BESTBASE
FOUNDATION SYSTEMS

Wafflemat System Design Considerations

DESCRIPTION

The Wafflemat System is a variation of the typical post-tensioned ribbed foundation, with some significant advantages. It possesses the greatest floor stiffness of any system in its class, with sufficient strength to resist differential swelling resulting from landscaping practices, surface drainage, or flooding. In addition, the Wafflemat System does not require presoaking underlying soil pads, and there is no need for additional footings.

Over 10 million square feet of Wafflemat System slabs have been poured since 1993, without a single failure or structural callback.

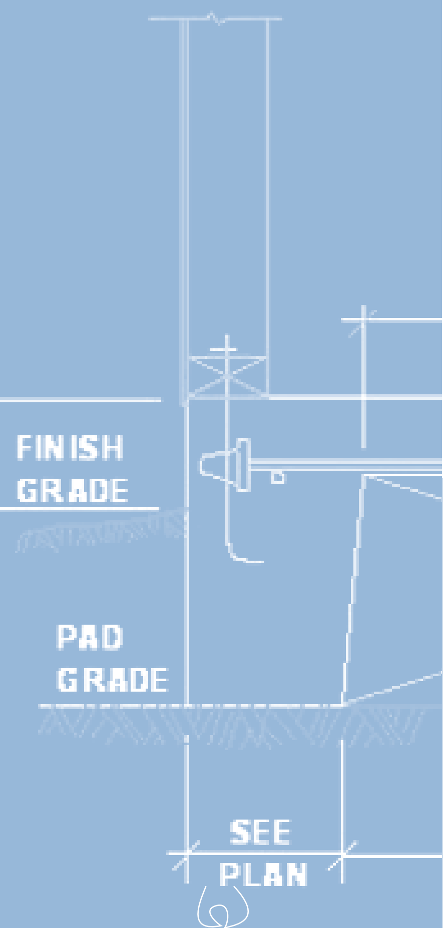
The Wafflemat System is intended for use in moderate to critically expansive soils. The design calculations for a Wafflemat System slab foundation adhere to the PTI method, with minor modifications described herein.

Dimensions & materials

The individual Wafflemat form (Wafflebox) is a 19 inch square, with a height of 8.5 inches. It is made from injection-molded polyethylene. The forms are designed to be used in arrays of up to four forms per void unit, typically with 6”-wide beams spaced 3’-8” on center. Wafflemat System foundations are formed and poured on grade, with no excavation required.

DESIGN FEATURES

The simplest foundation for residences is slab-on-grade. In perfect soil conditions, a relatively thin steel-reinforced concrete pad is adequate for a residential foundation. However, in many areas the land available for new housing construction is poor quality, and builders have increasingly relied on thicker pads to achieve acceptable performance. In many instances, builders have taken to excavating poor quality soil and replacing it with only marginally better fill in order to improve site soil conditions. Increasing the thickness of the concrete pad involves increased costs for materials and handling. Excavating and refilling takes time, labor, and energy, and often results in a tremendous volume of spoils that must be disposed of.



The original intent of the Wafflemat System was to devise a ground-level foundation that could be used on less than optimal soil, and that would save time and money in materials, labor, and ground preparation. After it was designed and implemented, other advantages became apparent.

The concept of waffle form floors is not new. Waffle slabs have been used for years in above-ground floors, where they are preferred because of their stiffness, stability, and strength. Above-ground waffle slabs are traditionally poured using expensive, reusable forms that must be disassembled, cleaned, and prepared for the next pour. This would obviously be impractical for slab-on-grade construction.

One approach to making waffle slabs-on-grade is to “carve” waffle forms into the soil. This involves tedious excavation and is highly dependent on prevailing weather conditions. The subsequent waffle grid is vulnerable to crumbling, backfilling, and damage or flooding from precipitation.

In Australia and New Zealand, builders have been pouring on-ground “waffle raft” foundations for 1 and 2 story buildings for many years. The waffle raft is structurally equivalent to the Wafflemat System, except the voids are formed using solid expanded polystyrene blocks, or “pods.” The popularity of waffle rafts persuaded the Australian Standards Committee to specifically include them in their building code (AS 2870) in 1988.

ADVANTAGES

While the waffle raft is a good idea, the Wafflemat System is even better. For instance, waste polystyrene is difficult to recycle, whereas the Wafflemat System uses polyethylene, which is 100% recyclable. Also, the polystyrene “pods” take up a lot of space because they are solid. Transportation and on-site storage of Wafflemat System components is much more efficient because the forms can be delivered in smaller loads for the same void volume, and stacked inside one another on pallets until needed. And, in windy conditions, a stack of Wafflemat forms is much less likely to blow away.

Other advantages of the Wafflemat System are revealed during the forming process. Wafflemat forms are strong enough to be walked on, which makes layout go faster, without risking damage to the forms. Also, Wafflemat forms fit together with clips which act as spacers for beams and supports for reinforcing tendons or steel. The Wafflemat System is an integrated package specifically designed to reduce labor costs and time.

