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[WHITE PAPER]

WAFFLEMAT™ SLABS PROVIDE SUPERIOR PERFORMANCE

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Principal, **MKM & Associates Structural Engineering**

April 2008

EXECUTIVE SUMMARY

This paper provides a discussion and summary of the performance of Wafflemat™ (US Patent 5,540,524) slabs on grade. The discussion contained herein is based upon studies performed by the geotechnical firm of Purcell Rhoades & Associates (ref. 1), as well as observations of the performance of installed Wafflemat foundations (Appendices A-D) over a 15-year period.

Post-tensioned, slab-on-grade construction and mild reinforced mats have been used for decades to provide adequate support for residential and light commercial construction. The original, post-tensioned slabs were constructed by trenching to form in-ground beams (or “ribs”) to provide stiffness when combined with a relatively thin slab. Subsequently, uniform thickness post-tensioned slabs (or, “UTF’s” for “Uniform Thickness Foundation”) were utilized with or without perimeter in-ground beams. The uniform thickness slabs are much thicker than slabs of the in-ground beam system, and have gained some prominence in certain parts of the world.

Post-tensioned slabs provide a mat foundation which tolerates movement to an acceptable limit. The deflection limits must be compatible with the type of construction supported by the post-tensioned slab. Deflection arises from differential swelling or shrinking of the soil underneath the slab, expressed in terms of edge lift or center lift. This deflection is mitigated by the slab stiffness and strength.

The soil contact area of the slab in both the in-ground ribbed slabs and the uniform thickness slabs is equal to the total slab area. This means that when the slab is subjected to uplift forces from soil expansion, 100% of the soil expansion area below the slab exerts force on the slab. The upward force is resisted by the slab stiffness, weight of the slab, and structure above.

More recently, a third-generation post-tensioned slab has been used in the United States and Mexico. It utilizes hollow forms, or "Waffleboxes," in a grid arrangement, the forms being placed directly on grade to create voids in a waffle-like pattern, with ribs in both directions and post-tensioning tendons located in the ribs. Concrete is then placed over the forms, creating the "Wafflemat" foundation.

Figure 1 | *Wafflemat foundation forms, ready for concrete pouring. Post-tensioning cables are positioned in the spaces between the Waffleboxes.*

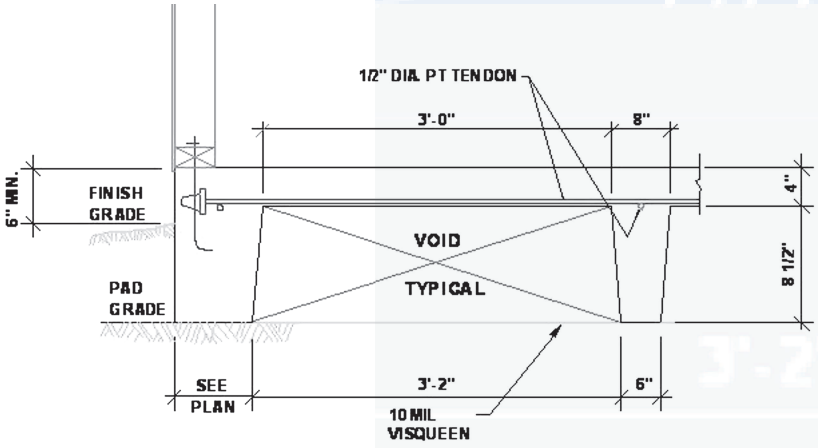


Figure 2 | *Cutaway view of the Wafflemat foundation. Only the perimeter and interior ribs are in contact with the soil, increasing the bearing stress while allowing swelling soils to expand into the void spaces between ribs.*

The Wafflemat is in contact with the ground only at the bottom of the ribs created by the Waffleboxes, a contact area much less than the total slab area. Reduction of the contact area is significant in that there is less surface upon which swelling soils can exert force and the superimposed bearing stress is increased. The resulting higher bearing stress from the structure counteracts soil swelling pressures. In contrast, in-ground ribbed slabs and uniform thickness slabs have lower bearing stress, and thus have a lower capacity to resist swelling pressures.

A study completed in 1997 (ref. 1) monitored 28 Wafflemat foundations under adverse conditions. The study showed that little movement was measured over a 12-month period for the Wafflemats, which were conventionally reinforced. The pad preparations varied greatly: some were heavily pre-soaked, others not at all. Level readings from the study showed excellent mitigation of expansive soil effects for the 28 Wafflemat foundations on soil with PI's ranging from 26 to 58.

