TN220_waffle_slabs_110415

POST-TENSIONED WAFFLE/JOIST SLAB CONSTRICTION[1]

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Where concrete is relatively expensive, spans are generous, and it is not critical to use a thin slab, post-tensioned waffle slab construction is likely to be the economical alternative. This Technical Note offers several views of such floor slabs, and lists the structural modeling central to their proper analysis and design.

1 – CONSTRUCTION

Waffles are generally limited to the interior of floor panels, leaving one or two of the forms out to create a solid fill around the supports. The solid fills provide added strength required for shear transfer to the supports. The fills also reduce the compression stresses at the soffit of the floor around the supports, thus avoiding the necessity of bottom reinforcement in this region. Figures 1 -1 through 1-3 illustrate typical waffle slab construction using unbonded tendons. A light top mesh over the waffles is generally the only top reinforcement at the interior of the floor panels.

FIGURE 1-1 POST-TENSIONED WAFFLE SLAB CONSTRUCTION
Each waffle stem is provided with post-tensioning tendons

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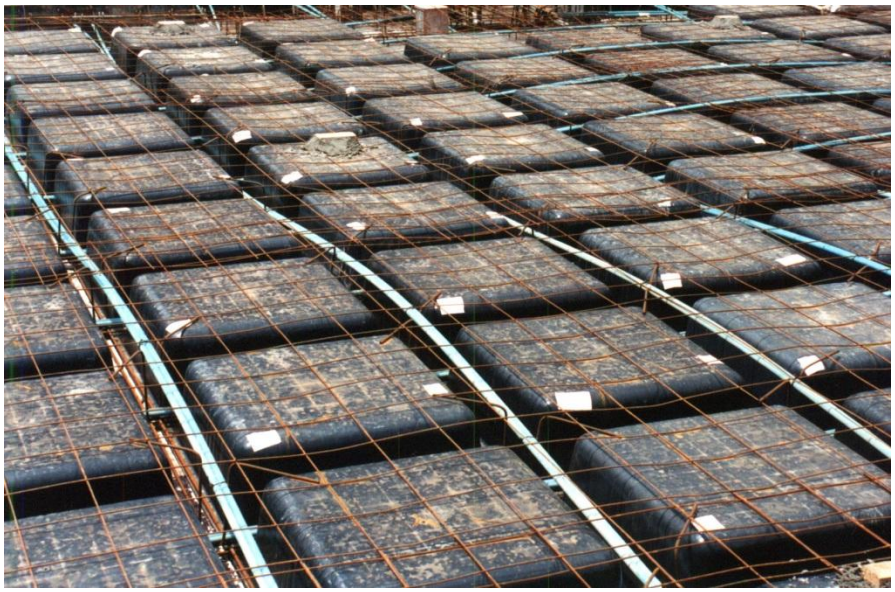


FIGURE 1-2 VIEW OF POST-TENSIONED WAFFLE SLAB CONSTRUCTION
Interior span with PT tendons in each stem

