Analysis #1: M Street Ramp Re-design – Steel vs. Concrete Structures (Structural & Mechanical Breadth)

Figure 4 & 5: the M Street Ramp Steel Structure

Problem Statement

The Office Building is primarily a cast-in-place (CIP) concrete structure with a post-tension system; however part of the building, specifically the structure above the M Street Ramp, is composed of structural steel framing and composite metal decking with CIP concrete flooring. Due to the structural steel and composite decking being erected after the primary structural systems are complete, separate pours must be made for the CIP concrete infill along with the erection of the steel. The underlying notion is that maintaining a CIP concrete structure is more efficient than the actual CIP building and steel structure combination. Some unfavorable issues related to the structural steel frame include the depth of the members, the lead time associated with steel shop drawings and procurement, the increasing costs of structural steel, and site congestion.

Goals

Utilizing concrete instead of the structural steel would allow the team to construct one complete level of the building as they progress upward. This would eliminate the time needed for construction on what feels like a "separate" entity of the overall building. By re-designing the structural system above the M Street Ramp, converting the steel structure to a completely concrete structure, a cost, constructability, and schedule analysis would be completed to determine the affects of the change on the project.

Research Steps

1. Structural drawings will be studied and analyzed relating to current structural steel system, specifically typical bay system between the 5^{th} Level and 10^{th} Level.
2. Obtain detailed assembly data and structural analysis methods on CIP concrete construction from general contractors and Professor Parfitt.
3. Do basic calculations to find the spacing and approximate size for proposed structure using CIP concrete.
4. Design a functional CIP concrete system.
5. Evaluate and redesign, where necessary, the mechanical system's duct located on each level between the 5^{th} Level and 10^{th} Level of the new M Street Ramp structure.
6. Develop and evaluate the construction impacts created by the new M Street Ramp structure, such as the cost estimate, schedule, and constructability. Compare steel structural system to CIP structural system and select the structure that will support the best overall project outcome.

Expected Outcome

Upon completing the research needed to effectively design and implement a new CIP concrete structure for the M Street Ramp, an evaluation can be made as to which of the two structural systems, steel or concrete, will guarantee an overall better design choice for the project.

Re-design of the M Street Ramp with CIP Concrete
(Structural Breadth Analysis)

Step 1: General Information

Please reference Appendix E, F, & G for CIP Concrete Calculations

Figure 6: Ramp's Wide Flange Beams and Columns

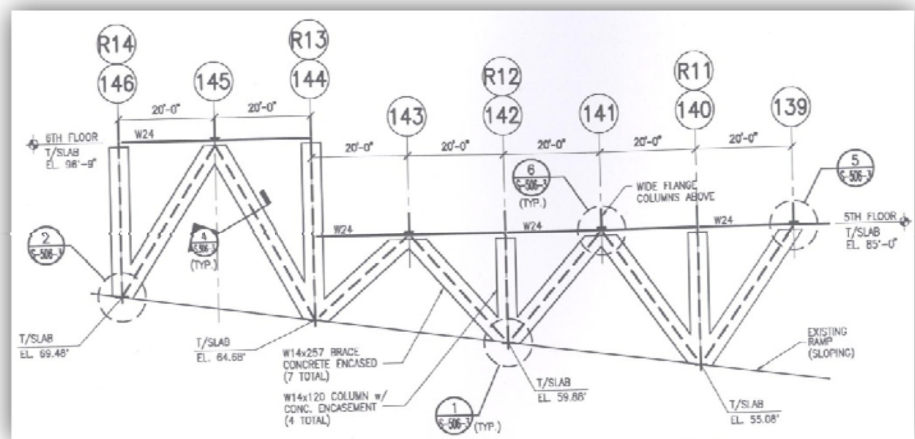
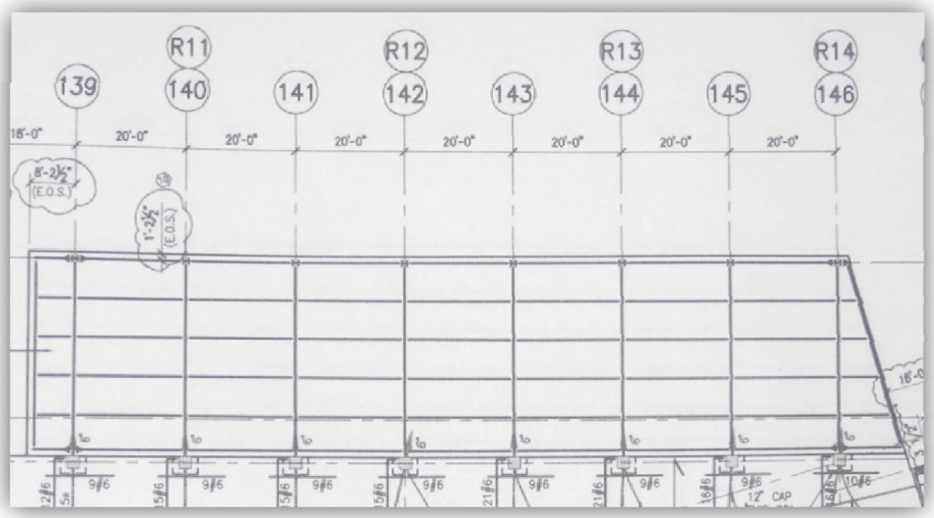


Figure 7: Ramp's Floor Plan



I began my analysis by reviewing the structural and architectural drawings of the steel structure. I made quick hand-sketches of each floor, noting the dimensions, bay sizes, and column locations to maintain all relationships between the as-built structure and my redesign. All floor heights and square-footages also remained unchanged.

