Post foundation design considerations

By David R. Bohnhoff, Ph.D., P.E.

In the vast majority of post-frame buildings, structural loads are transferred to the soil via embedded posts. The popularity of embedded post foundation systems is due to the fact that they use less material and can be installed much more quickly than foundation systems that rely on continuous concrete footings or concrete slabs and grade beams.

The typical embedded post foundation consists of three major elements: the post, a footing, and an uplift resisting system. For discussion purposes, it is advantageous to categorize designs according to footing type. For example, figure 1 shows post foundations with wood footings; figures 2 and 3 contain illustrations of foundations with precast concrete footings, and figures 4, 5, and 6 diagram foundations with poured-in-place concrete footings. Note that in many designs, the footing is part of the uplift resisting system.

Design of an embedded post foundation calls for careful evaluation of several factors. These factors are introduced under categories of foundation strength, durability, installation, and cost.

Foundation strength

Like any foundation system, each embedded post foundation must be designed to handle downward, uplift, and lateral forces. Downward forces are primarily due to snow and wind loads and weight of building components and contents. Uplift forces generally only result from wind loads. Lateral forces are induced by wind and seismic forces as well as any stored materials applying lateral wall pressures. If there is a difference between design of traditional foundations systems and embedded post foundation systems for post-frame buildings, it is that embedded post foundations concentrate greater loads over a smaller area than do most traditional foundation systems. For this reason, downward, uplift, and lateral foundation force calculations are an integral part of routine post-frame building design.

Bearing capacity

Minimum footing area is simply equal to vertical downward design force divided by allowable soil bearing pressure. Thus as vertical design load decreases and/or allowable vertical soil bearing pressure increases, footing size and post-to-footing connection strength can be decreased.

With minimal vertical loads and reasonable soil bearing strength, it is most economical to rely on an all-wood foundation system similar to those shown in figure 1. Both systems in figure 1 are fabricated entirely from nominal 2- by 6-inch lumber that has been adequately preservative-treated (described later). The system in figure 1a features a 2-ply post with two 12-inch long cleats. These cleats increase bearing area provided by the 2-ply post by more than 200 percent. The system in figure 1b features a 3-ply post and is designed for slightly greater downward forces. In this case, the combination of the wood footing and cleats increase the bearing area approximately 300 percent over that provided by the 3-ply post itself. Each wood cleat is sufficiently attached for bearing forces when the design shear strength of the attaching fasteners is greater than the product of the allowable soil bearing capacity and the bottom surface area of the cleat.

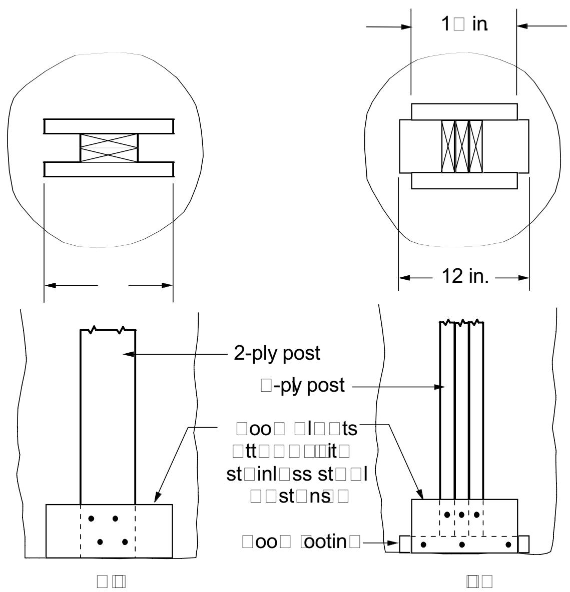

Figure 1. All-wood foundation systems (a) without, and (b) with a wood footer.

