POST-TENSIONED WAFFLE/JOIST SLAB CONSTRICTION[1]

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

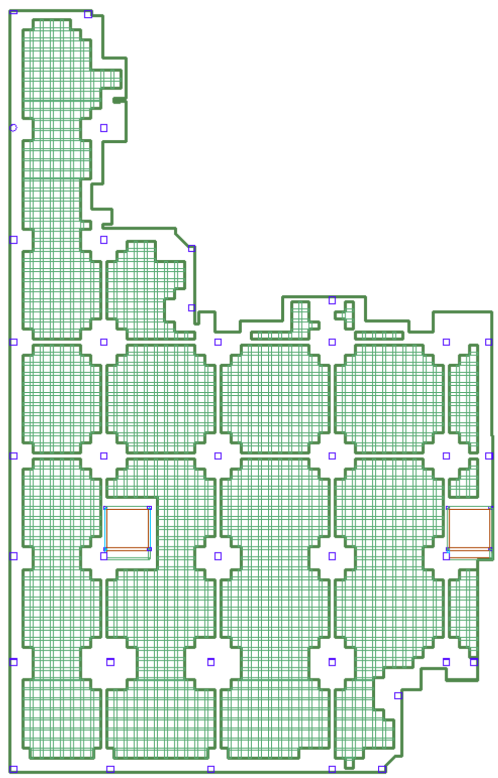
1 – CONSTRUCTION

Waffles are generally limited to the interior of a slab, leaving one or two of the forms out to create a solid fill around the supports. The solid fills provide the 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 and 1-2 illustrate typical waffle constructions 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

