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COST ASSESSMENT FOR SHIELDING OF C^3 TYPE FACILITIES

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

1 March 1980

Final Report for Period 29 January 1979—29 February 1980

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Riveted Shield
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Arc Sprayed Zinc
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Costs were estimated for four slightly different designs for an all-welded steel envelope shield to protect a C^3 facility against high-altitude EMP, and for an alternative shield design using overlapping steel sheets joined by powder-driven pins and with seams arc sprayed with zinc. The all-welded shields are substantially more expensive because of the high cost of MIG welding.

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SUMMARY

The purpose of this program was to assess the costs of providing all-welded steel envelope shields to protect C^3 facilities from the EMP effect of high-altitude nuclear detonations. Costs were to be developed for three levels of shielding -- 30, 60, and 100 dB -- both for new construction and for shield retrofit to an existing building. For purposes of estimating costs to shield a C^3 facility, a building size of 60 feet wide by 200 feet long by 20 feet high was assumed in all cases.

Baseline facility requirements, electrical design of the shield, and cost estimates for shield quality control were developed by IIT Research Institute. Baseline utilities design requirements, mechanical design of the welded shields, and cost estimates for the welded shield implementations were provided by L. B. Knight & Associates, Chicago, IL, an architectural and engineering firm acting as consultant and subcontractor to IITRI. Subsequently, IITRI developed a design outline and a rough cost estimate for a shield fastened by powder-driven pins instead of welding.

The practical limitations and relative costs for MIG welding of steel sheets in the field resulted in the choice of 11 ga (0.12 inch) material for all the welded shields. This thickness is more than adequate to provide a shielding effectiveness of 100 dB based on absorption loss within the material. Consequently, separate designs were not developed for 30 dB and 60 dB all-welded shields. The actual shielding effectiveness of a shield of this thickness would depend on seam imperfections and on penetrations. Long-conductor penetrants are assumed to enter the building through a one-quarter-inch thick entry plate and a shielded entry vault.

Four basic shield configurations were studied:

- I External shield for a new building
- II Internal shield for a new building
- III Internal shield retrofit for an existing building (existing internal walls/partitions removed and replaced)
- IV Internal shield retrofit for an existing building (existing internal walls retained)

Building construction of poured-in-place concrete was assumed for these four conditions. Two additional conditions, IIIA and IVA, were assumed for existing buildings with concrete block exterior walls.

Costs for shield construction and quality assurance for Conditions I and II are estimated to be slightly greater than $1,000,000. For Conditions III and IIIA, shield costs are approximately 50 percent greater, and for Conditions IV and IVA, approximately twice as great. A very substantial portion of the costs for all these configurations is due to the high cost of MIG welding of the shield seams.

As an alternative to an all-welded shield, a design was considered using overlapping sheets which are fastened together mechanically, as well as fastened to the inner surface of the building, using powder-driven pins (Condition V). Since welding of these sheets is not required, thinner material can be used (14 ga or 18 ga). Seams would be arc sprayed with zinc for good electrical continuity. The welded one-quarter-inch entry plate is still retained. The cost for this design was roughly estimated as $525,000 -- about half that for Condition II (all welded).

In comparing the costs of providing a shielded C^3 building, it may be desirable to include the cost of the building, especially if a new building is to be constructed (Conditions I, II, and V). In this case the costs for Conditions I, II, and III are comparable (within about 10 percent), Condition IV is approximately 30 percent more costly, and Condition V is approximately 35 percent less costly.

Table 10, Section 9 presents a summary of the costs associated with each configuration and/or option.

While the design for Condition V appears to be very attractive economically, no experimental evidence is available regarding the shielding effectiveness of a facility of this type. Also, the practicality of this type of construction for the floor shield is uncertain due to the resulting surface roughness caused by the pin heads, and also due to uncertainty of the long term integrity of the arc-sprayed zinc seams under heavy or varying weight loads. If a welded 11 ga floor shield were required, the cost would increase approximately $100,000.

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SECTION 1

INTRODUCTION

1.1 GENERAL

This is the Final Report on Tasks I, II, III, and IV of Contract DNA 001-79-C-0205, and is concerned with the development of cost estimates for shielding command, control, and communications (C^3) type facilities against electromagnetic pulse (EMP) radiation from high-altitude nuclear detonations. These four tasks consisted of:

(1) Establishing baseline requirements
(2) Electrical design of shield
(3) Mechanical design of shield
(4) Estimation of cost and ease of implementation.

This work was performed for the Defense Nuclear Agency, Washington, DC and was under the direction of Capt. Mike King (VLIS).

1.2 DESCRIPTION OF PROGRAM

1.2.1 Purpose

The purpose of the program was to provide electrical and mechanical concept design of envelope shielding alternatives to meet specified EMP field attenuation requirements, and to provide budgetary cost estimates for implementing these designs. The required shield designs are for an entire C^3 facility, i.e., a building, and not for individual shields for the equipments and systems within a facility. The various all-welded shield configurations considered were:

- New building construction; external shield
- New building construction; internal shield
- Retrofit construction with interior (room) walls removed and replaced; internal shield
- Retrofit construction with interior (room) walls retained; internal shield.

It was the intent of the program to determine designs and cost estimates for welded shields providing 30, 60, and 100 dB shielding levels. However, as will be pointed out in the report, a limitation on the minimum gauge of steel sheet which can be welded in the field resulted in a welded design of 100 dB only. Use of powder-driven pins, instead of welding, to fasten the shield could permit use of thinner sheets, and a preliminary design is presented for this case.

1.2.2 Procedure

The program was conducted by IIT Research Institute and by L. B. Knight & Associates, Inc., an architectural and engineering firm acting as a consultant and subcontractor to IITRI. IITRI was responsible for determining the general baseline facility requirements, electrical design of the shield, and shielding effectiveness validation and maintenance requirements. Knight was responsible for baseline utilities design requirements, the mechanical design of the welded shields, and estimating the cost and ease of the welded shield implementation. IITRI developed a design outline and a rough cost estimate for a thinner shield fastened by powder-driven pins instead of welding.

1.3 ORGANIZATION OF THE REPORT

Section 2 of the report presents the baseline design, including the assumed facility requirements, a floor plan of a building accommodating the functions typically required of a C^3 facility, and a general description of the required utilities.

Section 3 presents the electrical designs of the welded shields, Initially, the shielding requirements are discussed, followed by the design approach. First, linear behavior of the steel shield is assumed; then the effects of magnetic saturation are considered. Five shield configurations are listed.

Section 4 provides mechanical details of the welded shield construction. First, features common to each of the four configurations are given, followed by the construction details for the four individual configurations.

Section 5 presents the opinions of probable costs for each of the configurations of welded shields.

Section 6 outlines the mechanical design for a shield fastened with powder-driven pins, with the cost estimate given in Section 7.

Section 8 discusses requirements for shield quality control, effectiveness tests, and maintenance costs during the lifetime of the shield.

Conclusions and recommendations are given in Section 9, and References in Section 10.

Appendix A lists some factors affecting the cost estimates for the all-welded shield designs, and Appendix B presents detailed listings of construction materials and labor for all shield configurations studied.

SECTION 2

BASELINE DESIGN OF C^3 FACILITY

2.1 FACILITY REQUIREMENTS

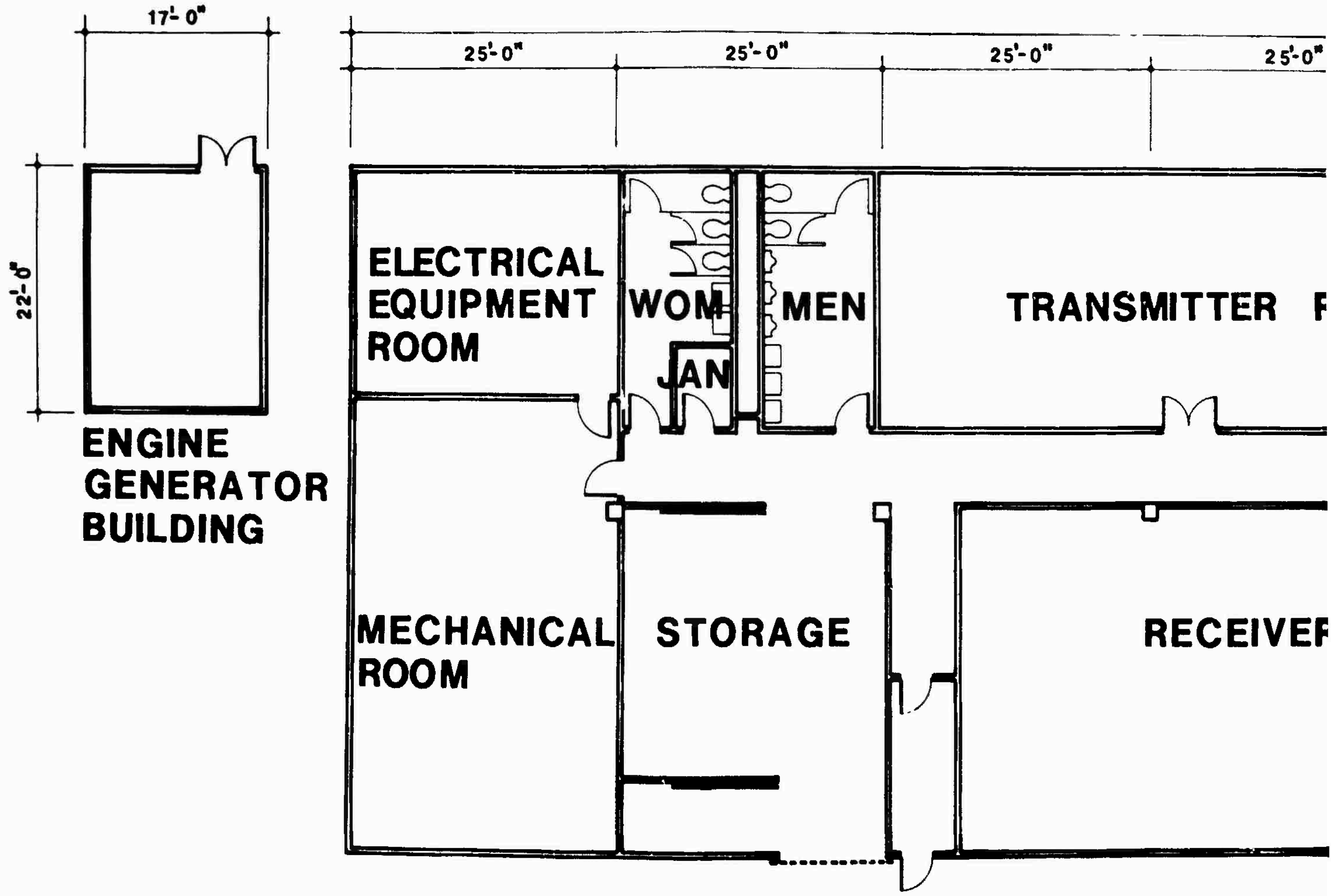
In order to obtain representative as well as comparative cost estimates for the various C^3 facility shield designs, the following parameters and characteristics were selected for an assumed prototype C^3 facility:

Building Size:	60 feet wide by 200 feet long by 20 feet high
General Construction:	One story, above ground, windowless, reinforced concrete
Personnel Occupancy:	60 to 80 men and 15 to 20 women, 24 hours/day, continuous use
Electronic Equipment:	3 transmitters, each 10 kW output power 20 to 30 receivers 8 to 10 TTY computer and peripherals standard office equipment
Geographic Location:	Midwestern U.S.
Shield Penetrants:	commercial power, 3ϕ, 440 v Rms, 4-inch conduit water and sewage pipes telephone cable, 100 pairs coaxial cables: ten one inch conduits, five two-inch conduits waveguides: two 1 1/2 x 3 inches
Shield Type:	steel envelope, continuous entry vault; 1/4 inch steel entry plate
Access Doors:	Personnel: main entrance/exit; emergency exit Cargo: sliding door
Shield Lifetime:	20 years minimum

2.2 BASIC ARCHITECTURAL AND STRUCTURAL DESIGN

For purposes of evolving shield designs and shield cost estimates, the building flo plan shown in Figure 1 was used. Approximately 70 percent of the floor area is devoted to four main rooms for receivers, transmitters, operations, and computer facilities. Th remainder of the building is allotted to an entry vault, a receiving and storage area, washrooms, janitor closet, and corridors. A separate, unshielded, Engine Generating Building is assumed.

The entry vault serves to house protective devices such as surge arresters, filters and circuit breakers to reduce the EMP energy which the penetrants would otherwise cause to couple into communications circuits and electrical power lines. Two separate section


17'- 0"
22'- 0"
ENGINE GENERATOR BUILDING
25'- 0"
25'- 0"
25'- 0"
25'- 0"
ELECTRICAL EQUIPMENT ROOM
WOM
JAN
MEN
TRANSMITTER
MECHANICAL ROOM
STORAGE
RECEIVER

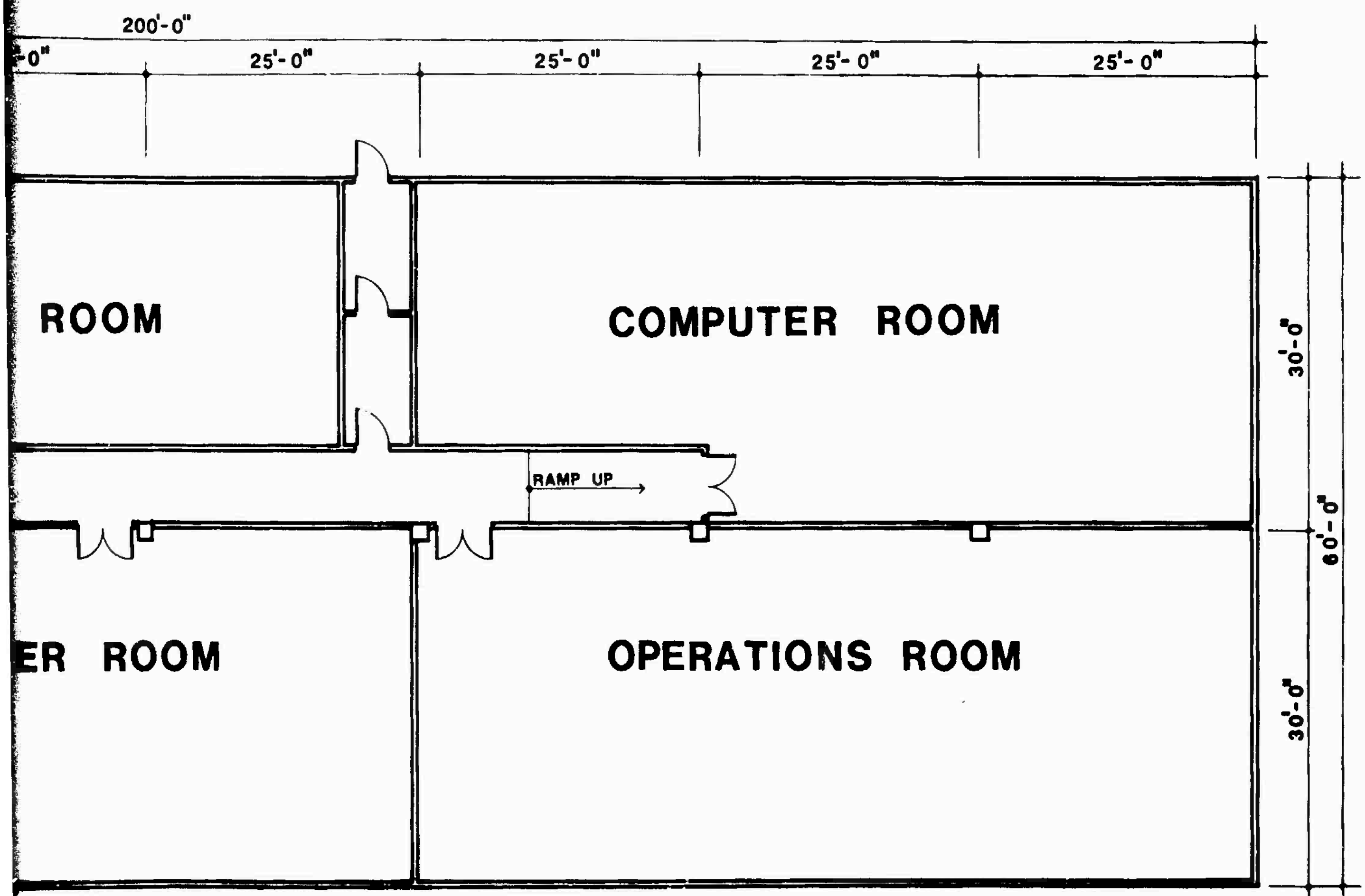


FIGURE 1. ARCHITECTURAL/STRUCTURAL FLOOR PLAN

of the vault are provided: one for the entering electrical power lines, and one for the communications lines. The costs for the protective devices normally within the entry vault are not included in this cost study.

All doors for personnel entry and exit in the C^3 facility are hinged. The main entrance/exit has a standard outside all-weather door plus two shielded doors in a shielded vestibule. The shielded doors are assumed to be interlocking so that only one can be open at any given time. The emergency exit has one shielded door, normally closed, and an all-weather exterior door.

The cargo/storage area has a standard exterior roll-up door on the cargo dock. The storage room itself has two shielded sliding doors, one on each side of the (shielded) storage room. Again, the doors are interlocked so that only one can be open at any one time.

The building is assumed to be poured-in-place reinforced concrete. The roof slab is 20 feet above a 6 inch floor slab on grade. Roof support is provided by seven columns 20 by 20 inches, 25 feet on center, along the building centerline, and by a 6 inch perimeter wall.

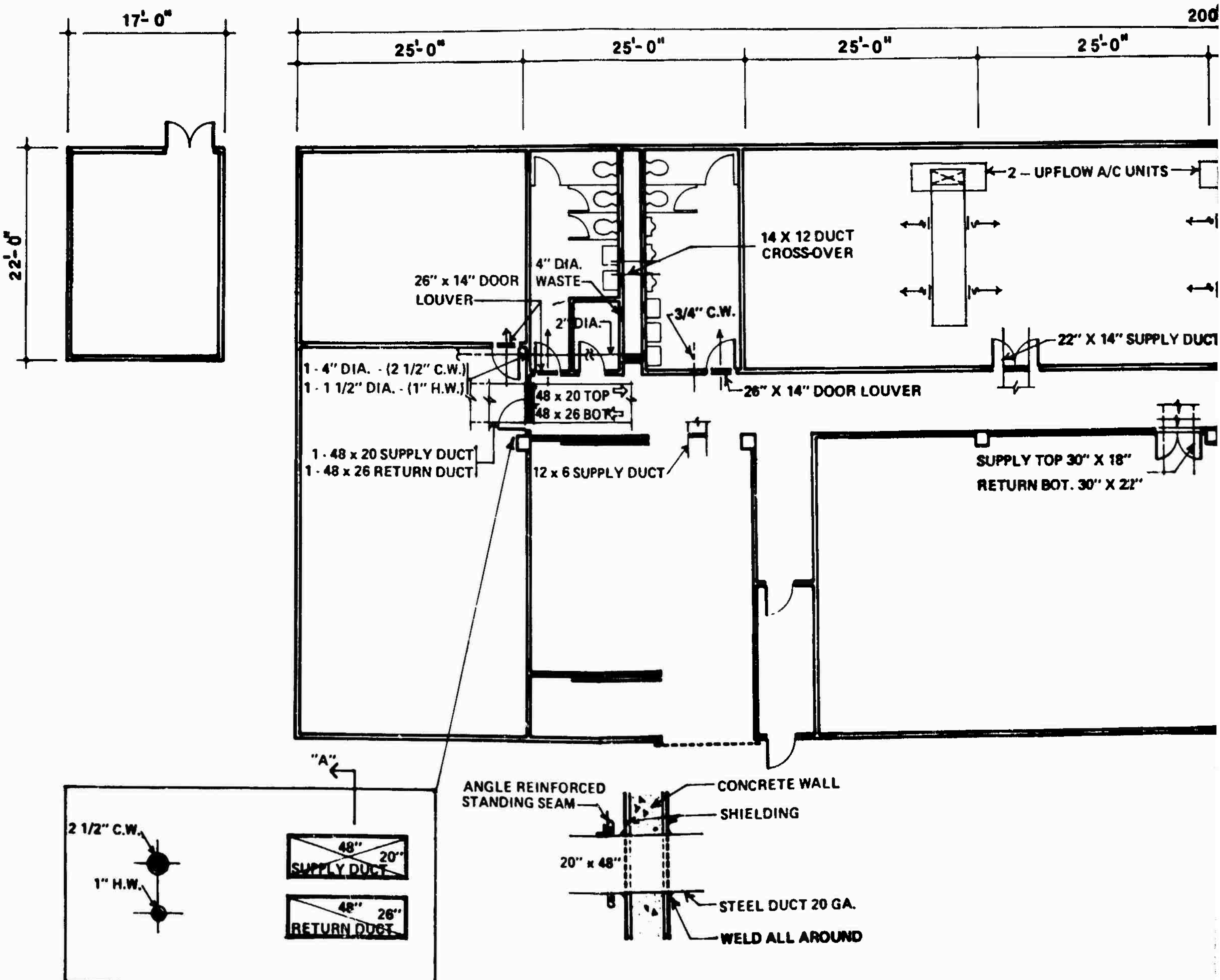
The building is not designed to be blast-proof. It was found that no additional structure is needed to carry the five pound per square foot loads imposed by the steel shielding. The structural design, therefore, is in no way different from that of a conventional building, and no additional costs are incurred. The building is designed in conformance with the Uniform Building Code, 1978 edition, under the category "Office Buildings".

The Computer Room is to have a raised floor, finished, as are floors in all other areas, in vinyl asbestos tile. Ceilings are to be acoustic tile with 2 x 4 foot fluorescent fixtures located four feet on center. Walls are assumed to be covered with painted gypsum wall board. When interior shielding is used, special techniques are required to apply to or suspend the ceiling from the ceiling shield.

2.3. UTILITIES DESCRIPTIONS

2.3.1 Heating, Ventilating, and Air Conditioning

Self-contained air-conditioning units, with an automatic temperature and humidity control panel, are utilized in the Transmitter and Computer Rooms. These units are to have individual, remote, dry cooler condensers on the roof, with interconnecting steel water piping penetrating the shield. Each of these rooms is to be provided with two units, each sized to handle two-thirds of the heat load for the room. Ventilation required for these rooms is to be provided by a central unit (see Figure 2).


17'- 0"
22'- 0"
200
25'- 0"
25'- 0"
25'- 0"
25'- 0"
2 – UPFLOW A/C UNITS
14 X 12 DUCT
CROSS-OVER
4" DIA.
WASTE
26" x 14" DOOR
LOUVER
2" DIA.
3/4" C.W.
22" X 14" SUPPLY DUCT
1 - 4" DIA. - (2 1/2" C.W.)
1 - 1 1/2" DIA. - (1" H.W.)
48 x 20 TOP
48 x 26 BOT
26" X 14" DOOR LOUVER
1 - 48 x 20 SUPPLY DUCT
1 - 48 x 26 RETURN DUCT
12 x 6 SUPPLY DUCT
SUPPLY TOP 30" X 18"
RETURN BOT. 30" X 22"
"A"
2 1/2" C.W.
1" H.W.
48"
20"
SUPPLY DUCT
48"
26"
RETURN DUCT
ANGLE REINFORCED
STANDING SEAM
CONCRETE WALL
SHIELDING
20" x 48"
STEEL DUCT 20 GA.
WELD ALL AROUND

SECTION "A"

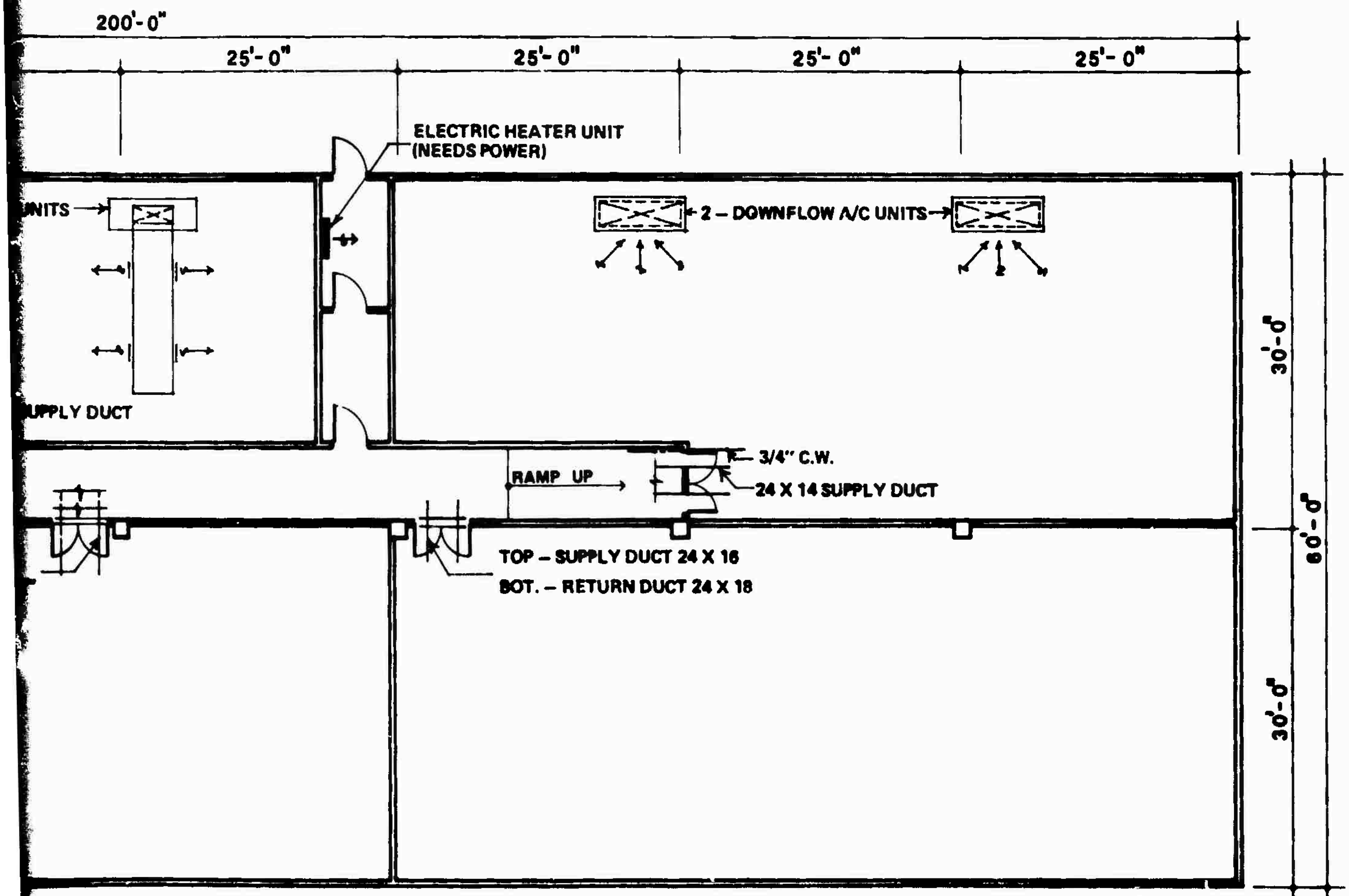


FIGURE 2. HVAC PLAN WALL PENETRATIONS

10 0 10 20 FT.

A separate, variable-air-volume, unit is to be located in the Mechanical Equipment Room to serve the Operations Office, Receiver Room, Corridor, and Storage Room. A matching air-cooled condensing unit mounted on the roof is also to be provided. An exhaust-return fan is to be provided to utilize outdoor air for cooling. Shield penetrations for this system are to be as follows: 5 feet by 2 feet for outdoor air intake; a 2 feet 6 inch exhaust return fan discharge; and steel piping from the condensing unit. Duct penetrations are to terminate at RF honeycomb shielded air vents. Air supply systems for this unit are to be arranged so that air can be temporarily diverted to either the Transmitter Room or Computer Room in case one of the room air-conditioning units is out of operation.

Exhaust fans for Toilet Rooms and the Mechanical Equipment Room are to be provided. Fans are to be located indoors, and the exhaust duct is to discharge outdoors through an RF honeycomb shielded air vent.

The heating system is assumed to be electrical and the main entrance is to be provided with an individual electric cabinet unit heater. Electrical unit heaters are to be provided in the mechanical, equipment room and in the emergency generator room.

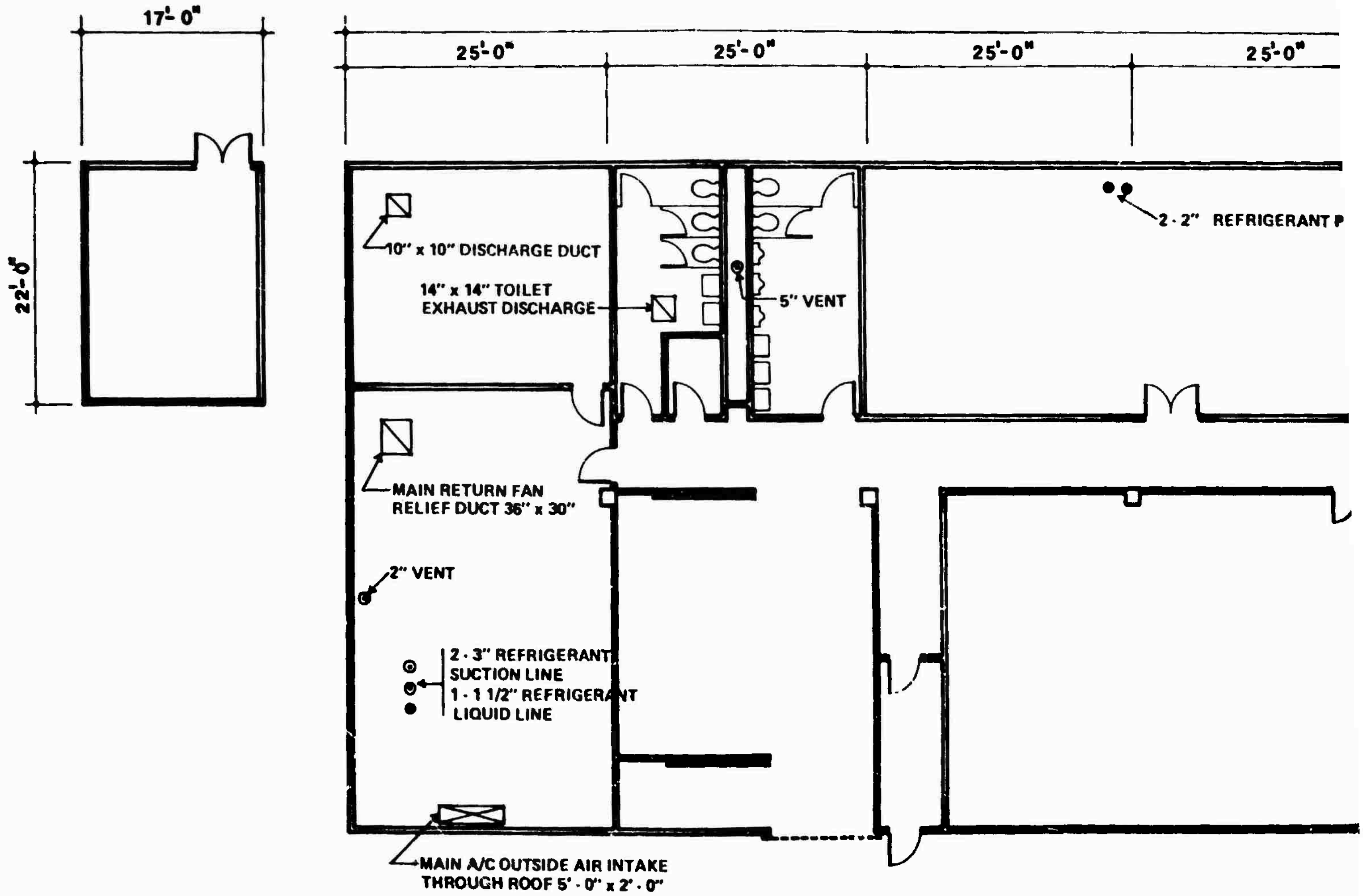
Ductwork and points of shield penetrations are identified in Figure 3.

2.3.2 Electrical

The plan in Figure 4 identifies all points at which electrical conduit penetrates the shield to serve the power, lighting, communications, and security systems. Each of these points is to be protected as detailed later in the discussion of penetrations. The size, location, and number of penetrations are based on maximum equipment power requirements as assumed here. They are as follows: Transmitter Room, 80 K W at 208V/120 volts; Receiver Room, 32 K W at 208V/120 volts; Computer Room, 100 K W at 208V/120 volts; and Operations Office, 10 K W at 208V/120 volts.

Lighting levels are based on Illuminating Engineering Society recommendations, and the system is designed to operate at 277 volts. The intensities are as follows: equipment areas 70-100 foot-candles (F C); corridor, 20-30 F C;

Diversity and demand figures are based on 24 hour-per-day, 7 day-a-week operation, with simultaneous equipment operation. The estimated total loads are as follows: equipment, 222 K W; lighting, 45 K W; and H V A C, 133 K W; total load is therefore 400 K W. Standby power generation is required to provide 100% emergency power for a 30-day period. On the basis of a load of 400 K W, a 440 KW, 480V diesel engine-generator, rated for continuous operation, is required.



