

Designing Structures in Expansive Clay

A Guide for Architects and Engineers



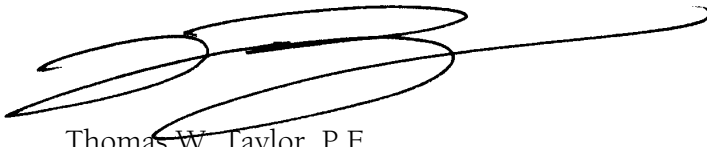
DATUM

Designing structures in expansive clay is a very important issue and one that requires special attention. At Datum we are always looking for new ideas and innovative solutions to deal with this problem. It is my belief that by sharing information and experiences we will find the right answers.

Over the years I have gained a considerable amount of experience and understanding in dealing with expansive clay and the overall effect it has on a project. Since we are continually faced with this problem and it's one that needs to be handled expertly, I have undertaken the effort of sharing some of my knowledge with you in this booklet.

I hope you will find this booklet useful. If it helps you solve a problem or if it just broadens your knowledge in this area, it will have been worthwhile.

Sincerely,

A handwritten signature in black ink, consisting of several loops and a long horizontal stroke extending to the right.

Thomas W. Taylor, P.E.
Chief Design Engineer of Datum Engineers

Table of Contents

1.	Introduction	Page 1
2.	Common Foundation Systems	Page 2
3.	Drilled Piers	Page 3
	a. Skin Friction Piers	Page 3
	b. Belled Piers	Page 5
4.	Construction Problems Common to Both Pier Systems	Page 8
5.	Grade Beams, Cast-in-Place Walls and Precast Tilt-up Walls	Page 11
	a. Void Space Construction	Page 11
	b. Water Exclusion	Page 12
	c. Side Forms	Page 13
	d. Member Depth	Page 14
	e. Reinforcing Details	Page 14
6.	Crawl Space Under Structural Ground Floor	Page 22
7.	Structural Slab-on-Void Boxes	Page 23
8.	Slab-on-Grade Construction	Page 24
	a. Acceptable Vertical Heave	Page 24
	b. Thoroughness and Accuracy of Geotechnical Investigation	Page 24
	c. Methods of Reducing Potential Vertical Rise	Page 25
	d. Protection of the Perimeter of the Building	Page 26
	e. Method of Preventing Damage to Slab	Page 29
9.	Exterior Sitework	Page 34
10.	Appendix 'A' Standard Details from Surevoid	Page 37
11.	Appendix 'B' Interoffice Memorandums	Page 43



I. INTRODUCTION

Expansive clay soil common to many parts of Texas, as well as elsewhere, has caused significant structural damage to an alarming number of buildings. Soil swells of over 12" have been recorded in the Las Colinas area northwest of Dallas. The pressures generated by swelling clay can be devastating to a foundation if not managed correctly.

Despite all of the technical knowledge available to combat the problem, new construction continues to suffer damage. Structural distress caused by swelling clay even occurs in cases where the geotechnical engineer, structural engineer, architect, and contractor have utilized every conceivable state-of-the-art precaution known to prevent distress.

No simple solution exists. Each project is unique in its location, soil properties, stratigraphy, drainage, and structural requirements. The expansive potential of soil at any given site can vary dramatically from one season to the next, due to moisture content which is the driving force in the shrink/swell cycle, i.e.; a building constructed after a rainy period may experience fewer problems than one constructed at the end of a dry summer. To complicate matters, soil conditions are not uniform between test boring locations. A dip in the rock, an underground spring or a variation in a clay seam can, and often does, occur between reasonably spaced borings. So the destructive capacity of the soil may go undetected and only later defeat the most carefully applied efforts of the design team.

Compounding the problem, a circuitous and somewhat unreliable process exists for dealing with expansive clay. Geotechnical engineers apply different formulas and techniques, so their predictions of movement and recommendations are not always uniform. Architects and structural engineers implement various concepts in response to their perception of the geotechnical engineer's recommendations. Then, contractors and subcontractors implement the requirements of the architect's and engineer's drawings to varying degrees of compliance and understanding so that the final product might not be what is truly needed to protect against swelling clay. The landscape architect and civil engineer also play major roles in contributing, however inadvertently, to the buildings distress through their design concepts and details. For example; irrigation sprinklers can have a devastating effect when located next to a corner of the foundation or carton forms.

Since each project is unique it's difficult to modify standard specifications and details to properly address the problem. Rather, there is an optimum solution for each project which must be pursued in a concerted effort by the design team on a project-by-project basis. A successful solution depends on dedication to this principle and an understanding that applying standard details or construction techniques used on a previous building, however successful they may have been, will not suffice.

Nevertheless, there are many basic principles one should apply when confronted with expansive clay soil conditions. The purpose of this booklet is to discuss these principles and their proper application by architects, engineers, and contractors. The designer must determine which specific details apply to a particular project. But, in most cases, these principles simply represent sound construction practices for all buildings constructed in expansive soil.

II. COMMON FOUNDATION SYSTEMS

Two of the most common foundation systems used in commercial building construction in the north Texas market are:

Pier and grade beam foundation with a structurally suspended ground floor slab.

Pier and grade beam foundation with a slab-on-grade (soil supported) ground floor.

Other areas might use footings or piles to support the concrete grade beams, but the concepts are the same.

A third system, which is common in residential construction, is a floating waffle slab foundation cast directly on the ground. However, there are many potential problems with this system when constructed on expansive soil and similar care and concern should be used. This system is not commonly found in commercial construction and will not be addressed in this booklet.

III. DRILLED PIERS

The foundation systems which are most prevalent in expansive clay areas utilize drilled piers to support the loads of the superstructure. The most common pier systems are:

- A. **SKIN FRICTION PIERS:** Are straight shaft piers ranging in diameter from a minimum of 12" (used on small lightly loaded elements of a building like a porch), up to about 72" (used on high-rise structures). These shafts extend down through the expansive soils layers into a firm bearing strata of limestone or shale. They socket deep into the bedrock bearing stratum and depend on both the end bearing and skin friction along the sides of the shaft in contact with the bearing stratum to support the structures load.

With this system the drilled pier shaft comes in contact with the expansive soil materials above the bearing material, however, it's customary to not count on skin friction in the expansive clay to support the structural loads. The upper clays are required to laterally brace the pier shaft so that the pier can be designed as a continuously braced concrete section in compression, without regard to buckling. Since the upper shaft is in direct contact with the expansive clay, a key concern is that the expansive clay is capable of gripping the sides of the drilled pier shaft and pulling it entirely out of the bearing stratum socket, or even pulling it apart.

In the early 1960's a system came into use to eliminate the gripping force of the expansive soils on the pier shaft. It consisted of drilling an oversized pier hole and lining its perimeter with 6" thick bags of vermiculite. These bags were held in place with a smaller diameter Sonotube form, then concrete was placed inside the Sonotube. The concept being that the vermiculite bags would insulate the drilled piers from the clay, thereby preventing the gripping process. However, the layer of vermiculite around the pier created a space in which water could flow down to the pier and initiate even greater swelling problems than would have been experienced had the vermiculite bags not been used. Also, the pier was separated from the ground by the vermiculite bags leaving it laterally unbraced requiring it to be designed as a column, which increased the cost of the pier. This system was used only a few times before it was determined to be too costly, slow, and difficult to verify that the construction quality had conformed to the desired intent..

We recently proposed a similar system, except we substituted Bentonite grout for the vermiculite. We feel that Bentonite will prevent seepage of water down the side of the pier (which tends to expand clays) and, at the same time, separate the pier from the surrounding expansive clays (*See Exhibit A and B*).

This system is for unusually difficult sites with deep expansive weathered shale that has a history of extreme movement and structural damage due to the depth of expanding material. Typically, the method of reinforcing the pier against uplift is satisfactory for most sites.

In the case of typical drilled pier shafts poured directly against expansive soil (as opposed to the vermiculite bag concept), the geotechnical engineer's soil report

should include design values, to be used by the structural engineer, for the following:

1. Anticipated upward force on the piers due to expanding soil.
2. Depth of expansive soil which should be included in the structural calculations for uplift force. The effective depth of the force is related to the anticipated maximum depth of moisture fluctuations within the expansive soil.
3. Anchorage capacity or minimum socket depth in the bearing stratum to prevent the piers from pulling out of the bearing stratum.

The gripping principle makes it readily apparent that when dealing with straight shafts drilled in expansive soil the following rules apply:

1. The smaller the diameter of the pier the less surface area of the pier exists for expansive soils to grip and push on. Therefore, within economic reason the shaft should be the smallest practical size necessary to support the load of the structure.
2. It's desirable to spread the piers out as far as practical and to apply as much dead load on each pier as possible. The more dead load there is holding the pier down the less the possibility of upheaval. The goal is to have more dead load on the pier than the calculated upheaval force caused by the expansive soil material. However, this isn't always possible at lightly loaded areas (such as porches and other appendages) but, as a rule, it should be attempted.
3. Drilled piers must be reinforced with extra vertical reinforcing steel to prevent being pulled apart wherever expansive soil forces exceed the dead load. It's typical to reinforce drilled shafts even if calculations don't indicate the need for reinforcement. The structural engineer should design the reinforcement based on uplift forces predicted by a geotechnical engineer. It has been customary to rely on minimum reinforcing steel percentages, however, this approach isn't always reliable. In expansive clay the general rule-of-thumb is to use a minimum area of reinforcing steel equal to 1.0% of the area of concrete. However, more reinforcing may be required if expansive soil forces exert a tensile force on the pier greater than the resistance of the minimum steel requirements.
4. The bottom of the pier must be anchored into the bearing stratum a sufficient depth to prevent pull-out from expansive clay uplift forces. This anchorage depth should be designed by a structural engineer based on the negative skin friction value given by a geotechnical engineer.
5. Where reinforcing steel is required to resist uplift forces, lap splices in the steel should be long enough to develop the ultimate tensile strength of the reinforcing. These splice lengths should be designed by the structural

engineer.

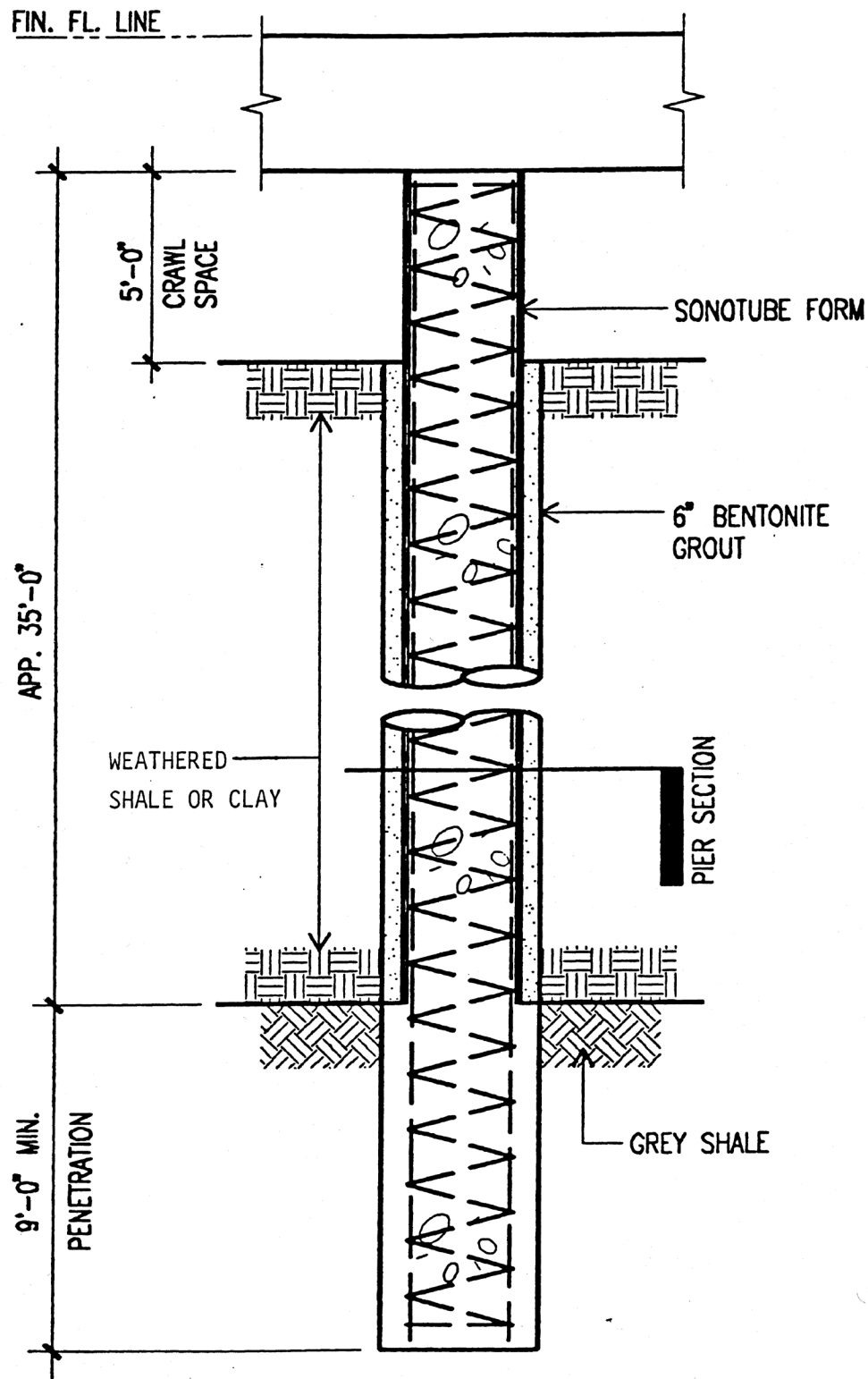
6. Connecting dowels, extending from the tops of the piers, should extend a sufficient distance above and below the connection to develop the ultimate strength of the reinforcing in tension. This is a prudent practice due to the possibility that swelling clay will exert uplift forces on the grade beam or wall supported by the pier, even if the beam or wall is detailed to be isolated from the soil.

There have been many cases of foundation beams pulling apart from piers in spite of having an isolating void space designed under the beam.

- B. BELLED PIERS:** Have the same characteristics as skin friction piers, except that they depend only on end bearing. The bottom of the pier is "belled out" by underreaming to a diameter two to three times larger than the pier shaft, in order to provide additional bearing area on the bearing stratum. This system is most commonly used in areas where competent shale or limestone is uneconomically deep. An expansive soil layer might itself serve as the bearing stratum for a belled pier. Weathered shale, for example, is often quite expansive yet strong enough to support piers.

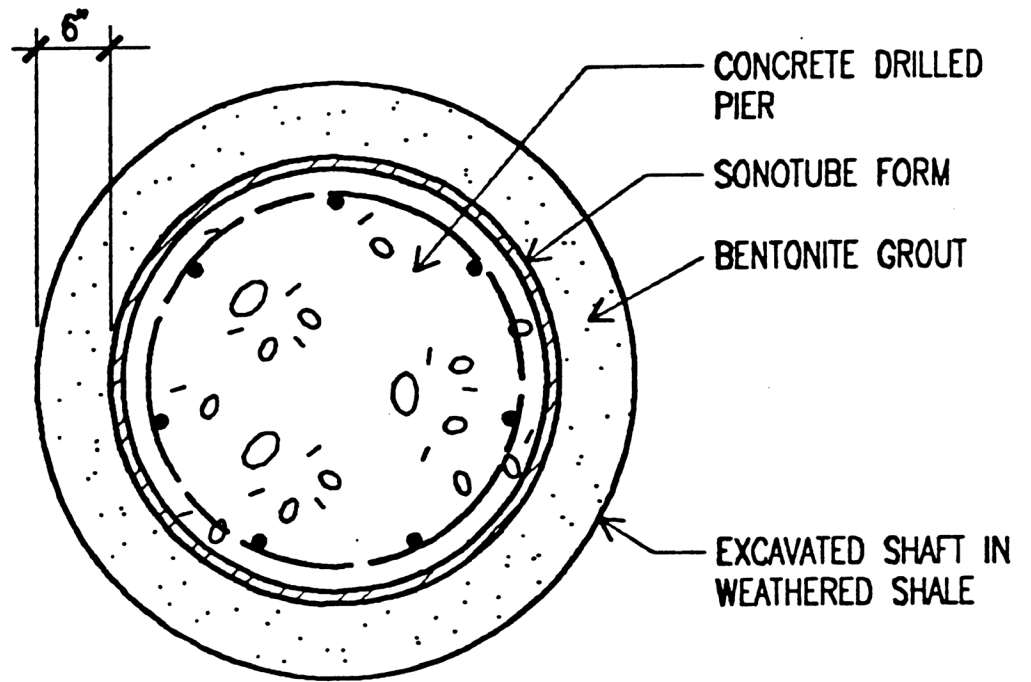
The major requirement here is to extend the bottom of the pier an adequate distance below the zone of seasonal moisture change to minimize its effect. Even so, settlements with this system are generally greater; especially where the bearing material is clay or sand.

