

A DESIGN OF A REINFORCED
CONCRETE AIR RAID SHELTER

Thesis for the Degree of B. S.
MICHIGAN STATE COLLEGE

Fred L. Warner

1943

THESIS

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**SUPPLEMENTARY
MATERIAL
IN BACK OF BOOK**

A Design of a Reinforced Concrete
Air Raid Shelter

A Thesis Submitted to

The Faculty of
MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

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Candidate for the Degree of
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THESIS

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INTRODUCTION

Although the United States, especially Michigan, seems too far removed to be bombed, it is still possible for a long range bomber based in occupied France or Japan to fly here and do considerable damage.

The range of bombers is ever increasing and it is possible but not probable, however, that we may soon be bombed regularly. We must be prepared for this bombing even if it is very improbable. It is with this thought in mind that this air raid shelter was designed.

Shelters may be divided into four types, (1) Domestic or Private; (2) Industrial and Commercial; (3) Public; and (4) Institutional Shelters. Each of these types varies in their requirements.

The cost of the shelter depends upon three factors which are size, degree of protection, and possible use in peace-time.

Location is determined by at least five variables; space required, time available, existing facilities, natural or artificial protection, and absence of hazards. Of course, the larger the shelter the more space it would require. Time available means the time necessary for persons to reach the shelter. At present, the time between detection of enemy aircraft and their arrival is approximately seven minutes. This would require the shelter to be fairly close to the personnel it is to serve. The facilities required would of course depend upon the type of shelter. The most common facilities required by shelters are electricity, sewage disposal, drinking water, and perhaps the telephone. The natural protection may consist of trees, bushes, or grass, while the artificial protection could be paint, nets, etc. All large shelters should be hidden from enemy airmen's view by either of these methods.

The protection from bombs can vary greatly. Only in large shelters can a high degree of protection be furnished or in those special cases where it is advisable to spend large amounts of money.

In a report of the Engineering Precautions Committee, a committee of Civil Engineers set up in England to study various standards of protection, four types or standards of protection were suggested:¹

Type I Based on resistance to blast and splinters, debris loads and small incendiary bombs.

Type II Based on resistance to the direct hits of medium weight incendiary bombs.

Type III Designed to give protection against the effects of heavy high-explosive bombs. The standard adopted is considered to be adequate against the effects of a medium-case bomb of the order of 500 lb. weight striking at its maximum velocity. It is also considered to be proof against light-case bombs of considerably greater weight.

Type IV This is similar to Type III Protection, but is designed to give protection against the effects of a heavy-case bomb.¹

WALL THICKNESS

Most shelters cannot be designed for type 3 or 4 protection.

Secondary effects are considered the best for design purposes.

"Since the majority of shelters must be designed for the lower degree of protection, the various factors will be considered in detail. To be properly designed from this point of view, a shelter should be able to resist the effects of blast and splinters from a 500 lb. bomb exploding at a distance of 40 feet, debris, antiaircraft shell fragments, fire, and gas. The shelters, of course, would not be able to withstand the effects of direct hits, hits within a forty foot radius, or the secondary effects of larger bombs except at somewhat greater distances."²

This is the basis for the design of this shelter. Shelters can be underground, partially underground, or totally above the ground. The partially underground type was chosen.

The thickness of the walls, ceiling, and floor is one of the first problems to be considered. In this case part of the walls are above the ground and part are below. It would seem probable, at first thought, that the wall above the surface of the ground should be thicker and

1. Aerial Bombardment Protection by H. E. Wessman and W. A. Rose
pg. 237

2. Ibid. pg. 238

better reinforced than the wall below. This is not true however. The wall above the ground is subject to penetration of fragments and to the blast, but the earth itself transmits the blast directly to the underground wall. This underground wall would not have to be so thick to resist the bomb itself but it must be strong enough to resist cracking, which would allow gases or water from fractured gas or water mains to seep into the shelter.

"It is evident that if an explosion under a street surface destroys water and gas mains and at the same time badly cracks a foundation wall the results may be serious."³

It was recommended in Aerial Bombardment Protection, pg. 204, that 24 inches of reinforced concrete be used underground.

Above the ground line the walls are subjected to fragments and to blast. The blast sets up air waves which can exert a tremendous pressure upon a wall panel. Since, however, the wall area above the ground in this case is small and, as will be stated later, covered with a protective layer of earth, the wall was designed to resist fragments only.

