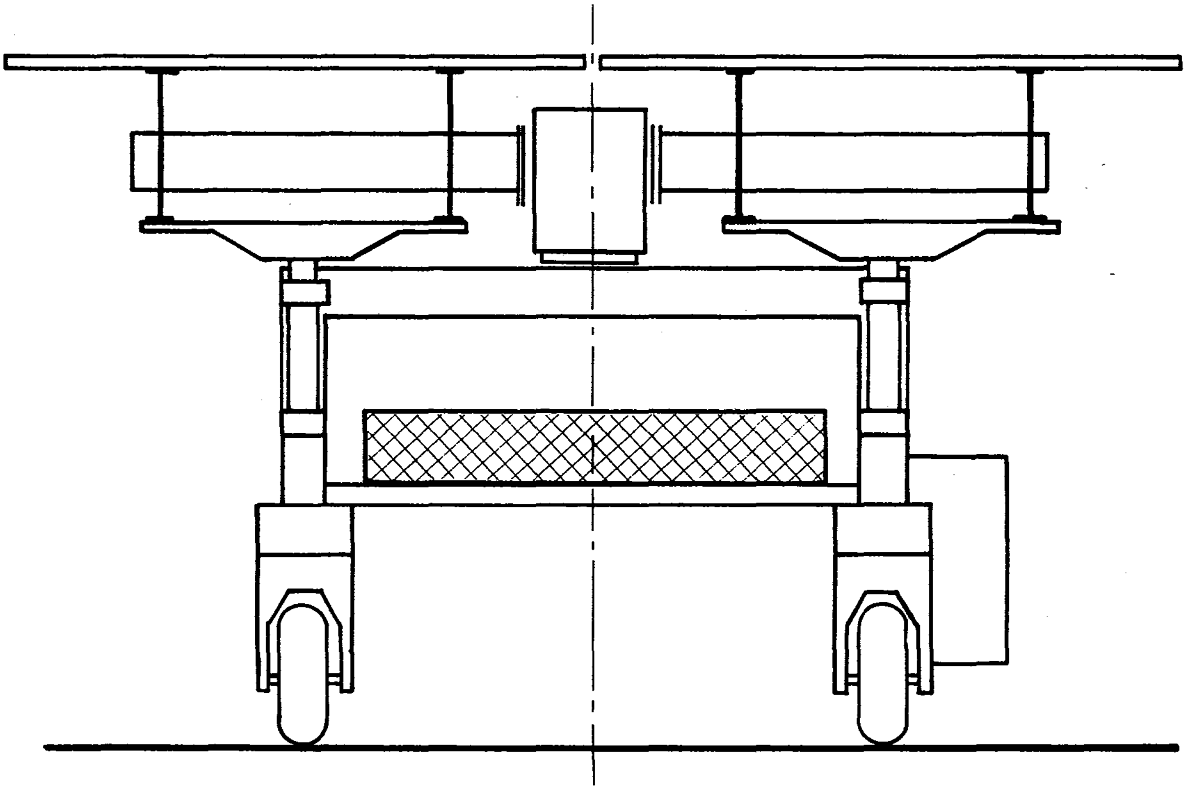


Figure 6-31 TRAVEL LIFT AND HELIOSTAT

The travel lift then transports the heliostat to the field pedestal. When the travel lift arrives at the pedestal it is met by a crew of three workers who unlatch the heliostat from the travel lift frame. The heliostat is then raised above the vehicle frame and the travel lift is maneuvered to place the heliostat drive assembly flange over the pedestal flange. With the crew positioned on the platform within the travel lift frame, the heliostat is lowered onto the pedestal. The washers and nuts are placed on the 12 drive assembly studs and are tightened with pneumatic wrenches.

The empty travel lift then returns to the dispatching pad as the installation crew meets the next travel lift at the next pedestal.

A time-line for heliostat installation using the travel lift indicated 4.7 work hours per heliostat are required, compared to 5.2 worker hours using conventional equipment. The cost of the travel lifts (8 required at approximately $30,000 ea.) however, caused the total installation cost per heliostat to slightly exceed the installation cost using conventional equipment.

The number of travel lifts required, and the associated worker hours required, was influenced by the 2 m/sec (5 mph) maximum travel lift transport speed assumed for this comparison. Further assessment of this approach might possibly show an advantage over conventional equipment. A definitive comparison would require field tests to establish reliable productivity values for the travel lift applied to the task of heliostat installation.

6.3.6 Installation Time-Line

The marshalling yard, which stores heliostats assembled during the second and third shifts, operates during all three shifts. All remaining field installation activities are conducted exclusively during the day shift.

Marshalling Yard	Time-Minutes
Yard Tractor Operator	
Load heliostat on cart	8
Secure to cart	4
Transport to storage slot	6
Fetch empty cart	4
Return	5
	27

4 Operators required (2 day shift, 1 second shift, 1 third shift).

Dispatching Pad

Loading Crew

	Time-Minutes
Rig C-frame to heliostat	7
Lift and place on trailer	6
Secure to trailer	7
	20

$$\frac{8 \times 60 \text{ minutes/day}}{20 \text{ minutes/heliostat}} = 24 \text{ heliostats/day/crew}$$

2 Crews required.

Truck Driver

	Time-Minutes
Unhitch empty trailer	4
Hitch loaded trailer	6
Transport to pile	4
Position and unhitch loaded trailer	6
Hitch empty trailer	6
Return to dispatch pad	4
	30

$$\frac{8 \times 60 \text{ minutes/day}}{30 \text{ minutes/heliostat}} = 16 \text{ heliostats/day/driver}$$

3 Drivers required.

Heliostat Field

Installation Crew

	Time-Minutes
Position crane and unlatch heliostat	8
Rig C-frame to heliostat	6
Lift and locate over pedestal	4
Lower onto pedestal flange	4
Tighten flange nuts-move to next pile	8
	30

$$\frac{8 \times 60 \text{ minutes/day}}{30 \text{ minutes/heliostat}} = 16 \text{ heliostats/crew/day}$$

3 Crews required.

Controls Installation Crew (10 electricians + 2 others)	Time-Minutes
Remove dummy cover plate	6
Install control assembly	26
Hook up with ground terminal	6
Hook up with drive assembly	6
Proceed to next pedestal	6
	50

$$\frac{8 \text{ X } 60 \text{ minutes/day}}{50 \text{ minutes/5 heliostats}} = 48 \text{ heliostats/day}$$

1 Crew required.

6.3.7 Heliostat Installation Labor Requirements

Mechanical	Work Hours/Day
Marshalling Yard	32
Dispatching Pad	64
Transport	24
Installation	96
Support	32
	248

$$\frac{248 \text{ Worker Hours}}{48 \text{ heliostats}} = 5.2 \text{ Hours/Heliostat}$$

Electrical	
Control Installation Crew (12 men)	96
Support Personnel	8
	104

$$\frac{104 \text{ Worker Hours}}{48 \text{ Heliostats}} = 2.2 \text{ Hours/Heliostat}$$

6.4 FUTURE IMPROVEMENTS

The material presented above pertains to the Northrup Second Generation Heliostat prototype design - two units of which were installed and tested at CRTF. Having completed the prototype design effort and the analysis of field operations required to assemble and install large numbers of heliostats, some improvements in design and procedures are now discernable. Among these are

- Shorter heliostat pile
- Thinner walled heliostat pile
- More efficient alignment of mirror modules
- Elimination of leveling shims

6.4.1 Shorter Pile

Due to the degree of uncertainty of the characterization of the CRTF soil properties, discussed in section 6.1.3, a conservative pile depth of almost 14 ft below grade was selected for the Northrup Second Generation Heliostat Prototype foundation at CRTF. the calculated values of pile tilt (at grade) shown in Figure 6-10 indicated that the alloted 1.05 milliradian rotation under maximum operating wind conditions might be attained with a pile depth ranging from as little as 6 ft to as great as 18 ft below grade depending on the soil properties. The range of pile depth indicated the degree of uncertainty regarding the support given to laterally loaded piles by the CRTF soil.

During actual installation of the piles at CRTF, the unexpected presence of rocks at 11 to 12 ft below grade forced the shortening of the two CRTF piles in order to successfully install them with the vibratory hammer. The final pile depths for the two CRTF piles were 11.3 ft and 11.9 ft below grade, respectively. A pull test was subsequently conducted on the shorter of these two piles with the results shown in Table 6-11.

Table 6-11

RESULTS OF CRTF PULL TEST

Load	Tilt at Top of Pedestal	Pile Tilt at Grade
pounds	measured milliradians	calculated milliradians
0	0	0
600	.339	.201
800	.446	.262
1000	.533	.303
1200	.630	.355
0	.063 permanent set	.063

From the information in this table it can be shown that the 1150 pound lateral load corresponding to the maximum operating wind condition gives a pile tilt of 0.342 milliradians at grade. Comparison of this result with the calculated pile tilt values of Figure 6-10, shown in Figure 6-32, reveals that the most optimistic of the CRTF soil characterizations is in best agreement with the pull tests. It follows that a pile depth as little as 6 ft might be satisfactory for soils like that at CRTF. Shortening of the Northrup Second Generation Heliostat pile depth from 13.6 ft to 10 ft for such soils gives a foundation design that is still conservative. This shortening of the pile appears to be justified. It permits a reduction of about $70 in the pile cost (@ $.30/lb).