It's not our intent to discuss all of the construction criteria necessary to construct belled pier foundation systems, but to point out that they are sometimes used and that all of the requirements listed previously for skin friction piers constructed in expansive soil also apply to belled piers. One additional requirement is that belled piers must be anchored into the soil below the zone of seasonal moisture change. Predictions for the depth of the seasonal moisture change and recommendations for the amount of anchorage must be obtained from the geotechnical engineer.



TYPICAL DRILLED PIER ELEVATION

EXHIBIT A



PIER SECTION

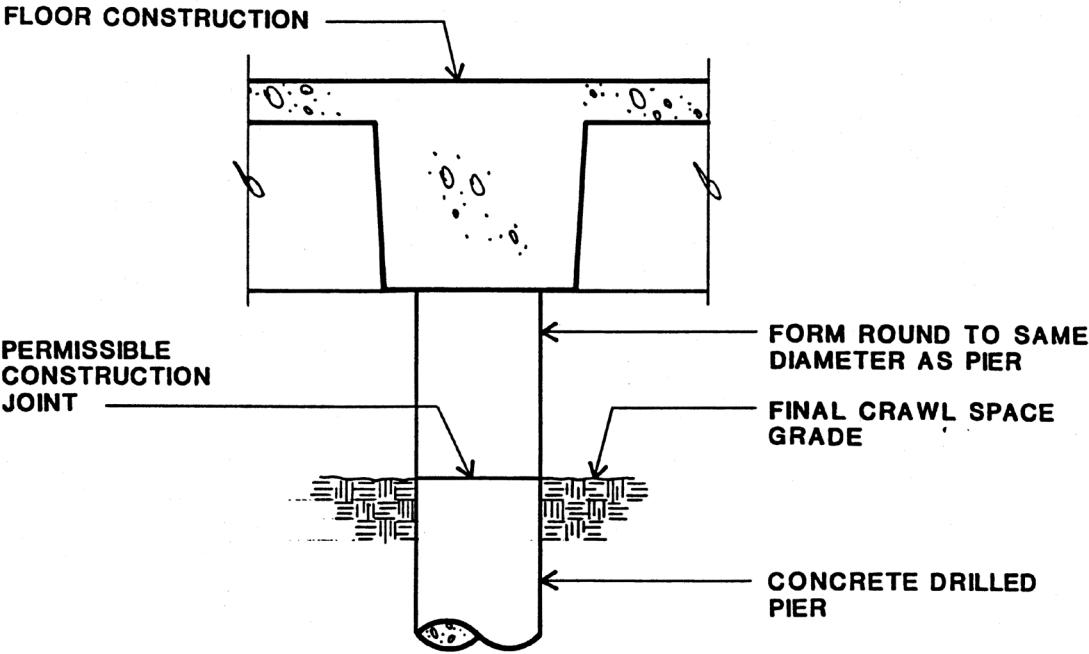
EXHIBIT B

IV. CONSTRUCTION PROBLEMS COMMON TO BOTH PIER SYSTEMS

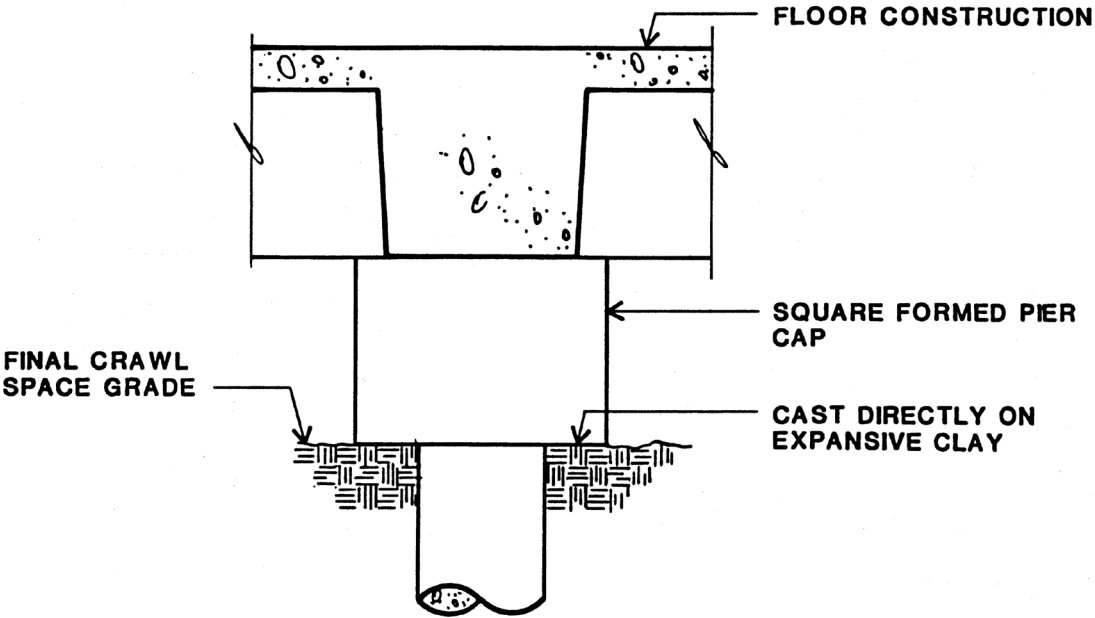
One of the most common problems encountered with both drilled pier systems in expansive soils is uplift, caused by upheaval pressures on the underside of the projecting pier cap formed at the top of the pier. If a pier cap overhangs the edge of the pier (which it almost always does) a void space should be constructed under the overhang so that the soil can swell without pushing it up.

When extending the top of a pier shaft up to the underside of a structure through a crawl space, as shown in the typical pier cap detail (*See Exhibit C*), the pier should be extended by using sheet metal or Sonotube forms of the same diameter as the pier itself. It is unacceptable to construct an oversized pier extension (*As Shown In Exhibit C*) poured directly on the grade, since this provides the expansive clay with a bearing area to push on which tends to pull the pier apart. Contractors prefer to form these pier extensions with square plywood boxes, but this is a known cause of severe problems and should be absolutely avoided. In conditions where an oversized pier extension is required, the overhanging portion must be poured on cardboard carton forms to make a void space. The use of carton forms (void boxes) is addressed in detail later.

Another common construction technique that has been encountered, and must be avoided, is allowing the pier concrete to overflow onto the uneven ground surface at the top of the hole, forming a flare (*As Shown In Exhibit D*). The same ill effect as discussed for an oversized pier extension can occur, even if the contractor has taken pains to form the pier extension at the same diameter as the pier itself. This type of overflow of concrete on top of drilled piers may be avoided by using a form above the point where the hole begins to flare out, or by chipping off the excess concrete shortly after it has hardened.

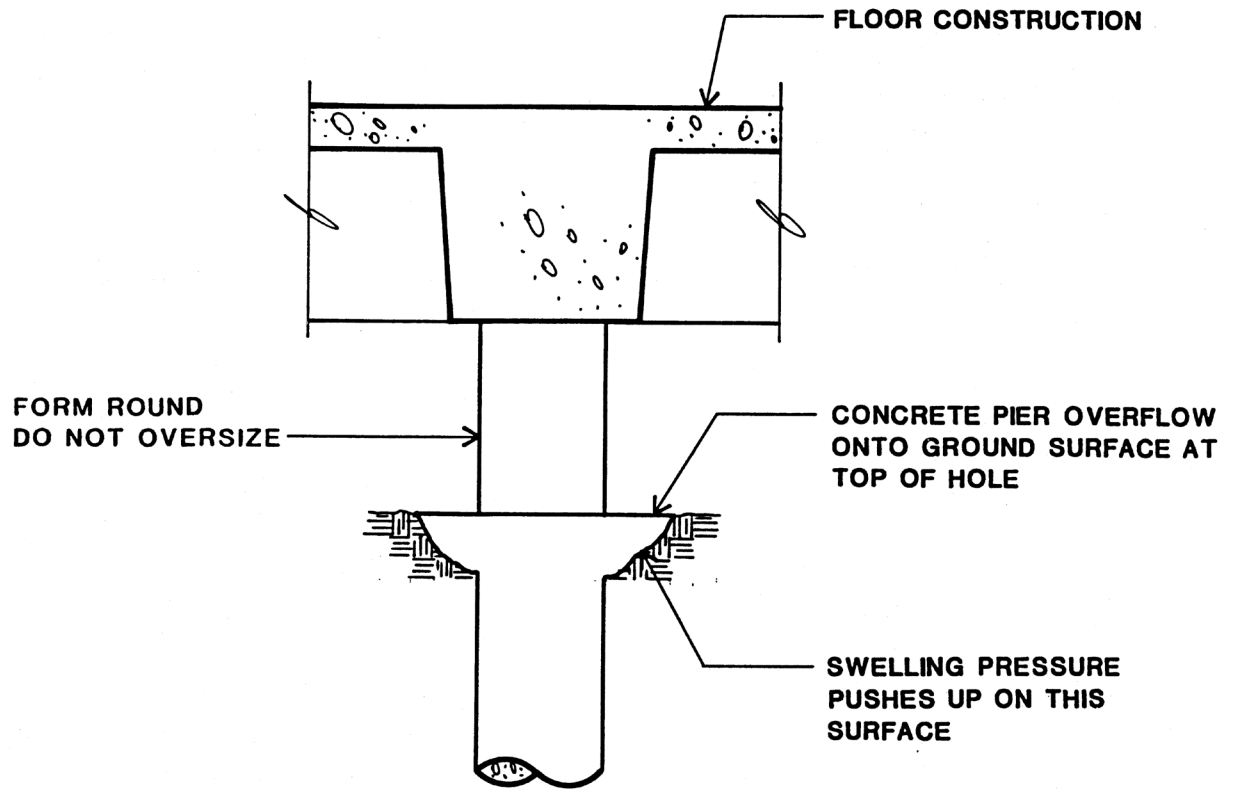


ACCEPTABLE



UNACCEPTABLE

EXHIBIT C



UNACCEPTABLE

EXHIBIT D

V. GRADE BEAMS, CAST-IN-PLACE AND PRECAST TILT-UP WALLS

Most grade beams and walls around the perimeter of a building, and interior grade beams which are used to support a structural floor, are poured directly on the ground. In expansive soil areas they are subject to the possibility of considerable upward forces generated by swelling clays, thus having a devastating affect on the building. A number of special precautions should be taken to eliminate or minimize these upward forces.

- A. VOID SPACE CONSTRUCTION:** The most common and fundamental approach to combat the problem of upheaval is to place void boxes (carton forms) under all grade beams, pilasters, and walls which are poured on soil but which are supported by drilled piers. Void boxes are wax-coated, folded cardboard blocks that are strong enough to support wet concrete but disintegrate after a few days when exposed to moisture. These void boxes leave a large void space between the bottom of the concrete and the soil; thus allowing expansive clay room to swell without pushing up on the bottom of the grade beam or wall. Void boxes can be bought in heights of 2" to 12" depending on the anticipated amount of soil movement.

A properly constructed void space is not as simple as it may seem and there are a number of special details that must be properly developed and implemented in order to create a successful void space:

1. There must be a permanent retainer on each side to prevent caving of soil into the void from the sides after the cardboard boxes have deteriorated. Two such options are:
 - a. Precast Concrete Retainers - "**Exhibit E**" illustrates precast retainers placed on both sides of a formed grade beam or wall soffit to prevent soil from sloughing into the void. This is probably the most functional solution with the best chance of permanent protection, and it may be the only feasible solution when required voids are greater than 8". The bottom of the member may be formed with rectangular carton forms instead of wood, in which case the carton would remain in place.

This system is probably the most expensive solution and may not be required when the size of the void specified in the soil report is 8" or less. This is the only practical solution when creating a void under a precast concrete tilt-up wall panel.

- b. Trapezoidal Void Boxes - "**Exhibit F**" illustrates a trapezoidal void carton configuration that allows concrete to pour down both sides of the carton to form a permanent retainer. This method is often used and appears to be an adequate solution for void cartons up to 8" tall. However, the retainer wedges break off easily on taller boxes, so extra care must be exercised to avoid this problem on voids taller than 4". This detail should not be used for voids taller than 8".
Trapezoidal void boxes are considerably less expensive to use than

precast retainers along each side of the grade beam. They only work under cast-in-place members and are not applicable on tilt-up precast walls. Rectangular void boxes are not acceptable and should not be permitted on the project.

2. Side forms of grade beams or walls must be firmly secured to prevent movement away from the void box. When side forms are allowed to bulge, concrete can pour down onto the expansive clays forming a surface for the clay to lift up on (*See Exhibit G*).
3. Ends of the void boxes must be capped off at the termination points; at corners, and on each side of piers. When left uncapped concrete can enter the void from the end, filling the void space as the pilaster or grade beam is poured. Specifications should always require that the discontinuous ends of all void boxes be capped by stuffing with paper or other filler which completely prohibiting concrete from entering the ends of the void boxes. Joints between boxes should be taped shut. The contractor must be made aware of the importance of this procedure.
4. In addition to capping the ends of void boxes and taping joints, it's important that the boxes be installed abutting the pier (without leaving space between the end of the box and the face of the pier). This prevents concrete from the grade beam or wall pour getting between the pier and void box and coming into direct contact with the ground (*See Exhibit H*).
5. A major problem with void boxes is the cardboard box collapses due to the weight of the wet concrete, sometimes aggravated by premature exposure to moisture (*See Exhibit I*). This can easily go undetected by the contractor and/or inspector. To avoid this problem the following quality control procedures must be implemented:
 - a. The boxes must be of sound quality and should be wax coated to resist premature deterioration due to moisture.
 - b. Carton forms should be designed with sufficient strength to resist the concrete's wet weight when placed on top of the cardboard boxes.
 - c. The cardboard boxes should be examined prior to each pour and any damaged, weakened, or overly wet boxes should be replaced.
 - d. Carton forms for slab pours should be protected with polyethylene and protection board which can both remain in place.

- B. WATER EXCLUSION:** Although void boxes under grade beams and walls are absolutely necessary, and when properly constructed have prevented major damage to many buildings due to expansive clay, they have also been known to contribute to structural damage.

These voids can, in effect, create tunnels that allow water (if permitted to seep into the void) to flow directly to the pier, causing saturation and expansion of the clay around the pier. This procedure has created considerable damage to many

buildings and should be regarded as a critical problem to be properly solved during both the design and construction of the building.

One method used to address this problem is to install a drain tile around the perimeter of the building, adjacent to and slightly lower than the void box. The concept is to attract the intruding water and divert it to a sump pump or positive drainage area. However, the drain tile is generally surrounded by gravel backfill so this solution has the potential of attracting even more water down to the level of the void box.

It is preferable to try and seal out the water from under the grade beams and walls with compacted clay soil against the outside of the beam or wall. This clay backfill, placed around the perimeter, should be at least 2'-0" thick and be highly compacted with hand tampers in 12" lifts, to approximately 85% of Standard Proctor Density or above (*See Exhibit J*). Typically, moisture won't penetrate the tightly compacted clay and is channeled off by the exterior grading. A strip of geomembrane material over the clay provides extra insurance against water intrusion.

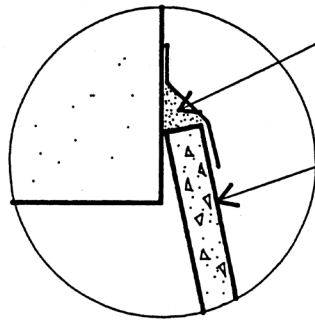
If a crawl space exists on the inside of the building, it is desirable to extend the bottom of the grade beam or wall at least 6" below the grade of the inside crawl space, and then compact the grade on both sides with hand tampers to approximately 85% Standard Proctor or above, leaving the grade of the crawl space inside the building sloping away from the grade beam or wall.

