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FOUNDATION FAILURE AND REPAIR: RESIDENTIAL AND LIGHT COMMERCIAL BUILDINGS

As with almost every undertaking, even the best made plans occasionally go awry. This is certainly true where foundation design and construction are concerned, and especially with light foundations. This section will address those instances where the problems do arise.

Section 7A defines the common cause for foundation failures and how to identify the problems. It describes some of the more common misconceptions associated with differential foundation movement.

Section 7B presents the full spectrum of foundation repair options and special conditions that resist restoration, and it describes actual field practices.

Section 7C provides maintenance procedures which, if implemented, could prevent or foundation problems.

Section 7D suggests steps helpful to prospective buyers for evaluating the structural conditions of real estate properties. In geographical areas with widespread foundation problems, it has become routine for lenders and insurers to require structural inspections before mortgages or certain insurance policies will be issued. Information in this section can also be useful for building inspectors (see Section 9A, this volume).

Much of this information was presented in *Foundation Repair Manual,* published by McGraw-Hill in 1999. This prior work is a complete reference to foundation behavior, failure, repair, and prevention of damage. Similar information included herein is intended to help separate this handbook from other handbooks.

SECTION 7A
CAUSE OF FOUNDATION PROBLEMS

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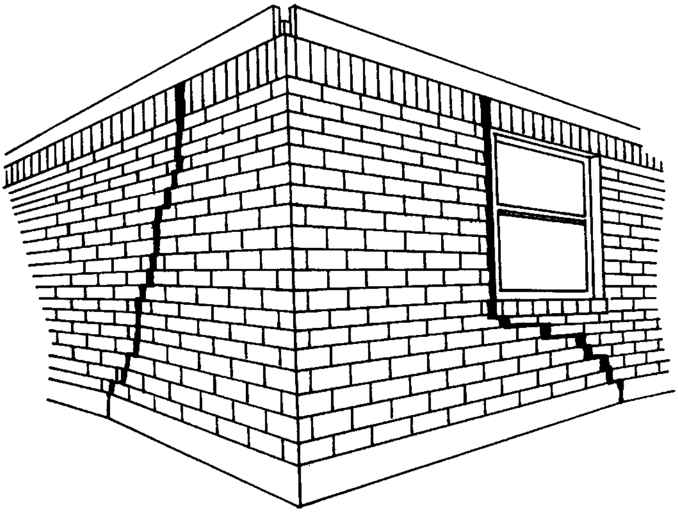
Certain of the issues discussed in this section are controversial, particularly in the sense of their true impact and influence on foundation failures. See Section 9A, this volume, for further information.

7A.1 INTRODUCTION

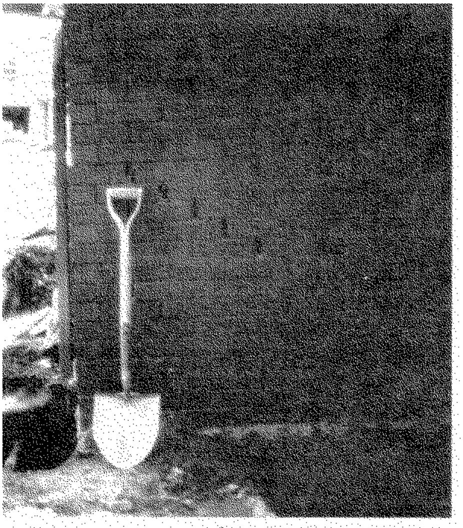
The major cause for foundation failures on expansive soil is water—too little or too much. Expansive soils suffer much more from this than nonexpansive soils, but foundations on either soil can be affected. The variation of water results in settlement (expansive or nonexpansive) and upheaval (expansive). Factors other than soil moisture variations will be the final cause to be discussed (see Section 7A.1.4). At what point does differential movement reach the point of requiring repair? The answer to this question is somewhat arbitrary, but the general consensus defines movement in excess of 1″ over 25 ft. as warrantying repair. Refer also to Section 7B.8.4.

7A.2 SOIL MOISTURE LOSS

Soil moisture loss occurs principally from either evaporation, transpiration, or a combination of both (evapotranspiration). Figure 7A.1 offers a drawing showing typical settlement as well as a photograph of an actual occurrence.



(a)



(b)

FIGURE 7A.1 (a) Typical foundation settlement. (b) Foundation settlement at the corner of the perimeter beam caused the very noticeable separation in the brick mortar. In this instance, the crack is in excess of 2 in (5 cm). Note that the brick has also slipped.

7A.2.1 Evaporation

Evaporation represents the natural loss of soil moisture through heat and wind. In expansive (cohesive) soils, the rate of loss is fairly slow and the depth of loss somewhat limited due to of very low permeabilities.

The depths to which the moisture loss occurs is referred to as the soil active zone (SAZ). Most published authorities suggest that the SAZ may extend to depths as great as 3.2 to 12.8 ft (1 to 4 m).[16,17,42,53,62,68,97,103]* However, a very high percentage of the *total* moisture loss (evapotranspiration) occurs at reasonably shallow depths. For example:

1. A study performed in Dallas, Texas, suggests that 87% of the total soil moisture loss occurred at depths above 3 ft (0.9 m).[103]
2. Holland et al. published data on an Australian soil describing an effective depth of 4 ft (1.25 m).[42]
3. Another study of several diverse areas in the United States indicates that over 80% of total soil moisture loss occurs within the top 1.5 m (4.5 ft).[68]
4. A similar study of an Israeli soil suggested that 71% of the total soil moisture loss occurred at depths above 3.2 ft (1 m).[62]
5. A study by Sowa presented data that suggested an active depth in a Canadian soil of 0.3 to 1.0 m (1 to 3.2 ft).[97]
6. A study in England described a London soil in which the range of principal moisture loss was 3 to 3.5 ft (0.9 to 1.1 m).[54]