When downward forces or soil bearing strength make all-wood foundations impractical, builders generally move up to circular precast concrete footings (figures 2 and 3). Precast concrete footings are manufactured and sold by concrete block manufacturers who generally refer to them as "post pads." The most common sizes are 4- by 12-inch and 4- by 14-inch. Thickness and diameter generally do not exceed 6 and 18 inches, respectively (note that a 6- by 18-inch concrete footing would weigh approximately 130 pounds and thus would be very difficult to manually place). To minimize inventory, most post-frame builders stock only one precast footing size. For builders looking for an alternative to precast concrete footings, plastic pads are available in some areas.

If the precast concrete footing stocked by a builder is not large enough for a specific application, the builder will auger larger diameter holes and either switch to a poured concrete footing (figures 4, 5, and 6), or increase the effective soil bearing area by placing non-hydrated concrete mix beneath the footing. As shown in figure 7b, the effective footing diameter can be assumed to increase by 2 inches for every inch of concrete mix placed below the footing. A non-hydrated concrete mix is generally assumed to have the bearing capacity of a well-graded gravel when initially placed, and a considerably higher strength when partially hydrated. Note that the same high moisture conditions that reduce the bearing strength of surrounding soil will help hydrate cement, and hence increase the strength of a concrete mix. Nevertheless, because of uncertainties discussed later in this article, use of non-hydrated concrete is largely restricted to code-exempt construction.

Because of the size and quality of typical precast concrete pads, punching shear (i.e., the post punching through the pad) and pad bending strength seldom, if ever, control design. However, as footing diameter (or width) to thickness ratio increases, the likelihood of one or both of these design variables controlling design increases, requiring the introduction of steel reinforcing into the footing. According to ASAE EP486.1 (2002), any time such reinforcing is used a 3-inch minimum concrete cover must be maintained above and below the reinforcing. ACI 318 Section 15.7 (ACI, 1999) requires a more substantial 6-inch minimum concrete cover above the bottom reinforcement in any footing, which would result in a minimum footing thickness of 10 inches for a 1-inch diameter reinforcing bar. ACI 318 does not contain a justification for the 6-inch cover requirement.

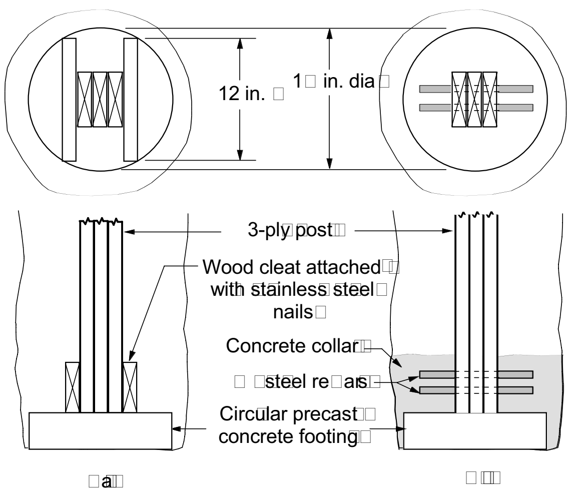

Figure 2. Post foundations featuring precast concrete footings. Uplift resistance provided by (a) wood cleats, and (b) concrete collar attached to post with steel rebar.

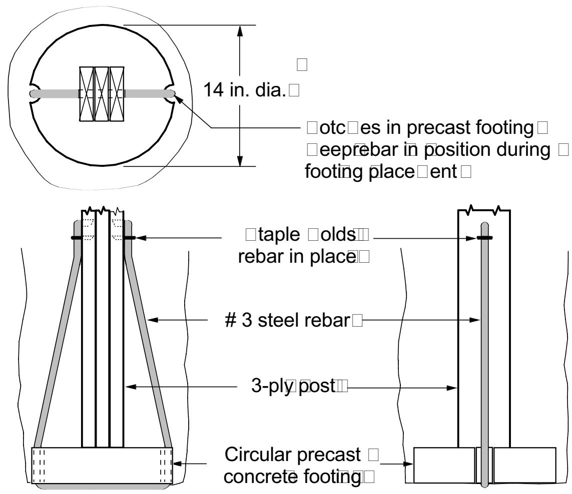

Figure 3. Post foundations featuring precast concrete footings. Uplift resistance provided by steel rebar wrapped under footing and attached to post at location above grade.