6.4.2 Thinner Pile Wall

The 1/4-inch wall thickness for the heliostat pile was selected to permit driving of the pile with a vibratory hammer - since no field experience was found to justify the driving of a thinner walled 2 ft diameter pipe. Survival load stresses permit reduction of the pile wall to 1/8 inch. This is a practical alternative if the pile is augered and set in concrete

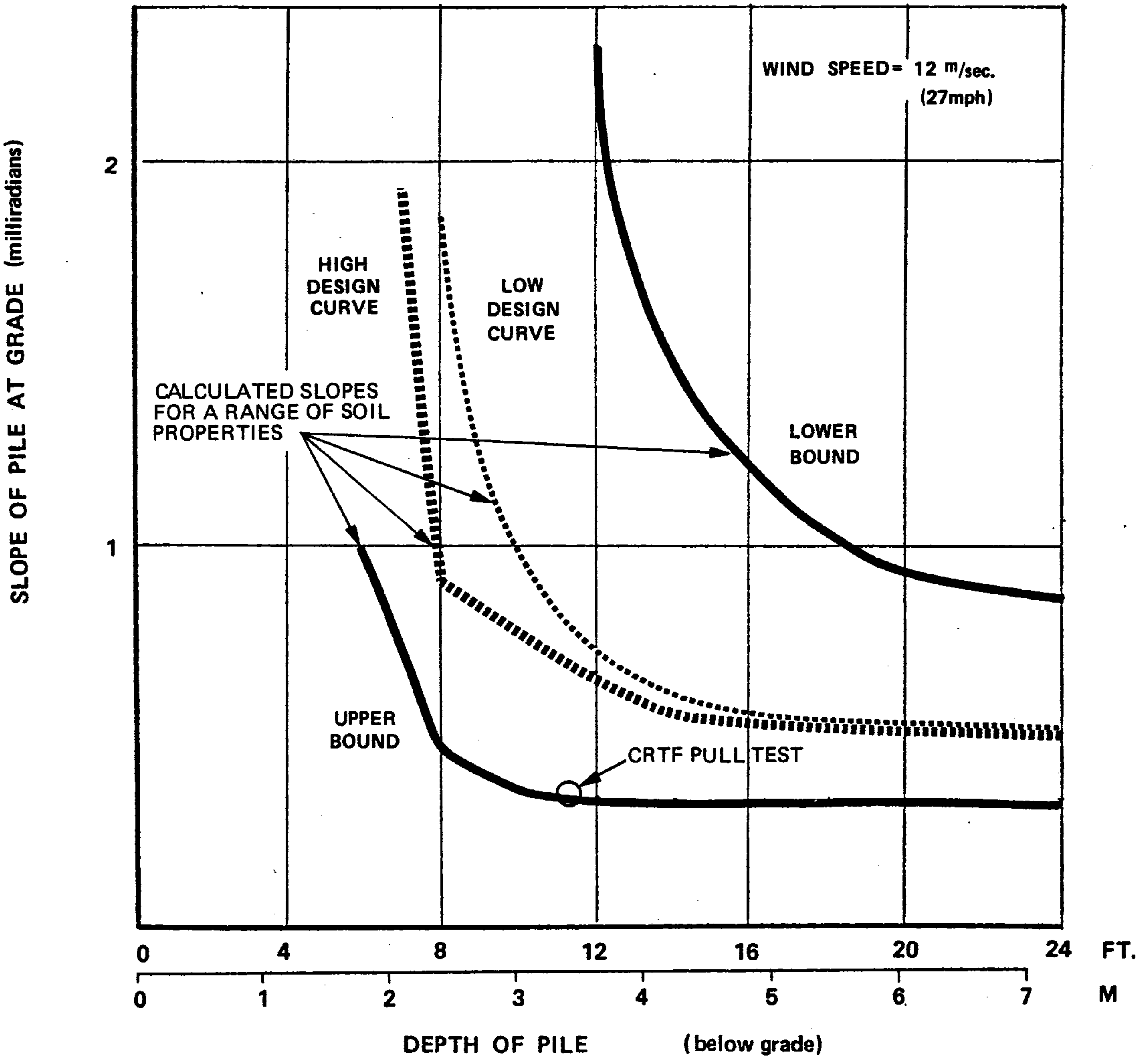


Figure 6 - 32 CRTF SOIL RESISTANCE TO PILE TILT DUE TO LATERAL LOADS

instead of driven. Halving the wall thickness of the (reduced length) pile reduces the cost of the pile by about $230 (@ $.30/lb). Installation of the pile by augering and setting costs $283 compared to $116 for installation with a vibratory hammer. Subtracting $167, for the increased cost of installation, from the $230 savings in pile cost gives a net gain of approximately $63 per pile.

Adoption of this approach also dispenses with the need for the M-104-3 cover plate that must be attached to the electric box opening when the pile is driven (see Figure 6-14, note 6).

6.4.3 Alignment of Mirror Modules

The time and labor required for alignment of the mirror modules can be decreased by replacing the conventional bubble levels, discussed in section 6.2.1, with sonic or electronic levels which provide an audible or visual reading of the mirror module orientation directly to the worker who does the module adjustment. This could cut the number of workers at Work Station No. 3 from 8 to 4 and reduce the overall heliostat labor from 19.5 to 17.5 work hours per heliostat. The coresponding reduction in heliostat assembly cost would be approximately $50.

Further reduction in mirror module alignment cost may be possible by using a triple screw device driven by the level signals to automatically and quickly make the required adjustments to the stand-off nuts.

6.4.4 Elimination of the Leveling Shims

The leveling shims, that are placed on the pile flange to provide a precisely leveled mount for the heliostat drive assembly, are not a cost-effective means for assuring a horizontal orientation for the elevation axis and a vertical orientation for the azimuth axis.

Elevation and azimuth axis errors caused by out of plumbness of the pile and lack of squareness of the pile flange can be offset by designing the heliostat control software to provide appropriate compensation in the calculation of the elevation and azimuth commands. Modification of heliostat control software to eliminate the need for leveling shims will reduce field costs by the approximately $35 per heliostat required for shim installation.

6.4.5 Potential Reduction in Field Costs

The changes discussed above indicate the potential reduction in field costs as follows:

	\$/heliostat	\$/m^2
Shortened Pile	70	1.33
Thinner Pile Wall	63	1.20
Improved Alignment	50	.95
Eliminating Shims	35	.67
	218	4.15

References

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6-3 "Laterally Loaded Drilled Piers", EPRI Journal, pg. 42, March, 1980

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SECTION 7.0
MAINTENANCE

7.1 SUMMARY

The Northrup II Heliostat has been designed to minimize the need for maintenance. Annual maintenance costs are summarized in Table 7-1. Failure rates used for this analysis are estimates based on judgment since extensive hardware testing would be required to verify the levels used.

About 50% of the maintenance cost is related to maintaining mirror reflectivity by periodic washing. This could be a highly variable cost dependent on local environmental conditions. The type of soiling and the pattern of natural rainfall could cause this cost to vary from zero to several times the estimated amount. An arbitrary wash cycle of one washing every two months was selected for this analysis.

The mechanical aspects of the heliostat represent about 35% of the total. The major portion of this area relates to providing clean-up and painting in the event of impeding corrosion of steel parts.

Electrical and electronic components contribute about 15% to the maintenance costs. Further refinement of controls along with advancements in control technology should serve to reduce these malfunctions in future years.

The total maintenance cost per year per heliostat is estimated to be $58.14. This estimate is used in Section 8.0 to determine the cost of owning, operating, and maintaining the collector field for a $50MW_e$ central receiver power plant.

7.2 MIRROR MODULE MAINTENANCE

Mirror module maintenance involves three potential malfunctions - loss of reflectivity, mirror deterioration and breakage, and corrosion

TABLE 7-1

MAINTENANCE COST PER YEAR PER HELIOSTAT

Malfunction	Corrective Action	Failure Rate per Year (Per Heliostat unless noted)	Cost of Corrective Action				Cost per Heliostat Per Year
			Mat'l	Labor	Ovhd	Total	
Mirror Modules							
Reflectivity loss	Wash mirrors	6.000	--	--	--	4.47	26.82
Deterioration-breakage	Replace module	.002*	100	10	10	120	2.88
Corrosion-Substrate	Clean & paint	.010*	2	5	5	12	1.44
Drive							
Deterioration of oil	Drain and replace	.100	50	5	5	60	6.00
Gears, bearings, seals	Replace-rebuilt unit	.001	1000	30	30	1060	1.06
Corrosion-Housing	Clean & Paint	.100	2	5	5	12	1.20
Motors	Replace	.002**	200	5	5	15	.84
Limit Switches	Replace	.002***	5	5	5	15	.24
Cables-connectors	Replace	.002****	10	5	5	20	.40
Controls							
Failed Components							
Mircoprocessor		.0013					
I O Timer		.0009					
ACIA		.0018					
Capacitors		.0004					
I C		.0044					
Translators		.0438					
Input Isolation		.0526					
Total	Replace-rebuilt asm.	.105	12	30	30	72	7.56
Corrosion-Housing	Clean & Paint	.100	2	5	5	12	1.20
Pedestal							
Corrosion-Pedestal	Clean & Paint	.100	5	5	5	15	1.50
Support							
Corrosion-racks	Clean & Paint	.100	30	20	20	70	7.00
							58.14

*per Module (12 per heliostat)
**per Motor (2 per heliostat)
***per Switch (8 per heliostat)
****per Cable (10 per heliostat)

of the module substrate. Loss of reflectivity is corrected by periodic washing of the mirrors to restore them to near-original condition.