17'- 0"
22'- 0"
25'- 0"
25'- 0"
25'- 0"
25'- 0"
10" x 10" DISCHARGE DUCT
14" x 14" TOILET
EXHAUST DISCHARGE
5" VENT
2 - 2" REFRIGERANT
MAIN RETURN FAN
RELIEF DUCT 36" x 30"
2" VENT
2 - 3" REFRIGERANT
SUCTION LINE
1 - 1 1/2" REFRIGERANT
LIQUID LINE
MAIN A/C OUTSIDE AIR INTAKE
THROUGH ROOF 5' - 0" x 2' - 0"

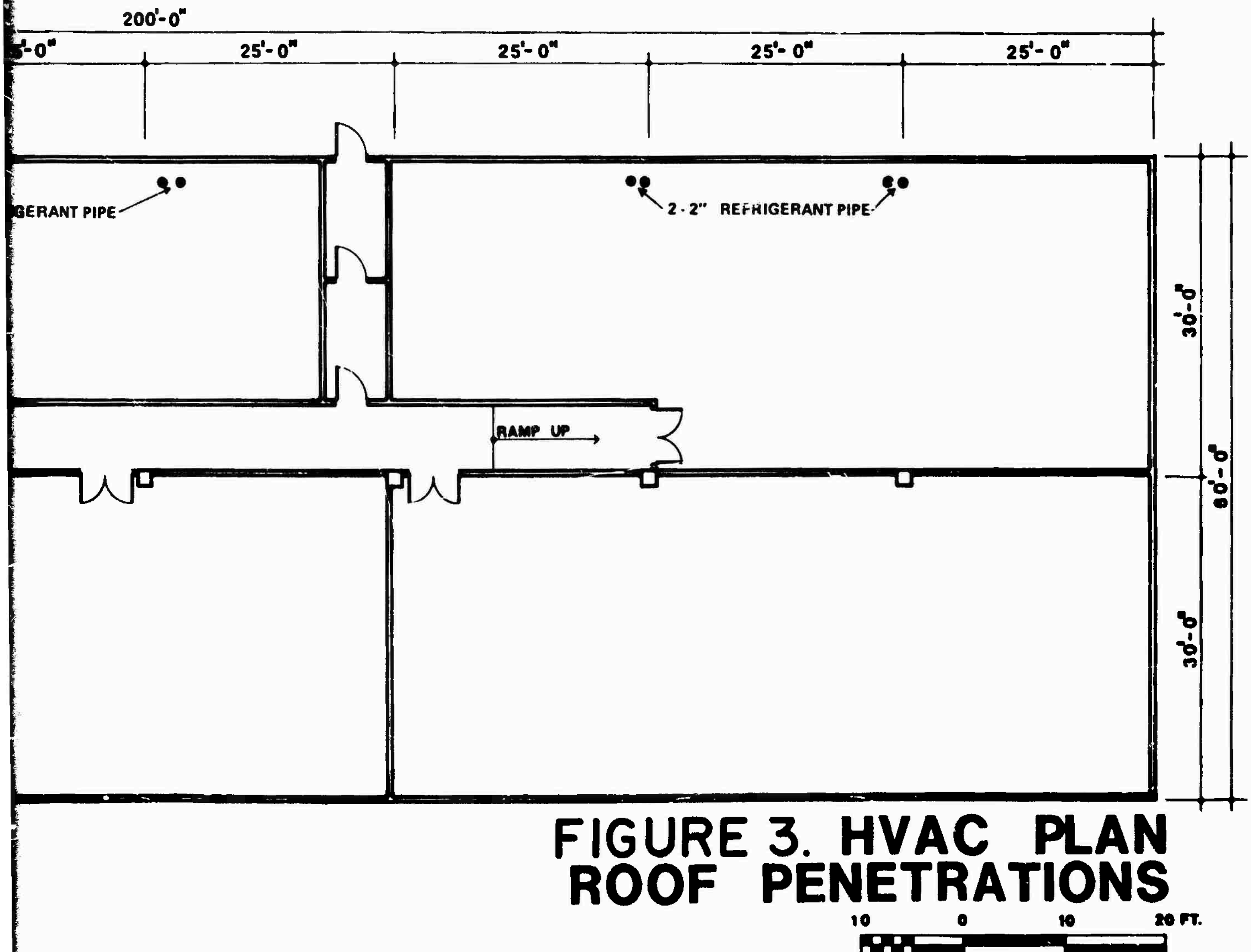
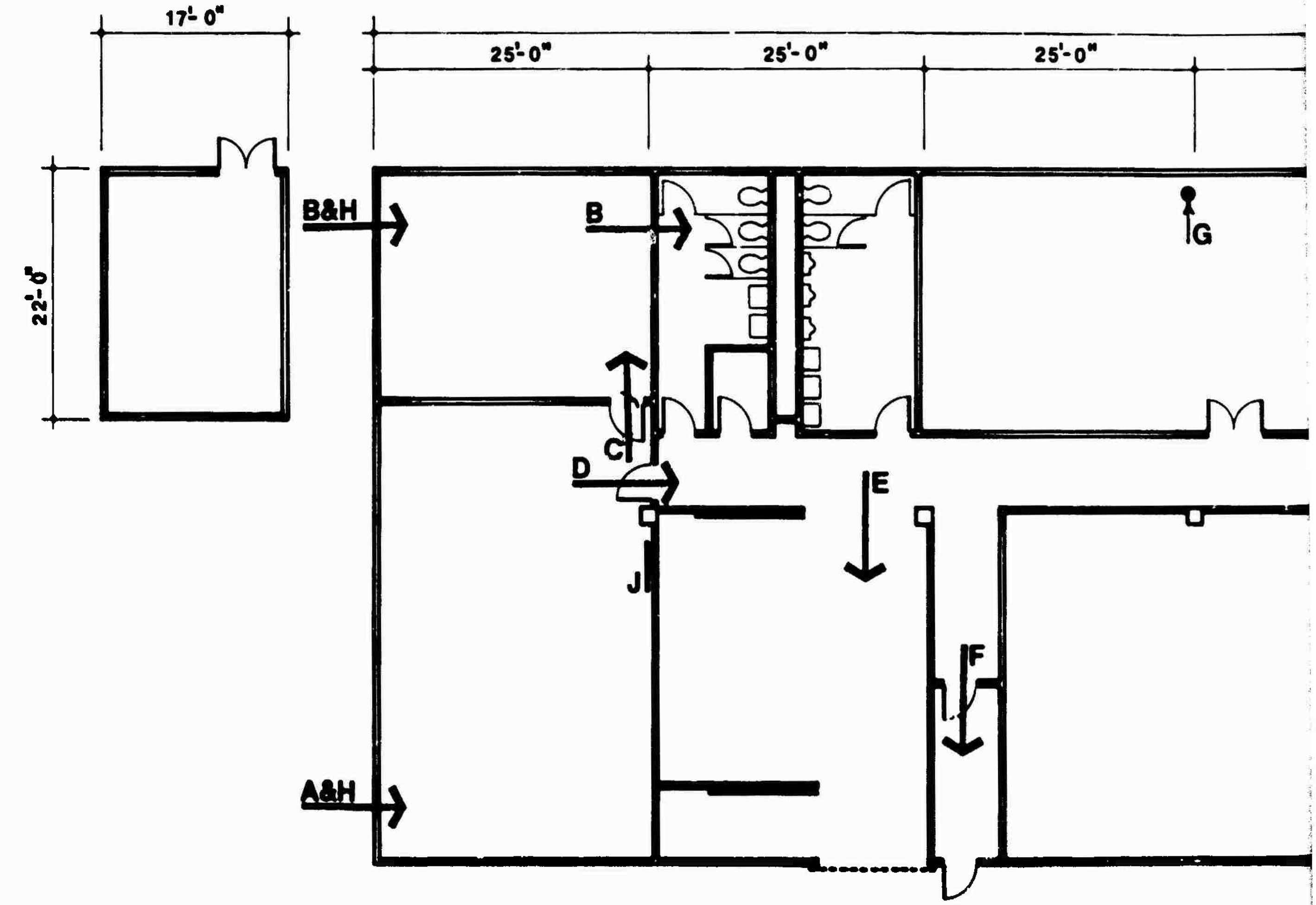


FIGURE 3. HVAC PLAN
ROOF PENETRATIONS



A. 2 - 3" C POWER
2 - 1" C CONTROL/ALARM
1 - 2" C SITE LIGHTING
1 - 1 1/2" C SECURITY
1 - 2" C GENERATOR BUILDING POWER

B. 3 - 2 1/2" C TELEPHONE
10 - 1" C RECEIVER
5 - 2" C TRANSMITTER
2 - 3" x 1 1/2" WAVEGUIDE

C. 1 - 3/4" C LIGHT & RECEPTACLE

D. 2 - 4" C POWER
3 - 2" C POWER
1 - 1 1/2" C SECURITY

E. 1 - 3/4" C LIGHT & RECEPTACLE
1 - 3/4" C SECURITY

F. 1 - 3/4" C LIGHT & RECEPTACLE
1 - 1 1/2" C SECURITY
1 - 1" C ELECTRIC HEATER

G. UP TO
1 - 1"
1 - 3/4"

H. SHIEL

J. POWE

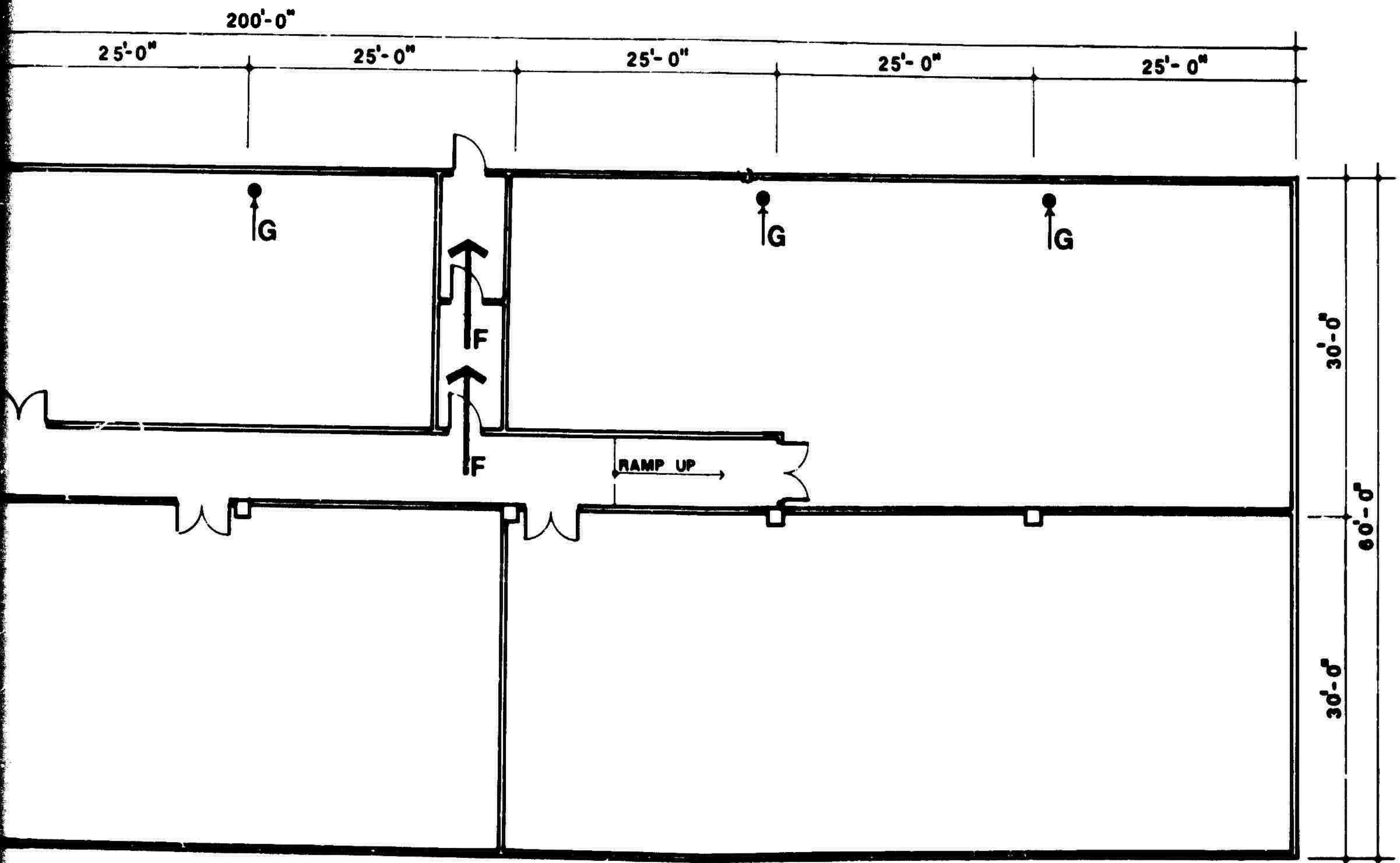


FIGURE 4. ELECTRICAL PLAN WALL/ROOF PENETRATIONS

10 0 10 20 FT.

UP TO ROOF
1 - 1" C POWER
1 - 3/4" C CONTROL

SHIELDED ENTRY BOX

POWER CABLE FILTERS
6 @ 400A
8 @ 200A
4 @ 100A

HARDEN THE FOLLOWING ITEMS LOCATED IN REMOTE GENERATOR BUILDING
1. CONTROLS
2. BATTERY CHARGER

The following conduit requirements are assumed: ten 1 inch conduits for the Receiver Room; five 2 inch conduits for the Transmitter Room; and two 3 by 1 1/2 inch wave guides. Telephone requirements are taken at three times the commercial need for similar occupancy, or 2 1/2 inch conduit. In addition, a 1 1/2 inch conduit is provided for security monitoring.

Because of engine heat rejection, combustion air requirements, and noise problems, it was considered desirable to locate the engine-generator in a separate building. Most of the control equipment is to be located in the shielded area of the C^3 building. However, such items as the engine alternator and battery charger are to be located in the Generator Building. These items are to be individually EMP-hardened. The Generator Building itself is not shielded.

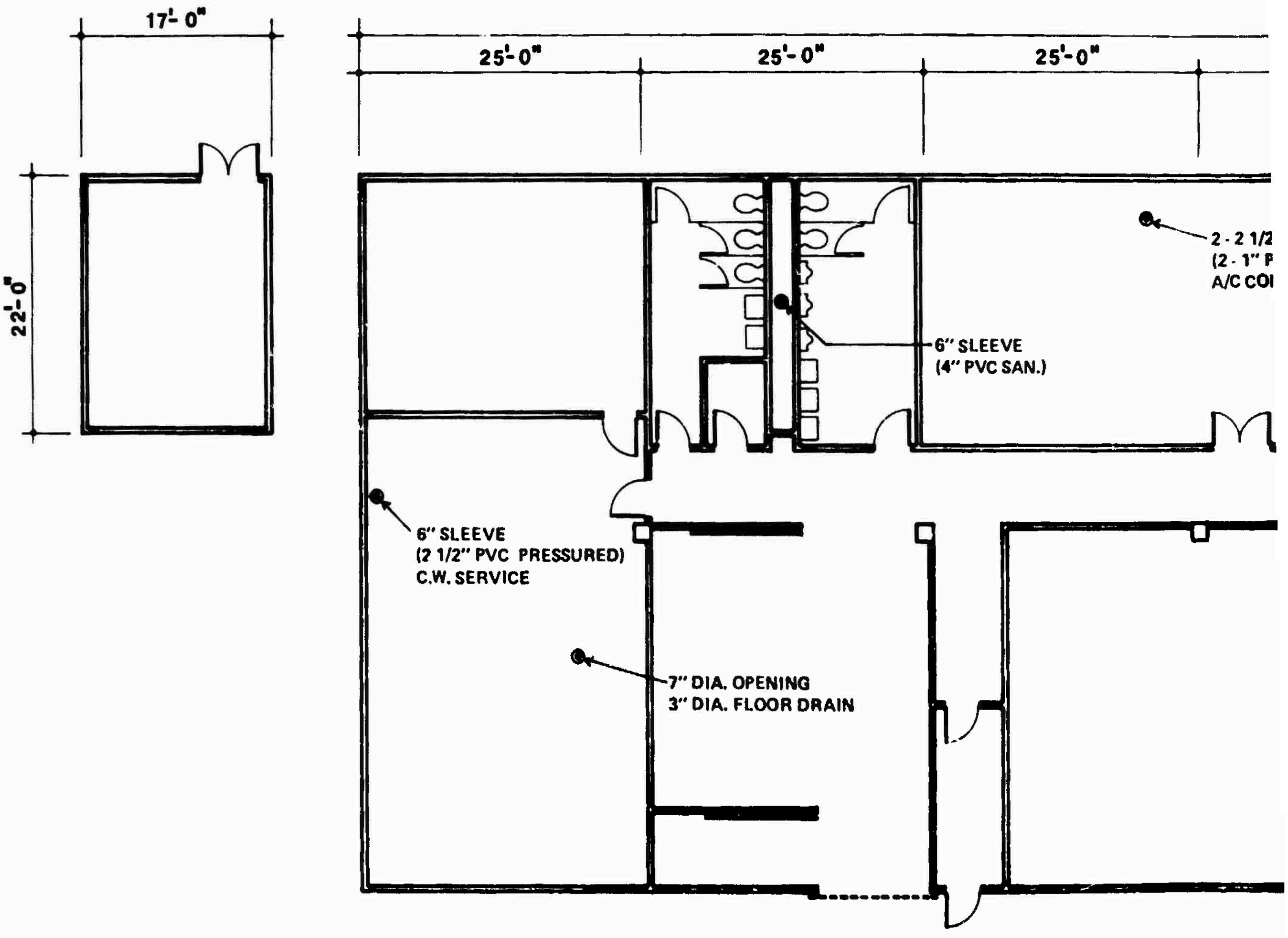
2.3.3 Plumbing/Fire Protection

The cold water supply is to be metered in the Emergency Generator Building before it is extended into the C^3 facility. A separate cold water source may be provided either by a storage tank or by a deep-well pump. An electrical hot water heater is to be provided in the Mechanical Equipment Room to serve all lavatories in the Toilet Rooms.

Roof drainage is to be collected through scuppers and outdoor metal downspouts. All plumbing fixtures with complete piping connections are to be provided, and shield penetrations are shown on the plan in Figure 5.

All piping below the floor slab is to be non-metallic. Floor penetrations of plumbing pipes are to be as discussed in Section 3, and are located on the plan in Figure 5. A second source of domestic water is to be carried to the building from municipal mains. It is assumed that no water-cooled computer equipment is to be provided for.

While it is certain that the C^3 building would have a fire protection system, these requirements have been omitted here since they would be expected to affect all shield designs approximately equally.



NOTES:

1. UNDERGROUND
PIPES TO BE PLA

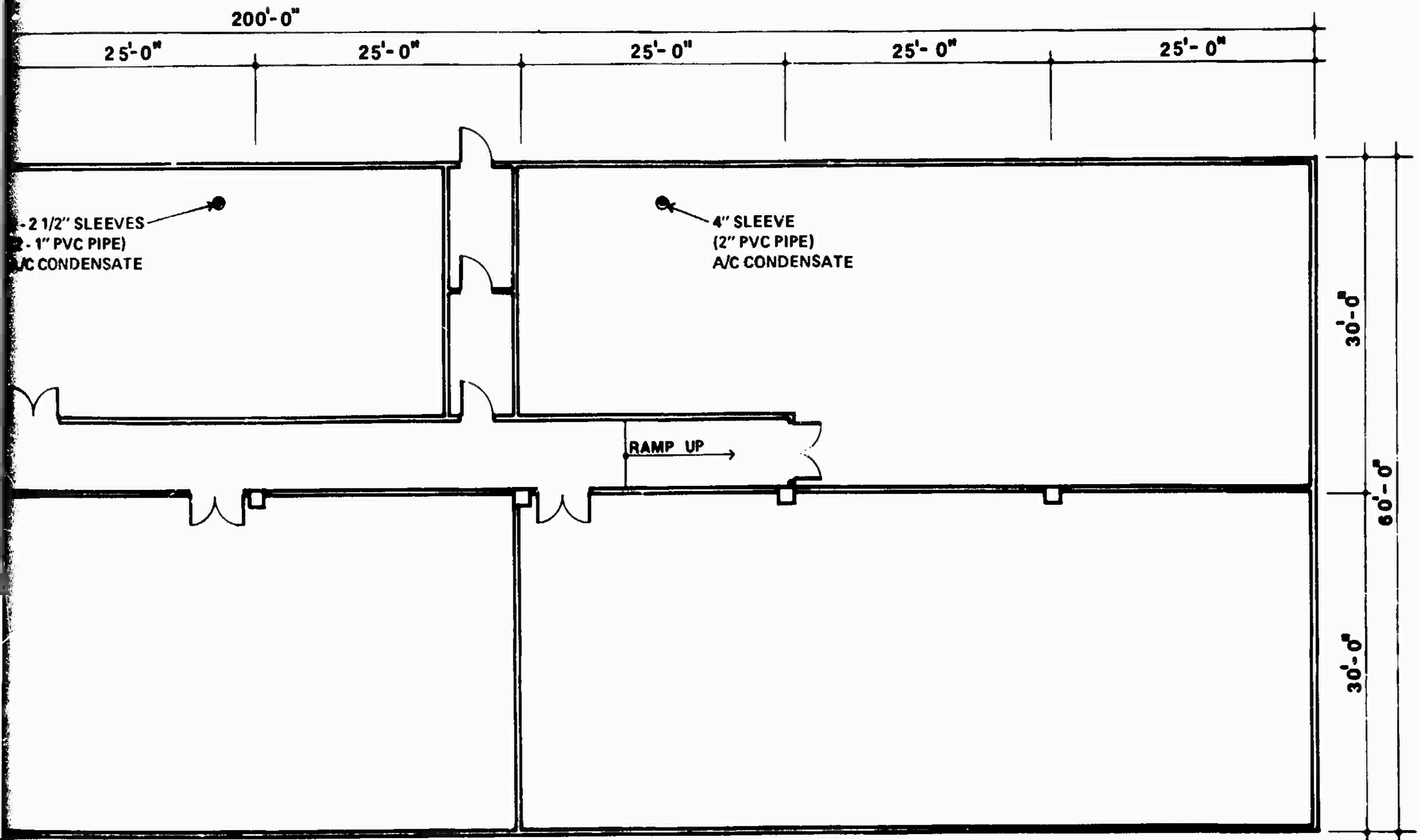


FIGURE 5. PLUMBING PLAN FLOOR PENETRATIONS

10 0 10 20 FT.

ROUND SANITARY & COLD WATER
BE PLASTIC

SECTION 3

ELECTRICAL DESIGN FOR SHIELDS

3.1 INTRODUCTION

This section of the report first discusses the shielding requirements in terms of a threat level of EMP radiation incident upon an infinite flat shield. Then the current concentrations along edges of a realistic shield and currents injected onto the shield from penetrants are considered.

Next, the design approach is discussed. Initially, linear behavior of the shield is assumed, and the transmission line approach is used. A rationale is presented for requiring the specified shielding to be obtained from absorption loss only, without relying on reflection loss. This requirement, in turn, indicates the use of a ferromagnetic material, if shield thickness is not to become unreasonable.

Realistic threat levels of EMP radiation can cause at least partial saturation of a steel shield. A simplified discussion of the possible effect of saturation on shielding effectiveness is presented, and a family of curves is plotted showing the shield thickness required for a given degree of shielding for incident pulses of various durations and amplitudes.

Sketches are later presented showing the shield configurations for each of the four facility construction options for a welded shield. A fifth construction option, using powder-driven pins for fastening the shield, uses the same shield configuration as one of the welded designs.

3.2 SHIELDING REQUIREMENTS

3.2.1 Plane Wave Incident on Infinite Flat Sheet

As the simplest example of an EMP threat, consider a plane wave with an electric field strength of 50 kV/m incident on an infinite flat shield. The magnetic field intensity of the incident wave is then:

$$H_i = \frac{E}{\eta} = \frac{50 \text{ kV/m}}{377 \text{ ohms}} = 133 \text{ A/m} \qquad (1)$$

where η is the intrinsic impedance of free space.

When a plane electromagnetic wave is normally incident on a good conductor, the reflected wave is virtually the same amplitude as the incident wave. At the reflecting surface, the incident and reflected magnetic fields are in phase. Therefore, the total magnetic field, H_s, at the surface is twice the incident field:

$$H_s = 2H_i = 266 \text{ A/m} = 3.3 \text{ Oersted} \qquad (2)$$

3.2.2 Corner Effects

For a box-like shielded enclosure, the shielding effectiveness is commonly said to be "degraded" at the edges and corners of the enclosure. This so-called degradation is not due to any change in the intrinsic behavior of the shield material (assuming a linear, non-saturating shield), but rather due to the particular distribution of currents on the outer surface of the enclosure. The higher current concentrations along the edges produce higher magnetic fields there, and these, in turn, cause higher magnetic fields on the inside of the enclosure, in the region of edges and corners.

Figure 6 shows this effect. For example, within a distance 0.1 a from a corner -- where 2a is the wall dimension -- the field is approximately 30 dB greater than if the shield were a planar sheet (of the same material and thickness). Therefore, for a 60 foot wall dimension, the internal field will be 20 dB higher within 3 feet of the corner.

It may be desirable to impose the restriction that sensitive, susceptible equipment be excluded from the small regions within some short distance from the corners. Then, under the conditions for which the given curve applies, maintaining a 3 foot corner clearance for a 60 foot wall would indicate that the field will be no greater than 20 dB above the planar condition.

Therefore, if it is desired to achieve a shielding level of 100 dB (except within three feet of a corner, where the fields would be stronger), the shield material and thickness should be selected such that an infinite planar sheet of that material and thickness would provide 120 dB shielding.

3.2.3 Currents from Penetrants

A metallic conductor, e.g., a pipe or a cable sheath, entering a shielded facility will be circumferentially welded to the shield at the entry point. Current flowing on the conductor is then discharged onto the outer surface of the shield. It is of interest to estimate the magnitude of the resulting current density on the shield.

If the current of magnitude I flows radially from the penetration point, the current density J at any radius r is:

$$J = \frac{I}{2\pi r} \cdot \qquad (3)$$

Assuming a current of 1500 A, and an observation point on the shield at a distance r = 1 meter away from the penetrant, J = 250 A/m. This is approximately the same as the level calculated in Section 3.2.1 for an incident plane wave.

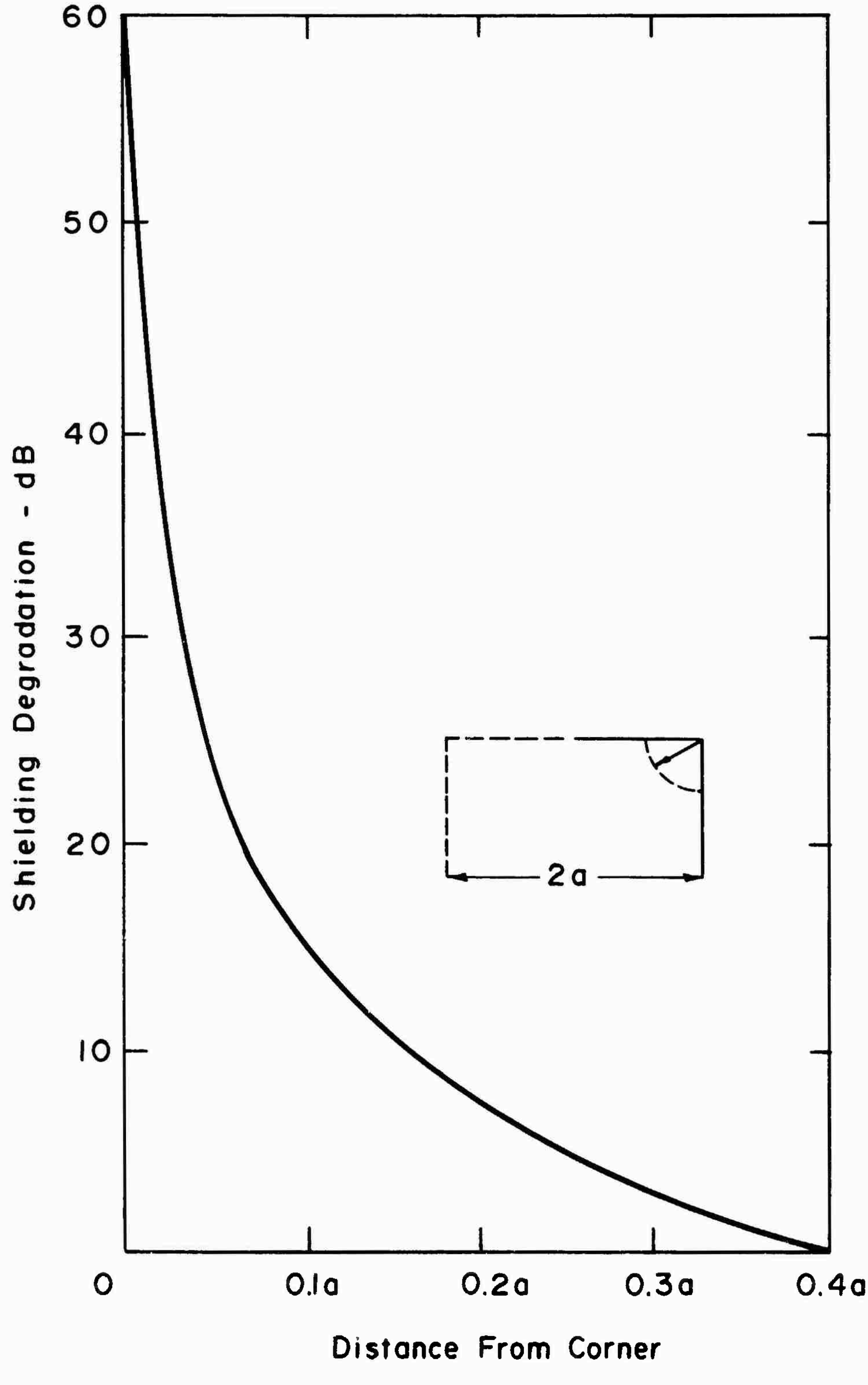


Figure 6 SHIELDING DEGRADATION NEAR CORNERS IN A SHIELDED SPACE

3.2.4 Numerical Examples

It has previously been reported[1] that a useful way to specify an upper limit on electromagnetic fields within a C^3 facility is to set a limit on the maximum time rate of change of magnetic field, dH/dt or $\dot{H}$. Such a specification can limit to safe values the maximum voltage induced in a typical electronic circuit. The maximum limit inside the C^3 facility was suggested as:

$$\dot{H}_{max} = 3(10)^5 \text{ A/m/second.} \quad (4)$$

If the field varies sinusoidally, i.e.,

$$H = H_i \sin \omega t, \quad (5)$$

then

$$\dot{H} = \omega H_i \cos \omega t, \quad (6)$$

and

$$\dot{H}_{max} = \omega H_i = 2 \pi f H_i \quad (7)$$

Letting $\dot{H}_{max} - 3(10)^5$ A/m/second and f = 10 kHz

$$H_i \simeq 2.5 \text{ A/m.} \quad (8)$$

If the shield provides 100 dB shielding, the maximum permissible current density (at 10 kHz) at the outer surface of the shield is $10^5 H_i$, or 250,000 A/m. If the shield provides 120 dB shielding, the permissible external current density (at 10 kHz) is 2.5 $(10)^6$ A/m.

From an alternative viewpoint, the required level of shielding can be derived by considering the transient phenomena of a 50 kV/m plane wave pulse of 10 nanosecond rise-time incident on the shield. In Section 3.2.1 the magnetic field at the outer surface of the shield was found to be 266 A/m. Then, for a 10 nanosecond rise time,

$$\dot{H}_{outside} = \frac{266 \text{ A/m}}{10^{-8} \text{second}} \simeq 3\ (10)^{10} \text{ A/m/second} \quad (9)$$

Using the previously suggested limit of $\dot{H}_{max} = 3(10)^5$ A/m/second inside the enclosure, the required shielding level is $3\ (10)^{10}/3\ (10)^5 = 10^5$, or 100 dB.

3.3 DESIGN APPROACH

3.3.1 Design Assuming Linear Behavior of Shield

For the purposes of this study, the achievable shielding effectiveness for a given shield material and thickness was estimated on the basis of the transmission line equations. While these equations are strictly valid only for a plane wave front incident upon an infinite planar sheet, or for certain other canonical examples, they were used as an approximation. Under these conditions the shielding effectiveness is given by:

$$S = R + A + B \tag{10}$$

where

S = Shielding effectiveness (dB)

R = Reflection loss (dB)

A = Absorption or penetration loss (dB)

B = Rereflection correction term (dB). Usually negligible; it must be included only if A is less than 15 dB.

The Reflection Loss tern can, itself, provide a very significant rejection of incident radiated energy because of the large mismatch between the impedance of the incident wave and the intrinsic impedance of the metallic shield. However, it may not always be possible to rely on reflection loss. A C^3 facility will ordinarily have attached power and telephone cables and possibly metallic pipelines. These long conductors can collect large EMP currents which, can then be injected directly onto the exterior surface of the shield. These large surface currents produce strong magnetic fields directly on the near surface of the shield. In this case, there is no reflection loss, and only the absorption loss can be relied on. Thus, the shield materials and thicknesses considered were based on absorption only, resulting in a relatively conservative shield design.

Shielding is required over the frequency range 10 kHz to 100 MHz. Through most of this range the shielded structure is small compared with a wavelength, and therefore does not even approximate the infinite planar surface assumed in applying the transmission line equations. The surface currents on the shield will therefore, not be uniform, but will tend to concentrate near the corners of the structure as discussed in Section 3.2.2. As explained there, in order to achieve 100 dB shielding effectiveness within three feet of a corner of the building, the shield material and thickness should be selected to provide 120 dB shielding as calculated for a planar shield.

For a shielding material with constant electrical parameters of conductivity and permeability, the absorption loss for a plane wave normally incident on a flat sheet of infinite extent is given by:

$$A = 3.34\,(10)^{-3}\,t\,\sqrt{\sigma_r \mu_r f} \tag{11}$$

where t = sheet thickness in mils (thousandths of an inch)

σ_r = conductivity, relative to copper

μ_r = permeability, relative to copper

f = frequency, in Hz.

As seen from the equation for A, the absorption loss increases rapidly with frequency, assuming constant values of σ_r and μ_r. Although some investigators have reported μ_r of ferrous materials to decrease with frequency, the effect is probably not as significant[2] as once believed. In any case, the product $\mu_r f$ increases with frequency, and therefore A increases with frequency for a given value of t. Thus for a given required value of absorption loss A, the material type and thickness t should be selected to provide the required value of A at the lowest frequency of interest.

In this case, where the specified level of shielding must be provided down to 10 kHz, the equation for A becomes:

$$A = 0.334\ t\ \sqrt{\sigma_r \mu_r} \quad (12)$$

This equation is graphed in Figure 7 for three materials with the following values[2] assumed for σ_r and μ_r:

	σ_r	μ_r
Copper	1	1
Stainless Steel	0.028	227
Hot Rolled Steel	0.16	160

It is seen from Figure 7 that for a given sheet thickness, the hot rolled (low carbon) steel provides substantially more absorption loss than either the stainless steel or copper. Or, conversely, hot rolled steel can provide a specified absorption loss with the thinnest sheet, whereas copper requires the thickest.

To achieve an absorption loss of 120 dB at 10 kHz would require a copper sheet approximately 360 mils (9 mm) thick. Such a shield would be very heavy and very expensive. For stainless steel, a thickness of only 142 mils (3.6 mm) would be required, but would also be expensive. For hot rolled steel, a sheet thickness of only 71 mils (1.8 mm) could provide 120 dB absorption.

However, as will be explained later in the report, due to a difference in the costs of field welding steel sheets, a shield constructed of 14 gauge* (75 mil) steel sheets would be more expensive than one using heavier gauge sheets, e.g., 11 ga. Therefore, use of 11 ga (120 mil or 3 mm) hot rolled, low carbon steel, is recommended for the welded shields. From Figure 7 it is seen that 120 mil hot rolled steel sheets could provide an estimated 200 dB planar absorption loss if the electrical parameters of the steel remained constant and the steel did not saturate. However, saturation of ferrous materials can occur for high incident levels of magnetic fields, affecting shield performance considerably. The effects of saturation are discussed in Section 3.3.2 below.

