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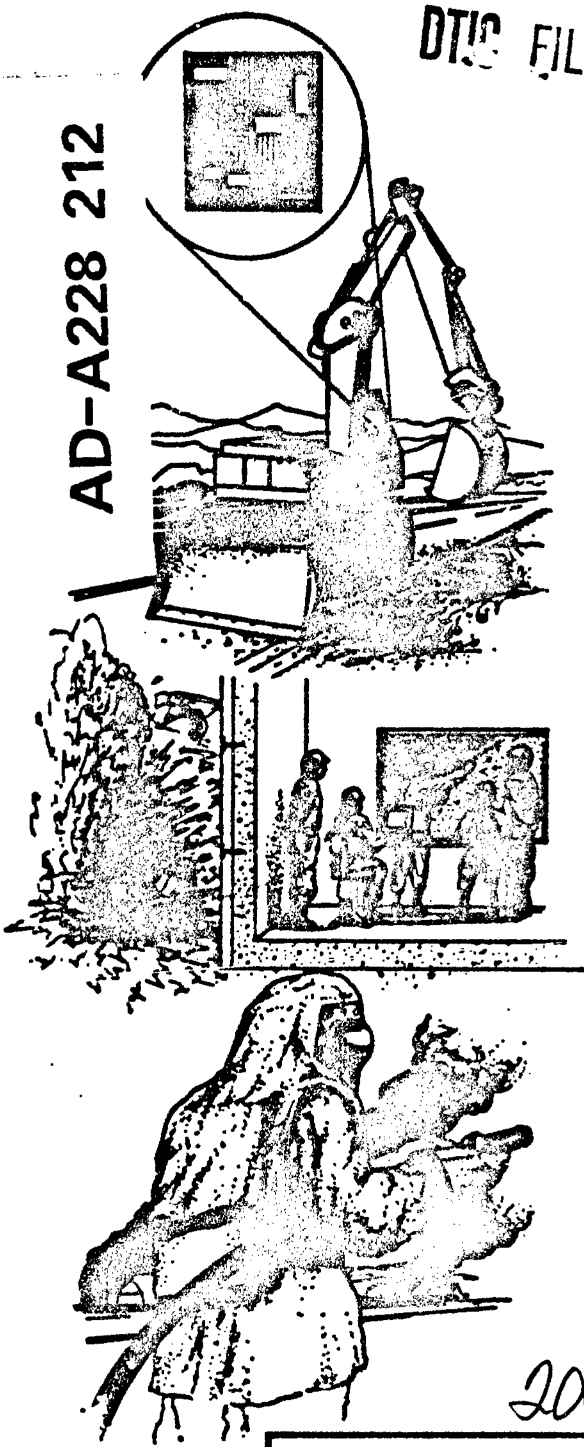

SPLINTER PROTECTION FOR AIRBASE FIREFIGHTING RESOURCES

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DECEMBER 1989

FINAL REPORT

JUNE 1987 — SEPTEMBER 1988

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

ENGINEERING RESEARCH DIVISION
Air Force Engineering & Services Center
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release. Distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NMERI WA3-62 (3.27)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFESC/ESL-TR-89-05
6a. NAME OF PERFORMING ORGANIZATION New Mexico Engineering Research Institute 6b. OFFICE SYMBOL (If applicable) NMERI	7a. NAME OF MONITORING ORGANIZATION Engineering and Services Laboratory
6c. ADDRESS (City, State, and ZIP Code) Box 25, University of New Mexico Albuquerque, New Mexico 87131	7b. ADDRESS (City, State, and ZIP Code) Air Force Engineering and Services Center Tyndall Air Force Base, Florida 32403
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract No. F29601-84-C-0080
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
SPLINTER PROTECTION FOR AIRBASE FIREFIGHTING RESOURCES

12. PERSONAL AUTHOR(S)
Golden E. Lane, Jr.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM 6/87 TO 9/88	December 1989	146

16. SUPPLEMENTARY NOTATION
Availability of this report is specified on reverse of front cover.

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Splinter Protection, Protective Construction, Hardened Construction, Shotcrete, Corrugated Steel Pipe, Conventional Weapons.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Firefighting resources, including consumables and vehicles, assigned to airbase fire departments in Europe and the Pacific are dispersed according to a predetermined plan before attack. Dispersal locations depend on availability of space in aircraft shelters and other protected areas designed and constructed for the protection of other resources; therefore, fire departments must compete for protected space. When an attack occurs, space may not be available or what is available may not satisfy the needs of the fire departments.

A series of concepts was considered for possible use as splinter protection for the firefighting resources. These concepts were evaluated and two designs were developed to protect the resources to minimize damage from an attack.

The two selected concepts were both earth-bermed structures. One structure was constructed from a corrugated steel culvert structure with a concrete floor and the other consisted of a reinforced concrete (shotcrete) arch.

A suggested test plan is included for field testing the selected structure to verify the hardness of the prototype structure and address the constructibility of the concept.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Hugh Pike	22b. TELEPHONE (Include Area Code) 904-283-6194 22c. OFFICE SYMBOL HQAFESC/RDCF

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

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Preface

This final report was prepared by the New Mexico Engineering Research Institute (NMERI), University of New Mexico, Albuquerque, New Mexico, under Contract F29601-84-C-0080, for the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.

This report summarizes work done between June 1987 and September 1988. LTJG Randy Burkett and Mr. Hugh A. Pike were AFESC/RD Project Officers. Mr James Hotell, was the HQ USAFE/DEMF Project Officer.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. BACKGROUND

Firefighting resources, including consumables and vehicles, assigned to airbase fire departments in Europe and the Pacific are dispersed before attack, according to a predetermined plan. Dispersal locations depend on the availability of space in aircraft shelters and other protected areas designed and constructed for the protection of other resources; therefore, fire departments must compete for protected space. When an attack occurs, space may not be available or the available space may not meet the needs of the fire department.

Dedicated splinter protected areas, located and designed specifically for firefighting vehicles and consumables, will improve the firefighting and rescue capability following an airbase attack. The use of dedicated areas will also greatly reduce or eliminate the competition for available protected space.

B. OBJECTIVE

The objective of this investigation was to develop optimum, affordable designs for protecting firefighting resources from damage or destruction, thereby, minimizing damage from an attack. Specifically, the objective requires the development of effective and practical designs based on off-the-shelf materials and standard construction techniques.

C. RESOURCES

Table 1 presents the major firefighting equipment considered for protection. Based on the vehicle geometry presented in Table 1, three shelter sizes were selected for final design. Table 2 presents vehicle envelopes on

TABLE 1. FIREFIGHTING EQUIPMENT DATA.

Truck	Description/Purpose	Height, in	Width, in	Length, in	Wheel Base, in	Ground Clearance, in	Turning Radius, in	Clearance, in-- per side
P- 2	Aircraft crash T.O. 36A 12-8-13-14	139	118.5	381 [a](420.02)	205	[b]12.0	55.0	49 Engine doors
P- 4	Multipurpose-- air transportable T.O. 36A 12-12-14-1	130	118	360	213	[b]12.0	50.0	30
P- 8	500 gal/min Brush and structural T.O. 36A 12-12-1	115	96	276	153	[b]11.5	33.0	44 Personnel doors
P-10	Forcible entry 4 x 4 crew cab T.O. 36A 12-12-13-11	84 [c](93)	99	241		[b] 8.0	20.3	39 Front doors
P-12	750 gal/min structural T.O. 36A 12-12-15-1	108	96	289	153	[b]10.0	22.5	43 Personnel doors
P-15	Aircraft crash WSN 4210-01-013-2825	165	122	542 [d](562.0)	304	[b]15.0	75.0	
P-19	Aircraft crash and structural (rapid intervention) T.O. 36A 12-8-17-2	[illegible]	96	325	170	[b]13.0	40.0	
P-20	Multipurpose and Ramp Patrol (rapid intervention)	91	91	225	153	8.0	20.3	39.5

[a]Roof turret extended

[b]Underaxle

[c]P-10A

[d]Rear turret extended

these three shelters. These envelopes were used to determine minimum shelter dimensions. Storage of supplies and equipment was not considered in selecting shelter dimensions for comparative evaluation because these functions are considered to be future determinations to be made by MAJCOM and individual bases. Additional work and storage space can be provided by adding length to any of the shelter concepts considered. Additional work space and other functional requirements are discussed in Section IV.

TABLE 2. BASIC SHELTER DIMENSIONS

Overall Vehicle Envelope

Shelter Designation	Length	Width	Height	Vehicle Sheltered
A	50 ft	10 ft, 2 in	13 ft, 9 in	P-15
B	36 ft	10 ft, 2 in	13 ft, 9 in	P-2, P-4
C	36 ft	8 ft, 3 in	9 ft, 7 in	P-8, P-10, P-12, P-19 P-20

SECTION II

SPLINTER PROTECTION CONCEPTS

Two general types of protection concepts were considered: (1) perimeter wall structures such as revetments and (2) fully enclosed structures such as bermed arches and buried steel culverts. All of the concepts could be constructed with off-the-shelf materials and established techniques.

Because of the requirement to develop affordable systems based upon off-the-shelf materials and standard construction techniques, none of the protection concepts considered includes door systems. Hardened doors do not provide a significant increase in the protection afforded by perimeter wall systems. Although they do provide a significant increase in the protection afforded by enclosed systems, they also significantly increase the cost and complexity of the shelter. If hardened doors are not installed, design threat weapons impacting within a sector, defined by the geometry of the shelter entranceway and the placement of equipment within the shelter can cause t and airblast damage to stored equipment. Free-standing revetments or berms can reduce the vulnerability of open entranceways; however, as a door system, they can be designed to stop fragments and projectiles, but they have little effect on airblast attenuation unless located close to the target being protected. Many of the factors affecting the size and siting of revetments and berms are site-dependent, and no general recommendations can be made for these features. Some of the factors affecting the design of revetment or berm systems are weapon miss distances, types of weapons, turning radius of vehicles, direction from which weapons may be delivered, size and proximity of other structures, and availability of real estate. Some earth berm concepts are illustrated and further discussed in Section IV.

The perimeter wall concepts considered were sand grids, precast concrete retaining wall materials, steel-soil-bin-type structures, and two types of aircraft revetments: reinforced concrete and a Slurry Infiltrated Fiber Concrete (SIFCON). The total enclosure concepts considered were multiplate steel structures, steel culvert shelters, and shotcrete arch structures. All fully enclosed structural concepts were considered to be bermed. The assumed berm geometry was 2-feet deep at the crown of structure and side slopes were 30 degrees relative to the horizontal.

Following are brief descriptions of the concepts considered, with a discussion of the following specific factors used in the evaluation of each: constructibility, performance, land use, aesthetics, and cost. The cost factor was based on a planned enclosed space of 18 by 53 feet, which is shelter designation A, the size required for the largest vehicle (P-15).

A. SAND GRIDS

Sand-grid material was originally developed at the Waterways Experiment Station (WES) as a soil confinement and erosion control system. A program was later undertaken to investigate the suitability of sand grid concepts for protective revetments. Some examples of uses for protective revetments are:

- Protective artillery emplacements
- Individual fighting positions
- Helicopter revetment positions
- Command post protection
- Protection of civilian structures against terrorist attack

Sand grid material is normally constructed from high density polyethylene plastic strips approximately 8 inches wide. The strips are bonded at 13-inch intervals to form a honeycomb grid section. The plastic material is normally treated with ultraviolet stabilizers to prevent breakdown of the grid material when exposed to field conditions. Protective revetments or perimeter walls are constructed by expanding the grid material and filling it with sand or soil and then stacking the sections. Sand grid revetments have been constructed as high as 8 feet. WES has shown that sand grid construction is more economical than sandbag construction.

1. Constructibility

Of all the concepts considered, the sand grids are the easiest to construct. They can be erected by unskilled labor and require only hand tools.

2. Performance

A variety of conventional weapons have been used by WES to test sand grid revetments containing different fill materials such as sand, soil or gravel. The results of the tests indicate the sand grid concept will provide a measure of protection to the splinter threat. However, if the maximum height used is only 8 feet, only the lower portion of the vehicle will be protected. No protection is provided from projectiles lofted over the revetment.

3. Land Use

The sand grid configuration results in walls approximately 3 feet wide; therefore, this concept allows for the smallest perimeter wall footprint of the approaches considered.

4. Aesthetics

Because the fill material on the top of the structure and the 8-inch layers of plastic on the sides are visible, this concept has less eye appeal than any of the others.

5. Cost

For an enclosed area 18 by 53 feet and open on one end, the cost of an 8-foot high sand grid wall is approximately $12,000, including a concrete floor slab.

B. PRECAST CONCRETE RETAINING WALL SYSTEMS

These structures consist of an assemblage of precase concrete block units that can be interlocked and stacked in almost any desired configuration to form a retaining wall structure. Overturning and sliding are resisted by the weight of the structure and fill material. Maximum constructed heights of this system exceed requirements for the shelters.

1. Constructibility

DOUBLEWAL^{tm} modular precast interlocking components are constructed by a licensee of the Atlantic Pipe Corporation (Figure 1). Walls are asssembled by stacking blocks to the required height in any configuration. No bolting or mechanical assembly is required. Corner modules and capping blocks are available. A crane is required for lifting and placing the blocks.

2. Performance

This concept has not been examined for protection against weapons effects. However, the units consist of two 5-inch-thick reinforced concrete walls with interlocking top and bottom surfaces separated by fill material which should provide adequate protection against the proposed threat. The added height over sand grids offers better protection from surface bursts, but not from lofted projectiles.

3. Land Use

Nominal block widths range from 4 to 16 feet. Using the narrower widths will provide a relatively small footprint.

4. Aesthetics

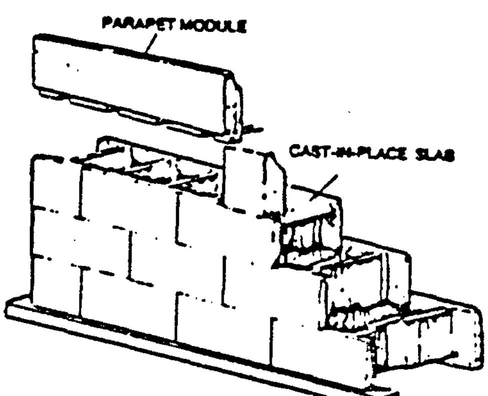
The bold, modular construction results in a pleasing appearance.

5. Cost

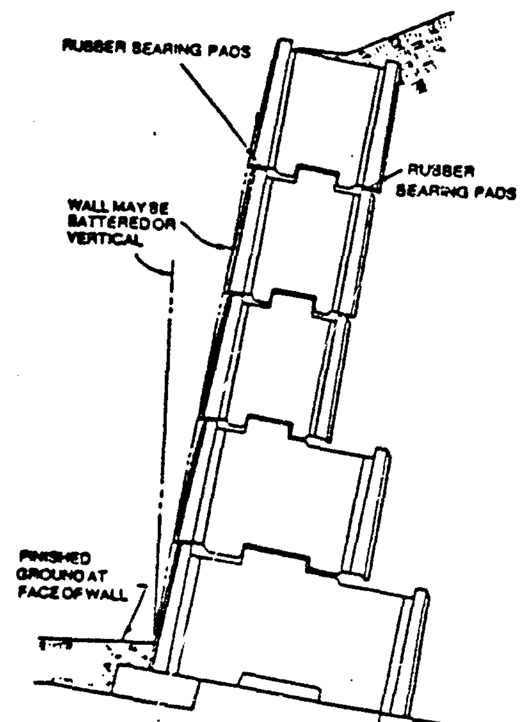
Based on a 12-foot wall enclosing an 18 by 53 foot area open on one

Technical Information

DOUBLEWAL UNIT PROPERTIES — 4' x 8' FACE								
WIDTH		4'	6'	8'	10'	12'	14'	16'
4 FOOT HIGH UNITS	CONCRETE WEIGHT lbs.	7,238	8,556	9,858	11,176	16,237	17,535	18,791
	FILL VOLUME cu. ft.	76.6	132.1	187.7	[illegible]	279.2	334.9	390.8



ISOMETRIC VIEW



TYPICAL SECTION

Figure 1. Doublewal® Wal Sections

end, the cost of material is over $35,000, which makes this one of the most expensive concepts.

C. STEEL-BIN-TYPE RETAINING STRUCTURES

Steel soil-bin-type retaining structures consist of adjoining closed face bins. The steel closure surrounds compacted masses of earth fill. The weight of the fill resists overturning and sliding forces.

These systems are widely used as retaining structures on highway and railroad projects, and similar systems were used extensively in Southeast Asia to erect revetments for the protection of aircraft. Installation is relatively easy and can be accomplished with inexpensive equipment and unskilled labor. As with the DOUBLEWAL^{tm} system, maximum height is not a limitation for this system.

1. Constructibility

The soil-bin-type retaining wall structure is commonly used and does not require a skilled labor force or extensive field supervision for assembly. The lightweight components require a minimum of handling equipment to erect.

2. Performance

While this concept has not been tested for this specific application, it has been tested for others with similar design threats. The earth fill material is more than adequate to provide the required protection. The system can be erected in any configuration and later expansion can be easily accommodated.

3. Land Use

The minimum width of these units is 10 feet, resulting in one of the larger footprints for a perimeter wall configuration.

4. Aesthetics

The modular construction with strong lines results in a pleasing appearance. Specially constructed concrete components may be substituted for the galvanized steel stringers to give any desired appearance. The steel stringers may also be punched for planting shrubs or other types of vegetation.

5. Cost

This concept is the most expensive of all considered. For a 14-foot high, 18 by 53-foot area, the cost is over $40,000.

D. AIRCRAFT REVETMENTS

For years the U. S. Air Force has used reinforced concrete revetments to protect aircraft and other support equipment and buildings. The revetments range in height from 2 to 4 meters (6.5 to 13 feet) and have a base that allows the revetment to serve as a retaining structure. In addition to standard reinforced concrete revetments, an alternate material, SIFCOM, was considered. Although it is a relatively new material, tests have shown that SIFCON possesses outstanding ballistic and blast-resistant characteristics.

1. Constructibility

Reinforced concrete requires skilled construction labor and field supervision. SIFCON construction requires less skilled labor but more trained field supervision. The moving and placing of precast revetments requires a crane or large forklift.

2. Performance

Concrete revetments have been extensively investigated for blast and fragment loading similar to the present threat. The 2-meter (6.5 foot) high Bitburg revetments are too low to provide adequate protection for the proposed vehicles. Current aircraft revetment designs will provide some protection if bermed; however, as with all the wall revetments, no protection from lofted projectiles is provided. A revised taller design could be used without a berm. The revetments provide a flexible system that can be easily moved to form any desired layout.

3. Land Use

The revetment concept provides a relatively large footprint. Bermed revetments require about 10 feet in width.

4. Aesthetics

Bare concrete revetments may be somewhat stark in appearance. Textured or special surface treatment could be used if desired. If the revetments were bermed, the selective planting of trees, shrubs or other vegetation could be done.

5. Cost

Preliminary cost estimates for a 12-foot high, 18 by 53-foot enclosure are $19,000 for reinforced concrete and $27,000 for SIFCON. These are both considered unbermed.

E. EARTH-BERMED CORRUGATED STEEL PIPE

The first of the fully enclosed structural concepts considered was the bermed, corrugated, multiplate, steel pipe. A concrete floor would be cast inside the pipe to form the wearing surface. Corrugated steel pipe structures are widely used as drainage systems in heavy construction. Examples of their use are culverts, storm sewers and service tunnels for highways, railways, airports, municipalities, and many other applications. Various cross-sectional shapes are available including circular, elliptical, pipe-arch, and underpass. A circular shape was chosen for ease of installation and a reasonable fit to geometry/space requirements. The manufacturer's standard, bolted lap joints were assumed to be adequate for the design loading environment. Modifications of these connections would result in increased costs.

1. Constructibility

This concept is widely used in the construction industry and does not require a highly skilled labor force for erection. Although the erection process is not complicated, it must be complicated it must be accomplished in accordance with the manufacturer's instructions. The material is relatively lightweight and requires minimal handling equipment. The backfill must be compacted so that the pipe will perform properly.

2. Performance

Bermed steel arch-type structures have been previously used for protective hardened shelters. The flexibility and geometry of the shelter make it an excellent structure to resist dynamic loads such as blast pressure and ground motion. The earth berm is sufficient to resist fragment penetration and loading from the splinter threat. The open ends of the shelter must be shielded through the use of either hardened end walls or auxiliary barriers such as revetments.

3. Land Use

Because of the earth berm, this concept requires more level area than the perimeter wall concepts. The edge of the berm will be approximately 25 feet from the edge of the shelter. Grouping two or more shelters together could reduce total land requirements.

4. Aesthetics

The planting of grass or other vegetation may be used on the earth berms to soften the appearance of the structure.

5. Cost

The approximate cost of an 18-foot diameter corrugated steel pipe with a concrete floor and compacted backfill is $24,000.

F. EARTH-BERMED CORRUGATED STEEL ARCH

Another fully enclosed shelter concept considered was a bermed steel arch structure. This type of structure was specifically intended for military shelter use. It consists of a reinforced concrete foundation/floor structure that also provides the tie forces between the arch walls. Because of the large size of this structure, it was considered only for multivehicle use, specifically for two or more vehicles parked side by side.

1. Constructibility

Like the steel pipe concept, these steel arch structures are widely used in the same applications as the steel pipe where larger spans are necessary. Because of the nature of the reinforced concrete floor and foundation system, the erection requires a higher degree of skill than the pipe structures and the same type of handling equipment. Depending on the specific design of the arch structures, the backfill may have to be compacted.

2. Performance

Bermed steel arch-type structures have been previously used for protective hardened structures. The flexibility and geometry of the shelter make it a good structure to resist dynamic loads such as blast pressure and ground motion. The earth berm is sufficient to resist fragment penetration and loading from the splinter threat. The open ends of the shelter must be shielded by hardened end walls or by auxiliary barriers like revetments.

3. Land Use

The footprint per vehicle is only slightly smaller than that of the bermed corrugated pipe.

4. Aesthetics

As with all earth-bermed structures, selected planting may be used to soften the appearance of the structure.

5. Cost

The approximate cost of this arch structure without end protection is $39,000.

G. SHOTCRETE ARCH

The last fully enclosed structure considered was an earth-bermed reinforced concrete (shotcrete) arch structure. The system was developed by Earth Systems, Inc. (ESI) of Durango, Colorado. The concept consists of the reinforced concrete floor/foundation system supporting a patented prefabricated structural forming system. Fabric panels are added over the steel frame to serve as a "backstop" for the later shotcrete stage. The necessary reinforcing steel is then overlaid according to the engineering design. Shotcrete or gunite is then shot into the reinforcing gridwork, smoothed, waterproofed, and backfilled. Figure 2 shows a typical ESI system.

1. Constructibility

The shotcrete operation is a widely used professional construction technique, and it requiresskill and practice to do a satisfactory job. The backfill does not require compaction as does the steel pipe concept.

2. Performance

While this concept has not been tested under the splinter threat, it has been tested under a high pressure blast and shock environment. The earth berm will provide the primary splinter protection.

3. Land Use

The footprint for this concept will be about the same as that of earth-bermed corrugated steel pipe--approximately 25 feet wider on each side of the arch.

4. Aesthetics

As with the other earth berming concepts, planting of shrubs or other

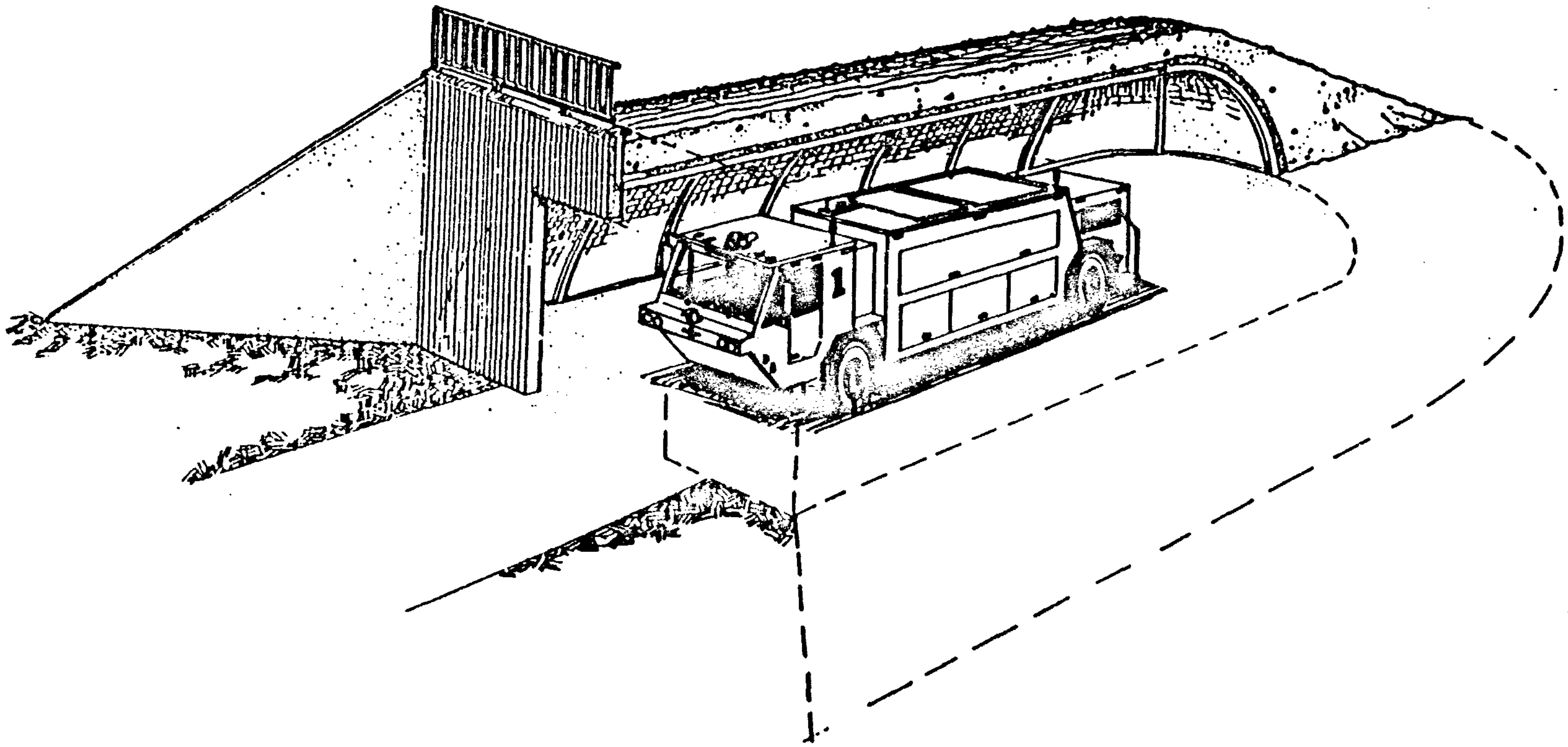


Figure 2. Earth-bermed Shotcrete Arch Concept

vegetation may be used to soften the appearance of the structure.

5. Cost

The preliminary cost of $37,400 was based on a dome/arch combination structure.

SECTION III

SELECTION PROCESS

A. EVALUATION CONSIDERATIONS

In order to determine objectively the best concept for the splinter protection of firefighting resources, a matrix of weighted evaluation factors was assembled. The eight factors employed in the evaluation process are described below.

1. Overall Protection

This factor assessed the degree to which the resources would be protected against all possible components of the splinter threat such as airblast, fragments, and ground shock. In general, perimeter wall concepts were not considered as good as full enclosures. In the perimeter wall group, the higher the wall, the better the rating. Sand grids have the shortest walls, whereas the bin-type walls could be constructed higher and thicker. Of the fully enclosed structures, the multivehicle shelter was considered a more vulnerable target than single vehicle shelters. A simplified analysis was performed on a bermed cylindrical shell subjected to the splinter threat. The analysis considered airblast and ground shock. Tests have shown that the berm would defeat any fragmentation threat. The structural model used was a corrugated steel pipe. The motions and associated stresses were small enough that a decision was made not to do an analysis of the concrete arch.

2. Field Constructibility

This factor considered how easy it would be to construct the concept and what degree of skill was required.

3. Aesthetics

Aesthetics is always a somewhat subjective parameter. In general the finished look of the article was evaluated. A permanent appearance was considered better than the temporary look of some of the perimeter wall concepts.

4. Maintenance

This factor considered the long-term permanence of the shelter and how susceptible it would be to the effects of the weather and the elements.

5. Expandability

This factor considered the ease with which the initial shelter could be expanded to accommodate larger or more vehicles. The perimeter wall concepts were rated more favorably in this area.

6. Land Use

This factor considered the footprint of the shelter concept. The perimeter wall concepts require the least space, whereas the full enclosures, because of the earth berm, require the most space.

7. Durability

This factor is related to the durability of the concept under repeated attack. The sand grid was judged the least substantial structure, with the fully enclosed structures being the best.

8. Overall Cost Per Vehicle

This factor was used to determine relative costs of the various concepts. The cost for each concept was based on an enclosed area of 18 by 53 feet. In general, the perimeter wall concepts were less expensive than the full enclosures. However, steel and precast concrete bin-wall-type structures were very expensive. The initial cost information for the shotcrete arch was based on a configuration that was more expensive than the final configuration.

B. SCORING

For each evaluation factor, each protective concept was given a score of

1 through 8, with 8 being the best. Where two or more concept were judged about equal, the scores were averaged. For example, if two concepts were about equal in one area, instead of awarding a 3 and a 4, both concepts would be scored 3.5.

Each rating factor was weighted based on an assessment of the overall importance of the factor. The weight factors ranged from 1 to 8.

The final score for each concept was then calculated as the sum of the products of the weight factor times the evaluation score for each concept. This evaluation matrix is shown in Table 3.

C. EVALUATION

The resulting overall scores for the various concepts do not indicate a clear best concept since the three highest scores are relatively close. Based on the scores, it is apparent that the perimeter wall concepts are less desirable than the fully enclosed shelters; therefore, the deicision was made to restrict further investigation to the fully enclosed concepts.

It was also decided to eliminate the multivehicle shelter from further consideration, mostly because of the increased vulnerability of vehicles being housed side by side together.

With the elimination of the perimeter wall concepts and the earth-bermed multivehicle structure, the evaluation process was reduced to the earth-bermed corrugated steel pipe and the earth-bermed shotcrete arch structure. Of the eight evaluation factors considered, five were judged essentially equal: (1) overall protection, (2) aesthetics, (3) expandability, (4) land use, and (5) durability. The remaining three factors were then investigated in more detail to make the final decision on the best concept.

1. Field Constructibility

The corrugated steel pipe was judged better in this category because

TABLE 3. SPLINTER PROTECTION CONCEPT MATRIX.

Favorable = 8
Unfavorable = 1

Factor	Weight factor	Fully Enclosed--Earth Covered: Single Vehicle shotcrete	Single Vehicle pipe	Multi-vehicle steel arch	Perimeter Wall: Reinforced concrete revetment	SIFCON revetment	Soil bin retaining wall	Precast concrete retaining wall	Sand grid
Overall Protection	8	7	8	6	2.5	2.5	4.5	4.5	1
Field Construction	1	2	3	1	6	7	4	5	8
Aesthetics	3	8	7	6	3	2	4	5	1
Maintenance	5	7.5	6	7.5	4	4	4	2	1
Expandability	2	1	3	2	6.5	6.5	4.5	4.5	8
Land Use	4	1	2	3	4.5	4.5	6	7	8
Durability	6	7	7	7	4	4	4	2	1
Overall Cost/Vehicle	7	2.8	2.9	4.9	5	3.4	1	2	6
Overall Score		187.1	194.3	196.8	145	131.8	136	129	120

of the specialized application equipment and techniques required for the shotcrete arch.

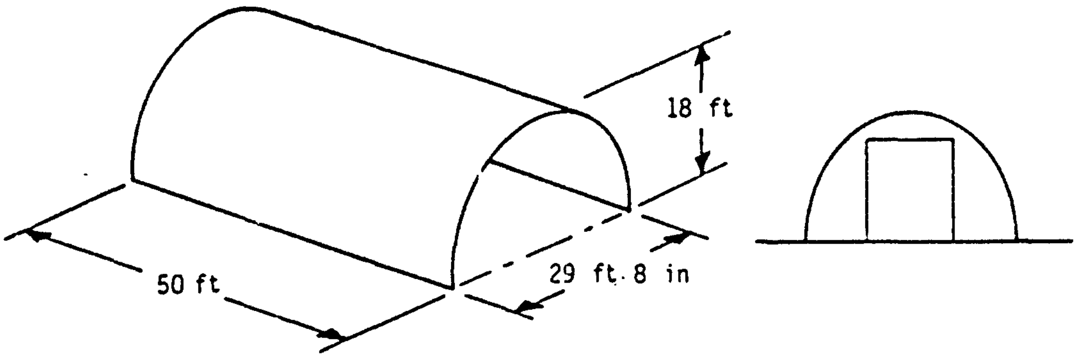
2. Maintenance

There have been extensive improvements in waterproofing of corrugated steel arch structures. These improvements were necessary because of a history of difficulties in the successful waterproofing of these structure types. Concrete is generally a very watertight material. Waterproofing can also be added to the concrete shell before backfilling. For these reasons, the concrete arch structure was judged slightly better in this category.

3. Cost

A more detailed cost estimate was prepared for the two remaining concepts. The shotcrete arch considered was a barrel shell 18 feet high by 29 feet wide by 50 feet long. The corrugated metal pipe was 21.5 feet in diameter and 50 feet long. Both structures were open at each end and bermed. It was assumed that the corrugated steel pipe structure required a compacted backfill and the shotcrete structure did not. The cost comparison is shown in Tables 4 and 5. These costs demonstrate an advantage for the shotcrete shelter, but the major difference is in the cost of waterproofing. The cost estimate given in Table 5 assumed, as a worst case, that all joints in the corrugated metal shelter would have to be sealed, and the corrugated surface would be more difficult to cover. A lower cost option would be to cover the structure, before completing the earth backfill, with a polyethylene geomembrane similar to those used as pond liners. Preliminary cost estimates indicate that this type of waterproofing might be installed for about $1.50/ft^2. If this unit cost for waterproofing is used for the corrugated metal shelter, the total costs for each type of shelter are more nearly equal.

TABLE 4. SHOTCRETE ARCH SHELTER--COST DATA.



	Quantity	Cost
Floor area	1424 ft^2	--
Shell surface area[a]	2605 ft^2	--
Foundation (18 x 36 in), slab (6 in), and tension beams (14 x 14 in)[b]	58.22 yd^3	$ 6,096.12
Shotcrete in shell[c]	39.76 yd^3	5,964.73
Frame erection[d]	---	3,540.00
Waterproofing[e]	---	2,605.00
Structural kit	---	14,110.00
Backfill (loose)[f]	580 yd^3	1,450.00
Total		$33,765.00

[a] Open ends

[b] Based on National Estimator @ $4.11/$ft^2$ of floor area.

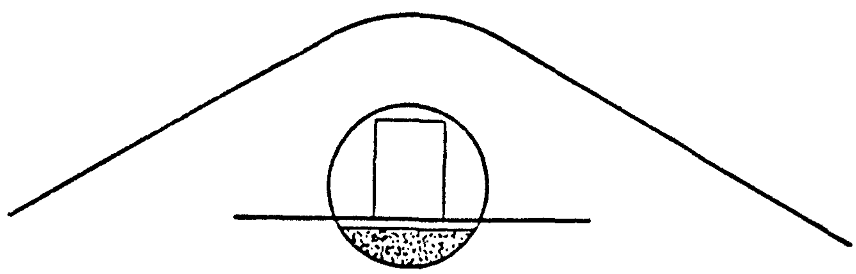
[c] Based on $150/yd nation average (including equipment and operators).

[d] Based on $1.25/$ft^2$ of shell surface area.

[e] Based on $1.00/$ft^2$ of shell surface area.

[f] Based on $2.50/$yd^3$.

TABLE 5. STEEL CULVERT SHELTER--COST DATA.



21 1/2 ft diameter by 50 ft long steel culvert
both ends open

	Quantity		Cost
Floor area	783.5	ft^2	--
Shell surface area	2495	ft^2	--
Culvert (SYRO)	1		$18,137.50
Culvert erection (@ $125/ft)	50	ft	6,250.00
Excavation (to set culvert, 50-hp buldozer; 1/2 day)	60.67	yd	172.51
Sand base (to set culvert and prevent rolling)	882	ft^2	182.22
Compaction (culverts require 90 percent compaction in 8-in lifts before compaction to achieve rated culvert strength; $5/yd)	750	yd	3,750.00
ABC fill (under slab floor)	692	ft^2	186.84
Six-inch concrete slab floor	13.96	yd	3,220.18
Seal tape (@ $7.50/lineal ft)	50	ft	375.00
Waterproofing (based on flat surface area; a corrugated surface will require greater amount)[a]	2495	ft^2	8,732.50
Total			$41,006.75

[a] $3.50/$ft^2$ Corp of Engineers Specifications.

D. CONCLUSION

Since the evaluation process did not show a clear advantage for either shelter concept, a decision was made to include construction drawings and cost information for both. The final cost estimates for the corrugated metal shelters assumed that a polyethylene geomembrane would be used for waterproofing.

SECTION IV

SELECTED SHELTER CONCEPTS

A. ESTIMATES

Figures 3 and 4 illustrate the primary and alternate splinter protection concepts for firefighting resources. The corrugated steel pipe shelter is shown open at both ends. A steel sheet-pile headwall is provided at each end. The shotcrete shelter is closed at one end by a partial dome. A reinforced concrete (shotcrete) headwall is provided at the open end. Although a drive-through capability is provided by having both ends open, it also increases the probability of damage to equipment parked in the shelter. There are sufficient clearances between the vehicle and the sidewalls of either shelter to permit safe backing of the vehicle into the shelter. Wheel guides could be placed on the floor of the shelters to ensure that vehicles are properly positioned during the backing operation.

Corrugated steel pipe and sheet pile are manufactured by several steel companies including ARMCO and SYRO. ARMCO products were assumed in dimensioning various portions of the shelters. Slight changes in these dimensions might be required if other products are used. Appendix A applies to the corrugated steel pipe.

The shotcrete system selected was developed by ESI of Durango, Colorado. Appendix B presents a portion of the ESI construction manual that is supplied with their structural kit. Only the portion of the manual dealing with the extended dome is included since that is the structure of interest.

As shown in Table 2, three shelter sizes (A, B, and C) were selected to house the several different fire trucks. A more complete cost estimate for the three shotcrete shelters is presented in Tables 6, 7 and 8. Tables 9, 10, and 11 present the cost estimates for the three corrugated steel pipe shelters.

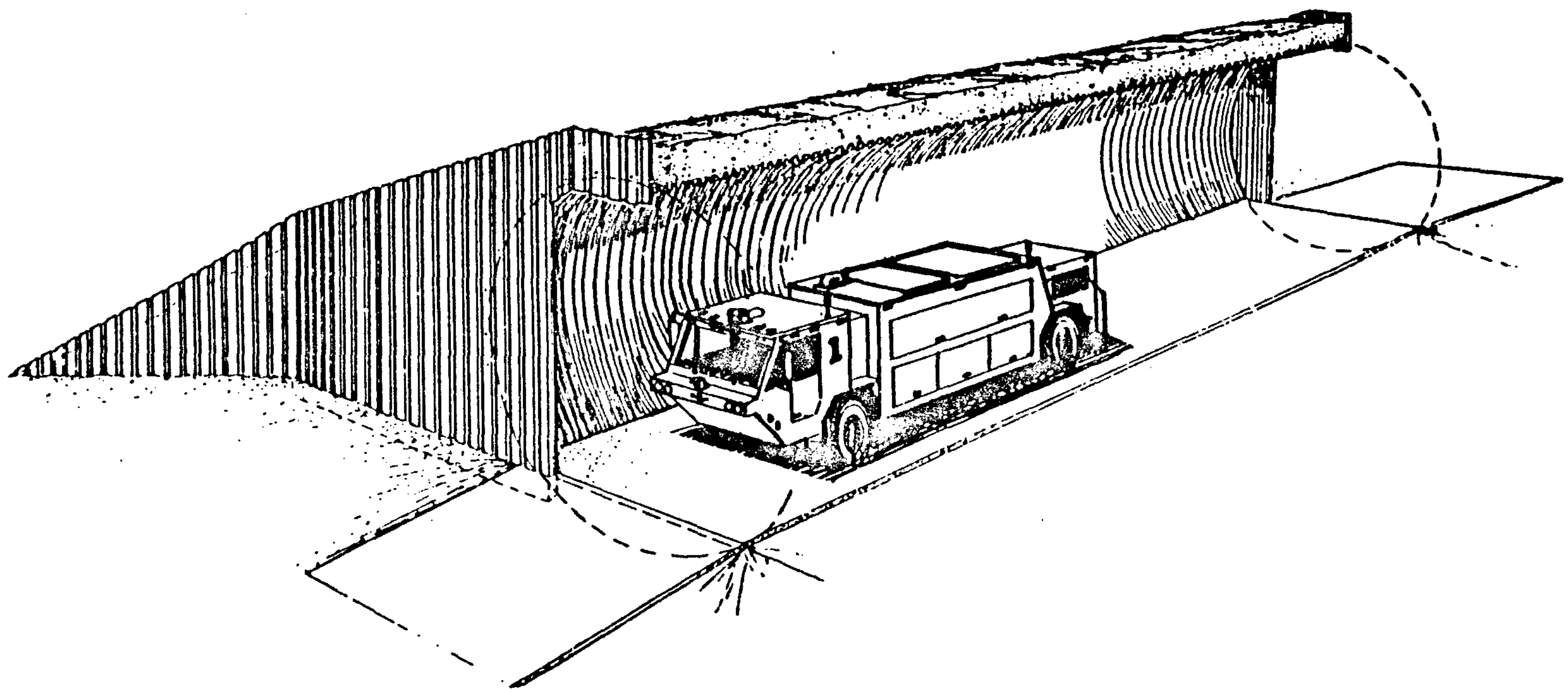


Figure 3. Earth-bermed Corrugated Steel Pipe

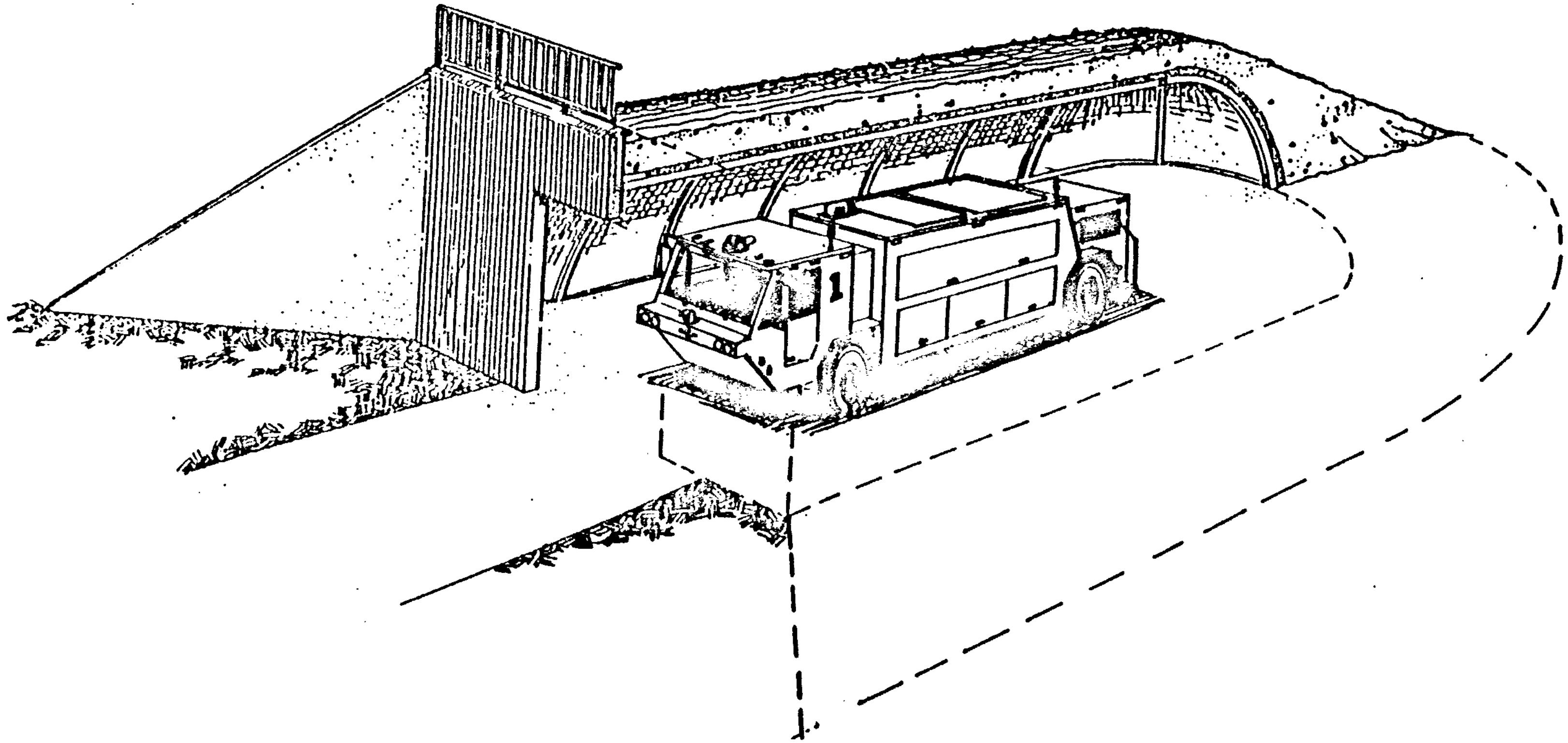


Figure 4. Earth-bermed Shotcrete Arch

TABLE 6. COST ESTIMATE FOR SHELTER A - SHOTCRETE ARCH.