Evaporation losses in expansive soils accounts for the very noticeable cracks in the Earth. As the soil becomes drier, the cracks grow wider and deeper until the soil moisture content might approach the shrinkage limit (SL).[16,65,99] The soil remains desiccated until water is once again made available. The soil then absorbs water and swells. The soil moisture content might then rebound to exceed the plastic limit (PL).[7,16,65,69,99] Overall soil (and foundation) movements are principally active when their in situ or "natural" moisture contents are between the SL and PL. However, shrinkage potential continues at moisture contents above the PL. In fact, the upper limit for soil shrinkage (evapotranspiration) probably extends to the field capacity, a point somewhere between the SL and PL.[69] Figure 7A.2 depicts the relationship between soil suction and volume. The range of soil moisture loss due to transpiration, which would be expected to influence foundations, is between the field capacity and plant wilt. Plant wilt is generally located at some point between the PL and the SL.[26,69] As soil suction increases, volume change decreases. (Soil suction describes the total moisture migration due to the combined forces of osmosis and capillarity. Thus, soil suction is a measure of the soils' capacity for water.) This relationship might lead one to assume that a foundation distressed by soil settlement would be *completely* restored by replenishing the lost water. This is not normally the case. Historically, as the moisture content cycles, the foundation moves up and down. However, each wet cycle leaves the foundation somewhat short of its original grade.[69] Figure 7A.3 shows shrink–swell profiles versus moisture content. In this study, the dry density was kept constant at 107.0 ± 0.6 pcf (1714 ± 9.6 kg/m^3) and initial moisture content (W%) was varied from 15.1% to 22.3%. This range of moisture essentially covers the spectrum between the SL and PL and is believed to be within the critical moisture range defined by Popescu.[69] A surcharge pressure of one psi (6.9 kPa) was applied at the initial moisture content (W%). At moisture contents of approximately 16% (SL) and 22% (PL), shrinkage is equivalent to swell. Between these points (A and B), shrinkage exceeds swell. At moisture content below Point A (SL), shrink is negligible and swell increases rapidly. Moisture contents greater than PL (B), depict a rapid decline in both shrink and swell. Only at Points A and B are the two equal at the same

*References are in Section 7E.

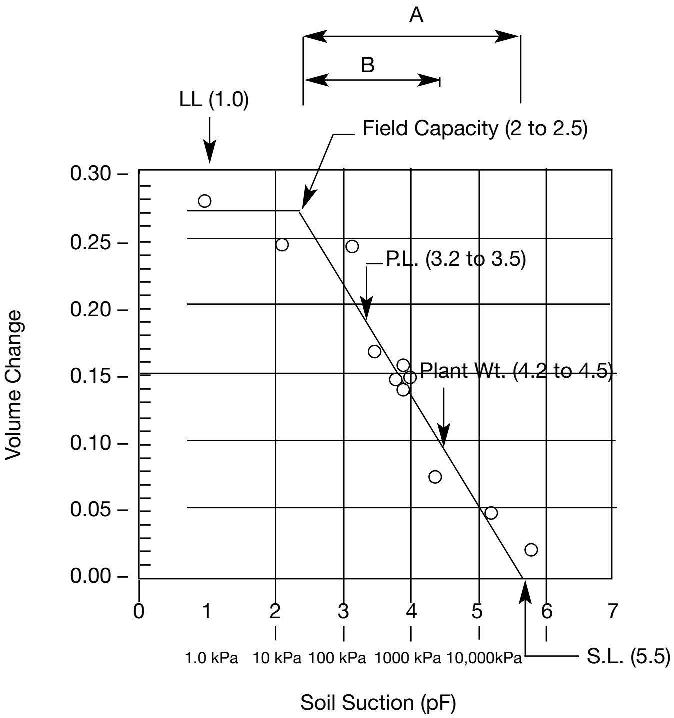


FIGURE 7A.2 Range of relative volume change. A = evaporation and transpiration; B = transpiration. After McKeen, 1992.[169]

moisture content. Hence, watering a foundation, once it has settled, might arrest further movement but will not likely bring it back to its original level.

7A.2.2 Transpiration

Transpiration is arguably a bigger thief of soil moisture than is evaporation (refer also to Section 7C). The removal of soil moisture attributed to transpiration declines substantially during a plant's dormant season, perhaps to less than 10% of the removal during the growing season. The depth of primary soil moisture loss due to transpiration is generally limited to the top shallow soils, 1.0 to 2.0 ft (0.3 to 0.6 m).[16,17,49,50,54,98,99] Under normal conditions the shallow "feeder" roots account for probably 90% of the plant's total requirement for nutrients and water. (In arid climates, deeper roots, i.e., tap roots, produce much of the water requirements for the plant. However, deep-seated moisture losses do not generally influence the stability of lightly loaded foundations). The lateral extent over which the shallow roots are active is generally limited to the canopy area of the plant or tree.[15–17,42] As a matter of curiosity, what would be a reasonable estimate for the soil moisture loss due to transpiration? This question has many answers, since transpiration depends largely upon the type, size, and density of vegetation as well as the ambient wind and temperature. Nonetheless, it is possible and practical to use reasonable assumptions and arrive at a representative number. Dr. Don Smith, Botany Professor at the University of North Texas, Denton, Texas, suggested that a "reasonable" value of water input for a 10 in (25 cm) diameter *Quercus stellata* (post oak) would be about 50

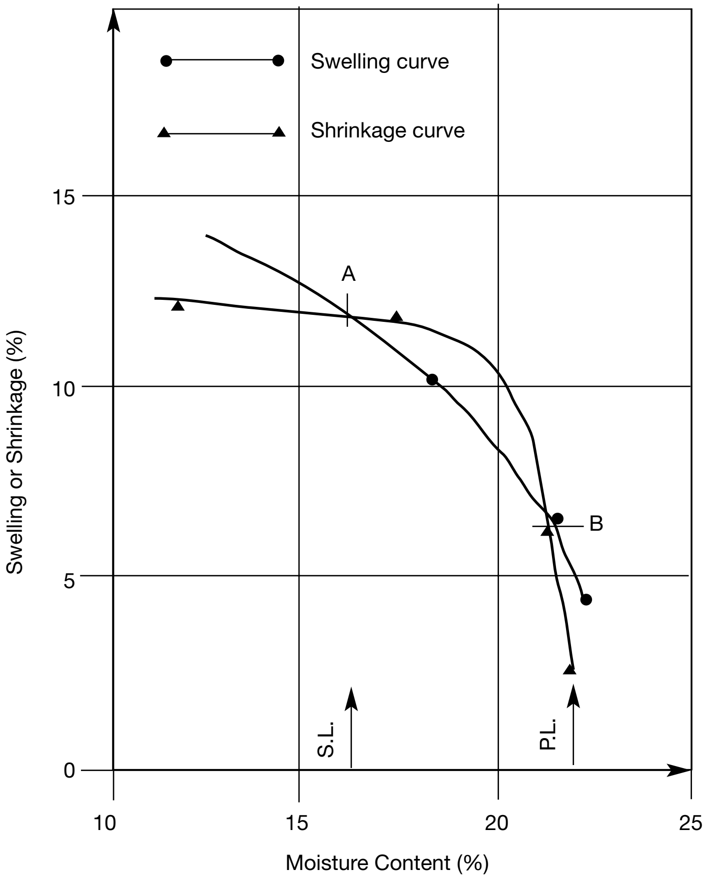


FIGURE 7A.3 Effects of moisture content on swelling and shrinkage. After Chen, 1988.[26]

gal/day in a semitropical climate. Assuming a 30 ft (9 m) canopy (root spread), the moisture loss per surface square feet would be 0.07 gal. (2.34 L) or 16.3 in^3 per day. A normal lawn watering program for the same geographical area would distribute 144 in^3 (0.62 gal) per square foot, twice weekly. Over a one week period, transpiration by the tree would account for 114 in^3 per square foot and the watering would add 288 in^3 per square foot (0.093 m^2). The surplus sprinkler would go into dead storage within the soil until removed by evaporation or transpiration. The main point of this is that tree roots would have adequate moisture and would not seek the inhospitable soil conditions beneath the foundation. This analogy excludes both the effects other vegetation might have on overall transpiration and the natural sources for precipitation (dew, rainfall, etc.). Generally speaking, if the vegetation has a healthy green color, the root moisture need is being satisfied.