Mirror deterioration can occur if, as a result of lack of manufacturing quality, moisture penetrates the system designed to protecting the silvered surface of the mirror. Breakage can be the result of hail, wind blown debris and physical abuse. The combination of these failure modes has a relative low frequency of occurrence and the corrective action would be to replace the module with a new part.

The module substrate is constructed of prepainted galvannealed steel and is subject to corrosion - especially on exposed cut edges. While this steel coating has a good history of resisting atmospheric corrosion, it is recognized that it may be necessary to touch up areas which demonstrate impending corrosion with a zinc-rich white paint.

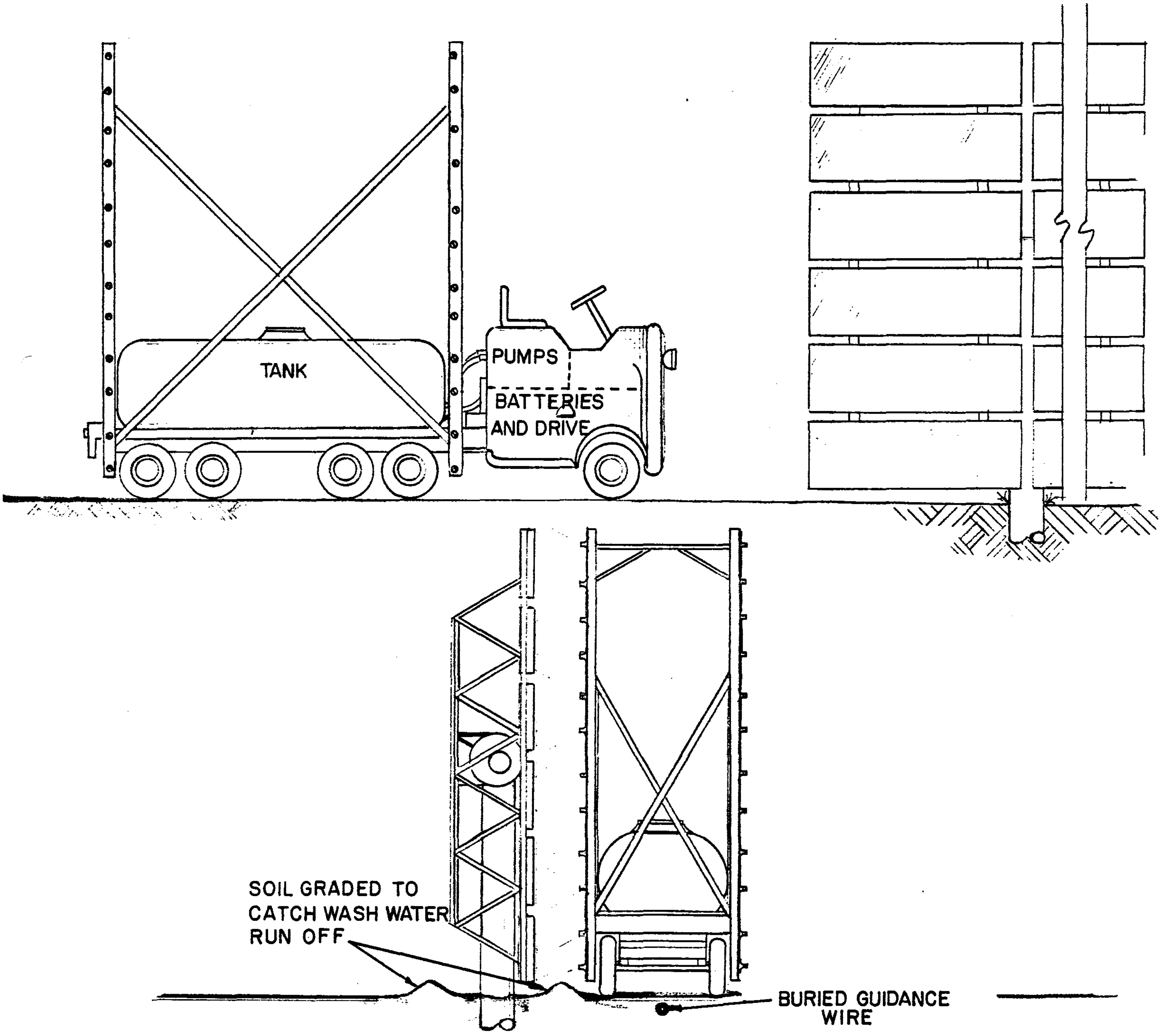
7.2.1 Mirror Washing

The summary of maintenance costs shows that the washing of mirrors to maintain a high level of reflectivity is potentially the most significant maintenance cost. Based on the budgeted six washings per year this one maintenance activity compromises approximately 50% of the estimated maintenance cost.

The normal stow position for the Northrup II heliostat is in a vertical orientation. During high winds it will assume a horizontal face-up position. It therefore always is in a position to receive the natural washing action of rain which has proved to be most favorable at the CRTF in Albuquerque, New Mexico.

Depending on type of soiling and frequency of rainfall it is conceivable that no artificial washing would be required under some circumstances. On the other hand, it would be imprudent to plan on this combination of favorable conditions for all heliostat fields.

FIGURE 7-1
HELIOSTAT WASHING RIG



Investigations reported by others and confirmed in our own facility indicates that washing can be accomplished through the use of high pressure sprays of deionized water. The sprays provide adequate agitation of the surface and the deionized water sheets off the surface leaving very little residue. These principles have been applied to our mirror washing concept which includes a high pressure soak spray followed in 5 to 10 seconds by a second high pressure rinse spray.

7.2.1.1 Washing Rig

A conceptual design of a mobile rig for accomplishing this washing action has been identified. It consists of tank truck with vertical arrays of washer heads which proceeds through the field of vertically stowed heliostats at a slow, but steady rate. A control system is included which automatically maintains rig spacing from the heliostat, initiates and terminates the spray action, and controls the rig speed. In this manner a planned uniform washing action which is not subject to operator variations can be imparted to the heliostats.

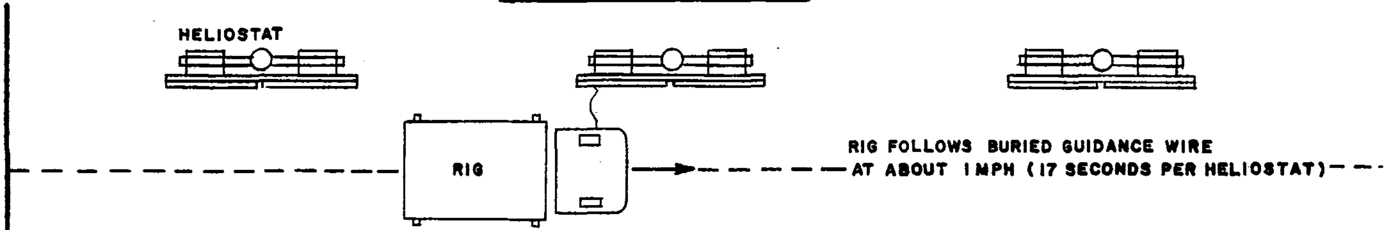
The washing rig is conceptually illustrated in Figure 7-1. It is an electric battery powered vehicle with a tank capacity of 3400 gallons. Pumps are provided to produce pressure to vertical arrays of spray heads. Arrays are provided on both sides of the rig so washing can be accomplished with heliostat mirror surfaces positioned either to the left or the right of the rig. As the rig proceeds past the heliostat one of the forward spray arrays is triggered to provide a momentary soak. This is followed some seconds later by a subsequent rinse spray from one of the aft arrays. When the rig makes a u-turn to move down the next row of heliostats the sprays on the opposite side are activated in sequence.