Earlier research, noted in the 1997 study, showed that pressures caused by swelling soils were reduced by the voids in Wafflemat foundations. The soil pressures were relieved by the soil expanding up to several vertical inches into the voids. Level readings taken on top of the Wafflemats showed little movement in spite of the Wafflemat having been built on moderately dry subgrade, and subsequently partially flooded on one side to simulate extreme conditions. Over time, the moisture under the Wafflemat stabilized and became uniform. Throughout this process the level readings varied little, and the performance of the Wafflemat foundations fell well within serviceability limits.

Current practice in the design of post-tensioned Wafflemat foundations utilizes the 3rd Edition of the Post Tensioning Institute's "Design of Post-Tensioned Slabs-on-Ground." This means a Wafflemat foundation is designed to obtain the same stiffness as ribbed mats or uniform thickness slabs (ref.2).

However, the inherent performance of the Wafflemat is superior. With the same stiffness, yet reduced contact area, the Wafflemat experiences less movement. In essence this foundation system, with equivalent stiffness, experiences significantly less upward loading.

In summary, millions of square feet of residential Wafflemat have been tested by observing behavior under severe conditions for over 15 years. During this time, foundation movement due to swelling soils has proven to be well within acceptable limits. Current design practice provides post-tensioned Wafflemat slabs with stiffness equal to or better than other post-tensioned slab types, but with less susceptibility to swell pressures exerted by expansive soils. The Wafflemat provides all of the benefits of the in-ground rib and uniform thickness slabs, but with better performance provided by its geometry and smaller contact area. This approach provides a superior performing slab as evidenced by field testing and lack of structural distress at installations to date.

REFERENCES

1. "***Wafflemat Performance Study for Richland Development Corporation***"
   Purcell, Rhoades & Associates, a Geotechnical Company, Hayward, California. March 14, 1997.
2. "***Design of Post-Tensioned Slabs on Ground***"
   Post-Tensioning Institute, 3rd Edition

APPENDICES

A. ENGEO's Test Slab Research Program, ENGEOVIEW, 1993.

B. Letter: ***Ground Supported Post-Tensioned Waffle Slab***, November 1995.

C. Letter: ***Black Diamond Knolls and Estates Sandhill Project***, October 2005.

D. Letter: ***Wafflemat Foundation, A Comparison of Black Diamond Knolls Estates and Franciscan Vistas, Ewa, Oahu, Hawaii***, October 2007.

ENGEO VIEW

ENGEO'S TEST SLAB RESEARCH PROGRAM

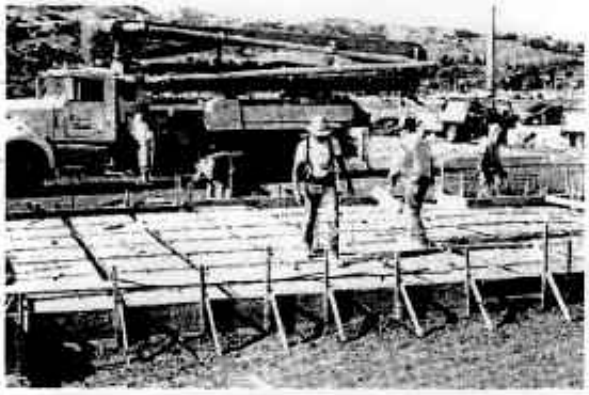
JEAN MCURIS

In July 1993, ENGEO hosted a full-day think-tank workshop on post-tensioned slabs.

Representatives of the Post Tension Institute, the construction industry, and the structural and geotechnical professions participated. A topic discussed was the compatibility of foundation slabs and superstructures in expansive soils environments, and the need for further research in this field.

Since then, Conco Cement has installed an experimental post-tensioned waffle-slab in the San Ramon Valley. ENGEO is monitoring its performance and providing geotechnical testing services. This type of slab derives its rigidity from a network of stiffening ribs in two directions, and may eventually become the foundation system of choice for residential construction.

The site for this experimental slab was graciously made available by Shapell Industries. The lot is located in San Ramon, in an area of highly-expansive clays. The slab was designed by CEC Engineering International. The method of construction, using stiff honeycombed cardboard boxes as forms for the waffle ribs, is being pioneered by Conco Cement.



The slab is 4 inches thick and the waffle ribs are 12 inches deep and 6 inches wide. The ribs are 3 feet apart in both directions.