	Quantity	Cost
Floor area	1,947 ft^2	--
Shell surface area	3,841 ft^2	--
Foundation (18 x 36 in), Slab (6 in) and tension beams (14 by 14 in)[a]	57 yd^3	$ 8,000
Shotcrete in shell[b]	54.5 yd^3	8,175
Rebar in shell[c]		2,300
Frame erection[d]		4,650
Waterproofing[e]		3,750
Structural kit		22,400
Berm[f]	789 yd^3	2,000
Retaining wall		6,000
Front wall		2,000
Total		$59,275

[a] Based on National Estimator @ $4.11/$ft^2$ of floor area.

[b] Based on $150/yd national average (including equipment and operators).

[c] No. 4 @ 24 in on center horizontal over, No. 4 @ 8 in on center verticle over, No. 4 @ 12 in on center horizontal.

[d] Based on $1.25/$ft^2$ of shell surface area.

[e] Based on $1.00/$ft^2$ of shell surface area.

[f] Based on $2.50/$yd^3$.

TABLE 7. COST ESTIMATE FOR SHELTER B - SHOTCRETE ARCH.

	Quantity	Cost
Floor area	1,591 ft^2	--
Shell surface area	3,185 ft^2	--
Foundation (18 x 36 in), Slab (6 in) and tension beams (14 by 14 in)[a]	48 yd^3	$ 6,500
Shotcrete in shell[b]	50.5 yd^3	7,600
Rebar in shell[c]		2,000
Frame erection[d]		4,000
Waterproofing[e]		3,200
Structural kit		18,380
Berm[f]	650 yd^3	1,625
Retaining wall		6,000
Front wall		2,000
Total		$51,305

[a] Based on National Estimator @ $4.11/ft^2 of floor area.

[b] Based on $150/yd national average (including equipment and operators).

[c] No. 4 @ 24 in on center horizontal over, No. 4 @ 8 in on center verticle over, No. 4 @ 12 in on center horizontal.

[d] Based on $1.25/ft^2 of shell surface area.

[e] Based on $1.00/ft^2 of shell surface area.

[f] Based on $2.50/yd^3.

TABLE 8. COST ESTIMATE FOR SHELTER C - SHOTCRETE ARCH.

	Quantity		Cost
Floor area	1,275	ft^2	--
Shell surface area	2,176	ft^2	--
Foundation (18 x 36 in), Slab (6 in) and tension beams (14 by 14 in)[a]	38	yd^3	$ 5,240
Shotcrete in shell[b]	31	yd^3	4,650
Rebar in shell[c]			1,310
Frame erection[d]			2,720
Waterproofing[e]			2,180
Structural kit			12,650
Berm[f]	325	yd^3	815
Retaining wall			3,500
Front wall			1,350
Total			$34,415

[a] Based on National Estimator @ $4.11/ft^2 of floor area.

[b] Based on $150/yd national average (including equipment and operators).

[c] No. 4 @ 24 in on center horizontal over, No. 4 @ 8 in on center verticle over, No. 4 @ 12 in on center horizontal.

[d] Based on $1.25/ft^2 of shell surface area.

[e] Based on $1.00/ft^2 of shell surface area.

[f] Based on $2.50/yd^3.

TABLE 9. COST ESTIMATE FOR SHELTER A - STEEL CULVERT.

	Quantity	Cost
Floor area	930 ft^2	---
Shell surface area	3,960 ft^2	---
Culvert		$18,000
Culvert erection (at $125/ft)		7,500
Excavation	440 yd^3	660
Sand base	440 yd^3	900
Compaction (Culverts require 90 percent compaction in 8-inch lifts before compaction to achieve rated culvert strength; $5/yd.)	900 yd^3	4,500
ABC fill (under slab floor)		200
Six-inch concrete slab floor ($4/$ft^2$)	930 ft^2	3,720
Seal tape		450
Waterproofing[a]	3,300 ft^2	4,950
Retaining and end walls (both ends)		13,000
Total		$53,880

[a]Waterproofing estimates are based on covering the upper half of the pipe with a geotextile, which would also extend one radius out from each side of the pipe. An installed cost of $1.50/$ft^2$ was used.

TABLE 10. COST ESTIMATE FOR SHELTER B - STEEL CULVERT.

	Quantity	Cost
Floor area	775 ft^2	---
Shell surface area	3,300 ft^2	---
Culvert		$15,000
Culvert erection (at $125/ft)		6,250
Excavation	367 yd^3	550
Sand base	367 yd^3	740
Compaction (Culverts require 90 percent compaction in 8-inch lifts before compaction to achieve rated culvert strength; $5/yd.)	750 yd^3	3,750
ABC fill (under slab floor)		200
Six-inch concrete slab floor ($4/$ft^2$)	775 ft^2	3,100
Seal tape		375
Waterproofing[a]	2,700 ft^2	4,050
Retaining and end walls (both ends)		13,000
Total		$47,015

[a]Waterproofing estimates are based on covering the upper half of the pipe with a geotextile, which would also extend one radius out from each side of the pipe. An installed cost of $1.50/$ft^2$ was used.

TABLE 11. COST ESTIMATE FOR SHELTER C - STEEL CULVERT

	Quantity	Cost
Floor area	675	---
Shell surface area	2,700	---
Culvert		\$12,500
Culvert erection (at \$125/ft.)		5,500
Excavation	300 yd^3	450
Sand base	300 yd^3	615
Compaction (Culverts require 90% compaction in 8-inch lifts before compaction to achieve rated culvert strength; \$5/yd.)	500 yd^3	2,500
ABC fill (under slab floor)		200
Six-inch concrete slab floor (\$4/ft^2)		2,700
Seal tape		350
Waterproofing[a]	2,200 ft^2	3,278
Retaining and end walls (both ends)		8,000
Total		\$36,093

[a]Waterproofing estimates are based on covering the upper half of the pipe with a geotextile, which would also extend one radius out from each side of the pipe. An installed cost of \$1.50/ft^2 was used.

B. SUMMARY

While the foregoing investigations and evaluations reveal general comparability between the two best candidate concepts, the factors of constructibility and proven protection performance indicate that the corrugated steel pipe is the better of the two final concepts. As shown in Figure 5, this concept allows for a flexible approach, which can then be used to incorporate protection for storage of ancillary materials and for additional functions. In this particular layout, the shelter includes a tent structure contamination control area (CCA) attached to a mobile hard-wall structure with rotary air lock and rest quarters for 4 to 6 firefighters. This gives the firefighters a protected area to don/doff their protective equipment and accommodates the reservicing of breathing apparatus. Such a facility can house two firefighting vehicles in a low profile perspective, while also affording protection to a mobile chemical decontamination unit, a 3,000 gallon water storage tank, war readiness materials, and spare parts. Where possible, the water storage should be connected to a deep well or a redundant, protected pipeline to a water reservoir. This decision should be made locally, based on layout, geological, and budgetary considerations.

The front protective berm can be short and front facing only as depicted in Figure 5; or as shown in Figure 6, it can be more elaborate to afford more protection. Again, economic and geographical aspects should guide this decision.

The elevation view of this layout is shown in Figure 7. The vehicles protected are the P-19 Crash Response Vehicle and the P-20 Rapid Intervention Vehicle. The interior of the shelter is 18 by 82 ft., while the overall length is 100 ft. The protective berm is lcoated 50 ft. from the front of the shelter and is 20 ft. high and 50 ft. wide.

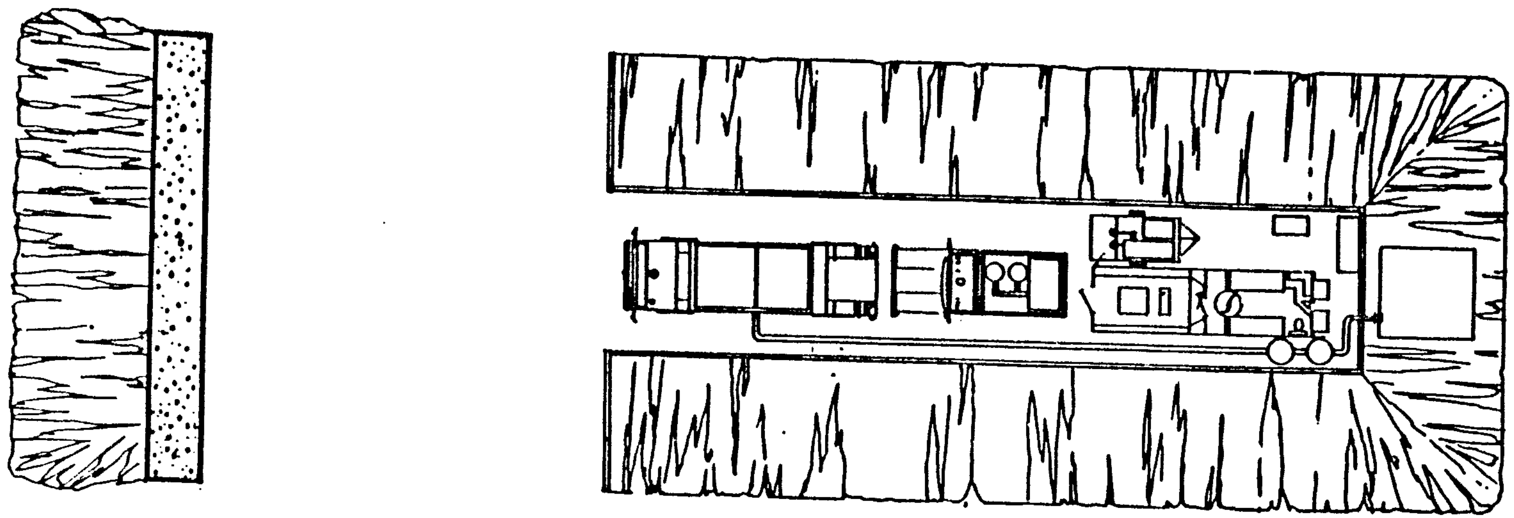


Figure 5. Corrugated Steel Pipe Concept Layout

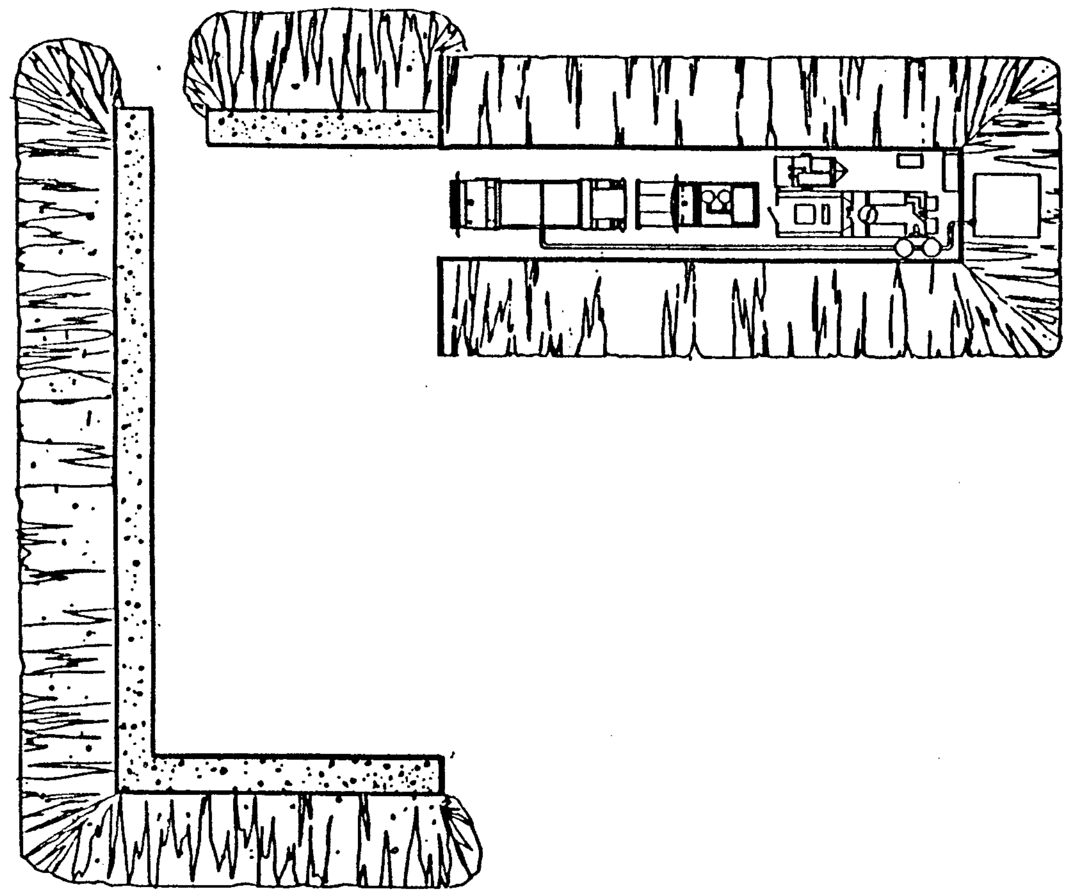
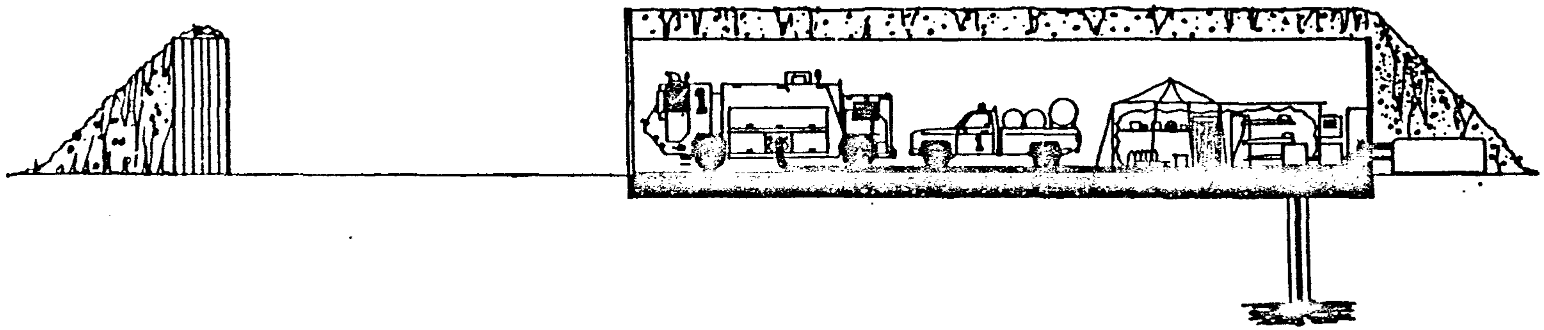


Figure 6. Corrugated Steel Pipe Concept Layout/Enhanced Front Protective Berm



- AIR BLAST & FRAGMENT SPLINTER PROTECTION FOR TWO VEHICLES & CREWS. SHOWN ARE:
  - -- P-19 CRASH RESPONSE VEHICLE
  - -- P-20 FAST RESPONSE VEHICLE
- MOBILE COLLECTIVE PROTECTION FACILITY
- MOBILE BREATHING APPARATUS RESERVICING UNIT
- DEEP WELL & 3,000 GALLONS OF WATER STORAGE
- WRM STORAGE: AGENTS, EQUIPMENT, SPARE PARTS

Figure 7. Corrugated Steel Pipe Concept Layout--Elevation

C. TESTING

Because of the large number of these shelters to be located at airbases in Europe and in the Pacific, a survivability verification program is well jsutified. A field-test program should be conducted to test the full-size shelters to the splinter threat. A test program, therefore, would also serve as a constructibility verification program. Appendix C presents a proposed test plan for the verification program.

APPENDIX A*

CONSTRUCTION MANUAL

FOR

CORRUGATED STEEL PIPE

This manual is a general guide on constructing ARMCO structures. Exact details and specifications are in plans.

*The information contained in Appendix A: **Construction Manual for Corrugated Steel Pipe** is copyrighted; it is the sole property of ARMCO STEEL. The information is reproduced here in their format, by written permission of ARMCO. (The manual is reproduced in part. Text and illustrations not directly relevant to splinter protection structures are not included.)

MULTI-PLATE

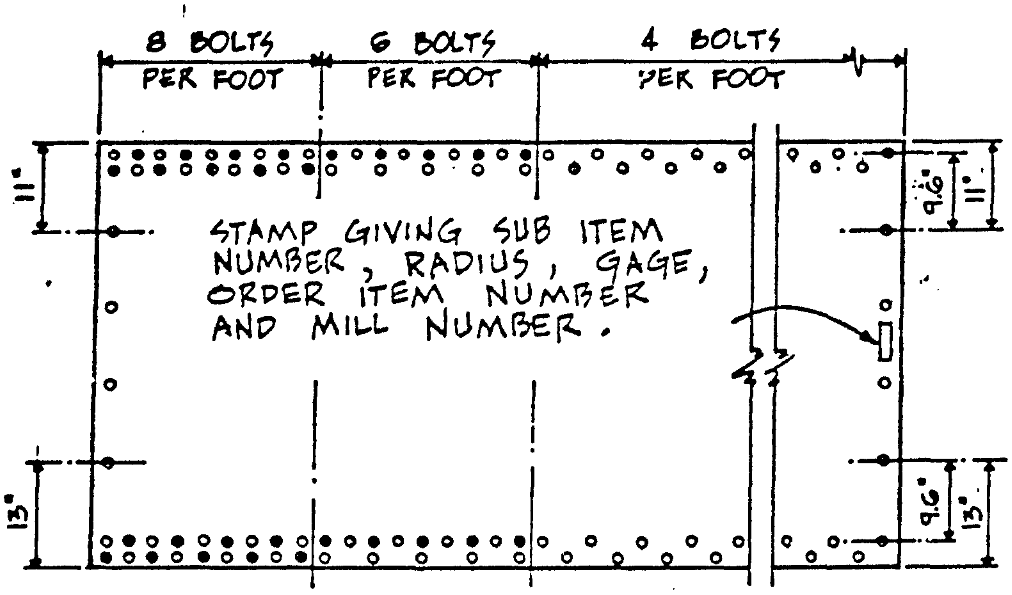
INSTALLATION INSTRUCTIONS

ROUND AND ELLIPTICAL PIPE

Description of Material:

Plates: The plates for MULTI-PLATE pipe are furnished in two lengths, nominally 10 feet and 12 feet long. In special instances, one or more 6-foot-long plate may be furnished. Plate widths are about 3 feet, 4 feet, 5 feet, 6 feet and 7 feet. The 3-foot-wide plate has 4 holes across each end; the 4 foot has 6 holes; the 5 foot has 7 holes; the 6 foot has 8 holes; and the 7-foot plate has 9 holes.

Each plate is identified by numbers stamped into the inside crest of an end corrugation near the middle of the plate except plates for special ends have these numbers stamped near each corner before cutting. The first three (3) numbers are the sub item number. The second three (3) numbers are the plate radius in inches. The seventh number is the plate gage number, with the exception that "0" is for 10 gage and "2" is for 12 gage and a blank designates thickness greater than 1 gage. The eighth number is the order item number. The last four (4) numbers are the mill order number (See Figure 1).



INSIDE VIEW

o Standard holes

• Added holes for 6- and 8-bolt construction

FIGURE 1

If the structure is to be erected with skewed or sloped ends, look for embossed identification marks on the inside of each cut plate. Plates to be used in an elbow section will be identified with similar embossed numbers on the inside of each cut and welded plate. These numbers will correspond to plates as marked on the cut end or elbow layout drawing.

Bolts: For convenience, MULTI-PLATE bolt and nut containers are stenciled as follows:

Size

3/4" x 1-1/4"
3/4" x 1-1/2"
3/4" x 1-3/4"
3/4" x 2"
3/4" x 3"
Nuts

Each structure will have six (6) 3-inch-long service bolts to use as assembly tools to temporarily draw plates together where needed. They should not remain in the structure. The required number of bolts for a structure rarely amounts to full keg lots for all sizes. The carton containing partial amounts of one size will also have the required 3-inch bolts. This carton will be re-marked accordingly.

Bolts are furnished in two lengths, the longer length for three (3) thicknesses of metal. Length of bolts furnished for various plate thickness is as follows:

Galvanized Plates:

Plate Gage (Thickness)	Bolt Lengths
1 Gage (.280")	1-1/2" and 2"
3 Gage (.249")	1-1/2" and 2"
5 Gage (.218")	1-1/2" and 1-3/4"
7 Gage (.188")	1-1/2" and 1-3/4"
8 Gage (.168")	1-1/4" and 1-1/2"
10 Gage (.138")	1-1/4" and 1-1/2"
12 Gage (.109")	1-1/4" and 1-1/2"

Asphalt Coated Plates:

Plate Gage (Thickness)	Bolt Lengths
1 Gage (.280")	1-3/4" and 2"
3 Gage (.249")	1-3/4" and 2"
5 Gage (.218")	1-3/4" and 2"
7 Gage (.188")	1-3/4" and 2"
8 Gage (.168")	1-1/2" and 1-3/4"
10 Gage (.138")	1-1/2" and 1-3/4"
12 Gage (.109")	1-1/2" and 1-3/4"

The longer of the two (2) bolt lengths go in the corners of the plates where three (3) thicknesses of metal overlap and in the hole next to the corner in the longitudinal seam. The shorter of the two (2) bolts go where only two (2) thicknesses of metal overlap (See Figure 2).

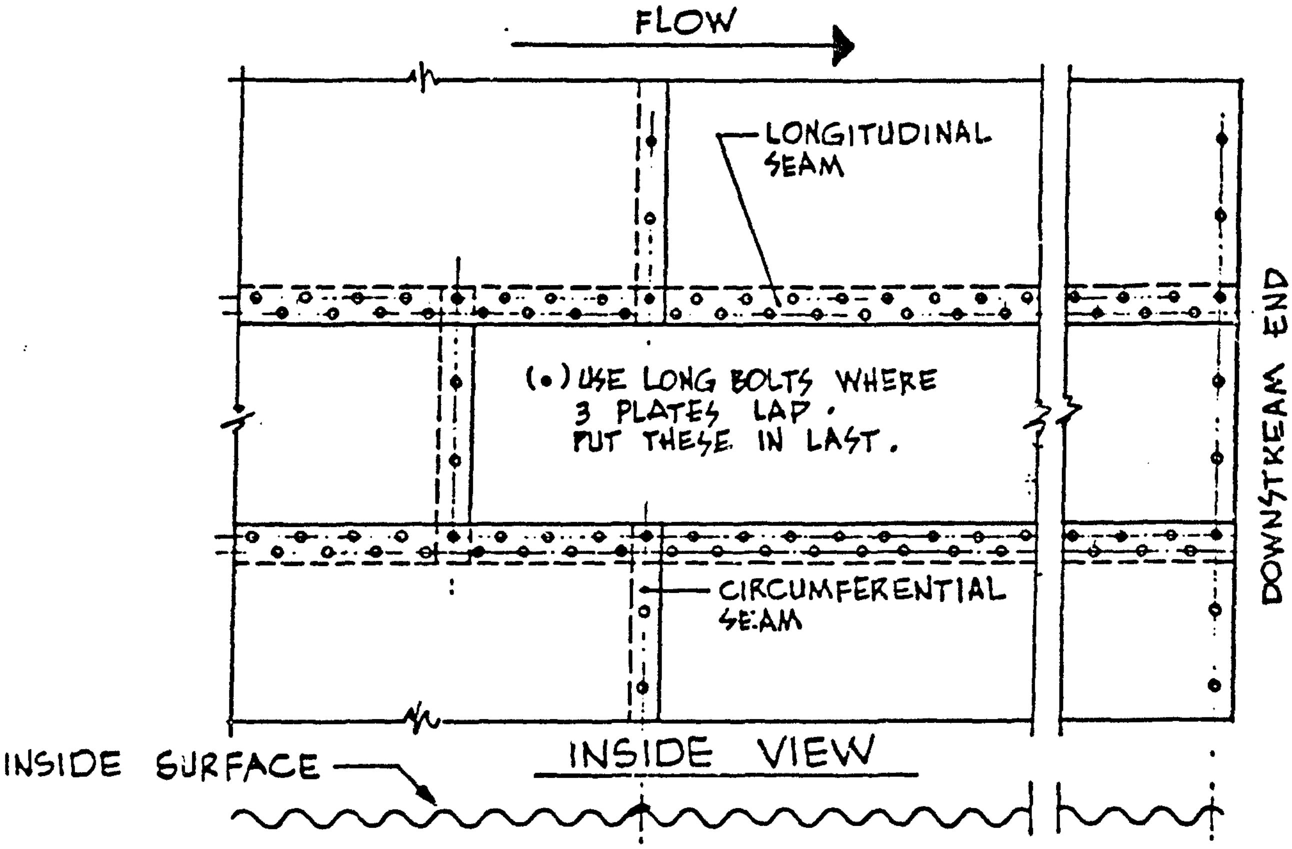


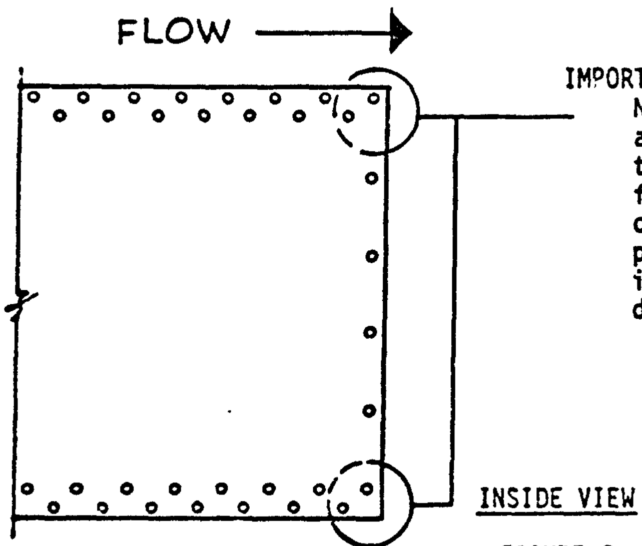
FIGURE 2

Plate Identification and Location: The various widths of plates are located in the barrel in accordance with the plate layout drawings. The numbers appearing in the barrel area or on the plates (numbers 4, 6, 7, 8 or 9) are the number of bolt holes across the end of each plate. The line layout and/or plate layout shows total 10-foot and 12-foot-long rings making up the structure.

Beginning and ending rings are shown for square end structures and these contain combinations of 10-foot and 12-foot rings required to obtain proper plate stagger. Special plates in cut end structures are shown on the plate layout together with necessary 10-foot and 12-foot long plates required to obtain proper seam stagger in the barrel. Intermediate barrel rings contain plates all the same length. For cut plates and elbow cut and welded plates, numbers appear on the plate layout corresponding to the embossed numbers on the plates themselves.

Pipe Assembly: The pipe is assembled in three (3) stages: 1) bottom; 2) sides; and 3) top.

1) Bottom (invert) plates are assembled by laying the first bottom plate at the outlet end, then placing each succeeding plate in the longitudinal row so it laps one (1) corrugation of the preceding plate (See Figure 2). Position invert plates accurately with a stringline.



IMPORTANT:
Note the two (2) corner bolt holes are different. One (1) is close to the plate edge, the other is set in from the plate edge. When beginning construction, the corner bolt hole pattern must match the pattern shown in detail "A" on the plate layout drawing.

FIGURE 3

2) After several invert plates have been laid down and aligned, start again at the outlet end and attach side plates to each side. These side plates may lap on the inside of the invert plates (see typical barrel end views on next sheet). Also, each additional side plate in a longitudinal row laps over the previous plate by one (1) corrugation.

3) Finally, the top plates are put in place. The upper half of the pipe is assembled with each plate lapping outside the plate immediately below it. (See Figure 4 and typical barrel end views at the bottom of this sheet.) Extend each row only far enough to support the next row of plates above to a place where one (1) final plate can be added to complete the ring. Each additional top plate in a longitudinal row laps over the previous plate by one corrugation.

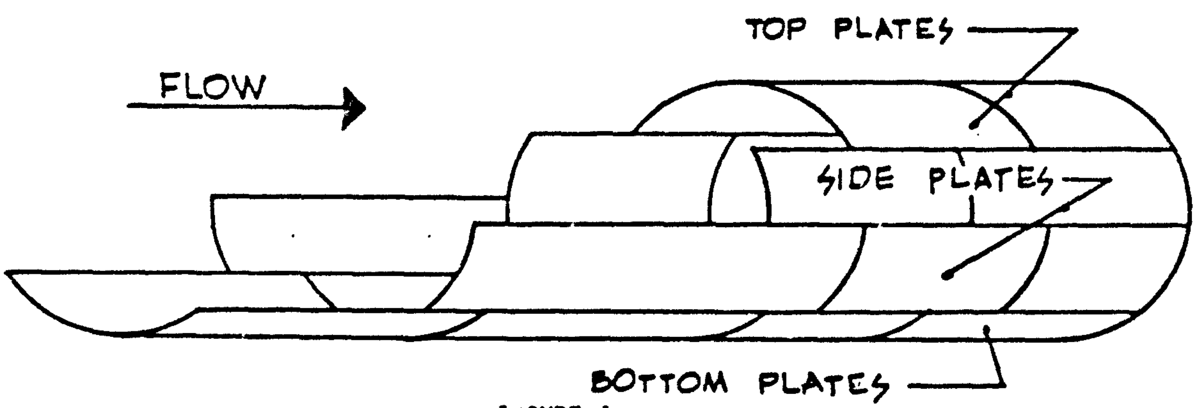
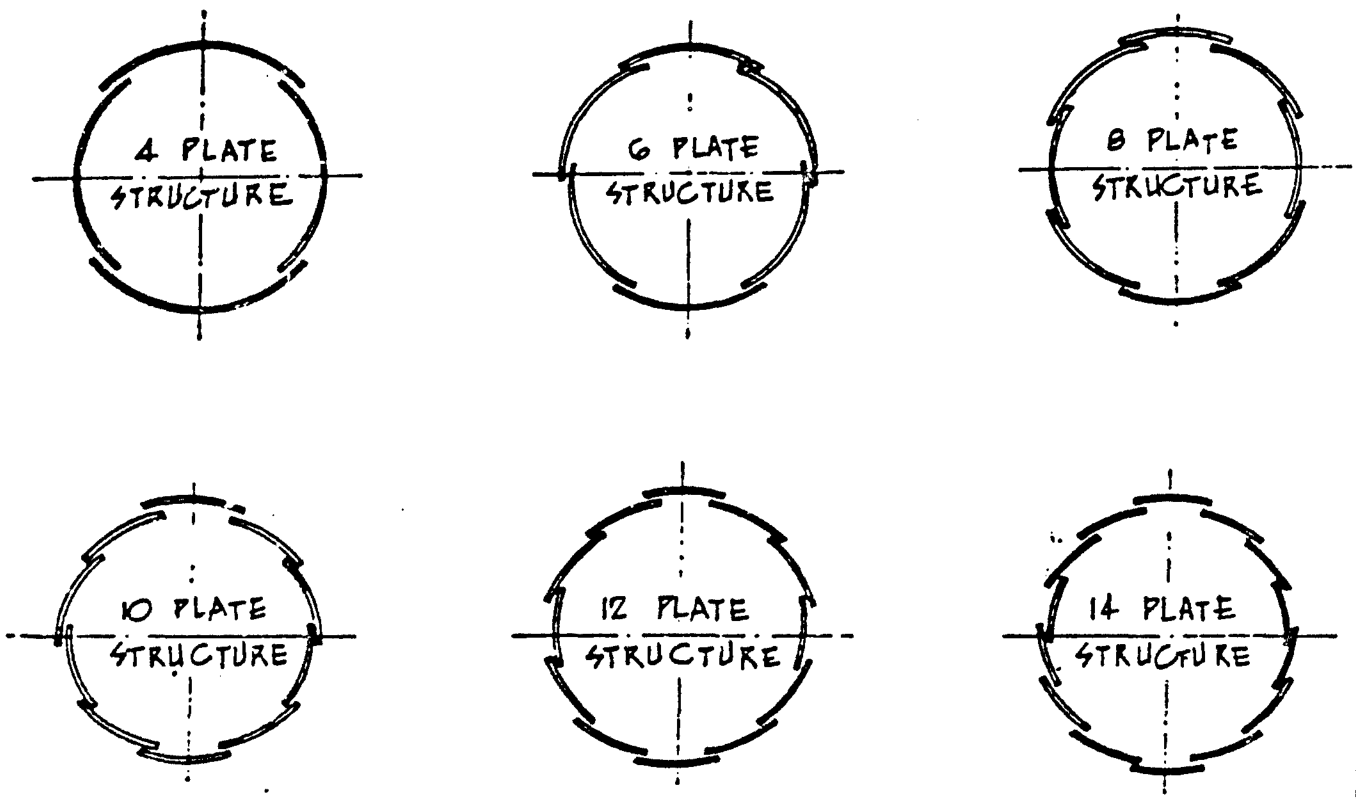
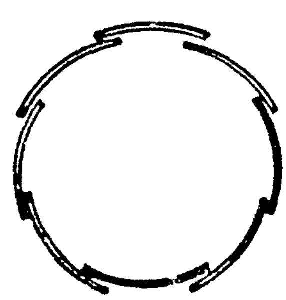


FIGURE 4

TYPICAL BARREL END VIEWS



WHERE INFILTRATION OF FINE GRAINED BACKFILL MATERIAL MAY OCCUR, <u>SHINGLE CONSTRUCTION</u> MUST BE USED.



SHINGLE CONSTRUCTION

Bolting: To facilitate alignment, initial assembly should be done with a minimum number of bolts. Insert sufficient bolts in each seam to hold plates in position, but do not tighten the nuts, thus leaving the plate free to move slightly to help in matching the remaining bolt holes. Bolting the circumferential seam is best done by first placing bolts near the middle of the plate. About three (3) rings behind plate assembly, insert remaining bolts, using pins or pry bar to align holes. After all bolts are in place, tighten nuts. Note, aligning of bolt holes is done easier when bolts are loose while drifting of holes is best done with adjacent bolts tight.

Sometimes it is desirable to insert and tighten all bottom plate bolts as the bottom is assembled. If this is done, be certain plates are properly aligned before tightening bolts. Always assemble corner and top plates with as few bolts as possible while initially assembling the structure.

Recommended range for bolt torque is between 100 and 300 foot-pounds. Maintain a balanced progression of tightening with respect to the axis of the structure to prevent a spiraling tendency.

Product Details for Armco MULTI-PLATE

Description of Plates

MULTI-PLATE plates are field assembled into pipes, arches, pipe-arches, box culverts, underpasses and other shapes. Corrugations of 6″ pitch and 2″ depth are at right angles to the length of each plate.

Thickness. Specified thickness of the plate varies from approximately 0.109″ to 0.280″ for uncoated plates. See Table 3.

Widths. Standard plates are fabricated in five net covering widths, 28.8″, 48.0″, 57.6″, 67.2″ and 76.8″. See Table 1. Widths are listed in terms of pi.

The "pi" nomenclature translates circumference directly into nominal diameter in inches. For example, four 15 pi plates give a diameter of 60″; four 21 pi plates = 84″, etc. Various widths may be used to obtain any diameter.

Lengths. MULTI-PLATE plates are furnished in either 10′ or 12′ nominal lengths. They are punched with 7/8″ holes on 3″ centers to provide the standard four bolts per foot of longitudinal seam, in two staggered rows on 2″ centers. They may also be punched to provide either six or eight bolts per foot of longitudinal seam on 0.280″ specified thickness material, if required.

The inside crests of the end corrugations are punched for circumferential seams on centers of 9.6″ or $9\frac{19}{32}$″ (= 3 pi).

Actual length of the square-end structure is about 4 inches longer than its nominal length because a 2″ lip protrudes beyond each end of every plate for lapping purposes.

Table 1. Details of Uncurved MULTI-PLATE Sections[1]

Net Width, in. Nominal	Net Width, in. Detail		Over-all Width, in.	Spaces at 9.6 in.	Number of Circumference Bolt Holes
9 Pi	28.8	$28\frac{13}{16}$	$33\frac{5}{16}$	3	4
15 Pi	48.0	48	$52\frac{5}{16}$	5	6
18 Pi	57.6	$57\frac{5}{8}$	$62\frac{3}{8}$	6	7
21 Pi	67.2	$67\frac{3}{16}$	$71\frac{15}{16}$	7	8
24 Pi	76.8	$76\frac{13}{16}$	$81\frac{5}{16}$	8	9

3 Pi = 9.6 in.

Table 2. Approximate Weight of Armco MULTI-PLATE Sections[1]

Net Width in.	Net Length, ft	Approximate Weight of Individual Plates Galvanized—in lbs—without Bolts* Specified Thickness, in. 0.109	0.138	0.168	0.188	0.218	0.249	0.280	Short Bolts per plate**
9 Pi	10	161	205	250	272	316	361	405	38
9 Pi	12	193	246	299	325	379	432	485	46
15 Pi	10	253	323	393	428	498	568	638	40
15 Pi	12	303	386	470	511	595	678	762	48
18 Pi	10	299	382	465	506	589	671	754	41
18 Pi	12	357	456	555	604	703	801	900	49
21 Pi	10	345	441	536	583	679	774	869	42
21 Pi	12	412	526	640	697	810	924	1038	50
24 Pi	10	396	504	613	667	775	878	986	43
24 Pi	12	473	603	732	797	927	1050	1176	51
Bolt lengths, in.		1¼ and 1½				1½ and 1¾		1½ and 2	Each plate also has 4 long bolts

*Weights are approximate. Standard punching, four holes per foot in longitudinal seams; galvanized. AASHTO 2 oz/ft² coating for 8 gage and lighter, 3 oz/ft² coating for 7 gage and heavier.

**For galvanized plates, gages 12 to 8, bolt lengths are 1-1/4″ and 1-1/2″; for gages 7 and 5, 1-1/2″ and 1-3/4″; for gages 3 and 1, 1″, 1-1/2″ and 2″. Weight of bolts only in pounds per hundred: 1-1/4″=33.2; 1-1/2″=35.1; 1-3/4″=37.8; 2″=39.9; 3″=46.4. Weight of 100 hexagonal nuts = 18.8 lbs.

Table 3. Physical Properties of Armco MULTI-PLATE

Specified Thickness, in.	Uncoated Thickness T, in.	Moment of Inertia* I, in.⁴	Section Modulus* S, in.³	Area of Section,* in.²	Radius of Gyration R, in.
0.109	0.1046	0.0604	0.0574	0.1297	0.682
0.138	0.1345	0.0782	0.0732	0.1669	0.684
0.168	0.1644	0.0962	0.0888	0.2041	0.686
0.188	0.1838	0.1080	0.0989	0.2283	0.688
0.218	0.2145	0.1269	0.1147	0.2666	0.690
0.249	0.2451	0.1462	0.1302	0.3048	0.692
0.280	0.2758	0.1658	0.1458	0.3432	0.695

*Per inch of horizontal projection

Figure 1. Bolt Hole Spacing

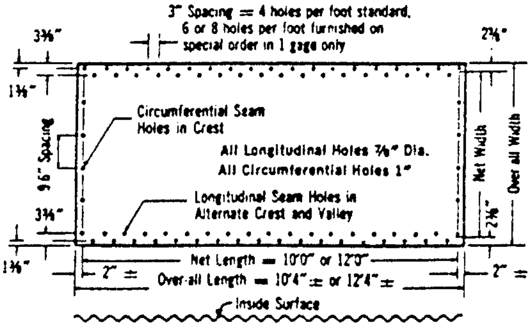
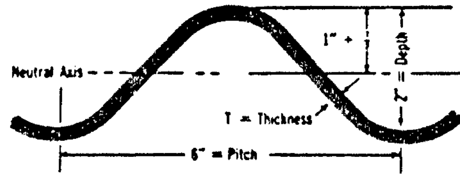


Figure 2. Standard 6″×2″ Corrugation



[1] Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute, 1000 16th Street N.W., Washington, D.C. 20036. 3rd Edition, 1983, pp. 56-57.

Figure 3. Channel Cross Section

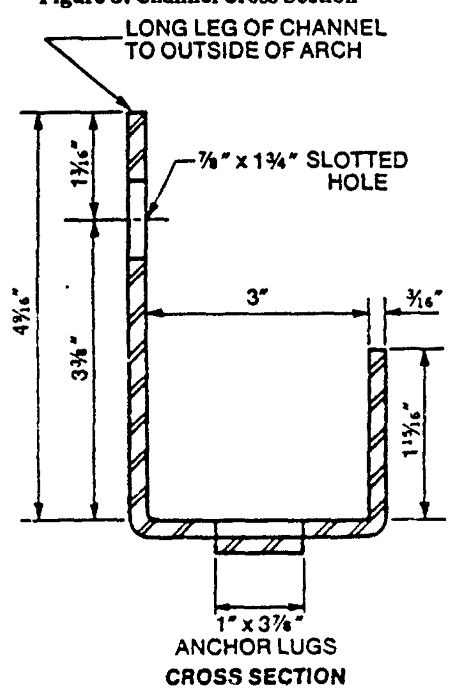
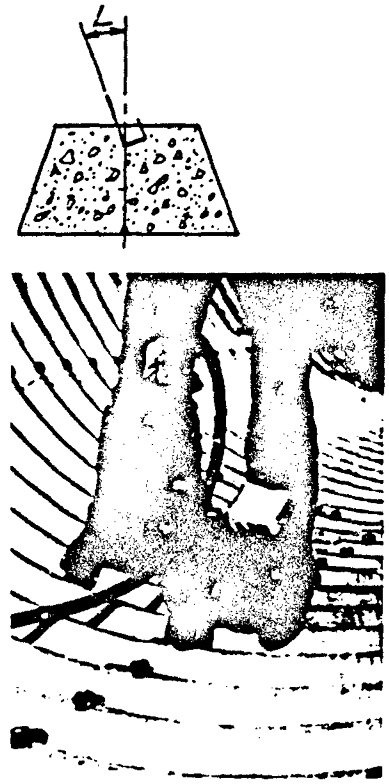


Figure 4. Channel Cross Section in concrete footing



Bolts and Nuts

Galvanized 3/4" diameter bolts of special heat-treated steel, in accordance with ASTM Specifications, are used to assemble MULTI-PLATE sections. The underside of the bolt head is uniformly rounded and does not require special positioning. In addition, the underside of the bolt head is ribbed to prevent bolt rotation while tightening. In fact, unlike conventional bolts, after the nut has been run up finger-tight on the Armco-developed Rib Bolt, final tightening can be accomplished by one worker. Eliminating the back-up holder can reduce bolting costs up to 40 percent.