The biggest threat that roots pose to foundations might be the presence of surface roots beneath a shallow foundation beam. As the root grows, a shallow beam can be literally "jacked" upward or heaved. Tree roots do not cause the foundation problems for which they are blamed.[16,26] Pier-and-beam foundations have interior floors isolated from the bearing soil, and slab foundations have interior floors isolated from the bearing soil and perimeter beams that should extend well into or below the surface root zone.

Removing a *mature* tree in close proximity to a foundation can cause more problems than it cures. The decaying plant roots can produce both permeable channels, which might funnel water beneath the slab foundation, resulting in upheaval, or voids, which result in settlement. On the other hand, tree roots can enhance foundation stability by increasing the soil's resistance to shear.[28,107] Over the past few years, one foundation repair contractor requested his drilling and excavation superintendents to keep track of instances where tree roots were encountered *beneath* the perimeter beam. At this point, no effort was made to specifically identify the type of root. Data was also not recorded concerning type, age, size or proximity of tree to the perimeter beam. The superintendents were instructed to merely record roots and type of foundation. On the average, a minimum of 20 piers or spread footings were installed per day. Assuming only a 5 day work week, this would provide about 100 daily observations, or 5200 per year. In cases where the depth of the beam below grade exceeded 18 in (0.45 m), roots were reported in less than 0.5%. When the perimeter beam depth was approximately 12 in (0.3 m), the instance increased to about 1%. When beam depths were less than about 6 in (0.15 m), the incidence increased to about 4%. Clearly, the data do not suggest a "real world" panic or, for that matter, even a particular concern. The quality of these data might be somewhat questionable, since the controls and specifics were less than "scientific." This would be an excellent area for more research.

7A.2.2.1 Summary Tree Roots versus Foundation Distress: Slab Foundations on Expansive Soil
Botanists, horticulturists, and agronomists uniformly seem to agree that:

1. The canopy of a tree determines the aerial extent of the feeder root system. The roots will extend only a short distance beyond the drip line of the canopy. According to Don Smith, a *reasonable* number to describe the radial pattern would be 1.25*C*, where *C* is the radius of the canopy, or the radial distance from the trunk to the drip line. (The 1.25 factor is conservative. For most trees under most conditions the factor is likely closer to 1.1 or less.)
2. Feeder roots tend to be quite shallow—no deeper than 1 to 2 ft (0.3 to 0.6 m)[49,50,98] This preference is promoted by the fact that tree roots prefer rich, aerated, and noncompacted soil.[50] Deeper roots may also contribute to the nutritional needs of the tree, depending upon the species and size of the tree and availability of water and to a lesser extent on ambient temperatures. (In conditions of drought, the deeper roots play an increased role. Shallow roots can become active when shallow moisture is restored.)
3. Soil moisture loss due to transpiration has been determined to extend to depths below the soil water belt.[16] However, in each of these cases, the *preponderant* loss (80 to 90%) occurs at relatively shallow depths, generally within the top 3 ft (1 m).[53,62,68,97,102,103] T. J. Freeman et al. suggest that soil moisture loss below 6.6 ft (2 m) may not materially influence foundation behavior.[42]
4. Chen states that "the end result of shrinkage around or beneath a covered area seldom causes structural damage and therefore is not an important concern to soil engineers."[26] This analysis obviously introduces the presence of the foundation slab into the soil moisture loss equation.
5. The presence of shallow roots can be beneficial to foundation stability because their presence increases the soil's resistance to shear.[28,107]
6. McKeen suggests that the range for relative volume change exists within the PL and SL.[26,69] Classically, this moisture loss tends to involve pore water, the loss of which does not necessarily relate to soil shrinkage.[26,28,69] [Water bonded to or within the clay particles can be transferred to pore water, but temperatures above 212° F (110° C) are required.]
7. One inch [2.5 cm of water spread over 1000 ft^2 (93 m^2)] equates to 623 gal (2360 L) of water. A tree with a canopy area (*C*) of 1000 ft^2 ($C = D/2 = 36/2 = 18$ ft, where *D* is the diameter of thre tree canopy) might require 50 to 100 gal (379 L) of water per day to remain healthy.[1] Effectively, a little over 1 in (2.5 cm) of water, once a week (whether supplied by watering or Mother Nature)

would satisfy the needs of the tree, neglecting serious run-off. Roots would not be "encouraged" to encounter the hostile environment found beneath the foundation.

The foregoing lists facts developed by the referenced academicians, engineers, and geotechnicians. Some of their work did not involve "real-world" situations. That is, the conclusions were drawn from tests: (1) made on exposed soil, (2) using slabs poured directly on the ground surface, or (3) wherein no reasonable effort was made to exclude evaporation from transpiration. Source supplying actual field data taken from situations involving real foundations suggests that the true root problem is really not much of an issue.[16] Data collected since 1964 and involving over 20,000 actual repairs suggest the following. Refer also to Section 9A.

1. During the process of underpinning ordinary slab foundations [perimeter beam depth in excess of about 14 in (3.5 cm)], roots were found *beneath* the beams in less than 2% of the excavations. (The average number of excavations per job was 13. This extrapolates to well over 250,000 observations.) In many of these instances, the roots noted may have been in place prior to the construction of the foundation.
2. Virtually never does the company supplying these data recommend either removal of trees or the installation of root barriers. Removal of a tree can create far more serious concerns than leaving it be. None of these projects require *later* removal of trees, which certainly suggests that roots were not a problem.
3. If tree roots were truly a serious problem, why wouldn't all foundations of similar designs placed on similar soil and surrounded by similar trees experience problems?[16] Section 7C and Figure 7C.4 present a discussion on the impact of tree roots on foundation stability. In all, this slab foundation [a 30 in (76 in) perimeter beam] has eight pin oak trees growing along the west and south walls. The trees average 18 in (46 cm) in diameter with a height of 36 ft (11 m) and canopy diameter of 32 ft (9.8 m). The trees are within 6 ft (1.8 m) of the perimeter beam. The foundation shows no ill effects after 17 years. The soil is fairly alluvial soil with a PI of about 42.