One feature of the Wafflemat System that offers unique advantages over any other slab foundation system is the integrated void spaces under the concrete pad. There are three major aspects. First, since the void forming components are water-tight polyethylene, they provide an excellent moisture barrier. In soil with high water content, water cannot leach up through the bottom of the concrete pad. This is significant for protecting the structure from water damage and mold.

Second, the void spaces in the Wafflemat System accommodate differential soil expansion without excessive uplift force on the slab itself. In expansive soils, edge or center uplift is a major cause of foundation failure. A typical P/T slab on grade (ribbed or uniform thickness) is subject to the entire uplift force, and can be prone to cracking and failure. The Wafflemat System, on the other hand, is designed to allow expanding soil to “flow” upwards into the void spaces. Since the entire weight of the foundation and structure rests on the bottom surface of the beams, the uplift force from expanding soil on the foundation is considerably less, because total uplift force is a function of the area of the foundation in direct contact with the soil. In addition, the concentrated “point loading” of the entire structure’s weight onto the surface area of the beams increases resistance to soil swelling.

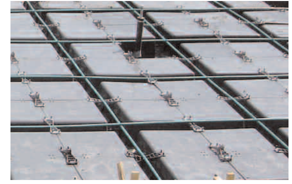
Third, the void spaces can be interconnected and vented. This is useful in areas where hydrostatic pressure is significant, because water would be free to collect in the void spaces, and then be pumped or allowed to drain out from under the foundation. Also, for basements and areas where radon gas is a concern, the interconnected polyethylene-lined void spaces could act as gas-impermeable collectors that would then be safely vented to atmosphere.

FOOTINGS AND CUTOFF WALLS

“Post-tensioned concrete foundations, designed in accordance with the PTI method, qualify as ‘designed’ footings in accordance with the IBC 2003 Chapter 18, Soils and Foundations, and UBC 1997 Chapter 18, Foundations and Retaining Walls. As such, post-tensioned slabs-on-ground are exempt from UBC 1997 Section 1806.7.2.” [Post-Tensioning Institute, 2004, “Design of Post-Tensioned Slabs-on-Ground, Third Edition”, Phoenix, AZ]

Additional footings are not necessary with the Wafflemat System, and are not recommended.

Vertical moisture barriers may be used to reduce the soil support parameters (e_m and y_m). Such barriers must be designed to virtually stop moisture migration to or from the foundation area on a permanent basis, around the entire perimeter of the foundation.



An embedded vertical moisture-impermeable membrane such as visquene should be used where impedance to moisture migration is desirable. The depth that the vertical barrier must extend below adjacent ground surface in order to be effective should be determined by the soils engineer.

In cold climates, frost-protected shallow foundation design (FPSF) techniques using rigid foam insulation have proven effective for preventing frost heave.

Conversion for PTI calculations

OVERVIEW

Section 1816 of the 1997 Uniform Building Code describes the structural design procedure for slabs on expansive soils based on specifications from the Post-Tensioning Institute (PTI). Following is the recommended procedure for designing Wafflemat System foundations according to PTI methodology.

PTI recommendations for ribbed slab design include spacing limitations for the ribs and limits on the rib depth and width.

> “Rib spacing S shall be a maximum of 15 ft. A minimum rib spacing S of 6 ft shall be used in the design of ribbed slabs; however the actual spacing may be less than that if desired.” (PTI Section 4.5.2.1)

> “...the total rib depth h shall be in no case less than 11 in., and the rib must extend at least 7 in. below the bottom of the slab (h ≥" t +7in.)” (PTI 4.5.2.2) & the rib width used in section property calculations must be limited to a range of 8 to 14 in. (PTI 4.5.2.3)

The Wafflemat system uses forms to create a waffle slab with a set geometry, with ribs typically spaced at 3’-8” on center. Calculations showed that the Wafflemat System is equivalent to a post-tensioned slab on grade that complies with PTI requirements, with ribs spaced at 6’-0” on center. The properties and post-tensioned tendon layouts for the Wafflemat slab were similar to the PTI Ribbed slab. The method described below complies with the requirements of the PTI methodology and is the design adaptation of the PTI method to the Wafflemat system.

The design process involved creating a design for the Wafflemat slab and another for the Ribbed slab, using guidelines for selecting initial values of geometry of the slab. If either of these designs exceeded allowable stress values, then an iterative process was used to bring the slab(s) into compliance. Both designs had to comply with allowable values and must also have had similar geometric section properties and prestressed tendon qualities (effective prestress, tendon locations, etc.)

PTISlab, version 2.06, from Geostructural Tool Kit, Inc (GTK) was used to perform structural calculations for a Wafflemat System and its equivalent PTI-conforming design. The results are presented below.

(This design process should be considered only an aid to performing numerical calculations. In no event will Pacific Housing Systems or MKM & Associates, its officers, owners, or employees be liable to anyone for any unfavorable conditions occurring from the use of this design methodology. Engineering judgment must be used to interpret the results of this design methodology. The engineer-of-record for a project should thoroughly review the results and must take responsibility for the use of the final calculations.)

