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MASTER OF ARCHITECTURE

THE ARCHITECTURE OF SUBTERRANEAN STRUCTURES

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Date

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THE ARCHITECTURE OF SUBTERRANEAN STRUCTURES

BY
ORAN R. WOODY
B.S., Eastern New Mexico University, 1971

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Architecture
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico

December, 1975

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THE ARCHITECTURE OF SUBTERRANEAN STRUCTURES

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ABSTRACT OF THESIS

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ABSTRACT

This paper presents the case for increased use of subterranean space. It does so by creating an awareness among architects and other design professionals that there are benefits to be found by underground designs that are unique to the concept. Secondly, it gives those professionals a base of knowledge in subterranean use that, when combined with their professional expertise, will give them a solid base from which to advocate subterranean architecture.

In order to achieve the above goal, this paper has been divided into historical precedents, current examples, terminology and definitions, functional classifications, conceptual theories, subterranean structures and energy conservation, soils and their physical characteristics, social, legal, and code restrictions, and design examples. Each area of information has the function of enlightening the architect about one specific facet within the subterranean concept.

The conclusion of this paper is that in spite of the benefits of underground use in energy conservation, architects continue to neglect a potentially valuable resource. They do so because of prejudice rather than because of any real deterrents to its use. Finally, it concludes with the supposition that as energy savings become more critical, subterranean design styles will become a more valid and acceptable form of architectural expression.

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INTRODUCTION

The purpose of this thesis is two-fold. Primarily it is to promote an awareness among architects and other design professionals that there are very valid reasons for considering subterranean structures as a design option. It has, in addition, the secondary purpose of giving them a solid base for their advocacy of the concept.

The concept of underground structures is not new, however it has been neglected in modern architecture. What has contributed to this neglect is not known, but increased knowledge of its benefits can help re-establish the validity of subterranean design.

This thesis has been sectioned into: 1) historical precedents, 2) current examples, 3) terminology and definitions, 4) functional classifications, 5) conceptual theories, 6) subterranean structures and energy conservation, 7) social, legal, and financial inhibitors to subterranean construction, and 8) examples of subterranean designs. Each of these sections has the specific purpose of acquainting the architect with one or more facets of the subterranean design concept.

HISTORICAL PRECEDENTS

HISTORICAL PRECEDENTS

Although most persons in modern-day America have not seen a great number of subterranean structures, other than basements or an occasional bermed building, there were times and places where underground living was the norm rather than the exception. From the time of the "cave man" to the present there have been people who have individually or as members of a society taken advantage of the shielding and protection offered by the earth.

Before the advent of readily expended fuels in large amounts, there often was no way to combat extremes in the climate of certain areas other than to go underground. Some of the precedents were primitive to be sure (some even more primitive than their contemporary surface structures), but they were used to fulfill a need for shelter that quite possibly could not have been matched by anything on top of the ground.

Roman Court Garden House

In the second century A.D. Roman colonists in North Africa were using subterranean structures to make their lives in that hot arid region somewhat more endurable.[1] Romans had at that time used underground facilities in their defensive outposts to the north, but it was in the deserts of Africa that they first began extensive use of the subterranean structures for shelter. The stone that they had so skillfully used in their native country offered too little protection from the searing heat of their new environment, and was often difficult to find.

The common design for the subterranean Roman building was that of the courtyard surrounded by the structure itself.[2] The open air courts were a valuable part of the ventilation system for the building.

In areas that were occupied by Rome urban services were located above the surface, on the surface, and below the surface. Romans had extensive underground water supply and waste disposal systems, as well as the far more famous aqueduct systems. Sometimes individual residences would even have running water, and an air circulation system for cooling in the daytime and heating in the nighttime. The air was forced through trenches located in the floor of the house.

So common was the use of underground facilities by Rome that widespread use of underground services has only recently given modern day man a comparable system with that which was used by the inhabitants of Pompeii.

Anasazi Pit House

Early man's permanent living sites were caves or other natural shelters. Gradually they became adaptations of that subterranean style. These modified subterranean dwellings are sometimes referred to as "pit houses."[3] They were dug partially below ground with a wood pole frame erected above the surface. This frame was covered with sticks, twigs, and earth.

In the top center of the covering was a smoke hole. It allowed smoke from interior cooking and heating fires to escape, and provided for limited ventilation. Combined with the natural insulation of the earth covering, the smoke hole's ventilation helped maintain reasonably comfortable interior temperatures year-round.

Pueblo I is an archaeological division that encompasses the Anasazi Indians.[4] They were the forerunners of the pueblo tribes. Their homes were, at first, typical pit houses. Later they began to use a large amount of stone work to aid the structural elements. This style is still apparent in the ruins of pueblo kivas (religious sites within the pueblos).

An identifying feature of the Anasazi pit house was the entry. Located in the top center of the structure, it had a dual function. It served as an entry and as a smoke-hole.

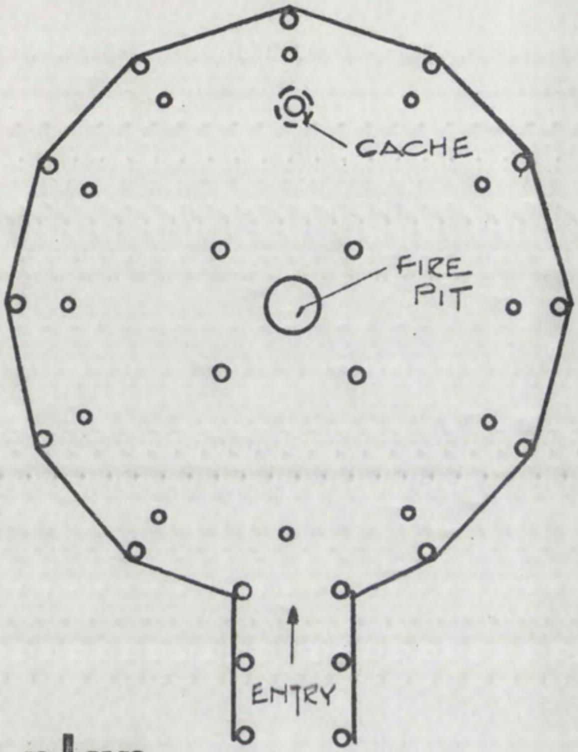
Mandan Earth Lodge

The Missouri River was the site of an early subterranean structure known as the Mandan earth lodge.[5] It was quite large, circular in plan and about forty feet in diameter. The Mandan earth lodge was capable of housing several family units.

The lodge floor was excavated to a point several feet below the ground surface. At the perimeter of the inside wall, the normal height was about six feet. The ceiling rose to an interior height of twelve to fifteen feet. The lodge was built with a post and beam system. The wall poles were leaned against the perimeter beams and covered on the exterior with earthblocks and sod. The berm layer was about 18 inches thick at the roof line and expanded to several feet thick at the ground surface. The roofing system was several layers of poles which rested upon the roof beams. The poles were laid in parallel rows perpendicular to the layer below. On top of the poles were placed layers of twigs and leaves. Above them went a surface coating of woven grass matting and sod.

The smoke hole was located as usual in the top center of the structure. The Mandan earth lodge was unusual in having an elaborate stick dome. The dome was covered with an adjustable layer of skins to regulate ventilation or heat loss.

The entrance to the lodge was a single doorway about five feet wide and ten to twelve feet long. It was very similar to that found on the familiar



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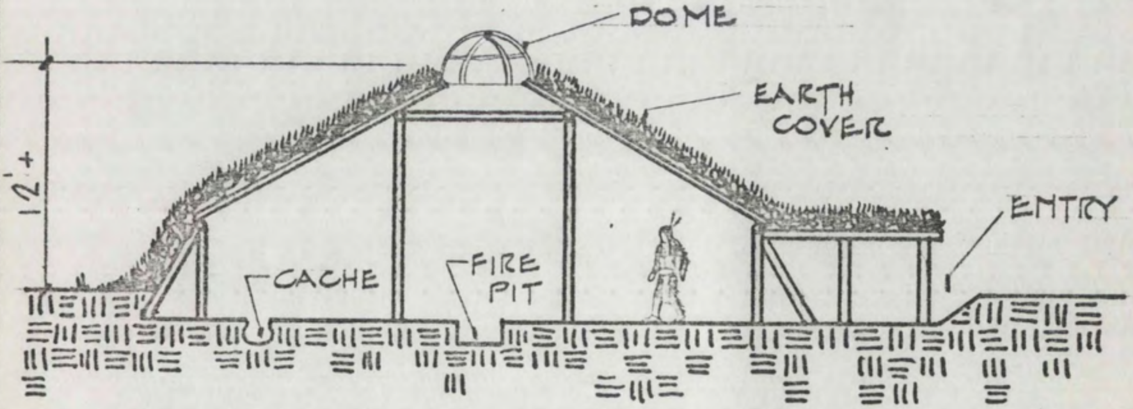


section

FIGURE 1
MANDAN EARTH-LODGE[6]

Eskimo igloo. The exterior and interior ends were covered by skins during inclement weather.

Many of the Missouri River Indian tribes lived in earth lodge style dwellings.[7] A turning point occurred when use of the horse began to be common. At that time the Chipewyan, Arapaho, Cree, Cheyenne, Souix, Dakota, and Crow abandoned their earth lodges. They became wanderers, and hunters, and accepted the harsh life of the nomad.

Although other tribes began to use the horse, they chose to continue to live along the middle Missouri water shed. They kept their earth lodge cultures until the Anglo invasion displaced them. The early cultural anthropologists found many settlements of Arikara, Mandan, and Hidatsa still living in earth lodges in the latter part of the nineteenth century.

European Long House

By 7500 B.C. European agricultural peoples had begun to use a circular dwelling that was very similar to that of the Mandan Earth Lodge, although the entrance was not nearly so sophisticated.[8] It was just an opening in the wall that was covered with skins during bad weather.

The size of the lodge was originally limited by the length of poles that were available for the rafters. The size was increased by those Neolithic farmer-builders when they began to lengthen a rectangular form of lodge. Known as the "long house," the section continued to resemble a section through the earlier circular earth lodge. Actually, a series of connected squares, the "long house" had almost infinite potential.

As the "long house" became larger, the structural system became lighter and more sophisticated. It began to be constructed of lashed poles. The earth berms were banked against a reinforced wall of split logs and interwoven

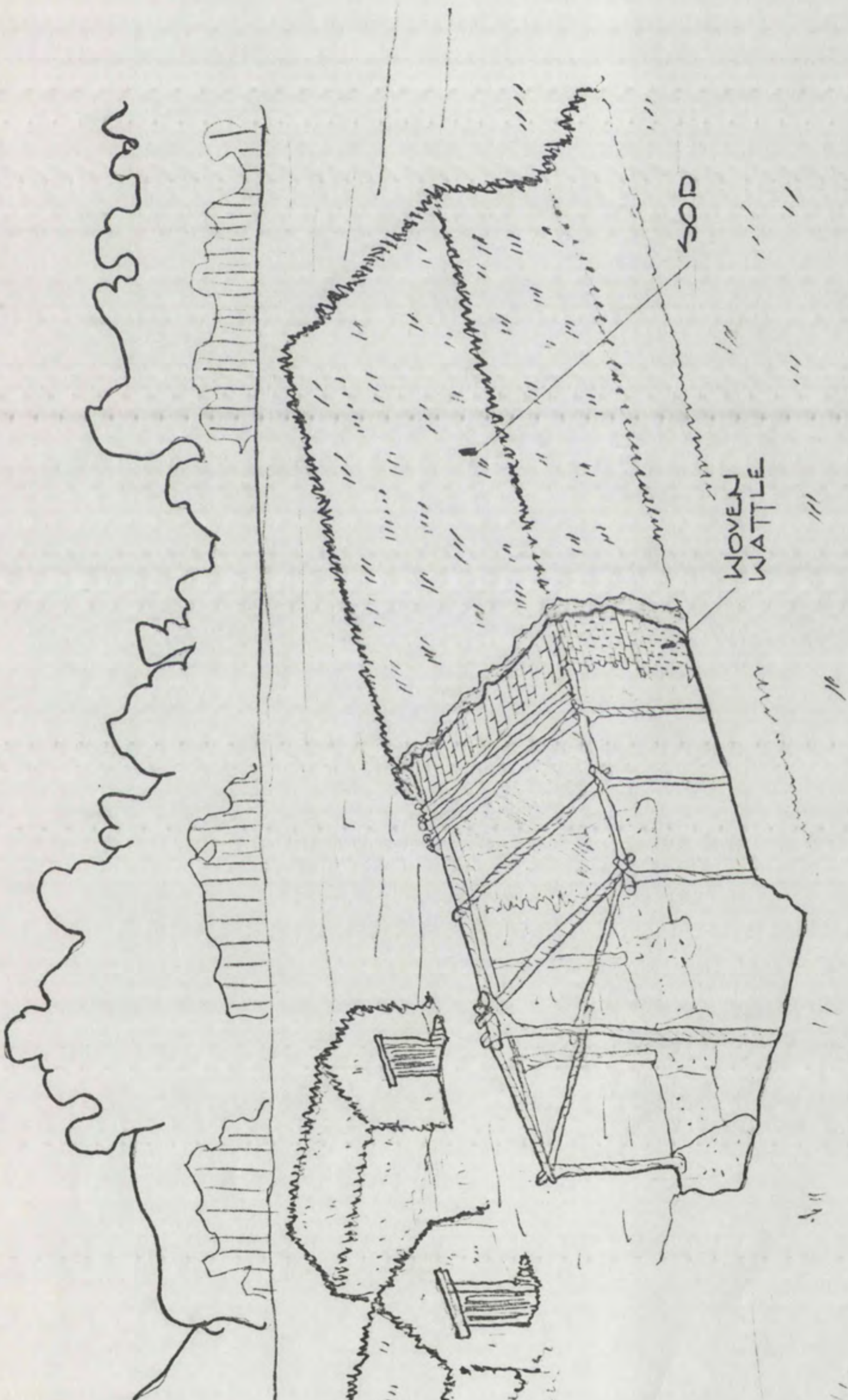


FIGURE 2
EUROPEAN LONG HOUSE[9]

wattle. The roof was made from long tapered poles that had their butt ends set into the berm. Over these rafters a deck of sticks and wattle was constructed to carry the sod roof.

There was adequate protection from the weather in the earth covered "long house," but there were limitations. The high moisture level made them damp clammy dwellings. Wood rafters and rawhide lashings rotted rapidly in the wetness. Many attempts were made by those early subterranean dwellers to find a solution to the problem of moisture penetration, but apparently no satisfactory answer was found by them.

Cappadocia, Turkey

In Turkey there is a volcanic region that supports a veritable apotheosis of troglodytism.[10] The Goreme Valley was first inhabited over a thousand years ago by monks and nuns who were seeking a life of seclusion and self-imposed solitary confinement. The colony became known as Cappadocia when later travelers began to pass through the region.

The settlement grew to include secular members as well as its members of the monastic orders. Even as the size of the population grew, the communities continued to live and function underground.

The geologic uniqueness of the region made the inhabitants of the region have a less difficult time in creating housing underground than on the surface. There are large mountains of volcanic stone known as "tufo." It is a very soft type of rock that lends itself readily to being hollowed out, yet is strong enough to span reasonably long distances without collapsing.

Large cities have been housed in the Cappadocian cones. One was the equivalent of a sixteen-story building, only going down rather than up.[11] It went to a depth of 265 feet. Another city which housed as high as 20,000

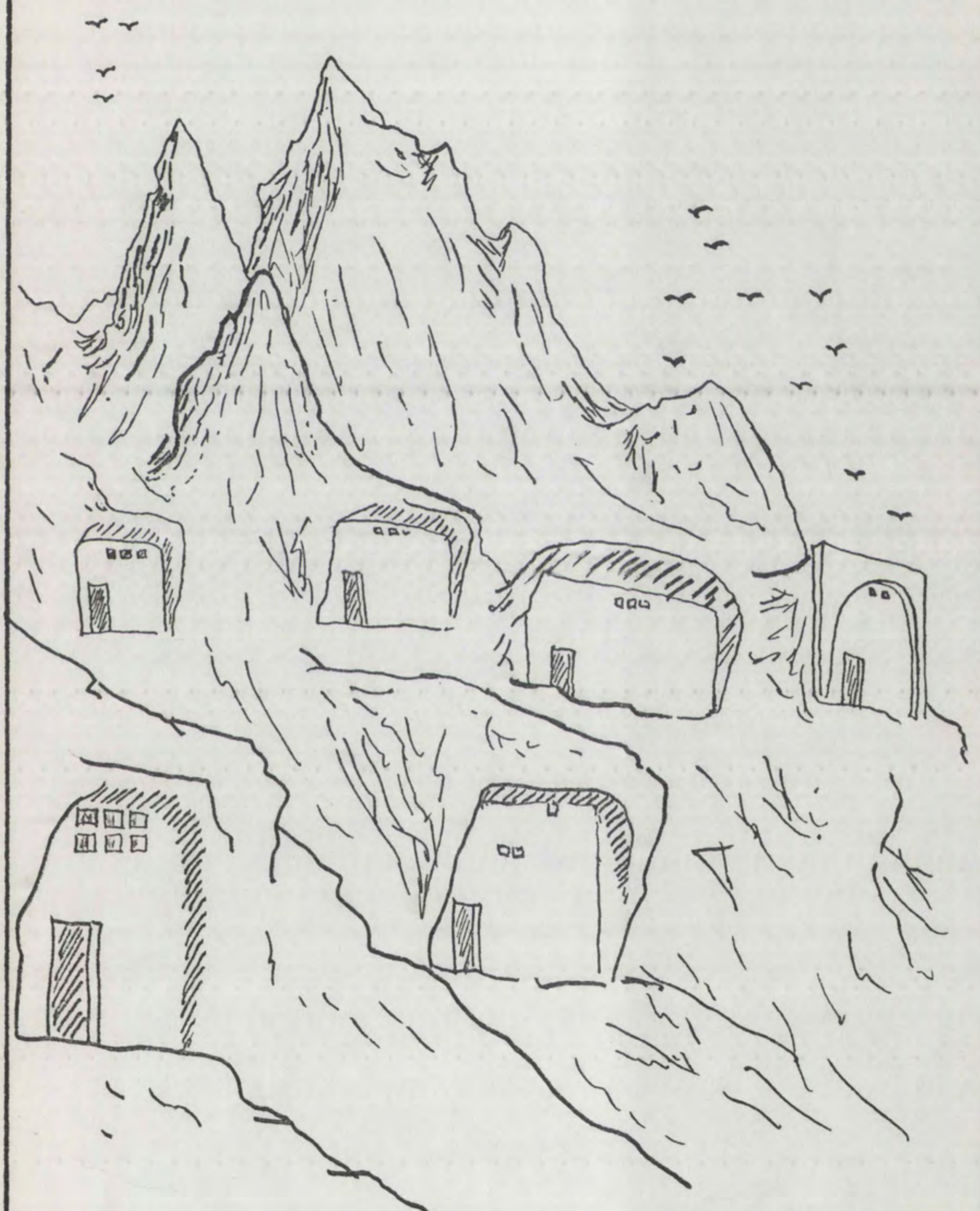
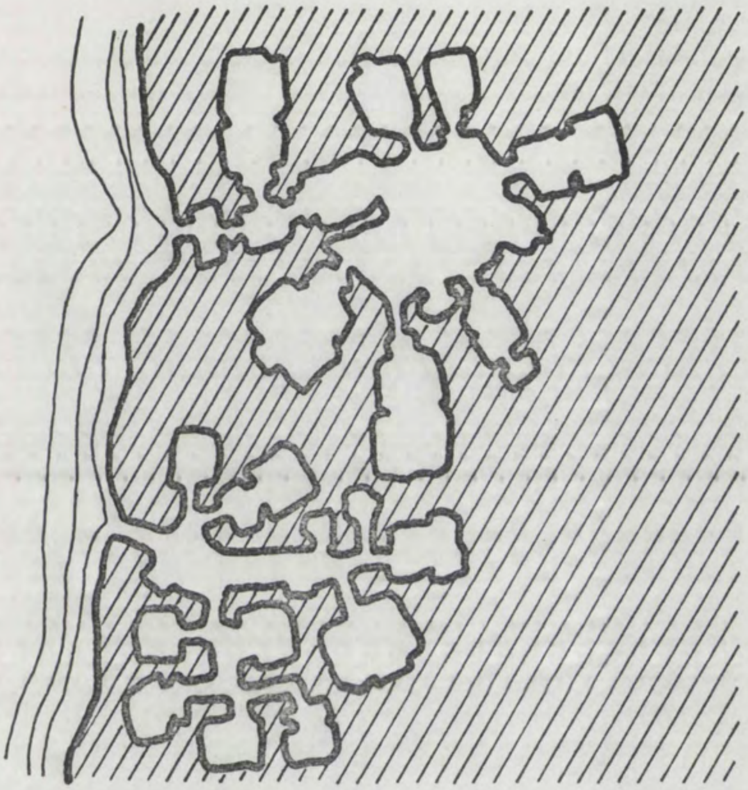


FIGURE 3
CAPPADOCIA, TURKEY 12



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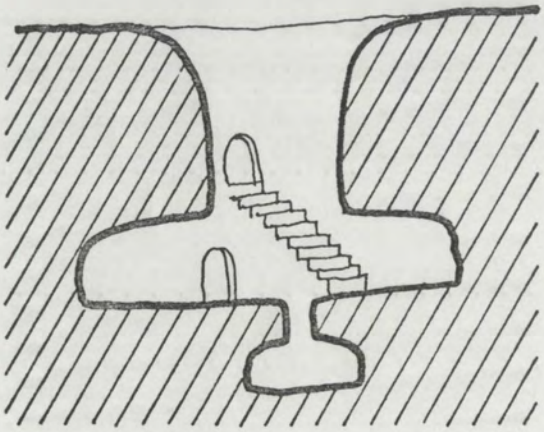

section

FIGURE 4
MATMATA, TUNISIA[13]

inhabitants was connected to a smaller city by means of a six-mile tunnel through the tufo.

Matmata, Tunisia

There are subterranean dwellings at Matmata, in Tunisia,[14] North Africa. They are cut out of a form of sponge-like sandstone that is unique to the area. It is nearly free from internal moisture and dries even further when exposed to the open air. Upon drying it becomes rock-like and very stable.

The dwelling consists of a large central courtyard surrounded by living units. Then each of the living units is dug from the sides of the courtyard by those who are to occupy each. At the center of the courtyard is an open air cistern that gathers as much of the sparce rainfall as possible. Meager supplies of water are valuable to those Spartan-like inhabitants of that hostile land.

The courtyard provides a shaded cool area for housework. Hanging screens provide control for the circulation of breezes. Sometimes the screens are moistened, and cool the air in a manner very similar to the evaporative cooler with which we are so familiar. "The troglodyte shelter is suited to bright dry regions, whether hot or cold. They provide the ultimate in insulation. Unfortunately, they do not provide for much visability or well-lit interior space."

Honan, China

Honan, China is the site of a two thousand-year-old subterranean society that clings to its old ways.[15] The dwellings are similar in style to the courtgarden houses of the Roman colonists in North Africa, except they are far more utilitarian and basic. Dug thirty to forty feet beneath the surface, the square courts are surrounded by the cave dwellings of the farmer-residents.

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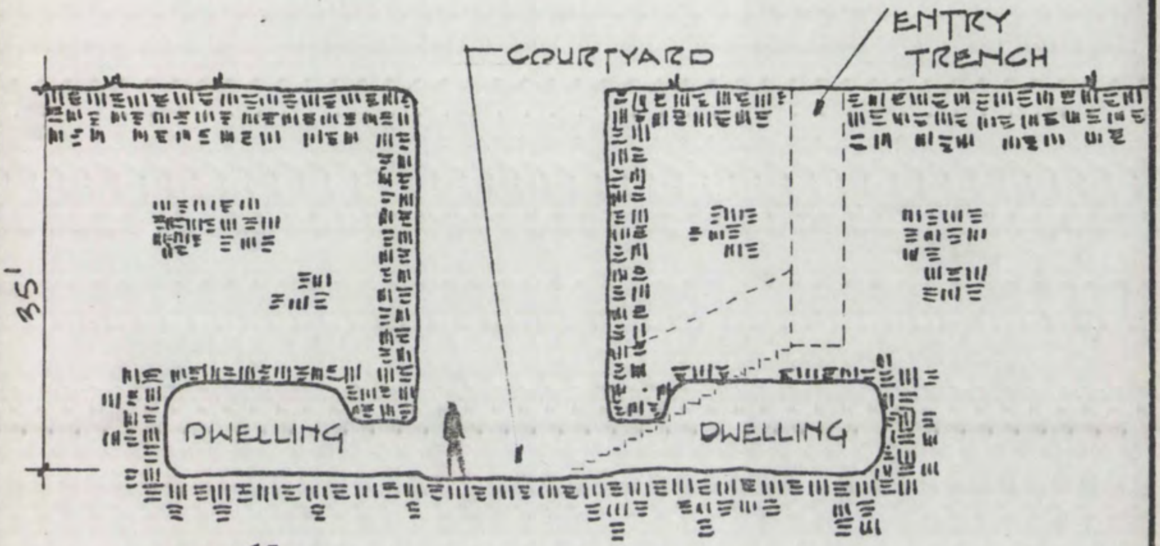

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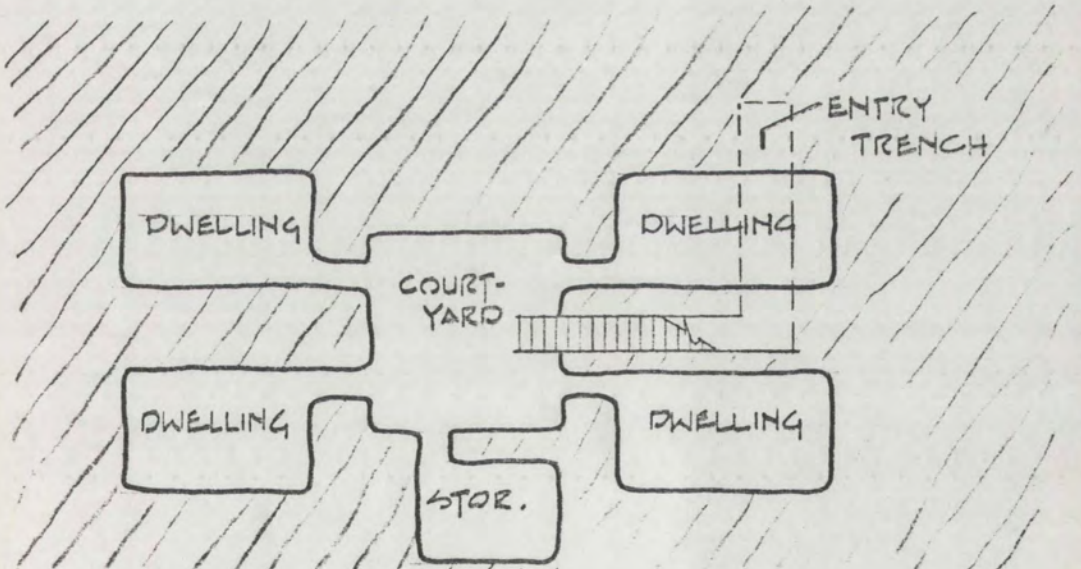

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FIGURE 5
HONAN, CHINA[16]

Entry is provided by means of a small L-shaped stairway that begins at ground level and works its way to the courtyard.

Reportedly some 10 million people in China live in similar underground inhabitations. The largest concentration of subterranean dwellers is that of the Honan Province, but many persons live underground in the Shansi, Shensi, and Kansu Provinces. Factories, schools, hotels, and government offices are also placed underground.

FOOTNOTES

1. Jacquetta Hawkes and Sir Leonard Wooley, *History of Mankind, Cultural and Scientific Development* (London: George Allen and Unwin Ltd., 1963), p. 132.

2. Opinion expressed by A. W. Hancock, Personal interview, January 5, 1975.

3. Royce La Nier, "Geotecture, Subterranean Accomodation and the Architectural Potential of Earthworks" (unpublished Master of Science thesis, Notre Dame University, 1970), p. 5.

4. Watson Smith, *Prehistoric Kivas of Antelope Mesa, Northeastern Arizona*.

5. *Shelter* (Bolinas: Shelter Publications, 1973), p. 18.

6. *Ibid.*

7. *Ibid.*

8. *Ibid.*, p. 21.

9. Ibid.

10. Bernard Rudolfsky, "Troglodytes, Putting Architecture Underground," *Horizon*, Spring, 1967, p. 28.

11. *Ibid.*

12. Fahriye Hazer, "Cultural-ecological Interpretation of the Historic Underground Cities of Goreme, Turkey" (paper read at Conference on Alternatives in Energy Conservation: The Use of Earth Covered Buildings, July, 1975, Fort Worth, Texas).

13. Jason C. Shih, "Optimum Subsurface and Underground Shell Structures for Better Housing in Hot Arid Lands" (unpublished doctor's dissertation, Duke University, 1970), p. 21.

14. *Ibid.*

15. Kenneth Labs, "Architectural Use of the Underground" (unpublished Master of Science thesis, Washington University, 1975), p. 17.

16. Ibid.

CURRENT EXAMPLES

CURRENT EXAMPLES

Subterranean structures in the United States generally exist only as isolated buildings. They are usually designed and built to satisfy a particular need that a surface design might not fill as well. Sometimes they have been built after a surface design has been constructed and then found to be unsatisfactory. No matter what their purpose, they have proven that in many instances subterranean is a logical alternative.

It will most likely be a long time before the subterranean concept is automatically considered by an architect as an option for almost any design problem. Culturally, we are unaccustomed to spaces which have no clear relationship (via windows, doors, etc.) to the surrounding environment. Even when there is no logical need for windows (for instance in a climate controlled building), we tend to feel a requirement for contact, even if it is only visual.

The examples which follow indicate that in spite of cultural bias against subterranean construction and design, they are being built in this country and others to meet specific design requirements.

Kracow, Poland

The salt mines of Kracow, Poland have been worked since the 11th century.[1] They are the world's most elaborate underground space. Excavations now reach eight hundred feet below the surface. There are seven levels that total more than seventy-five miles in length. Inside the spaces are public areas that include churches, offices, and even a ballroom. It is easy to assume that the present day visitors can expect to enjoy their stay far more than did the 11th century Polish miners who often labored to death in those very spaces.

Other salt mines are used for a variety of purposes. Almost all underground heavy industry in Poland is sited in abandoned salt mines.[2] Storage of liquified gases such as ammonia, propane, propylene, and butane is made less expensive, and done more easily when placed in salt caverns. Storage of these gases in subterranean areas decreases or eliminates dangers from fire, explosions, or contamination. Leakage (an ever-present hazard in surface storage tanks) is eliminated because the toxic materials may be kept hundreds of feet below ground where the hydro-stratic water table prevents out-leakage.

Kansas City Limestone Mines

Kansas City, Missouri is the location of one of the world's most extensive subterranean facilities. Measured in acres rather than in square feet, the underground area is the result of a hundred years of mining for limestone.[3]

The mines of Kansas City are also notable for having large amounts of limestone left in the "mined-out" areas. Because far-sighted entrepreneurs in the first part of the 20th century saw the possibility of using the mines for long-term financial gain, they rejected old mining techniques. The miners went into the limestone strata and stripped the stone from top to bottom. Supporting piers were placed at random, and finally removed as the limestone lease ran out. This removal allowed the overburden to gradually settle.

Eventually the settling would reach the surface where the ten to fifteen foot settling could and did damage some surface structures beyond repair.

Now the modern mine owner bases his operation on the concept of a primary use and a secondary user.[4] The mining of the limestone is the primary use. The secondary user might be anyone, from an individual who needs above or below ground office space to a large corporation that needs inexpensive storage for warehouse goods. (See figure 7). The mined areas appear to fulfill almost any client's needs as fully as would a surface structure.

A sign of the mine-owner's awareness of the secondary user concept is that the support piers are no longer round, nor are they located haphazardly.[5] They are presently twenty feet square and placed eighty-five feet on center, in a definite grid arrangement. This spacing and arrangement is very useful in allowing wide roadways and optimum user area between piers. Also the mining companies no longer remove the limestone completely. A layer several feet thick is left at the roof and a layer of lesser thickness is left on the floor. These two layers provide additional structural strength because they are tied directly to the support piers. Access to and from the mines is by means of auto transport on high speed elevators.[6] In 1975, unimproved warehouse storage space leased for 80 cents per square foot. Even office space is inexpensive because interior walls do not have to be structural; they have only to be partitioned and sometimes fire-rated. The most common material used to surround the office space in the mines is normal concrete masonry units. Due to their having to function only as a curtain wall, reinforcing is minimal. They are laid floor to ceiling with the top course joined to the ceiling as per fire codes. Some walls are filled with insulation material so that the space can be used as freezer storage.

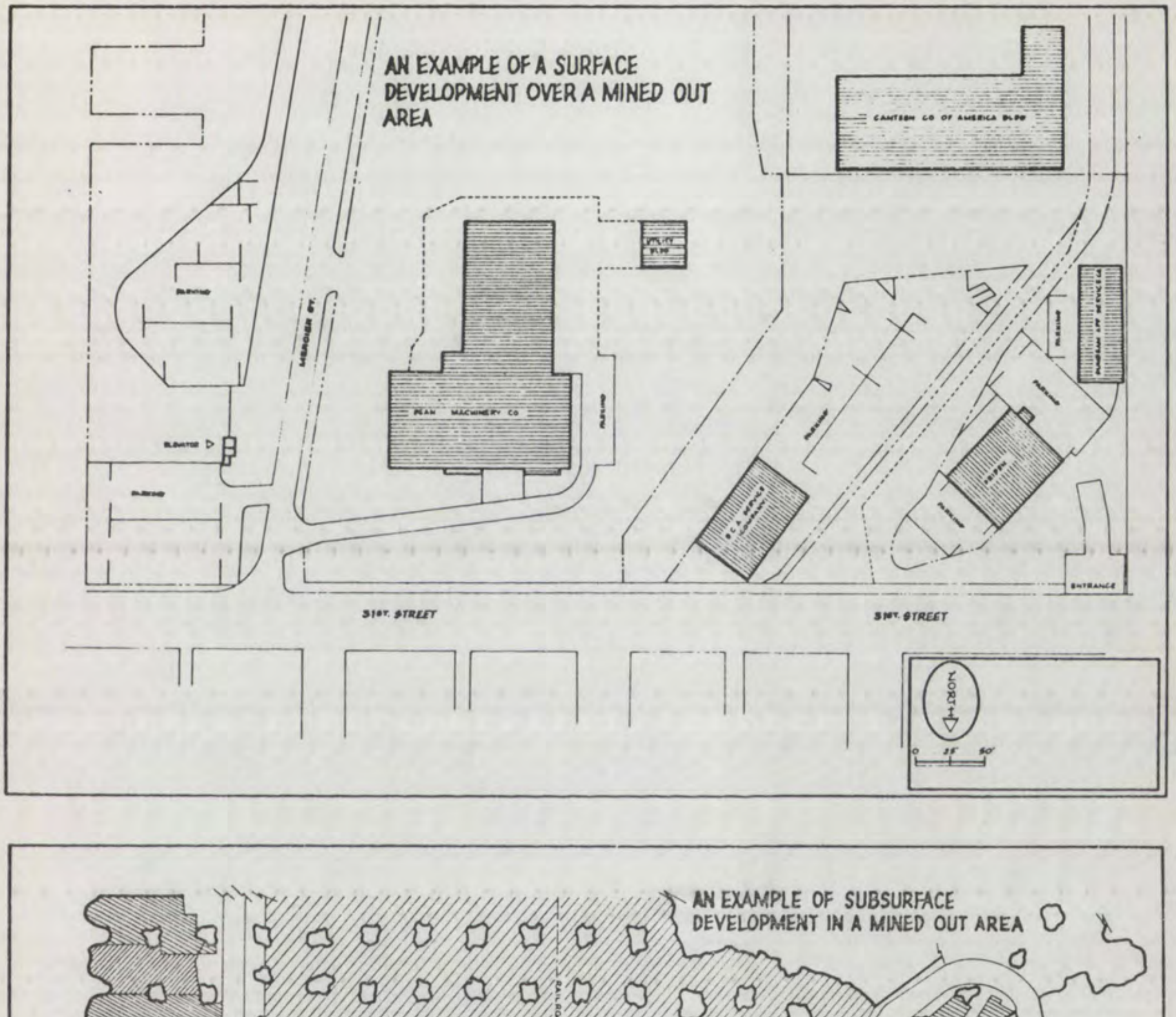


FIGURE 6
SURFACE AND SUBSURFACE USE OF MINED SPACE [7]

Underground storage is not unique to Kansas City, but it is best exemplified there. In 1965 five million square feet of storage space was in use, and presently that amount has quadrupled. The leasing of space is now more profitable to Kansas City mine owners than was the original limestone mining operation.

One of the firms located in the Kansas City mines is the Brunson Instrument Company. It is a manufacturer of precision instruments that are used extensively by the armed services, the construction industry, and the space and missile industry.[8] Nuclear submarines and the Apollo Lunar Program both rely on parts that are manufactured in the Kansas City mines. The manufacture of these parts requires a factory with fully controlled humidity and temperature. A totally vibration-free floor is imperative in close toleration manufacturing, which in the case of some of the parts, may be to dimensions of 50 millionths of an inch. It was to obtain this degree of consistency that the underground plant was planned and constructed. At the former surface located building, the precision calibration of instruments could be accomplished only between the hours of 2:00 and 4:00 a.m. when traffic vibrations were at a minimum. At the underground location this work can be accomplished at any hour, day or night.

The Brunson Instrument Company is unique in that it is the first underground installation in the area in which the primary object was to use the mined out area.[9] Preliminary investigation into the possibility of locating an underground site where exacting conditions for precision instrument manufacture could be met were begun in 1948 by Mr. A. N. Brunson, owner of the company.

The decision to excavate his own underground area was made after consideration of a number of abandoned mines, all of which proved unsuitable for the purpose of precision instrument manufacture. Mining operations began in 1954

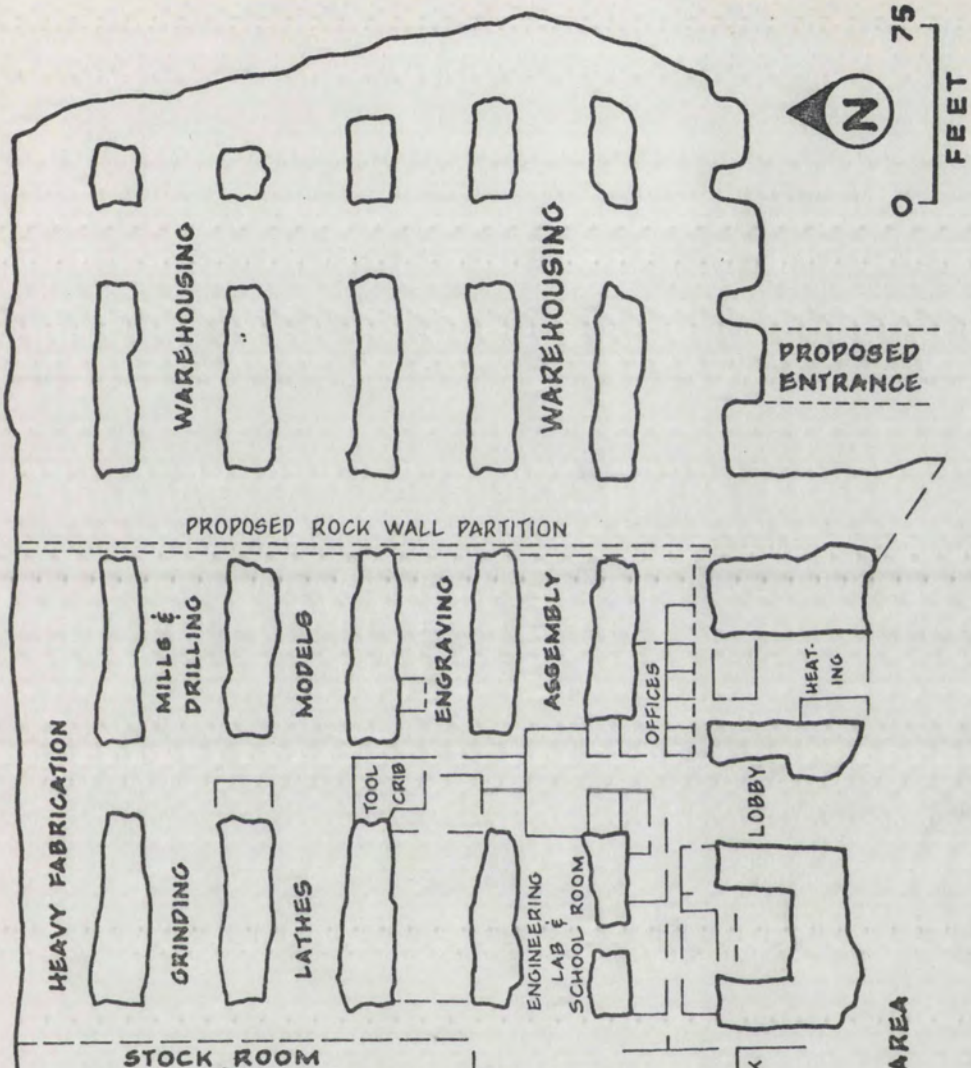


FIGURE 7
FLOOR PLAN OF BRUNSON INSTRUMENT CO.[10]

and continued for six years. The limestone was crushed and sold as it was removed thus reducing the cost to about one-third that of an above-ground facility. The move to the present site was completed in 1961.

Because the site was developed for a specific purpose, it was excavated to the specifications required by the designer. The open rooms and pillars were designed for the effective use of assembly line procedures. Pillar distribution in existing limestone mines was commonly irregularly spaced and not suitable for assembly line techniques. One of the major problems in utilizing old or abandoned mines for underground storage and other uses has been the tendency of miners to mine rock in a random fashion, leaving irregular pillars, inconsistent pillar spacing and arrangement, and poorly arranged bays. Most mines are now being planned with ultimate use of the underground space in mind before mining begins. The mine plans are laid out so that pillar spacing will be orderly and consistent with the planned ultimate usage of the space.

The pillars in the Brunson factory are 75 feet long, 15 feet thick and 45 feet apart, center to center.[11] These pillar dimensions result in bays 30 feet wide and several hundred feet long. There are six east and west tunnels and seven north and south tunnels. In the past two years this facility has been expanded in an eastward direction to include over 100,000 feet of newly mined space. The total space is now approximately 250,000 feet. Of this amount 75,000 square feet is used for the factory and office and the remainder is being converted into storage area for warehousing.

Room height is 12 to 13 feet with 8 to 10 feet of the upper part of the Bethany Falls limestone forming a stable roof. The ceiling coincides with a prominent bedding place of a thick massive bed forming the roof. No roof bolting is required. The mining procedures innovated by the Brunson Company have been followed by later developers of underground space. Particular care is taken to insure that adequate support is given to the roof, so that no problems of roof failure occur. It has been found that careful mining practices leaving 6 to 8 feet of limestone for the roof of the mine and utilizing the remaining thickness for a 12 to 14-foot opening is good practice.

The factory floor is sealed with a concrete sealer to prevent dust. The limestone ceiling and walls are sealed with latex. Where it was necessary to have a straight wall, concrete blocks were installed. The sewers are connected directly to the city sewers, and the water supply is furnished by the city. All sewer pipes are graded for drainage and are in the Hushpuckney shale under the floor. Water pipes are also buried in the shale beneath the concrete floor.

Underground areas are unaffected by surface weather conditions and remain year round at a constant temperature of approximately 54^o. Heating, air conditioning and dehumidifying costs are kept at a minimum relative to comparable surface facilities.

Granite Mountain Genealogy Center

In Utah the Morman Church has entrusted their most valuable records on earth to underground storage.[12] These are their genealogy records. They believe that the documentation of family background is crucial in gaining admittance into heaven. So complete are the studies and compilations of faithful church members, that in spite of wars, holocausts, and senseless acts of destruction, church members can directly trace their genealogical records back to before the time of Christ.

When looking for a truly safe place to store those invaluable records, the Church decided that the best decision was to place them underground. A

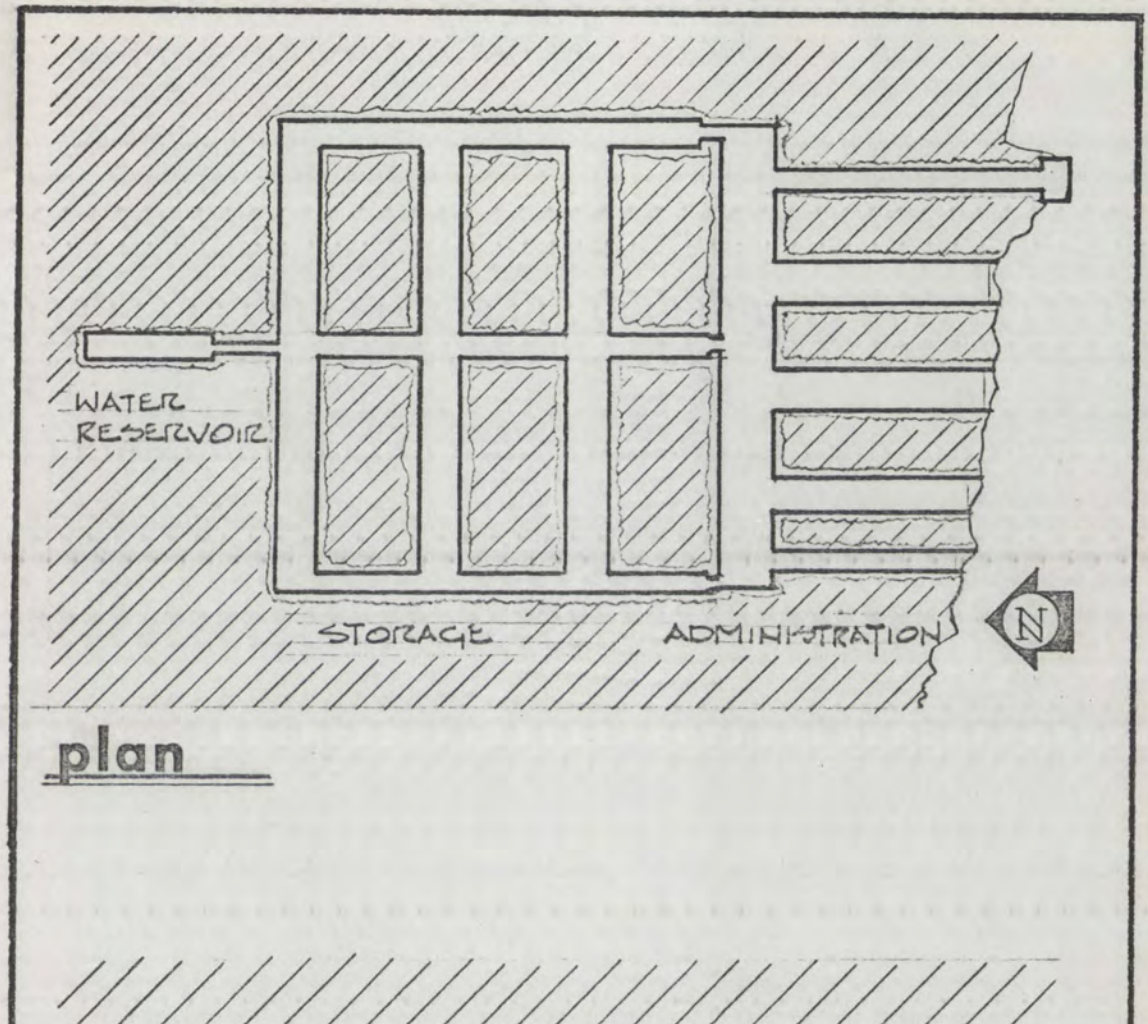


FIGURE 8
GRANITE MOUNTAIN GENEALOGY CENTER[13]

study was made of several sites, and Granite Mountain, Utah was selected as the best one. Using the experience and expertise of the Swedish engineers (who have been placing city utilities underground in solid granite for many years) the Genealogy Center was excavated and built far back inside the mountain. The Center's work is done at the front area, and includes photo and microfilm development, quality central, organizing, and microfilm preparation for storage. Storage is done in the central area. At the near of the center is an underground water reservoir that provides the Center's water supply.

Construction of the Center was begun with exploratory work in 1958. It was completed in 1965. "The protection the vault affords cannot be equalled in an outdoor structure."[14] Concrete encased corrugated steel tubes, a fourteen ton vault door protects, and seven hundred feet of granite covers the workers and records. Perfect conditions for their microfilm storage of 58° F. and 40% relative humidity are maintained year-round regardless of the heat or cold outside the mountain.

The cost of the facility was very low compared to a really incomparable surface structure. The sixty-five thousand square feet of floor space was constructed at a cost of just under two million dollars. This works out to a figure very close to thirty dollars per square foot. In spite of the low cost, the facility offers almost total protection from fire, theft, sabotage, and even nuclear weapons.

Florida Dune Houses

The conservation of a relatively fragile coastline ecosystem prompted William Morgen to place his "dune houses" underground.[15] Placed on the coast of Florida, the units leave the coastal dunes fairly well intact, provide housing, and do not intrude into the natural environment. As a housing

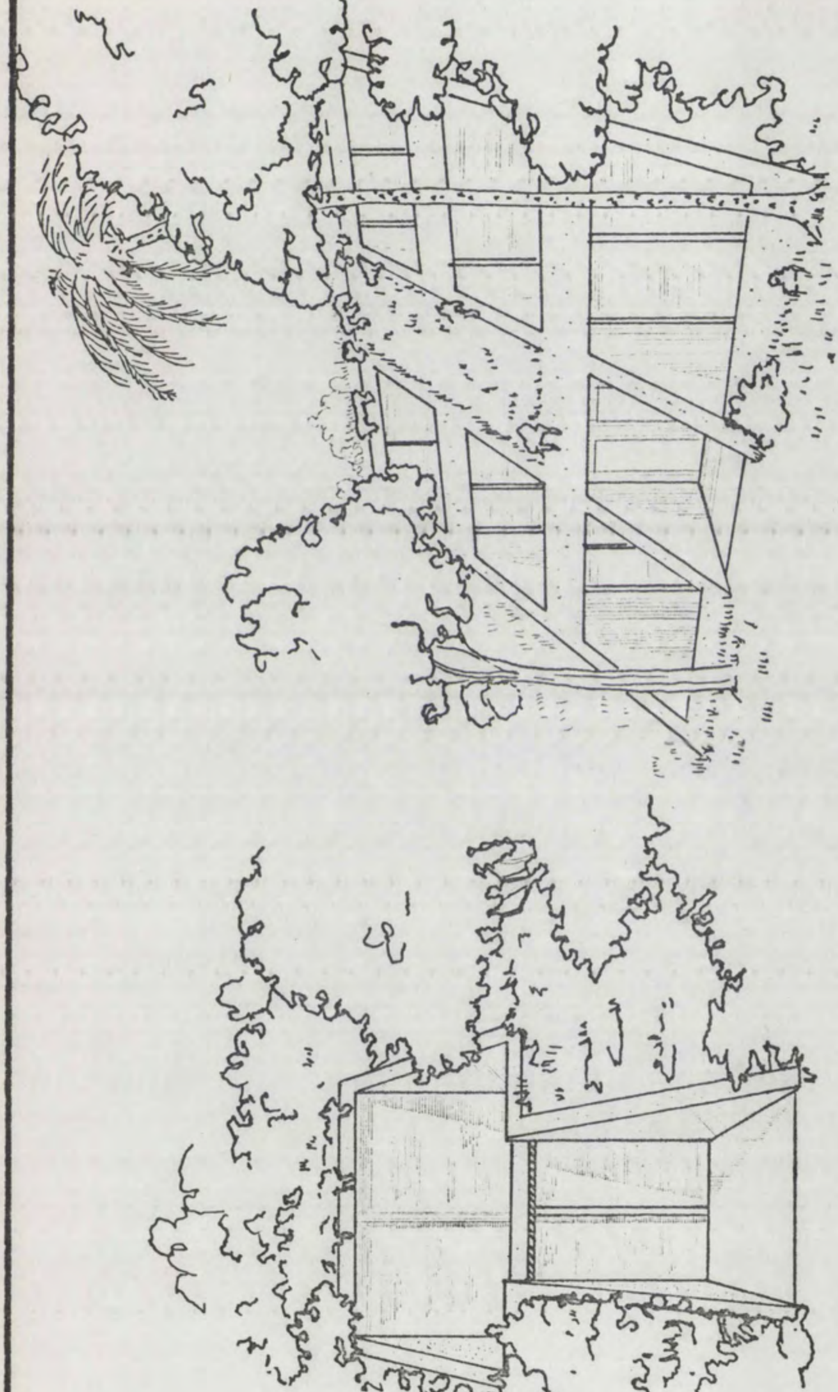


FIGURE 9
FLORIDA DUNE HOUSES[16]

development it is outstanding by the nature of its exemplifying much of what subterranean structures can do and be when designed by the ecologically and aesthetically sensitive architect.

> The houses are entered through a small court incised into the duneside. Bedrooms occupy the upper levels, with the main living space turned outwards toward views of the forest floor.[17]

The units were set into the dunes by tunneling. They were built from reinforced block walls and concrete slabs, and have partitions and decks made from standard wood framing. The units are two and three bedroom duplexes. There is a unit density of seven per acre.

New Mexico Indian Auditorium

A small auditorium in northern New Mexico was placed underground by the architects, Brooks and Orendain.[18] The program was supplied by the Pueblo Indians for a site owned by them. They expressed a desire to have the structure express their cultural roots. The ceremonial kiva of the pueblos gave the perfect linkage to the earthen covering on the auditorium. The large meeting area has a central skylight, a hearth, a traditional perimeter bench, and a depressed seating arrangement. The two main approaches converge diagonally on the platform. The mechanical equipment is roof mounted, but shielded from the severe climate of the region.

New Jersey Architect's Office

A subterranean office facility is the home of Malcom Wells and Associates, Architects.[19] It is an example of well planned underground design. Following Well's philosophy of "gentle architecture," the building is buried under three feet of earth. The earth is intended to eventually support the native vegetation of the New Jersey countryside. The entrance is a recessed

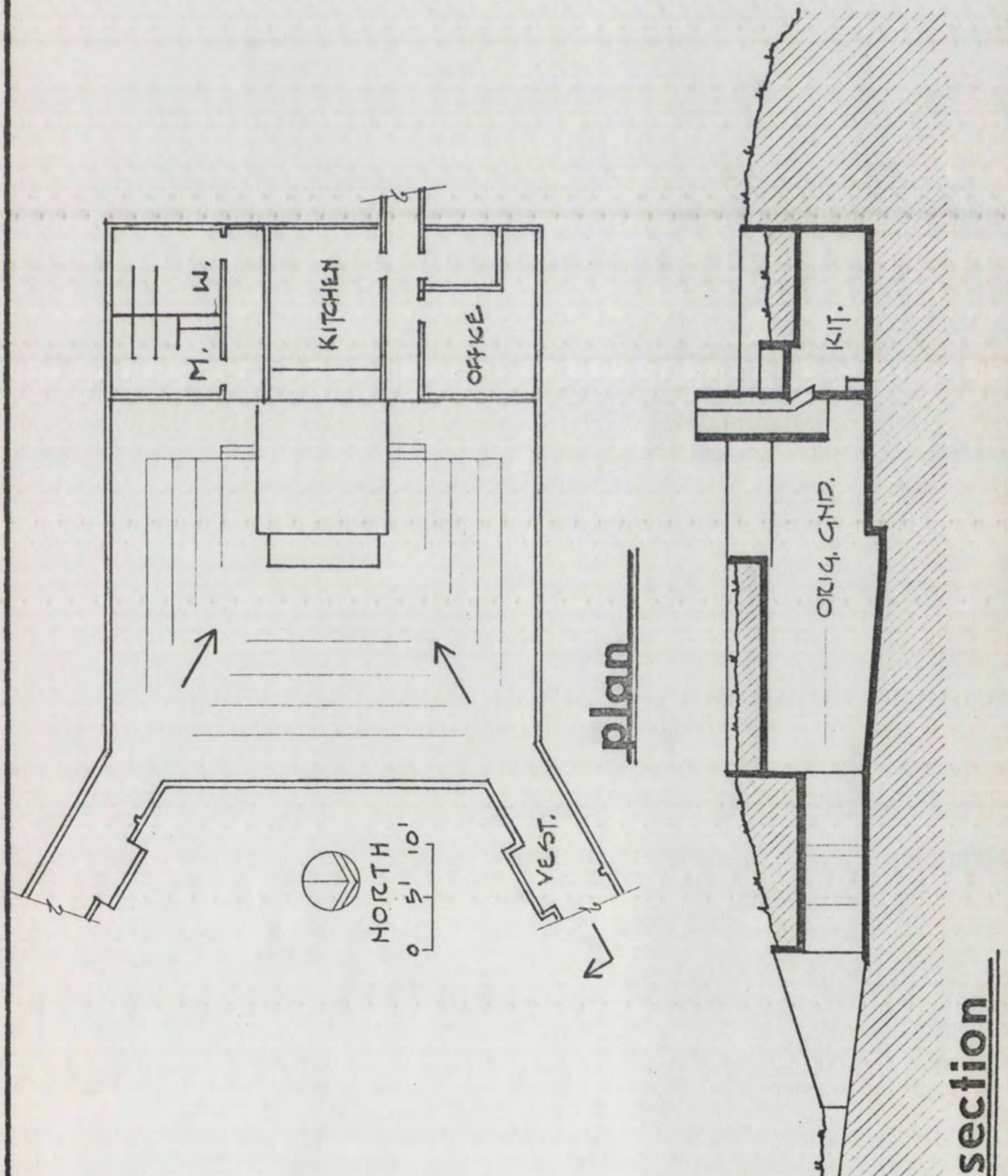


FIGURE 10
NEW MEXICO INDIAN AUDITORIUM[20]

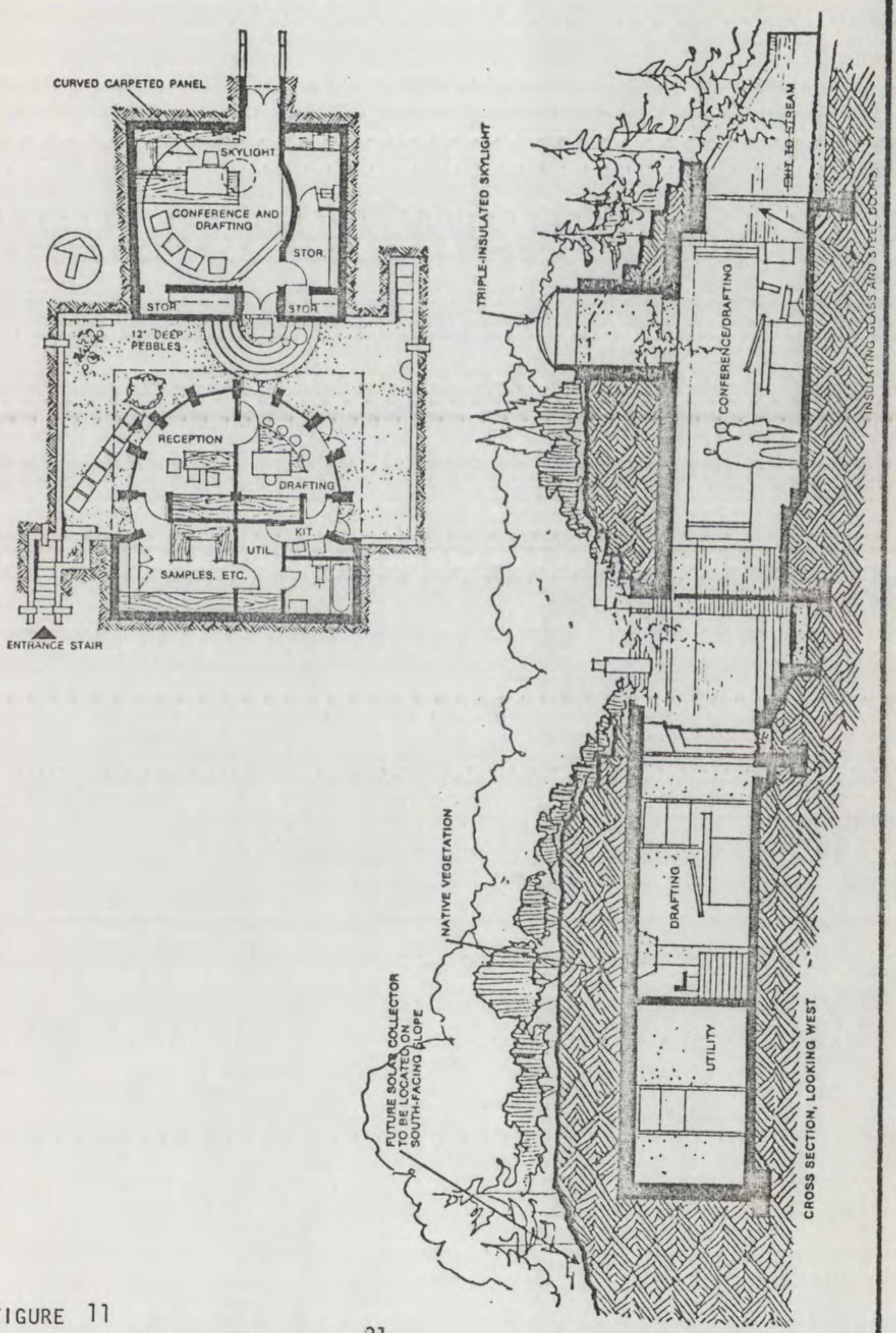


FIGURE 11
NEW JERSEY ARCHITECT'S OFFICE[21]

permeable courtyard of white limestone pebbles. Office functions are not disturbed by the adjacent freeway because of the excellent acoustical absorption of the surrounding earth. Initial cost of construction was increased because of a roof design load of five hundred pounds per square foot.