It would appear that many investigators confuse perimeter settlement with center heave. From hundreds of engineering reports on file, it seems that many of the investigations arbitrarily assume the highest point within the foundation to be the bench or reference point. This obviously forces all surrounding measurements to be negative. Negative readings are generally associated with settlement. The preponderant conclusion then points to settlement. In lieu of another "culprit," nearby trees become the guilty party. This practice may be the result of either intent or oversight.

As a matter of fact, settlement is rarely the cause for foundation repair.[16,26] The preponderant cause for repair is upheaval, brought about by water accumulation beneath the slab. The source for the water can be natural (poor drainage) or domestic (utility/sewer leaks). The latter accounts for perhaps 70% of all foundation repair.

7A.2.3 Evapotranspiration

Evapotranspiration is the combined loss of moisture due to both evaporation and transpiration. This is the mechanism which in the end accounts for soil shrinkage and foundation settlement. However (to quote F. H. Chen), problems relative to "normal" settlement are comparatively few and minor. Chen states, "The end result of shrinkage around or beneath a covered area seldom causes structural damage and therefore is not an important concern to engineers".[26] Other publications have supported Dr. Chen.[15–17]

7A.2.4 Remedy

Restoration of foundations distressed by settlement is fairly straightforward. One needs merely to raise the settled area back to the "as built" position. With slab foundations, this involves mudjacking and, in some cases, underpinning. With pier-and-beam foundations, the lower perimeter areas are underpinned and the interior floor reshimmed. (Refer to Sections 7B.1, 7B.2, and 7B.4.) With any foundation-raising operation, it is often necessary, and frequently wise, to remove all patches that have been used to fill prior cracks. This is particularly true for any masonry patches. The "free space" is required to permit the foundation to be safely raised.

7A.2.4.1 Recourse

If you suspect a serious problem, the best course of action is probably to consult an attorney. This does not in any form recommend or suggest litigation; however, reliable advice is quite valuable. Recourse from settlement problems must generally involve negligent behavior on someone's part. For "new" construction, this could involve builders, engineers, architects, inspectors, contractors and/or developers. The statute of limitations in many states is ten (10) years. Example of negligent acts could include: 1) Failure to properly design the foundation to accommodate the site conditions; 2) Failure to comply with the plans or specs; 3) Negligent inspections during critical states of construction; 4) Not exercising a prudent attempt to grade the lot to control drainage or 5) Insurance providers who offer structural coverage.

In pre-owned properties recourse again is generally limited to some form of negligence and could involve realtors, engineers, inspectors or neighbors. Events that might be covered here would be: 1) Negligence of inspectors and/or engineers whose responsibility it was to inspect the property to ensure that no structural problems existed; 2) Realtors and sellers can be at fault under "latent defects" provisions. 3) Neighbors can be negligent if they cause undue drainage onto your property.

7A.3 TYPICAL CAUSES FOR SOIL MOISTURE INCREASE (UPHEAVAL)

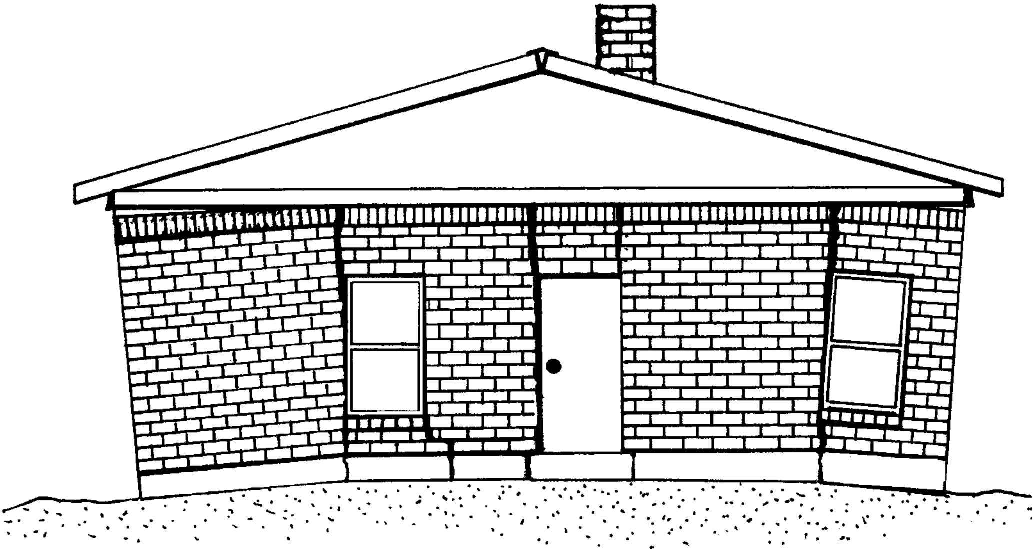
The foregoing paragraphs have related broadly to soil moisture gain or loss, with no consideration being given as to the source or cause for this moisture variation. Since upheaval is, by far, the most serious foundation concern—especially when dealing with concrete slab-on-grade foundations—this eventuality will be addressed first. Figure 7A.4 contains a drawing typifying upheaval and an actual photograph of interior slab heaval. The drawing (a) is an over simplification of upheaval but tends to serve as an example. Note the preponderant vertical cracks, wider at the top, the separation of the frieze boards from the brick soldier course, the open cornice trim and the bow in the slab. In the real world, the perimeter brick may not show the major results of upheaval but the weaker interior slab will. Often, the exterior mortar joints are mostly level. The photograph (b) shows upheaval as it normally appears. The central slab is clearly "domed." The down spout appears to be level, yet the ends are several inches off the floor.

Sources for soil moisture could include such diverse origins as:

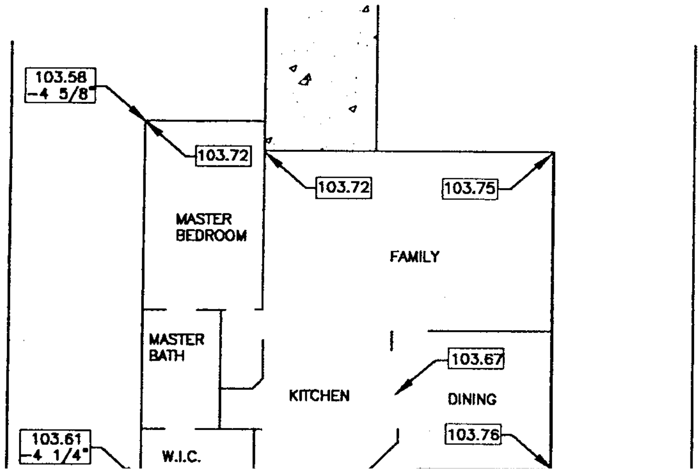
1. Rainfall
2. Domestic sources, which include:
3. Redistribution of soil moisture from wetter to drier soils or
4. Subsurface water

7A.3.1 Rainfall

Rainfall is perhaps the principal source for bulk water. However, as far as foundations are concerned, this threat is minimized due to the mere presence of the foundation itself. First, the structure isolates the foundation-bearing soil from contact with the rain. (The perimeter beam tends to



(a)



(b)

FIGURE 7A.4 (a) A drawing typifying upheaval (b) an actual photograph of interior slab heaval. In both examples, the "hump" in the floor is obvious.

restrict any lateral transfer of water.) Second, proper surface drainage adjacent to the beam should severely limit (if not eliminate) any availability of surface water to the soil beneath the foundation (run-off).