*Thicknesses of standard gauge metal sheets are listed in Table 1.

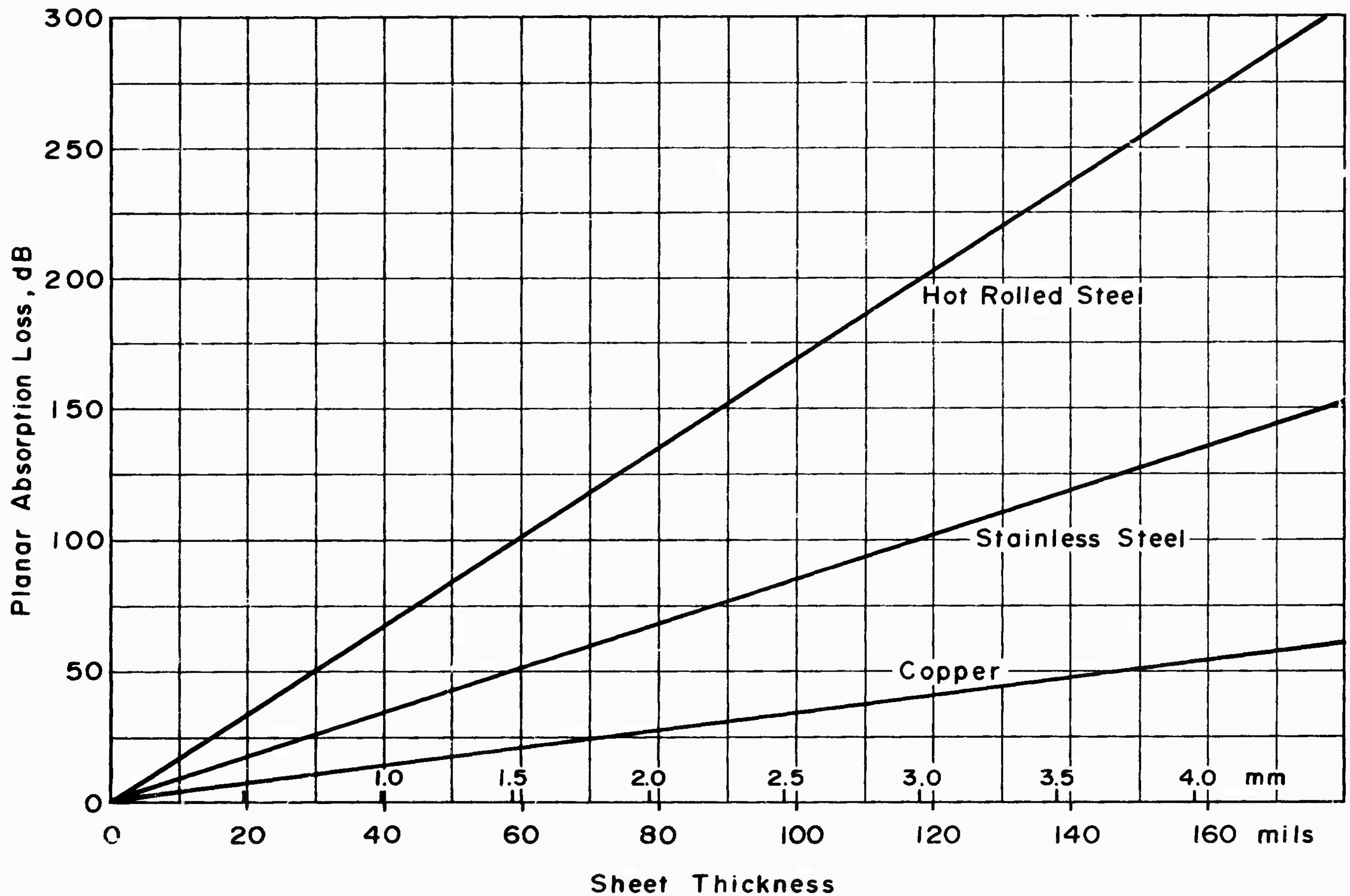


Figure 7. PLANAR ABSORPTION LOSS AT f=10KHz

Table 1

Standard Thickness of Metal Sheets

	Steel		Non-Ferrous	
Gauge	Inches[1]	MM	Inches[2]	MM
1				
2				
3	0.2391	6.1	0.2294	5.8
4	0.2242	5.7	0.2043	5.2
5	0.2092	5.3	0.1819	4.6
6	0.1943	4.9	0.1620	4.1
7	0.1793	4.6	0.1443	3.7
8	0.1644	4.2	0.1285	3.3
9	0.1495	3.8	0.1144	2.9
10	0.1345	3.4	0.1019	2.6
11	0.1196	3.0	0.0907	2.3
12	0.1046	2.7	0.0808	2.1
13	0.0897	2.3	0.0720	1.8
14	0.0747	1.9	0.0641	1.6
15	0.0673	1.7	0.0571	1.45
16	0.0598	1.5	0.0508	1.3
17	0.0538	1.36	0.0453	1.15
18	0.0478	1.2	0.0403	1.02
19	0.0418	1.1	0.0359	0.91
20	0.0359	0.91	0.0320	0.81
21	0.0329	0.84	0.0285	0.72
22	0.0299	0.76	0.0253	0.64

Notes: 1) Manufacturers Standard
2) Brown & Sharp

Source: Central Steel & Wire Company
Chicago, Illinois

As discussed in Section 6, thinner material, e.g., 14 ga (75 mil) or 18 ga (48 mil) might be used if the shield were fastened using powder-driven pins rather than welding. It is seen from Figure 7 that sheets of these thicknesses could provide planar absorption losses of 120 dB and 80 dB, respectively, at 10 kHz.

3.3.2 Effect of Magnetic Saturation on Shield Design

The calculations of shielding effectiveness (absorption loss) as determined in Section 3.3.1 were based on linear behavior of the shield material. While a non-ferromagnetic material such as copper can be assumed to be linear for all electromagnetic field levels of interest, steel will be nonlinear and could become magnetically saturated at some threat levels. This section presents a simplified discussion of the possible effect of saturation on the shielding effectiveness of a steel shield. The depth of saturation of the shield is dependent on the time integral of the density of surface current flowing on the shield. A family of curves is plotted showing the shield thickness required for a given degree of shielding (120 dB shielding at 10 kHz) for incident pulses of various durations and amplitudes.

The calculations presented here initially follow the approximate approach by Ferber and Young[3-5] in which a limiting nonlinear theory predicts a lower bound on shielding effectiveness. The procedure adopted here is as follows. As shown in Figure 8, the actual magnetization curve of the ferromagnetic material is approximated by a limiting curve characterized by two parameters:

B_{SAT}, the saturation magnetization (Wb/m^2)

H_c, the coercive force of the material.

If a high intensity magnetic field H_s (where $H_s > H_c$) is applied to the surface of the steel sheet, the region exposed to the strong field saturates, and the region or depth of saturation propagates into the material as long as the magnetic field incident wave exceeds the saturation level. The field at the inner edge of the saturated region is of magnitude H_c, the coercive force of the material. Thus, even with the saturation phenomena, the material still may provide a significant amount of shielding.

Figure 9 shows a cross-section of the steel plate (of infinite extent) with an incident magnetic field, H_s, strong enough to saturate the material, applied to one surface. This field is considered to be due to a surface current flowing on the sheet. The current is pulsed, with a duration T. During the time T the saturated region propagates into the sheet a depth of δ^{SAT}, and the magnetic field intensity at the inner edge of the saturated region is H_c.

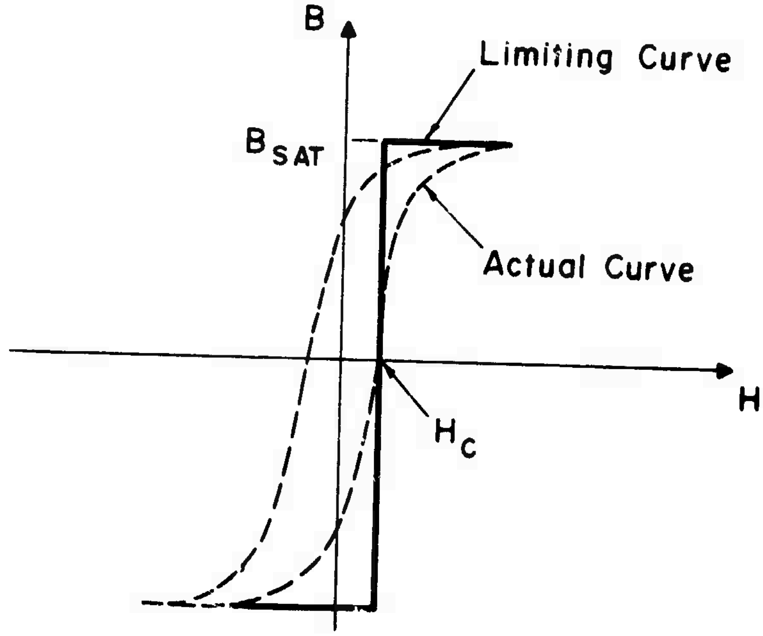


Figure 8. APPROXIMATION OF NONLINEAR MAGNETIZATION CURVE

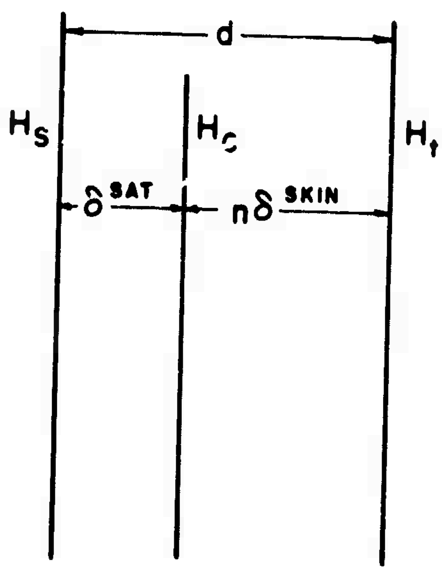


Figure 9. MAGNETIC FIELD IN STEEL PLATE

After time T the surface current, and hence the applied field, are assumed to drop to zero. The inward propagation of the saturated region then ceases, and the field within the material then decays. The maximum depth of saturation δ^{SAT} depends on the magnitude and duration of the applied surface current which causes field H_s.

The remaining thickness of the steel sheet, $\eta\ \delta^{SKIN}$, is unsaturated and provides absorptive shielding at the rate of 8.68 dB for every skin depth of material in the unsaturated region. Thus, an unsaturated thickness of $\eta\ \delta^{SKIN}$ provides $\eta \cdot 8.68$ dB of additional shielding besides the shielding due to the saturation effect in the region of thickness δ^{SAT}.

The nature of the analysis here is to determine the minimum thickness, d, of the steel plate which will provide at least the required amount of shielding, designated here as SE (Shielding Effectiveness, in dB). In turn, the required thickness depends on the required number of skin depths and the magnitude of the skin depth, δ^{SKIN}. Since the magnitude of skin depth varies ˙.versely with frequency, the procedure has here been adopted to determine the minimum required thickness of region $n\delta^{SKIN}$ based on the minimum frequency at which the required shielding effectiveness is specified, i.e., 10 kHz. Thus the calculation is made on a worst-case basis and will be conservative for other frequencies.

The shielding effectiveness is defined as:

$$SE = 20 \log_{10} \frac{H_s}{H_t} \tag{13}$$

where H_t is the magnitude of the field on the far side (inner surface) of the shield.

The exponential attentuation of n skin depths in the unsaturated region provides the relationship

$$H_t = \frac{H_c}{e^n} = \frac{H_c}{\frac{d - \delta^{SAT}}{\delta^{SKIN}}} \tag{14}$$

Therefore:

$$SE = 20 \log_{10} \frac{H_s}{\dfrac{H_c}{e^{\frac{d - \delta^{SAT}}{\delta^{SKIN}}}}} \tag{15}$$

$$= 20 \log_{10} \left[\frac{H_s}{H_c} e^{\frac{d - \delta^{SAT}}{\delta^{SKIN}}}\right] \quad (16)$$

$$= 20 \log_{10} \frac{H_s}{H_c} + 20 \log_{10} e^{\frac{d - \delta^{SAT}}{\delta^{SKIN}}} \quad (17)$$

$$= 20 \log_{10} \frac{H_s}{H_c} + 20 \left(\frac{d - \delta^{SAT}}{\delta^{SKIN}}\right) \log_{10} e \quad (18)$$

$$= 20 \log_{10} \frac{H_s}{H_c} + 8.68 \left(\frac{d - \delta^{SAT}}{\delta^{SKIN}}\right) \quad (19)$$

Next, δ^{SAT} must be determined. An expression for δ^{SAT} has been previously derived[4] for current flowing along the outer surface of a cylindrical tube:

$$\delta^{SAT} = \sqrt{\frac{\int_0^T i\,(t)\,dt}{\pi\, r_o\, \sigma\, B_{SAT}}} \quad (20)$$

where $i\,(t)$ = current flowing on cylindrical tube

r_o = outer radius of tube

σ = conductivity of conductor

B_{SAT} = saturated flux density

Two approximations will be made for applying this type of relationship to the present problem. First, it will be assumed that the current waveform is a rectangular pulse of amplitude I and duration T. Thus, the time integral of the current can be replaced by the product I·T. Thus:

$$\delta^{SAT} = \sqrt{\frac{I \cdot T}{\pi\, r_o\, \sigma\, B_{SAT}}} \quad (21)$$

The second approximation will apply this type of relationship to a current of uniform density flowing on one surface of a flat sheet rather than on one surface of a cylindrical tube. The above equation can be rewritten:

$$\delta^{SAT} = \sqrt{\frac{I}{2\pi\, r_o} \cdot \frac{2\, T}{\sigma\, B_{SAT}}} \quad (22)$$

The term $I/2\pi\ r_o$ is the surface current density in Amperes/meter flowing on the tube. Denoting this surface current density by J_s, the equation becomes:

$$\delta^{SAT} = \sqrt{\frac{2\ J_s\ T}{\sigma\ B_{SAT}}} \qquad (23)$$

This expression will be assumed to apply to a current of density J_s flowing on one surface of a large flat sheet of ferromagnetic material.

The equation for shielding effectiveness then becomes:

$$SE = 20\ \log_{10} \frac{H_s}{H_c} + 8.68 \left[\frac{d - \sqrt{\frac{2J_s T}{\sigma\ B_{SAT}}}}{\delta^{SKIN}} \right] \qquad (24)$$

Setting the surface magnetic field intensity H_s equal to the surface current density J_s, and rearranging to solve for d:

$$d = \frac{\delta^{SKIN}}{8.68} \left[SE - 20\ \log_{10} \frac{J_s}{H_c} \right] + \sqrt{\frac{2J_s T}{\sigma\ B_{SAT}}} . \qquad J_s \geq H_c \qquad (25)$$

This equation applies for $J_s \geq H_c$, i.e., for the case of at least partial saturation of the shield. If $J_s < H_c$, no saturation occurs, and the required relationship becomes:

$$d = \frac{\delta^{SKIN}\ SE}{8.68} \qquad J_s < H_c \qquad (26)$$

The following parameters will be used as representative for hot-rolled, low-carbon steel:

$\sigma_{r_{cu}} = 0.16$; $\sigma = 0.93\ (10)^7$ mhos/m

$\mu_{r_{cu}} = 160$

$H_c = 2$ Oe $= 160$ A/m

$B_{SAT} = 1.5$ wb/m^2

$\delta^{SKIN} = 1.31\ (10)^{-4}$ m (0.13 mm; 0.0051 inch)
(Applies for 10 kHz)

SE = 120 dB

Inserting these values in the equation for d:

$$d = 10^{-3} (2.47 - 0.30 \log_{10} J_s + 0.38 \sqrt{J_s T}) \text{ meter.} \qquad (27)$$

Equation (27) is plotted in Figure 10 for values of $J_s \geq H_c$ (160 A/m). Also shown for $J_s < H_c$ is the required thickness (71 mils) for conditions where shield behavior is linear. It should be noted that the shielding effectiveness calculated in the linear region was for a single frequency (10 KHz) which is the worst-case. These curves are not intended to provide data to calculate the actual shielding effectiveness over the entire pulse spectrum.

Figure 10 shows that for a pulse duration of 10 microseconds, for example, a steel shield 120 mils thick (11 gauge) can provide 120 dB shielding for current surface densities up to approximately $4 (10)^6$ A/m. This density is approximately four orders of magnitude above the current density which would result from a 50 kV/m plane wave incident on an infinite flat sheet. For a shield of realistic shape, e.g., a rectangular parallepiped, the current concentration near the edges and corners, might be estimated to be approximately three orders of magnitude above the density for an infinite flat sheet. Thus, it would appear that even with partial saturation, an 11 gauge steel shield can provide adequate shielding (e.g., 120 dB) under these conditions. Also, a shield 71 mils thick (14 ga) can provide 120 dB shielding at 10 kHz in the absence of any saturation.

3.4 SPECIFIC SHIELD CONFIGURATIONS

Figures 18, 22, 26, and 30, to be discussed later, show the shield configurations for each of four construction options:

- Condition I - New Construction, External Shield
- Condition II - New Construction, Internal Shield
- Condition III - Retrofit Construction, Internal Shield, Interior Walls Replaced
- Condition IV - Retrofit Construction, Internal Shield, Interior Walls Retained

The shield configuration for Condition V, New Construction, Internal Shield is the same as that for Condition II. For Condition V, however, the shield is fastened by powder-driven pins as will be described in Section 6.

In addition to an envelope shield enclosing the operational areas, entry vaults are provided for both the communications and the electrical power systems. If it were desired to consider a facility with a lower level of shielding, e.g., 30 dB, the entry vaults could be eliminated. In that case the entering communications and power lines would be routed through steel entry boxes.

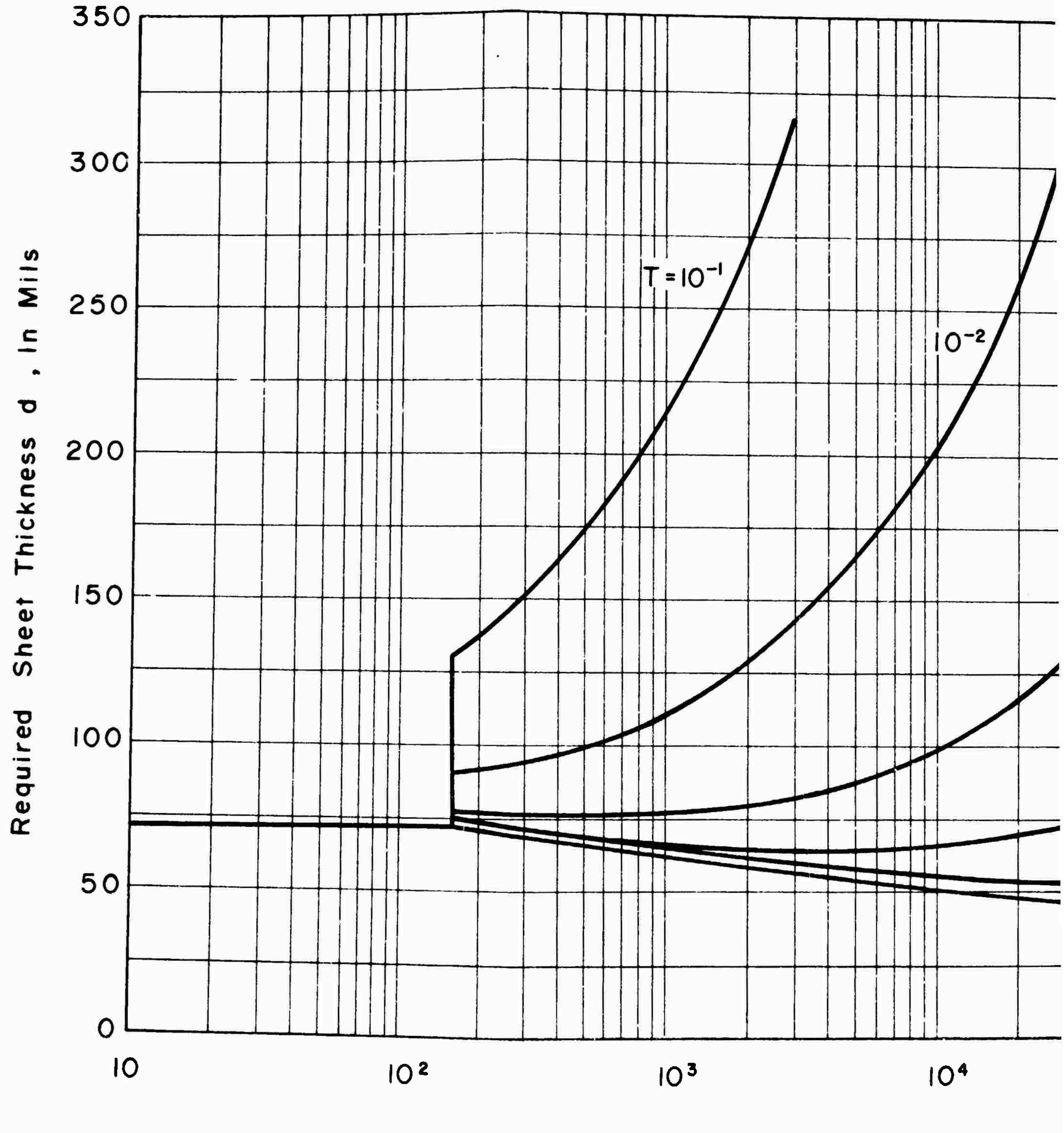
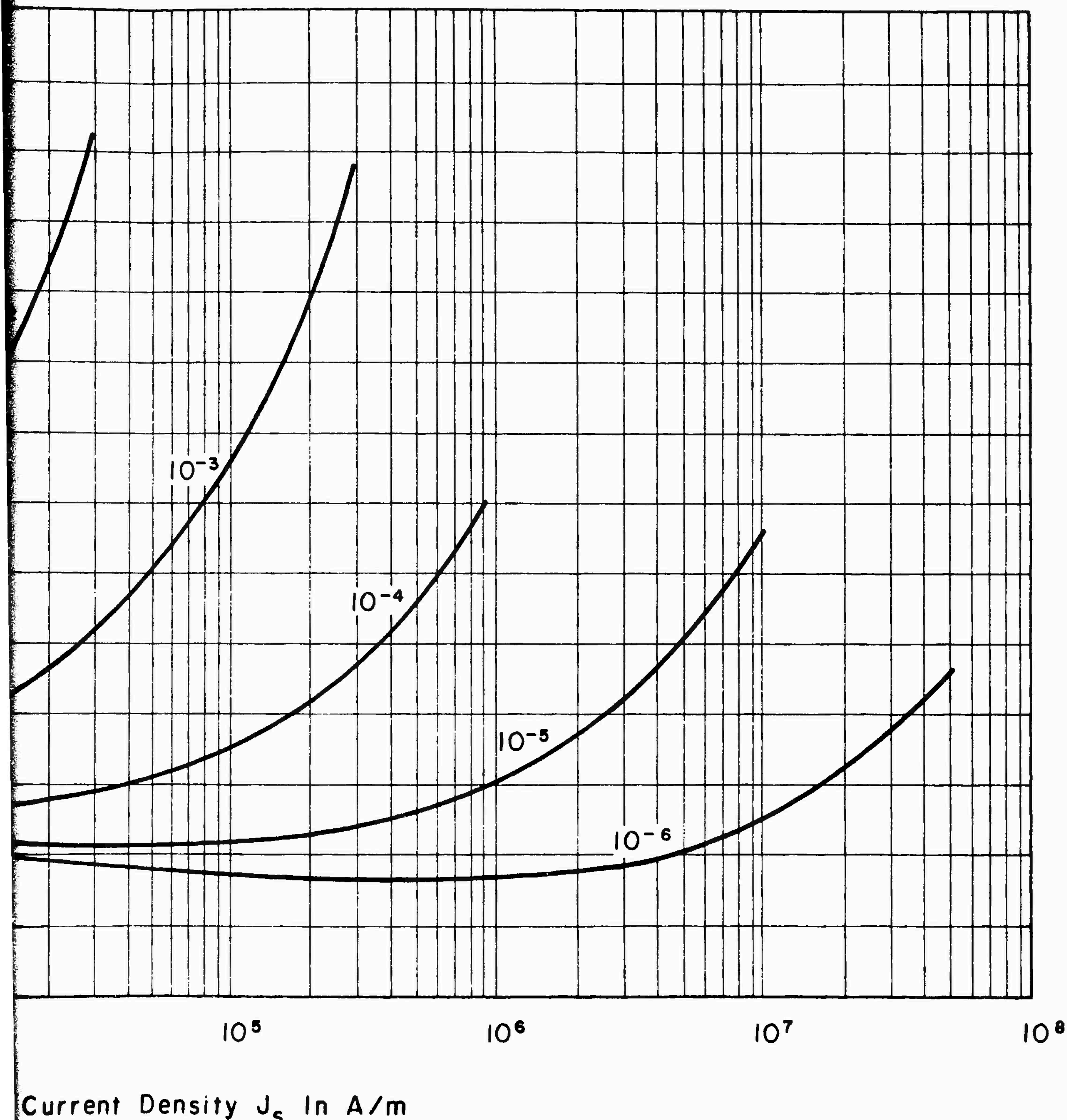


Figure 10. MINIMUM THICKNESS OF STEE



STEEL SHIELD FOR 120DB ABSORPTION LOSS

The entry plate is 1/4 inch steel plate. Penetrants entering the facility through the entry plate are circumferentially welded to the plate.

It should be noted that for Condition I, New Construction, External Shield, a significant amount of internal shielding is required, including internal ceiling shields on the personnel entry vestibule and the storage room, in addition to the entry vaults.

The next section of the report describes mechanical details of the welded shield construction for each of the four conditions. Section 6 describes the design for a shield fastened by powder-driven pins.

SECTION 4

MECHANICAL DESIGN FOR WELDED SHIELDS

4.1 GENERAL

4.1.1 Envelope Shield

At the outset of this study, it was considered that three different levels of shielding 30, 60, and 100 decibels (dB) -- would be analyzed for each of the four welded shield designs (Conditions I, II, III, and IV). This would have indicated the use of three gauges of steel plate -- 22, 18, and 14 gauge, respectively, for the major portion of the shield.

As the study progressed, it was learned that 18 and 22 gauge steel cannot be field-welded, although 18 gauge can be factory-welded under controlled conditions. Consequently, no further consideration was given to these lighter gauge plates.

Fourteen gauge plate can, under carefully controlled contions and with special equipment, be field-welded. However, it is difficult to ensure continuity of the weld (and, therefore, the shield), and some wastage of material burned through during welding is to be anticipated. It is estimated that approximately $20,000 in materials cost can be saved by using 14-gauge as opposed to 11-gauge steel for Condition I. However, it is also estimated that labor costs would rise by approximately 30% (90,000 dollars). It appears that, in the long run, $70,000 can be saved by using the heavier material. This saving, about ten percent, is found to be typical in all four conditions.

The cost-effectiveness of using only 11 gauge steel has the obvious benefit of providing 100 dB shielding in all cases being studied. The only possible saving for any of the three shielding levels is that an entry vault would not be required for the 30 dB shielding level. Instead, incoming lines penetrating the entry plate could pass through shielded entry boxes, welded to the entry plate for interior shields as shown in Figure 11. These shielded entry boxes would have the surge arresters, etc. In view of the relatively small cost saving associated with this design change for 30 dB shielding, it has not been included, and only the 100 dB shielding level has been considered for the welded shield designs.

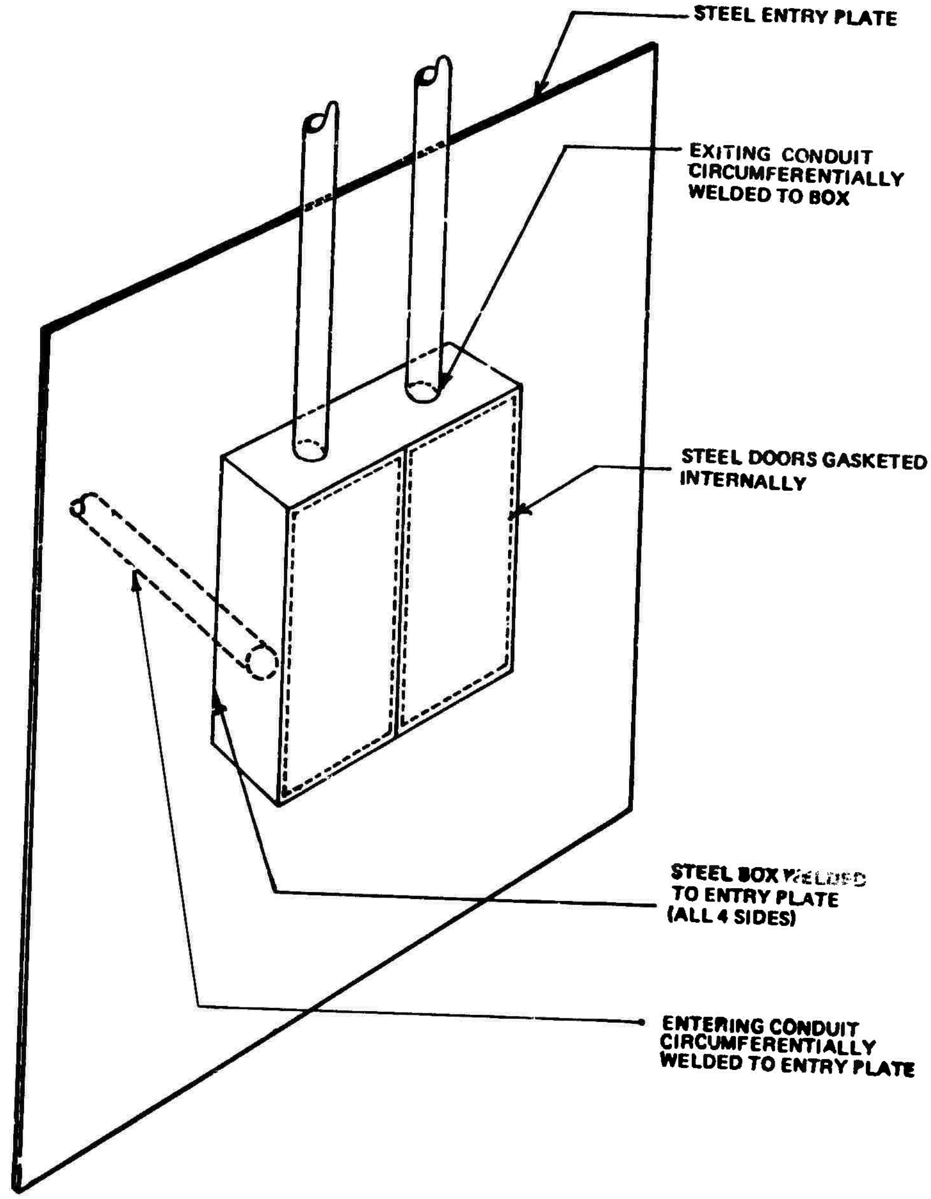


FIGURE II. **TYPICAL SHIELDED ENTRY BOX (FOR 30db SHIELDING)**

The entry plate in all cases is a 1/4 inch thick steel plate extending the width and height of one end of the building through which all penetrants are assumed to enter.

The typical 11 gauge plate to be used is standardized at 5 by 10 feet in size. When applied to walls, the long dimension is always vertical, thereby maximizing vertical joints, but reducing horizontal joints to one (see Figure 12). This has two advantages: it is easier to full-fillet weld vertically than it is horizontally, and it eliminates the need for an expansion joint, since thermal movement is distributed over 40 panels and joints in the length of the building. A maximum width of 3/8 inch is to be allowed between panels to compensate for allowable dimensional discrepancies in building construction. This corresponds to the maximum practical width for the full-fillet weld used to fill the gap between panels.

Panels are to be fastened to walls or slabs as follows: a 1/4 inch by 4 inch steel bar is attached to the wall with 3/8 inch by 4 inch steel studs driven through, or cast into, the concrete 10 feet apart in the long dimension of the panel, and approximately 1.7 feet apart in the short dimension. In this manner, there is a bar around all panel edges, and at third points parallel to its long dimension (see Figure 13).

Likewise, the panel has rows of 1/2 inch diameter holes pre-punched on 2-foot centers* on lines at third points parallel to the long dimension. When the panel is positioned on the wall or slab, the holes (which align with the bar behind) are filled with plug welds, this securing the panel to the bar and wall. Plug welds on floors, and wall shielding in Condition 1, are to be ground smooth. Joints between panels (which also occur along bars) are full-fillet welded, thereby providing continuity of shielding between panels and completing the installation of that panel.

This procedure is used in all instances, except when the wall material is concrete block, not poured-in-place concrete. In these cases, the bar and wall are both pre-drilled, and an anchor bolt replaces the steel stud as the means of initial attachment. Otherwise, the procedure described above remains identical.

The steel plate is to be hot-rolled low carbon steel conforming to ASTM A569-72, or similar specifications. Metal Inert Gas (MIG) continuous fillet welds are to be applied in alternate strips of weld no more than six inches long. Exposed exterior panels are to be protected by a chromate primer and paint.

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*One foot for exterior wall application.