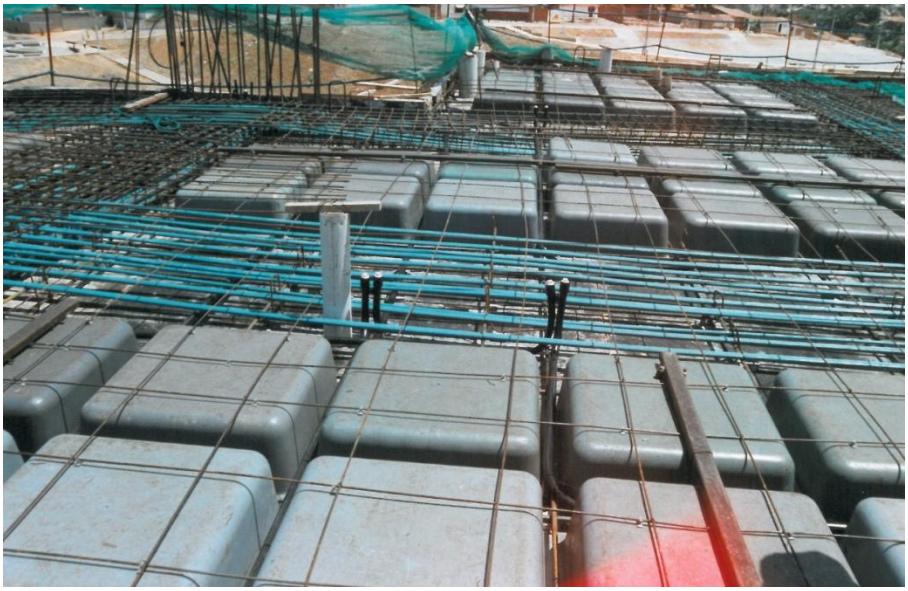


FIGURE 1-3 VIEW OF POST-TENSIONED WAFFLE SLAB CONSTRUCTION
In this construction, post-tensioning is provided in solid slab bands along the line of columns. No tendons are placed in the waffle stems

FIGURE 1-4 VIEW OF POST-TENSIONED WAFFLE FOUNDATION SLAB
Post-tensioned waffle slabs are also used for foundations of low residential buildings, where seasonal volumetric changes in the foundation soil result in unacceptable soil movement at the structure's perimeter

The number of strands in each rib is typically limited to one or two, with bottom rebar not exceeding two (#5; 12 mm). Where design requirements demand more reinforcement that is used as base rebar in the typical interior waffle stems, solid strips along the lines of supports are used to accommodate the added reinforcement. Figure 1-3 shows a waffle floor with moderately sized solid slab bands along the support lines.

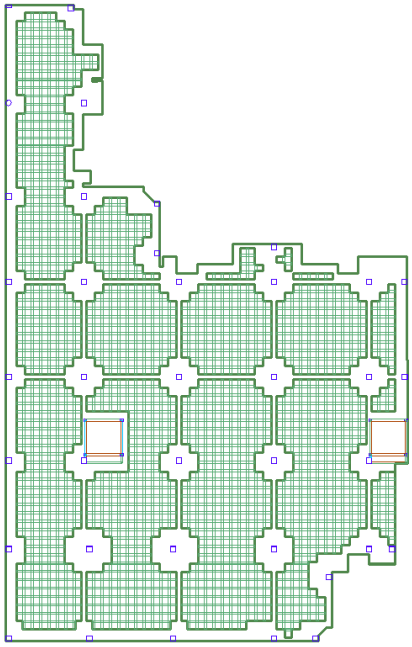


FIGURE 1-5 ANALYSIS MODEL OF A WAFFLE SLAB WITH MODERATE SIZE SOLID SLAB BANDS ALONG SELECTED LINES OF SUPPORT[3]

[3] Analysis model using ADAPT-Builder software

With larger loads and longer spans, a heavier solid slab band between the supports accommodates the overage of reinforcement from the individual waffle stems in each direction (Fig. 1-4).