Table 9: Design Criteria

Design Criteria		
Use	***SDL***	***LL***
Office	10 PSF	80 PSF + 20 PSF (Partition)

Table 10: General Steel Structure Information

Current Structural Steel System	
Floor to Floor Height	
(5th Level to 9th Level)	11'-9"
(10th Level)	12'-9"
Maximum Member Depth	24"
Maximum Composite Slab Thickness	5" + 1.5"
Space of Structure in Pendulum	30.5"
Maximum Bay Span	37'

Step 2: Design Slab Thickness, Beams, and Girders

The initial limiting factor for one-way beams with 10' spans in the ACI is slab thickness. For a one-way beam design, the slab thickness is restricted by ACI (318-08 Table 9.5a) to be h_1 > ln/ 28 for both end continuous spans.

Thickness = (8' * 12)/ 28 = 3.43" → 5"

A slab thickness of 5" was chosen in order to meet Fire Protection standards, thus only a slight change occurred to the current thickness. At this point, calculations were performed to find the moment at three locations and shear checks. The chart below displays the dimensions and reinforcing required to construct the slabs, beams, and girders for the alternative CIP concrete design.

Table 11: Alternative CIP Concrete Structure Information

CIP Concrete Structural System	
Slab Thickness	*5"*
Beam	
Width	*24"*
Depth	*19"*
Girder	
Width	*24"*
Depth	*19"*
Reinforcing:	
Slab	
Top of Slab	*#6 @ 12" (As = 0.44 in^2)*
Mid-span	*#6 @ 12" (As = 0.44 in^2)*
Shrinkage & Temperature	*#6 @ 12" (As = 0.44 in^2)*
Beam	
Bottom of Beam	*(12) - #6 (As = 5.28 in^2)*
Stirrups	*(2) - #3 : (1) @ 2", (8) @ 18"*
Girder	
Bottom of Girder	*(5) - #6 (As = 2.2 in^2)*
Stirrups	*(2) - #3 : (1) @ 2", (4) @ 18"*
Space of Structure in Pendulum	*24"*

Step 3: Design Ramp Columns & Building Columns

The steel columns will be re-analyzed and calculated as equivalent CIP concrete columns. A program known as PCAColumn is a highly popular design program used by many structural engineers to determine efficient concrete columns. Data about each column is input from size, the loads, amount and size of rebar, as well as the strength of concrete. The program then analyzes this information and outputs an interaction diagram. This diagram informs the designer of whether the columns will or will not fail as well as if the column is the most efficiently designed, from the size of the column to the size of the rebar.

Prior to using PCAColumn, a general model of the columns, reaching from the ramp to the Fifth Level, was created in STAAD Pro 2006 to determine the axial forces and bending moments, while hand calculations were preformed to find the loads acting on the building columns. The data sheet and hand calculations can be found in Appendix E, F, & G. Once the forces were found, the sizes and lengths of each steel column were analyzed from the drawings and placed into PCAColumn. From here, the loads for each column were then input into the program and the strength assumed for each of the concrete columns was 4000 psi. Each column was analyzed as a square column, while 1.5 inches of cover was used as the standard in each column for all of the rebar specifications. Once all necessary data was placed into PCAColumn, each column was designed.