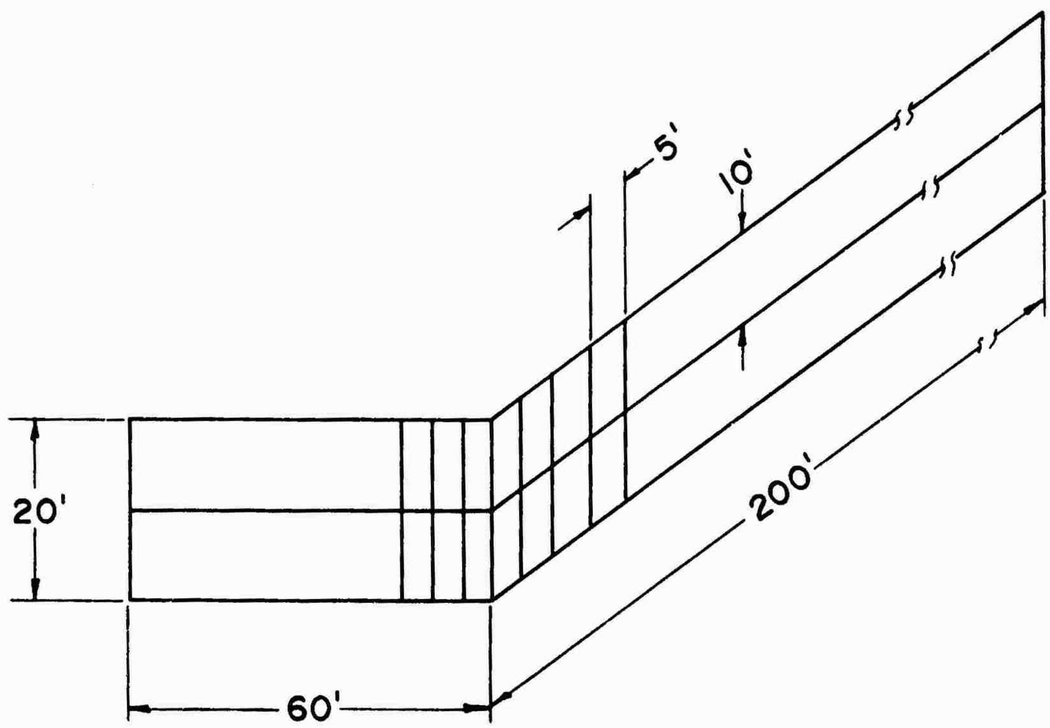


Figure 12. ARRANGEMENT OF WELDED STEEL PLATES ON WALLS

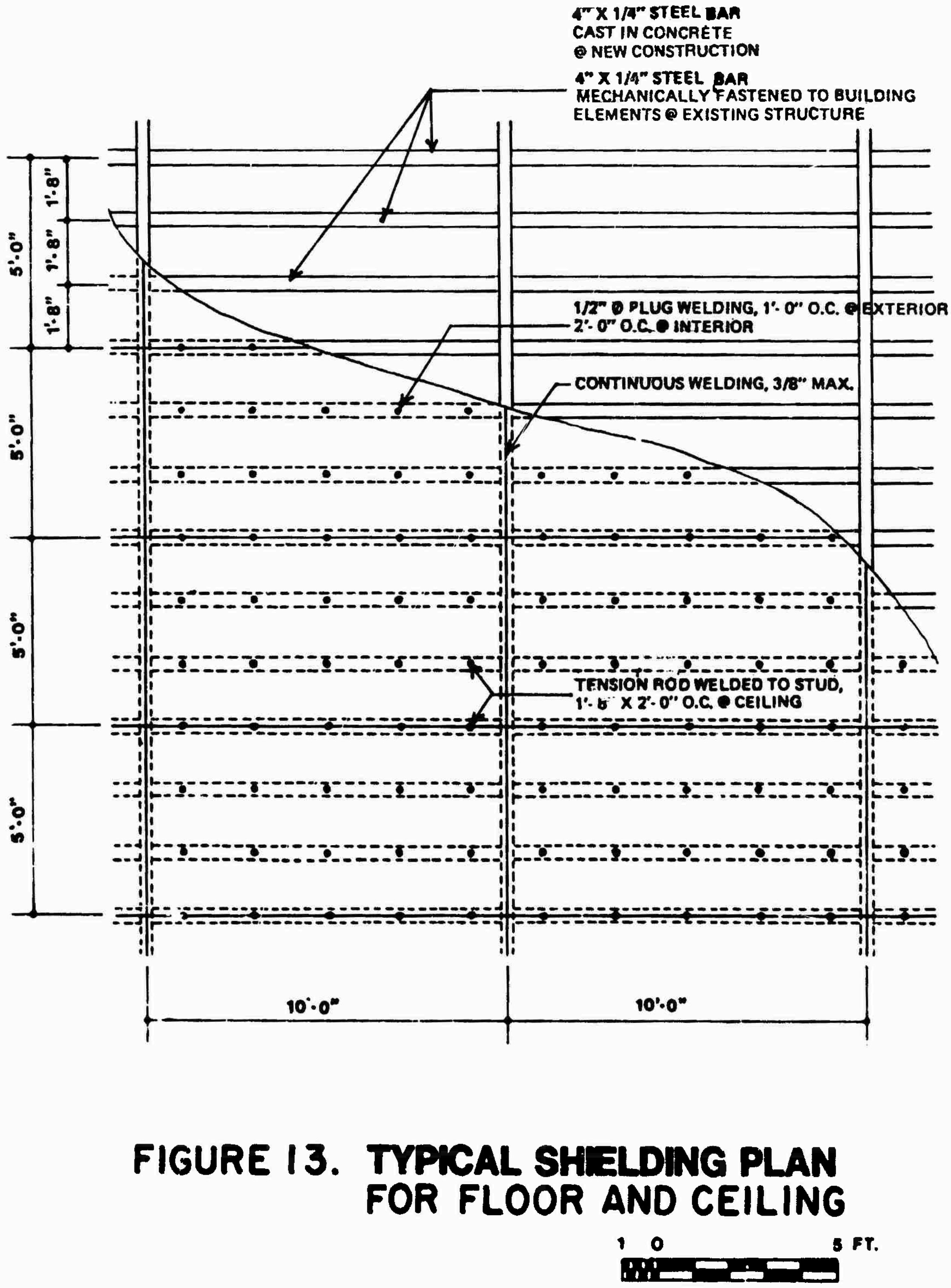


FIGURE 13. **TYPICAL SHIELDING PLAN FOR FLOOR AND CEILING**

4.1.2 Penetrations

Each time the shield is interrupted by an opening or penetration, special measures must be taken to re-establish the continuity of the shield as well as possible. These penetrations are of three general types: doors (the C^3 structure has no windows), ducts (air intake and discharge), and piping (electrical conduit, water supply, sanitary drainage, etc.). In order to minimize the number of penetrations, roof drainage is limited to the exterior of the building by the use of gutters and downspouts.

As mentioned earlier, penetration by doors is accomplished using shielded doors in conjunction with a shielded vestibule. The doors themselves are properly shielded and their edges are in close contact with the door frame. For hinged shielded doors, the door edge closes tightly against finger stock recessed in the door frame (Figure 14). Hinged shielded doors 3 feet by 7 feet are assumed.

For sliding doors, a design is available with pneumatic sealing and not requiring finger stock or RF gaskets. It is claimed to be reliable both mechanically and electrically for five years. Over a 20 year shield lifetime, several replacements would be required, as indicated in Section 8. Sliding shielded doors 8 feet by 8 feet are assumed for the cargo/storage area.

Ductwork to introduce fresh air and discharge stale air is protected with a RF honeycomb air vent utilizing the waveguide-beyond-cutoff principle (See Figure 15). For the largest intake duct, 5 feet by 2 feet, and a honeycomb cross-section of 2 inches by 2 inches, the honeycomb length must be at least 13 inches in order to provide 120 dB attenuation of the highest EMP frequencies of interest.

Piping penetrations are handled in either of two ways as shown in Figure 16. Continuous metal pipes are circumferentially welded to the entry plate as shown in Figure 16(a). Non-metallic pipes pass through the steel entry plate via a metal penetration pipe or "stuffing tube" which is circumferentially welded to the entry plate (Figure 16(b)). Here, again, the waveguide-beyond-cutoff principle is used; the section of metal penetration pipe must be at least 3 times its diameter. Similarly, Figure 17 shows a metallic pipe penetration and termination into a non-metallic pipe. Again, the length of the metal penetration pipe must be at least 3 times its diameter.

These three methods of maintaining continuity of shielding for penetrations of doors, ducts, and pipes are common to each of the specific shield configurations considered.

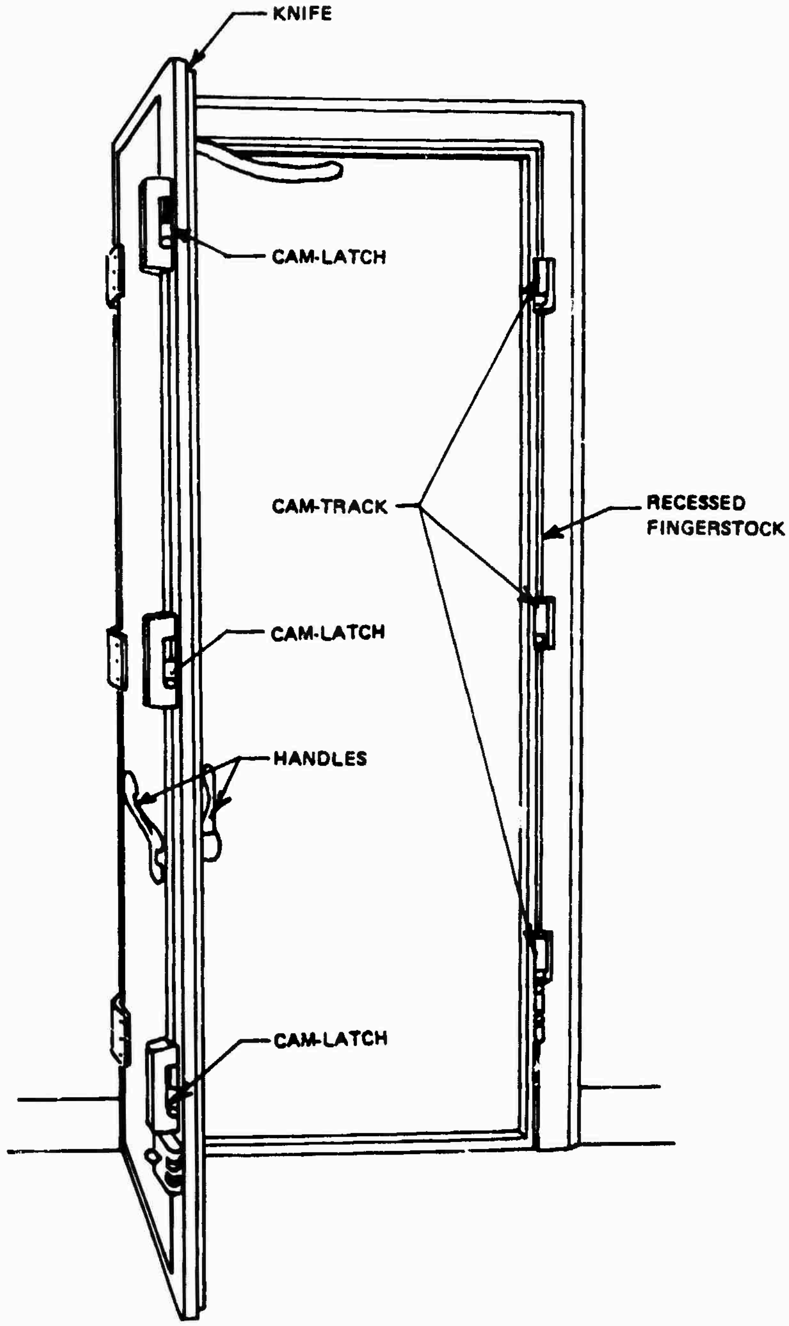


FIGURE 14. TYPICAL SHIELDED DOOR

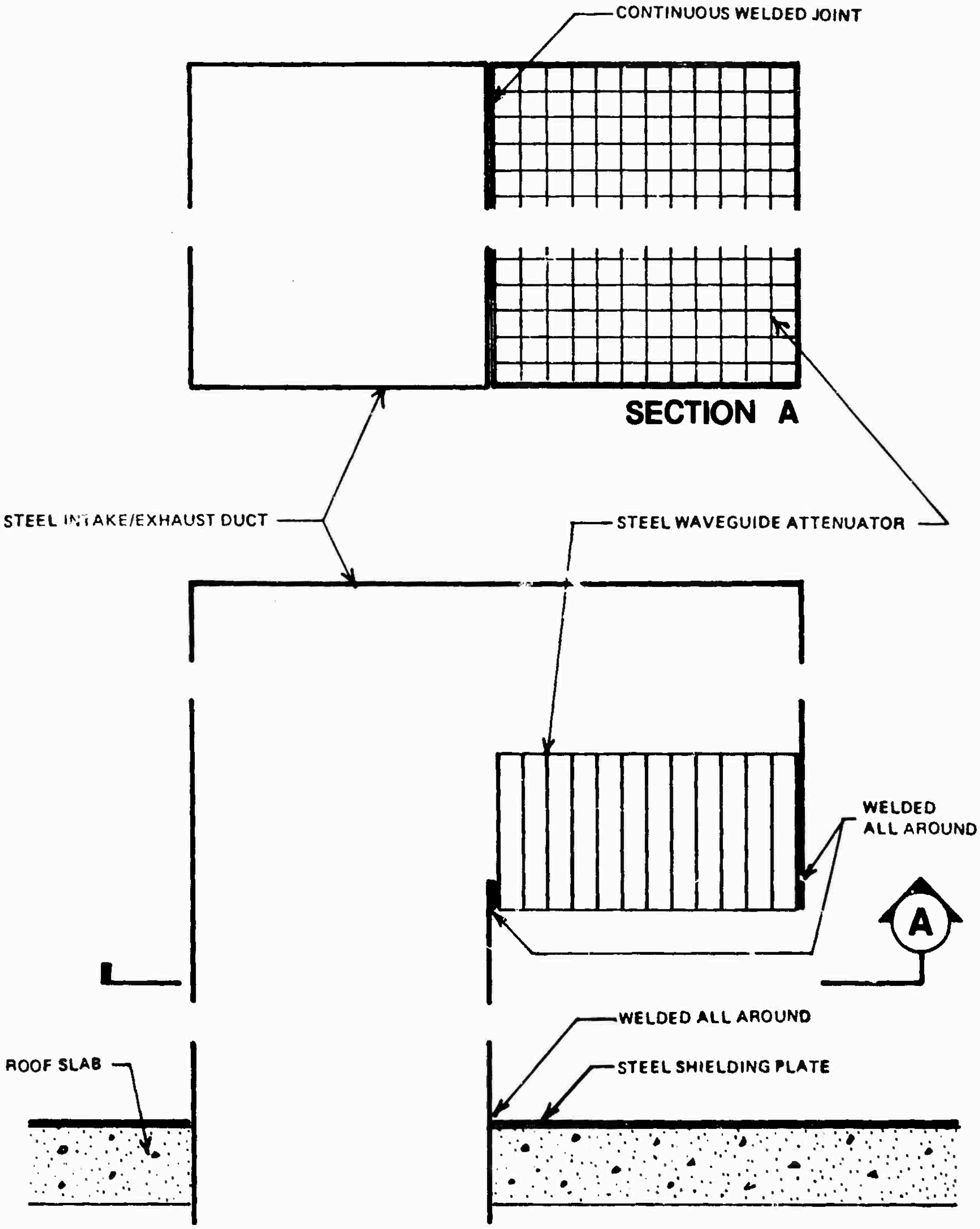
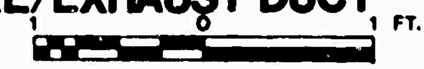
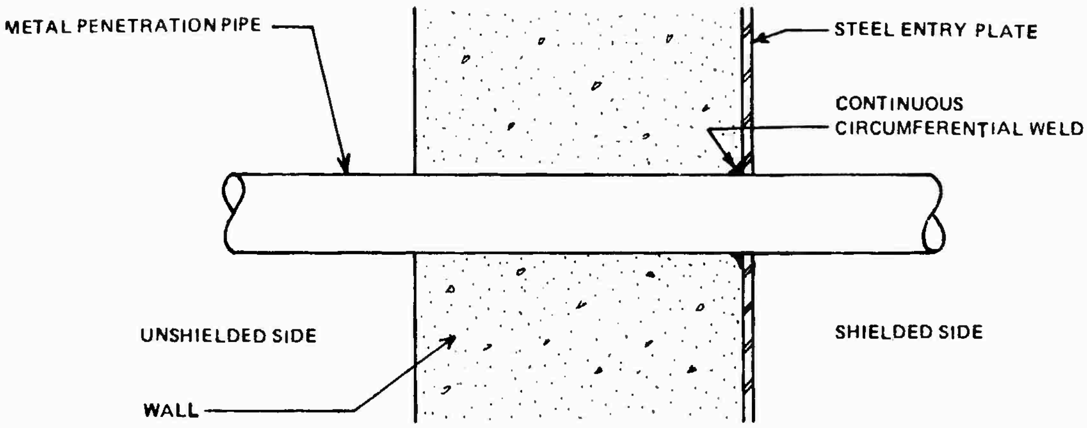
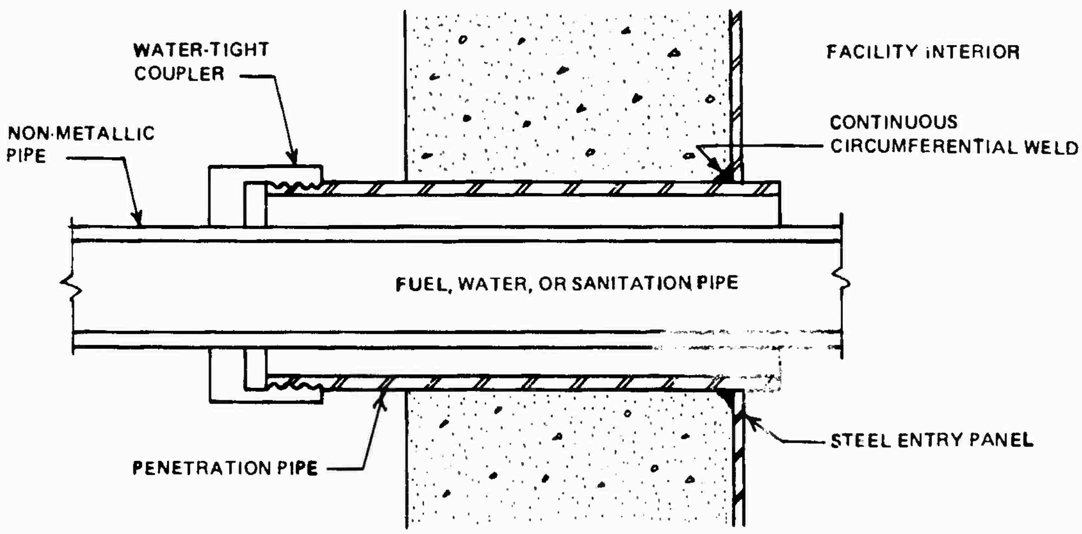


FIGURE 15. TYPICAL PENETRATION DETAILS INTAKE/EXHAUST DUCT



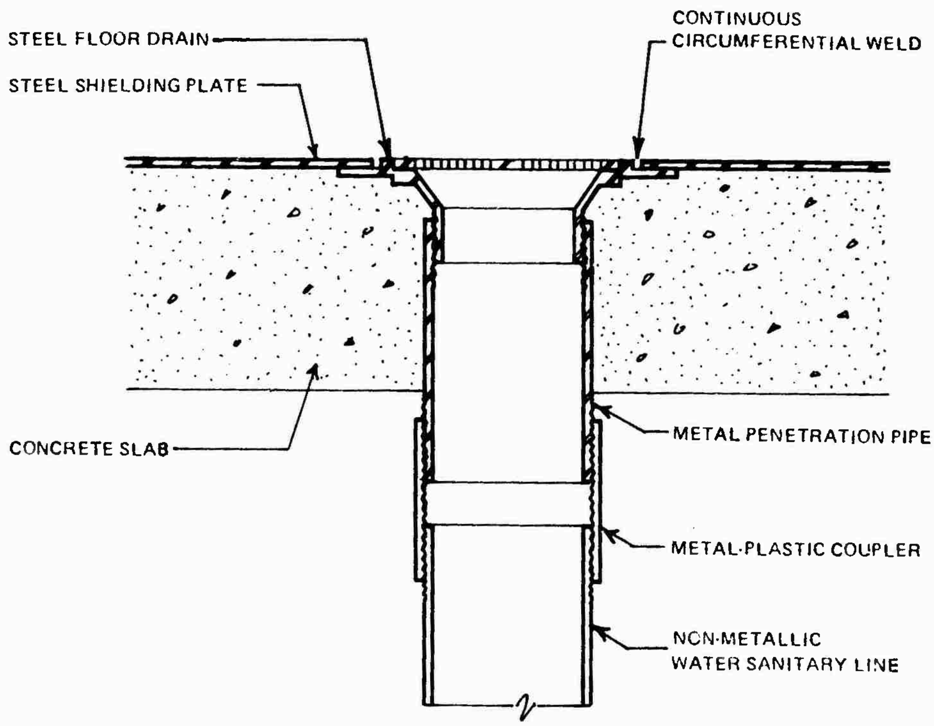


CONDUIT OR METAL PIPE PENETRATION



PIPE FEEDTHROUGH

FIGURE 16. TYPICAL PENETRATION DETAILS PIPE & CONDUIT



FLOOR DRAIN & PIPE TERMINATION

FIGURE 17. **TYPICAL PENETRATION DETAILS (FLOOR DRAIN)**

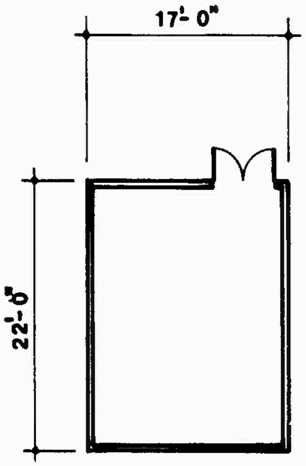
4.2 CONDITION I, NEW CONSTRUCTION, EXTERNAL SHIELD

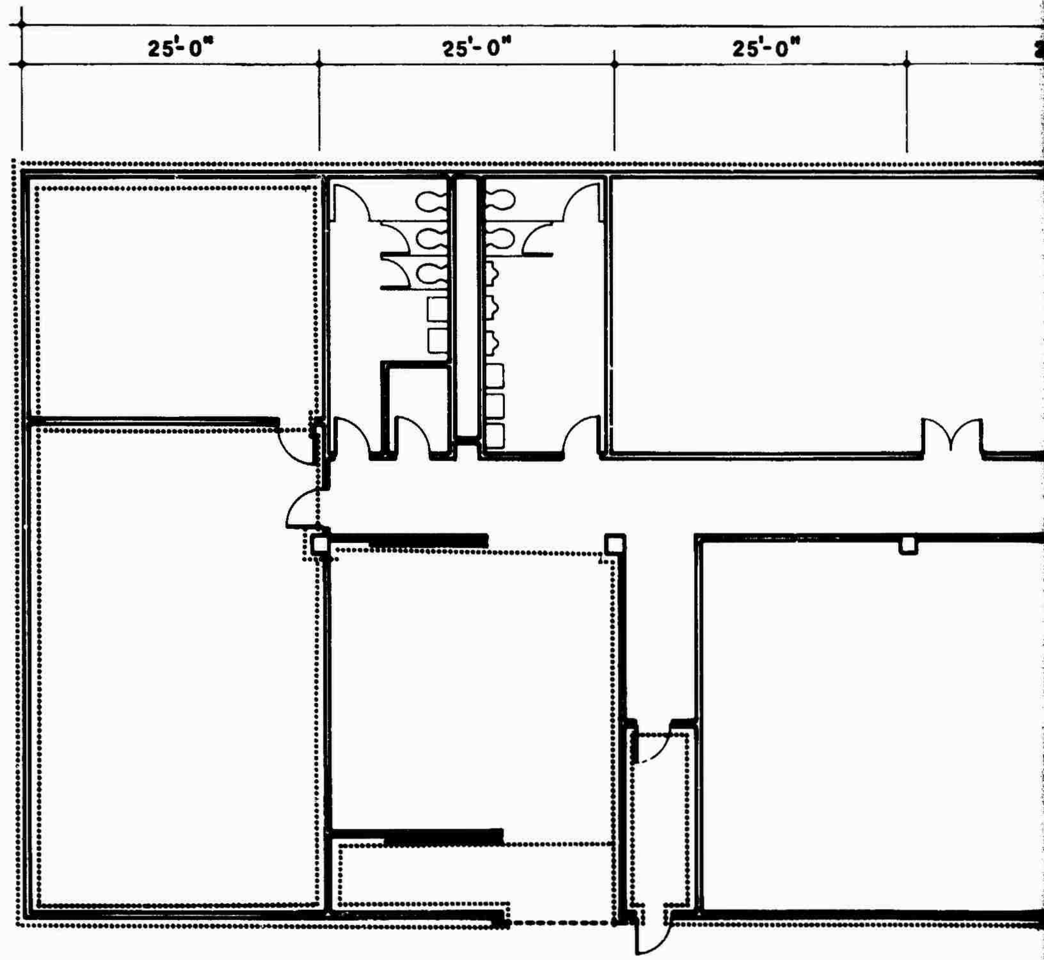
In the first of the four Conditions it is assumed that the prototype C^3 structure is to be of new construction and that the shielding will be applied to the exterior of the building as shown in Figure 18. In addition, internal shielding, including ceiling shielding, is required in the entry vault, storage room, and vestibule. These details are shown in the isometric sketch in Figure 19.

Generally, shielding and penetration details are as previously described in Section 4.1. However, certain details are unique to this Condition, It is assumed that, once the formwork for the footings and foundation walll is constructed and the concrete has been properly placed, a prefabricated steel cap plate is to be used to close the top of the form. This plate is to be 5 feet long, the width of the foundation wall, and is to be penetrated by steel reinforcing bars welded to it. These bars, which are to extend both above and below the plate, are to provide continuity of structural reinforcement between the foundation and upper walls. As will be shown, the plate will also provide continuity of shielding.

Once the foundation concrete has set and the forms have been stripped, the floor slab and walls can be poured. The prefabricated base plate is to be equipped with two elements in addition to the reinforcing bars. The first is a 1/4 by 4 inch steel bar cast into the edge of the floor slab. This is to provide a continuous perimeter "seat" onto which the floor shielding is to be fillet-welded to the cap plate. The second is a 2 by 2 inch continuous-steel angle pre-welded to the topside of the "exterior" edge of the base plate. It is to this angle that the bottom edge of each exterior wall plate is to be fillet-welded. In this manner, continuity of shielding between interior floor and exterior wall shielding is maintained as it passes through the foundation wall (Figure 20).

Although the floor slab is separated from the foundation by a construction joint, slab and foundation steel reinforcing is continuous to prevent separation of floor slab and walls during normal building settling, and consequent cracking of the shield. Also, although not shownin Figure 20, steel reinforcing is used at the wall-roof joint and other joints to prevent separation. Similarly, in subsequent wall-detail sketches, steel reinforcement is not shown but should be understood to be included at all construction joints to prevent separation and damage to the shield.


17'- 0"
22'- 0"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25'- 0"

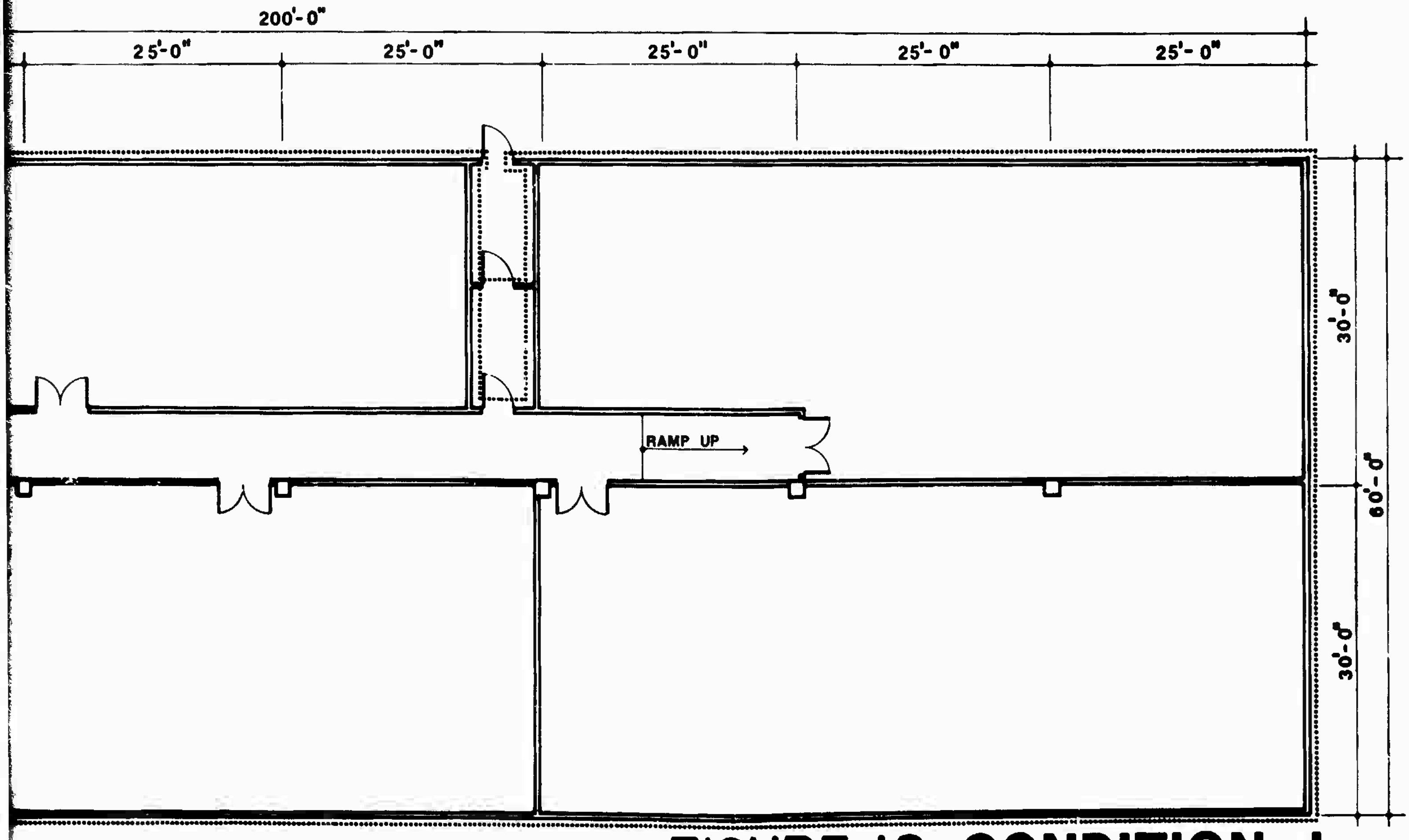
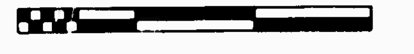


FIGURE 18. CONDITION I SHIELDING PLAN



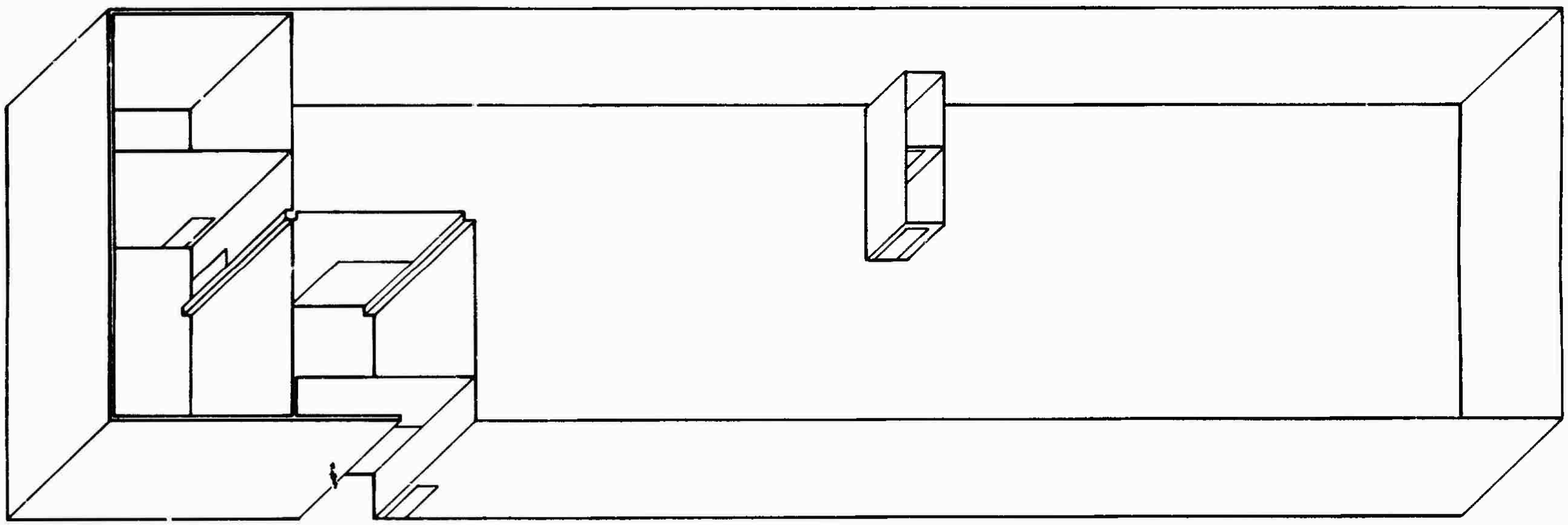


FIGURE 19. CONDITION I
ISOMETRIC

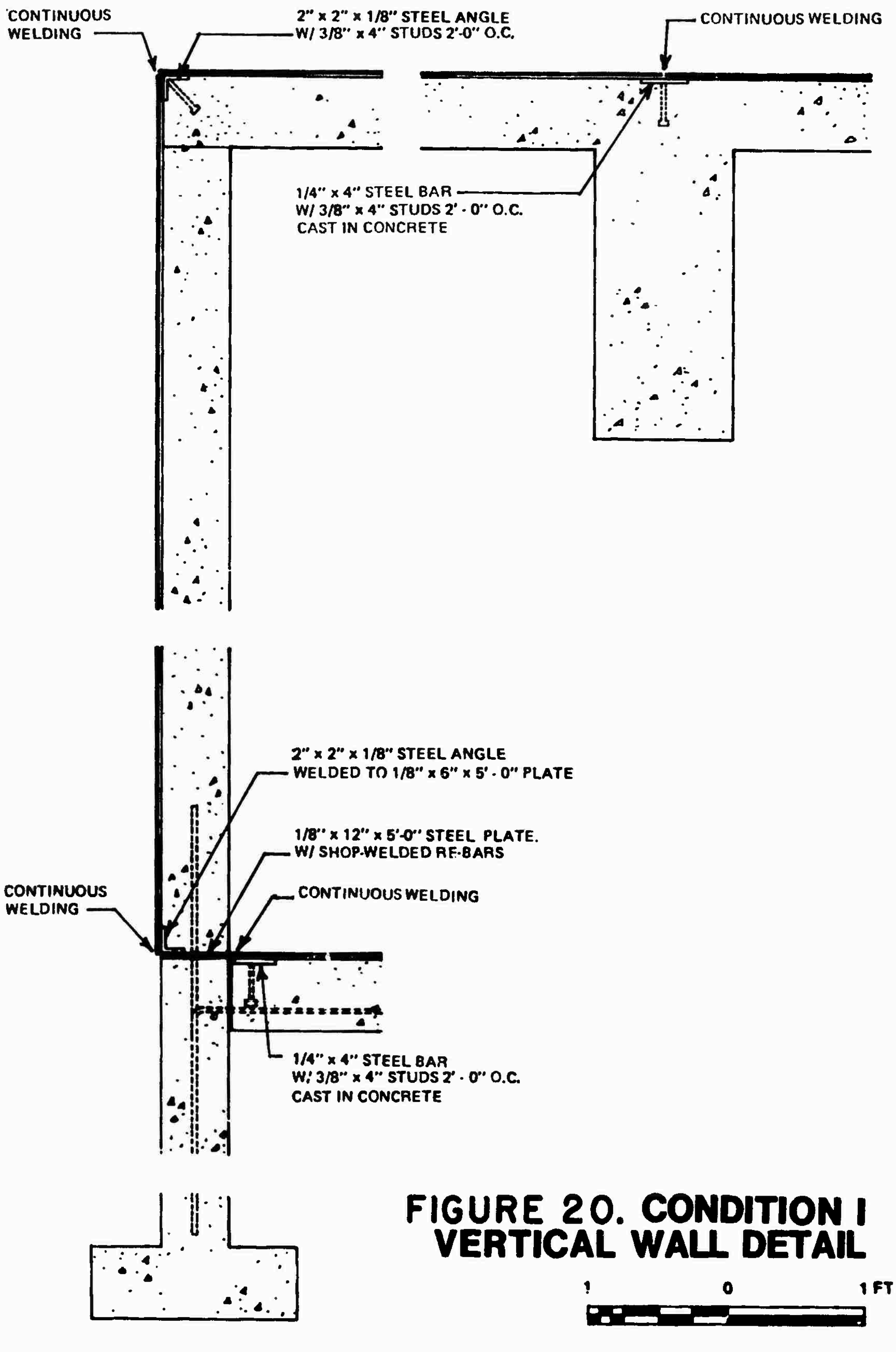


FIGURE 20. CONDITION I VERTICAL WALL DETAIL

When the roof slab is poured, a continuous 4 x 4 x 1/8 inch steel angle is to be cast into it along the perimeter. The upper edge of wall panels and the outside edge of roof panels are then to be continuously fillet-welded to this angle. A similar angle was cast into the vertical outside corner of walls, to which the vertical edges of the end walls panels are to be fillet-welded (Figure 21).