Poured-in-place concrete footings can be located completely under the post (figure 4), completely around the post (figure 5), or around and under the post (figure 6). Whenever all or part of the post extends completely through the footing, post-to-footing connections must be properly designed and installed.

Uplift resistance

Wind forces acting on lightweight buildings and/or partially enclosed buildings can apply significant uplift forces to the foundation system. Because post-frame buildings are relatively light buildings that typically feature several large wall openings, ensuring that post foundations can adequately handle uplift forces is fundamental to post-frame building design.

A post foundation uplift resisting system consists of an anchor and anchor-to-post connection. An anchor that encircles the entire post is called a collar.

In many systems, the footing serves as the anchor. In figure 1, wood cleats function both as footings and anchors. In figure 3, the precast concrete footing also functions as an anchor. This is accomplished by wrapping a corrosion-protected reinforcing bar or metal banding around the pad, and then securing both ends of the rebar/banding to the post at a location above grade. In figures 5 and 6, poured concrete footings also function as anchors.

Post foundation uplift resistance is due to soil shear strength. In order to withdraw a post foundation with a round collar, a conical shaped failure plane must form in the soil as shown in figure 8. This requires all soil within the conical-shaped volume be moved upward against the force of gravity. The force required to accomplish this is the maximum potential uplift resistance of the post. If the post does not contain an attached footing or anchor, the designer must rely solely on soil-to-post friction and cohesion to resist uplift forces. Experience has shown that concrete slabs used to laterally restrain posts at grade make it more difficult to withdraw posts. Additional research is needed to quantify the increase in uplift resistance attributable to concrete slabs.

Tests conducted by Bohnhoff et al. (2001) demonstrated that significant uplift resistance could be obtained with relatively inexpensive uplift resisting systems. In their study, 4.5- by 5.5-inch posts without uplift resisting systems had an average withdrawal resistance of 1,400 pounds when embedded 50

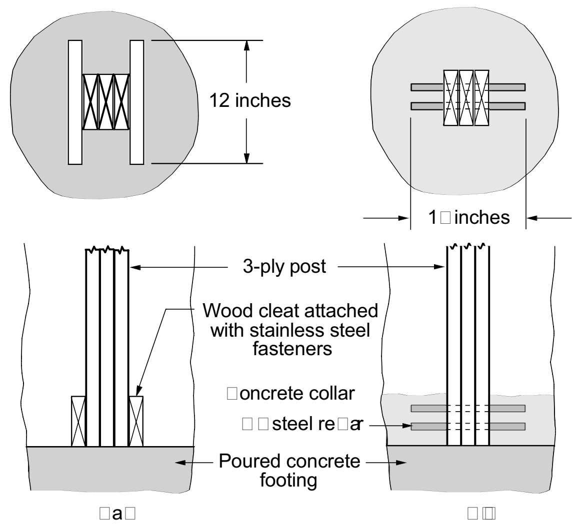

Figure 4. Post foundations with poured-in-place concrete footings. Uplift resistance provided by (a) wood cleats, and (b) concrete collar attached to post with steel rebar.

inches. With the addition of two 10-inch long wood cleats to these posts, average withdrawal resistance increased to 5,630 pounds. In this same study, post foundations with 19-inch diameter concrete collars provided uplift resistances in excess of 22,000 pounds when embedded to the same 50-inch depth.

Equations for calculating the soil mass within the conical-shaped shear plane (figure 8) are given in ASAE EP486.1 (ASAE, 2002). This soil mass increases with an increase in anchor depth, anchor diameter, soil density, and soil friction angle. It follows that the uplift resistance of the post foundation is limited by (1) the gravitational force acting on this soil mass, or (2) the shear strength of the post-to-anchor connection(s).