7.2.1.2 Guidance System

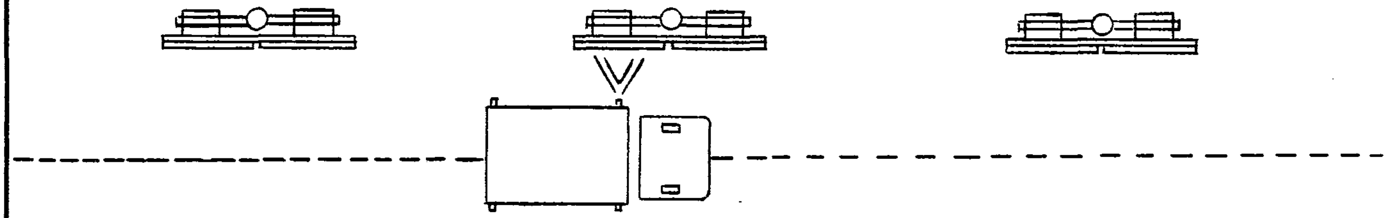
The rig is automatically guided through the field following a buried copper guidance wire which is positioned an equal distance from the front surface of the heliostats. The wire is buried at a depth of one to two feet and transmits guidance signals which directs the

FIGURE 7-2

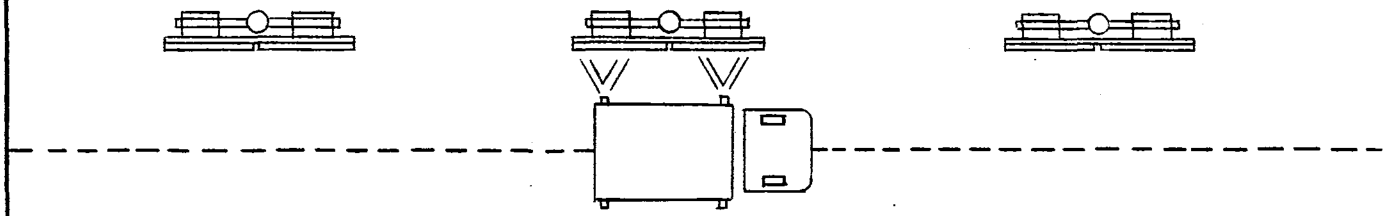
WASHING SEQUENCE



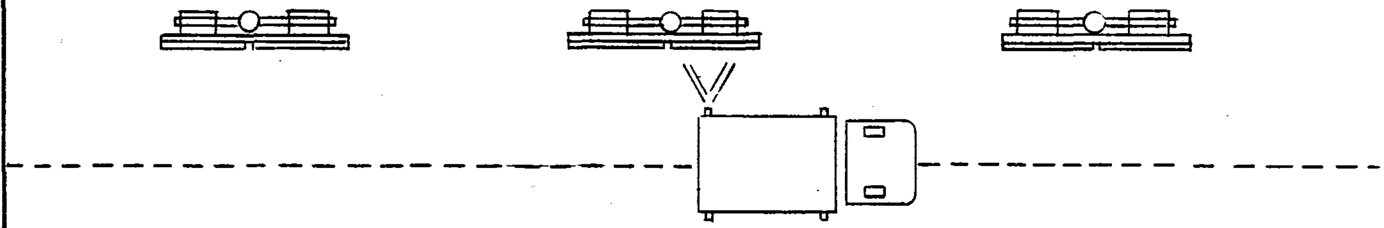
RIG SENSES HELIOSTAT TO INITIATE CYCLE



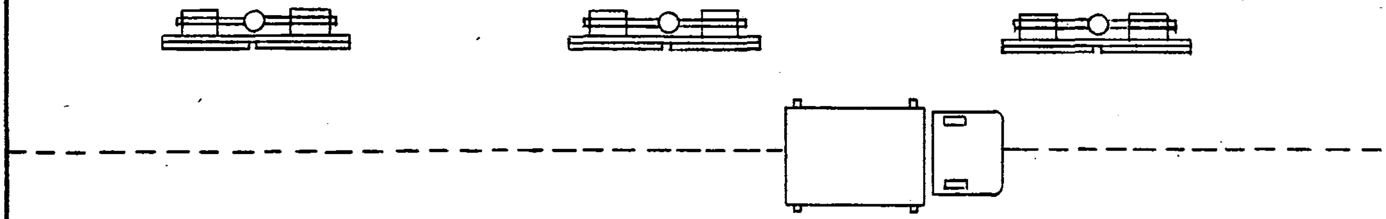
SOAK SPRAYS ON (12 SPRAYS AT 5 GPM = 1 GPS)



RINSE SPRAYS ON (12 SPRAYS AT 5 GPM = 1GPS)



SOAK SPRAYS OFF (17 GALLONS USED)



RINSE SPRAYS OFF (17 GALLONS USED)

rig to track in a precise manner. Deviation from proper tracking produces error signals to the rig steering control to maintain proper orientation of the rig and the row of heliostats. Automatic shut-off is provided if the rig deviates beyond the intended path. These guidance concepts have been successfully applied to factory conveyer systems and center-pivot irrigation systems. As the rig proceeds down the row of heliostats at a controlled speed a radar-type sensor detects the leading edge of a heliostat. This initiates the timing sequence to fire off and terminate the appropriate sprays for that heliostat. In this manner variable spacing of heliostats can be accommodated. This sequence is demonstrated in Figure 7-2.

7.2.1.3 Washing Procedures

The semi-automatic washing procedure permits washing at night so as not to interfere with field operation. The heliostats in the rows to be washed that night would be stowed in a vertical position parallel to the buried guidance wire. The driver would manually steer the rig to the end of a row to straddle the guidance wire. He would then switch to automatic control which would steer the rig along the guidance wire at a preset steady speed. As the heliostat sensor detects the leading edge of each heliostat it initiates the selected washing cycle. The operator is free of any steering or washing duties so he can visually observe the heliostats for mirror breakage, leaking oil or other malfunctions. He can switch the rig from automatic to manual control of speed and steering if needed to avoid unexpected obstacles in the intended path of the rig. When the water in the tank on the rig is depleted the driver would steer the rig to a water refilling point, refill the tank, and then return to the field for another series of washes. Several trips per day to the watering supply would be required so rest breaks and lunch breaks could be scheduled while refilling the tank. The semiautomatic operation of the washing procedure along with periodic breaks to refill the tank reduces operator fatigue and should substantially reduce the risk of heliostat collision damage.

7.2.1.4 Daily Schedule

A typical eight hour shift would operate as follows:

	MILES	MPH	TIME IN HOURS
Drive to water supply	1	4	0.25
Fill tank - check out rig			1.00
Drive to field	1	4	0.25
Wash 100 heliostats	1	1	1.00
Drive to water supply	1	4	0.25
Fill Tank - (Lunch)			1.00
Drive to field	1	4	0.25
Wash 100 heliostats	1	4	1.00
Drive to water supply	1	4	0.25
Fill tank - (Break)			1.00
Drive to field	1	4	0.25
Wash 100 heliostats	1	1	1.00
Drive to rig storage area	1	4	0.25
Secure rig			0.25
Total	10		8.00

In one eight hour shift one rig with one operator can wash 300 heliostats using about 10,200 gallons of deionized water. The short distance traveled per day (10 miles) along with low speeds (1 to 4 mph) are ideal for an electric battery powered vehicle. The pumps which produce the pressurized sprays would also be battery powered. The sixteen hour off-cycle provides adequate time for battery charging.

7.2.1.5 Washing Parameters

A summary of some of the field washing parameters is as follows:

No. of heliostats in field	5974
Average spacing between heliostats	53 feet
Distance through field per wash	60 miles
Washing rate - 20 day cycle	300/day

Miles per day - wash - 3 in transit - 7	10 miles/day
Rig speed - when washing	1 mph (1.47 fps)
in transit	4 mph
Time per wash - 25 ft. wide heliostat	17 seconds
Water usage per wash - 24 heads @ 5 GPM each	34 gallons/wash
Washes per 3400 gallon tank	100 washes/tank
Water used per hour	3400 gallons
Pump pressure	500 psi
Power to pump (50% eff pump)	28.6 horsepower
Power to pump motor (80% eff motor)	26.7 Kw
Tank refills per day	3 tanks/day

7.2.1.6 Water Usage

The washing concept uses a relatively small quantity of water. At 34 gallons per heliostat and 300 heliostats/day a well supplying 10,200 gallons/day would be adequate. This is only 7 GPM which is equivalent to the flow rate which can be obtained from a well serving a single residence. The impact of this amount of water usage is as follows:

Water per wash	34 gallons
Heliostat area	590.7 ft^2
Approximate packing density	0.25
Land area/Heliostat	2362.8 ft^2
Equivalent inches of rainfall/wash	0.023 in
Maximum depth if impounded in 5 ft. wide trough	0.23 in

At six washes per year this is equivalent to 0.14 inches of rainfall per year. This low amount of water drain off would have negligible environmental impact. To prevent wash water from flowing into the path of the washing rig it may be desirable to grade the soil to provide small earthen dams of several inches elevation parallel to the stowed washing position of the mirrors. If spaced five feet apart the maximum depth of the impounded water from a wash would be about 1/4 of an inch. This amount of water would quickly be absorbed by the soil.

7.2.1.7 Cost Estimate

The estimated costs of the washing system are as follows:

Fixed Costs

Washing Rig	250,000
Control System	100,000
Guidance wire	150,000
Deionizer and storage tanks	50,000
Total Investment	$550,000

Annual Capital charges (30 yrs. @ 15%)	83,400

Annual Variable Costs (6 washes/year)

Direct Labor (1040 x 7.50/hour)	7,800
Benefits (25%)	1,900
Maintenance	25,000
Supplies	12,000
Electricity	6,000
Water (2,000,000 gallons @ $.002/gal)	4,000
Deionizing Chemicals	10,000
G&A	10,000
Total Annual Cost	$160,100

6 x 5974 = 35,844 washed heliostats/year $4.47/wash

7.3 MIRROR SUPPORT RACKS AND PEDESTAL MAINTENANCE

The mirror support racks consisting of torque tubes and trusses and the pedestal are constructed of steel with a durable paint finish. Over the life of the heliostat it is anticipated that some touch-up of exposed surface exhibiting corrosion would be desirable. The corrective action would be to clean the rusted areas and apply paint.