Exterior wall welds, whether continuous fillet (at joints between panels) or plug type, (along third points of the panel) are to be ground smooth. The wall is then to be protected with a chromate primer and paint. Floor plate welds are also to be ground smooth and covered with vinyl asbestos tile. Roof slab shielding is to be painted with a chromate primer prior to being covered with conventional built-up roofing. All other architectural details and finishes are as described in Section 4.1.

4.3 CONDITION II, NEW CONSTRUCTION, INTERNAL SHIELD

In the second of the four Conditions, it is assumed that the prototype C^3 building is to be of new construction. In this case, however, the shielding is assumed to be applied to the interior surfaces of the structure as shown in Figures 22 and 23.

Generally, shielding and penetration details are as described in Section 4.1. However, certain details are unique to this Condition (See Figures 24 and 25). Continuity of floor, wall, and roof shielding is to be achieved by the use of 4 x 4 x 1/8 inch angles cast into the concrete at the intersections between the wall and the floor or roof slabs. The steel panels are then to be fillet-welded to the angles to provide a continuous shield. In this condition, beams and columns also need to be covered. Columns are encased in prefabricated steel "U" shaped sections of steel plate which are to be welded to steel bars cast into the column. Beams are to be similarly encased in prefabricated "U" shaped sections. These brake-formed sections also have an additional "ear" at the top of the "U" shape. This is done so as to make the interval between beams an even 10 feet -- the dimension of the standard steel panel. The beam enclosure plate itself utilizes a 6-foot wide panel, also an industry standard size.

All floor welds are to be ground smooth prior to installation of vinyl asbestos tile. Standard metal studs are to be tack-welded to vertical steel plate and shimmed as required by any irregularities of the wall surface. Gypsum wallboard is then to be applied in standard fashion, taped and painted.

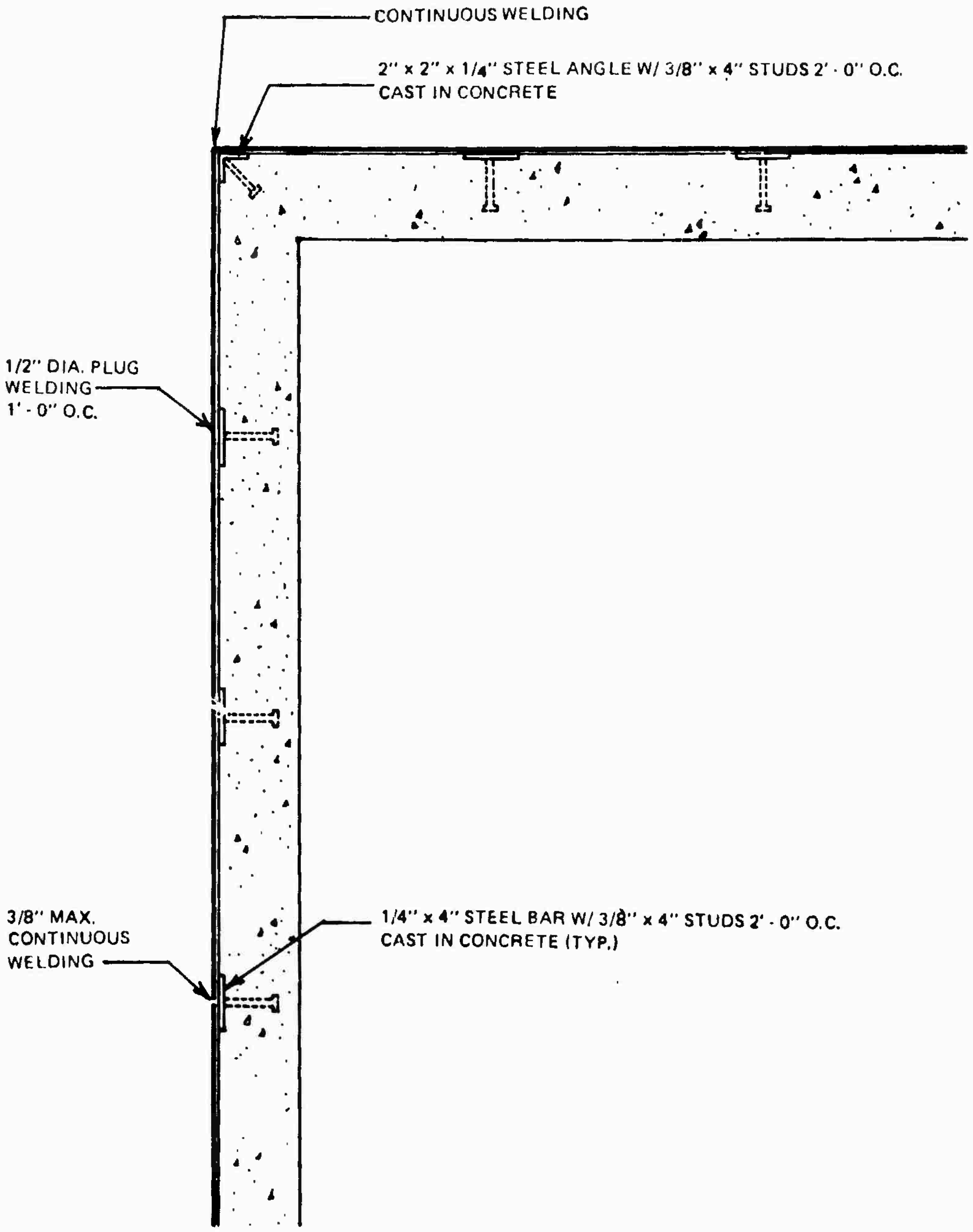
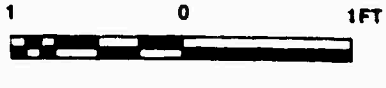
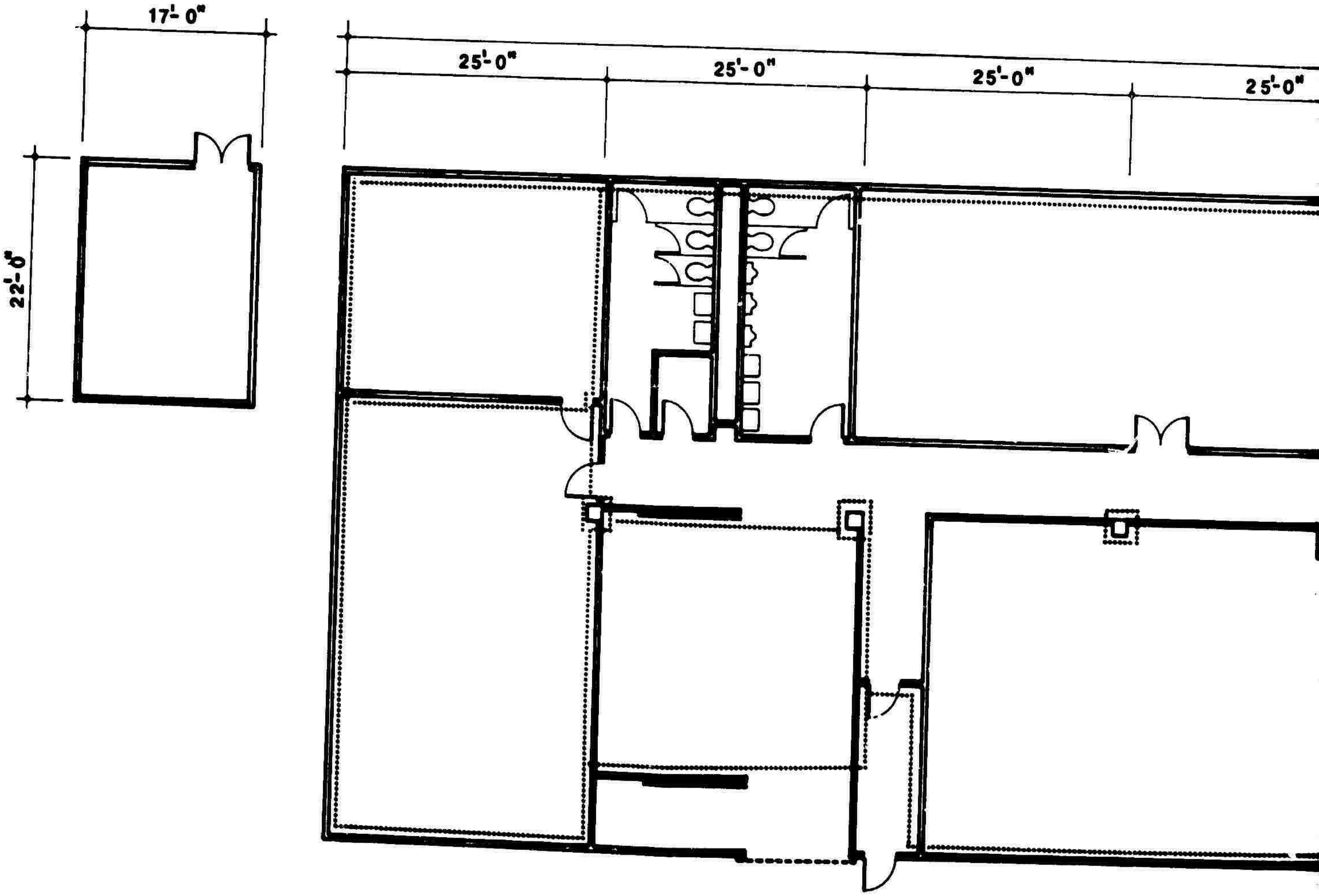


FIGURE 21. CONDITION I HORIZONTAL WALL DETAIL





17'- 0"
22'- 0"
25'- 0"
25'- 0"
25'- 0"
25'- 0"

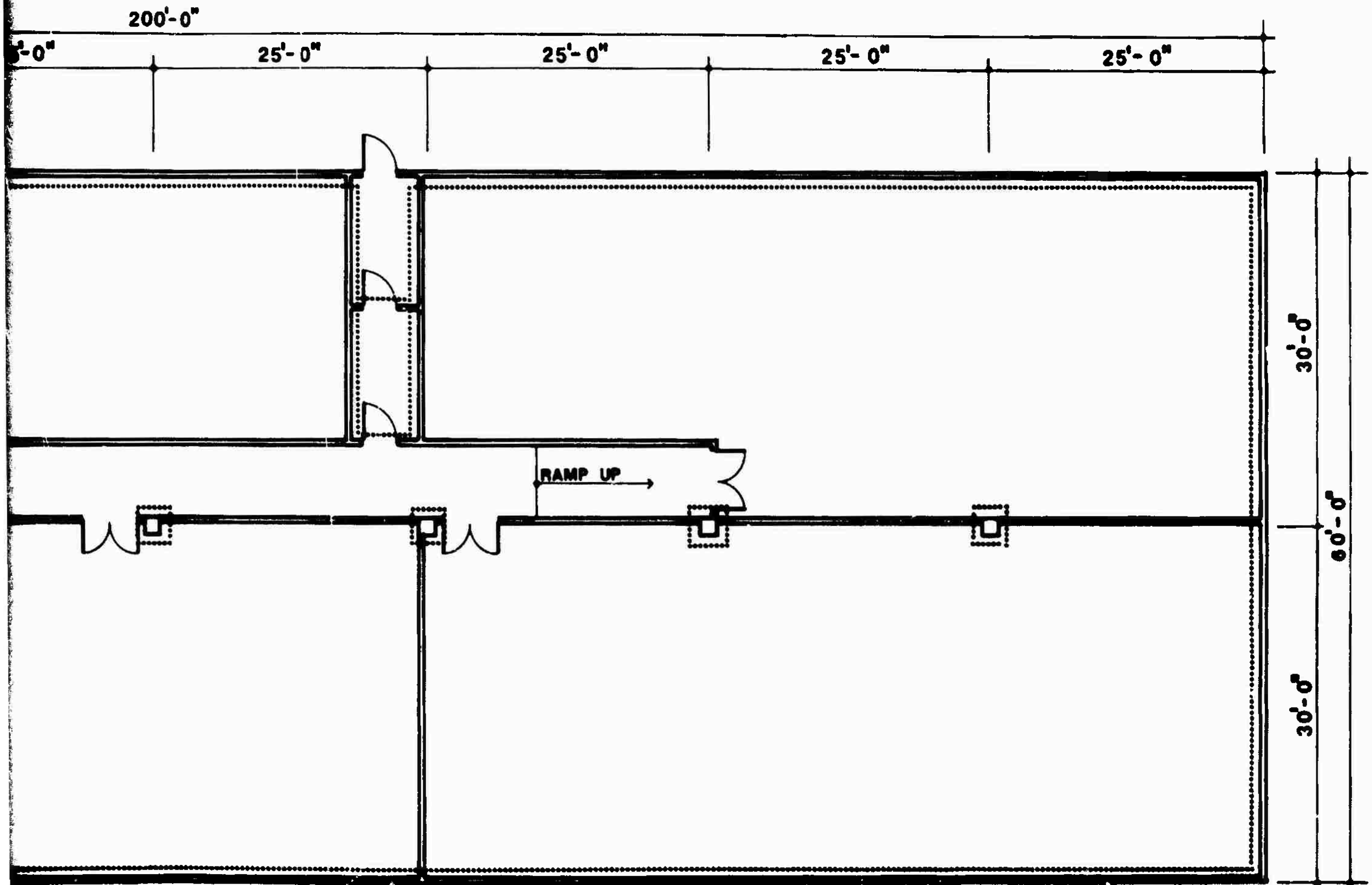


FIGURE 22. CONDITION II SHIELDING PLAN

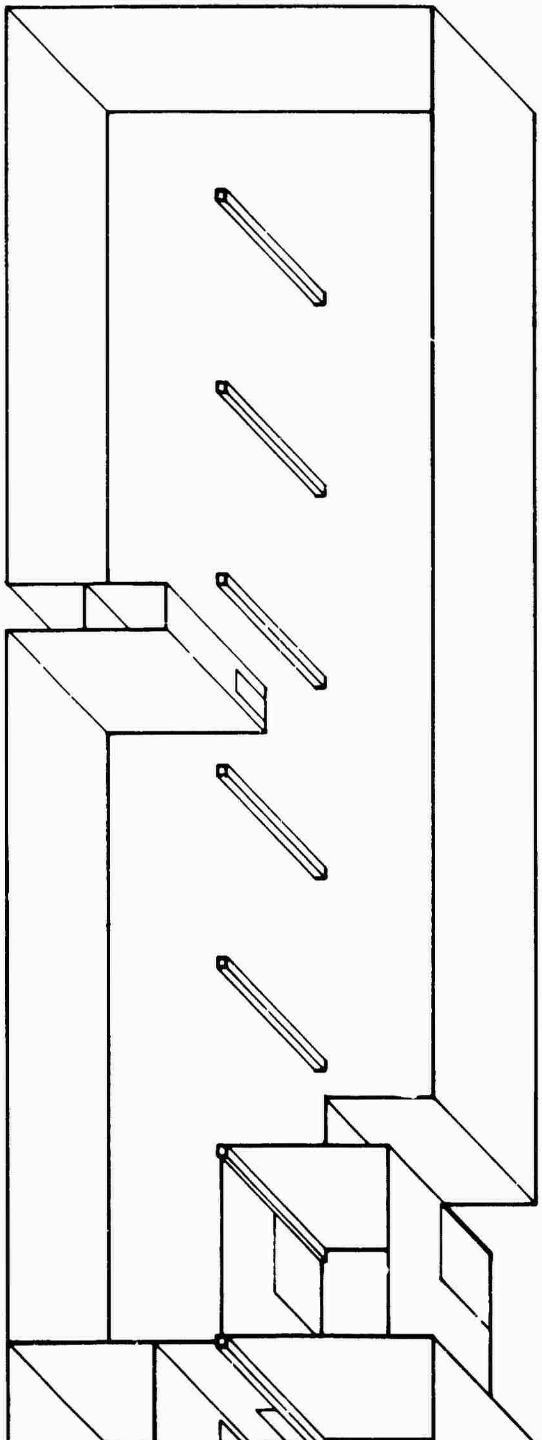


FIGURE 23. CONDITION II
ISOMETRIC

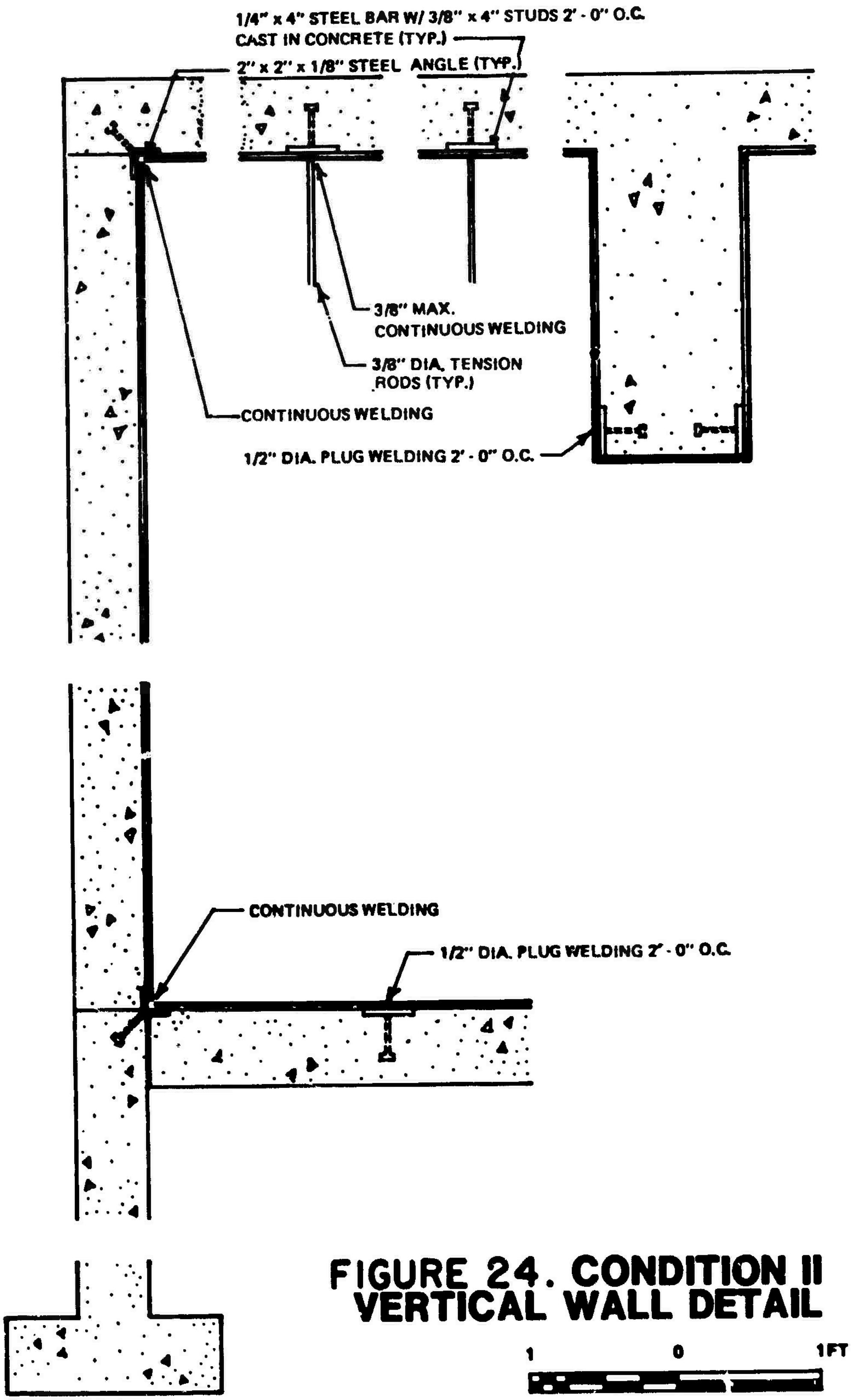


FIGURE 24. CONDITION II VERTICAL WALL DETAIL

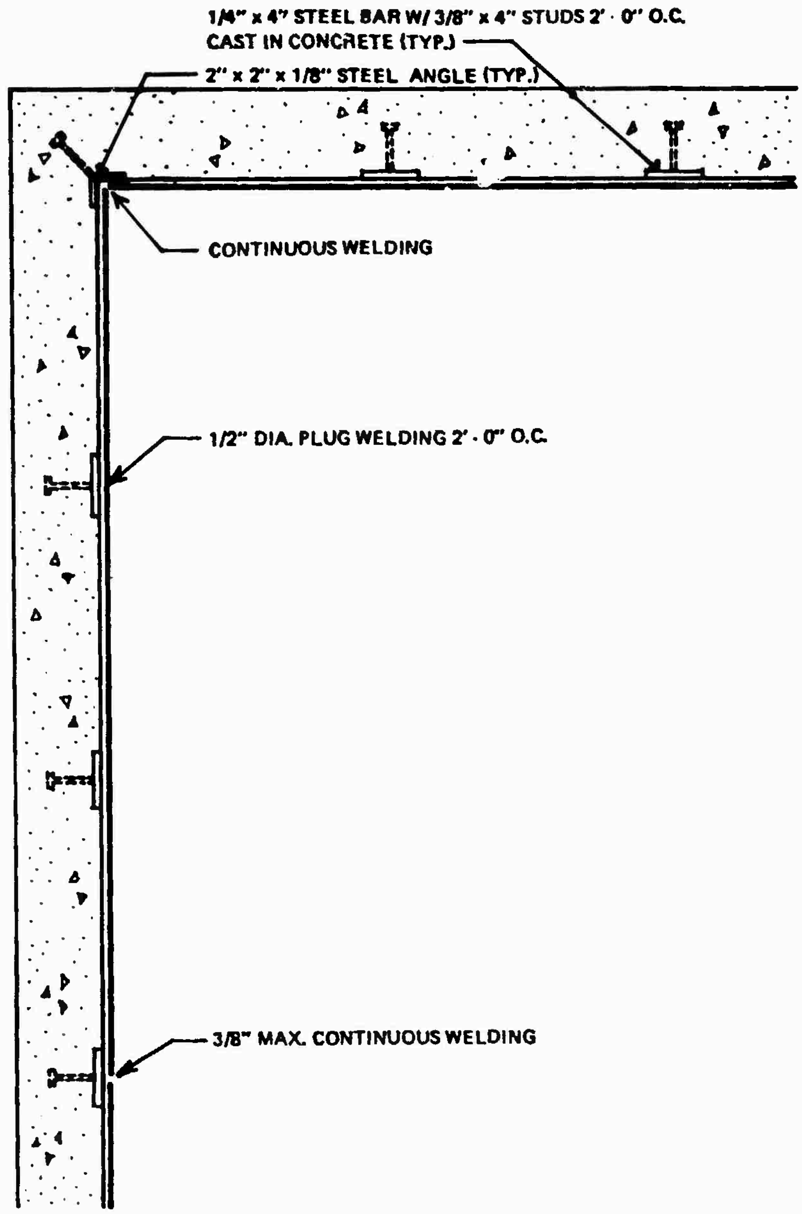


FIGURE 25. CONDITION II HORIZONTAL WALL DETAIL

1 0 1 FT.

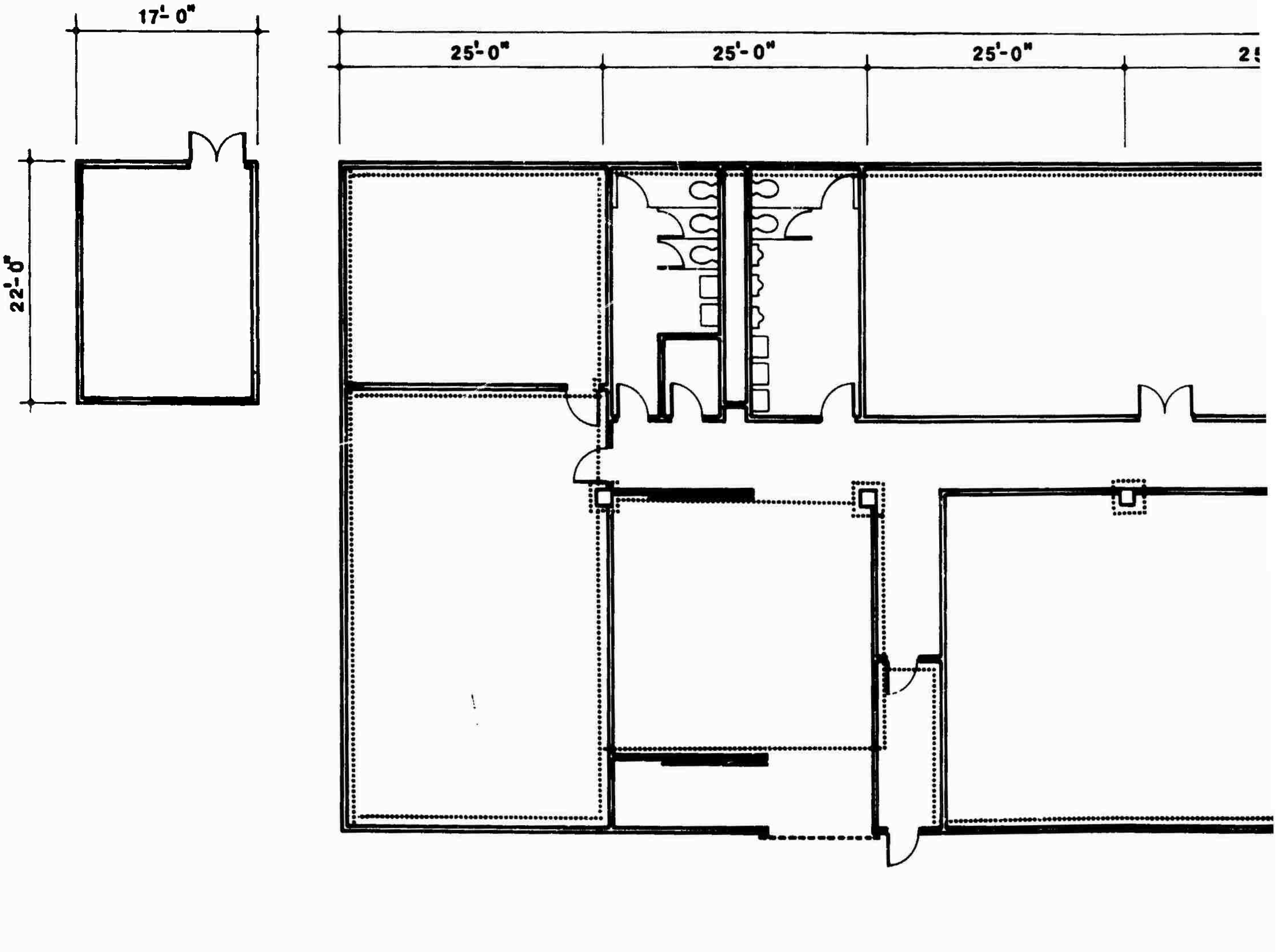
The ceiling system and ductwork is to be suspended from steel rods welded to the underside of the roof slab shielding. The rods are placed on 2 foot centers and in rows 20 inches apart. This is done so that the rods are located along the same lines of support as is the plate, which is attached to the slab by means of 1/4 by 4 inch steel bar and cast-in-place steel stud. In this way, the weight of the ceiling, light fixtures, and ductwork is transmitted directly to the slab without penetrating the shield (see Figure 24). All other architectural details and finishes are as described in Section 4.1.

4.4 CONDITION III AND III A, RETROFIT CONSTRUCTION, INTERNAL SHIELD, INTERIOR WALLS REPLACED

In the third of the four Conditions, it is assumed that the prototype C^3 structure is an existing building for which the shield is to be retrofitted. It is further assumed that the shield is to be applied to the interior surface of the building and that all existing interior partitions are to be removed before, and replaced after, the shielding is installed. Sub-Condition IIIa differs from Condition III only in that concrete block, rather than poured-in-place, walls are assumed. Figures 26 and 27 show the shield.

Generally, shielding and penetration details are as previously described in Section 4.1. Those details which pertain to this condition are similar to those described for Condition II in Section 4.3 except for two items. One difference is the additional work involved in the removal and replacement of all interior partitions - a procedure which in no way affects the design or details of the shield itself. It is assumed that little, if any pre-existing fixtures, ductwork, wiring etc. will be salvaged and be re-used.

The second difference between Condition III/IIIA and Condition II is the manner in which the 1/4 by 4 inch steel bar behind panel joints is secured to the wall. With new construction (Conditions I and II) the bar is to be prefabricated with 3/8 by 4 inch steel studs welded to it. The bar is then to be nailed to the formwork through pre-drilled holes and is to be subsequently cast into the concrete. In the retrofit situations (Condition III and IV), the bar is to be positioned against the wall, and the 4 inch steel stud shot through the bar into the poured-in-place concrete behind it as indicated in Figures 28 and 29. This procedure is not feasible when the existing wall is of concrete block construction (Conditions IIIa and IVa). In these instances, it is necessary to pre-drill both the bar and the concrete block wall, and secure the one to the other with toggle or expansion bolts. Once this work has been completed, installation of the shield can proceed.