Figure 5. Unbalanced Channel for MULTI-PLATE Arch

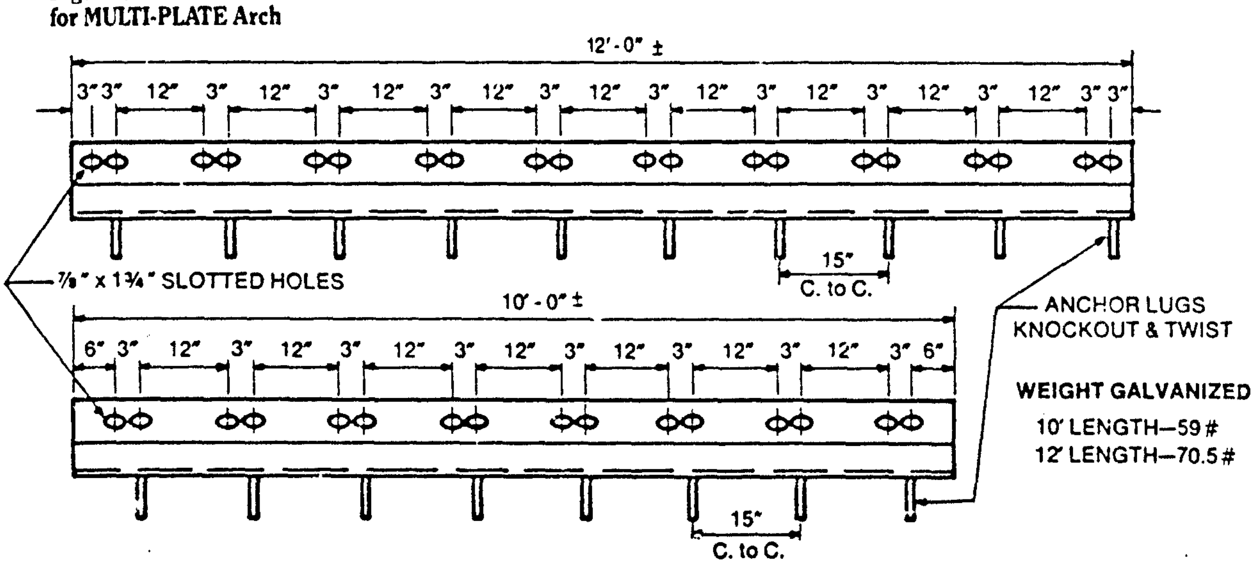


Table 4. MULTI-PLATE Pipe

Pipe Diameter, ft	End Area, ft²	Pipe Diameter, ft	End Area, ft²	Pipe Diameter, ft	End Area, ft²
5.0	19.1	12.5	124.0	20.0	320.6
5.5	23.2	13.0	134.3	20.5	337.0
6.0	27.8	13.5	144.9	21.0	353.8
6.5	32.7	14.0	156.0	21.5	371.0
7.0	38.1	14.5	167.5	22.0	388.6
7.5	43.9	15.0	179.4	22.5	406.6
8.0	50.0	15.5	191.7	23.0	425.0
8.5	56.6	16.0	204.4	23.5	443.8
9.0	63.6	16.5	217.5	24.0	463.0
9.5	71.0	17.0	231.0	24.5	482.6
10.0	78.8	17.5	244.9	25.0	502.7
10.5	87.1	18.0	259.2	25.5	523.1
11.0	95.7	18.5	274.0	26.0	543.9
11.5	104.7	19.0	289.1		
12.0	114.2	19.5	304.7		

Figure 6. Round and Ellipse Pipe

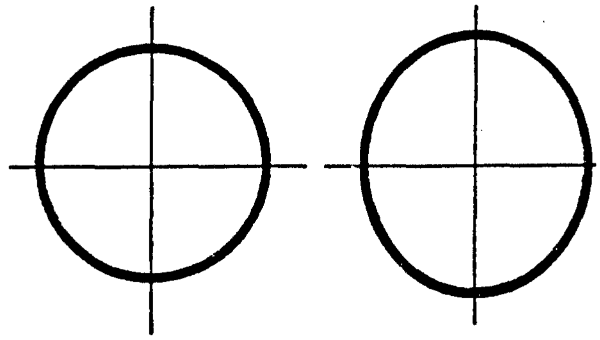
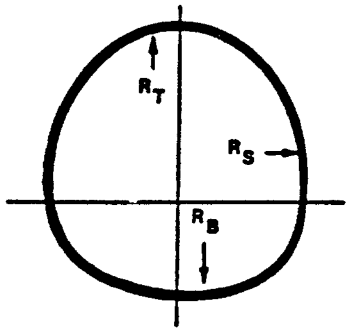


Table 5. MULTI-PLATE Pipe and Ellipse Plate Arrangement and Approximate Weight per Foot

Pipe Diameter, in.	Ellipse Dimensions		Number of Plates Per Ring				Approximate Weight Per Foot of Structure, lbs						
									Specified Thickness, in.				
	Horizontal	Vertical	15 Pi	18 Pi	21 Pi	24 Pi	0.109	0.138	0.168	0.188	0.218	0.249	0.280
60	56	62	4				106	131	158	172	199	227	253
66	62	68	2	2			114	144	174	189	219	250	279
72	67	75		4			124	157	190	206	239	272	304
78	73	81		2	2		134	170	206	223	259	295	329
84	79	88			4		145	183	222	240	279	318	355
90	85	94			2	2	155	196	238	257	299	340	380
96	91	101				4	165	209	253	275	319	363	405
102	97	107	2	4			175	222	269	292	339	386	430
108	103	114		6			186	235	285	309	359	408	456
114	109	120		4	2		196	249	301	326	379	431	481
120	115	127		2	4		206	262	317	343	398	454	506
126	120	133			6		217	275	333	360	418	476	532
132	126	139			4	2	227	288	349	378	438	499	557
138	132	146			2	4	237	301	364	395	458	522	582
144	138	152				6	248	314	380	412	478	544	608
150	142	157		6	2		258	327	396	429	498	567	633
156	148	164		4	4		268	340	412	446	518	590	658
162	153	170		2	6		279	353	428	463	538	612	684
168	159	176			8		289	366	444	481	558	635	709
174	165	183			6	2	299	379	459	498	578	658	734
180	171	189			4	4	310	392	475	515	598	680	760
186	177	195			2	6	320	406	491	532	618	703	785
192	182	202				8	330	419	507	549	637	726	810
198	189	209		4	6		341	432	523	566	657	748	836
204	195	215		2	8		351	445	539	583	677	771	861
210	200	222			10		361	458	554	601	697	794	886
216	206	228			8	2	372	471	570	618	717	817	912
222	212	235			6	4	382	484	586	635	737	839	937
228	217	241			4	6	392	497	602	652	757	862	962
234	224	247			2	8	403	510	618	669	777	885	988
240	229	254				10	413	523	634	686	797	907	1013
246	236	261		2	10		423	536	649	704	817	930	1038
252	241	267			12		433	549	665	721	837	953	1063
258	248	274			10	2	444	562	681	738	857	975	1089
264	253	280			8	4	454	576	697	755	876	998	1114
270	259	287			6	6	464	589	713	772	896	1021	1139
276	266	294			4	8	475	602	729	789	916	1043	1165
282	271	300			2	10	485	615	744	807	936	1066	1190
288	277	306				12	495	628	760	824	956	1089	1215
294	283	313			14		506	641	776	841	976	1111	1241
300	288	319			12	2	516	654	792	858	996	1134	1266
306	294	326			10	4	526	667	808	875	1016	1157	1291
312	302	332			8	6	537	680	824	892	1036	1179	1317

Dimensions are to inside crests and are subject to manufacturing tolerances.

Figure 7. Pipe-Arch and Underpass



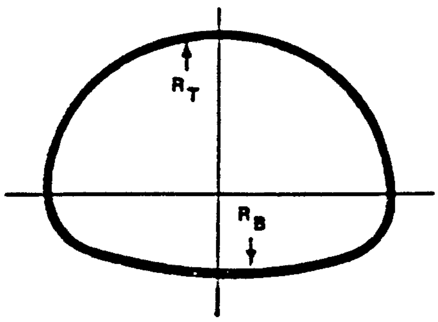


Table 6. MULTI-PLATE Underpass

	Span, ft-in.	Rise, ft-in.	Area, ft²	Layout Data,* in.		
				R_T	R_S	R_B
R_c = 38"	12-2	11-0	106	68	93	136
	12-11	11-2	114	74	92	148
	13-2	11-10	124	73	102	161
	13-10	12-2	133	77	106	168
	14-1	12-10	143	77	115	183
	14-6	13-5	155	78	131	174
	14-10	14-0	165	79	136	193
	15-6	14-4	177	83	139	201
	15-8	15-0	190	82	151	212
	16-4	15-5	200	86	156	217
	16-5	16-0	208	88	159	271
	16-9	16-3	215	89	168	246
R_c = 47"	17-3	17-0	234	90	174	214
	18-4	16-11	244	99	157	248
	19-1	17-2	258	105	156	262
	19-6	17-7	271	107	158	295
	20-4	17-9	281	114	155	316

*To nearest whole number

Dimensions are to inside crests and are subject to manufacturing tolerances.

Table 7. MULTI-PLATE Pipe-Arch

	Span, ft-in.	Rise, ft-in.	Area, ft²	R_T, in.	R_B, in.
R_c Corner Radius = 18"	6-1	4-7	22	36.8	76.3
	6-4	4-9	24	38.1	98.6
	6-9	4-11	26	41.0	83.5
	7-0	5-1	28	42.3	104.2
	7-3	5-3	31	43.5	136.2
	7-8	5-5	33	46.5	109.8
	7-11	5-7	35	47.7	137.9
	8-2	5-9	38	48.9	182.9
	8-7	5-11	40	51.9	141.0
	8-10	6-1	43	53.0	178.7
	9-4	6-3	46	56.2	144.6
	9-6	6-5	49	57.3	177.5
	9-9	6-7	52	58.3	227.7
	10-3	6-9	55	61.5	178.3
	10-8	6-11	58	64.9	153.2
	10-11	7-1	61	65.9	180.4
	11-5	7-3	64	69.4	157.9
	11-7	7-5	67	70.2	183.2
	11-10	7-7	71	71.1	216.4
	12-4	7-9	74	74.7	186.5
	12-6	7-11	78	75.5	216.8
	12-8	8-1	81	76.4	257.4
	12-10	8-4	85	77.3	314.7
R_c Corner Radius = 31"	13-3	9-4	98	80.1	192.6
	13-6	9-6	102	81.3	220.0
	14-0	9-8	106	84.4	197.9
	14-2	9-10	110	85.6	222.6
	14-5	10-0	115	86.6	256.6
	14-11	10-2	119	89.8	227.7
	15-4	10-4	124	93.1	208.5
	15-7	10-6	129	94.1	232.1
	15-10	10-8	133	95.2	260.6
	16-3	10-10	138	98.5	236.0
	16-6	11-0	143	99.5	263.2
	17-0	11-2	148	102.9	241.0
	17-2	11-4	153	103.8	266.8
	17-5	11-6	158	104.8	297.9
	17-11	11-8	163	108.2	270.6
	18-1	11-10	168	109.1	299.7
	18-7	12-0	174	112.6	274.5
	18-9	12-2	179	113.5	302.3
	19-3	12-4	185	117.0	278.6
	19-6	12-6	190	117.9	305.1
	19-8	12-8	196	118.8	336.5
	19-11	12-10	202	119.7	374.3
	20-5	13-0	208	123.2	338.1
	20-7	13-2	214	124.0	373.5

Dimensions are to inside crests and are subject to manufacturing tolerances.

Table 8. MULTI-PLATE Pipe-Arch Plate Arrangement and Approximate Weight per Foot

Span, ft-in.	Rise, ft-in.	Pi	Total	Number of Plates Per Ring: 9 Pi C	9 Pi B	15 Pi C	15 Pi B	15 Pi T	18 Pi B	18 Pi T	21 Pi B	21 Pi T	24 Pi B	24 Pi T	Approximate Weight Per Foot of Structure, lbs Specified Thickness, in.: 0.109	0.138	0.168	0.188	0.218	0.249	0.280
6-1	4-7	66	5	2			1	1		1					118	149	180	195	226	257	288
6-4	4-9	69	5	2			1			2					124	156	188	204	237	269	201
6-9	4-11	72	5	2					1	2					129	162	196	213	247	280	314
7-0	5-1	75	5	2					1	1		1			134	169	204	221	257	292	327
7-3	5-3	78	5	2					1			2			140	176	212	230	267	304	340
7-8	5-5	81	5	2							1	2			145	183	220	239	278	315	353
7-11	5-7	84	5	2							1	1		1	150	189	229	248	288	327	366
8-2	5-9	87	5	2							1			2	156	196	237	257	298	339	379
8-7	5-11	90	5	2									1	2	161	203	245	266	308	350	392
8-10	6-1	93	6	2				1		2			1		167	210	253	274	319	362	405
9-4	6-3	96	7	2	1			1	1	2					172	217	261	283	329	374	418
9-6	6-5	99	7	2	1				1	3					177	223	269	292	339	385	431
9-9	6-7	102	7	2	1				1	2		1			183	230	278	301	350	397	444
10-3	6-9	105	7	2			2			2		1			188	237	286	310	360	409	458
10-8	6-11	108	7	2			1		1	2		1			193	244	294	319	370	420	471
10-11	7-1	111	7	2			1		1	1		2			199	250	302	328	380	432	484
11-5	7-3	114	7	2					2	1		2			204	257	310	336	391	444	497
11-7	7-5	117	7	2					2			3			209	264	318	345	401	455	510
11-10	7-7	120	7	2					2			2		1	215	271	327	354	411	470	523
12-4	7-9	123	7	2					1		1	2		1	220	277	335	363	422	479	536
12-6	7-11	126	7	2					1		1	1		2	226	284	343	372	432	490	549
12-8	8-1	129	7	2					1		1			3	231	291	351	381	442	502	562
12-10	8-4	132	8	2					1	3	1	1			236	298	359	390	452	514	575
13-3	9-4	138	7			2			2					3	241	305	368	399	464	527	590
13-6	9-6	141	8			2			2	3		1			247	311	376	408	474	538	603
14-0	9-8	144	8			2			1	3	1	1			252	318	384	417	484	550	616
14-2	9-10	147	8			2			1	2	1	2			257	324	392	425	494	561	628
14-5	10-0	150	8			2			1	1	1	3			262	331	400	434	504	572	641
14-11	10-2	153	8			2				1	2	3			267	338	408	443	514	584	654
15-4	10-4	156	8			2				1	1	3	1		273	344	416	451	524	595	667
15-7	10-6	159	8			2					1	4	1		278	351	424	460	534	607	680
15-10	10-8	162	8			2					1	3	1	1	283	358	432	469	544	618	693
16-3	10-10	165	8			2						3	2	1	288	364	440	477	554	630	705
16-6	11-0	168	8			2						2	2	2	294	371	448	486	565	641	718
17-0	11-2	171	9			2	1		2			2		2	299	377	456	495	575	653	731
17-2	11-4	174	9			2	1		2			1		3	304	384	464	503	585	664	744
17-5	11-6	177	9			2	1		2					4	309	391	472	512	595	675	757
17-11	11-8	180	9			2			3					4	315	397	480	521	605	687	770
18-1	11-10	183	10			2			3	2		3			320	404	488	529	615	698	782
18-7	12-0	186	10			2			2	2	1	3			325	411	496	538	625	710	795
18-9	12-2	189	10			2			2	1	1	4			330	417	504	547	635	721	808
19-3	12-4	192	10			2			1	1	2	4			336	424	512	556	645	733	821
19-6	12-6	195	10			2			1		2	5			341	430	520	564	655	744	834
19-8	12-8	198	10			2			1		2	4		1	346	437	528	573	665	756	847
19-11	12-10	201	10			2			1		2	3		2	351	444	536	582	675	767	859
20-5	13-0	204	10			2					3	3		2	357	450	544	590	685	779	872
20-7	13-2	207	10			2					3	2		3	362	457	552	599	696	790	885

18" Corner Radius (spans 6-1 through 12-10)

31" Corner Radius (spans 13-3 through 20-7)

Galvanized, with Bolts

B = Bottom
T = Top
C = Corner

These plate arrangements will be furnished unless noted otherwise on drawings.

Note: Dimensions are to inside crests and are subject to manufacturing tolerances.

Table 9. MULTI-PLATE Underpass Plate Arrangement

Span, ft-in.	Rise, ft-in.	Total Pi	Number of Nominal Pi Width Plates, in.																Total Plates Per Ring
			Top				Sides					Corners		Bottom					
			15	18	21	24	9	15	18	21	24	15	18	15	18	21	24		
12-2	11-0	141		1	1					2		2		2					8
12-11	11-2	147			2					2		2		1	1				8
13-2	11-10	153			2						2	2		1	1				8
13-10	12-2	159			1	1					2	2			2				8
14-1	12-10	165			1	1	2		2			2			2				10
14-6	13-5	171				2	2		2			2			1	1			10
14-10	14-0	177				2		4				2			1	1			10
15-6	14-4	183	1	2				4				2				2			11
15-8	15-0	189	1	2				2	2			2				2			11
16-4	15-5	195		3				2	2			2				1	1		11
16-5	16-0	201		2	1				4			2				2			11
16-9	16-3	204		2	1				4			2				1	1		11
17-3	17-0	210		2	1				4				2			1	1		11
18-4	16-11	216		1	2				4				2				2		11
19-1	17-2	222			3				4				2	1	2				12
19-6	17-7	228			3				2	2			2	1	2				12
20-4	17-9	234			2	1			2	2			2		3				12

Dimensions are to inside crest and are subject to manufacturing tolerances.

Table 10. MULTI-PLATE Underpass Approximate Weight per Foot

Span, ft-in.	Rise, ft-in.	Approximate Weight per Foot of Structure, lbs* Specified Thickness, in.							Area ft²
		0.109	0.138	0.168	0.188	0.218	0.249	0.280	
		12 Ga	10 Ga	8 Ga	7 Ga	5 Ga	3 Ga	1 Ga	
12-2	11-0	247	311	376	408	474	538	603	106
12-11	11-2	257	324	392	425	494	561	628	114
13-2	11-10	267	338	408	443	514	584	654	124
13-10	12-2	278	351	424	460	534	607	680	133
14-1	12-10	288	364	440	477	554	630	705	143
14-6	13-5	299	377	456	495	575	653	731	155
14-10	14-0	309	391	472	512	595	675	757	165
15-6	14-4	320	404	488	529	615	698	782	177
15-8	15-0	330	417	504	547	635	721	808	190
16-4	15-5	341	430	520	564	655	744	834	200
16-5	16-0	351	444	536	582	675	767	859	208
16-9	16-3	357	450	544	590	685	779	872	215
17-3	17-0	361	458	554	601	697	794	886	234
18-4	16-11	372	471	570	618	717	817	912	244
19-1	17-2	382	484	586	635	737	839	937	258
19-6	17-7	392	497	602	652	757	862	962	271
20-4	17-9	403	510	618	669	777	885	988	282

*Galvanized, with bolts

Dimensions are to inside crests and are subject to manufacturing tolerances.

Table 11. MULTI-PLATE Arches 6"×2" Corrugation[2]

Dimensions		Waterway Area, ft²	Rise over Span	Radius, in.	Nominal Arc Length
Span, ft	Rise, ft-in.				Pi, in.
6.0	1-9½	7½	0.30	41	27
	2-3½	10	0.38	37½	30
	3-2	15	0.53	36	36
7.0	2-4	12	0.34	45	33
	2-10	15	0.40	43	36
	3-8	20	0.52	42	42
8.0	2-11	17	0.37	51	39
	3-4	20	0.42	48½	42
	4-2	26	0.52	48	48
9.0	2-11	18½	0.32	59	42
	3-10½	26½	0.43	55	48
	4-8½	33	0.52	54	54
10.0	3-5½	25	0.35	64	48
	4-5	34	0.44	60½	54
	5-3	41	0.52	60	60
11.0	3-6	27½	0.32	73	51
	4-5½	37	0.41	67½	57
	5-9	50	0.52	66	66
12.0	4-0½	35	0.34	77½	57
	5-0	45	0.42	73	63
	6-3	59	0.52	72	72
13.0	4-1	38	0.32	86½	60
	5-1	49	0.39	80½	66
	6-9	70	0.52	78	78
14.0	4-7½	47	0.33	91	66
	5-7	58	0.40	86	72
	7-3	80	0.52	84	84
15.0	4-7½	50	0.31	101	69
	5-8	62	0.38	93	75
	6-7	75	0.44	91	81
	7-9	92	0.52	90	90
16.0	5-2	60	0.32	105	75
	7-1	86	0.45	97	87
	8-3	105	0.52	96	96
17.0	5-2½	63	0.31	115	78
	7-2	92	0.42	103	90
	8-10	119	0.52	102	102
18.0	5-9	75	0.32	119	84
	7-8	104	0.43	109	96
	8-11	126	0.50	108	105
19.0	6-4	87	0.33	123	90
	8-2	118	0.43	115	102
	9-5½	140	0.50	114	111
20.0	6-4	91	0.32	133	93
	8-3½	124	0.42	122	105
	10-0	157	0.50	120	117
21.0	6-11	104	0.33	137	99
	8-10	140	0.42	128	111
	10-6	172	0.50	126	123
22.0	6-11	109	0.31	146	102
	8-11	146	0.40	135	114
	11-0	190	0.50	132	129
23.0	8-0	134	0.35	147	111
	9-10	171	0.43	140	123
	11-6	208	0.50	138	135
24.0	8-6	150	0.35	152	117
	10-4	188	0.43	146	129
	12-0	226	0.50	144	141
25.0	8-6½	155	0.34	160	120
	10-10½	207	0.43	152	135
	12-6	247	0.50	150	147

Dimensions are to inside crests and are subject to manufacturing tolerances.

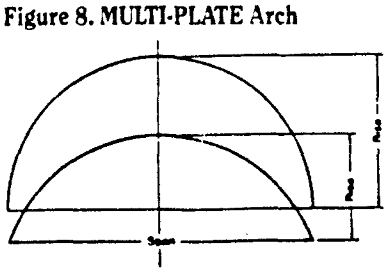
To determine proper gage, use information on page 21, tables 19 and 20.

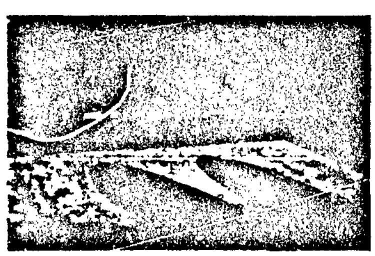
[2]Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute, 1000 16th Street N.W., Washington, D.C. 20036, 3rd Edition, 1983, pp. 63-64.

Table 12. MULTI-PLATE Arch Plate Arrangement and Approximate Weight per Foot

Arch Arc Length Pi Inches	Number of Plates per Ring					Approximate Weight Per Foot of Structure, lbs Specified Thickness, in.						
	9 Pi	15 Pi	18 Pi	21 Pi	24 Pi	0.109 (12 Ga.)	0.138 (10 Ga.)	0.168 (8 Ga.)	0.188 (7 Ga.)	0.218 (5 Ga.)	0.249 (3 Ga.)	0.280 (1 Ga.)
24					1	41	52	63	68	80	90	101
27	1		1			46	59	71	77	89	102	114
30		2				51	65	79	86	99	113	126
33		1	1			57	72	87	94	109	124	139
36			2			62	78	95	103	119	136	152
39			1	1		67	85	102	111	129	147	164
42				2		72	91	110	120	139	158	177
45				1	1	77	98	118	128	149	169	190
48					2	82	104	126	137	159	181	202
51		1	2			87	111	134	145	169	192	215
54			3			93	117	142	154	179	203	227
57			2	1		98	124	150	163	189	215	240
60			1	2		103	130	157	171	199	226	253
63				3		108	137	165	180	209	237	265
66				2	1	113	143	173	188	219	248	278
69				1	2	118	150	181	197	229	260	291
72					3	123	156	189	205	238	271	303
75			3	1		129	163	197	214	248	282	316
78			2	2		134	169	205	222	258	294	329
81			1	3		139	176	213	231	268	305	341
84				4		144	182	220	239	278	316	354
87				3	1	149	189	228	248	288	328	366
90				2	2	154	195	236	257	298	339	379
93				1	3	159	202	244	265	308	350	392
96					4	165	208	252	274	318	361	404
99			2	3		170	215	260	282	328	373	417
102			1	4		175	221	268	291	338	384	430
105				5		180	228	276	299	348	395	442
108				4	1	185	234	283	308	358	407	455
111				3	2	190	241	291	316	368	418	467
114				2	3	195	247	299	325	375	429	480
117				1	4	201	254	307	334	387	440	493
120					5	206	260	315	342	397	452	505
123			1	5		211	267	323	351	407	463	518
126				6		216	273	331	359	417	474	531
129				5	1	221	280	339	368	427	485	543
132				4	2	226	286	346	376	437	497	556
135				3	3	231	293	354	385	447	508	569
138				2	4	237	300	362	393	457	519	581
141				1	5	242	306	370	402	467	531	594
144					6	247	313	378	410	477	542	606
147				7		252	319	386	419	487	553	619

Figure 8. MULTI-PLATE Arch



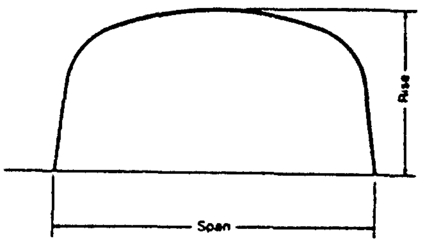


Box Culverts

MULTI-PLATE Box Culverts approach the rectangular shape of a low, wide box in spans to 19 feet 3 inches. This is made possible by the addition of reinforcing ribs to standard MULTI-PLATE sheets.

The design criteria presented elsewhere in this catalog do not apply to box culverts. The extreme geometry and shallow cover over these structures prevent the use of the ring compression method of design. Finite element computer programs have been used to solve the indeterminate structural problems presented by the heavy stiffened box shapes. Design moments and axial forces are resisted by the combined section of MULTI-PLATE and rib stiffeners with appropriate margins of safety.

Figure 9. Box Culverts



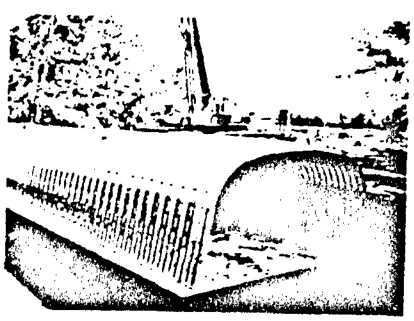


Table 13. MULTI-PLATE Box Culverts

Span, ft-in.	Rise, ft-in.	Area, ft²
9 8	2 7	20.8
10 1	3 4	28.4
10 5	2 8	23.2
10 7	4 2	36.4
10 10	3 5	31.4
11 0	4 11	44.7
11 1	2 9	25.7
11 2	4 3	39.9
11 5	5 8	53.3
11 6	3 6	34.5
11 7	5 0	48.7
11 10	2 10	28.3
11 10	4 4	43.5
11 10	6 5	62.2
12 0	5 9	57.9
12 2	3 8	37.7
12 3	5 1	52.9
12 3	7 3	71.5
12 5	6 6.5	67.3
12 6	2 11	31.1
12 6	4 5	47.3
12 7.5	5 10	62.6
12 10	3 9	41.1
12 10	7 4	77.1
12 10.5	5 2	57.2
13 0	6 8	72.5
13 2	4 6	51.2
13 2.5	3 1	34.1
13 3	6 0	67.4
13 5	7 5	82.8
13 6	3 10	44.5
13 6	5 4	61.7
13 7	6 9	77.9
13 10	4 8	55.3
13 10	6 1	72.4
13 11	3 2	37.1
13 11	7 6	88.6
14 1	5 5	66.3
14 2	3 11	48.2
14 2	6 10	83.3
14 5	6 2	77.5
14 6	4 9	59.5
14 6	7 8	94.5
14 7	3 3	40.4
14 9	5 6	71.0
14 9	7 0	88.9
14 10	4 1	52.0
15 0	6 4	82.7
15 0	7 9	100.6
15 1	4 10	63.8
15 3	3 5	43.8
15 4	5 8	75.8
15 4	7 1	94.6
15 6	4 2	55.9
15 7	6 5	88.1
15 7	7 11	106.8
15 9	5 0	68.3
15 10	7 3	100.5
16 0	3 6	47.3
16 0	5 9	80.9
16 1	8 0	113.1
16 2	4 4	60.1
16 2	6 7	93.6
16 4	5 1	73.0
16 5	7 4	106.5
16 7	5 11	86.1
16 8	3 8	51.1
16 8	8 2	119.6
16 9	6 9	99.3
16 10	4 6	64.4
17 0	5 3	77.8
17 0	7 6	112.7
17 2	6 1	91.4
17 2	8 4	126.2
17 4	3 10	55.0
17 4	6 10	105.1
17 6	4 7	68.9
17 6	7 8	119.0
17 7	5 5	82.8
17 8	8 5	133.0
17 9	6 2	96.9
17 11	7 0	111.1
18 0	3 11	59.1
18 1	4 9	73.5
18 1	7 9	125.5
18 3	5 7	88.0
18 3	8 7	139.9
18 4	6 4	102.6
18 6	7 2	117.3
18 7	7 11	132.1
18 8	4 1	63.4
18 9	4 11	78.4
18 9	8 9	147.0
18 10	5 8	93.4
18 11	6 6	108.5
19 1	7 4	123.7
19 2	8 1	138.9
19 3	8 11	154.2

Dimensions are to inside crests and are subject to manufacturing tolerances.

Convenient fill height tables are provided on pages 21, 22 and 23. These can be used for routine applications to select the required thickness of steel. There are, however, projects that justify individual structure design for maximum economy.

Computation of Loads

Underground conduits are subject to two principal types of loads:

1. Dead loads developed by the embankment or trench backfill, plus stationary superimposed surface loads, uniform or concentrated.
2. Live loads that encompass all moving loads, including impact.

Dead Loads

The dead load is considered to be the soil prism over the pipe. The unit pressure of this prism acting on the horizontal plane at the top of the pipe is equal to:

Unit weight of soil × height of fill

or

$DL = w \times h$

where w = Unit weight of soil, lbs/ft³
h = Height of fill over pipe, ft
DL = Dead Load pressure, lbs/ft²

Structural Design

The structural design process consists of the following:

- Select the backfill soil density to be required or expected.
- Calculate the design pressure.
- Compute the compression in the pipe wall.
- Select the allowable compressive stress for the pipe size, corrugation and soil density.
- Determine the thickness required.
- Check minimum handling stiffness.
- Check seam sealants (when applicable).
- Check pipe-arches and arches.

Backfill Density

Select a percent compaction of pipe backfill for *design*. The value chosen should reflect the importance and size of the structure, as well as the quality that can reasonably be expected. The recommended value for routine use is 85 percent. This value easily applies to ordinary installations in which specifications call for 90 or 95 percent. However, for more important structures in higher fill situations, design should be based on higher quality backfill.

Design Pressure

Design Pressure, P_v, is equal to the Dead Load Pressure, DL, plus the Live Load Pressure, LL, acting at the crown of the pipe.

$$P_v = DL + LL$$

Where: P_v = Design Pressure, lbs/ft²
DL = Dead Load Pressure, lbs/ft²
LL = Live Load Pressure, lbs/ft²

Recent research has shown that typical highway live loads do not produce a ring thrust as large as indicated by straight application of live load pressure at the crown multiplied by half the pipe span. This can be significant for large structures (span greater than 8′). Research suggests the live load be applied to only 3/4 of the span. This amounts to a 25 percent reduction in the live load pressure as used in these formulae.

For a more accurate evaluation of Live Load Stress, the following modified formula for P_v is suggested:

$$P_v = DL + 0.75LL$$

Ring Compression

The compressive thrust in the conduit wall is equal to the radial pressure acting on the wall multiplied by the wall radius or: $C = P \times R$. For conventional structures in which the top arc approaches a semicircle, it is convenient to substitute half the span for the wall radius.

Then: $C = P_v \times \dfrac{S}{2}$

Where: C = Ring compression, lbs/ft
P_v = Design Pressure, lbs/ft²
S = Span, in feet

HS-25 Loading

Some agencies are using this loading for their Bridge Designs. Unlike bridges, buried culverts are designed for live load pressure exerted on the crown of the structure. The amount of total concentrated load at the surface isn't important. The distribution of that load is. HS-25 loading does not appear to create a significant increase in pressure on shallow buried culverts over that generated by HS-20. This conclusion is based on the normal practice of using a larger surface footprint for HS-25 vehicles. The single wheel of 16 kips in HS-20 is not ordinarily increased to 20 kips in HS-25. Most commonly tandem duals (4 wheels per 20 kips) are used and at worst, duals (2 wheels) are used. This increased distribution of the heavier load keeps the pressure about the same. As a result, HS-20 live load pressure curves can ordinarily be used for HS-25 as well.

Live Loads

Table 14. Live Loads for Various Heights of Cover

H 20 Loading*	
Height of Cover, ft	**Load, lbs/ft²**
1	1800
2	800
3	600
4	400
5	250
6	200
7	175
8	100

E 80 Loading*	
Height of Cover, ft	**Load, lbs/ft²**
2	3800
5	2400
8	1600
10	1100
12	800
15	600
20	300
30	100

*Neglect live load when less than 100; use dead load only.

*"Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. 20036, 3rd Edition, 1983, pp. 98-155.

Allowable Wall Stress

The allowable wall stress is determined from the curves in Figure 9. These curves account for the variance in Load Factor, K, and incorporate a Safety Factory of 2.0 applied to ultimate wall stress to arrive at an allowable (design) stress.

For the convenience of anyone wishing to calculate the values of allowable wall stress, the curve formulae are as follows:

For $D/r < 294$, $f_a = 33{,}000/2K$

For $D/r > 294$ and < 500, $f_a = [40{,}000 - 0.081(D/r)^2] \div 2K$

For $D/r > 500$, $f_a = 4.93 \times 10^9/2K(D/r)^2$

Where:

f_a = Allowable Wall Stress, lb/in.^{2}

F = Load Factor

r = Radius of Gyration, in.

D = Diameter, in.

For 85% Standard Density, K = 0.86

For 90% Standard Density, K = 0.75

For 95% Standard Density, K = 0.65

Wall Thickness

Required Wall Area, A, is computed from Calculated Compression in the pipe wall, C, and the Allowable Stress, f_c.

$A = C/f_c$

From Table 15, select the wall thickness providing the required area in the same corrugation used to select the allowable stress.

Table 15. Sectional Properties per Foot of Section Width for 6"×2" Corrugation

Specified Thickness, in.	Area of Section, in.^{2}/ft	Moment of Inertia, in.^{4}/ft	Radius of Gyration, in.
0.109	1.556	0.725	0.682
0.138	2.003	0.938	0.684
0.168	2.449	1.154	0.686
0.188	2.739	1.296	0.688
0.218	3.199	1.523	0.690
0.249	3.658	1.754	0.692
0.280	4.119	1.990	0.695

Corrugation dimensions are nominal, subject to manufacturing tolerances.

Note that the maximum ring compression should be limited to 1/2 the ultimate seam strength for pipe thicknesses which do not develop seam strengths corresponding to an allowable wall stress ≥ 16,500 psi.

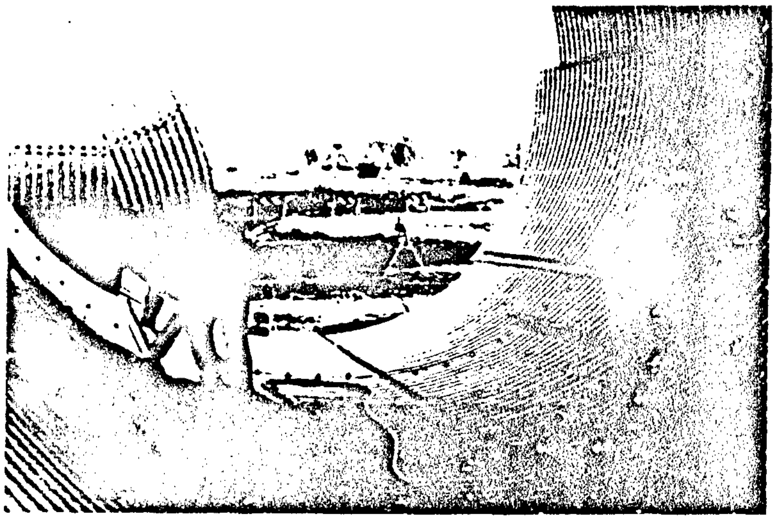
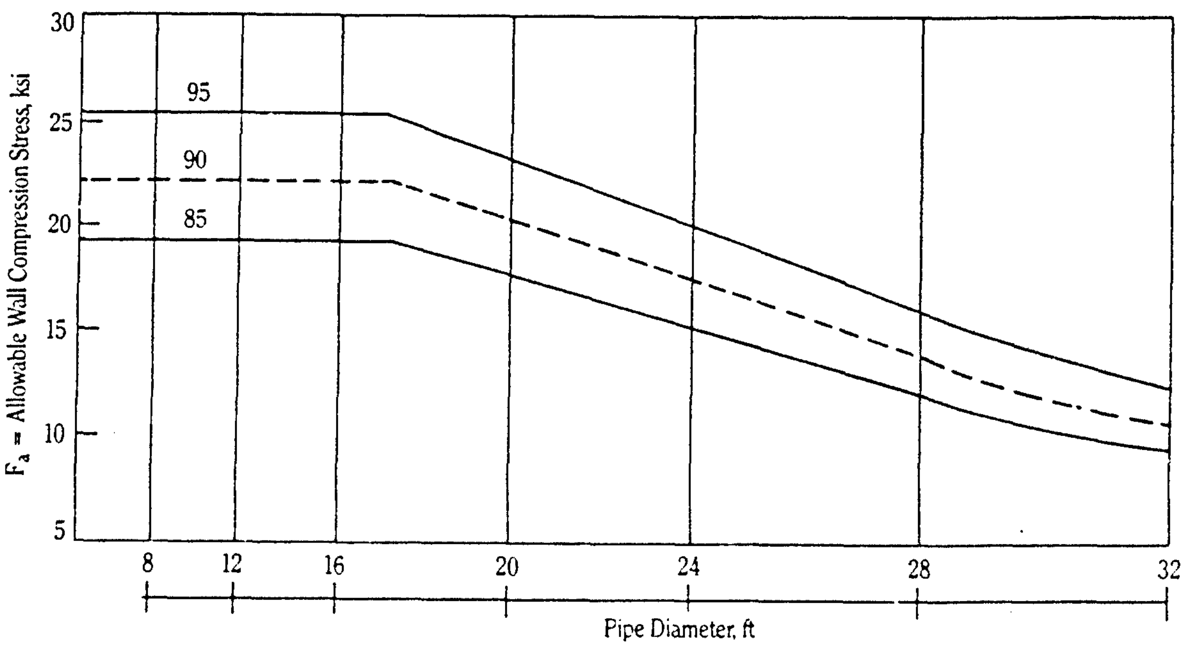


Figure 9. Allowable Wall Stress for MULTI-PLATE Pipe with backfill compacted to 85%, 90% and 95% standard density, AASHTO-T99



Check Handling Stiffness

Minimum pipe stiffness requirements for practical handling and installation without undue care or bracing have been established through experience. The resultant Flexibility Factor, FF, limits the size of each combination of corrugation and metal thickness.

$FF = D^2/EI$

Where: E = Modulus of Elasticity $= 30 \times 10^6$ psi.
D = Diameter or Span, in.
I = Moment of Inertia of Wall, in.^{4}/in.

Recommended maximum values of FF for ordinary installations:

FF = 0.020 for field-assembled pipe with 6″×2″ bolted seams.

Increase the maximum values of the Flexibility Factor, FF, for pipe-arch and arch shapes as follows:

Pipe-Arch FF = 1.5 × FF shown for round pipe
Arch FF = 1.3 × FF shown for round pipe

Higher values can be used safely if reasonable care is exercised or when experience has so proved.

Check Bolted Seams

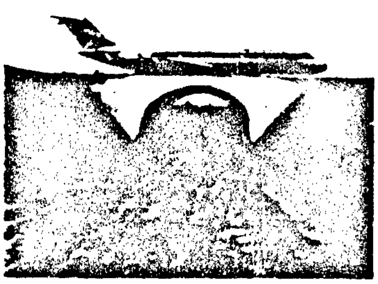
A bolted seam (standard for structural plate) must have a test strength of twice the design load in the pipe wall.

Table 16 lists the values of one-half the ultimate compressive strength of bolted joints for 6″ × 2″ corrugations tested as unsupported short columns. For convenience, the wall stress which corresponds to one-half the joint strength is also given.

Table 16. Bolted Seam Design Data

Specified Thickness, in.	Structural Plate Pipe 6″×2″ Corrugation (Four ¾-in. bolts per ft)	
	Ultimate Strength, 2 lbs/ft	Corresponding Wall Stress, psi
0.109	21,000	13,500
0.138	31,000	15,500
0.168	40,500	16,500
0.188	46,500	17,000
0.218	56,000	17,500
0.249	66,000	18,100
0.280	72,000	17,500

Note that the maximum ring compression should be limited to 1/2 the ultimate seam strength for pipe thicknesses which do not develop seam strengths corresponding to an allowable wall stress ≥ 16,500 psi.



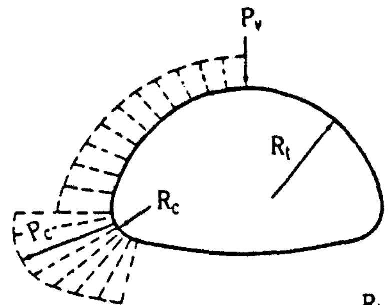
Check Pipe-Arches, Underpasses and Arches

Pipe-Arches

The pipe-arch shape poses special design problems not found in round or vertically elongated pipe. Pipe-arches generate corner pressures greater than the pressure in the fill. This becomes the practical limiting design factor rather than stress in the pipe wall.

To calculate corner pressure, ignore the bending strength of the corrugated steel and establish allowable loads based on the allowable pressure on the soil at the corners. Assuming zero moment strength of the pipe wall, Ring Compression, C, is the same at any point around the pipe-arch. Thus, $C = P \times R$ at any point on the periphery. This means normal pressure to the pipe-arch wall is inversely proportional to the wall radius.

Figure 10. Corner Pressure on Pipe-Arches[3]



Corner Pressure $P_c = P_v \times \frac{R_t}{R_c}$

P_c = Pressure acting on soil at corners, lb/ft^2
R_t = Radius at crown, ft
R_c = Radius of corner, ft
P_v = Design pressure, lbs/ft^2

The pressure on a pipe-arch varies with location and radius, being greatest at the corners.

Limiting design pressure is established by the allowable soil pressure at the corners. Special backfill such as crushed stone or soil cement at the corners can extend these limitations. A maximum value of 3 tons/ft^2 for corner pressure is suggested for routine use.

Arches

Another special case is involved in the structural design of MULTI-PLATE arches on unyielding foundations. Because the steel ring is restrained at the base of the arch and cannot move into the backfill at this point, the influence of column-type buckling must be considered.

The most restrictive case is that of the arch that is less than semi-circular in shape (rise over span less than 0.50). The ultimate compressive strength of these shapes has been shown to be less than equivalent to that of full-round pipe. Only the use of higher safety factors has made this common arch shape practical. The allowable compressive stresses in such shapes should be less than the equivalent round pipe. It is suggested to reduce f_c (Compressive Stress) by 25 percent for arches whose rise to span is less than 0.50.

Arches on Yielding Foundations

An opportunity exists on all arch designs to permit the footing to settle and relieve the load on the arch. Positive soil arching can be assured by such practice and lower safety factors utilized.

Other Designs

Key-Hole Slot

A new, positive method of relieving the load on MULTI-PLATE steel structures by providing for slippage in the longitudinal lapped seams is available with the newly designed Key-Hole Slot. It provides a self-indexing, controlled, yieldable joint between the adjacent lapped plates along the longitudinal joints. These joints permit the lapped joint to yield under compressive load and reduce the circumference of the structure so that the soil carries much of the load instead of the structure.

The result is the ability to reduce metal thickness. It also allows for higher fills over a structure.

With the Armco Key-Hole Slot, 3/4-inch-diameter MULTI-PLATE bolts are inserted in the 7/8-inch-diameter round-hole portion of the slot. This ensures proper positioning of the plates in relation to one another. The slotted portion is smaller than the bolt and will allow the bolt to enter the slot only under significant load.

In this concept, the longitudinal joint has the ability to:

1. Sustain a significant compressive load without abnormal slippage; then,
2. Yield approximately 1 inch under normal compression load; and
3. Develop the ultimate strength of a regular MULTI-PLATE seam.

Present Key-Hole design will provide 1 inch of available slip or yield in each longitudinal seam. Full-scale testing confirms that this amount of yield assures long-term performance.

SUPER-SPAN Structures

The SUPER-SPAN design adds longitudinal stiffeners—thrust beams—to conventional MULTI-PLATE. This concept allows the design of larger sizes and increased live and dead loads. It is possible to achieve clear spans up to 50 feet and clear areas up to 1,000 square feet.

SUPER-SPAN structures are particularly suited for relatively low, wide-opening requirements. Depth of cover generally is limited to 20 to 30 feet.

SUPER-SPAN structures are available in elliptical, arch, and pear-shaped designs for application as storm sewers, stream enclosures, vehicular and railroad underpasses.

End Treatment

Hydraulic forces must be considered when designing end treatments for culverts or storm drains. Structures subject to severe peak flows with ponding at the inlet must withstand significant uplift force on the end. Scouring is also a threat. If an end finish such as a bevel is used, it may be necessary to reinforce the cut edges against hydraulic pressure.

Standard end finishes for MULTI-PLATE are square ends, step bevels, skews, partial bevels and skew bevels. These cut ends are weaker than the pipe barrel. Exercise caution when placing backfill around them to avoid distortion. Extreme cut ends should be avoided on any structure. Step bevel is recommended over other designs.

Appropriate end treatment design is beyond the scope of this catalog. Complete design information can be obtained in FHWA Circular Memo, "Plans for Culvert Inlet and Outlet Structures," Sheets G-39-66 to G-44-66, 1966.

General Note: Height of Cover Tables 17 through 22 are presented for the designer's convenience for use in routine applications.

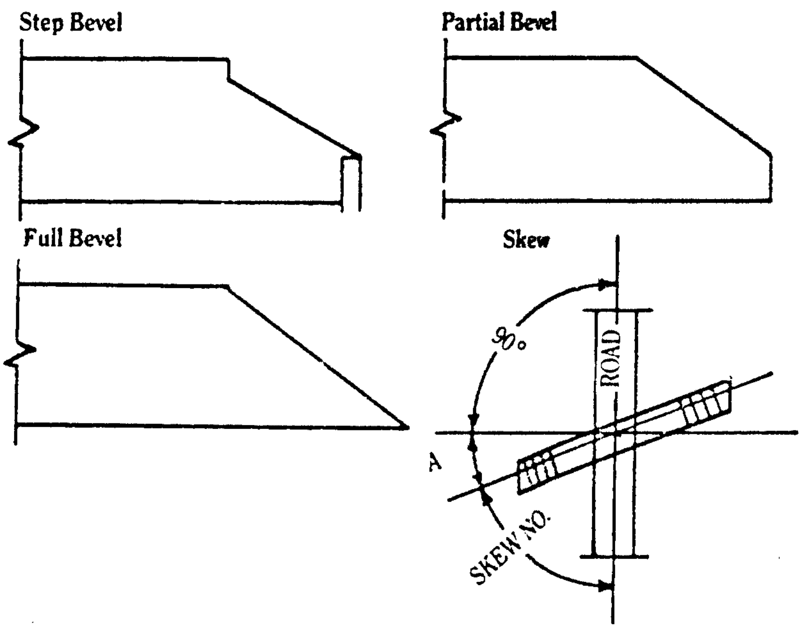
They are based on the design procedures presented herein, using the following values for the soil and steel parameters:

Unit weight of Soil—120 lb. per ft³

Relative Density of Compacted Backfill-Minimum 85% Standard AASHTO, T-99

Yield Point of Steel—33,000 psi

Figure 11. MULTI-PLATE End Finishes



Height-of-Cover Limi

for Arm— MULTI-PLATE Pipe and Arches (in ...