Figure 8: Ramp's Wide Flange Beams and Columns in CIP Concrete - STADD Pro 2006

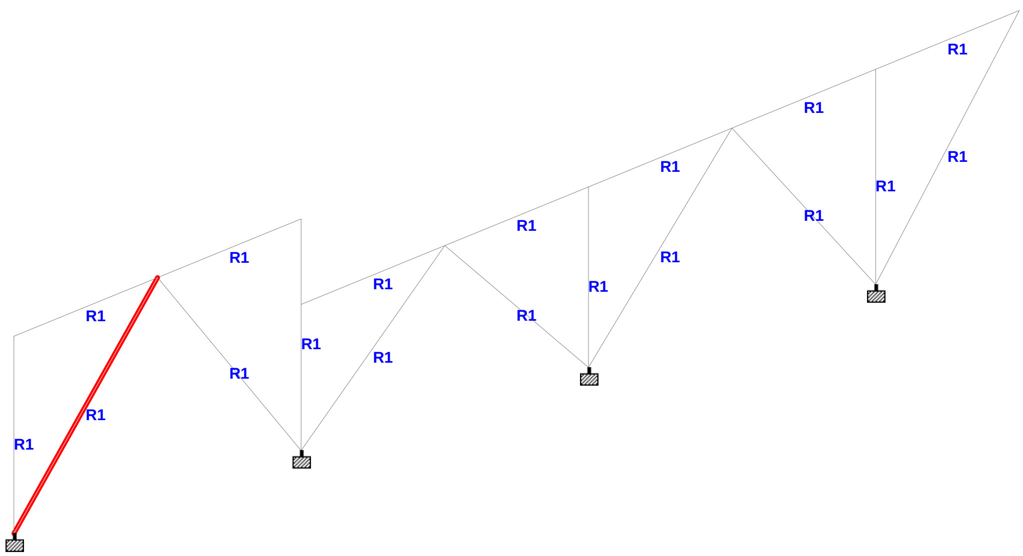
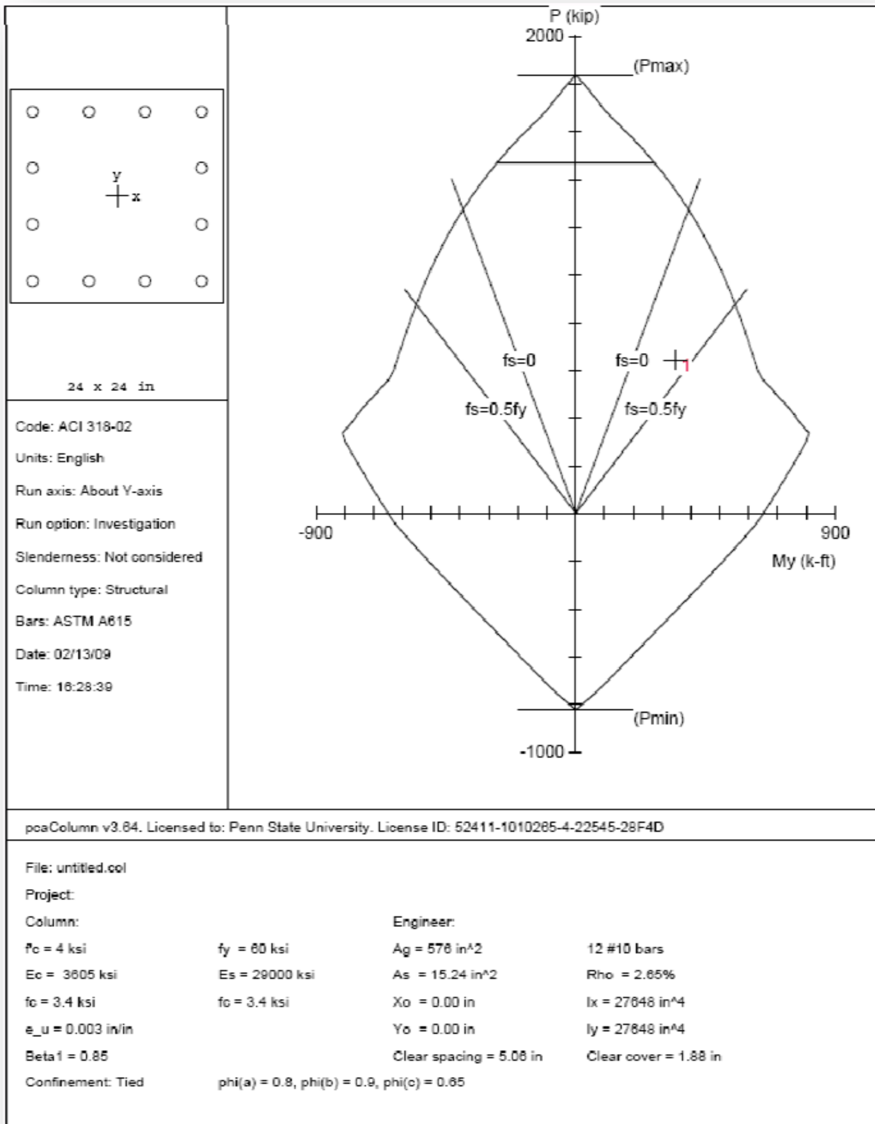


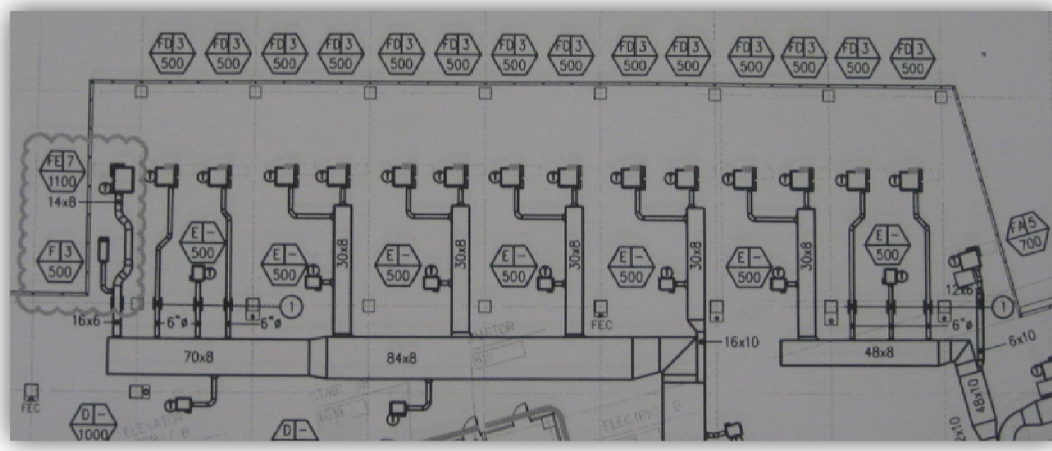
Figure 9: Example of Ramp's Columns in CIP Concrete – PCA Column



Increase Plenum Depth
(Mechanical Breadth Analysis)

To insure that the CIP concrete structure would not conflict with the M Street Ramp's VAV and ductwork components, overlays of each system were examined. As seen in the image below, there are no apparent coordination issues with the concrete structure. By retaining the existing column layout and bay sizes, the alternate structural system can easily accommodate the HVAC system.

