ANALYSIS 2: STRUCTURAL INTEGRITY OF THE PARKING GARAGE WAFFLE SLABS

Structural Breadth

Problem / Opportunity Statement

The structural integrity of the parking garage waffle slabs was a construction management topic that incorporates a structural breadth. There were areas of the parking garage that had to supported, the selection torn out, and a new area poured. Because of these areas, quadrants of the three level parking garage were closed for months at a time. These closures provided less construction parking and less onsite storage.

Structural Breadth

Analysis of the structural system will be conducted in order to determine the renovation requirements of the waffle slab. If necessary, an updated or new system will be proposed. There are two options for a redesign: a two-way reinforced concrete system or a flat plate, drop panel with column capitols. Both of these redesigns will have to have a detailed analysis on loads, cost, and schedule and will provide a structural breadth to be applied to the construction management issue.

Potential Solution(s)

A potential solution is to determine if there are other ways to renovate the slab without hindering the use of the quadrant for both construction parking and material storage.

Research Steps

1. Research how the waffle slabs were renovated.
2. Determine what qualified a section to be renovated.
3. Interview DAVIS project team in order to determine the schedule requirements of the renovation of the waffle slabs.
4. Interview the subcontractor in order to determine the steps necessary for the renovation.
5. Research other means of fixing the waffle slabs.
6. Determine if there are schedule acceleration options available and used on other sites.

Expected Outcome

By conducting this research, the outcome that I expect to find is if there are other ways to renovate the waffle slab, without taking away the structural integrity.

Analysis

Throughout the three levels of the parking garage, there were sections that needed to be updated structural in order to insure they would not only hold the weight of the parking garage, but also support the floors above, including the additional of a Pent House level. In order to determine if a section needed to be updated, there were several tests that were preformed. First, a few occasions were recommendations of the engineers, even when the concrete looked sound. One type of test that was completed was using "sounding" to test every area of the garage to see if it was sound. This test consisted of listening to the tones of the reverberations caused by dragging heavy chains over the concrete. To know if an "area (contained) bad concrete, the sound became hollow." [20] The second type of test that was performed was using a hammer or pole to check the overhead parts of the waffle slab. This test produced the same hollow sounds if a section contained bad concrete. Additionally, manual inspection was complete in order to replace exposed and/or corroded rebar, along with visual spalled sections. Figure 17 provides an example of a spalled section.

Figure 17: Section of the waffle slab that was contained spalling concrete with rebar exposure.

After a section was identified by the engineer as an area that was in need of repair, they marked the section with spray paint in order to easily recognize the areas that were not sound. Then the subcontractor, Concrete Restoration Services (CRS) began to chip away at the concrete with a jackhammer. The size of the jackhammer depended on the section; however it was typically a nine to 15 pound device. They continue to chip away at the section until one of the following occurred: 1. Reached sound concrete, which is difficult to chip 2. Corroded rebar was fully exposed 3. Clean non-deteriorated rebar was found. After this, the next step was to either clean the rebar or remove it completely. To clean the rebar, the subcontractor used sand blasting, grind wheel, or a wire brush, depending on the severity of the damage. After cleaning it, the rebar would then be coated with a corrosion inhibitor. If rebar was found with more than 20% loss of section, then it would have to be removed and replaced. New rebar would be installed that is epoxy coated. Shortly after, the subcontractor forms one side of the section and has the engineer inspect the work. After approval, 5,000psi concrete was poured back into place. The shoring which was used to hold the formwork "in place until the concrete test cylinders broke at 100% of the design strength."[21]

Figure 18: Photo showing the poly-wall used in the parking garage

While all of the above steps were taking place, the area of the parking garage that they were repairing would be completely sectioned off. This meant that no other construction could take place in the area. Poly-walls (Figure 18) were used to contain the dust created in this area and prevent people from walking on a weakened section. The areas were also sectioned off due to the risk of falling debris, open holes, dust, and sound controlled. A safety requirement for the CRS employees is that respirators were required and that the shoring had to remain in place until the concrete was at 100% strength.