Table 17. H 20 Live Load[a]—Pipe

Diameter or Span, ft	Diameter or Span, in.	Min. Cover in.	Maximum Cover, ft — Specified Thickness, in. 0.109	0.138	0.168	0.188	0.218	0.249	0.280
5	60	12	81	120	157	176	205	234	264
5.5	66		74	110	143	159	186	213	240
6	72		68	101	131	146	171	195	220
6.5	78		62	92	121	135	157	180	203
7	84		58	86	112	125	146	168	188
7.5	90		54	80	105	117	137	156	176
8	96	12	51	75	98	111	128	146	165
8.5	102	18	48	71	92	103	120	137	155
9	108		45	67	87	97	114	130	146
9.5	114		43	63	82	92	108	123	139
10	120		40	60	78	87	102	117	132
10.5	126		39	57	74	83	97	112	126
11	132		37	54	71	79	93	106	120
11.5	138		35	52	68	76	89	102	114
12	144	18	34	50	65	73	85	97	110
12.5	150	24	32	48	63	70	82	93	106
13	156		31	46	60	67	79	90	101
13.5	162		30	44	58	65	76	87	98
14	168		29	43	56	62	73	83	94
14.5	174		28	41	54	60	70	80	91
15	180		27	40	52	58	68	78	88
15.5	186		26	39	50	56	66	75	85
16	192	24	25	37	49	54	64	73	82
16.5	198	30		36	47	53	62	71	80
17	204			35	45	51	60	68	77
17.5	210			34	43	49	57	65	74
18	216			33	42	47	55	63	71
18.5	222				40	45	52	60	68
19	228				38	43	50	58	65
19.5	234				37	41	48	55	62
20	240	30			35	40	47	53	60
20.5	246	36				38	45	51	57
21	252					36	43	49	56
21.5	258					35	41	47	53
22	264						39	45	51
22.5	270						38	43	49
23	276						36	41	46
23.5	282							40	45
24	288	36						38	43
24.5	294	42						36	41
25	300							35	39
25.5	306								37
26	312	42							35

Values shown also apply to HS 20 and HS 25 Loadings

Table 18. E 80 Live Load[a]—Pipe

Diameter or Span, ft	Diameter or Span, in.	Min. Cover in.	Maximum Cover, ft — Specified Thickness, in. 0.109	0.138	0.168	0.188	0.218	0.249	0.280
5	60	24	81	120	157	176	205	234	264
5.5	66		74	110	143	159	186	213	240
6	72		68	101	131	146	171	195	220
6.5	78		62	92	121	135	157	180	203
7	84		58	86	112	125	146	168	188
7.5	90		54	80	105	117	137	156	176
8	96		51	75	98	111	128	146	165
8.5	102		48	71	92	103	120	137	155
9	108		45	67	87	97	114	130	146
9.5	114		43	63	82	92	108	123	139
10	120	24	40	60	78	87	102	117	132
10.5	126	30	39	57	74	83	97	112	126
11	132		37	54	71	79	93	106	120
11.5	138		35	52	68	76	89	102	114
12	144		34	50	65	73	85	97	110
12.5	150	30	32	48	63	70	82	93	106
13	156	36	31	46	60	67	79	90	101
13.5	162		29	44	58	65	76	87	98
14	168		28	43	56	62	73	83	94
14.5	174		26	41	54	60	70	80	91
15	180	36	25	40	52	58	68	78	88
15.5	186	42	24	39	50	56	66	75	85
16	192		23	37	49	54	64	73	82
16.5	198			36	47	53	62	71	80
17	204			35	45	51	60	68	77
17.5	210	42		34	43	49	57	65	74
18	216	48		33	42	47	55	63	71
18.5	222				40	45	52	60	68
19	228				38	43	50	58	65
19.5	234				37	41	48	55	62
20	240	48			35	40	47	53	60
20.5	246	54				38	45	51	57
21	252					36	43	49	56
21.5	258					35	41	47	53
22	264	54					39	45	51
22.5	270	60					38	43	49
23	276						36	41	46
23.5	282							40	45
24	288							38	43
24.5	294							36	41
25	300							35	39
25.5	306								37
26	312	60							35

Table 19. H 20 Live Load[b]—Arches

Arch Span, ft	Minimum Cover, in.	Maximum Cover, ft — Specified Thickness, in. 0.109	0.138	0.168	0.188	0.218	0.249	0.280
5	12	61	90	117	131	153	175	198
6		51	76	98	109	128	146	165
7		44	64	84	94	110	125	141
8	12	38	56	73	82	96	110	123
9	24	34	50	65	73	85	97	110
10		30	45	59	66	77	88	99
11		28	40	53	60	70	80	90
12		26	37	49	55	64	73	82
13		23	34	45	51	59	68	76
14		22	32	42	47	55	63	71
15		20	30	39	44	51	58	66
16	24	19	28	37	41	48	55	62
17	36	18	27	34	39	45	52	58
18		17	26	32	35	41	47	54
19			25	29	33	38	44	49
20			25	27	30	35	40	45
21				24	28	32	37	42
22				23	25	30	34	39
23					23	27	31	35
24	36				21	25	29	33
25	48					23	26	30
26	48					21	24	27

For arches with rise/span ratio ≥ 0.50, use round pipe tables or 1.33 × these values. Values shown also apply to HS 20 and HS 25 loadings.

[b]Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. ...

Table 20. E 80 Live Load[b]—Arches

Arch Span, ft	Minimum Cover, in.	Maximum Cover, ft — Specified Thickness, in. 0.109	0.138	0.168	0.188	0.218	0.249	0.280
5	24	61	90	117	131	153	175	198
6		51	76	98	109	128	146	165
7		44	64	84	94	110	125	141
8		38	56	73	82	96	110	123
9		34	50	65	73	85	97	110
10	24	30	45	59	66	77	88	99
11	36	28	40	53	60	70	80	90
12		26	37	49	55	64	73	82
13		23	34	45	51	59	68	76
14		22	32	42	47	55	63	71
15	36	20	30	39	44	51	58	66
16	48	19	28	37	41	48	55	62
17		18	27	34	39	45	52	58
18		17	26	32	35	41	47	54
19			25	28	33	38	44	49
20	48		25	25	30	35	40	45
21	60			23	26	32	37	42
22				20	23	30	34	39
23					21	26	31	35
24					18	23	28	33
25						20	25	30
26	60					18	22	26

For arches with rise/span ratio ≥ 0.50, use round pipe tables or 1.33 × these values.

[b]Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. 20036, 3rd Edition, 1983, pp. 138-139.

Table 21. H 20 Live Load, 6" × 2" Corrugations*

Span, ft-in.	Rise, ft-in.	Minimum Specified Thickness Required, in.	Minimum Cover in.	Maximum Height-of-Fill Over Pipe-Arch for the Following Corner Bearing Pressure, tons/ft²		
				2 Tons	3 Tons	4 Tons
6-1	4-7	0.109	12	19	28	38
6-4	4-9			18	27	36
6-9	4-11			17	26	34
7-0	5-1			16	25	33
7-3	5-3			16	24	32
7-8	5-5			15	23	30
7-11	5-7		12	14	22	29
8-2	5-9		18	14	22	28
8-7	5-11			13	21	27
8-10	6-1			13	20	26
9-4	6-3			12	18	25
9-6	6-5			12	18	24
9-9	6-7			10	17	24
10-3	6-9			9	16	22
10-8	6-11			9	16	21
10-11	7-1			9	16	21
11-5	7-3			8	15	20
11-7	7-5			7	15	20
11-10	7-7		18	7	14	19
12-4	7-9		24	6	12	19
12-6	7-11			6	12	18
12-8	8-1			6	11	18
12-10	8-4		24	6	11	18
13-3	9-4	0.109	30	15	22	30
13-6	9-6			14	22	29
14-0	9-8			12	21	28
14-2	9-10			12	21	28
14-5	10-0			11	20	28
14-11	10-2			11	20	27
15-4	10-4			11	19	26
15-7	10-6			11	19	25
15-10	10-8			10	19	25
16-3	10-10			10	18	24
16-6	11-0			10	18	24
17-0	11-2			10	17	23
17-2	11-4			10	17	23
17-5	11-6			9	17	22
17-11	11-8			9	16	22
18-1	11-10			9	16	22
18-7	12-0			9	16	21
18-9	12-2			9	16	21
19-3	12-4	0.109		8	15	20
19-6	12-6	0.138		8	15	20
19-8	12-8	0.138		7	15	20
19-11	12-10	0.138	30	7	15	20
20-5	13-0	0.138	36	7	14	19
20-7	13-2	0.138	36	6	14	19

Note: Values shown also apply to HS 20 and HS 25 loadings.

*Handbook of Steel Drainage and Highway Construction Products
American Iron and Steel Institute, 1000 16th Street, N.W.,
Washington, D.C. 20036, 3rd Edition, 1983, pp. 132-133

Height-of-Cover Limits

for Armco MULTI-PLATE Underpasses

Table 22. H 20 Live Load, 6" × 2" Corrugations[7]

Size		R, Corner Radius, in.	Minimum Specified Thickness Required, in.	Minimum Cover, in.	Maximum Height-of-Fill Over Pipe-Arch for the Following Corner Bearing Pressures in Tons per ft²		
Span, ft-in.	Rise, ft-in.				2 Tons	3 Tons	4 Tons
12-2	11-0	38	0.109	24	20	30	33
12-11	11-2	38			19	28	31
13-2	11-10	38			18	28	30
13-10	12-2	38			17	26	30
14-1	12-10	38			17	26	29
14-6	13-5	38			17	25	28
14-10	14-0	38			16	24	27
15-6	14-4	38			15	23	26
15-8	15-0	38	0.109	24	15	23	25
16-4	15-5	38	0.138	36	15	22	30
16-5	16-0	38			14	22	30
16-9	16-3	38			14	22	29
17-3	17-0	47	0.138		17	26	35
18-4	16-11	47	0.168		16	25	33
19-1	17-2	47	0.168		16	24	32
19-6	17-7	47	0.168		15	23	31
20-4	17-9	47	0.188	36	15	22	30

Note: Values shown also apply to HS 20 and HS 25 loadings.

[7]Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. 20036, 3rd Edition, 1983, pg. 136.

Installation

Unloading and Handling

Plates for MULTI-PLATE structures are shipped in nested packs. They are sized so that cranes, tow motors or other on-the-job construction equipment can be used to unload them. Ordinary handling care is required to keep the plates clean and damage-free.

Bolting

MULTI-PLATE Structures are shipped with all plates, bolts and nuts needed for erection. Inside one clearly marked keg of bolts are detailed erection instructions showing the order of assembly and position of each plate. Bolt containers are color-coded for different lengths.

Initially, plates should be assembled with as few bolts as possible. Three or four untightened bolts near the center of each plate, along the longitudinal and circumferential seams, are enough. This procedure gives maximum flexibility until all plates are fitted into place.

After the structure has been partially assembled, the remaining bolts can be inserted and hand-tightened. Always work from the center toward the plate corner. Do NOT insert the corner bolts until all others are in place and tightened.

Bolt hole alignment is easier when bolts are loose. Drifting with a drift pin is easier when adjacent bolts are tight.

Tighten nuts, progressively and uniformly, starting at one end of the structure only after all plates are in place. Repeat the operation to make sure all bolts are tight.

If the plates are well aligned, the torque applied with a power wrench need not be excessive. A good plate fit is far better than high torque. Bolts should not be overtightened, torqued initially to a minimum 100 ft-lbs and a maximum 300 ft-lbs.

MULTI-PLATE Arches

Generally MULTI-PLATE Arches are erected on reinforced concrete foundations. The arch rests in a groove or unbalanced channel which must be built to line and grade accurately for easy plate assembly. When the arch is set on a skew, the holes in the unbalanced channels must line up with those in the plates. Layout for channel installation is shown on special plate assembly drawings furnished with each skewed structure. For straight end structures on which headwalls are to be built, design should allow for a 2" lip at each end.

Asphalt Coating

When MULTI-PLATE requires a protective coating in addition to the galvanizing, asphalt is available for field application or for plant pre-assembled structures. This coating is a fibrated asphalt mastic sprayed on under high pressure to a 1/16" thickness which has been found more satisfactory than hot-dip coatings.

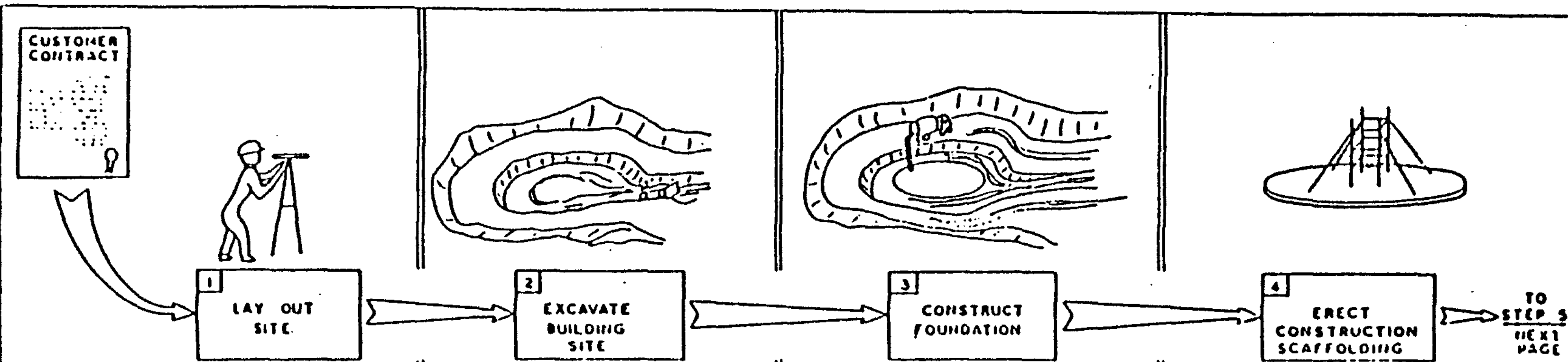
APPENDIX B*

CONSTRUCTION MANUAL
FOR
SHOTCRETE ARCH STRUCTURE

This manual is a general guide on constructing Earth Systems structures. Exact details and specifications are in plans.**

* The information contained in Appendix B: **Construction Manual for Shotcrete Arch Structure** is copyrighted; it is the sole property of EARTH SYSTEMS, INC., P.O. Box 3270, Durango, Colorado. The information is reproduced here in their format, by written permission of EARTH SYSTEMS, INC. (The manual is reproduced in part. Text and illustrations not directly relevant to splinter protection structures are not included.)

**NOTE: The manual discusses the erection of dome and extended dome structures. The splinter protective structure is the extended dome.



END RESULT

HOUSE CORRECTLY LOCATED FOR VIEW, SEWER, SOLAR, TERRAIN, DRAINAGE, ETC. CONSIDERATIONS.

END RESULT

1. EXCAVATION OF CORRECT DEPTH.
2. EXCAVATION BOTTOM LEVEL & SMOOTH.
3. ACCESS RAMPS READY.
4. TOP SOIL SAVED & STORED.
5. TRENCHES FOR FOOTERS, UNDER SLAB DUCTING, RACEWAYS, ETC. READY.

CAUTIONS

1. LEAVE 5' WORKING CLEARANCE BETWEEN FOOTER & EXCAVATION WALLS.
2. KEEP EXCAVATED DIRT BACK AWAY FROM EDGE OF EXCAVATION TO PROVIDE ACCESS FOR CEMENT TRUCKS, EQUIPMENT, DELIVERY TRUCKS, ETC.

SEE

FIG. 2-1 EXCAVATION CLEARANCES

END RESULT

FOUNDATION READY FOR DOME CONSTRUCTION.

CAUTIONS

1. BE CERTAIN THAT THE VERTEX & ANGULAR REFERENCE RODS ARE PLACED SOLIDLY IN THE GROUND SO THERE IS NO CHANCE OF MOVEMENT.
2. VERTICAL BEAM ANCHOR PLATES MUST BE LINED UP WITH WIRE STRETCHED BETWEEN VERTEX & ANGULAR REFERENCE RODS.
3. VERTICAL BEAM ANCHOR PLATES MUST BE FLUSH WITH CONCRETE SURFACE & PERFECTLY LEVEL.
4. REBAR LOCATION TUBES MUST BE AT THE CORRECT RADIUS & 12" O.C. ON CURVES & 8" O.C. ON STRAIGHT SECTIONS.
5. SET 1/2" REBAR STUBS BEFORE FOOTER/SLAB IS POURED.

SEE

FIG. 3-1 (A) & (B) DOME FOOTER CONSTRUCTION

END RESULT

SCAFFOLD READY.

CAUTIONS

1. TIE SCAFFOLD ENDS TOGETHER SO THEY DON'T POP OPEN UNDER LOAD.
2. ANCHOR SCAFFOLD BRACING WIRES SO OPPOSING VERTICAL BEAMS CAN BE ERECTED WITHOUT INTERFERENCE.

DOME TYPES TO CONSIDER

1. 24' DOME – NO SPECIAL SCAFFOLDING NEEDED.
2. LARGER DOMES WITH CENTRAL COMPRESSION RING – SEE FIG. 4-1.
3. EXTENDED DOMES WITH STRAIGHT SECTIONS & ELONGATED COMPRESSION RING – SEE FIG. 4-2.

TOP LEVEL – DOME DEVELOPMENT SEQUENCE

EXAMPLE: With the concrete poured (Step 3.7) and starting to set up, the builder will either finish the slab surface (Step 3.10) if the design has a slab floor...OR...place the foundation bolts (Step 3.11) if the design has a raised floor with a crawl space underneath or a two pour floor slab (floating slab.)

This combination of flow diagram and integrated numbering system is used for:

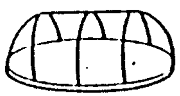
1. Estimating the schedule and resources required for each step and the total process end-to-end (i.e. manhours, the direct cost of manhours, material, equipment, power, etc., and overhead costs) for new jobs or projects.

2. Budgeting the same kinds of manhours and costs.

3. Related manhours and cost collection so that "actuals" can be compared with "planned" as a means for steadily improving both profit and the ability to better estimate and budget.

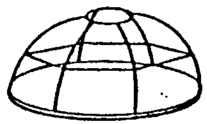
4. Delegating the responsibility, authority, budget, and schedule target dates for whole phases or individual steps.

In short, it provides a simple means for individual and organizational self-improvement.



24' DOME

OR



32' OR 40' DOME

FROM STEP 4 → **5** ERECT STEEL FRAME →

END RESULT

1 DOME FRAME ERECTED.
2 2ND FLOOR SUPPORT BEAMS IN PLACE.

CAUTIONS

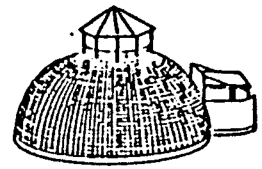
1 ALIGN COMPRESSION RING WITH REFERENCE LINES ON FLOOR BEFORE RAISING INTO POSITION.
2 INSTALL OPPOSING BEAMS FIRST TO HELP MAKE THE STRUCTURE SELF-SUPPORTING.
3. CLEAR ALL DEBRIS FROM ANCHOR PLATES, ESPECIALLY BETWEEN WELDED ANGLES, SO VERTICAL BEAMS SIT FLAT ON ANCHOR PLATES.
4. DO NOT USE MORE THAN 2 SHIMS PER 2ND FLOOR SUPPORT BEAM.

DOME TYPES TO CONSIDER

1. 24' DOME – SEE FIGS:
   - 5-2 OPPOSING BEAMS ERECTED
   - 5-3 END ATTACHMENTS
   - 5-4 SIDE ATTACHMENTS AT TOP
   - 5-5 ANCHOR PLATE ATTACHMENTS
   - 5-6 STRUCTURE ERECTED
2. LARGER DOMES WITH CENTRAL COMPRESSION RING – SEE FIGS:
   - 5-1 READY TO ERECT STEEL STRUCTURE
   - 5-7 (A)-(C) 1ST 4 OPPOSING BEAMS IN PLACE
   - 5-8 COMPRESSION RING ATTACHMENTS
   - 5-9 ANCHOR PLATE ATTACHMENTS
   - 5-10 STRUCTURE ERECTED
   - 5-12 SIDE ATTACHMENTS AT TOP
   - 5-14 2ND FLOOR SUPPORT ATTACHMENTS
   - 5-15 2ND FLOOR SUPPORT BEAMS IN PLACE
3. EXTENDED DOMES WITH STRAIGHT SECTIONS & ELONGATED COMPRESSION RING – SEE FIGS:
   - 5-1 READY TO ERECT STEEL STRUCTURE
   - 5-7 (A)-(C) 1ST 4 OPPOSING BEAMS IN PLACE
   - 5-8 COMPRESSION RING ATTACHMENTS
   - 5-9 ANCHOR PLATE ATTACHMENTS
   - 5-11 OPPOSING BEAMS IN PLACE
   - 5-12 SIDE ATTACHMENTS AT TOP
   - 5-13 STRUCTURE ERECTED
   - 5-14 2ND FLOOR SUPPORT ATTACHMENTS
   - 5-15 2ND FLOOR SUPPORT BEAMS IN PLACE

24' DOME

OR



32' OR 40' DOME

→ **6** ATTACH MESH PANEL & REBAR GRID → TO STEP 7 NEXT PAGE

END RESULT

READY FOR SHOOTING OUTSIDE CONCRETE.

CAUTIONS

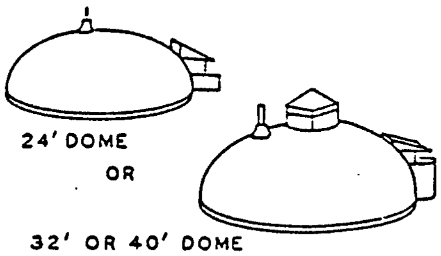
1. BEND BEAM TABS BACK OVER THEMSELVES FOR CORRECT ANCHORING OF HORIZONTAL REBAR.
2. BE CERTAIN TO TIE 6X6 SCREEN IN MESH PANEL, 1ST ROW OF HORIZONTAL REBAR, & VERTICAL REBAR ALL TOGETHER WITH EACH TIE.
3. REBAR TIE SPACING SHOULD NEVER EXCEED 12" HORIZONTALLY OR VERTICALLY.
4. MINIMUM REBAR SPACING SHOULD NEVER BE LESS THAN 6" TO ENSURE CONCRETE CAN WORK ITS WAY DOWN TO THE MESH PANELS OR POURING FORMS.
5. THE 2ND ROW OF HORIZONTAL REBAR IS PURPOSELY SPACED CLOSE IN THE 1ST 4 ROWS AT THE BASE FOR STRENGTH. IT IS THEN 24" APART FROM THIS POINT UP THE DOME.
6. BE SURE ALL SERVICES TO GO IN THE DOME WALLS ARE ROUGHED IN BEFORE THE CONCRETE IS SHOT.
7. ANY DOME PENETRATION OVER 3' HIGH & 12" DIA. IS A SPECIAL CASE & MUST BE SPECIALLY ENGINEERED.

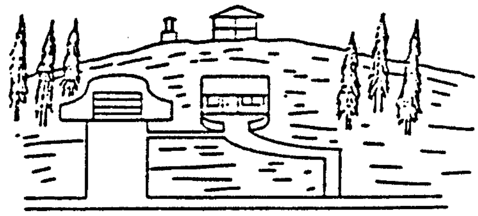
FIGURES COMMON TO ALL 3 TYPES OF DOMES

- 6-1 PANEL IDENTIFICATION
- 6-2 REBAR ATTACHMENT GENERAL DETAILS
- 6-3 ATRIUM/ENTRY TIE-IN PREPARATION
- 6-7 CATCHING 6X6 SCREEN WITH TIE WIRE
- 6-8 1ST. ROW HORIZONTAL REBAR (LAYOUT)
- 6-9 1ST ROW HORIZONTAL REBAR (PERSPECTIVE)
- 6-10 3/4" VERTICAL REBAR (LAYOUT)
- 6-11 3/4" VERTICAL REBAR (PERSPECTIVE)
- 6-14 REMAINING VERTICAL REBAR (LAYOUT)
- 6-15 REMAINING VERTICAL REBAR (PERSPECTIVE)
- 6-16 FINAL HORIZONTAL REBAR (LAYOUT)
- 6-17 FINAL HORIZONTAL REBAR (PERSPECTIVE)
- 6-18 ATRIUM/ENTRY TIE-IN
- 6-21 TOP VIEW OF VERTICAL REBAR CONNECTED OVER THE TOP
- 6-22 TOP VIEW OF 1ST LAYER TOP DIAGONALS
- 6-23 TOP VIEW OF COMPLETED
- 6-24 TOP & LOWER SURFACE PENETRATIONS

LARGER & EXTENDED DOMES

- 6-4 CUPOLA FRAMING
- 6-5 BASIC ENTRY PARAPET LAYOUT
- 6-6 SECTION VIEW FROM FIG. 6-5
- 6-12 3RD 3/4" VERTICAL
- 6-13 HORIZONTAL & VERTICAL REBAR ON PARAPET
- 6-19 STEEL AROUND ATRIUM/ENTRY
- 6-20 MAINTAINING CURVE AT TOP OF DOME





FROM STEP 6 → **7** COMPLETE DOME WORK → **8** COMPLETE SUPPORTING WORK → TURN OVER TO CUSTOMER

END RESULT

READY FOR BACKFILL, LANDSCAPING, OTHER SURFACE CONSTRUCTION, & INTERIOR DOME FINISH WORK.

CAUTIONS

1. INSPECT REBAR TIES, ROUGHED-IN SERVICES, & DOME PENETRATIONS BEFORE SHOOTING CONCRETE.
2. HAVE ALL INTERIOR DOME SUPPORTS IN PLACE BEFORE SHOOTING CONCRETE.
3. START SHOOTING CONCRETE AT BASE & WORK COMPLETELY AROUND THE DOME BEFORE MOVING UP TO THE NEXT HIGHER LEVELS.
4. BE CERTAIN THERE ARE NO GAPS OR VOIDS IN THE WATERPROOF COVERING.
5. ATTACH PROTECTIVE COVERING FOR WATERPROOFING BEFORE BACKFILLING.

SEE FIGS:

7-1 COMPRESSION RING SUPPORT
7-2 UPPER DOME SUPPORT
7-3 LOWER DOME SUPPORT
7-4 ATRIUM/ENTRY OPENING SUPPORT
7-5 SUGGESTED SCAFFOLDING

END RESULT

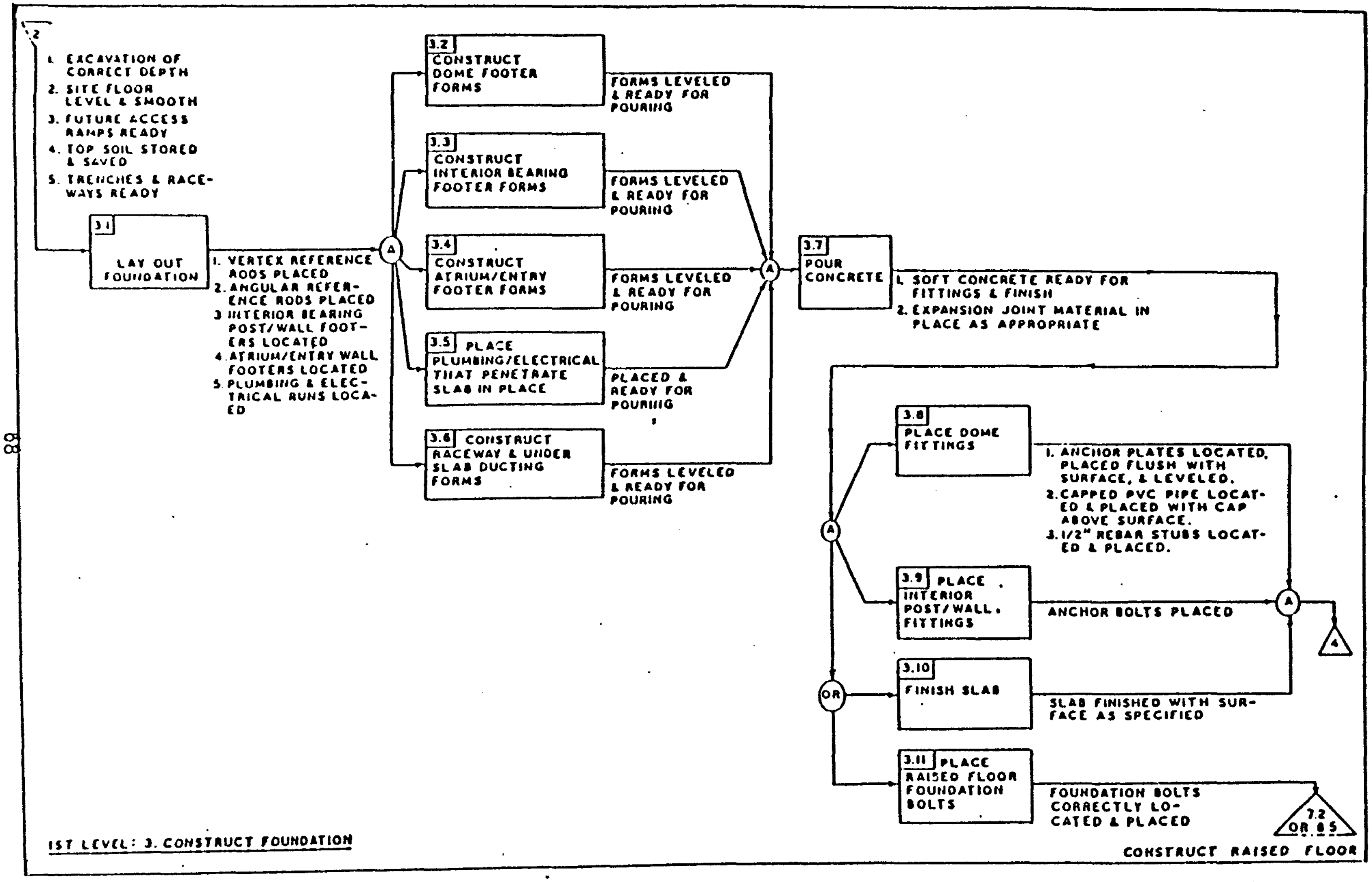
READY FOR CUSTOMER OCCUPANCY.

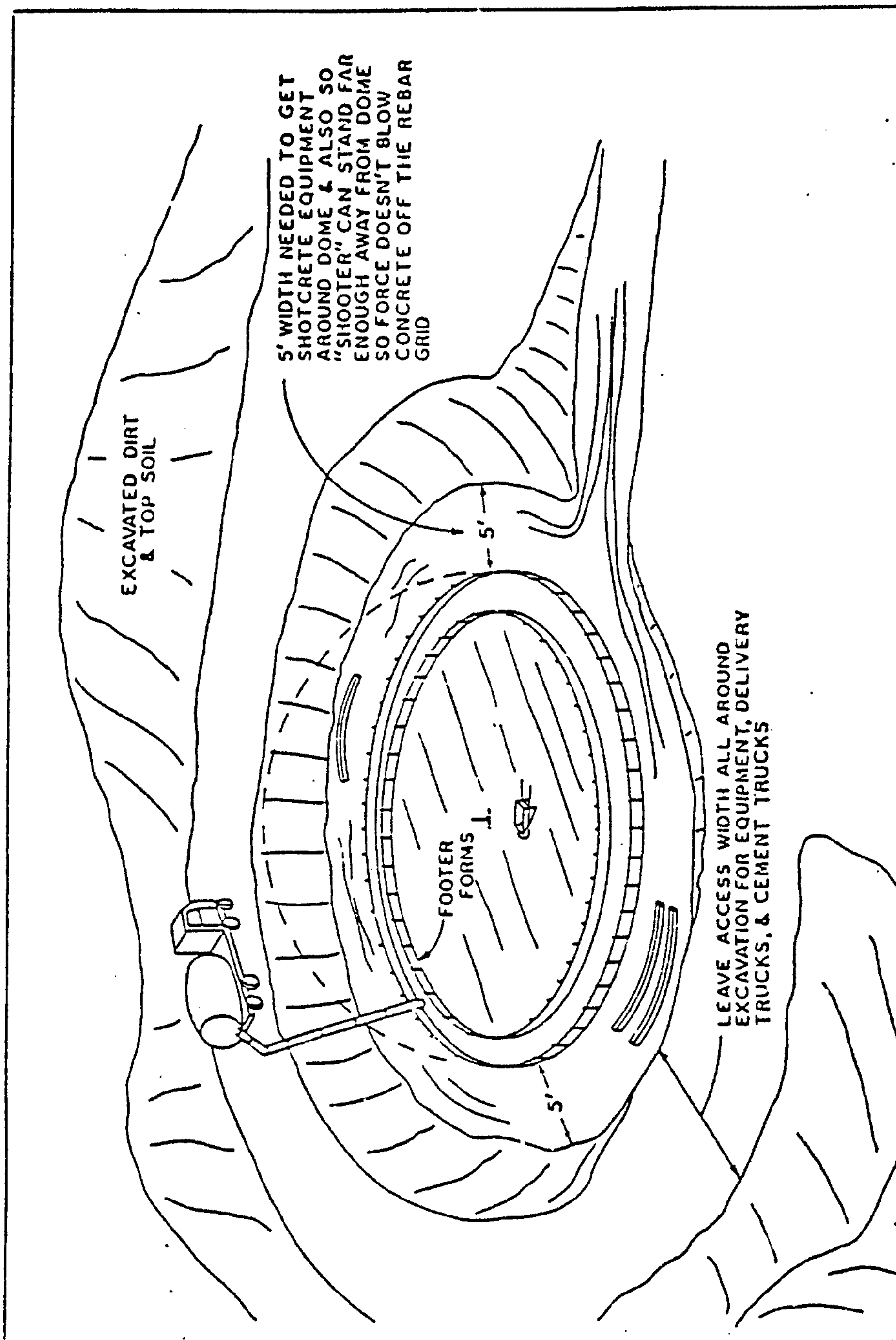
CAUTION

NO HEAVY STRUCTURES OR FOUNDATIONS ARE PERMITTED ON DISTURBED BACKFILL. DO NOT PLACE FOUNDATIONS CLOSER THAN 2' FROM THE EDGE OF UNDISTURBED VIRGIN SOIL.

SEE

FIG. 8-1 MINIMUM SETBACKS FOR GARAGES & OTHER STRUCTURES


2
1. EXCAVATION OF CORRECT DEPTH
2. SITE FLOOR LEVEL & SMOOTH
3. FUTURE ACCESS RAMPS READY
4. TOP SOIL STORED & SAVED
5. TRENCHES & RACEWAYS READY
3.1 LAY OUT FOUNDATION
1. VERTEX REFERENCE RODS PLACED
2. ANGULAR REFERENCE RODS PLACED
3 INTERIOR BEARING POST/WALL FOOTERS LOCATED
4. ATRIUM/ENTRY WALL FOOTERS LOCATED
5. PLUMBING & ELECTRICAL RUNS LOCATED
A
3.2 CONSTRUCT DOME FOOTER FORMS
FORMS LEVELED & READY FOR POURING
3.3 CONSTRUCT INTERIOR BEARING FOOTER FORMS
FORMS LEVELED & READY FOR POURING
3.4 CONSTRUCT ATRIUM/ENTRY FOOTER FORMS
FORMS LEVELED & READY FOR POURING
3.5 PLACE PLUMBING/ELECTRICAL THAT PENETRATE SLAB IN PLACE
PLACED & READY FOR POURING
3.6 CONSTRUCT RACEWAY & UNDER SLAB DUCTING FORMS
FORMS LEVELED & READY FOR POURING
A
3.7 POUR CONCRETE
1. SOFT CONCRETE READY FOR FITTINGS & FINISH
2. EXPANSION JOINT MATERIAL IN PLACE AS APPROPRIATE
A
3.8 PLACE DOME FITTINGS
1. ANCHOR PLATES LOCATED, PLACED FLUSH WITH SURFACE, & LEVELED.
2. CAPPED PVC PIPE LOCATED & PLACED WITH CAP ABOVE SURFACE.
3. 1/2" REBAR STUBS LOCATED & PLACED.
3.9 PLACE INTERIOR POST/WALL FITTINGS
ANCHOR BOLTS PLACED
A
4
OR
3.10 FINISH SLAB
SLAB FINISHED WITH SURFACE AS SPECIFIED
3.11 PLACE RAISED FLOOR FOUNDATION BOLTS
FOUNDATION BOLTS CORRECTLY LOCATED & PLACED
7.2 OR 8.5
1ST LEVEL: 3. CONSTRUCT FOUNDATION
CONSTRUCT RAISED FLOOR



EXCAVATION CLEARANCES

FIG. 2-1

CONSTRUCTION FOUNDATION

3.1 Layout foundation:

This is a KEY step in the whole construction process for two important reasons:

1. The engineered steel frame depends upon a precise angular and dimensional layout so that all parts will easily line up and fit into place during erection.

2. The line-up of the two vertex reference rods on an elongated dome will determine the orientation of the finished structure. The customer may be depending on this precise orientation for either view or solar heating reasons.

CAUTION....Be certain that the vertex and angular reference rods are placed SOLIDLY in the ground so there is no chance of movement during the layout and erection process. These are KEY reference points.

3.2 Construct Dome Footer Forms

When a monolithic slab is a part of the foundation, the footer forms on the inside of the curved footer are not needed. See Fig. 3.1

Steps 3.3-3.7 all follow standard practices and will not be commented on here.

3.8 Place Dome Fittings

As in the placement of the vertex and angular reference rods in Section 3.1, the placement of the vertical beam anchor plates, plastic rebar location tubes, and the ½ inch rebar stubs are also KEY. See Fig. 3.1 for reference.

CAUTION....If the angles on the anchor plate are not placed parallel with the reference wire, or if the anchor plate is not levelled perfectly, the vertical steel I-Beam column will either be tilted or pointing toward the center at the wrong angle. Either or both of these conditions will cause it to miss its connection point on the compression ring or center beam at the top.

CAUTION....If the rebar locator tubes are not spaced properly and installed vertically at the correct radius, the vertical rebar will not align properly.

3.8.1 Prefabricated Anchor Plates

Set anchor plate in the soft concrete so:
1. The reference wire from the vertex reference rod passes between the welded angles and lines up with the pre-set angular reference rod outside the pouring form.

2. The welded angles lie parallel to the reference wire from the vertex reference rod.

3. The surface of the anchor plate is flush with the surface of the concrete footer.

4. The surface of the anchor plate is level, both parallel and perpendicular to the reference wire from the vertex reference rod.

3.8.2 Rebar Location Tubes

1. These are 6" lengths of 3/4" I.D. PVC tube with caps placed on both ends in order to keep cement out of the tubes.

2. Submerge the capped tubes vertically in the soft concrete so the whole top cap is left exposed above the concrete.

3. Remove the exposed caps just prior to vertical rebar placement so they can be used to locate the vertical rebar.

3.8.3 1/2" Rebar Stubs

These are 1/2" rebar, three and one-half feet long, with an "L" bent on one end. They are placed in the concrete footing.

Note: These stubs should be tied to footing rebar and located prior to pouring concrete.

1. Two feet of this stub should stick up above the finished surface to serve as a stub for tying into the rebar grid.

2. They will be next to the rebar locator tubes that will hold the 3/4" rebar which will tie into the stub. See Fig. 3.1 for reference.

Three locations are used:

36° and 45° curved sections--Place these stubs next to the locator tubes at intervals of about 1/3 the distance between anchor plates.

18° curved sections--Place these stubs next to the rebar locator tubes that are midway between the anchor plates.

Straight sections--Place these stubs next to the rebar locator tubes that are midway between the anchor plates.

Check final positioning for accuracy after concrete is poured and before the concrete hardens.

PREFABRICATED ANCHOR PLATES

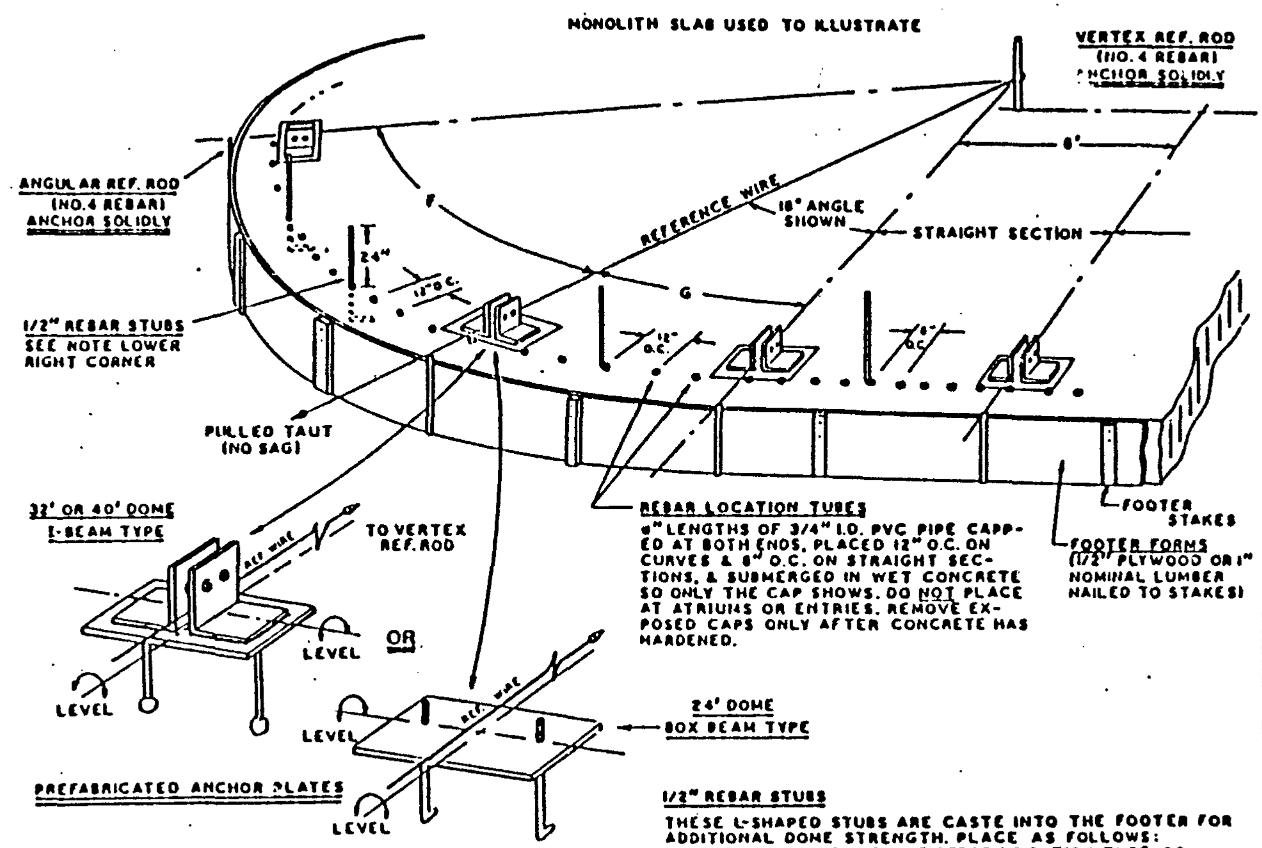
2 TYPES ARE USED.

SET ANCHOR PLATES IN SOFT CONCRETE SO:

1. REFERENCE WIRE FROM VERTEX PASSES DOWN THE CENTER (24' DOME) OR BETWEEN THE WELDED ANGLES (32' & 40' DOMES) & LINES UP WITH PRE-SET ANGULAR REFERENCE RODS OUTSIDE THE FOOTER FORM.
2. THE WELDED ANGLES LIE PARALLEL TO THE REFERENCE WIRE FROM THE VERTEX (32' & 40' DOMES).
3. THE SURFACE OF THE ANCHOR PLATE MUST BE FLUSH WITH THE CONCRETE SURFACE.
4. THE SURFACE OF THE ANCHOR PLATE IS LEVELED, BOTH PARALLEL & PERPENDICULAR TO THE REFERENCE WIRE FROM THE VERTEX. SEE SKETCHES OF EACH TO THE RIGHT.

NOTE:

ALL EARTH SYSTEMS STRUCTURES ARE DESIGNED FOR A MINIMUM SOIL BEARING CAPACITY OF 1500 PSF. BE SURE TO CHECK LOCAL SOIL CONDITIONS.



SEE FIG. 3-1(B) FOR TYPICAL FOUNDATION CROSS-SECTIONS & LAYOUT DIMENSIONS.

1/2" REBAR STUBS

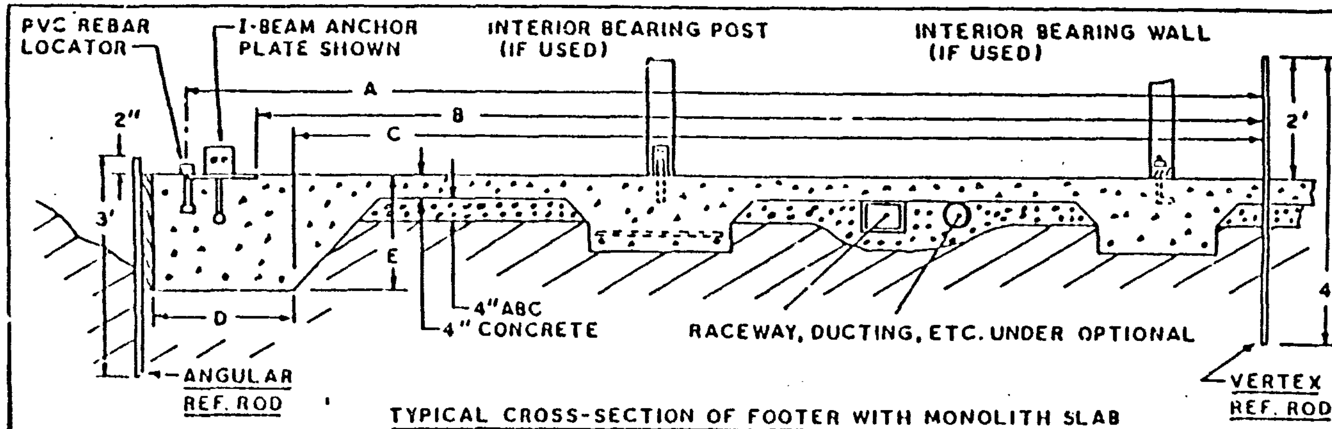
THESE L-SHAPED STUBS ARE CASTE INTO THE FOOTER FOR ADDITIONAL DOME STRENGTH. PLACE AS FOLLOWS:

1. PLACE ALONGSIDE PVC REBAR LOCATION TUBE SO THAT REBAR CAN BE TIED TO THE STUB.
2. PLACE STUBS IN THE CENTER OF STRAIGHT SECTIONS & 18° CURVES.
3. PLACE 2 STUBS ON 36° & 45° CURVES ABOUT 1/3 THE DISTANCE FROM EACH ANCHOR PLATE (I.E., ABOUT 4').