7.4 DRIVE UNIT MAINTENANCE

The drive unit is a sealed system in which the gears operate in a bath of oil. The most likely malfunction would be deterioration of the oil due to aging, chemical action, or exposure to foreign material or moisture. An oil replacement program is planned on a 10 year cycle. Mechanical failure modes include gear, bearing, or seal failure. Due to the normal low stresses on these parts the incidence of these types of failures will be low. Any corrosion of painted cast iron housing will be corrected by cleaning and touching up with paint.

7.5 MOTORS AND CONTROLS MAINTENANCE

For consideration of maintenance we have grouped the drive motors and drive motor controls into four areas:

Motors
Limit switches
Cables - connectors
Controls

7.5.1 Motors

Separate, but identical stepper motors are used for azimuth and elevation drives. These motors are totally enclosed so corrosion due to atmospheric effects will be minimal. The failure modes will generally be short circuited and opencircuited windings resulting from random wire insulation and wire termination weaknesses coupled with transient voltage surges. Quality magnet wire insulation is specified for the motors and close quality control of wire terminations is an essential part of the manufacturing process. Line voltage surges are buffered and suppressed by the power supply and control system. The combination of these measures results in high motor reliability. In the event of failure, the defective motor is replaced with a new motor.

7.5.2 Limit Switches

The limit switches on the drive unit are quality, weather protected devices which have proven high reliability in other applications. Four of the eight switches are used strictly in a limiting role and are not exercised on a duty basis to provide heliostat control. Operating cycles on these switches will occur only in the event of malfunction of the step counting system. Failures are expected to be low and the repair procedure will be to replace the non-functioning switch.

7.5.3 Cable-connectors

Factory built connector assemblies are used to connect the drive motors, limit switches, control boxes and field wiring terminal boxes. Weather-protected connectors and cable is used throughout so the frequency of failure due to the environment is anticipated to be minimal. The usual cause of failure will be loss of continuity in a marginal electrical connection. Factory control of the joining process is the key to high reliability in this area. In the event of failure the affected part or cable assembly would be replaced.

7.5.4 Controls

The electronic components used in the control system are specified to MILSPECS to achieve a significantly higher level of reliability than can be obtained from commercial grade components. As a result it is projected that the combined overall failure rate of component boards will be only about 10.5% per year. The control system is designed for easy board replacement, so the usual repair procedure will be to replace the defective board with a spare. The malfunctioning board is then returned to a shop location for diagnosis, repair, and test prior to returning the board to the spare parts supply.

SECTION 8.0

COST ESTIMATES

8.1 COST ESTIMATING APPROACH AND ASSUMPTIONS

Two cost estimates have been generated. They are:

- The cost per installed heliostat.
- The annual cost of owning, operating and maintaining a collector subsystem for a 50 MW_e (peak) solar central receiver electrical power plant.

Cost estimates for component manufacture, transportation to field sites, field assembly and installation, collector field operation and maintenance and other activities were developed by subcontractors and Northrup personnel. All estimates were submitted to the Northrup Financial Department for review of accounting procedures and business consistency. These component estimates were then integrated to produce an installed selling price per unit and the annual combined cost of the power plant subsystem.

All costs have been determined utilizing the following assumptions:

- Costs are reported in April 1980 dollars.
- Production of 50,000 heliostats per year, with a minimum total production of 520,000 units.
- Basically a two-shift operation. Some machining operations extend into a third shift and some simple operations are completed on a one-shift basis.
- A relatively stable product design throughout the product life cycle.
- Minimal marketing expenses required to establish and maintain a small, stable customer base such as a group of electric utilities.
- All installations are within 400 miles distance from the manufacturing plant.
- No significant risk of large variations in unit sales volume or unit sales price.

TABLE 8-1

Major Prototype and Production Design Differences

CBS	CBS Area	Prototype Design	Production Design	Comments
4410	Reflective Unit	.094 float glass mirrors	.094 low-iron float glass mirrors	Low-iron float glass not available for prototypes
		.028 galvannealed mirror backing sheet	.022 galvannealed mirror backing sheet	.022 stock of adequate flatness not available in warehouse stocks--requires mill run.
		.120 box channel for mounting bracket	Mounting bracket fabricated from .078 stock.	Standard structural channel used for prototypes.
		Painted galvannealed substrate.	Pre-painted galvannealed substrate.	Pre-painted material uneconomic in small lots.
4420	Drive Unit	Purchased ball bearings	Integral ball bearings	Prototype time cycle did not permit development of integral bearing system.
4430	Controls	Off-the-shelf electronic hardware	Custom electronic hardware	Prototype volume did not warrant design of customized electronics.
4440	Foundation	Pile - 24"O.D. x .250" wall x 25 ft long	Pile - 24"O.D. x .125" wall x 21.4 ft long	Test of installed piles indicated adequacy of shorter, thinner wall piles.
4450	Support	------------	Same as prototype design	-----------------
4460	Installation	Pile set with vibratory hammer	Pile set in grouted augered hole	Thinner wall pile requires augered hole.
		Tapered shims used for leveling	Computer software used to correct for out-of-plumb condition	Software corrections not available in early stages of prototype testing.

- No customer delays in accepting delivery of finished goods.
- Collection of receivables on a 30-day cycle with no contingency for bad debts.
- Product warranty costs limited to the initial break-in period.
- The tax rates and applicable tax credits are interpreted according to the tax laws in effect on April 1, 1980.

Any significant deviation from these assumptions would cause a corresponding revision to the overall cost estimates.

8.2 COST BREAKDOWN STRUCTURE

To facilitate evaluation of cost data, the main cost elements are categorized into a Cost Breakdown Structure (CBS). The structure used consists of the following categories:

CBS	Description
4410	Reflective Unit
4420	Drive Unit
4430	Controls
4440	Foundation
4450	Heliostat Support

8.3 PRODUCTION DESIGN

The design projected for the production rate of 50,000 units a year is not the same as the delivered prototypes. The major differences between these two designs is summarized in Table 8-1. These projected changes have no adverse effect on heliostat performance and have been introduced in this section so that a more truly representative production cost can be estimated.

8.4 CAPITAL COSTS

Capital costs are accumulated into three categories:

- Equipment
- Building
- Land

This enables these costs to be depreciated on a schedule which is consistent with the useful life of the asset.

8.4.1 Equipment

Equipment required to manufacture the heliostat components represents the largest investment cost and totals $72,207,000. It is split out by cost breakdown structure as follows:

CBS	Description	Equipment Cost
4410	Reflective Unit	$ 9,161,000
4420	Drive Unit	54,262,000
4430	Controls	680,000
4440	Foundation	1,464,000
4450	Heliostat Support	6,640,000
		$72,207,000

These costs include the cost of the equipment plus the cost for transportation to the plant site, unloading and installation. Details of these costs can be found in the Appendix.

The equipment to manufacture the drive unit represents the largest part of this category comprising 75% of the total. The bulk of this is required for the machining operations required for the gears, worms, and housings.

8.4.2 Building

The building required to house the manufacturing activity is distributed as follows:

		FT^2
Manufacturing -	Ground Floor	600,000
	Penthouses	60,000
Office		20,000
		680,000

Cost of these facilities were estimated using the following costs per square foot:

		$/FT^2
Manufacturing -	Ground Floor	30.00
	Penthouses	15.00
Office		45.00

On this basis the building cost is:

Manufacturing -	Ground Floor	$18,000,000
	Penthouses	900,000
Office		900,000
		$19,800,000

8.4.3 Land and Improvements

The land requirement is based on an area which is about four times the building area. This requires 60 acres at a cost of $12,000 per acre which includes improvements. The total amount invested in land is $720,000.

8.4.4 Total Investment

The total investment required for this facility is the sum of these three investment subtotals:

Equipment	$72,207,000
Building	19,800,000
Land	720,000
Total	$92,727,000

8.5 MANUFACTURING COST

The principal element of the cost of the heliostat is the manufacturing cost. This is defined as the cost to order, receive and process materials, complete and test subassemblies and then load into trailers for subsequent transportation to the field site. The elements of manufacturing cost used in this study are:

- o Direct Materials
- o Indirect Materials
- o Direct Labor

- Overtime and Shift Premiums
- Variable Indirect Labor
- Fixed Indirect Labor
- Utilities
- Depreciation
- Property Taxes

The cost of each element has been estimated using conventional accounting methods.

8.5.1 Manufacturing Cost Elements

The cost elements used in this accumulation are defined as indicated.

Direct Materials

Includes the cost of all raw materials and purchased parts included in the Bill of Materials. In-bound freight costs are included in this category.

Indirect Materials

Includes the cost of non-durable tools, factory supplies, and maintenance supplies. They are included as a percentage of Direct Material Cost.

Direct Labor

Includes the cost of all direct labor applied to the fabrication, assembly and test of hardware produced in the factory. It is included at a straight time rate.

Overtime and Shift Premiums

The factory is operated over three shifts and at some production levels, overtime is required. Wage premiums are included for these categories:

- Second Shift
- Third Shift
- Overtime

Variable Indirect Labor

All labor-related costs which vary with production levels and are not included in Direct Labor are covered in this category. This includes Direct Labor down-time, Direct Labor fringe benefits, and labor and fringe for material receiving, material handling, inspection, shipping and some first line supervision. For this study these costs are estimated as a percentage of Direct Labor costs.

