DEPTH STUDY – FLAT PLATE CONCRETE SLAB

Overview

Initial investigation of options for structural systems for this type of building revealed that the existing steel structure is typically the ideal selection. Given the height, spans, and use of the structure, composite steel beam with slab on composite deck is most often the choice because of its cost and ease of construction due to the medial project size. This structural redesign will focus on utilizing a cast in place, two-way concrete flab plate system in place of the existing steel structure.

The main discussion of this study will weigh upon the value of using a flat plate concrete system as opposed to the existing steel structural system, be it a positive value or not. The purpose for choosing a study in redesign with concrete is to learn more about the concrete design process and determine the cost and feasibility differences between a steel and concrete system. By covering the design of most of the structural elements, critical issues will be revealed that will demonstrate the norms and nuances of executing a concrete design. This design does not necessarily aim to prove that concrete is a better option, but rather intends to explore the possibilities of structural design.

In addition to exploring the concrete design process, this study will consider the cost and constructability advantages. It is possible that concrete is the better option for a structural system in some cases. Given the right conditions such as cost, time of year, and material availability, a concrete system could have an edge over the use of a steel system.
Gravity System Design

There is an intimate correlation between good structural design and cost effective design. Additionally, execution of the design is equally or more important than the design itself. A design that constructs easily can construct at a higher quality for less money. In exploring the topic of efficient design, the CRSI Engineering Data Report #30 and #32 offered a valuable perspective toward good design and execution. Also, these reports guided many factors in the structural redesign of the DSU Administration building.

At the beginning of the redesign, the PCA computer program ADOSS was used to determine what slab and column geometries were needed to support the loading conditions. My initial investigations indicated a flat slab design with drop panels would be the best option to support the applied loads. The drop panels were critical in controlling the shear stresses around the columns. Flat slab systems with drop panels, however, use a large amount of formwork to create the drop panels; formwork can often account for nearly half the cost of the concrete structural system.

In order to limit formwork costs, a flat plate system will alternatively be used. With a flat plate system, drop panels are not used and a flying truss system can be utilized to form the slabs. A flying truss system uses metal trusses to support framing. The framing can either be wood or aluminum. The trusses are supported by vertical members with adjustable heights that rest on the previously poured slab. Using a crane, this formwork system can be removed and lifted to be used on the next floor. The disuse of drop panels saves formwork costs because the slabs are then continuous with no interruptions. Also, designing the columns to be the same size on both floor-to-floor cases, as well as the columns on the same floor can be a money saver for formwork costs.

The flat plate system may save money on formwork, but it requires the use of a heavier slab than a flat slab system. Around the columns, the shear stresses create a high risk for punching shear. In order to prevent the column from puncturing the slab, appropriate shear reinforcement, slab thicknesses, and column geometries are required. In order to preserve the existing look and layout of the building, the column locations and bay widths are preserved within reason so as not to affect architectural interests.
Gravity Loading

The gravity loads used in this redesign are as they were determined for the existing design by the engineer. The existing structure was designed using the BOCA '96 code, but the loads comply with the IBC 2003 building code. The few changes pertain mostly to load combinations and mechanical load designation.

Typical Floor Loads: Mechanical Area Loads:

- Hung M/E/P: 10.0 psf
- Hung Ceiling: 5.0 psf
- Fireproofing: 5.0 psf
- Exterior wall: 1.4 klf
- NW Concrete: 145.0 pcf
- Live Load: 100.0 psf

Total Dead ≈ 185.0 psf (12” slab)
Total Live ≈ 100.0 psf

Roof Loads:

- Rigid insul.: 4.0 psf
- Built up Memb.: 13.0 psf
- Hung M/E/P: 10.0 psf
- Hung Ceiling: 5.0 psf
- Fireproofing: 5.0 psf
- NW Concrete: 145.0 pcf
- Snow Load: 20.0 psf

Total Dead ≈ 192.0 psf (12” slab) + drift
Total Live ≈ 20.0 psf + drift

Diaphragm and Columns

The design of the flat plate slab utilized the ADOSS computer design system. ADOSS is a program used often in industry and is a useful tool in
concrete design. ADOSS performs the equivalent frame method of design and uses ACI 318 standards, which are the governing rules to design by. The version of the program available uses a dated version of the ACI 318, so appropriate changes were made to account for this. From ACI 318 the minimum slab depth for a span is $L/30$ for an interior panel without drop panels. The final design of the gravity elements produced the following:

- Slab depth of 12" with 4 ksi concrete
- 22"x22" columns with 4 ksi concrete

After a preliminary floor design done by hand with the equivalent frame method, the design and calculations were replicated in ADOSS. The design results from ADOSS yield a slab reinforcement suggestion, but often the design lacks ease of construction. Bar spacing produced in ADOSS often does not allow for vibrators and certain concrete mixes to penetrate the grid.

By limiting the range of rebar sizes and governing the spacing, a more feasible design can be created. Limiting the range of bar sizes helps constructability in that it helps the rebar placer to be able to differentiate between the bars without measuring. This saves time and in turn money. Controlling the bar spacing helps avoid congestion and allows the concrete to flow around the bars better and allows room for a vibrator to access the wet concrete through the grid of rebar.