ABO School

The ABO school in Artesia, New Mexico was built as a study for combined disaster shelter/educational facility.[22] All classes are located below ground with only the concrete slab roof showing above ground. The exposed roof is used as a recreational court for the grade school-age children (See Figures 12 and 13). More direct information such as cost comparisons, educational evaluations, etc., are covered in Appendix IV, V, and VI.

In addition to normal educational equipment, the school has an internal water well, a power generator, radioactive fall-out filter, food, bedding, decontamination units, a sewage ejection system, and medical facilities. All of this raised the cost of the school by about 20% over the cost of a comparable surface facility.

Goddard High School

The largest public fallout shelter in the United States is Goddard High School in Roswell, New Mexico.[23] It has space for 6,500 persons. The design for the school was done by Frank Standhart, the same architect who designed ABO School in Artesia, New Mexico.

The building is windowless, with the air recirculated once per minute. There is an above-ground level section and a below-ground level section, as shown in Figure 14. The surface area houses two gymnasiums, an auditorium, a bandroom, a dining area, and a manual arts facility, for a total of 100,000 square feet. The below-ground area is 86,000 square feet. It contains

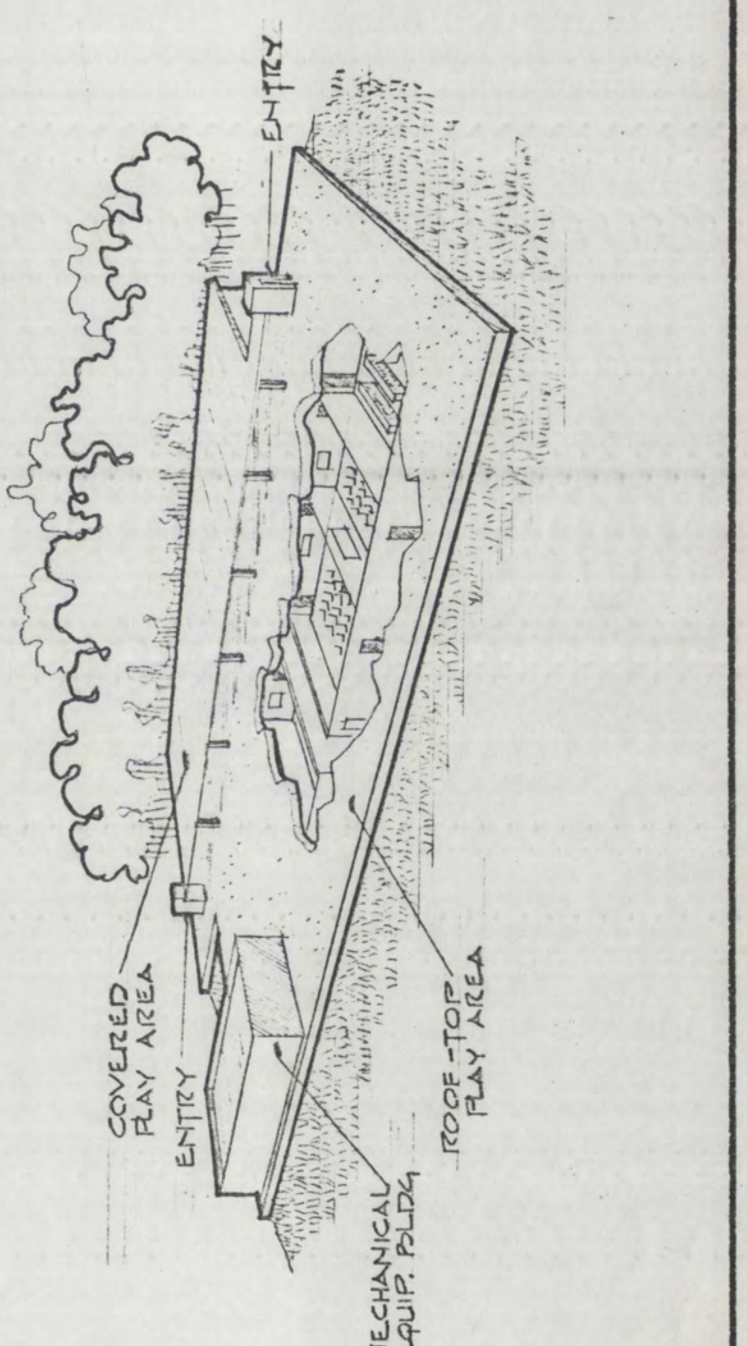


FIGURE 12
ABO SCHOOL[24]

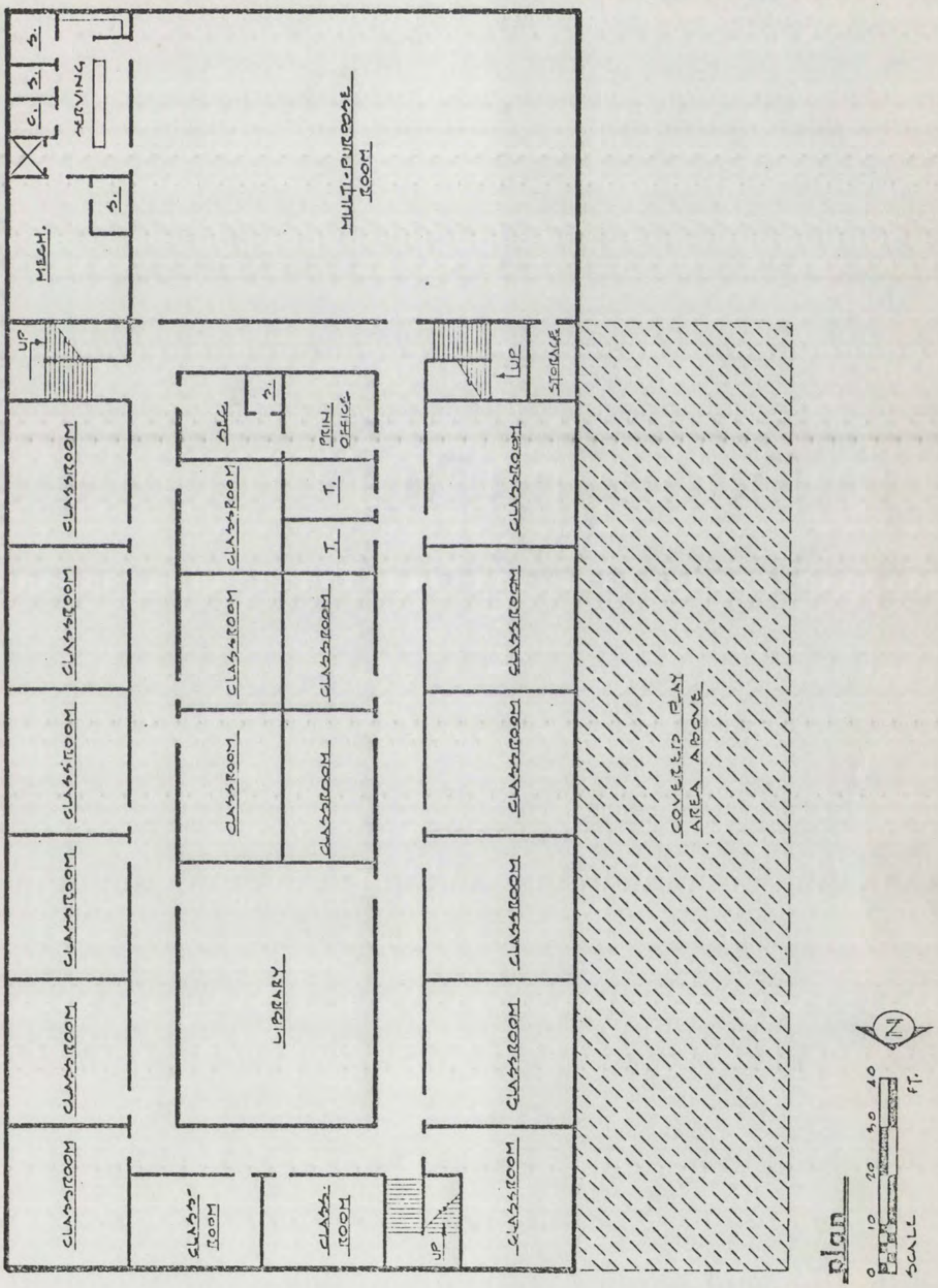


Figure 13
ABO School[25]

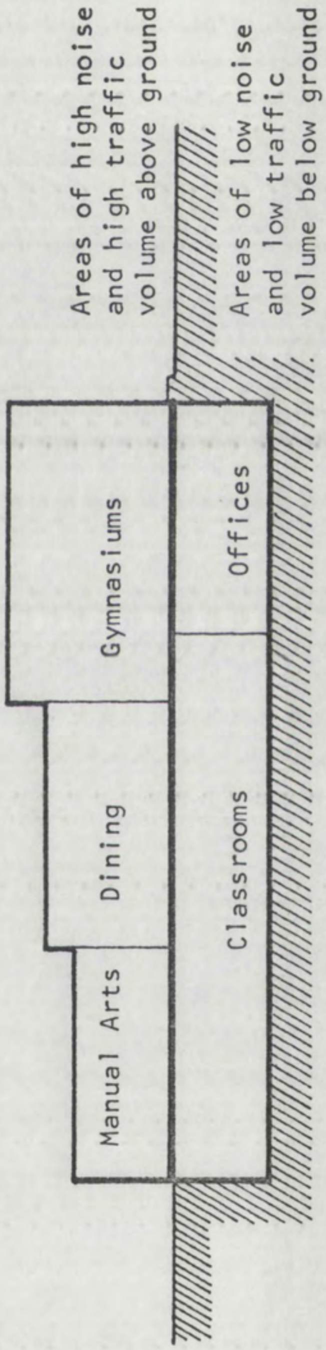


FIGURE 14
GODDARD HIGH SCHOOL[26]

the offices, classrooms, laboratories, and emergency support facilities.

There are two auxillary power generators to supplement service in emergencies. With them all normal lighting and air conditioning can continue. The walls underground are one foot thick reinforced concrete. The above ground walls are 18" thick to provide radiation protection.

The cost of the school was $2.4 million, or $14 per square foot. It was completed in 1966.

"Atomitat"

The use of the atom bomb and the resulting fear of it caused widespread building of atomic bomb shelters during the 1950s. Americans (and other nationalities to a lesser extent) fashioned elaborate "root cellars" in anticipation of atomic attack with the government's and private industries' encouragement (See Appendix 242). The modern versions of the "Ark" began to be transformed into game rooms, bedrooms, and other secondary household spaces as the fear of imminent atomic attack subsided.

There are existing subterranean structures that were built in the early 1960s. They are far more sophisticated than were the early atomic shelters. Although they were descendents of the atomic bomb mentality, they were designed to perform a definite role, and could be used as a very serviceable shelter as well.

One of the first modern subterranean single family dwellings was constructed in Plainview, Texas.[27] The designer and builder, Mr. Jay Swayze, promotes use of the subterranean. He made "Atomitat" the most advanced house of its day. Its cost per square foot was high because it had incorporated into it many of the equipment needs of the modern disaster shelter.

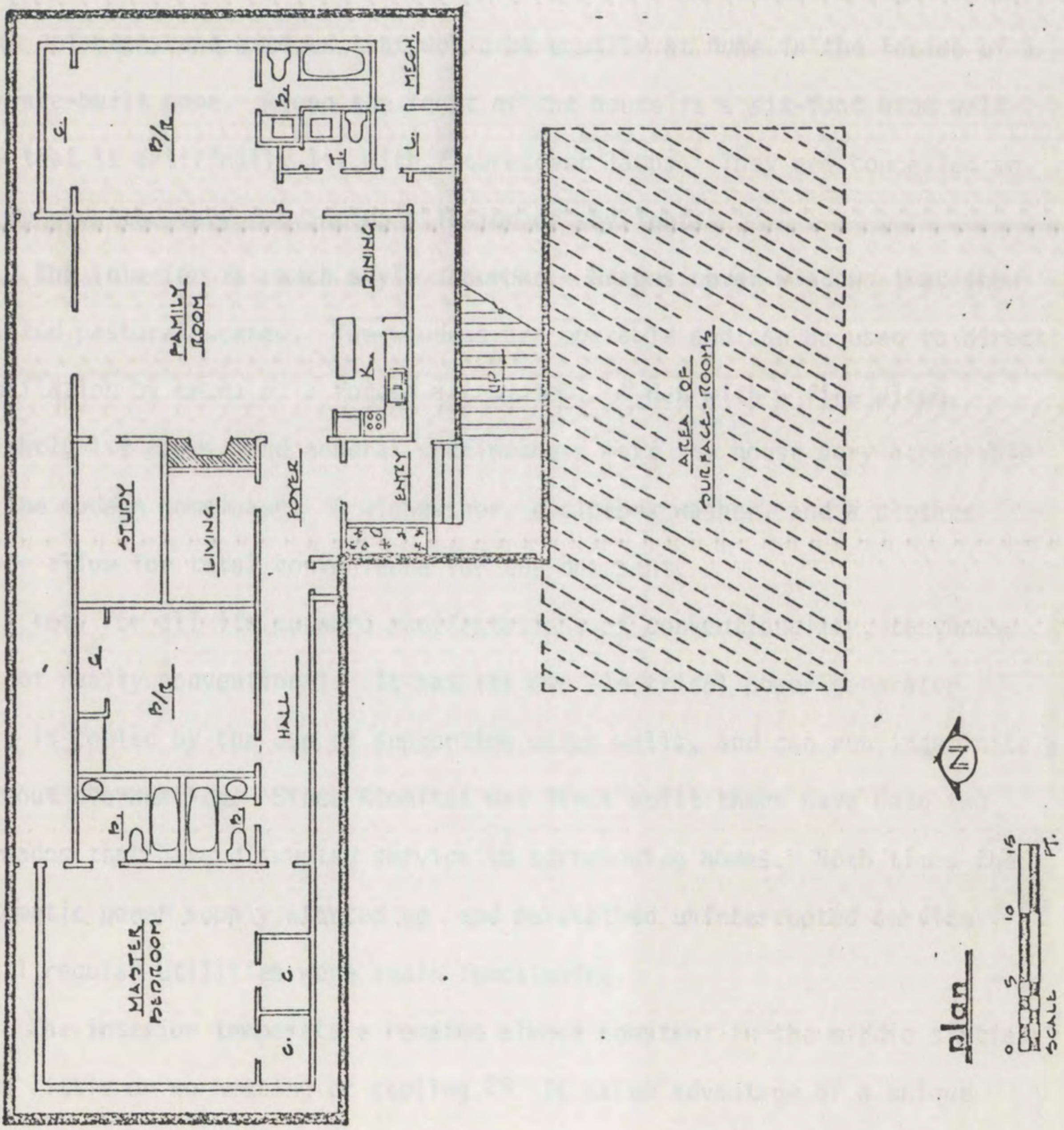


FIGURE 15
"ATOMITAT" 28

The entrance to the house is via a spacious stairwell. It is wide and well-lit to avoid giving a feeling of claustrophobia to someone who is entering the home. One must descend twelve feet below the ground line to reach the floor level. At the front of the house at floor level is a very typical mid-sixties ranch style entry-way. The facade is light brick with planters and windows that would be equally at home in the facade of a surface-built home. Along the front of the house is a six-foot wide walkway that is artifically lit with fluorescent lamps. They are concealed so as to give the very convincing illusion of skylights.

The interior is ranch style suburban. Drapes cover windows that show painted pastoral scenes. The windows are operable and can be used to direct ventilation by means of a forced-air system. A den with a fire place, brightly lit rooms, and general spaciousness make the house very acceptable to the modern homemaker. A dishwasher, a clothes washer, and a clothes dryer allow for total convenience for the occupant.

Yet, for all its outward manifestations of conventionality, the house is not really conventional. It has its own electrical power generator that is cooled by the use of supporting water wells, and can run indefinitely without overheating. Since Atomitat was first built there have been two tornados that have disrupted service to surrounding homes. Both times the automatic power supply started up and maintained uninterrupted service until regular utilities were again functioning.

The interior temperature remains almost constant in the middle sixties, with little or no heating or cooling.[29] It takes advantage of a unique design concept called a double-walled system, which will be explained in greater detail on page 74 . The insulative value of the system is so good that the present occupants of this house feel that the fireplace is generally unusable. It is such a high heat source that the ventilation equipment has to do an undue amount of work, just to cool the house when the fireplace is in use.

FOOTNOTES

1. Royce La Nier, "Geotecture, Subterranean Accomodation and the Architectural Potential of Earthworks" (unpublished Master of Science thesis, Notre Dame University, 1970), p. 5.

2. Kenneth Labs, "Architectural Use of the Underground" (unpublished Master of Science thesis, Washington University, 1975), p. 17.

3. Truman Stauffer, "Underground Space, Kansas City's 3rd Dimension" (paper read at Symposium on Underground Space Use, March, 1975, Kansas City, Missouri).

4. *Ibid.*

5. *Ibid.*

6. *Ibid.*

7. *Ibid.*

8. Opinion expressed by Abner Brunson, Personal interview, March 5, 1975.

9. *Ibid.*

10. *Ibid.*

11. Stauffer, *op. cit.*

12. "Records Protection in an Uncertain World" (publication by the Church of Jesus Christ of Latter-day Saints, Salt Lake City, Utah).

13. *Ibid.*

14. *Ibid.*

15. James. W. Scalise, Earth Integrated Architecture (Tempe, Arizona: University of Arizona Press, 1975), p. G-13.

16. Scalise, *loc. cit.*

17. Labs, *op. cit.*, p. 18.

18. Labs, *op. cit.*, p. 117.

19. Malcom B. Wells, "An Underground Office," Progressive Architecture, June, 1974, p. 112.

20. Labs, op. cit.

21. Wells, op. cit.

22. "ABO Elementary School and Fall-out Shelter," (publication by Artesia Public School District, Artesia, New Mexico, 1966).

23. The Herald Tribune (Sarasota, Florida), January 17, 1966, p. 1, col. 3.

24. "ABO Elementary School and Fall-out Shelter," op cit.

25. Ibid.

26. Opinion expressed by Richard Bach, personal interview, January 8, 1975.

27. Opinion expressed by Jay Swayze, personal interview, November 10, 1974.

28. Ibid.

29. Opinion expressed by William B. Hammond, personal interview, December 16, 1974.

TERMINOLOGY AND DEFINITIONS

TERMINOLOGY AND DEFINITIONS

The comparative newness of subterranean design in the U.S. is part of the reason that there is a general lack of awareness of subterranean terminology and definitions. Advocates of subterranean construction have been creating and submitting terms, classifications, and divisions to enhance a commonality of usage among architects, designers and builders.

The following is an abbreviated list to acquaint the reader with some of the varieties of subterranean spaces and uses.

Geotecture is the concept of subterranean construction that provides for a variety of purposes, thereby reducing the conflict of demands upon the Earth's services, and in order to achieve economy in energy requirements.[1]

The classifications of subterranean construction are:

Terra space: (earth-type) Underground space developed as a basement or in the immediate sub-surface, not geologically separated from the surface, or space developed from the surface by excavation.[2]

Lithospace: (rock-type) Underground space developed in geologic strata and geologically separated from the earth surface that is developed by mining.

Geospace: (geodial-type) Underground space developed or occurring naturally which exists as a cavernous chamber suitable for use in the storage of fluids, semi-fluids, or gases.

Surficial: Underground space that is created by molding or reshaping the surface in any fashion which does not prohibit visual contact with the surrounding land. Includes subdivisions of molding, carving, and berming.[3]

Recessed: Underground space of any form that penetrates into vertical or steeply graded surface. There is no limitation to depth of penetration so long as visual contact with the horizon remains uninterrupted. Includes subdivisions of tunnels, galleries, and chambers.

Subterranean: Underground space that implies complete enclosure or isolation from view of the horizon. Includes open excavations, chambers and tunnels.

Most design situations will involve the terra space type of enclosure because of the rather uncommon occurrence of lithospatial or geospatial uses. Within the area of terra space, one will find three basic styles of construction and design; 1 cut and fill, 2 matching of existing grade, and 3 adaptation to terrain.[4]

The "cut and fill" style is the most easily introduced and constructed style of underground structure. It can be almost entirely above the level of the ground, but because of the earth that is bermed against its sides and placed over it, it is considered to be underground.

When the "matching of existing grade" style is used, the top of the structure is not above the level of the surrounding ground line. This type of subterranean structure will necessarily involve the most excavation, and possibly be the most expensive of any of the three styles.

The third and final terraspatial style of construction is that known as "adaptation to terrain." In this type of design the slope of the Earth

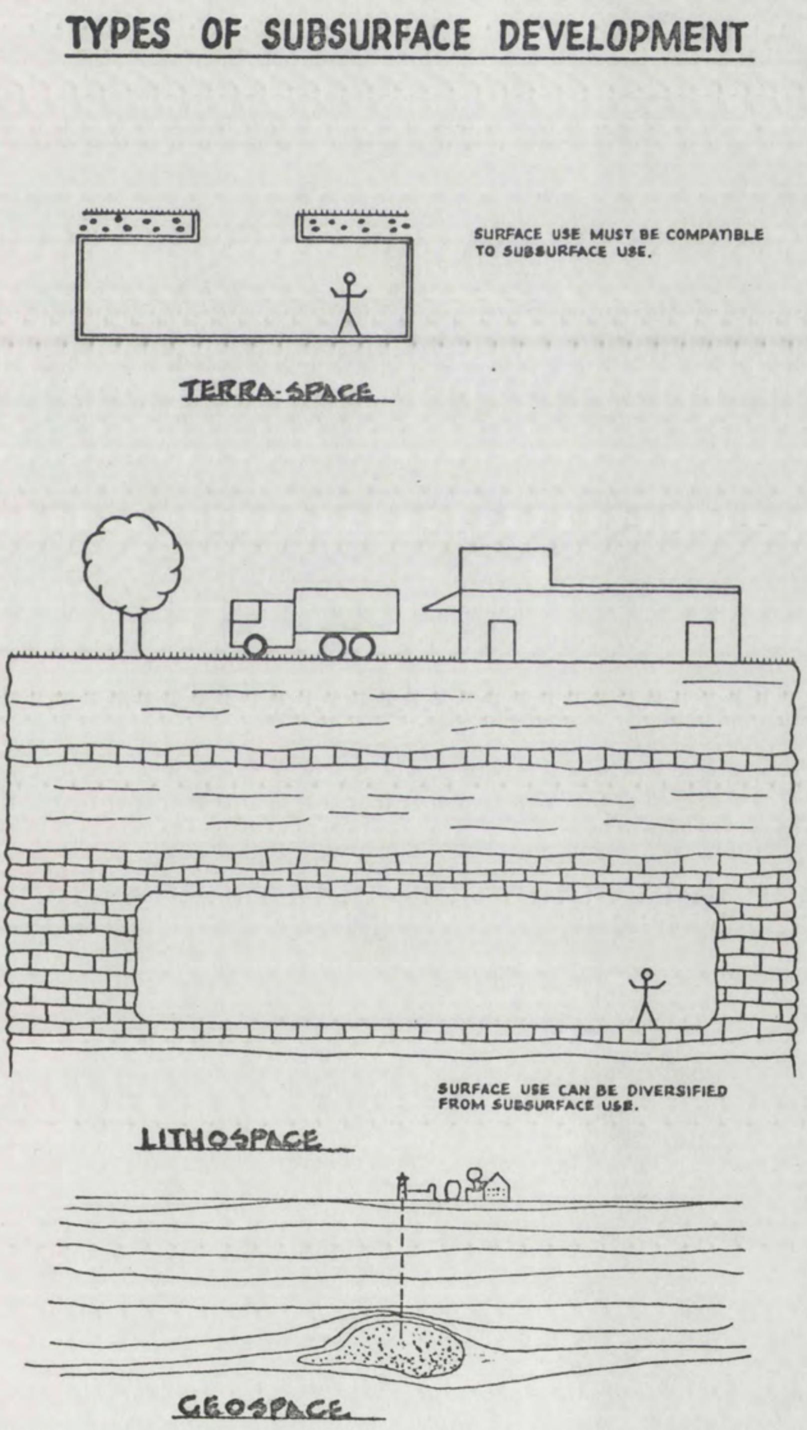


FIGURE 16
SUBSURFACE TYPES[5]

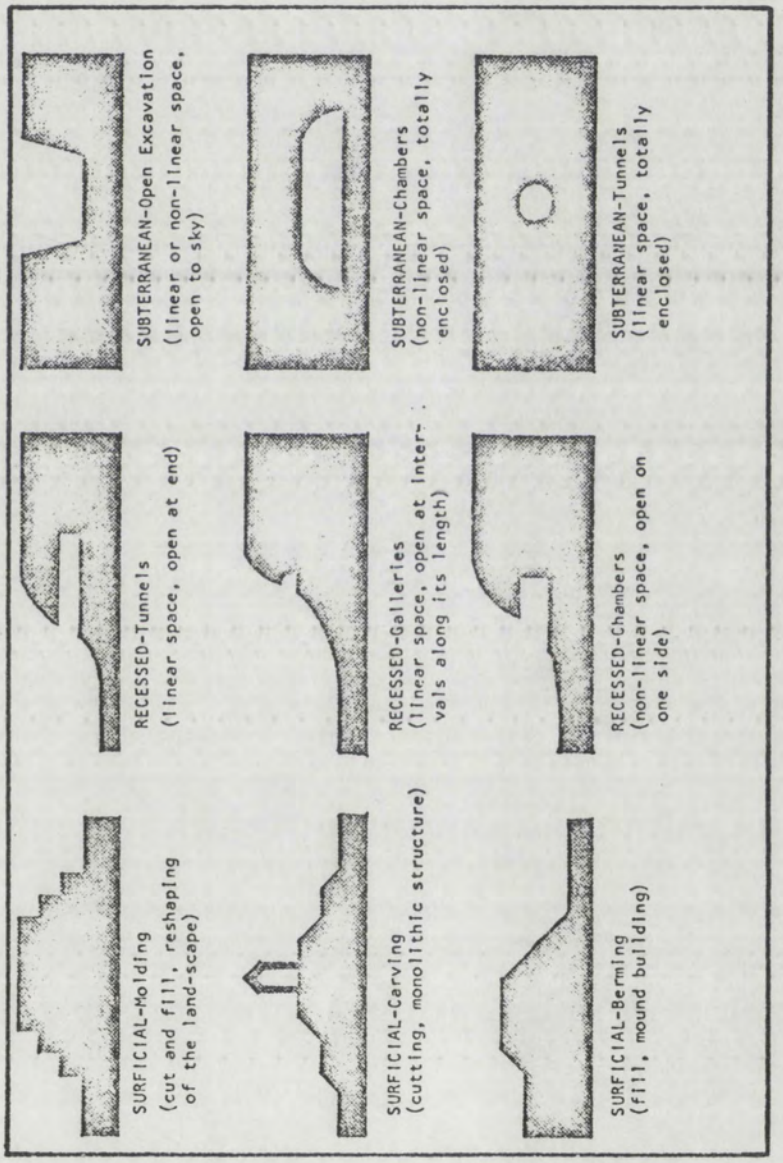
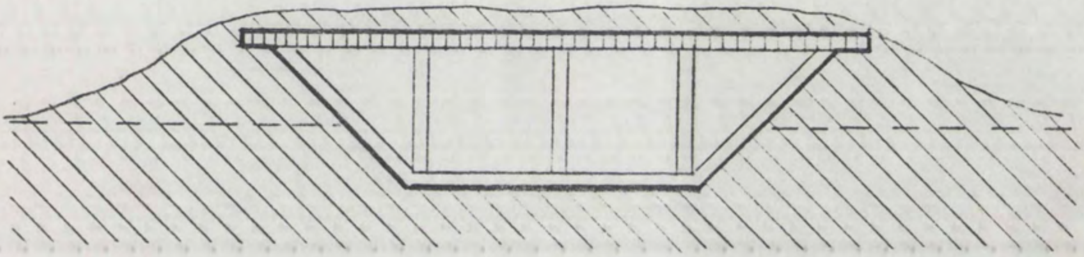
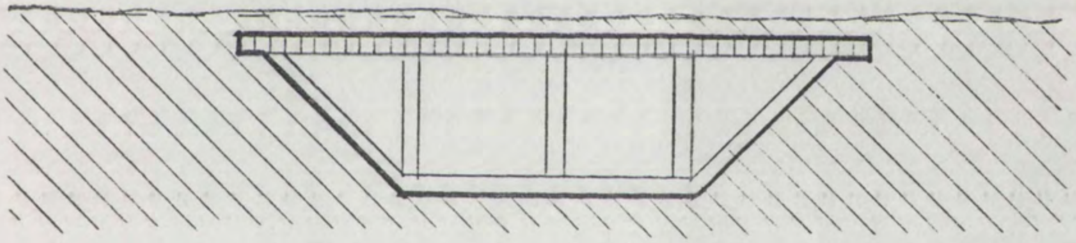


FIGURE 17
FORM SURFACE CLASSIFICATIONS[6]

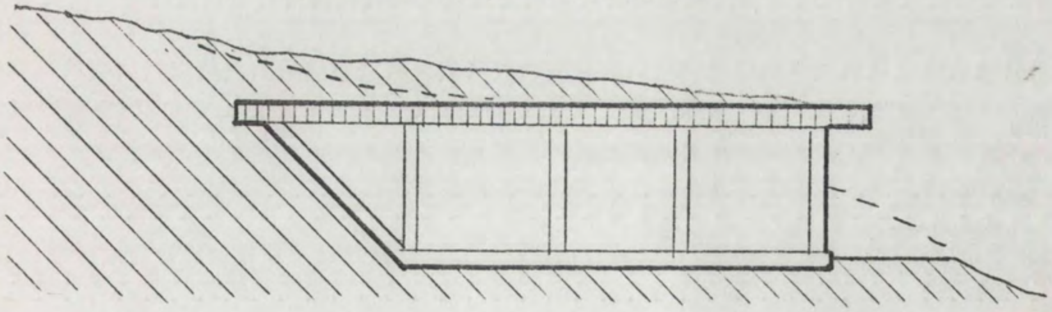
is used to both enclose the structure, and to allow openings in the structure and the surrounding Earth to let in natural light and ventilation. This style may, in the long run, become the most common type of subterranean structure because of its relative ease of construction and compatibility with the more common surface design styles.



CUT AND FILL



MATCHING OF EXISTING GRADE



ADAPTATION TO TERRAIN

FIGURE 18
SUBTERRANEAN CONSTRUCTION STYLES[7]

FOOTNOTES

1. Patrick Horsbrugh, "Urban Geotecture: The Invisible Features of the Urban Profile" (paper read at conference on Alternatives in Energy Conservation, The Use of Earth-Covered Buildings, July, 1975, Fort Worth, Texas).

2. Stauffer, op. cit.

3. La Nier, op. cit., p. 20.

4. Gunnar Birketts, "Liberating Land," Progressive Architecture, March, 1973, p. 78.

5. Stauffer, op. cit.

6. Lanier, op. cit., p. 21.

7. Ibid.

FUNCTIONAL CLASSIFICATIONS

FUNCTIONAL CLASSIFICATIONS

Just as there are functional classifications of spaces on the Earth's surface, there are also functional classifications of spaces below the surface. Because of the comparative rareness of subterranean use in the contemporary design, some of the categories are speculative rather than proven. Others are tried and true forms of subterranean use that have examples that can be visited and evaluated by interested persons.

In the previous section the spatial classifications were generally clear-cut, but in the functional classifications the divisions may not be quite so definite, or they may cross over slightly. The divisions are in some cases arbitrary, and may encompass more than their title implies. In cases such as that, the division may someday be subdivided to make the list of classifications more accurate for purposes of functional identification. Presently the divisions are: 1, agricultural; 2, defensive; 3, industrial; 4, urban services; 5, public facilities; 6, educational and recreational; and 7, aesthetic.

Agricultural

Agricultural uses of the subterranean have scarcely been explored. Most attempts at underground agriculture have been made in abandoned mines and have essentially been for growing plant species that require little or no light for development, such as mushrooms. One proponent of subterranean living, Jay Swayze, foresees the day when subsurface agriculture might be the rule rather than the exception.[1] He bases his judgments on several facts. Technology and agriculture go hand in hand. Use of the subterranean might allow food crops to be grown year-round. Twenty-four-hour growing days that were not dependent upon weather cycles would allow crops to develop regardless of the season. This might pay for itself, for foodstuffs would not have to be stored for extensive periods of time. There would be no more shortages in the winter and overabundance during the summer. The crops would be at all stages of development at any one time because of total climate control.

Crops that provide food for humans usually base their life cycle on the hours of daylight. The question of the expense of lighting such systems might easily be solved through use of light transmitting tubes bundled together and supplemented by artificial plant growing light. This year-round growth capability would mean that there would seldom, if ever, be any usable subterranean farm land lying unused and waiting for the proper growing season, as is now common with surface agricultural land.

Another advantage of subterranean agriculture is that crops would grow to optimum size and yield. This would be easily accomplished because the perfect growing season and conditions could be established for each plant type, regardless of its normal geographical boundaries. There would be no climatic damage to subterranean grown crops as now happens to surface crops. This in itself might allow the cost of subterranean agriculture to be negligible after a cost recovery period.

Crops grown beneath the Earth's surface would need far less irrigation than is needed by surface grown crops. Humidity control would help also. High yield crops that are now so very vulnerable to parasites would be much safer in the closed ecosystem of the subterranean farm. Even when parasites were found, the subterranean concept would aid in their control at a much more basic stage than today's surface technology can accomplish. The chance for parasitic growth would be minimal in the closed system of the subterranean farm.

Some of the Earth's once most highly productive agricultural lands have been used to the state where they are only marginal producers today. They have been over-used, and salt from massive irrigation has created alkaline earth of slight value. Nitrates have to be replaced by rain, bacterial action, or by plants that return nitrogen to the soil in a process called "the nitrogeon cycle."[2] In subterranean farming the soil nutrients could be naturally replaced at anytime.

The future of subterranean agriculture may be one of continued expansion. Climate control will provide high growth rates, and the closed ecosystem could make fantastically high yields for today become just average tomorrow.

Defensive

The defensive function is the most widespread of all subterranean concepts.[3] The defense forces of France constructed the Maginot Line after the Treaty of Versailles in 1919. The Treaty had given the Alsace-Lorraine provinces to France, and the line was built to defend them.

Peace slowed construction of the line, but the Nazi rise to power stimulated further growth. There were complexes that could accomodate 1,200 men each. Gunners, observers, reconnaisance personnel, and supplies were housed in adjacent subterranean facilities. The Line had command post, hospitals, barracks, kitchens, ventilation plants, generators, and ammunition magazines, all in underground areas. Some were as far as a hundred feet below the surface. There was a narrow gauge rail line entirely underground that connected the lines of supply to the front lines.

The impressiveness and apparently unassailable defenses of the Maginot Line inspired Switzerland to build many subterranean fortresses--Jargans Gotthard in Saint Maurice. They are still in use as part of the Swiss defensive systems. Czechoslovakia and Germany built similar underground systems. The most famous of the German defenses was the Ziegfried Line along the Rhine River.

Problems were encountered in these subterranean facilities and were never solved very satisfactorily. Most had a positive pressure ventilation system. It created a hurricane-like roar and made voice communication impossible. Condensation was a constant enemy. Only by turning on the heating system to its full power could the condensation be removed and the walls dried. The cure was sometimes worse than the disease because the heat could be endured only for short periods of time. Sanitary arrangements were never adequate. Septic tanks located internally were a constant source of irritation from their foul odors, blockage of drains, and overflows. Two novels that tell of life in the underground defense system are The Mare's Nest and The Great Wall of France. Defense against tornados, high winds, and other natural disasters have prompted construction of underground shelter.

Storm shelters have long been in use in areas where tornados or high winds are common, and result in extensive loss of life and property.[4] They have generally served two functions. First, they were for safety from the storm. Secondly, they served as storage for foodstuffs. For many years the potato bin or root cellar has taken advantage of the Earth's natural coolness to extend the useful life of that tuber.

Industrial

It is perhaps in the field of light industry that the advantages of locating underground have been most accepted.[5] Normally sited in mined space such as that below Kansas City or near Krakow, Poland, industry is finding the low cost of leasing, stability of conditions, safety of operation, and security to be factors that frequently cannot be equalled on the surface.

At Gibbstown, New Jersey, DuPont Industries has a 20,000 static ton capacity underground storage area for ammonia. It is situated on the flight path to the local airport where a surface storage area for ammonia would be a major safety hazard.

In Wampum, Pennsylvania there is an 18,000 square foot research laboratory built underground. It takes advantage of the year-round subterranean temperature of 54^{o} in its precision construction work. Cost of the laboratory's construction was less than half what it would have cost on the surface. Heating requirements are half as great. Also, there is virtually no vibration from heavy floor loads.

Urban Services

Urban services have been located underground since the time of Rome.[6] The linear tunnel is the most common form of providing underground access between two points. Storm water tunnels and transportation tunnels are highly developed in most major cities. Highways and rail lines often go underground to allow passage through a mountain, instead of around it, or to go under a river instead of over it. Subway systems help to alleviate some of the over-crowding on urban streets and highways. Telephone and electrical lines no longer create the unsightly mess that they did twenty years ago. This is because they have been relocated in subterranean tunnels.

Public parking for private vehicles has gone high-rise, and it has gone underground. In downtown Stockholm, a thousand foot long tunnel provides parking space for five hundred and fifty cars. Manhattan has several underground municipal parking areas as do Chicago and Dallas. Hotels and college dormitories also provide parking underground to conserve surface space.

Public Facilities

Most examples of public facilities that are located underground are there because of a lack of available surface areas. In Springfield, Illinois this, plus an additional consideration prompted the municipal parking to be subterranean.[7] The preservation of the historic Illinois State Capitol Building forced a decision to locate parking below grade. The Capitol Building was disassembled in 1965. Upon completion of the construction of the underground parking area, the capitol was reassembled. Finished in 1965, the procedure had provided much needed parking underground while the surface was left free to serve the historic nature of the site.

Recreational/Educational

There are several schools in the southwestern United States that have helped to prove that underground schools can be a very satisfactory choice (for that hot dry area). Goddard High School in Roswell, New Mexico has its classroom facilities located underground and seems to be generally satisfactory to the students and the faculty. Artesia, New Mexico has a junior high school and the previously-mentioned ABO grade school built beneath the Earth's surface.

Lake Worth Junior High School near Fort Worth, Texas is built underground.[8] It was at one time located on the surface. Unfortunately the surface was right under the approach path to Carswell Air Force Base. The significant loss in teaching time due to aircraft noise prompted architect, Thad Harden, to look to the field of "geotecture" to provide a solution.

It did. The structure is two stories deep and is completely soundproof. "The school....looks best from the air. SAC pilots see only a neatly landscaped plot, beneath which 475 students peacefully study, full time."[9]

Aesthetics

A subterranean promotion of aesthetics is exemplified by a class building located on the University of New Mexico campus.[10] Designed by Pacheco and Graham, Architects, the building is absolutely unimposing. Flanked on both sides by rather large buildings, this building of significant size almost disappears into the earth. Had it been designed and built as a surface structure, the area would have been congested and out of harmony with the open and spacious campus. Because it is underground, it can offer space for education and still allows space for students to easily move through the area.

The surface deck is so unintruding that many students are unaware of the building, and believe it to be a courtyard. Figures 19 and 20 show how the structure is situated and its general relationship to its locale. Figure 21 is the program concept that tells how the architects justified their decision to place a portion of the building underground.

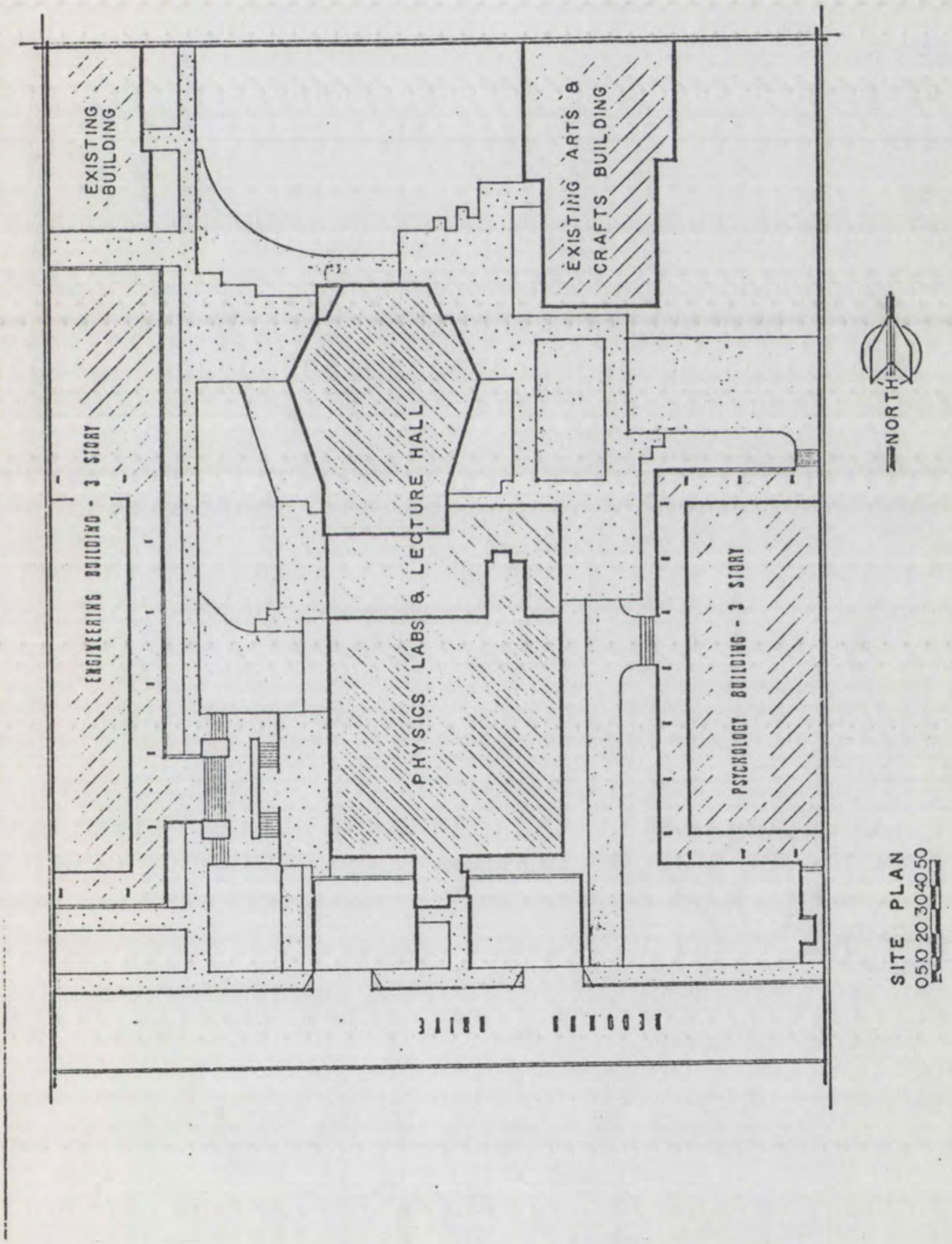


FIGURE 19
PHYSICS BUILDING SITE PLAN[11]

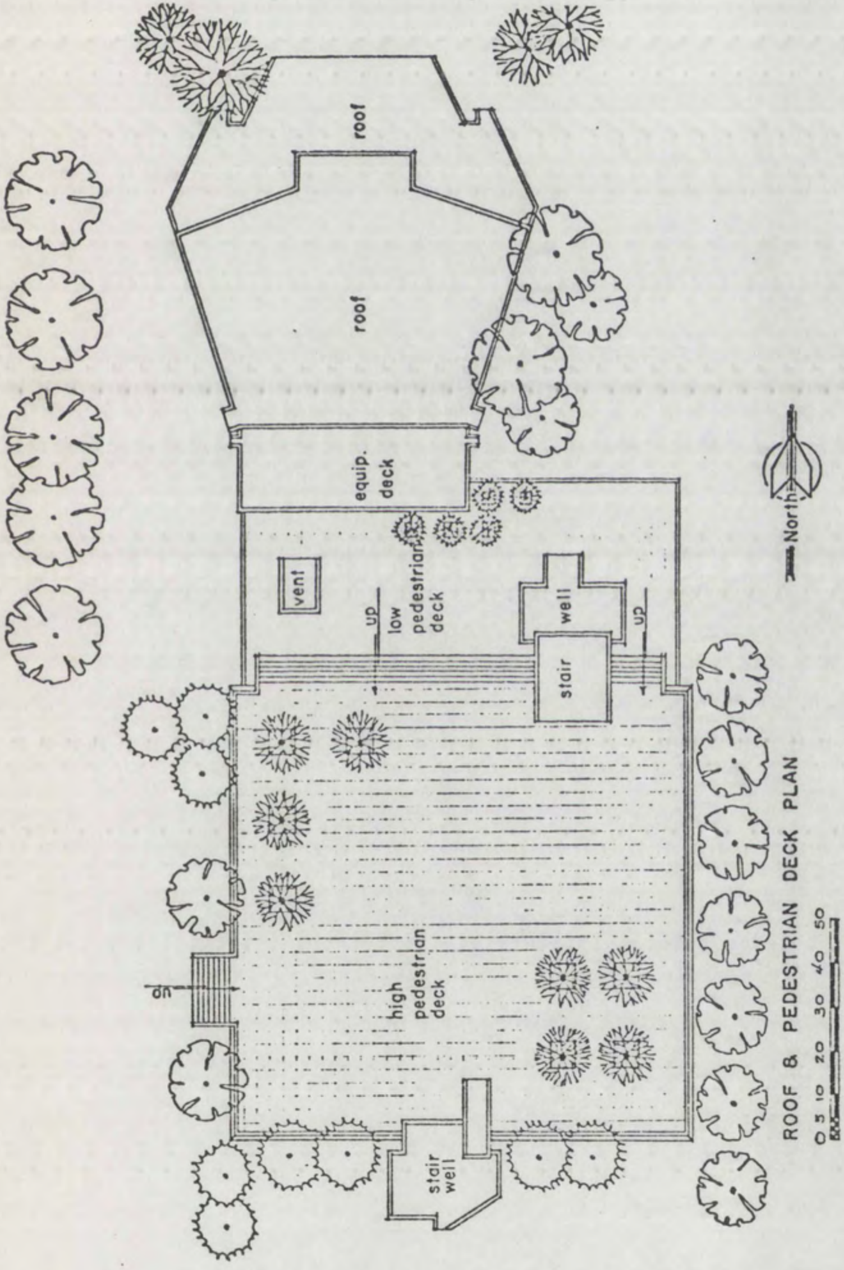


FIGURE 20
PHYSICS BUILDING ROOF AND DECK PLAN[12]

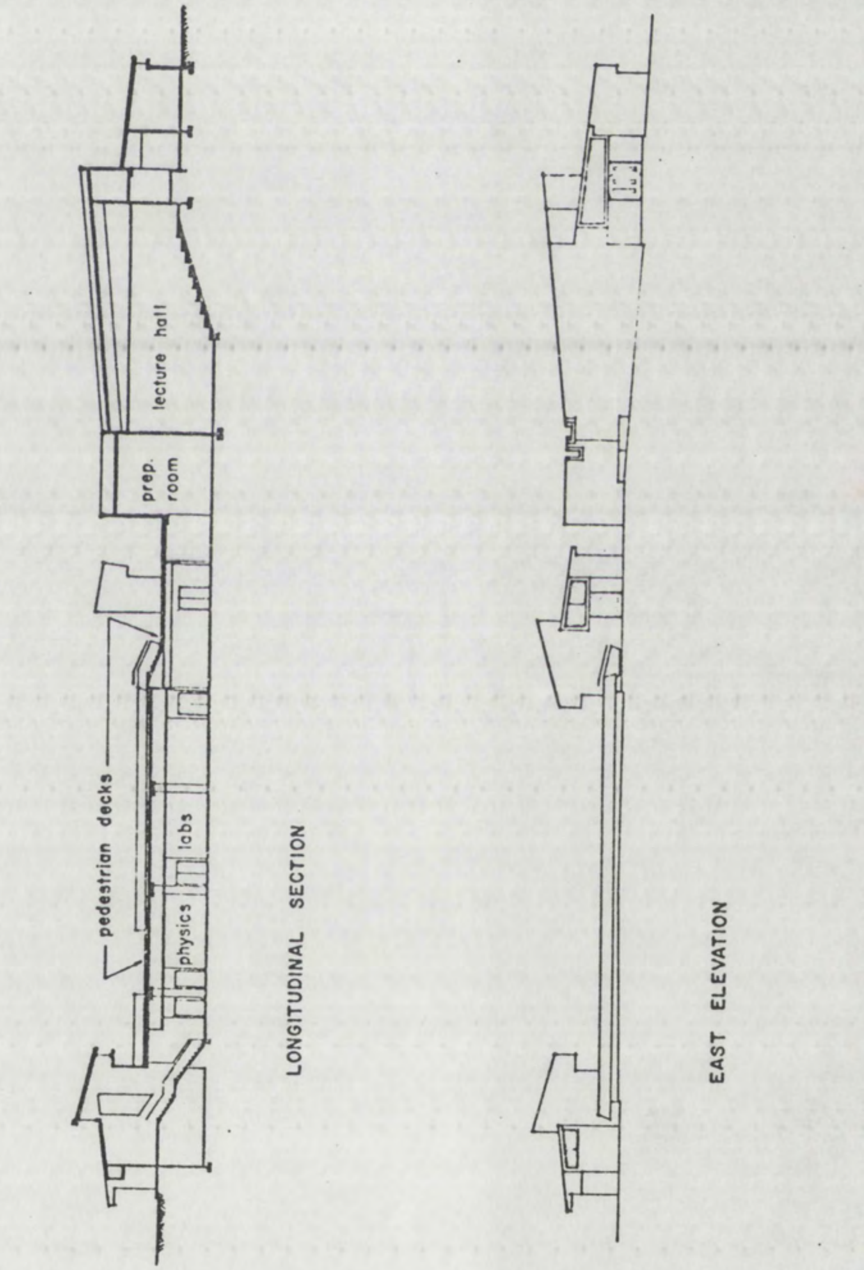
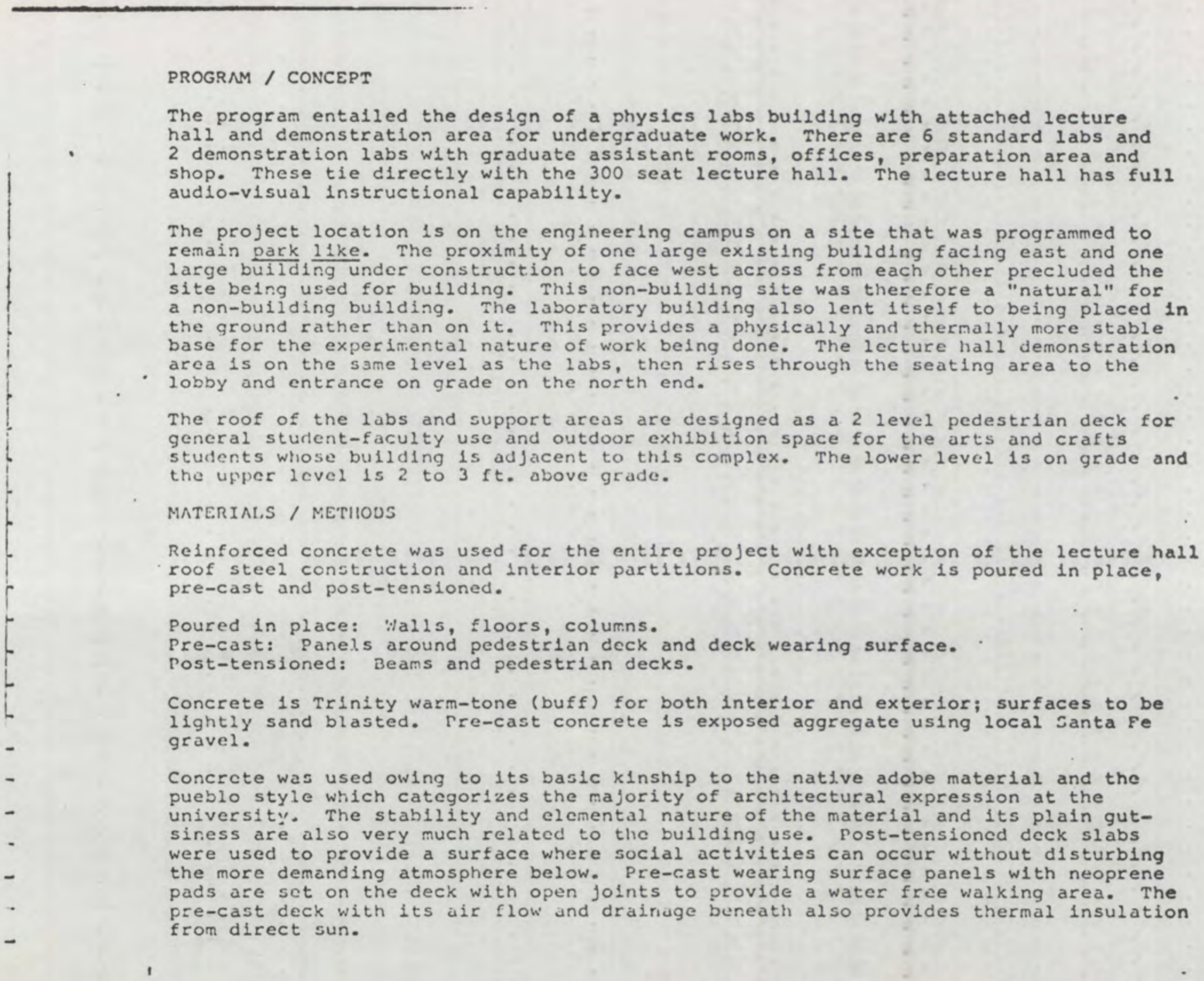


FIGURE 21
PHYSICS BUILDING SECTION AND ELEVATION[13]



PROGRAM / CONCEPT

The program entailed the design of a physics labs building with attached lecture hall and demonstration area for undergraduate work. There are 6 standard labs and 2 demonstration labs with graduate assistant rooms, offices, preparation area and shop. These tie directly with the 300 seat lecture hall. The lecture hall has full audio-visual instructional capability.

The project location is on the engineering campus on a site that was programmed to remain park like. The proximity of one large existing building facing east and one large building under construction to face west across from each other precluded the site being used for building. This non-building site was therefore a "natural" for a non-building building. The laboratory building also lent itself to being placed in the ground rather than on it. This provides a physically and thermally more stable base for the experimental nature of work being done. The lecture hall demonstration area is on the same level as the labs, then rises through the seating area to the lobby and entrance on grade on the north end.

The roof of the labs and support areas are designed as a 2 level pedestrian deck for general student-faculty use and outdoor exhibition space for the arts and crafts students whose building is adjacent to this complex. The lower level is on grade and the upper level is 2 to 3 ft. above grade.