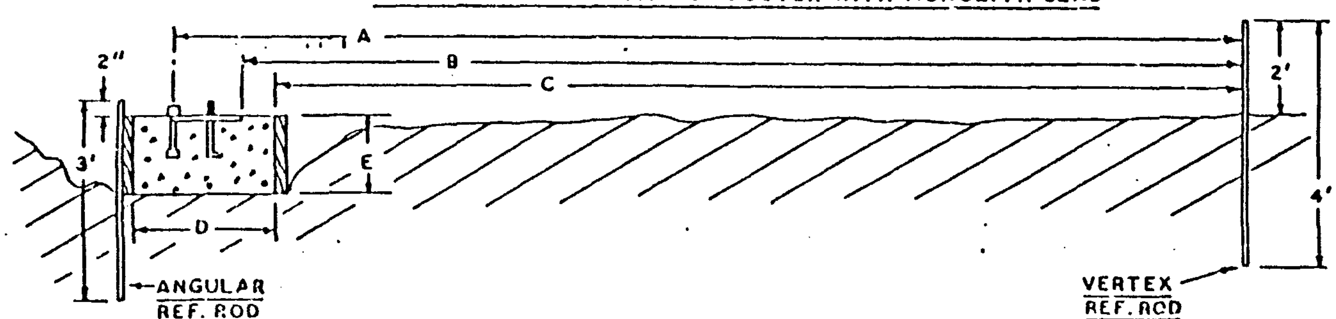
24" SHOULD BE ABOVE THE SURFACE FOR TYING.

DOME FOOTER CONSTRUCTION

FIG. 3-1(A)



TYPICAL CROSS-SECTION OF FOOTER WITH MONOLITH SLAB

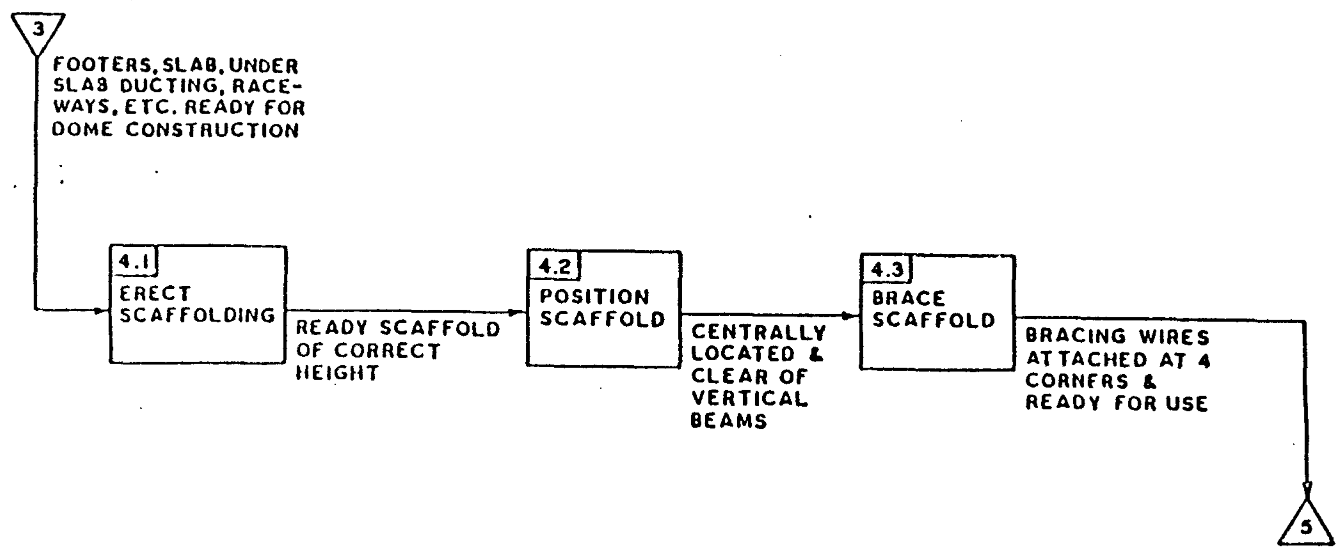


TYPICAL FOOTER CROSS-SECTION FOR RAISED FLOOR

DOME DIAMETER	FOUNDATION LAYOUT DIMENSIONS					ANGLE(°)		ANCHOR PLATE TYPE
	A	B	C	D	E	F	G	
24'	12'4"	11'11"	11'6"	24"	18"	45	NA	DOUBLE J BOLT
32'	16'5"	15'11"	15'6"	24"	18"	43	NA	WELDED ANGLE
40'	20'5"	19'11"	19'6"	36"	18"	36	18	WELDED ANGLE

DOME FOOTER CONSTRUCTION

FIG. 3-1(8)



NOTE

SCAFFOLDING IS SET UP FOR 3 DIFFERENT DOME TYPES:

1. 24' DOME WITH CENTER BEAM
2. LARGER DOMES WITH CENTRAL COMPRESSION RING
3. EXTENDED DOMES WITH STRAIGHT CENTER SECTIONS & ELONGATED CENTRAL COMPRESSION RING, WITH OR WITHOUT A DOME AT BOTH ENDS

1ST LEVEL: 4. ERECT CONSTRUCTION SCAFFOLDING

4. Erect Construction Scaffolding

Note: Scaffolding is set up for three different types of domes:
1. 24 ft. dome with center beam at top.

2. Larger domes with central compression ring.

3. Extended domes with straight sections and elongated central compression ring.

Each case will be discussed separately where differences are significant.

4.1 Erect Scaffolding

The scaffolding must be strong enough to support the combined weight of a miniumum of two grown men, the central beam or compression ring (regular or elongated), platform material, all attachment hardware, and any tools needed for the job. A 5' X 7' scaffold is recommended.

CAUTION....The built-in diagonal bracing of commonly used scaffolding has not proven totally adequate when platform personnel are bearing down to lift the heavier compression rings. The tops tend to spread open under these loads and can be dangerous. To counter this, hold the scaffold ends together, as in Detail A of Figs. 4.1 and 4.2, by securing the cross pieces with straps, wire, chain, or rope.

To top of the scaffold should be approximately 4 feet above the final height of the central beam or compression rings so the beams or rings can be lifted up and into position under the bracing wires without interference.

4.2 Position Scaffolding

In general terms, the scaffolding should be positioned so it is clear of all frame elements that are to be erected and attached, and also so that the anchor plates used to anchor scaffold bracing wires are selected to insure there will be anchor plates left over so that opposing vertical beams can be erected on each side of the central top beam or compression ring. These opposing beams are needed to make the first part of the erected structure self-supporting.

4.2.1 24 Ft. Dome

Since the top center beam is only 12 ft. off the floor, no special scaffolding is needed. It is light enough to be held in place with regular equipment until the end and side attachments are made.

4.2.2 Larger Domes with Central Compression Ring

The scaffold is centered over the vertex reference rod so it will be centered inside the compression ring when it is in place (see Fig. 4.1). Position it so that the bracing wires can be attached to anchor plates as shown such that it or the wires will not be in the way of opposing vertical beams.

4.2.3 Extended Dome

In general terms, the scaffolding of Fig. 4.1 is usually adequate when there is only one straight 6 ft. section that connects to either a flat end or another dome. However, when you go beyond that, either another scaffold is needed or you erect the half-dome on one end, make it self-supporting, move the scaffold to the other end and fill in the middle steel structure.

Figure 4.2 shows scaffolding set up for an extended dome with at least three straight sections. The right end could either connect with another half-dome, a flat end, or more straight sections.

CAUTION....When anchoring the second scaffold, be sure to allow for the opposing beams as in Section 4.2.2 above.

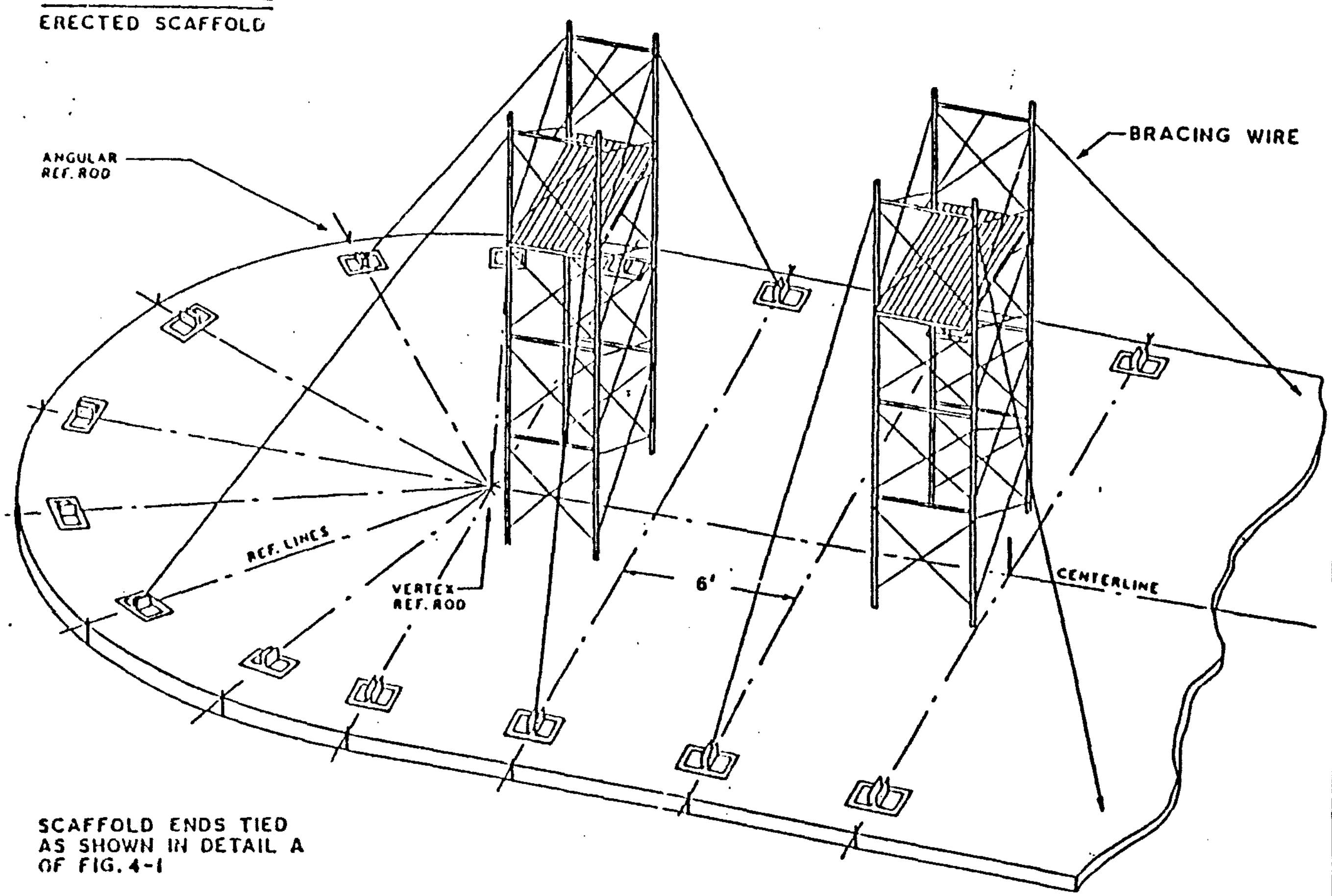
4.3 Brace Scaffold

Bracing wires are required to prevent the scaffold from tipping over as people lift and handle the top beams and compression rings.

String taut bracing wires from the uppermost corners of the scaffolding to selected anchor plates as discussed in Sections 4.2, 4.2.1, and 4.2.3.

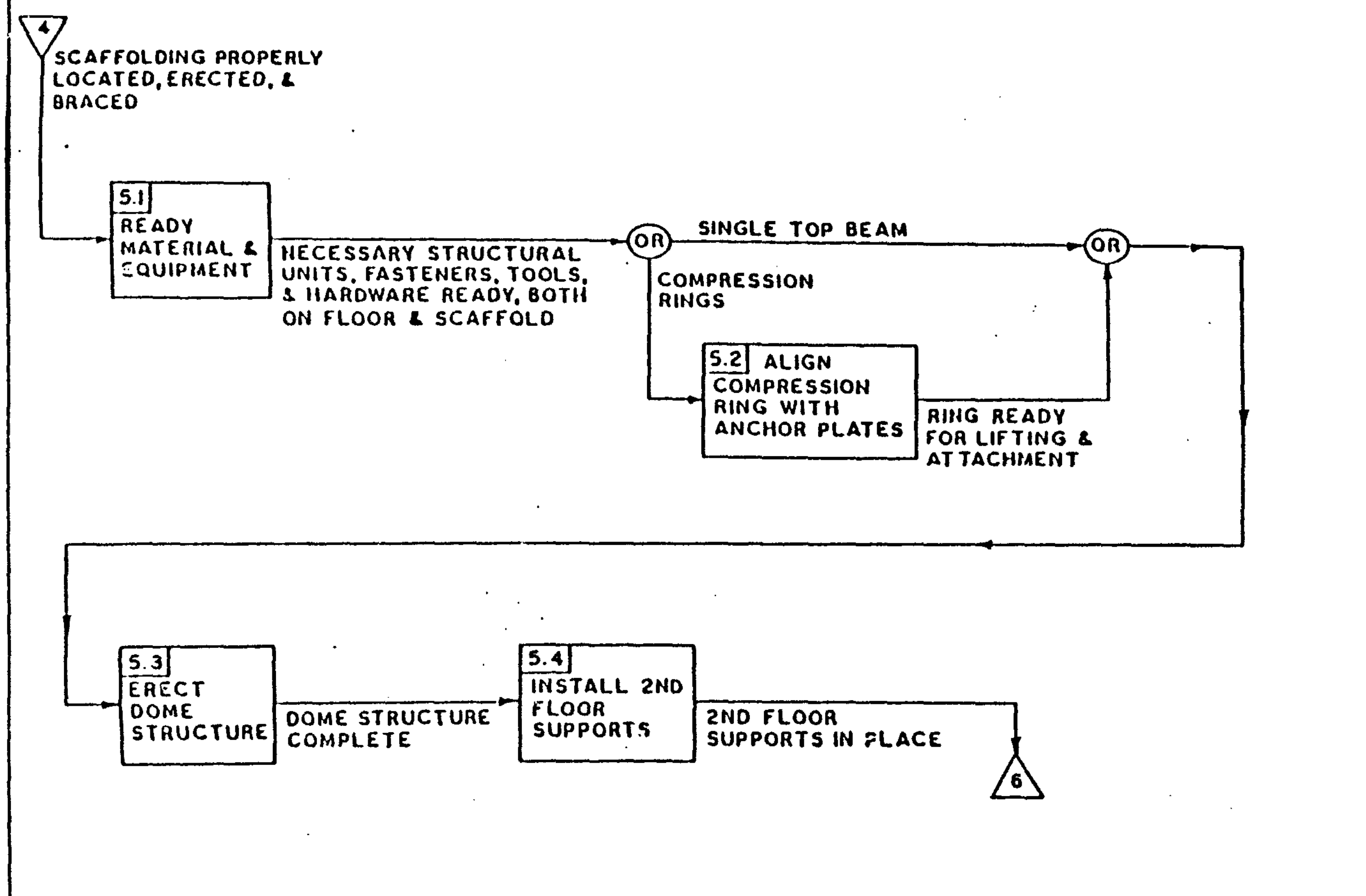
EXTENDED DOME

ERECTED SCAFFOLD



SCAFFOLD ENDS TIED AS SHOWN IN DETAIL A OF FIG. 4-1

FIG 4-2



1ST LEVEL: 5. ERECT STEEL FRAME

5. Erect Steel Frame

5.1 Ready Material and Equipment

1. Double check all equipment for safety. The steel frame members are both heavy and conducive to shorting out electrical equipment if the electrical cords are frayed or have breaks in the shielding.

2. Identify special beams (e.g. those with seats to be used adjacent to atriums) and position all vertical beams adjacent to their respective erection point.

3. Sort all hardware and fasteners and position respective sets adjacent to anchor plates and on the scaffold.

4. Identify tools needed on the floor and scaffold and position sets in both locations.

5. Bend rebar tabs out perpendicular (except for about 6 ft. from the bottom of the beam) since it is easier at this stage.

CAUTION....If the beam should slip or turn during the erection process the rebar tabs can cut or injure the ground crew. The tabs at the lower part of the beam can be bent out after the steel is erected, making handling the beams easier and safer during erection.

5.2 Align Compression Ring with Anchor Plates and Angular Reference Rods

See Fig. 5.1 for reference.

1. Snap a chalk line from the vertex reference rod through the angles on each anchor plate to the angular reference rod at the outer edge of the floor.

2. Assemble the compression ring around the scaffold and align each corner and its welded angles along the angular reference lines. This will prevent having to rotate the heavy compression ring later.

3. Connect a hoist chain on each end as shown, making sure it is connected on the same corner/angular reference line that the scaffold bracing wire is connected. This will insure that the hoisting chain won't be in the way of attaching the opposing beams.

CAUTION....Use a short enough chain so the compression ring will end up at the correct height for installation of beams when you also take into account the cable on the come-along hoist.

5.3.3 Extended Domes With Straight Center Sections and Elongated Central Compression Ring.

In this case, the compression ring could be variations of that shown in Fig. 5.11; that is, it could be the "D" shaped ring to the left of the scaffold or it could be the end "D" with the next 6 ft. section around the scaffold on the left. If it is the whole unit shown in Fig. 5.11, it would be lifted using both scaffolds. Regardless:

1. Hoist the compression ring into position.

2. Lift each vertical beam into place one at a time. Bolt the top end first and then the bottom. See Figs. 5.7 (A), (C). The same approach applies.

3. Install opposing beams on the end (e. g. Attachment A) and on opposite sides of the compression ring (Attachment C) first as shown in Fig. 5.11 in order to create a self-supporting structure.

Fig. 5.8 shows the top end attachments to the compression ring (Attachment A). Fig. 5.9 shows the bottom attachment of the vertical beam to the anchor plate (Attachment B). Fig. 5.12 shows the top attachment along the sides (Attachment C). Fig. 5.13 shows all the vertical beams in place.

Note: Open-ended structures tend to "lean" toward the open end. Be sure beams are plumb by pulling them in to a plumb position and anchoring them in place.

CAUTION....Make sure you clear all debris from the slot between the welded angles on the anchor plate so the I-Beam can sit all the way down on the anchor plate surface.

5.4 Install 2nd Floor Supports.

Once the dome structure is erected, the second floor supports are added. These serve as a ledge upon which to rest the 2 X 12 floor joists for the second floor. Use a level to keep the supports level horizontally, as well as the edges vertical, for solid seating of the floor joists.

5.4.1 24 Ft. Dome

24 ft. domes have no second floor support beams.

5.4.2 Larger Domes

Fig. 5.14 shows the attachment method for the vertical I-Beams. Reinforcement B on both sides essentially creates a box section at the bolting point on the I-Beam. Note the angular cut on the support beam end plate to assist in making the edges of the support beam vertical. Rectangular spacers (C) may be needed between reinforcement B and support beam end plate D. Fig 5.15 shows the support beams in place on a 40 ft. dome. Extended domes would be similar in appearance.

Note that 2 X 4's are attached to the support beam with self-tapping screws placed 4 ft. on center. The second floor joists sit on these and are anchored in place with toe nails or Simpson fittings. When the floor joists are cut to fit, be sure the end of the floor joist is cut to match the curve of the dome.

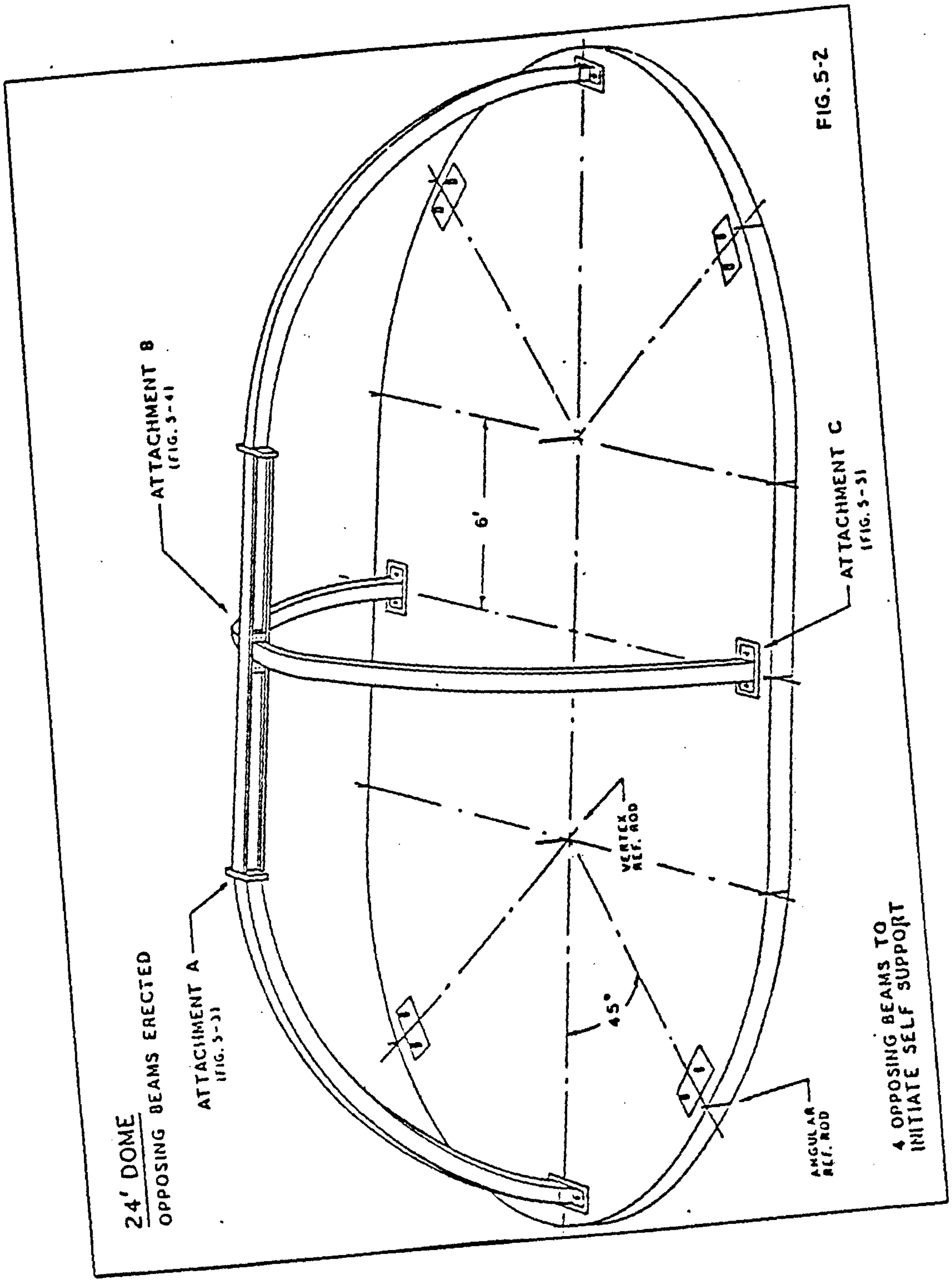

24' DOME
OPPOSING BEAMS ERECTED
ATTACHMENT A
(FIG. 5-3)
ATTACHMENT B
(FIG. 5-4)
ATTACHMENT C
(FIG. 5-5)
6'
VERTEX
REF. ROD
45°
ANGULAR
REF. ROD
4 OPPOSING BEAMS TO
INITIATE SELF SUPPORT

FIG. 5-2

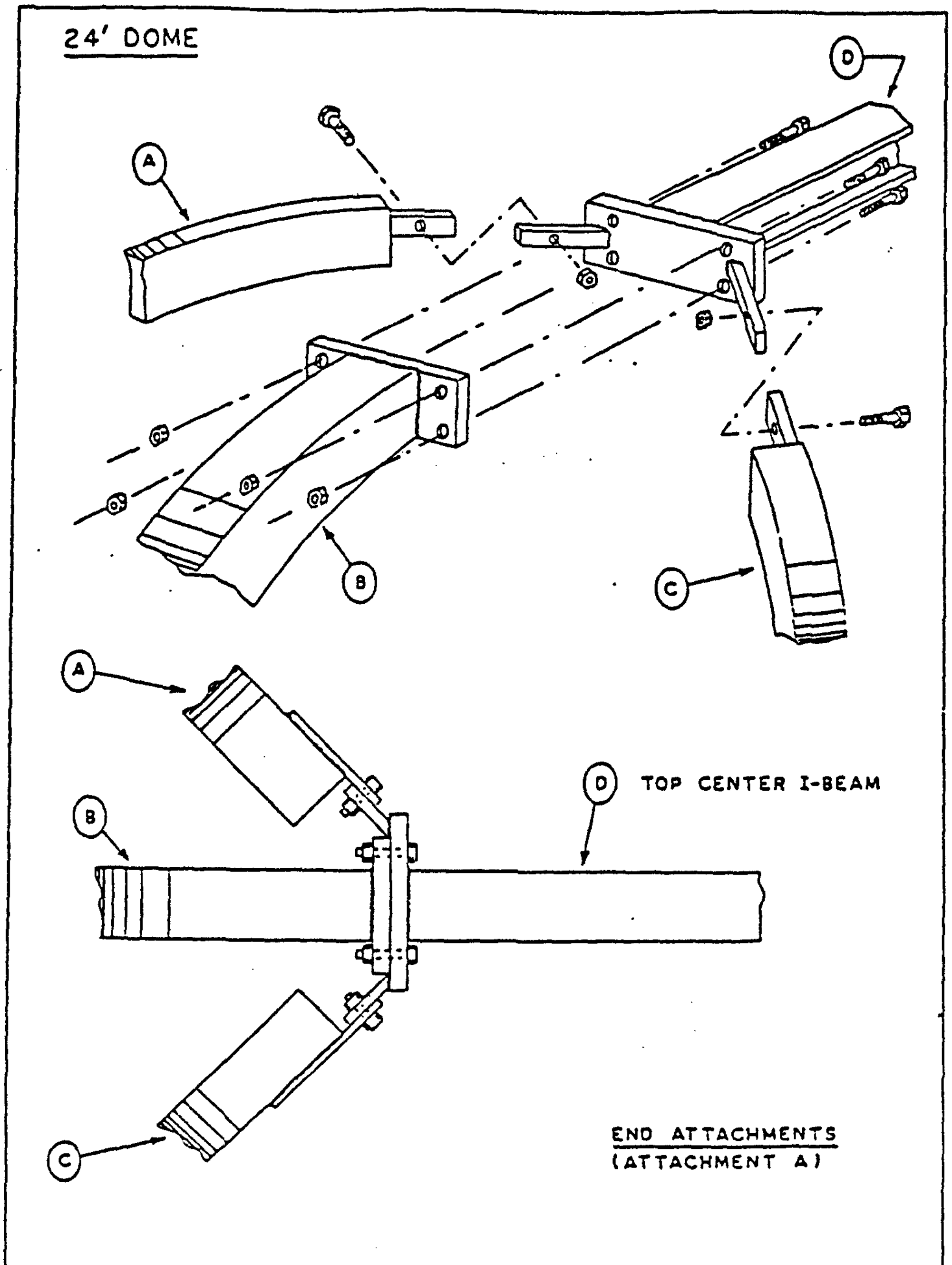
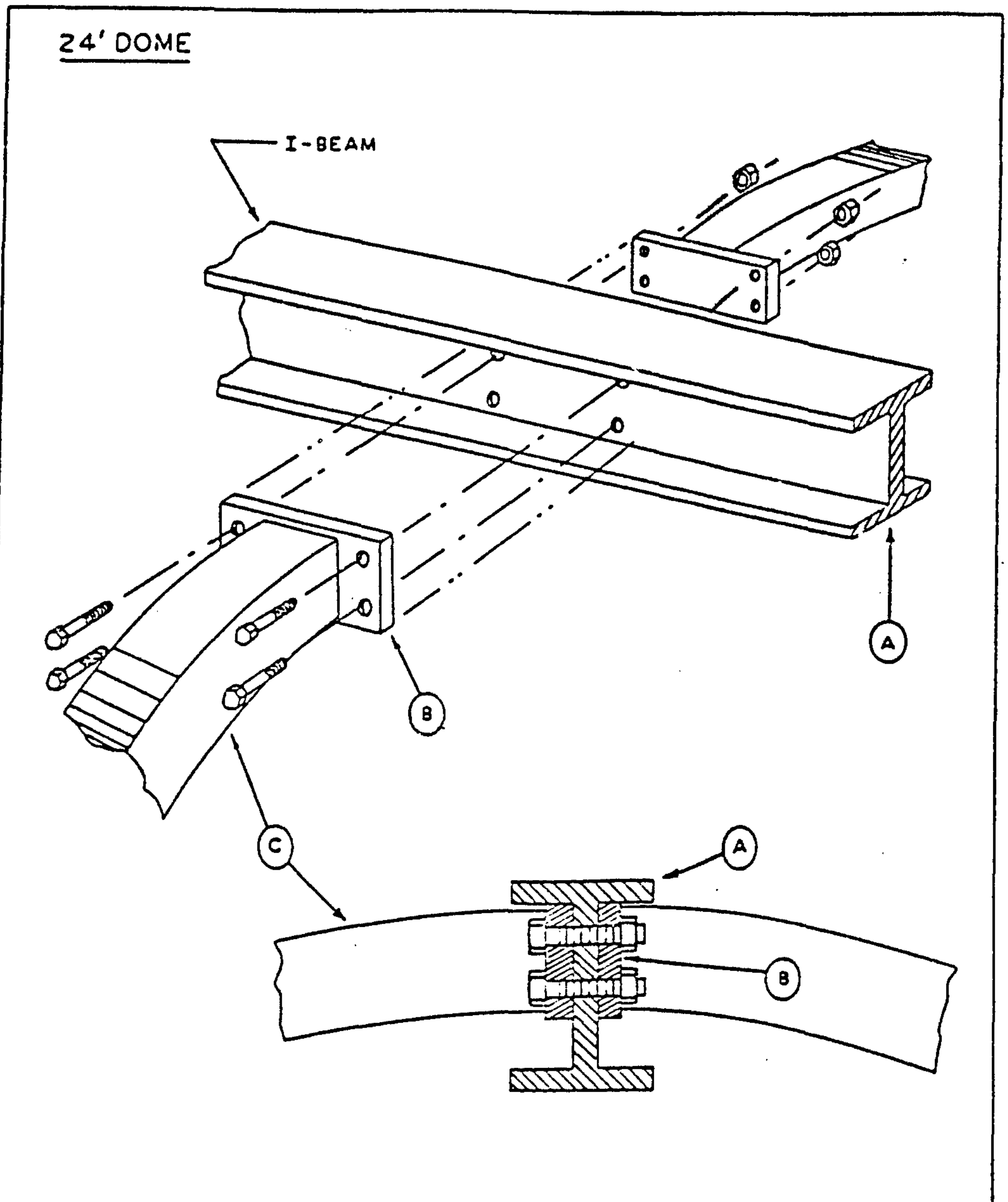
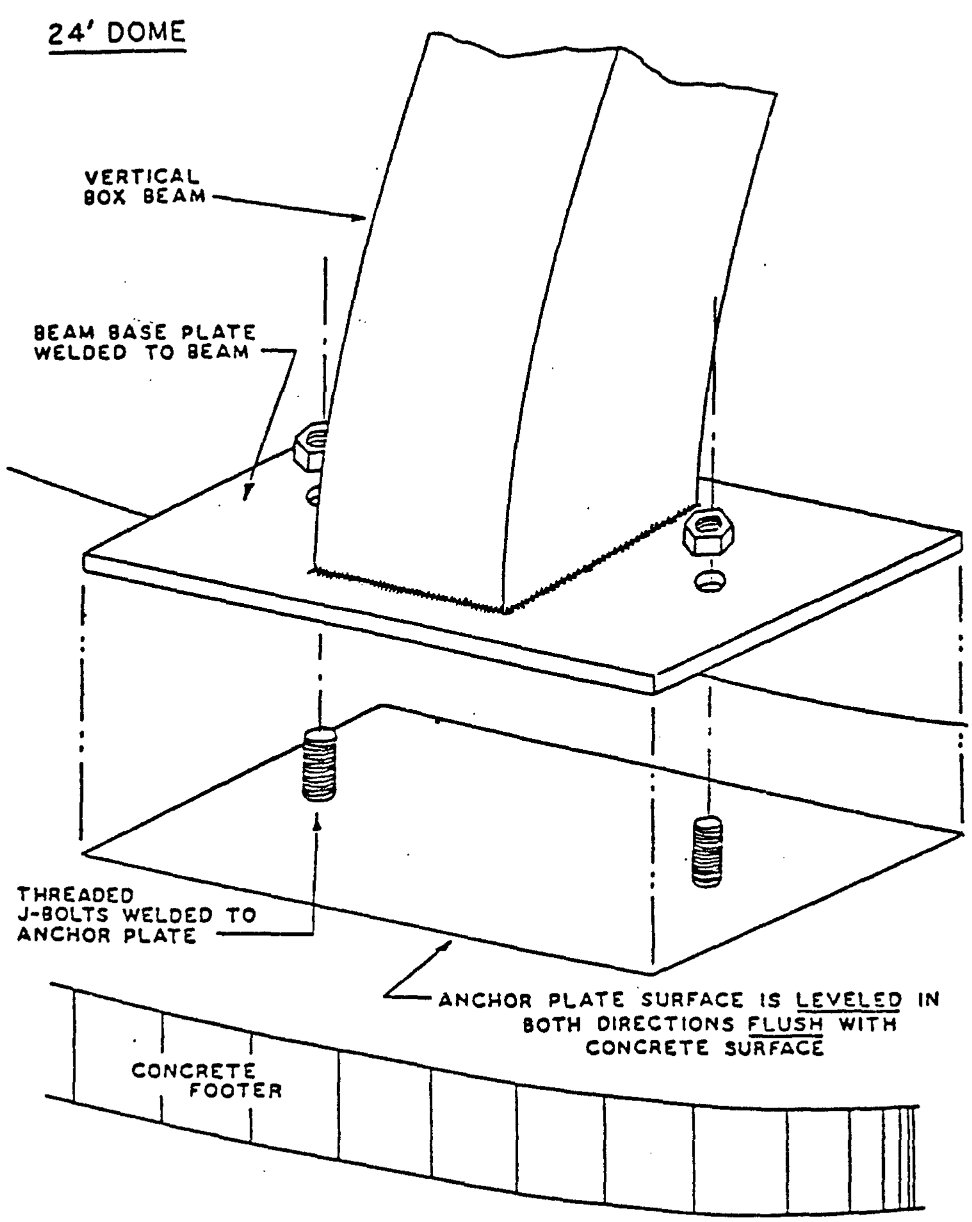

24' DOME
A
B
C
D
A
B
C
D
TOP CENTER I-BEAM
END ATTACHMENTS
(ATTACHMENT A)

FIG. 5-3



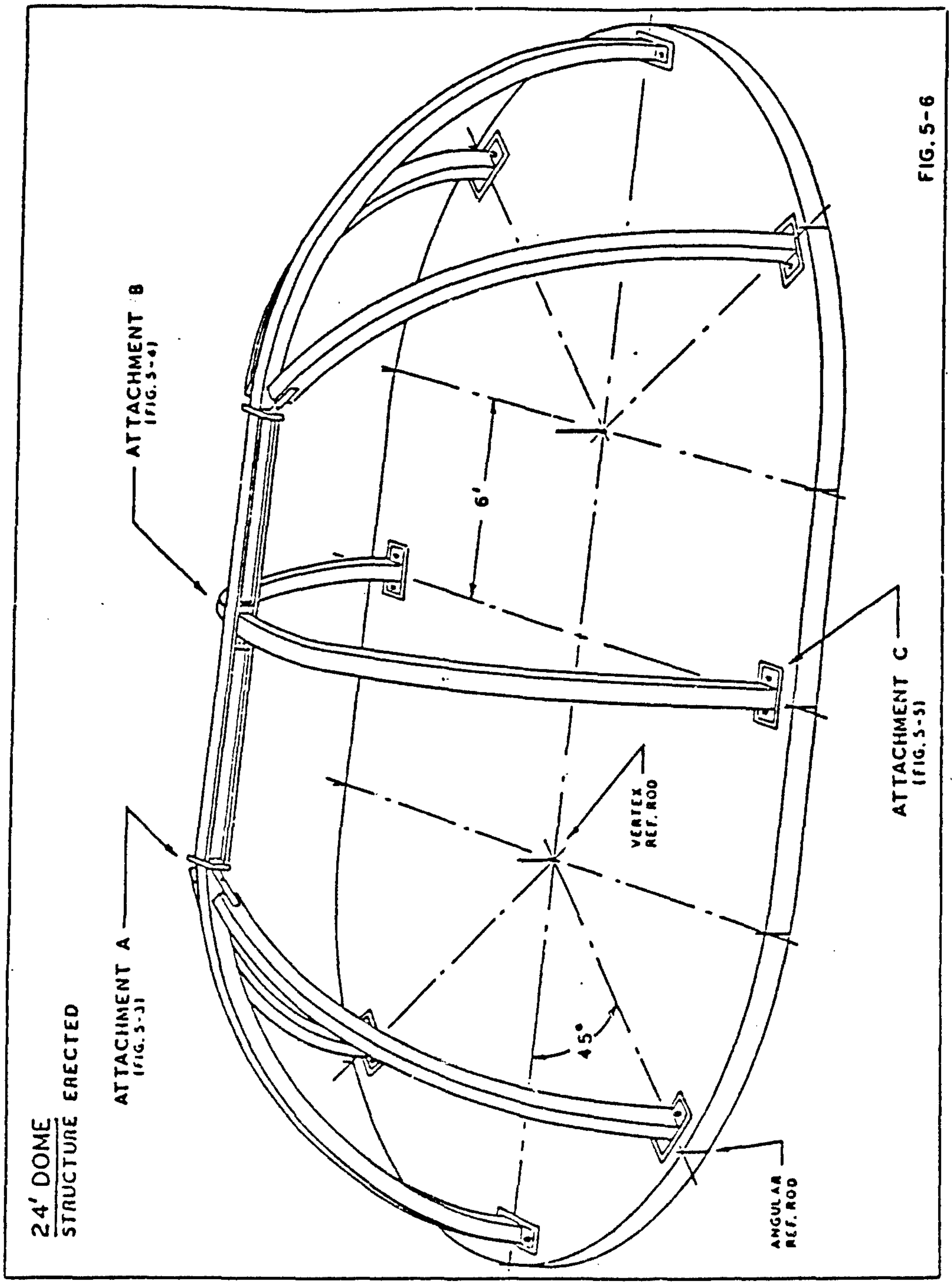
SIDE ATTACHMENTS AT TOP
(ATTACHMENT B)

FIG. 5-4

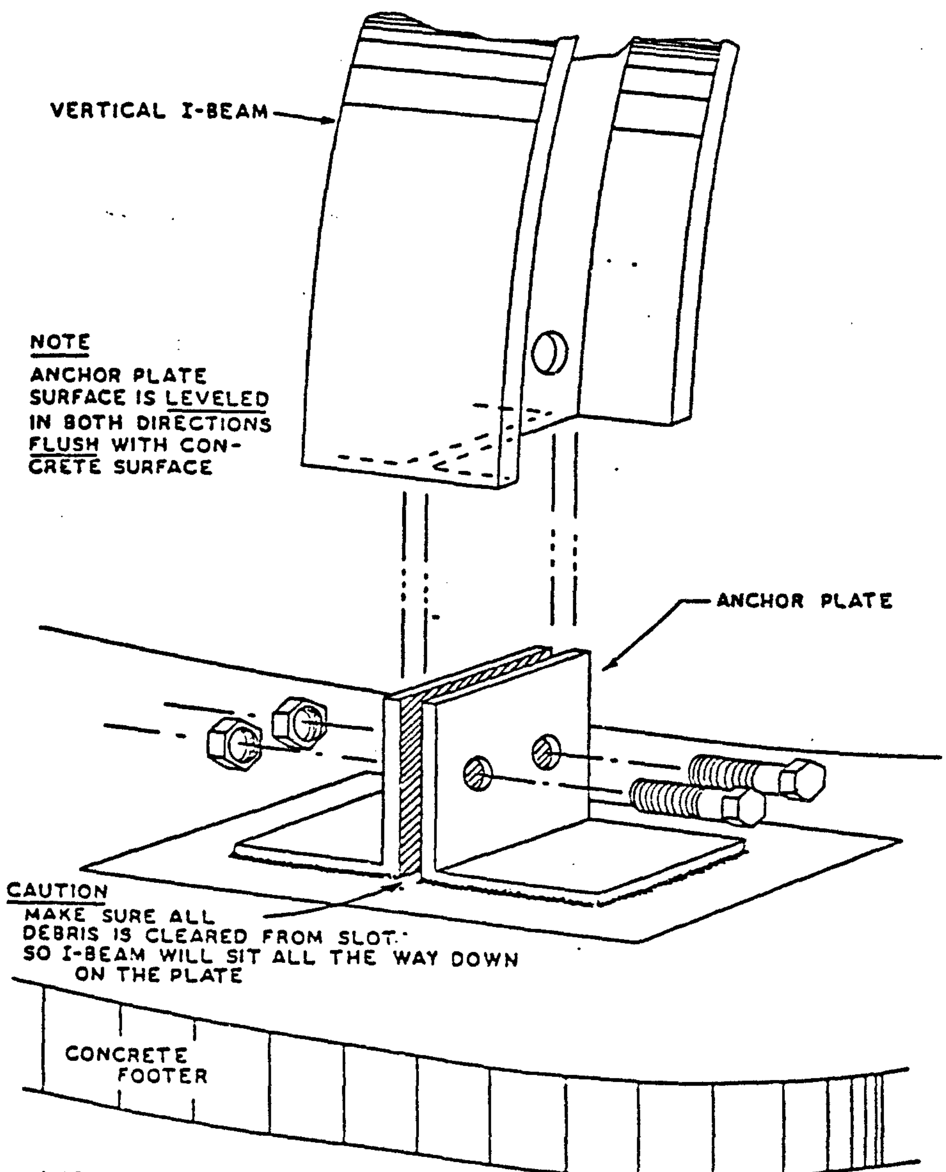


ANCHOR PLATE ATTACHMENTS
(ATTACHMENT C)

FIG. 5-5


24' DOME
STRUCTURE ERECTED
ATTACHMENT A
(FIG. 5-3)
ATTACHMENT B
(FIG. 5-4)
ATTACHMENT C
(FIG. 5-5)
6'
VERTEX
REF. ROD
45°
ANGULAR
REF. ROD
FIG. 5-6

LARGER DOMES



ANCHOR PLATE ATTACHMENTS
(ATTACHMENT B)