Lateral strength

Horizontally applied building loads induce bending moments and shears in embedded posts and result in lateral movement of the post foundation. Designers must insure that this movement does not induce soil stresses that exceed allowable lateral soil pressures. If soil stresses are too high, consideration must be given to increasing: (1) post thickness, (2) post width, (3) embedment depth, (4) size of attached footing/collar, (5) post restraint at grade, and/or (6) lateral bearing capacity of the backfill.

Equations used to insure that soil stresses are not exceeded under lateral loads are frequently referred to as post embedment equations because embedment depth is the dependent variable in the equations. Embedment equations for different post restraint conditions, and for posts with and without attached footings and collars, are compiled in ASAE EP486.1 (ASAE, 2002). Note that by restraining a post at grade and/or attaching the post to a footing or collar, the post

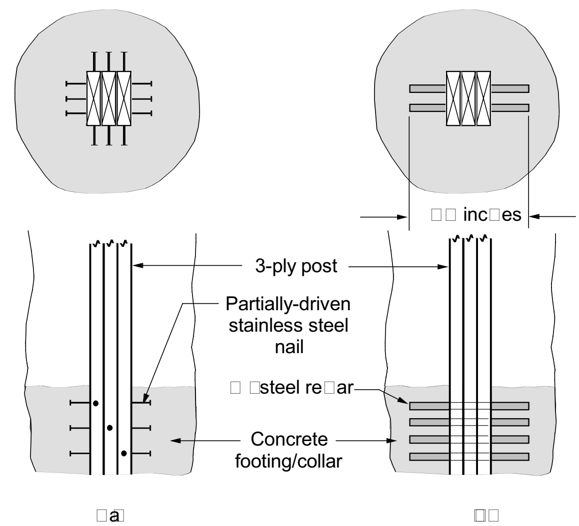

Figure 5. Post foundations with poured-in-place concrete footing/collar. Post bears directly on soil. Load transferred to footing/collar via (a) stainless steel nails, and (b) steel rebar.

foundation is capable of resisting much higher lateral forces.

Backfill is an extremely important design variable where a post foundation is subjected to high bending and/or shear forces near the groundline, and high lateral soil resistance is required. The best way to obtain this high soil resistance is to backfill with concrete. Concrete has such a high compressive strength that the diameter of a concrete backfill can be used as the effective post width in embedment calculations. The downside of using concrete is its high cost and its susceptibility to frost heave when surrounded by poorly drained silt and clay soils that are subjected to sub-freezing temperatures.

Durability

Wood preservative treatment

Because post foundation replacement is relatively expensive, post durability is taken seriously during design. American Wood Preservers' Association (AWPA) commodity standards specify that structural wood columns be treated to a retention level of 0.60 lb/ft^3 with such waterborne preservatives as CCA Types I, II, and III and ACQ Types B and D (note: CBA is included in AWPA commodity standards for aboveground use only). Builders who warranty against post decay for upwards of 50 years often specify a minimum average waterborne preservative retention level of 0.80 lb/ft^3.

Treatment penetration to a depth of 0.75 inches ensures that virtually all wood in a post fabricated from nominal 2-inch thick lumber (actual thickness of 1.5 inches) is protected. The same is not true for a solid-sawn, nominal 6- by 6-inch post (actual size of 5.5- by 5.5-inches) where a treatment penetration of 0.75 inches leaves a 4- by 4-inch center region without treatment. For this reason, avoid using larger solid-sawn timber when holes that expose untreated wood are located near or below grade.