17'- 0"
22'- 0"
25'- 0"
25'- 0"
25'- 0"

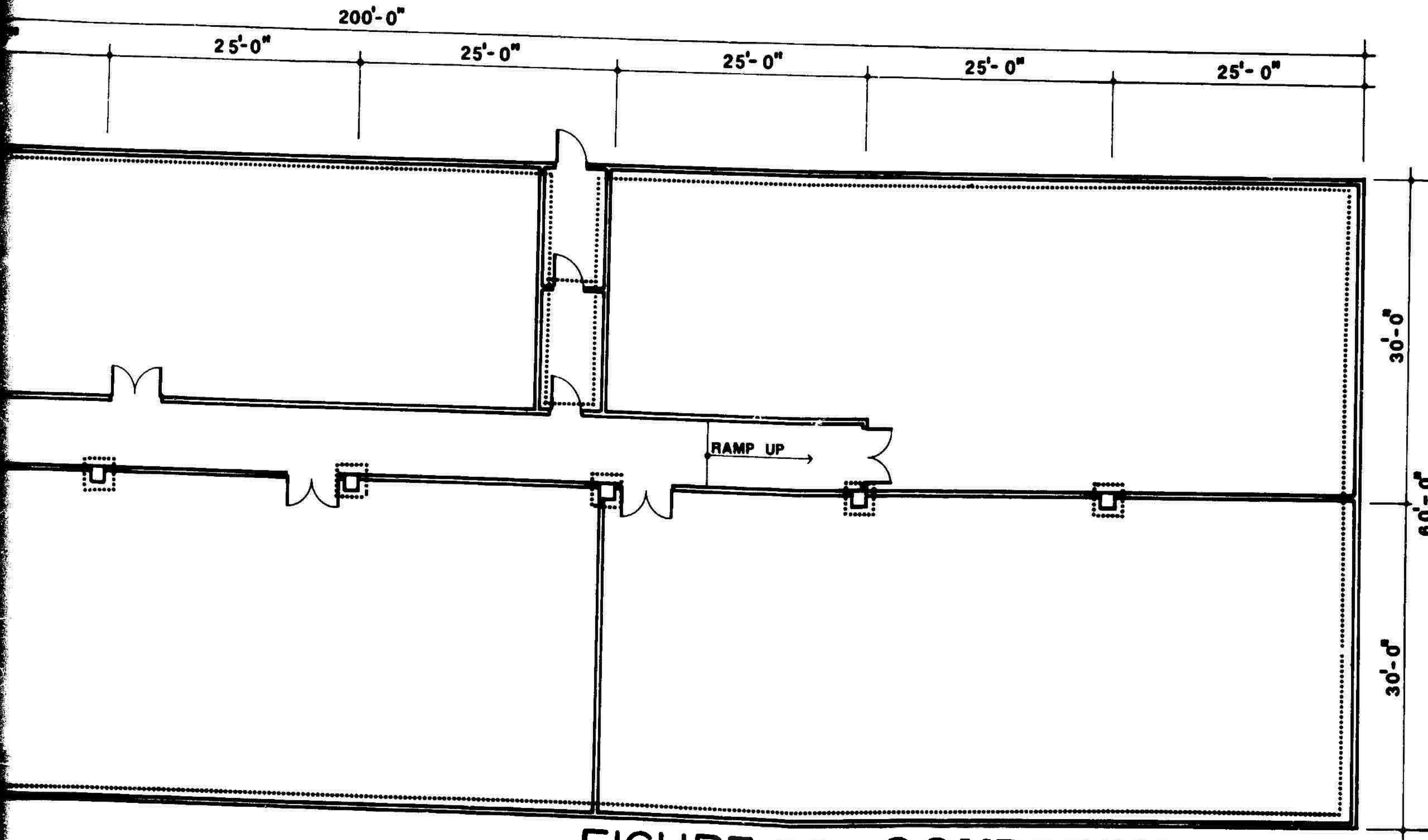


FIGURE 26. **CONDITION III/IIIa SHIELDING PLAN**

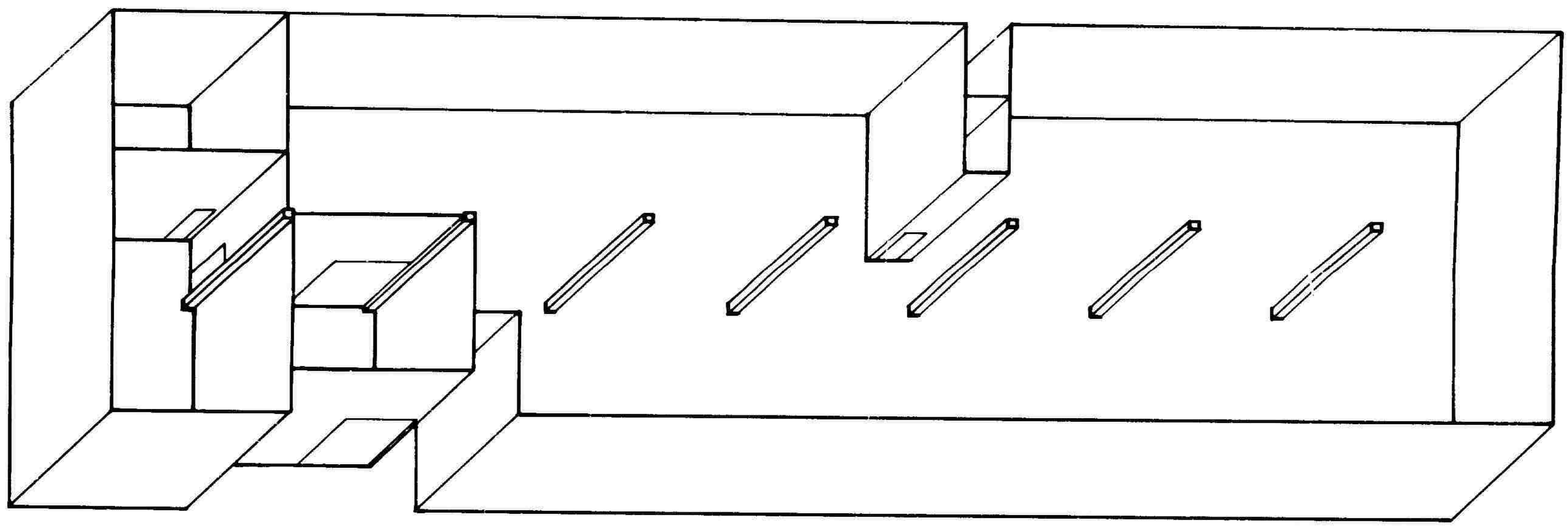


FIGURE 27. **CONDITION III/IIIa ISOMETRIC**

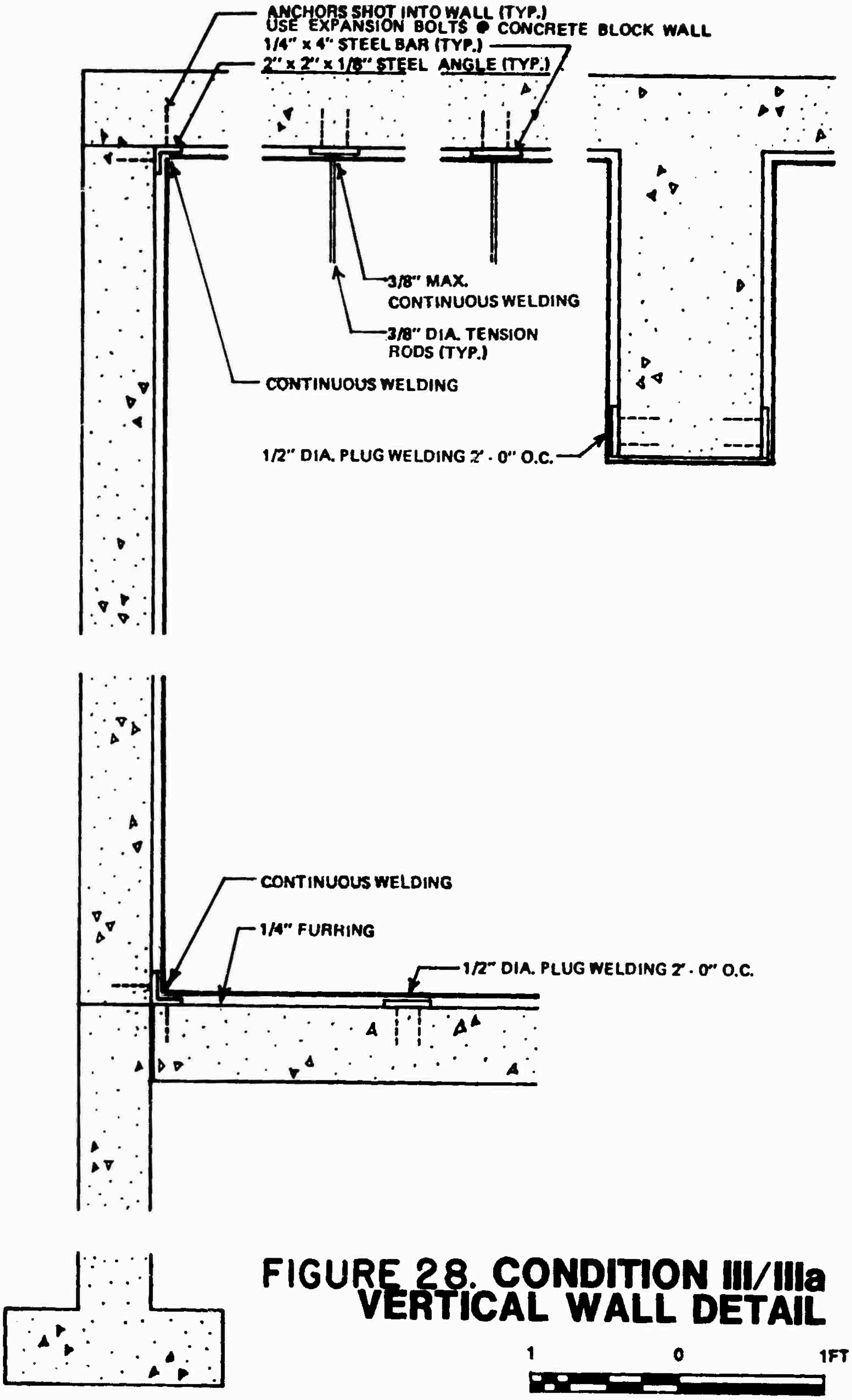


FIGURE 28. CONDITION III/IIIa VERTICAL WALL DETAIL

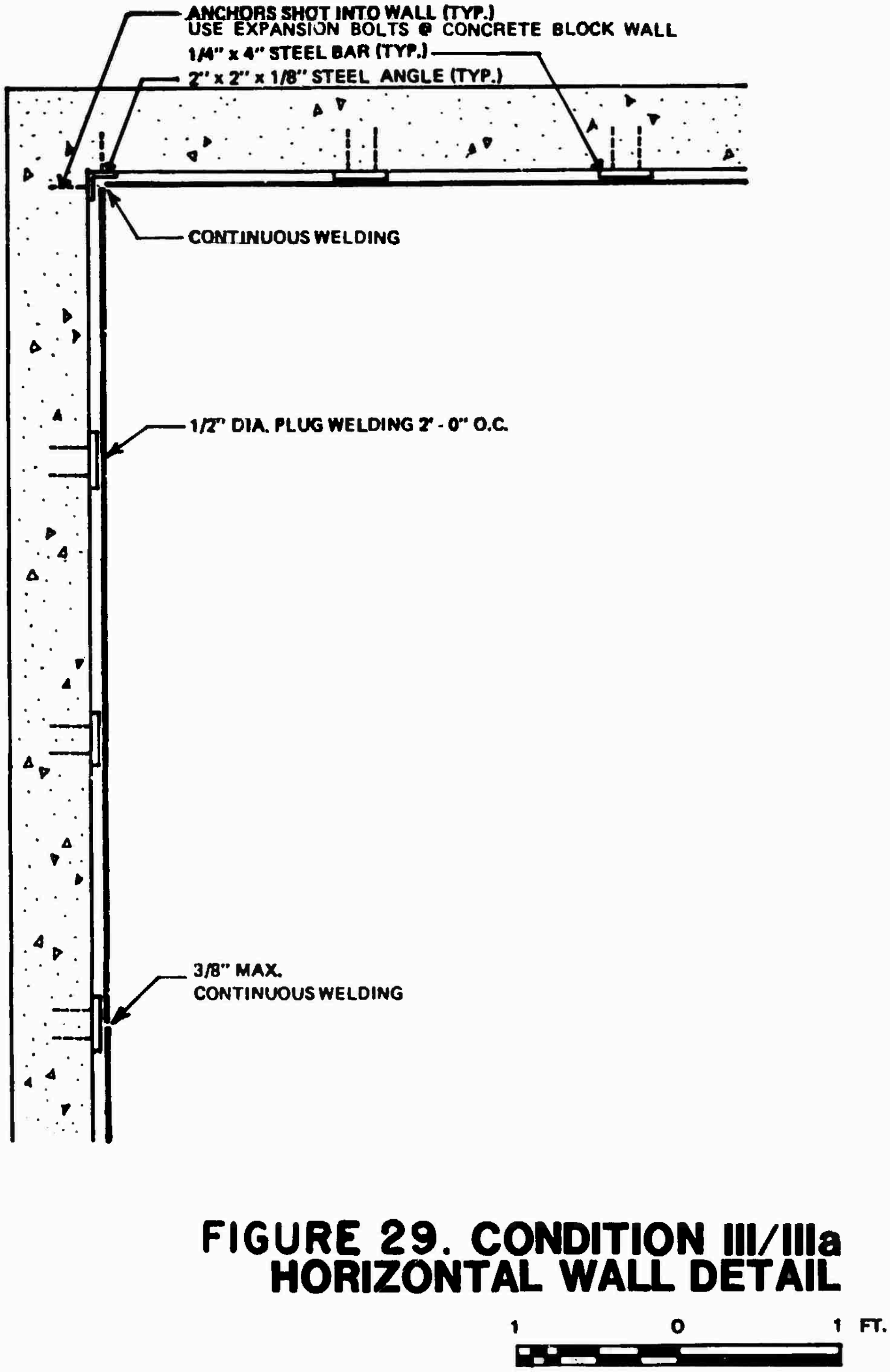


FIGURE 29. CONDITION III/IIIa HORIZONTAL WALL DETAIL

The interior finishes also remain the same and are installed in a manner similar to that described under Condition II. New partitions are assumed to be gypsum wallboard on steel studs. The studs and baseplate are to be tack-welded to wall and floor shielding, respectively.

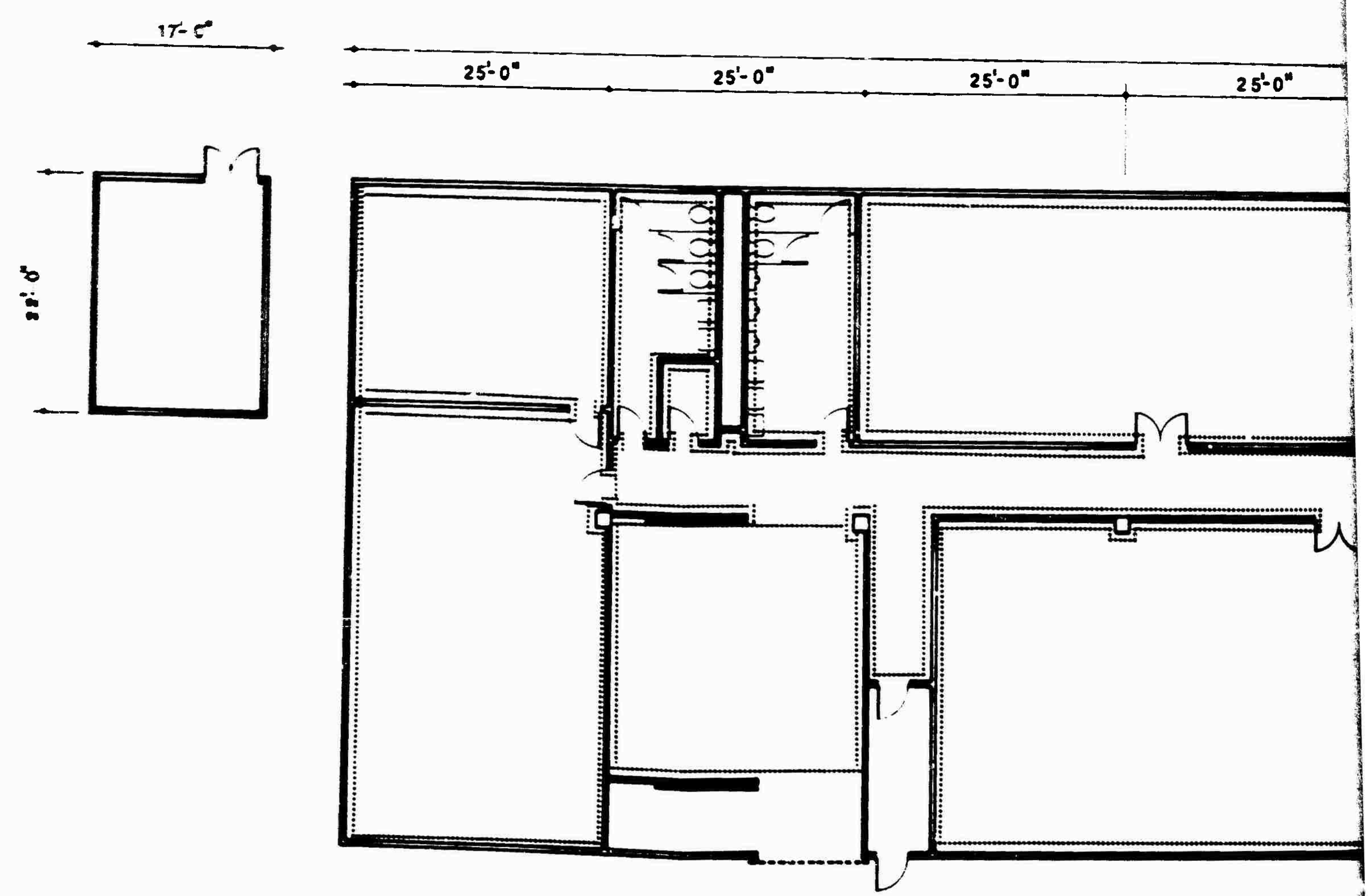
4.5 CONDITIONS IV AND IVA, RETROFIT CONSTRUCTION, INTERNAL SHIELD, INTERIOR WALLS RETAINED

In the last of the four Conditions for the all-welded shield it is assumed that the prototype C^3 structure is an existing building which is to be retrofitted, that the shield is to be applied to the interior surface of the building, and that all existing interior partitions are to remain in place. Sub-Condition IVa differs from Condition IV only in that it assumes concrete block rather than poured in place concrete exterior walls. Generally, shielding and penetration details are as previously described in Section 4.1. Many details which pertain to this condition are similar to those described for Conditions II and III. Again, it is assumed that little, if any, pre-existing fixtures, ductwork, wiring, etc., will be salvaged and re-used.

A major difference with Conditions IV/IVA compared with Condition II is the problem of providing a continuous floor shield and a continuous ceiling shield in the presence of floor-to-ceiling interior partitions which are to remain in place. A continuous shield can be constructed only by shielding both faces of all interior partitions, as shown in Figures 30 and 31. This understandably results in substantially increased amounts of material and labor. Beam enclosures must be fabricated in two "L" shaped sections rather than one "U" shaped section where beams are on partition lines, for instance. Details of horizontal and vertical walls are given in Figures 32 and 33.

The interior finishes are also to remain the same, and are to be installed in a manner similar to that described for Conditions II and III. Interior wall shielding is assumed to be covered with painted gypsum wallboard on steel studs tack-welded to the steel panels. Floor welds are to be ground smooth prior to the installation of vinyl asbestos tile, and the acoustical tile ceiling is to be suspended from rods welded to the shield along its lines of support.

As with Sub-Condition IIIa, Condition IVa assumes concrete block rather than poured-in-place concrete exterior wall construction. As a consequence, toggle or expansion bolts are to be used to attach the 1/4 by 4 inch bars to the existing walls. Otherwise, the architectural details and finishes are identical to Condition IV.


17'- 0"
25'- 0"
25'- 0"
25'- 0"
25'- 0"
22'- 0"

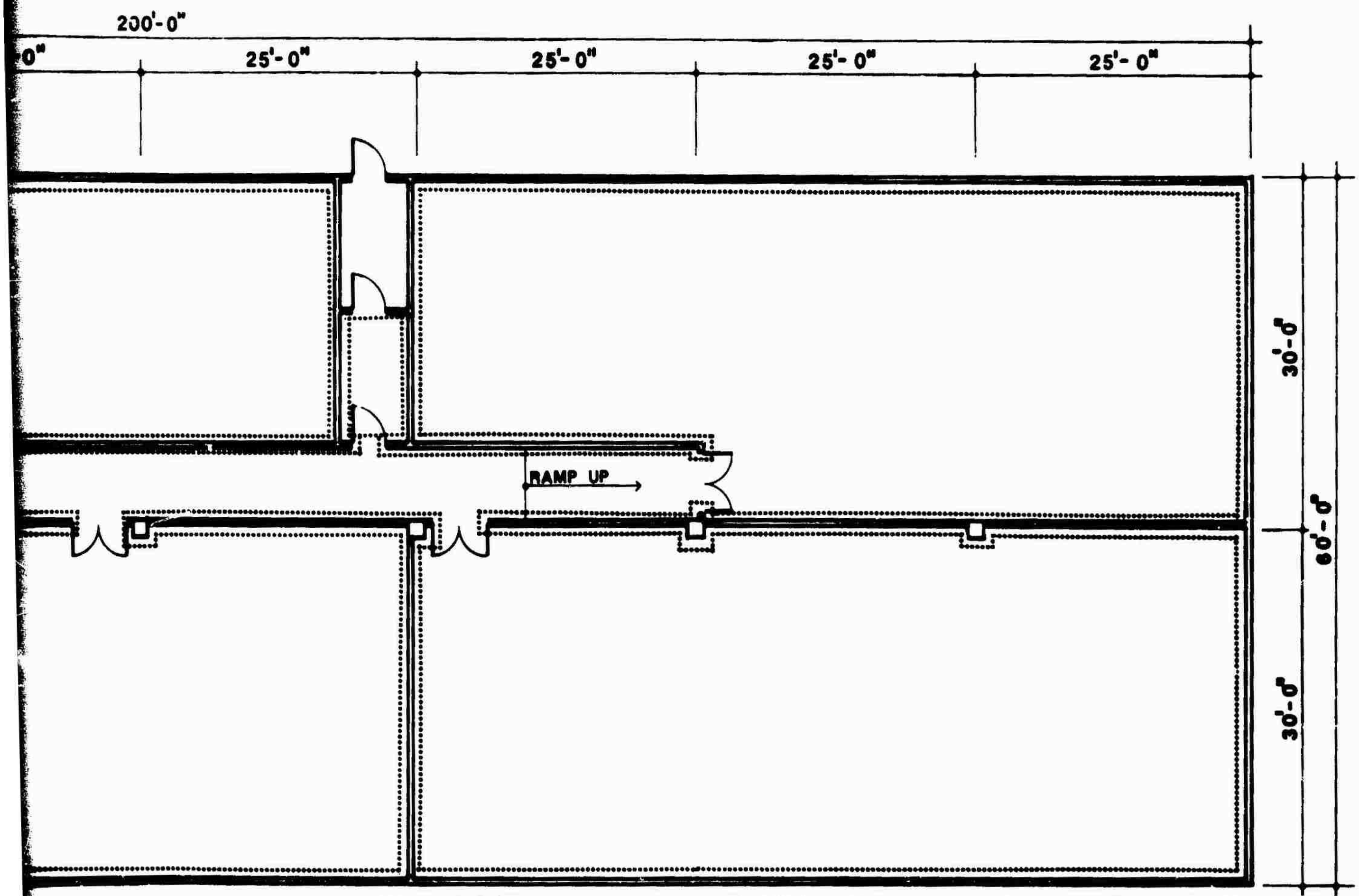


FIGURE 30. CONDITION IV/IVa SHIELDING PLAN

10 0 10 20 FT.

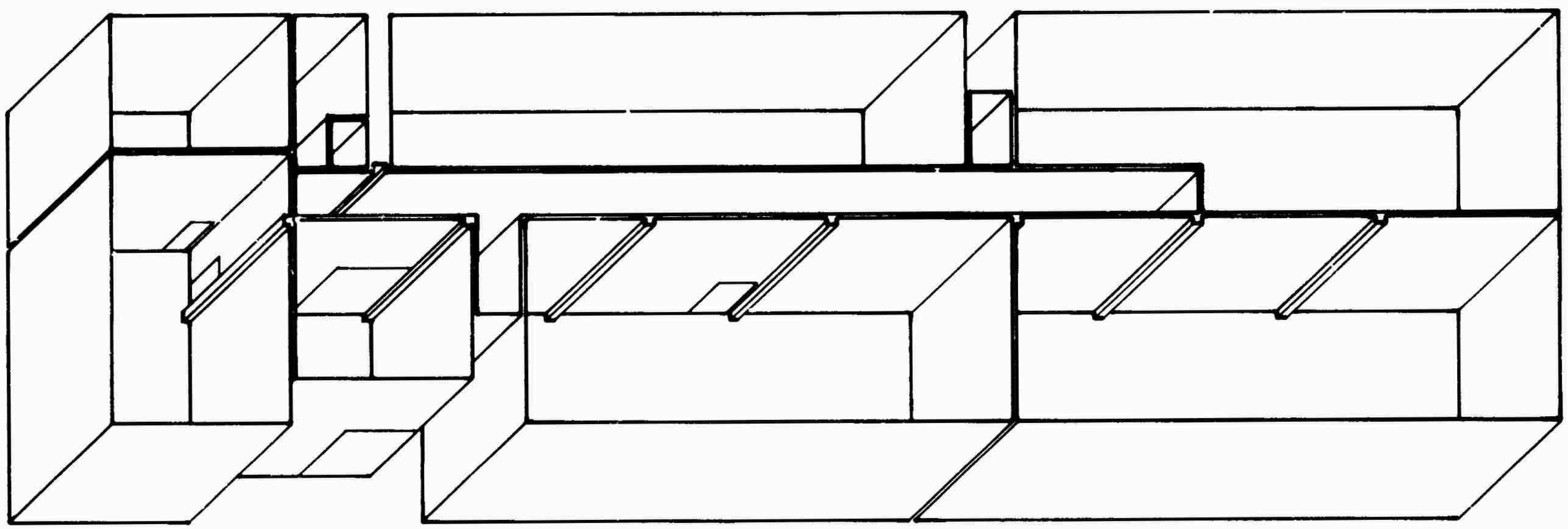


FIGURE 31. CONDITION IV/IVa
ISOMETRIC

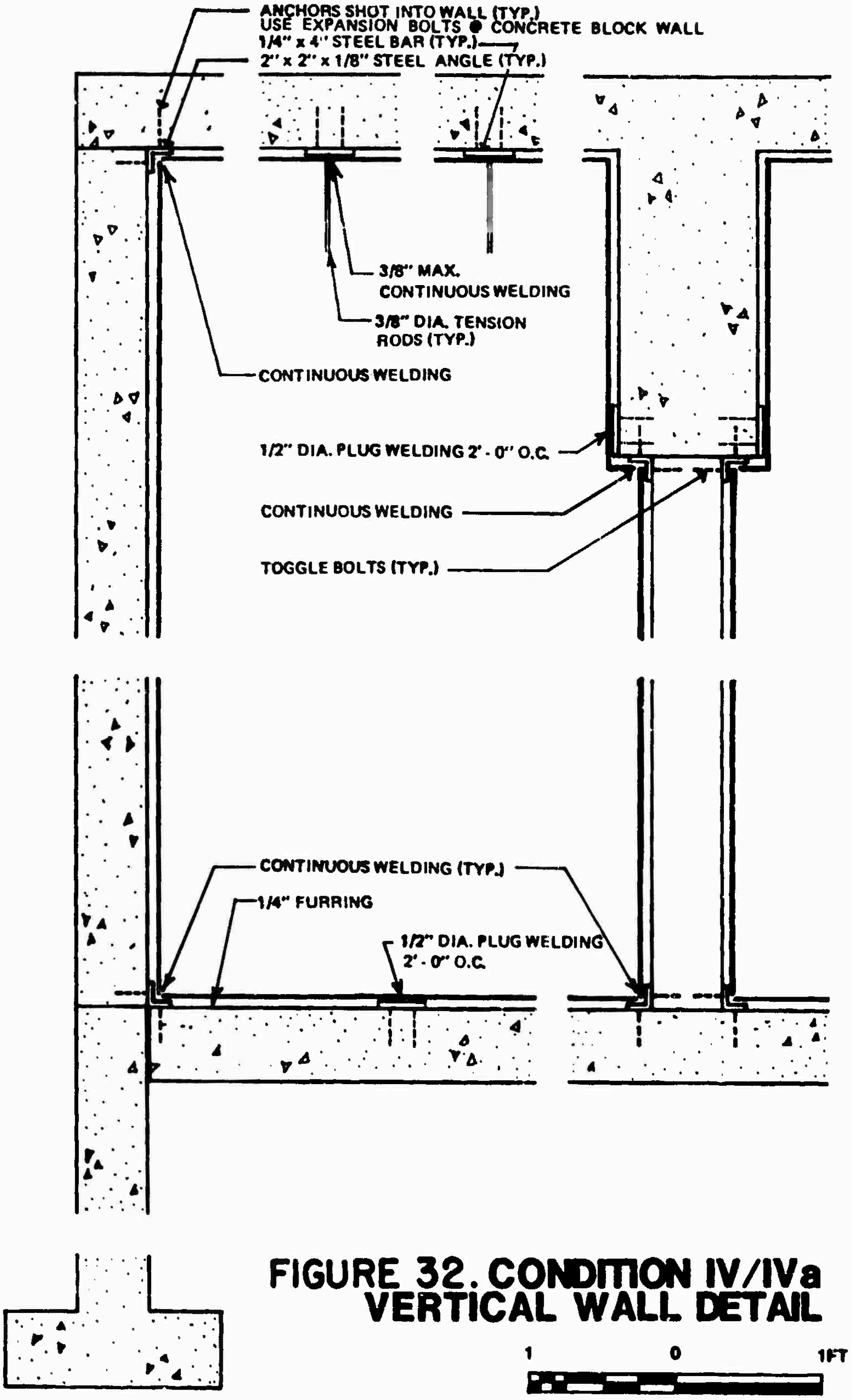


FIGURE 32. CONDITION IV/IVa
VERTICAL WALL DETAIL

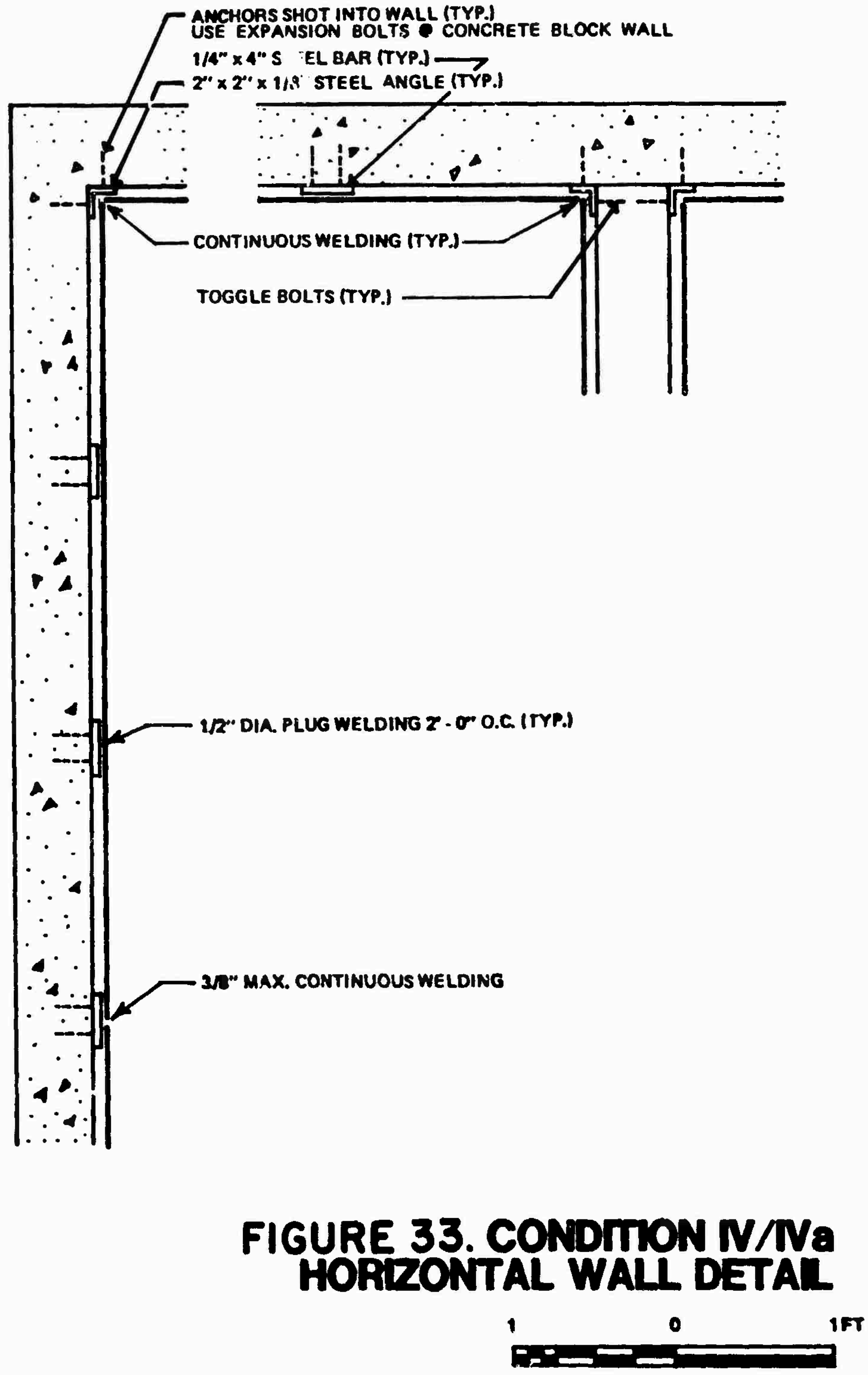


FIGURE 33. CONDITION IV/IVa HORIZONTAL WALL DETAIL

SECTION 5

COST ESTIMATES FOR WELDED SHIELDS

The Opinions of Probable Cost presented here (Tables 2 to 7) for the all-welded shields are based upon a series of assumptions discussed in Section 4 and a list of additional assumptions given in Appendix A.

One assumption is that the location of the C^3 structure is in the Chicago Metropolitan Area, and local labor and material costs are used exclusively, as of December, 1979. Publications such as Engineering News Record, Dodge Reports, or Building Construction Cost Data published by R. S. Means Co., Inc. can be consulted for costs in other cities. The prices cited here are for average, conventional construction. Local variations in the labor supply required for EMP shield construction could affect the actual rates.

Appendix B contains the worksheets used to arrive at the Opinions of Probable Cost in Tables 2 to 7. The individual costs listed in Appendix B are the costs to the General Contractor. To these, have been added ten percent for contractor's overhead, ten percent for contractor's profit, and a five percent contingency, in arriving at the totals given in Tables 2 to 7.

The cost of acquisition of land, or of an existing building to be retrofitted, are considered to be beyond the scope of this report, as are taxes. As indicated in the description of Conditions III and IV, it is considered unlikely that any substantial portion of the pre-existing HVAC, Electrical or Plumbing systems will be salvaged and re-used. For this reason, the Opinions assume the worst possible case of total replacement of these systems.

Finally, those costs of providing a shielded C^3 structure NOT attributable to the costs of providing and installing the shield itself, are not included. Stated another way, the costs represent the premium to be paid for shielding an otherwise conventional C^3 installation. It is assumed that those base costs to build the structure would be approximately $475,000, or about $39.50 per square foot. This figure includes the cost of the reinforced, poured-in-place concrete structure, interior walls (partitions), paint, false ceiling, and electrical, plumbing, heating and air conditioning facilities, as well as overhead, profit, and construction contingency. In comparing the total costs necessary to provide a completed, shielded C^3 structure, this figure ($475,000) should be added to the cost estimates for Conditions I and II in order to obtain a comparison of the acquisition costs for the four conditions. Such comparative totals are given in Section 9. (No provision has been made to consider the value of an existing building for which a shield is to be retrofitted, as in Conditions III and IV.)