Figure 10: Example of Ramp's Mechanical Plan



However, changing the M Street Ramp's structure from steel to concrete allowed the plenum space to be increased, as shown in Table 12.

Table 12: Plenum Depth Comparison

Plenum Depth Comparison	
Floor to Floor Height	
(5th Level to 9th Level)	11'-9"
(10th Level)	12'-9"
Steel Structure	
Maximum Member Depth	24"
Maximum Composite Slab Thickness	5" + 1.5"
Space of Structure in Pendulum	*30.5"*
CIP Concrete Structure	
Maximum Girder/Beam Depth	19"
Slab Thickness	5"
Space of Structure in Pendulum	*24"*
Increase Plenum Space	**6.5"**

Since the plenum space has increase by 6.5”, the square duct that supplies air to the VAV’s can now change in size, a Ductulator will resize the duct to the correct dimension. This will permit for better air flow to the VAV’s and allow for easier installation to the now 17”x13” square duct, instead of the original 30”x8” square duct.

Budget and Schedule Comparison

Budget

Upon completing the design of the M Street Ramp to CIP concrete, a budget and schedule were compiled using R.S. Means 2007 Cost Data. As seen in the tables below, detailed estimates were preformed for each structural system. The overall cost of the steel structure was roughly $909,000 and approximately $24.00 per square foot of the building area. The CIP concrete structure, being the less expensive of the two, had a total cost of roughly $584,000 and approximately $15.00 per square foot.

Table 13: Assumption for Budget – CIP Concrete

Budget Assumptions for CIP Concrete structure:
4000 ksi concrete
Rebar was calculated per ton
Forms are same as those used for the other pours on the site; one and four use rectangular ply-wood form

Please reference Appendix C &D for Detailed Steel & CIP Concrete Estimates

R.S. Means Steel Structure Estimate

Detailed Cost Analysis of the Steel Structure								
Description	**Amount**	**Material Price**	**Material Cost**	**Labor Price**	**Labor Cost**	**Equipment Price**	**Equipment Cost**	**Total Cost**
Rebar	21 Ton	$935.00	$19,635	$430.00	$9,030	$30.35	$637	$29,302
Composite Decking	352 CY	$108.00	$38,016	$24.00	$8,448	$11.80	$4,154	$50,618
Steel	334 Ton	$2,125.00	$709,750	$370.00	$123,580	$127.00	$42,418	$875,748
TOTAL STEEL ESTIMATE :		**$908,458**		**Location Factor: 98% Time Factor: 0.97**	**Total Labor Cost:**		**$141,000**	
Total Material Cost:		**$767,400**			**Total Equipment Cost:**		**$46,200**	

R.S. Means CIP Concrete Structure Estimate

Detailed Cost Analysis of the Cast-In-Place Concrete Structure								
Description	**Amount**	**Material Price**	**Material Cost**	**Labor Price**	**Labor Cost**	**Equipment Price**	**Equipment Cost**	**Total Cost**
Columns	161 CY	$108.00	$17,388	$32.50	$5,233	$16.00	$2,576	$25,197
Beams	518 CY	$108.00	$55,944	$50.00	$25,900	$25.00	$12,950	$94,794
Slab	625 CY	$108.00	$67,500	$24.00	$15,000	$11.80	$7,375	$89,875
Girder	136 CY	$108.00	$14,688	$35.00	$4,760	$17.25	$2,346	$21,794
Rebar	165 Ton	$935.00	$154,275	$430.00	$70,950	$30.35	$5,008	$230,233
FIP - Curb (4 use)	195 SFCA	$0.48	$94	$4.94	$963	$0.00	$0	$1,057
FIP - Slab (1 use)	4196 SFCA	$2.33	$9,777	$3.81	$15,987	$0.00	$0	$25,763
FIP - Slab (4 use)	9091 SFCA	$1.43	$13,000	$3.06	$27,818	$0.00	$0	$40,819
FIP - Girders (4 use)	5713 SFCA	$0.90	$5,142	$5.25	$29,993	$0.00	$0	$35,135
FIP - Beams (4 use)	1503 SFCA	$0.91	$1,368	$4.34	$6,523	$0.00	$0	$7,891
FIP - Column (1 use)	4078 SFCA	$2.57	$10,480	$5.85	$23,856	$0.00	$0	$34,337
FIP - Column (4 use)	1152 SFCA	$0.84	$968	$4.67	$5,380	$0.00	$0	$6,348
TOTAL CIP ESTIMATE :		**$582,947**		**Location Factor: 98% Time Factor: 0.97**	**Total Labor Cost:**		**$232,400**	
Total Material Cost:		**$350,700**			**Total Equipment Cost:**		**$30,300**	

Table 14: R.S. Means Square Foot Cost Comparison

Square Foot Cost Comparison	
M Street Ramp Square Foot	38628
CIP Concrete per SQ FT Cost	$15.09
Steel per SQ FT Cost	$23.52