Site preparation was kept to a minimum in order to simulate adverse subgrade conditions. It consisted only of minor cutting to provide a roughly level area; no moisture conditioning or recompaction of the subgrade soils was done.

After the slab was completed in November 1993, fine grading was done on the west side of the slab to provide drainable grades away from the slab. The ground on the east side was bermed to encourage adverse storm water ponding.

As the slab was being constructed, soil samples were obtained on its east and west sides to establish reference in-situ soil moisture profiles. Additional soil sampling will be done at least through the winter and next summer to monitor variations in the soil moisture profiles.

The performance of the slab will be monitored by ENGEO, initially on a monthly basis, by making water level measurements on a predetermined grid. An outside reference survey monument installed on a pier foundation is being used.

The data will be analyzed by ENGEO and published in conjunction with Conco Cement and San Francisco State University.

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November 09, 1995

Ground Supported Post-Tensioned Waffle Slab

I have reviewed the proposed geometry and the construction features of your waffle slab for use on expansive soil. The proposed slab is intended as an alternative to the sparsely ribbed conventional post-tensioned slab-on-ground (SOG), or the other recently introduced option - the slab with uniform thickness.

For equal material quantities, and from the standpoint of structural performance, the waffle slab has several advantages over both the uniform and the sparsely ribbed slabs. A qualitative evaluation of the features of the waffle slab is summarized below.

- The waffle slab provides a more uniform distribution of stiffness than the sparsely ribbed slab. The waffle alternative can readily eliminate the necessity of pads below interior columns, or beams below interior walls.
- The waffle slab provides a greater stiffness, and hence a greater resistance to induced soil displacement than does a uniform slab with comparable material quantities.
- The waffle slab does not suffer from the shear-lag-caused inefficiency in resisting flexural stresses, a condition which is inherent in the thin flange of the sparsely ribbed slabs, and which is overlooked by many SOG design engineers.
- The voids between the waffle ribs allow unimpeded deformation of the soil due to moisture variation. This reduces the impact of the soil's volume change on the overlain slab.
- The contact area of the waffle slab with the soil for the transfer of the loading from the superstructure and the slab weight is less than the other SOG options. The waffle slab, therefore, develops a higher stress at its interface with the soil. The higher stress

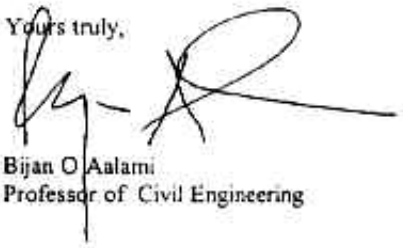
- dampens the swell of the expansive soil and results in a lesser imposed deformation of the waffle slab. This leads to an improvement in the performance of the waffle slab.

- Since the total depth of a waffle slab construction is likely be less that the perimeter beam of a ribbed slab, the waffle slab provides a lesser barrier to moisture penetration to the underneath of the SOG from the outside. It should be investigated whether it is advisable to install a curtain wall around the perimeter of the waffle slab to fend off moisture ingress.

- Until specific computational aids are developed for the design of post-tensioned ground-supported waffle slabs, it is recommended to base the structural design of the waffle slab on the spanability method for both in-service stress and deformation control.

Please call me if there is a question.

Yours truly,



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October 6, 2005

Pacific Housing Systems
696 San Ramon Blvd, Suite 213
San Ramon, CA 94526

Subject: **Black Diamond Knolls and Estates**
Sandhill Project
Antioch, California

Gentlemen:

You have requested information from our firm concerning our experience in the use of the Waffleмat Foundation System within the Antioch area where expansive and corrosive soils are present.

Richland Development has constructed almost 1200 homes over the last 10 years or so in the Antioch area. We retained the Geotechnical firm of Purcell, Rhoades & Associates to perform a preliminary study, which was reported by their firm in their March 13, 1989 and May 8, 1989 reports, which disclosed among other Geotechnical concerns, the presence of expansive to highly expansive site soil conditions with several foundation recommendations provided. Post-tension slabs included pad pre-soaking with exterior 18-inch below pad grade stiffener beams and interior stiffener beams 15 ft. on-center with the post-tension design based on the 1982 publication titled, "Design & Construction of Post-Tension slabs in Ground". As we constructed the first 250 or so of our homes, and we went through an evolution of foundation types, primarily classic post-tensioned slabs of varying thicknesses and with various levels of additional safeguards (stiffeners, cutoff walls, and perimeter French drains included) with marginally satisfactory results.