TABLE 2 - OPINION OF PROBABLE COST - CONDITION I

LABOR AND MATERIAL	HOURLY WAGE RATE	HOURS	DOLLARS
Iron Worker (Field)	17.13	29,365	503,030
Iron Worker (Shop)	13.00	2,648	34,430
Painter (Field)	12.50	138	1,720
Carpenter (Field)	15.00	1,766	26,500
Material (Shielding)			122,270
Material (Other)			1,140
Subtotal			689,090
Contractor's Profit and Overhead (21%)			144,710
Subtotal			833,800
Contingency (5%)			41,690
Total			$875,490
		SAY	$875,000

TABLE 3 - OPINION OF PROBABLE COST - CONDITION II

LABOR AND MATERIAL	HOURLY WAGE RATE	HOURS	DOLLARS
Iron Worker (Field)	17.13	25,357	434,360
Iron Worker (Shop)	13.00	7,448	96,820
Painter (Field)	12.50	-	-
Carpenter (Field)	15.00	1,766	26,500
Material (Shielding)			153,325
Material (Other)			7,500
Subtotal			718,505
Contractor's Profit and Overhead (21%)			150,886
Subtotal			869,391
Contingency (5%)			43,470
Total			$912,861
		SAY	$910,000

TABLE 4 - OPINION OF PROBABLE COST - CONDITION III

LABOR AND MATERIAL	HOURLY WAGE RATE	HOURS	DOLLARS
Iron Worker (Field)	17.13	24,185	414,300
Iron Worker (Shop)	13.00	5,864	76,230
Painter (Field)	12.50	1,360	17,000
Carpenter (Field)	15.00	3,330	49,950
Electrician (Field)	17.00	2,837	48,230
Plumbing (Field) Sheet Metal (Field) Steam Fitters (Field)	Av. 15.90	6,478	103,000
Laborer (Field)	12.00	5,742	68,900
Material (Shielding)			143,600
Material (Other)			224,300
Subtotal			1,145,510
Contractor's Profit and Overhead (21%)			240,560
Subtotal			1,386,070
Contingency (5%)			69,300
Total			$1,455,370
		SAY	$1,455,000

TABLE 5 - OPINION OF PROBABLE COST - CONDITION IIIa

LABOR AND MATERIAL	HOURLY WAGE RATE	HOURS	DOLLARS
Iron Worker (Field)	17.13	24,814	425,060
Iron Worker (Shop)	13.00	7.242	94,140
Painter (Field)	12.50	1,360	17,000
Carpenter (Field)	15.00	3,330	49,950
Electrician (Field)	17.00	2,837	48,230
Plumbing (Field) Sheet Metal (Field) Steam Fitters (Field)	Av. 15.90	6,478	103,000
Laborer (Field)	12.00	5,742	68,900
Material (Shielding)			160,070
Material (Other)			224,300
Subtotal			1,190,650
Contractor's Profit and Overhead (21%)			250,040
Subtotal			1,440,690
Contingency (5%)			72,030
Total			$1,512,720
		SAY	$1,515,000

TABLE 6 - OPINION OF PROBABLE COST - CONDITION IV

LABOR AND MATERIAL	HOURLY WAGE RATE	HOURS	DOLLARS
Iron Worker (Field)	17.13	33,854	579,920
Iron Worker (Shop)	13.00	7,262	94,410
Painter (Field)	12.50	1,350	16,870
Carpenter (Field)	15.00	3,991	59,870
Electrician (Field)	17.00	2,837	48,230
Plumbing (Field) Sheet Metal (Field) Steam Fitters (Field)	Av. 15.90	6,478	103,000
Laborer (Field)	12.00	4,307	51,680
Material (Shielding			185,010
Material (Other)			240,090
Subtotal			1,379,080
Contractor's Profit and Overhead (21%)			289,600
Subtotal			1,668,680
Contingency (5%)			83,420
Total			$1,752,100
		SAY	$1,750,000

TABLE 7 - OPINION OF PROBABLE COST - CONDITION IVa

LABOR AND MATERIAL	HOURLY WAGE RATE	HOURS	DOLLARS
Iron Worker (Field)	17.13	33,904	580,770
Iron Worker (Shop)	13.00	10,530	136,890
Painter (Field)	12.50	1,350	16,870
Carpenter (Field)	15.00	3,991	59,870
Electrician (Field)	17.00	2,837	48,230
Plumbing (Field) Sheet Metal (Field) Steam Fitters (Field)	Av. 15,90	6,478	103,000
Laborer (Field)	12.00	4,307	51,680
Material (Shielding)			209,910
Material (Other)			240,090
Subtotal			1,447,310
Contractor's Profit and Overhead (21%)			303,940
Subtotal			1,751,250
Contingency (5%)			87,550
Total			$1,838,800
		SAY	$1,840,000

SECTION 6

DESIGN FOR SHIELD FASTENED BY POWDER-DRIVEN PINS

6.1 INTRODUCTION

At the conclusion of the study and costing of the welded shield design (Sections 3, 4, and 5), it was evident that a substantial portion of the shield cost was due to the MIG welding of the shield seams. Consequently, as a possible means of providing a lower cost shield, an alternative design was considered which, except for the entry plate, does not utilize welding to fasten the steel sheets together. The alternative design considered uses powder-driven pins which serve both functions of fastening the sheets together mechanically and fastening the sheets to the building's concrete walls, floor, and roof. For practical purposes, the powder-driven pins can be considered to fasten the sheets together with about the same characteristics as would be provided by bolts or rivets. This section of the report describes the features of the design; Section 7 presents a cost estimate.

The basis for considering this alternative design is the report[6] of a recent study by SRI International on bolted lapped-joint EMP shields. The study showed that good overlap joints can be made for EMP shields using aluminum or galvanized steel if the panels have good metal-to-metal contact, if fastener spacings are no larger than 7.5 cm (3 inches), and if joint overlap is at least 10 cm (4 inches).

Since the alternative design considered here was evolved near the conclusion of the present program, only limited time and effort could be applied. As a result, the design is much less detailed than the designs for the welded shield, and the cost figures provided must be considered to be only a rough estimate.

It must also be emphasized no experimental evidence is available regarding the shielding effectiveness of a total facility shield of this type. Also, as will be pointed out, the practicality of this type of construction for the floor shield is not at all certain. Furthermore, while this type of construction eliminates the welding requirements for most of the shield, an entry plate consisting of 1/4 inch steel sheets welded together, is retained on the end of the building through which all the penetrants are assumed to enter.

6.2 GENERAL DESCRIPTION

The proposed shield consists of galvanized steel sheets, primarily 4 feet by 8 feet, covering the inner surfaces of the exterior walls, roof, and floor. As shown in Figure 34, the edges of adjacent sheets would be overlapped four inches, and the sheets would be fastened together, as well as attached to the building surfaces, by powder-driven pins

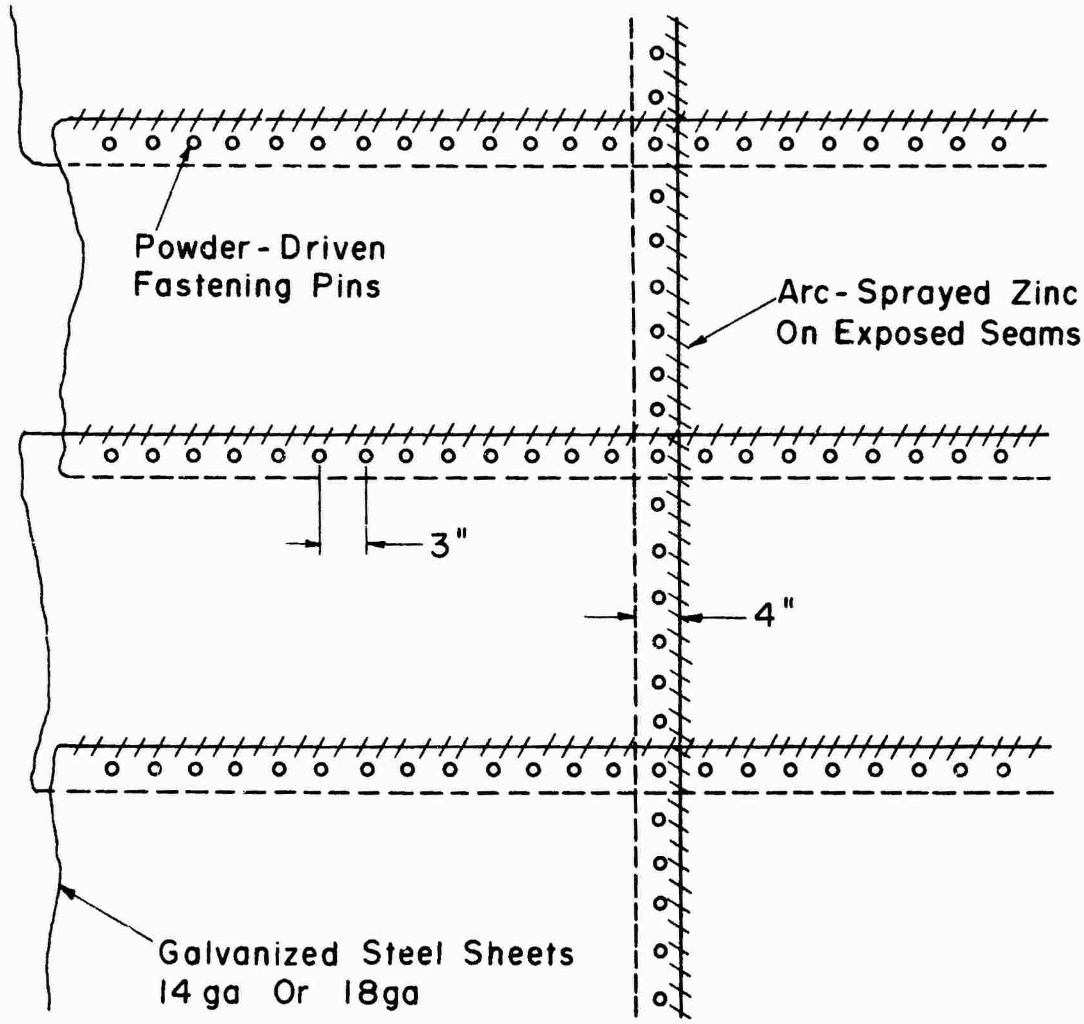


Figure 34. SHIELD DESIGN FOR CONDITION V

every three inches along each overlapped seam. After the complete shield is emplaced in this manner, all of the seams would be lightly grit blasted to remove any surface dirt, and the seams would be arc sprayed with zinc to provide electrical continuity between sheets.

In the welded-shield design (Sections 3, 4, and 5), 11 gauge (0.12 inch or 3.0 mm) steel was proposed to prevent the sheets from buckling during welding. For the alternative design considered here using powder-driven pins, that restriction is removed, and thinner material can be used. Two shield thicknesses are considered:

14 gauge (0.075 inch or 1.9 mm), and
18 gauge (0.048 inch or 1.2 mm).

By reference to Fig. 7, it is seen that the absorption loss for 14 ga and 18 ga steel is approximately 120 dB and 80 dB, respectively at 10 KHz. The mechanical designs for the two shield thicknesses are assumed to be the same. The only difference considered is the difference in cost of the material, essentially due to the difference in weight of the sheets: 105 lb./sheet for 14 ga; 69 lb./sheet for 18 ga.

6.3 SOME CHARACTERISTICS OF POWDER-DRIVEN PINS

The powder-driven pins are made of galvanized steel. They are available in various shank diameters from 1/8 to 1/4 inch and shank lengths from 1/2 to 2 1/4 inch. One end of the shank is tapered for penetrating the steel, concrete, etc., while the other end is available in various configurations such as a threaded end, an eyelet end, or a flat-headed end (optionally with an additional metal washer).

The pins are installed or driven using a hand-held, gun-shaped tool. The barrel accommodates the pin which is to be driven, and an explosive charge of gun powder. Firing is accomplished by pressing the muzzle of the barrel against the work surface, and squeezing the trigger. With an automatic tool, pins can be driven at a fairly rapid rate, with rates of six to ten per minute quoted by suppliers.

For pins driven into concrete, as anticipated here for the shield, maximum holding strength in the concrete occurs when the penetration into the concrete is approximately eight times the shank diameter. For 1/8 inch diameter pins, a one inch length should be suitable for fastening the sheets to the concrete walls, floor, and ceiling. The holding force depends strongly on the characteristics of the concrete, including the compressive strength, the type of aggregate, and whether the cement mixture is vibrated after it is poured. Pins with 1/8 inch diameter shank driven into concrete having a compressive strength of 2500 psi can have an average holding strength of approximately 500 to 900 pounds per pin. Thus it appears that such pins should provide adequate support to fasten the steel sheets to the concrete. To assure that the pins driven into concrete that the pins driven into concrete maintain their holding power constant over a long period of time, e.g., 20 years, it is recommended that they be installed in concrete which has cured for a minimum of 28 days.

Uniformity of depth of pin penetration will depend on the uniformity of the concrete. Soft regions such as sand spots could permit excessive penetration, with the result that the head of the pin may be driven right through the sheets being fastened, putting a hole in the sheet.

For attachment of ceiling hanger straps to support a false ceiling, lighting fixtures, conduits, etc., additional powder-driven pins could be installed in the ceiling on 16 inch centers. Pins with eyelet holes could be used for accommodating hanger wire directly.

6.4 GRIT BLASTING

Prior to arc spraying of zinc on the exposed sheet metal seams, it is recommended that the region along the seams be lightly grit blasted to remove any surface dirt or grease. The floor must be swept and probably vacuumed prior to application of the zinc arc spray.

6.5 ZINC ARC SPRAYING

While the powder-driven pins can provide good mechanical fastening of adjacent steel sheets to each other, the mechanical attachment alone cannot be relied on to provide good electrical continuity. Even a small amount of "dimpling" of the sheets at each pin location will cause the sheets to bow slightly, possibly preventing even good mechanical contact along much of the seam. In addition, in the region of the pins, where the sheets are held in firm mechanical contact, electrical contact may still be poor because of surface dirt on the mating surfaces. In order to provide good electrical contact between sheets, and therefore low resistance across seams, arc spraying of the seam with a layer of zinc is proposed.

Commercial equipment to perform metallic arc spraying consists primarily of an arc spray gun, a high-current power supply, and a source of compressed air. Two bare wires of the metal to be sprayed are electrically isolated except for contact near the nozzle of the gun, where their ends are in contact. The power supply, connnected between the two wires, causes current flow at the junction of the wires, causing the wire tips to melt. A continuous jet of air blows the molten metal as a fine spray out of the gun's nozzle. As the metal spray is deposited on the surface to be coated, a dense integrally bonded coating builds up.

The sprayed zinc is said to have a density equal to 94 percent of the density of solid zinc. (It contains a slight amount of oxidation products.) The conductivity of sprayed zinc is reported to be less than that of solid zinc, but greater than that of steel.

To estimate the amount of zinc required to cover a surface to a specified depth, a guide is that 0.9 ounce of zinc is required to cover one square foot of surface to a depth of 0.001 inch. A typical commercial arc spray machine is capable of spraying zinc at an average rate of 36 pounds/hour.

6.6 PROBLEMS ASSOCIATED WITH THIS SHIELD DESIGN

Perhaps the major questions regarding the applicability of powder-driven pins for the shield fabrication relate to the floor shield. One possible problem is the lack of a smooth surface due to the heads of the pins protruding above the surface of the steel sheets. This roughness would probably make it impossible to apply directly a thin plastic floor covering, e.g., vinyl.

Another problem might possibly arise in regard to the shielding performance. Floor loading might affect the electrical continuity of the floor shield if it causes fracturing of the arc-sprayed zinc seams over a period of time. Such fracturing may possibly occur due to constant heavy loading on portions of the floor, e.g., by heavy equipment or internal walls, or else possibly by varying loads and resulting flexing, for example due to repeated walking over the seams.

If satisfactory answers cannot be found for these questions, it may be necessary to require the use of a welded steel floor as provided in the designs in Sections 3 and 4 of this report.

SECTION 7

COST ESTIMATE FOR SHIELD FASTENED BY POWDER-DRIVEN PINS

Table 8 shows the cost estimate for the shield design designated here as Condition V -- New Construction, Internal Shield, Galvanized Steel Sheets Fastened by Powder-Driven Pins. A more detailed listing is given in Appendix B. As mentioned earlier, the design features and cost estimate for Conditions V were developed by IITRI near the end of the contract and were not done in the same degree of detail as were the designs and cost estimates developed by L. B. Knight for Conditions I, II, III, and IV. The assumptions made in costing the shield design for Condition V are given below.

7.1 GALVANIZED STEEL SHEET

Material costs for flat stock:

14 ga 48 inches x 96 inches, flat sheets, 105 pounds at $28.25/100 pounds = $30/sheet

14 ga 48 inches x 96 inches and 30 inches x 96 inches, formed sheets (predominantly a single bend)

$40 est.

18 ga 48 inches x 96 inches flat sheets, 69 pounds at $29.00/100 pounds

= $20/sheet

Labor Costs: The labor costs for installing the steel sheets were based on the estimated time required to install the powder-driven pins used for attaching the sheets to the concrete. With an average seam length of 12 feet per sheet (4 feet on one edge, 8 feet on the other), with four pins per foot of seam, 48 pins are required per sheet.

It is estimated that pins could be installed at an average rate of 6 pins per minute, thus requiring 8 minutes for one sheet. Some additional time is required for initially positioning the sheet properly, etc. A total installation time of 20 minutes per sheet is allocated. On this basis, the time required for installing the total of 1808 sheets for the entire shield would be 603 hours.

A five-man installation crew was assumed:

- one man driving pins
- two men positioning and holding the steel sheets
- one man carrying materials
- two men, half time, positioning the moveable scaffold

Therefore the total man-hours = 603 x 5 = 3015. Assuming an average wage of $16/hour, the total labor cost (for installing 1808 sheets) is 3015 x $16 = $48,240, or $27 per sheet.

TABLE 8

COST ESTIMATE FOR CONDITION V

Galvanized Sheet (Material) 14 ga	62,240[†]
Galvanized Sheet (Labor)	48,816
Powder-Driven Pins	29,750
Grit Blasting	7,500
Shielded Doors	26,500*
Zinc	12,290
Zinc Arc Spraying (Labor)	12,240
Ceiling Hangers (Material)	7,500*
Ceiling Hangers (Labor)	4,000
Penetrations	29,500*
1/4 inch Entry Plate	27,530*
	267,866
Contractor's Profit and Overhead (21%)	56,252
	324,118
Contingency (5%)	16,206
	340,324
	≈ 340,000

†Approximately $44,000 for 18 ga material

*Cost items identical with those of the all-welded shield designs.

7.2 FASTENING PINS

Estimated total number of pins for 1372 sheets 48 inches x 96 inches, and 436 sheets 30 inches x 96 inches ≃ 85,000. Cost is estimated at \$0.35 per pin, or a total of \$29,750.

7.3 GRIT BLASTING OF SEAMS

Total seam length = 21,042 feet

Assume a 3-man crew blasts 200 feet of seam/hour, requiring 100 hours, or 300 man-hours.

Assume \$25/man-hour for labor, equipment, and materials, or a total of \$7,500.

7.4 SHIELDED DOORS

Itemized costs are listed in Appendix B, Condition V.

7.5 ZINC ARC SPRAYING

Total seam length = 21,042 feet

Seam width = 3 inches = 1/4 foot

Seam thickness = 1/32 inch = 0.031 inch

Seam area = 5,260 $ft.^2$

Seam volume = 5,260 $ft.^2$ x 31 mils

Required weight of zinc = 0.9 ounce for area 1 $ft.^2$ by 1 mil

Therefore zinc required for seams =

0.9 ounce x 5,260 x 31 = 146,754 ounces = 9,172 pounds

Application rate = 36 pounds/hour (est).

Therefore total application time = 255 hours.

Only one man is required for arc spraying.

Assume two men positioning a moveable scaffold and carrying materials.

<u>Labor</u>: 255 hours x 3 x \$16/hour (ave.) = \$12,240

Material: Cost of zinc = 9,172 pounds x \$1.34/pound = \$12,290

7.6 CEILING HANGERS

Material: 7,500 hangers at \$1 ea. (est.) = \$7,500

Labor: Assume 1 hanger per minute is installed by a crew of 2, requiring 125 hours, or 250 man-hours, at \$16/man-hour, or \$4,000.

7.7 PLATE, 1/4 INCH

Estimates based on L. B. Knight data for Conditions I, II, III, IV.

7.8 PENETRATIONS

L. B. Knight estimate for Conditions I, II, III, and IV is used here.

SECTION 8

SHIELD QUALITY CONTROL, EFFECTIVENESS TESTS, AND MAINTENANCE COSTS

8.1 INTRODUCTION

The costs of assuring proper shielding effectiveness of the C^3 facility can be grouped as follows:

- Quality control during construction
- Testing the facility for initial performance certification
- Periodic inspection and maintenance.

A discussion of each of these items, along with cost estimates, are given below. A summary including the total cost estimate based on a 20 year shield lifetime, is given in Table 9. These results do not include costs of any required reworking of defective seams, as no information is available on the frequency of occurrence of such defects.

8.2 QUALITY CONTROL DURING CONSTRUCTION

8.2.1 Testing of Steel Samples

Laboratory tests of samples of the steel sheets should be made to measure the conductivity, the low-field permeability (non-saturating), and the saturation characteristic. Suitable test procedures have been described[7]. While the steel sheets are not procured to a conductivity or permeability specification, suitable conductivity and permeability characteristics are of such importance that it is felt to be desirable to perform laboratory tests on representative samples from the same mill run as the plates to be used to assure that the shield will have the desired attenuation properties. Effort is estimated at 80 man-hours at $30 per man-hour, including overhead, for instrumentation set-up and testing time, for a total of approximately $2,400.

8.2.2 Floor Plates at Perimeter Wall

For Condition I, New Construction, External Shield, it is necessary for the prefabricated steel floor shield plates (on top of the floor slab) to pass through the perimeter walls to be welded to the exterior wall shield. The construction design provides for 520 linear feet of 11 ga steel plate penetrated by steel reinforcing rods welded to it. Time to factory inspect welds is estimated at 8 man-hours, at $15 per man-hour, or a total of $120. This item is negligible compared with other items.

8.2.3 Seams, Plug Welds, and Conductor Penetrations

Quality control of welds during construction will consist of supervision and careful visual inspection of all welds. Magnetic inspection techniques such as magnafluxing are not considered necessary. While the time and costs will depend on the total linear footage of seams and the number of plug welds, they will not necessarily be proportional since an on-site inspector will be able to supervise and inspect the work of a number of welding crews or pin-driving crews working in parallel. It is estimated that approximately 1,000 man-hours of inspection time would be required at a cost of approximately $30/man-hour, or a total of $30,000. This same estimate is assumed for Condition V (use of powder-driven pins) as well as for the welded-seam construction.

8.3 INITIAL PERFORMANCE CERTIFICATION

A series of performance certification tests are recommended using

1) The Shielded Enclosure Leak Detection System (SELDS) which uses current injected directly onto the enclosure walls

2) Small antennas to illuminate the enclosure walls.

First, each of these types of tests is described briefly. Then an outline of a test program is given.

8.3.1 SELDS Testing[8]

This type of test, often referred to as the Seam Sniffer Test, employs CW current at a frequency of approximately 100 kHz injected directly onto the outer walls of the shielded enclosure (See Figure 35). A small, calibrated detector probe, designed to measure the magnetic field leakage component perpendicular to the shield wall, is moved along each seam on the interior of the enclosure. A defective seam in the shield produces an increase in the measured field if the direction of the seam is such as to disrupt the flow of current on the surface of the shield. In order to assure that a proper directional relationship will be achieved, it is necessary to perform three separate tests, each with the current applied from a different pair of diagonally opposite corners (See Figure 35).

The magnetic pickup coil of the detector is moved along the seam as the detector output (visual and audible) is observed. A commercially available SELDS equipment has as 0-140 dB shielding effectiveness measurement range. For the present purpose of estimating the cost of testing, it is assumed that the seam can be scanned at a rate of one foot per second where the seam is within easy reach (floor and lower portion of walls), and half that rate for the more difficult areas (internal ceiling shield and upper portion

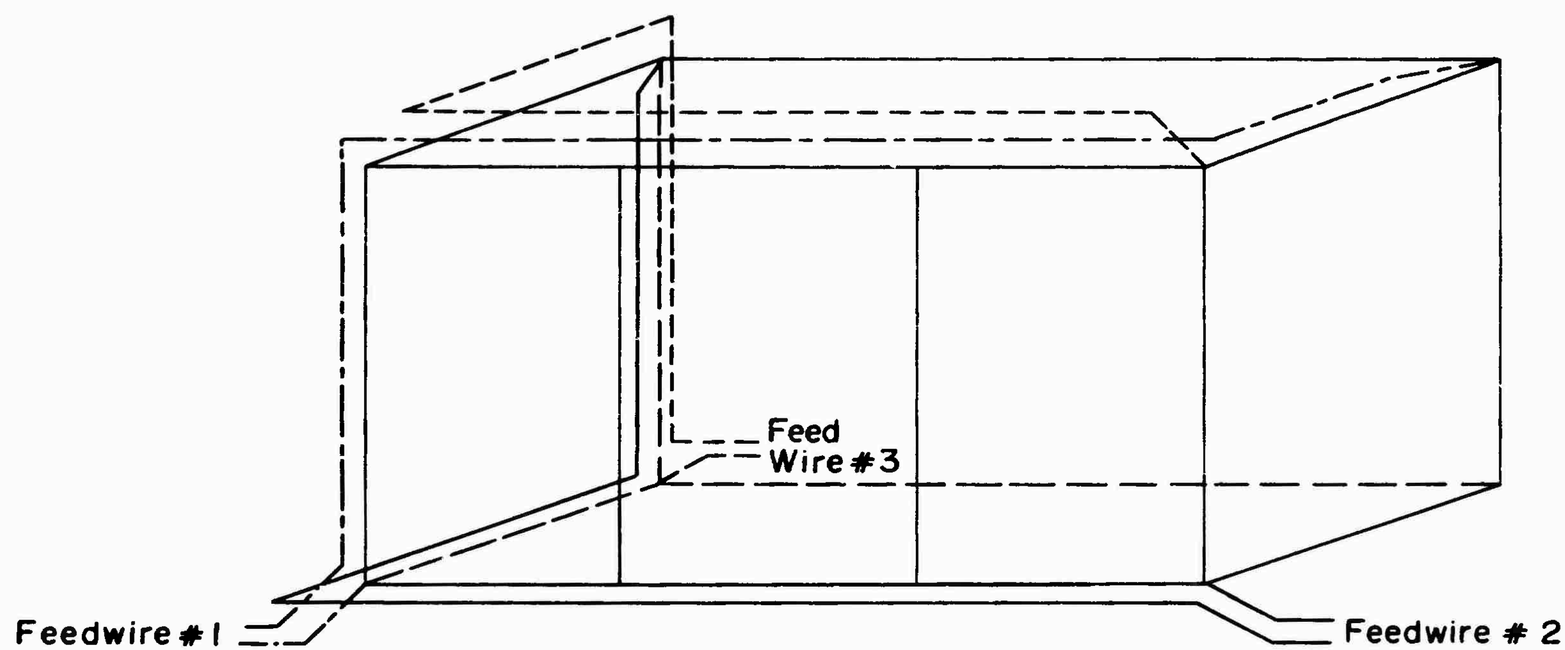


Figure 35. PLACEMENT OF FEEDWIRES FOR SELDS TESTING OF SHIELDED FACILITY

of walls).

In customary application to shielded enclosures, the SELDS current is applied to the exterior surface of the shield, and the seams on the interior surface are scanned. This procedure would generally be applicable here, except for Condition I (Exterior Shield), where the seams will not be available on the inside of the facility. In this case it would appear preferable to apply the current to the inner surface of the shield (through electrical leads brought through the concrete wall to the inside of the building) and scan the seams on the exterior.

The SELDS is usually applied to a shielded enclosure having the shape of a rectangular parallelepiped. The C^3 facility shields for Conditions I, II, III, and V approximate that shape except for entry and exit vestibules, etc., and the SELDS technique should provide useful results over the structure as a whole. In addition, it will be necessary to apply the SELDS to four individually shielded regions:

1) the communications entry vault,
2) the electrical power entry vault,
3) the storage area,
4) personnel entry vestibule.

For Condition IV (Internal Shield, Retrofit, Interior Walls Retained), the shield follows both surfaces of all interior walls. As a result, current applied to diagonally opposite extremities of the building will flow very irregularly on the shield surfaces. In regions where the current flow is sparse, the applied magnetic field intensity is low, and the detection system loses sensitivity. Consequently, a test using current injection at the building corners might not provide a 100 dB test of the shield on the interior walls because of the peculiar current distribution. It is possible that the total current injected onto the shield will also be small because of the impedances of the irregular shield envelope. It may be desirable to attempt measurements by injecting current at the corners of each of the four operational rooms. However, it should be emphasized that each room is not totally enclosed by a shield (doorway is unshielded), and therefore, such a test may not be conclusive.

8.3.2 Small-Antenna Radiation Testing

It has been shown elsewhere[9] that the SELDS or Seam Sniffer results, obtained at 100 kHz, cannot be used to provide an estimate of shielding effectiveness at widely removed frequencies. Therefore, for the present requirement for shielding effectiveness over the range 10 kHz to 100 MHz, additional tests are required, and tests based on MIL-STD-285 are recommended. Specifically, tests such as the following are suggested:

- Magnetic Field tests, using small-loop antennas, at frequencies of 10 kHz, 100 kHz, 1 MHz, 10 MHz
- Electric Field tests, using monopole antennas, at frequencies of 10 MHz, 100 MHz

Measurements should be made at the center and at each corner of all doors, center of all air vents, and at a representative number of points along each outer wall, and possibly on the ceiling shield. Measurements are required on the portions of the envelope shielding the facility as a whole, the communications entry vault, the power entry vault, the storage area, and the personnel entry vestibule.

In general, no special difficulties are foreseen in applying these MIL-STD-285 type tests to shield configurations for Conditions I, II, III, or V. However, for Condition IV (Internal Shield, Retrofit, Interior Walls Retained), the shield is on both surfaces of all interior walls. Therefore it will not be possible to gain access to two locations--one for a transmitting antenna and one for a receiving antenna--on opposite sites of these parts of the shield. Consequently, this type of test would not appear to be applicable for those portions of the shield.

8.3.3 Outline of Certification Test Program

The following types of tests are recommended for the initial performance certification:

(1) SELDS tests, prior to addition of interior walls, wall covering or floor covering, or welding of steel hangers from internal ceiling shield (for conduit, false ceiling, etc.)

(2) MIL-STD-285 type tests, again, prior to addition of interior walls, wall coverings, steel hangers, etc.

(3) Initial benchmark tests using SELDS and MIL-STD-285 type tests but with the detector used for exploring and measuring the fields in the interior volume of the building, not at the wall as in (1) and (2) above. These tests would also be performed prior to addition of interior walls, steel hangers, etc.

(4) Secondary benchmark tests, similar to those in (3) above, but after the addition of interior walls, steel hangers, false ceiling, etc., and the installation of all operational equipment, cabling, etc. The purpose of the secondary benchmark tests is to provide a set of baseline data against which subsequent test data -- to be obtained during the 20 year shield lifetime -- can be compared to detect any changes in shielding performance.

Costs of labor for testing are estimated to total approximately $11,000 as shown in Table 9. Within the uncertainty of the estimation, this total is considered to apply to each of the five shield configurations. It should again be mentioned that the procedures for testing the shield for Condition IV are somewhat indeterminate due to the extensive shielding on both sides of all interior walls.

8.4 PERIODIC INSPECTION AND MAINTENANCE

The main requirements for inspection, testing, and maintenance are estimated as follows:

Doors:
(a) inspect weekly, one man-hour total for 5 doors
(b) clean monthly, including vacuuming the recesses; 8 man-hours total for 5 doors
(c) test semi-annually: 40 man-hours total for 5 doors.

Replacement:
(a) Two hinged doors at Main Entrance; replace every 5 years
Cost ea: $2,000 material, $500 labor; $5,000 total
(b) One hinged door at Emergency Exit and two hinged doors in Entry Vault; replace after 10 years
Cost ea: $2,000 material, $500 labor; $7,500 total
(c) Two sliding doors in Storage Room: replace every 5 years
Cost ea: $6,000 material, $1,000 labor; $14,000 total

Recheck of Secondary Tests: Spot-test semiannually; two man weeks.

Using $10 per man-hour for the routine items of inspection, maintenance, and testing, and including the estimated door replacement costs, the total maintenance cost for a 20-year shield life is estimated as $142,500.

8.5 TOTAL COSTS FOR SHIELD QUALITY ASSURANCE AND MAINTENANCE

From the previous cost estimates for quality control during construction, the performance of certification tests, and the periodic inspection, testing, and door replacement, the total costs for a 20-year shield life are estimated at $186,000.

It should be noted that all tests described here for the completed shield employ only low-level, continuous-wave test signals. Based on past experience[10] it was estimated that the cost of testing a large shielded facility using a high-level pulse simulating an EMP radiation would be approximately $500,000 (in 1975).

TABLE 9

COSTS FOR SHIELD QUALITY CONTROL, TESTING, AND MAINTENANCE

<u>Quality Control During Construction</u>		
Testing steel samples	$ 2,400	
Inspection of perimeter floor plates	120	
Weld inspection	30,000	
	32,520	
<u>Initial Performance Certification</u>		
Initial SELDS tests	2,500	
Initial MIL-STD-285 tests	2,500	
Initial Benchmark tests	3,000	
Secondary Benchmark tests	3,000	
	11,000	
<u>Periodic Inspection and Maintenance</u>		
Weekly inspection of doors	10,000	
Monthly cleaning of doors	20,000	
Semiannual tests of doors	16,000	
Door Replacement		
Two hinged doors after 5, 10, 15 yrs.	15,000	
Three hinged doors after 10 yrs.	7,500	
Two sliding doors after 5, 10, 15 yrs.	42,000	
Semiannual recheck of Benchmark tests	32,000	
	142,500	
		186,020

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

The shielding cost estimates for the various construction options considered are tabulated in Table 10. For the welded shield designs, costs for shield construction and quality assurance for conditions I and II (New Construction) are estimated to be slightly greater than $1,000,000. If the cost of the new building is added, the total is slightly greater than $1,500,000 -- approximately $100,000 less than the shield costs for retrofitting an existing building, with removal and replacement of interior walls (Condition III). Costs for Condition IV, retrofit with interior walls retained, are approximately $2,000,000. A very substantial portion of the costs for all these configurations is due to the high cost of MIG welding of the shield seams.

In regard to the all-welded designs, the total costs for Conditions I, II, and III are similar, if the cost of the new building is included for Conditions I and II. Condition IV is the least attractive from the viewpoint of cost, and should be considered only when required by other factors.

To begin with, in Condition IV (retrofit, partitions are to remain in place), it is clear that a high premium is paid for additional labor and material. The amount of shielding required is greater. The cost of labor is increased not only by the increase in shielding, but by the necessity of working within a constrained environment which involves logistical problems for the Contractor. Also, retrofit conditions always carry an unknown factor; even an extensive survey of existing conditions may fail to uncover problems which may subsequently affect construction costs. Additionally, the savings involved in retaining interior partitions are more than offset by the costs involved in providing a completed, habitable, shielded C^3 structure.

Shielded walls and floors are assumed to be recovered with painted gypsum wallboard and vinyl-asbestos tile, respectively. Ceilings, necessarily removed to install shielding, have to be replaced along with above-ceiling ductwork. It is considered unlikely that light fixtures or electrical conduit will be salvaged and re-installed. The existing heating/air conditioning plant has to be removed in order to install the shielding. For purposes of this report, it was considered unlikely that the condition of old equipment and plumbing fixtures would justify reinstallation. The Owner is left with a situation in which only the building shell and interior partitions (assuming that they run from floor to roof slab) are re-used. Offset against the savings are the labor and material costs for both shielding and new Architectural/Mechanical/Electrical work.

TABLE 10

COMPARISON OF SHIELDING COST ESTIMATES

Condition	Building and Shield	Shield Location	Shield Fabrication	Estimated Costs				
				Shield Construction	Quality[5,6] Assurance	Shield Subtotal	New Building	Total
I	New	Exterior	Welded	875,000	186,000	1,061,000	475,000	1,536,000
II	New	Interior	Welded	910,000	186,000	1,096,000	475,000	1,571,000
III[1]	Retrofit	Interior	Welded	1,455,000	186,000	1,641,000	-	1,641,000
IIIA[2]	Retrofit	Interior	Welded	1,515,000	186,000	1,701,000	-	1,701,000
IV[3]	Retrofit	Interior	Welded	1,750,000	186,000	1,936,000	-	1,936,000
IVA[4]	Retrofit	Interior	Welded	1,840,000	186,000	2,026,000	-	2,026,000
V	New	Interior	Powder-Driven Pins	340,000[6]	186,000	525,000	475,000	1,001,000

NOTES: 1. Poured concrete building; interior walls removed and replaced.