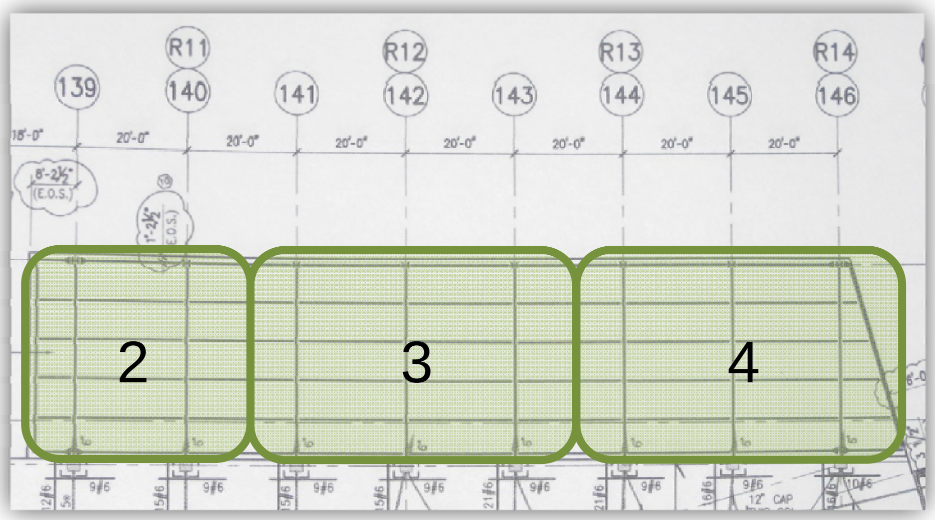
As seen from above, the total cost savings is estimated to be **$325,511**. This is a significant amount of money that could be distributed to other demands on the project (NOTE: Steel costs were obtained from Technical Assignment #2).

Schedule Impacts

Once the pricing had been completed, the next step was to evaluate the impact this proposed redesign would have on the construction schedule. The goal, again, is to compress the duration of the M Street Ramp structure. The original schedule had the steel construction beginning on March 10, 2008 with an approximate duration of 109 days to complete. The schedule for the steel structure can be found on the following page, separated into levels.

The alternate CIP concrete structural system will begin on December 27, 2007, using the R.S. Means 2007 daily crew output data for each activity, the approximate duration for completion is 81 days. The schedule for the CIP concrete design is divided into three or four pours per a level, this allows for the pour to occur at same time as the building's pour schedule.

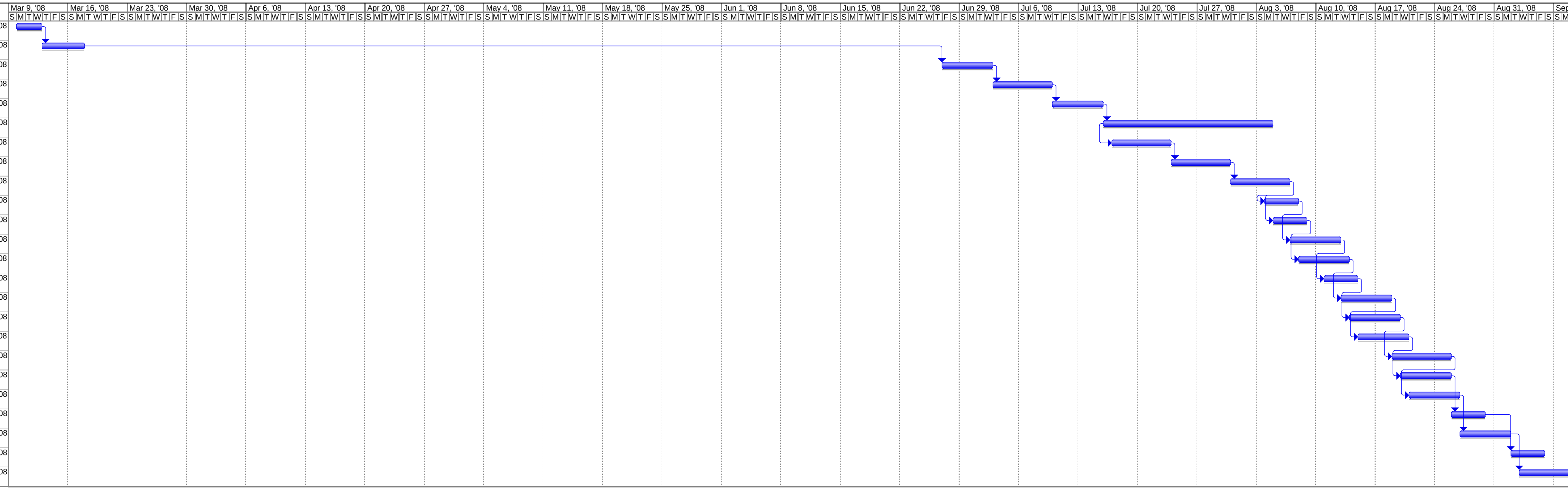
Figure 11: Pour Sequencing



The schedule is then separated further into each level; the CIP concrete structural schedule can be found after the original structural schedule.

The difference between the two structural durations is quite significant. By implementing the CIP concrete structure the project team will save about **28** days - almost a month as compared to the original steel structure duration.