MATERIALS / METHODS

Reinforced concrete was used for the entire project with exception of the lecture hall roof steel construction and interior partitions. Concrete work is poured in place, pre-cast and post-tensioned.

Poured in place: Walls, floors, columns.
Pre-cast: Panels around pedestrian deck and deck wearing surface.
Post-tensioned: Beams and pedestrian decks.

Concrete is Trinity warm-tone (buff) for both interior and exterior; surfaces to be lightly sand blasted. Pre-cast concrete is exposed aggregate using local Santa Fe gravel.

Concrete was used owing to its basic kinship to the native adobe material and the pueblo style which categorizes the majority of architectural expression at the university. The stability and elemental nature of the material and its plain gutsiness are also very much related to the building use. Post-tensioned deck slabs were used to provide a surface where social activities can occur without disturbing the more demanding atmosphere below. Pre-cast wearing surface panels with neoprene pads are set on the deck with open joints to provide a water free walking area. The pre-cast deck with its air flow and drainage beneath also provides thermal insulation from direct sun.

FIGURE 22
PHYSICS BUILDING PROGRAM[14]

FOOTNOTES

1. Opinion expressed by Jay Swayze, personal interview, November 10, 1974.

2. Wilfred W. Robbins, T. Elliot Weir, and C. Ralph Stocking, Botany, An Introduction to Plant Science (New York: John Wiley and Sons, 1960), p. 56.

3. La Nier, "Geotecture, Subterranean Accomodation and the Architectural Potential of Earthworks" (unpublished Master of Science thesis, Notre Dame University, 1970), p. 27.

4. Michele G. Melaragn, "Tornado Forces and Their Effects on Buildings" (Kansas State University, 1968).

5. La Nier, op. cit., p. 36.

6. La Nier, op. cit., p. 34.

7. Ibid., p. 38.

8.

9. "New Digs; Lake Worth Junior High School," Time, February 5, 1965, p. 62.

10. Opinion expressed by Van Dorn Hooker, personal interview, March 19, 1975.

11. Promotional Literature from Pacheco and Graham.

12. Ibid.

13. Ibid.

14. Ibid.

CONCEPTUAL THEORIES

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CONCEPTUAL THEORIES

Subterranean architecture is an area of study by architects and other design professionals who seem to feel that the task of providing a livable environment should not be limited only to surface-built design. It is therefore proper that the basic concept of underground living is branching out into theoretical areas of advocacy, most of which are not at odds with one another. They are instead areas of support into which each proponent puts his concentration of energy.

Structural Permanence

One of the proponents of the concept of structural permanence is Malcomb Wells, A Cherry Hill, New Jersey architect.[1] His advocacy is based on the feeling that if one must "rape" the landscape, then it is best to do it only once, and then allow the natural cycle of replacement to begin as quickly as possible. One should perpetuate a sound environment for living (not just for humans, but for animal and plant life also). Wells assumes that only by building for the long-term use can more persons benefit by the increase of a natural environment. When a person designs, builds or moves into a country home set in the woods, and surrounded by wildlife, he may feel proud of his contribution to an ecological renaissance, yet he should also feel guilt about what he has not done.

> The man who pays the greatest price for all my ecological mistakes is the guy I'd be leaving behind; the blue collar worker, the black man, the Indian, or the Chicano. He can't build that woodland highway with its lush organic garden. He'd have to stay behind, and breath the worst of air, drink the worst of the water, eat the worst of the food, and live in the meanest of houses because I, who could afford to escape, refused to offer the job or friendship he needed to leave the city.[2]

The permanent concept of construction for subterranean structures as advocated by Wells would open up large areas of surface for the enjoyment of the general population. Through proper planning, subterranean construction would require a much lower rate of repair and replacement than would similar surface facilities.[3] A worthy note is that the subterranean house in Plainview is fifteen years old; it has never been repainted, and does not appear to need to be painted within the forseeable future. (See page 33 for details.)

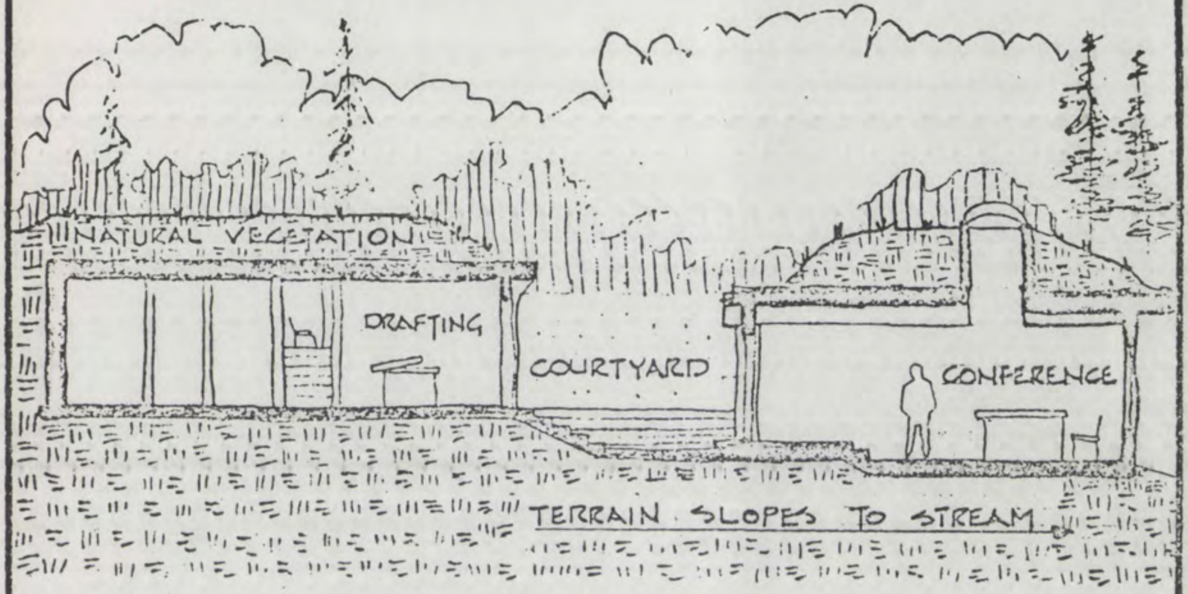
Atrium/Courtyard

A concept of obvious merit for the subterranean oriented designer is one that is sometimes necessitated by building codes or aesthetic concerns. It is the design of a facility that surrounds an atrium or other opening to the outside.[4] This does trade energy conservation for a view. The atrium's heat loss results in the need for greater heating and cooling capacity within the facility, because of outside temperature variations. It does allow natural light and ventilation to meet certain codes.

An existing atrium-type house was built underground by John Barnard, a Marstons Mills, Massachusetts architect. The house is constructed of prefabricated concrete slabs. They were set into a hole previously dug into the earth. It is insulated by two-inch thick waterproofed styrofoam. In spite of the energy lost by use of the atrium, the "Ecology House" costs 50 percent less to heat and cool than would a surface built house of the same size. It has a projected cost of 30 to 45,000 dollars in 1974.

Shell, Vaulted, and Dome Structures

Architects and architectural designers will need to be very careful when they look to the subterranean concept as the choice for their "design."



MALCOM WELL'S OFFICE

ECOLOGY HOUSE

FIGURE 23
ATRIUM/COURTYARD STYLE[5]

A subterranean design may be somewhat harder to deal with structurally than would a surface design.[6] This is especially true if the design requires that large amounts of earth be carried by the structural shell of the building. Larger loads mean shorter spans, and shorter spans mean smaller spaces. The smaller spaces may conflict with the designer's desire not to close in upon the occupant of an underground facility.

Normally, the greater load placed upon the structural system of the subterranean structure will require a very heavy and therefore, expensive structure design. It may mean increased amounts of reinforcing in concrete, or larger steel beams and columns. Thicker roof and floor slabs will also add to the expense of a subterranean design.

Problems almost always lead to questions, and questions to answers. This will be true of subterranean design. The engineering solutions may be foreign to what we are accustomed to for surface-built structures, but they will be solutions nevertheless.

Dr. Jason C. Shih of Duke University has professed the belief in the use of cylindrical and dome shells for optimum material usage.[7] The curvature incorporated into these two concepts gives far more strength to the structural shell than can be achieved in a linear design that uses the same amount of materials.

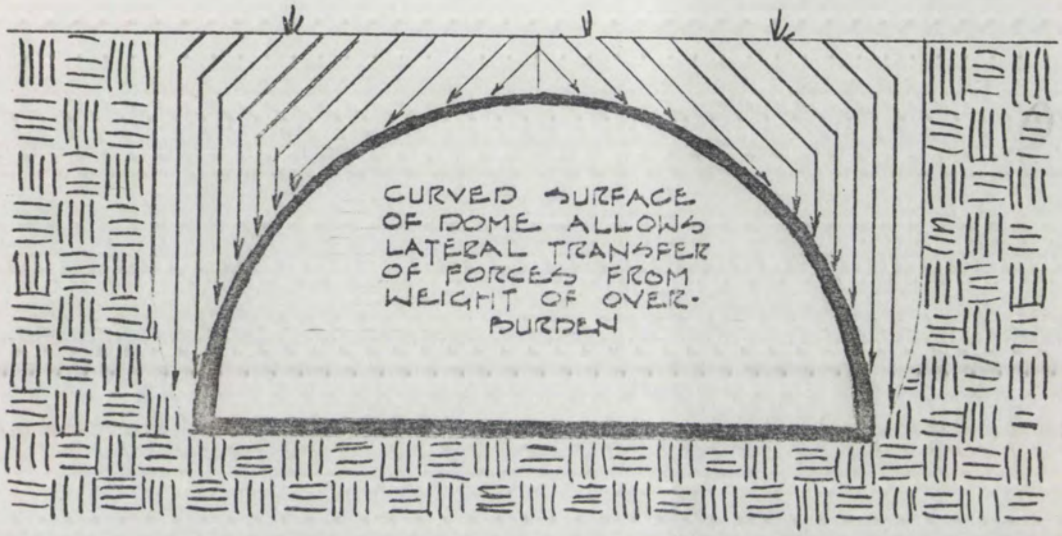
The use of domes and cylinders has drawbacks. Design loads are very critical.[8] Pressure concentrations upon shells can create indeterminate results. The most serious drawback is that there may be a great deal of wasted space in a rounded area.

Dome shapes do take advantage of the earth's arching action. The term "Earth arch action" indicates the capacity of the soil located above the structure to transfer a major portion of the total weight of the overburden onto the earth located on both sides of the structure. The body of earth which transfers the load is referred to as the ground arch. As can be seen in Figure 24, the earth surrounding a dome carries a great deal of the weight that would have to be supported by the structural shell of a flat roofed design.

Structural considerations for underground designs include, live loads and dead loads, seismic loads, soil characteristics, surcharge of overhead traffic, and the existing or anticipated water table.[9] Each of these will be familiar to the designer of surface buildings. The difference between surface and underground designs will be that the wind factor of surface designs can be disregarded in subterranean structures.

Earthquakes and Subterranean Designs

Earthquake resistance is a major consideration in the structural design of surface structures.[10] It appears to be less critical in subterranean design. The reason for this is that in subterranean structures forces are not externally applied, and therefore do not create the structural oscillation that normally contributes heavily to the damage of surface structures. Instead, they are a continuum of the internal inertia effect that result from the acceleration to which the subterranean structure is subjected. The forces remain externally induced, since the internal responses are being resisted by the direct contact of the structure with the surrounding earth. Most authorities accept the premise that an underground structure would escape damage by most earthquakes, except where an active fault appeared directly beneath structurel supports.



EARTH ARCH EFFECT

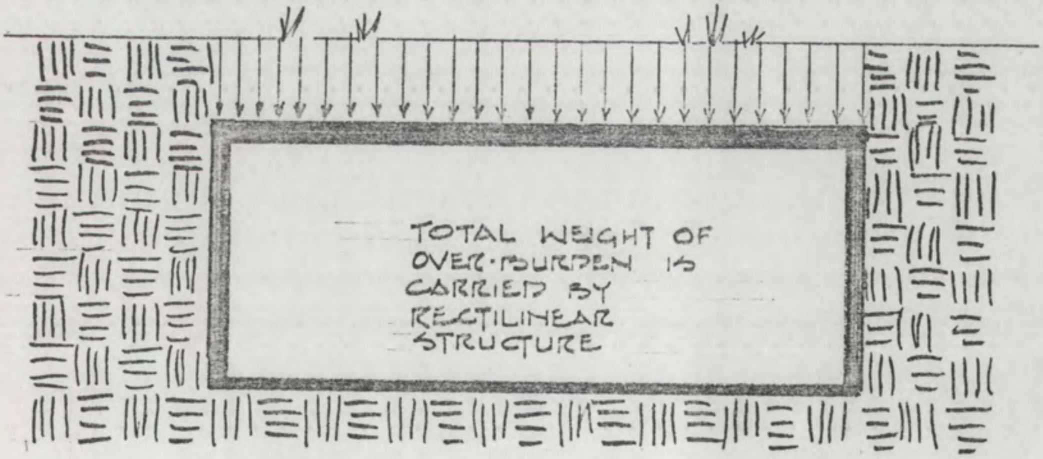


FIGURE 24
EARTH ARCH EFFECT ON SUBTERRANEAN STRUCTURES[11]

FOOTNOTES

1. Malcom B. Wells, "Light and Shiny vs. Thick and Heavy," A.I.A. Student Newspaper, Summer, 1973.

2. Ibid.

3. Swayze, op. cit.

4. Kenneth Labs, "Architectural Use of the Underground" (unpublished Master of Science thesis, Washington University, 1975), p. I-20.

5. Labs, op. cit., p. 121 & p. 126.

6. Opinion expressed by John King, personal interview, December 8, 1974.

7. Jason C. Shih, "Optimum Subsurface and Underground Shell Structures for Better Housing in Hot Arid Lands" (unpublished doctor's dissertation, Duke University, 1970), p. 21.

8. King, op. cit.

9. Shih, op. cit., p. 95.

10. King, op. cit.

11. Shih, op. cit., p. 96.

SUBTERRANEAN STRUCTURES AND ENERGY CONSERVATION

SUBTERRANEAN STRUCTURES AND ENERGY CONSERVATION

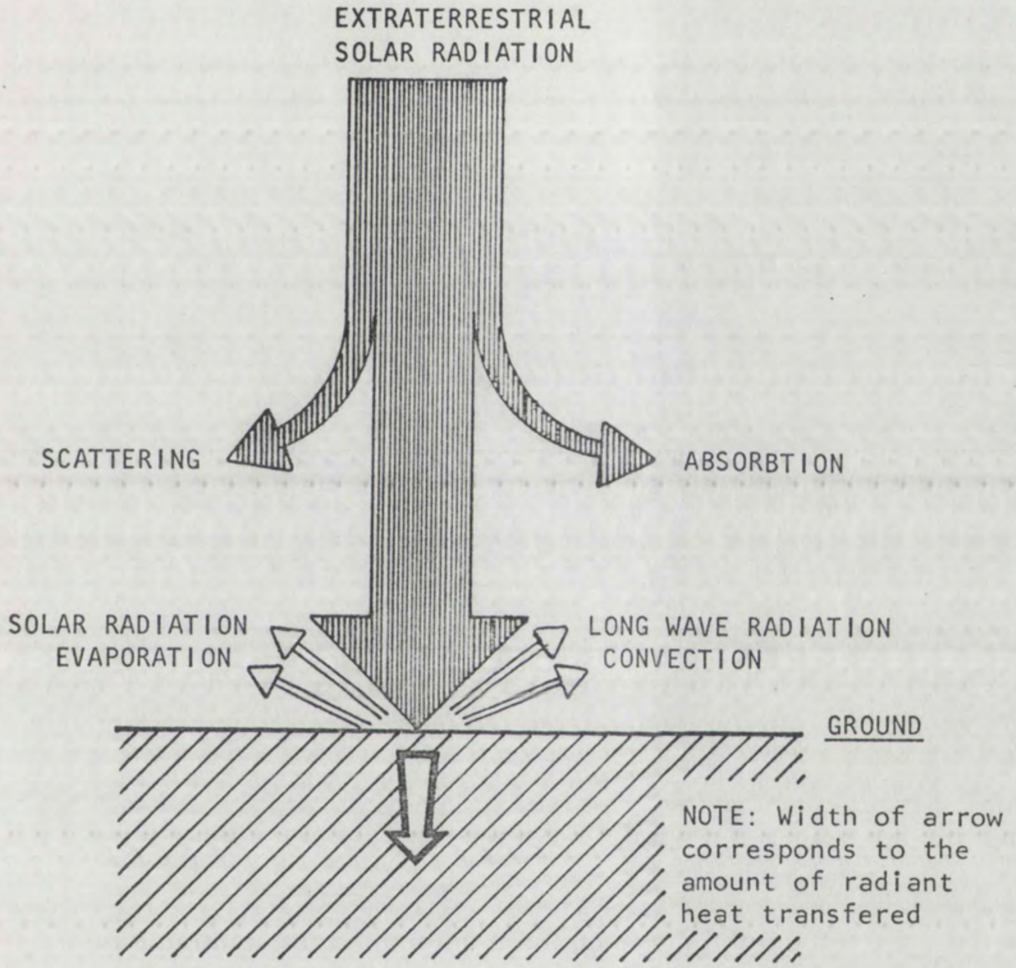
One of the critical advantages of subterranean structures is their potential for energy conservation. Because such structures are not directly subject to climatic extremes, they can take advantage of the earth's insulating properties and therefore depend far less than surface structures on fossil fuels for their interior climate regulation.

Existing subterranean structures are in their infancy of potential energy savings. As technology finds other less direct methods of tapping the consistency of underground temperatures, subterranean structures will become even more efficient.

The concept of subterranean design is a viable option for energy conservation.[1] It is not an untried or even a new attempt to deal with the current energy shortage. It has been tried and proven throughout man's history. In areas of low technology and difficult climates. One additional answer to the question of how to survive has been to go underground.

Now as we look at a world whose high state of technology is largely based upon the use of rapidly depleating amounts of fossil fuels, the subterranean concept appears to be one way to make the remaining energy reserves go much farther. Improper designs, and lack of careful study can make the concept seem a poor trade for the sake of conservation. Well thought out designs, combined with a real care on the part of the architect can make subterranean facilities create an environment equal to surface-built structures.

The Earth's heat energy comes from the direct rays of the sun which falls upon the surface of the Earth and heat it.[2] The effect of the



NOTE: Width of arrow corresponds to the amount of radiant heat transfered

33% of incoming solar radiation directly strikes the Earth's surface

13% of the radiation that strikes the surface is left at a depth of one foot

FIGURE 25
HEAT EXCHANGE DIAGRAM[3]

sun's radiation falls off rapidly if inhibited by poor conductors of heat, such as wood or soil. Metals, on the other hand, transmit heat rapidly because of their dense nature. The figure on the previous page illustrates how the sun's radiation reacts upon entering the Earth's atmosphere.

In the field of modern design there is almost no consideration given to subterranean design. Even in the world's hot dry regions the usual solution is to make the walls very thick or to provide large amounts of insulating materials within the building itself.[4] Energy exploitation creates a comfortable environment in surface buildings, but energy conservation can create a comfortable environment in subterranean designs. The surface structure usually depends upon large amounts of heating or air conditioning to bring the natural temperature up or down to acceptable limits. Both depend upon the expenditure of large amounts of energy to function. It is because of this energy expenditure and waste that subterranean design should be viewed as a very real option for energy conservation.

Desert Lab Study

Studies made by the Desert Laboratory, Tucson, Arizona, help advocate subterranean design and conservation of energy.[5] The study was concerned with thermal gradients of air and soils. It was concentrated more toward high surface temperatures and lower subsurface temperatures, but it is reasonable to assume there would be significant energy savings when the reverse situation existed.

The Carnegie Institute of Washington, D.C. undertook the analysis of the Laboratory's statistics. The tests had shown that in some cases the surface temperature would reach as high as 158°F (with building materials such as metal roofing reaching 175°F). Yet, only two feet beneath the surface, the temperature might be as much as 85°F less than that on the surface. As the depth increased, the daily variation decreased until it reached an almost constant temperature. That temperature was very nearly equal to the mean temperature for the locale.

The use of the earth's natural insulating value has led to two schools of thought relative to subterranean design.[6] There are those who believe in a stable-earth temperature theory, and there are those who are concerned with limiting heat loss wherever possible. The proponents of the stable-earth temperature theory feel that the heat from a subsurface structure will bleed into the surrounding earth until the soil reaches a constant temperature. They expect energy expenditures to taper off to almost nothing at that point.

The designers who favor the heat-loss limitation theory support the concept of insulating the subterranean structure in a manner almost like that of insulating a surface-built structure. They feel that by not doing so, the heat will be allowed to dissipate into vast surrounding earth-mass in a never-ending flow. By using insulation in addition to the natural earthen insulation, the overall rate of energy consumption should be greatly decreased.

Generally, the structural requirements of the subterranean building will be greater than for the surface building, thereby making the initial cost somewhat higher. There is a real energy savings currently in using the subterranean concept. It is assumed that it will increase with future knowledge. As more advanced methods of subterranean design develop, even initial costs would be expected to decrease.

The temperature beneath the Earth's surface stays reasonably constant (See Figure 26). It is certainly not completely static. The variations are small when compared to those of the surface. The internal temperature is constantly changing, but it changes at a decreasing rate that corresponds with an increase in depth.

There are two conditions of change.[7] First is the "positive" radiation balance where maximum temperatures occur at the surface and decrease very quickly at first; then decrease more slowly as the depth increases. Positive radiation balance is in reference to incoming radiation through the Earth's atmosphere.

There is also "negative" radiation balance. This condition exists with low surface temperatures, and the increase in depth corresponds to an increase in temperature. In this condition there is a natural heat radiation outward from the Earth into the atmosphere.

There is a daily variation between these two conditions. The fluctuations in temperature generally penetrate to a depth no greater than two meters. As the depth increases, the isoderm becomes more constant and is subject to change only to longer trends. These trends are referred to as annual temperature variations. This characteristic of Earth temperature variation gave basis to a proposal by P. Horsbrugh of Notre Dame University; that the first layer of the Earth which is subject to rapid temperature variations be called the base layer.[8] It is analagous to the first 1/2 kilometer of the Earth's atmosphere. All dinural changes and weather variations take place in that layer.

There are several conditions that affect this "base layer." The depth changes in different types of soils. Some soils are loose and allow great amounts of air between the grains. This loose soil acts as a better insulative material than soils that are very tightly packaged. The density of the soil

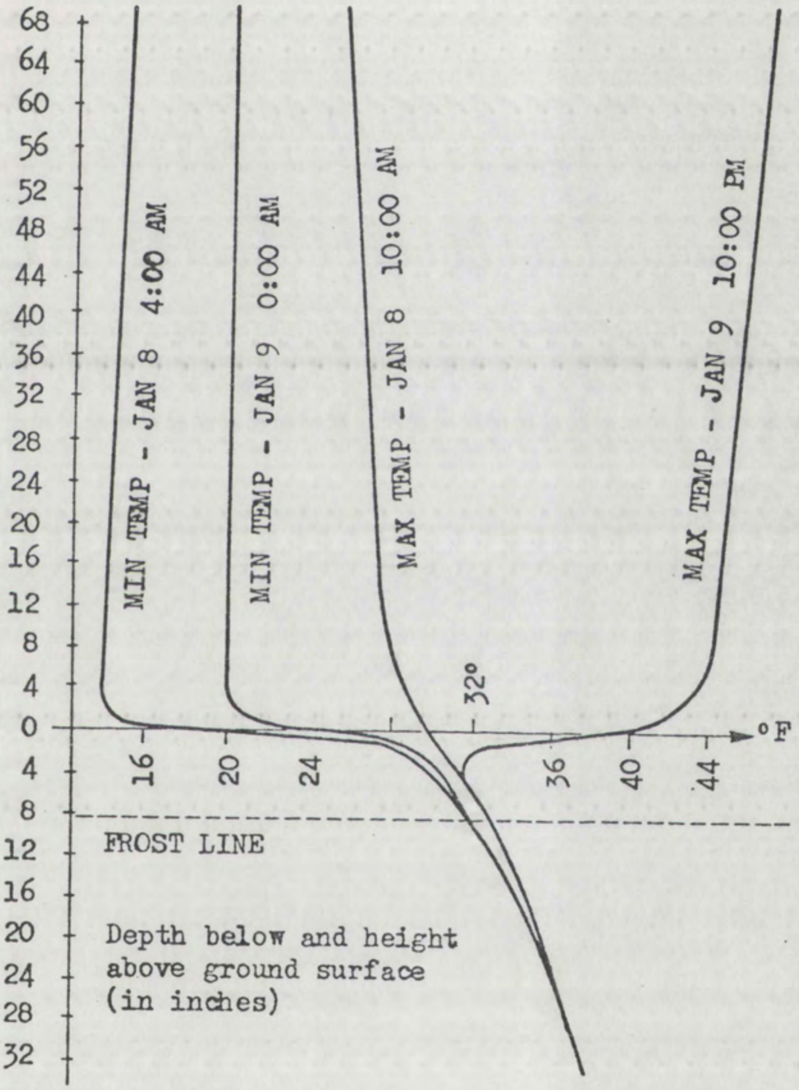
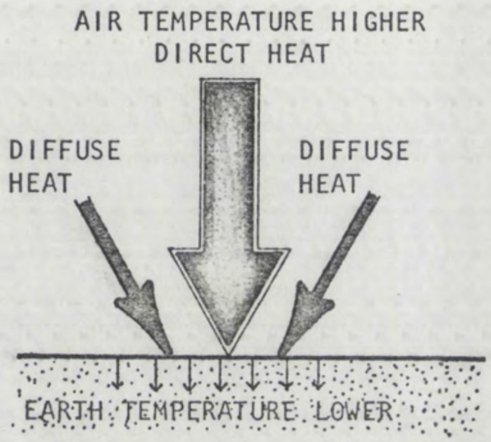
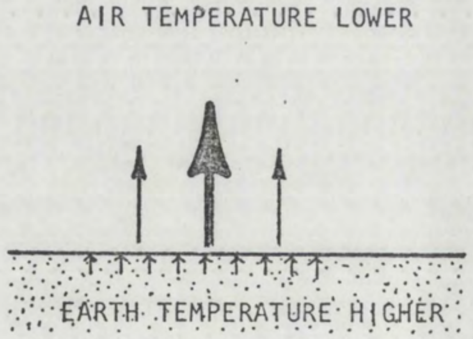


FIGURE 26
MAXIMUM AND MINIMUM TAUTOCHRONE,[9]



POSITIVE HEAT CONDITION



NEGATIVE HEAT CONDITION

FIGURE 27
POSITIVE AND NEGATIVE CONDITIONS OF RADIATION[10]

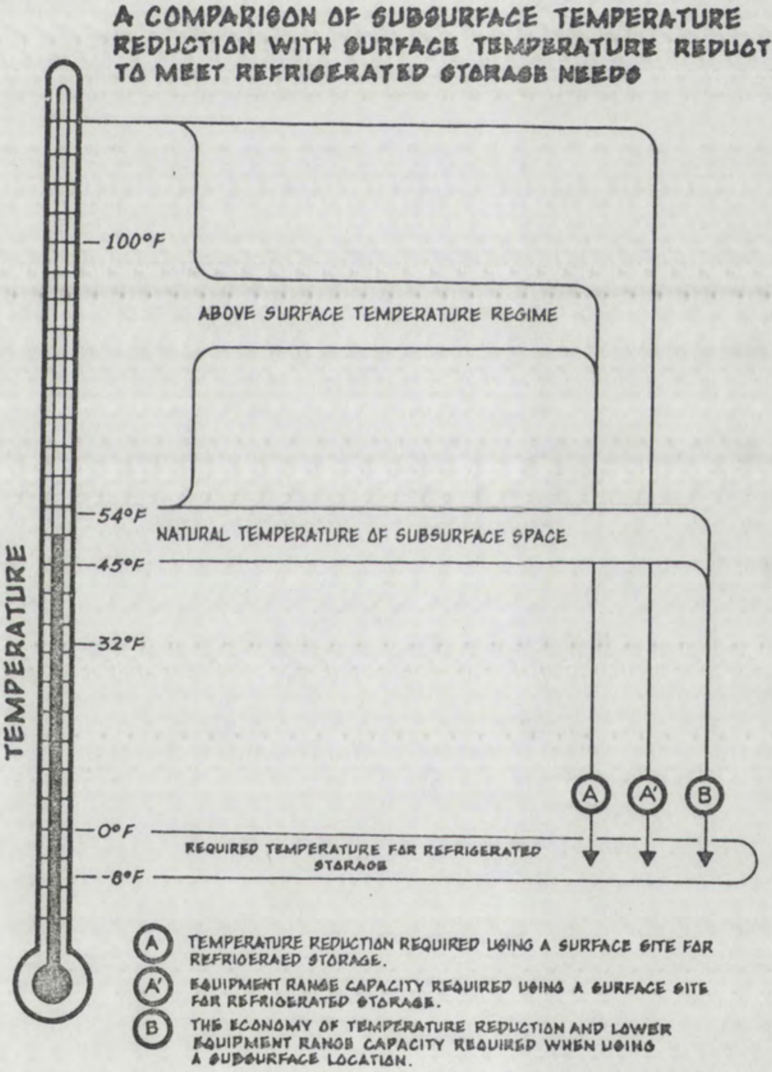
is approximately a thousand times greater than that of the air, so the fluctuations in temperature of the two react at completely different rates.

An increase in wetness of the soil increases the thermal diffusivity of the soil.[11] This increase is due to a greater thermal contact between the soil grains and a decrease of air pockets which act as insulators.

There are existing subterranean facilities in use as warehouse and freezer storage that illustrate the long range energy savings through use of the subsurface. In some cases the savings in energy consumption can be up to 90 percent, although 65-70 percent is a more reliable figure.[12]

John Meuller, the owner of several freezer-storage facilities in the Kansas City area, found that there is a substantial amount of energy saved by use of the subsurface.[13] An initial comparison with a surface facility of the same size and space as his subterranean facility could be in operation 24 hours after the completion of construction. The insulative value of the construction type allowed the refrigeration equipment to cool the storage to below 0°F in a one-day period. The same size facility underground needed ninety full days with the same capacity refrigeration equipment to draw the heat from the surrounding earth. Then the subterranean facility began to need less and less refrigeration to maintain a temperature of below 0°F, whereas the surface facility continued to use the same amount as it had initially (See Appendix X and XI).

After three years the subterranean facility's energy requirement had decreased by 50 percent. A comparison of the two types is: after three years, 530 square feet could be cooled to below 0°F per ton of refrigerated air in the surface facility, while 1,240 square feet per ton of refrigerated air could be cooled to below 0°F in the subterranean storage area. After seven years....the surface structure was still maintaining 530 square feet



Ⓐ TEMPERATURE REDUCTION REQUIRED USING A SURFACE SITE FOR REFRIGERAED STORAGE.

Ⓐ' EQUIPMENT RANGE CAPACITY REQUIRED USING A SURFACE SITE FOR REFRIGERATED STORAGE.

Ⓑ THE ECONOMY OF TEMPERATURE REDUCTION AND LOWER EQUIPMENT RANGE CAPACITY REQUIRED WHEN USING A SUBSURFACE LOCATION.

FIGURE 28
SUBSURFACE CONSERVATION OF ENERGY IN REFRIGERATION [14]

per ton of refrigerated air, while the subterranean storage area was cooling 2,500 square feet per ton of refrigerated air.

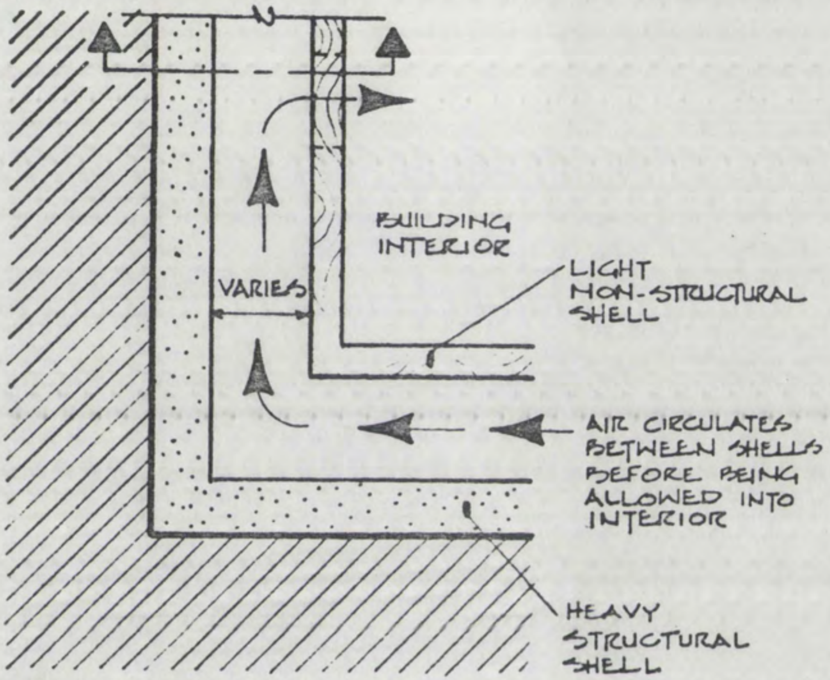
Another side benefit of underground freezer storage is that the life of the refrigerating equipment has been greatly increased because of decreased demands. The cooling system is designed so that the equipment runs at its optimum power level. The total area cooled per ton of refrigeration might be greater if doors to unrefrigerated areas could be opened less often, and if the transport equipment could be designed to give off less heat. Time and motion studies will allow optimum use of what has proven to be a very efficient design concept for energy conservation.

Double Wall System

Modern subterranean architecture was given a tremendous boost as an energy conservative design method when the double-wall system was designed and perfected by Mr. J. Swayze. The system was first introduced in the "Atomitat."[15] It takes advantage of the constant temperature of the Earth, and uses that consistency to reduce heating and cooling loads upon the mechanical system. It removes any natural condensation while providing a very acceptable interior temperature.

The double-wall system consists of a heavy-load-bearing structural shell that acts as a retaining wall and a waterproof barrier. Inside the structural shell is a nonstructural inner shell that creates the efficiency of the system. It allows the area between the two shells to serve as an air duct for ventilation.

Just as a glass of ice water has condensation occur around the surface that is in contact with warm moist air, the inside surface of an underground structure will also have condensation where the cool outside wall is in contact with the warm air of the building. It can cause paint to peel or



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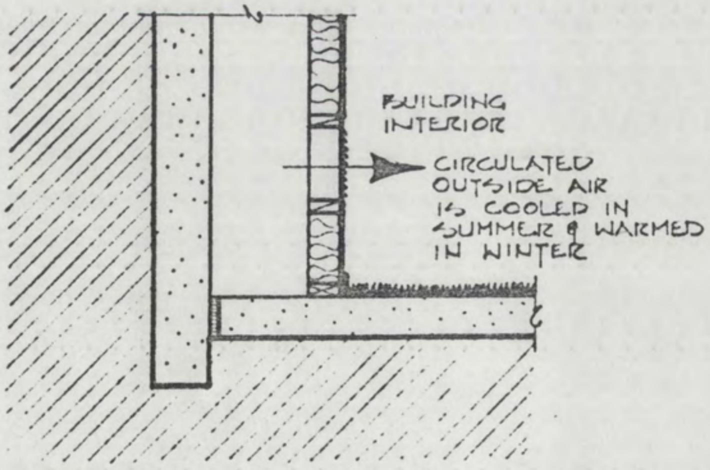

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FIGURE 29
DOUBLE-WALLED SYSTEM [16]

fabric to mildew and rot. This was one of the greatest problems in basements.

In the double wall system a normal forced air ventilator moves outside air between the inner and outer shells. On a hot day the air is cooled as it passes along the exterior wall. On a cool day it is warmed as it moves by the wall (See Figure 29). This is because of the consistency of the Earth's temperature, and resultant consistent temperature of the wall that touches it. By the time the air is allowed into the inner shell it is a comfortable 65° to 70°F and needs very little artificial heating or cooling.

In its passage the air between the walls has been doing an additional service. Hot air is capable of carrying a larger amount of moisture than cool air, so it will pick up any condensation on the cool structural wall. Cool air will not create the situation necessary for the condensation process.

The double-wall system is slightly more expensive than the conventional single wall of most basements. Even in surface structures built by Mr. Swayze, the system provides benefits. By building a basement for the structure, and incorporating the double-wall system into it, the home or office owner can reduce his heating and cooling rates by a considerable amount.

Denver House

An underground house in Denver, Colorado, had detailed records kept on its energy consumption (See Page 77).[17] These were compared to those of a similar house (in cost, $7,365 for the subterranean design vs. $7,413 for the surface design in 1971) that was nearby, but surface built. The comparisons were significant.

The surface design needed almost four times the total fuel energy. Code requirements for odor-free air ventilation of 25 CFM/person consumed 60 percent of the total energy for the underground design. In situations of larger open areas, the code only requires 7CFM/person and would make the energy/area ratio much smaller. Results of the energy requirements were:

		Surface Design	Underground Design
Winter heat loss (BTU)		39,927	12,720
Summer Heat gain (BTU)		44,650	0
Annual Energy Demand/Cost			
Winter:	Gas (cub. ft.)	93,826($65.80)	30,777($ 27.62)
	Fuel Oil (gal.)	710(129.93)	233(42.60)
	Electricity (KWH)	23,157(428.81)	7,596(191.07)
Summer:	(Air Conditioning)		
	Electricity (KWH)	3,962(98.39)	0

Annual Cost of Environmental Control

Using:	Gas	Fuel Oil	Electricity
Surface Design	$395	$459	$758
Underground Design	120	135	283
Underground Compared to Surface requirements	30%	29%	37%
Reduction in Cost	70%	71%	63%

It can be seen by the above table that the underground design was highly efficient when compared to the surface design. The differential might prove to be even greater if taken from a hot dry region such as Phoenix or Albuquerque. The possibility exists that the savings incurred over the thirty-year span of the purchaser's loan could easily be one-third the original value of the structure. That would be, assuming the cost of energy does not increase. If it does, the dollar amount of savings would likewise increase. This considerable economic savings should make the architect/designer look at the subterranean concept very seriously if he is at all concerned about giving his client the best for the longest period of time.

In figuring energy savings derived from building on or below the surface there are other factors in addition to costs of long-term utilization (See Appendix 141).[18] There are three categories for consideration. First the cost of construction. Second is its cost of use. Third is the expense of renewal. Documented by Ken Yeang in Architectural Design, the system of total cost evaluation may prove to be invaluable.

Application of this novel system combined with an economic analysis of the surface built environment would provide an insight into both investment and return for the financial proponent, as well as the energy conservationist.

Climatic Variations

A wide range of climatic types are found in New Mexico. This in itself would allow for optimum use and experimentation in subterranean systems. Extremes in temperature that are found on the surface are more easily dealt with in their modified form underground.[19] Recorded highs of over 100°F, lows of under 0° are not uncommon, so the climate makes the use of the subterranean more attractive in areas such as New Mexico, than it would be in areas of more moderate temperature variations.

Wind as an energy loss factor is a serious consideration in the southwestern United States for the architect who designs buildings for the Earth's surface. The subterranean design can negate the effect of wind to a completely minimal point.[20] Some designs which have surface structures for entryways or courtyard style structures must have a certain amount of thought as to wind effect put into the design, although not anywhere near the amount that must go into the totally surface-built design.

Precipitation is of real concern to the designer of subterranean structure, just as it is to the designer of a surface structure.[21] The natural tendency of soil to absorb and hold rainfall must be taken into account when figuring for structural loads. The water table of an area can rise and fall enough to affect both surface and underground structures. It is for this reason that the design of subterranean structures may be the most easily accepted by the public at large in hot arid regions much more easily than in areas of high amounts of annual rainfall.

Urban Effect

Urban forms when found in large numbers, such as in Albuquerque, Phoenix, Los Angeles, or other metropolitan areas, may significantly affect the climate of a given area (See Figure 30).[22] As the morning sun begins to warm the streets, parking lots, rooftops, walls of a city, heat begins to rise at a much faster rate than is normal in the rural (surrounding) areas. This, combined with heat created by cars and other forms of mechanical equipment, causes the air to rise at an even faster rate as the day's activities begin. This column of air carries particles of dust, smoke, and other pollutants. Some of the lighter smaller particles will be drawn by the rising currents of air high into the atmosphere, where they will spread out over the rural areas, and descend into the suburban portions around the city. Larger particles will not rise high enough to be drawn out of the urban area, and will hang all day in the air over the city.

The large particles of pollutants add to the heat convection by absorbtion, reflection, and radiation of solar energy that is falling upon them. This energy is combined with that falling on and radiating from the city proper. Over an extended period of time, the haze will become a constant dome-shaped layer of haze above a metropolitan center.

As the night cools the city, the "dust dome" above it will gradually settle, bringing the greater warmth of the dome-layer air back into the city. At dawn the city may still be 5°F to 10°F higher than the surrounding rural or suburban areas. With the new day's heat added to the leftover heat of the previous day, the cycle begins again at an even greater level of activity than before.

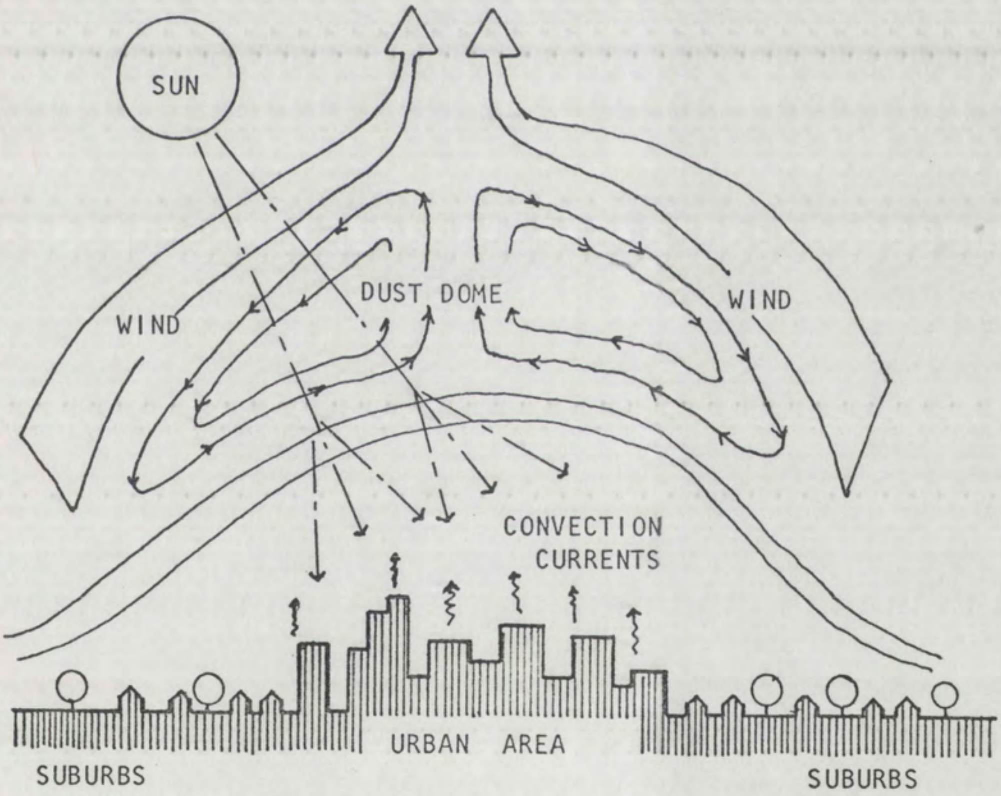


FIGURE 30
URBAN DOME EFFECT[23]

FOOTNOTES

1. Opinion expressed by Jay Swayze, personal interview, November 10, 1974.
2. William P. Lowry, Weather and Life (New York: Academic Press, 1969), p. 10-11.
3. Rudolf Geiger, The Climate Near the Ground (Cambridge: Harvard University Press, 1950), p. 3.
4. Opinion expressed by Phillip Springer, personal interview, March 7, 1975.
5. Jason C. Shih, "Optimum Subsurface and Underground Shell Structures for Better Housing in Hot Arid Lands" (unpublished doctor's dissertation, Duke University, 1970), p. 13.
6. Malcom B. Wells, "Light and Shiny vs. Thick and Heavy," A.I.A. Student Newspaper, Summer, 1973.
7. Geiger, op. cit., p. 2.
8. Patrick Horsbrugh, "Urban Geotecture: The Invisible Features of the Urban Profile" (paper read at conference on Alternatives in Energy Conservation, The Use of Earth-Covered Buildings, July, 1975, Fort Worth, Texas).
9. Kenneth Labs, "Architectural Use of the Underground" (unpublished Master of Science thesis, Washington University, 1975), p. 17.
10. Geiger, op. cit., p. 2.
11. James W. Scalise, Earth Integrated Architecture (Tempe, Arizona: University of Arizona Press, 1975), p. A-12.
12. John Mueller, "Energy Conservation Through Use of the Subsurface," (paper read at Symposium on Underground Space Use, March, 1975, Kansas City, Missouri).
13. Ibid.
14. Ibid.
15. Swayze, op. cit.
16. Ibid.
17. Lloyd Harrison Jr., "Is It Time to go Underground?" Navy Civil Engineer, Fall, 1973, p. 28-29.

18. John E. Williams, "Application of Life-cycle Cost Techniques for Earth-Covered Building Analysis," (paper read at Conference on Alternatives in Energy Conservation; The Use of Earth-Covered Buildings, July, 1975, Fort Worth, Texas).

19. Swayze, op. cit.

20. King, op. cit.

21. Swayze, op. cit.

22. William P. Lowry, Weather and Life, an Introduction to Biometeorology (New York: Academic Press, 1969), p. 271.

23. Ibid., p. 276.

SOILS AND THEIR PHYSICAL CHARACTERISTICS

SOILS AND THEIR PHYSICAL CHARACTERISTICS

The physical properties of soils will determine what an architectural designer may do or not do.[1] The physical properties may include such things as chemical composition, specific gravity, void ratio, texture, granual size, unit weight, salinity, and thermal characteristics.

By the very nature of their design, subterranean structures are tied into the physical characteristics of the soil far more than are surface structures. The subterranean structure must rest upon soil (as must the surface structure) that is strong enough to bear its weight without shifting or settling, and it must also be able to resist the pressure of the soil that surrounds it.

In order to fully evaluate soils and their reactions upon an underground design, the architect should consult with an engineer, but this section should help to clarify when specific soils are compatible with most subterranean designs. By applying a basic knowledge of the physical properties of soils to architectural design, the architect can avoid attempting to promote an underground design, if he finds that it is either nearly impossible to construct or is too expensive for the client to afford.

Soil Description

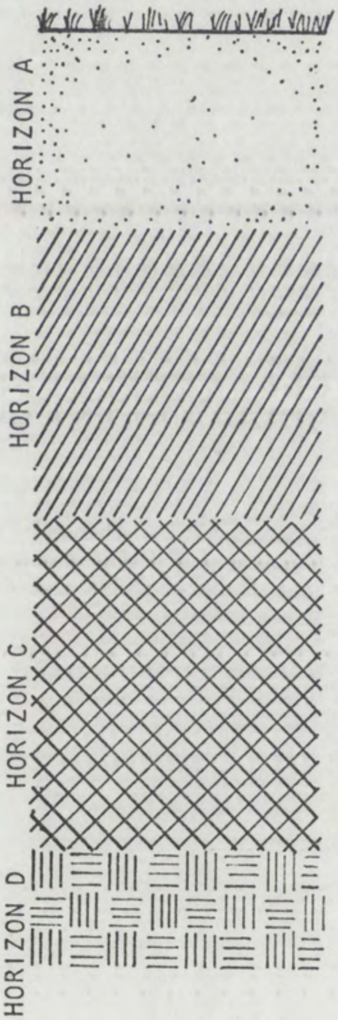
Soil is generally described as the unconsolidated layers of earth, rock, and organic materials that lie on top of bedrock.[2] The depth of this material varies tremendously from place to place, as does its consistency and composition. It is the result of weathering and environmental activities, such as erosion, leaching, and organic decomposition, upon the uppermost strata of the bedrock below.

The stages that are found in soils are shown in Figure 31. These stages are described as the "Soil Profile." This profile is a vertical cross-section (idealized) of the soil layer from the surface of the ground down to the top layer of bedrock. Each of the separate layers of earthen strata are referred to as "horizons."[3] These horizons are quite distinguishable as separate intervals in the geological process of rock becoming soil.

Soil is usually described upon the basis of its origin (parent material, geological history) and grain size or by its relative composition of principle constituents (gravel, sand, silt, and clay). Although it is occasionally found in relatively pure states of the constituents, it is normally found in a combination thereof. The size and description of the constituent variations are:

gravel	2 mm. in diameter
sand	between .05 mm. and 2 mm.; grains visible and gritty to the touch.
silt	between .002 mm. and .05 mm.; grains invisible, but can be felt (smooth and fine)
clay	.002 mm.; very smooth and fine, in smooth lumps when dry, sticky when wet, slippery and unstable

When found in combination as is usually the case, soil may be simply described by its major constituents, such as "silty sand" which would indicate soil having a major portion of sand with a smaller portion of silt. Other combinations are; 1, loam; 2, gumbo; 3, humus; 4, hardpan; and 5, loess.



SURFACE

HORIZON A: TOPSOIL
zone of humification process,
leaf litter
humus soil
leached material

HORIZON B: SUBSOIL
zone of mineralization,
little biotic activity
fewer roots than topsoil

HORIZON C: PARENT MATERIAL
level of weathering activity,
no biotic activity
few roots
soil source material in
a variety of degrees of
modification by inorganic
agents

HORIZON D: UNDERLYING MATERIAL
consolidated bedrock,
hardpan

FIGURE 31
SOIL PROFILE IN SECTION 4

Loam	a friable (easily crumbled or pulverized) soil which usually contains some organic matter.
Gumbo	a finely particled, sandless clay which is dark, plastic, and very sticky. It expands and contracts greatly with variations in moisture content, and is therefore thought of as one of the most difficult soils to handle in excavation.
Humus	a dark brown amorphous earth, top-soil, consisting of partially decomposed organic matter (usually vegetal) which will continue to decay, some clay, and a small amount of sand and silt. The continuously decaying organic matter makes this combination unsuitable for foundations as it will hold water and continue to shrink as the decaying matter loses moisture content.
Hardpan	a densely-cemented, cohesive, and hard rock-like soil that will not soften when wet. It is difficult to excavate and resists penetration by boring tools.
Loess	a uniform, cohesive, porous, and coherent deposit of very fine particles. This soil will when dry, stand very nearly vertical when excavated.

Classifications

The Unified System of Soils Classification and the American Association of State Highway Officials Soil Classification System are the two most commonly used (in the United States) systems of soil type differentiation.[5] The Unified System breaks soils into groups dependent upon particle size, plasticity, liquid limit, and organic matter. They are grouped into 15 classes, with 8 classes of coarse grained soils, 6 classes of fine grained soils, and one class of "highly organic" soil. Borderline soils can have a double symbol representation.

The American Association of Highway Officials Soils Classification System is used to break down soils into their characteristic types, determinant based upon their affect upon highway construction and maintenance. The seven basic groups of the A.A.H.O.S.C.S. are dependent upon the basis of grain size distribution, liquid limit, and plasticity index. They range from group A-1 that is a gravely soil of high bearing strength (with good foundation quality), to group A-7, which is a clay soil having a low strength when wet, and is therefore of very poor quality for foundation or subgrade use.

Thermal Conductivity

Subterranean structures as an energy conservative design concept is greatly influenced by a soil's thermal conductivity. Outside factors that affect the thermal conductivity of a soil are radiation, air moving over, into, and out of the soil, the water vapor in the air, and the penetration of cold or warm rain into the soil.[6] A soil that is a good conductor has more moderate surface temperatures than does a poor conductor. More radiant heat is retained by a good conductor than by a poor conductor, and good conductor's average temperature fluctuations are able to penetrate deeper into the soil. It is for all of the above reasons that the designer of a subterranean structure should make an attempt to select the best combination of surrounding soil for low thermal conductivity, thereby making the energy conservation aspect of the subterranean design achieve an optimum level.

The moisture content of a soil is closely related to its mean temperature. A constantly moist soil will be of generally lower temperature than would be the same soil in its dry state. This is because of three factors.

First, in saturated soil much of the incoming heat radiation is spent in evaporation, rather than in heating the soil. Second, the specific heat (the amount of energy required to raise one CM^3 of soil by one degree) is higher in saturated soil than it is in dry soil. Third, the thermal conductivity of a soil is increased by soil saturation, enabling heat received at the surface to be more readily conducted downward. This rapid transfer of heat to the lower layers gives the surface a cooler temperature while the deeper areas are warmer in wet soil as compared to dry soil.

The relation of thermal conductivity to seasonal/depth variations in temperature are important. Loose, dry soil such as found in the Gobi desert was studied over a ten-day period in the month of August.[7] The average temperature of the soil, 20 feet beneath the surface, was 53.0°F (varying from 52.2° F. to 53.7°F), while the temperature of the soil .08 inches below the surface ranged from 36.7°F to 101°F. The actual surface temperature was not noted, but similar studies in the American desert have found objects placed in the direct rays of the sun may reach temperatures of 175°F.

Strength Properties of Soils

With the decision to design and build a subterranean structure, the question of the strength properties of a soil type becomes critical.[8] Tests must be taken on a soil's cohesiveness, internal friction, and shear, plus some minor additional field tests, to determine its structural strength.

Cohesion is the mutual attraction of soil through molecular force plus the presence of moisture films which act as a binder. Each soil's cohesive force will vary therefore with its moisture content. Some soils have high cohesiveness in a dry state, but the addition of large amounts of moisture cause them to reach their level of plasticity limit, and then the internal cohesiveness rapidly drops off.

Resistance to internal mass disruption or sliding is called the internal friction of soil. Sand and gravel have a high internal friction, so a soil's internal friction will increase along with the increase in a soil's content of sand or gravel. Clay has a low internal friction with dry clay having a higher internal friction than does clay saturated with moisture.

The angle of repose of a soil is directly related to its internal friction, and is described as the maximum slope which a given soil may assume and continue to remain stable.[9] Bermed slopes should never exceed the angle of repose or they will be in danger of slippage. As can be seen below, the angle of repose changes in some soils with its humidity content.

Soil and Condition	in °	A/S Ratio
Clay		
Firm	20	2.75:1
Moist	15	3.73:1
Soft plastic	7	8.1:1
Gravel, dry	35-40	1.3:1
Sand		
Dry	30-35	1.6:1
Moist	20	2.75:1
Saturated	15	3.73:1
Silt	5	11.4:1
Loess	25	2.1:1

A design value of 33° (1.5:1 slope) is normally used for common soils, although rainfall and other weather conditions may modify this figure somewhat. It is for this reason that berms may have tendency to slip unless stabilized artificially. This can be done by driving stakes into this berm, by creating subsurface (therefore invisible) terraces, or to use retaining walls or step curbs across the plane of the slope.

Just as the angle of repose causes the soil adjacent to a structure to slip away when exceeded, it can create the condition known as sliding wedge

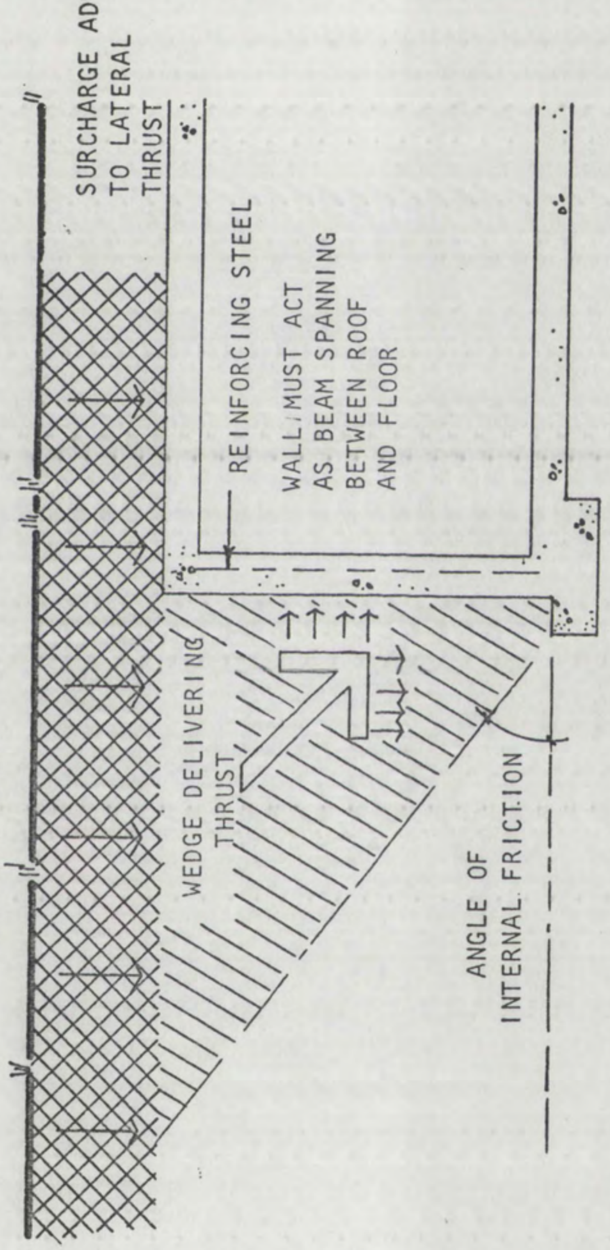


FIGURE 32
SLIDING WEDGE CONCEPT[10]

in a subterranean structure. Figure 32 shows how this affects an underground structure.

The bearing capacity of soil is its ability to support loads without failures or deformations within the soil mass. The area of contact between the footing and the soil is called the loaded or bearing area.[11]

> The ultimate bearing capacity of a soil is the ultimate value of the average contact pressure, stress or load intensity transmitted by the base of the footing to the soil, causing the soil mass to rupture, fail in shear, or have excessive settlement. The allowable pressure or safe bearing capacity of soil is the ultimate bearing capacity divided by a safety factor, which, depending upon the importance and type of structure, varies between two and five.[12]

Subterranean structures are so thoroughly integrated into the Earth that the workability of soils may present problems too difficult to overcome and still remain within the limits of sound economic returns. Soils that have very high organic content continue to settle for long periods after the excavation work is completed, and the excavation has been loaded with fill. Sometimes the settlement is due to soil consolidation. At other times it may result in lateral plastic yield or from continued decay of the internal organic matter.