In table 23, pg. 197, Aerial Bombardment Protection, various thicknesses are given for different materials to resist fragmentation. The value used in this design was taken from this table and is 12 inches of reinforced concrete. This thickness was also used for the floor.

"For overhead protection a somewhat lower standard of resistance proves satisfactory, providing that overhead blast effects are not possible. Where overhead blasts can occur, overhead protection should be

3. Ibid. pg. 203

made identical with lateral protection requirements. In general, overhead protection is based on resistance to antiaircraft and incendiary bombs. In some cases debris must be considered.⁴"

In this case no debris was considered. This necessitates the placing of the shelter in the open and away from tall building. In table 29, pg. 242, Aerial Bombardment Protection, the required thickness for overhead protection is given as 4 inches. However, in table 31, pg. 245, Aerial Bombardment Protection, 6 inches of reinforced concrete is necessary for protection from a 2 Kg. incendiary bomb. Since larger incendiary bombs are seldom used this value was considered sufficient.

Additional resistance is given to bomb fragments and incendiary bombs by an earth cover which is placed over the shelter. This cover is to be 2 feet thick at the centerline of the structure and at least 1 foot thick at the outer edges. This covering not only gives added protection from bombs but also camouflages the shelter. The only visible concrete is that used in the ramps and this should be either painted or covered with a net to blend in with the surroundings.

The ramp walls and floor consist of plain concrete six inches thick. These walls may be made thicker or may be reinforced if possible but, since the collapse of one or two of the ramp walls would not necessarily cause any casualties, the added expense seems uncalled for.

To reduce the casualties to a minimum, in case of a direct hit or a near miss, the shelter is divided into two compartments by a 1 foot reinforced concrete wall running lengthwise of the shelter.

4. Ibid. pg. 238

SIZE

The size of the shelter is determined directly from the number of people occupying it.

"Within any shelter space or shelter compartment it is necessary to consider three factors:

- a. Floor space provided per person.
- b. Volumetric capacity per person.
- c. Superficial area of walls, floor, and ceiling or roof"⁵

It is stated, pg. 246, Aerial Bombardment Protection, that for a shelter ventilated at a rate not greater than 150 cu. ft. of air per hr. per person the requirement to be met should be:

Floor area	6 sq. ft. per person
Volume	50 cu. ft. per person
Superficial Area	25 sq. ft. per person

Since one hundred people are presumed to occupy this shelter, the minimum requirements are:

Floor area	600 sq. feet
Volume	5,000 cu. feet
Superficial area	2,500 sq. feet

The design was checked and was found to fulfill these requirements.

The shelter is divided into two compartments. Each of these compartments is 72' long, 8' wide, and 9' high.

REINFORCEMENT

No special type of loading can be assumed in this type of a structure and therefore it is impossible to compute the actual amount of steel necessary. Since no specific amount of steel can be determined the amount must be assumed. A large amount of reinforcement was assumed and it is

5. Ibid. pg. 245

presumed to be adequate.

ROOF

The roof reinforcement consists of $\frac{1}{2}$ " circular bars spaced six inches center to center. (see drawing)

WALLS

Three quarter inch circular bars are used in the walls. These are also spaced six inches center to center. The lower portion of the wall, which is two feet thick, has eight layers of bars while the upper portion, one foot thick, has only four layers. (see drawing)

FLOOR

The floor is to be reinforced the same as the upper part of the wall since both of them are one foot thick.

VENTILATION

Two ventilation units are provided. One is for normal use and the other is an auxiliary unit to be used only in case of the failure of the regular system. Electric motors should be the source of power with auxiliary power to be furnished by manual operation or gas engine driven generator.

Air intakes should be placed high enough to limit the amount of gas which can enter. Also both units should be equipped with filters to remove poisonous gases. These filters are to be placed between the intakes and the fans.

The ducts carrying the air to the various parts of the shelter should be placed along the ceiling and outlets to the shelter should be placed at regular intervals. The toilets should have separate ducts and should be ventilated at a rate of forty cu. ft. per min. per sanitary fixture.⁶

6. Ibid. pg. 256

Therefore each toilet room should be ventilated at a rate of 120 cu. ft. per min. since there are three fixtures in each. Each pair of rooms require 240 cu. ft. per min. Since the toilets are placed near the ventilating equipment and would probably fail if the ventilating system did, it is necessary to only ventilate the toilets from the nearest system. This would remove the necessity of having separate ducts leading from the regular ventilating system to the auxiliary toilets and vica versa.