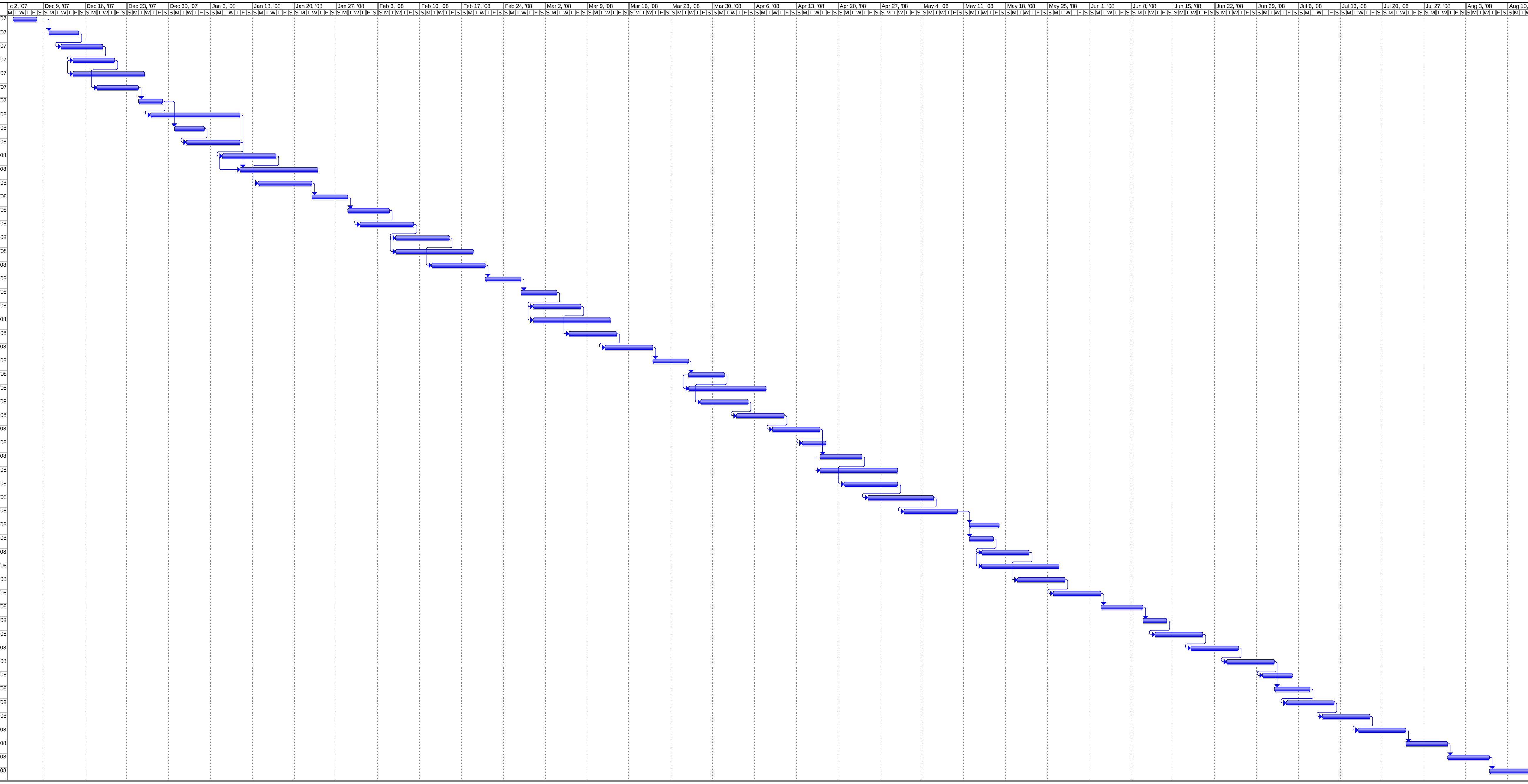
ID		Task Name	Duration	Start	Finish
1		Steel Blast Resistant Steel Columns Level 4	3 days	Mon 3/10/08	Wed 3/12/08
2		Steel Blast Resistant Steel Columns Level 5	3 days	Thu 3/13/08	Mon 3/17/08
3		Metal Deck Level 5	4 days	Fri 6/27/08	Wed 7/2/08
4		Deck Studs & Edge Angles Level 5	5 days	Thu 7/3/08	Wed 7/9/08
5		Place/Finish Level SOD	4 days	Thu 7/10/08	Tue 7/15/08
6		Columns & Beamns Level 4 to Main Roof	14 days	Wed 7/16/08	Mon 8/4/08
7		Place/Finish Level 6 SOD	5 days	Thu 7/17/08	Wed 7/23/08
8		Place/Finish Level 7 SOD	5 days	Thu 7/24/08	Wed 7/30/08
9		Place/Finish Level 8 SOD	5 days	Thu 7/31/08	Wed 8/6/08
10		Metal Deck Level 6	4 days	Mon 8/4/08	Thu 8/7/08
11		Deck Studs & Edge Angles Level 6	4 days	Tue 8/5/08	Fri 8/8/08
12		Place/Finish Level 9 SOD	4 days	Thu 8/7/08	Tue 8/12/08
13		Metal Deck Level 7	4 days	Fri 8/8/08	Wed 8/13/08
14		Deck Studs & Edge Angles Level 7	4 days	Mon 8/11/08	Thu 8/14/08
15		Place/Finish Level 10 SOD	4 days	Wed 8/13/08	Mon 8/18/08
16		Metal Deck Level 8	4 days	Thu 8/14/08	Tue 8/19/08
17		Deck Studs & Edge Angles Level 8	4 days	Fri 8/15/08	Wed 8/20/08
18		Place/Finish Main Roof SOD	5 days	Tue 8/19/08	Mon 8/25/08
19		Metal Deck Level 9	4 days	Wed 8/20/08	Mon 8/25/08
20		Deck Studs & Edge Angles Level 9	4 days	Thu 8/21/08	Tue 8/26/08
21		Metal Deck Level 10	4 days	Tue 8/26/08	Fri 8/29/08
22		Deck Studs & Edge Angles Level 10	4 days	Wed 8/27/08	Mon 9/1/08
23		Metal Deck Main Roof	4 days	Tue 9/2/08	Fri 9/5/08
24		Deck Studs & Edge Angles Main Roof	4 days	Wed 9/3/08	Mon 9/8/08