If there is a basement, the backfill will usually be a free draining granular material, with a french drain at the bottom. In this case, the top 2'-0" of backfill should be a compacted clay cap (*See Exhibit K*).

An ideal moisture barrier, but one which is often architecturally unacceptable, is to place a sidewalk or paving strip against the building at least 6'-0" wide.

- C. SIDE FORMS:** Another major contributor to soil-related damage of buildings is pouring the grade beams or walls directly against the earth excavation. When the earth is compact and strong enough to make a virtually vertical cut, the contractor may desire to eliminate the cost of forming the grade beam or wall and pour concrete directly against the earth. This cannot be allowed in expansive clay. The surface of the grade beam or wall would be so rough that upheaval skin friction against the side of the member could occur. In all cases, the grade beam or wall trench should be excavated wide enough to allow the contractor to form the face of the grade beam or wall and backfill against the smooth formed concrete surface. A smooth face is not subjected to as much skin friction upheaval (*See Exhibit O*).

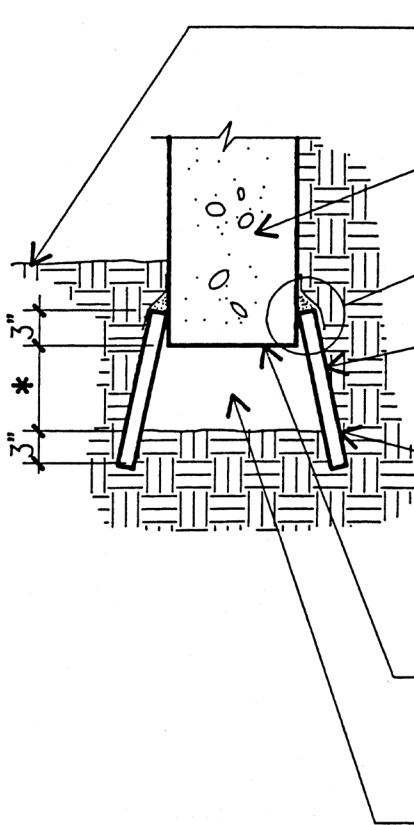
- D. MEMBER DEPTH:** The grade beam or wall should be as deep as economically practical, in order to install the void box deeper in the ground which makes it subject to less seasonal moisture change. Also, the depth of the clay backfill on either side of the grade beam or wall would be deeper providing better protection against moisture infiltration into the void box. A value engineering study for this condition should be made by the structural engineer. He should compare the cost of spacing the piers further apart and making the grade beam deeper. Some of the extra cost of the deeper grade beams or walls would be offset by the savings in pier cost and the piers would be more heavily loaded, which has proven to be beneficial.
- E. REINFORCING DETAILS:** Another appropriate precaution to take in the design of grade beams or walls is to include continuous top steel. This prevents cracking at midspan if all else fails and expansive soils attempt to heave the grade beam. If the grade beam is properly doweled into the piers (as previously described in the drilled pier section) and also designed to resist a certain amount of reversal of stress due to upheaval, then reasonable precautions have been taken.



DETAIL

GROUT

6" WIDE 30# FELT STRIP CONTINUOUS
ALONG THE TOP OF EACH BULKHEAD &
CENTERED OVER EACH VERTICAL JOINT
BETWEEN BULKHEADS. SEAL FELT
WITH MASTIC.



FINAL CRAWL SPACE GRADE

STRUCTURAL GRADE BEAM, CAST IN
PLACE WALL OR TILT UP WALL

DETAIL

1 1/2" THICK X 2'-0" TO 4'-0" LONG
PRECAST CONCRETE RETAINER SLABS.
REINFORCE WITH 4"X4"XW1.4 WIRE MESH
IN CENTER

SLIGHTLY CANT PRECAST
BULKHEADS AND DRIVE INTO
CLAY TO OBTAIN FIRM SEATING

FORMED SOFFIT. REMOVE FORMS
FROM VOID BEFORE INSTALLING
BULKHEADS.

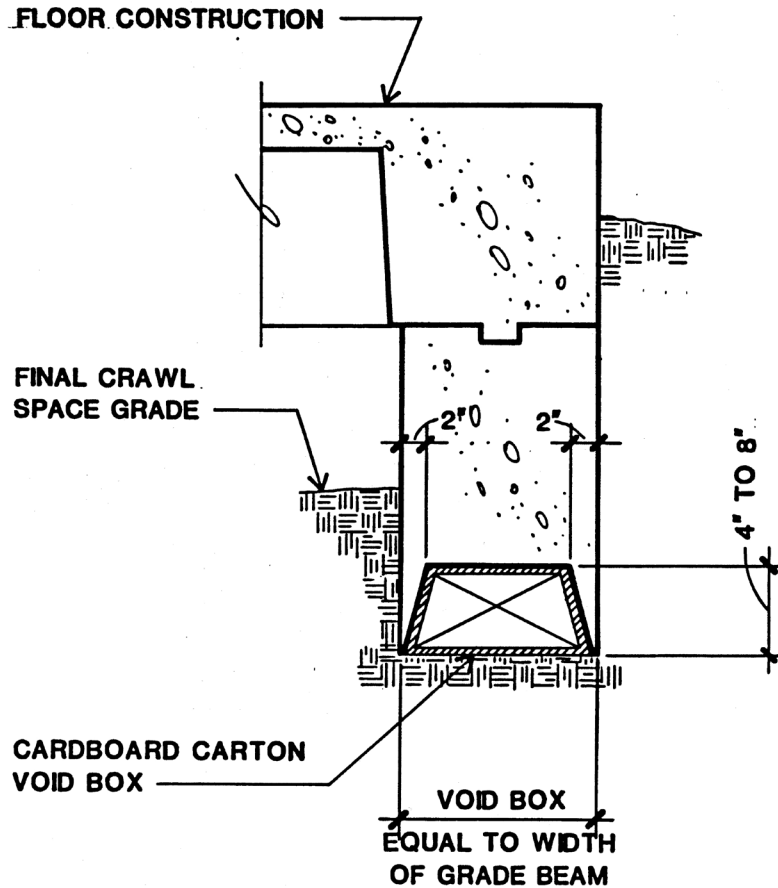
AIR SPACE

*DIMENSION SUPPLIED BY SOIL ENGINEER

NOTE:

CONSTRUCT UNDER ALL STRUCTURAL
CONCRETE PIER CAPS, PILASTERS,
GRADE BEAMS AND WALLS IN CONTACT
WITH THE GROUND.

EXHIBIT E

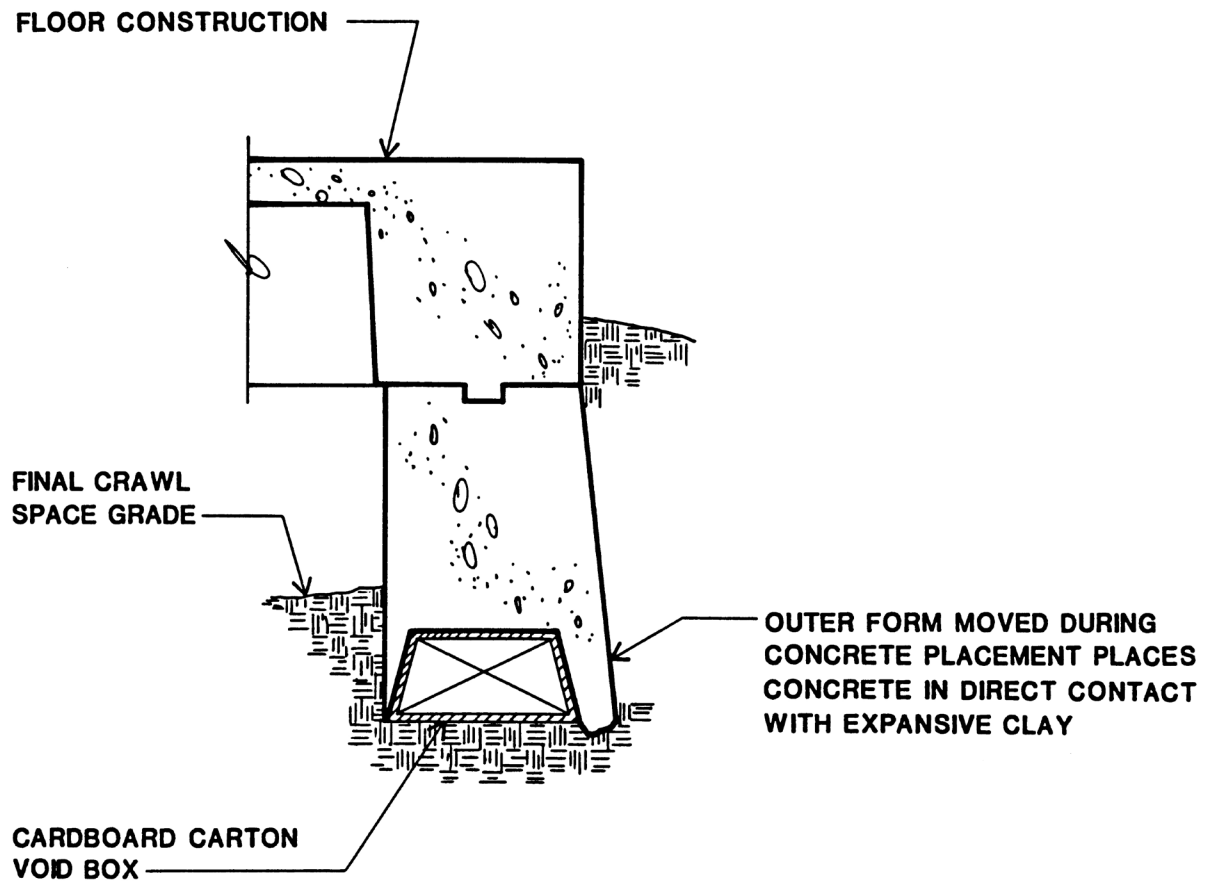


NOTES:

1. PLACE VOID BOXES UNDER ALL STRUCTURAL CONCRETE PIER CAPS, PILASTERS, GRADE BEAMS & WALLS SHOWN TO BE PLACED DIRECTLY ON EARTH. ALL STRUCTURAL CONCRETE EXCEPT SLAB ON GRADE SPECIFIED TO BE CAST ON EARTH SHALL BE SEPARATED FROM EXPANSIVE CLAY.

2. CONTRACTOR SHALL PROTECT VOID BOXES & PLACE CONCRETE IN A MANNER TO PREVENT COLLAPSE OF THE VOID BOX. COLLAPSED VOID BOXES SHALL NECESSITATE REJECTION OF THE WORK.

**TRAPEZOIDAL VOID
BOX (CARTON FORM)
EXHIBIT F**



UNACCEPTABLE

EXHIBIT G

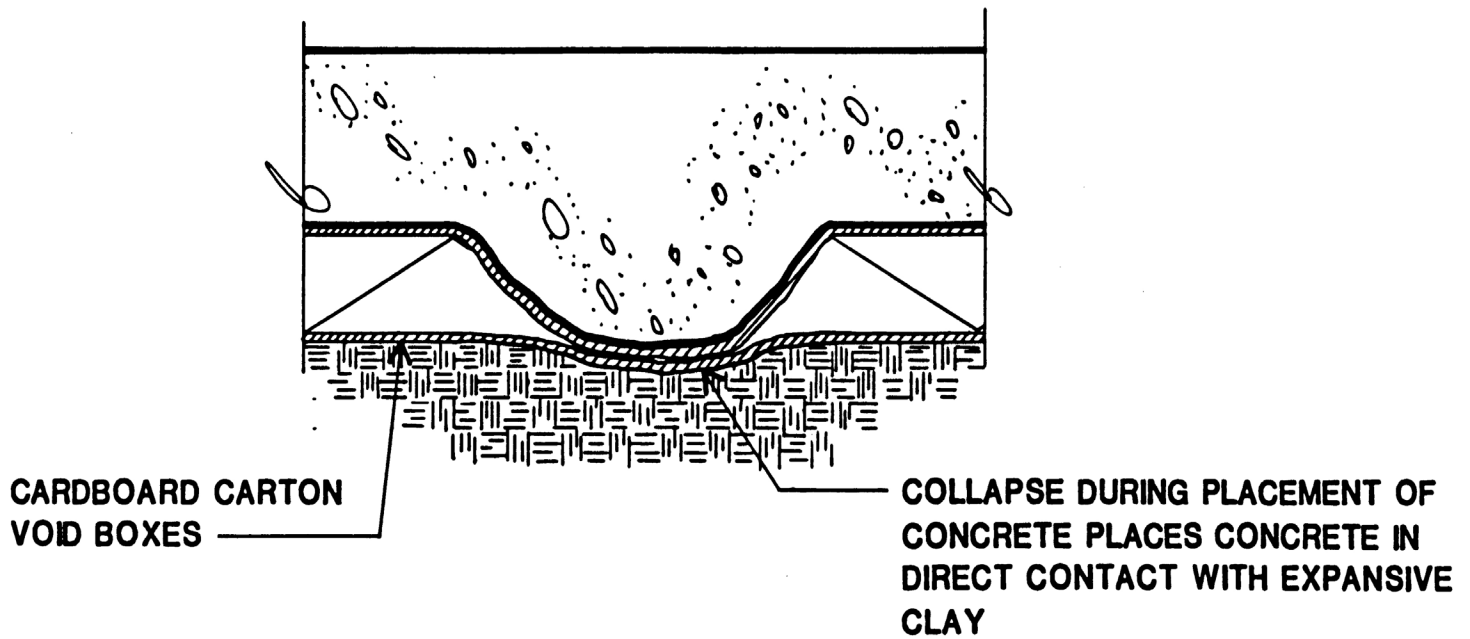


PIER

**- VOID BOX PROPERLY CAPPED
OFF BUT NOT INSTALLED
ABUTTING THE PIER ALLOWS
CONCRETE TO POUR DOWN
ONTO THE EXPANSIVE CLAY**

UNACCEPTABLE

EXHIBIT H



UNACCEPTABLE

EXHIBIT I

FLOOR CONSTRUCTION

LANDSCAPING SOIL

COMPACTED CLAY BACKFILL

ORIGINAL GRADE SLOPING
BACK TO THE BUILDING

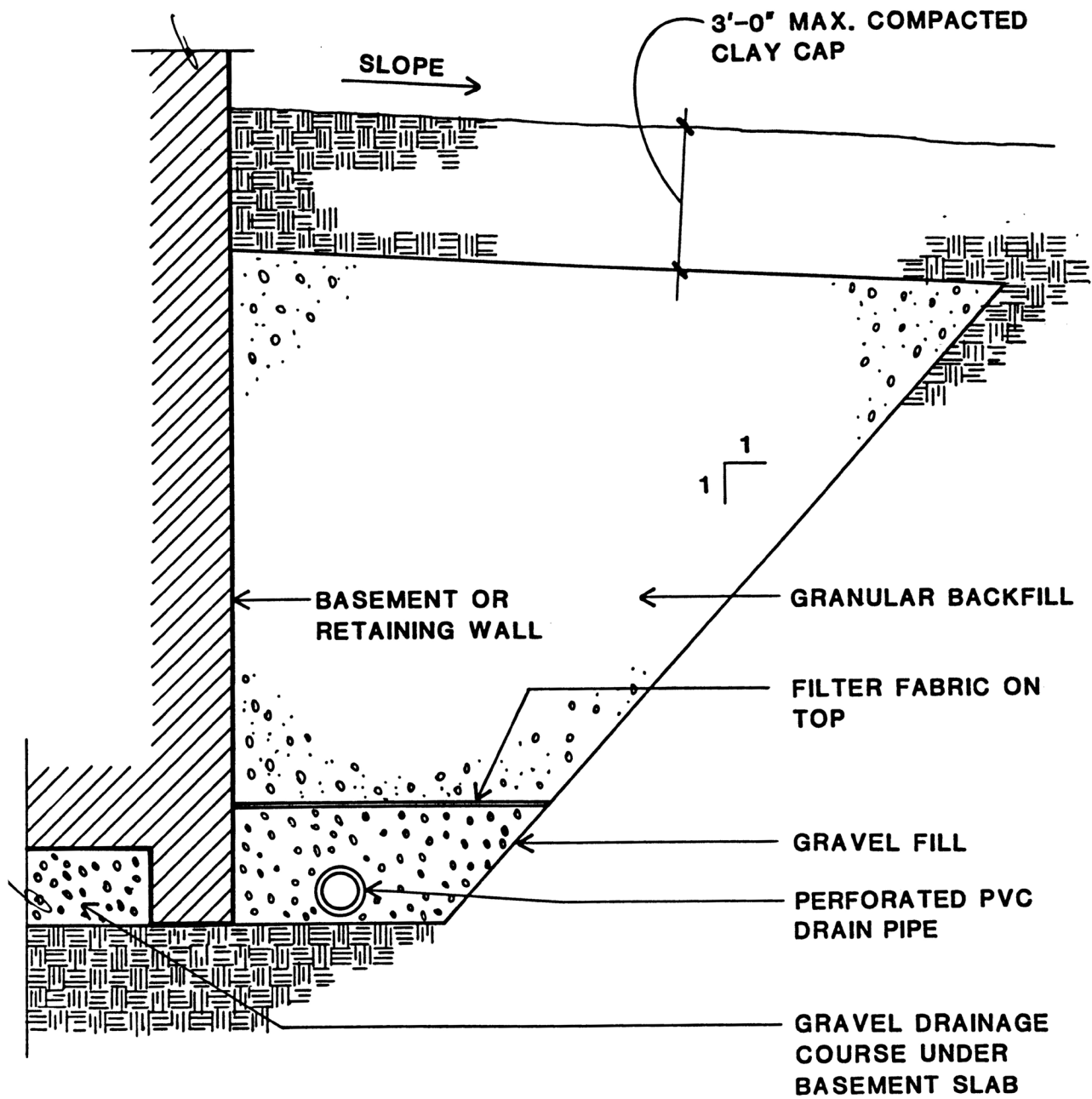
FINAL CRAWL
SPACE GRADE
SLOPE TO SUMP

GRADE SITE TO DRAIN BEFORE
STARTING FOUNDATION
CONSTRUCTION

HAND TAMP COMPACTED
CLAY BACKFILL

CARDBOARD CARTON
VOID BOX

IDEAL GRADING
EXHIBIT J



BACKFILL DETAIL
EXHIBIT K

VI. CRAWL SPACE UNDER STRUCTURAL GROUND FLOOR

A pier and beam foundation system, where a suspended ground floor slab is called for, will normally have a crawl space. This crawl space may be anywhere from 16" to 48" deep and is intended to separate the floor structure from potentially expansive soil materials. It also provides access space below the ground floor for maintenance and the addition or relocation of plumbing lines, electrical lines, etc. Certain precautions need to be taken in the construction of the crawl space to minimize the damage caused by the expansive soil.