Soil hardness is another area of problems for the designer-builder of underground structures. Some soils are almost rocklike, such as caliche, which is found over large areas of the American Southwest. It is often so hard that excavations may be all but impossible for those having limited budgets.

FOOTNOTES

1. James W. Scalise, Earth Integrated Architecture (Tempe, Arizona: University of Arizona Press, 1975), p. A-5.

2. Kenneth Labs, "Architectural Use of the Underground" (unpublished Master of Science thesis, Washington University, 1975), p. II 21.

3. _Ibid._ p. II 23.

4. _Ibid._ p. II 24.

5. Scalise, _op. cit._ p. A-9.

6. _Ibid._, p. A-12.

7. Jason C. Shih, "Optimum Subsurface and Underground Shell Structures for Better Housing in Hot Arid Lands" (unpublished doctor's dissertation, Duke University, 1970), p. 14.

8. Scalise, _op. cit._, p. A-12.

9. Labs, _op. cit._, p. II 25.

10. _Ibid._

11. Scalise, _op. cit._, p. A-13.

12. _Ibid._ p. A-28.

CONSTRUCTION CONCEPTS

CONSTRUCTION CONCEPTS

Subterranean design is far more limited in its feasible building system than is surface design. The designer of subterranean structures does not have the options of wood, metal, plastic, or concrete. The designer of underground structures must look primarily to concrete as a building's structural system.[1]

> Woods, metals, and plastics do not perform adequately in underground structures. They lack the ability to withstand subterranean pressures for economically feasible periods of time. Related to structural durability is the problem of water-tightness. Structures crack and develop leaks where the greatest strains occur. This places a greater demand on the designer to carefully check all materials at points of maximum stress. Wood and plastics cannot resist the shear and metals develop corrosion pits which allow penetration of water vapor.[2]

Fire resistance of plastic and metals is low, and attempts to bring them to ASTM Fire code add to the cost of the structure. Wood may pass the test if it is laminated or fire-treated, causing it to be very expensive also. Because of these problems, viable underground structures from wood, metal, or plastic is not presently considered feasible.

Waterproofing of underground structures can be a major problem, especially in areas that have high water tables or large amounts of rainfall. Moisture seepage into a subterranean facility can result in unnecessarily heavy burdens being placed upon ventilation equipment. It can damage and stain paneling, rot wood and carpet, and contribute to mildewing.

In the world's hot, dry areas there is not nearly so much ground moisture as is found in the soil of the wetter regions. This in itself can contribute to the greater advantage of underground usage in hot dry regions over their use anywhere else. Proper application of waterproofing will still be a must in hot arid regions, although less so than in wet climates. Waterproofing of underground structures can be accomplished in wet regions and even below the level of a water table. At the New York World's Fair an underground house was built as an exhibit. It was partially below the level of the water table, but had no problems from leakage.

Subterranean structures must be thought of and designed as "hydraulic structures."[3] In the design of concrete systems this term applies to all structures that are or may be directly exposed to water, and must resist intrusion into the interior from the exterior or vice-versa. The durability of the structural concrete will affect the water-tightness and quality of the structure.

Concrete is porous, and is subject to water penetration, either in liquid or vapor form. Penetration may result from capillary action or it can occur from existing pressure, or from a combination of both. A concrete's permiability is dependent upon how rapidly this process takes place. Although permiability is a property that virtually all concrete mixtures possess, it is possible to create a concrete mixture which is impervious to the degree that no leakage or dampness will be visible on interior surfaces opposite the point that the liquid entered.

A comparison of cast-in-place concrete systems with precast concrete systems is important in the proper design of subterranean structures.[4] Each has advantages and disadvantages, both in construction and ability to resist earth-pressures and water penetration. It seems through comparative analysis of the jointing details required by each system that cast-in-place concrete systems have more advantages and fewer disadvantages in subterranean structures. This superiority is due to the homogeneous nature of the finished

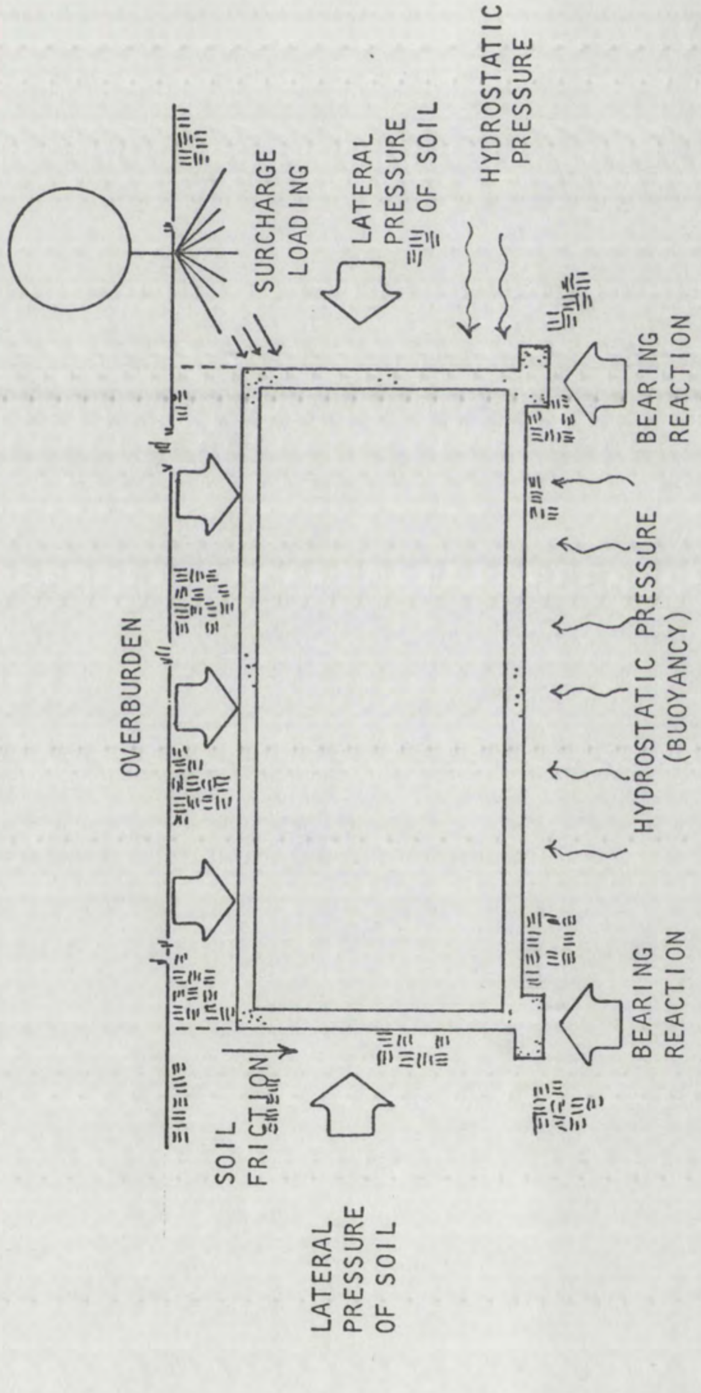


FIGURE 33
TYPICAL PRESSURES ON SUBTERRANEAN STRUCTURE[5]

surface of the cast-in-place system, relative to the many joints (which must and can be waterproofed, although possibly at great expense) found in the precast concrete system.

Shotcrete is another application of cast-in-place concrete systems. It is created by forcing sand and cement, by pressure, through a hose to a nozzle where water is added just prior to the mixture's discharge. The mixture leaves the nozzle at a very high velocity, and has several desirable qualities: a) low water cement ration, giving it high strength and low permiability, b) dense concrete because of its low water/cement ratio and high impact velocity; c) superior bonding ability; d) relatively simple work area requirements, e) shotcrete lends itself to the production of many shapes or thin sections with a minimum of frame work.

Subterranean structures are subject to several forces that affect its design. Figure 33 shows how each of these apply to the standard rectangular structure. Arch structures are subject to the same forces, but by the nature of their design, react differently.

Construction systems are constantly being improved through experience and technological discoveries. What is true today may change in a very few years. Presently, for underground structures, the system with the fewest inherent problems is the cast-in-place concrete system. It can be most easily water-proofed, is long-lasting, has less chance of movement during seismic distrubances, and can be built sufficiently strong to withstand normal pressures from the surrounding earth.

Waterproofing and Moisture Control

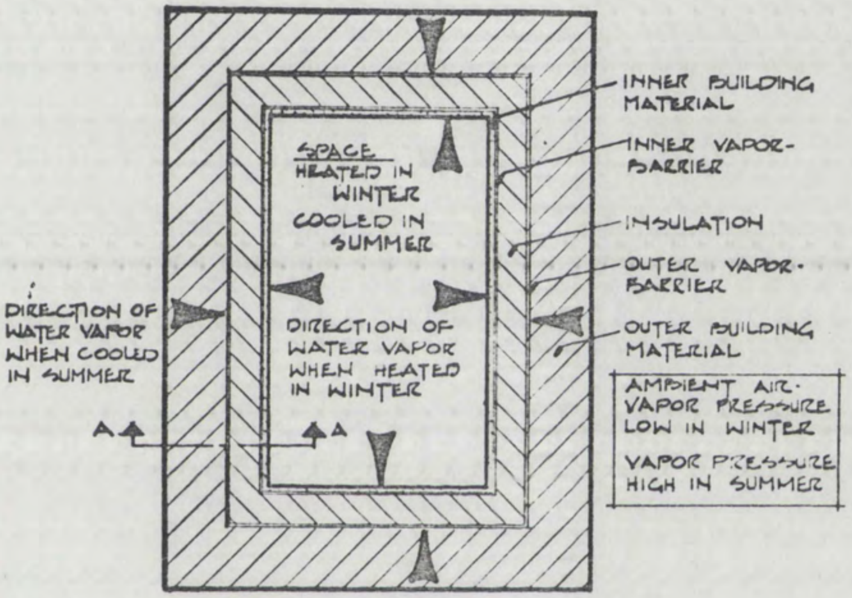
As with many solutions to problems, it is not always a matter of one waterproofing solution only for any given moisture control problem. An awareness of problem areas in moisture control can make the designer of subterranean structures less apt to design with built-in problems. There are several sources of moisture that create problems in underground structures: a) ground water, the level of which rises or falls as a result of rain or snow; b) water vapor in the voids within the soil (generally the same as ground water, but less subject to accute change over extensive periods of dry weather), c) water vapor in air within the structure itself, which leads to condensation where the warm moist air makes contact with the cool structural materials.[6] This can occur in either or both of two ways, as surface condensation or concealed condensation.

Surface condensation takes place at the point where the air is cooled to its point of total saturation (below its dewpoint), and normally occurs on the surface of walls that are in direct contact with surrounding earth. Activities within the structure can, by raising the amount of moisture within the structure, lower the dewpoint to where condensation can occur (See Figure 34).

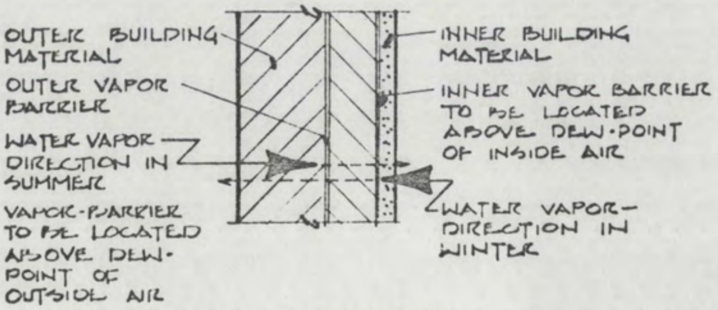
Concealed condensation occurs within the structural elements as they reach the dewpoint temperature. Sometimes insulation can itself be at fault for concealed condensation.

> It not only results in increased temperature on the warm side of the element over the insulation, but it also inevitably results in decreased temperature on the cold side as well... the possibilities of condensation are increased toward the cold side of the element.[7]

Water vapor is in some cases more difficult to control than liquid water, because some materials that are impermeable to liquid water have a level of permanence that allows water vapor to travel from areas of high concentration to areas of low concentration.

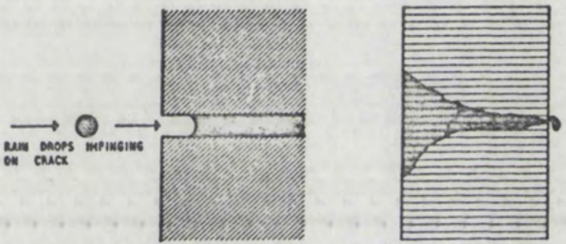


PLAN



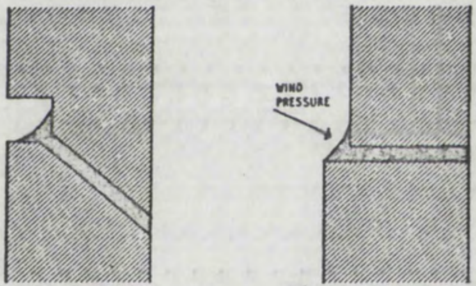
SECTION A-A

FIGURE 34
MOISTURE FLOW IN SUBTERRANEAN STRUCTURES[8]



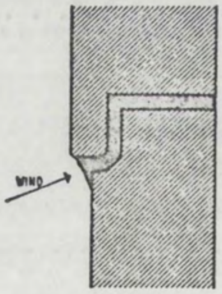
(a) WATER PENETRATION BY KINETIC ENERGY

(b) WATER PENETRATION DUE TO CAPILLARITY



(c) WATER PENETRATION DUE TO GRAVITY

(d) WATER PENETRATION DUF TO WIND PRESSURE



(e) WATER PENETRATION DUE TO WIND FORCES AND CAPILLARITY

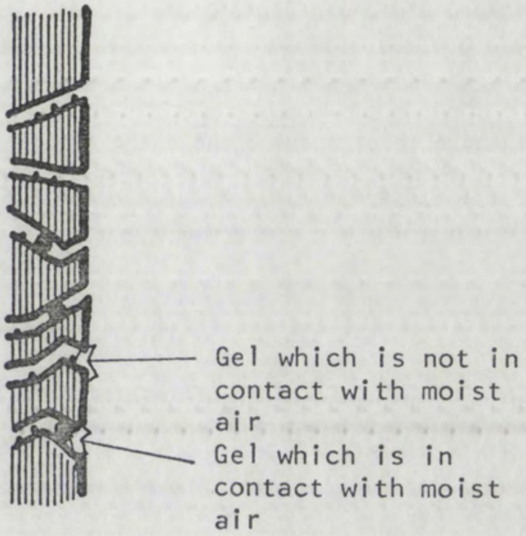
FIGURE 35
WAYS IN WHICH WATER MAY PENETRATE STRUCTURES[9]

The two primary ways to stop water from moving through materials are with surface treatments and proofing materials.[10] Each has its own specific qualities. It is the responsibility of the designer of a subterranean structure to thoroughly study each type in order to evaluate which is best for a given situation.

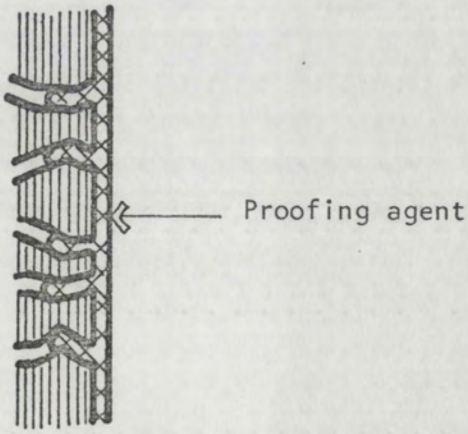
Surface treatments involve the exterior pores of the materials. They penetrate only a small distance into the pore, and render the pore non-wetable With this done, the process of capillary action is unable to begin. A side benefit, and possibly the best, is that air is still able to penetrate through the concrete. Gels may be applied to or mixed with the concrete. They expand to seal pores when in contact with moist air, but still allow dry air to pick up attached moisture.

Water proofing materials are non-porous, such as wax, plastics, and tar felt. All are added to the wall to waterproof it. They prevent the pores of the material to allow passage of water, liquid or vapor. They stop evaporation extremely well. Yet, by their nature they can cause problems. They stop water from traveling completely through the material; therefore, it is trapped on the material side of the waterproofing sealant. The structure may then become waterlogged, and damage may, and probably will result.

Another method of dealing with water within the soil is to drain it away from the underground structure as rapidly as possible. This can be done on the surface and underneath the surface. Where the water table is low and of no problem, infiltration can be minimized by normal surface drainage practices (in addition to waterproofing techniques described earlier), such as sloping the ground surface away from the structure to prevent as much direct seepage as possible. Another method, which can be expensive, is



SURFACE TREATMENT



WATERPROOFING MATERIAL

FIGURE 36
METHODS FOR WATERPROOFING SUBTERRANEAN STRUCTURES[11]

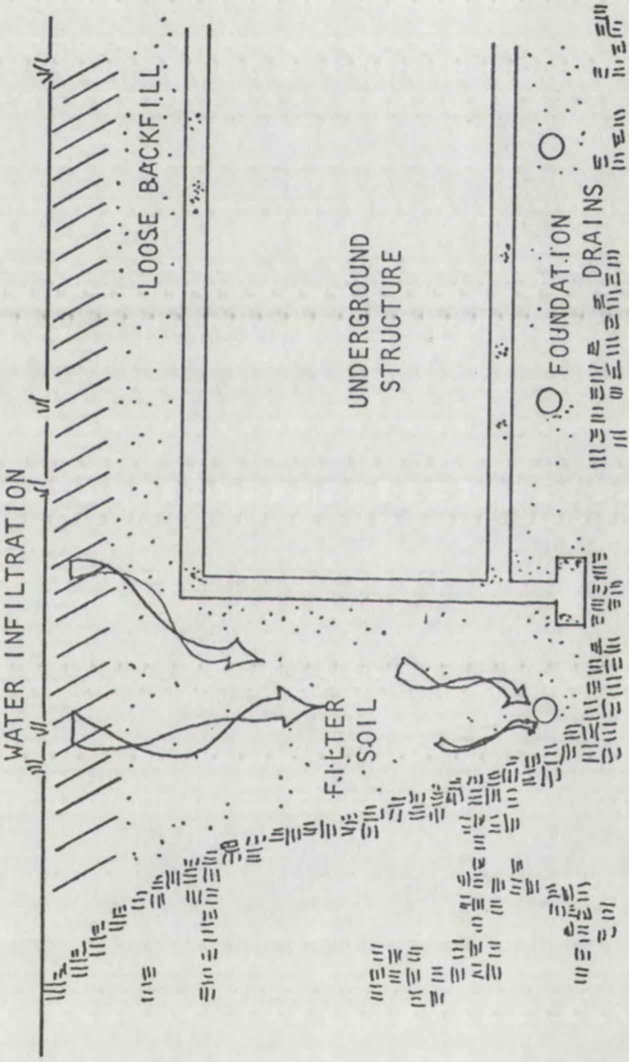


FIGURE 37
INFILTRATED WATER REMOVAL[12]

to seal the surface with asphalt or concrete, but in some cases is necessary if the soil immediately adjacent to the structure would hold large amounts of standing water. Possibly the easiest and least expensive is to use a very loose back fill around the entire structure in combination with foundation drains. Figure 37 shows how this is typically installed.

FOOTNOTES

1. James W. Scalise, Earth Integrated Architecture (Tempe, Arizona: University of Arizona Press, 1975), p. G-13.

2. Ibid.

3. Scalise, op. cit., p. D-5.

4. Ibid. p. D-6.

5. Ibid., p. D-9.

6. Opinion expressed by John King, personal interview, December 8, 1974.

7. R. M. E. Diamant, Insulation of Buildings (Van Nostrand-Reinhold Co., 1969), p. 117.

8. Ibid., p. 138

9. Ibid., p. 140.

10. Scalise, op. cit., p. E-8.

11. Ibid.

12. Kenneth Labs, "Architectural Use of the Underground" (unpublished Master of Science Thesis, Washington University, 1975), p. 17.

SOCIAL, LEGAL, AND CODE RESTRICTIONS

SOCIAL, LEGAL, AND CODE RESTRICTIONS

Society places restrictions upon its member's actions, normally for the good of the society as a whole.[1] They, the members of society, do benefit, through increased safety and well-being, if the regulations are well thought out, and are not overly restraining. Governing agencies, laws, regulations, and controls are formed or inacted to achieve the goal of social good. "These concepts interact with the creation of the built environment in the form of legal and financial constraints which establish parameters in which the built environment must operate."[2] Building codes, zoning ordinances, fire regulations, mortgage practices, investment methods, and sources of special funding are all constraints which will be of concern to the designer of a subterranean structure, as much as they are to the designer of a surface structure. Each of the items has a particular area of control, although in a few cases, they cross over slightly. They establish limits of control, and are particular to those limits of control.

Space arrangements and minimal area sizes are covered by building codes (See Appendix 57). Land-use, visual controls, structural design, area-use, and relationships are controlled by ordinances. Both are directed at conventional building types, and may be a source of constant exasperation to the designer of a presently non-conventional type, such as an underground structure.

Mortgage regulations and investment funding are financial constraints. They control the scale of the project and its scope of design. Their areas of concern are for the safety of investment and in guarantees of returns on investments. FHA regulations, HUD programs, and other funding or regulatory bodies may govern the design by making it impossible for the designer to elect the subterranean option for a client.

Financing of a project may come from one of several types of lending institutions. Commercial banks, savings and loan associations, and thrift and lending institutions may directly help finance the project. Investment trusts, insurance corporations, and the federal government may assist the project indirectly. Financial backers of construction projects are conservative institutions, and they encourage conservative designs. Unproven or non-conventional design is difficult to justify to a financial organization that "thinks" in terms of investment safety and guaranteed returns on investments.

Financing institutions look at three areas of a project in their evaluation of its loan feasibility: a) the person, evaluation of his past credit records, his status as a responsible credit risk, and his financing request in relation to his financial status; b) the land, its value, the real estate around it, projected valuation, market trends, and community influence; c) the project, which is the largest factor of control in lending, through appraisal and market evaluation, aesthetics and style, anticipated durability and maintenance. Each of these three factors can be extremely important, and may make or break the financial backing of a building project, either surface or subterranean.

The designer who feels that the subterranean concept has merits should attempt to determine which tangible objections he will have to consider. There might also be hidden intangibles that would negate his entire design. Why do some people dislike an underground environment? Do they even feel uncomfortable underground? Do they imagine large numbers of underground facilities would create a surface environment that was uninviting and uninhabited except by troglodytes hurrying from one subterranean complex to another? Would the lower visability of underground structures give rise to higher density construction that would result in even more "urban blight?" No one knows the number of questions that will develop if use of the subterranean structures becomes widespread. Psychological and cultural factors will need to be explored and better understood as part of the design process.

The ABO School was the world's first completely underground elementary school.[3] Because of the age of the pupils (and their conditioning) and the age of the faculty and staff (and assuming their more fixed state of conditioning), there were highly detailed and thoroughly evaluated records kept of every conceivable aspect of life in the ABO school. Pupil achievement, anxiety and mental health, opinions about the school, psychological effects, and general health were topics that were studied for ten years following construction. The conclusion of the study was:

> It seems that after ten years of experience with children attending an underground and windowless school, the professionals concerned with the health care of children....are generally convinced that not only is the school not detrimental to the physical and mental health of their patients, but it is actually a benefit to some.... the public clearly favored the school.[4]

Architects have neglected to take advantage of the merits of subterranean structures. Part of the reason for that neglect may be that there is a certain psychology of enclosure. For some persons it is as obviously manifest as a fear of having their face covered by a blanket. In others it may appear as a fear of death and subsequent burial. The sense of enclosure does not have to be linked with real restrictions; it need only be implied.

This psychological reluctance of some persons to look at the underground facility with an open mind, may lead to a real perceptual barrier to subterranean design and construction. Tests have proven that workers and students are generally not subject to additional psychological stress by the use of windowless or underground facilities. Often there is a reduction of worker stress, as well as work-related accidents.

The existence of a perceptual barrier leads one to assume that there may be a promotional barrier to underground design also (See Appendix IV).[5] Architects with little experience in creating pleasant subterranean environments fall back upon surface design techniques, (generally with poor results). Initially, designers of subterranean facilities try to move the facades of surface structures to the underground, and they seem out of place. If subterranean architecture becomes widely accepted, it will evolve its own style that will appear as incongruous on the surface as surface design appears underground.

It is important to note that there appear to be no adverse psychological effects from working or living in properly designed subterranean facilities.[6] Interviewers find some particular situations that create disfavor among isolated users of subterranean facilities. "My hours were so long that it was dark when I went in and dark when I came out."[7] "I'm an amateur meteorologist, and I want to see what kind of weather is developing."[8] However, the normal situation is one that finds the occupant to be very enthusiastic. "The children respond to audio-visual aids more than any other learning tool, and here (ABO school) we have ideal conditions for their use."[9] "Symptoms of hay fever and other allergies are almost non-existent among our employees."[10] "I like it here."[11]

The growing "recreational craze" is one thing that might be greatly helped from the opening up of surface area as a result of subterranean construction. More free time and more interested participants have created larger crowds at most recreational sites. The use of the underground for the living and owrking portions of our lives will open up large areas for the recreation and social part of living. It should not create a society of "moles." Instead the convenience and use of ever-expanding areas of open surface will bring out people in greater numbers than ever before.

FOOTNOTES

1. Robert Ardrey, The Social Contract (New York: Del Publishing Co., 1970), p. 3.
2. James W. Scalise, Earth Integrated Architecture (Tempe, Arizona: University of Arizona Press, 1975), p. F-1.
3. James G. Cooper and Carl H. Ivey, Final Report of the ABO Project, New Mexico Department of Education (Santa Fe: 1964).
4. Ibid.
5. Richard E. Lonsdale, "Underground Space as a Locational Consideration in Industry," (paper presented to Symposium on Underground Space Use," Kansas City, Missouri: 1975).
6. Opinion expressed by Abner Brunson, Personal interview, March 5, 1975.
7. Statement by Bob Schmitt in Personal Interview, November 13, 1974.
8. Statement by Lance Sommers in Personal Interview, December 16, 1974.
9. Opinion expressed by Richard Bach, Personal Interview, January 8, 1975.
10. Brunson, op. cit.
11. Statement by Larry Williams in Personal Interview, January 21, 1975.

DESIGN EXAMPLES

DESIGN EXAMPLES

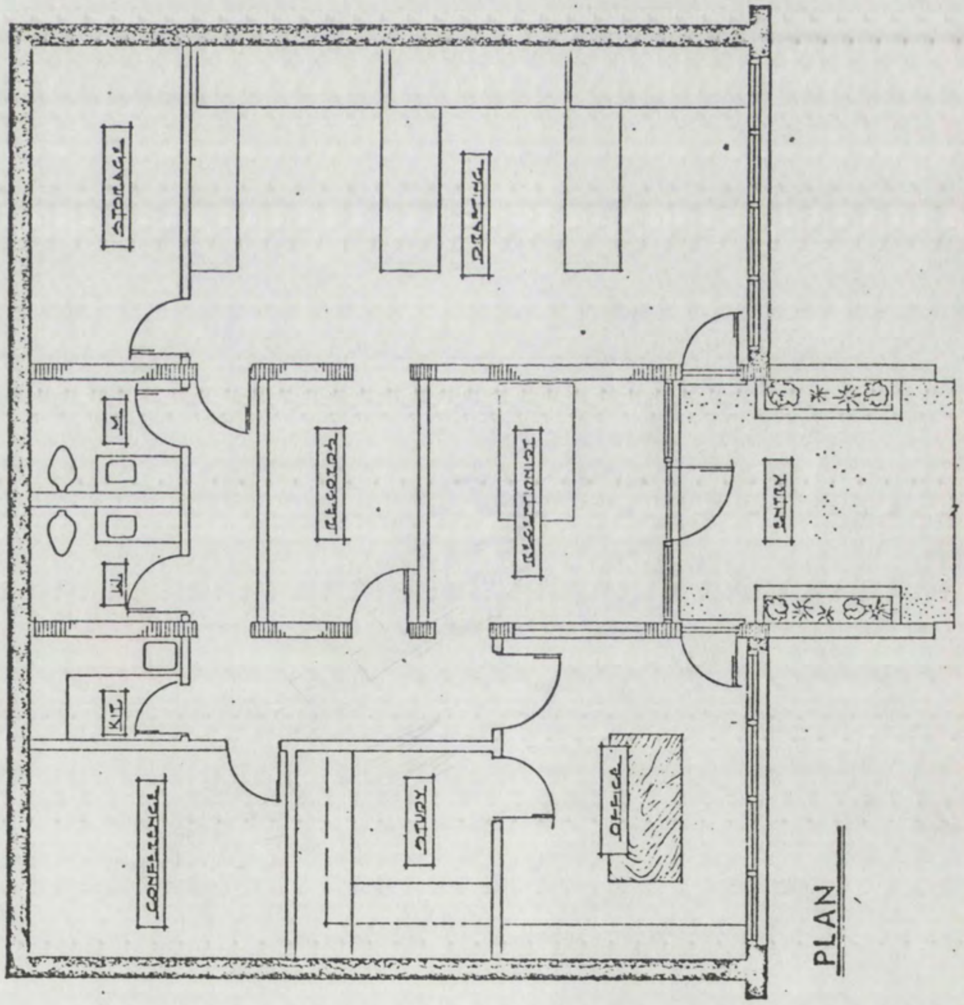


FIGURE 38
BERMED AND COVERED OFFICE - FLOOR PLAN

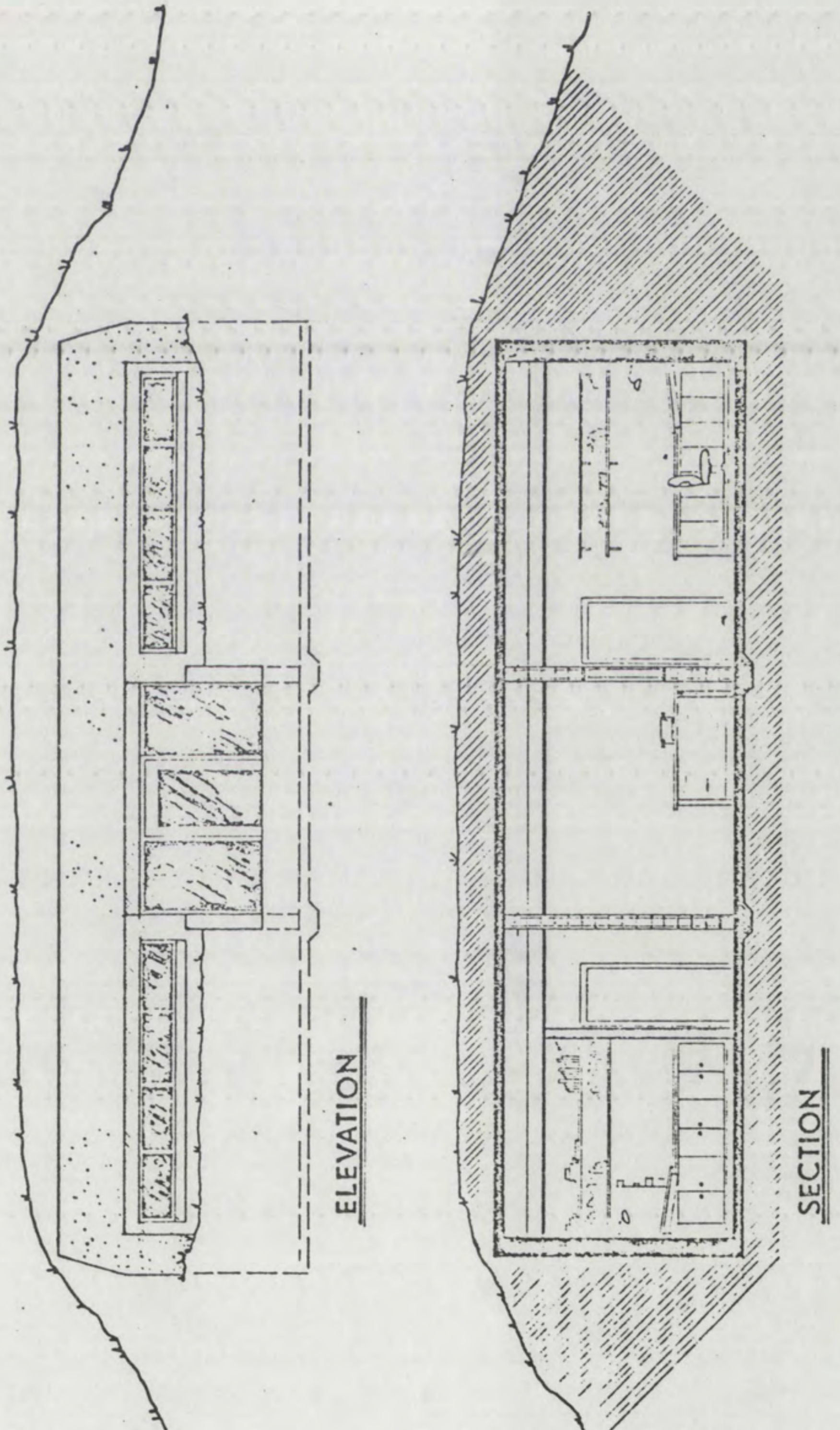


FIGURE 39
BERMED AND COVERED OFFICE - ELEVATION AND SECTION

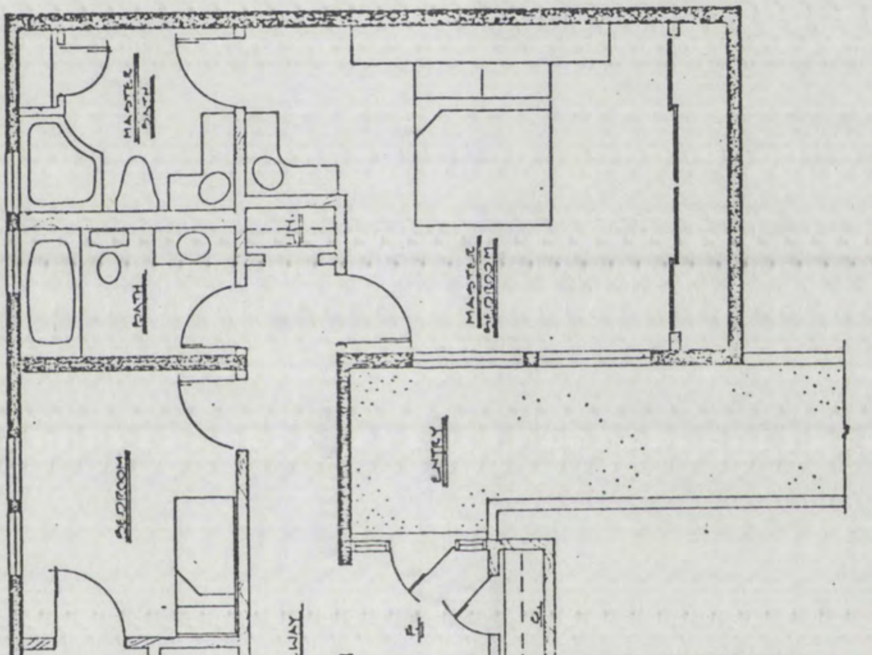


FIGURE 40
COURT GARDEN HOUSE - FLOOR PLAN

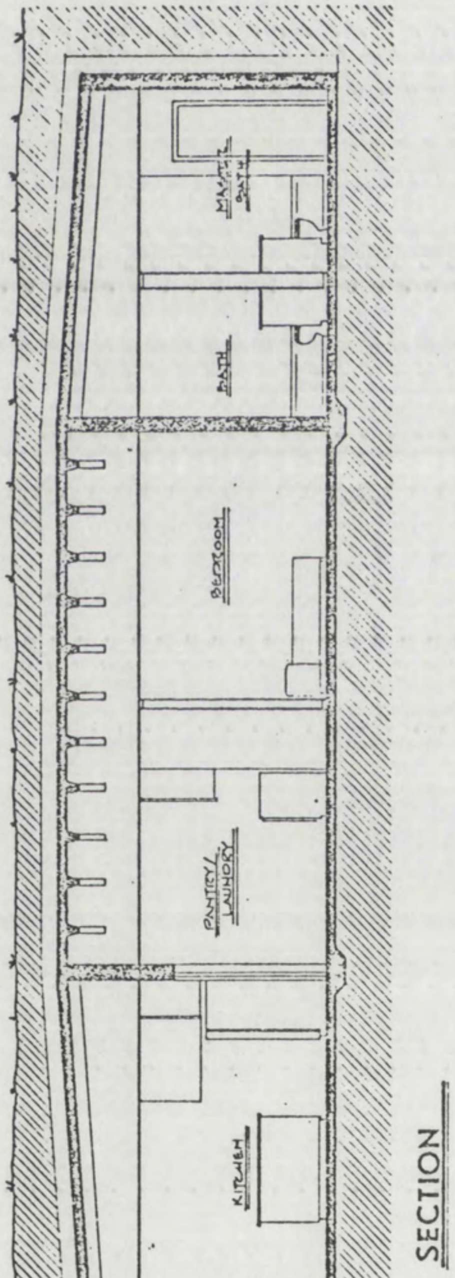


FIGURE 41
COURT GARDEN HOUSE - SECTION

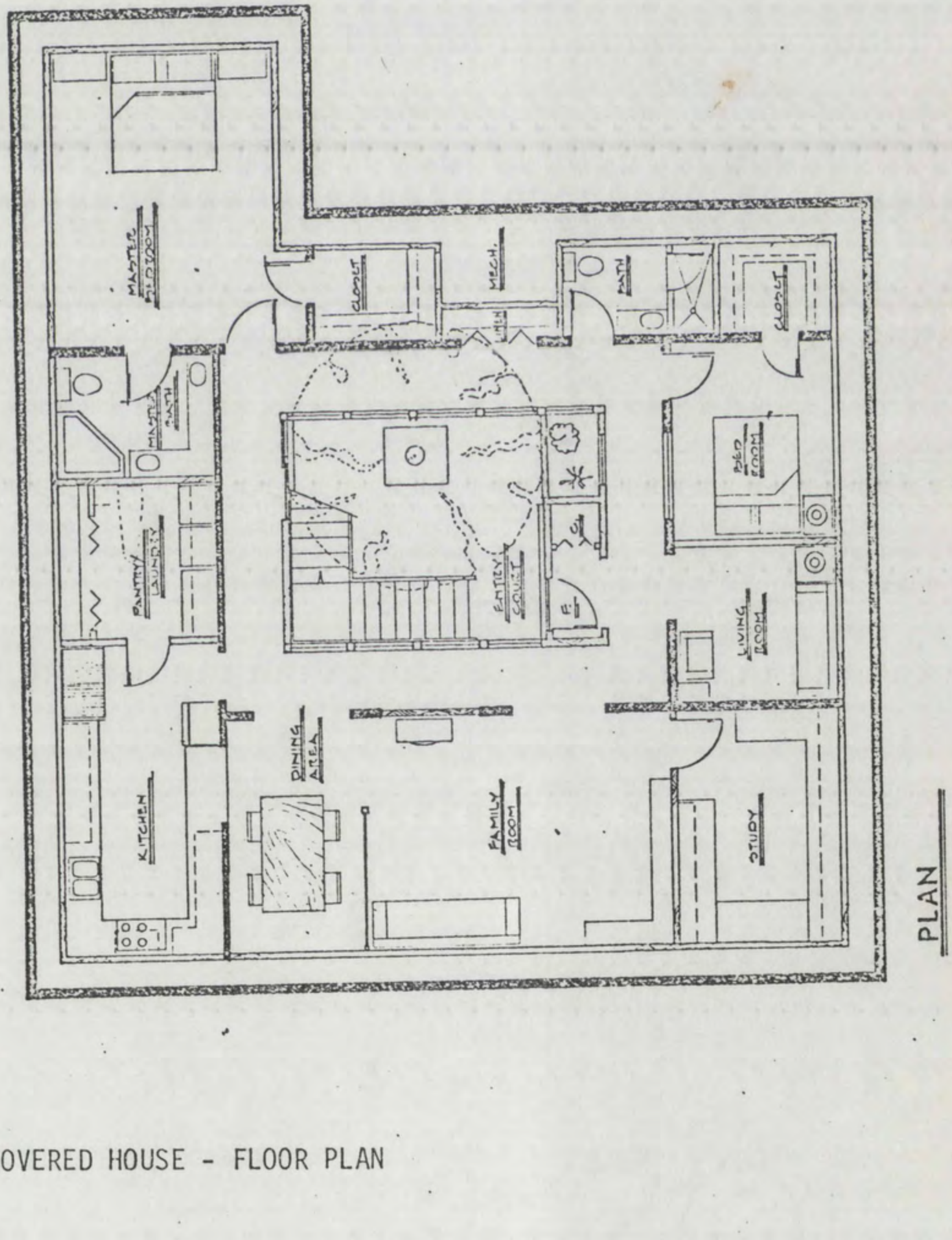


FIGURE 42
BERMED AND COVERED HOUSE - FLOOR PLAN

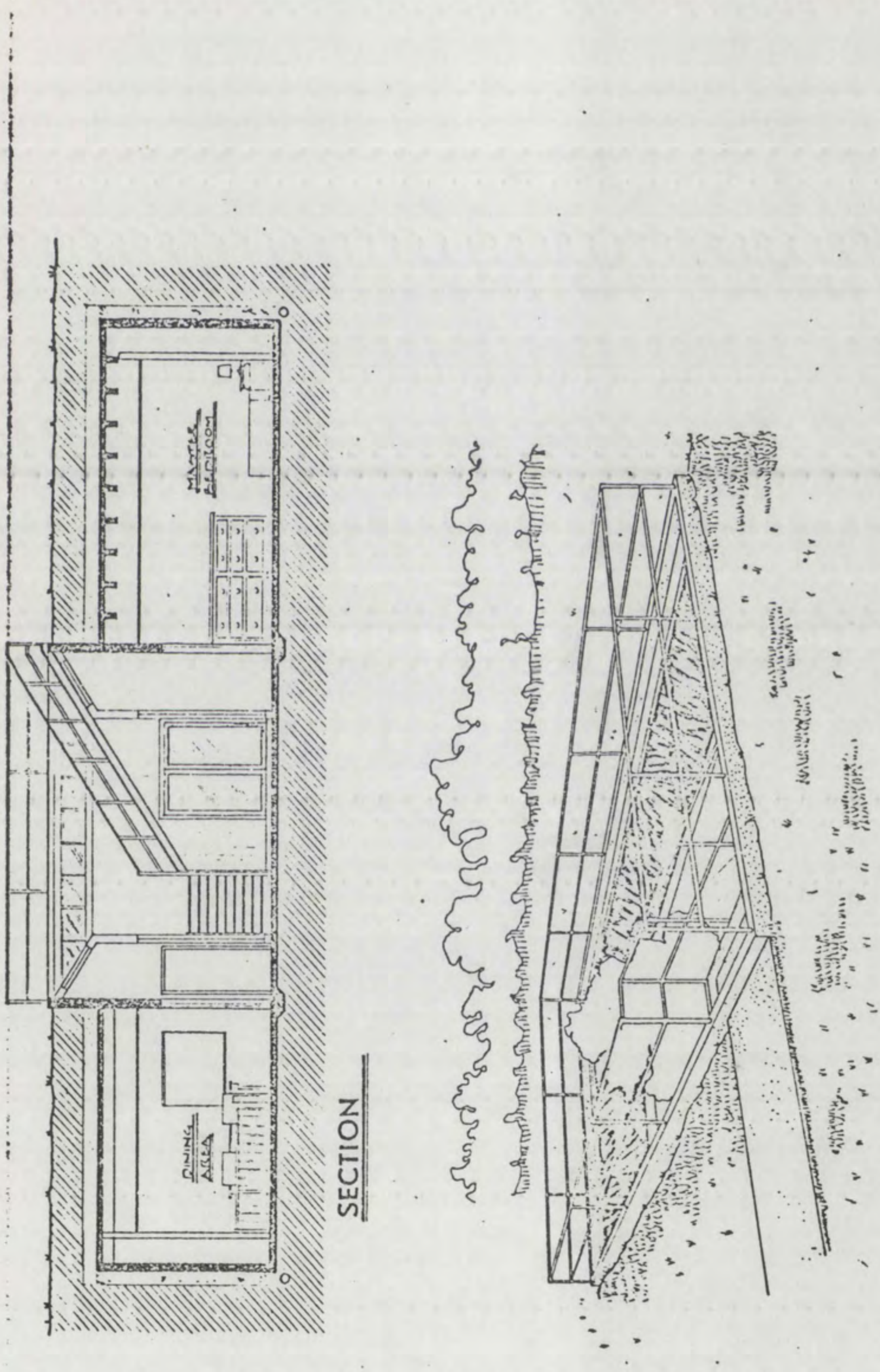


FIGURE 43
BERMED AND COVERED HOUSE - SECTION AND PERSPECTIVE

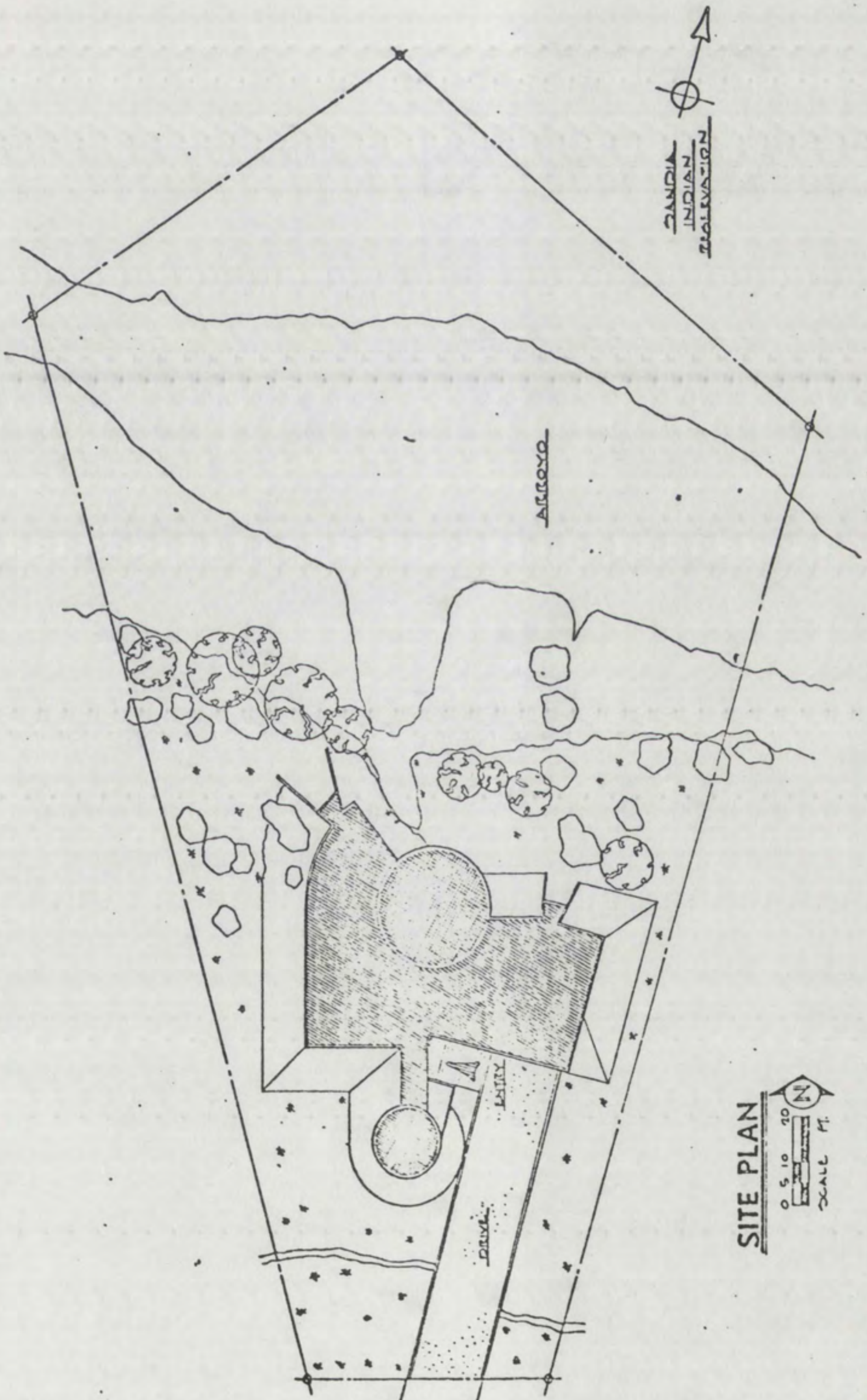


FIGURE 44
BERMED AND COVERED HOUSE - SITE PLAN[1]

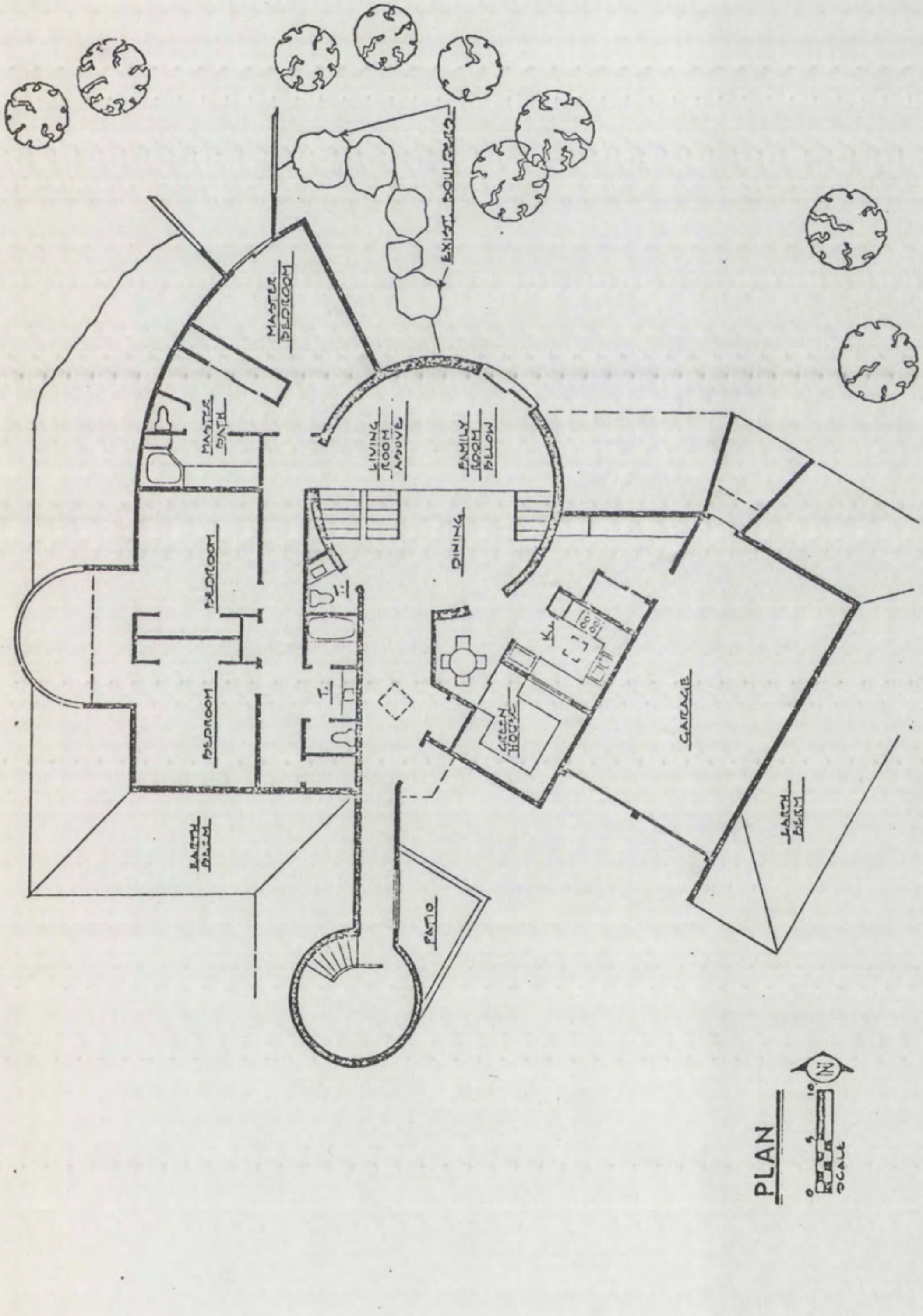
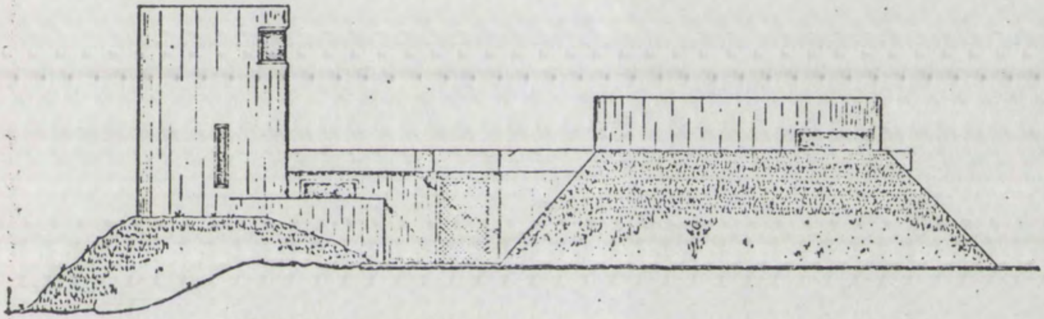
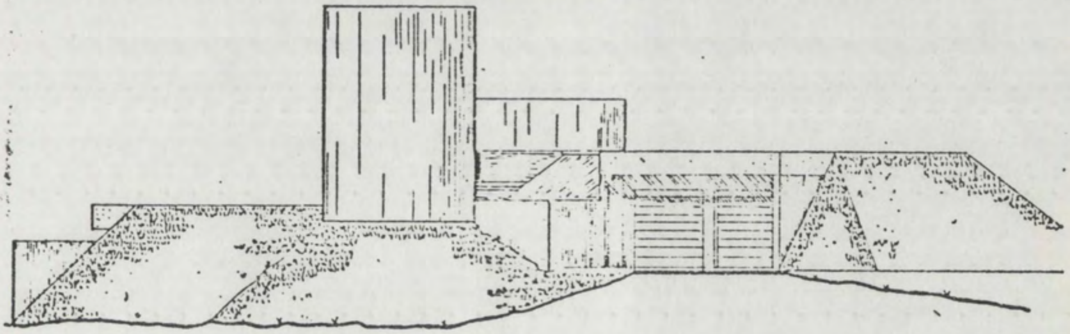


FIGURE 45
BERMED AND COVERED HOUSE - FLOOR PLAN[2]

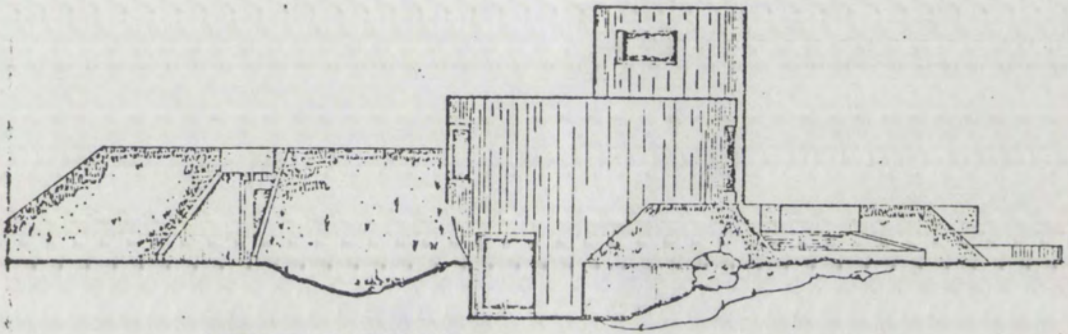


EAST ELEVATION

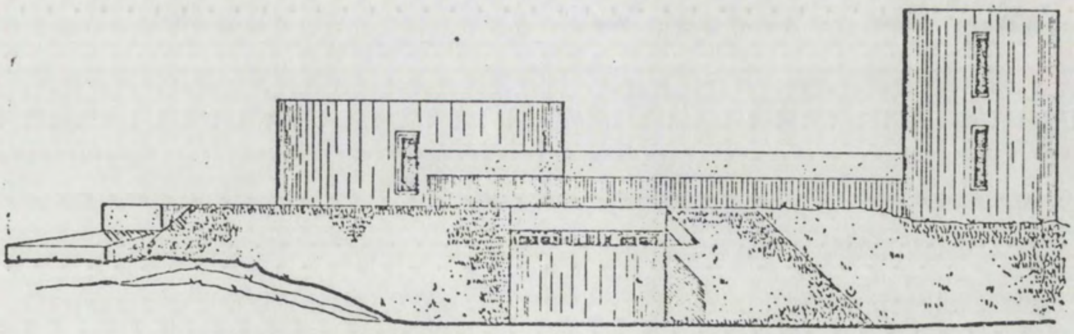


SOUTH ELEVATION

FIGURE 46
BERMED AND COVERED HOUSE - ELEVATIONS[3]



NORTH ELEVATION



WEST ELEVATION

FIGURE 47
BERMED AND COVERED HOUSE - ELEVATIONS[4]