Project: Steel Strucuture
Date: Sat 4/4/09

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

ID		Task Name	Duration	Start	Finish
1		Con. Reshoring Removed from P1	4 days	Tue 12/4/07	Fri 12/7/07
2		F/R/P #1 Level 03	5 days	Mon 12/10/07	Fri 12/14/07
3		F/R/P #2 Level 03	5 days	Wed 12/12/07	Tue 12/18/07
4		F/R/P #3 Level 03	5 days	Fri 12/14/07	Thu 12/20/07
5		Columns Level 03 to 04	8 days	Fri 12/14/07	Tue 12/25/07
6		F/R/P #4 Level 03	5 days	Tue 12/18/07	Mon 12/24/07
7		Con. Reshoring Removed from LL	4 days	Tue 12/25/07	Fri 12/28/07
8		Column at Ramp	11 days	Thu 12/27/07	Thu 1/10/08
9		F/R/P #1 Level 04	5 days	Mon 12/31/07	Fri 1/4/08
10		F/R/P #2 Level 04	7 days	Wed 1/2/08	Thu 1/10/08
11		F/R/P #3 Level 04	7 days	Tue 1/8/08	Wed 1/16/08
12		Columns Level 04 to 05	9 days	Fri 1/11/08	Wed 1/23/08
13		F/R/P #4 Level 04	7 days	Mon 1/14/08	Tue 1/22/08
14		Con. Reshoring Removed from GF	4 days	Wed 1/23/08	Mon 1/28/08
15		F/R/P #1 Level 05	5 days	Tue 1/29/08	Mon 2/4/08
16		F/R/P #2 Level 05	7 days	Thu 1/31/08	Fri 2/8/08
17		F/R/P #3 Level 05	7 days	Wed 2/6/08	Thu 2/14/08
18		Columns Level 05 to 06	9 days	Wed 2/6/08	Mon 2/18/08
19		F/R/P #4 Level 05	7 days	Tue 2/12/08	Wed 2/20/08
20		Con. Reshoring Removed from 2nd Floor	4 days	Thu 2/21/08	Tue 2/26/08
21		F/R/P #1 Level 06	4 days	Wed 2/27/08	Mon 3/3/08
22		F/R/P #2 Level 06	6 days	Fri 2/29/08	Fri 3/7/08
23		Columns Level 06 to 07	9 days	Fri 2/29/08	Wed 3/12/08
24		F/R/P #3 Level 06	6 days	Thu 3/6/08	Thu 3/13/08
25		F/R/P #4 Level 06	6 days	Wed 3/12/08	Wed 3/19/08
26		Con. Reshoring Removed from 3nd Floor	4 days	Thu 3/20/08	Tue 3/25/08
27		F/R/P #1 Level 07	4 days	Wed 3/26/08	Mon 3/31/08
28		Columns Level 07 to 08	9 days	Wed 3/26/08	Mon 4/7/08
29		F/R/P #2 Level 07	6 days	Fri 3/28/08	Fri 4/4/08
30		F/R/P #3 Level 07	6 days	Thu 4/3/08	Thu 4/10/08
31		F/R/P #4 Level 07	6 days	Wed 4/9/08	Wed 4/16/08
32		Con. Reshoring Removed from 4nd Floor	4 days	Mon 4/14/08	Thu 4/17/08
33		F/R/P #1 Level 08	5 days	Thu 4/17/08	Wed 4/23/08
34		Columns Level 08 to 09	9 days	Thu 4/17/08	Tue 4/29/08
35		F/R/P #2 Level 08	7 days	Mon 4/21/08	Tue 4/29/08
36		F/R/P #3 Level 08	7 days	Fri 4/25/08	Mon 5/5/08
37		F/R/P #4 Level 08	7 days	Thu 5/1/08	Fri 5/9/08
38		Con. Reshoring Removed from 5nd Floor	5 days	Mon 5/12/08	Fri 5/16/08
39		F/R/P #1 Level 09	4 days	Mon 5/12/08	Thu 5/15/08
40		F/R/P #2 Level 09	6 days	Wed 5/14/08	Wed 5/21/08
41		Columns Level 09 to 10	9 days	Wed 5/14/08	Mon 5/26/08
42		F/R/P #3 Level 09	6 days	Tue 5/20/08	Tue 5/27/08
43		F/R/P #4 Level 09	6 days	Mon 5/26/08	Mon 6/2/08
44		Con. Reshoring Removed from 6nd Floor	5 days	Tue 6/3/08	Mon 6/9/08
45		F/R/P #1 Level 10	4 days	Tue 6/10/08	Fri 6/13/08
46		F/R/P #2 Level 10	6 days	Thu 6/12/08	Thu 6/19/08
47		F/R/P #3 Level 10	6 days	Wed 6/18/08	Wed 6/25/08
48		F/R/P #4 Level 10	6 days	Tue 6/24/08	Tue 7/1/08
49		Con. Reshoring Removed from 7nd Floor	5 days	Mon 6/30/08	Fri 7/4/08
50		F/R/P #1 Level Roof	4 days	Wed 7/2/08	Mon 7/7/08
51		F/R/P #2 Level Roof	6 days	Fri 7/4/08	Fri 7/11/08
52		F/R/P #3 Level Roof	6 days	Thu 7/10/08	Thu 7/17/08
53		F/R/P #4 Level Roof	6 days	Wed 7/16/08	Wed 7/23/08
54		Con. Reshoring Removed from 8nd Floor	5 days	Thu 7/24/08	Wed 7/30/08
55		Con. Reshoring Removed from 9nd Floor	5 days	Thu 7/31/08	Wed 8/6/08
56		Con. Reshoring Removed from 10nd Floor	5 days	Thu 8/7/08	Wed 8/13/08