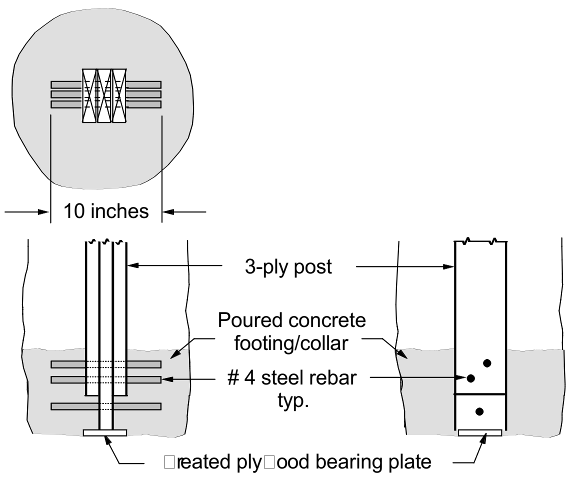

Figure 6. Post foundation with poured-in-place concrete footing/collar. Post supported by center ply until footing/collar is poured. Downward load transferred from post to footing/collar by steel rebars and by direct bearing of outer post plys.

Properly treated lumber has an outstanding track record. Presently, there is no known documented evidence of a post decaying when it has been fabricated from dimension lumber that has been fully treated to a minimum retention level of 0.60 lb/ft^3 with a CCA preservative.

Fastener corrosion resistance

Without corrosion protection, thin metallic components located below grade, especially in preservative-treated lumber, will disintegrate in a relatively short period of time. For this reason, it is highly recommended that smaller diameter fasteners (i.e., nails and screws) used to attach collars and/or footings to treated posts be manufactured from silicon bronze or AISI type 304 or 316 stainless steel. Although hot-dipped galvanized (zinc-coated) fasteners are frequently used in highly corrosive environments, studies advise against their use in treated wood located below grade (Baker, 1992). If corrosion of hot-dipped galvanized fasteners is enhanced by increased concentrations of copper, expect corrosion of the fasteners to be no less of an issue in ACQ treated wood than it is in CCA treated material.

To counter corrosion of reinforcing bars used in preservative treated wood below grade, coat the bars with epoxy or increase the bar diameter so that adequate strength remains despite material loss to corrosion.

Molded plastic post casings

Molded plastic post casing (MPPC) herein refers to any molded plastic device that fits over, and completely encases, the end of a post prior to its embedment. Currently, at least three companies produce and market an MPPC.

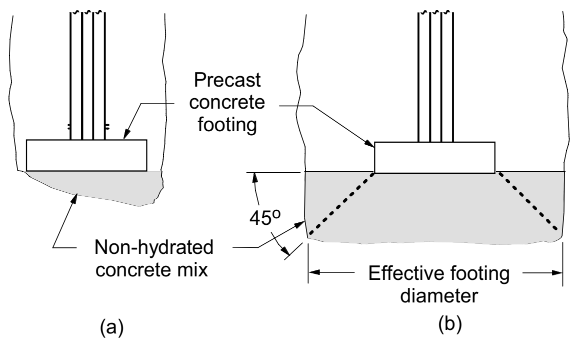

Figure 7. Concrete hydrated in-situ used to (a) level the bottom of a hole, and (b) increase the effective diameter of a precast concrete footing.

The first MPPC on the market was patented by David Gruhlke of Zimmerman, Minn. (Gruhlke, 1994). Sold under the trade name Plasti-Sleeve, it is made from HDPE plastic, has an overall length of 5.5 feet, and comes in two sizes — one that fits a nominal 6- by 6-inch post, the other that fits a 3-ply post fabricated from nominal 2- by 6-inch lumber. The 5.5-foot length ensures that the MPPC will extend at least 6 inches above grade for post embedment depths of 5 feet or less. This in turn helps ensure that the top of the MPPC will be above the bottom of the skirt board and protected from precipitation.

The second MPPC on the market was patented by Ken McDonnell of Pottsville, Pa. (McDonnell, 2002). Sold under the trade name Post Protector, it is similar in size but has thicker walls than the Plasti-Sleeve and it contains special venting channels. A third post protector developed by Keith Niehaus of Iowa, is sold under the trade name Post Cover but has not been patented.