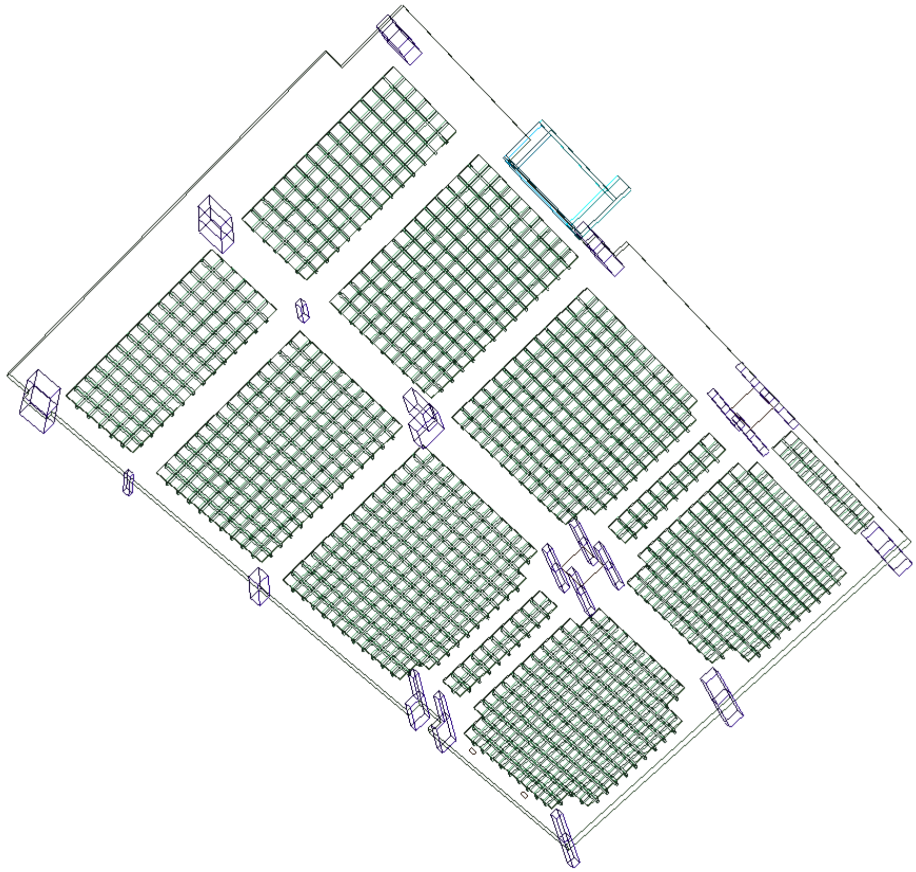
FIGURE 1-2 VIEW OF POST-TENSIONED WAFFLE SLAB CONSTRUCTION

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



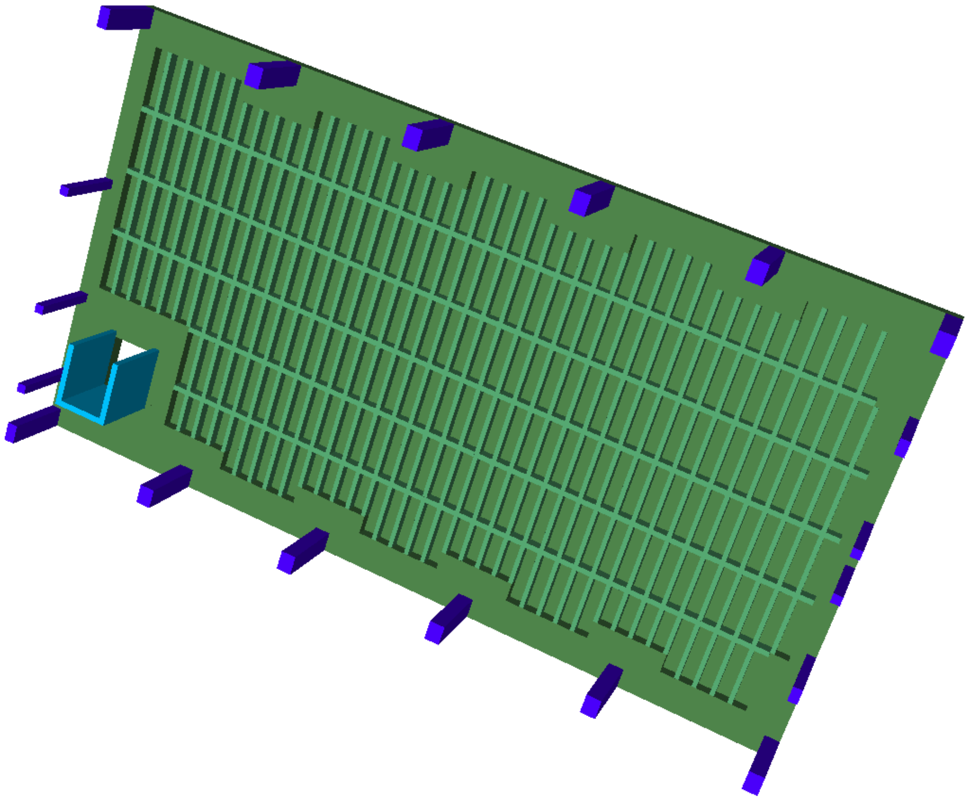
FIGIRE 1-3 ANALYSIS MODEL OF A WAFFLE SLAB WITH MODERATE SIZE SOLID SLAB BANDS ALONG SELECTED LINES OF SUPPORT

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



FIGIRE 1-4 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, 1-5). 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 genially accounted for by precompression in slabs with smaller aspect ratios.



2 – STRUCTURAL MODELING DESIGN CONSIDERATIONS

The 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, contributing moment from a post-tensioning tendon relies primarily to the position of a tendon with respect to the centroidal axis of the construction. In summary, substituting a ribbed geometry by a simplified model invariably results in losing some of the advantages that led to the selection of a waffle/joist construction in the first instance. 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 might be an approximation acceptable for deflection analysis of conventionally reinforced concrete, but does not work for post-tensioned floor systems. There are two reasons. why the approximation is not acceptable. 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 value of 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, make it impractical to find a substitute 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 system for analysis and design. 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 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 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.