An August 2, 1995, "Geotechnical Study Update Report", by Purcell, Rhoades & Associates for the July 2, 1990 report included additional foundation recommendations with the thickened post-tension slabs Y_m values modified to 3.9-inches for center lift and 2.9-inches for edge lift with e_m values of 4-1/2 ft and 5-1/8 ft, respectively. This report included recommendations for the newly introduced Waffle Slab Foundation System, which we were aware that Conco Concrete Company was proposing for expansive to highly expansive soils as an alternate to the post-tension slabs.

Upon review of the Waffleмat Foundation concept, Richland Development Company utilized the Waffleмat System in 1995 as a test case on Lots 10 through 19, for Tract 7515 with variable pad preparation including pad pre-soak and none, visqueen and no visqueen and also with and without a sand cushion.

The Purcell, Rhoades & Associates report "Waffleмat Performance Study", dated March 14, 1997, included the results of five slab level survey readings from January 9, 1995 through January 7, 1997.

with all readings within acceptable level tolerance and no indications of movement or distress to the finished structure associated with the Wafflemat System.

Richland has used the waffle slab system exclusively on our homes since late 1995 (almost 1000 homes) and we believe that the performance has exceeded our expectations, and we would wholeheartedly recommend the use of the Wafflemat system for any area with expansive soils.

If you have any questions or would like further information please do not hesitate to contact me.

Sincerely yours,
Richland Development Corporation

Steven A. Johnson
President

Purcell, Rhoades & Associates, Inc.

Geotechnical, Environmental, & Materials Testing

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No. 16-189/7193-03
October 29, 2007

Mr. Jim Winslow
Pacific Housing Systems, Inc.
696 San Ramon Valley Road, Suite 213
Danville, California 94526

Subject: **WAFFLE MAT FOUNDATION**
Franciscan Vistas
Ewa, Oahu, Hawaii

References:
1. GeoLabs, Inc., June 23, 2006, "Geotechnical Engineering Exploration, Franciscan Vistas, Corner of Renton Road and O'Ohao Street, Ewa, Oahu, Hawaii," W.O. #5515-00.
2. Purcell, Rhoades & Associates, March 14, 1997, "Waffelmat Performance Study," Project No. 16-195/6238-02.

Dear Mr. Winslow:

At your request, we have reviewed the referenced geotechnical report by GeoLabs, Inc., and have discussed the use of the wafflemat foundation system with Mr. Francis Chan, P.E., of the GeoLabs, Inc., Oakland, California, office encouraging Mr. Chan to attend a site inspection of the wafflemat system organized by Pacific Housing Systems, Inc. Our firm has had extensive experience with the wafflemat foundation system going back to the mid-sixties, which resulted in the Reference No. 2 document, when the wafflemat system was introduced to Northern California by one of our major clients, Richland Development Corp. The enclosed letter from Richland attest to their personal experience with the wafflemat foundation system that has been used exclusively on their projects, where expansive soils are present.

On page 4 of Reference No. 2, the wafflemat system was placed as stated on Lot 10 without any ground preparation or visqueen cover upon the sun backed expansive soils somewhat comparable to the stiff to hard expansive surface soils as listed in the GeoLabs' report (Reference No. 1).

On Table III of Reference No. 2, the elevation movement over a seasonal wet to dry cycle was measured revealing the slab movement was well within the California Building Performance Guidelines for Residential Construction that specifies a maximum vertical deviation not exceeding 1/2-inch over any 20 ft. section. The foundation system on Lot 10 was in compliance with the stated tolerance and a residence was built on Lot 10 upon completion of our 1996 study with no adverse foundation movement noted to date.

We conclude, from our experience, with hundreds of waffle mat developments completed where our firm was the Geotechnical-Engineer-of-Record (GEoR), that the waffle mat foundation system is the best slab-on-grade foundation system to use where adverse subsoil conditions, including highly expansive subsoils or soft compressible soils are present.

It is a pleasure to assist in the introduction of a superior foundation system to a new market area, where the use is beneficial to all parties involved from the Land Owner, the Engineer, the Foundation Contractor, the Builder, the Municipalities, the Homeowner, and all parties that desire and expect a reliable foundation system for their development and ultimate use.

Please let us know if we can provide further details regarding the waffle mat foundation system and its performance in adverse subsoil conditions.

Very truly yours,

PURCELL, RHOADES & ASSOCIATES

Daniel J. Rhoades, R.G.E.
Principal
R.G.E.-716, Expires 06/30/2007

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