Assuming the rate of ventilation in the main shelter to be 150 cu. ft. per hour per person, the output to the shelter should be 250 cu. ft. per minute. The total output of the fan would be 250 plus 240 or 490 cu. ft. per minute.

The two fans are to be placed in the rooms provided. These rooms should also hold any tools such as picks, shovels, crow bars, etc. which are thought to be necessary. No attempt was made to specify the type or make of ventilating equipment to be used.

LIGHTING

The lighting is to be electric with auxiliary current to be provided by the generators provided for the ventilating system. The power lines from the outside to the shelter are to be underground. If possible two lines should be run in from opposite sides of the shelter.

COMMUNICATION

A telephone is to be placed in the shelter and also, if possible, a two way radio should be installed to be used only in case the telephone is disabled.

SLEEPING

In these days, long air raids are very common. For this reason people may be required to spend a whole night in the shelter. To accomodate a few, of perhaps the oldest or the youngest, forty eight bunks are provided.

These are arranged in three decks along the two outside walls. The upper two rows are composed of bunks which fold up against the wall when not in use. These bunks are 6 feet long and 2 feet wide with a 6 inch space between each bunk in a row. The frames can be either of wood or of metal. Springs may be provided but canvas, as in a camp cot, would be more satisfactory since no mattress would be required.

The lower row of bunks is merely a long bench. This bench is used to sit on during raids of short duration, also this bench has a space provided under it for storing various articles. If seen fit this space may be divided into separate compartments for each occupant of the shelter. A bench is also provided along the inner wall for sitting only.

On the other side of the inner wall the floor is reserved for a width of two feet for stretchers.

ENTRANCES

Two entrances are provided. One at each end. Each entrance has two ramps connecting it to the outside. At each entrance is an air lock. The inner door is of a sliding type made up of two parts which disappear into the wall when not in use. The outer doors to the air lock are regular hinged doors. Both the outer and inner doors are air tight and have small windows in them. These doors are to be used only in case of a gas raid. Some person, preferably an air raid warden, should be designated to operate these air locks to prevent their miss-use.

The ramps are four feet wide. The walls are of 6 inch concrete. The slope of the walk is 8%. The sloping begins at the outer door of the air lock. The ramps are divided into two thirty foot lengths, the inside thirty feet are at 60° with the center line of the shelter and the outside thirty feet are parallel with the center line.

A drain is provided in the ramps just outside the outer air lock door to take care of rain water which runs down the ramp.

The ramps are covered for a distance of 6.25 feet with a 6 inch roof. This roof is an extension of the roof over the air lock. A retaining wall is to be placed at the end of this roof to prevent the earth, which covers the structure, from falling into the ramp.

The ramps do not necessarily have to be laid out in the described manner but they should be designed with at least one turn in them. This turn should be placed in such a way that the fragments of a bomb exploding at the entrance could not reach the air lock and damage it. If shorter ramps are needed, steps may be used instead of the sloping ramps.

Signs should be placed near the entrances to direct people to the entrance. Blackout lights should be placed along the ramps to mark the passage.

The entrance door into the shelter from the air lock is seven feet wide and seven feet high. The sliding doors, which close these inner doors, are made up of two parts which meet in the middle. They may be manually operated but would be more efficient if mechanically operated.

SANITARY FIXTURES

Two ladies and two mens toilet rooms are provided. Only one of each is to be used at a time however. The auxiliary toilets are placed as far away from the regular toilets as possible. Each toilet room is five feet wide, nine feet high, and ten feet long. Three water closets and one lavatory are present in each. It was recommended in Aerial Bombardment Protection that one fixture be provided for each twenty five people. If possible the auxiliary closets should be of a chemical type.

The entrances into the toilet rooms are 2.5 feet wide and seven feet high. The partition between these rooms and the shelter proper may be

either of wood or steel. A screen is placed just inside the rooms and in front of the door.

Drinking fountains are placed at both ends of the shelter.

ENTERTAINMENT

Some type of entertainment should be provided although no imperative. The entertainment should also be of a type which does not require the participants to exercise too vigorously and thereby use up excessive amounts of oxygen.