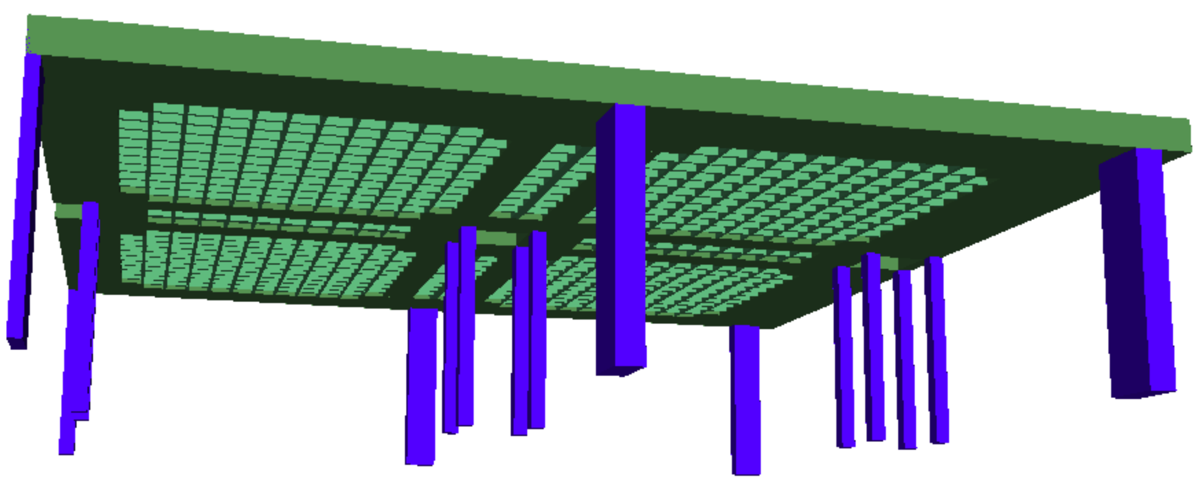
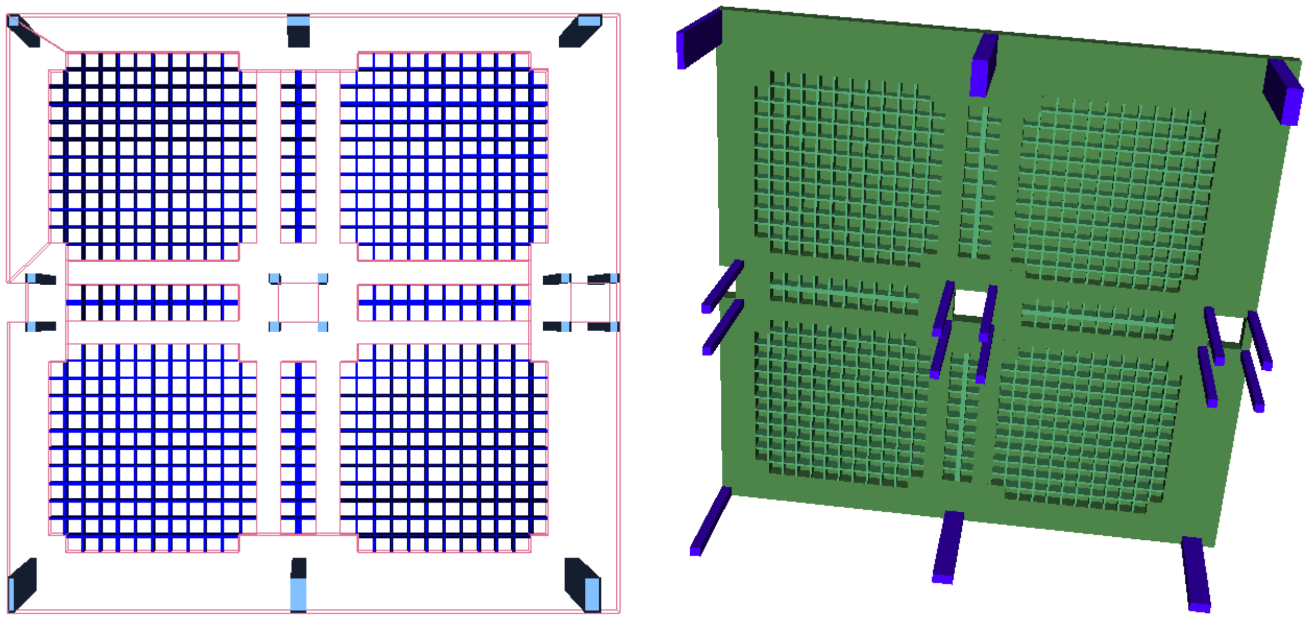