MPPCs are marketed as a means to reduce (1) consumer concerns regarding post rot, decay, and insect damage, (2) soil exposure to treated wood, and (3) post uplift due to freeze/thaw in heavy soils. While these claims seem reasonable, they have not been documented. Like newer wood preservatives, MPPCs have not been in use long enough to determine long-term effectiveness. One major unanswered question relates to moisture entrapment. Specifically, are there circumstances under which moisture entrapped within an MPPC increases wood deterioration rate?

A relatively recent study by Scheffer and Morrel (1997) supports MPPC use. The researchers inserted small ponderosa pine sapwood stakes in forest soil within a greenhouse. The below ground portions of half the stakes were encased in 2-mil polyethylene bags. Soil moisture was maintained by spraying to a level suitable for gardening and no attempt was made to keep water from entering the upper end of the bags. Stakes with polyethylene bag protection had little evidence of decay, while those without bags experienced large weight loss and extreme shrinkage and deformation during the two-year study. Based on research by Merrill and Cowling (1966), Scheffer and Morrel surmise that soil nutrients may aid the development of fungi, and thus wood is more susceptible to attack when directly exposed to soil.

Encasing a post in a plastic can significantly reduce post uplift resistance. There are two ways to counter this. The first involves penetration of the MPPC with mechanical fasteners. These mechanical fasteners can simply attach the MPPC to the post, or they can be used to attach an anchor to the MPPC and post. For example, stainless steel screws can be used to tightly fasten wood cleats to the base of the encased post. Another option would be to pour concrete around the base of the MPPC after stainless steel nails have been driven through the MPPC and partially into the post. To completely avoid fastener penetration of the MPPC, designers can switch to an uplift resisting system similar to that shown in figure 3. When a poured-in-place footing is used, anchorage can be achieved by embedding a steel reinforcing bar in the footing, running the bar up alongside the MPPC, and affixing it to the post at a location above the MPPC. When this rebar is disconnected, the post can be easily withdrawn from the MPPC. Note that the durability of this system is largely dictated by coatings used to minimize rebar corrosion.

When a post is not tightly encased in an MPPC, lateral stiffness is reduced (i.e., lateral movement under load is increased). Such effects on post foundation behavior must be documented before a building can be properly designed.

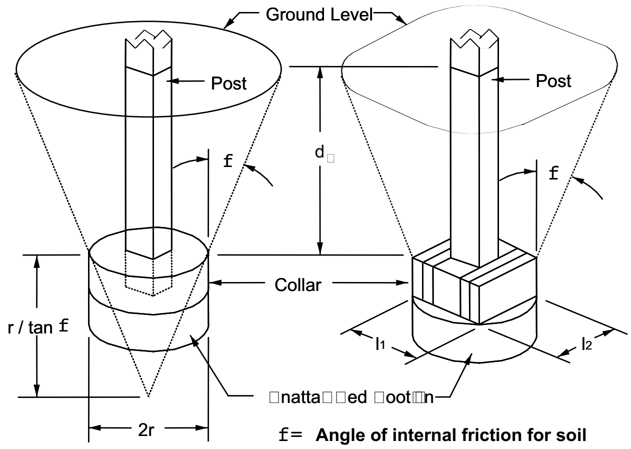

Figure 8. Conical-shaped failure planes that must form before post foundation can be withdrawn.

Frost heave

Freezing temperature in soil results in formation of ice lenses in spaces between soil particles. Under the right conditions, these ice lenses will continue to attract water and increase in size. This expansion of lenses increases soil volume, and if this expansion occurs under a footing or along a foundation with a rough surface, that portion of the foundation will be forced upward — a situation referred to as frost heave.