[20] (Lefler)
[21] (Lefler)

The schedule requirements for the concrete repairs of the waffle slabs depended on the overall condition of the concrete. Typically one quadrant, which included all three levels, was sectioned off for a period of time. DAVIS predicts that about "150,000sqft of garage was repaired every 4 months."[22] Below, Table 6 outlines the estimated schedule of the repairs. It is estimated that about 35-45% of the concrete was completely replaced.

Quadrant	Time Frame
Northeast	November 2007 – February 2008
Southeast	February 2008 – May 2008
Southwest	May 2008 – August 2008
Northwest	August 2008 – November 2008

Table 6: Schedule of waffle slab repairs

When a section was being repaired, it took away numerous things that the area could be used for. One particular thing was for storage used by several different subcontractors. Additionally, the parking garage was used for construction parking; therefore the entire level could not be used for parking. Additionally, the columns of the garage were being wrapped in steel jackets, which would have to be schedule around both the waffle slab repairs and the parking sequences. The addition of another elevator in all the quadrants had to also be scheduled around the repairs. The existing elevator concrete walls were to be hardened; therefore this was something else that played a part in the scheduling of the repairs. Overall, the schedule of the repairs interfered with numerous construction related activities, therefore it had to be planned to have the least impact on the construction progress.

Direct Design for a Two Way Reinforced Concrete System

It was determined that the parking garage waffle slab could also be repaired by replacing it with a two-way reinforced concrete system. An analysis of the system was performed in order to verify if both the cost and the schedule requirements would be better for the overall construction of Constitution Center.

First the parking garage was broken up into 4 sections. The four sections are Frame A, Frame B, Frame C, and Frame D. Frames A and C are interior frames, which Frames B and D are end frames. Please see Figure 19 for a visual representation of the areas that the frames cover. After determining the frames, we know that each of the bays are 30' by 30' and the columns are 26" by 26". The other given information can be found in Appendix F. After all the given information was determined, the values were imported into an excel spreadsheet made to calculate the number of rebar needed for each frame. These spreadsheets can also be found in Appendix F. Table 7 is a summary of the tables, which shows how many pieces of #8 rebar are needed.

Design Reinforcement for CS	
Frame A	11
Frame B	5
Frame C	14
Frame D	5

Design Reinforcement for MS	
Frame A	8
Frame B	5
Frame C	8
Frame D	5

Table 7: Summary of the number of pieces of rebar needed for each frame type

[22] (Lefler)