Fixed Indirect Labor

Labor-related costs which are independent of production rates are included in this category. This includes labor costs relating to plant management, purchasing, production control, maintenance, quality control, and plant engineering. For these studies these costs are estimated as a percentage of Direct Labor costs when operating at planned capacity. At other production rates these costs are allocated over the number of units produced.

Utilities

This includes the cost of energy and water for operating the plant facility. These costs are estimated at a flat rate per heliostat unit produced.

Depreciation

This includes the depreciation of the initial cost of plant and equipment at prescribed rates for each type of asset.

Property Taxes

Real estate and personal property taxes are estimated based on land, facility and equipment values. The applicable tax rate and capital evaluation for Albuquerque, New Mexico have been applied to determine the annual tax.

8.5.2 Direct Materials

The direct material cost per heliostat was determined to be as follows:

CBS	Description	Direct Material Cost Per Heliostat
4410	Reflective Unit	$ 960.36
4420	Drive Unit	1,318.39
4430	Controls	233.48
4440	Foundation	309.40
4450	Heliostat Support	450.84
		$3,272.47

A detailed breakout of these costs can be found in the Appendix.

Direct material cost per unit produced is essentially independent of production levels between 50 and 135% of planned capacity.

8.5.3 Indirect Materials

Indirect materials cost have been included at a rate of 2% of direct material cost. This relatively low percentage is typical of high volume manufacturing operation. Since this cost varies with direct material cost, the cost per unit produced is constant as production volume varies.

8.5.4 Direct Labor

The Direct Labor Cost per heliostat was determined to be as follows:

CBS	Description	Direct Labor Cost Per Heliostat
4410	Reflective Unit	$ 15.48
4420	Drive Unit	76.82
4430	Controls	10.47
4440	Foundation	4.50
4450	Heliostat Support	10.96
		$118.23

These costs are detailed in the Appendix. They include straight time earnings only of productive labor. This cost per unit is independent of production level.

8.5.5 Shift and Overtime Premiums

Direct labor has been figured on a straight time basis and adjustments to cost are needed for changes in production levels which affect manpower loading of shifts and introduce overtime. Premiums included are as follows:

Second Shift - 5%
Third shift - 7.5%
Overtime - 50%

At 50% of planned capacity the direct labor work force is distributed as follows:

First shift - 85%
Second shift - 15%
Third shift - 0%

On this basis the average shift premium is 0.8% (0.15 x 5) of Direct Labor or $.95 per heliostat.

At 100% of planned capacity the direct labor workforce is distributed as follows:

First shift - 49%
Second shift - 36%
Third shift - 15%

The shift premium, therefore, is 2.9% [(0.36 x 5) + (0.15 x 7.5)] of Direct Labor or $3.43 per heliostat produced.

At 135% capacity the distribution of effort by shift is as follows:

First shift - 40%
Second shift - 36%
Third shift - 24%

In addition 12% of the hours worked are on an overtime basis. The shift premium is 3.6% [(0.36 x 5) + (0.24 x 7.5)] of direct labor or $4.26 per heliostat. The overtime premium is 6.0% [0.12 x 50] of direct labor or $7.09 per heliostat. Those two premium payments combine to total $11.35 per heliostat at this higher level of output.

8.5.6 Variable Indirect Labor

This segment of indirect labor is that which varies directly with production output so the cost per heliostat produced is constant. These costs are allocated on the basis of 70% of Direct Labor. This amounts to $82.76 per heliostat at all production levels.

8.5.7 Fixed Indirect Labor

This segment of indirect labor is that which is constant and is independent of production volume. At 100% of standard capacity this cost is allocated at 50% of direct labor. At other levels this same total cost is proportioned over the output. On that basis the cost of fixed indirect labor is as follows:

% of Planned Capacity	Fixed Indirect Labor Cost
50	$118.23
100	59.12
135	43.79

8.5.8 Utilities

Utilities costs are closely tied to plant output levels and are estimated to be $75.00 per heliostat independent of the production level.

Some utility costs are independent of production levels but they were considered to be negligible.

8.5.9 Depreciation

Capital costs have been determined to be

Land	720,000
Building	19,800,000
Equipment	72,207,000
Total	92,727,000

Referring to Table 8-2, depreciation per year for the plant has been determined to be $8,210,700. Allocating this on a per unit output basis yields the following depreciation cost:

% of Planned Capacity	Depreciation Cost
50	$328.42
100	164.21
135	121.64

8.5.10 Property Taxes

Property taxes in Albuquerque are figured at a tax rate of 0.0234. An average asset value over the ten year period is used to determine the property tax per heliostat produced.

Asset Value	First Year	Tenth Year
Land	720,000	720,000
Building	19,800,000	9,900,000
Equipment	72,207,000	0
	92,727,000	10,620,000
Tax rate	.0234	.0234
Tax	2,169,812	248,508
Tax per Heliostat	$43.40	$4.97
Avg. Tax per Heliostat	$24.19	

This average tax per heliostat is based on standard output.
At the various capacity levels the property tax per heliostat is as follows:

TABLE 8-2

DEPRECIATION COST SUMMARY

Item	First Cost	Annual Depreciation	Depreciation[3] Per Heliostat
Land	720,000	---	---
Building	19,800,000	990,000[1]	19.80
Equipment	72,207,000	7,220,700[2]	144.41
Total	92,727,000	8,210,700	164.21

1. Twenty years - straight line - 0 salvage value
2. Ten years - straight line - 0 salvage value
3. 50,000 heliostats/year

% of Planned Capacity	Property Tax Per Heliostat
50	$48.38
100	24.19
135	17.92

8.5.11 Effect of Production Level on Costs

The cost per heliostat has been examined for three levels of production.

Operating Level in Percent of Planned Capacity	Quantity Produced Per Year	Manufacturing Cost Per Heliostat
50	25,000	$4108 (106)
100	50,000	3863 (100)
135	67,000	3808 (99)

The results of this anaylsis are shown in Table 8-3. Note that over this range of operating levels the cost per heliostat varies only seven percent. This is due to the dominance that direct material costs (which do not vary with production volume) have in the total cost picture.

8.6 TRANSPORTATION COSTS

Transportation cost are usually determined on a cost per truck-mile basis. A recent figure published by the American Transportation Association (ATA) indicates an average of $0.915 per mile. This includes:

Vehicle depreciation
Interest on equity
Insurance
Licenses
Fuel and tires
Driver cost

TABLE 8-3

Manufacturing Cost per Heliostat

	% of Planned Capacity		
	50	100	135
Direct Materials	3272	3272	3272
Indirect Materials	65	65	65
Direct Labor	118	118	118
Overtime & Shift Premiums	1	3	11
Variable Indirect Labor	83	83	83
Fixed Indirect Labor	118	59	44
Utilities	75	75	75
Depreciation - P & E	328	164	122
Property Taxes	48	24	18
	4108	3863	3808
	(1.06)	(1.00)	(0.99)

8.6.1 Equipment Costs

To handle the transportation of 200 heliostats per day production will require 80 tractors and 240 trailers. The capital equipment cost for this fleet is as follows:

Capital Equipment	
80 tractors @ 54,000	$4,320,000
240 trailers @ 10,000*	2,400,000
	$6,720,000

*Includes custom racking and tie-down provisions

Tractor Miles	
Tractors	80
Life - miles per tractor	600,000
Tractor - miles	48,000,000
Equipment Cost per Tractor - Mile	$0.14

8.6.2 Costs Per Mile

Utilizing this depreciation cost and other cost factors an estimate on the cost per mile has been prepared. In summary form it is as follows:

	Cost Per Mile
Depreciation	$0.14
Fuel (5 MPG @ $1.00/gallon)	0.20
Tires (18 @ $330 for 60,000 miles)	0.10
Maintenance	0.16
Insurance, taxes, etc.	0.19
Driver (11.00/hr + 30% fringes)	0.36
	1.15

This figure which is reasonably close to the ATA figure will be used for determining transportation costs.

8.6.3 Costs per Heliostat

The transportation cost per heliostat is determined by the product of:

Miles - round trip	533
Truck loads per heliostat	0.194
Cost per truck-mile	$1.15

to obtain:

Cost per heliostat	$119

Allocating these costs based on truckloads to the various CBS categories yields the following:

CBS		Transportation Cost
4410	Reflective Unit	$ 46
4420	Drive Unit	17
4430	Controls	--
4440	Foundation	23
4450	Heliostat Support	33
	Total	$119

8.7 FIELD ASSEMBLY AND INSTALLATION COST

8.7.1 Basis For Cost Estimates

The estimate for field assembly and installation costs are based on the engineering information prepared by Bechtel National. This includes task descriptions, equipment lists, plot plans including building layouts and manhour time-lines. In addition, information was used from previous Bechtel work, adjusted to the exact requirements of this project.

8.7.1.1 Pricing

First Quarter 1980 pricing levels were used for all equipment, subcontracts, bulk materials, and labor. Costs of significant subcontracts and major bulk items were based on written or telephone quotes supplied for estimating purposes by vendors. Pricing for all other items were based on in-house historical data.

8.7.1.2 Labor

The estimate is based on labor productivity and wages for unionized, direct hire construction workers. Labor rates were developed from craft agreement information published by the Associated General Contractors of California, Inc. The overall labor rate of $20.00/hour is composed of an average direct rate of $13.00 and an indirect rate of $7.00 covering craft benefits, payroll burdens and subsistence. Manhour installation rates were developed using Bechtel experience in the southwestern United States.