Several steps can be taken to reduce frost heave. First, extend the base of an embedded post foundation below the frost line. Second, grade the site so that all water is directed away from the building. This includes filling in depressions that form around posts as backfill settles. Third, refrain from building on or backfilling with clay and silt soils (although a few inches of clay just below the surface can effectively prevent water infiltration around a post). Fourth, guard against the "sump effect." This occurs when a hole is drilled into, but not through a relatively impervious soil. If course backfill is used in this case, water traveling horizontally above this impervious layer will move downward when it reaches the backfill and get trapped in the base of the hole. Alleviate this situation by providing an alternative flow path for ground water.

Concrete backfill against irregular soil surfaces, or in holes with diameters that decrease with depth, can increase the likelihood of frost heaving.

Installation

Hole preparation

All footings must be placed on undisturbed or properly consolidated soil. In general, the shallower the footing, the easier it is to remove loose material from the bottom of the hole and/or to consolidate loose material in the bottom of the hole. A flat metal plate welded to the end of a pipe is generally used to level/tamp the bottom of the hole. Where precast concrete or wood footings are used, the base of the hole must be flat (i.e., void of high and low spots) and level. If not, any footing not attached to the post will only make line or point contact with the post, and any footing attached to the post will only make line or point contact with the compacted base.

Rainfall occurring between drilling and foundation placement can be problematic. Holes drilled into granular material will generally collapse under heavy rains, requiring considerable re-excavation. Heavy rains in other materials will generally result in a mixture of soils (including top soil) at the base of the hole that must be removed prior to footing placement. Additionally, the material at the base of the hole is no longer consolidated to the degree it was prior to the rain. In such cases it is beneficial to replace several inches of material from the base with non-hydrated concrete mix. Such "dry mix" not only provides a base with a relatively high bearing capacity, but by removing water from surrounding soil, it also improves the soil's bearing capacity. As shown in figure 7a, non-hydrated concrete mix can also be used to help level the base of a hole prior to footing placement.

Poured-in-place concrete footings have an advantage over wood and precast concrete footings in that they do not require a flat, level soil surface for placement. However, if the post is to bear properly on a poured-in-place footing, the footing must have a level finish, or the post must be positioned on the footing surface before the concrete completely sets.

Footing placement

Once a post has been placed in a hole, it is imperative that it can be realigned and plumbed with ease. Repositioning a post is more problematic when a post is already attached to a footing and/or collar, or when the hole is drilled at an angle or off-center. The latter is more problematic with deeper holes in rocky soils. Lateral repositioning is obviously more difficult if the post has settled into soil, partially set concrete, or non-hydrated concrete mix.

Precast concrete footings should be lowered into a hole with special tools or hardware so as to maintain a flat, level, properly compacted base under the footing. With the system in figure 3, this lowering is accomplished with the rebar used to attach the precast concrete footing to the post. While this ensures that the base of the hole remains level, the top of the footing must be tamped to ensure the section of rebar located under the footing is seated in the soil.

Combination concrete footings/collars

The foundation in figure 4b requires two separate concrete pours — one for the footing and one for the collar. This is an expensive and time-consuming venture that can be avoided by using the designs in figures 5 and 6, which feature combination footing/collars that are poured-in-place after the post has been aligned and plumbed. The difference between figure 5 and 6 designs lies in the number of post plies that are in direct contact with the soil. In figure 5, all post plies rest on the soil, in figure 6 only a single ply is used to support the post during alignment/plumbing.

Extending only a single post ply for post support during placement was recommended by Zimmermann (2000) and found to work well in practice by this author. By supporting the post on a single ply, fresh concrete can be easily worked under the remaining plys during concrete placement. The end result is a foundation system with excellent footing-to-soil contact and excellent post-to-footing contact. Where a single ply is not sufficient to hold the post in place during post alignment/plumbing, a small preservative-treated piece of plywood can be tacked to the extended ply (as shown in figure 6) to increase its bearing area. For durability, the plywood should have a minimum waterborne preservative treatment level of 0.60 lb/ft^3 and be marked PS 1, PS 2, or APA Standard PRP-108.