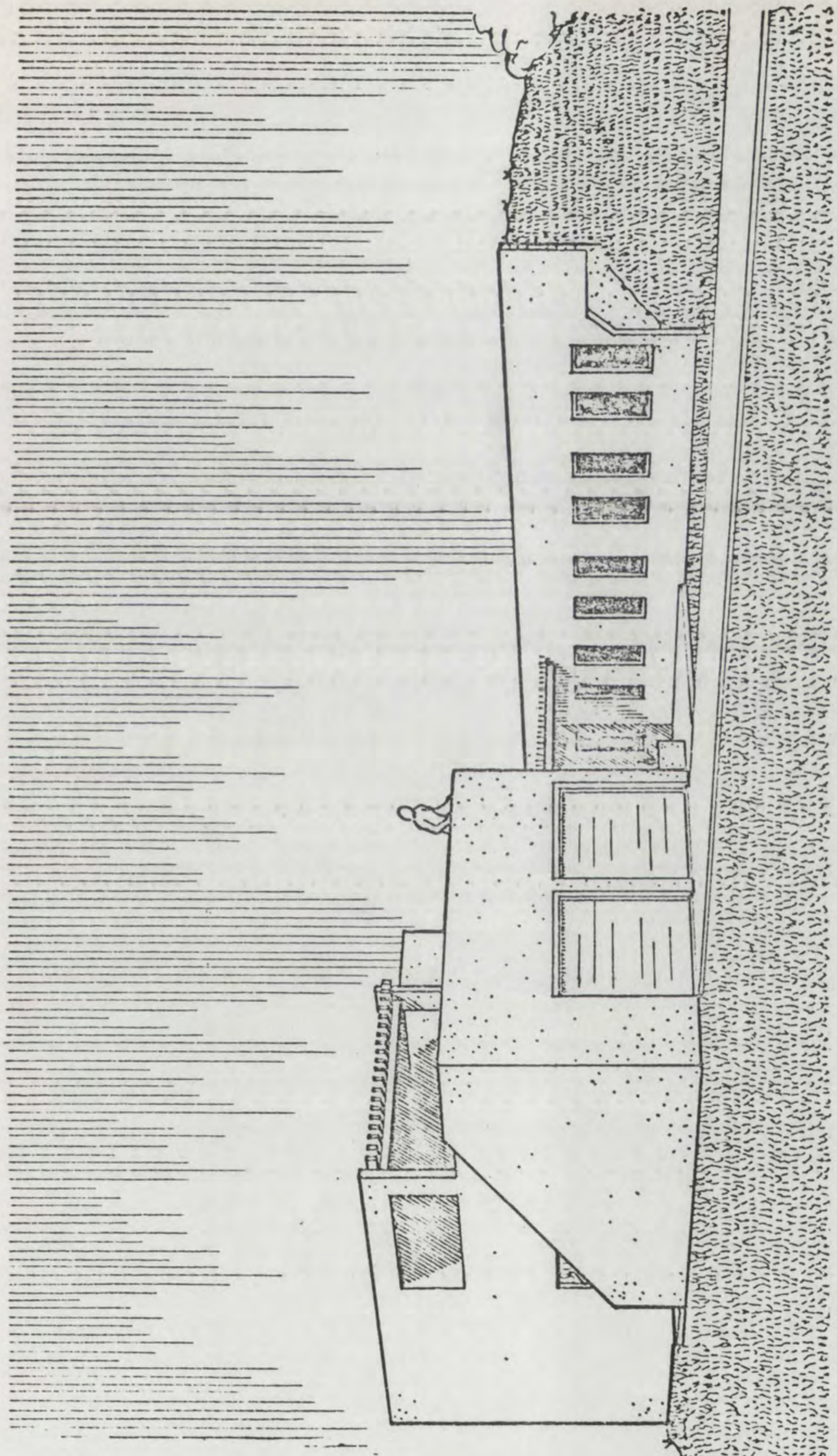


FIGURE 48
BERMED AND COVERED HOUSE - PERSPECTIVE

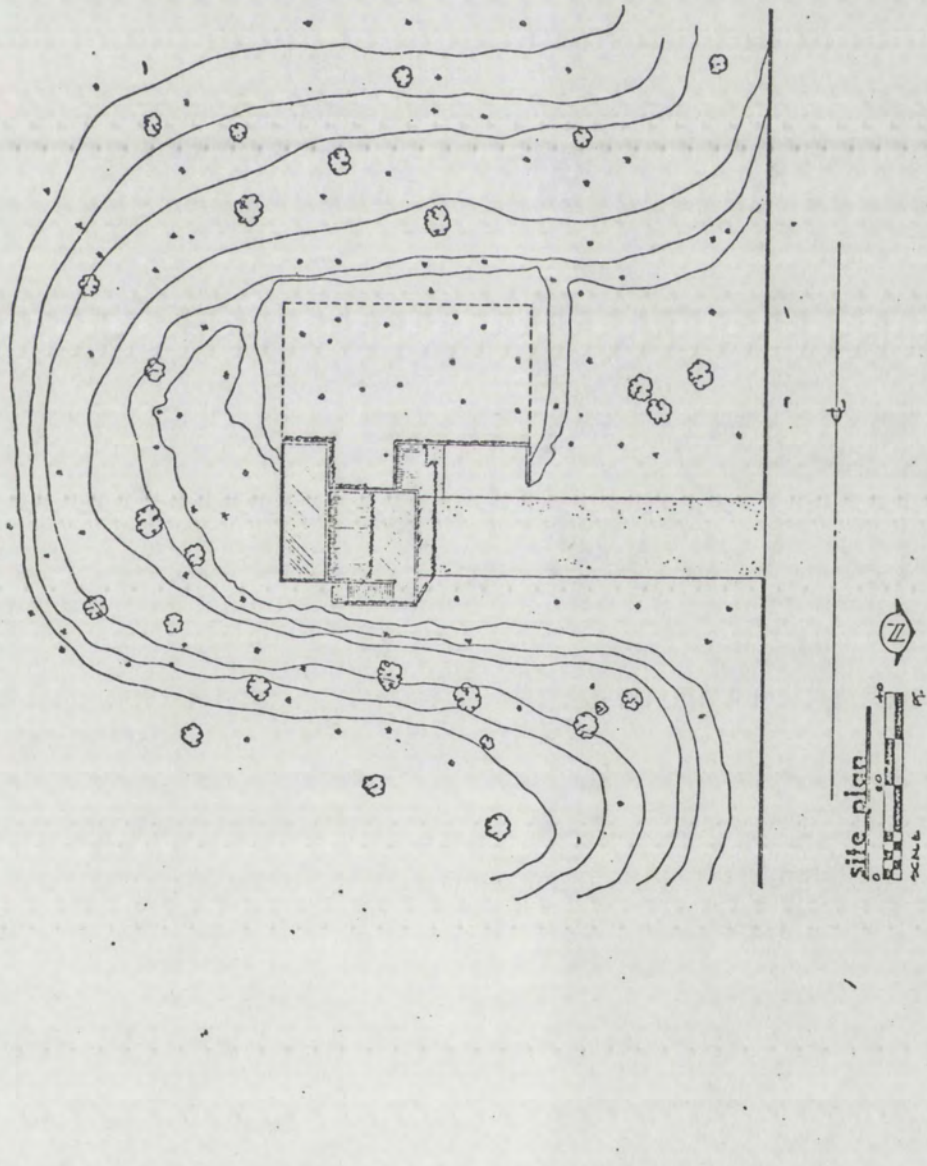


FIGURE 49
BERMED AND COVERED HOUSE - SITE PLAN

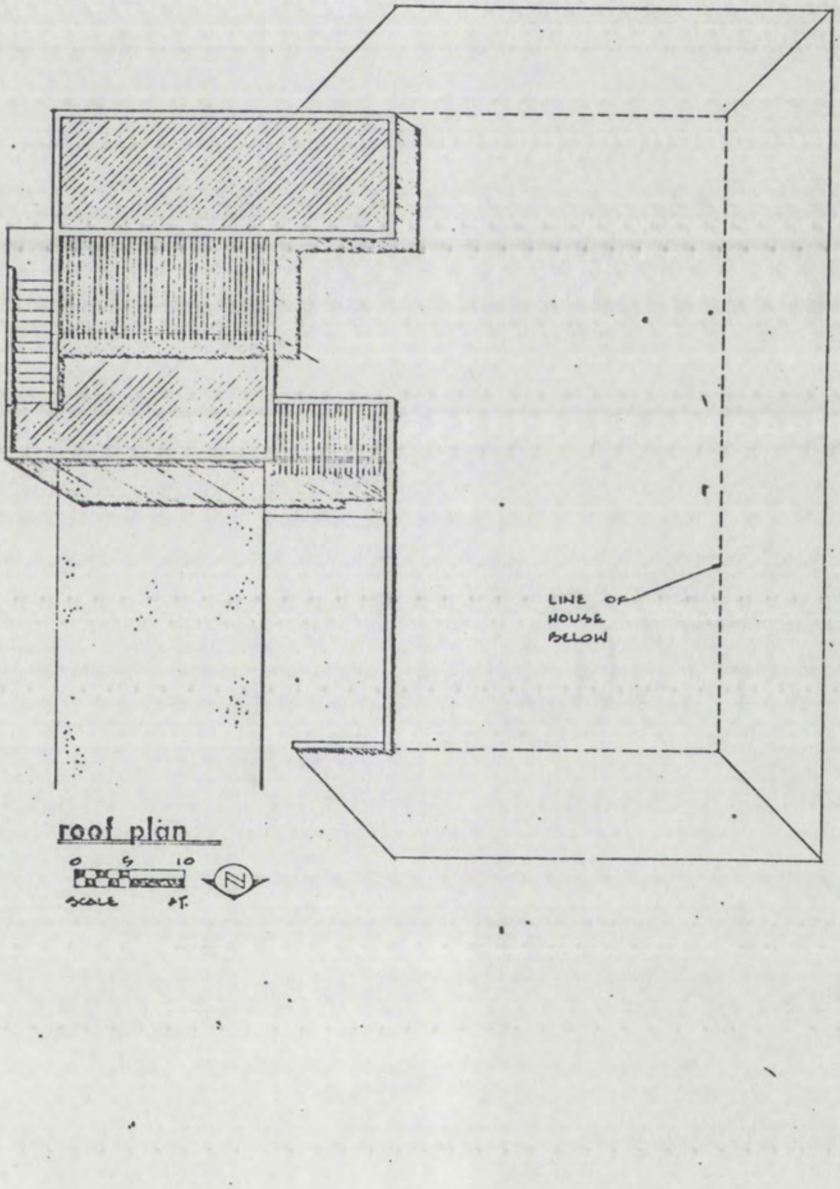


FIGURE 50
BERMED AND COVERED HOUSE - ROOF PLAN

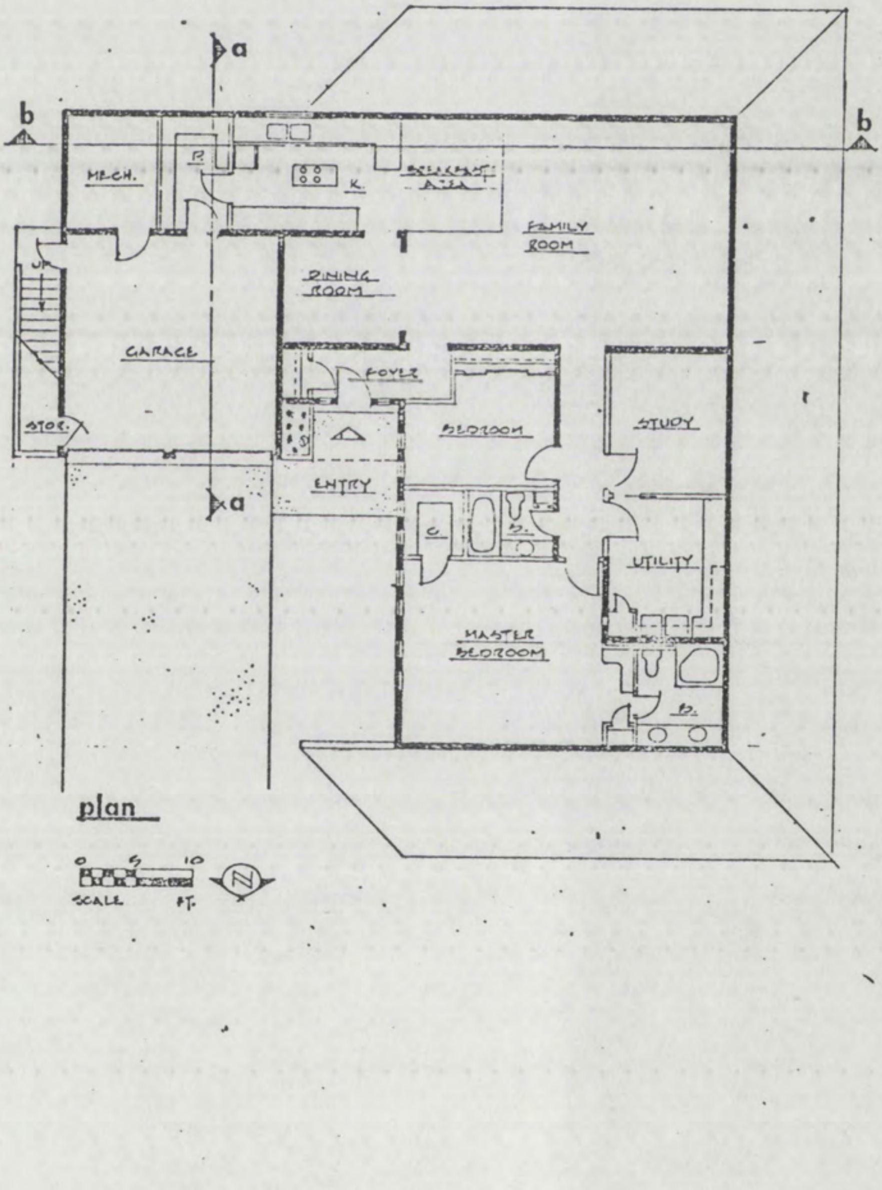


FIGURE 51
BERMED AND COVERED HOUSE - FIRST FLOOR PLAN

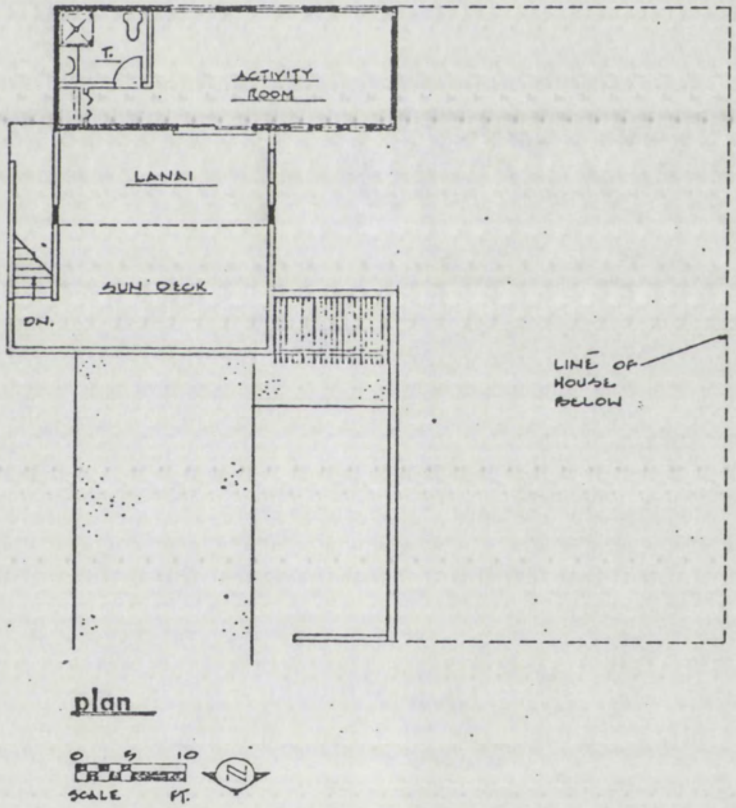
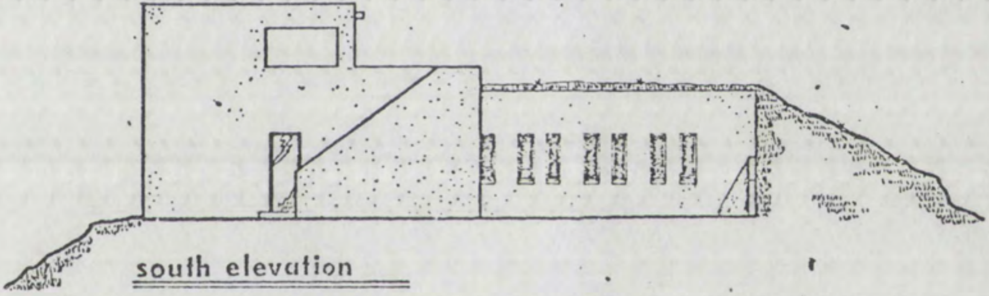
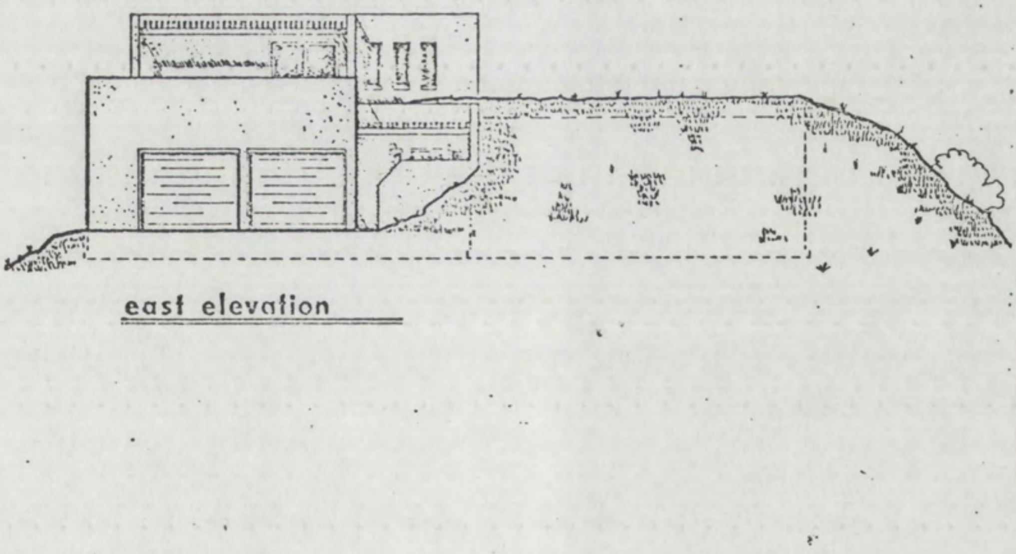


FIGURE 52
BERMED AND COVERED HOUSE - SECOND FLOOR PLAN

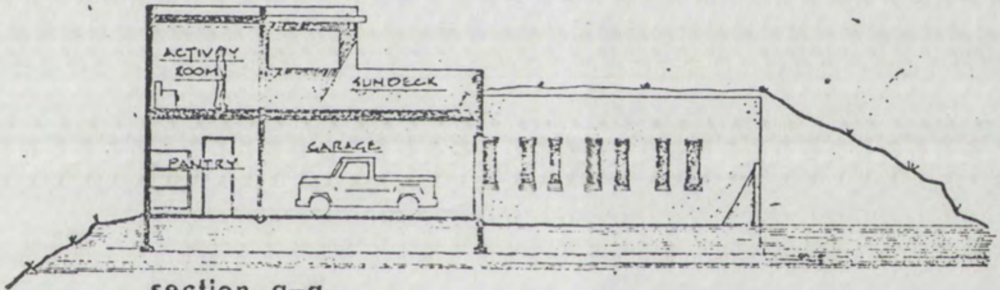


south elevation

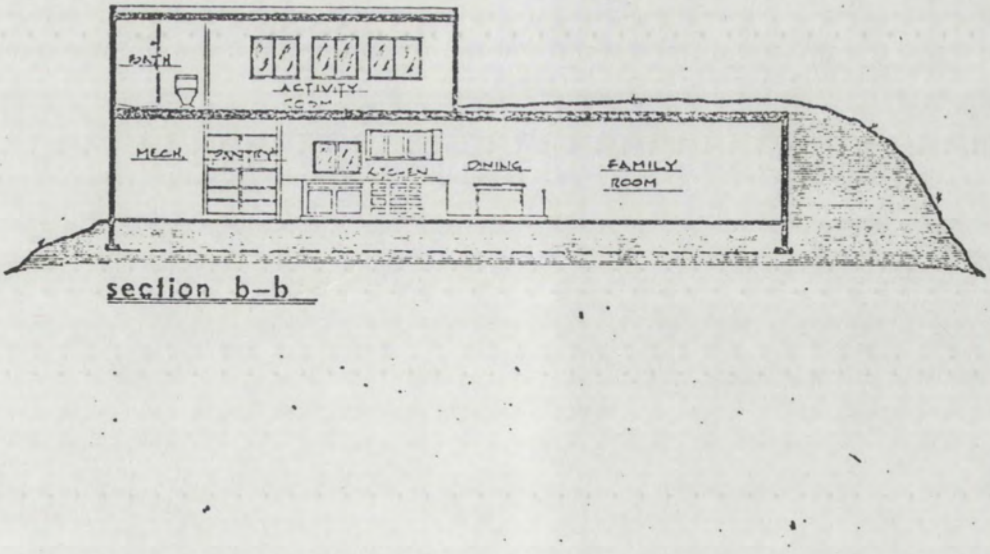


east elevation

FIGURE 53
BERMED AND COVERED HOUSE - ELEVATIONS



section a–a



section b–b

FIGURE 54
BERMED AND COVERED HOUSE - SECTIONS

FOOTNOTES

1. Design by David Fry, 1975, (redrawn by author).
2. _Ibid._
3. _Ibid._
4. _Ibid._

SUMMATION

SUMMATION

This paper has shown that the subterranean design concept is a valid option for achitects and other design professionals. It has also provided them with the information needed to advocate a subterranean design. It has done this by showing examples of historical usage of the underground concept, presenting examples of current use of subterranean space, emphasizing the different classes of subterranean use, mentioning areas of advocacy within the concept, covering the thermal advantages of earth covered-buildings, touching upon the relationship of the underground structure and the surrounding earth through the physical characteristics of soils, explaining the limitations of underground construction concepts, telling of the social, legal, and code inhibitors of subterranean design, and by showing several basic design types that can presently be built within the framework of present technology and legal restrictions.

Each separate facet of the subterranean design concept is important. Taken separately they can give a negative impression of the concept, but together they show that architects have been neglecting a very important area of design when they ignore the positive usage of subterranean architecture.

APPENDICES

UNDERGROUND SPACE USE: CLAIMS PRO AND CON

The following list is compiled from references in the literature and from issues cited in documentation of design proposals; no attempt will be made here to identify those sources, as most of these issues are discussed in the text or should be self-evident, at least under certain conditions.

+amelioration of, and protection from climatic extremes (both constant and seasonal severity)

+a more stable atmospheric environment (internal with respect to temperature and humidity

+protection from many natural and man-made disasasters, incl. tornadoes, hurricanes, fires, earthquakes, warfare, airplane crashes (primarily for near-airport locations)

+acoustical isolation: both internally and externally (keeps sound in, keeps sound out)

+increases security and control over both access and egress

+a more suitable (by a multiplicity of factors) environment for some activities and functions (see Kansas City warehousing, e.g.)

+separation of conflicting and unrelated functions in space, e.g., pedestrian and vehicular circulation systems, utility lines (may also involve public safety)

+preclusion of land use districting as a result of disruptive and undesirable surficial applications (highways, factories)

+more intensive and more efficient land use, resulting in multiple economic returns

+economic savings due to decreased energy consumption

+savings due to decreased overhead--fire insurance rates, maintenance, other operating costs

+preservation of open space in congested areas, of landscape in "Natural" areas

+aesthetic gains through the elimination of "visual pollution" and the overtaxing of senses

-restrictions imposed by climatic and physiographic region, and of geological circumstance

-difficulties with condensation and high humidity

-lack of visual identity, image, "presence"

-modes of access less direct and perceptable

-difficulties of linkage with surficial and other (present and future) underground facilities

-higher initial cost of construction (investment)

-objections to windowlessness and assumed effects

-problems of palatability and public acceptance

-inflexibility w/ respect to future expansion

-economic gains primarily on long term basis

The underground dwelling:*

Forms its own shelter against most natural and man-made disasters. These disasters include tornadoes, airplane crashes, wars, and fires in the adjoining residences.

Offers additional security against burglary by limiting access to the building interior only through the doors.

Reduces the effect of vibrating equipment by the 3-dimensional support of the surrounding earth. This could include motors as well as nearby aircraft.

Requires less exterior periodic maintenance to maintain the neighborhood image since the exterior is buried.

Isolates the resident from exterior acoustics because of the outstanding sound attenuation characteristics provided by several feet of earth. In this way it would provide a psychological privacy presently unknown to city dwellers.

Preserves the landscape, which would be interrupted only be streets and entrances. A resident upon emerging would look on greenbelt rather than a series of houses although the dwelling density would be the same.

Requires less energy consumption for environmental comfort because the earth maintains a 54-degree temperature and low heat transfer coefficient below the frost-line.

Additionally, an underground subdivision offers several possibilities to the planner:

Since privacy can be maintained with a limited separation between houses, dwelling separation could be reduced.

The useable yard area would include the area above the house; yard size could be reduced without restricting the resident.

Smaller lot sizes and smaller house separation would reduce utility runs.

The disadvantages to the underground subdivision are believed to be fewer in number:

The structure could not be used in an area of high ground water level or in a flood plain.

Exterior air would have to be brought into the house in a fan duct system for odor free air. Normal surface house infiltration takes care of this requirement. The expense of installation of the system would be minor.

The electrical lighting expense of the house would be increased by one-third due to the lack of exterior light.

Areas of potential seismic disturbance would require substantial structural reinforcement or would preclude such dwellings.

Some individuals react against a windowless environment, even though there is no apparent differences between a windowless office in a building interior and one under the ground. This is the most difficult complaint to quantify.

*From: IS IT TIME TO GO UNDER GROUND? By Lt. Lloyd Harrison, Jr. CED-USN.

LEARNING UNDERGROUND

By Dean Robinson
Principal, Abo Elementary School

The Abo Elementary School is one of eleven elementary schools in the Artesia school district. The only difference between this school and several others in this district is that this building facility is underground. There has been much national publicity about Abo School and many articles have been written about the school. The Abo Elementary School is probably the best-known elementary school in America today.

This building affords an ideal climate for maximum learning. Being built underground, it is possible to completely control the physical environment. The lighting is controlled artificial lighting with the same intensity in all parts of the classroom and is better than most conventional buildings as there is no glare from outside natural light sources. This makes possible any type of room arrangement necessary for group study or maximum learning situations or activities.

The building has year-round refrigerated air conditioning so that the temperature remains constant at a very comfortable 72°-74°. The air is filtered entering the building, removing pollen and dust particles and making it possible for students with allergies to enjoy school to its fullest. Children with severe cases of asthma and other allergies have been transferred from our conventional schools to Abo. Their health improved and there was a concurrent decrease in absences.

One important advantage for teaching in Abo is the opportunity for using visual aids in the classroom. Each classroom is equipped with a screen and the classrooms, of course, are easily darkened. We are in the process of equipping each room with an overhead projector for desk use. We are in a good position to take advantage to the maximum of the new visual aid devices being offered to schools today. Cable television within the building makes it possible for us to use the educational programs available now and those coming in the future.

Flexibility--Maximum

The rooms themselves offer advantages for maximum teaching. There are four walls available for display purposes. The chalkboards are magnetic boards and are movable from place to place in the room. It is possible to adjust and arrange the chalkboards, bulletin boards, and pegboards in the individual classrooms in any arrangement desired for maximum learning and teaching opportunities.

Another great advantage to learning offered by the building is its quiet. The structure of this building subdues noise and the building is unusually quiet even with normal student movement. The most frequent remark of teachers visiting the building from other places is the unusual quietness. The quiet tends to bring forth an attitude of dignity and respect. All street noises, and playground noises have been eliminated. It is impossible to hear the fire siren, rain, thunder, or the wind in spring. Eliminating outside noises and distractions allows us to realize the maximum teaching time in a day. This means having more time and a better atmosphere for extending student interest and broadening horizons.

The question has been raised by some as to the emotional and psychological effects on children, and adults in working and going to school underground. There was an extensive research project conducted in our district to find out if there was any adverse effect on children and adults. It was found there were no significant differences between our students and teachers than any others in the Artesia school district.

They Like It

We also conducted eye examinations for four years to see if there were any harmful effects upon the eyes. They found there were none. The school has been in operation for five years, and it is my sincere belief there have been no ill effects on any students or teachers who have attended Abo School. We have, I believe, the happiest, most contented students and teachers you would find in any school building in New Mexico. I doubt if anyone in Abo School would trade positions with anyone else if they were given the choice.

These features make this an outstanding school facility because they contribute to an excellent atmosphere for teaching, learning, and working. Where the physical conditions are nearly ideal and distractions are at a minimum, as in this building, there can be little doubt that students and teachers have the opportunity for maximum success in their work. We are all--the staff, the Board of Education, Superintendent, students, parents, and community--extremely proud of this fine school facility.

GENERAL INFORMATION

Abo Elementary School and Fallout Shelter

1. 18 classrooms, size 28' x 28' - multi-use rooms - administrative offices - storage - built to accommodate up to 540 students.

2. 34,000 sq. ft. at a cost of $13.85 per sq. ft. (This is approximately $2.00 per sq. ft. more than a conventional building would cost.)

3. Total cost of the building was $467,608.00, with Civil Defense participating in the amount of $134,000.00. (This is a pilot project for the nation.(

4. Structure is concrete and steel - 140 tons of steel - 4,000 cu. yds. of concrete.

5. Concrete is 21" thick over the entire building.

6. 13' - 9" from floor to top of building -- classroom ceilings are 9' 4" hall ceiling is 8' -- milti-use ceiling is 12'.

7. The building can be self-contained if need be:

    a. Water well under building is used for air conditioning at all times, and will be used for consumption if needed for an emergency.

    b. The building is equipped with an emergency generator to operate all equipment, and over half of the lights in an emergency.

    c. Plans for emergency food rations and sleeping facilities are being completed.

8. Designed as a fallout shelter -- Abo will take care of 2,000+ if needed for disaster use.

9. Advantages of windowless classrooms:

    a. Body comfort -- heat and cool
    b. Proper lighting
    c. Minimum distractions
    d. Immediate light and ventilation for A-V
    e. Use of window walls as a teaching wall; chalk board, display, etc.
    f. Minimum of dust, etc.
    g. Elimination of window breakage; washing and painting; no shades or maintenance of same
    h. Reduces allergies and asthmatic conditions to a minimum

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   h. Reduces allergies and asthmatic conditions to a minimum

The Stimulus--

Artesians are influenced by the birth of the atomic age July 16. 1945, at neighboring Alamogordo, plus the proximity of the system of Atlas missile complexes surrounding Walker AFB, an arm of the Strategic Air Command.

The Concept--

Several windowless schools have been built in Artesia and nearby districts for optimum environment via light, temperature and ventilation control; minimization of dust, allergy and distraction; an extra wall for teaching space, and constant audio-visual readiness.

Frank M. Standhart of Roswell, N. M., the Abo architect, was first to design a windowless school.

The underground school, a logical extension, was conceived in a meeting between Standhart, the Artesia Board of Education and school Superintendent Vernon R. Mills. Civil Defense officials participated in the prototype school to the extent of the difference in cost between it and that of a conventional school, with authority for a research project on the psychological effects of education underground.

Ground was broken for Abo School on June 12, 1961. The contractor, W. R. Bauske and Company of Clovis, N. M., also built one of the first windowless schools.

The Product--

Completed April 20, 1962, Abo School is first in America and so far as is known first in the world to double as a fallout shelter. It will withstand blast pressures and tornadoes (rare in this region) which would demolish any type of above-ground structure.

Other expected advantages are more uniform temperature, reduced maintenance cost and long useful life.

Summary

☆ 540 students or 2,000 persons two weeks in emergency.

☆ 33,835 square feet at $13.85 with $336,780 local bond issue, CD contribution $131,843, total Abo cost $468,623.

☆ Approximate comparative costs: $11.44 square foot conventional window, $12.56 windowless, $13.85 underground.

☆ Named for Abo (AH-bo) geological formation 7,000 feet deep in vicinity, source of a major oil discovery. Its Manzano Mountain outcrop to the northwest is near site of Abo, possibly one of fabled Seven Cities of Cibola sought by conquistador Coronado, and certainly one of the "Cities That Died of Fear" of Apache raids. Name origin presumed Indian but meaning lost in antiquity.

☆ Late innovations; cafeteria tables wall-folded for multi-purpose, classroom seating adaptable any direction, acoustical ceiling, flexible pegboard and blackboard wall displays. Grounds 10 acres with school roof part of playground, an economy feature in high-value real estate districts.

☆ Integrated well, power generator, radioactivity filtered out, food-bedding storage, decontamination, sewage ejection, medical facilities, morgue. Both CD short-wave and KSVP standard AM radio facilities installed.

☆ Disaster plan: school-hour student priority, adjacent residential priority off-school periods; exact schedule for bathroom, eating, instruction, sleeping, recreation.

☆ Normal excavation, construction, topped with insulated concrete slab 21 inches thick. Steel doors $\frac{7}{8}$-inch thick, 1,800 pounds, bolted shut in crisis. Building material 140 tons steel and 4,000 cubic yards concrete.

☆ Joint study by U. S. Dept. of Health, Education and Welfare and state education department showed no adverse effects on teacher-pupil relations, anxiety, attitudes or scholastic acheivement in an underground school.

☆ No window breakage, washing, shade maintenance; usual window wall used for teaching display.

☆ Directional signs to Abo placed on highways, streets. Visitor guide service during normal business hours by calling school administration office, Abo, Chamber of Commerce, or City Police Department.

TABLE 1

Costs of Abo Aboveground "Windowless" Elementary School Compared with Costs of Abo Belowground "Windowless" Elementary School and Fallout Shelter.

Item	Bid A - Belowground				Bid B - Aboveground				Difference
	Quan.	U.	Unit Cost	Cost	Quan.	U.	Unit Cost	Cost	Cost
			$	$			$	$	$
1a. Plant & Equip.		LS		1282		LS		973	309
2a. Bond, Ins., Permit		LS		4650		LS		3750	900
2b. Administration		LS		20088		LS		14766	5322
3a. Excav. & Fill	20302	CY	.59	11953	4818	CY	1.47	7075	4878
3b. Conc. & Masonry Walls	840	CY	35.40	29755	358	CY	81.30	29111	644
3c. Other Concrete	2432	CY	25.85	62862	694	CY	26.84	18626	44236
4a. Steel & Iron	161	T.	285.00	45870	80	T	342.00	27363	18507
5a. Misc. Metals		LS		5535		LS		2252	3283
7a. Carpentry		LS		5810		LS		5653	157
8a. Millwork		LS		18337		LS		18337	
9b. Hollow Metal	13	Ea.	200.00	2600	20	Ea.	125.00	2500	100
9c. Toilet & Shower Compartments	28	Ea.	121.00	3394	17	Ea.	79.40	1350	2044
9d. Chalk & Tackboard	5534	SF	1.09	6055	5534	SF	1.09	6055	
9e. Finish Hardware		LS		5827		LS		5827	
9f. Builders Specialties		LS		1156		LS		1090	66
10a. Surfacing, Sidewalk	3000	SY	2.62	7867	3000	SY	2.62	7867	
11. Insulating Deck	534	CY	25.47	13604	301	SQ	39.50	11911	1693
12. Waterproof, Rfng.	664	SQ	14.32	9509	301	SQ	29.80	8964	545
13. Generator	1	Ea.		15631					15631
14. Elevator	1	Ea.		6774					6774
15. Floor Covering	21000	SF	.25	5250	21000	SF	.25	5250	
16. Ceramic Tile	4300	SF	1.50	6432	3172	SF	1.50	4758	1674
17. Painting		LS		6244		LS		6244	
18. Lath & Plaster		LS		31500		LS		29950	1550
19. Plbg. & Air Cond.		LS		100239		LS		82820	17419
20. Electrical		LS		30300		LS		29900	400
21. Furn. & Equip.		LS		11323		LS		10836	487
TOTALS				469847				343228	126619

Considering only the additional cost of making Abo Elementary School a dual purpose shelter, the cost of each shelter space is $63.39.

THE APPLICATION OF LIFE CYCLE COST TECHNIQUES FOR EARTH COVERED BUILDING ANALYSIS:

A Preliminary Evaluation

John E. Williams
Georgia Institute of Technology
Hanscomb Associates

THE INTENT

With the evolution of energy conservation as a national policy objective, earth covered buildings may again become viable competitors for housing human and mechanized activities traditionally reserved for their above grade counterparts. The arguments suggesting dramatic energy and maintenance cost savings are persuasive, citing reductions in excess of 90 percent for specific underground installations.[4,6] The results are, of course, particular to each case and can only be generalized to the extent that other pertinent factors are considered. Prominent among these is the total cost of building ownership, commonly termed life cycle cost (LCC). LCC techniques, when applied to buildings, illustrate the relative merits of alternatives based on planning, design, construction, operation, maintenance, renovation, and occupancy costs for various economic horizons. The intent here is to (1) outline a conceptual framework which facilitates comparison of such costs for above and below grade buildings and (2) to examine the sensitivity of the respective estimated total costs to variable energy rates, planning intervals, interest rates, and levels of initial and long term investment. The resultant evidence is speculative by definition, directed toward the future potential and not the past performance of underground space.

EXISTING UNDERGROUND SPACE

Social Feasibility

Earth covered buildings have a continuous history of providing shelter for man's activities from the caves of Paleolithic and Mesolithic times through contemporary schools, storage chambers and strategic military installations. Protection from the natural elements and human predators, the comfort of relatively stable thermal conditions, and minimal disruption of the natural surface environment; topography, flora an' fauna are three principal benefits of below grade habitation.

Of the three, protection from the possible acts of other human beings appears to be the dominant factor in deciding to go underground. Of the 19 projects described in Table I, 10 are identified as shelters or disaster centers designed to shield occupants in the event of a nuclear explosion or natural disaster. With the exception of military installations, all serve dual functions as schools, corporate meeting centers, parking garages or equipment rooms. Storage is the second most frequently identified major use, with 9 examples recorded. The relative ease of controlling temperature and humidity, lower fire and theft risks and, in some instances, reduced cost are the primary reasons cited. At least three of the documented facilities, 2 libraries and an art gallery, were constructed underground for the expressed purpose of preserving the existing surface environment. Two structures, both located in existing mine chambers, take advantage of the high load bearing capacity and minimum vibration characteristics of below grade sites. Finally, one building was placed underground as a result of the high density, and consequent lack of land in the surrounding area. It can be concluded then, that the stimuli for erecting most contemporary earth covered buildings were not far removed from those of our early ancestors, protection and comfort in a natural setting, a difficult factor to measure and price.

Economic Feasibility

Cost has not been a consistent, overriding factor in the construction of socially essential underground structures. It is an uavoidable measure when evaluating other non-critical, yet necessary facilities for industrial, commercial and educational purposes.

Initial Cost

Although few reliable statistics have been published, earth covered buildings are suspected of having substantially higher acquisition costs than comparable surface structures. This supposition is reinforced by Wells who writes, "There is, in fact, nothing adverse about underground construction except its initial cost . . ."[3] At first observation, the statement is neither confirmed nor denied by the cost data shown in Table I. Closer examination, however, reveals 3 potential conditions, each governed by the excavation requirements. Facilities having 1 or 2 floors created by open excavation exhibit little cost variation, excluding special protective equipment, from typical above grade buildings erected during the same period. For the single case where drilling and blasting of rock was required, the cost per square foot was an impressive $710.00 in 1965, prohibitive for all but military installations even after deduction of possible armament expenditures. When abandoned mine chambers and tunnels are adapted for reuse, requiring little or no excavation and minimum structural modification, estimated acquisition costs are reduced by 50 to 75 percent, exclusive of land. Reviewing the dimensional variations for main structural components indicates that walls are not appreciably different from those of common basements, ranging from 12 to 16 inches, and floor slabs are essentially unchanged. Roof slab thickness, however, appears to increase, being 13 and 21 inches respectively for the two recorded cases. Another factor implied, but not documented, is the ease of installing water and power distribution and waste disposal systems. This brief review suggests that, for many typical soil conditions, underground projects are likely to experience slightly increased expenses for excavation and structure while minor reductions can be expected for plumbing and electrical system installation. Potential reductions resulting from smaller mechanical plants will be explored further.

Long Term Cost

It has not been conclusively demonstrated that the higher initial costs for most earth covered buildings are recoverable through reduced long term expenditures. Supporting data is sparse, imprecise and to some extent conflicting as suggested by a statement from the administrators of an underground school in New Mexico. "Electric load for the Abo Elementary School is one-third again as much as a conventional school. This premium, however, is more than offset by substantial savings in maintenance - there are no windows to replace and other maintenance costs are at rock bottom."[4]

In contrast, estimated and actual comparative statistics for a storage complex and manufacturing facility in Kansas City, shown in Table I, indicate possible reductions equalling 10 to 16 times the recorded costs. Heating requirements for an underground laboratory in Wampum, Pennsylvania are thought to be only one half of those for a comparable surface structure. Similarly, the total rental rate for space in a Kansas City industrial park complex is approximately one half of that for conventional above grade space. Bligh and Hamburger[6] have developed theoretical data which suggest that heating and cooling loads are significantly lower for below grade buildings than those for well insulated surface structures in regions with average ground temperatures of approximately 50°F. Other questions have been raised regarding the need for higher lighting levels and extended ventilation in underground facilities, which could enlarge energy requirements. On balance, the meager evidence available suggests that some long term cost savings can be expected for carefully designed below grade space, located in proper geographic and climatic areas. The savings are likely to result from reduced energy and exterior building maintenance requirements.

TABLE I

Project Descriptions

	NAME LOCATION	USE AND DESCRIPTIVE DATA	COST DATA	ENERGY DATA
1	Abo Elementary School[1,4] Artesia, New Mexico	School/Shelter (28,800 SF) (1 floor) Completed 1962 Open Excavation Roof Slab-21" Walls-12" Floor-4" Capacity-540	Initial-$469,847.00 Initial-$343,228.00* Initial-($11.90 SF) General Maintenance- (lower, no windows, etc.)	Electricity (1/3 greater)
2	Goddard Senior High[4] School Roswell, New Mexico	School/Shelter 182,000 SF 82,000 SF Below Grade (2 floors) Completed 1965 (Open Excavation) Basement Roof Slab-13" Capacity-2,000	Initial-$1,944,070.00 Initial Shelter-$130,000 Initial-$10.42/SF	
3	The United High[1,4] School Laredo, Texas	School/Shelter 2 floors Completed 1964 Capacity-540	Initial-$10.35/SF	
4	Combat Operations Ctr.[4] North American Air Defense Command Colorado Springs, CO	Military/Shelter 11 Buildings 200,000 SF 1-2-3 floors Completed 1965 Tunnels/Chambers Steel Frame Independent Structures on Springs Capacity-450	Initial-$142,000,000.00 Initial-$710.00 SF)	

Notes: * Indicates an estimated equivalent value for an above ground facility.
( ) Indicates an approximate value.

	NAME LOCATION	USE AND DESCRIPTIVE DATA	COST DATA	ENERGY DATA
5	Musco Naval Base[4] Musco Island, Sweden	Military/Shelter Completed (1968-69)	Initial-$60,000,000.00	
6	Malmo Shelter[4] Malmo, Sweden	Parking/Shelter/Convention# Capacity-4,300 Shelter occupants		
7	Katerinaberget Garage[4] Stockholm, Sweden	Parking/Commercial/Shelter# Capacity-500 cars		
8	Stockholm Shelter[4] Stockholm, Sweden	Shelter# Capacity-10,000 Shelter occupants		
9	Iron Mountain Shelter[4] Hudson, New York IM..S.S.C.	Shelter/Record Storage 700 Storage Clients Manufacturers Hanover Trust Company Capacity-24 Shell Oil Capacity-44 44,000 SF Standard Oil Capacity-200 20,000 SF Existing Mine Chambers/Tunnels Roof-5 ply Built up Walls-C.C. Block		
10	Manned Communication[4] Centers 26 Locations Between Boston and Miami American Telephone and Telegraph Company	Equipment/Shelter Open Excavation Walls/Roof- 7-oz. Copper Sheathed		
11	Refrigerated and Dry[6,7] Storage Complex Kansas City, Missouri Spacecenter, Inc.	Food Storage Existing Mine Chambers/Tunnels Standby Equipment Not Required Underground	Initial-$2.50/SF## Initial-$8-10/SF## Initial-$10.00/SF# Initial-$30.00/SF##	Mine temp. rises 1°F per day Above Ground Facilities 1°F per hour

Notes:
* Indicates an estimated equivalent value for an above ground facility.
( ) Indicates an approximate value.
Dry Storage
Refrigerated Storage

	NAME LOCATION	USE AND DESCRIPTIVE DATA	COST DATA	ENERGY DATA
12	Laboratory and Storage[4] Complex Wampum, Pennsylvania Medusa Portland Cement Company	Laboratory/Storage Laboratory 18,000 SF No Vibration Existing Mine Chambers/Tunnels Capacity-75 Storage Page Airways Weyerhaeuser Co. U.S. General Services Admin.	Initial-(½)	Heating-(½) Ground Temp. 54°F
13	Storage Complex[4] Boyers, Pennsylvania National Storage Co., Inc.	Record Storage Completed-1956 Existing Mine Chambers/Tunnels H. J. Henry Koppers Westinghouse PPG Painted Mine Walls-Aluminum Enamel		
14	Industrial Park Complex[4] Kansas City, Missouri Downtown Industrial Park Company	Warehouse/Office 2,000,000 SF# Excavated Chambers/Tunnels Sprayed Walls-Cement	Rental Rate (½)	
15	Precision Instrument[6,7] Manufacturing Facility Kansas City, Missouri Brunson Instrument Co.	Manufacturing 140,000 SF (Existing Mine Chambers/Tunnels) Shale Load Capacity-200 tons/SF No Vibration Capacity-125	Total Operating $3,200.00 $50-70,000.00* Fire Insurance $ .10/$1,000.00 $2.85/$1,000.00*	Heating 750,000 BTU/h 2,000,000 BTU/h* Refrigeration 57 tons 500-700 tons* Ground Temp. 54°F

Notes: * Indicates an estimated equivalent value fro an above grade facility.
( ) Indicates an approximate value.
Ultimate size.

	NAME LOCATION	USE AND DESCRIPTIVE DATA	COST DATA	ENERGY DATA
16	Theater[4] Paris, France	Theater 1 Floor 65 Diameter Floor Slab-20" Capacity-1,000 Open Excavation		
17	University Library[4] Urbana, Illinois University of Illinois	Book Storage/Retrieval 98,000 SF 2 Floors Open Excavation Floor Slab-6" Walls-16" Lower 12" Upper	Initial-$2,950,000.00 Initial-$30.00/SF	Heating- Central Steam Refrigeration- Central
18	College Library[4] Conway, Arkansas Hendrix College	Book Storage/Retrieval Beamed Capacity- 110,000 volumes Walls-Concrete Roof-Waffle Slab	Initial-$24.75/SF	
19	Art Gallery[1,4] New Canaan Philip Johnson	Art Storage/Display Beamed		

LIFE CYCLE COST FRAMEWORK

The Concept

Building life cycle cost analysis is widely acclaimed as a necessary and desirable part of any rational building decision process. Proliferation of interest in the subject has been exceeded only by the number of definitions of the term. As a consequence, the precise meaning of the terminology remains blurred and it is unclear whether or not an industry standard can be forged to resolve the issue.

Ideally, the objective of LCC is the minimization of all applied resources (materials, personnel, facilities, equipment, etc.) to achieve a desired result within a prescribed time frame (such as the delivery of health care, the production of automobiles or the provision of education). Because of the general complexity of the problem and, in particula , inadequate methods of measuring the effectiveness of the results, this ideal objective can only be partially realized at this time.

The Components

The examination of resources must be limited to buildings and equipment, and their operation, replacement and maintenance, and must exclude what is probably the most significant economic resource, the building occupants. The causal links between building space and the quality of activities, such as education, are tenuous at best and difficult to measure in any case. For example, although it is possible to assign a cost per student for provision of adequate educational space, it has not been shown that a relationship exists between the cost of space and the quality of learning. Indeed, factors which affect learning, and thus the quality of education, are so numerous as to prohibit isolation and analysis of building space as a single variable. Therefore, results must be defined and measured within the framework established by adequacy alone. The ideal objective can now be modified to be the minimization of applied resources, i.e. the construction materials, M & O personnel, energy required, etc., in providing adequate building space.

To achieve this limited objective, appropriate definitions of and methods of measurement for resources and building space must exist. Resources are generally defined to include labor, equipment and materials required for each stage of the building life cycle (planning and design, construction, maintenance and operation, and renovation). By applying appropriate economic techniques such as discounting, the values of the resources required for different alternates, can be measured in uniform dollars.

The adequacy of building space is generally defined by separating a building into parts and measuring the contribution of each to the thermal, acoustic, luminous and visual environment. For example, an adequate classroom space could require an artificial lighting system that maintains 50 foot candles of illumination on the working plane. Although the link between illumination level and learning is ill-defined, an analysis of the total costs for various lighting systems which will satisfy the criteria is perfectly feasible. Further, the effects of altering the lighting criteria can be reviewed. This procedure can be applied to each individual building part, or a summation of required resources and performance can be used to evaluate a building as a totality.

The Theoretical Model

A theoretical LCC model(s) is required to develop LCC plans, establish LCC budgets and evaluate design and decisions on an LCC basis. At the broadest level, the objective is minimization of applied resources to achieve a desired result. This can be stated as:

$$\text{Min} \left[R_T \;\middle|\; Q_T \right] \tag{1}$$

where: R_T = Life Resources

Q_T = Life Results

If the objective is limited to minimization of resources to provide adequate building space, then:

$$\text{Min} \left[\sum_{i=1}^{n} R_i \;\middle|\; \sum_{j=1}^{m} Q_j \right] \tag{2}$$

for n Resources
m Performance Measures

Further, measuring resources in discounted costs and categorizing them into the more manageable sub-groups of construction and maintenance and operation (M & O) results in:

$$\text{Min} \left[C + \int_{1}^{k} M \; e^{-rk} \;\middle|\; Q \right] \tag{3}$$

where: $C = \sum_{i=1}^{n1 \text{ Categories}} R_i$ = Construction Cost

$M = \sum_{i=1}^{n2 \text{ Categories}} R_i$ = Annual M & O Cost Stream

$Q = \sum_{j=1}^{m \text{ Categories}} Q_j$ = Performance

k = Analysis Interval
r = Discount Rate

Further sub-grouping yields:

$$\text{Min}\ \left[T\right] = \left[\sum_{j=1}^{m}\left(\sum_{i=1}^{n1} C_{ij} + \int_{1}^{k} \sum_{l=n1}^{n2} M_{ij}\ e^{-rk}\ \middle|\ Q_j\right)\right] \tag{4}$$

where: T = Total Life Cycle Cost

C_{ij} = Construction Cost Category i for system j

M_{ij} = Annual M & O Cost Stream Category i for system j

Q_j = Performance for system j

n1 = Number of Construction Cost Categories

n2 = Number of M & O Cost Categories

i = 1, n2 Cost Categories

j = 1, m Systems

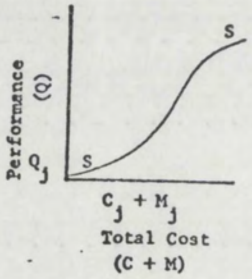
Note that the optimum solution is the minimum value for the total building and is not necessarily derived by minimizing the results for each individual system.

If equation (4) adequately describes the problem, then appropriate parameters must be selected to forecast values for the variables "C" and "M". The performance variable "Q", is assumed to be deterministic, i.e., a desired level of performance is specified for each analysis. There is, however, a relationship between "Q" and the total cost, "C + M". Assume that for building system j, there exists an independent scalar performance measure, Q_j, then:

$$C_j + M_j = f(Q_j) \tag{5}$$

for j = 1, m systems

or:



Obviously, "Q" is the set $\left[q_1, q_2, \ldots\ldots, q_n\right]$ of n performance factors upon which "C+M" is dependent. Further, for a unique set "Q", there may not exist a unique total cost, "C+M". If "C" and "M" are not independent, then they must be treated separately. It is also possible that for a given performance "Q", neither "C" nor "M" is unique. To resolve this dilemma, both "C" and "M" must be dissected into meaningful components such that:

$$M_{ij} = f\,(C_j, Q_j) \qquad (6)$$

for $j = 1, m$ systems
$i = 1, n2$ cost categories

If the relationship in equation (6) can be defined, C_j estimated and the set Q_j determined, then equation (4) can be evaluated and a minimum total cost T established for any building.

There are, of course, many conditions which occur subsequent to building occupancy which cannot be correctly anticipated for the initial application of equation (3). There also exist a variety of annual M & O strategies which will yield different values for the variable "M", given "C". To examine the alternatives, let:

$C_{1,j}$	Building Construction Cost
$C_{2,j}$	Administrative Construction Cost
$C_{3,j}$	Consultants Construction Cost
$M_{4,j}$	General M & O Cost
$M_{5,j}$	Fuel & Utilities Cost
$M_{6,j}$	Cleaning Cost
$M_{7,j}$	Service Cost
$M_{8,j}$	Repair Cost
$M_{9,j}$	Replacement Cost
$M_{10,j}$	Painting Cost
$M_{11,j}$	Alterations Cost

Potential M & O relationships can then be stated as:

$$M_{8,j} = f(M_{7,j}, Q_j) \qquad (7)$$

and

$$M_{9,j} = f(M_{8,j}, Q_j) \qquad (8)$$

The objective is:

$$\text{Min} \left[T_M \right] = \left[\sum_{j=1}^{m} \int_{y}^{k} \left(M_{7,j} - M_{8,j} - M_{9,j} \right) e^{-rk} \;\middle|\; C_j, Q_j \right] \qquad (9)$$

It can now be tentatively assumed that equation (3) is the model for building life cost planning, equation (4) is the building design decision model, and equation (9) will yield results useful for developing annual M & O strategies. While these models may provide a logical framework for analysis, it remains to quantify and fully define the relationships in equations (6), (7) and (8). This task is fundamental to the implementation of the method.

COMPARATIVE ECONOMIC ANALYSIS

Scope

This brief analysis illustrates an application of the life cycle cost methodology to develop comparative cost forecasts for underground vs. above grade structures. Progressive computations are performed to examine the sensitivity of total cost estimates for the two alternatives to variable analytic intervals, interest and discount rates, energy rates, and initial/annual cost ratios. All results are based on estimated values derived from a conditioned and intuitive, yet systematic restructuring of recorded data for traditional above grade structures. A number of factors, not affected by above or below grade location, are assumed to be constant for both building types.

The General Model

The following equation is used as the comparative economic model.

$$PV\left[TC\right] = \overset{\text{Construction Cost}}{\begin{Bmatrix} C_u \text{ or} \\ C_a \end{Bmatrix}} + \left|(C_u - C_a)\right| \overset{\text{Opportunity Cost/Construction}}{\left\{\left[\frac{(1 + i_{roi})^n}{(1 + i_{infla})^n}\right] - 1\right\}} \cdots$$

$$+ \overset{\text{Opportunity Cost/Operation and Maintenance}}{\left\{\sum_{k=1}^{n} \left[\frac{\left|(OM_{uk} - OM_{ak})\right|}{\frac{1}{(1 + i_{roi})^{n-k}}}\right] - \left|(OM_{uk} - OM_{ak})\right|\right\} \left\{\frac{1}{(1 + i_{infla})^n}\right\}} \cdots \tag{10}$$

$$+ \overset{\text{Operation and Maintenance Cost}}{\left\{\sum_{k=1}^{n} \frac{\begin{matrix} OM_{uk} \text{ or} \\ OM_{ak} \end{matrix}}{\left[\frac{1}{(1 + i_{infla})}^{k-}\right]}\right\}}$$

$$\text{for: } OM_{uk} = \left[(OM_{uk - 1})\ (i_{infla})\right] + OM_{uk}$$

$$k = 1,n$$

$$OM_{ak} = \left[(OM_{ak - 1})\ (i_{infla})\right] + OM_{ak}$$

$$k = 1,n$$

Where: $PV[TC]$ - Present Value of Total Cost
C_u - Construction Cost Below Grade
C_a - Construction Cost Above Grade
OM_u - Operation and Maintenance Cost Below Grade
OM_k - Operation and Maintenance Cost Above Grade
i_{roi} - Return on Invested Capital
i_{infla} - Discount Rate, Inflation
n - Analysis Interval

Production costs for goods and/or services produced are not reflected in equation 10, nor are moving, lease and other costs which will very likely remain constant for either alternative. Opportunity costs for construction, and operation and maintenance are added to the total cost of the option having the greater value for each respective cost center. Operating Costs are assumed to be increasing at a constant rate of inflation, with no adjustment for building age, size, location, etc.

Initial and Long Term Cost Estimates

The relative starting values for initial costs are shown in Table II. Using BOMA statistics as the basis, costs for each major system are adjusted intuitively as a result of the previous general review. An increase of approximately 11 percent is anticipated for comparable underground construction.

The relative starting values for annual operation and maintenance costs are shown in Table III. Using statistics from BOMA, combined with the experience of several other projects, values for each cost center are adjusted as a result of the previous general review. A decrease of approximately 30 percent in annual O & M cost is anticipated for underground construction.

Analysis

A computer-based version of the model was applied to generate the estimated total relative costs of ownership which are displayed in Figures 1-6. All cost values are computed from an above grade construction unit cost of 1. The expected annual return on investment was set at 10 percent. Construction cost for below grade facilities was adjusted from 1.11 to 1.5, or an approximate 11 to 50 percent additional requirement over surface construction. Two annual rates of inflation, 7½ and 12 percent were used to test the model and three levels of fuel and electrical costs, the existing average plus 100 and 500 percent assumed price increases, were applied to explore the sensitivity of estimated total cost to these possible conditions. Five year analysis intervals were used, beginning at year 1 and continuing through a maximum 60 year life.

Results

For each of the six alternative cost configurations analyzed, the below grade structure maintained a higher total cost during the early life of the building and subsequently became a desirable economic option later in the life cycle. Figure 1 displays the results for the initial conditions of 10 percent construction cost increase and a 30 percent annual O&M cost

94.4

TABLE II

Estimated Construction Cost Distribution and Savings by System

ELEMENT	ABOVE GRADE[1]	BELOW GRADE[3]	BELOW GRADE[2]
(Construction Cost Center Only)	Average % of Total Construction Cost	Estimated % Change/Element (+ increase - decrease)	Estimated % Total Construction Cost
FOUNDATIONS	3.8% 4.	100%	7.6% 8
SUBSTRUCTURE	1.5% 1.6	—	
SUPERSTRUCTURE	15.5% 16.4	100% --	34.0% 36
EXTERIOR CLOSURE	12.6% 13.4	-20%	10.1% 10.7
ROOFING	1.7% 1.8	-20%	1.4% 1.4
INTERIOR CONSTRUCTION	16.2% 17.5	0	16.2% 17.5
CONVEYING SYSTEMS	5.6% 5.9	0	5.6%
MECHANICAL	(19.8%) 21.		18.7
Plumbing	5.9% 6.3	-5%	5.7% 6
HVAC	12.7% 13.5	-20%	10.2% 10.8
Fire Protection	.7% .7	-5%	.6% .7
Special	.5% .5	0	.5% .5
ELECTRICAL	9.5% 10.1	0	9.5% 10.1
EQUIPMENT	1.0% 1.1	0	1.0% 1.1
SITEWORK	7.4% 7.8	50%	3.7% 3.9
GENERAL CONDITIONS AND PROFIT	5.0% 5.3	0	5.0% 5.3
TOTAL	100.0%		111.1% 112

8

Notes: [1] BOMA Office Building Exchange Report, 1973.
[2] This is the remaining cost for below grade structures as a % of the original above grade building cost center.
[3] This is the estimated % reduction in the % for each cost center for below grade structures.