FIG. 5-9

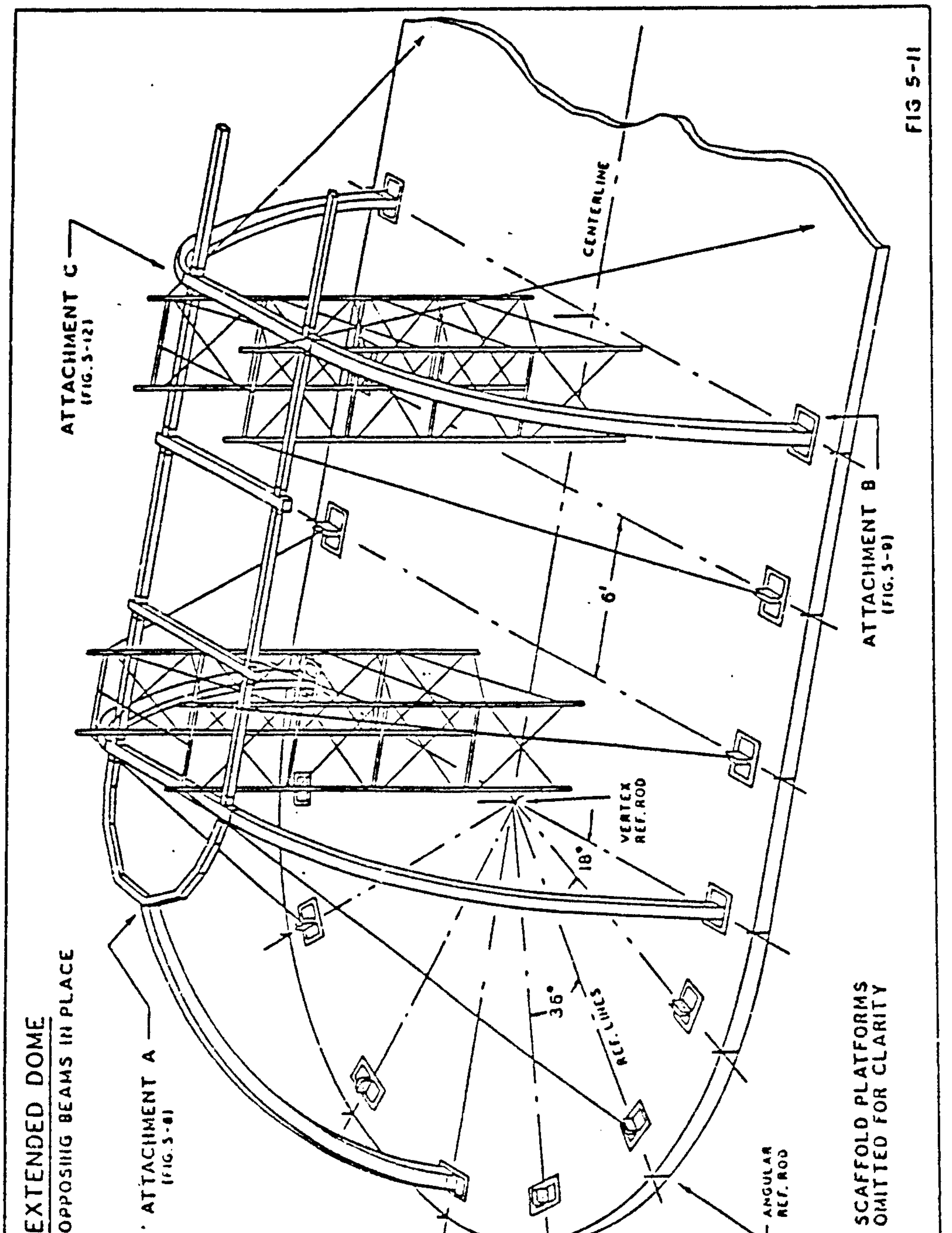
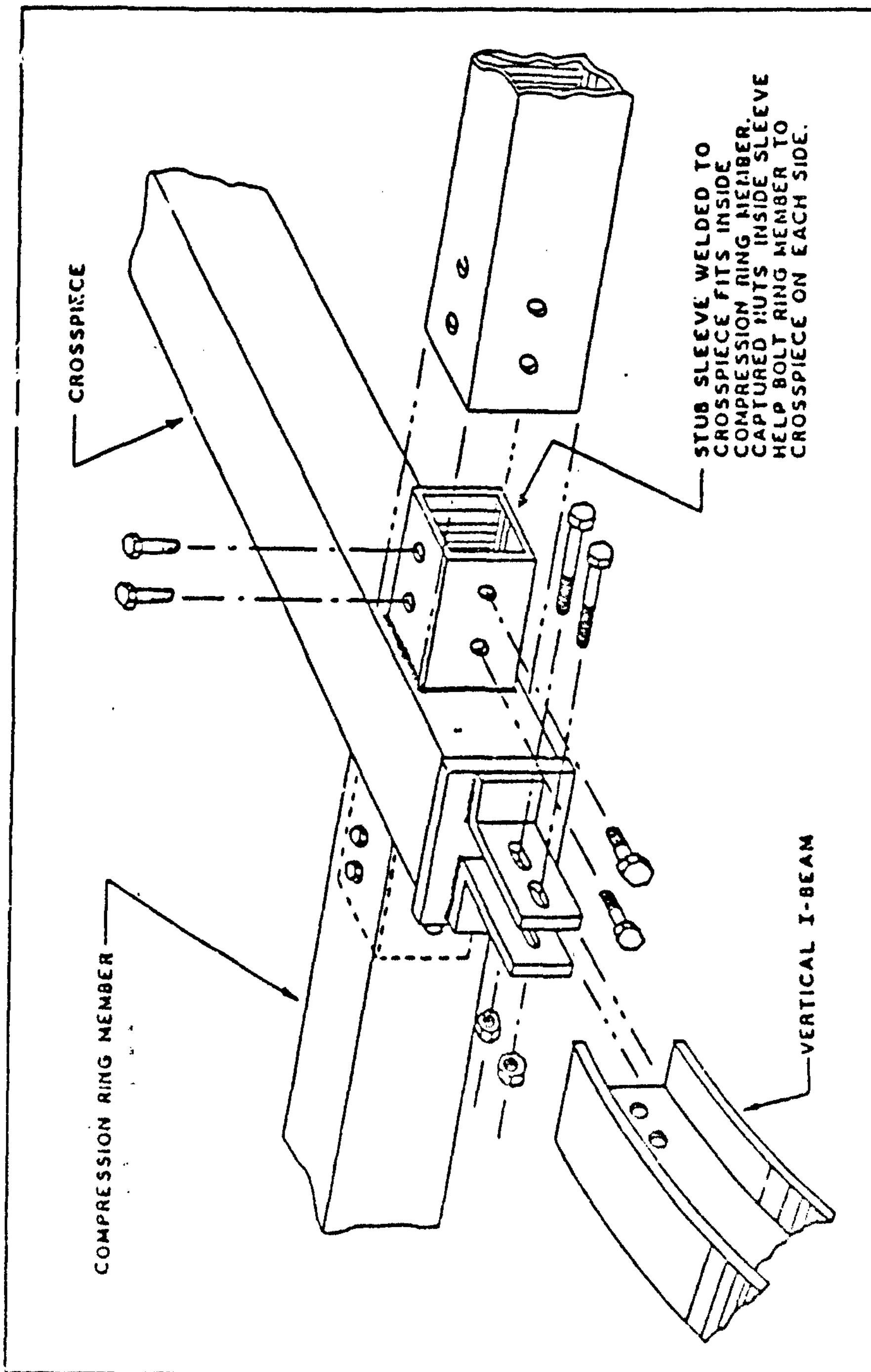

EXTENDED DOME
OPPOSING BEAMS IN PLACE
ATTACHMENT A (FIG. 5-8)
ATTACHMENT C (FIG. 5-12)
ATTACHMENT B (FIG. 5-9)
CENTERLINE
6'
VERTEX REF. ROD
18°
36°
REF. LINES
ANGULAR REF. ROD
SCAFFOLD PLATFORMS OMITTED FOR CLARITY

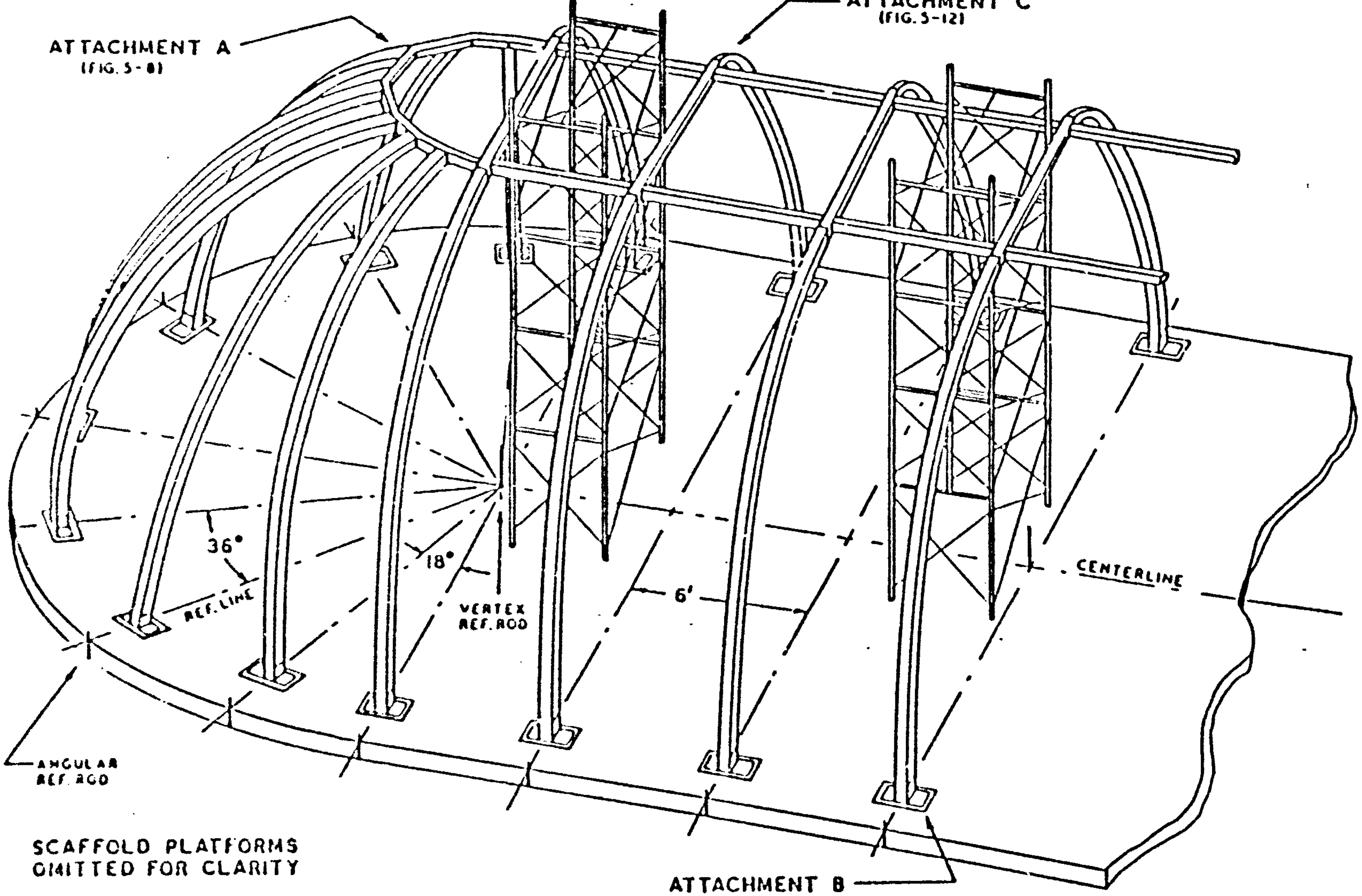
FIG 5-11



SIDE ATTACHMENTS AT TOP
(ATTACHMENT C)

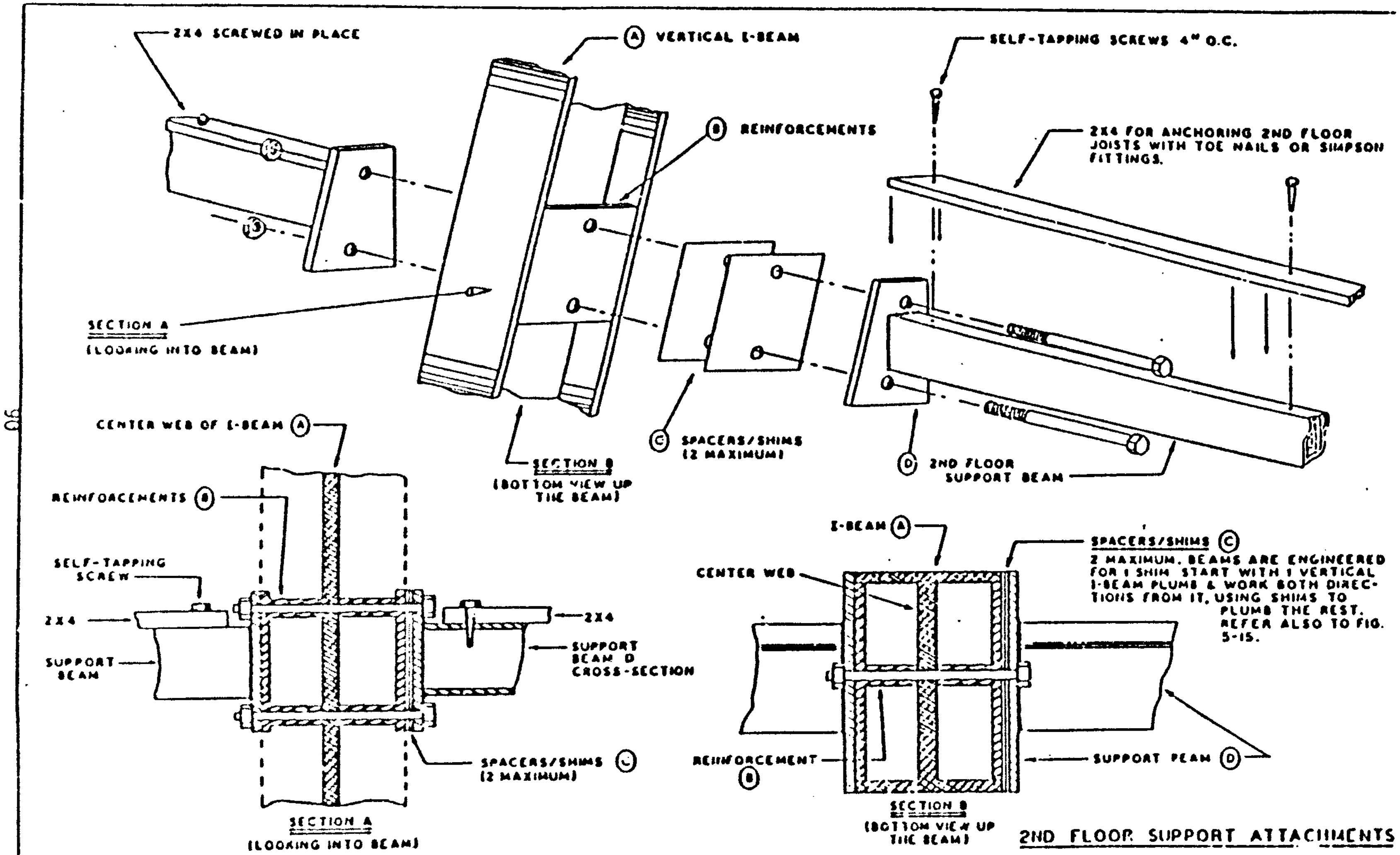
FIG 5-12

EXTENDED DOME
STRUCTURE ERECTED



SCAFFOLD PLATFORMS
OMITTED FOR CLARITY

FIG. 5-13



2ND FLOOR SUPPORT ATTACHMENTS

FIG 5-14

6. Attach Mesh Panels and Rebar Grid

The mesh panels and rebar grid not only reinforce the entire dome shell, but also tie the concrete to the shell structure. The correct placement of this steel grid insures its structural integrity, and the correct anchoring and tying of the individual grid layers also insure that the layers will not separate during the shotcrete process. You are provided a variety of sketches to assist you in this important phase.

6.1 Install Mesh Panels

The mesh panels come pre-formed to fit various size domes and both the curved and straight sections. Fig. 6.1 identifies the various panels to be used in each part of the dome structure.

The mesh panels are delivered in a roll with the panels linked together in just about the order to be used. Each panel is identified and can be cut loose when it is needed. The wrapper protecting the roll is also a good panel and should be saved in case it is needed.

Before attaching the panels, refer to the top part of Fig. 6.2. Metal tabs are welded on to each vertical beam to hold both the mesh panels and the first horizontal row of rebar. About 1/3 the distance from the top, the tabs are attached in a direction OPPOSITE to those at the bottom. This is NOT a mistake, but are purposely reversed to prevent the forces in the top rings from trying to pop them off the flatter upper surfaces of the dome.

Bend the tabs out roughly perpendicular to the beams.

Refer to X-Section 1, of Fig. 6.2 for the following steps:

1. Select the correct mesh panel for the dome section and level being constructed.

2. Start at the bottom with the mesh panel resting on the base. Work all the way around the dome before going to the next higher level.

3. Lay the panels across the beams. On the first panel, follow the curve just inside the plastic tubes to establish the shape at the bottom of the panel. Stretch the panel tight at the top. On subsequent panels the bottom edge follows the contour of the panel below and the top edge is stretched tight.

4. Impale and hang the mesh on the beam tabs by pushing it against the tabs so the tabs punch through the fabric.

5. As you work your way toward the top of the dome, be sure that the next higher panel overlaps the one below by 6 inches.

CAUTION....If you are in a windy area or have high winds temporarily, tie the panels to the beams with loops of wire that catch the 6 X 6 screen and beam.

6.2 Construct Atrium Wall

These need to be built so they are ready to be tied into the dome rebar grid BEFORE the concrete is shot. Regardless of the construction method (i.e. poured concrete or concrete block), the KEY end result needed is to have about 2 feet of 1/2" rebar sticking out from the end of the finished wall toward the dome so that these pieces of rebar can be tied into the dome's rebar grid BEFORE the concrete is shot.

See Fig 6.3 for a typical wall connection. Note that the dome's horizontal rebar is bent out toward the wall. In the case of the first row, once it is tabbed in place, the tab will help you bend the rebar outward.

Note...The length of rebar needed beyound the tab will increase as you go up the dome in order to reach the wall. See the top part of Fig. 6.3 to see why.

6.3 Construct Cupola Frame

If a cupola is part of the design, this needs to be built per the customer's drawing so the base of it can be used to attach the structural rebar grid and serve as a form for the shotcrete so the cupola is tied directly into the finished dome structure. The wood cupola frame is attached to the steel compression ring using self tapping screws as shown in Fig. 6.4.

Fig. 6.4 also shows the KEY point of providing a removable lip to help form a sloped top surface on the finished concrete. When covered with flashing during the final trim phase, this sloped lip will help shed runoff water.

6.4 Construct Partially Buried Entries

If the customer chooses to use a partially buried entry instead of using a fully exposed flat end on the dome, then three considerations need to be handled in getting ready for the rebar and shotcrete phases:

1. Attaching the entry wall to the dome is essentially the same manner as described in Section 6.2 above.

2. Constructing the earth retaining and drainage parapet walls above the entry. These details will be described in this section.

3. Selecting the type of entry wing wall to be used (i.e. vertical or a diagonal that follows the dome curve) since it holds the rebar grid for forming the side retaining walls (see the top part of Fig. 6.5).

The vertical I-Beams used on each side of the buried entry are special beams in that they have pockets attached for holding the entry roof beams (see Figs. 6.5 and 6.6). Plywood backed 2 X 4 stud walls are built using these pockets as the dome anchor points. The plywood is placed on the earth side of the frame so it will serve as the pouring form during the shotcrete process.

Note the removable lip form at the top of the parapet walls. Like the cupola in Section 6.3., this helps form a sloped top edge on the finished concrete to help it drain properly.

Note...While only the back parapet wall is shown in Fig. 6.6 to illustrate this lip, the lip should also be installed on the side parapet walls for the same reason.

Fig. 6.2 gives a cross-sectional overview of the basic rebar installation sequence. Individual stages will be covered in more detail as we walk through the sequence.

X-Section 1 of Fig. 6.2 shows the installed mesh panel which provides the backing for the exterior shotcrete. The 6 X 6 steel screen on the inside holds the interior shot surface in place.

X-Section 2 shows the "intermediate" rebar grid. Note again the comments on the way the tabs are attached to the beam.

The first horizontal row of rebar is set on the beam tabs and the tabs are bent back over themselves to lock the rebar in place against the beam. This is the PRIME anchor point for the whole rebar grid.

When the horizontal rebar is anchored flat across the surface of the beam, this will automatically start forming the required curved shape when the vertical rebar is tied to the horizontals. When anchored to the beam, these horizontal rebars will provide a "ladder" of sorts if you keep one foot on each side of the vertical beam and close to it. However, there is not much toe room at this stage.

When the verticals have been placed, the steel screen of the mesh panel, the horizontal rebar, and the vertical rebar are all wired together at EACH interesection to insure a MAXIMUM tie spacing of 12 inches, both horizontally and vertically. Ties closer that 12 inches are OK, but NEVER exceed a 12 inch spacing. This ties the "intermediate" grid together, as well as the vertical beams.

The fabric and wire panel should be tied at every junction of the first horizontal and vertical rebar. This will place the ties at 12 inches at the very bottom of the structure and about 3-4 inches at the top of where the vertical rebar converge. This is important as the wet concrete is a horizontal load at the bottom and changes to a more vertical load at the top. The closer ties at the top prevent "sagging" between the ties.

There are two basic ways to catch the interior 6 X 6 screen in the tie:
1. When working alone--there is enough stretch in the fabric that by pushing it down over the inside screen (see Fig. 6.7) you can easily poke the wire through the fabric and under the screen crosspiece to catch it in the tie.
2. Preferred way--have a helper inside who can cut the wire to an adequate length for tying all the rebar together, bend the wire into a "U", and poke the wire through the fabric so it catches the 6 X 6 screen inside and the open end of the "U" goes around EACH junction of the horizontal and vertical rebar outside. There is enough light

coming through the fabric so the helper inside can easily locate the horizontal rebar outside. The steel man on the outside then pulls the wire tight around the steel and completes the tie. The helper can be preparing the next tie wire while the steel man is making the tie.

X-Section 3 shows the final horizontal row. It is tied to each vertical rebar which locks it to the rest of the grid. As each row is tied in place, starting from the bottom, it provides a stronger "ladder" on which to work as you move up the dome. This second row also provides a lot more toe room since it is further out from the mesh panel inside.

Note...The spacing of the second horizontal row is quite different from the first:

1. The close spacing of the rebar at the bottom accomplishes two things:
   a. It provides a base structure for the concrete to build on during the shotcrete process, and
   b. These dimensions center the remaining rebar in between the rebar of the first row.

2. The 5th and remaining rows are placed 24 inches apart, instead of 12 inches as in the first horizontal row.

Taking each stage in more detail....................

Stage 1

Install the mesh panels as previously described, prior to installing the first row of rebar over them at any level.

Stage 2

Anchor the first row of 1/2" horizontal bar to the beams using the tabs. Start at the bottom and work completely around the dome before going to the next higher row. See Figs. 6.8 & 6.9.

Note...Maintain proper radius on ALL horizontal rebar--Don't allow the bar to flatten out between beams.

When the first two rows are complete, tie the 1/2" rebar stubs in place. This will help in shaping the curved surface. Work as high as you can reach from the ground as shown in Fig. 6.9. The remainder can be installed once the grid "ladder" becomes strong enough and safe enough to climb on.

Stage 3

Install two 3/4" rebar vertically in the PVC tube locators at 1/3 intervals between the end beams as shown in Figs. 6.10 and 6.11. Each rebar is twenty feet long.

Note...A 36° section of a larger dome with a cupola will be used as a typical case throughout this discussion. The basic principles and approach apply to other types and sizes of structures. The major variation is that on straight 6 ft. sections or in the 18° curved sections, only one 3/4" rebar is used and is placed about halfway between the vertical beams.

Once the 3/4" vertical rebar is in place, tie it to the 1/2" rebar stubs. The work up the dome.

At this stage, use a minimum number of ties between the horizontal rebar and these first 3/4" vertical rebar. The main thing is to generally start working things into shape. Let the vertical rebar start assuming its curved shape and spacing towards the top as the horizontals start helping pull the grid into its curved shape. Once each horizontal rebar is tied to the 3/4" verticals, it is OK to climb on the grid PROVIDED you keep one foot on each side of the 3/4" vertical. Do NOT climb in between verticals.

Stage 4

Install the horizontal 1/2" rebar around the cupola frame as shown in Fig. 6.12. Use 16 penny nails driven into the studs and bent over to hold the rebar.

The top rebar should not be more than 3 inches below the forming lip, and not spaced more than 12 inches apart vertically. Also install the three extra pieces shown in Section A of Fig. 6.12 in the intersection of the cupola frame and vertical beam.

Stage 5

Install the horizontal 1/2" rebar around the parapet walls as shown in Fig 6.13. Use 16 penny nails driven into the studs and bent over to hold the rebar.

As with the cupola, the top rebar should not be more than three inches below the forming lip, and should not be spaced more than 12 inches apart vertically. Also install the two extra pieces at the intersection of the walls, beams, and domes.

Stage 6

On 40 ft. domes where the 20-ft. lengths of 3/4" rebar won't reach the cupola, install a third 3/4" piece of rebar FROM the cupola DOWNWARD:

1. In between the first two pieces on the curved ends as shown in Fig. 6.12, and

2. Alongside the single pieces in the straight sections and in the 18° curves.

On 32 ft. domes, the 20 ft. rebar will reach to the cupola so the third pieces are not needed.

Stage 7

See Figs. 6.14 and 6.15 for reference.

The remaining verticals are 20 or 30 ft. lengths of 1/2" rebar. 30 ft. lengths are preferred because they reach the cupola on 40 ft. domes and tie at the top on domes without a cupola.

Locate each one using the PVC tube locators in the base and run vertically up to the cupola. Also splice in the pieces around the parapet walls as shown in Fig. 6.13.

Tie each vertical as shown in X-Section 2 of Figs. 6.12 and 6.15 so it locks the vertical, first horizontal and the inside screen of the mesh panel all together. The MAXIMUM spacing for ties, both horizontal and vertical, is 12 inches. DO NOT EXCEED 12 INCH SPACING.

As the verticals naturally come together toward the top, the spacing will be less than 12 inches (more like 3-4 inches or less), so some of these can be cut out so the remaining pieces that run up to the cupola frame for tying will not be more than 12 inches apart.

If the dome is to be built without a cupola, look ahead to the Stage 11 discussion to see how the end verticals are to be used before any are cut out.

Stage 8

See Figs. 6.16 and 6.17 for reference.

The second horizontal row also uses 1/2" rebar. As with the first row, start at the bottom and work completely around the dome before moving up to the next higher row. As each row is tied in place, it becomes a solid "ladder" to climb on to work on the higher rows. Each of these horizontal rows is tied to the verticals as shown in X-Section 3 of Fig. 6.2 and also Fig. 6.16.

Note...As discussed before, the spacing on this second row of horizontal rebar is quite different from the first row, and for this reason, important to note.

Whereas the first row was uniformly spaced 12" apart vertically (as shown to the left of Fig. 6.16), this second row is spaced closer together at the bottom and then further apart once you get above the first eighteen inches from the base (as shown to the right of Fig. 6.16).

The first four rows are spaced close together as the concrete has to have something to build on and serve as a base as you move up the dome in the shotcrete process. This close spacing also sets up the pattern so the rest of the horizontal rebar falls in between the rebar of the first row, but every two feet as shown.

Once the first four base rows are installed, the remaining rows are spaced 24 inches apart vertically as shown in Fig. 6.16. As a result, there are fewer rows of rebar in this second horizontal layer.

Stage 9

See Figs. 6.3 and 6.18 for reference.

Fig. 6.3 shows the preparation for tying the atrium wall into the dome structure. This approach is also used to tie in the entry wing walls (below the parapet) shown in Fig. 6.5. Leaving 24 inches of rebar sticking out of the atrium wall provides enough to splice into.

Looking at the top views of Figs. 6.3 and 6.18, you can see the 2 X 4 stud backed with 3/8" plywood which doubles as part of the interior wall and pouring form. You will aslo note the 1/2" of rigid insulation placed between the stud wall and the concrete or block atrium wall. This serves as a thermal break to help minimize any heat loss from the dome out into the atrium wall, part of which will be exposed.

Stage 10

Fig. 6.19 shows the final horizontal rows tied into the parapet wall above the entry. The basic approach for tying in the side walls is shown in Fig. 6.18.

Stage 11-No Cupola at Top.

When a dome is built without a cupola, the 1/2" rebar must be brought over the top and tied in such a manner to preserve the curved top of the dome which is ESSENTIAL for full dome strength.

1. Regular Dome--On a circular dome, all the rebar will converge at the center. Because all these pieces will be too close together to work the concrete down into the grid, some of it must be cut away so the remaining grid has a tied MINIMUM spacing of 6 inches.

See Fig. 6.20 for how to use either a 2X8 or a 2X10 to help hold the top curve until the rebar is tied.

2. Extended Dome--
Step 1-The rebar on the curved end is brought up, cut and tied just as on the regular dome described above. Fig. 6.20 shows the two sized pieces of wood to hold the top curve. The 2X4's are then wedged under the vertical rebar to help hold the curve. Tack these in place, otherwise they will pop out under load.

Step 2-The 1/2" rebar along the sides are then extended over the top to form the curve over the straight section. 30-ft. rebar is preferred. See Fig. 6.21.

On the 32 ft. dome, the 30-ft. lengths will reach over the top to about the other side of the compression ring, providing an overlap on top which can be tied together.

On the 40 ft. dome, the 30-ft. lengths will not reach over the top. A third piece is therefore needed over the top and must be spliced and tied into each side piece.

If only 20-ft. lengths are available, three pieces will be needed for both the 32 ft. and 40 ft. domes, with the third piece placed over the top and spliced and tied into each side piece.

Step 3-See Fig 6.22. Run the second rebar over from e vertical beam up and over the top as shown in the figure. This is close to a 45° angle. This first piece will serve as the angle guide for the first top layer.

Tie in other pieces of 1/2" rebar placed parallel to the first piece and no more than 12 inches apart. Each piece must be long enough to run down over the sides on each end so it can be tied into the horizontal or vertical rebar below the compression ring.

Step 4- See Fig. 6.23. Go to opposite side of the curved end and run the second rebar over from the vertical beam up and over the top as shown in the figure. This rebar is also close to a 45° angle and will help weave a grid on top of which is fairly close to square. This first piece will serve as the angle guide for the second top layer.

Tie in other pieces of 1/2" rebar placed parallel to this first piece in the second layer and no more than 12 inches apart. As in the first top layer, each piece must be long enough to run down over the side on each end so it can be tied into the horizontal or vertical rebar below the compression ring.

6.6 Install Rough Services in Wall

The rough-in for all services to be included in the outside dome walls must be installed at this time BEFORE the concrete is shot. These would include things like:

1. Electrical conduit for wall and ceiling lights, plugs, fans, switches, smoke alarms, wall circuit breaker or switch panels, meters, etc.

2. Electrical conduit for telephone or intercom outlets.

3. Water pipe.

4. Vent pipe (sewer, kitchen or bath exhaust, clothes dryer, etc.)

5. Sewer and drain pipes.

6. Duct work for heating, cooling, outside air, or cold air return.

PLAN AHEAD....because once the concrete is shot, it is too late.

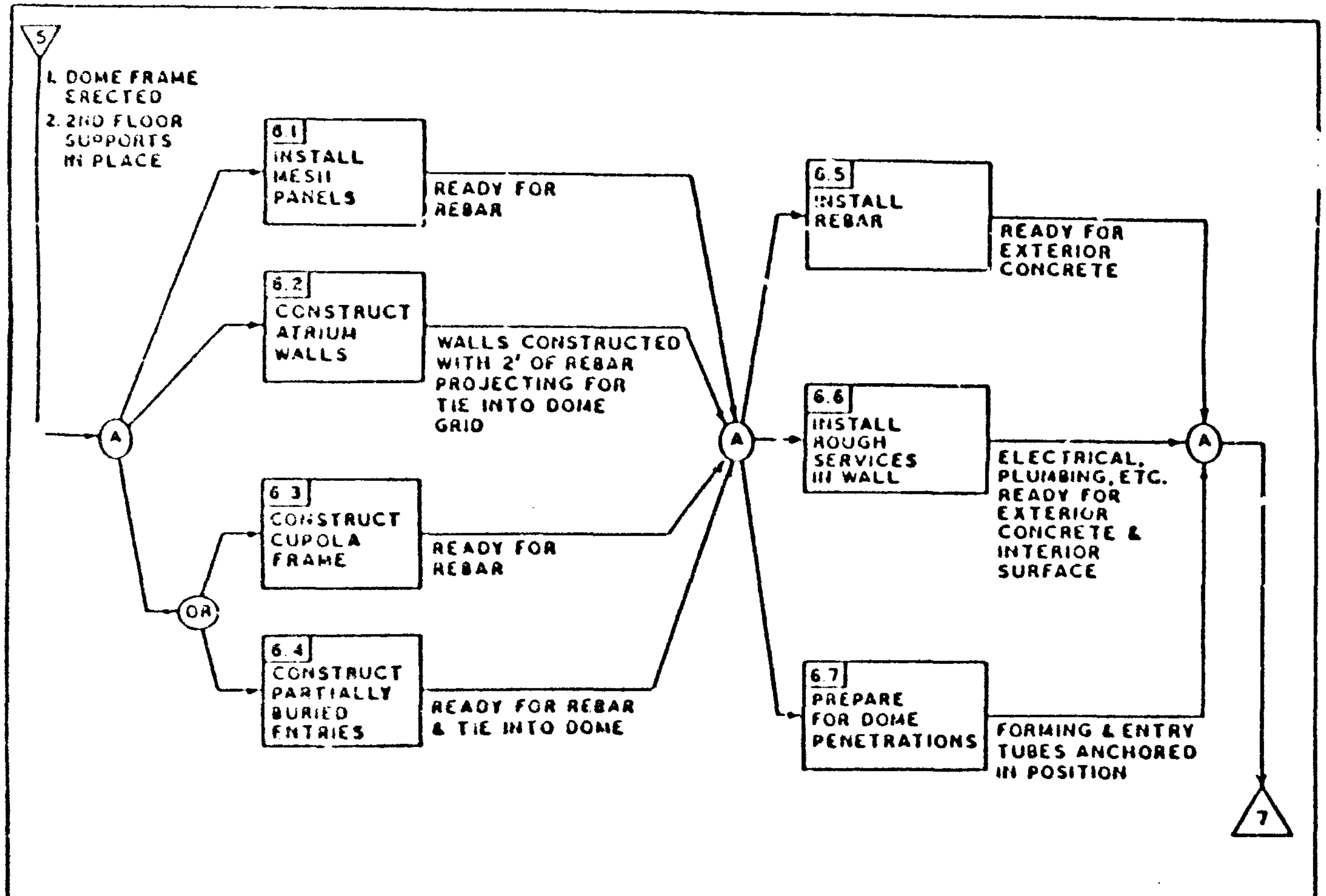
6.7 Prepare for Dome Penetrations

Small diameter penetrations through the dome (e.g. plumbing vents, flues, small diameter stove pipe, power cable entries, etc.) are prepared for by running tubes through the rebar at the proper location and anchoring them so they will stay in place during the shotcrete process. One of the most foolproof methods is to use interior wall frame as both the location guide and the anchor point.

Penetrations up to 4 inches in diameter merely have the concrete shot around it without any reinforcement. Over 4" and up to triple wall stovepipe, use Fig. 6.24 as a guide. Reinforcing rebar and concrete mesh are needed to hold the concrete in place.

Penetrations over three feet high, greater than 12 inches in diameter, and those rising to the surface from a point lower down on the dome all have to be engineered before installation. Types like these will be subjected to far greater stress.

Small penetrations in the lower dome (such as power cable) are also handled as shown in the lower part of Fig. 6.24. The KEY point to remember is to tilt the penetration tube DOWNWARD at a slight angle so that any moisture will run OFF instead of going inside. Suitable waterproof plumber's packing also helps insure a waterproof seal below ground.



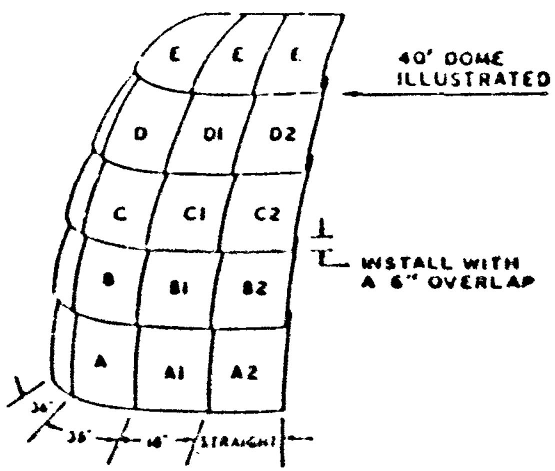
1ST LEVEL: 6. ATTACH MESH PANELS & REBAR GRID

PANEL IDENTIFICATION

PANELS TO BE USED WITH VARIOUS DOME SIZES

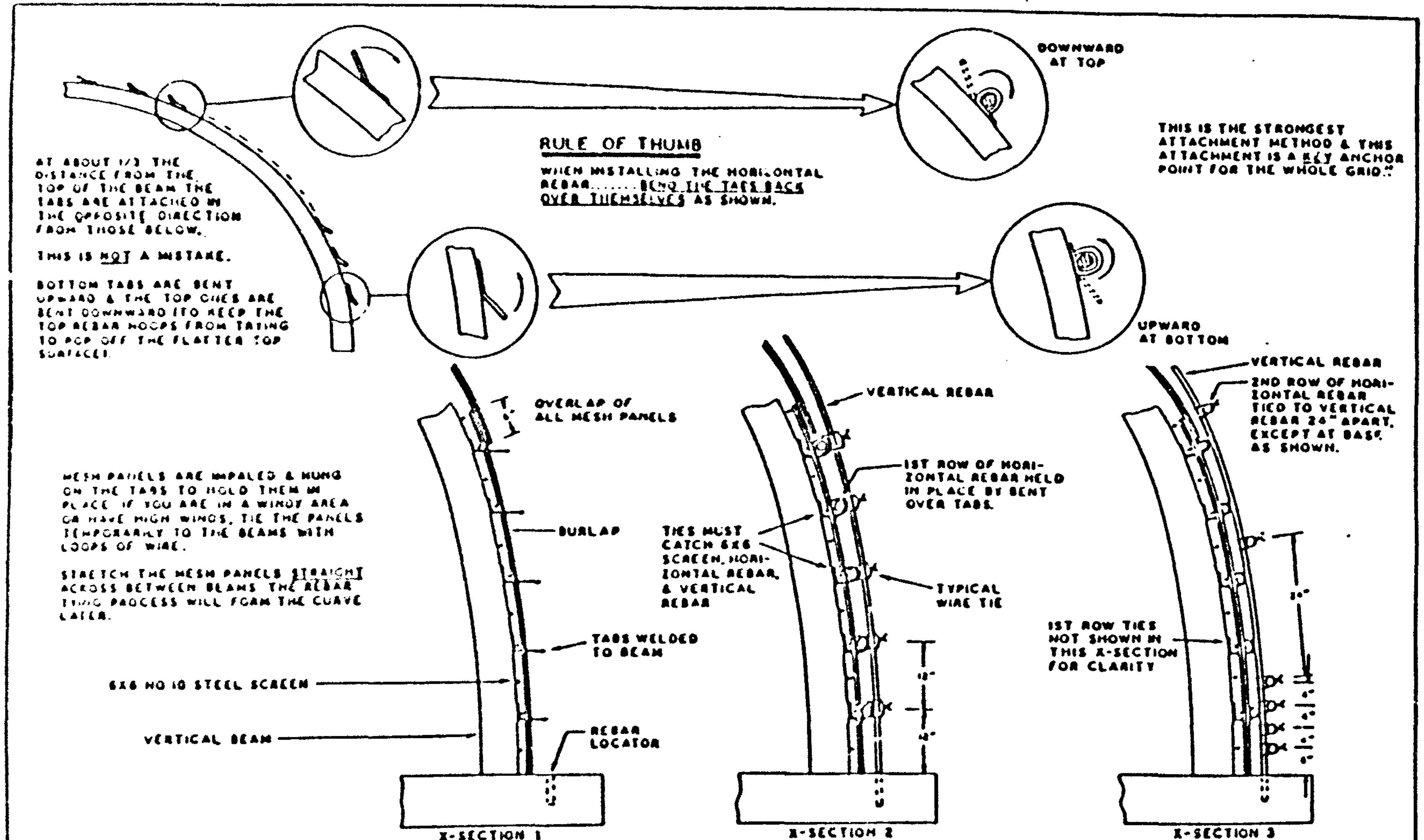
DOME SIZE	36° & 45° END SECTIONS	18° SECTIONS	STRAIGHT SIDE SECTIONS	TOP
24'	A & B	NA	A2 & B2	C
32'	A,B,C	A1,B1,C1	A2,B2,C2	D
40'	A,B,C,D	A1,B1,C1,D1	A2,B2,C2,D2	E

NA = NOT APPLICABLE



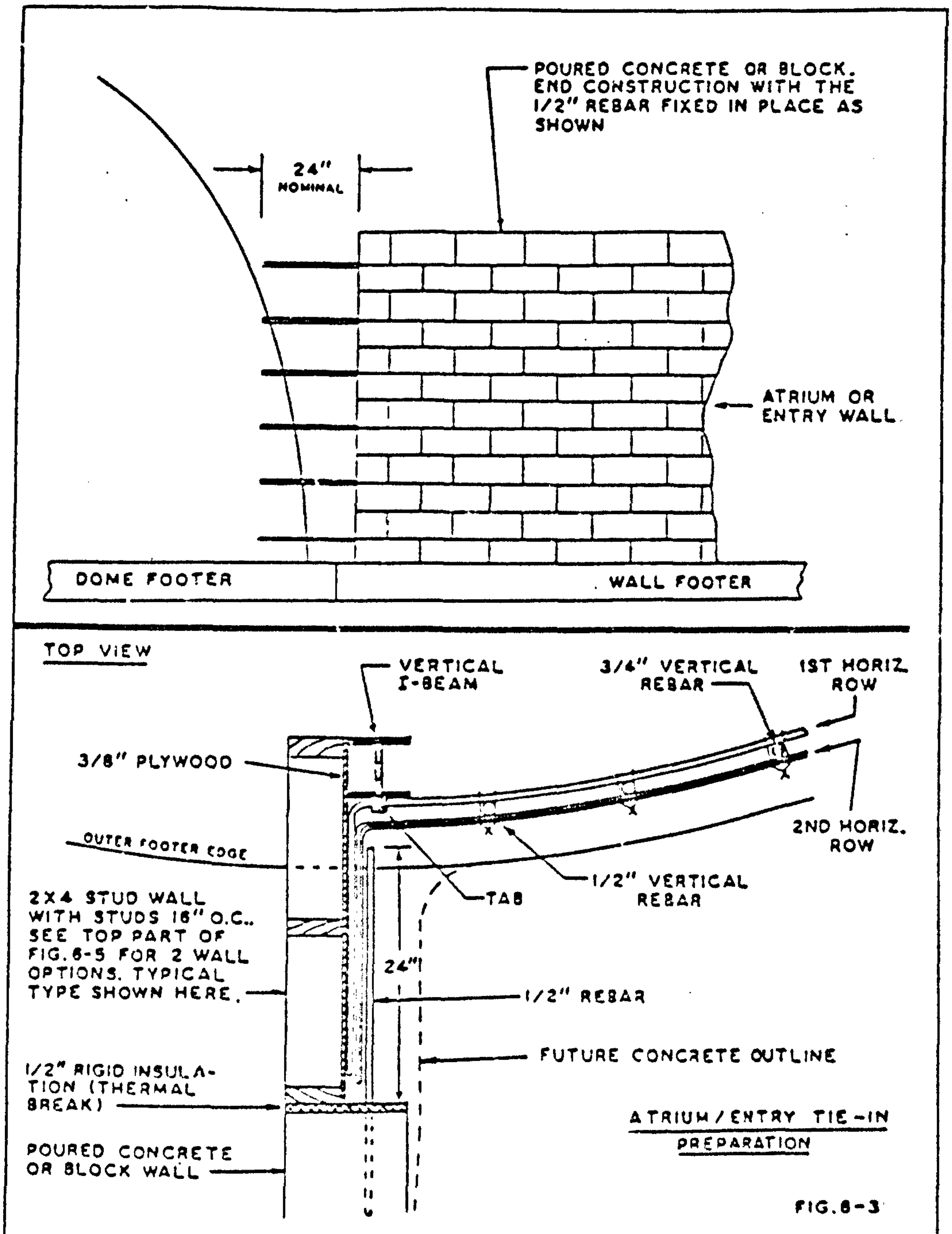
NOTE:
1. MESH PANELS COME IN A ROLL JUST ABOUT IN THE ORDER READY FOR USE; THAT IS, ALL THE BOTTOM A PANELS 1ST, B PANELS 2ND, ETC.
2. THE OUTER PANEL THAT SERVES AS THE WRAPPING FOR THE ROLL IS AN EXTRA GOOD PANEL. SAVE IN CASE IT IS NEEDED.
3. SEPARATE INDIVIDUAL PANELS, REMOVE FROM ROLL, & PUT IN PLACE ON THE STEEL FRAME, STARTING AT THE BOTTOM.

FIG 6-1



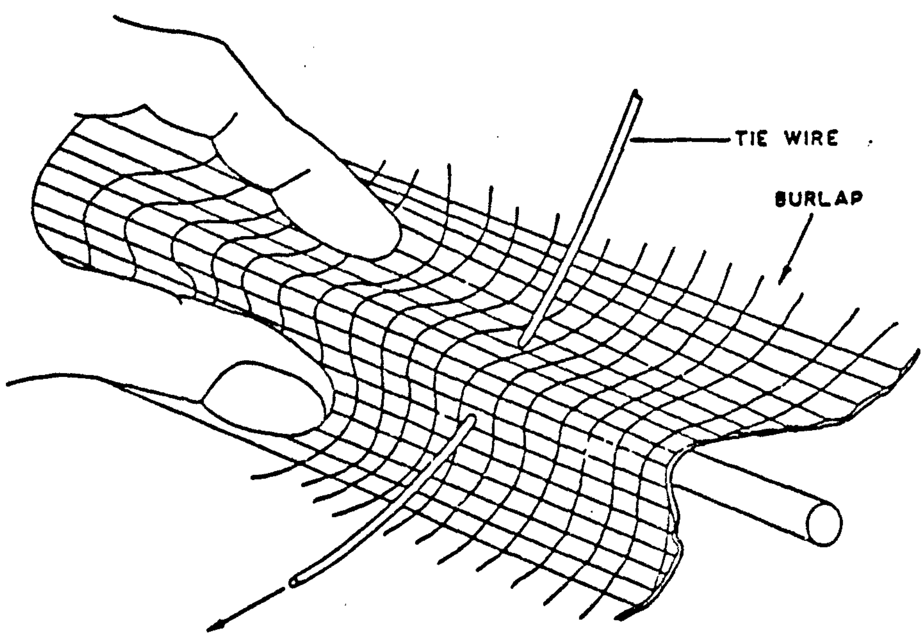
REBAR ATTACHMENT GENERAL DETAILS

FIG. 6-2



ATRIUM/ENTRY TIE-IN PREPARATION

FIG.6-3



PREFERED/FASTER APPROACH

HAVE A HELPER INSIDE TO:

1. CUT TIE WIRE TO ADEQUATE LENGTH FOR TYING ALL REBAR TOGETHER
2. BEND IT INTO A "U"
3. POKE WIRE THROUGH THE BURLAP SO IT CATCHES THE 6X6 SCREEN INSIDE & THE OPEN END OF THE "U" GOES ON EACH SIDE OF THE HORIZONTAL REBAR OUTSIDE. ENOUGH LIGHT COMES THROUGH THE BURLAP TO LOCATE THE HORIZONTAL REBAR FROM THE INSIDE.

THE STEEL MAN ON THE OUTSIDE PULLS THE TIE WIRE TIGHT AROUND THE STEEL & COMPLETES THE TIE.