The size of the shelter limits the amount of room a game can occupy. Card games can be played very easily. Also such games as checkers, chess, etc. If books are available a library should be established for those who prefer to read. These games and books can be kept under the benches. A custodian should be appointed whose duty it is to take care of these articles.

EQUIPMENT

First Aid is very vital during an air raid. It is therefore imperative to set up a first aid post inside the shelter. A space has been set aside for stretcher cases and the first aid equipment should be as close to this area as possible.

Tools such as shovels, picks, fire extinguishers, etc. are to be stored in the rooms provided for the ventilating systems. Each tool should have a duplicate in the auxiliary ventilating system room.

Gas masks should be kept on hand for emergency and may be stored under the benches.

LUNCHES

In case of long raids a lunch counter has been added to serve light lunches. The lunch counter is not essential but is very convenient during a long raid.

GAS DETECTION

Some type of gas detection device should be placed near the entrances. These devices should be outside the shelter so the gas will be detected before it has had time to enter the shelter and do any damage. This equipment should be in the hands of an Air Raid Warden.

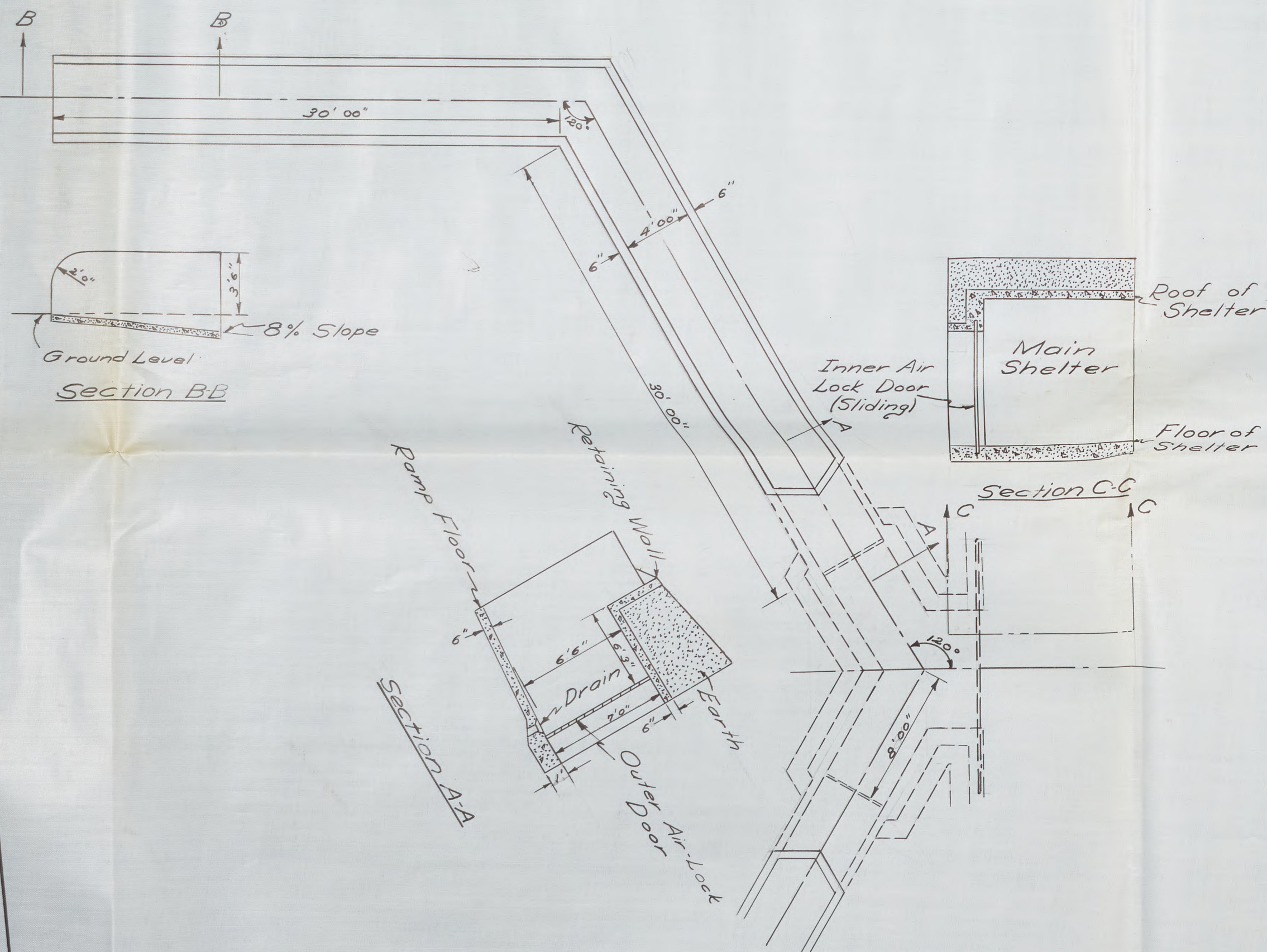
HEATING

Heating does not present a very large problem in most shelters. The body warmth given off by a large number of people assembled in fairly small quarters is quite large and would prove to keep the shelter warm in rather low temperatures. In this case the shelter is very well insulated from the outside by the layer of earth and also the two air-lock doors may be closed to keep out the cold. It would therefore seem necessary to provide only a small heating system for a shelter of this size unless the temperatures are accustomed to being very low.

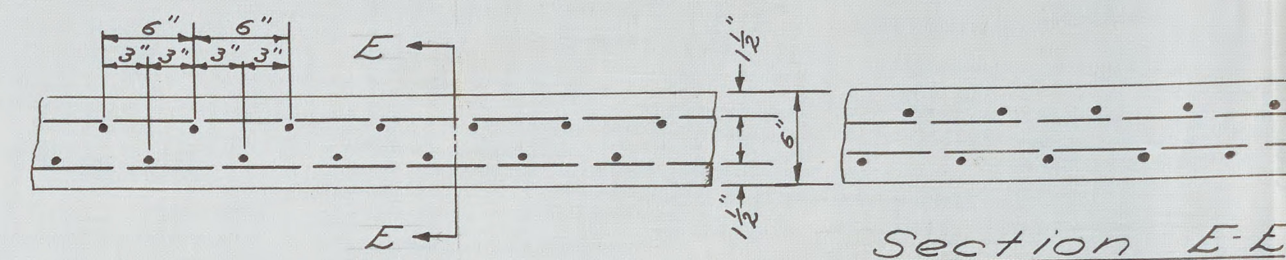
Some type of hot air system which could be used in connection with the ventilation would probably prove to be the most satisfactory. Steam heat could be used but some means would have to be provided to supply the heat in case the supply of steam became cut-off.

CONCRETE

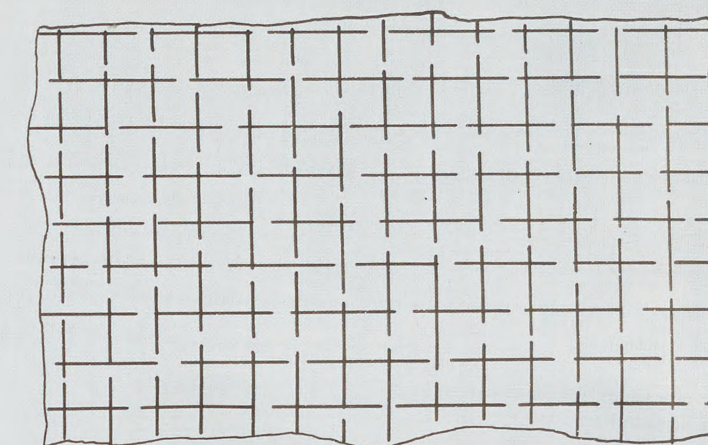
The concrete is to have a 28 day strength of 4000# per sq. inch in compression.



Details of Ramp and Air Lock
 Scale 1" = 6'