7A.3.2 Domestic Water

Domestic water is statistically the greatest concern, not so much from watering as from some form of leak. Watering can be controlled and, with the maintenance of adequate and proper drainage, any excess water can be safely directed away from the foundation. Leaks, on the other hand, are another matter. Supply line leaks can contribute a large quantity of water over a short period of time. However, a pressure leak is usually heard or noticed on the water bill and quickly repaired. The big threat, particularly to slab foundations, is the silent sewer leak.[15–17,40,52,64,86] This problem can exist years before detection. In fact, the existence of a leak is most often suspected or identified as a result of foundation damage. Upheaval can occur and advance rapidly with a rather extensive range and scope of damage. Very little water can cause serious distress. Under certain conditions, as little as six drops of water per hour, persisting over 12 months, can heave a slab foundation over 1″ (2.54 cm).[15–17,102] (Refer to Sections 7B.8 and 9A.) Actual data indicate that over 70% of all slab foundation repairs are caused by upheaval (water accumulation beneath the slab). A high percentage of the recorded cases of upheaval have been linked to sewer leaks.[15–17]

A small cadre of engineers tend to deny the propensity and extent of sewer leak problems.[15–17,26]The principal reason for this minority position might be traced to their clientele, i.e., insurance companies who have no liability for foundation losses attributable to causes other than “the accidental discharge of water from utilities” (or upheaval). Settlement is not an insured act. Refer to Texas Court of Appeals Case No. 13-92-C, Corpus Christi, December 16, 1993, styled Nicolau vs. State Farms Lloyds. Familiarity with this case is a *must* for those involved in foundation repair, appraisal, or engineering evaluation. (At the time of this writing the Appealant Court Decision has been appealed to the Supreme Court.)

Along these lines refer to Figure 7A.5. This drawing, prepared by one insurance company’s engineer, depicts floor elevations taken inside a distressed slab foundation. The peak point is indicated to be about six inches (15 cm) as shown. The basic central high as shown is 4.5 to 5.5 inches (11 to 4 cm). The engineer acknowledges the two sewer leaks but states, “since the leaks are not located near the heaving in the foundation, and there is no change in floor slope around the leak areas, I conclude that the reported underground plumbing leakage did not adversely affect the foundation.”

Review the engineering elevations: 1) the grade differential is 6″ (15 cm). This heave would require a *significant* quantity of water. 2) The sewer line and leak *are* included within the central high. 3) Water following along either the sewer ditch and/or interior beams could very well account for the accumulation at the central as well as the peak point. (Some geotechnicians believe that water can flow through fill sand or coarse base material. This could account for an unpredictable pattern.) 4) the foundation area between the cross beams (including bath leak) is somewhat aligned in the 5.0 to 5.5 inch (13 to 14 cm) high, and 5) The redistribution of *existing* soil moisture could not reasonably account for the magnitude and location of the heave.[16,26,102,103] The 6” heave would require a seemingly impossible soil suction and water availability. The only logical source would be the sewer leak. (The location of both the sewer lines and the probable interior beams was added by the author based on “best available information.”) The author had not inspected the property at the time of this analysis. If the issue goes to litigation, the author’s inspection will become necessary.

Another curious point lies in the facts that: 1) the group of engineers (who basically state that sewer leaks are not a significant cause of foundation distress) invariably recommend that the leaks be repaired and 2) once the leaks are repaired, foundation movement, generally, ceases after some relatively short period of time. (The exception is most often the result of another undetected leak.) Both facts clearly suggest that the sewer leak is, in fact, the source of the problem.

The range of upheaval has been recorded as high as 12″ (30 cm). [Conversely, settlement caused by soil moisture loss seldom exceeds 2–3″ (5–7.5 cm).] The general statement that upheaval is

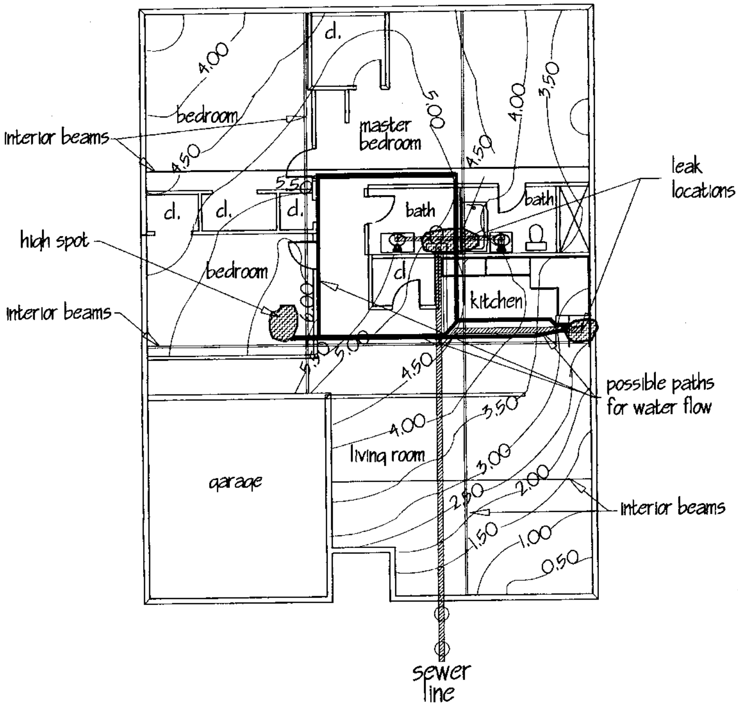


FIGURE 7A.5 Floor heave versus floor elevations.

caused by water is true. However, water introduced into an expansive soil does not *always* cause upheaval. If the in situ soil moisture is near the PL, much of the soils' swell potential may have already been exhausted. Figure 7B.6.2 gives the relationship between free swell and moisture content. The swell potential decreases dramatically as moisture content increases. (For these tests, a confining resistance equal to the assumed overburden was used.) At some point, additional moisture produces little or no swell.[15–17,86]

7A.3.3 Redistribution of Existing Soil Moisture

Redistribution of existing soil moisture can occur to some extent, particularly when dealing with slab foundations. The presence of the foundation slab prevents, or inhibits, both the evaporation and penetration of water. This, in itself, conserves moisture and tends to encourage upward capillary flow. Given time, the bearing soil confined beneath the foundation will likely increase in moisture content.[7,8] This increase will not be centralized but will be essentially constant over the expanse of the covered soil.[15,16,42,52,79,102,103] The vertical permeability in a clay soil is often approximated to be in the range of less than 1 ft/yr.[65,99] The horizontal permeability is frequently assumed to be at least ten times that or 10 ft/yr.[65,86,99] This means that lateral water flow can occur ten times more readily than vertical flow. There is a very serious doubt that the natural accumulation of soil moisture beneath a slab foundation has ever been sufficiently serious as to cause the need for foundation repair.[52,53] (Refer also to Section 9A.) Certainly, in the author's experience, spanning nearly 35 years and well over 20,000 residential repairs, no such instance has ever been documented.