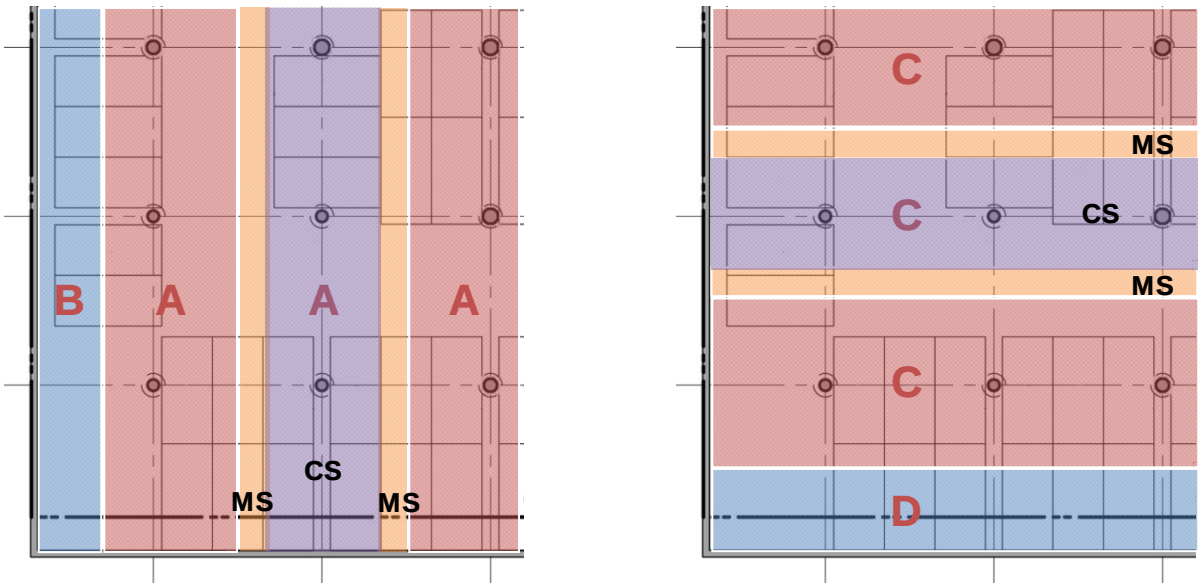

Figure 19: Diagram showing the frames used for the calculations

The footprint of each level of Constitution Center's parking garage is 202,500sqft and the slab is 12 inches thick. Therefore 202,500 cubic feet of concrete or 7,500 cubic yards is needed for each level. The total amount of concrete needed is 22,500 cubic yards. Using #8 rebar (which is assumed to come in 30' sections), Table 19 shows how many pieces of rebar are needed for each section. Since there are two Frame B and two Frame D, there will need to be a total of 20 rebar per bay (300 #8 rebar). For Frame A, 19 pieces are needed per bay (285 #8 rebar) and for Frame C, 22 pieces are needed per bay (330 #8 rebar). Therefore for each level, there needs to be 915 pieces of #8 rebar, for a total of 2,745 #8 rebar (915 are Slab on Grade).

Below, Table 8 outlines the cost of the Two Way Reinforced Concrete System. As one can see the total cost of this system redesign is slightly over $3.5 million. From Table 4, the concrete repairs and traffic coating costs $4,403,032. This total is higher, however it contains traffic coating for all three levels of the parking garage, therefore the two-way reinforced concrete system is more expensive then the basic repairs CRS performed. Additionally, the two-way reinforced concrete system is replacing all of the existing concrete and does not include the demolition cost which would make this system even more expensive.

	Quantity	Unit	Extended Total	Extended Total O & P
Structural Concrete, Ready Mix, Normal Weight, 4,000psi	22,500	CY	$1,040,875	$3,356,500
Reinforcing steel, in place, elevated slab, #8	74	Ton	$107,418.4	$136,207.36
Reinforcing steel, in place, Slab on Grade, #8	37	Ton	$54,063.29	$70,008.44
		Total	**$3,202,356.69**	**$3,562,765.80**

Table 8: Cost of Two-Way Reinforced Concrete System

Table 9 gives a brief overview of the schedule requirements for the two-way reinforced concrete system. As one can see it is roughly 171 days, which is about 9 months of work. However, the calculations below do not take in account that multiple levels can be worked on at the same time. Also, it does not factor in the schedule for demolition. If it did, it would for sure take longer than the one year that is scheduled for the repairs that CRS is currently performing.

	Quantity	Unit	Daily Output	Total (Days)
Structural Concrete, Ready Mix, Normal Weight, 4,000psi, elevated slab, pumped	15,000	CY	180	84
Structural Concrete, Ready Mix, Normal Weight, 4,000psi, slab on grade, pumped	7,500	CY	185	41
Reinforcing steel, in place, elevated slab, #8	74	Ton	2.30	33
Reinforcing steel, in place, Slab on Grade, #8	37	Ton	2.90	13
			Total	**171**

Table 9: Schedule of Two-Way Reinforced Concrete System

Outcome

After performing this analysis, it was determined that the current way that CRS is repairing the parking garage waffle slab is the most efficient. The cost would be much more to do the proposed two-way reinforced concrete system because they would have to do demolition work on the entire garage, not just sections with bad concrete and rebar. Additionally, the cost would increase due to formwork needed to properly place the concrete. Although the schedule mentioned above has the work being completed before the repairs that are currently taking place, the schedule does not take into account the demolition. Overall, it is suggested that the renovations of the parking garage waffle slab be performed the same way as planned.