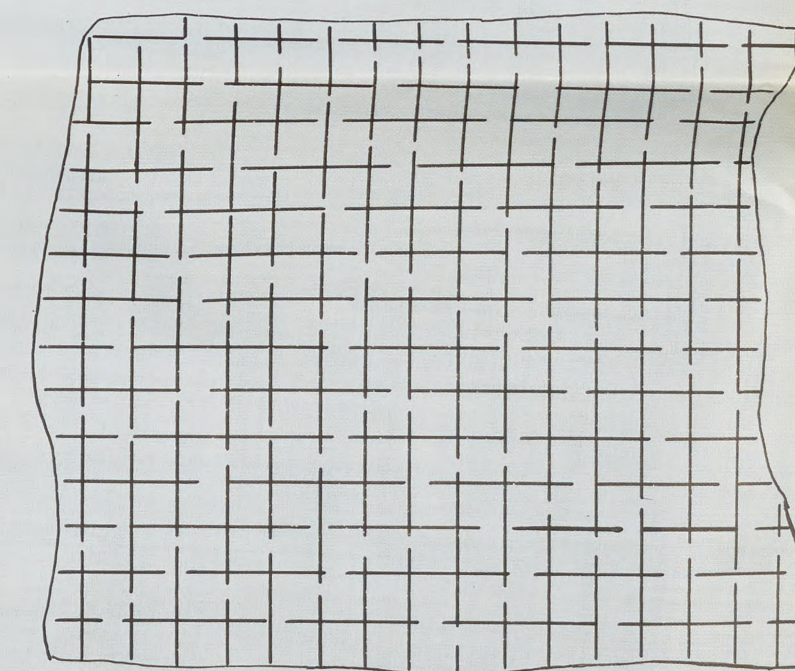
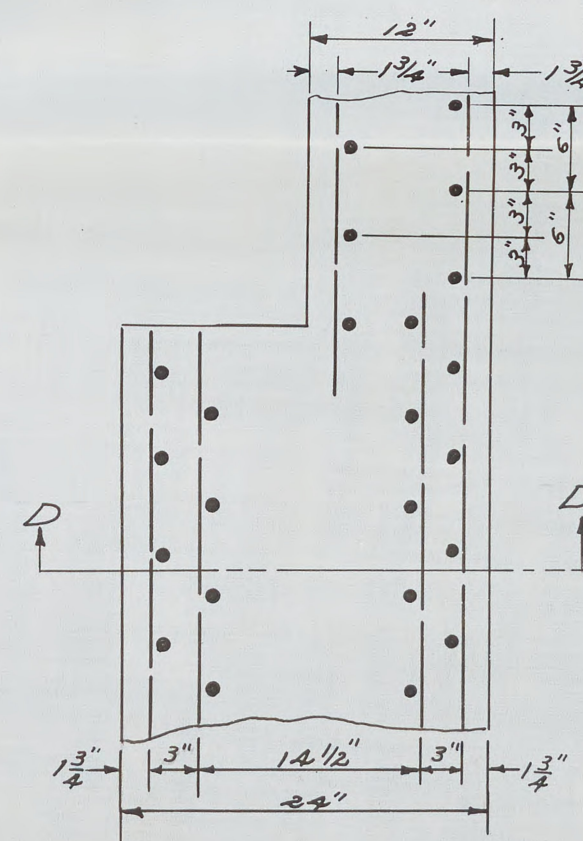
Section E-E



Reinforcement consists of
 1/2" Φ Bars

Scale 1" = 12"

Section of Roof Showing
 Reinforcement



Reinforcement consists of
 3/4" Φ Bars

Scale 1" = 12"