TABLE III

[1]Estimated Operating and Maintenance Cost Distribution and Savings

COST CENTER	ABOVE GRADE	BELOW GRADE[3]	BELOW GRADE[2]
	Average % of Total O & M Cost	Estimated % Change/Cost Center (+ increase - decrease)	Estimated % Total O & M Cost
General	22% 27.	-25%	16.5 % 20.3
Janitorial	19% [illegible]	0	19.0 %
Fuel and Utilities	(25%) 30.9	95%	(15.47%) 19.89
Water	6% 7.44	- 5%	5.07% 7.03
Fuel/Steam	9% 11.1	-40%	5.4 % 6.66
Electricity	10% 12.43	-50%	5.0 % 6.2
Maintenance	8% 10	-30%	5.6 % 2
Repair	4% 5	-30%	2.8 % 3.5
Replacement	10% 12	-30%	7.0 % 8.4
Cleaning	7% 9	-50%	3.5 % 3
Painting	5% 6	-20%	4.0 % 4.8
TOTAL	100%		70.5 % 70.29

Notes: [1] All figures are estimates based on BOMA statistics, and actual data from GSA and University of Michigan Buildings.

[2] This is the remaining ost for below grade structures as a % of the original above grade buildings.

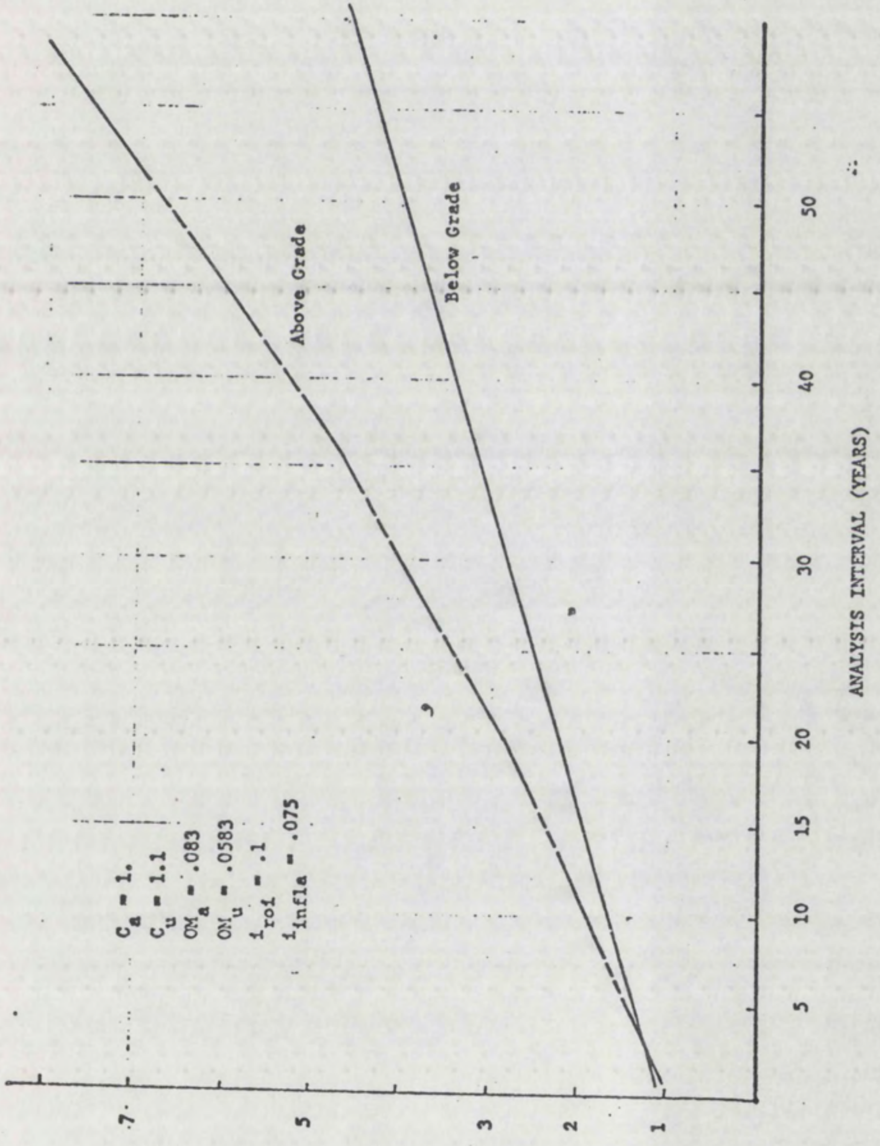
[3] This is the estimated % reduction in the % for each cost center for below grade structures.

decrease for the underground option. The intersection occurs approximately in year 3, after which estimated savings for below grade construction increase substantially. When the inflation rate is altered from 7½ to 12 percent, the equal cost point moves to about year 8. Returning to an inflation rate of 7½ percent, but increasing estimated energy cost by 100% shows a point of indifference at year 6. Inflating the estimated energy expenditure causes the alternatives to have equal costs close to year 1. Figures 5 and 6 illustrate the effects of increasing the relative below grade construction cost by 25 and 50 percent. As the relative value increases, underground construction becomes a less attractive option with equal total costs at 11 and 19 years respectively. In general, given the suppositions and assumptions stated, it is possible that earth covered buildings could provide an acceptable economic solution to certain building needs. However, firm recommendations are not advised pending acquisition and analysis of a substantial, accurate historical data base.

Conclusions

As a result of this brief review several conclusions, not unlike those of other writers, are evident. First, an articulate set of data requirements should be developed and documented. They will include as a minimum (1) initial costs by system, (2) operation and maintenance costs preferably by cost center and building system, (3) system descriptors, (4) total building descriptors, (5) operating policies, and (6) use patterns. Appropriate installations should be identified and documented within the framework defined above. Since it is generally not possible to acquire energy consumption data by system (lighting, heating, etc.) at least one typical facility should be instrumented as a basis for distribution of the associated costs for other buildings.

A thorough statistical analysis should be performed on the data to reveal consistent patterns, if they exist, which may be used to forecast future costs for earth covered buildings. Finally, further studies should be executed to determine the potential impact of inflation and energy prices on the relative cost of above grade vs. below grade structures.



RELATIVE TOTAL COST
Figure 1

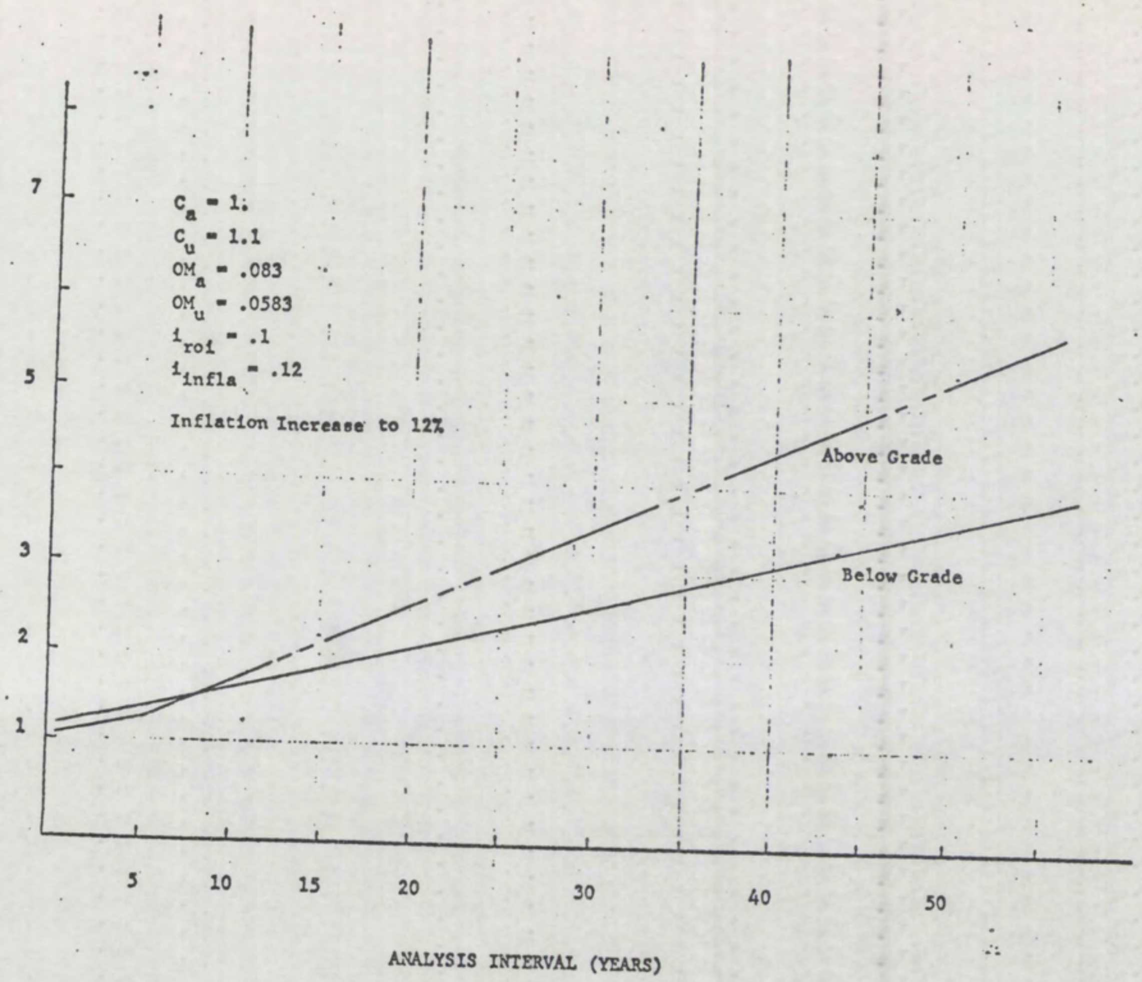

RELATIVE TOTAL COST
7
5
3
2
1
C_a = 1.
C_u = 1.1
OM_a = .083
OM_u = .0583
i_{roi} = .1
i_{infla} = .12
Inflation Increase to 12%
Above Grade
Below Grade
5
10
15
20
30
40
50
ANALYSIS INTERVAL (YEARS)

Figure 2

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France

In France the story of underground development is one of converting formerly wasted areas into usable space. The Loire and Cher Valleys, a little over one hundred miles south of Paris have long been noted for their beautiful chateaux built during the past several centuries by wealthy rulers of France. An example is the famous Chateau de Cheverny, a hunting lodge, shown in Figure 26 with a close-up view of its walls showing the hewn stone in Figure 27. This stone, known locally as "tuffeau jaune" left countless tunnels into the bluffs some of which were subsequently used for storage by farmers, hideouts for criminals, and many of these were eventually developed into living space. An estimated 2,000 people live in some type of housing adaptation using these mined out areas.

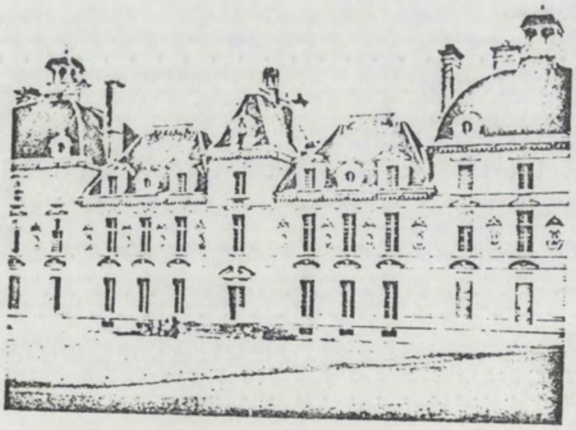

Figure 26. The Chateau de Cheverney.

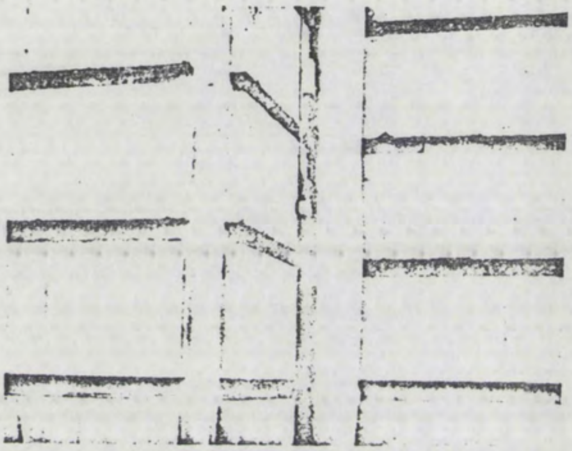

Figure 27. Close view of the stones of Chateau de Cheverney.

The adaptations range from adding a simple external shelter somewhat like a patio as seen in Figure 28 where there are three occupants pictured in front of their rock home. A view inside their rock house shows the plaster along the ceiling following the curve of the old mined out room (Figure 29). Not all of the converted mined rooms were refinished. Some were semi-finished and others farther back in the bluff were used for storage much as they were left by mining. In back of this home, I was shown an area where soldiers were sheltered. During the war of religions in France these caverns and abandoned quarries sheltered important numbers of refugees as well. When the occupants were asked if they were more subject to arthritis or rheumatism by living in the rock, their reply was an emphatic "No!" and that their family had lived there for three generations without any problems. When asked their reason for preferring an in-rock home, their answer specifically mentioned warmth in winter, coolness in summer, and economic advantages. They seemed quite knowledgeable of living conditions elsewhere in the world but still preferred their rock homes. A more elaborate adaptation of a mined out area for living purposes is shown in Figure 30 where half of a wood frame is built externally and the other half of the home makes use of the mined space. Variations of this partially external construction type is quite common along these valleys and other examples are shown in Figures 31 and 32. In some instances the former mine opening is merely enclosed into a door and window arrangement made of wood as seen in Figure 33 or a brick enclosure of an opening as seen in the exact center of Figure 34. A troglodytes night shirt hangs in the door of an opening shown in Figure 35, and a curtain waves from a window in the rock in Figure 36.

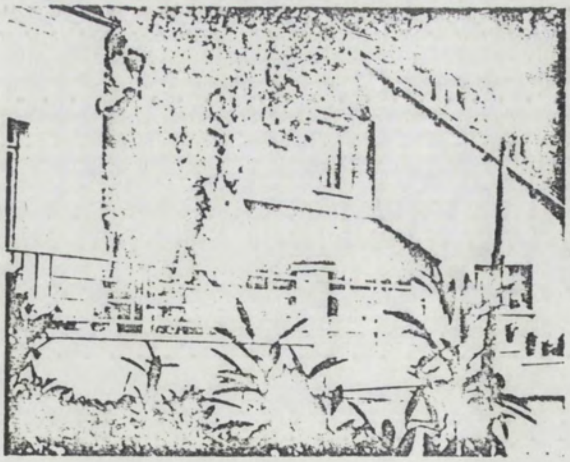

Figure 30. Elaborate adaptation of a mined area to residential use.

Where the mined opening is used commercially as in the use of the mined rooms for wine storage it may be enclosed as shown in Figure 37. Inside these storage areas are wine serving rooms.

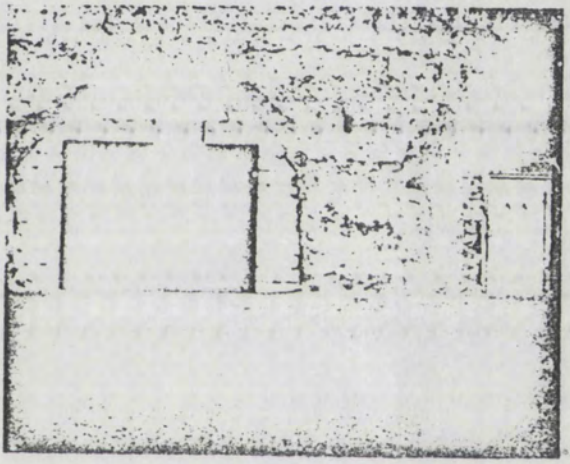

Figure 37. Mine converted to wine storage and sales room.

Parisians are looking to some of these areas for secondary homes for weekend use at a cost much less than a comparable cottage.

Conclusions

The Loire and Cher valleys seemed to have much in common with Kansas City. The uses here were secondary to an original mining venture and in this way both areas are conserving by reuse what was once considered mined out wasted area. The physiographic presence of rivers and their resultant bluffs have played an important part in both the Kansas City and the Loire-Cher regions.

Both developments are in-rock types of subsurface uses.

Differences occur mainly in that the Kansas City area is urbanized and its underground uses have been predominately industrial whereas the rural nature of the Loire-Cher valleys have made economical housing to be the most desirable use for the abandoned mines. This is being augmented now by Parisians who are developing these areas as unique and interesting ways to economically afford vacation sites.

Whether exchange of ideas relative to subsurface usage may occur between Kansas City and the Loire-Cher valleys remains to be seen.

Further study is indicated in both Sweden and France on subsurface use.

[illegible] [illegible] ... [illegible], economic & energy considerations
in the use of underground space"
National Academy of Eng. No NSF/RA/S-74-[illegible]

You'll find this article quoted in much of the existing, or at least recent
literature — Fairhurst, e.g. Currently appears in RANN report NSF/RA/S-74-002
as noted by Bligh on top of page; this is a pre-publication copy from the author, but is
almost exactly identical (I think only the intro. differs slightly) to the NAS/NSF article in the book

CONSERVATION OF ENERGY BY USE OF UNDERGROUND SPACE

Thomas P. Bligh - University of Minnesota
Richard Hamburger - U. S. Atomic Energy Commission

Introduction

Occasional statements in the technical literature indicate that placing some human activities below ground may result in appreciable savings in energy consumption as well as other cost savings such as lesser overhead and maintenance, lower insurance rates, a better environment for some activities, and for some an improvement in health. (1) (2) (3) Based on these hints, a preliminary investigation was undertaken to identify the policy issues bearing on such use and to collect data in order to establish the extent to which energy could be conserved.

In section A, issues of public policy are discussed, while energy considerations are examined in section B.

A. POLICY CONSIDERATIONS

Public Policy

As a broad generality, public policies are formulations of goals that guide societal decisions. As a practical matter, public policies also constitute a final arbitration and expression of competing value judgments. These individual judgments (policies) vary in time, space and with interest groups. Public policies are enunciated in legislative action (statues), court decisions on competing claims, through administrative procedures, or by the conscious decision of legislators to let precedent stand. (4) Although such policies ordinarily reflect compromise between conflicting value judgments, it is well to remember that public policies stated at different times and on separate, but related, subjects frequently conflict at their interfaces requiring further arbitration, clarification [illegible] [illegible] "Legal, Economic & Energy Considerations in the Use of Underground Space" National Academy of Eng. No NSF/RA/S-74-[illegible]

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When public policies on use of underground space are developed these should be done in a manner to minimize conflicts. For instance, these policies should not be viewed as separable from other major public policies.

The authors acknowledge the assistance of William L. Oakley, U. S. Atomic Energy Commission, in the development of this statement on policy.

Assumptions

It is well to remember that assumptions underly value judgments which guide formation of public policies. Thus it is essential, if we are to suggest a public policy on this matter, that we start by re-examining and questioning our assumptions.

Competent people working in the same field may have different basic assumptions. Since it often is difficult to isolate the assumptions of one's own field, we will illustrate the fundamental role of assumptions by an example in another area. Here are the basic assumptions given in two recent publications on ecology. Both are by people of recognized stature. Since it is not our field we will not evaluate which assumption is better. The first is, "We approach this set of problems with an ecologist's basic assumption that it is advantageous to man to keep the environment stable .... Stability is an objective because the alternative, progressive degradation of the environment, is unacceptable .... Human influences on the total amount of life cause a systemic and predictable degradation of structure."(5) Compare that assumption with this from another recent publication: "Man's bondage to nature does not imply, however, that the quality of human life is linked inexorably to an unchangeable order of things. Human nature and external nature possess multiple potentialities that man can discover and use according to his fancy .... The surface of the earth can be profoundly altered without desecrating it or decreasing its fitness for life; ...."(6) It is obvious, to us at least, that policies based on these two assumptions would not be similar.

We can start by making explicit some of the Conference's assumptions:

(1) Technologic improvements will make underground usage more attractive in the future than it is now, and significantly narrow the cost differential between underground construction and surface construction;

(2) It is in the national interest to use the underground dimension for societal purposes; and

(3) Policy guidelines at national levels can be formulated to optimize use of underground space and to reduce to a minimum disputes among claimants for this space.

In this paper we simply note these assumptions without analyzing their validity.

Our assumptions should be set side-by-side with available data to see if they are supported by facts. If our assumptions are supported by facts, two further policy aspects must be considered. These are: (1) how the proposed policies interface with other policies and (2) how best to implement them.

Policy Interfaces

One of the "national policy" decisions which sometimes is used as a case example of effective public policy is the Air-Commerce Act of 1926. This Act stated the policy that the United States has "complete and exclusive national sovereignty in air space" over land. (7) This policy is opposed diametrically to the older doctrine of common law that ownership of land carries with it ownership of the overlying air space to the periphery of our universe. It has been suggested that a similar, sweeping policy could be transferred to use of underground space. It should be noted, however, that courts have held that even under the Air-Commerce Act the land owner owns at least as much of the air space above his ground as he can occupy or use in connection with the land. (8) Jack can grow his bean stalk to any height he desires. This is not a severe limitation when considering the usual dimensions of buildings even including TV towers and skyscrapers, but in the context of usage of subsurface space, the analogy leaves us exactly where we are today.

As noted, public policy developed at different times and places may result in conflicting policy interfaces. Future policy decisions, such as guidelines for use of subsurface space, should be formulated in such a way as to reinforce good existing policies and not to create new conflicts. Such formulation would make each policy supportive of the other. It is suggested that development of such supportive policies may be more effective than starting out anew to develop broad, general guidelines.

As an example, there is a federal policy on conservation of energy. This policy has been enunciated in the President's Energy Message of April 18, 1973, directing the establishment of an Office of Energy Conservation within the Department of the Interior. Policies for governance of underground space which would encourage its use to conserve energy would be supportive of this policy. That the potential to conserve energy exists is the substance of this paper.

Policy Implementation

National policy, even if enunciated at a federal level, can be implemented at state or local as well as the federal level. Implementation consists of structuring the instruments of governments towards stated policy objectives; in this case conservation of energy. At all levels this can be done by legislation, economic incentives, standards and codes, zoning, regulations, planning and education.

Economic controls can be such as to discourage some uses and encourage others. One familiar form of economic incentive is the use of tax structures. Taxes related to human shelter are structured so as to make, for many people, home ownership more economically advantageous than renting. (9)

This policy of tax subsidy to home-owners is derived from an older tax policy originally devised "to meet the conditions of organized business, such as merchants and manufacturers..."(10) (11) The present tax subsidy to home-owners represents a conscious decision to let this stand.(4)

Other examples of economic incentives to implement public policy involve low interest loans, depreciation allowances, etc. We can visualize that if use of underground space to conserve energy is to be encouraged, similar allowances could be made to eliminate the difference between underground and surface construction costs. As Charles H. Jacoby suggested in a prior paper (12), there might be an "appreciation allowance" for every cubic yard of underground space preserved for use (to cover extra cost). Investment credit allowances have been proposed to encourage exploratory drilling for oil and gas; i.e., use underground space to get fossil fuel energy. Other, more direct, government participation to encourage the development of underground space could be a commitment by the government to buy and utilize excavated material in those instances where it is shown that use of such space would conserve energy.

Zoning, likewise, may be used to implement such a national policy. Some shopping centers presently are constructed underground. Others are so fully enclosed that for all practical purposes they might as well be underground. One can visualize that local zoning authorities might allow, for example, a shopping center to be constructed in an area advantageous to merchants, if this were done underground with the surface area dedicated to "the highest and best use" for civic purposes such as an in-town public park or the maintenance of open space or farm land close to urban centers. A corn field on top of a shopping center, in season, could be a valuable asset to the urban area, individuals, and merchants.

Long range planning also can be used in conjunction with other tools of governance to encourage use of subsurface space for conservation of energy. For instance, in conjunction with construction of subways in urban areas, exits could be planned to make access to below ground areas attractive to merchants or manufacturers.

B. ENERGY CONSIDERATIONS[*]

In this section three main questions are discussed:

1. Is there a potential for conserving energy by using subsurface space rather than above ground space?
2. Is there a good data base from which to design heating, cooling and air-conditioning facilities for underground construction? and finally,
3. How much energy could be saved by building underground?

---

[*] We acknowledge the assistance of Dr. Charles R. Nelson, University of Minnesota, in compiling the data on underground space.

Before people will consider seriously subsurface construction as a viable option there must be available good data in which engineers, architects and planners have confidence. Equally, before time, effort and inevitably, dollars are expended to produce data in an acceptable form, the potential of recovering these costs should be demonstrated; this we hope to do, however tentatively.

1. IS THERE A POTENTIAL FOR CONSERVING ENERGY BY USING SUBSURFACE SPACE?

The affirmative answer to this question will be illustrated by a number of examples. Energy is required to heat and cool buildings and to control the relative humidity of air both for comfort and for dry storage of materials. Less energy is required in an equivalent underground facility to achieve the same result as in one above ground. Consider the following examples.

1.1 Underground storage and refrigeration

Energy can be saved since the temperature underground varies only slightly from the yearly average temperature - mother earth is a marvelous averager. Hence less heating in winter, and less cooling in summer, is required. Subsurface construction avoids direct sun radiation which, in summer, can contribute significantly to the cooling load.

The surrounding mass acts as a heat sink so that standby refrigeration equipment is unnecessary. Cooling plants can be shut down for many days for maintenance and repair or due to local power failures without adverse effects to frozen goods. In underground cold storage facilities in Kansas City, for example, temperature rises of typically 1°F per day after plant shutdown are reported. Similar above ground facilities rise 1°F per hour and hence, here, standby equipment is imperative. Table 1 lists the experience of

Spacecenter, Inc. (13) who operate similar facilities underground in Kansas City and above ground in St. Paul, Minnesota.

Table 1. Cost comparison of above and below ground storage and refrigeration

(Cost $/square foot)	Installation costs[1,2]		Operating costs	
	Above ground	Underground	Above ground	Underground
Dry storage	10	2.50	0.03	0.003
Refrigeration	30	8 to 10	0.12	0.010

Note: 1. Excluding cost of land or underground space.
2. No standby equipment required underground.
3. Underground space in Kansas City in millions of square feet.

	Total in Kansas City	Spacecenter, Inc.
Already mined	120	7
Mining rate/year	5	0.25
Dry storage and refrigeration	3	1

The operating costs, which reflect the energy consumption, underground are typically one tenth those for above ground facilities. In addition to this, capital outlay is reduced considerably. Energy is required to produce raw materials for, and to manufacture, the cooling equipment so that in an overall view the smaller plant requirement contributes to the conservation of National Energy.

1.2 Underground Manufacturing

The experience of Brunson Instrument Company (14), a precision instrument manufacturer, is cited to illustrate many advantages of underground location in addition to the energy saved by such location. These are:

(a) Maintenance - everything underground is protected from wear and tear of weather extremes - wind, moisture, heat, freezing, etc, no roof or exterior walls to maintain.

(b) Utility savings - electrical utilities, pipes, sewers and drains can be either hung from the ceiling or put in shallow ditches as there is no problem of freezing.

(c) Insurance - fireproofing construction costs less and windstorm hazard is non-existent. Thus, excellent insurance rates are available.

(d) Strength - floor loads are almost unlimited. Heavy machinery does not require elaborate foundation support - e.g. in Kansas City the shale can be loaded to 200 tons per square foot.

(e) Stability - no vibration. Delicate machines and instruments need not be isolated, an expensive and difficult task.

(f) Operating savings - machines remain accurate for much longer without realignment due to very stable temperature and humidity conditions.

The greatly reduced energy requirements for an underground plant are illustrated in Table 2.

Table 2. Cost and Energy Comparisons for a Precision Manufacturing Plant Above and Below Ground[1]

	Above Ground (Estimate) (15)	Underground (Brunson Inst)
Heating units (BTU/hour)	~2,000,000	750,000
Refrigeration (tons) (for dehumidification)	~500 to 700	57
Operating Costs ($/year)	~50,000 to 70,000	3200[2]
Fire insurance ($/$1,000)	2.85	0.10

Note: 1. Brunson Instrument Co.: 140,000 sq ft
125 employees
77 ft below surface
54°F initial rock temperature

2. This figure is particularly low since the air conditioning plant is operated only during nights to bring temperature and humidity below that required. Due to the heat capacity of the rock, temperature and relative humidity of the air then slowly rise during the day. This technique reduces the electrical demand factor.

At full capacity the Brunson Company will employ 500 people and install more machines. It has been estimated (14) that under these conditions no more heating equipment will be needed, due to the added heat input from people and machines, and that only two thirds more air conditioning plant will be required.

1.3 Underground Commerce and Habitation

Neanderthal man lived in caves, not because he was too dumb or too lazy to build a shelter, but for far more suble reasons which only now, as man reaches out beyond the moon, are beginning to dawn on us.

A subsurface home can be kept at a pleasant temperature with little expenditure of energy and is defended easily.

Substantial amounts of energy could be saved by greater use of subsurface space for commerce and habitation. Technical changes, however, must be economically and socially sound, and must be implemented widely to have a significant impact on energy consumption.

At a recent Energy Conservation Conference, K. Saulter (16) stated, "In particular, potential technical developments which reduce the use of fuels in residential and commercial space heating and cooling, and the transportation section are regarded as those with the largest potential pay-offs." Of the total U. S. energy consumption for 1974 (16), 20.4% was used for residential and commercial heating and cooling and 25.1% on all transportation. It is interesting to note that at the conference not one mention was made of the potential use of underground space to conserve energy.

What can be done and where does the energy go? Energy is wasted by unwanted heating or cooling of the surroundings. By reducing heat transferred to and from surroundings less energy is consumed to maintain desired conditions. It is often stated, by architects and engineers alike, that it is as effective, and more economical to use better insulation than to build underground. The following example will demonstrate that underground structures are far superior from an energy conservation standpoint.

Example of heat flow

The equation for heat flow rate is

$q = UA(t_1-t_2)$ or $Q = q/A = U(t_1-t_2)$

where q = heat flow rate, BUT/hour

Q = heat flow rate per unit area, BTU/hour/square foot

U = thermal transmission coefficient

A = area through which heat is transferred, square feet

t_1 = inside temperature, ^{o}F

t_2 = outside temperature, ^{o}F

(Note that when t_2 is greater than t_1, i.e. during summer, q is negative so that heat flowing into a building is considered negative).

In a given region the temperature difference is determined by weather extremes for above ground structures. Underground, however, as noted, the temperature remains at almost the yearly mean temperature. For example, the temperature ten feet underground in the Minneapolis area varies from 47 to 51°F, while the daily temperature varies from -30 to 95°F. Table 3 lists typical thermal transmission coefficients, U values (17).

Table 3. Typical thermal transmission coefficient, U, values.

Material	U BTU/hour
Roof, asphalt plus one inch timber	0.45 to 0.53
Windows, double glazed, 70% glass	0.45 to 0.55
Wall 1, no insulation	0.30 to 0.45
Wall 2, 4 inch insulation	0.20
Wall 3, 8 inch insulation	0.13
Basement, in contact with soil, no insulation	0.10

Table 4 gives Q, the heat flow rate per unit area, above and below ground in Minneapolis, for the mean, maximum and minimum daily temperatures in winter and summer. This shows, for example, that on a cold winter day the heat flow rate per unit area will be 5.5 times greater above ground for a wall with 8 inches of insulation (wall 3) and 8.4 times greater for a wall with 4 inches of insulation (wall 2) compared to an uninsulated wall underground and Q can be 19 to 22 times greater through a roof than underground.

During summer large amounts of heat, which must be removed, flow into a building above ground, while heat flows out of an underground structure lowering the cooling load. The ratio Q above/Q below is not given in summer because heat flow underground is out of a building, which is desirable since heat is produced by lights, cooking, machines, people, etc., while heat flow above ground is into a building, which is undesirable since it adds heat to the internal heat load. On a hot summer's day, for example, to maintain an above ground building (of wall 2 construction) at the same temperature as a similar underground building, (4.0 + 2.5) BTU/hour/square foot of wall area, plus (9.0 + 2.5) BTU/hour/square foot of roof area would have to be removed by an air-conditioning plant, assuming the heat loss through the floor is comparable to the underground case.

In no way can improved insulation on an above ground building begin to compete with subsurface structures from an energy conservation standpoint.

Table 4. Heat flow rate per unit area, Q , for buildings above and below ground.

	Above Ground				Below Ground[2]
	Roof	Wall 1	Wall 2	Wall 3	t_2=50°F
January mean,[2,3] t_1=75°F		t_2=10°F	(t_1-t_2)=65°F		(t_1-t_2)=25°F
Winter Q, BTU/hr/sq ft	29 to 35	19 to 29	13.0	8.5	2.5
Ratio Q above/Q below	12 to 14	8 to 12	5.2	3.4	
January minimum,[5] t_1=75°F		t_2=−30°F	(t_1-t_2)=105°F		(t_1-t_2)=25°F
Winter Q, BTU/hr/sq ft	47 to 56	32 to 47	21.0	13.7	2.5
Ratio Q above/Q below	19 to 22	13 to 19	8.4	5.5	
July mean,[4] t_1=75°F		t_2=80°F	(t_1-t_2)=−10°F		(t_1-t_2)=25°F
Summer Q, BTU/hr/sq ft	-4.5 to -5.3	-3.0 to -4.5	-2.0	-1.3	2.5
Ratio[6]	3.1				
July maximum,[4] t_1=75°F		t_2=95°F	(t_1-t_2)=−20°F		(t_1-t_2)=25°F
Summer Q, BTU/hr/sq ft	-9.0 to -11.6	-6.0 to -9.0	-4.0	-2.6	2.5
Ratio[6]					

Note:
1. Negative sign indicates heat gained.
2. An inside temperature of t_1=75°F and an underground temperature of t_2=50°F were used throughout.
3. In the winter or heating cycle, the mean temperature for the full 24 hour period averaged over the month was used since buildings must be heated continuously; here t_2=10°F.
4. During summer the mean temperature during the day was used since buildings need cooling only when the outside temperature exceeds 75°F; here t_2=85°F.
5. A minimum winter temperature of t_2=−30°F, and a maximum summer temperature of t_2=95°F were used as an example of the maximum heat flow rate conditions. The heating and cooling plant size must be sufficient for these extremes.
6. A ratio Q above/Q below is not listed for summer since above ground heat flows into, while underground heat flows out of, a building (see text).

2. IS THERE A GOOD DATA BASE?

Briefly no. A preliminary search indicated little better data than that available to Neanderthal man. Most engineers and architects confronted with the problem of heating and cooling immediately turn to the ASHRAE[17] volumes. The 1972 edition of this work consists of four large volumes comprising 2478 pages in all. One half a page is devoted to basements, the nearest approach to subsurface space, and begins, "Unfortunately, complete data on ground temperature adjacent to buildings are not available...". Certainly there are a few reports spread throughout the country which do give some useful information; these should be collected and critically evaluated.

3. HOW MUCH ENERGY COULD BE SAVED?

If the living quarters of residential units were placed above ground with the accustomed windows and view, with bedrooms and bathrooms along with rooms usually associated with a basement semi-underground, that is, underground but with greater access landscaped into window anclaves , considerable energy could be conserved.

The National Bureau of Standards, Building Environment Division [18] have calculated potential cost savings over the next 25 years if thermal transmission characteristics of new and existing housing units are upgraded. They predict that the present 60 million dwelling units will increase to about 100 million if, of the existing dwellings, 3% are built and 1% are retired each year for 25 years.

If heat transmission characteristics could be reduced by 50% in all new buildings and by 10% in all existing buildings, savings in energy and cost for the next 25 years are shown in figures 1 and 2. Savings in energy would be in excess of 70×10^{15} BTU, almost equal to the total energy consumed for all purposes in the USA in 1972 (the actual total for 1972

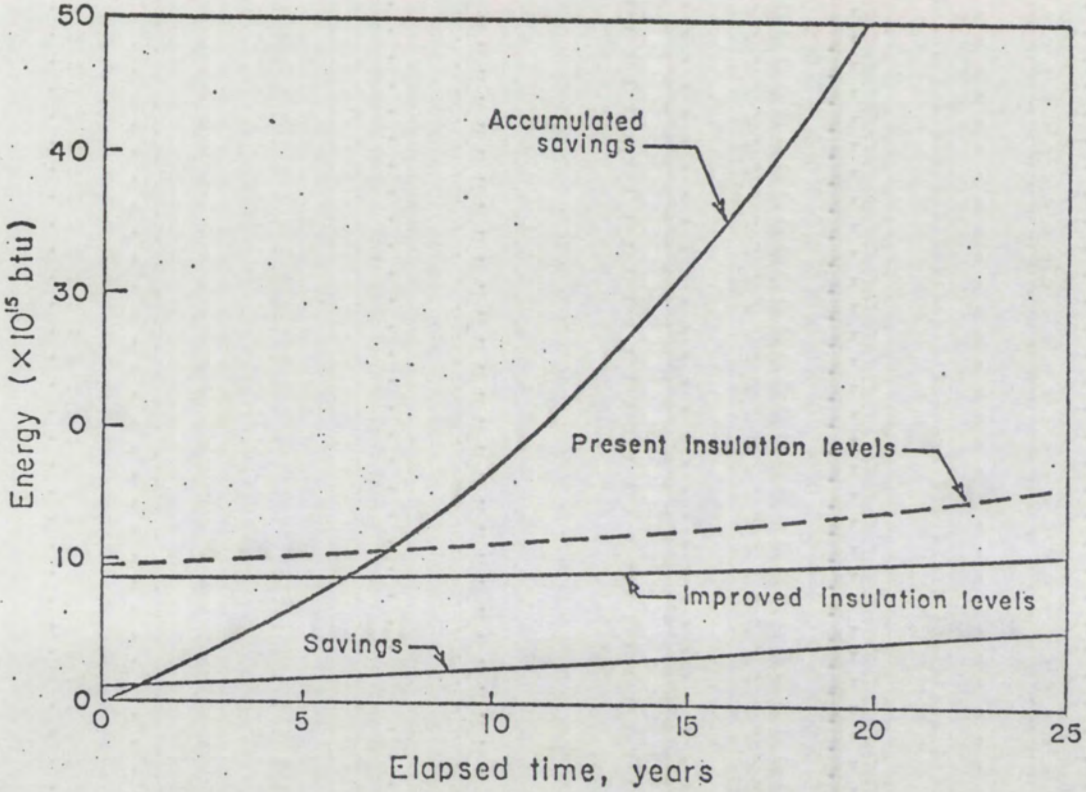

Figure 1.' Energy Usage and Energy Savings Achievable by Improved Thermal Design of Dwelling Units. (From (18) P. R. Achenbach)

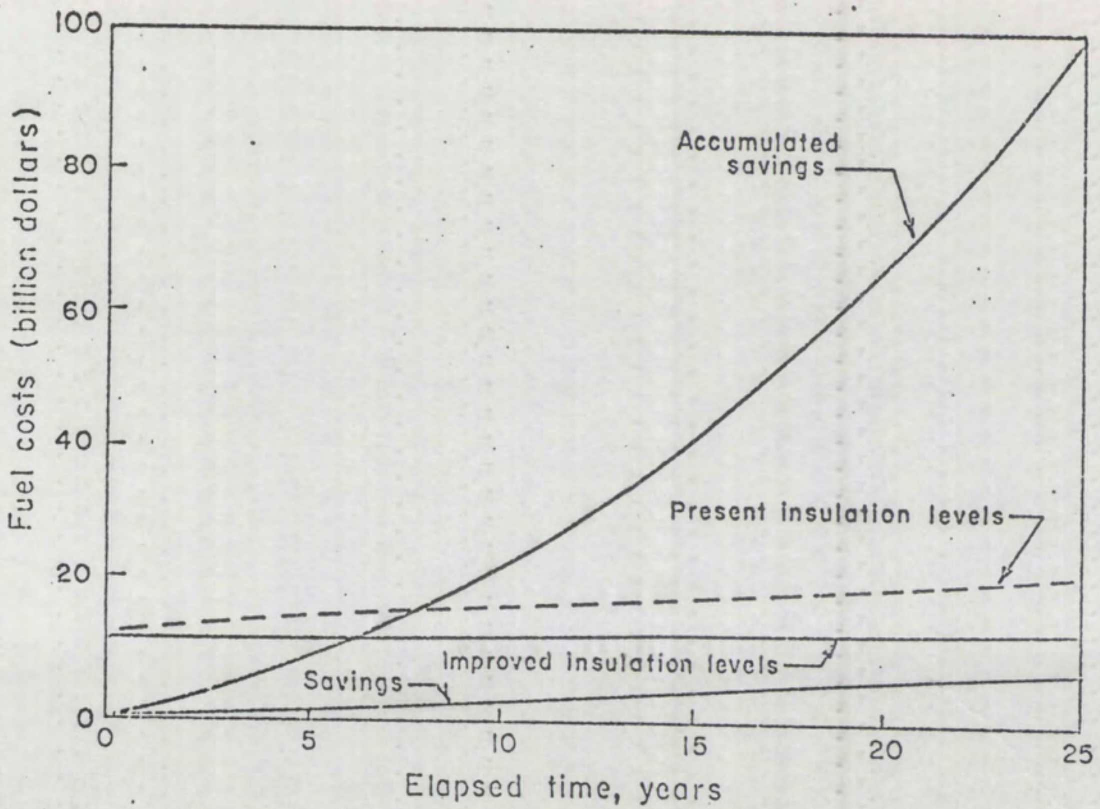

Figure 2. Cumulative Cost Savings at Current Fuel Prices from Improved Thermal Design of Present and Future Residential Buildings. (From (18) P. R. Achenbach).

was 71.9 x 10^{15} BTU(16) lost savings totalling 100 billion dollars would accrue at present fuel prices. Almost all predictions show that the relative cost of energy is almost certain to increase substantially in the future so that actual savings could amount to considerably more.

These savings are for dwelling units only and do not include those from subsurface manufacturing and commerce which, in addition, could be very substantial.

As shown in Table 4, heat transmission is reduced most effectively by placing the structure underground and in so doing reductions by factors of 3 to 8 are obtained easily.

Since energy is required to manufacture goods, the smaller air-conditioning and heating units and vastly reduced amounts of insulation needed in underground buildings, represent an additional energy saving. The extra energy required for underground construction must be subtracted from these potential savings. If the assumption that technological improvements will significantly narrow costs between underground and surface construction is borne out, the energy conservation becomes proportionately larger.

A well landscaped residential area, with possibly only one third the normal above-ground-volume of houses visible, would be less cluttered with buildings, creating a feeling of greater outdoor space. Some rooms could extend below the garden or outdoor patio. With imaginative architecture this could be exceedingly attractive.

PSYCHOLOGICAL AND HEALTH EFFECTS.

The first completely underground elementary school in the world was opened in Artesia, New Mexico in September, 1962. An evaluation of the

Abo Elementary School (and fallout shelter) in which a detailed study of pupil achievement, anxiety and mental health, opinions about the school, psychological effects and general health was made in 1972 (1). The authors concluded that "It seems that after ten years of experience with children attending an underground and windowless elementary school the professionals concerned with the health care of children in Artesia, N.M. (where the Abo school exists), are generally convinced that not only is the school not detrimental to the physical and mental health of their patients but it is actually a benefit to some." And that: "Although not as supportive of the school - fallout shelter facility as the parents of pupils who attended, the sample of the public clearly favored the school. Nine out of ten recommended that other schools be built like Abo, if such schools cost no more to build than other schools."

Manufacturing and consulting engineering firms in Kansas City, in general, found (19) that their employees "are extremely pleased with the working conditions ———. We have found efficiency to be better than that of offices above ground, probably because our people are not distracted by what is going on out in the street."

CONCLUSION

Building design, we believe, should be directed towards more advanced conservational systems. Underground construction is one of these systems. However, it is apparent to us that, at this time, there has not been given sufficient thought to the energy conservation aspect of the use of underground space to enunciate appropriate policies. The data base is too thin and too particularized. On the other hand, there appears to be ample promise for such use to warrant further investigations.

We conclude that:

(1) There is a considerable potential for conserving energy through greater use of subsurface space.

(2) Energy can be saved by placing storage, refrigeration and manufacturing plants underground and dwellings semi-underground.

(3) In no way can improved insulation for above ground construction begin to compare with underground buildings for conserving energy.

(4) There appears to be no adverse psychological effects of working in properly designed underground buildings.

We recommend several areas that need to be examined in greater detail before sensible new policies can be suggested:

(1) Existing data on historical initial construction costs, historical operating costs and all reports concerning heating and cooling of subsurface space should be collected. Research should be supported to generate new reliable data where needed. The data must be analyzed in context of the total energy input and output, i.e., construction, manufacture and use.

(2) All data, design procedures and conclusions then should be consolidated (e.g. in a well known source, such as ASHRAE(17)) so that judgments can be made as to whether there is sufficient societal savings to be worth either enunciating a national policy or pursuing the subject in connection with supporting another policy.

(3) Review current policy and legislation to identify where it may be either in conflict or supportive of a proposed policy, i.e., fire rules, lighting requirements, insurance practices, health and safety regulations, etc.

(4) Identify special interest groups which might be affected positively or adversely;

(5) Study potential sociological and psychological implications;

(6) What new institutional arrangements can be made;

(7) Define government role and responsibilities;

(8) Determine if there are other options which accomplish the same purpose and may be simpler to implement.

Thought might be given to developing a comprehensive and integrated set of policies for the use of underground space. Presently, those policies concerning this use seem to have been ad hoc and not part of a rationalized scheme. In the interim, wise and beneficial use of subsurface space can be directed best by developing reinforcing policies supportive of good existing public policies such as the one on the conservation of energy.

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from
ENERGY CONSERVATION THROUGH USE OF THE SUBSURFACE
AS RELATED TO THE OPERATION OF FOOD STORAGE PLANTS

John G. Muller, Vice President of Engineering
Southeastern Public Service Company

ABOVE AND BELOW GROUND FREEZER STORAGE STATISTICS

SPACE COMPARISON

	Gross Sq. Ft.	Usable Sq. Ft.	Usable Cu. Ft.	Est. Max. Hold--Tons	Sq. Ft. Req'd/Ton
Plant I		79,200	1,587,920	14,000	5.64
Plant II		154,800	2,998,800	19,000	8.14
Total Pl. I & II:		234,000	4,586,720	33,000	7.8 Av.
Plant III	185,083	132,700	1,725,000	11,000	12.0
Plant IV					
Rm B-3	76,000	61,500	738,800	5,263	11.7
Rm B-8	122,000	98,340	983,400	6,028	16.3
Rm B-10	201,300	165,110	1,981,320	10,366	15.9
Total/Av.	399,300	324,950	3,703,520	21,657	15.0
Total/Av. Pl. III & IV:		457,650	5,428,520	32,657	14.0

COOLING UNITS AND COMPRESSOR COMPARISON

	Total Unit T.R.	Sq. Ft./ Unit T.R.	Comp. T.R.	Sq. Ft./ Compr. T.R.
Plant I	180.0	440.0	100.6	792
Plant II	278.4	556.0	278.4	556
Tot/Aver.	458.4	510.5	379.0	617
Plant III:				
Orig. Inst.	176.0	754.0	214.5	618.6
Today (comp)	88.0	1508.0	143.0	930.0
1 comp. est. 50% capacity, 50% time.			107.0	1240.0
Plant IV - Original Installation:				
Rm B-3 (1968)	66	932	113.5	524
Rm B-8 (1973)	90	1090	224.0	1160
Rm B-10 (1962)	260	635	262.0	630
Tot/Aver.	416	781	N.A.	N.A.
Plant IV - Today:				
Rm B-3	66	932	77 est.	800
Rm B-8	90	1037	80 "	1230
Rm B-10	185	892	80 "	2064
Tot/Aver.	341	959	237	1363

COMPUTER STUDY OF EARTH INSULATION

Purpose of Study

The purpose of this study is to determine the advantages of using earth as insulation in building design. These advantages will be recognized as savings in energy which reduce the operating cost of the building. To determine these savings the computer will calculate the heat losses and heat gains over a year's time based on building material and climate data. This information can then be used to determine the cost of the power required to heat and cool the building.

Cases

Case 1. Case one is a Hallcraft Holliday Home, 1800 Square Feet used as a baseline model.
Case 2. Same as Case one except with added insulation.
Case 3. A Hallcraft Holliday Home with a four foot high soil berm.
Case 4. A Hallcraft Holliday Home with a four fout high soil berm plus added insulation.
Case 5. An underground house with a 12" sod roof with the same amount of square feet as a Hallcraft Home.
Case 6. The same underground house with more insulation and double layer glass.

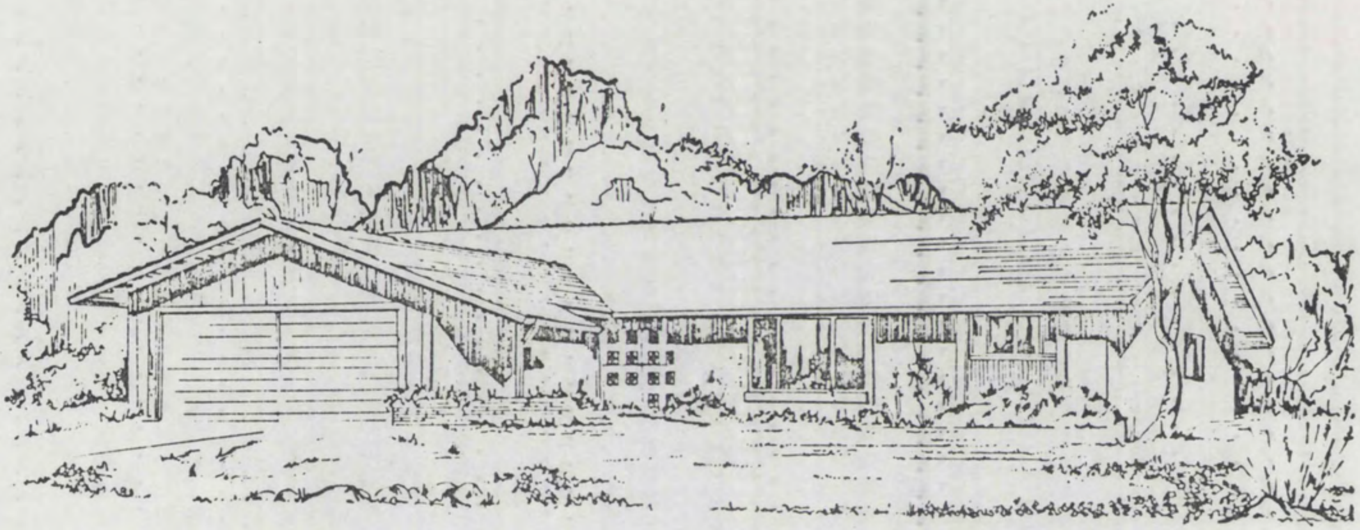
Computer Input

The input data of the program consisted of:

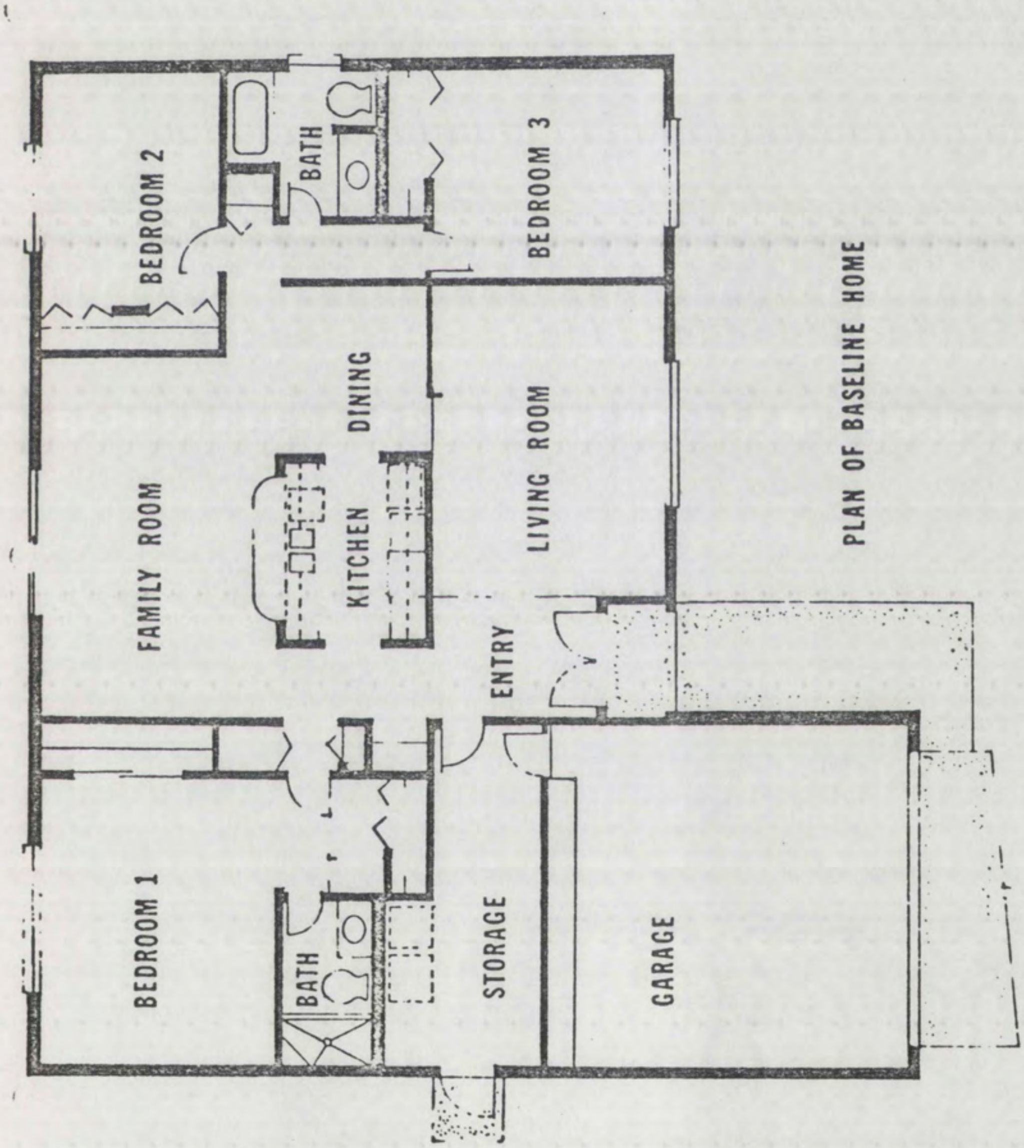
1. Operating schedule of building
2. Construction materials of walls, roof, floor, glazing.
3. Thermodynamic properties of these materials
4. Building orientation

Results of Data

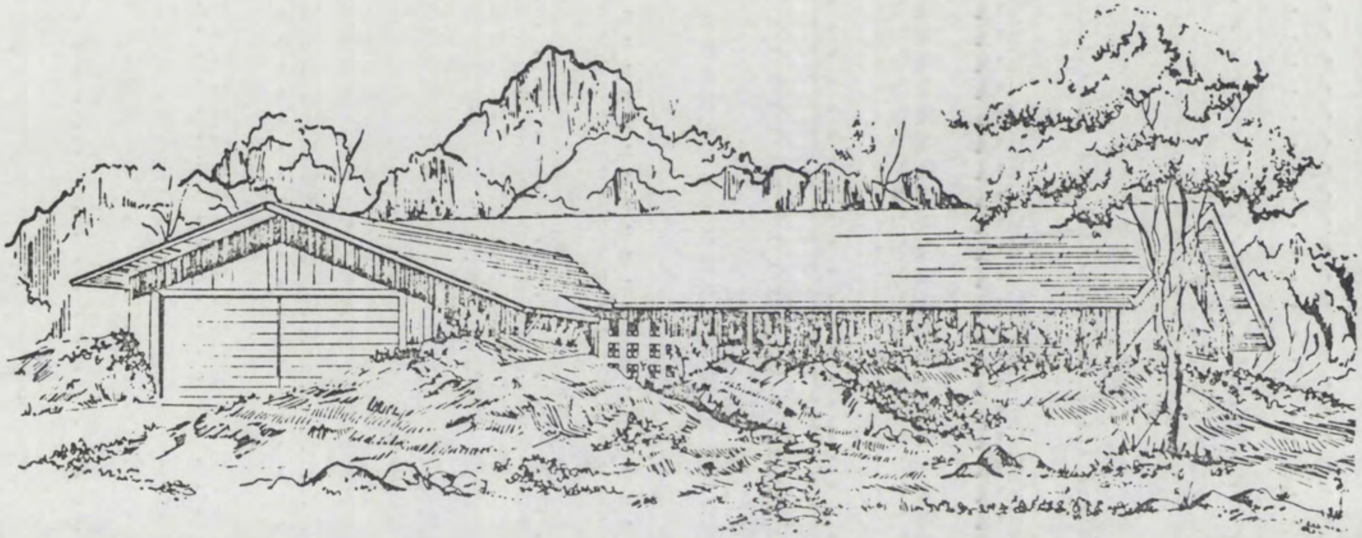
The actual results of the program are tabulated in figures
The underground house, Case 6, showed the best results with 29% overall savings in utility cost; Case 3 (the bermed house) proved to be the greatest savings for the least amount of initial cost. This initial cost would be paid back in 2 to 4 years with energy savings.