CATCHING 6X6 SCREEN WITH TIE WIRE

FIG. 6-7

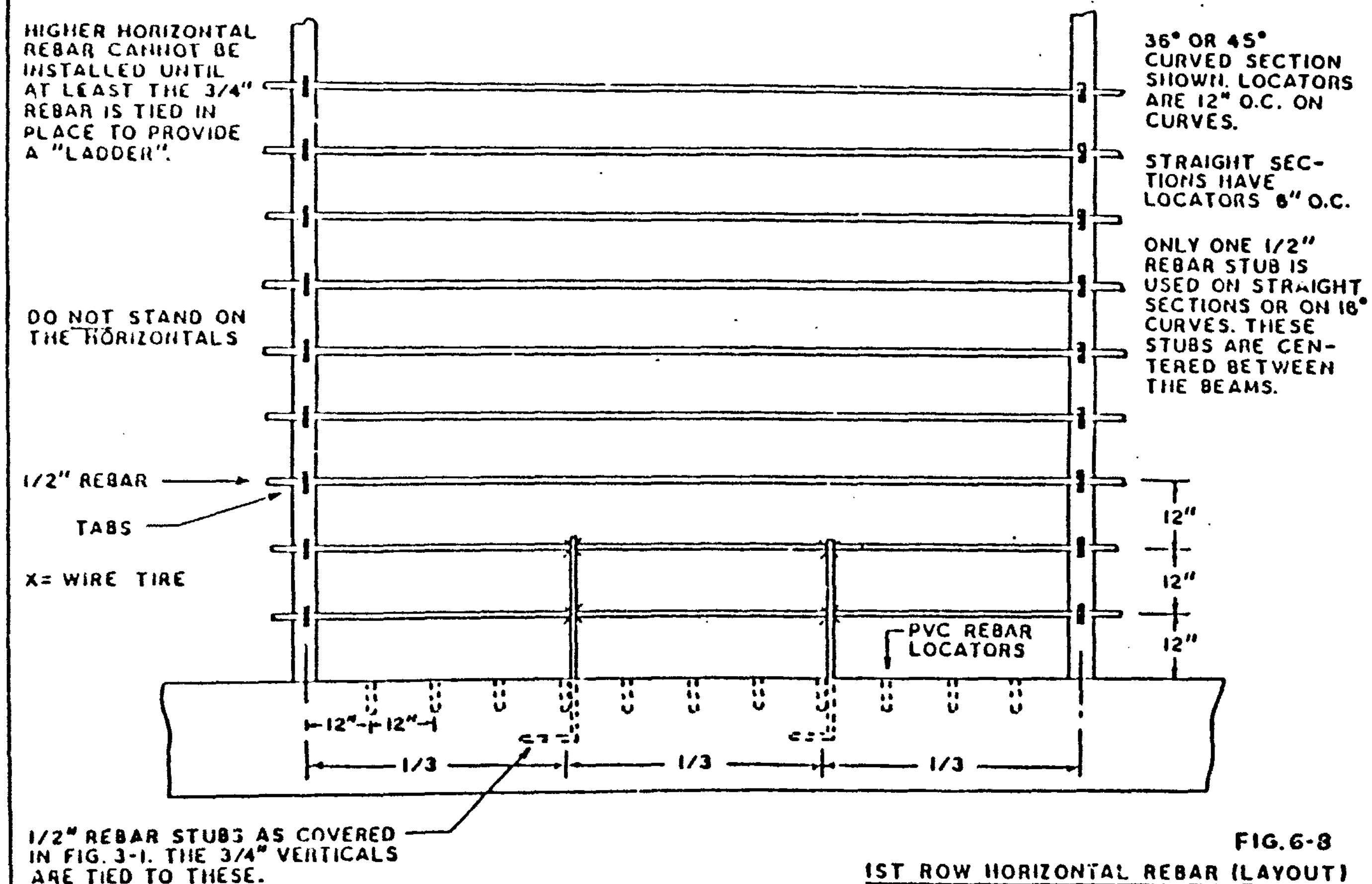
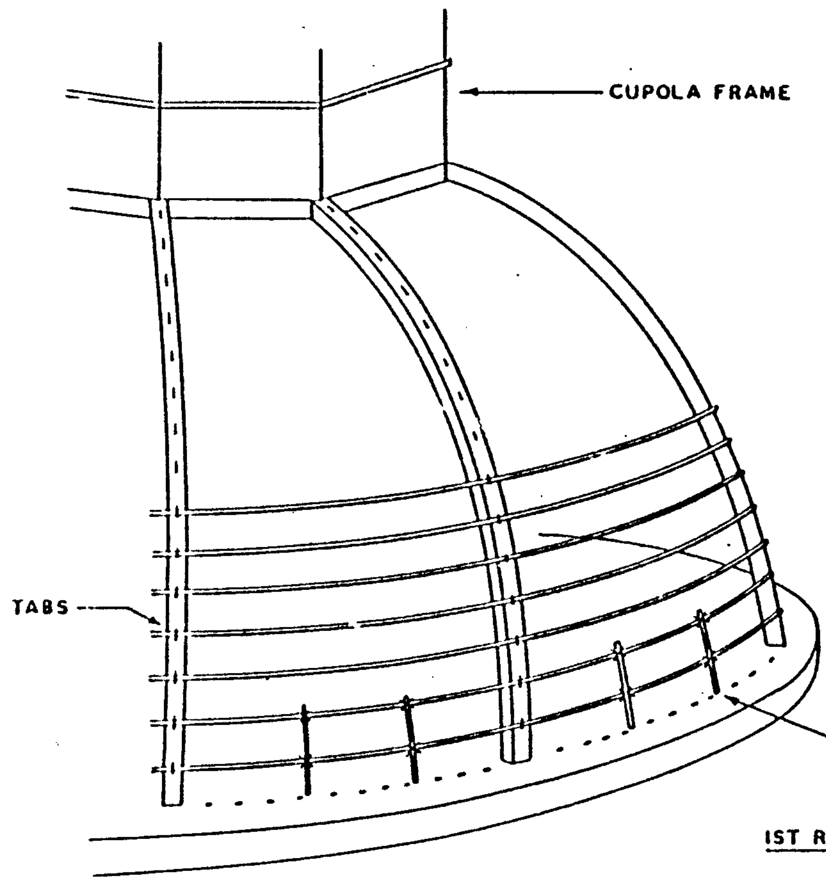


FIG. 6-8

1ST ROW HORIZONTAL REBAR (LAYOUT)

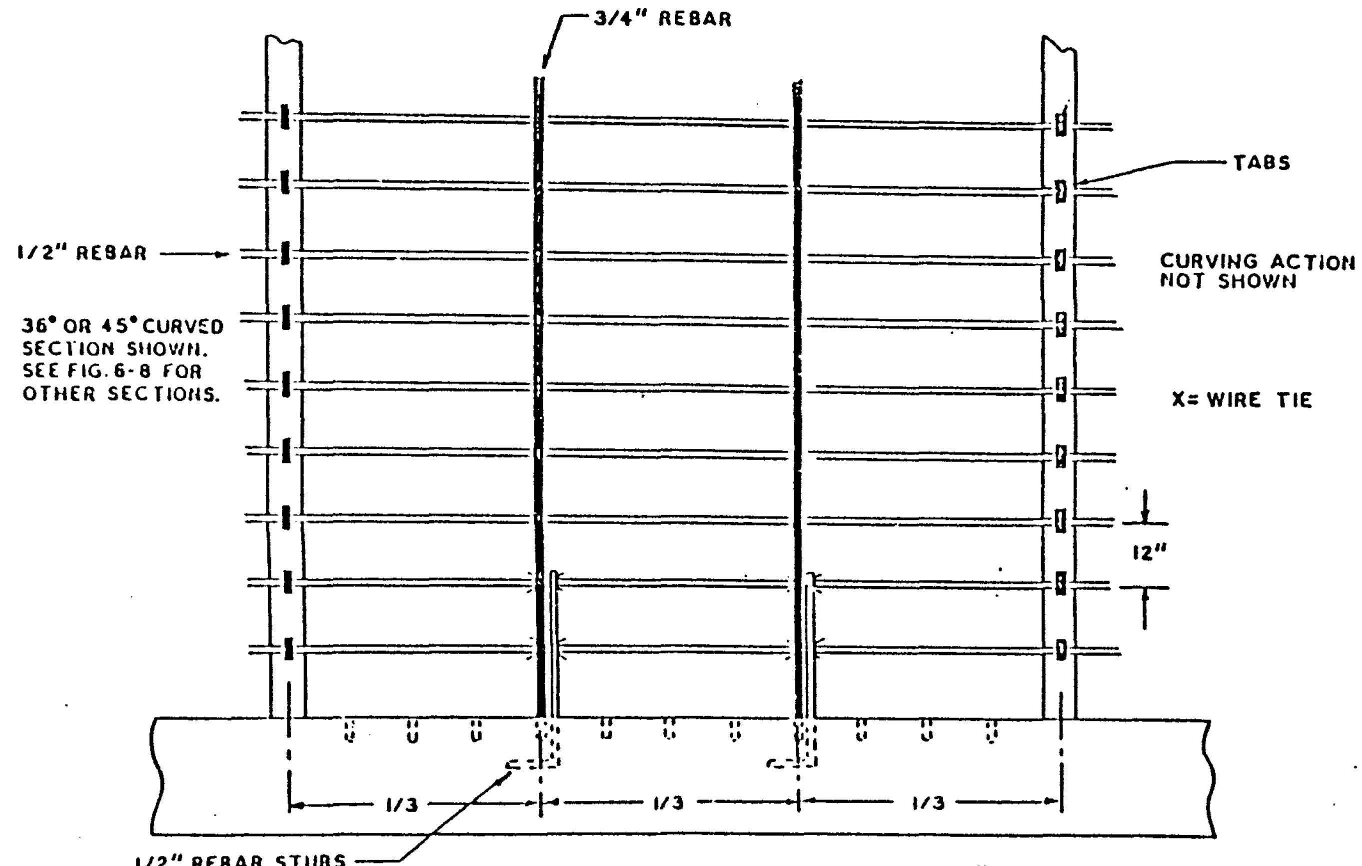


SHOWN ARE THE 1ST ROW OF HORIZONTALS THAT CAN BE REACHED FROM THE GROUND.

START AT THE BASE. TAB THE REBAR FLAT AGAINST THE BEAM & ESTIMATE THE CURVE USING THE STUBS TO HELP. USE LOWER RINGS TO HELP ESTIMATE THE CURVE OF THOSE ABOVE. THE VERTICALS INSTALLED LATER WILL ALSO HELP PULL THE CURVE INTO SHAPE.

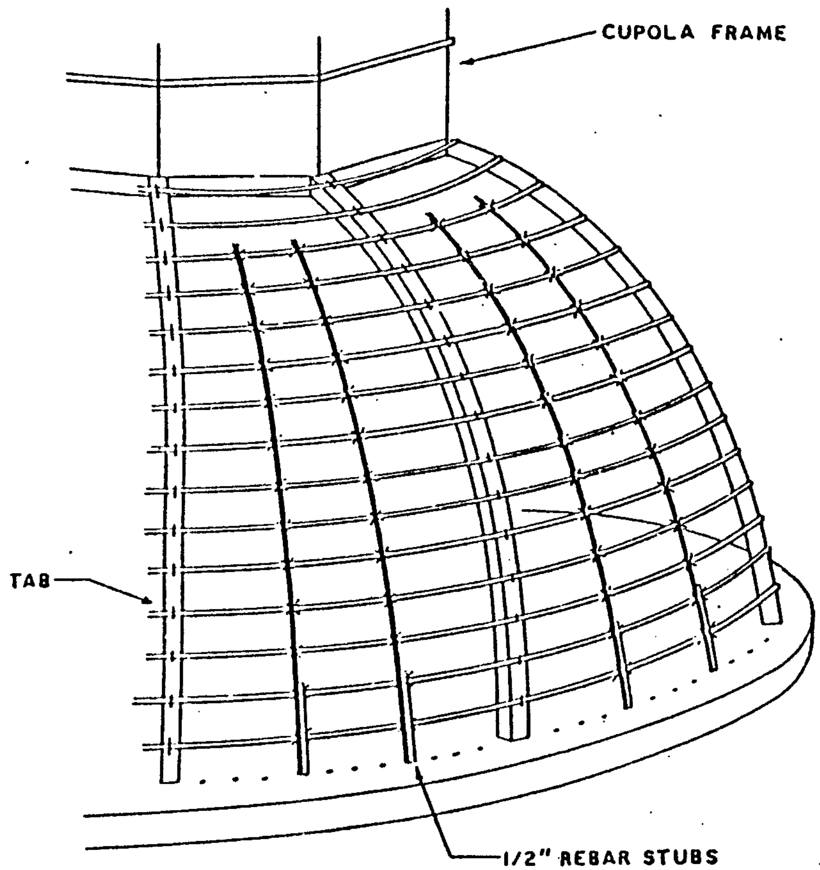
1ST ROW HORIZONTAL REBAR (PERSPECTIVE)

FIG 6-9



3/4" VERTICAL REBAR (LAYOUT)

FIG 6-10

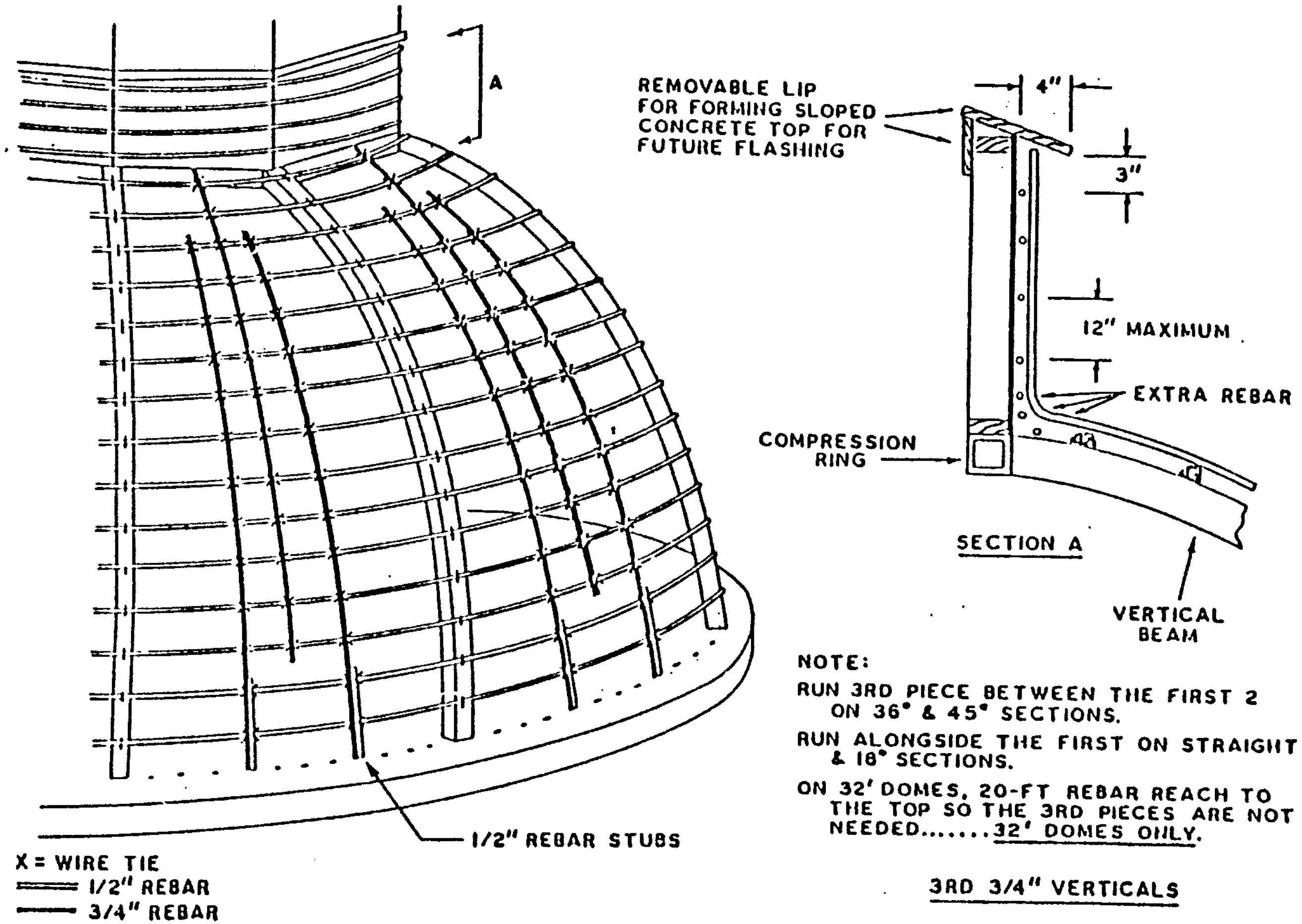


SHOWN ARE 3/4" VERTICALS & THE REST OF THE 1ST ROW HORIZONTALS.

THE 3/4" VERTICALS NOT ONLY HELP PULL THE HORIZONTALS INTO THE CURVED SHAPE, BUT ALSO PROVIDE A "LADDER" ON WHICH TO WORK THE HIGHER ROWS ONCE THE VERTICALS ARE TIED TO THE HORIZONTALS.

3/4" VERTICAL REBAR (PERSPECTIVE)

FIG 6-11



A
REMOVABLE LIP FOR FORMING SLOPED CONCRETE TOP FOR FUTURE FLASHING
4"
3"
12" MAXIMUM
EXTRA REBAR
COMPRESSION RING
SECTION A
VERTICAL BEAM
1/2" REBAR STUBS
X = WIRE TIE
1/2" REBAR
3/4" REBAR
NOTE:
RUN 3RD PIECE BETWEEN THE FIRST 2 ON 36° & 45° SECTIONS.
RUN ALONGSIDE THE FIRST ON STRAIGHT & 18° SECTIONS.
ON 32' DOMES, 20-FT REBAR REACH TO THE TOP SO THE 3RD PIECES ARE NOT NEEDED.......32' DOMES ONLY.
3RD 3/4" VERTICALS

FIG. 6-12

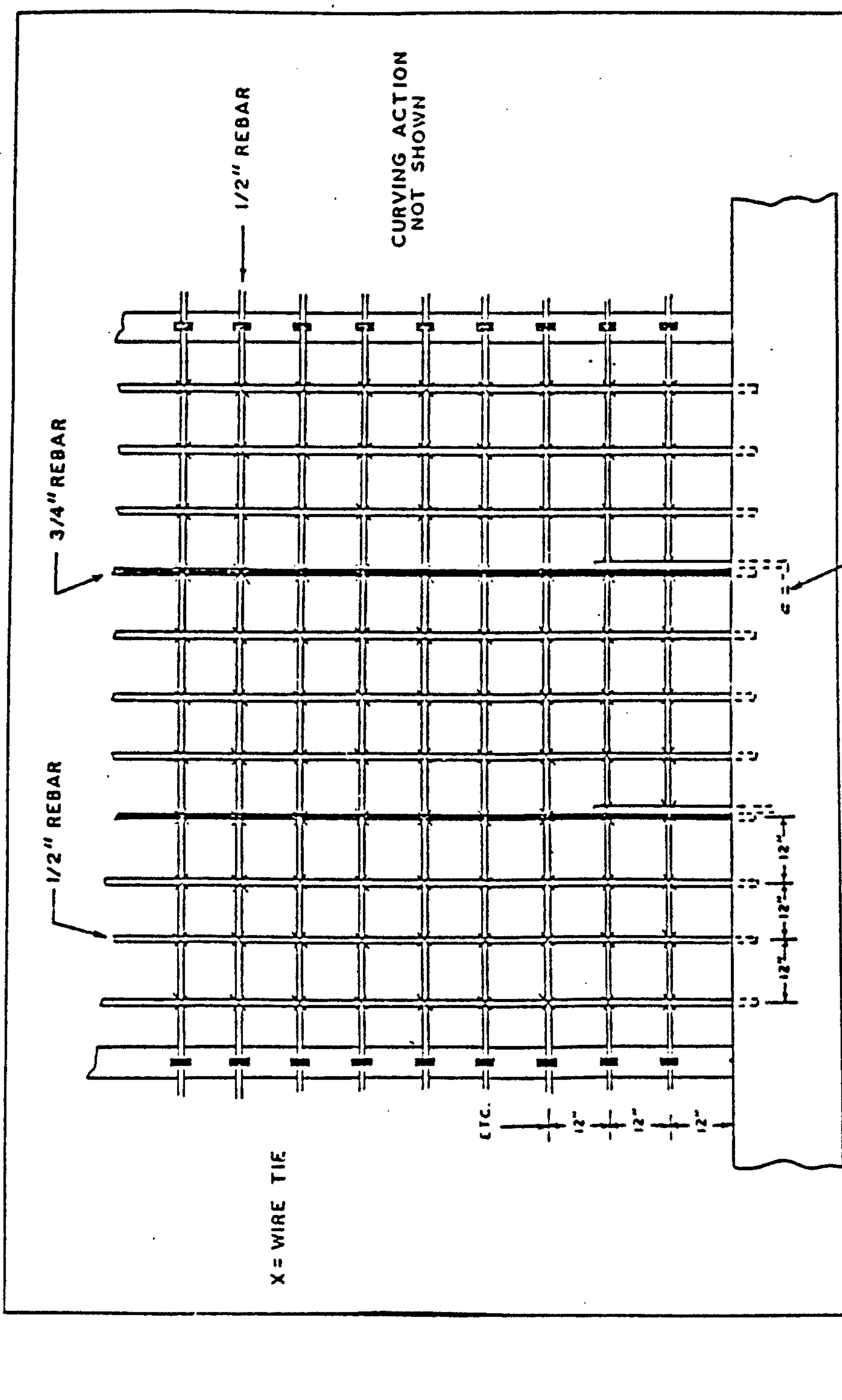


FIG. 6-14
REMAINING VERTICAL REBAR (LAYOUT)

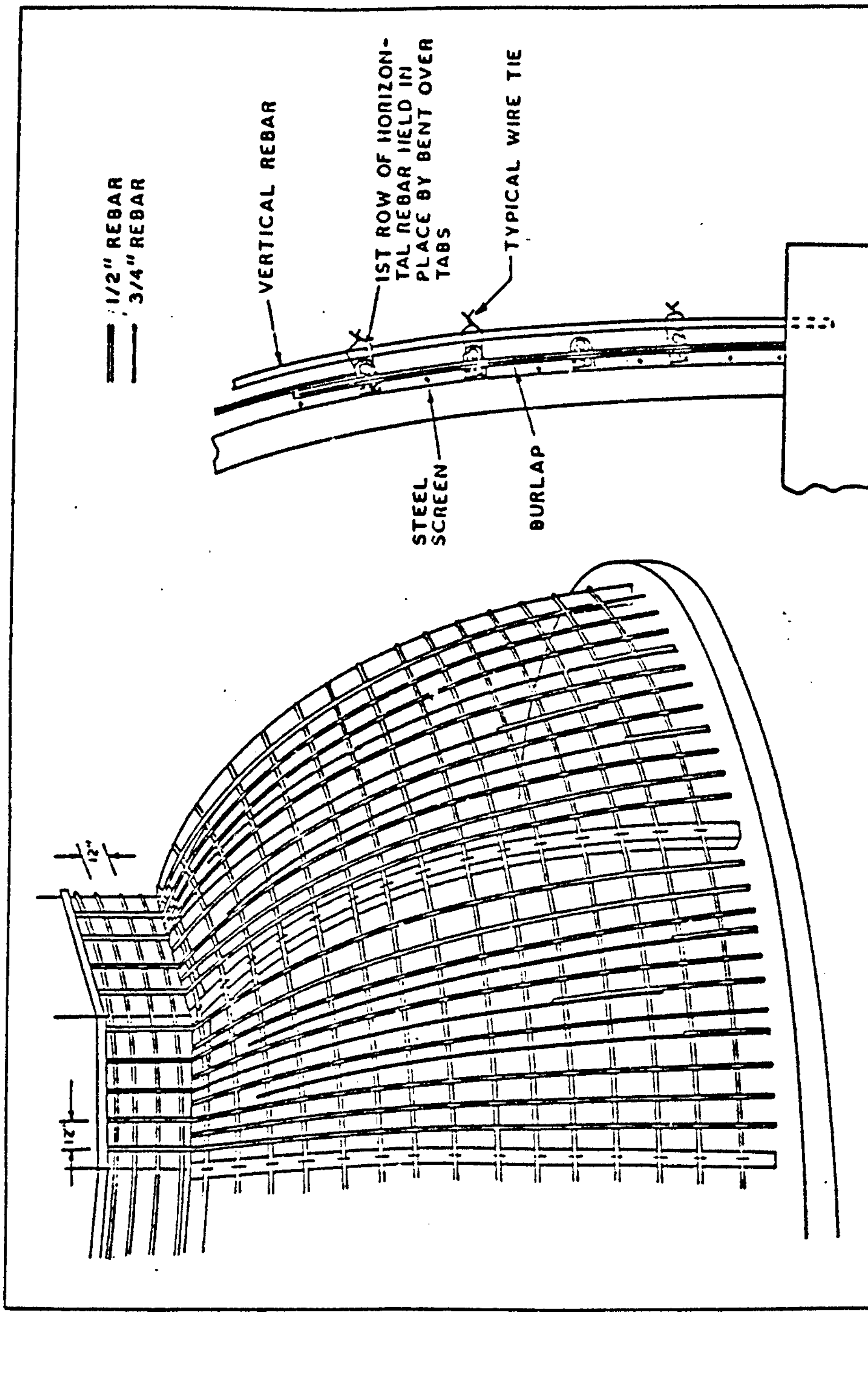
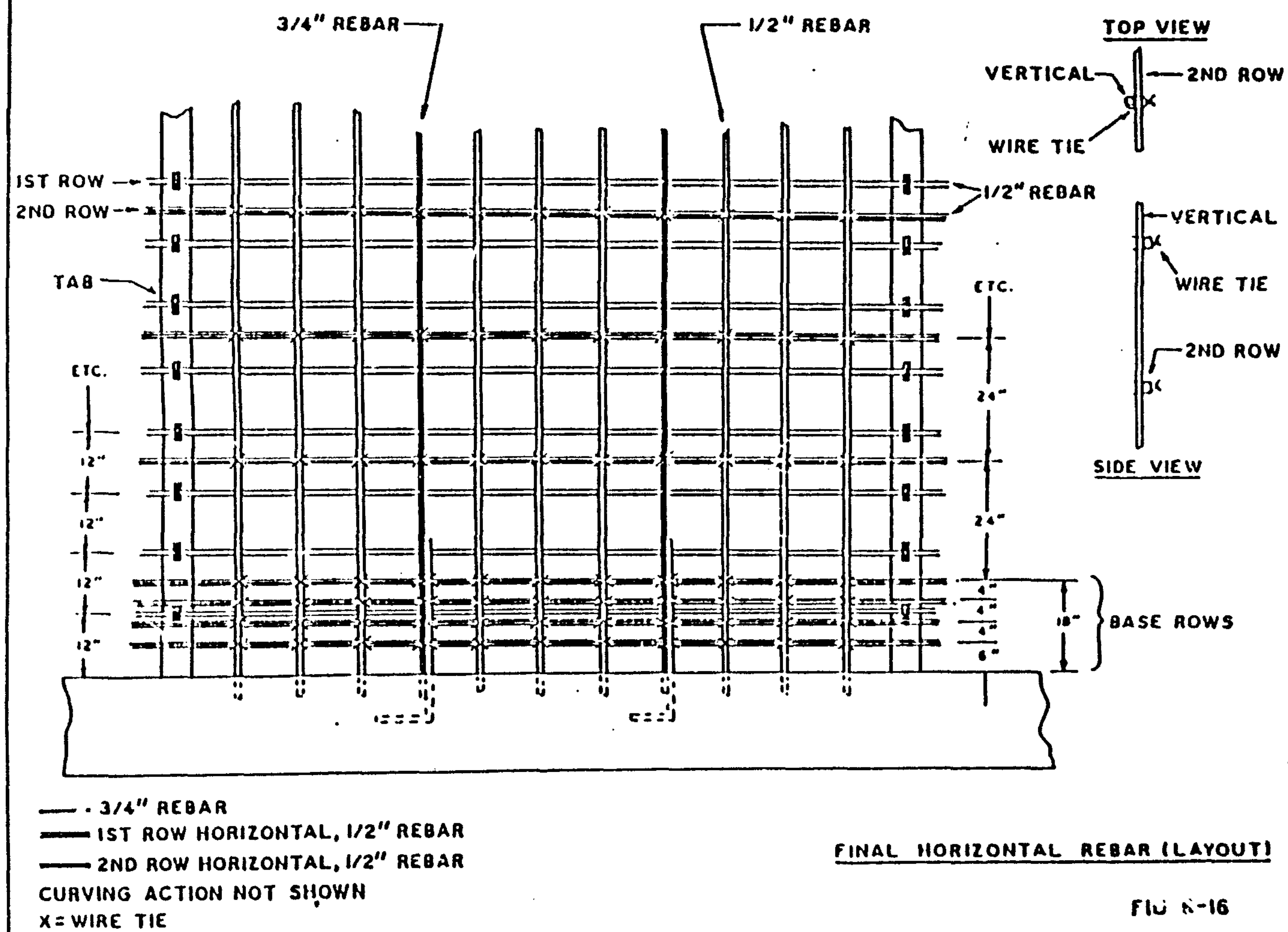
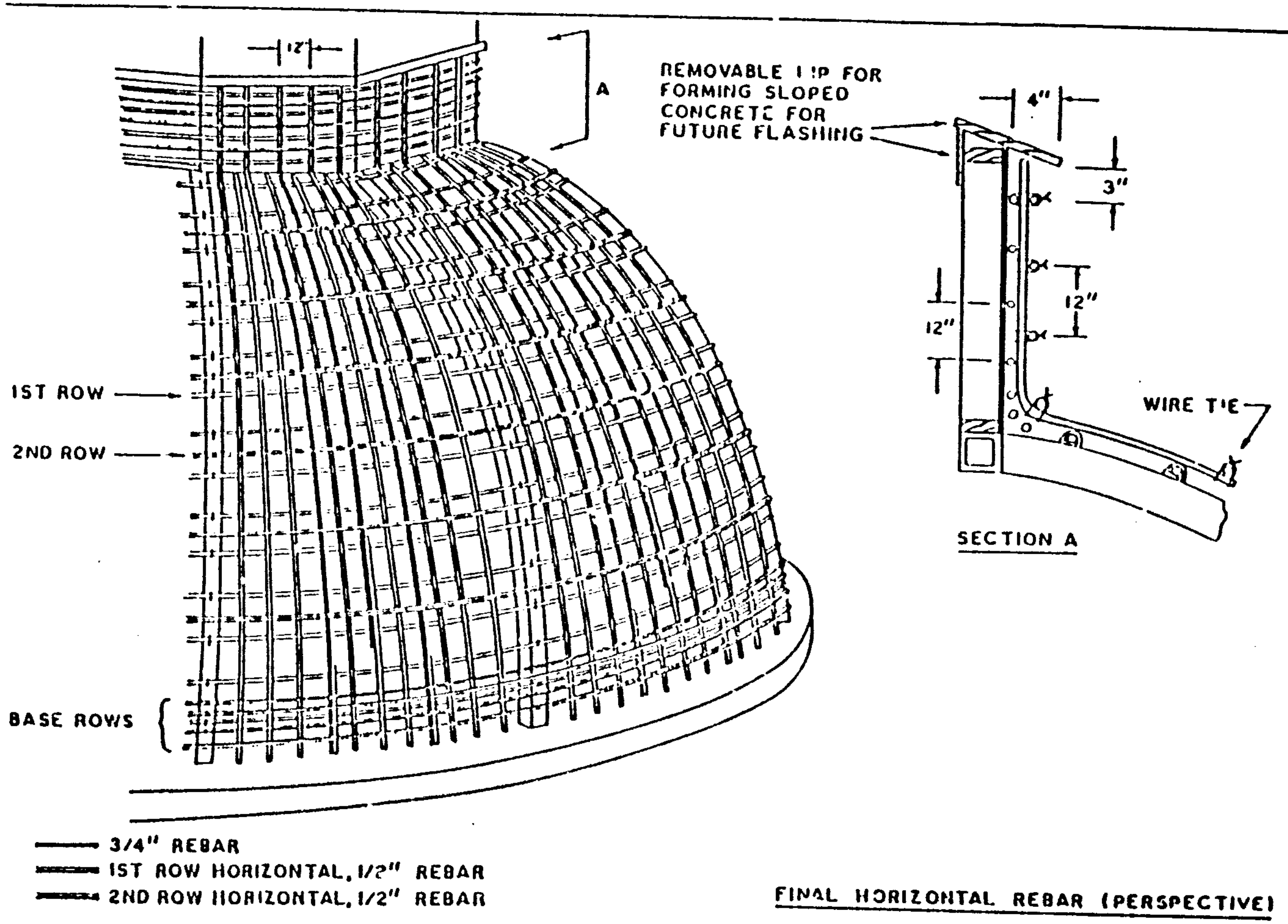


FIG. 6-15
REMAINING VERTICAL REBAR (PERSPECTIVE)



FINAL HORIZONTAL REBAR (LAYOUT)

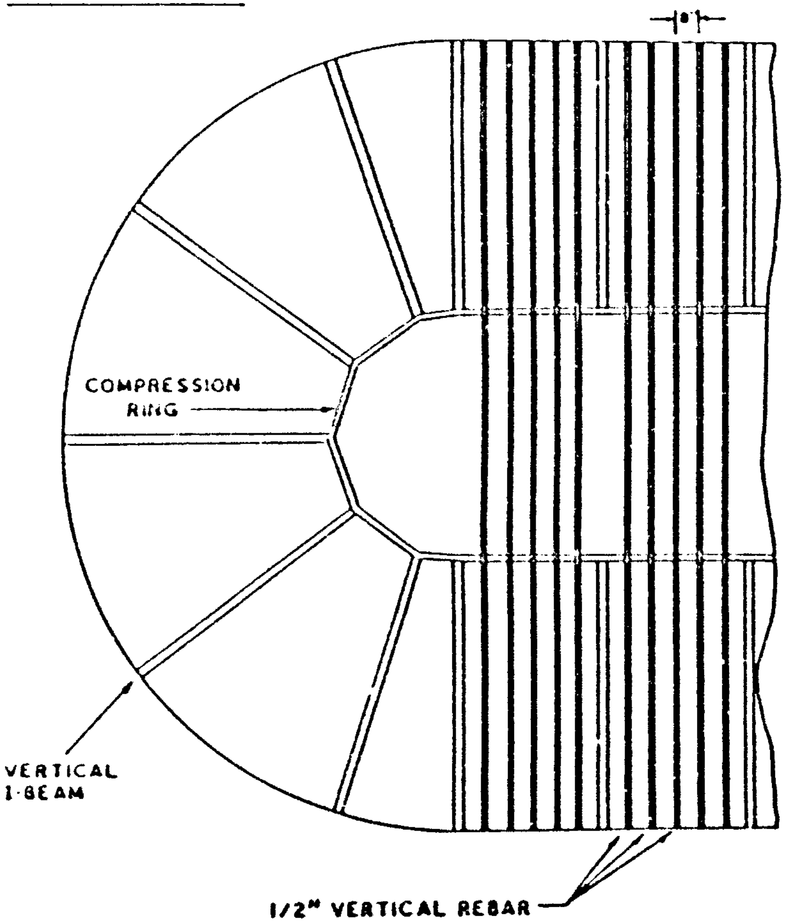
FIG K-16



FINAL HORIZONTAL REBAR (PERSPECTIVE)

FIG 6-17

EXTENDED DOME



REST OF REBAR NOT SHOWN

SPLICES ON VERTICAL REBAR AT TOP NOT SHOWN

30' 1/2" REBAR ON 32' DOME WILL REACH OVER TOP FROM EACH SIDE. TIE AT TOP.

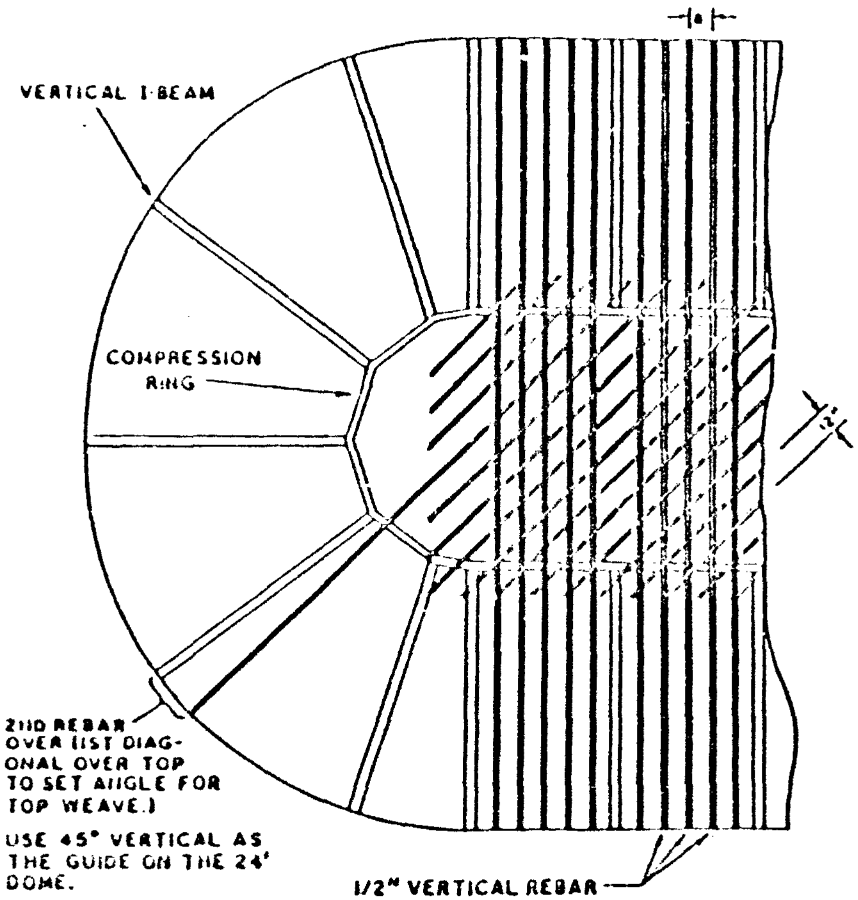
30' 1/2" REBAR ON 40' DOME WILL NOT REACH OVER TOP & WILL REQUIRE A 3RD PIECE OVER THE TOP. SPLICE IN & TIE.

IF ONLY 20' LENGTHS ARE AVAILABLE, A 3RD PIECE WILL BE NEEDED TO GO OVER THE TOP ON THE 32' & 40' DOMES. SPLICE IN & TIE.

TOP VIEW OF VERTICAL REBAR CONNECTED OVER THE TOP

FIG G-21

EXTENDED DOME



REST OF REBAR NOT SHOWN

TIE OF OVER-THE-TOP DIAGONALS INTO DOME REBAR NOT SHOWN

REMAINING 1ST LAYER TOP DIAGONALS ARE LAID PARALLEL TO FIRST & 12" APART MAXIMUM.

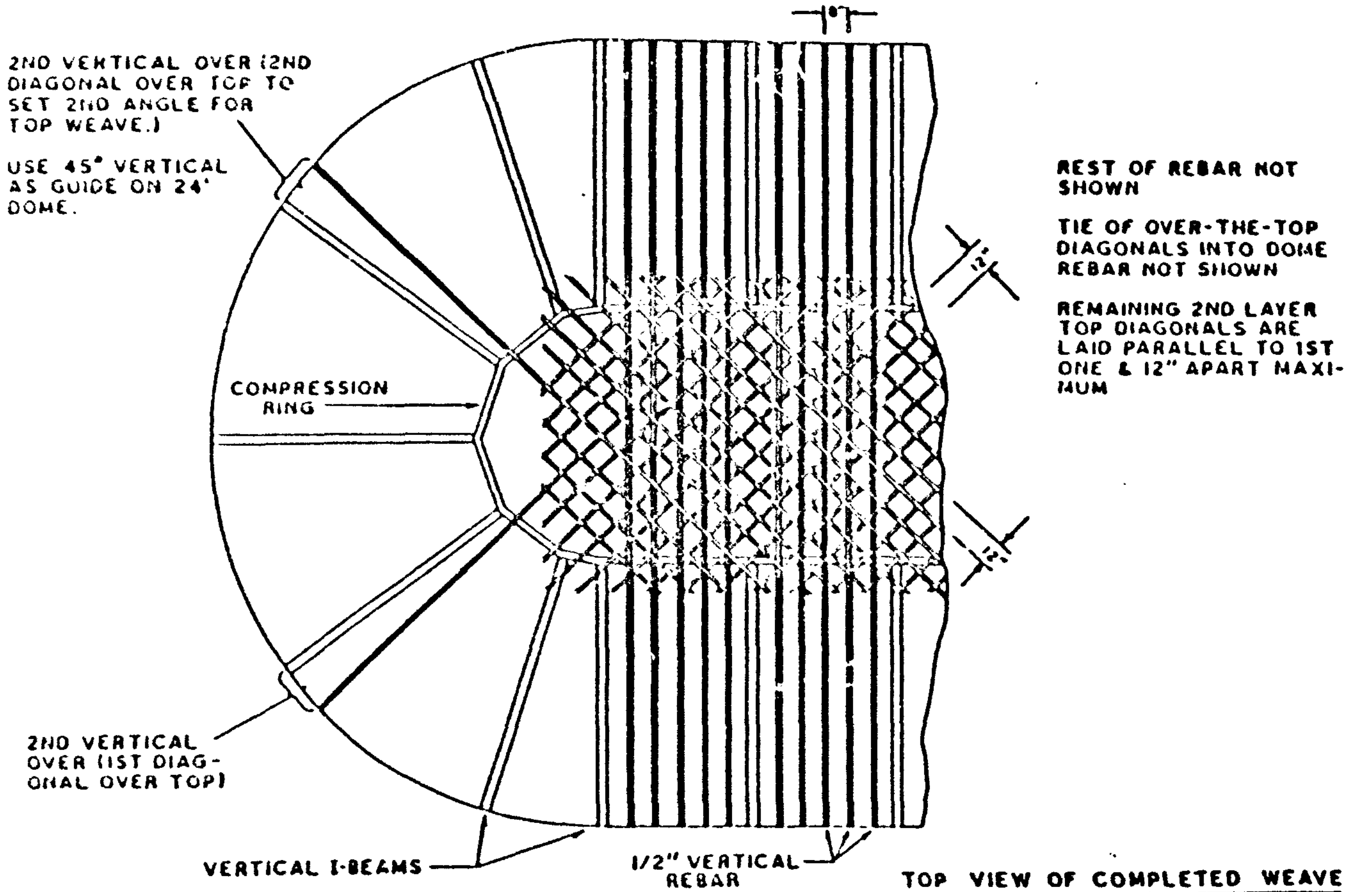
NOTE:

BRING THE END VERTICALS UP BEFORE LAYING THE TOP DIAGONALS. SINCE ALL THE END VERTICALS CONVERGE AT TOP CENTER OF THE HALF COMPRESSION RING, SOME WILL HAVE TO BE CUT OUT TO MAINTAIN THE 6" MINIMUM SPACING SO CONCRETE CAN BE WORKED DOWN THROUGH THE REBAR TO THE MESH PANELS.

TOP VIEW OF 1ST LAYER TOP DIAGONALS

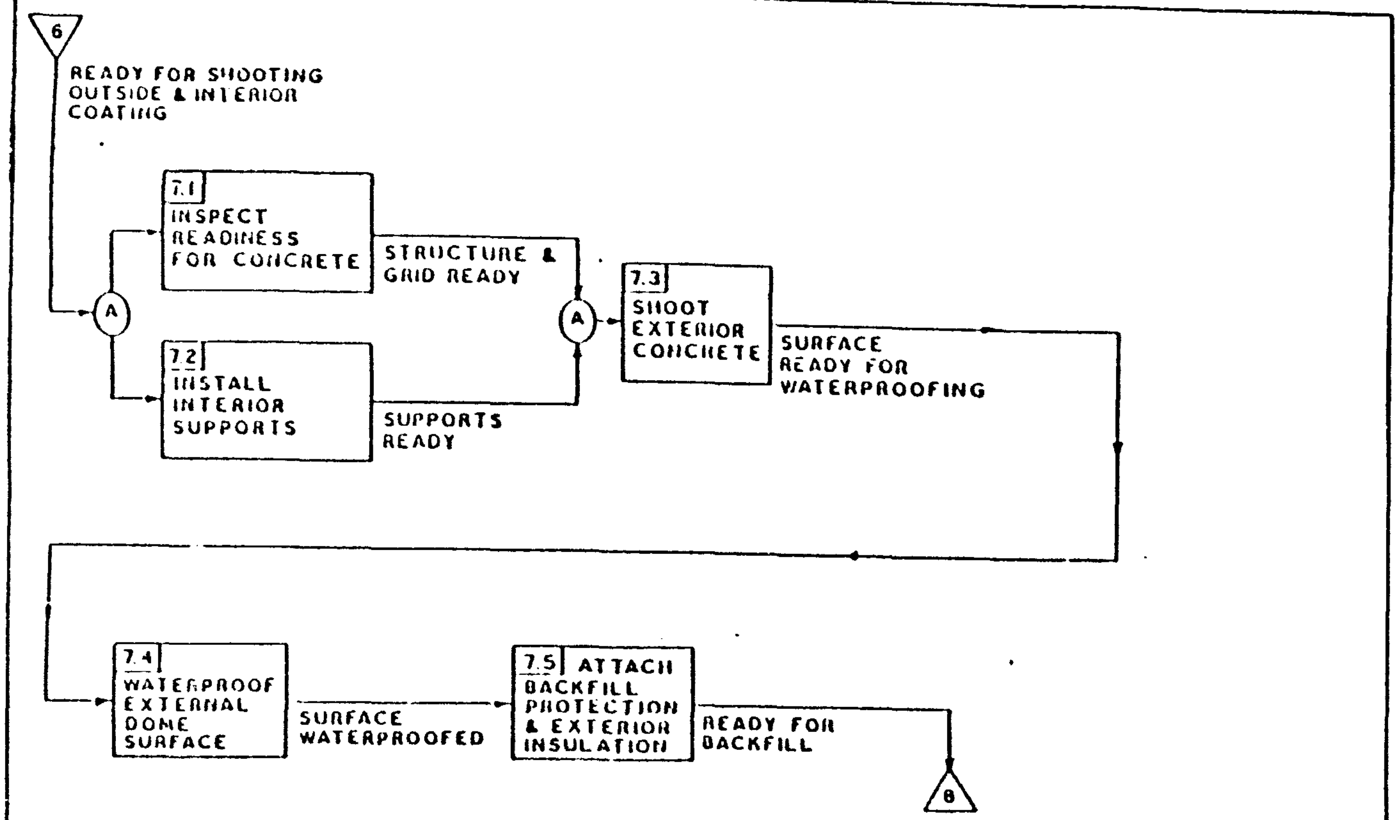
FIG 6-22

EXTENDED DOME



TOP VIEW OF COMPLETED WEAVE

FIG G-23



1ST LEVEL: 7. COMPLETE DOME WORK

7. Complete External Dome Work

7.1 Inspect Readiness for Concrete

The main considerations here are things that affect the future strength and waterproofing of the dome. For example:

1. Check all rebar to insure:
   a. First row horizontals are locked to the vertical beams with the tabs.
   b. The inside 6 X 6 screen has been tied to the horizontal and vertical rebar so the interior surface can't separate later.
   c. Second row horizontals are tied to the verticals so this layer can't separate.