Rebar lengths for the slab were designed per ACI 318 and areas calculated with ADOSS. The resulting layout provides more steel than is required, but provides a simpler building solution and helps the slab better endure the construction loads. A summary of the rebar is shown in the tables below. Look to Appendix A to view ADOSS rebar suggestions and to view the method for selecting the final sizes.
After the moment considerations are accounted for in the slabs, the next area of concern is the shear stresses around the columns. When the ratio of the column dimensions \( (c_1/c_2) \) is less than 2.0, the allowable shear stress in slabs equals 252.96 psi. Exceeding this value could lead to the column punching through the slab. In order to control punching shear, some type of shear reinforcement is needed.

ADOSS displays resultant shear stress values in the slab at each of the column locations. A calculation of the punching shear strength of the slab indicates a value of 342 kips at interior columns, 190 kips at corner columns, and 285 kips at exterior columns when calculated per ACI Code. The largest shear value at the interior column locations is approximately 300 kips, approximately 80 kips at corner columns, and 130 at exterior columns. Theoretically, this puts the slab at all column locations well within a safe value for punching shear strength.

Though the slab may be adequate when considering punching shear, it is also necessary to check for other shear types that may be critical. Beam-
type shear can lead to a diagonal tension failure across the slab. The slab shear strength for this case per ACI Code is approximately 260 kips. This value is exceeded by some of the reaction forces (300 kips) at the column locations. Failing to meet or exceed the loading values, requires the slab to include shear reinforcement around some of the interior column locations.

Usually bent bar shear reinforcing is used in the design of shear reinforcement around columns. However, the process of bending rebar for shear reinforcing is a difficult task requiring time that slows the rebar placing process. Additionally, the use of bent bars further congests the already crowded area at the columns. Shear stud reinforcing strips are a good alternative to bent bars. Shear stud reinforcing strips are fabricated with vertical bars with anchoring heads at the top. The vertical bars are connected at the bottom to a steel strip. Shear stud strips are fastened in place in the forms before the slab steel is placed. The use of these strips provides a stronger, timelier solution to shear reinforcement around the columns. ACI 318-02 provides no design information concerning this rather new type of shear reinforcing. Due to time constraints and the mild loading situation the shear design will be left out of this study.

Floor slab deflection values are within ACI 318 Code requirements. ACI 318 allows a maximum computed deflection of L/360 for floors unattached and not supporting nonstructural elements at risk of damage due to large deflection. Also, creep deflection values were calculated with ACI 318. The largest creep value calculated for 5 years is .41". The combined value of the immediate deflection and long term deflection must maintain a value less than L/240. This deflection limit of 1.1" (L/240) is not exceeded by the .41" creep value and the .07" immediate deflection value. Immediate deflection values are readily available from ADOSS outputs, while creep values were found through calculation. To view the details of this calculation, see Appendix D.

CRSI Engineering Report 30 encourages uniform column spacing for concrete structures; it will lead to columns and slabs of the same size. Maintaining a constant column size is important in formwork cost savings. By keeping a consistent column size, formwork does not need rebuilt from column to column and can then be reused over and over again in an assembly line process.

With 22" square columns, the required reinforcement is controlled by the minimum steel area required as opposed to the design strength. This is
especially true of the columns in the upper floors, and of the perimeter columns. It is at the interior columns near the base that require an increased area of steel.

To determine the design moments, computer analysis ETABS was used to create a three-dimensional model and calculate the resulting moments from the load combinations. The longitudinal column reinforcement was designed per ACI Code, as were the horizontal ties. The size and spacing of horizontal ties come from ACI 318 section 7.10.5.

<table>
<thead>
<tr>
<th>Location</th>
<th>Interior</th>
<th>Exterior</th>
<th>Corner</th>
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<tbody>
<tr>
<td>Roof</td>
<td>Col. Size</td>
<td>Long. Bars</td>
<td>Horiz. Bars</td>
</tr>
<tr>
<td>4th</td>
<td>22&quot;x22&quot;</td>
<td>4 #10</td>
<td>4 @ 18&quot;</td>
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<td>3rd</td>
<td>22&quot;x22&quot;</td>
<td>4 #10</td>
<td>4 @ 18&quot;</td>
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<td>2nd</td>
<td>22&quot;x22&quot;</td>
<td>4 #10</td>
<td>4 @ 18&quot;</td>
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<tr>
<td>1st</td>
<td>22&quot;x22&quot;</td>
<td>4 #10</td>
<td>4 @ 18&quot;</td>
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<tr>
<td>Base.</td>
<td>22&quot;x22&quot;</td>
<td>4 #10</td>
<td>4 @ 18&quot;</td>
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</tbody>
</table>

The existing floor-to-floor heights are a typical 14' tall. The floor thicknesses include 16" to 18" deep beams in addition to the 5 ½" slab resting on top, creating a 22-24" typical floor thickness. With the flat plate system, the floor thickness is not much larger than the 12" slab. This decrease in floor thickness allows for shorter floor-to-floor heights and resultantly a shorter building height. A shorter building height saves costs for finishes, cladding, walls, stairs, and other items due to decreased quantity. Also, since the building height can be decreased, the concrete columns are designed to be 12' tall. Decreased column sizes lessen formwork and material costs.