2. Concrete block building; interior walls removed and replaced.

3. Poured concrete building; interior walls retained.

4. Concrete block building; interior walls retained.

5. Includes shield testing and door replacement for 20 years; no weld rework

6. IITRI estimates; others are LBK estimates.

Condition III (retrofit, partitions removed and replaced) is considered to be somewhat more advantageous. Some cost savings are to be achieved through a reduction in the amount of shielding, less constrained working conditions, and a consequent reduction in labor and material costs. On the other hand, all of the costs for new architectural/mechanical/electrical work cited will be incurred. Added to these will be the costs of new partitions with their electrical conduit and outlets.

Conditions IIIa and IVa (retrofit, concrete block exterior walls) are considered to be less desirable than a cast concrete building shell. The necessity to predrill the 1/4 by 4 inch attachment bars and the concrete block prior to inserting toggle bolts is costly. All of the previously cited costs (and potential unknowns) also apply to these alternatives.

It is, therefore, considered that retrofit installations are to be avoided if possible. The savings involved in re-using an existing structure are, in this particular type of re-cycling, offset by the unusually large labor and material cost required to result in a habitable building. It should be noted the cost of shielding a building in the cheapest manner (new construction), amounts to twice the cost of actually building the (unshielded) C^3 facility. By comparison, the cost of shielding an existing building is three times the cost of a new, unshielded building, and approximately the same as the cost of a completely shielded, new C^3 installation. In conclusion, no significant savings are realized in retrofitting an existing building, and it may even cost more than totally new construction.

In comparison of the two shield designs for new construction, Condition I (exterior shield) is most subject to climatic influences. Extreme cold makes an already sophisticated welding process more difficult. Extreme heat makes exposed metal-skinned buildings substantially more difficult to cool. Condition I also requires relatively more highly skilled labor, in that the welds are exposed to view. Periodic maintenance is also a consideration. The last three problems could be alleviated by covering the exterior wall shielding with an architectural veneer. While that would result in, among other things, a more pleasing looking structure, it would introduce problems of its own. Among them would be devising a means of attaching the veneer to the shielding. It would also increase construction cost.

For these reasons, Condition II (new construction, interior shielding) may, under many circumstances, be considered to be more advantageous. While it involves more shielding, and is, therefore, slightly more costly, the shielding is protected from both view and weather. Moreover, the interior shielding can be installed and function independently of climatic conditions. Condition II is therefore considered to be less problematical to a wide range of geographical applications.

Finally, there are two factors which can influence all of the Conditions in a manner disproportionate to their present cost relationships. These factors are (1) the ready availability of materials, and (2) local labor rules. They relate directly to the amount of shielding material and the consequent amount of welding labor.

As an alternative to an all-welded shield, the use of powder-driven pins for fastening the steel sheets, and zinc arc-spraying of the seams (Condition IV) appears to be approximately $500,000 less costly than the all-welded designs of Conditions I, II, and III. However, in comparing this estimate with those for the welded designs, the following observations should be kept in mind: (1) the design for Condition V is less detailed and the cost estimate more approximate than for the welded designs; (2) no experimental evidence is available regarding the shielding effectiveness of a building shield with this type of seam; (3) the protrusion of pin heads on the floor seams, as well as the uncertainty of the integrity of the floor shield under expected weight loads, may require a welded floor shield, with an additional cost of perhaps $100,000. It is recommended that experimental work be undertaken to evaluate the performance of a shield of this type, with particular emphasis on the required design of the floor shield and on the long-term integrity of the shield, including the effect of heavy or variable floor loading.

SECTION 10

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10. Safeguard EMP/RFI Lessons Learned, Vol. I, U. S. Army Corps of Engineers. Huntsville, Alabama, Report HNDSP-75-350-ED-SR; 31 December 1975.

APPENDIX A

FACTORS AFFECTING THE OPINIONS OF PROBABLE COST FOR THE ALL-WELDED SHIELD DESIGNS

FACTORS AFFECTING THE OPINIONS OF PROBABLE COST FOR THE ALL-WELDED SHIELD DESIGNS

1. All 5' by 10' or 6' by 10' plates have two (2) interior rows of five (5) 1/2" diameter holes each, except for the walls, which have two (2) interior rows of eight (8) 1/2" diameter holes each.
2. All vertical steel reinforcing bars that penetrate the floor plates at interior columns and perimeter walls are welded to horizontal plates. Each bar is welded to both the upper and lower surface of the plate.
3. All beams in the 60' direction are 12" by 24".
4. All beams in the 200' direction are 20" by 24".
5. All interior columns are 20" by 20".
6. All columns and beams have been deleted from the perimeter walls.
7. All pre-punched holes in the shielding are 1/2" diameter.
8. All concrete-imbedded plates (4" wide by 1/4" thick and 2" by 2" by 1/8" angle) will be delivered with 1 3/8" by 4" long Nelson studs welded to them at 2'-0" o.c. and pre-drilled with nail holes spaced at 2'-0" o.c. in a staggered pattern.
9. All continuous welding is priced midway between the cost of an easy and difficult operation which would be required to level the scheduled surfaces.
10. Grinding of welds will be required on exterior walls for the exterior wall Condition I, and for floors in all Conditions.
11. Grinding of welds for interior shielding will not be required except for floors.
12. Documents concerning the concrete work are to stress rigid concrete insert requirements.
13. Beam ceiling plates, for new construction interior shielding, will be horse shoe-shaped with four (4) rows of five (5) 1/2" diameter holes, each welded to four (4) rows of 4" wide by 1/4" thick plate.
14. Cost of installing angles and plates to concrete forms is to be included in estimate.
15. All costs used were derived from costs given by U.S. Steel, Inland Steel, Ryerson Steel, the Zack Co., Reliable Welding, and Ralph Simpson Co.
16. All prices are based on conditions that occur in Chicago, IL as of 12/14/79, without any contingencies or escalation as stated by the firms listed in 15 above.
17. Five (5) single-leaf swing doors with shielding applied have been included in all Conditions.
18. Two shielded sliding doors, to be used on the storage room, have been included for all Conditions.

19. Ceiling hangers have been included at 20 by 24 inch centers.

20. In Conditions III and IV, interior partitions are assumed to be gypsum wall board on metal studs.

21. Existing exterior doors, not to be shielded, are to be retained.

22. No acquisition costs are included for land or existing building.

23. Costs include demolition in Conditions III and IV, and total replacement costs for HVAC, Electrical and Plumbing Systems.

24. No architectural/engineering costs are included.

25. Costs for scaffolding have been included.

APPENDIX B

DETAILED LISTS OF SHIELD CONSTRUCTION COSTS

APPENDIX B

LESTER B. KNIGHT & ASSOCIATES, INC.
MANAGEMENT CONSULTANTS CONSULTING ENGINEERS
CONSTRUCTION MANAGERS
549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE CONDITION I

SHEET NO. 1 OF 1

PROJECT EXTERIOR SHIELD - NEW CONSTR. - 11 GA. TYPE OF ESTIMATE BUDGET ESTIMATE NO. 5128

LOCATION I.I.T.R.I. ARCHITECT DATE 2/18/80

TAKE OFF BY J.S. QUANTITIES BY J.S. PRICES BY J.S. EXTENSIONS BY J.S. CHECKED BY

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
1	PLATE - 11 GA. - 5'x10'				892	EA	55.	49060	103.	91870	A	140930
2	PLATE - 11 GA. - 5'x10' - REWORK				45	EA	55.	2475	113.	5100	B	7575
14	PUNCH WELD PLUG HOLES IN 11 GA. PL				10974	EA	.10	1100	.85	9330	B	10430
3 4	WELD - CONTINUOUS @ 11 GA. PL, GRIND FL., EXT. WALLS				16329	L.F.	.10	1630	17.13	279715	A	281345
18	WELD PLUG HOLES & GRIND IN 11 GA. PL				3384	EA	.05	170	3.	10150	A	10320
18	WELD PLUG HOLES IN 11 GA. PL				7590	EA	.05	380	2.50	19000	A	19380
5 9	ANGLE - 2"x2"x1/8"				2282	L.F.	.50	1140				1140
6 10	NELSON STUDS WELDED TO 2"x2"x1/8" ANGLE				1141	EA	.83	950	.30	340	B	1290
7 11	DRILL HOLES FOR CONCRETE FORM NAILS IN 2"x2"x1/8" ANGLE				1141	EA			.50	570	B	570
8 12	INSTALL 2"x2"x1/8" ANGLE TO CONC. FORM				2282	L.F.			3.	6850	A	6850
16 17	PLATE - 4"x1/4"				29616	L.F.	1.25	37020				37020
19 20	NELSON STUDS WELDED TO 4"x1/4" PLATE				14808	EA	.83	12290	.30	4440	B	16730
21	DRILL HOLES FOR CONCRETE FORM NAILS IN 2"x2"x1/4" ANGLE				14808	EA			.50	7400	B	7400
	INSTALL 4"x1/4" PLATE TO CONC. FORM				29616	L.F.			2.	59230	A	59230
13	DOORS	(Allowance)			7	EA		22000		4500		26500
15	PLATE - 11 GA. - 1'W. x 520 L.F. (FROM 5'x10' SHEETS)				11	EA	75.	825	150.	1650	B	2475
15	DRILL HOLES FOR REBAR IN 1'W x 520 L.F. PL				1040	EA			1.	1040	B	1040
15	REINF. RODS - 3' LG. x #4				1040	EA	.70	730	1.	1040	B	1770
15	WELD REINF. ROD TO 1'W x 520 L.F. PL				1040	EA	.10	105	3.	3120	B	3225
15	WELD 1'W x 520 L.F. PLATE TO FLOOR PL - CONT.				520	L.F.	.10	50	17.13	8910	A	8960
23	PAINT STEEL @ EXT. WALL				11440	S.F.	.10	1140	.15	1720	C	2360
24	SHIELD PENETRATIONS	(Allowance)			27	EA	400.	10800	100.	2700	A	13500
	PLATE - 1/4" - 5'x10'				30	EA	112.	3360	160.	4800	A	8160
	PUNCH WELD PLUG HOLES IN 1/4" PL				360	EA	.12	40	1.10	400	B	446
	WELD - CONTINUOUS @ 1/4" PLATE				535	L.F.	.16	85	35.	18725	A	18810
	WELD PLUG HOLES & GRIND IN 1/4" PL				360	EA	.15	60	3.	1080	A	1140
								145410		543680		689090

APPENDIX B

LESTER B. KNIGHT & ASSOCIATES, INC.
MANAGEMENT CONSULTANTS — CONSULTING ENGINEERS
CONSTRUCTION MANAGERS
549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE

CONDITION II

SHEET NO. 1 OF 1

PROJECT Interior Shield - New Constr. - 11GA — TYPE OF ESTIMATE Budget — ESTIMATE NO. 5128

LOCATION I.I.T.R.I. — ARCHITECT — DATE 2/20/80

TAKE OFF BY JS — QUANTITIES BY JS — PRICES BY JS — EXTENSIONS BY JS — CHECKED BY

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	PLATE - 11 GA. - 5'x10'				460	EA	55.	25300	103.	47380	A	72680
	PLATE - 11 GA. - 5'x10' - REWORK				297	EA	55.	16335	113.	33560	B	49895
	PLATE - 11 GA. - 5'x10' - SHOP FORM & REWORK				180	EA	126.	22680	126.	22680	B	45360
	PLATE - 11 GA. - 6'x10' - SHOP FORM & REWORK				46	EA	110.	5060	141.	6490	B	11550
	PLATE - 1/4" - 5'x10'				18	EA	112.	2020	160.	2880	A	4900
	PLATE - 1/4" - 5'x10' - REWORK				6	EA	112.	670	180.	1080	B	1750
	PUNCH WELD PLUG HOLES IN 11GA. PL				14182	EA	.10	1420	.85	12050	B	13470
	PUNCH WELD PLUG HOLES IN 1/4" PL				288	EA	.12	40	1.10	320	B	360
	WELD PLUG HOLES IN 11GA. PL	(GRIND 2400)			14182	EA	.05	710	2.58	36650	A	37360
	WELD PLUG HOLES IN 1/4" PL				288	EA	.15	40	3.00	860	A	900
	WELD - CONTINUOUS IN 11GA. PL	(GRIND 3740' @ FLOOR)			15132	L.F.	.10	1510	17.13	259210		2 60270
	WELD - CONTINUOUS IN 1/4" PL				440	L.F.	.16	70	35.00	15400	A	15470
	ANGLE w/STUDS & NAIL HOLES	(2x2x1/8)			3342	L.F.	.92	3060	3.40	11350	A&B	14410
	PLATE w/STUDS & NAIL HOLES				20916	L.F.	2.01	42140	2.50	60760	A&B	102900
	DOORS		(Allowance)		7	EA		22000		4500		26500
	SHIELD PENETRATIONS		(Allowance)		59	EA	400	23600	100.	5900	A	29500
	CEILING HANGERS @ 1'-4" o.c.				7500	EA	1.00	7500	1.00	7500	A	15000
	FLOOR SHIELDING @ COLUMN				7	EA	250.	1750	50.00	350	A	2100
	COLUMN SHIELDING @ BEAM				7	EA	100.	700	400.	2800	A	3500
	4"x4"x1/4"	ANGLE w/STUDS & NAIL HOLES			2200	L.F	2.83	6220	1.80	3960	A&B 1/3 2/3	10180
								182825		535680		718505

LESTER B. KNIGHT & ASSOCIATES, INC.
MANAGEMENT CONSULTANTS — CONSULTING ENGINEERS — CONSTRUCTION MANAGERS
549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE

CONDITION III

SHEET NO. ____ OF ____

PROJECT: RETROFIT - INTERIOR SHIELD WITH INSIDE WALLS REMOVED
TYPE OF ESTIMATE: BUDGET
ESTIMATE NO. ____

LOCATION: 11 GA. SHIELD - CONCRETE EXTERIOR WALLS
ARCHITECT: LBK & ASSOCIATES
DATE ____

TAKE OFF BY: WM — QUANTITIES BY: WM — PRICES BY: WM — EXTENSIONS BY: WM — CHECKED BY: ____

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	DEMOLITION OF INTERIOR COMPLETE				11,484	SF		—	6.00	68900		$ 68900.00
	PLATE 11 GA. 5' x 10'				460	EA	55.	25300	103.	47380	158.	72680
	PLATE 11 GA. REWORK 5' x 10'				297	EA	55.	16335	113.	33565	168.	49900
	PLATE 11 GA. SHOPFORM 5' x 10'				150	EA	128.	19200	124.	18600	252.	37800
	PLATE 11 GA. SHOPFORM - REWORK	5' x	10'		30	EA	116.	3480	136.	4080	252.	7560
	PLATE 11 GA. SHOPFORM 6' x 10'				23	EA	116.	2670	136.	3130	252.	5800
	PLATE 11 GA. SHOP FORM - REWORK	6' x	10'		23	EA	104.	2390	148.	3400	252.	5790
	PUNCH - WELD PLUG HOLES IN 11 GA. PLATE				14,182	EA	.10	1420	.85	12060		13480
	WELD CONTINUOUS AT 11 GA. PLATE	(3,740 GRIND @ FLOOR)			15,132	LF	.10	1510	17.13	259210		260720
	WELD PLUG HOLES IN 11 GA. PLATE				11,782	EA	.05	590	2.50	29455		30050
	WELD PLUG HOLES & GRIND - 11 GA. PLATE				2400	EA	.05	120	3.00	7200		7320
	PLATE 4" WIDE x 1/4" THICK				24,258	LF	1.25	30320	.65	15770		46090
	INSTALL 4" x 4" x 1/4" ANGLE				2,200	LF	1.90	4180	.60	1320		5500
	SHOOT IN PLATE ANCHORS TO WALL				14,330	EA	.10	1430	1.25	17910		19340
	SHIELD PENETRATIONS (AVG)				59	EA	400.	23600	100.	5900	500.	29500
	CEILING HANGERS WELDED TO SHIELD	1'-4"	O.C.		7,500	EA	1.00	7500	1.00	7500		15000
	WELD CIRCUMFERENCE OF COLUMNS				42	LF	.10	10	17.13	720		730
	CONCRETE COLUMN COVERS AT BEAM ABUTMENT				7	EA	100.	700	400.	2800		3500
	DOORS (HINGED)				5	EA	2000.	10000	500.	2500		12500
	DOOR (SLIDING) - SHIELDED				2	EA	6000.	12000	1000.	2000		14000
	1/4" PLATE 5' x 10'				18	EA	112.	2020	160.	2880		4900
	1/4" PLATE REWORK 5' x 10'				6	EA	112.	670	180.	1080		1750
	PUNCH - WELD PLUG HOLES IN 1/4" PLATE				288	EA	.12	35	1.10	315		350
	WELD CONTINUOUS AT 1/4" PLATE				440	LF	.16	70	35.	15400		15470
	WELD PLUG HOLES IN 1/4" PLATE				288	EA	.15	45	3.00	865		910

LESTER B. KNIGHT & ASSOCIATES, INC.
MANAGEMENT CONSULTANTS CONSULTING ENGINEERS
CONSTRUCTION MANAGERS
549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE

CONDITION III

SHEET NO. ____ OF ____

PROJECT: RETROFIT - INTERIOR SHIELD WITH INSIDE WALLS REMOVED
TYPE OF ESTIMATE: BUDGET
ESTIMATE NO. ____

LOCATION: 11 GA. SHIELD - CONCRETE EXTERIOR WALLS
ARCHITECT: LBK & ASSOCIATES
DATE ____

TAKE OFF BY: WM
QUANTITIES BY: WM
PRICES BY: WM
EXTENSIONS BY: WM
CHECKED BY ____

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	INTERIOR FINISHES - CEILINGS - FLOOR WALLS - DOORS				11,484	SF	5.15	59,200	3.39	38,920		$ 98,120.00
	ELECTRICAL				11,484	SF	1.20	13,780	1.80	20,670		34,450
	ELECTRICAL - SPECIAL SYSTEMS				11,484	SF	3.60	41,340	2.40	27,560		68,900
	HVAC. & PLUMBING				11,484	SF	6.03	69,260	8.97	103,000		172,260
	PERIMETER FINISHES				10,200	SF	.94	9600	.64	6520		16,120
	PAINT - INTERIOR FINISHES				76,680	SF	.12	9120	.22	17000		26,120
								367,900		777,610		$ 1,145,510

LESTER B. KNIGHT & ASSOCIATES, INC.
MANAGEMENT CONSULTANTS — CONSULTING ENGINEERS — CONSTRUCTION MANAGERS
549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE — CONDITION IIIA

SHEET NO. ____ OF ____
ESTIMATE NO. ____
DATE ____

PROJECT: RETROFIT - INTERIOR SHIELD WITH INSIDE WALLS REMOVED — TYPE OF ESTIMATE: BUDGET
LOCATION: 11 GA. SHIELD - CONCRETE BLOCK EXTERIOR WALLS — ARCHITECT: LBK & ASSOCIATES
TAKE OFF BY: WM — QUANTITIES BY: WM — PRICES BY: WM — EXTENSIONS BY: WM — CHECKED BY: ____

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	DEMOLITION OF INTERIOR COMPLETE				11,484	SF.		—	6.00	68900		$ 68900.00
	PLATE 11 GA. 5' x 10'				460	EA.	55.	25300	103.	47380		72680
	PLATE 11 GA. REWORK 5' x 10'				297	EA.	55.	16335	113.	33560		49900
	PLATE 11 GA. SHOP FORM 5' x 10'				150	EA.	128.	19200	124.	18600		37800
	PLATE 11 GA. SHOP FORM - REWORK	5' x	10'		30	EA.	116.	3480	136.	4080		7560
	PLATE 11 GA. SHOP FORM 6' x 10'				23	EA.	116.	2670	136.	3130		5800
	PLATE 11 GA. SHOP FORM - REWORK	6' x	10'		23	EA.	104.	2390	148.	3400		5790
	PUNCH - WELD PLUG HOLES IN 11 GA. PLATE				14,182	EA	.10	1420	.85	12060		13480
	WELD CONTINUOUS AT 11 GA. PLATE	(3,740	GRIND @ FLOOR)		15,132	LF	.10	1510	17.13	259210		260720
	WELD PLUG HOLES IN 11 GA. PLATE				11,782	EA	.05	590	2.50	29455		30050
	WELD PLUG HOLES & GRIND - 11 GA. PLATE				2400	EA	.05	120	3.00	7200		7320
	PLATE 4" WIDE x 1/4" THICK				24,258	LF	1.25	30320	.65	15770		46090
	INSTALL 4" x 4" x 1/4" ANGLE				2,200	LF	1.90	4180	.60	1320		5500
	DRILL 1/2" ϕ COUNTERSUNK HOLES @ 2'-0" O.C. IN PLATE				14,330	EA	.10	1430	1.25	17910		19340
	DRILL AND SET MASONRY ANCHORS				14,330	EA	1.00	14330	1.00	14330		28660
	SCREW PLATE TO CONCRETE BLOCK WALL				14,330	EA	.15	2150	1.00	14330		16480
	SHIELD PENETRATIONS (AVG.)				59	EA	400.	23600	100.	5900		29500
	CEILING HANGERS WELDED TO SHIELD	1'-4"	O.C.		7,500	EA	1.00	7500	1.00	7500		15000
	WELD CIRCUMFERENCE OF COLUMNS				42	LF	.10	10	17.13	720		730
	CONCRETE COLUMN COVERS @ BEAM ABUTMENT				7	EA	100.	700	400.	2800		3500
	DOORS (HINGED)				5	EA	2000	10000	500.	2500		12500
	DOOR (SLIDING) - SHIELDED				2	EA	6000	12000	1000.	2000		14000
	1/4" PLATE 5' x 10'				18	EA	112.	2020	160.	2880		4900
	1/4" PLATE REWORK 5' x 10'				6	EA	112.	670	180.	1080		1750
	PUNCH - WELD PLUG HOLES IN 1/4" PLATE				288	EA	.12	35	1.10	315		350
	WELD CONTINUOUS @ 1/4" PLATE				440	LF	.16	70	35.	15400		15470
	WELD PLUG HOLES IN 1/4" PLATE				288	EA	.15	45	3.00	865		910

LESTER B. KNIGHT & ASSOCIATES, INC.
MANAGEMENT CONSULTANTS — CONSULTING ENGINEERS
CONSTRUCTION MANAGERS
549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE CONDITION IIIA

SHEET NO. ___ OF ___

PROJECT: RETROFIT - INTERIOR SHIELD WITH INSIDE WALLS REMOVED TYPE OF ESTIMATE: BUDGET ESTIMATE NO.

LOCATION: 11 GA. SHIELD - CONCRETE BLOCK EXTERIOR WALLS ARCHITECT: LBK & ASSOCIATES DATE

TAKE OFF BY: WM QUANTITIES BY: WM PRICES BY: WM EXTENSIONS BY: WM CHECKED BY

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	INTERIOR FINISHES - CEILINGS - FLOORS - WALLS - DOORS - PAINT				11,484	SF	5.15	59200	3.39	38920		$ 98120.00
	ELECTRICAL				11,484	SF	1.20	13780	1.80	20670		34450
	ELECTRICAL - SPECIAL SYSTEMS				11,484	SF	3.60	41,340	2.40	27560		68900
	HVAC. & PLUMBING				11,484	SF	6.03	69260	8.97	103,000		172260
	PERIMETER FINISHES				10,200	SF	.94	9600	.64	6520		16120
	PAINT - INTERIOR FINISHES				76,680	SF	.12	9120	.22	17000		26120
								384380		806270		$ 1,190650

LESTER B. KNIGHT & ASSOCIATES, INC.
MANAGEMENT CONSULTANTS — CONSULTING ENGINEERS — CONSTRUCTION MANAGERS
349 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE CONDITION IV

PROJECT: RETROFIT - INTERIOR SHIELD — TYPE OF ESTIMATE: BUDGET — SHEET NO. ___ OF ___

LOCATION: 11 GA. SHIELD - CONCRETE EXTERIOR WALLS — ARCHITECT: LBK & ASSOCIATES — ESTIMATE NO. ___

DATE ___

TAKE OFF BY: WM — QUANTITIES BY: WM — PRICES BY: WM — EXTENSIONS BY: WM — CHECKED BY: ___

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	DEMOLITION OF INTERIOR - CEILING & LIGHT FIXTURES				11,484	SF		—	4.60	51680		$51,680.00
	PLATE 11 GA. 5' × 10'				712	EA	55.	39160	103.	73340		112500
	PLATE 11 GA. REWORK 5' × 10'				429	EA	55.	23600	113.	48480		72080
	PLATE 11 GA. SHOP FORM 5' × 10'				150	EA	128.	19200	124.	18600		37800
	PLATE 11 GA. SHOP FORM - REWORK	5' × 10'			30	EA	116.	3480	136.	4080		7560
	PLATE 11 GA. SHOP FORM 6' × 10'				23	EA	116.	2670	136.	3130		5800
	PLATE 11 GA. SHOP FORM - REWORK	6' × 10'			23	EA	104.	2390	148.	3400		5790
	PUNCH - WELD PLUG HOLES IN 11 GA. PLATE				18022	EA	.10	1800	.85	15320		17120
	WELD CONTINUOUS @ 11 GA. PLATE		(3,740 GRIND @ FLOOR)		21,632	LF	.10	2160	17.13	370560		372,720
	WELD PLUG HOLES & GRIND - 11 GA. PLATE				2400	EA	.05	120	3.00	7200		7320
	PLATE 4" WIDE × 1/4" THICK				38918	LF	1.25	48650	.65	25300		73950
	INSTALL 4" × 4" × 1/4" ANGLE				2200	LF	1.90	4180	.60	1320		5500
	WELD PLUG HOLES IN 11 GA. PLATE				15,622	EA	.05	780	2.50	39060		39840
	SHOOT IN PLATE ANCHORS TO WALL				21,660	EA	.10	2170	1.25	27080		29250
	SHIELD PENETRATIONS (AVG)				59	EA	400.	23600	100.	5900		29500
	CEILING HANGERS WELDED TO SHIELD	1'-4"	O.C.		7500	EA	1.00	7500	1.00	7500		15000
	WELD CIRCUMFERENCE OF COLUMNS				42	LF	.10	10	17.13	720		730
	CONCRETE COLUMN COVERS @ BEAM ABUTMENT				7	EA	100.	700	400.	2800		3500
	DOORS (HINGED) - SHIELDED				5	EA	2000.	10000	500.	2500		12500
	DOOR (SLIDING) - SHIELDED				2	EA	6000.	12000	1000.	2000		14000
	1/4" PLATE 5' × 10'				18	EA	112.	2020	160.	2880		4900
	1/4" PLATE - REWORK 5' × 10'				6	EA	112.	670	180.	1080		1750
	PUNCH - WELD PLUG HOLES IN 1/4" PLATE				288	EA	.12	35	1.10	315		350
	WELD CONTINUOUS @ 1/4" PLATE				440	LF	.16	70	35.	15400		15470
	WELD PLUG HOLES IN 1/4" PLATE				288	EA	.15	45	3.00	865		910

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549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE CONDITION IV

SHEET NO. ____ OF ____

PROJECT RETROFIT – INTERIOR SHIELD TYPE OF ESTIMATE BUDGET ESTIMATE NO. ____

LOCATION 11 GA. SHIELD – CONCRETE EXTERIOR WALLS ARCHITECT LBK & ASSOCIATES DATE ____

TAKE OFF BY WM QUANTITIES BY WM PRICES BY WM EXTENSIONS BY WM CHECKED BY ____

CSI CODE	DESCRIPTION	NO.	DIMENSIONS			UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	INTERIOR FINISHES – CEILINGS – FLOORS – WALLS – DOORS – PAINT						11,484	SF	7.36	84,520	4.82	55,360	$	139,880.00
	ELECTRICAL						11,484	SF	1.20	13,780	1.80	20,670		34,450
	ELECTRICAL – SPECIAL SYSTEMS						11,484	SF	3.60	41,340	2.40	27,560		68,900
	HVAC. & PLUMBING						11,484	SF	6.03	69,250	8.97	103,010		172,260
	PAINT – INTERIOR FINISHES						76,680	SF	.12	9,200	.22	16,870		26,070
										425,100		953,980	$	1,379,080

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CONSOLIDATED ESTIMATE CONDITION IVA

SHEET NO. ____ OF ____
ESTIMATE NO. ____
DATE ____

PROJECT: RETROFIT - INTERIOR SHIELD
TYPE OF ESTIMATE: BUDGET
LOCATION: 11 GA. SHIELD - CONCRETE BLOCK EXTERIOR WALLS
ARCHITECT: LBK & ASSOCIATES
TAKE OFF BY: WM
QUANTITIES BY: WM
PRICES BY: WM
EXTENSIONS BY: WM
CHECKED BY: ____

CSI CODE	DESCRIPTION	NO.	DIMENSIONS	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	DEMOLITION OF INTERIOR - CEILING &	LIGHT	FIXTURES	11,484	SF		—	4.50	51680		$ 51680
	PLATE 11 GA 5'×10'			712	EA	55.	39160	103.	73340		112500
	PLATE 11 GA REWORK 5'×10'			429	EA	55.	23600	113.	48480		72080
	PLATE 11 GA SHOP FORM 5'×10'			150	EA	128.	19200	124.	18600		37800
	PLATE 11 GA SHOP FORM - REWORK	5'×	10'	30	EA	116.	3480	136.	4080		7560
	PLATE 11 GA. SHOP FORM 6'×10'			23	EA	116.	2670	136.	3130		5800
	PLATE 11 GA. SHOP FORM - REWORK	6'×	10'	23	EA	104.	2390	148.	3400		5790
	PUNCH - WELD PLUG HOLES IN 11 GA.	PLATE		18,022	EA	.10	1800	.85	15320		17120
	WELD CONTINUOUS @ 11 GA. PLATE		(3740 GRIND @ FLOOR)	21,632	LF	.10	2160	17.13	370560		372720
	WELD PLUG HOLES & GRIND - 11 GA.	PLATE		2400	EA	.05	120	3.00	7200		7320
	PLATE 4" WIDE × 1/4" THICK			38,918	LF	1.25	48650	.65	25300		73950
	INSTALL 4"×4"×1/4" ANGLE			2200	LF	1.90	4180	.60	1320		5500
	WELD PLUG HOLES IN 11 GA. PLATE			15,622	EA	.05	780	2.50	39060		39840
	DRILL 1/2 φ COUNTERSUNK HOLES @ 2'-0"	O.C.	IN PLATE	21,660	EA	.10	2170	1.25	27080		29250
	DRILL & SET MASONRY ANCHORS			21,660	EA	1.00	21660	1.00	21660		43320
	SCREW PLATE TO CONCRETE BLOCK	WALL		21,660	EA	.15	3250	1.00	21660		24910
	CEILING HANGERS WELDED TO SHIELD	1'-4"	O.C.	7500	EA	1.00	7500	1.00	7500		15000
	WELD CIRCUMFERENCE OF COLUMNS			42	LF	.10	10	17.13	720		730
	CONCRETE COLUMN COVERS @ BEAM	ABUTMENT		7	EA	100.	700	400.	2800		3500
	DOORS (HINGED) - SHIELDED			5	EA	2000.	10000	500.	2500		12500
	DOOR (SLIDING) - SHIELDED			2	EA	6000.	12000	1000.	2000		14000
	1/4" PLATE 5'×10'			18	EA	112.	2020	160.	2880		4900
	1/4" PLATE - REWORK 5'×10'			6	EA	112.	670	180.	1080		1750
	PUNCH - WELD PLUG HOLES IN 1/4" PLATE			288	EA	.12	35	1.10	315		350
	WELD CONTINUOUS @ 1/4" PLATE			440	LF	.16	70	35.	15400		15470
	WELD PLUG HOLES IN 1/4" PLATE			288	EA	.15	45	3.00	865		910
	SHIELD PENETRATIONS (AVG)			59	EA	400.	23600	100.	5900		29500

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549 WEST RANDOLPH STREET, CHICAGO, ILLINOIS 60606

CONSOLIDATED ESTIMATE CONDITION IVA

SHEET NO. ___ OF ___

PROJECT RETROFIT - INTERIOR SHIELD
TYPE OF ESTIMATE BUDGET
ESTIMATE NO.

LOCATION 11 GA. SHIELD - CONCRETE EXTERIOR WALLS
ARCHITECT LBK & ASSOCIATES
DATE

TAKE OFF BY WM
QUANTITIES BY WM
PRICES BY WM
EXTENSIONS BY WM
CHECKED BY

CSI CODE	DESCRIPTION	NO.	DIMENSIONS		UNIT	QUANTITY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR TOTAL	TOTAL COST UNIT	TOTAL COST TOTAL
	INTERIOR FINISHES - CEILINGS - FLOORS - WALLS - DOORS - PAINT					11,484	SF	7.36	84,520	4.82	55,360	#	139,880
	ELECTRICAL					11,484	SF	1.20	13,780	1.80	20,670		34,450
	ELECTRICAL - SPECIAL SYSTEMS					11,484	SF	3.60	41,340	2.40	27,560		68,900
	HVAC. & PLUMBING					11,484	SF	6.03	69,250	8.97	103,010		172,260
	PAINT - INTERIOR FINISH					76,680	SF	.12	9,200	.22	16,870		26,070
									450,010		997,300	#	1,447,310

CONDITION V

NEW CONSTRUCTION, INTERIOR SHIELD, POWDER DRIVEN PINS, 14 GA

Budgetary Estimate - IITRI - Feb 1980

Description	Quantity	Unit	Material Unit	Material Total	Labor Unit	Labor Total	Total Cost
Galvanized Sheet 14 GA, 48"x96"	1,008	EA	30.00	30,240	27.00	27,216	57,456
Galvanized Sheet 14 GA, 48"x96" formed	364	EA	40.00	14,560	27.00	9,828	24,388
Galvanized Sheet 14 GA, 30"x96" formed	436	EA	40.00	17,440	27.00	11,772	29,212
Fastening Pins	85,000	EA	0.35	29,750			29,750
Grit Blasting of Seams	21,042	LF				7,500	7,500
Shielded Door (Sliding)	2	EA	6,000	12,000	1,000	2,000	14,000
Shielded Door (Hinged)	5	EA	2,000	10,000	500	2,500	12,500
Zinc, Arc Sprayed	9,172	LB	1.34	12,290		12,240	16,658
Ceiling Hangers	7,500	EA	1.00	7,500		4,000	11,500
Plate 1/4" 5'x10'	18	EA	112.00	2,020	160.00	2,880	4,900
Plate 1/4" 5'x10' Rework	6	EA	112.00	670	180.00	1,080	1,750
Punch Weld Holes in 1/4" Plate	288	EA	0.12	40	1.10	320	360
Weld Plug Holes in 1/4" Plate	288	EA	0.15	40	3.00	860	900
Weld Seams, 1/4" Plate	440	LF	0.16	70	35.00	15,400	15,470
4"x1/4" Plate w/Studs & Nail Holes	920	LF	2.01	1,850	2.50	2,300	4,150
Penetrations	59	EA	400.00	23,600	100.00	5,900	29,500
				162,070		105,796	267,866

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