As previously mentioned, it is important to extend the piers up to the underside of a floor slab through the crawl space by using a round form of the same diameter as the pier, this prevents ledges or pilasters that may be lifted by expansive soils. We also addressed the importance of backfilling with properly compacted material against the perimeter grade beam on the crawl space side, as well as the exterior of the grade beam.

Proper drainage is crucial during the construction of the building, damage can be prevented by sloping the crawl space excavation. It's not anticipated that much water will get into a properly constructed crawl space after the building is completed and, therefore, the need for underfloor drainage in a crawl space is minimal for this purpose. However, some moisture will exist and the crawl space should be properly graded for drainage and ventilated by mechanical or other means. This precaution not only proves useful during the buildings construction but is an added benefit throughout the life of the building, by assisting in drainage of any water intrusion from plumbing leaks or other sources of moisture.

All plumbing pipes should be hung from the structure and separated from the grade to prevent damage to the pipes from expansive clay. Where a pipe leaves the crawl space through the grade beam, to be buried in the soil outside the building line, a transition detail is required. Either a vertical slot in the grade beam or a flexible joint detail in the pipe should be installed to allow movement to occur in the pipe at the grade beam.

"Exhibit J" shows the ideal grading condition around the perimeter of a foundation over crawl space.

VII. STRUCTURAL SLAB ON VOID BOXES

Casting a structural slab on void boxes is another approach used when constructing a structural ground floor separated from the expansive soil. This system can and has been used successfully. However, all of the problems listed in Chapter V of this booklet concerning void boxes, exist and are compounded; wet boxes collapse, concrete runs down between the ends of void boxes and piers, etc. Instead of an isolated problem under a grade beam or wall, the problem may exist throughout a large portion of the floor. Therefore, we do not encourage the use of this system and do not recommend it except in rare instances where no other system seems to apply.

If this system is used, several precautions need to be taken to improve its chances for success:

- A. Follow all of the guidelines established in Chapter V for void boxes.
- B. Specify waterproof, wax-coated void boxes.
- C. Inspect and replace all damaged boxes before pouring concrete.
- D. Place a polyethylene sheet and 1/4" thick protection board over the top of the void boxes. This protects them from moisture and spreads out concentrated or uneven loading over a number of boxes.

VIII. SLAB-ON-GRADE CONSTRUCTION

A slab-on-grade ground floor, combined with drilled piers and grade beams to support the superstructure, is the most economical foundation system for commercial buildings in expansive clay areas. However, it has a higher risk potential for damage by expansive soils due to the ground floor slab being cast directly on the ground. The same attention to details mentioned previously (regarding drilled piers and grade beams) applies to this system. In addition to the required care needed for those elements of the building, the slab-on-grade itself presents a difficult problem to solve in expansive soils. The success of slab-on-grade construction depends on numerous variables; ranging from the thoroughness and accuracy of the original soil investigation, to design concept, and the construction quality. Any one of these variables improperly dealt with can create unacceptable damage to the slab.

The first step, when considering the use of slab-on-grade construction, is for the geotechnical engineer to predict the potential amount of vertical rise that may occur in the floor slab over the life of the building and to make recommendations on how to reduce that vertical rise to an acceptable limit.

A. ACCEPTABLE VERTICAL HEAVE: Acceptable limits of vertical heave in slab-on-grade construction are dependent on the architecture of the building. Normal limits range from 1/2" to 3/4" in office buildings, schools, or housing, to as much as 2" to 3" in warehouse space. Of course, the acceptability of floor slab heave varies from project to project and should be established on an individual basis with all parties, including the owner, involved. If an owner is unaware that a decision has been made that allows a 2" heave in his warehouse or 3/4" heave in his office space, and then it happens, a major controversy can arise between the owner and the building designers. This situation must be averted at the beginning of the project by discussing with the owner of all of the options available and their attendant costs.

B. THOROUGHNESS AND ACCURACY OF GEOTECHNICAL INVESTIGATION: Major variables that need to be dealt with thoroughly and accurately are as follows:

1. The geotechnical engineer must use proper formulas for the actual subgrade materials to predict the potential vertical. There are several formulas that are commonly used, such as the Texas Highway Department's Method "Tex 124-E," another method proposed by Vijayvergiya and Ghazzaly, and the conventional pressure swell test. There are many valid arguments among the geotechnical engineers as to the relative validity of these different approaches in predicting vertical heave on a given project. The structural engineer is not qualified to make that determination but should suggest that a geotechnical engineer with considerable experience in dealing with expansive soil materials be employed, and that the most accurate analytical method be used. The results obtained from these various formulas differ considerably and the geotechnical engineer should be able to explain their variations.
2. Based on his knowledge of the areas geology and a study of the borings that

have been made the geotechnical engineer should determine whether an ample number of borings have been taken within the building footprint and that variations between borings are not drastic enough to adversely influence the prediction of potential vertical rise. Borings commonly are located 200 to 250 feet apart. But borings at that spacing are inadequate where the probability of variations between borings is significant enough to create problems which would not be anticipated in the soil report.

C. METHODS OF REDUCING POTENTIAL VERTICAL MOVEMENT:

There are a number of treatment methods that have been recommended by geotechnical engineers to reduce the magnitude of potential vertical movement. The most successful of these are:

1. Replacement with select fill: The most common method is to install several feet of select (Low P.I.) fill material under a slab-on-grade. The installation of select fill under the poured slab does two things:
 - a. It adds dead weight on top of the expansive soils, which reduces the ability of the soil to absorb moisture and expand.
 - b. It reduces the amount of expansive soil left under the building (assuming some of it is excavated to make room for the select fill).

It should be stressed that there is a risk involved with installing select fill below grade. Water travels easily through granular select fill and its very existence may result in the attraction and ponding of surface-supplied water beneath the structure. Ponding water may result in greater expansion of the deeper clays and create more vertical rise in the slab than if select fill had not been installed. This is sometimes referred to as the "bathtub effect." Consequently, many geotechnical engineers only recommend the installation of select fill when it can be placed on top of the natural grade, such as under dock-height buildings.

2. Pre-swelling: Another successful method used is to pre-swell the soil below the slab-on-grade by saturation. Various techniques for doing this have been proposed by geotechnical engineers. One technique is to drill holes approximately 7'-0" deep, on a grid 5'-0" on center and keep the holes filled with water until the soil has attained the desired moisture level. This method has had some success and deserves discussion with the geotechnical engineer, but it is slow and time-consuming, and some precautions are needed to prevent damage to the drilled piers or other elements that were constructed before the pre-swelling began.
3. Water Injection: Another method of pre-swelling the soils has been to use pressure injection equipment to inject the soil with water on a grid of 5'-0" to 7'-0" on center, to a depth recommended by the geotechnical engineer. The process is repeated until moisture content of the expansive clay has reached the desired level. This system has problems with uniformity of moisture content but it is an option and should be discussed with the geotechnical engineer.

4. Lime Injection: Some geotechnical engineers recommend mixing lime with water and injecting this solution into the expansive soils by the same method as described above. In theory lime reduces the expansive characteristics of clay soils. The question of application of lime through the injection process is valid and should be discussed.
5. Lime Stabilization: Consists of removing and pulverizing a predetermined amount of expansive clay (usually 2 to 4 feet) and mixing it with dry lime, then replacing and recompacting it in its original location as if it were select fill.

When thoroughly mixed lime dramatically reduces the plasticity index of the soil, making it less expansive. This method has the added advantage of being less permeable than select fill, so water will not travel freely and collect under the building as it can with select fill placed below grade.

- D. PROTECTION OF THE PERIMETER OF THE BUILDING:** It's fairly realistic to anticipate that the moisture content of expansive soils below the slab-on-grade at the interior of a large building footprint will increase a minor amount over the life of a building. This increase is due to capillary migration of moisture from the water table. However, around the perimeter of the building the subgrade clays are susceptible to moisture fluctuations caused by weather, irrigation, and poor surface drainage and large trees. These factors play an integral part in the predictions and recommendations made by the geotechnical engineer. Therefore, considerable attention to details around the perimeter of the building is essential to the success of a slab-on-grade floor system.

It may even be architecturally impossible to meet all of the requirements of the soil report to adequately seal off water from the perimeter of the building in a manner that will keep the vertical heave of the slab to the predicted amount. For that reason alone slab-on-grade construction may need to be abandoned. So it is important to emphasize the point that the architect, landscape architect, civil engineer, and structural engineer must each recognize and abide by the requirements that are dictated by the geotechnical engineer for protection against moisture infiltration around the perimeter of the building, or seek an alternative system. Some common recommendations are:

1. The geotechnical engineer may recommend that the entire perimeter of the building have a skirt of paving placed against it. This is impractical for many building types and needs to be resolved with the geotechnical engineer.

However, this is an excellent approach where possible because the pavement, when properly sloped away from the building, would seal the moisture in around the buildings perimeter for a considerable distance and would efficiently reduce seasonal changes in moisture content in the expansive materials below the slab-on-grade.

2. Since proper site drainage is important, even during the initial stages of

construction, the site should be graded away from the building eliminating water infiltration. It is always recommended that the building be situated so that proper drainage and runoff can be provided. This can be as effective as paving around the building. Unfortunately, on sites with significant slopes it may be impossible to achieve an adequate slope away from the building on all sides. In this case, prudent steps need to be taken to prevent improper drainage from increasing the moisture content of the soil under the building.

3. For a building that is cut into a hillside, installation of a drain tile system is recommended to intercept water draining toward the building and to prevent water from penetrating beneath the floor slab.
4. In certain cases, when paving cannot be installed directly against the building, a heavy PVC sheet ("lake liner") is installed below the landscaped area and the finished grade is sloped away from the building (*See Exhibit L*). This approach works when properly conceived and constructed and should be discussed with the geotechnical engineer.
5. Rainwater from the roof must be carried away from the site in a manner which prevents it from infiltrating under the building. Rainwater dumping out of the ends of downspouts around the building in landscaped areas will soak into the ground and is totally unacceptable.
6. Many underground pipes installed during construction (plumbing lines, electrical ducts, roof and floor drains, sprinkler systems, etc.) enter and exit beneath the building, creating hidden conduits for water infiltration. Often these pipes are surrounded by loose backfill, which may consist of porous material (such as gravel, sand, or select fill). This backfill collects water and allows it to flow along the trench and under the foundation or into the void boxes. This type of water infiltration has caused many slab problems and can easily go undetected during construction. Specifications should require all pipe beneath the building be backfilled and compacted to the density of the surrounding soil. Compliance with this requirement should be monitored during construction. Clay backfill with a 10% mixture of Bentonite is recommended on highly expansive sites (*See Exhibit Q*).
7. Final grade must slope away from the building. In fact, the slope should be increased over the desired amount in anticipation of possible future heave reversing the direction of the flow back toward the building. If the new grading materials are not properly compacted water may penetrate the top material and actually flow along the plane of the original grade of the site, which may be sloping toward the building (*See Exhibit J*). Therefore, compaction of site fill around the building is critical to the performance of slab-on-grade construction and the civil engineer and contractor must be made aware of this. Compaction of external backfill against the grade beam is equally important. The contractor must recompact the grade beam excavation back to the density of the existing soils. The fact that it is on the outside of the building might lead the contractor to lose sight of its importance, but it can have a resultant affect on the inside of the building.

8. We recommend that the main line of the sprinkler system be held 10'-0" \pm away from the building to avoid excavating in the properly prepared backfill around the building and damaging the compaction.
9. Landscaping abutting the building is another serious source of water infiltration. It needs to be designed and controlled in a proper manner that minimizes the water infiltration to a degree that is acceptable to the geotechnical engineer. There are several acceptable solutions to the problem such as controlling where landscaping is installed, installing a membrane below the landscaping, or installing the landscaping over concrete paving. A proper solution must be found for each project.
10. During drought seasons the moisture reduction under the slab can cause settlement of the slab. Also large trees, hedges, etc. require a lot of water and the root system of these plants can also absorb a lot of moisture. The plants close to the building can contribute to slab settlement.
11. Another way to help minimize water infiltration around the perimeter of the building is to install the concrete grade beam deeper into the ground than required by the structural design. This provides a moisture barrier down to the bottom of the grade beam. However, the depth may not be sufficient to stabilize the moisture content to the desired degree. In any case, the grade beam should be deeper than the depth of the Low P.I. fill in order to prevent water from traveling under the grade beam into the Low P.I. fill where it is freer to move and soak into the clay below.
12. Installing a deep Bentonite slurry wall barrier around the buildings perimeter, to the geotechnical engineers requested, is permanent and prevents horizontal travel of water within the depth of the slurry wall. This approach deserves consideration on a project by project basis. It is more expensive than adding a geomembrane with the landscaping, but may be considered a more positive alternative by the geotechnical engineer.
13. Some soil reports recommend extending select fill beyond the building perimeter by 3 to 5 feet, this approach should be seriously questioned. It appears that this has attracted water into the select fill material underneath the building and has caused more harm than good. Sometimes this condition exists and the designer doesn't realize it during the design phase and he specifies the depth of Low P.I. fill in a note on the Drawings and fails to compare the note to the grade beam sections. We must watch for this condition and avoid it.
14. In all cases the perimeter grade beam should go down to the bottom of the Low P.I. fill, to help prevent water from entering the area, and expanding the clay below (*see figures M & N*). However, if the required Low P.I. fill is so deep as to make the depth of the grade beam unrealistic, then a Bentonite slurry or other technique must be implemented in order to protect the Low P.I. fill.
15. It is essential to backfill around all grade beams immediately after grade beams are cast. If rain occurs before backfill can be placed in excavations around the grade beams, the excavation must be pumped dry immediately and kept dry until backfilling is complete.