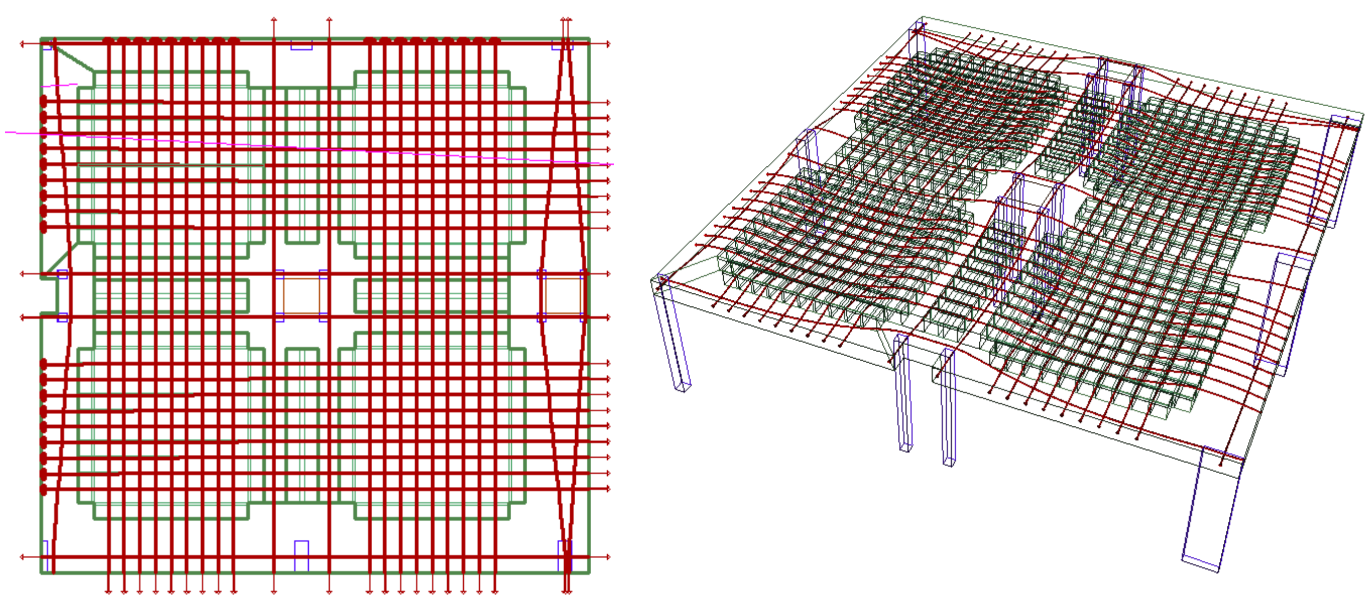