8.7.1.3 Indirect Field Costs

Indirect field costs are those items of construction that cannot be directly attributed to the permanent plant facilities and thus are accounted for separately. They were estimated on the basis of Bechtel experience on previous jobs in the western United States, and adjusted to reflect the specific characteristics of the project.

In this study, a 65% indirect rate was applied to all field construction activities, and a 30% indirect rate was applied to all heliostat field assembly activities. Items covered by these indirect costs include:

- o Temporary construction facilities
- o Construction consumable supplies
- o Field engineering and craft supervision
- o Equipment rental

8.7.2 <u>Heliostat Field Costs</u>

8.7.2.1 Heliostat Assembly

The costs shown for the assembly of the heliostats includes the manhours necessary to receive and assemble the heliostat modules. In addition, an assembly building has been estimated. It is assumed that this building will be completely written off over

TABLE 8-4

FIELD ASSEMBLY AND INSTALLATION COST SUMMARY

<u>Pile Installation</u>		
Contract Installer		$220
<u>Heliostat Field Assembly</u>		
17.5 hours @ $26*	455	
Facility and Equipment	65	
		520
<u>Heliostat Transport and Erection</u>		
5.2 hours @ $26*	135	
Equipment	10	
		145
<u>Control Installation</u>		
2.2 hours @ $26*	57	
Equipment	1	
		58
		$943

*Direct	$13
Benefits	7
Overhead	6
Total	$26

the life of the assembly activities, with zero salvage value. It is not expected that it would be economical to move the building to another site to accommodate additional assembly requirements, but the building should be able to be utilized as a maintenance or storage building, which would reduce the cost that is directly attributable to the assembly activity.

8.7.2.2 Foundation Installation

The field cost for the installation of the heliostat foundation includes a subcontractor who will auger the hole, set the pile and grout the void in between.

8.7.2.3 Heliostat Installation

The cost of the installation of the heliostat is directly related to the installation time-line. This cost reflects the manhours required to transport and install the heliostat at its given location. In addition, the cost of renting equipment to perform this installation task has been included based upon current equipment lease agreements.

8.7.2.4 Field Cost Summary

A summary of field related heliostat costs is presented in Table 8-4. The total for this activity is $943 per heliostat.

8.8 OTHER BUSINESS COSTS

In addition to manufacturing cost, transportation-out costs, field assembly costs and installation costs, a manufacturing concern must consider other cost elements in establishing the selling price of an installed product. These include:

R & D Expense - A business must continue to invest in R & D so that its product maintains a competitive position relative to performance, quality, cost and features. A budget of $5,000,000 per year is anticipated which at standard output adds $100 to the cost of each heliostat.

General and Administrative Expense - This expense area covers all administrative, financial, marketing and personnel activities and includes the cost of general management and his immediate staff. An annual budget of $15,000,000 is provided at a cost per heliostat of $300.

Taxes - Profits of the firm are subject to state and federal income taxes and they are estimated to be $10,000,000 per year which allocates out to $200 per heliostat produced.

Profit After Taxes - An essential element of the cost build-up is a profit after taxes which provides the manufacturer an adequate return on investment (ROI) and an adequate return on sales (ROS). For operations of this type the profit after taxes should provide at least a 20% ROI and a 6% ROS. For the health of the business both of these criteria should be met.

An annual profit after taxes of $20,000,000 meets the ROS requirement on projected sales of $300,000,000. It also provides about a 20% return on the $93,000,000 invested in plant and equipment and the $7,000,000 invested in tractors and trailers. As these assets are depreciated this ROI percentage will increase.

On this basis the required profit after taxes per heliostat produced is $400.

8.9 OTHER FIELD COSTS

In addition to the cost of the planted heliostats we have included the cost of land, field wiring and controllers to arrive at the collector subsystem cost per heliostat. Through the use of the DELSOL computer code, Sandia determined that 5974 Northrup II heliostats would be required for a $50MW_e$ collector field. The DELSOL program also indicated that 313 acres of land would be required for the field. Land costs were figured at 313/5974 = 0.0524 acres per heliostat at $8000 per acre--a figure which includes basic improvements.

Wiring of the heliostat field consists of bringing 115 volt power to the base of each heliostat. The electrical current requirements for each heliostat are less than 10 amperes. Also a six wire data bus is run from the Heliostat Controller to up to 64 heliostats in a series string. The total cost of field wiring the 115 volt system and the 6 wire control bus is estimated to a flat rate of $200 per heliostat.

A Heliostat Controller with a budgeted cost of $1,000,000 is needed to control the field. Its cost is allocated across the 5974 heliostats.

8.10 TOTAL COST SUMMARY

The costs identified in this section are summarized on Table 8-5. This table shows a manufacturing cost of $3683, a factory selling price for the installed heliostat of $5925, and a total installed cost per heliostat including the field related costs of land, field wiring and controllers of $6711. This results in a projected cost per m^2R of $139.67. On a 90% experience curve these costs diminish at the following pace:

1st year of production	$139.67/$m^2R$
2nd year of production	125.70/m^2R
4th year of production	113.12/m^2R
8th year of production	101.82/m^2R

8.11 COST GOAL

In the proposal which Northrup submitted in response to the solicitation for the development of a second generation heliostat, a cost goal of $70/$m^2$ for a heliostat with a net reflectivity of 0.87 was indicated. This goal was stated in 1978 dollars and did not include the cost of land, field wiring, and heliostat array and field controllers. This proposal goal has been adjusted and is now expressed in $/$m^2R$ to account for variations in reflectivity, to show costs in April 1980 dollars, and to include an adjustment for the added elements

TABLE 8-5

TOTAL COST SUMMARY

Heliostat	10^6\$/Yr (%) (50,000 units)	\$/Heliostat	\$/m^2 (52.8m^2)	\$/m^{2}R (R=0.91)	
Manufacturing Cost	193.2 (65.2)	3863	73.16	80.40	
Transportation Out	6.0 (2.0)	119	2.25	2.48	
Field Assembly and Installation	47.1 (15.9)	943	17.86	19.63	
R & D	5.0 (1.7)	100	1.89	2.08	
General and Administrative	15.0 (5.1)	300	5.68	6.24	
Income Taxes	10.0 (3.4)	200	3.79	4.16	
Profit after Taxes	20.0 (6.7)	400	7.58	8.32	
Total	296.3 (100.0)	5925	112.21	123.31	
Land (.0524 acres @ \$8000/acre)		419	7.94	8.72	
Field Wiring (HC to Heliostat)		200	3.79	4.16	
HC (1/5974 of \$1,000,000)		167	3.16	3.48	
Total Installed Cost		6711	127.10	139.67	
	0.9 Experience Curve				
	2nd Year	6040	114.39	125.70	
	4th Year	5436	102.95	113.13	← Goal 116.85
	8th Year	4892	92.66	101.82	

of land, field wiring, and controllers.

$$\begin{aligned}
\text{Adjusted Goal} &= \begin{pmatrix}\text{Proposal}\\ \text{Goal}\end{pmatrix}\left(\frac{1}{\text{Proposal Reflectivity}}\right)\begin{pmatrix}\text{inflation}\\ \text{factor}\\ \text{2-1/3 years}\end{pmatrix} + \begin{pmatrix}\text{Adjustment}\\ \text{for land,}\\ \text{field wiring}\\ \text{and HC}\end{pmatrix}\\
&= (70)\left(\frac{1}{0.87}\right)(1.10)^{2.33} + (16.36)\\
&= 100.49 + 16.36\\
&= \$116.85/\text{m}^2\text{R}
\end{aligned}$$

This represents an adjusted goal which is consistent with the proposal targets. As shown in Table 8-5 this goal is expected to be reached somewhere between the second and fourth year of production.

8.12 COST OF 50 MW_e COLLECTOR FIELD

8.12.1 Methodology

The annual cost of owning and operating the collector field for a $50MW_e$ power plant was obtained by summing the annual capital charges, operating costs, and maintenance costs for such a field. The capital charges are based on the installed cost of the heliostats. These costs are amortized over the life of the system. Operating costs are based on the electrical costs for powering the controls and motors used in the field. The maintenance costs are those developed in Section 7.0 of this report.

8.12.2 Capital Costs

Through use of the DELSOL computer code, Sandia determined that 5974 Northrup II heliostats would be required for a $50MW_e$ collector field. This cost has been multiplied by the cost per heliostat to arrive at installed heliostat costs. These capital costs are adjusted for income tax credits and then amortized over 30 years at 15%.