E. METHOD OF PREVENTING DAMAGE TO THE SLAB

1. Some geotechnical engineers recommend the slab be separated from the grade beam around the perimeter of the building to allow the slab to heave without restraint. If this concept is implemented, care must be taken to detail the joint to occur inside the inside face of the exterior wall to prevent damage to the wall. Also, the problem of a rising slab at doors, causing door to jam or people to trip over the offset must be addressed.
2. Many structural engineers require a tie into the exterior grade beam for other structural requirements, such as dock-height type buildings where the grade beam is tied in at the top with the slab to prevent rotation due to backfill under the slab. In these cases, some geotechnical engineers recommend a construction joint about 5'-0" away from the grade beam and then dowel the slab into the grade beam. In theory, as the slab heaves, it will hinge at the construction joint, creating a slight slope down from the construction joint to the grade beam over a 5'-0" length.
3. If the projected heave is 3/4" or less, it may be acceptable to tie the slab into the grade beam and allow the slab to crack at will instead of attempting to concentrate the crack 5'-0" away with a joint. This approach would probably be more acceptable where carpet or other floor finishes hide the crack.

There are probably many other techniques that could be employed or conceived on a project by project basis and the design team is challenged to do just that. The main point throughout the preceding discussion is the importance of controlling water infiltration around the perimeter of the building. All reputable soil reports have statements in them that point this out; unfortunately, they have often been overlooked.

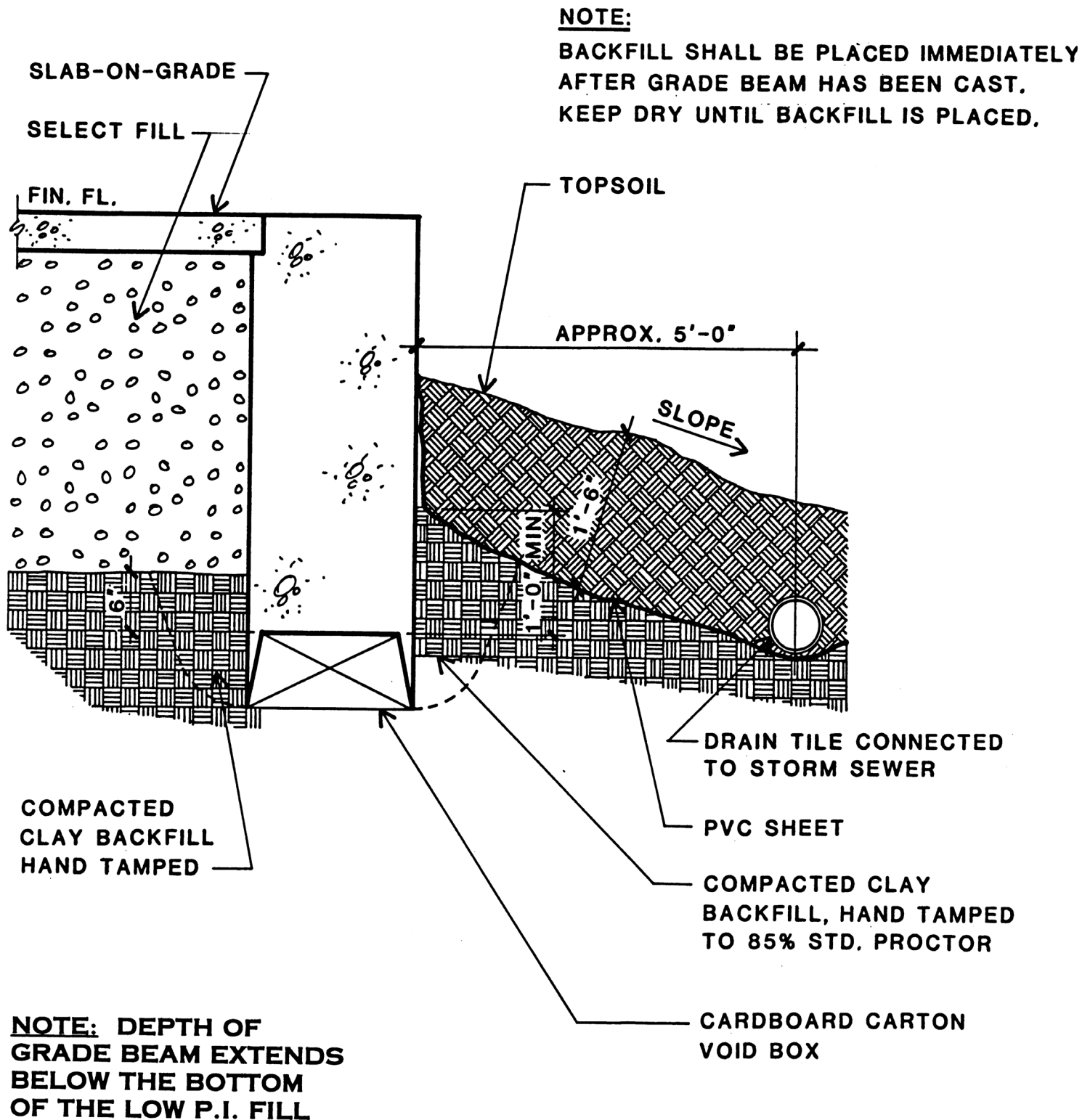
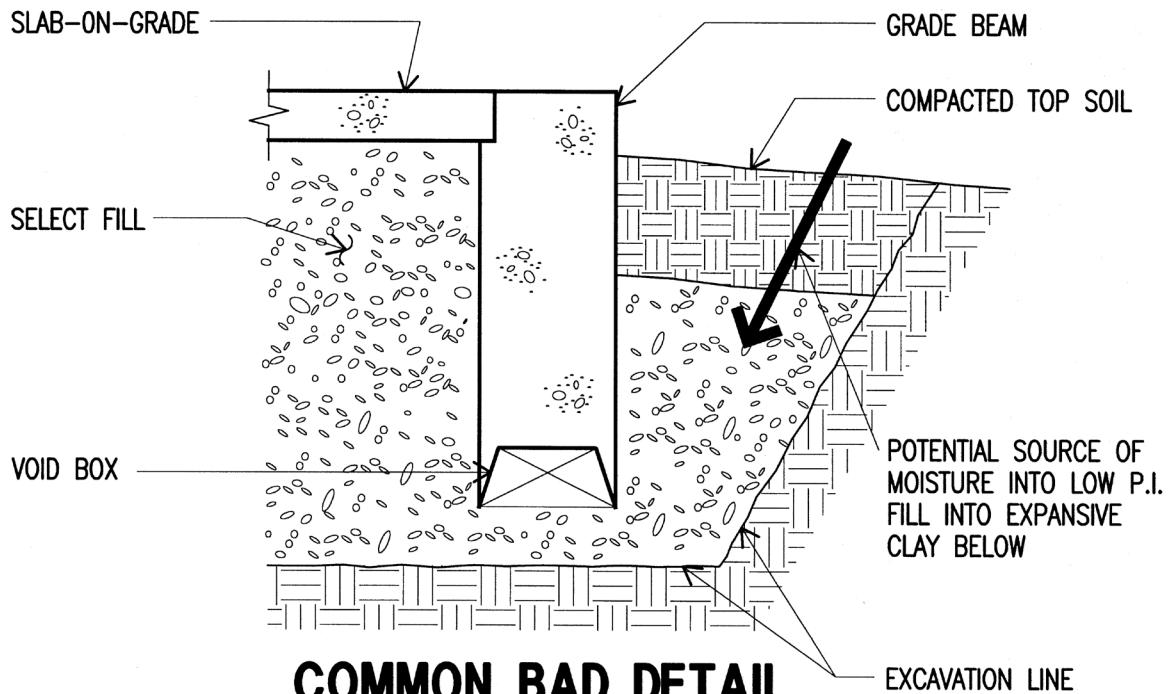
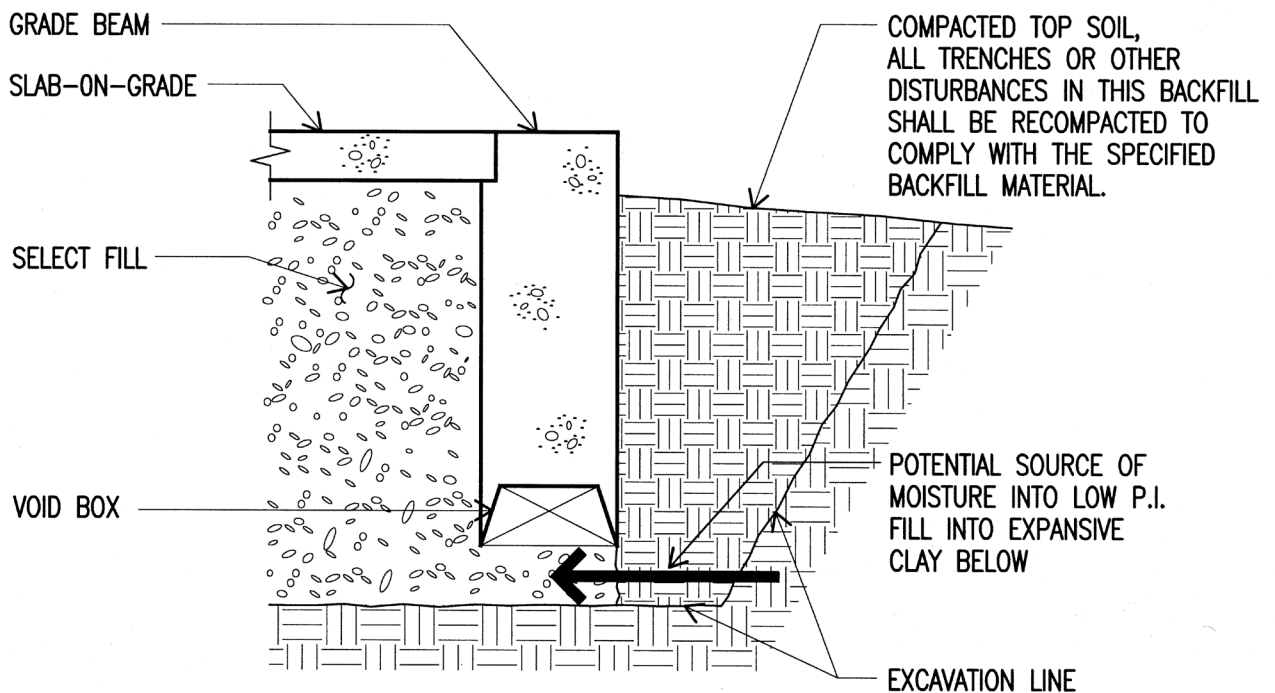


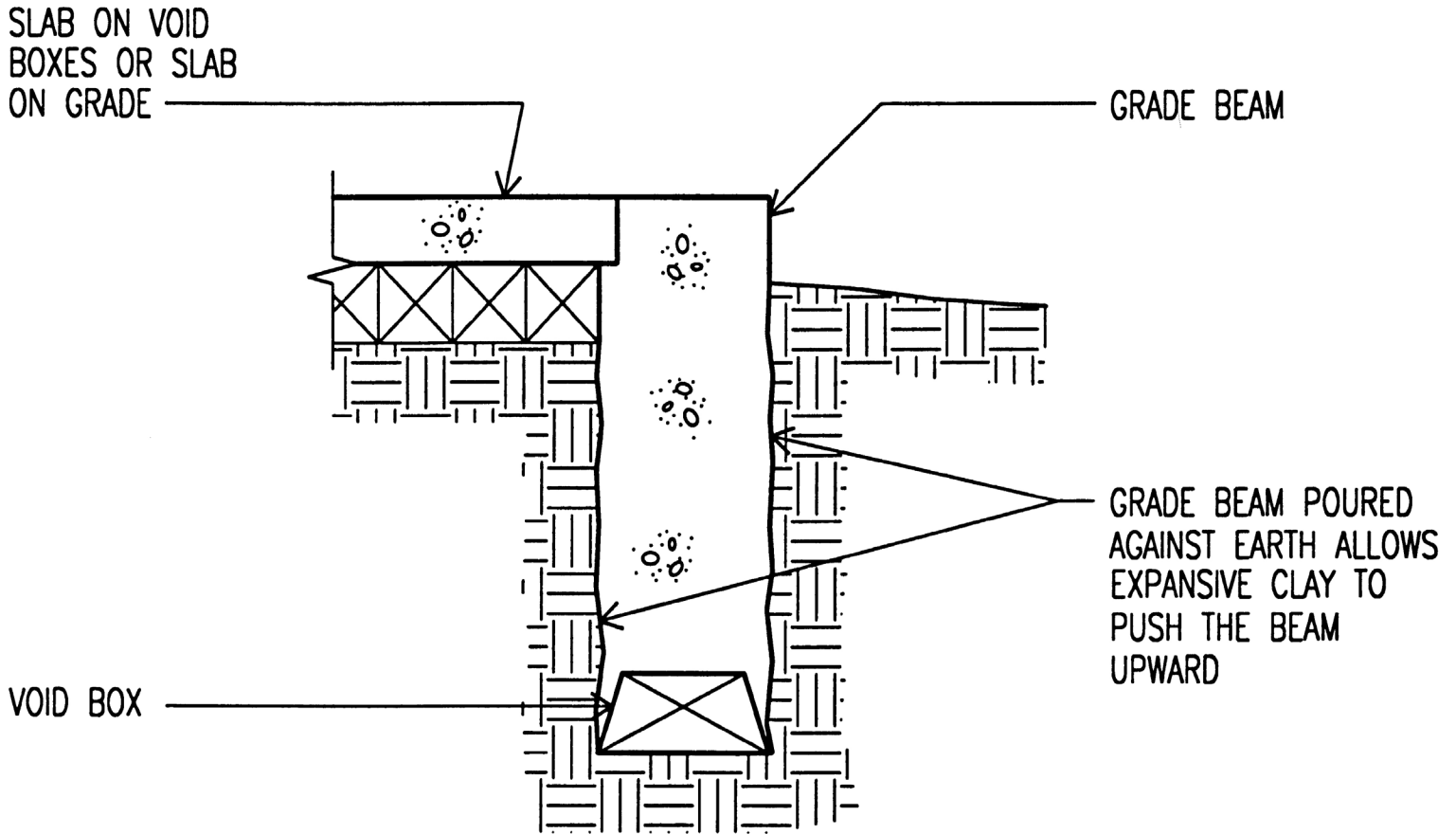
EXHIBIT L



COMMON BAD DETAIL **EXHIBIT M**



BETTER BUT STILL BAD DETAIL **EXHIBIT N**

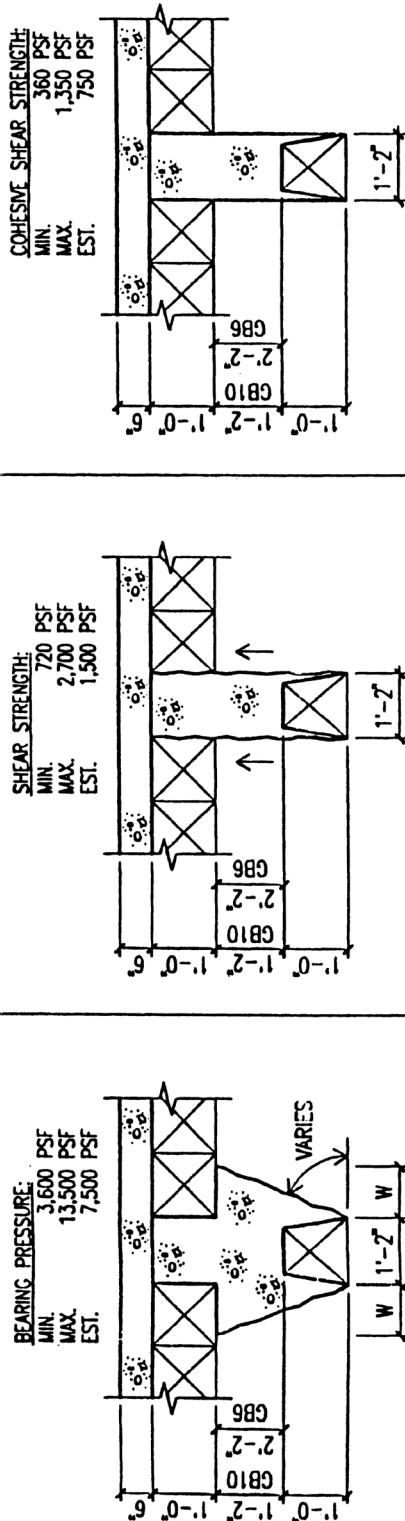


ECONOMICAL BAD DETAIL

EXHIBIT 0

IX. EXTERIOR SITEWORK

EXHIBIT P



ANGLE	W' - GB10	W' - GB6
80°	4.6"	6.7"
70°	9.5"	13.8"
60°	15"	21.9"
50°	21.8"	31.9"
45°	26"	38"

SLOPING EARTH FORMED SIDES			
ANGLE	MARK	MIN.	MAX.
80°	GB10	9.0 KLF	18.7 KLF
80°	GB6	13.1 KLF	27.4 KLF
70°	GB10	5.7 KLF	11.9 KLF
70°	GB6	8.3 KLF	17.3 KLF
80°	GB10	2.8 KLF	5.8 KLF
80°	GB6	4.0 KLF	8.4 KLF

STRAIGHT EARTH FORMED SIDES			
MARK	MIN.	EST.	MAX.
GB10	3.1 KLF	6.5 KLF	11.7 KLF
GB6	4.6 KLF	9.5 KLF	17.1 KLF

FORMED SMOOTH SIDES			
MARK	MIN.	EST.	MAX.
GB10	1.6 KLF	3.3 KLF	5.9 KLF
GB6	2.3 KLF	4.8 KLF	8.6 KLF

DATUM
DATUM ENGINEERING INC.