Various sources for *subsurface moisture* would include: wet weather aquifers, perched water zones, ponds, springs, and/or shallow water tables. As long as the bearing soil moisture content remains constant, little or no differential soil movement would be anticipated. However, cyclic water availability often produces soil movement—swell or shrink. Water intrusion into shallow soils can cause the upheaval described above. Natural water drawdown can result in settlement. This sometimes occurs as the result of draining or lowering the water level in surface ponds or subsurface aquifers. For the former, the soils are often nonexpansive. When subsurface water exists, the problem is best resolved prior to construction and the practical solution is to initiate whatever steps are necessary to level the availability of water.

In some instances, chemical stabilization of the expansive clay might present a useful alternative.[16,17] (Refer to Section 7B.6.) Most chemicals are designed to abate swell and have, at best, limited capacity to influence moisture loss or settlement.

7A.3.3.1 Summary of Center Doming

The relationship of edge or center lift to describe potential foundation slab failures was introduced in the mid to late 1970s.[90] From design concerns, the approach seems technically sound. Problem can arise, however, through interpretation and application of the failure modes to actual foundation failure.

Edge lift rarely becomes a significant problem in foundation repair, although it remains a viable concern to design. Classically, this phenomenon occurs when the soil moisture beneath a segment of the perimeter beam exceeds that beneath the interior slab. Heave of a perimeter beam is somewhat rare, due in large part to the structure load transmitted to the beam. In residential and other lightly loaded construction, the load imposed on the beam might be on the order of 600 lb/ft^2 (290 kg/m^2) on interior floors. The added weight (load) substantially inhibits heave.[20] Further, the drastically reduced (or absence of) resistance (or load) on either side of a beam encourages the heave to be directed toward the path of least resistance. Areas adjacent to the beam might heave, but the loaded beam would be resistance to heave. Whatever the reason, problems associated with perimeter beam heave due to water are rare. (Tree roots have been known to heave a perimeter beam, particularly on pier-and-beam foundations.) Center lift actually refers to two different modes of failure: (1) perimeter settlement or (2) center lift, or as it is sometimes called, center doming.

Perimeter settlement is a concern and certainly should be an issue in foundation designs. However, foundation problems related to moisture losses in expansive soils are clearly overstated.[16,20] Soil moisture removal is slow, limited in scope, and easily abated if not reversed. When problems do develop, of all foundation repairs actually performed, less than 30% are the result of settlement and therefore are generally less costly.[16]

Center lift is a serious concern to both design and repair. The fact of center heave is not in question. The principal cause for foundation repair is, in fact, upheaval. The cause for upheaval is generally beyond question. The presence of water beneath the foundation is generally accepted to be the cause. However, there are diverse opinions as to the source of water that causes the soil to swell. Refer also to Section 9A.

"Natural" Center Doming. A few geotechicians and engineers (mostly hired by insurance companies) advocate the natural occurrence of "center doming" beneath slab foundation on expansive soils. A few seem to believe that virtually all slab foundations will experience "center doming," given sufficient time. The theory is that soil suction will increase the moisture within the central area of the soil confined by the foundation to the point where soil swell and foundation heave is inevitable. First, for this to come about, the soil moisture in deeper soils must initially be higher than that for shallow soils. Soil suction and perhaps elevated temperatures could then make water migrate to dryer surface soils, resulting in soil swell. (The shallow soils are of primary concern because these soils have the greater propensity for volumetric movement.)[36,65,86] However, the soil permeability in the vertical direction is less than one-tenth that in the horizontal direction. Tom Petry has given an estimate of horizontal permeability (K_H) to be on the order of 10 to 20 ft per year.[6] Others may have given a broad value for vertical permeabilities of 0.1 to 1.0 ft per year

(10^{-7} to 10^{-6} cm/sec) for heavy clay.[20,65,68] (Increased K_H over K_V is due largely to roots, fissures, fractures, and/or normal sedimentary planes.) The disparity between K_V and K_H would seem to preclude the "dome" theory in itself. A moisture content would more likely be distributed rather uniformly over the entire surface soil, not as a "dome."[16,52,53,78,102] This theory would prevail even if interior perimeter soils were to lose moisture to the exterior. Second, bear in mind that (1) the natural doming wouldn't be dependent on or influenced by other moisture sources. For example, the mere process of repairing a leaking sewer system would have no influence on arresting the heave. (2) All foundations of similar design, with other factors being equal, would eventually suffer the problem, and this simply does not occur. (3) Based on the extremely low permeabilities involved, natural doming, if possible, would require a long period of time to develop, perhaps in excess of 10 years. How then could this theory explain upheaval in foundations 2 to 10 years old? Reasonable design concerns can, however, resolve the problems of center heave as defined in the foregoing paragraphs.

Center Heave Due to Extraneous Water. One source of reliable data suggests that center doming is in fact a particularly serious threat to the stability of concrete slab foundations. The heave of concern involves the introduction of water beneath the foundation. This water can originate naturally (precipitation accumulated by bad drainage) or from domestic sources (plumbing leaks, supply or waste). Water produced naturally can be alleviated by conventional drainage improvements. The hidden "cancer" represented by domestic leaks, in particular the silent sewer, is the foremost problem. Perhaps the only reliable data concerning foundation repair identifies sewer leaks as the cause of 70% of all slab repairs. These data point out that once the cause of the problem (i.e., sewer leaks) has been eliminated, movement arrests in about 90% of the documented cases. (In the remaining 10%, the continued movement was traced to an undiscovered plumbing leak in over half the cases.)

A few engineers and geotechicians completely discount plumbing leaks as a cause of foundation failure. Generally, they identify settlement (usually due to root or natural doming) as the cause for the failure. Again most of these proponents work exclusively (or nearly so) for insurance companies. Although these investigators deny plumbing leaks to be the cause of the problem, all agree to immediately repair the leak, even though such repairs are typically quite expensive. To put the repair costs into some perspective, consider the example in Table 7A.1. The foundation repair cost on this same job was proposed at $4908. The insurance company paid for the sewer repairs but denied responsibility for the foundation claim. Note that the "typical" cost for sewer repair was $6,900.00 plus $2,500.00 for mudjacking. This produced a "typical" sewer repair cost of $9,400.00, nearly twice the cost for foundation repair in this example.