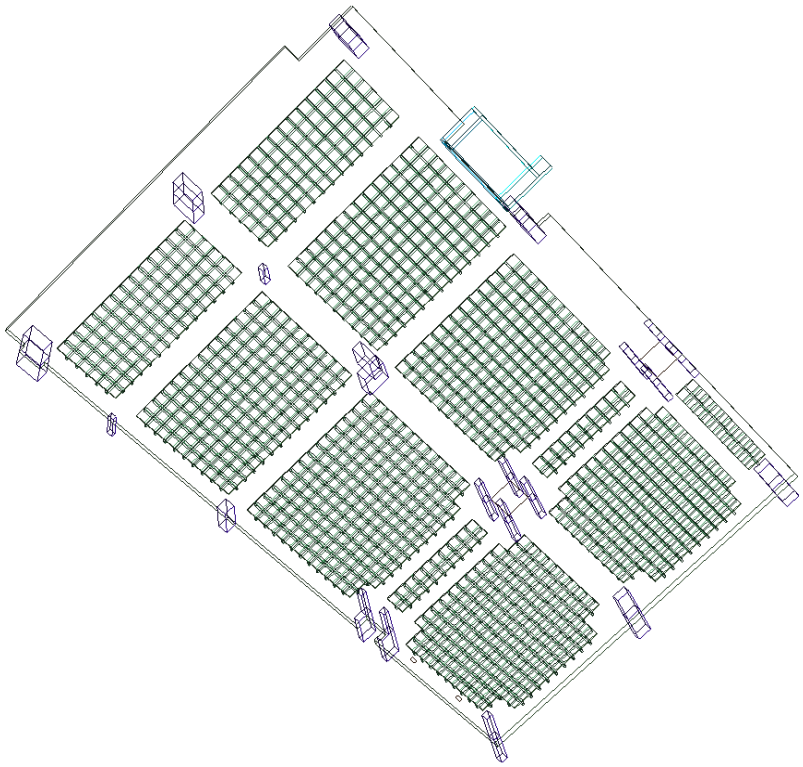


FIGURE 1-6 ANALYSIS OF A LONG-SPAN WAFFLE SLAB WITH STOUT SOLID SLAB BANDS ALONG THE LINES OF SUPPORTS

Where aspect ratio of a panel exceeds 2 (ratio of one side over the other), it becomes more economical to use a joist slab construction (Fig, 1-7). In joist slab constructions, such as the one shown in the figure, each joist is typically provided with one or more strands. The joists in the transverse direction serve to distribute the loads among the primary joists in the short direction. It is not economical to post-tension the longitudinal joists. The post-tensioning required to account for the strength of the structure is limited to the slab bands along the two long sides of the structure shown in the figure, where profiling of tendons between adjacent supports can best serve the in-service and safety of the structure. Top mesh in the slab is used to address the shrinkage and temperature considerations that are generally accounted for by precompression in slabs with smaller aspect ratios.

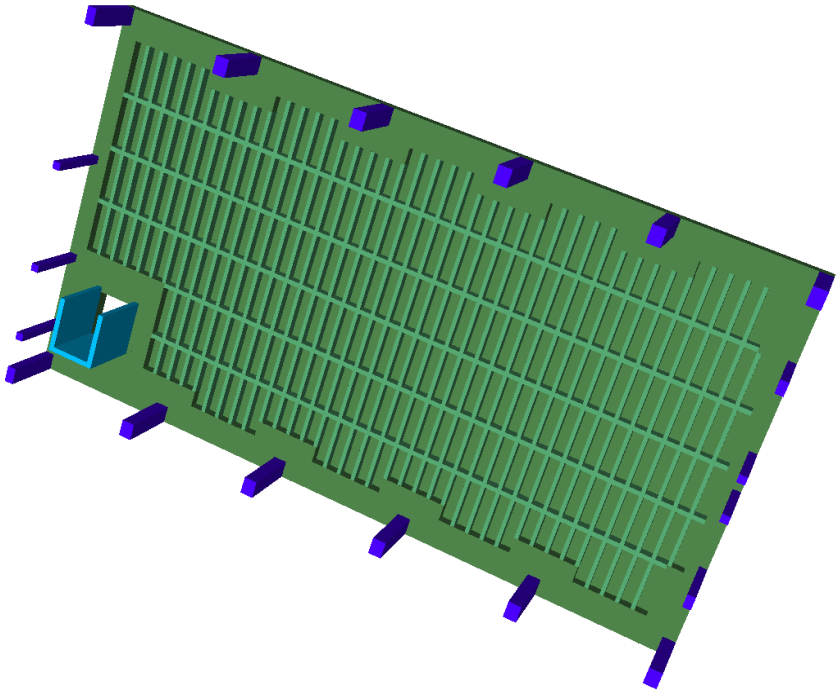


FIGURE 1-7 3-D VIEW OF A POST-TENSIONED JOIST SLAB CONSTRUCTION
Tendons are placed in the joist stems spanning the short direction and in the perimeter bands along the long side of the slab