ENTERPRISE FINANCIAL vs. MCKEE BUILDING SERVICES

SK-1

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PROJECT 95196
DATE 7/1/97

DRAWING

Exterior sitework is typically designed by the landscape architect, project architect, and civil engineer. The structural engineer is not usually involved. The civil engineer specifies paving base and paving and the architect specifies sidewalk thickness and reinforcing. Curbs and gutters are usually standard details that conform with local practices or codes. Unlike the building, separating these items from expansive clay is normally not economical or practical.

Since it's not possible to structurally support all streets, sidewalks, curbs, and gutters the civil engineer and architect must be aware of expansive clays effects on the sitework and detail accordingly. There are gray areas where the judgements of the architect and engineer enter into detailing the sitework. For example, retaining walls may be better designed if supported on structural foundations that separate them from the expansive clays. Other objects in the sitework, such as fountains, light poles, walls, sculptures, etc., may need to be erected on foundations separated from the expansive clays. These are judgement considerations that should be made on a project by project basis.

Another area of concern is where the exterior sitework interacts with the building structure. The building structure may be founded on deep piers and totally separated from expansive clays, therefore, when exterior sitework abuts the building, is placed on expansive clays and differential movement between the two becomes a problem. Usually it is best to allow this movement to occur where possible and detail accordingly, since it is almost impossible to resist the forces of expansive clays. Sidewalks that butt against the buildings should be completely free of the structure and separated by an expansion joint that allows the sidewalk to move with the expansive clay. Often, it is desirable to have the sidewalk sit on a ledge to prevent settlement due to poor compaction.

A major concern is at the entranceways and doors into the building where the exterior sitework is placed on expansive clay and the building foundation is stabilized. It's unacceptable for the exterior sidewalk to heave at the doors causing them to jam or creating a "trip" condition. Therefore, it is necessary to tie the sitework down at the entrances.

If there is a porch it may be necessary to support the entire porch for appearance purposes, as well as to prevent differential movement from occurring. If the porch has steps, the desired location for separation of sitework and porch is at the lowest step. If upward movement is not expected to be too severe, it may be possible to simply let the sidewalk abut the lowest riser of the steps, separated with a 1/2" expansion joint which allows the sidewalk freedom of movement. This simply means that the lowest riser may become slightly shorter than the other risers. The advantage is that paving materials on the porch remain stable and attractive throughout the life of the building, and the doors do not jam. There is added cost associated with this concept of building a structured porch, which must be weighed against the risk and budget of the project. Another approach is to design the porch as a stabilized slab on select fill. The perimeter of the porch is structurally supported on piers and separated from the expansive clay with void boxes and the slab can be doweled into the grade beam at the building face.

If the budget doesn't allow for either of the above, or if the risk is not too severe, then the porch can be a slab-on-grade, but it must be doweled to the grade beam at the entranceway to prevent door jams. The slab in this case must be designed to hinge at the entranceways and float at the outer edge of the porch, much like an approach slab.

It is important that all porches supported on grade slop away from the building. This aids in drainage and protects the building structure. Control joints and expansion joints in the slab

should always coordinate with the joints in pavers or tile that are placed on top of the slab. Paving abutting structured walls, light poles, benches, etc., needs to be separated from the structured elements with an expansion joint that allows vertical movement.

Differential heaving conditions in exterior flat work will often change the direction of drainage flow of the site. Therefore, the civil engineer and landscape architect need to be aware of the possibility of differential heaving conditions and account for the potential reversal of slope to drain. Slopes to drain may need to be more extensive than normal to allow for possible bulges in the sitework and still have adequate drainage. Additionally, along with the soils engineer, they should identify recognizable locations where heave might occur such as at a tree well in a paved parking lot. This is a location where water is introduced under the slab and heave should be anticipated. Preferably delete the tree wells from the parking lot, but, if needed, the grading should be designed to allow for the magnitude of potential heave that may occur.

Backfill around underground miscellaneous structures on the site (such as electrical vaults), can be a catalyst for heave in the surrounding sitework. Low P.I. backfill around such structures is usually recommended by the soils engineer to minimize pressures on the walls. However, if not properly drained, this Low P.I. material allows water to enter the surrounding clay soils and generate heave in the surrounding sitework.

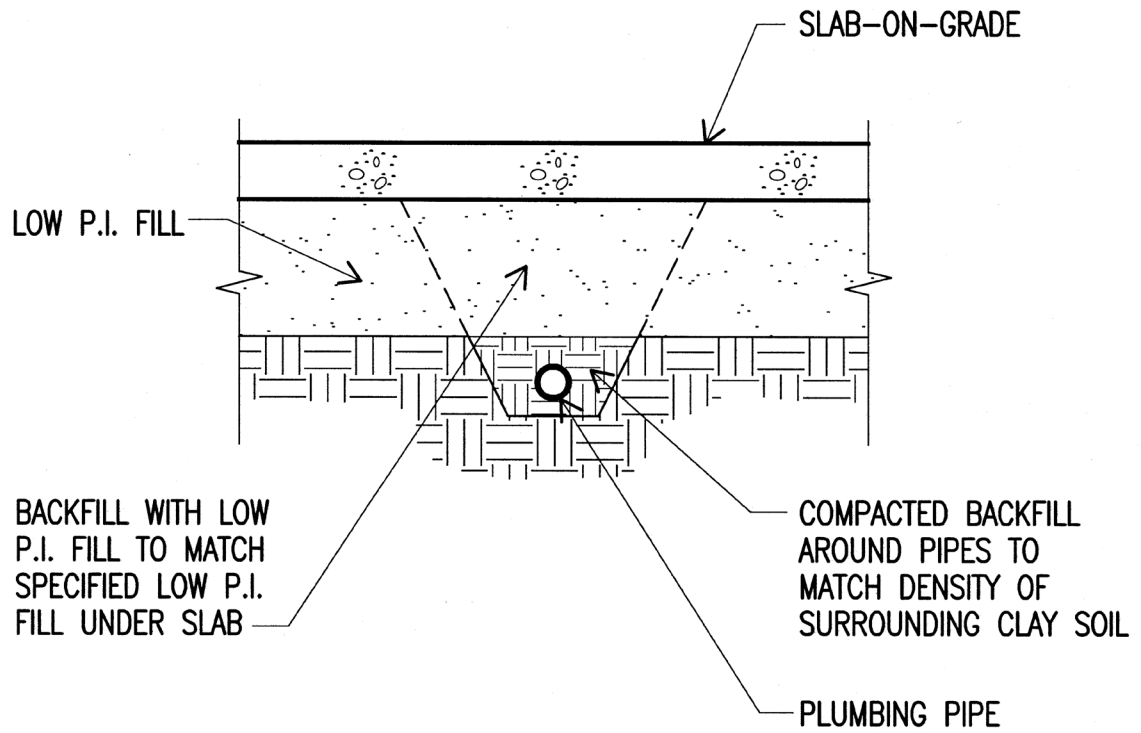


EXHIBIT Q

APPENDIX 'A'
STANDARD DETAILS FROM SUREVOID



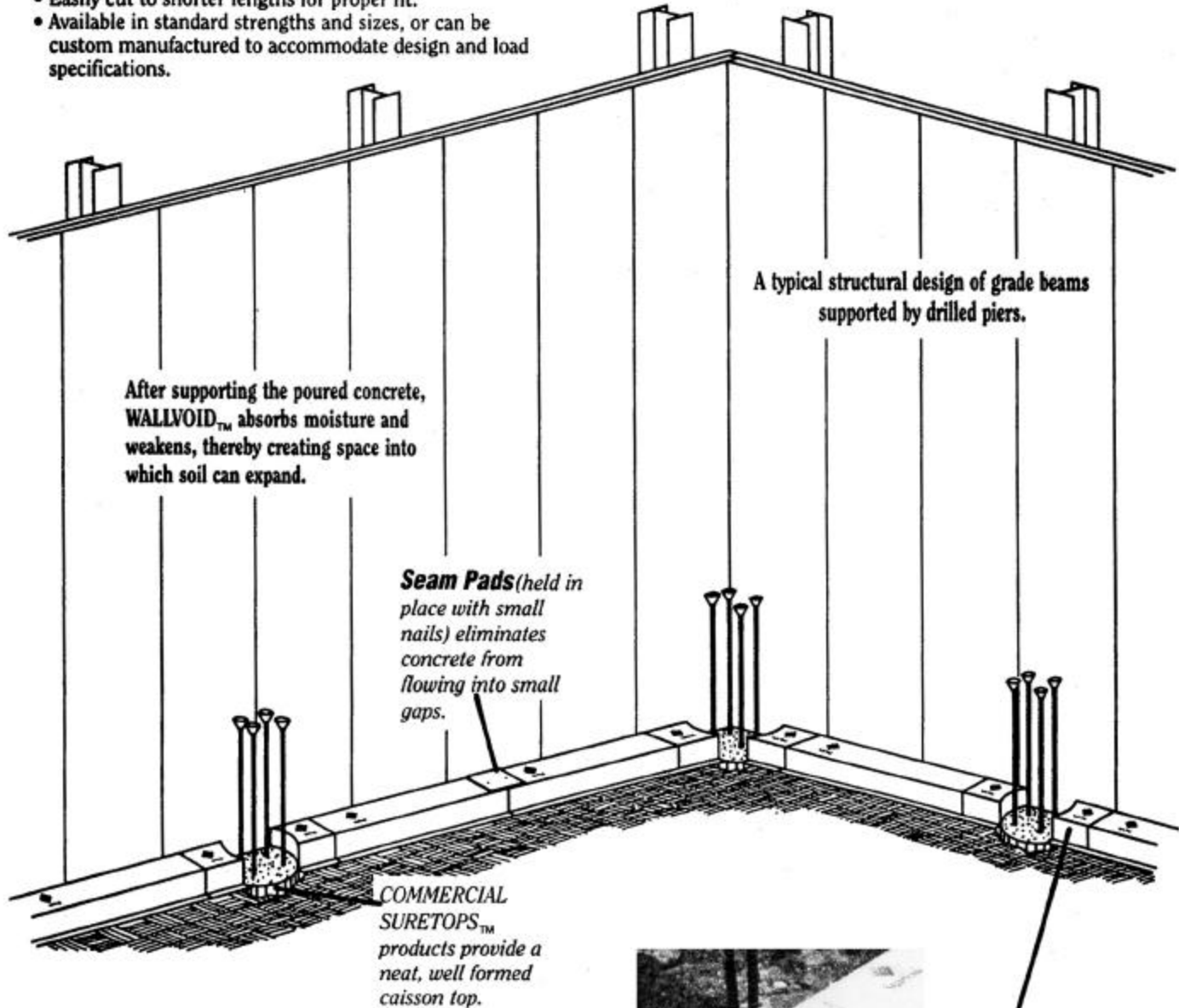
WallVoid™ with ArcVoid™ to
correctly void the circular
edge of a drilled pier.

WallVoid™ with SureRound
PierVoid™ to correctly void
beneath a pier cap or pilaster.

Benefits of WallVoid™

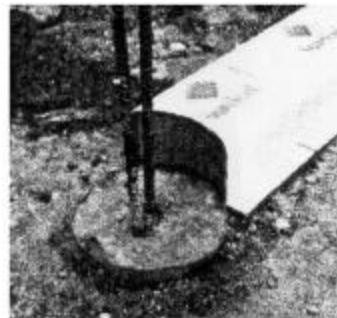
- Lightweight and easy to install.
- Available either factory assembled or knock-down (K.D.) for lower shipping and storage costs.
- Easily cut to shorter lengths for proper fit.
- Available in standard strengths and sizes, or can be custom manufactured to accommodate design and load specifications.

- Placed end-to-end between drilled piers or spread footings.
- End caps and seam pads available to prevent concrete from flowing into void.



Composition / Maintenance

WallVoid™ products are manufactured from corrugated paper material with a moisture resistant exterior, and are designed to withstand imposed loads during construction. Products should be kept dry at all times prior to concrete placement. MSDS information available upon request.



ArcVoid™ Used to correctly void the circular edge of a drilled pier.

Commercial SureTops™

SureVoid Products, Inc.
is the industry leader in
corrugated paper products
for concrete construction.

With more than 25 years
of experience, SureVoid
Products, Inc. has manufac-
tured millions of square feet
of products that have been
used throughout the United
States, Canada and Mexico.

Included among many major
projects are:

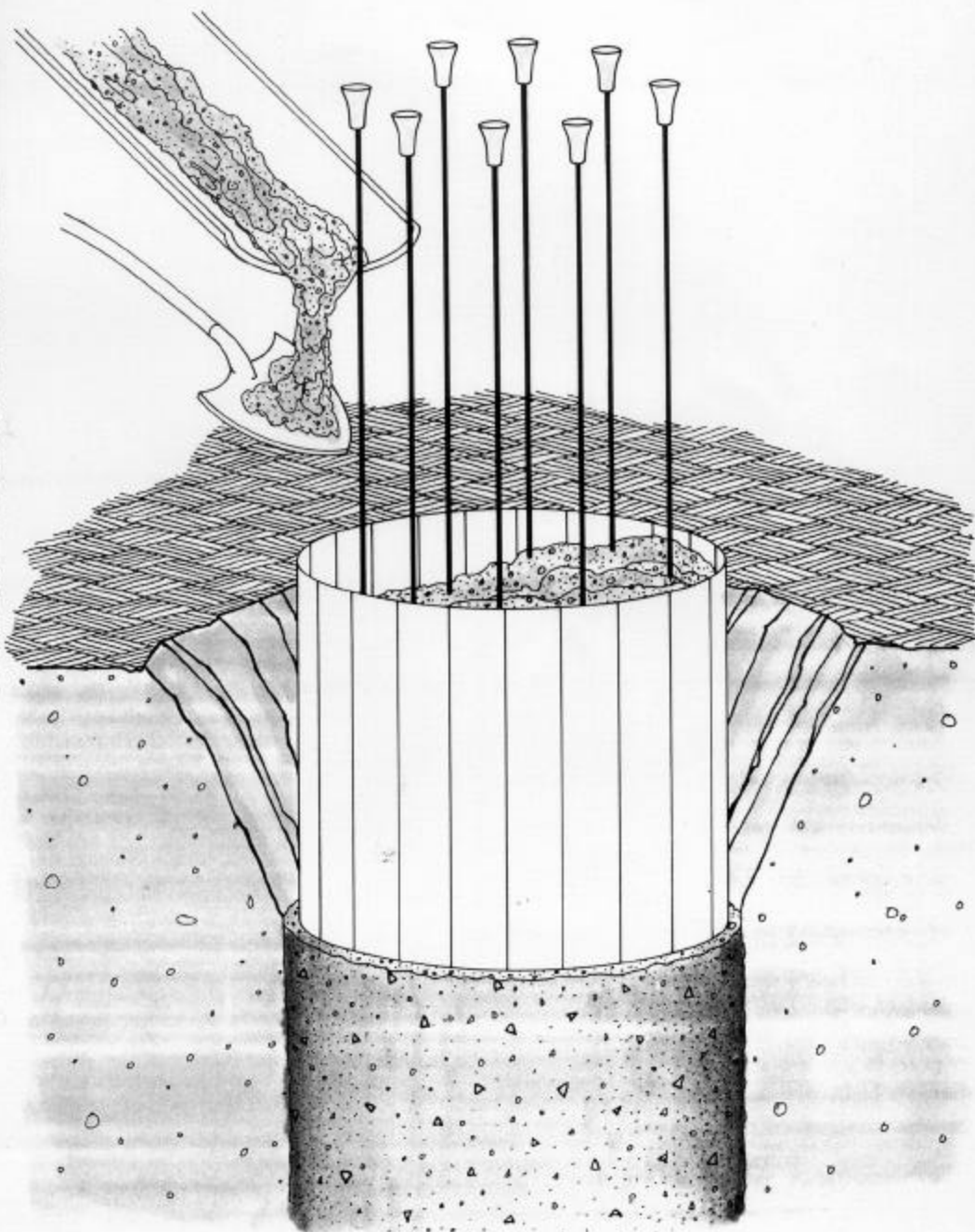
- Denver International Airport
- Ft. Carson Army Base
- Hyperion Water/Sewage
Treatment Plant,
City of Los Angeles
- Bridge Rehabilitation,
Commonwealth of
Massachusetts
Medical Center and
• Parking Garage,
University of Mississippi
- Texas A & M University
educational facilities
- Colorado Maximum
Security Prisons,
Florence and Canon City, CO
- Anchorage Sports Facility,
City of Anchorage, Alaska
- Coors Field, Denver, CO
- Federal Justice Center,
Golden, CO



SureVoid
Products, Inc.