Cost

Footing size

The major factor controlling post foundation cost is footing size. When required footing diameter exceeds the size of the largest available auger, the base of the hole must be spooned out, or a backhoe used for footing excavation. The more material that is removed for footing placement, the more time and energy must be spent tamping backfill. In addition, large concrete footings, unlike smaller concrete footings, may require a grid of steel reinforcing bars for adequate strength.

Labor

Labor costs are generally lowest with all-wood foundation systems and highest with foundations featuring poured-in-place concrete footings and collars. When the latter are used, selecting a design that enables simultaneous footing and collar placement should reduce costs.

Concrete

Ready-mix concrete for post foundations is relatively expensive because of premiums charged for delivery of small quantities (e.g., quantities less than 3 cubic yards) and jobsite inconvenience. Relying on an off-site batching plant for concrete requires better on-site scheduling and communication. Any time spent waiting for delivery by outside vendors increases on-site labor costs.

Because of inconveniences and costs associated with poured-in-place concrete footings, many builders use non-hydrated (i.e., dry) concrete mix to form both footings and collars. The assumption is that soil moisture will adequately hydrate the mix with time. There is evidence that this occurs. In two separate studies (Friday and Bahler, 1976; Ferguson and Curtis, 1978), settlement and uplift resistance of post foundations fabricated with non-hydrated concrete mix were compared with those of post foundations featuring precast concrete footings. In both studies, the foundations were loaded three months after placement, and in both studies, the posts bearing on the precast concrete footings had greater settlement. That this occurred was attributed to (1) the better post-to-footing and footing-to-soil contact obtained with the use of the dry concrete mix, (2) poor tamping of soil under the precast concrete footings, and (3) measurable hydration of the dry concrete mix over the three-month period.

The strength of concrete hydrated in-situ was monitored in two studies conducted by Bohnhoff et al. (2001, 2003). In both studies, compressive strength of in-situ hydrated concrete was very near that of the same mix when conventionally hydrated (i.e., when mixed with water before placement). In their latest report, Bohnhoff et al. note that the strength of concrete hydrated in-situ is likely a function of dry mix gradation, initial consolidation, confinement pressure, uniformity of dry mix after placement, as well as conditions related to water movement into the confined mix. Additional studies are being planned to get a better handle on these variables. Once relationships between these variables and concrete strength have been quantified, special concrete mixes and installation procedures can be developed. In the meantime, hydrating concrete in-situ should be considered an experimental practice.

Molded plastic post casings

Builder price for an MPPC ranges from slightly less than $20 for the Plasti-Sleeve and Post Cover to slightly over $50 for the Post Protector. For comparison purposes, material for a 3-ply post fabricated from nominal 2- by 6-inch, 14-foot, 0.60 lb/ft^3 CCA preservative-treated lumber costs approximately $30.

Summary

Post foundations are one of the identifying characteristics of post-frame buildings and find extensive use in deck/porch construction. In addition to the magnitude of downward, uplift, and lateral forces, post foundation design requires consideration of durability, installation, and cost issues.

Constructing for durability requires that steps be taken to prevent wood decay, metal corrosion, and frost heave. Molded plastic post casings are now widely marketed as a means to reduce consumer concerns regarding soil exposure to treated wood, and post decay and insect damage.

Non-hydrated concrete mix is frequently used in post foundation construction to level a hole base after soil compaction, increase bearing capacity of a hole base after flooding, increase bearing area under precast concrete pads, and to form concrete collars.

Cost is primarily a function of the magnitude of the downward force. The least expensive foundations are the all-wood systems. The most expensive are those featuring poured-in-place concrete footings and collars. Addition of a molded plastic post casing can add considerable cost to a post foundation.

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Web site addresses

Post Cover: www.postcover.com
Post Protector: www.postprotector. com
Plasti-Sleeve: www.homework-design inc.com

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