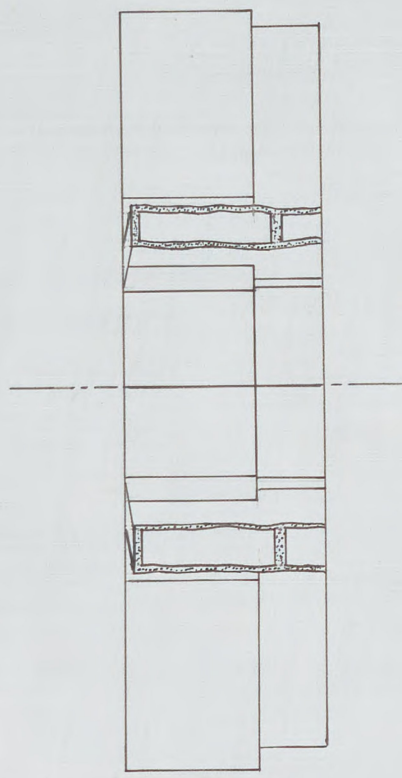


Section D-D

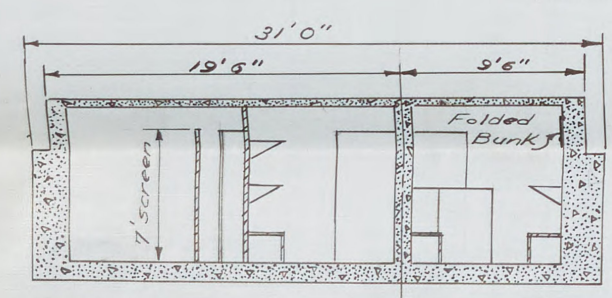
Section of Wall Showing
 Reinforcement

8250929

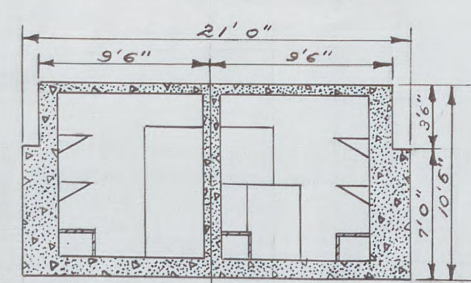
MALE
SUPPLEMENTARY



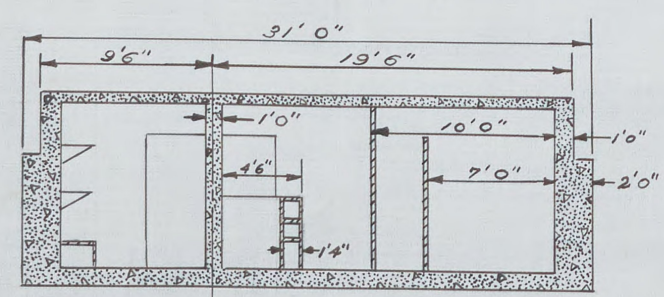
Elevation
(End)