Materials Properties

Concrete
Compressive strength was set to 4500 PSI.
(Minimum 2500 PSI is recommended for PTI method designs.)

Unit Weight was set to 145 PCF

Tendons
1/2” diameter, 270 KSI tensile strength

Slab Properties

Rectangle Geometry
Slab thickness was initially set at 5”.

A rectangular slab footprint (34 ft x 45 ft) was used.

Slab Reinforcement
A minimum prestress of 50 psi was selected.
(This is the minimum prestress value recommended by PTI.)

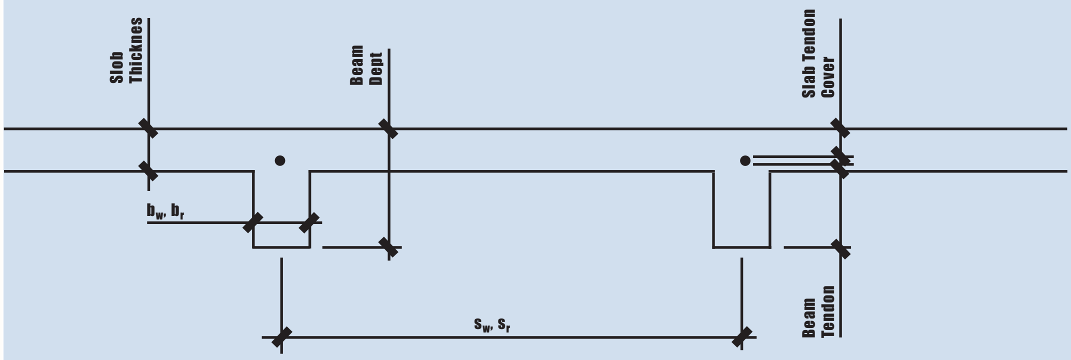


Figure 1 - Slab and Beam Dimensions.

Beam Properties

The number of beams in each direction should be the slab dimension divided by rib spacing, plus one. That is, the number of 3'-8" or 6'-0" wide spaces (depending on which analysis is being performed) that can fit into the slab, plus one, to reflect that there is also a rib at each edge.

The depth of the beams is the slab thickness plus the depth of the Wafflemat form, for example: 5" + 8.5" = 13.5".

The width of the interior beams was specified as 6" for the Wafflemat System slab, and 9.8" for the PTI Ribbed Slab. The relationship between the beam width (b_r) and beam spacing (s_r) of the Ribbed analysis and the beam width (b_w) and beam spacing (s_w) of the Wafflemat analysis is

$$\frac{b_w}{b_r} = \frac{s_w}{s_r} .$$

The width of the edge beams was set to 12", the typical minimum width for edge beams in the Wafflemat System.

One tendon was placed in each beam.

The beam tendon cover (from the bottom of the beam to the tendon) was initially set to 9" to reflect default tendon positioning in the Wafflemat System. (If design analysis required repositioning of the tendons, the beam tendon cover setting was adjusted accordingly.)

The following table provides suggestions for initial values to be entered based on the analysis type and the Wafflemat form depth. These were the initial values used in the example analysis. If either of the designs do not work using these parameters (see the "RESULTS" section), modify the geometry of the system until design requirements are met. Modifications may include changing the slab thickness, number of beams, number of tendons, or tendon cover. If the number of beams (beam spacing) and beam widths are edited,the relationship $\frac{b_w}{b_r} = \frac{s_w}{s_r}$ must still be satisfied.

ANALYSIS	SLAB THICKNESS [IN]	DEPTH OF WAFFLEMAT FORMS [IN]	BEAM DEPTH, [IN]	BEAM WIDTH, b [IN]	TENDON COVER [IN]	BEAM SPACING s [FT]
RIBBED	5	8.5	13.5	9.8	9	6
WAFFLEMAT	5	8.5	13.5	6	9	3.67

Initial Design Parameters

Soil Properties

Actual values from a geotechnical report were used for moderate, high, and critically expansive soil types. In addition, the critically expansive soil condition was enhanced by increasing the Edge Moisture Variation Distance (e_m) in order to challenge the default design. The Soils parameters were as follows:

	MODERATELY EXPANSIVE	HIGHLY EXPANSIVE	CRITICALLY EXPANSIVE	INCREASED e_m
ALLOWABLE BEARING VALUE [PSF]	2000	2000	2000	2000
MODULUS OF SUBGRADE REACTION [PCI]	100	100	100	100
EDGE LIFT [y_m]	0.5"	1.0"	2.5"	2.5"
CENTER LIFT [y_m]	0.375"	1.0"	3.6"	3.6"
EDGE MOISTURE VARIATION DISTANCE [e_m]	2.5'	2.5'	2.5'	3.2'
CENTER MOISTURE VARIATION DISTANCE [e_m]	4.75'	4.75'	4.75'	6.4'

(When identifying the edge Moisture Variation Distance, e_m, and the Differential Soil Movement, y_m, verify with the geotechnical engineer that these values have been derived using the appropriate edition of the PTI methodology. In this example, the 2nd edition was used.)