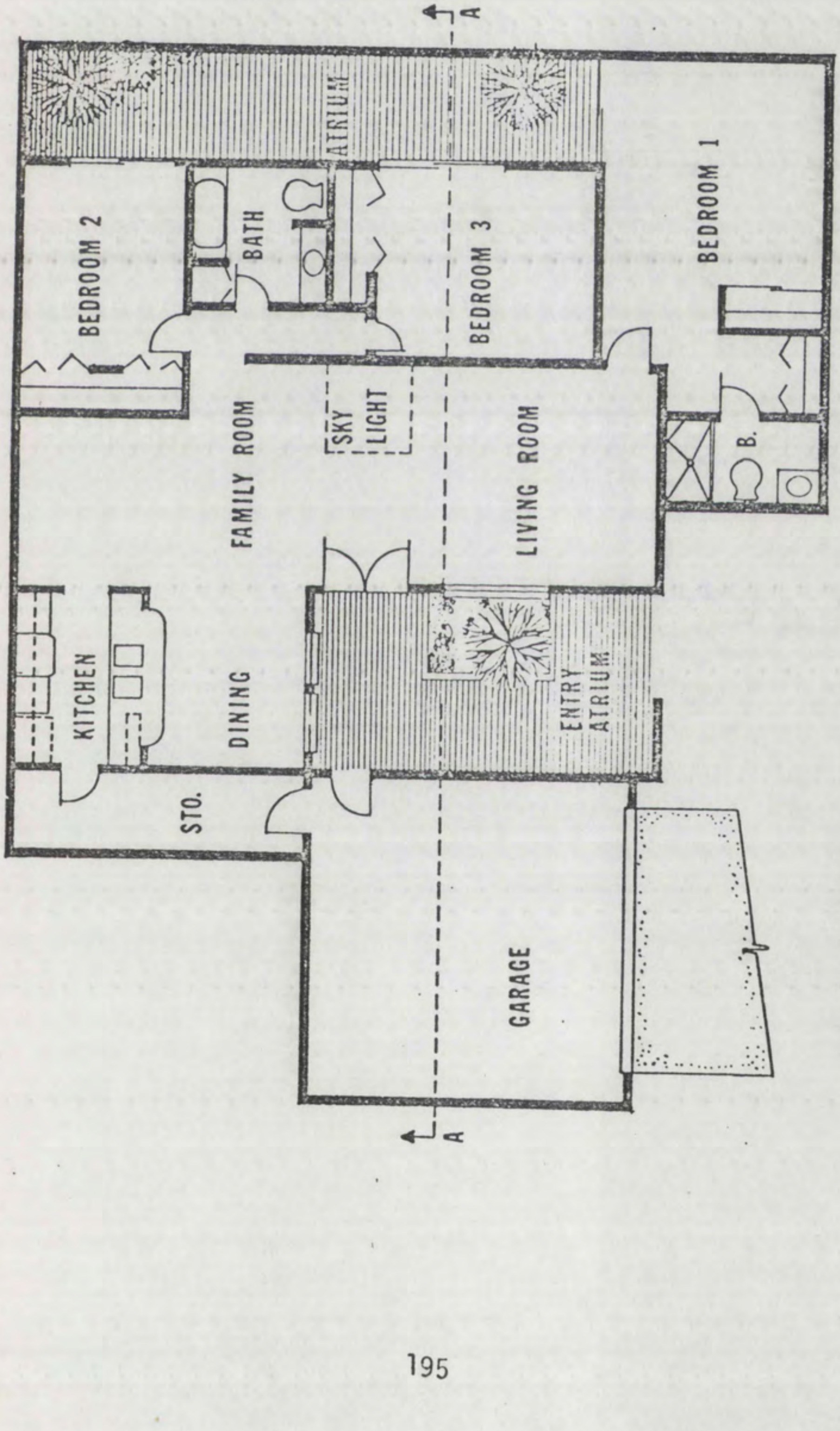
ELEVATION OF BASELINE HOME



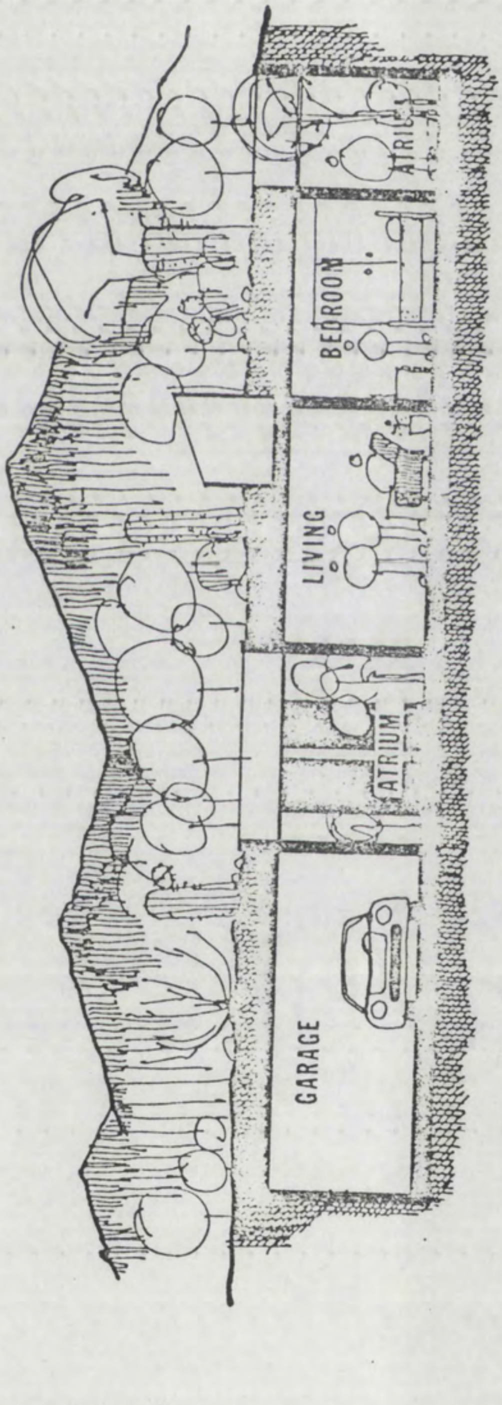
PLAN OF BASELINE HOME



ELEVATION OF MODIFIED BASELINE HOME



PLAN OF SUBTERRAINIAN HOME



SECTION OF SUBTERRAINIAN HOME

HALLCRAFT HOLIDAY HOME DATA

Case No.	Configuration	Additional Cost	Yearly Heating Load (Btu)	Yearly Cooling Load (Btu)	Total Yearly Load (Btu)
(1) Baseline (Standard Model)	6" Insul in Ceiling 3/4" Air in Walls	0	1.224×10^7	4.139×10^7	5.363×10^7
(2) Modified Baseline	10" Insul in Ceiling 3/4" Insul in Walls	$200	1.079×10^7	3.898×10^7	4.977×10^7
(3) Modified Baseline	6" Insul in Ceiling 3/4" Air in Walls 4' Soil Berm	$200	1.101×10^7	3.776×10^7	4.786×10^7
(4) Modified Baseline	10" Insul in Ceiling 3/4" Insul in Walls 4' Soil Berm	$400	9.372×10^6	3.656×10^7	4.593×10^7

Figure 1

UNDERGROUND HOUSE DATA

Case No.	Configuration	Additional Cost	Yearly Heating Load (btu)	Yearly Cooling Load (btu)	Total Yearly Load (btu)
(5) Underground (Standard)	6" Insul. in Ceiling Regular Glass No Zeolite	$1250	1.44×10^7	3.81×10^7	5.25×10^7
(6) Underground w/ Optional Insulation	10" Insul. in Ceiling Thermopane Glass Zeolite in Walls	$1550	6.6×10^6	3.14×10^7	3.80×10^7

Figure 2

ENERGY USE STUDY OF TWO SIMILAR SURFACE AND SUBTERRANEAN OFFICE BUILDINGS

This paper has proposed that the placing of buildings underground can reduce their over-all consumption of energy. The concept is based on the principle of the reduction of heat transmission through the building's shell, there-by lowering the heating and cooling needs with-in the building.

This supplement to the previous examples of energy conservative subterranean use is theoretical. It compares the energy that would be required by an underground office building with that required by an office built on the earth's surface. Both are assumed to have 2,475 square feet net area. The reason that office buildings were chosen as examples is that the use of office space can be assumed to be very similar. Where-as in a comparison of single family dwellings, there would quite possibly be such large variations in life styles, that an accurate comparison could not be made.

Design A will be the surface building. Design B will be the underground building.

BUILDING DATA

	Design A	Design B
Floor Area (sq. ft.)	2,475	Same
Dimensions (ft)	75x33	Same
Net Wall Area (sq. ft.)		
N & S	1,420	1,500
E & W	644	660
Glass Area (sq. ft.)		
N & S	80	-
E & W	16	-
Roof Area (sq. ft.)	2,475	Same
Slab Length (ft.)	216	-

Note: The roof of Design B is assumed to be covered with 24" of earth.

U-values (BTU/Hr. -ft.^{2}-°F)		
Walls	0.10	0.10
Roof	0.05	0.05
Floor	-	-
Slab	0.4	-

Note: Slab value is per foot of length.

Ventilation Rate		
Occupied hours	330	Same
Unnocupied hours	80	Same
Internal Load		
People	10	Same
Heat gain (BTU/person)	450	Same

TEMPERATURE DATA

	Design A	Design B
Inside	75	75
Outside		
Summer	100	-
Winter	15	-
Ground (summer)		
Roof Level	-	80
Wall (average)	-	65
Floor Level	-	60
Ground (winter)		
Roof Level	-	40
Wall (average)	-	55
Floor Level	-	60
Average Outside Temperatures		
Summer Daylight	85	-
Winter Daylight	55	-
Night	45	-

DESIGN COOLING LOADS

Internal (Lights, People, etc.)	32,930	Same
Transmission	9,450	-3,105
Ventilation Air	19,600	19,600
Solar Radiation	2,550	-
Total, BTUH	64,530	49,425
In Tons	5.5	4.2

DESIGN HEATING LOADS

Transmission	16,190	13,635
Ventilation	21,385	Same
Total, BTUH	37,575	35,020
In KW	11.5	10.8

Note: The equipment capacity savings of the underground building is 1.3 tons of cooling and .7 KW of heating.

ENERGY CONSUMPTION

In this study the energy usage is divided into three main categories: 1 Base electric load, 2 Cooling load,and 3 Heating load.

1. Base electric load includes all energy used for lighting, air handling, and other miscellaneous loads. The maximum base electric load was estimated at 3.2 watts per square foot, which is about 8 KW for these buildings. The annual load factor is assumed to be about 40%. Using this figure, the annual energy consumption for base electric load would be about 28,000 KWH. In a typical office the base electric load usually represents two-thirds of the total consumption.

2. Cooling load energy usage was determined by manual calculations based upon the average ambient and ground temperatures, the U-values of the building shell, and ventilation rates. This allowed the calculation of average transmission and ventilation loads. These loads were combined with the average solar loads (surface building) and the internal load which is a constant during occupied hours, in order to arrive at the average cooling loads. It is assumed that offices need cooling during most of their occupied hours because of their high internal load. Cooling would be shut down during unoccupied hours.

   Summary of cooling loads

Design A	Summer	Winter
Internal	32,930	32,930
Transmission	2,850	-5,690
Ventilation Air	7,130	-7,130
Solar	3,435	3,050
Total, BTUH	46,365	23,160
In Tons	3.9	1.9

Design B		
Internal	32,930	32,930
Transmission	-5,580	-11,160
Ventilation Air	7,130	-7,130
Total, BTUH	34,480	14,740
In Tons	2.9	1.2

Annual Usage

Occupied Hours	1,320	1,320

Design A (3.9 x 1,320) + (1.9 x 1,320) x 1.4
=1,070 KWH/Yr.

Design B (2.9 x 1,320) + (1.2 x 1,320) x 1.4
=760 KWH/Yr.

3. Heating load energy usage in offices is normally higher during unoccupied hours. A variation in maintained temperature of 65° F. during unoccupied periods lowers the heating needs of the building.

Summary of heating loads

Design A	Winter
Internal	1,710
Transmission and Solar	-5,690
Ventilation Air	-1,730
Total, BTUH	-6,710
In KW	1.7

Design B	
Internal	1,710
Transmission	-5,580
Ventilation	-1,730
Total, BTUH	-5,600
In KW	1.6

Annual Usage

Unoccupied Hours	3,060

Design A (1.7 x 3,060) =5,200 KWH/Yr.

Design B (1.6 x 3,060) =4,900 KWH/Yr.

Summary of annual energy usage

Design A		KWH
Base Electric		28,000
Cooling		10.700
Heating		5,200
	Total	43,900
Design B		
Base Electric		28,000
Cooling		7,600
Heating		4,900
	Total	40,500

Annual Costs

Design A 43,900 x .02 = $880

Design B 40,500 x .02 = $810

Difference/Yr. $70

CONCLUSION

Considering the overall building usage, the savings are not as large as one might be led to believe they would be when evaluating the advantages of earth insulation. Part of the reason for this is:

1. The base electric load represents almost two-thirds of the total energy consumption, and is common to both designs.
2. The two primary HVAC loads are the internal gain and the ventilation air, and are common to both designs.

From the standpoint of energy usage, the subterranean building relies on far less energy than the surface building when comparing the variables of the two designs. As costs of energy increase this consideration will become more and more important to the total life costs of a structure.

UTILITIES FOR UNDERGROUND STRUCTURES

By Kirby T. Meyer, P.E.

Presented at a Conference:

Alternatives In Energy Conservation:
The Use of Earth Covered Buildings

July 9-12, 1975

Sponsored by
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UTILITIES FOR UNDERGROUND STRUCTURES

By Kirby T. Meyer, P.E. *

ABSTRACT

Considerations of utility service for underground structures are presented with emphasis on drainage and sewerage. Topics include clear water vs. solids carrying water, pumping vs. gravity flow, typical technology for accomplishing wastewater pumping including costs, construction approaches and serviceability. Deep utility main construction is covered, including considerations of cut and cover vs. tunneling, again with descriptions, cost comparisons, environmental and neighborhood impact being analyzed. Small diameter horizontal bore techniques are described. An extensive description of the Austin Crosstown Interceptor Tunnel, including purpose, routing, cost effectiveness, design and investigative approaches, and construction aspects, concludes the presentation.

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* Vice President, Snowden and Meyer, Inc., Consulting Engineers, Austin, Texas

INTRODUCTION

Utility requirements for underground structures are basically the same as for any other structure with several interesting differences. One consideration is the fact that many underground structures will require that wastewater be pumped instead of drained by gravity. In addition, consideration must be given to potential danger from flooding in the event of pump or power failure and leaking of the water supply or wastewater or ground water backflow into the structure. This paper considers some factors affecting the pumping of drainage water and sewage, including several new types of pumping equipment such as grinder pumps and bio-filter installations, with considerations of capital costs and energy consumption in a hypothetical underground structure. Where cost comparisons and installation descriptions are made with regard to an underground structure in this paper, it is assumed that the structure is completely buried and that pumping must be done against a total dynamic head of 50 feet (Fig. 1). It is recognized that these assumptions are completely arbitrary and an infinite number of variations would be possible.

Other items considered include some aspects of deep pump installation and serviceability and deep utility main construction, including comparisons of cut and cover vs. tunneling techniques. Horizontal boring techniques for small diameter lines are discussed, as well as a detailed discussion of the Austin, Texas Crosstown Interceptor Tunnel.

Because of many pressures of society and technology, the use of tunneling and boring construction for utility lines will become more widespread. This will make the construction of buried structures more feasible in that the availability of economical gravity drainage of wastewaters will be increased.

WATER AND POWER

The use of underground or buried structures will produce no unusual demands on utility technology with regard to water and power supplies since both of these systems are typically buried in many instances today. Direct burial power cable is readily available, and water lines are normally buried and function in any position. The only possible added consideration would be the fact that the pressure in water lines increases at the rate of 0.43 PSI for each additional foot of depth, relative to the pressure in the water main. Consequently, extreme depths of burial such as 100 feet would require consideration of pressure reducing equipment to keep water supply pressures within tolerance limits of the fixture capacity. In addition, the design of the water supply, and to some extent the power supply, would have to give more consideration to "flooding fail-safe" features than above-ground structures. A failure of a water valve, for example, coupled with a power failure of the wastewater pumping system could flood an underground structure (Fig. 2), whereas an above-ground structure probably would be self-draining.

DRAINAGE AND SEWERAGE

Clear Water Vs. Solids Bearing Water

Clear water, such as the majority of storm water runoff and drainage picked up around a basement from ground water, for example, or ordinary tap water, is relatively simple to remove either by gravity or pumping. Such water will flow through very small diameter gravity drains on the order of 1 inch, or could be pumped under slight pressure for considerable distances and elevations through lines even smaller, on the order of 1/2 inch or 3/8 inch, if necessary.

On the other hand, solids bearing water such as domestic sewage, some storm water, or even the runoff from washing down floors poses considerably more difficulty in removal either by gravity or pumping. In the case of gravity lines, a minimum of a 4 inch line would be necessary to handle solids bearing water, and many authorities prefer a 6 or 8 inch line. In addition, solids bearing water should maintain a minimum velocity (1)* as well as a minimum diameter of pipe so that solids do not settle and cause blockages. The pumping of solids bearing water also requires that pump clearances, self cleaning features and servicing access all be considerably enhanced over a clear water type pump, causing increased first cost and reduced pump efficiencies. In addition, lines for solids carrying water must be constructed to carefully set grades and consideration given for servicing features such as cleanouts and manholes.

Gravity Vs. Pumping

The removal of wastewater by gravity pipeline has several advantages over removal by pumping. A big advantage is the lack of power requirements and moving

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* Numbers in parenthesis refer to List of References at end of paper

parts to wear out and require maintenance. Gravity drainage is simply more reliable and much less expensive operationally than a pumping system (Fig. 3). It is truly hands-off-automatic, works even during a power failure, and costs nothing to operate.

Pumping systems (Fig. 4), on the other hand, are subject to various difficulties that beset equipment with regard to maintenance, the constant consumption of power over its lifetime, the problem of reliability, and non-availability during power failure. In some instances the capital cost of the installation is also higher than that of a gravity system, but not in all cases. A compensating factor for a pumping system is that the pressure lines may be smaller and do not have to be laid to a precise grade as is the case with gravity lines. Consequently, these lines can follow the contour of the land and generally do not require deep excavations.

A major consideration in pumping of wastewater is the arrangement for dealing with solids carrying water. As a general rule, it is considerably less expensive to pump non-solids carrying water. Therefore, several possible alternative approaches to pumping solids carrying water are of interest, aimed at either clearing up the water before pumping or finely dividing the solids so that the liquid acts almost as clear water.

Clarifying Solids Bearing Water

There are several possibilities available for clearing up solids bearing water prior to pumping. These possibilities include clarification by settling or by filtration. Both of these methods involve problems which cause clarification to be more expensive than pumping solids bearing water in most cases. One possible exception is the bio-filter approach, as illustrated in Figure 5. In this unit, wastewater is filtered by a gravity pass-through unit and the residue is subjected to digestion on the spot. This is accomplished without additional power and is a minimum service arrangement. Simple clear water pumps and very small diameter pressure lines can then be used for moving the clarified wastewater.

Grinder Pump Systems

Another alternate in pumping wastewater is the grinder pump system. These units are usefule for small systems such as individual residences or clusters of residences, as is the bio-filter arrangement. In the grinder pump system, wastewater is ground and finely divided by cutter blades prior to being pumped, similar to a sink garbage disposal unit. Thus, the size of solids suspended in the water is very small and the fluid can be pumped through small diameter pipes, even as small as 1-1/4 inches. These installations are relatively expensive on first cost and are possibly highly maintenance prone in addition to being subject to blockages. They also probably require more power than the clear water pumps or solids carrying water pumps. However, in the size installation in which their use is applicable, this type of equipment can create a large savings in pipeline costs as the small diameter pressure lines can be laid following the contour of the ground. Figure 6 illustrates a cut-away view of a grinder pump.

Typical Pumping Costs

Table I below indicates approximate capital costs and power requirements for various types of pumping installations at various rates of pumping. Many arbitrary assumptions had to be made in preparing this table and in actual practice variations from the figures indicated will prevail.

TABLE I - APPROXIMATE COSTS OF PUMPING WASTEWATER (TDH = 50') PF = .8

Daily Avg. Rate (GPM)	Solids Handling eff = .6		Grinder Pumps eff = .5		Bio-Filter & Pumping eff = .7	
	Capital	Kwh/day	Capital	Kwh/day	Capital	Kwh/day
2	$ 1000	0.8	$ 1000	1	$ 800*	0.7
20	1500	8	5000	10	12000*	7
100	8000	42	10000	48		36
200	10000	84		96		72

* Includes primary treatment

It should be recognized that normally only smaller facilities such as 1 to 10 single family units or small apartments can be economically served by grinder pumps or the bio-filter type installations. More units, of course, can be served by ganging this equipment or it could be helpful for widely spaced individual installations, but the solids handling pumping arrangements are probably still the best for major municipal wastewater flows. Figure 7 indicates a plot of the information in Table I.

Ground Water: Sealing Vs. Drainage

In any deep structure considerations of ground water can be important and expensive. Two approaches are possible in dealing with ground water to keep the interior of the structure dry - sealing or drainage. Sealing consists of waterproofing the below grade walls so that no water can enter. In effect, one builds an underground boat. This is important, but seldom completely successful for a long period. If persistent high ground water tables are to be expected, a good job of sealing must be done and in addition, the water table immediately around the structure should be lowered by means of drainage. This adds to the wastewater pumping problem since the drainage water must also be removed by pumping from our hypothetical completely buried structure.

Further complicating the picture is the fact that many local municipal codes (2) do not permit ground water to be drained into the sanitary sewer system, so it may be that dual systems would be required. In fact, a large percentage of the loading on any sanitary sewer system can be contributed by ground water, either by deliberate introduction as from basement wall drains or by infiltration through pipe joints and into wet wells. The exclusion of ground water from sanitary sewer systems is desirable to avoid wasteful economics in conveying and treatment.

These considerations are important in underground structures not only because of economics, but because a power or pump failure could lead to flooding the entire structure.

Pumping Reliability

Reliability factors for wastewater and drainage water pumps for underground structures will need to be higher than that for above-ground structures, everything else being equal. This will translate into higher construction budgets in many cases due to the possibility of duplex equipment and standby power units being required, along with generally higher than normal quality level of equipment and workmanship.

Reduction of Water Use

As capital costs and energy consumption increase because of requirements for pumping out wastewater and drainage, it becomes more interesting to consider ways and means to reduce the volume of liquids to be handled. Several methods present themselves. With regard to ground water drainage, as has been previously discussed, simply an excellent job of waterproofing and sealing might eliminate the need for pumping ground water from around the structure, or require only a small pump to remove a small amount of seepage from inside.

With regard to wastewater flows, several types of equipment have been marketed or proposed which would greatly reduce water consumption for sanitary purposes. Some types of compressed air toilets have been used for railroads and other water scarce facilities which reduce the customary four gallons of water per flush to one quart (3). In addition, recycling of other drain water within a structure could be feasible for some uses. For example, laundry, lavatory and shower drains could be recycled for use in flushing toilets.

Infiltration

Infiltration into sewer lines has long been a problem for design engineers and maintenance personnel. It is quite possible in poorly designed or faulty installations for sewer lines to pick up more ground water by infiltration than the wastewater flows themselves. This is a definite design consideration in sizing pipes and treatment plants which are eventually to receive the flows, and large energy and economic factors are involved. Recent practice has been to specify much lower permissible infiltration rates into wastewater lines by use of better jointing techniques and tighter controls during construction. Whereas formerly up to 1000 gallons per inch of pipe diameter per mile of infiltration was considered a good installation specification, it is current good design practice to allow no more than 250 gallons per inch per mile.

Venting Gravity Lines

Gravity lines serving sewers to structures have traps, sometimes called P-traps, to prevent backflow of sewer gases into the structure. These traps can be drained and the water seal broken by vacuum if the lines are not properly vented downstream from the traps. The venting line should be kept in mind as an additional piece of plumbing that will have to go up to the outside atmosphere above any underground structure.

INSTALLATION OF DEEP WASTEWATER PUMPS

Deep wastewater pumps should be installed with the thought in mind that they may someday have to be taken back out for replacement or repair. Small capacity pumps which can be moved by one or two men could be installed within an underground structure or basement satisfactorily. However, the larger equipment which will require hoists to remove probably should have careful consideration given to installation in a straight vertical shaft outside the structure to facilitate pulling the equipment. Large earth auger machines are suitable for drilling large diameter vertical shafts. In many cases these shafts can be drilled large enough to accommodate the complete wastewater pump installation. Some types of equipment are more readily serviced than others, such as the submersible type pumps which are rail mounted as indicated in Figure 4. These make up with a quick slide coupling and are readily lifted for clearing or maintenance.

DEEP UTILITY MAIN CONSTRUCTION

Cut & Cover Vs. Tunneling

When installing utility lines in the ground, the two basic methods of installation are cut and cover or digging a trench and filling it after the pipe is placed, and tunneling or boring. Traditionally, the choice of the two methods is hinged on economics with a certain depth of installation being the cutoff point for economical installation of pipelines by trenching, and tunneling or boring being more economical beyond this depth. For a variety of reasons, the breakover depth has been steadily rising closer to the ground surface in recent years. These reasons include advancements in tunneling and boring technology, greater stress on the environmental impact of construction, and neighborhood disruption which is attendant upon the cut and cover method. Additionally, increases in energy costs have tended to favor a deeper installation method such as tunneling or boring, in that a gravity drain system can be maintained without the necessity of lift stations or pumping as would be the case should a relatively shallow trenching installation be utilized.

For reasons outlined previously in this paper, deep utility mains for drainage of water and wastewater would be of great advantage to underground structures. These advantages include enhancement of reliability and great reduction in energy consumption for this function. In many cases capital costs would also be reduced. However, gravity drain lines are not traditionally installed at depths great enough to service buried structures or even partially buried structures. The increased use of deep interceptor tunnels will greatly benefit the potential cost and energy-effectiveness of underground structures.

Table II below indicates some average figures on costs per lineal foot of installation of various sizes of gravity wastewater lines installed at different depths in earth and in rock. These figures are applicable to the Central Texas area and because of the variety of factors that could influence any given job, are subject to wide variation in actual practice. However, the relative relationships are probably about right.

TABLE II - GRAVITY WASTEWATER LINES - AVG. COST OF INSTALLATION PER L.F.

Size	Depth: 4'	6'	8'	12'	14'	20'	25'	30'	35'	Bore or Tunnel
Earth 4"	$4.50	5.00	5.50	6.25	7.50	18.00	30	40	60	45
Rock 4"	6.50	7.25	9.00	12.00	14.75	22.50	40	65	90	100
Earth 8"	5.00	6.50	7.50	9.00	10.00	20.00	32	42	62	55
Rock 8"	8.00	8.25	10.00	13.00	15.75	28.50	41	66	91	125
Earth 42"				55.00	80.00	100.00	130	150	185	250
Rock 42"				150.00	160.00	175.00	180	190	225	300
Earth 84"					105.00	135.00	170	200	225	350
Rock 84"										363

Costs of the smaller diameter lines (up to 8 inches) assume relatively open country and very little disruption of existing pavements and streets. The larger diameter interceptor lines assume disruption of existing streets. This is generally the case in that the need for large diameter lines is usually not recognized until considerable development of an area has taken place.

Figure 8 is a graphical presentation of the data contained in Table II. The data for the 84 inch tunnel in rock was taken from the Austin Crosstown Tunnel project. It should be noted that the $363 per foot cost reduces to $275 when the inlet structures are removed from the cost calculations. It should also be noted that capital costs are not the total criteria for judging which method of installation would be best. The total cost per year over the design life of the facility must be considered. This would include the yearly debt service, as well as yearly operating and maintenance costs. Also, things that must be considered are the relative costs of land, legal costs, and auxiliary costs of services to the interceptor. In other words, it may cost more to take advantage of the interceptor at one depth than it would at another. Many intangible differences must also be evaluated, including the level of community disruption and outrage engendered by the construction operations and the subtle effects on the environment, loss of historical and archaeological sites, and loss of income to businesses established along the route which could be seriously affected by prolonged construction.

Figure 9 indicates the impact on a county road of the installation of a 60 inch interceptor by the cut and cover method. Basically, the road was entirely blocked for a period of several months. Figure 10 shows the impact on a city collector street by the construction activity of the 84 inch Crosstown Interceptor Tunnel.

The amount of surface area impacted by the installation of a utility line by trenching and filling can vary from a 10 to 15 foot wide strip for small diameter lines placed at depths not exceeding 8 to 12 feet, to a minimum of a 50 foot wide strip impacted by a large diameter line 15 to 20 feet deep. Not only the width of the trench involved is greater, but the room required for construction equipment and storage of excavated earth is considerably greater. Very deep cut and cover operations may require double excavation or shouldering and sheeting and bracing, and even wider surface disruption widths.

In many cases, major wastewater interceptors are routed down creek valleys in urban areas. This is because creeks are the natural drainage low point in an area and the installation of sewer lines traditionally is more economical following the contour of the land. The typical city will have a major interceptor running down the valley bottom of each of its major creek watershed systems. The installation of major interceptors causes fairly severe environmental impact in these creek bottoms. Since creek bottoms generally harbor some of the last remaining wildlife and plant preserves in an urbanizing area, and since these areas are generally unsuitable for major construction due to the dangers of flooding, they are usually prime targets for parks and greenbelts. Thus, confrontation between municipal and utility authorities and environmentalists is readily generated over these major interceptors. One result of this has been to increase the cost required to make the interceptors environmentally acceptable during construction and afterwards. Measures may include reducing creek siltation during construction, planning to reduce construction impact on the surrounding neighborhood, protection of designated plant and animal species, and extensive and exhaustive sociological, geological, biological and hydrologic studies prior to construction. Increased legal costs, presentation costs, and public information programs and hearings also add to the general time lag and cost load of these project. These routes are often the locale of archaeological sites and historical routes or settlements, adding to the general resistance to disruption by major construction.

As a consequence of these pressures building to resist the placement of major interceptors down creek bottoms, the use of extensive tunneling for interceptor installation is becoming more popular from a community pressure and political point of view, as well as through the economics of the situation. This type of installation is by no means immune to the environmental considerations and exhaustive studies described above;

however, it is much more able to provide satisfactory solutions to the problems posed as opposed to the open cut and cover method. As a consequence, more tunnels will probably be seen in the future for major interceptor line construction. Various forces are tending to push the crossover point of capital and total costs closer to the surface, and often the intangible benefits of tunneling will decide the issue. The fact is that in some cases tunnels are less expensive in first cost, and in many cases less expensive in total yearly cost over project life than cut and cover installation. In addition, they are, on many counts, less dangerous to construct, much more energy effective as far as long term operation, and are much less painful projects for local governments to execute with regard to neighborhood disruption and environmental protests.

Small Diameter Horizontal Bores

Another method akin to tunneling is what is commonly termed "road boring". This type of equipment, illustrated in Figure 11, can create a bored opening from 4 inches to 30 inches in diameter, and is commonly used for placing utilities beneath existing roadways. Many authorities such as the Texas Highway Department and city officials do not permit open cutting of existing pavement but require any utility crossings placed after paving to be bored. The length of such bores seldom can exceed 300 feet between pits excavated for repositioning equipment and reestablishing alignment. The costs vary considerably depending on the type of material and the size of bore, but complete installations including the carrier pipe can range from $25 to $125 per foot. It is possible that such equipment could find applicability in underground structures in providing a direct heading for gravity drainage lines to a deep interceptor or a drop inlet to a deep interceptor.

THE AUSTIN CROSSTOWN INTERCEPTOR TUNNEL

The Austin tunnel is nearing completion after having been under construction for the last two years. Its purpose is to serve as a wastewater interceptor stretching from the northwest side of Austin to the east side and discharging at the Walnut Creek wastewater treatment plant. This interceptor is intended to serve much of the present and all of the future needs of the north side of Austin for many years to come. (4) The design capacity is not expected to be reached until the year 2020. The interceptor is 57,900 feet long or approximately 11 miles. It ranges in size from 84 inches on the upper end to 96 inches on the lower end inside diameter. The depth averages 120 feet below the ground surface and in some places is as deep as 450 feet. Excavation was by tunneling machines or "moles" with the walls being lined with a minimum of 8 inches unreinforced, special mix concrete. The tunnel has a total drop in grade of 36 feet from one end to the other and flow is entirely by gravity.

The cost of the interceptor is approximately $21 million. At full capacity the tunnel will discharge 131 million gallons per day of wastewater for treatment at the Walnut Creek plant. This is equal to serving an equivalent population of 1,310,000 persons, which produces a cost effectiveness ratio of $.16 per gallon per day per capita at design capacity. Considerations of infiltration in tributary lines will reduce actual equivalent population served.

Construction by tunneling was chosen for many of the reasons outlined in previous sections of this paper. The total cost analysis including the cost of operating the 11 lift stations it replaced, power, maintenance personnel, plus initial capital costs, indicated the tunneling method would prove superior to the economics of open cut and fill and traditional lift station methods by the year 1985. This study was performed before the recent dramatic increases in the cost of energy. It is believed that the breakover date may be much sooner now, perhaps by the year 1980.

Design of this facility required extensive studies of future population trends, growth patterns and wastewater production data. (5) Considerations had to be given to existing and future sewer infiltration rates, as well as economic analyses of operations, maintenance and capital costs. An extensive geological investigation was required, as well as special considerations of materials for maximum cost effectiveness over the design life of the structure. An example of this is a special concrete design intended to reduce the effect of sewer gas corrosion on the concrete liner.

CONCLUSIONS

1. It is much more desirable for underground structures to be drained by gravity for ground water and wastewater than by pumping, from the standpoint of energy consumption, functional reliability, and economics, in most cases.

2. This may not be possible in many cases unless a deep wastewater interceptor is available nearby.

3. If pumping is required, considerations should be given to clarifying or grinding solids carrying water or reduction of volume to be pumped.

4. Economics and environmental and neighborhood impact cause deep interceptors installed by tunneling to be preferred from many points of view other than simply energy conservation.

5. Greater reliability and "fail-safe" features must be built into utilities for underground structures, with a resulting increase in cost.

SUGGESTIONS FOR FUTHER RESEARCH

1. Catalog all existing interceptors and tabulate the economics and technical feasibility of establishing underground structures near the route of such interceptors to take advantage of the possibility of gravity drainage.

2. Analyze the total economics of cut and cover utility installation vs. tunneling in urbanized or urbanizing areas. This should include initial capital costs, total energy and maintenance costs over the project design life, economic impact of neighborhood disruption including loss of business, loss of community cohesion, environmental and aesthetic impacts and considerations of construction safety. These studies should take into account the accelerating curve of energy costs as well as projects of construction technology. This study is broader than simply a consideration of energy alternatives but would fall well within the scope of "urban studies".

LIST OF REFERENCES

1. Texas State Department of Health, Design Criteria for Sewerage Systems.
2. Plumbing Code, City of Austin Municipal Building Code.
3. News & Views, a publication of the California State Dept. of Parks and Recreation, "New Waste Disposal System Eyed for Parks".
4. Engineering News Record, "Austin Bores Past Environment with 11-mile Sewer Interceptor", May 16, 1975, pg. 28.
5. Horner & Shifrin, Inc., "Study of Wastewater System - Phase I" for Austin Crosstown Interceptor, Oct. 1969.

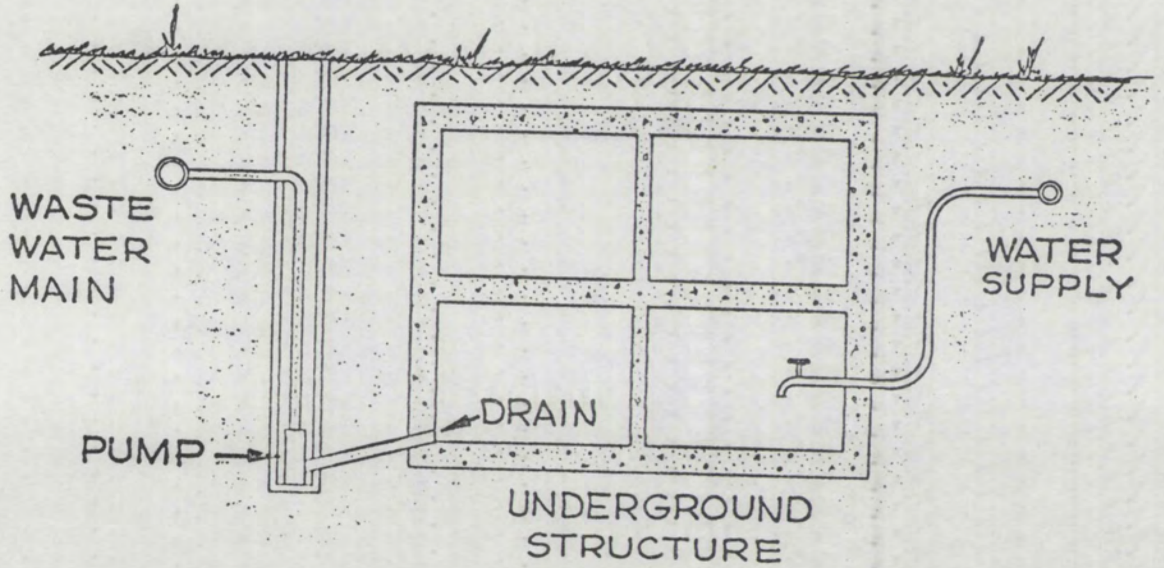


FIG. 1 - UNDERGROUND STRUCTURES: WATER & WASTEWATER

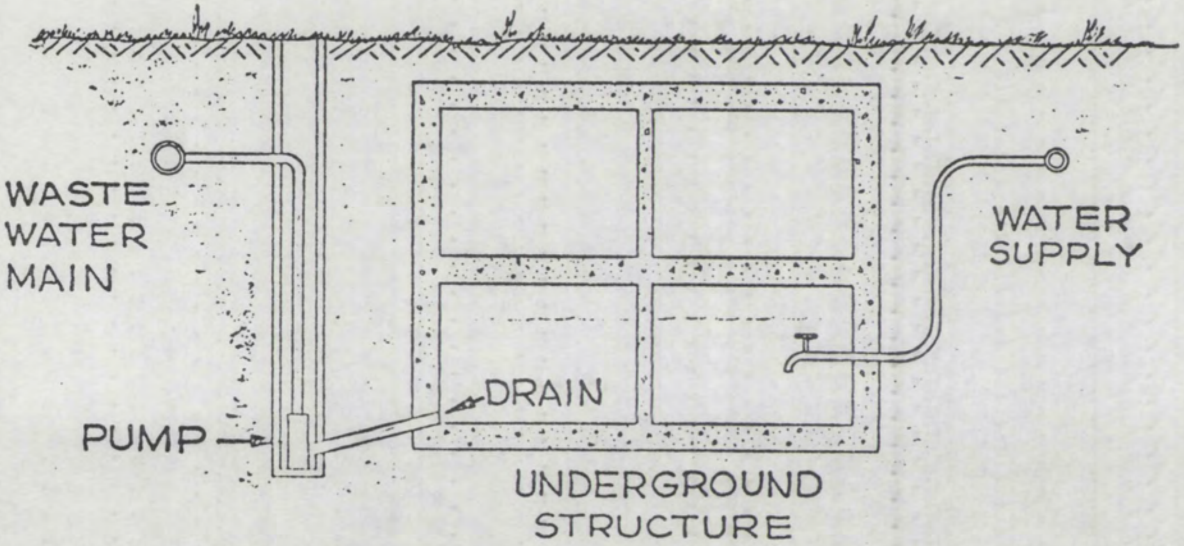


FIG. 2 - UNDERGROUND STRUCTURES:
PUMP FAILURE

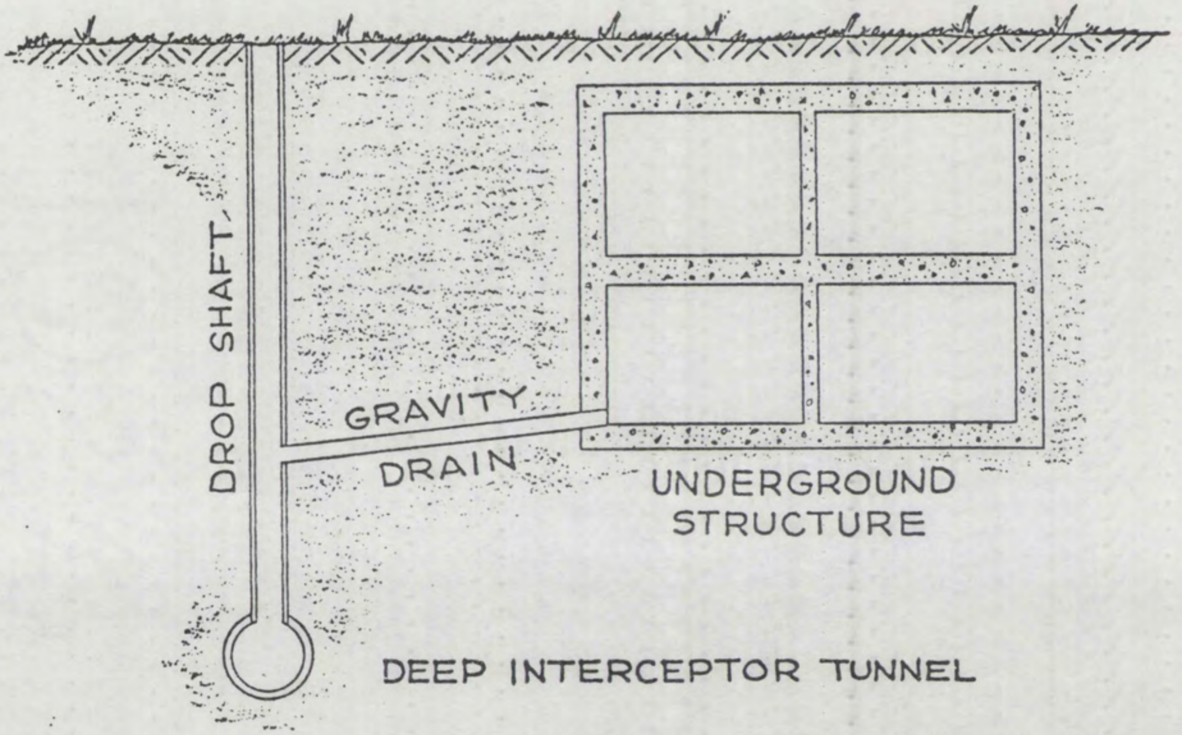
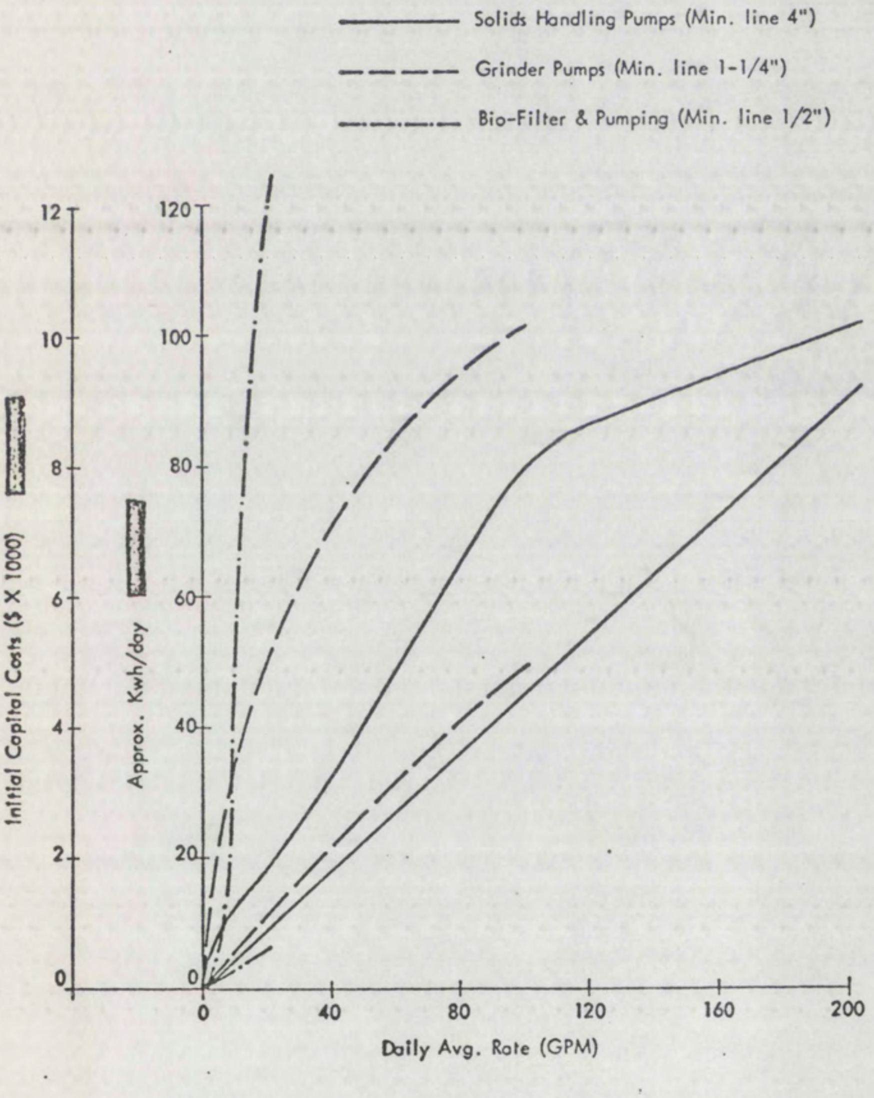
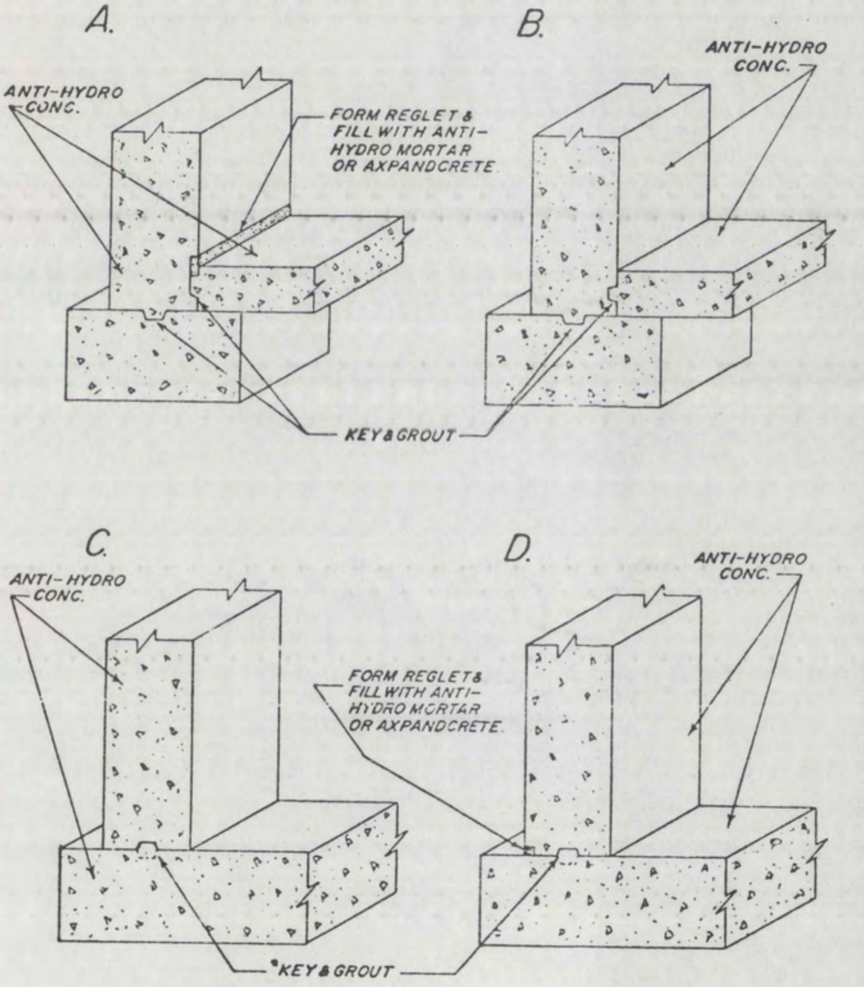


FIG. 3 - UNDERGROUND STRUCTURES:
GRAVITY DRAINAGE

FIG. 7 - APPROX. COSTS OF PUMPING WASTEWATER
(THD 50 ft.)



RIGID WATERTIGHT JOINTS

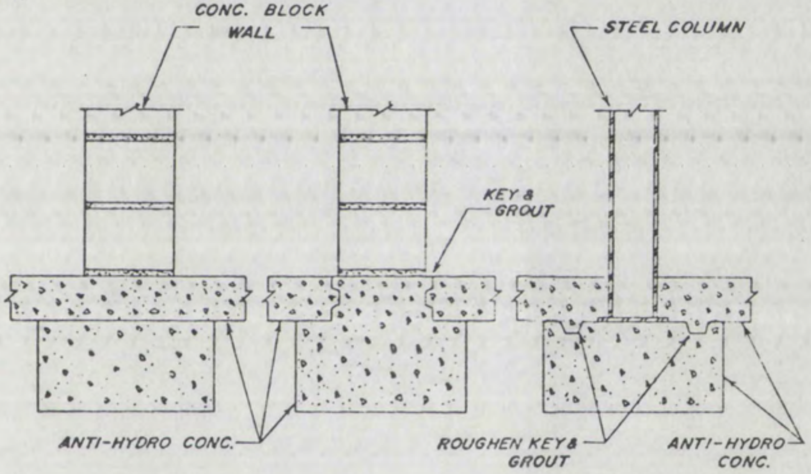


*NOTE: CAN BE DROP KEY OR INVERTED AS SHOWN.

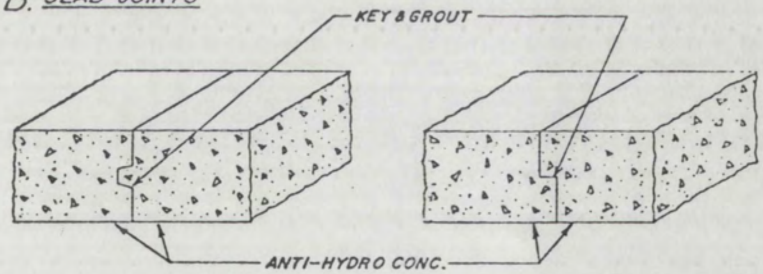
A-H STANDARD WATERPROOF JOINT DETAILS	SHEET 1

RIGID WATERTIGHT JOINTS

A. INTERIOR WALL OR COLUMN



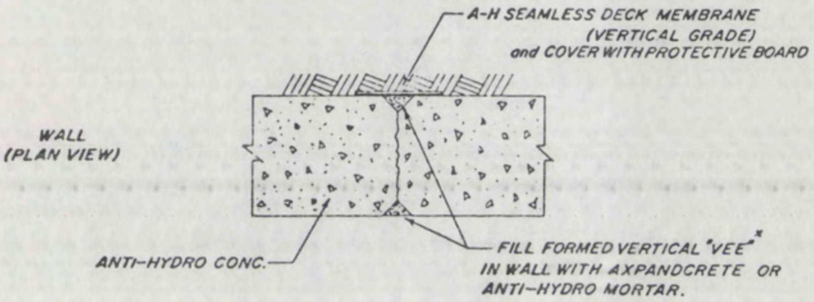
B. SLAB JOINTS



*NOTE: STEP KEY FOR LIGHT LOADING OR SLAB ON GRADE

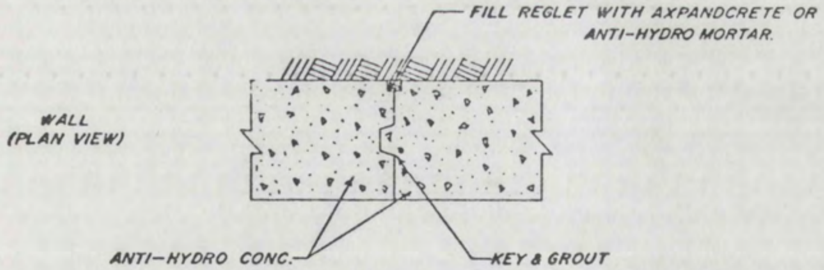
A-H STANDARD WATERPROOF JOINT DETAILS	SHEET 2

A. WATERTIGHT VERTICAL CONTROL JOINT

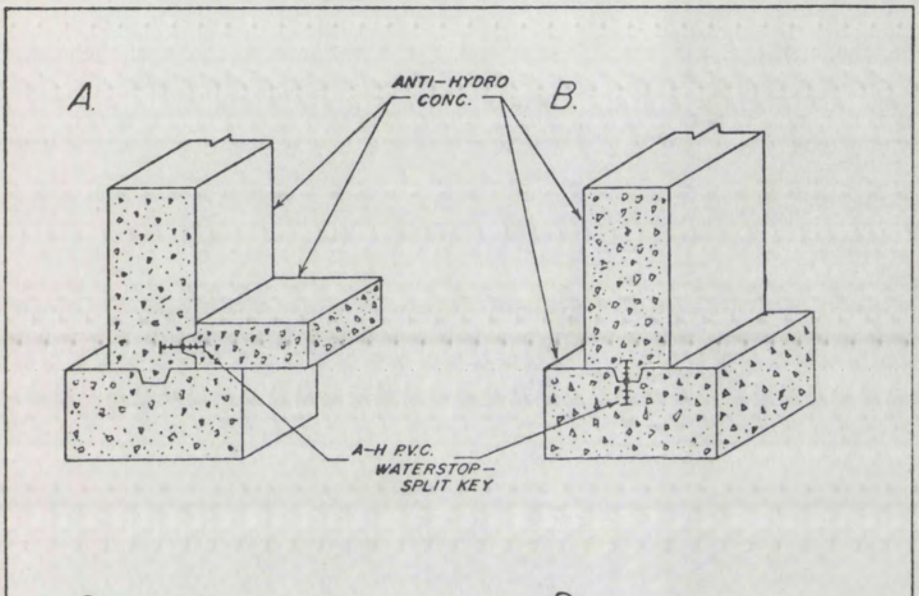


*NOTE: COAT "VEE" FORM WITH A-H CONTROL SET-FORM FOR ADDED BONDING STRENGTH.