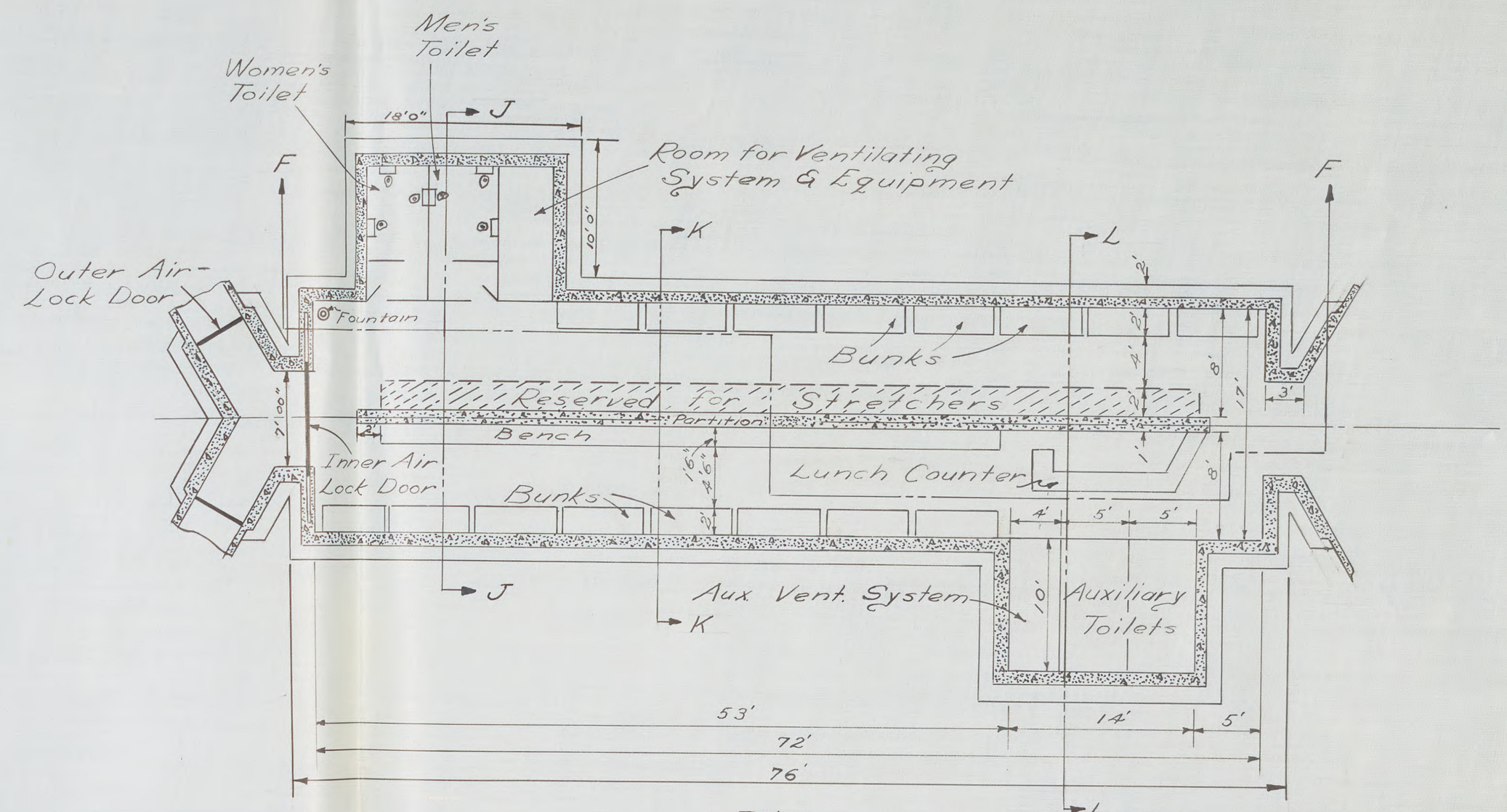
Section J-J



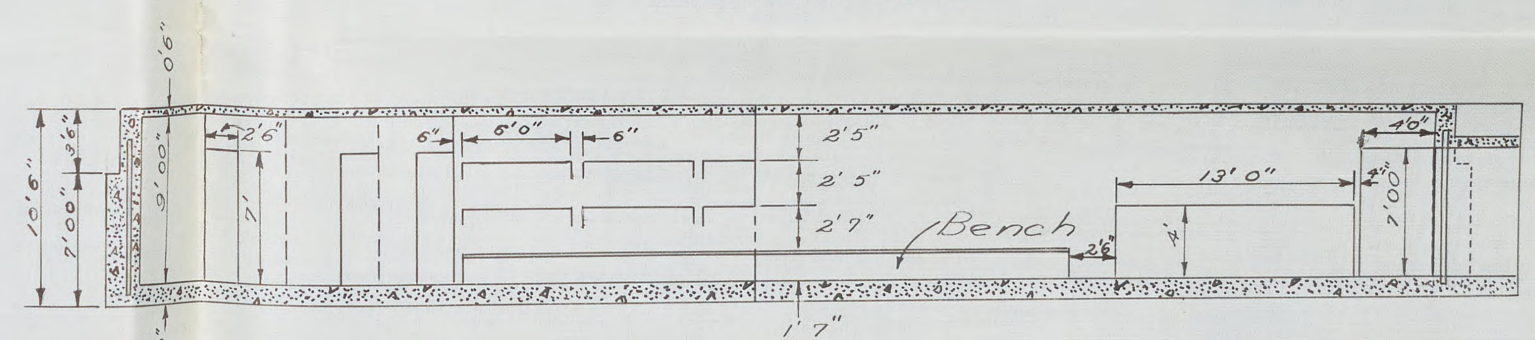
Section K-K



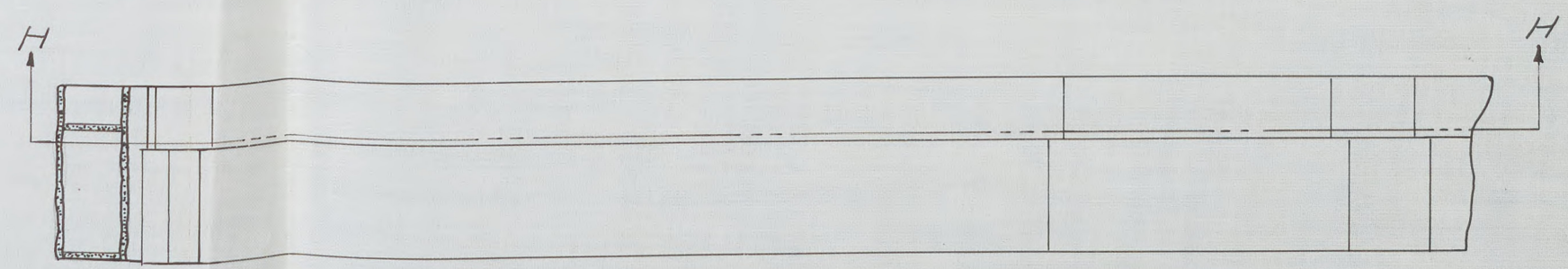
Section L-L



Plan
Section H-H



Section F-F



Elevation
(Side)

DETAILS OF MAIN SHELTER
Scale 1" = 10'

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