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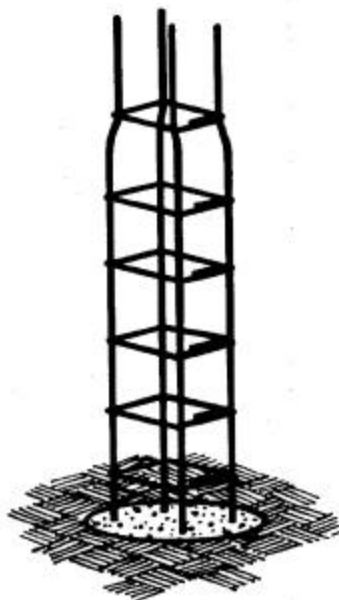
**THE SUREST WAY TO PROPERLY FORM
THE TOPS OF DRILLED PIERS AND PREVENT STRUCTURAL
DAMAGE FROM UPLIFTING SOILS.**



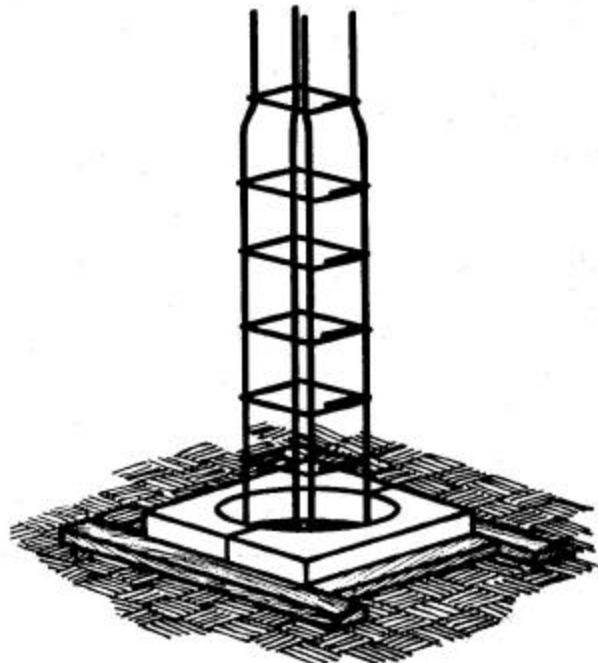
- Shipped flat or rolled for freight and storage savings.
- Pre-cut and pre-scored for easy installation.
- Slightly undersized diameter fits easily into caisson.
- Allows above-grade concrete elevation.

Benefits of SureRound PierVoid™

- Available in a full range of depths, widths, lengths and pier diameters.
- Custom-made to not exceed the drilled pier diameter.
- Can be used for drilled piers that are above or below grade.
- Sealed to prevent concrete from flowing into void form.
- No field cutting required.
- Shipped fully assembled, ready for installation.
- Design allows for easy installation around extended or awkward rebar configurations.
- Eliminates field cut, odd-shaped pieces that do not create a proper void.



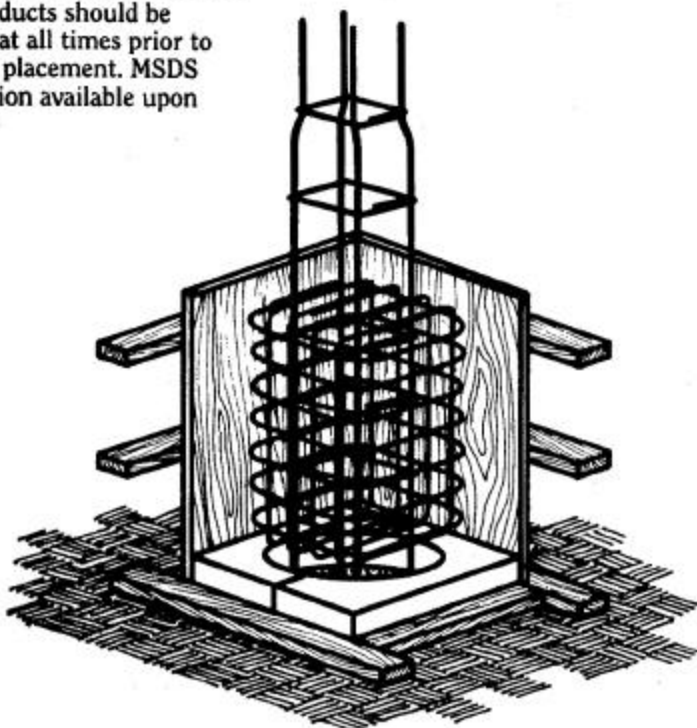
Poured drilled pier
with rebar



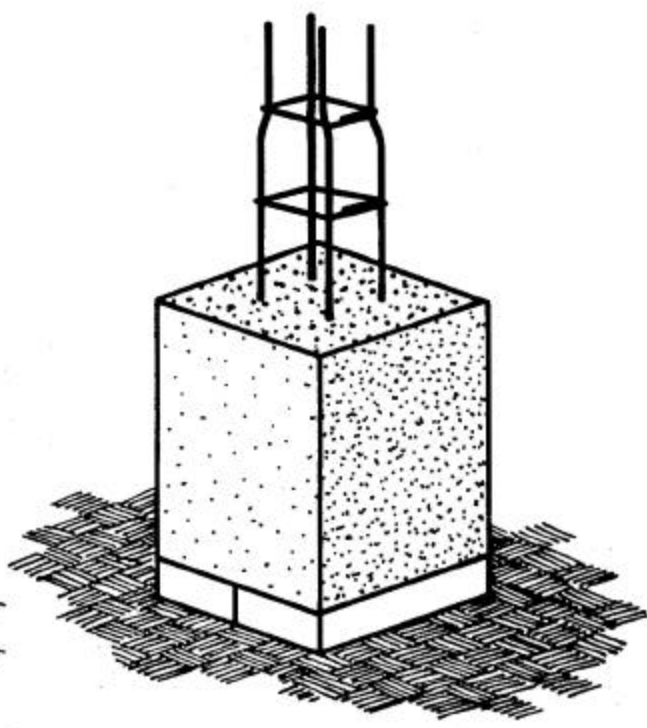
Properly positioned SureRound
PierVoid™ surrounding concrete
drilled pier

Composition / maintenance

SureRound PierVoid™ products are manufactured from corrugated paper material with a moisture resistant exterior, and are designed to withstand imposed loads during construction. Products should be kept dry at all times prior to concrete placement. MSDS information available upon request.



Partial formwork with rebar and
void form in place



Finished pier cap with underlying
SureRound PierVoid™

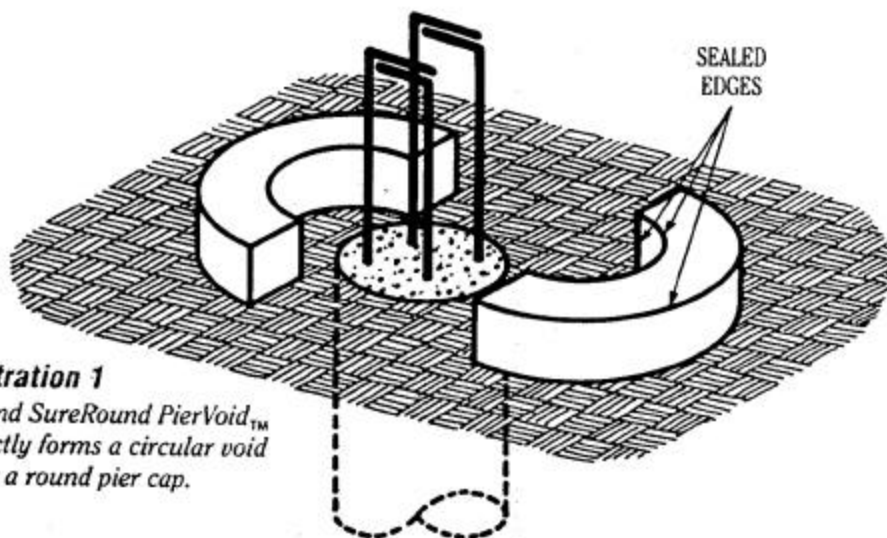


Illustration 1

A round SureRound PierVoid™ correctly forms a circular void under a round pier cap.

SureRound PierVoid™ products are available in round, square or rectangular exterior shapes, all having sealed circular cutouts to correctly surround drilled piers.

Square or rectangular shapes are designed to be used in conjunction with SlabVoid™ corrugated paper void forms. These products create a temporary support for the placement of structural slabs over expansive soils.

Other related products:

WallVoid™: Corrugated paper void forms placed between piers or intermittent footings to create a temporary support for the placement of concrete walls and grade beams where expansive soils are present.

Commercial SureTops™: Corrugated paper formwork that correctly shapes the upper portion of cast-in-place concrete drilled piers.

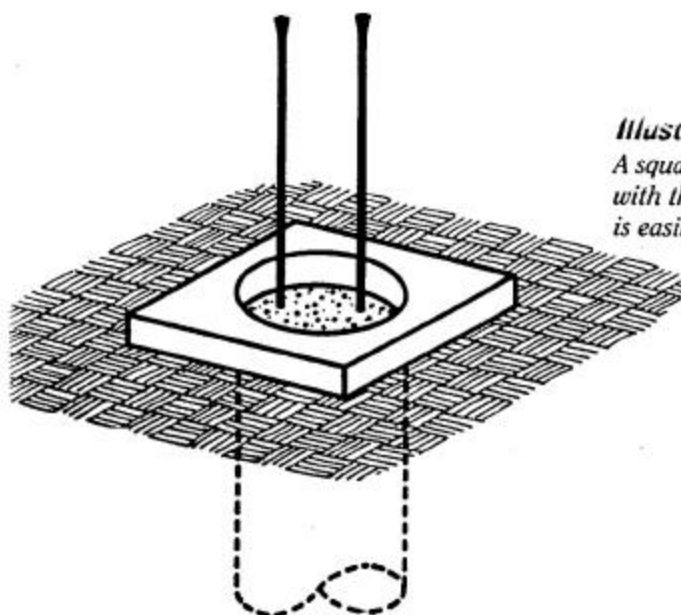


Illustration 2

A square SureRound PierVoid™ with the pier top at ground level is easily placed into position.

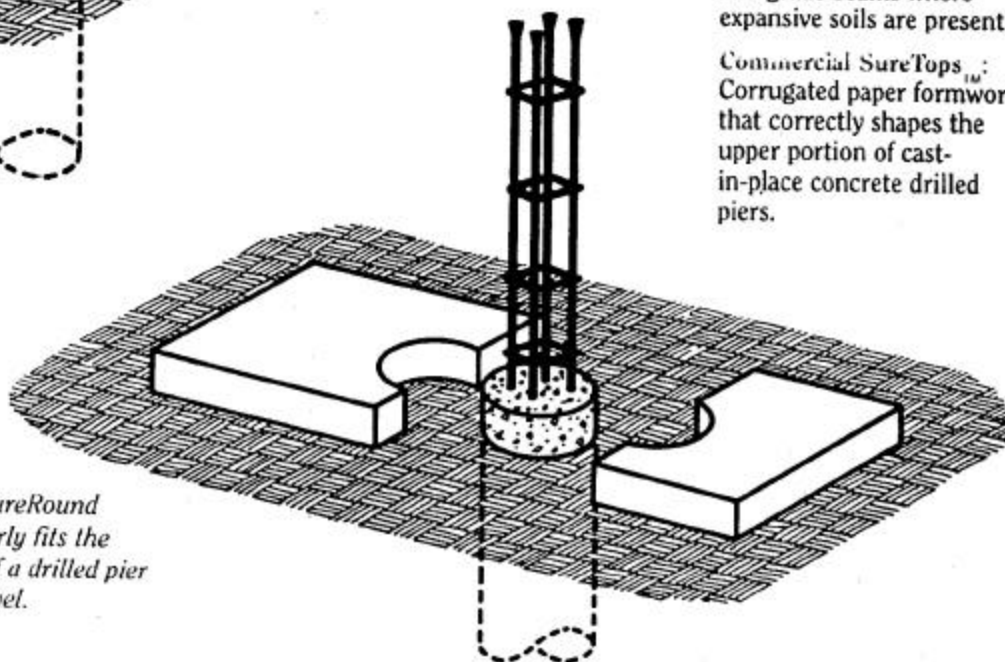


Illustration 3

A rectangular SureRound PierVoid™ properly fits the circular shape of a drilled pier above ground level.

APPENDIX 'B'
INTEROFFICE MEMORANDUMS

DATUM

MEMORANDUM

TO: Staff

FROM: Thomas Taylor

SUBJECT: **Expansive Clay Problems to Know About**

DATE: July 12, 2011

I have attached copies of several memos I wrote over 10 years ago regarding two topics:

1. Allowable heave criteria for slab on grade construction
2. Problems associated with building slab on void box construction

All of these memos are in the back of the expansive clay manual for your periodic review. We can't lose sight of these issues just because time goes by, new people on staff, etc. All of these memos are in the manual and our technical staff is responsible to be aware of them. Of course, they are over 10 years old and maybe you can add some new and better suggestions based on our experiences of the last 10 years, please do so.

But, in the meantime, I wanted to add some additional issues regarding use of slab on void box construction that must be understood and satisfactorily addressed before proceeding with slab on void box construction on your next project. The other pitfalls associated with slab on void boxes mentioned in the attached memos still need to be addressed as well. This is just another major issue and cause for damage that we need to be aware of. We should pass on our suggestions but it is MEP Architect responsibility to solve.

Now, we don't have responsibility for plumbing pipes and we don't want our suggestions to be more than passing on prior experience. The plumbing engineer should read the soils report and address the issue. Not us. We don't want the next thing to happen is for some lawyer to assume we have a "duty" to notify the plumbing engineer of the possible problem. The only "duty" to recommend is by the geotechnical engineer. But, we can comment and suggest that the entire design team read the soil report.

But, two recent cases have come up.

1. We were recently designing a hospital clinic in a highly expansive clay area and the recommended structure by the Architect was a slab on void boxes. This building is a medical clinic with plumbing all over the footprint of the building serving sinks etc that exist in almost every room of the facility. It was a little hard to get the architect and MEP on board to be concerned about the problem we saw of plumbing pipes laying in expansive clay all over the footprint. These pipes would have to be subject to movement with the expanding clay which can and will lead to broken pipes and fixtures being pushed up off the floor.

2. Simultaneously, with this assignment, we were asked by an attorney to help defend his architect/MEP client for broken pipes under a slab on void boxes in a dormitory facility. Dormitories may not have as many pipes as a clinic, but with bathrooms all over the footprint of a dormitory, pipes are everywhere and the Architect/MEP engineers are being sued by the owner for broken pipe problems.

So, the point of the two above examples is that building types that have plumbing pipes distributed throughout the building like a dormitory or clinic (and maybe other building types) are not reasonable slab on void box candidates.

If you have an office building or a school or a church where the bathrooms are grouped and concentrated in one area, the best recommendation, if slab on void boxes is to be used, is to create a crawl space below the bathroom footprint and hang the pipes from the slab. Of course, taking the advice about not assuming a “duty” to advise, this is the MEP engineer’s responsibility. But, we can make this suggestion to the architect and MEP. Seems like a sound recommendation that we should strongly suggest without becoming responsible for design of the pipe hangers and separation of the pipes from the soil.