B. WATERTIGHT VERTICAL CONSTRUCTION JOINT

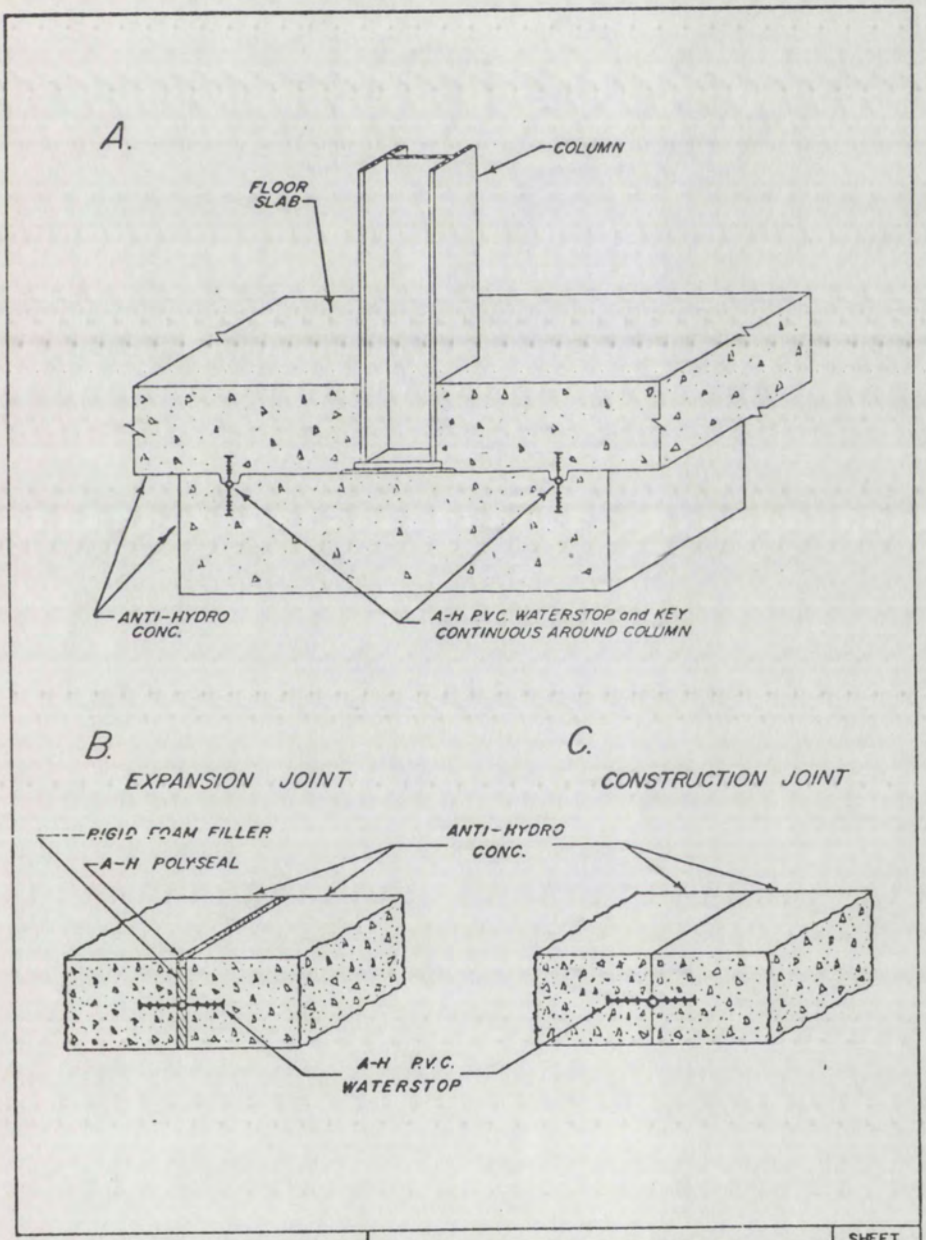


WATERTIGHT VERTICAL JOINTS	SHEET 3



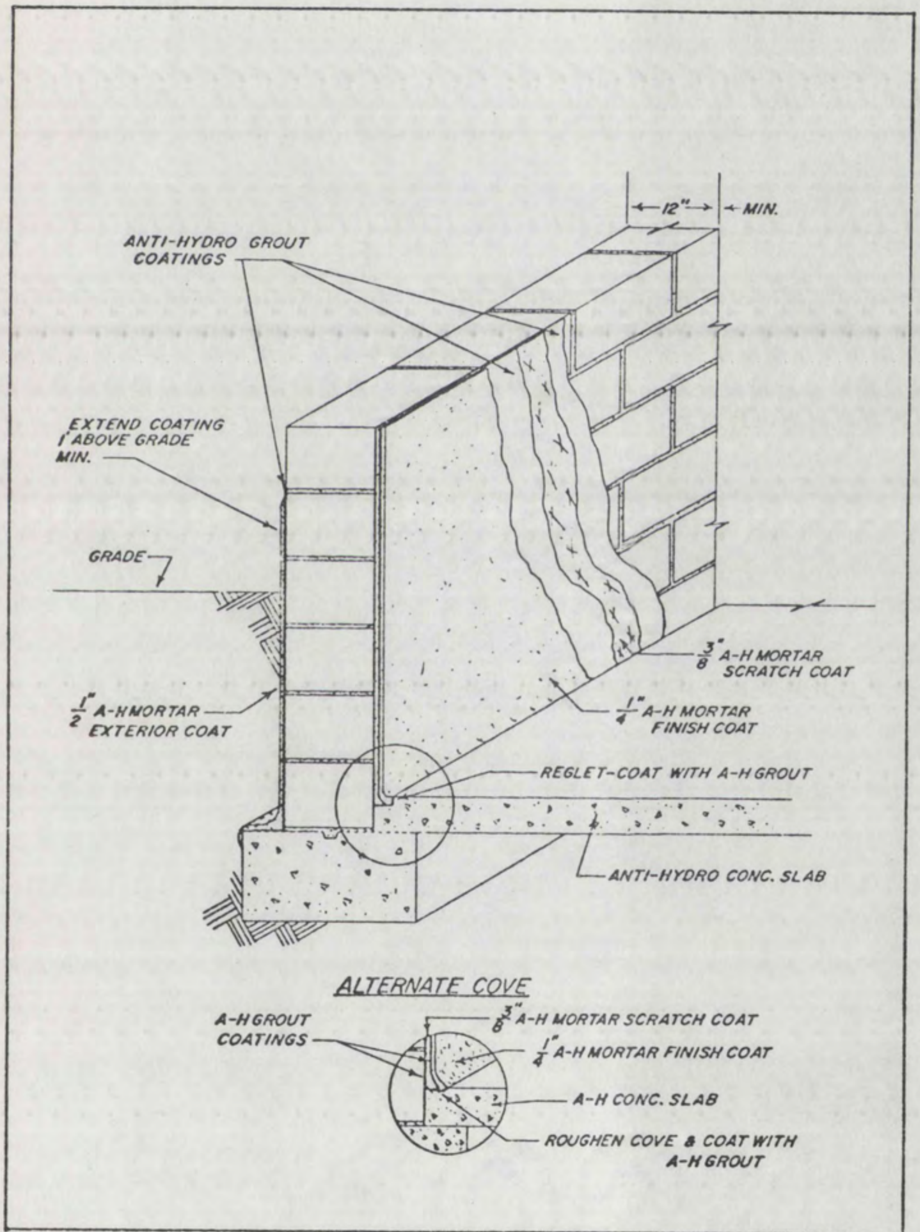
A-H P.V.C. WATERSTOP
JOINT DETAILS

SHEET
4



A-H P.V.C. WATERSTOP
JOINT DETAILS

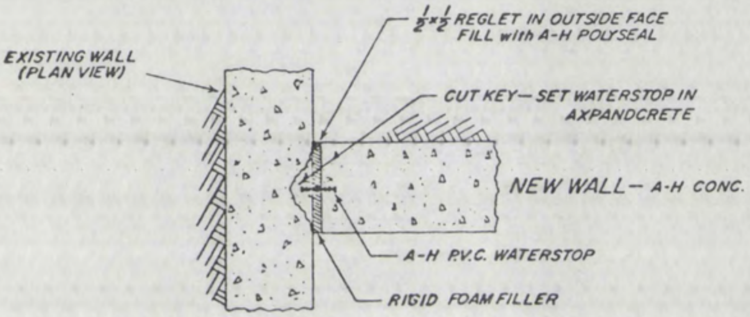
SHEET
5



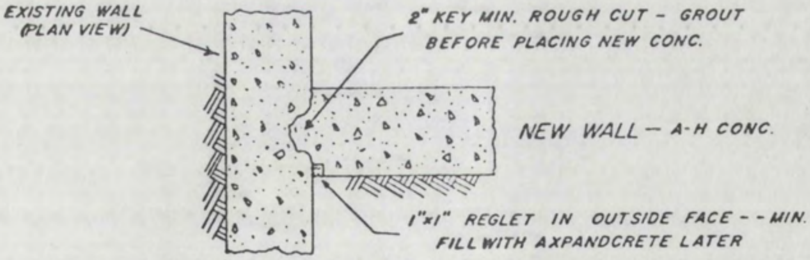
A-H PLASTER COATING
WATERPROOFING DETAIL

SHEET
6

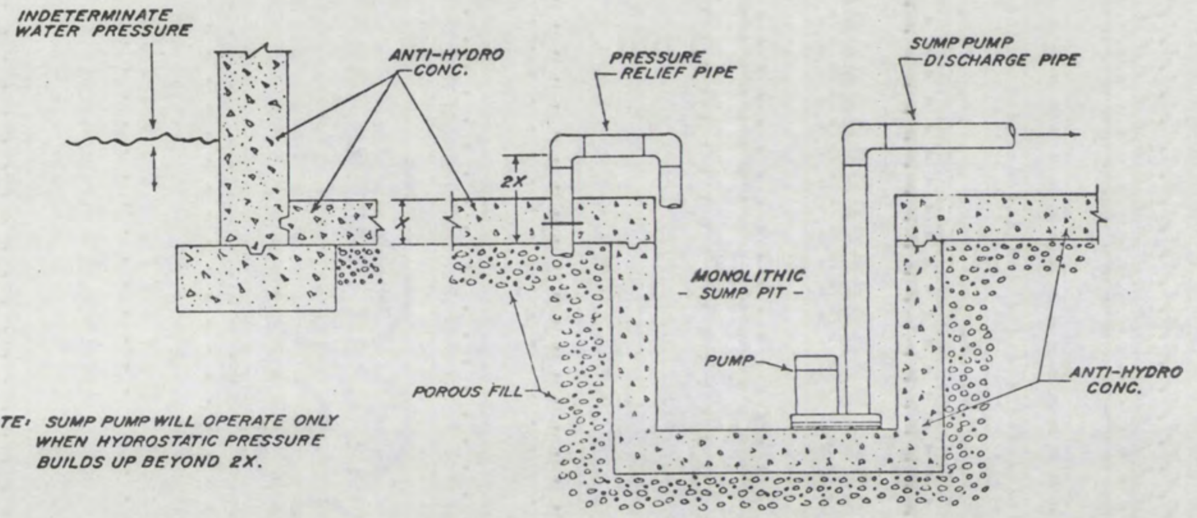
A. WATERTIGHT EXPANSION JOINT



B. RIGID WATERTIGHT JOINT



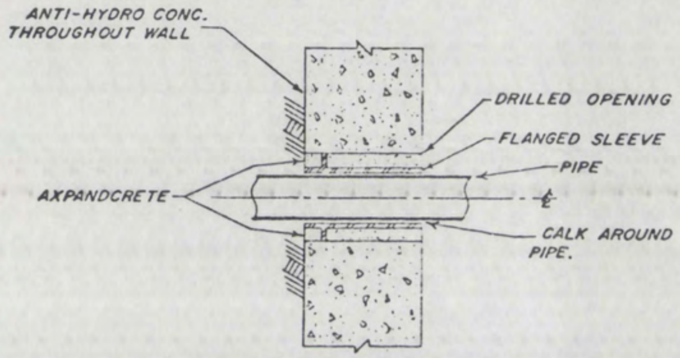
WATERTIGHT JOINTS BETWEEN EXISTING and NEW WALLS	SHEET 7



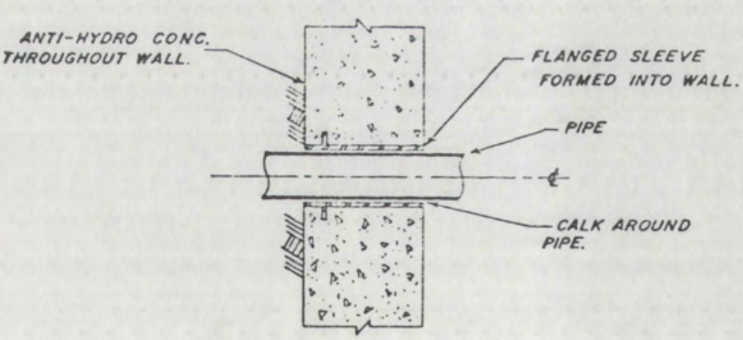
NOTE: SUMP PUMP WILL OPERATE ONLY WHEN HYDROSTATIC PRESSURE BUILDS UP BEYOND 2X.

	HYDROSTATIC PRESSURE RELIEF SYSTEM	SHEET 8

A.

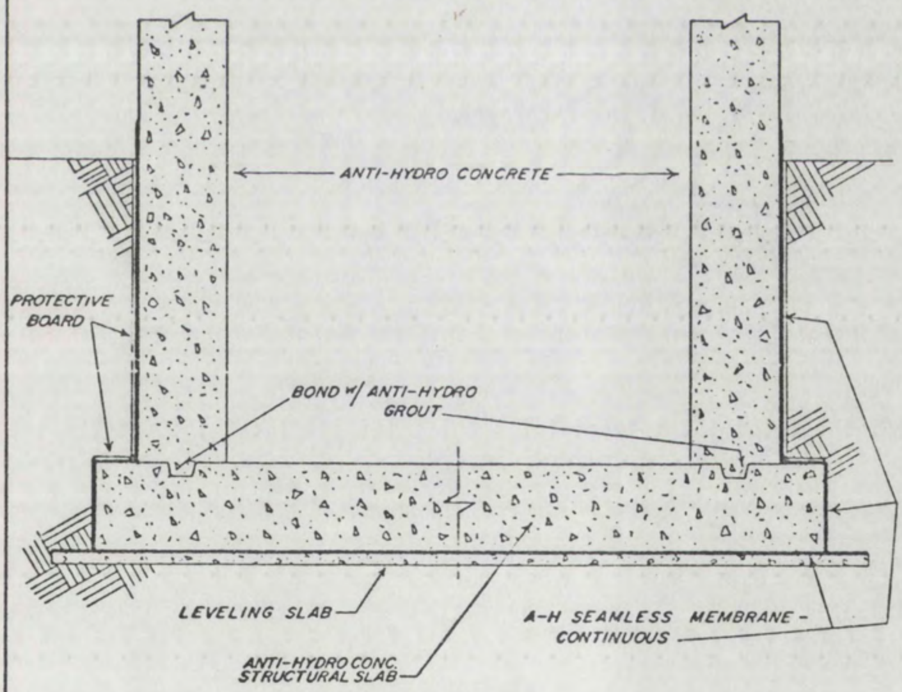


B.



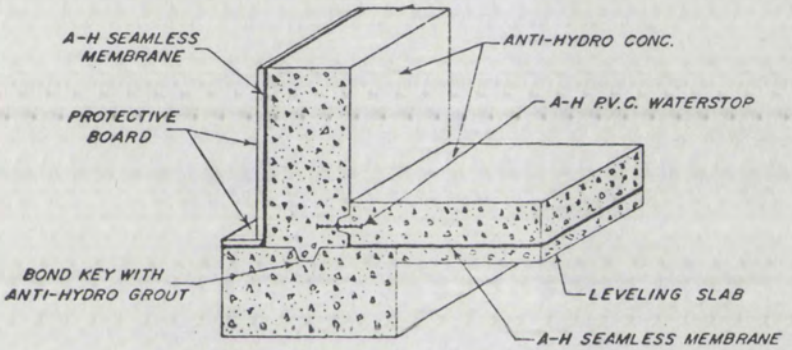
WATERPROOF SLEEVE PENETRATIONS	SHEET 9

BASEMENT W/ WALLS BEARING ON STRUCTURAL SLAB

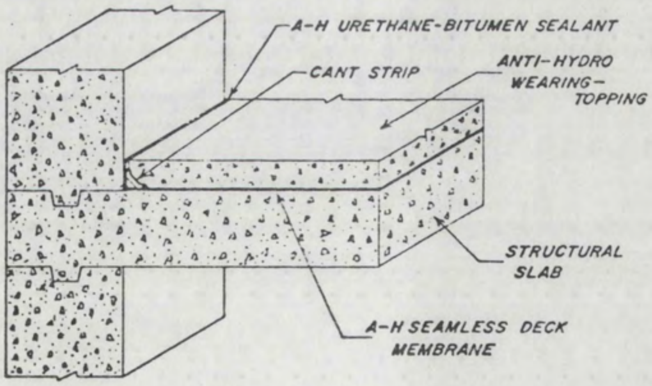


CONTINUOUS A-H SEAMLESS MEMBRANE SYSTEM FOR BELOW GRADE APPLICATIONS	SHEET 10

A. TYPICAL BASEMENT WALL BEARING ON FOOTING & SLAB KEYED LATERALLY TO WALLS.



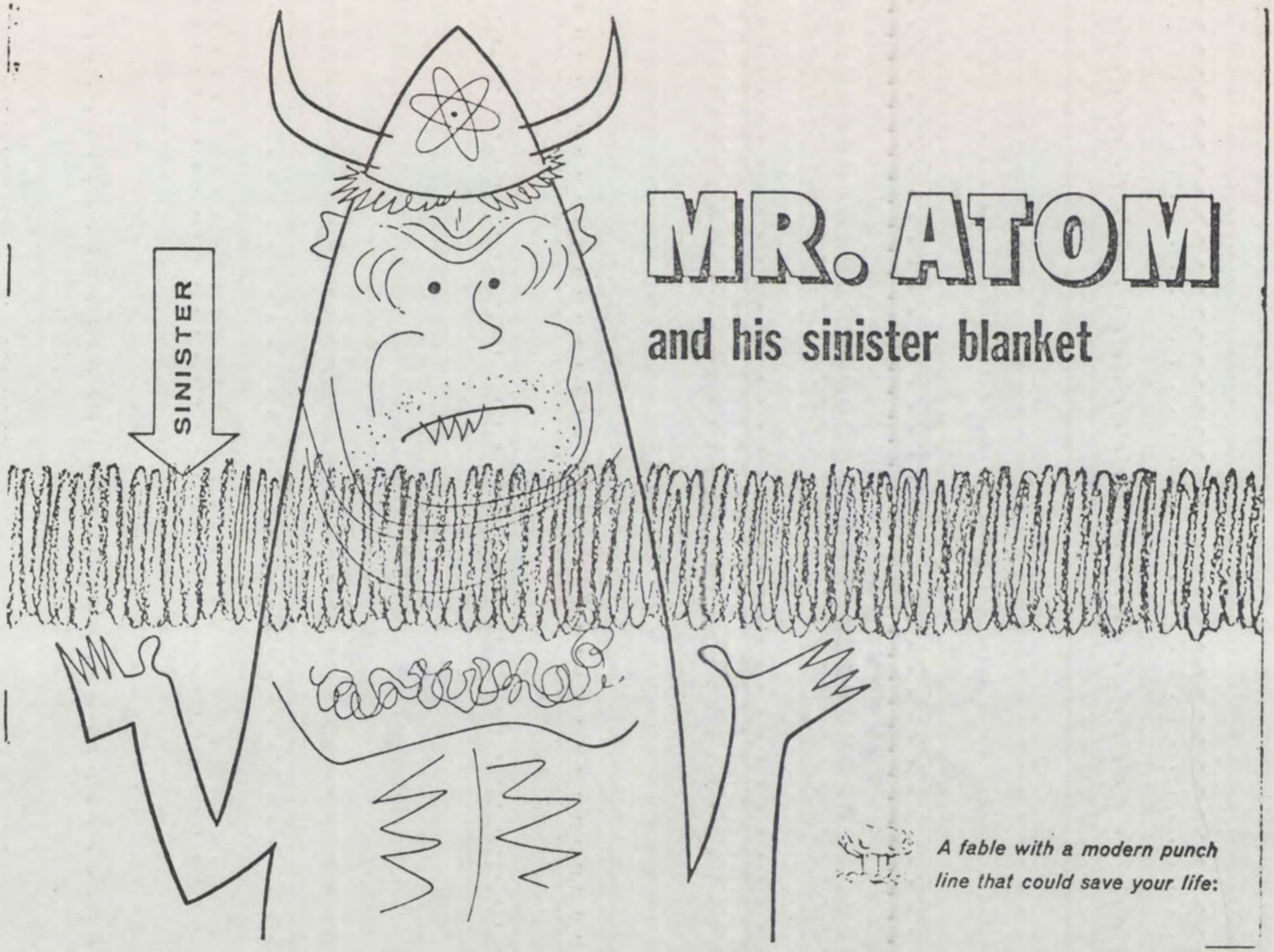
B. TYPICAL TWO COURSE SLAB FOR PARKING DECKS.



A-H SEAMLESS MEMBRANE SYSTEMS	SHEET 11

MR. ATOM

and his sinister blanket



A fable with a modern punch line that could save your life:

Indolencia was fat, dumb and happy

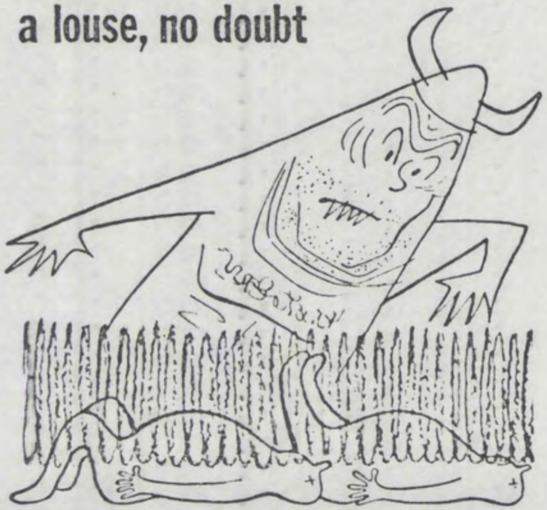
There was, long ago, give or take a couple of whiles, a little island called Indolencia populated by a goodly number of frisky Wombats.

A happier bunch of Wombats you never did see.

They frolicked around Maypoles, bought Kala Grass on the installment plan and were generally fat, dumb and happy.

But—there was a big, fat fly in the ointment.

MR. ATOM was a louse, no doubt



Into this unspoilt and bliss-laden Eden stomped a real heel—Mr. Atom and his Sinister Blanket.

Just before coming to Indolencia, he had kicked the stuffing out of the neighboring island, Deliria. His boot was bad enough, but when he flung his sinister blanket, it was the absolute end.

Every Wombat six-ways-from-Sunday was in Happy Hunting Ground.

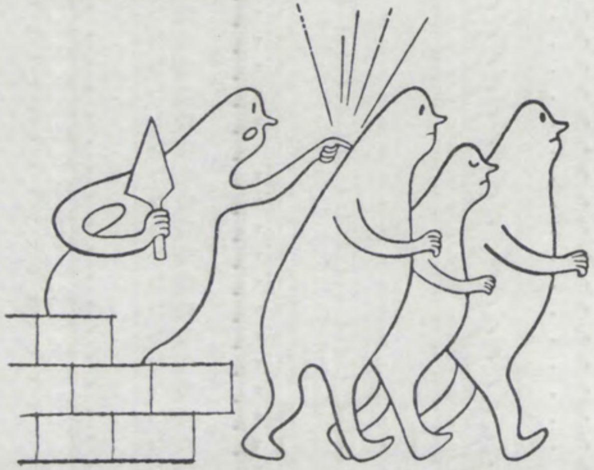
© NCWA [illegible]

It can't happen here, we're too good

While the majority of the little Wombats went on wild Maypole dances and refinanced their Kala Grass and blabbered about it not happening here, a few of the wiser Wombats—who knew a bad deal when they saw one—skittered around looking for ways to survive old Atom's clout.

And they sure skittered.

Some serious work beforehand was indicated



It took three or four whiles for the sharp Wombats to figure there was no way to lick Atom's boot—but they could beat that blanket bit. Cassandra, a sharper than sharp Wombat, made a shelter, snug and safe from Atom's blanket.

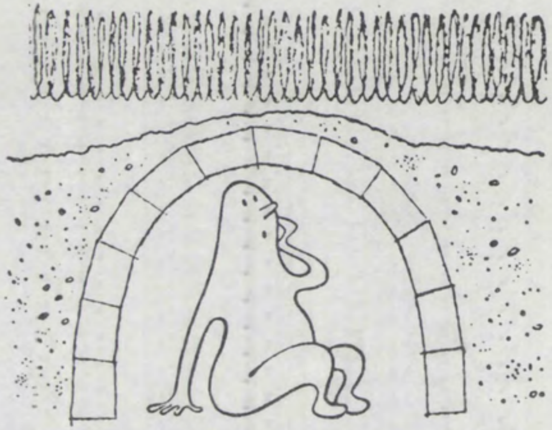
It worked.

Who needs it?

Cassandra ran all over Indolencia telling the Wombats how to beat Atom's blanket. Who needs it, they chirped, intent on their Maypole dancing and refinancing. While they were thus occupied, Atom wound up and let Indolencia have it right in the chops. Out spread his sinister blanket.

All over.

And then there was one



Sad story.

And now the moral:

Survival in nuclear war is up to you

Areas in the immediate vicinity of a thermo-nuclear explosion are subject to immediate and total destruction.

But the danger does not stop with the explosion; it begins.

One effect is the disruption of essential services which all of us take for granted: water, electricity and gas may be cut off, normal distribution of food supplies may cease.

The other, far more insidious since it may go unobserved in darkness or bad weather, is fallout, and radioactive fallout can be fatal.

The fallout shelters in this book show you how you can do something to protect your family on both counts—provide them food and water, protect them from deadly radioactivity.

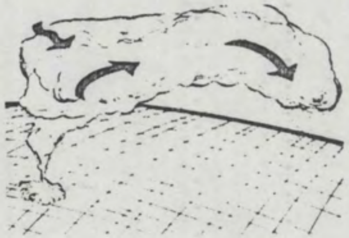
Read it well.

Radioactive Fallout . . . what is it?

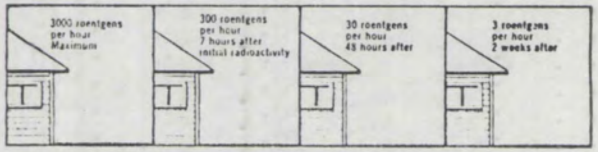
When a nuclear explosion occurs on or near the surface of the earth, the intense heat and force of the explosion vaporizes large quantities of earth and other materials. This material is borne aloft by the violent updrafts caused by the explosion. Here it becomes mixed with the intensely radioactive fission products of the bomb. It cools and then falls to earth over a wide area. This material is known as radioactive fallout.

DISTRIBUTION OF FALLOUT

The characteristic mushroom shaped cloud, which carries the radioactive material, may rise to heights of 15 to 20 miles before it begins to disperse on the wind currents. No one can predict for sure where the fallout will be deposited. The type and size of the bomb, weather conditions and the number of bombs exploded all will help determine the extent of fallout. It usually will take about an hour for dangerous amounts of fallout to arrive on the ground, outside the immediate blast area. Nearly all fallout will reach the ground within two days after the explosion. Such fallout can cover thousands of square miles.



GAMMA RAY RADIATION EFFECTS ON HUMANS



RADIATION DECAYS RAPIDLY

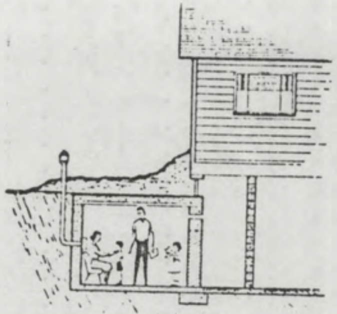
EFFECTS OF FALLOUT

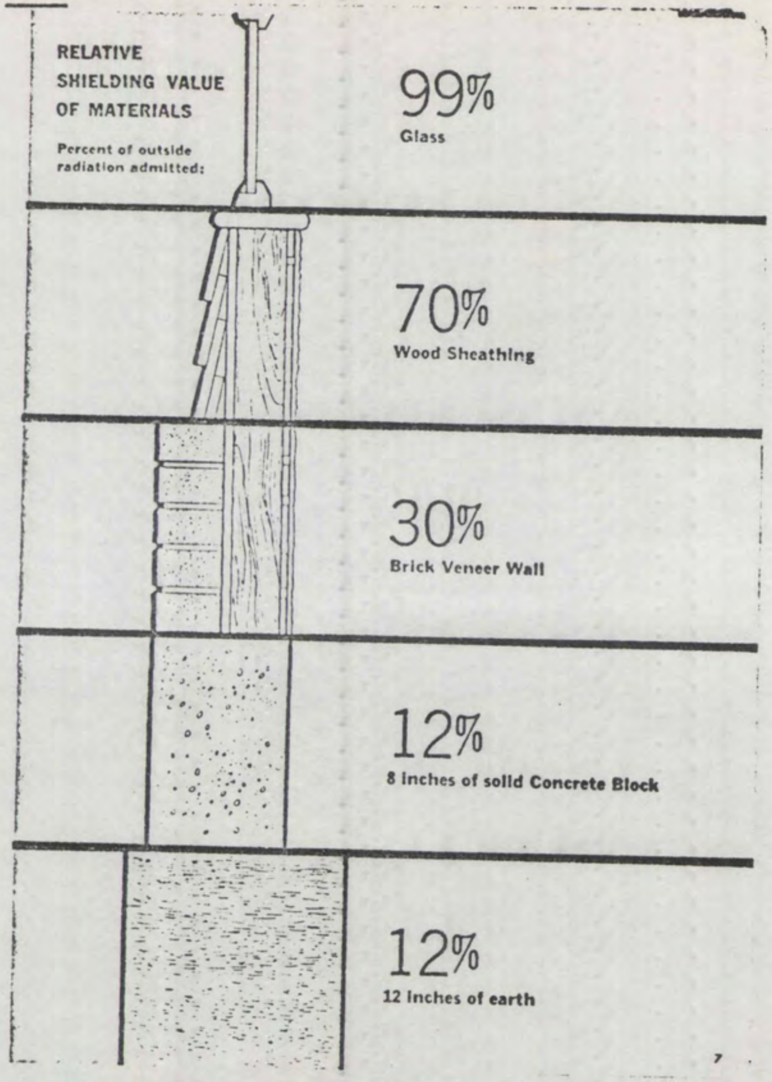
Fallout might be compared to a nearly invisible snowstorm—it covers all exposed objects, buildings and persons. The chief danger in fallout is the Gamma rays—something like X-rays—which are emitted from the radioactive fallout particles. These particles are very penetrating and can cause fatal damage to living tissue. Dosage of radioactivity is measured in roentgens. The top table on this page shows the probable effect on humans of Gamma radiation. As you can see, a dose of over 600 roentgens is nearly always fatal. The need for protection from these rays is obvious.

THE PROTECTION FACTOR

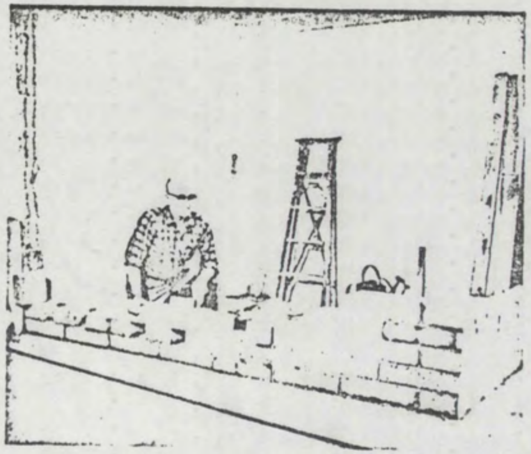
If you have protection from fallout, time is on your side. From the time of its formation when the explosion occurs, radioactivity decreases. The rate of decay shortly after the explosion is extremely rapid. The time of greatest danger is in the first two or three days and it is during this time protection is needed most. The chart with the houses on the preceding page shows the decline in radioactivity with the passage of time.

Protection from the damaging Gamma rays varies with different thicknesses of different materials. For example, materials of equal shielding are: 8" of solid concrete block, 2½" of steel, 1½" of lead, 30" of wood, 12" of earth or sand. And here's where a basement shelter in your house makes sense. Not only does the house itself reduce the penetration, but an enclosed basement shelter, below grade, of concrete block will give adequate protection for your family in the immediate danger period following an explosion. Gamma ray penetration will be reduced to a safe level.





So build a Fallout Shelter for you and



A

Here Walt Durbahn, TV's family handyman, shows how a concrete masonry basement fallout shelter is built. First, the 8" x 4" x 16" solid concrete blocks are laid up on a bed of mortar at the corners. Small apertures appearing in the second course are for ventilation.

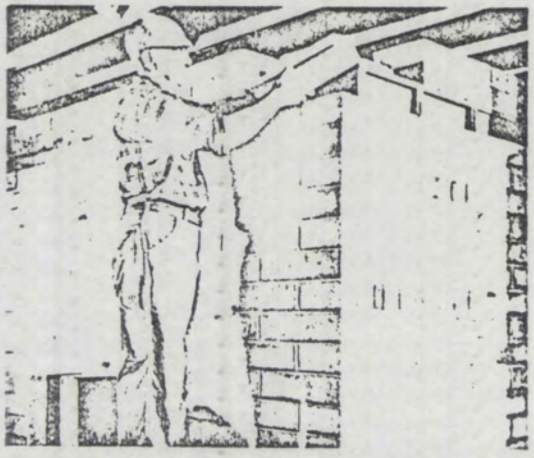
B

Walt is demonstrating here the importance of leveling each block as they go into the wall. To level the block, Walt tamps the unit down into the mortar bed until it is perfectly true. A full bed of mortar is necessary, not only for wall strength, but needed fallout protection.

(...it's not as

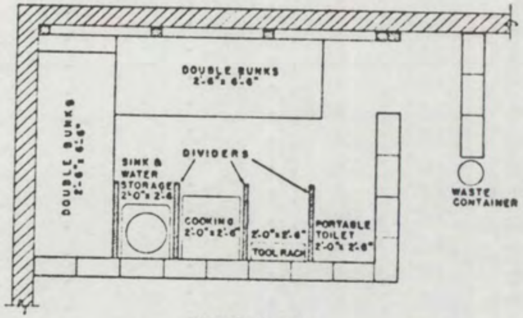
your family

C After the masonry work is completed on the walls, Walt installs the ceiling joists of 2 by 6s. Joists are securely braced with solid blocking and are double nailed. Ceiling joists rest on wooden posts which are bolted into the basement wall of the house. Masonry roof comes next.

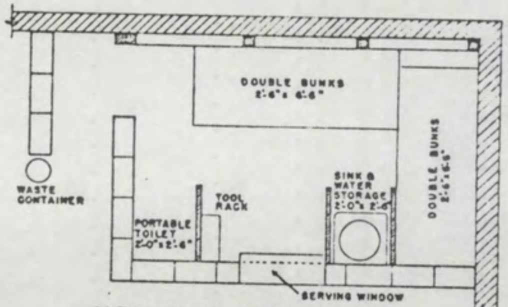


D Walt is putting the finishing structural touches on the shelter with the application of a double row of solid masonry units. Units are not mortared together, but are laid tightly together forming a protective roof over the shelter.

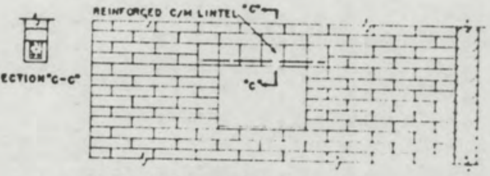
difficult as you may think!)



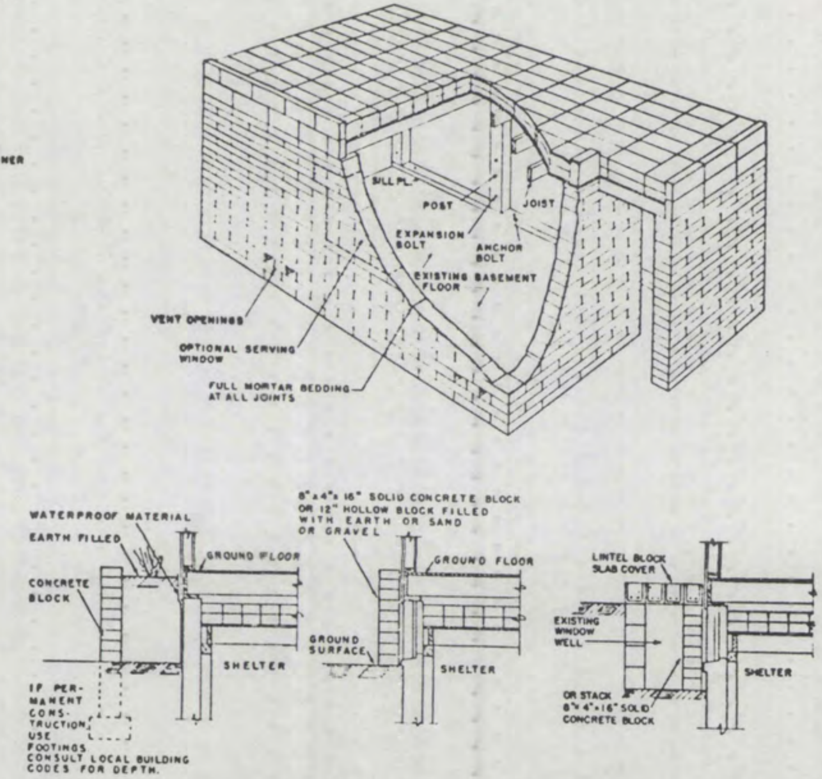
FLOOR PLAN



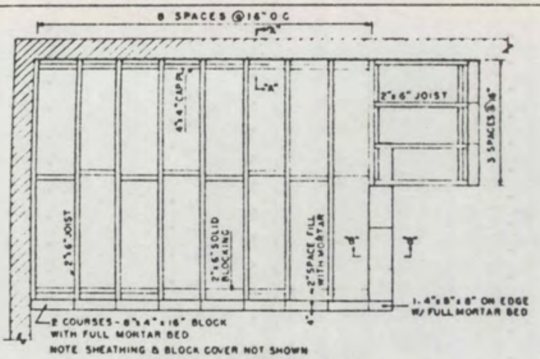
ALTERNATE FLOOR PLAN
(WITH SERVING WINDOW)



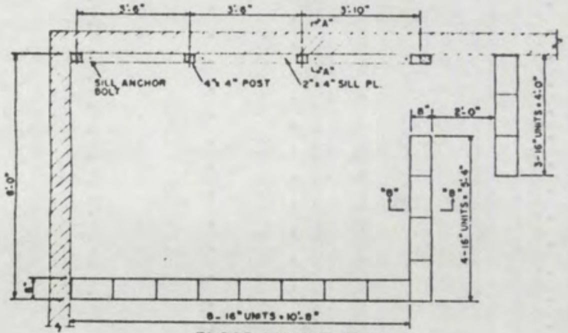
ELEVATION AT OPTIONAL SERVING WINDOW



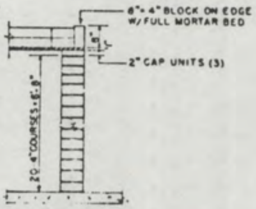
EXPEDIENT METHODS OF CONCRETE BLOCK SHIELDING
FOR EXPOSED BASEMENT WALLS AND WINDOWS



ROOF FRAMING PLAN



FLOOR LAYOUT PLAN



SECTION "B-B"

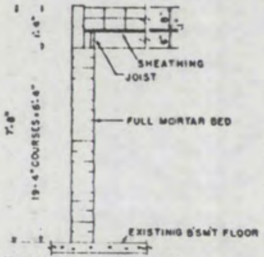
NOTES

1 THIS PLAN APPLIES GENERALLY TO EXISTING BASEMENT FACILITIES.

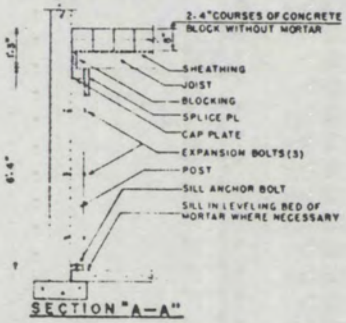
2 CONSULT LOCAL BUILDING CODE AND STRUCTURAL ENGINEER FOR UNUSUAL AREA CONDITIONS.

3 FOR BASEMENT HEADROOMS OTHER THAN THAT ASSUMED, ADJUST SHELTER HEIGHT AS NECESSARY, E.G. 6'-0" HEADROOM (TO BOTTOM OF JOIST) REQUIRES 5'-6" POSTS (SAME SPACING) 18 COURSES 4" HIGH SOLID CONCRETE BLOCK TO BOTTOM OF JOIST, TOTAL HEIGHT 7'-3", ADJUST BILL OF MATERIALS ACCORDINGLY

4. WHEN OPTIONAL SERVING WINDOW IS INCORPORATED, 12-8"x4"x16" SOLID CONCRETE BLOCKS SHALL BE STORED IN CONVENIENT AREA TO FILL THE WINDOW OPENING FOR FALLOUT PROTECTION



TYPICAL SECTION
THRU MASONRY WALL



SECTION "A-A"

BILL OF MATERIALS

ITEM	DESCRIPTION	UNIT	QUAN.
1.	CONCRETE MASONRY ASTM C145 (100% SOLID)		
	8"x4"x16" SOLID	EA.	545
	8"x2"x16" SOLID CAP UNITS	EA.	3
2.	MORTAR (TYPE M) MIX 1: 1/4 : 3	CU.FT.	14
	CEMENT	CU.FT.	4
	LIME	CU.FT.	1
	SAND	CU.FT.	12
3.	LUMBER: STRUCTURAL GRADE		
	POSTS 4"x4"x5'-10"	EA.	3
	CAP PL. 4"x4"x11'-4"	EA.	1
	SILL PL. 2"x4"x11'-4"	EA.	1
	JOISTS 2"x6"x7'-8"	EA.	8
	JOISTS 2"x6"x4'-0"	EA.	1
	JOISTS 2"x6"x2'-10"	EA.	4
	SPLICE PL. 2"x4"x0'-10"	EA.	3
	BLOCKING 2"x6"	FT.	40
	SHEATHING 1"x8"	FT.	150
4.	EXPANSION BOLTS 3/8"x7"	EA.	18
5.	SILL ANCHOR BOLTS 3/8"x5"	EA.	4
6.	NAILS		
	16 PENNY	LB.	9
	8 PENNY	LB.	2
A.	ITEMS FOR OPTIONAL SERVING WINDOW		
	LINTEL		
	8"x8"x16" CONCRETE LINTEL BLOCK	EA.	6
	REINFORCING BARS 3/8"Φ x 3'-8" LG.	EA.	2
	CONCRETE MIX 1:2½:2½	CU.FT.	0.8
	MORTAR (INCLUDED ABOVE)		
B.	SERVING COUNTER		
	LUMBER 1"x12"x2'-8"	EA.	1

NOTES:

BILL OF MATERIAL VALUES ARE APPROXIMATE
MORTAR VALUES INCLUDE 10% ALLOWANCE FOR WASTE

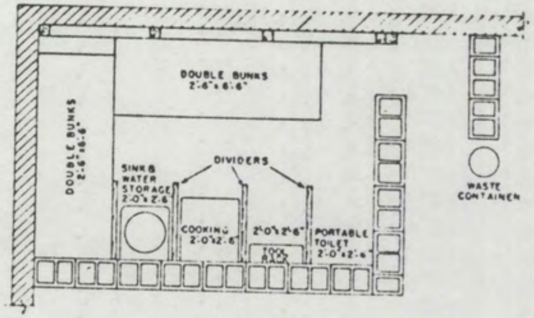
LEGEND

▨	◫	▨	▨
EXISTING BASEMENT WALL	SOLID CONCRETE MASONRY	WOOD	EARTH

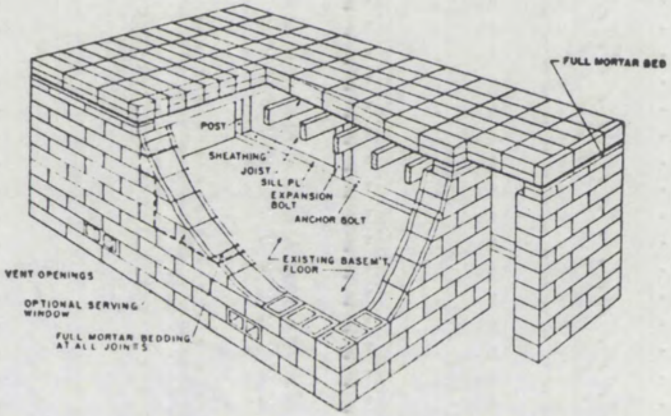
GRAPHIC SCALE

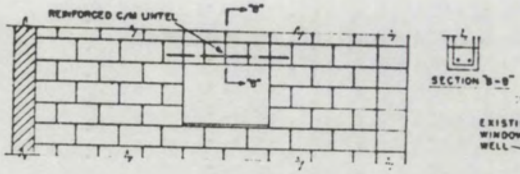
PLAN 1

FAMILY FALLOUT SHELTER
FOR EXISTING BASEMENTS
USING
8" THICK SOLID CONCRETE
MASONRY UNITS

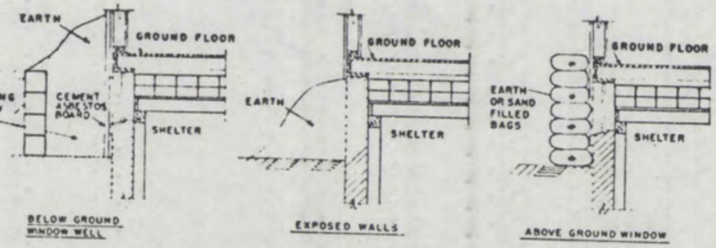


FLOOR PLAN



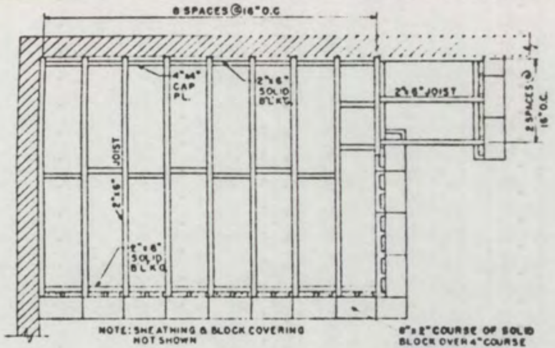


ELEVATION AT OPTIONAL SERVING WINDOW



EXPEDIENT METHODS OF EARTH SHIELDING FOR EXPOSED BASEMENT WALLS AND WINDOWS

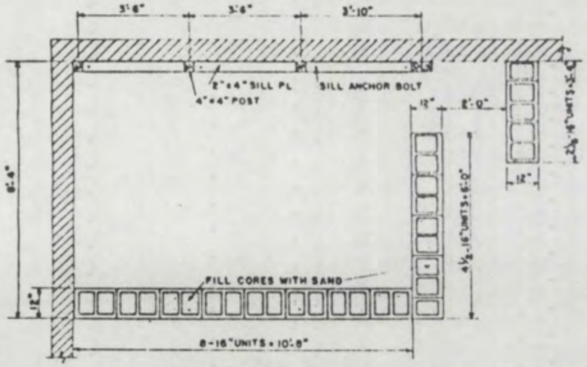
14



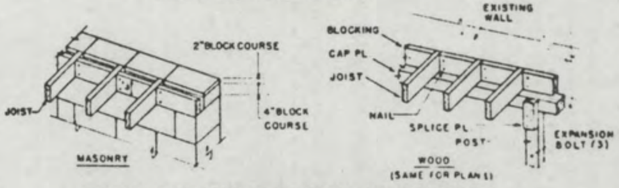
NOTE: SHEATHING & BLOCK COVERING NOT SHOWN

8"x2" COURSE OF SOLID BLOCK OVER 4" COURSE OF SOLID BLOCK ON ALL EXTERIOR WALLS

ROOF FRAMING PLAN



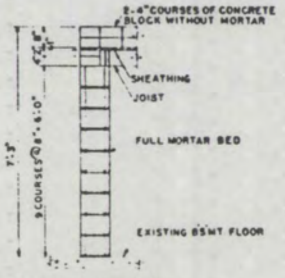
FLOOR LAYOUT PLAN



DETAILS OF JOISTS FRAMING INTO WALLS

NOTES:

1. THIS PLAN APPLIES GENERALLY TO EXISTING BASEMENT FACILITIES.
2. CONSULT LOCAL BUILDING CODE AND STRUCTURAL ENGINEER FOR UNUSUAL AREA CONDITIONS.
3. WHEN OPTIONAL SERVING WINDOW IS INCORPORATED 12-8"x4"x16" SOLID CONCRETE BLOCK SHALL BE STORED IN A CONVENIENT AREA FOR FILLING WINDOW FOR FALLOUT PROTECTION.
4. FOR BASEMENT HEADROOMS OTHER THAN THAT ASSUMED, ADJUST SHELTER DIMENSIONS AS NECESSARY. SEE EXAMPLE DESCRIBED ON PLAN 1



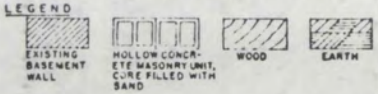
TYPICAL SECTION THRU MASONRY WALLS

BILL OF MATERIALS

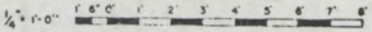
ITEM	DESCRIPTION	UNIT	QUAN
1.	CONCRETE MASONRY ASTM C-90		
	12"x8"x16"	EA.	140
	8"x4"x16" SOLID UNITS	EA.	260
	8"x2"x16" SOLID CAP UNITS	EA	15
	8"x4"x16" HOLLOW FOR VENTS	EA	2
	8"x8"x16" HOLLOW FOR VENTS	EA	2
2	MORTAR (TYPE M) MIX 1:¼:3	CU FT.	6
	CEMENT	CU FT	2
	LIME	CU FT	05
	SAND	CU FT	6
3.	LUMBER STRUCTURAL GRADE		
	POSTS 4"x4"x5'-6"	EA	5
	CAP PL 4"x4"x11'-4"	EA	1
	SILL PL 2"x4"x11'-4"	EA	1
	JOISTS 2"x6"x7'-8"	EA.	8
	JOISTS 2"x6"x3'-2"	EA.	4
	SPLICE PL 2"x4"x0'-10"	EA	5
	BLOCKING 2"x6"	FT	40
	SHEATHING 1"x8"	FT.	170
4	EXPANSION BOLTS ⅜"x7"	EA.	15
5.	SILL ANCHOR BOLTS ⅜"x5"	EA.	4
6.	NAILS		
	16 PENNY	LB.	9
	8 PENNY	LB	2
7.	SAND FOR CORE SPACE (PIT RUN)	CU YD	2
	ITEMS FOR OPTIONAL SERVING WINDOW		
A	LINTEL		
	12"x8"x8" LINTEL BLOCK	EA	6
	⅜" DIAM x 5'-8" LG REINFORCING BARS	EA	2
	CONCRETE MIX 1:2½:2½	CU FT	1.2
	MORTAR (INCLUDED ABOVE)		
B.	SERVING COUNTER		
	LUMBER 1"x12"x32" LONG	EA.	1

NOTE: BILL OF MATERIAL VALUES ARE APPROXIMATE
MORTAR VALUES INCLUDE 10% ALLOWANCE FOR WASTE.

LEGEND

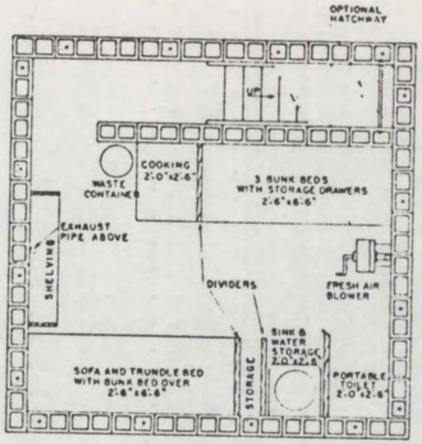


GRAPHIC SCALE

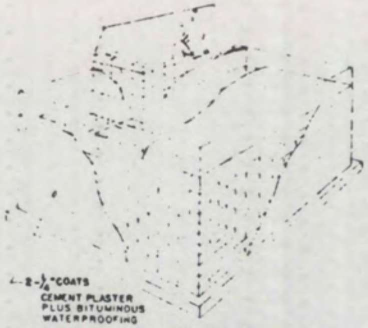


PLAN 2

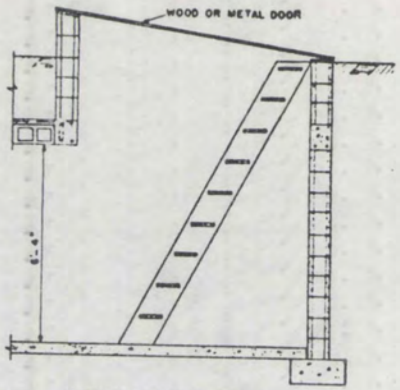
FAMILY FALLOUT SHELTER
FOR EXISTING BASEMENTS
USING
12" THICK HOLLOW CONCRETE
MASONRY UNITS



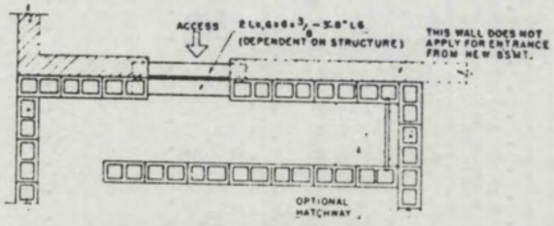
FLOOR PLAN



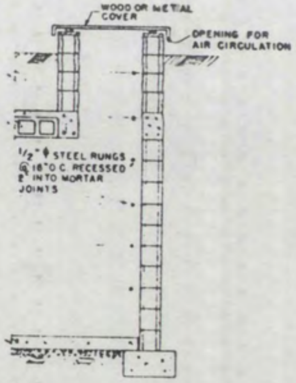
INDEPENDENT SHELTER



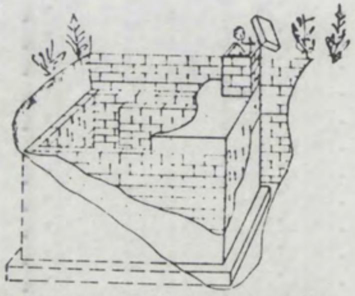
SECTION THRU STAIR



PLAN FOR ENTRANCE FROM EXISTING BASEMENT



OPTIONAL HATCHWAY



SHELTER ADJACENT TO EXISTING BASEMENT

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF CIVIL AND DEFENSE MOBILIZATION
WASHINGTON 25, D. C.

OFFICE OF THE DIRECTOR

The necessity for fallout protection is widely recognized. But this awareness must be translated into action through an accelerated program of fallout shelter construction.

Joining forces with numerous Americans vitally concerned about civilian preparedness, the National Concrete Masonry Association has published this booklet designed to make fallout protection for you and your family a practical reality.

In addition to covering many points you should know about radiation and its effects, this booklet contains plans for fallout shelters which have been approved by the Office of Civil and Defense Mobilization. They provide protection and present suggestions for everyday family use.

Read this booklet. Take advantage of its timeliness and build your shelter now!

COMPARISON CHART

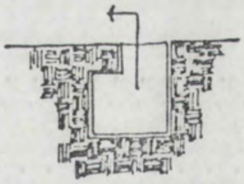
In the attempt to illustrate the general areas of interaction of Earth Integrated Architecture concepts with the present social constraints, the following chart has been developed. Comparisons will be made of typical regulations involved in the building process. The chart will focus on typical building codes, zoning ordinances and other traditional controls. It is apparent that all regulations and controls cannot be illustrated and that all interactions will not be typical, thus the generalizations are intended to direct this investigation and open other areas of concern.

The components of the chart are as follows: Title of Code, Ordinance or Regulation under discussion, with a) statement of a particular article paraphrased and its area of control or direction and b) the effect which this article has on building construction and how it will conflict with earth-integrated structures. Included are references to related areas of construction which might be indirectly involved.

Uniform Building Code 1973 Edition

1. Types of occupancy

   - Building areas require fire rated separation based on the intended occupancy. Types of occupancies are rated as 4 hr., 3 hr., 2 hr., 1 hr., fire rated occupancy.
   - Basically any building form must comply with this performance requirement.
   - Materials used must conform to the controls as the rating requires and thus selection of systems will be affected.



2. Restrictions on openings

   - The number and size of openings are controlled by the fire rating and occupancy types.
   - The design of connections between spaces will be affected as in any building design.

3. Location on property, general restrictions

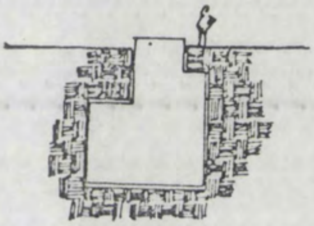
   - Buildings should adjoin or have access to a public space, yard or street on not less than one side.
   - A conflict arises if no sides of the building are above ground, an assumption made by the code.

4. Allowable floor area

   - The maximum floor area of a building is set by the fire rating and the occupancy type.
   - This does not conceptually conflict with Earth Architecture.
   - Allowances are made for increases when additional equipment is installed, i.e. sprinkler system.

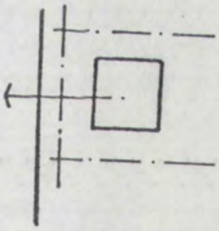
5. Maximum height of buildings

   - The height of a building is controlled by the character of the occupancy and the type of construction.
   - No direct conflicts develop, but unusual definitions develop - what is a high building if all the stories are underground?
   - This will affect the types of construction systems selected and the types of materials.



6. Location on property

   - Generally the placement of a building on a site is controlled by a minimum access to a public street. This to be direct or via an access way and shall be unobstructed.
   - Conflicts will develop in the siting of the building and the design of the entrance way.
   - This will indirectly affect the vertical circulation of the structure.



7. Requirements based on locations in fire zones

   - Construction types are limited by the classification of the fire zone in which the building is located.
   - A performance standard.
   - Fire zone determination will vary according to the community.

8. Requirements based on types of construction

   - Statements defining various types of construction systems and materials and their respective ratings.
   - A consideration in the selection of the proper components of a project.

9. Engineering regulations

   - All buildings shall be designed and constructed to sustain loads as specified in the code.
   - A performance statement which all structural systems must take into consideration.

10. Detailed regulations

- Codes for various items including retaining walls and foundations.
- Each individual project will be affected differently.

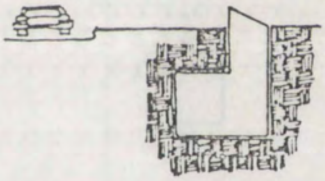
National Building Code 1963
by National Board of Fire Underwriters

11. Sprinklers

- Allowance of a 200% increase of floor area restrictions with the addition of a sprinkler system.
- This can strongly influence any project, its system design, and material selection. ______

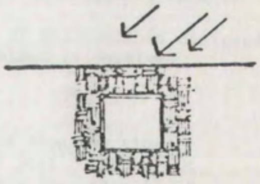
12. Frontage to street

- A formulated increase of an area is allowed when a building fronts on a street.
- Conflicts develop in determination of what constitutes frontage.
- A limitation is written into this code, ". . . in no case shall any side of a building that does not have suitable access openings, as defined in section 810.1(f) to each story above the basement be given credit as frontage on a street of public place".
- Conflicts of definitions of terms also develop.



13. Habitable rooms

- Every habitable room shall be provided with natural light and ventilation, opening on a street, alley or court.
- This could seriously conflict with Earth Architecture and become a definite design determinant.
- Questions arise as to the reasoning behind this item under present technology.

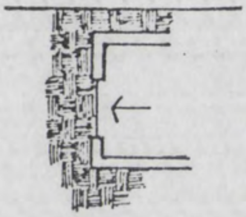


14. Light and Ventilation

- Every bathroom and watercloset compartment shall be provided with natural or artificial light and be ventilated by windows, vent shafts or vent ducts.
- A design consideration in space organization

15. Glazed areas

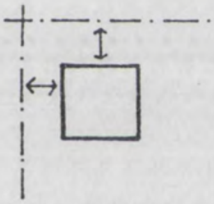
- Aggregate area of approved glazing shall not be less than 1/10 of floor area of room served.
- This relates to #13 and similar questions it raises.



Zoning Ordinance

16. Front yard setbacks

- Building shall be a minimum of 40 feet from front property line.
- This will conflict with the possible sub-surface use of the front yard.
- Consideration should be made for when structure is near road surface, for surcharge of road surface.



17. A building's area

- A building may not occupy more than the prescribed area of a lot as determined by the zoning.
- Conflict develops in determining the amount of land used if none of the building is exposed.
- Questions also arise as to whether this type of ordinance is designed as a visual control or if some performance intent is involved.

18. Minimum Height

- No building allowed on an RE-35 zoned lot less than one story.
- The conflict develops as to the definition of what a "story" is. This particular ordinance states that basements less than 4'-6" above grade are not considered a story.

CONCLUSION

The constraints which a society demands from itself can be complex and entangling, involved processes of protection which protect only to minimal standards. The validity of controls can only be judged on the result of their influence, and the performance of their intent. Presently, controls are commonly outdated in purpose, minimal in intent and unresponsive to change. Thus, a true statement of effect is difficult to make. A statement of actual effect of an alternate system and its interaction with present controls is purely conjecture. Each control in each system and in each type of built environment will react differently.

The most useful effect which the proposal of a non-conventional system has is the investigation into the present controls. The present controlling regulations are elements of reaction to problems and not always proper determinents toward achieving intents. By challenging the present system, changes may occur in the design, making regulations more responsive and performance directed. Building codes will have to be challenged by a non-conventional system to prove themselves. Zoning ordinances will also have to be justified as valid regulations contributing to realizing community goals. Are the ordinances truly producing the visual quality desired and public standard as was intended, or just items resulting in bureaucratic entanglement of misguided intentions? These legal controls will be pressed to justification when alternate systems are proven to meet the intended goals by different means. The designer of the controls will then realize the need for comprehensive concepts of controls.

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