2. Check rebar in joints and intersections to see:
   a. There is enough to carry the corner stresses.
   b. There are not too many to prevent the concrete from being worked all the way into the corners and up against the pouring mesh or forms.

3. All necessary rough-in services (e.g. electrical) are installed in the walls with sufficient lengths sticking out so the working ends won't be covered with exterior concrete or interior surface material.

4. All dome penetrations have been set up as described in Section 6.7 to help prevent any future leakage.

7.2 Install Interior Supports

These supports are needed to prevent any sagging, shell movement, or compression ring tipping (even small amounts will throw the cupola out of alignment) due to accidental overload during concrete application.

While the preferred way to handle the top part of the dome is to have the interior load bearing walls and rough second floor constructed to serve as the upper anchor points, 2 X 4 supports reaching from the bottom floor have been successfully used. The preferred approach is used to illustrate.

There are four main areas that require supporting.

1. Compression Ring--To prevent tipping or misalignment. See Fig. 7.1. Level the ring and use one support on each side. These must be either 4 X 4's or two 2 X 4's nailed together to carry these higher loads. When an elongated compression ring is used with one or more straight sections, support the ring at each vertical beam.

2. Upper Dome--To help support the down loads of the concrete and people walking on the top part of the dome during the shotcrete phase. 2 X 4's are adequate. See Fig 7.2. Use the illustrated types of supports centered in each bay.

3. Lower dome--To help support the inward loads generated near the base of the dome. 2 X 4's are adequate. See Fig. 7.3. These supports are centered in each bay.

4. Atrium and Entry Openings--To help support the structure around these fairly large openings in the dome shell until the concrete tie to these external walls has hardened and become self-supporting. 2 X 4's are adequate. See Fig. 7.4 for supports around all these types of openings, using these types of supports on each side of the openings at the tops and bottoms of each opening, as well as in the center of each adjacent bay.

All rough framing, second floor decking, front wall (if used) and entries should be in place prior to concreting exterior surface. This makes fabrication of the dome easier, eliminates much scaffolding, and provides better support points.

7.3 Shoot Exterior concrete

Three basic rules are to be followed during the shotcrete process:

1. Start at the bottom and work upward, building on that below.

2. Work completely around the dome at one level before moving up to the next level.

3. Smooth each completed layer before it hardens. This will help the waterproofing go on easier and insure no gaps or holes are created that could leak later.

Apply the concrete uniformly to the dome. Insure it is worked in between the rebar all the way down to the mesh or pouring forms. Leave no voids. Also insure that no rebar remains exposed on the surface. This concrete and rebar structure has to hold the full weight of all the backfill, top soil, and sod placed on top of it.

Standing on the ground at the base, you can usually apply concrete about 7-8 feet up the dome surface without scaffolding. Once you get high enough that the dome starts to flatten out on top, the dome can be walked on during the shotcrete process. It is the intermediate stage between what can be reached from the ground and where it can be walked on that scaffolding is needed.

Fig. 7.5 illustrates just one type of temporary scaffolding that has been used successfully. Other types, a front bucket loader or a "cherry picker" could also be used to elevate the person shooting the concrete.

- Complete all trowel and edging work before the concrete sets up.

7.4 Waterproof External Dome Surface

The special TPM waterproofing material is applied at a uniform rate of 22 sq. ft. per gallon (110 sq. ft. per pail) over a smooth surface. A 60 mil. dry thickness is achieved. The material can be troweled or brushed on.

CAUTION....Complete coverage is mandatory!!! This is the waterproof covering that prevents future leakage or dampness inside the dome.

7.5 Attach Backfill Protection and Exterior Insulation

The thin TPM waterproofing needs to be protected during the backfill operation. Rocks can easily punch through the TPM when they hit the solid concrete dome.

If backfill is principally soil without sharp rocks, the insulation material which is applied against the waterproofing will protect the TPM coating. If there are large or sharp rocks in the backfill, check with Earth Systems home office for suggestions on how to further protect both insulation and waterproofing during backfill.

Note...Check with Earth Systems for the exterior insulation requirements to be compatible with the dome design. soil conditions, and climatic conditions.

8. Complete Supporting Work

8.1 Complete Backfill

The dome is backfilled roughly to grade with the backfill and top soil that has been saved or provided for this purpose. As the backfilling takes place, the soil must be compacted or allowed sufficient time to settle to prevent future settling around the dome.

Care should be taken to prevent large rock or boulders, especially those with sharp edges, from banging against the dome so as not to puncture the waterproofing protection.

The great strength of the hardened dome allows for backfilling the dome with standard equipment (e. g. skip loaders, front end loaders, small cats) rather than by hand or with specially designed equipment.

8.2 Construct Supporting Surface Structures

These include garages, barns, shops, retaining walls, etc. All depend upon properly compacted or settled soil for long term stability.

Larger structures like garages are a special case. Since it is essential that these structures be built on undisturbed virgin soil for long-term stability, the MINIMUM distance such structures can be built from the dome are shown in Fig. 8.1.

8.3 Coat Interior

The interior dome is plastered with 3-coat stucco or hardened plaster to tie into the internal 6 X 6 screen. It is not normally necessary to lath around the beams before applying the plaster. The third plaster coat provides the final plastering, texture, or covering of the interior dome walls in the manner specified by the customer.

8.4 Grade and Landscape Surface

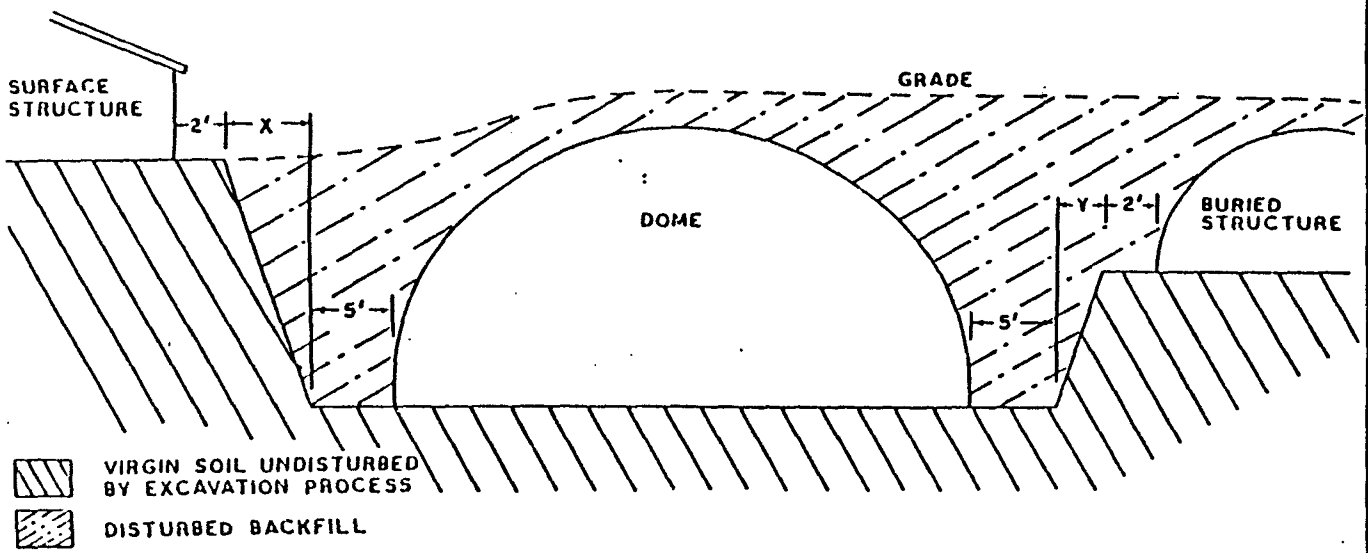
Once the surface structures, retaining walls, etc. have been completed, the final grading of the top soil can also be completed in preparation for walks, garage ramps, driveways, and landscaping.

8.5 Complete Interior Finish Work

This is the typical construction, wall covering, cabinet, equipment installation, and trim work common to any type of residential or commercial construction that is carried out to the customer specs.

CAUTION..... —DON'T BUILD ANY HEAVY STRUCTURES ON DISTURBED SOIL.
—ALL STRUCTURAL FOUNDATIONS MUST BE BUILT ON UNDISTURBED SOIL.

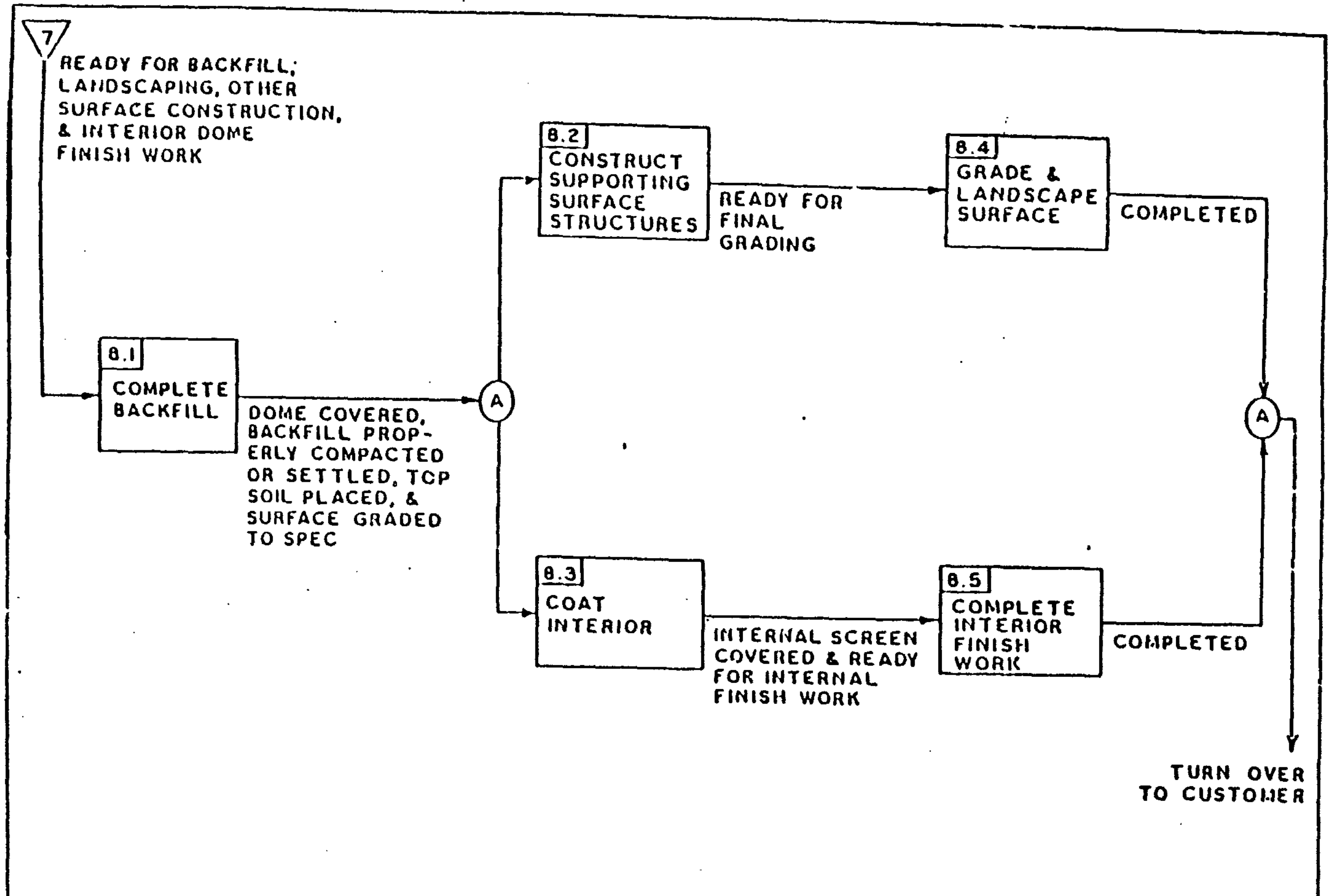
NOTE.......... ALL EARTH SYSTEMS STRUCTURES ARE DESIGNED FOR A MINIMUM SOIL BEARING CAPACITY OF 1500 PSF.



X & Y ARE DETERMINED BY THE SLOPE OF THE EXCAVATION CUTS

MINIMUM SETBACK FOR GARAGES & OTHER STRUCTURES

FIG. 8-1



1ST LEVEL: 8. COMPLETE SUPPORTING WORK

APPENDIX C

PROPOSED TEST PLAN FOR
SPLINTER PROTECTION OF AIRBASE
FIREFIGHTING RESOURCES

SECTION I
INTRODUCTION

A. BACKGROUND

Firefighting resources, including consumables and vehicles, assigned to airbase fire departments in Europe and the Pacific are dispersed according to a predetermined plan before attack. Dispersal locations depend on the availability of space in aircraft shelters and other protected areas designed and constructed for the protection of other resources. The fire department must therefore compete for protected space. When an attack occurs, space may not be available or the available space may not satisfy the needs of the fire department.

Dedicated splinter protected areas, located and designed specifically for firefighting vehicles and consumables, can improve the current survivability during an attack and enhance firefighting and rescue capability following an airbase attack. The dedicated areas will also greatly reduce or eliminate the competition for available protected space.

An investigation was undertaken to develop practical designs to protect firefighting resources to minimize damage during an attack. The objective of the investigation was to develop the designs using off-the-shelf material and standard construction techniques.

From the investigation, two protective concepts were selected: an earth-bermed, reinforced concrete (shotcrete) arch and an earth-bermed, corrugated steel pipe. The investigation also included a simplified analysis that indicated both concepts were capable of protecting the firefighting resources against the splinter threat. Further analysis shall lead to the selection of one of these concepts for field construction and testing.

B. OBJECTIVES

The objective of this experimental program is to verify the survivability of the selected protective concept to the specified splinter threat. A sufficient number of these facilities are planned at Air Force bases throughout Europe and the Pacific to justify an intensive performance validation effort.

C. SCOPE

A full-size shelter will be constructed for these tests. Constructability data will be gathered and documented during construction. The shelter will be earth-bermed per the construction specifications. The shelter will then be subjected to the splinter threat by detonating Mark 83 General Purpose Bombs. Performance will be evaluated with instrumentation placed on and around the structure.

SECTION II
TEST DESCRIPTION

A. INTRODUCTION

The weapons testing will be conducted to verify performance of the design and construction of the shelter for the protection of firefighting resources to the splinter threat. Three tests are recommended to evaluate the shelter performance fully. Approximately 30 channels of active and passive instrumentation will be recorded for each test. High-speed photographic documentation will be provided for both the interior and exterior of the shelter during each test.

B. TEST SITE

The site for these tests has not yet been determined. For purposes of this proposed test plan, the McCormick Ranch Test Site adjoining Kirtland AFB, New Mexico, is used. However, this test plan can be modified to accommodate any other appropriate test site chosen.

The McCormick Ranch Test Site is located about 7 miles south of Albuquerque adjoining the southwest corner of Kirtland AFB (Figure C-1). It lies approximately 5270 feet above sea level within the sagebrush--bursage plant association of the desert region of the Rio Grande Valley. The climate is semiarid with a rainfall of 6 to 10 in. annually. The near surface geology is that of Pleistocene Playa consisting of clayey-silty soil. The water table is at an estimated depth of more than 200 ft below the surface.

The McCormick Ranch Test Site is continually used for testing involving up to 3000 pounds of a variety of high explosives. This weapons test series is consistent with the current land use and is covered by the CERF Environmental Assessment of April, 1977. Surface and subsurface geological characteristics considered of importance to the tests can be provided once the exact test location on McCormick Ranch is known. A compilation of geologic data gathered in numerous test programs over years of testing at various locations on McCormick Ranch is available.*

*Summary of Geotechnical Testing and Material Models for Subsurface Soil Conditions at McCormick Ranch, Kirtland Air Force Base, New Mexico, David A. Bedsun, NMERI 7.11-TA7-20, September 1983.

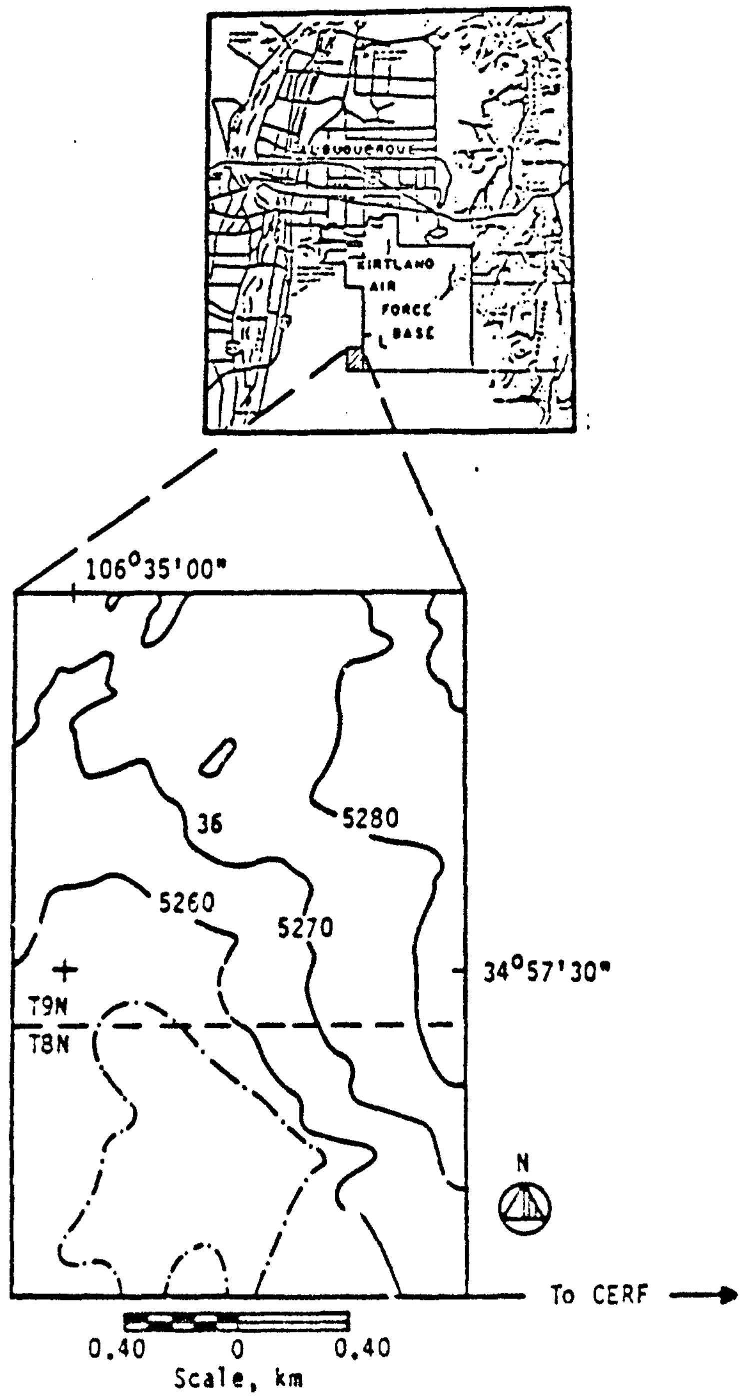


Figure C-1. Location of the McCormick Ranch Test Site

C. CONSTRUCTION

Before construction, standard soil properties will be determined for both the subgrade and the backfill material. Data will be compiled on moisture content, grain size distribution, soil classification, and proctor densities.

During construction of the shelter, material samples will be taken of all reinforcing steel and concrete. Testing will be accomplished in compliance with applicable American Society for Testing Materials (ASTM) specifications and American Concrete Institute (ACI) standards. Preconstruction testing will be accomplished according to ACI standards. This testing will be done to verify the mix design and to qualify the application crew. During construction, samples will be taken, and after construction, cores will be taken and tested.

During construction all phases of progress and problems will be carefully monitored and documented.

D. TESTING

It is recommended that the program consist of three shots (designated Events A, B, and C) using MK 83 (1000 lb) general purpose bombs. Figure C-2 shows the bomb locations. Event A is intended to determine the response of the main body of the shelter. Event B will provide information on the behavior of the entryway. Event C will challenge the structure to a threat greater than the splinter threat. If final design of the shelter includes a blast door, then a justifiable fourth event would be a bomb located in front of the entry of the shelter.

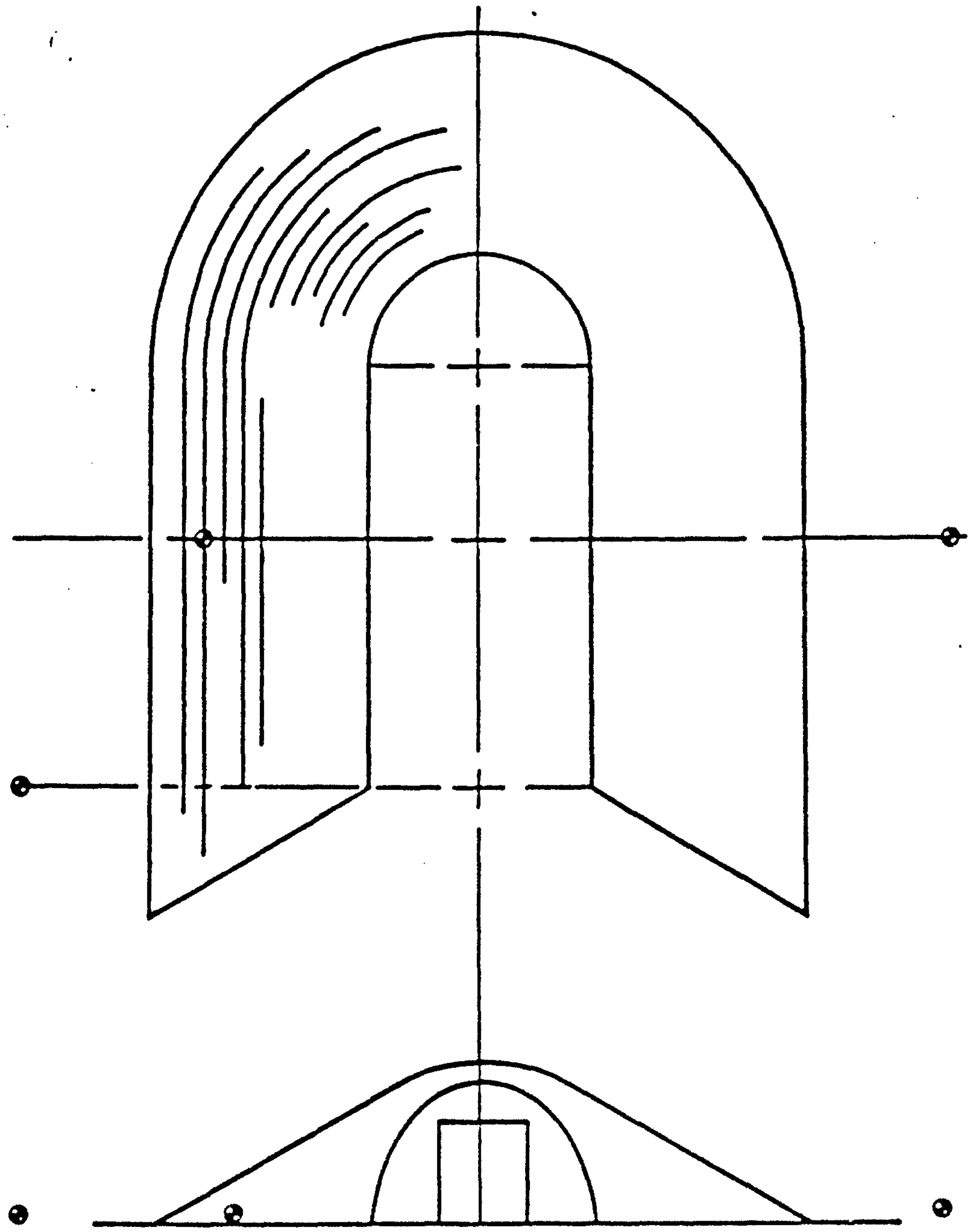


Figure C-2. Proposed Bomb Locations (Not to Scale)

E. INSTRUMENTATION

The number of channels and type of instrumentation depend on the objectives of the test program and its budget. The instrumentation proposed here is considered a minimum program to provide test data for comparison with theoretical predictions. More channels of data would generate a more complete description of the loading environment and shelter response.

Instrumentation measurements will consist of blast pressure, acceleration, interface pressure, steel strain, and passive displacement. Figures C-3 through C-7 show proposed locations for measurements.

The information from the instrumentation measurements will be used to determine the dynamic response of the shelter under the various loading conditions. The posttest analysis of the data will be compared to the simplified analysis. A more comprehensive modeling calculation may be required depending on the test results.

F. RESPONSIBILITIES AND SUPPORT

A matrix of assigned responsibilities cannot be completed until the responsible organizations and test site location have been identified. Once that occurs, appendixes will be written to this test plan in the following areas.

- Organization and responsibility
- Test events
- Testbed location and description
- Schedule
- Safety plan
- Explosives transit and storage
- Environmental effects monitoring
- Security
- Communications
- Meterological support

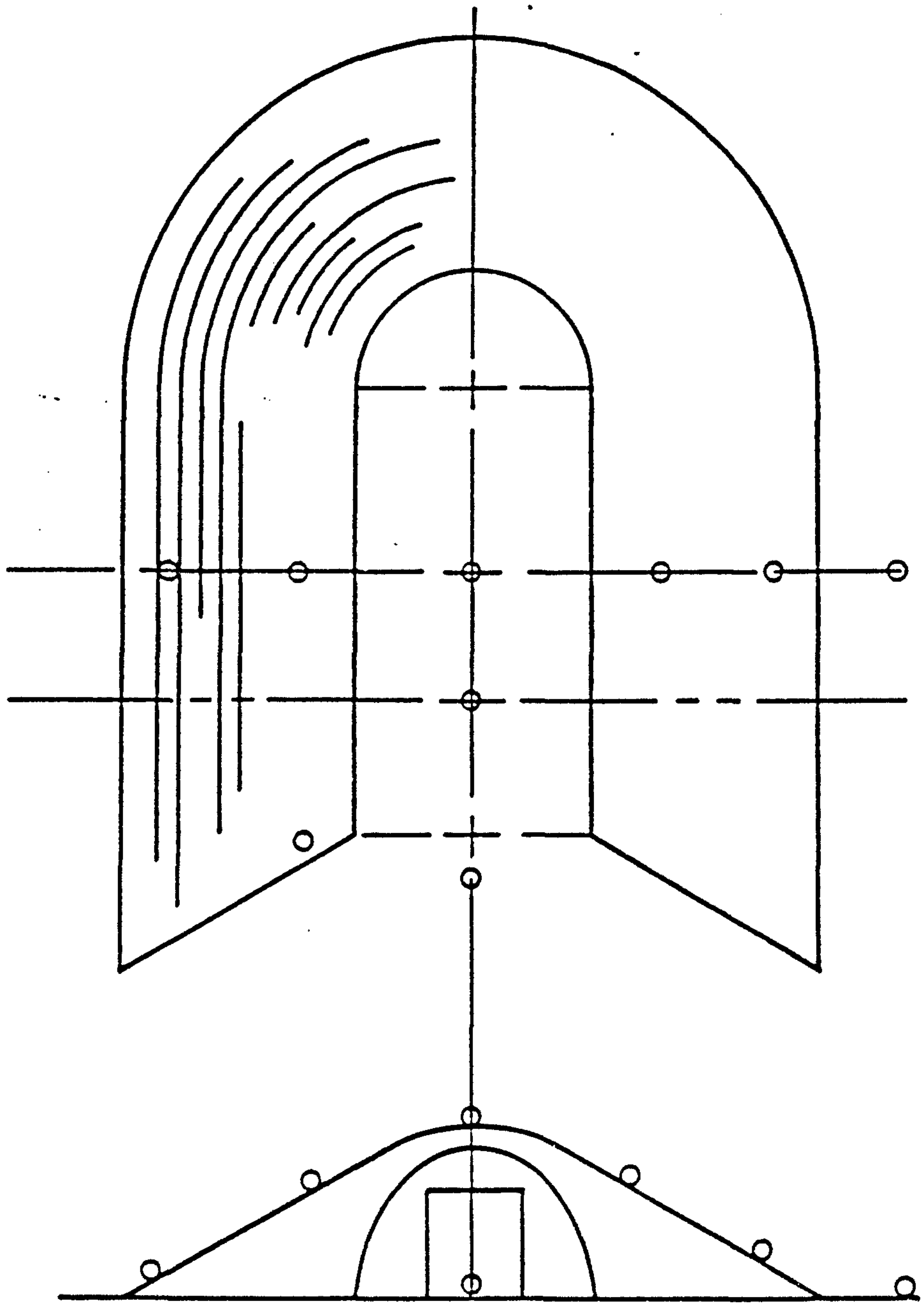


Figure C-3. Blast Pressure Gage Locations

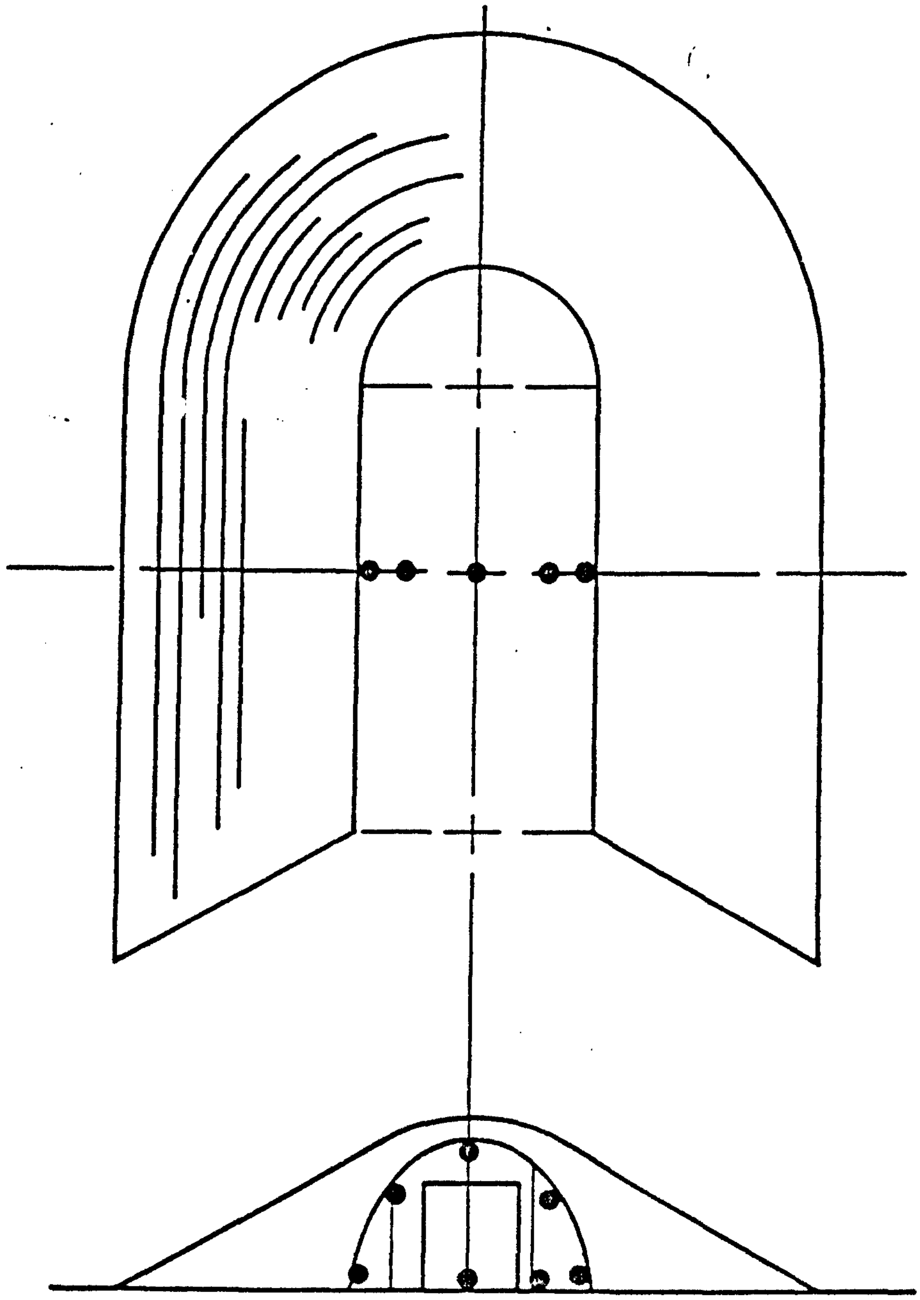


Figure C-4. Accelerometer Gage Locations

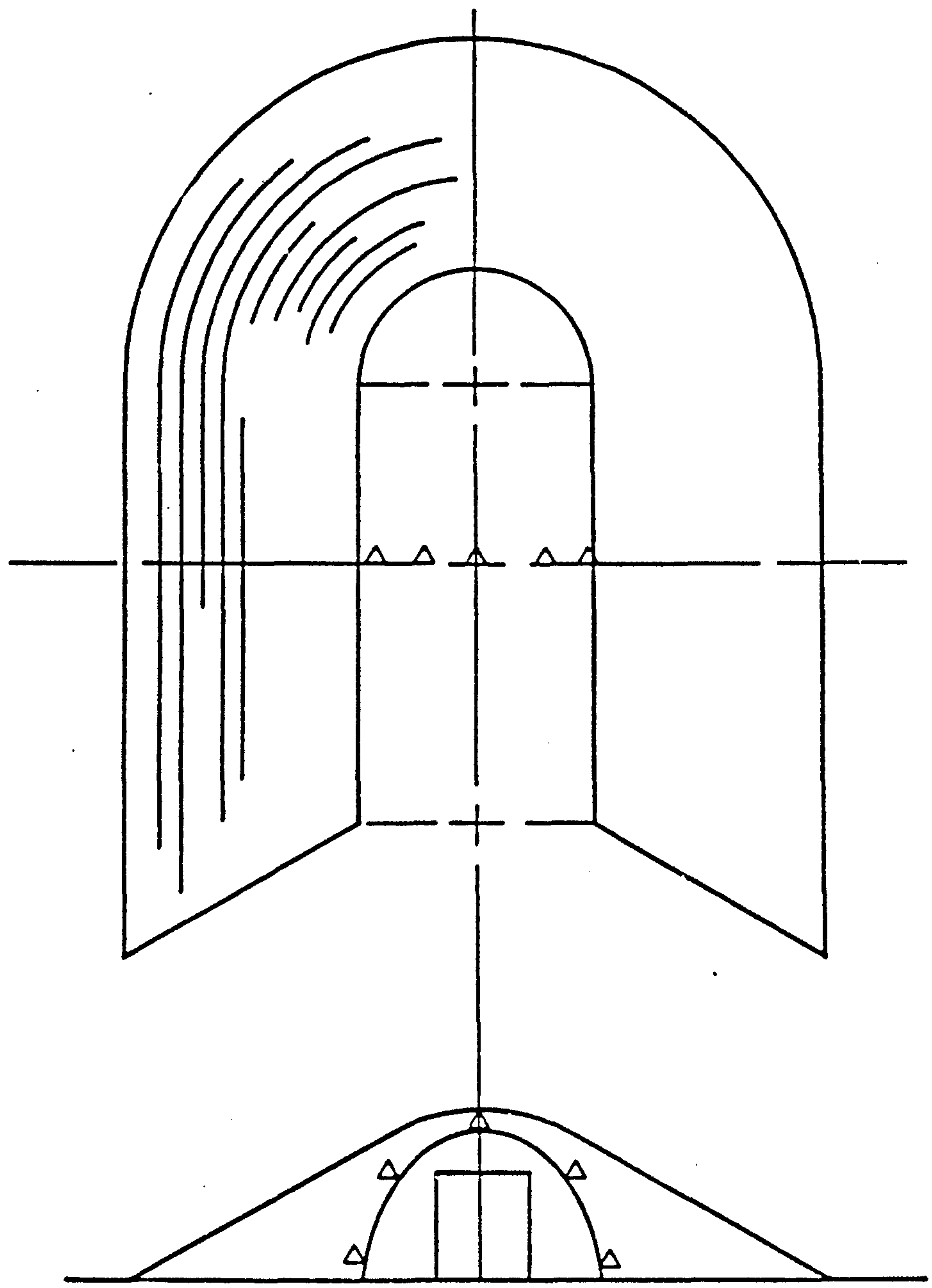


Figure C-5. Interface Pressure Gage Locations

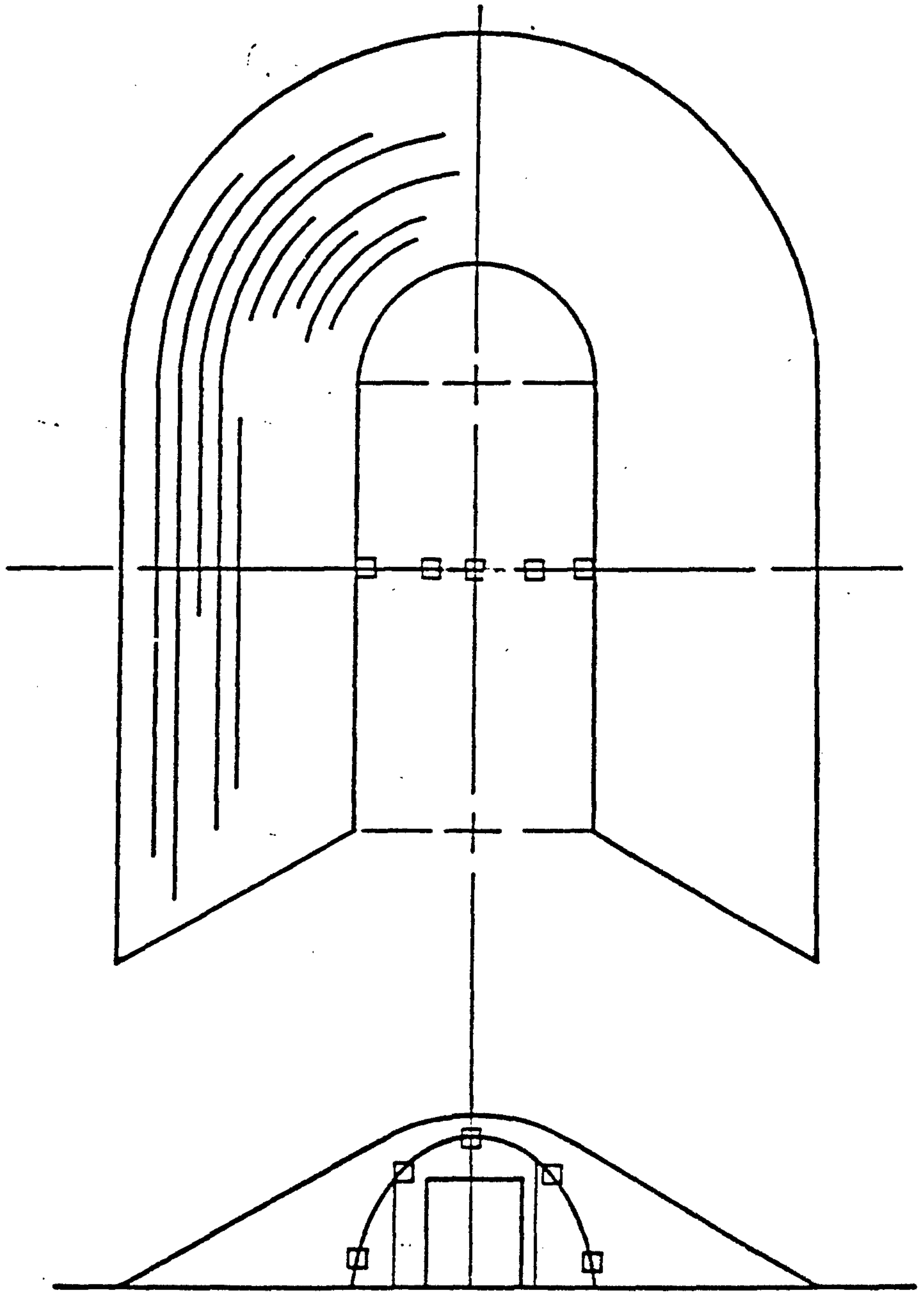


Figure C-6. Stee' Strain Gage Locations

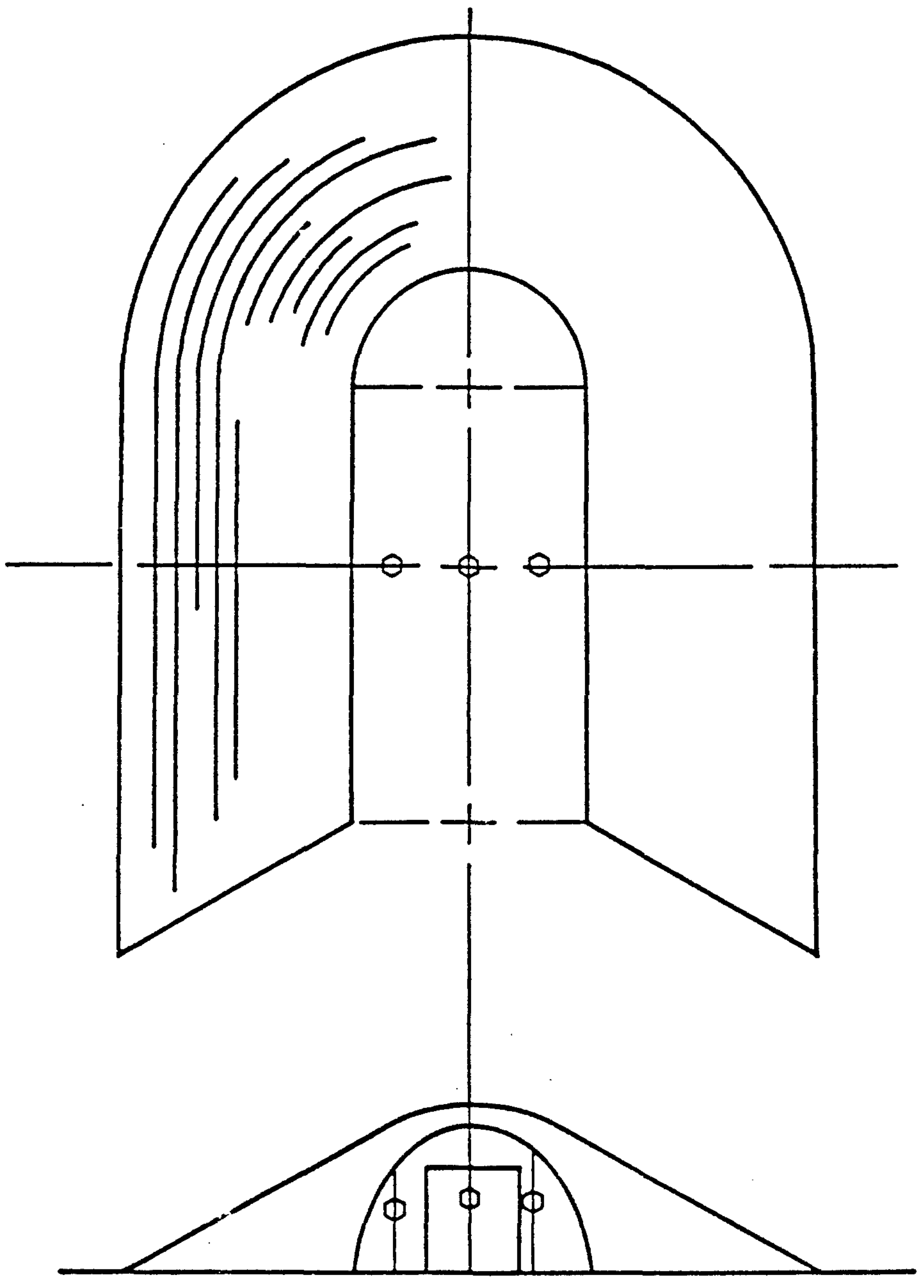


Figure C-7. Passive Displacement Gage Locations

- Photo
- Field operations
- Instrumentation systems
- Data Collection, reduction and distribution

The use of appendixes will facilitate the update/revision process without reissue of the entire test plan. Revisions will be reviewed and approved by appropriate program personnel prior to distribution.

G. REPORTING

The evaluation of the construction process for both shelters will be closely monitored and the results documented in a Construction Report. During the test program, Quick-Look Reports will be written within 30 days after each test event. At the conclusion of the test program a Final Report will be written documenting the entire program.

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