Unfortunately, these restrooms are not always located at the perimeter of the building and pipes will have to leave the crawl space and extend to the sewer and water lines outside the building. We should recommend that these pipes be grouped as much as possible into as few trenches as possible and hung from the slab. The pipes would have to be set on void boxes and the fill over the pipe should be low PI fill and the hangers should extend up to be cast into the slab when it is poured. We have done this before and it is costly. But, they need to do something and they should be responsible for specifying what to do. But, this is the best suggestion we have to give them. Reducing the cost by grouping the pipes in to only a few trenches would be the key to reducing the cost.

The plumbing engineer also has to create a flexible detail in the pipes where the pipe that is hung from the structure on the inside of the building extends out beyond the building into the site where it is buried in the site and free to move with expanding clays. But he also needs this detail on a slab over a crawl space project as well.

These are simply constructability issues that we need to be knowledgeable about and assist the architect and MEP to not let this damage to the facility occur.

Please review all of the attached memos as well and remember they are in the expansive clay manual if you need to refresh your memory. This one will be added to the manual.

encl.

DATUM

MEMORANDUM

TO: Staff

FROM: Thomas W. Taylor

SUBJECT: **Slab-on-Void Box Lawsuits**

DATE: March 11, 1997

It seems reasonable to think that a slab-on-void box structural slab would be immune to damage from expansive clay since the slab is separated from the clay with void boxes. These boxes can be any depth as required to allow the clay to swell without damaging the slab. This system is popular because it appears to be inexpensive and simple to construct.

Then why have we been called in as expert witnesses on four damaged slab-on-void box foundations that had to be torn out and replaced? The last one we investigated had heaved 6 inches and the piers had been pulled apart in spite of 8-inch void boxes under the slab. The one just before this one had 12-inch void boxes under the slab and the slab had to be totally removed. The one before that was a large ballroom in a major hotel on 6-inch void boxes that had to be totally replaced.

We have found that the problem is due to lack of attention to all of the required special details such as;

1. Portions of the foundation are actually still in contact with the clay such as piers, pier caps, grade beams and other areas.
2. Lack of specification requirements to assure that the void boxes do not collapse and the void boxes do not fill up with concrete during construction.
3. Contractor not respecting the fact that his whole forming system is just cardboard boxes. Maybe the boxes have been rained on and are soggy and weak. Maybe he just dumped a 3 yard (12,000 pound) bucket of concrete in one area and, unknowingly, crushed the boxes.

There are many successful slab-on-void box structures and there can be many more if proper procedures are followed. There are also probably many unsuccessful slabs that are just waiting for the clays to expand and damage the structure.

We need to pay attention to all of the details of this system that we have discussed so many times and follow our standard procedures to make sure our clients do not suffer the kind of damage that we know has occurred.

DATUM

MEMORANDUM

TO: Staff

FROM: Thomas W. Taylor

SUBJECT: **Slab-on-Void Box Lawsuits**

DATE: October 22, 1997

We recently sent a copy of the staff memo I wrote on slab-on-void box lawsuits to friends and associates in the industry. I had a very interesting call from a friend who was the Construction Superintendent on a large slab-on-void box project that I would like to share with you.

He called to thank us for sending him a copy of the memo. He agreed with all of the concerns I had expressed and wanted to share with me his success story on a large slab-on-void box project he had been responsible for. He personally supervised all phases of the process and made absolutely sure that each step was performed at the highest level of workmanship. He felt this high degree of personal attention by the Superintendent was essential to accomplishing the success he obtained.

He was shocked to learn that this project was one that had experienced severe damage and the entire floor slab had been removed and replaced.

Further, the Contractor he worked for was found to be at fault due to the faulty construction such as collapsed void boxes, reinforcing steel smashed down into the boxes, etc.

The point I want us to be aware of is that all of these things went wrong and caused severe foundation problems right under the watchful eye of a conscientious Superintendent and he was not able to see it happening.

There are times when this system seems to make complete sense for the given project condition and we will agree to design it. However, if we do design this system, we must continue to help the Contractor to recognize hidden difficulties of this system and to continue to write a quality specification for the forming system, the reinforcing steel placing, allowable tolerances, and concrete placing.

We cannot be satisfied if the owner experiences foundation problems even if it not due to design errors. We must help with constructability issues as well.

DATUM

MEMORANDUM

TO: Staff

FROM: Thomas Taylor

SUBJECT: **Expansive Clay Uplift on Grade Beams**

DATE: October 22, 1997

As you are aware, we have a company policy to require the Contractor to form the portion of the concrete grade beam poured below grade and to not allow him to pour the beam against earth sides in expansive clays. The purpose of this policy is to prevent the expansive clay from gripping the sides of the beam and exerting an upward pressure.

Depending on how irregular the surface of the beam side becomes, when formed against the earth, the uplift pressure from either direct bearing or cohesion can negate the benefits of the void box under the beam and push the beam upward.

I realize this adds cost to construction and we often get criticized by the Contractor for putting him to this extra labor. Sometimes we have had the Contractor ignore our specification requirement and pour the beam against the earth anyway.

During a recent lawsuit that I was an expert witness in, I had the opportunity to generate the attached set of values that shows the extreme increase in uplift forces that could be generated by simply pouring the sides of the beams against the earth.

In the highly expansive clays found on this specific site, the clays were capable of breaking the beam with upward forces even if the earth trench was perfectly vertical. Even the upward forces on formed sides were extremely high and worthy of concern.

This was a highly expansive clay site and considerable damage to the foundation occurred. Unformed grade beams probably contributed substantially to the damage.

Since neither you nor the Contractor have control over how irregular the beam trench will be, it is important that we enforce our policy of forming all grade beams below grade in expansive clay soils to prevent foundation damage with the same intensity employed with enforcing proper installation of void boxes.

DATUM

MEMORANDUM

TO: Staff

FROM: Thomas W. Taylor, P.E.

SUBJECT: **Slab-on-Grade In Expansive Clay WILL HEAVE!**

DATE: April 8, 1999

HOW MUCH HEAVE IS ACCEPTABLE?

Somehow, over the years, the industry has settled on a cookbook standard that 3/4" heave due to expansive clay in a slab-on-grade is an acceptable limit for most buildings. Actually I've noticed over the last five years or so that 1" heave is being recommended as the acceptable limit in numerous geotechnical reports. I'm hopeful we don't get lulled into sleep and slowly and quietly begin to accept this increased limit lightly. It may be fine for some buildings, but it could be low or high for others.

HOW DO WE DECIDE WHAT HEAVE IS ACCEPTABLE?

The acceptable limit of the amount of heave in a slab is totally dependant on a combination of the following issues:

1. The functional use of the facility.
2. The long term anticipated quality of the facility.
3. The owner's tolerance for risk versus cost.

Each project must be evaluated, based on satisfying this criteria. There is no cookbook answer to this question.

3" HEAVE CRITERIA

Most of you know that we have designed standard warehouse floors for up to 3" of heave. This can be considered acceptable in many simple storage warehouses. Of course, we need the owner's input and concurrence, but allowing the limit to go up to 3" can considerably reduce soil preparation or structural separation cost. However, even in these facilities we recognized that 3" would be too great for the office area and generally constructed structured slabs separated from the clay in the office area. Therefore, the functional use of the facility was considered and a different answer was applied to various portions.

0" HEAVE CRITERIA

However, the other extreme can occur in warehouse type facilities, where the proper functional use of the space requires super flat floors. Floors where they can install extremely tall racks that are operated with automatic equipment is one example where flat floors are essential. The flat floor needs to remain flat during the life of the facility even after heave has occurred. Obviously, in this case acceptable heave criteria must be extremely tight. It is also possible that this criteria is limited to a small section of the building and a different criteria can be used elsewhere.

3/4" TO 1" HEAVE CRITERIA

This is normally acceptable for office space and other generally occupied facilities. Some minor damage to partitions, etc., should be expected, even with this movement, and the owner should be made aware of the risk associated with the construction savings of slab-on-grade construction.

SURPRISE CRITERIA

In spite of all of our efforts and experience, I often run into surprises and I want to pass a recent one on to you.

Most of the time a mechanical room area is considered a low priority space where heave can be tolerated. Even in structures we have separated from the clay, we often revert back to slab-on-grade construction in the mechanical room.

I was in a mechanical room last week where the spring isolators under the equipment were smashed down and not functioning. The slab had only heaved about 1/2 " which, based on the criteria listed above, would be considered a high quality performing slab.

The slab had heaved but the pipes above the equipment were rigidly connected to the structure above and wouldn't allow the equipment to move upward. This caused the spring isolators to completely close tight and stop functioning due to only 1/2" of heave.

This points out the need to be thorough in our research of the criteria and the importance of communication with the other design professionals.

NO COOKBOOK CRITERIA

As I said earlier, there is no cookbook answer and don't get lulled to sleep. I think we can design fine, economical, functioning buildings in expansive clay if we are alert to the issues involved.

DATUM

MEMORANDUM

TO: Staff

FROM: Thomas Taylor

RE: **Reducing Movement Due to Expansive Clay Can Be in the Details**

DATE: July 6, 2000

Randy Lackner and I have been involved in an effort to salvage a major educational facility that had been so damaged by expansive clay movement that the only apparent solution was to demolish this relatively new (nine years old) large single story structure. I thought you would be interested in what we were able to accomplish.

Movement in the building apparently had been detected since almost before the building was finished. Numerous efforts to solve the problem had been unsuccessfully undertaken over the years before we were called in.

You can always talk to Randy to get more details, but I want to give you a condensed version of what we found, what we did, and the kind of surprisingly good results we obtained.

This building was supported on 14'-0" deep belled piers. It had a heavy precast concrete roof and the floor slab was a structural concrete slab on **8" void boxes**. Considerable money had been spent in the foundation to separate the structure from expansive clay.

During our investigation of the building, we found slab and structural movements in the neighborhood of 5 ½". We found several piers that were broken around 3'-0" below grade. Upon further investigation we found numerous piers that were actually pulled 5" out of the ground.

You know how skittish I am about pouring slabs on void boxes. So, we investigated the void space with a video camera on a crawler and found that the void space was generally in good shape and the collapsed void boxes I expected to find did not exist.

In short, we concluded the heave was due to:

1. Skin friction on the piers.
2. Bearing of the slab on the clay directly around the piers.
3. The piers were too shallow to properly anchor the structure in the ground.

We continued to measure the movement in the structure over nine months to a year during our investigation and movement of the foundation was continuing. Also, the soils engineer's test indicated several more inches of movement were still possible.

We quickly realized that the cost to attempt to reconstruct this type of foundation would be enormous and realistically impossible.

We decided that our only option was to try to cut off the source of water under the building to see if we could control the movement with this relatively economical effort.

We took the following steps:

1. We directed some poor drainage away from the building.
2. We removed a drain tile someone had added at the bottom of the grade beam.
3. We had a contractor excavate down to the bottom of the grade beam around the perimeter of the building for two reasons:
 - 1) We wanted to clean out any collapsed void areas under the grade beam.
 - 2) We wanted to re compact the backfill against the grade beam with densely compacted clay to create an impervious barrier to water.
4. Then we installed a lake liner type membrane 10'-0" out from the building around the perimeter.

See the attached detail.

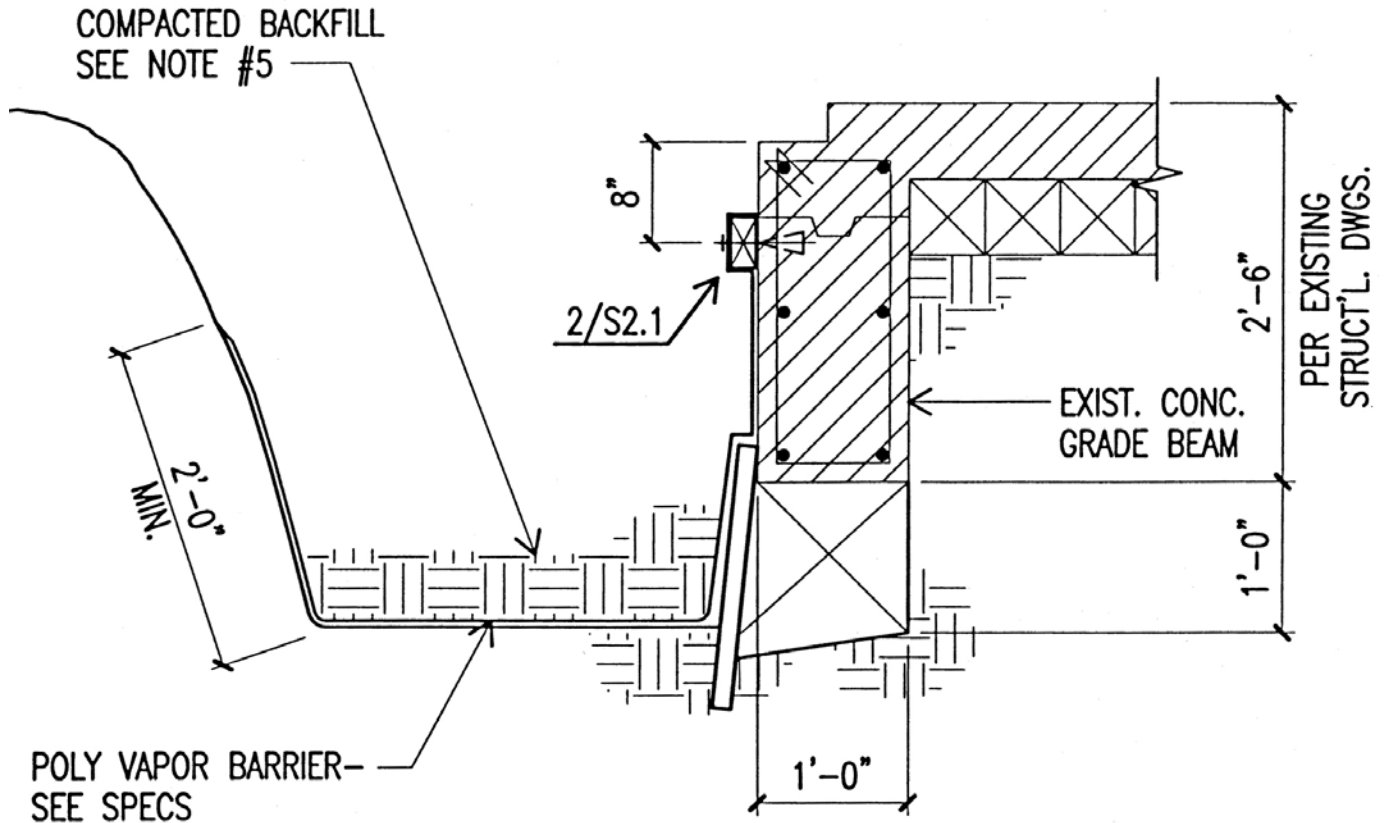
The building still has broken piers and 5" differential slab elevations. But, in spite of how bad this sounds, we all felt we could accept this amount of damage if it didn't get any worse.

Our best hope was to slow the movement. But, much to our surprise, the movement has actually reversed itself over the last year. The building appears to be stable and in a slightly improved state.

The point of this is not that we have found a magic solution to expansive clay problems. But, to remind all of you of the importance of every little expansive clay detail we have developed over the years.

We get so much resistance to having to compact backfill on the outside of the grade beam to minimize water infiltration under the building and we often don't get quality control support in the field. I hope you will continue to stress the importance of this detail to your architect clients and contractors. This experience should help everyone remember how important compacted dense backfill against the grade beam can be to the success of your next project.

Enclosure



4. WRAP VAPOR BARRIER AROUND TREATED 2x4 AND ATTACH TO GRADE BEAM AS SHOWN. VAPOR BARRIER SHOULD EXTEND ALONG THE BOTTOM OF THE EXCAVATION AND UP THE SIDE FOR A DISTANCE OF AT LEAST 2'-0".
5. FILL EXCAVATION WITH WELL COMPACTED ON-SITE CLAY SOIL TO REQUIRED ELEVATION. COMPACTED CLAY SHALL BE HAND-TAMPED IN 8" LIFTS TO AT LEAST 92% OF STANDARD PROCTOR DENSITY AT +3% OR MORE OF OPTIMUM MOISTURE CONTENT.

STEP #2

The Art of
Structural
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