2 – STRUCTURAL MODELING AND DESIGN CONSIDERATIONS

A principal advantage of a waffle slab or joist constriction is the composite interaction of the stem and the topping slab. The relative position of one with respect to the other provides the stiffness characteristic of a ribbed slab. Moreover, contribution of moment from post-tensioning rests on the position of tendon relative to the centroidal axis of the construction. In summary, substituting a ribbed geometry by a simplified model invariably results in losing several of the advantages of a waffle/joist construction. In summary:

- Smearing the geometrical properties of a waffle/ribbed slab, such as its second moment of area into an equivalent slab of uniform thickness is an approximation acceptable for deflection analysis of conventionally reinforced concrete, but does not work for post-tensioned floor systems. There are two reasons. First, the presence and contribution of axial pressure from tendons require that in the analysis, in addition to the second moment of area and total depth, the cross-sectional area to be retained. Second, the necessity of the three parameters, namely: second moment of area, total depth, and cross-sectional area in each of the two orthogonal directions, makes it impractical to find an equivalent slab of uniform thickness for analysis. Hence, the necessity of modeling the structure in its true geometry.
- Topping slab and stems should be modeled and analyzed as a contiguous medium, in order to properly represent the stiffness of the structure. Disjointed modeling, meaning, modeling the stems as standalone beams not monolithic from the topping slab does not adequately represent the mechanical properties of a stemmed floor. The structural modeling used in most commercially available software, where stems are considered as disjointed from the topping slab does not deliver the advantages associated with waffle/slab construction. More importantly, where the stems are shifted in the simplified analyses to have the stems' centroids line up with the topping slab grossly misrepresent the effects of post-tensioning in the structure.

- Tendons in each stem should be modeled with their actual eccentricity with respect of the combined centroid of the stem and topping slab, in order to adequately represent their impact on the design of the structure.
- To capture variation of actions in each waffle stem, the finite element cells generated for the analysis should represent each stem separately, as opposed to larger cells across two or more stems. The finite element representing the stem has different properties from the element representing the topping.

The ADAPT-Floor Pro software correctly accounts for the continuity between the stems and the topping slab. As it is illustrated in the following project example, the program carries each critical feature of a floor slab's geometry to the model for an authentic analysis and design.

3 – PROJECT EXAMPLE

The following figures describe several of the salient features of ADAPT-Floor Pro program for the analysis of a waffle slab construction.