FIGURE 3-1 VIEW OF A WAFFLE SLAB CONSTRUCTOIN
USING FLOOR Pro PROGRAM



(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 ROTOTYPE



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

FIGIRE 3-3 TENDON ARRANGMENT IN THE WFFLE SLAB CONSTRUCITON

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 captured by the model. The section view also shows the presence and position of tendon at the tip of each stem.

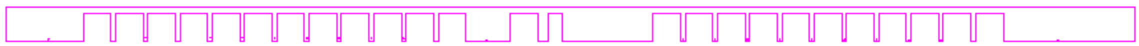


FIGURE 3-4 SECTION THROUGH THE FLOOR SYSTEM GENERATED BY THE ANALYSIS MODEL

The finite element mesh generated by the program is cognizant of the stem and void positions, thus allocating a minimum of one finite element cell to each stem segment associated with a void, and a minimum of one cell to each slab topping of a void, Figure 3-5 shows the finite element cell generates automatically by the program for analysis.

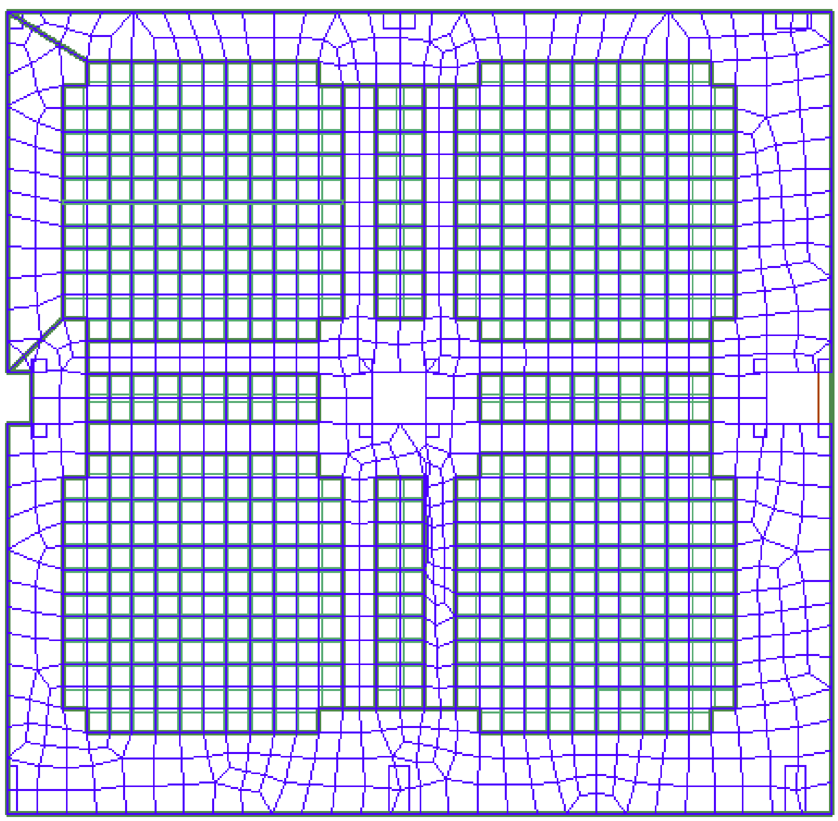


FIGURE 3-5 FINITE ELEMENT MESH USED FOR ANALYSIS AND DESIGN

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

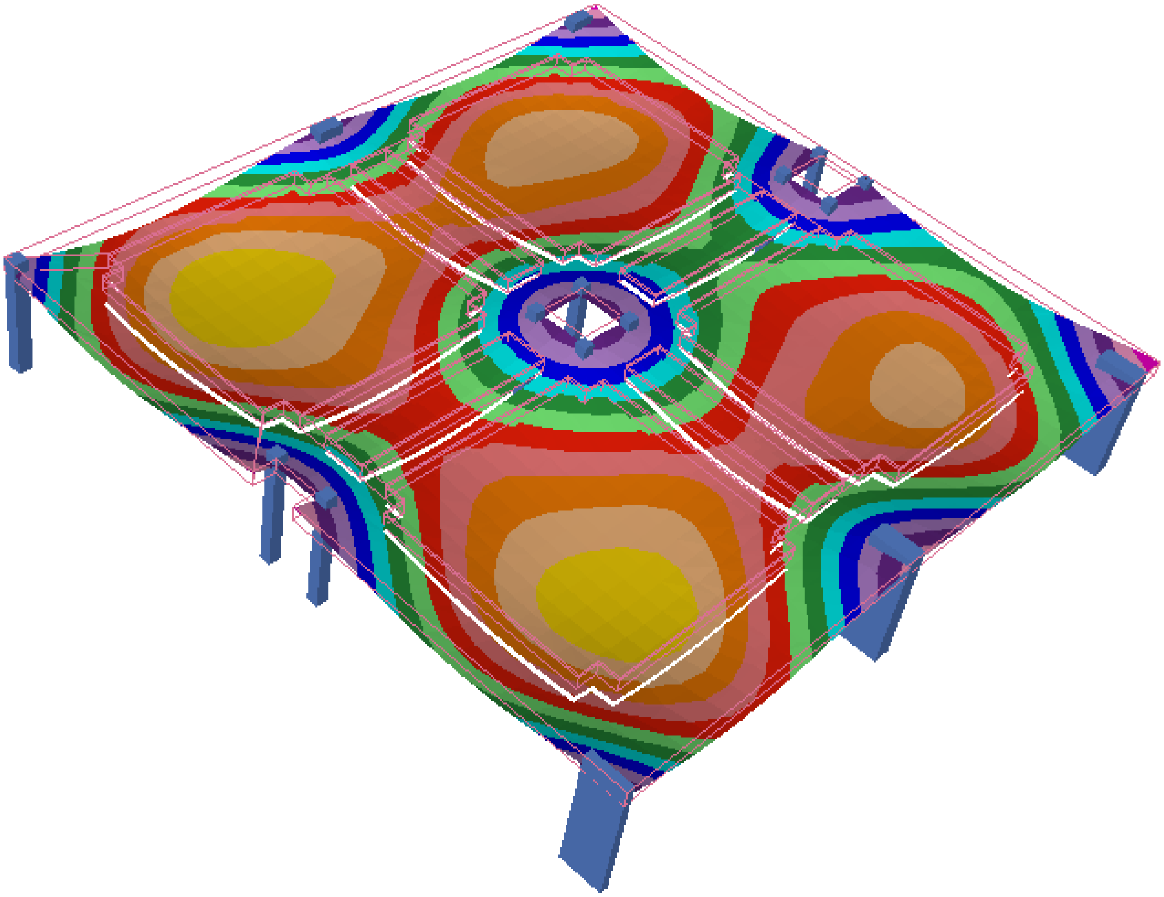


FIGURE 3-6 DEFLECTED SHAPE OF THE FLOOR SYSTEM UNDER SEFLWEIGHT