Project: CIP Concrete Schedule
Date: Thu 2/19/09

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Constructability Comparison

The project site will remain unaffected by the alternative CIP concrete structure at the M Street Ramp. Since the building is CIP post tensioning, the project's site plan already accommodates for concrete construction, thus allowing the project team to maintain the current site layout plan. However, the set back to this alternative structure is caused by the Ramp being closed during construction, thus allowing no individuals to access any of the parking allotted for the other two buildings. The Ramp will be closed for three weeks due to the formwork needed to construct the 5th Level of the structure. Once the formwork is removed, reshores will be placed and designed per the structural engineers specifications to accommodate a single driving lane for cars under the CIP concrete structure above the ramp. The reshores will not be removed from the ramp until construction has begun on the 10th Level.

To accommodate for this, alternative parking at a nearby parking garage or Metro Passes will be given to the individuals during the three weeks the M Street Ramp with be closed due to the 5th Level construction. Pricing for each can be found in the charts below, and a general estimate of about 350 parking spaces was assumed for the parking garage.

Table 15: Cost of Parking for Ramp Closure

Cost of Parking Due to Ramp Closure	
Avg. Cost of Parking in DC per day	$23.00
Duration (days)	15
Number of Parking Passes	350
Total Cost	**$120,750**

Table 16: Cost of Metro for Ramp Closure

Cost of Metro Due to Ramp Closure	
Cost of One Day Pass per day	$7.80
Cost of Parking at Metro Station	$4.25
Duration (days)	15
Number of Metro Passes	350
Total Cost	**$22,313**

The costs shown above that allot for alternative parking/transportation for the M Street Ramp closer must be applied to the total estimate of the CIP concrete structure. Thus, depending on which method of parking/transportation is chosen to be given to individuals, the overall budget for the CIP concrete structure is a maximum of **$704,300** or a minimum of **$605, 900**, these values can be found in the figure below.

Table 17: Adjusted Cost to CIP Structure for Ramp Closure

Adjusted Cost of CIP Structure Due to Ramp Closure	
Total CIP Structure Estimate	$582,947
Added Cost of Parking Due to Ramp Closure	$703,697
Added Cost of Metro Due to Ramp Closure	$605,260

Even through adjusting the CIP concrete structure's budget for the 3 week M Street Ramp closer, the cost difference between the two structural systems is **$204,700** with CIP concrete still being the less expensive of the two.

LEED Impact

Selecting the most appropriate structural system should be determined not only by cost and schedule, but also the environmental impact of the system throughout its lifecycle. In terms of concrete vs. steel, there is much debate as to which material is more 'green'.

Proponents of steel note that it is a 100% recyclable material and it can be recycled continuously without degradation to its physical properties. Steel also allows for clean, dust-free construction with minimum site waste 11. Furthermore, when steel structures reach the end of their life span, the members can sometimes be reused rather than scraped.

While steel has many favorable attributes, concrete can also be considered an environmentally friendly material. Concrete can be made from local materials, namely the fine and coarse aggregates used in the mix. Concrete is also recyclable in that it can be crushed and used for fill and aggregate in asphalt among other applications. Besides being 'green' in itself, concrete also reduces wastes from steel production. Fly ash and blast-furnace slag, by-products of steel production, can be used in concrete mixes rather than being disposed in landfills 12.

In general, research suggests that the environmental benefits of steel construction are comparable to those of concrete construction. Given this conclusion, either structural system would adequately maintain the sustainable design ideals of the LEED rated Office Building.

Conclusion & Recommendations

Through the detailed analysis and design of an alternate structural system, it is concluded that CIP concrete structure would be a viable option for the Office Building's M Street Ramp. By selecting the CIP concrete structure the schedule would compress and unify the overall construction of the superstructure, thus allowing for one complete level of the building to be constructed. It will also decrease the budget for the M Street Ramp, even with the adjustments made for parking. Plus the increase in plenum space will also contribute to a smoother coordination between the MEP trades in that section of the building. Lastly, due to a shorter duration, it is possible to reduce the number of days for crane rental cost.

In contrast, while a concrete system may be viable, it is not necessarily the best structure for the building. Even though the steel system has a longer duration and cost more, it does offer a smoother construction process than the CIP concrete structure. Overall, the original steel system is considered to be the most appropriate structure through its value to the owner.