TABLE 7A Typical Costs for Sewer Repair (Slab Foundations)

Description	Quantity	Unit cost, $	Estimated cost, $
Dig and fill access for tunnel; includes pump protection	1	600	600
Tunnel under foundation	26	150	3900
Install pipe, fitting, and connections under slab materials plus labor	1	250	250
Backfll tunnel area	26	75	1950
Clean up		100	100
Permit/fees	1	100	100
Total		6900	

*Does not include mudjacking to complete the tunnel backfill. This "typically" adds another $2,500.00 to the costs.

These same proponents also seem to state that a sewer leak does not produce sufficient water to cause a serious heave. Without getting into the absurdity of this position (based on elementary soil mechanics or engineering, plumbing practices, the Manning equation, or common sense), it merely requires one to note that when the source for water is removed, movement ceases. Obviously, the sewer leaks did contribute to (if not cause) the problem. All other arguments seem to suddenly become moot.

The cause for the foundation failure does not influence the pocketbook of the reputable repair contractor, who gives repair estimates without concern for who pays the bill. The contractor does not have responsibility to customers and should carefully inform them about the cause of distress. This is simply because the contractor knows that if the original problem is not eliminated, the problem will recur. If the contractor correctly identifies the cause and this is not eliminated subsequent to repair, the contrators' warranty is likely null and void. The consumer is the party who suffers most. As a rule, the insurance companies are the only parties affected by the cause of problem. Refer also to Section 9A.

7A.3.4 Restoration

Upheaval represents that condition in which some area of the foundation is distorted in a vertical direction while other areas remain "as built." Remedial action involves raising the lowermost (unaffected) areas to a new, higher elevation in an effort to "feather" the crown or high area. Seldom is the end product "perfectly level," if such a term exists. However, the consolation lies in the fact that the foundation was never level. The repair procedures are those described in Sections 7B.1, 7B.2, and 7B.4 and are dependant upon whether the foundation is slab or pier-and-beam.

7A.3.5 Possible Recourse

Possible recourse due to foundation upheaval could include those cited in Section 7A.2.4. However, conditions of upheaval might also be subject to insurance coverage. Again, as with Section 7A.2.4, it is wise to consult an attorney experienced with this type of law. Until about 1996, many homeowner's B insurance policies contained coverage "for accidental discharge of water and damage resulting therefrom." This is, of course, not verbatim, but the intent is clear. However, conditions of upheaval caused by domestic water leaks are generally subject to insurance coverage.

Any act by others to subject your residential foundation to water (particularly a slab) might constitute "negligence." This could be a neighbor changing his drainage to adversely impact your property. It might be flooding caused by a broken city water line. An improperly installed sewer or water supply system might also represent culpable acts. For the same reasons as those stated in 7A.2.4 for preowned properties, sellers, realtors, engineers, and/or inspectors can be held accountable for negligent acts.

7A.4 FOUNDATION PROBLEMS NOT MOISTURE-RELATED

7A.4.1 Lateral Movements

Serious soil movement can be the result of some variety of lateral displacement. Lateral movements can be the result of soils eroding, sliding, or sloughing. This is generally associated with construction on slopes with unstable bearing soils. Movement is often precipitated or exacerbated by the intrusion of water into the soil to the extent that both cohesion and structural strength are threatened or destroyed. California mud slides are one prime, though extreme, example. The structural damage caused by these problems is often complete destruction. When remediation is possible, the situation is addressed in a manner generally consistent with that for acute settlement. Severe lateral movement is generally beyond the methods available to the repair contractor. However, the contractor can often provide measures to stop lateral movement. This could involve the placement of retaining walls, earth anchors, terraces or other such measures. This problem is generally considered beyond the scope of this book.

7A.4.2 Consolidation or Compaction

Settlement can also occur as a result of *consolidation* or *compaction* of fill, base or, subbase materials. With respect to residential construction, the most common problem deals with construction on either abnormally thick fill or a sanitary landfill. In either case, over time, the intended bearing soils fail due to consolidation. Normal settlement of fill is often active for periods up to 10 years and is somewhat dependant upon the cycles of precipitation and drought. Sanitary landfills can be active for longer periods of time due to voids continually provided by the decay of organic materials.

Consolidation of nonexpansive soils often results from the removal of pore water. One example of this might be instances where the water levels of lakes or ponds are lowered, allowing water to drain from the surrounding soils, often sand or coral. Elutriation of soluble material (usually salts) from soils, facilitated by the invasion of water, can create voids that at some point collapse and cause consolidation. In many cases, deep grouting is a required remedial procedure for the correction of either problem. Refer to Section 7B.6.[16] Once the deep-seated cause has been addressed, procedures common to foundation settlement can be used to "relevel" the structure.

7A.4.3 Frost Heave

Frost heave occurs as a result of soil water freezing with sufficient expansion to cause the foundation member to heave, or in some cases, as with basement walls, to collapse inward. Soils in subfreezing climates are the most susceptible to this problem. Frost heave can best be addressed in new construction design.

Frost heave in existing structures can result in slab heave or, in the case of basements, collapsed walls. Both should be very carefully treated, with the first step being to consult a geotechnical engineer who is skilled with this particular problem as well as the geographic location. Refer particularly to Sections 7A.3.4, 7B.2, and 7B.4.

7A.4.3.1 Basements and Foundation Walls

Failure in basement walls occurs in areas with or without expansive soil and is often preponderant in colder climate regions. Where concern for frost lines exists, the propensity toward construction with basements is enhanced. As far as expansive soils are concerned, Colorado is one principal area where basements are common. As stated earlier, frost heave can exert sufficient lateral load on a basement wall to cause inward collapse, much the same as hydrostatic loads (expansive or nonexpansive soils) or the expansion of expansive soil. Regardless of the cause, the repair approach would be similar. Refer to Section 7B.5 for details.

It might be interesting to note that above-grade foundation walls (with built-up floor systems, i.e., dock-high) suffer failures similar to those described in this section, except that the foundation failure (rotation) is toward the exterior and temperature is not a factor. Repair or restoration procedures are often much the same as those described in following examples. As a rule, the retaining or aligning procedures are installed on the external side of the foundation wall where property lines permit. Refer to Section 7B.5 for details on repair.

7A.4.4 Permafrost

Permafrost is a reverse problem to frost heave. Both require the same conditions, i.e., prolonged very cold climate and lenses of water trapped within the bearing soil. The end result of melting permafrost is subsidence. Unless the permafrost melts, there is no problem (foundation-related). Once the problem has occurred, a possible solution might be deep (intermediate) grouting, as discussed in Section 7B.3. This approach could be successful, if the free water is eliminated. Again, the first and best option is to consult a local geotechnical engineer familiar with the specific problem, whether it be of a design or remedial measure.