8.12.3 Operating Cost

The only significant operating cost of a collector sub-system is

TABLE 8-6

Annual Costs for a 50MW$_e$ Collector Subsystem

	Year of Production			
	1st	2nd	4th	8th
Investment				
5974 Heliostats (includes land, field wiring and HC)	$40.1 x 10^6	$36.1 x 10^6	$32.5 x 10^6	$29.2 x 10^6
$ per KW	$802	$722	$650	$584
Annual Costs				
Capital charges after ITC (30 yrs @ 15%)	$ 5.0 x 10^6	$ 4.5 x 10^6	$ 4.0 x 10^6	$ 3.6 x 10^6
Operating Cost	.6 x 10^6	.6 x 10^6	.6 x 10^6	.6 x 10^6
Maintenance Cost	.3 x 10^6	.3 x 10^6	.3 x 10^6	.3 x 10^6
Capital + O & M Costs	$ 5.9 x 10^6	$ 5.4 x 10^6	$ 4.9 x 10^6	$ 4.5 x 10^6
$ per KW	$118	$108	$ 98	$90
¢ per KWH*	4.8¢	4.4¢	4.0¢	3.7¢

*Based on 123 x 10^6 KWH/year per 50 MW$_e$ plant the cost of the electrical energy which is consumed by the controls, translators, power supplies and motors. As shown in Section 3.0 this amounts to 2.958 KWH per day per heliostat. A 5974 heliostat field will consume 6.18x 10^6 KWH/yr. Based on a value of 10¢/KWH the cost of this energy represents operating costs. For the $50MW_e$ plant this amounts to $618,000 per year.

8.12.4 Maintenance Cost

In Section 7.0 the cost of maintenance was determined to be $58.14 per heliostat per year. This cost estimate was used to determine the cost for the $50MW_e$ collector field. For 5974 heliostats this amounts to $347,000 per year.

8.12.5 Total Annual Cost

The total annual cost for the collector field for a $50MW_e$ power plant is summarized in Table 8.6. The table shows that the costs vary from $5.9 million down to $4.5 million in the first eight years of heliostat production (based on a 90% experience curve). On a delivered energy cost basis the cost of the collector field varies from 4.8¢/KWH down to 3.7¢/KWH.

8.13 POTENTIAL COST REDUCTIONS

At this point in the program our cost estimates indicate that we are 20% over our cost target. Based on a 90% experience curve, the goal would be reached sometime between the second and fourth year of production. In this subsection we will identify some potential cost reductions which could accelerate this cost reduction accomplishment.

8.13.1 Reflective Unit

Three areas of cost reduction have been identified for the mirror modules. They are to eliminate the painting of the substrate, the use of thinner glass and the use of a one piece mirror.

Since the back of the mirror modules are never exposed to direct sunlight, the need for the reflective white surface is subject to question. The galvannealed coating on the steel provides adequate corrosion protection. This change not only reduces factory costs but also reduces the need for subsequent field painting in later years.

Thinner glass offers opportunity not only for reducing costs but also increasing performance and thus reducing the number of heliostats required to produce a required power level. A move to thinner glass has greater impact than any other cost reduction proposal.

The prototype mirror modules were constructed of two 4 feet x 6 feet mirror lites. For large fields a 4 feet x 12 feet mirror lite would provide adequate performance. This eliminates the hardware required to seal and contain the lites throughout the center of the module. In addition a small gain in net reflective area is accomplished.

8.13.2 Drive Unit

The drive unit utilizes 10 major iron castings. The prototypes were constructed of conservative casting designs which had low pattern costs. Work has already been started which indicates that about 30% of the weight of the castings can be reduced by the conventional methods of coring and scalloping which is typical of high volume pattern design.

The D.C. stepper motors used in the azimuth and elevation drives have never been produced in high volume and are very costly for the function provided. Some alternative motor concepts may be developed which significantly lower the cost of producing torque.

In the maintenance area the crankcase oil and the gear drive housing paint are planned to have a 10 year average life. Maintenance costs can be reduced if a life-time oil and a life-time paint can be identified. New developments in lubricants and protective coatings indicate a high probability of obtaining materials with lifetime properties in future years.

8.13.3 Controls

The electronics industry is a fast-paced technology with dramatic year-to-year improvements in performance and cost. This sets the stage for improvements to control systems which reduce the energy consumption of the drive electronics and thus reduce operating costs.

The life-time paint predicted for the drive unit housing would also reduce maintenance costs for the control housing.

8.13.4 Foundation

The only identified cost reduction for the pedestal is a life-time paint finish.

8.13.5 Heliostat Support

Preliminary tests have indicated that the truss cross bracing and lower braces may not be required. This eliminates the factory cost for these parts and the cost of field-assembly.

The torque tube can be designed of larger diameter, of thinner wall thickness and of lower weight. The prototype design was of compromise dimensions which provided an appropriate mating diameter for the drive units. Subsequent studies have indicated that the large diameter thin-wall tube can be used with an appropriate tapering section to match the drive unit coupling area.

As with the other painted parts this area can also be benefited by reduced maintenance costs through the use of a life-time paint.

TABLE 8-7

COST REDUCTION SUMMARY

		Heliostat Cost Reductions				Capital Cost Reductions $10^3$$	50 MW_e Field Annual Cost Reductions in $10^3$$			
CBS		Mfg. Cost	Install. Cost	Total	$/m^{2}R		Capital Cost	Oper. Cost	Maint. Cost	Total Cost
4410	Reflective Unit									
	Eliminate paint	86	--	86	1.79	514	64	--	9	73
	Thin glass ($\Delta R=0.04$)[1]	86	--	86	7.60	2184	271	26	15	312
	One piece mirror[2]	6	--	6	.82	237	29	3	2	34
4420	Drive Unit									
	Reduce wt. of castings	159	--	159	3.31	950	118	--	--	118
	Redesign motors	150	--	150	3.12	896	111	--	--	111
	Lifetime oil	---	--	--	---	---	---	--	36	36
	Lifetime finish	---	--	--	---	---	---	--	7	7
4430	Controls									
	Reduce wattage	---	--	--	---	---	---	309	--	309
	Lifetime finish	---	--	--	---	---	---	--	7	7
4440	Foundation									
	Lifetime finish	---	--	--	---	---	--	--	9	9
4450	Heliostat Support									
	Eliminate braces	47	52	99	2.06	591	73	--	--	73
	Redesign torque tube	93	26	119	2.48	711	88	--	--	88
	Lifetime finish	---	--	--	---	---	--	--	42	42
4460	Field Assembly									
	Replan labor	---	259	259	5.39	1547	192	--	--	192
	Use vibratory hammer	---	130	130	2.71	777	96	--	--	96
		627	467	1094	29.28	8407	1042	338	127	1507

1 - Increases reflectivity by 4.4% - Reduces number of heliostats in 50MW_e field to 5722 (Reduction of 252)

2 - Increase reflective area by 0.5% - Reduces number of heliostats in 50MW_e field to 5944 (Reduction of 30)

8.13.6 Field Assembly

The field labor costs for assembling and installing the heliostat are currently estimated to be $647 per heliostat. Through modification of heliostat design, shifting high cost field labor to the factory and/or improved field labor planning this cost should be reduced rapidly as experience is gained. A target of a 40% reduction seems reasonable.

The prototype foundation design has been costed on the basis of a thin wall pedestal set in an augered and grouted hole. With reinforcement of the insertion end of the pile or stiffening the pile by fluting, the thinner wall pile may be capable of being inserted with a vibrating hammer. This would then permit the use of the lower cost pile with the lower cost insertion method.

8.13.7 Summary of Cost Reduction Potential

The potential cost reductions are summarized in Table 8-7. They total $29.28 per m^2R which is a 21% reduction from the current cost estimate. If achieved the cost per m^2R would drop to $110.39 which is 6% below our cost goal.

The annual cost of owning, operating and maintaining a $50MW_e$ collector field is also reduced significantly. If all the identified cost reductions materialize, this cost would drop by $1.5 million per year.

8.14 COST CONCLUSIONS

Results of this study indicate that installed heliostat cost levels approaching $100 per m^2R are achievable on a volume basis. The cost of owning, operating and maintaining a collector field for a solar central receiver electric power plant is in the vicinity of 4¢ per KWH of output. This cost of the collector field can be considered as fuel cost.

Nuclear and coal-fired plants have fuel costs in the 1¢ to 2¢ per KWH range and at today's economics are unchallenged by this solar alternative on a fuel cost basis. On the other hand, rapidly rising costs of scarce fuels such as oil and gas present a different comparative picture.

Efficient electric power generating plants have a fuel rate of about 10,000 Btu per KWH of output. Oil has a heat value of about 6,000,000 Btu per barrel so it requires 1/600 of a barrel of oil to produce one KWH in an oil-fired plant. For various levels of oil cost, the fuel cost comparison to solar central receiver systems is as follows:

OIL			SOLAR CENTRAL RECEIVER SYSTEM
Oil Cost		Fuel Cost per KWH_e (1/600 Barrel)	"Fuel Cost" Per KWH_e
\$ per Barrel	\$ per 10^6 Btu		
\$ 6	\$1	1¢	Solar Central Receiver System More Costly
12	2	2	
18	3	3	
\$24	\$4	4¢	4¢
\$30	\$5	5¢	Solar Central Receiver System Less Costly
36	6	6	
42	7	7	

This indicates that solar central receiver systems have the potential of matching the fuel cost of oil-fired plants which have a per unit fuel cost of \$24 a barrel, or in a more general sense, the potential of matching the fuel cost of any generating plant which has a per unit energy cost of \$4 per million Btu. With foreign and decontrolled domestic oil prices well above that threshold value at this time, solar central receiver systems are in a favorable competitive position with that energy source. If the cost of gas on a Btu basis approaches the world market price of oil, solar central receiver systems will also assume a favorable fuel cost position relative to that currently price-controlled fuel.

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