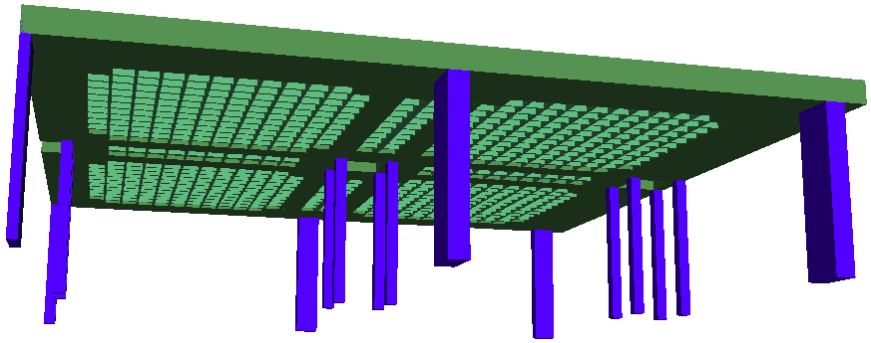
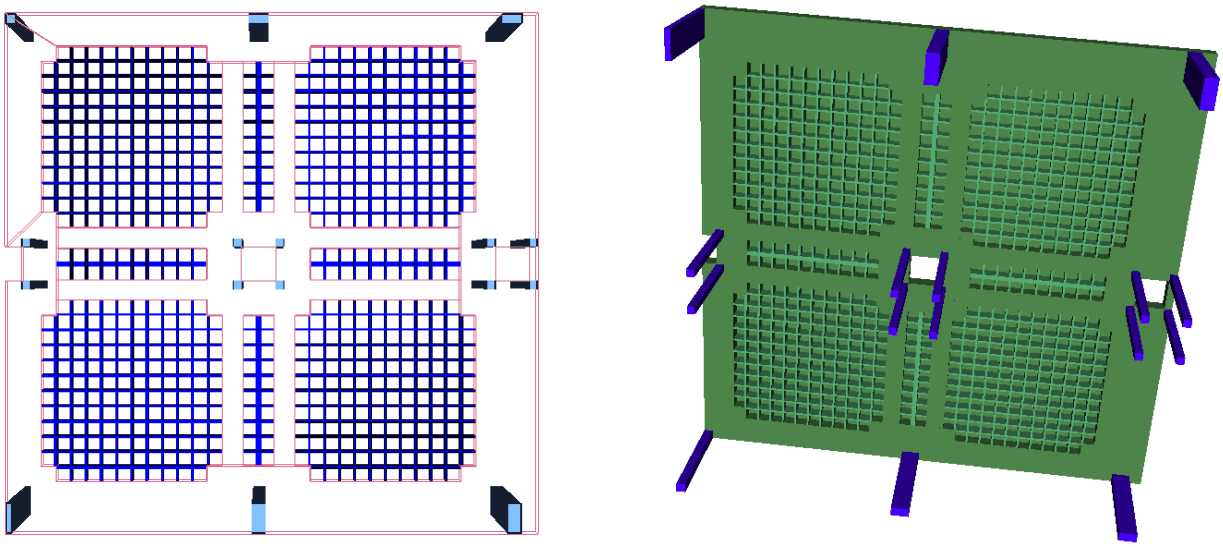
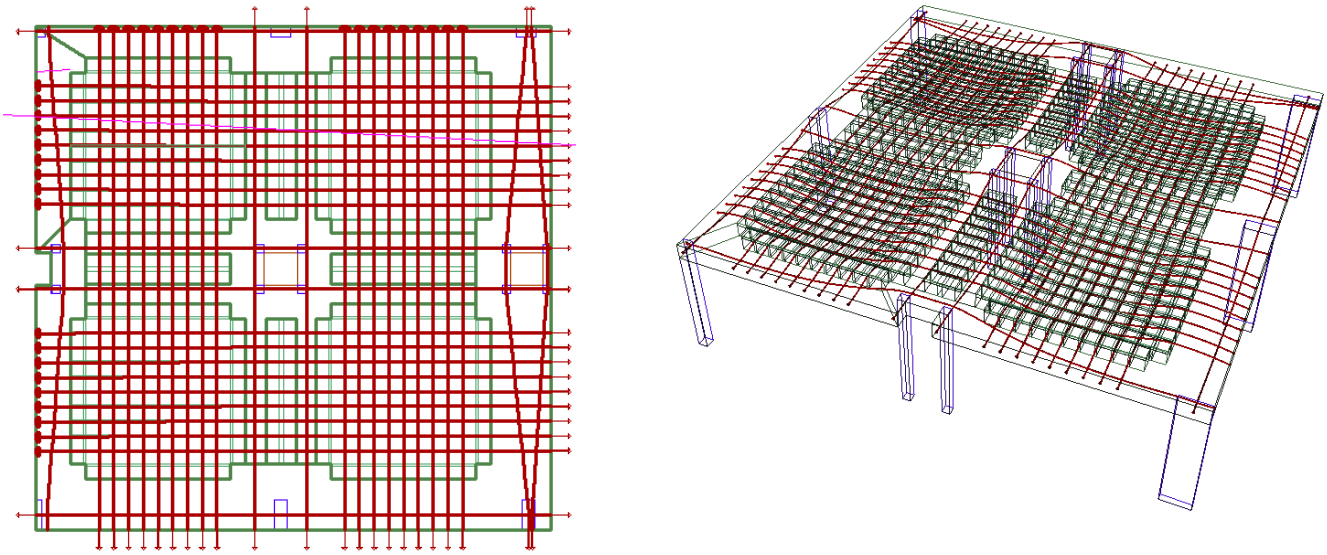