7A.4.5 Construction Defects

Construction practices or mishaps often create conditions that are conducive to foundation problems. Where possible, these factors are grouped for either slab or pier-and-beam foundations.

7A.4.5.1 Slab Foundations

There seems to be a number of events inherent to the original construction that can possibly result in foundation problems or in other cases impede the desired repairs. Some of these are:

1. *Utility leaks* beneath the foundation (refer also to Section 7A.3)
2. *Pouring the slab foundation off grade*. Figure 7A.6 presents grade elevation at various points over the area of the foundation. Note the differential of –4⅝ in (12 cm). Interior surfaces of the dwelling show only minor cracks in sheetrock and only a few doors are out of plumb. If leveling repairs were attempted based on these elevations, the structure would suffer severe distress. In fact, the extent of true differential movement noted in this foundation is "nominal" by most standards. Refer to Section 7C. At least part of the problem with this job originated from the fact that the brick ledge was used as a "bench mark". This is not acceptable. The brick ledge is most often off grade. In fact, brick masons use the first few courses of brick in order to attain a level mortar joint. Elevations should be taken off the mortar joint on top of the fifth brick course. Reliance on faulty information would encourage frivolous litigation.
3. Faulty slab design or construction. Slab foundations poured with: a) insufficient slab and/or beam thickness, b) undersized, improper placement or absence of reinforcement, c) *too much water* in the concrete, which results in poor quality and substantial loss in strength are faulty. Not only do these defects encourage foundation problems but they also hamper (if not prevent) proper repair.
4. *Add-on slabs* poured in contact with another slab that already suffers differential deflection. This situation is most difficult to improve. The common joint poses a real problem. If the faulty slab is raised, the add-on will be low. If the add-on slab is also raised, the existing framing will be destroyed. A rule of thumb, "Never construct an add-on unless proper remediation has restored the original foundation." This situation affects slab and pier-and-beam foundations alike.
5. *Faulty exterior grade*, nonconsistent watering practices, location and design of landscape plants each can promote foundation problems. See Section 7C.

7A.4.5.2 Pier-and-Beam Foundations

The problems of foundations constructed with the pier-and-beam design probably happen with the same frequency as those of other foundations but their *degree* is much less. The crawl space provides access for correcting minor grade problems experienced by interior floors. Other factors not so easily addressed include:

1. *Limited or no crawl space*. See Section 7B.1.5.
2. *Insufficient ventilation*. Refer to Section 7B.1.5.
3. *Water collected in crawl space*. This problem requires both proper drainage at the perimeter beam to prevent accumulation of excess water and adequate ventilation to control normal amounts of water. This is particularly important when the pier-and-beam foundation is of the "low profile" design. (See Section 4D.)

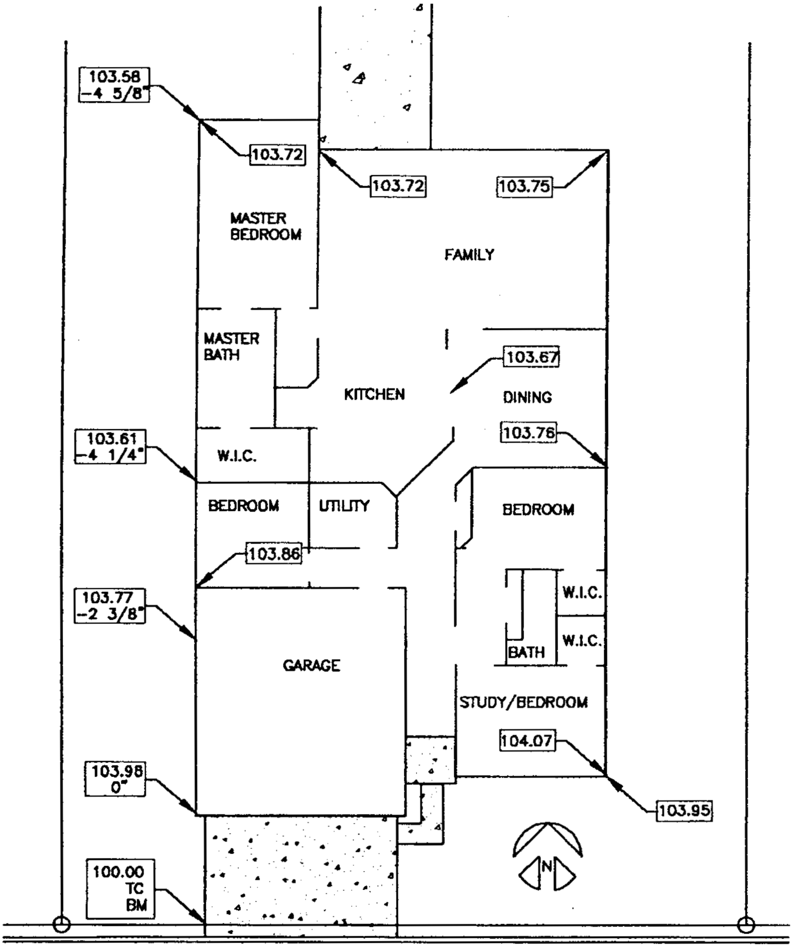


FIGURE 7A.6 Foundation elevations.

4. *Warped wood*, particularly affecting the joists and/or girders. When the wood substructure is subjected to a prolonged distortion (particularly in the presence of moisture), the individual wood members are subject to warp. If the warp is severe or well set in the wood, it is not likely that this condition can be reasonably cured. That is, leveling by reshimming existing pier caps (or even adding supplemental ones) is not likely to produce level floors. Some improvement is generally possible but some compromise is required.
5. *Faulty placement or design of piers and/or pier caps*. In some cases, deficient materials were used to support the wood superstructure. This is particularly pronounced in older foundations where wood "stiff legs" were used to support the foundation. These members were subject to deterioration as a result of decay and insect infestation. In modern-day practices, it is not particularly uncommon for a pier and pier cap to be located such that the girder is not properly supported. Sometimes the pier cap may be off-center, tilted, short, or miss the girder altogether.

7A.4.6 Negligent Maintenance

Negligent maintenance could refer to instances where

1. Standing water is permitted to approach and/or invade the foundation. Moisture accumulating in the crawl space of pier-and-beam foundations acerbates wood warping and contributes to instability of interior piers and pier caps. A substantial warp will prevent proper leveling (shimming pier caps) and cause increased costs. Water beneath slab foundations frequently causes upheaval.
2. Failure to address problems caused by erosion before they become critical. This concern would also include embankment failure.
3. The neglect of proper maintenance procedures is probably the foremost issue in the category.

Proper maintenance is fully discussed in Section 7C.