FIGURE 3-1 VIEW OF A WAFFLE SLAB CONSTRUCTION USING FLOOR PRO PROGRAM



(a) Reflected ceiling view of the model (b) Construction details

FIGURE 3-2 VIEWS OF THE ANALYSIS MODEL GENERATED IN FLOOR-PRO FEATURING THE CONSTRUCTION DETAILS OF THE PROTOTYPE



(a) Plan of tendon layout (b) 3D view of tendons

FIGURE 3-3 TENDON ARRANGEMENT IN THE WAFFLE SLAB CONSTRUCTION

A section through the analysis model generated by the program Floor-Pro and shown in Fig. 3-4 illustrates the details of the floor geometry represented by the analysis model of the computer program. The section view also shows the presence and position of tendons at the tip of each stem.

FIGURE 3-4 SECTION THROUGH THE FLOOR SYSTEM
GENERATED BY THE ANALYSIS MODEL

The finite element mesh generated by the program recognizes the stem and the void positions. Figure 3-5 shows the finite element cells generated automatically by the program for analysis.

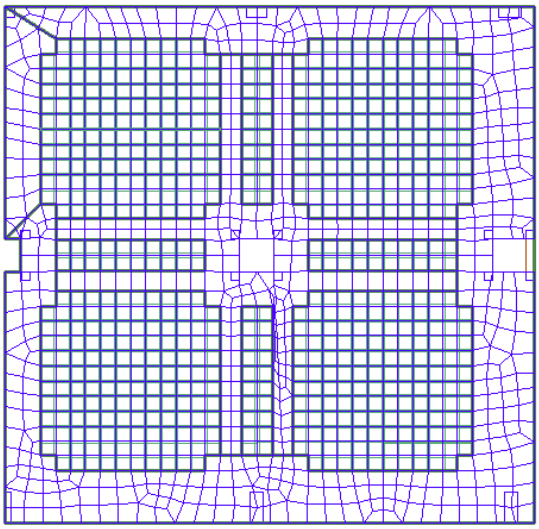


FIGURE 3-5 FINITE ELEMENT MESH USED FOR ANALYSIS AND DESIGN

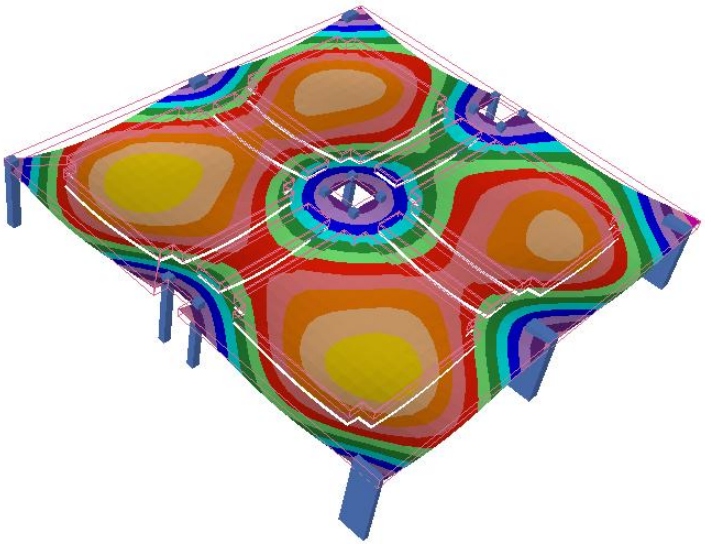


FIGURE 3-6 DEFLECTED SHAPE OF THE FLOOR UNDER SELFWEIGHT

The deflected shape of the waffle slab from the analysis is illustrated in Fig. 3-6