

RESIDENCE INN

BY MARRIOTT

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Analysis 1: Structural Design of Underground Garage - Breadth

Background

The underground garage is entirely constructed of cast in place concrete with an 8” slab and 5.5” drop panels at the columns totaling a 13.5” slab at the deepest sections. The cast in place floor area was averaged to 14,700 SF per floor. The rebar in the beams was estimated by the specifications in the drawings by using 2/3 the length of the beam for the top rebar and the full length for the bottom rebar. An original floor plan can be found in Appendix D. This system was designed to minimize the floor depth, to be able to help maximize the total number of floors in the building, enabling construction of 15 floors compared to 14 floors. Unexpected water problems associated with excavation pushed the project behind schedule. The added time for curing the cast in place concrete to the full 28 day strength only slowed the project more. The project has a relatively tight schedule of approximately a year and a half, so any time that can be saved once the schedule is behind, needs to be saved or the project will not finish on time.

One possible solution is to switch the cast in place concrete to a Filigree concrete system. Filigree virtually eliminates formwork and is very easy and quick to install. This system uses a small amount of shoring to support the pre-stressed prefabricated Filigree panels. The Filigree panels once supported act as the “formwork” for the topping slab that ties the system together structurally. The Filigree panels come with shear studs imbedded and can be used as a flat plate system or a slab and beam system.

Goal

The goal of the re-design is to decrease the floor depth, materials, and cost while accelerating the construction sequence utilizing the flat plate system of cast in place concrete or the pre-cast Filigree panels of either flat plate or a slab and beam system as seen on the following page. The Filigree panels are thin pre-stressed concrete panels that are prefabricated then tied together by a topping slab that is poured on site. This reduces the amount of poured concrete and the curing time needed before shoring is removed. The topping slab concrete needs to be at 75% of the full strength for the shoring to be removed; compared to the full 28 day strength as originally specified by the structural engineer. There are two systems that can be designed: a flat plate or a slab and beam. The flat plate system, Figure 7 on the following page, has all flat wideslab panels tied and grouted together and composite with the topping slab. The slab and beam system, Figure 8 on the following page, uses a thinner slab system as described earlier, in conjunction with one way beams. The drop down beams are tied to the flat wideslab panels to create the structure.

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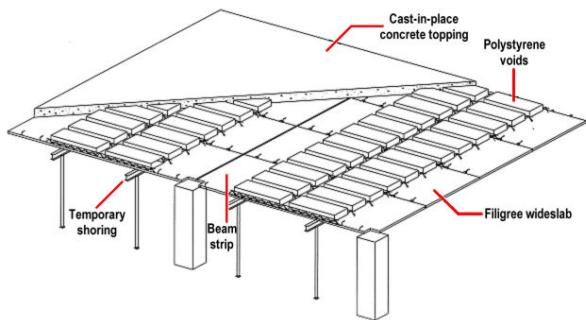


Figure 7: Flat Plate Filigree System

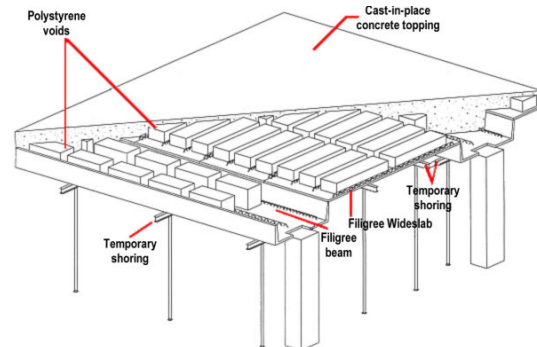


Figure 8: Slab and Beam Filigree System

The design will compare three systems: 1) the original cast in place slab with drop panels and stud rails to 2) a flat plate system with only stud rails and no drop panels to 3) the pre-cast Filigree system (either flat plate or slab and beam). Each design will be compared based on:

- Lbs. / SF of Steel
- Total steel tonnage
- Steel Cost
- CY of Concrete
- Depth of slab, beam, and drop panel
- Concrete Cost
- Total formwork SF
- Formwork Cost
- Total Duration

Resources

- Structural Engineering Faculty – Professor Lepage
- Midstate Filigree Systems website and contact – Gene McDermott
- Healy Long & Jevin, Inc. contact – Mike Jevin
- Balfour Beatty on-site staff
- Textbook: Design of Concrete Structures, 13th ed.

Structural Analysis

Please refer to Appendix D for Structural calculations and comparisons.

❖ *Step 1: Standardizing the Column Grid*

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- Parking Level P-1 was chosen for the analysis because the columns run through the lowest parking level and the first floor. This level also has the most common steel characteristics between the first floor and the first parking level; it shows an average of the steel layout per floor of the P-2, P-1 and 1st floor. This level was previously estimated during the detailed structural take off in Technical Report 2 and was deemed accurate to the original with help of the onsite Balfour Beatty staff.
- The column grid was “standardized” to form a typical spacing. The current grid has column lines that are off-set from one another. To perform this breadth study a standardized grid was used for ease of calculations based on the recommendation of Professor Lepage.
- The average bay size was found to be 27' x 17'.

❖ *Step 2: Stud Rail Design*

- As noted in the structural drawings the Live Load used was 40 PSF.
- For this design the columns were not being re-designed and the Dead Load is assumed to be only the weight of the concrete slab of 150 PCF.
- Based on page 436 in the concrete design textbook and lengths of the spans, it was determined that the minimum allowable slab depth could be 9.6”, rounded to 10”. This means the Dead Load is 125 PSF.
- The Live and Dead loads were then factored by multiplying by 1.6 and 1.2 respectively, according to ASCE 7 – ‘05, and was found to be 214 PSF.
- Next the distributed load, effective width, and shear were found at the critical distance from the column face. The shear force was determined to be 234.4 kips which is significantly more than the tributary load at the columns and means that stud rails were not needed.
- This analysis was double checked, by recommendation of the structural practitioners, using Decon Studrails. This online calculation verified that stud rails were not necessary. The calculation sheet can be found in Appendix D.

❖ *Step 3: Flat Plate Design*

- As determined in the stud rail design the minimum allowable slab depth of 10” was used as well as a steel depth of 8.5” assuming a 1.5” cover.
- A picture of the averaged column grid and frames analyzed can be seen on the following page.
- All columns were assumed to be 18” x 30” which is the most common column size as well as 10 column lines.
- All frames were analyzed using the direct design method.
- For each frame analyzed the moment at the frame was calculated then the interior/exterior positive and negative moments were calculated.

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- With these moments, the column strip and middle strip moments were calculated.
- By using the effective widths and moments of each column strip and middle strip, the nominal moment, R value, ρ , and required steel area and bar number were calculated to determine what rebar is need to satisfy the loading.
- The rebar solution is shown at the bottom of each frame analysis in Appendix D.
- From there the lengths of the rebar were calculated based on design standards in the concrete design textbook, and the lengths were tallied and a cost was calculated using data from R.S. Means 2008.
- The cubic yards of concrete were also tallied and a cost was calculated.
- Calculations include all three levels in the re-design.

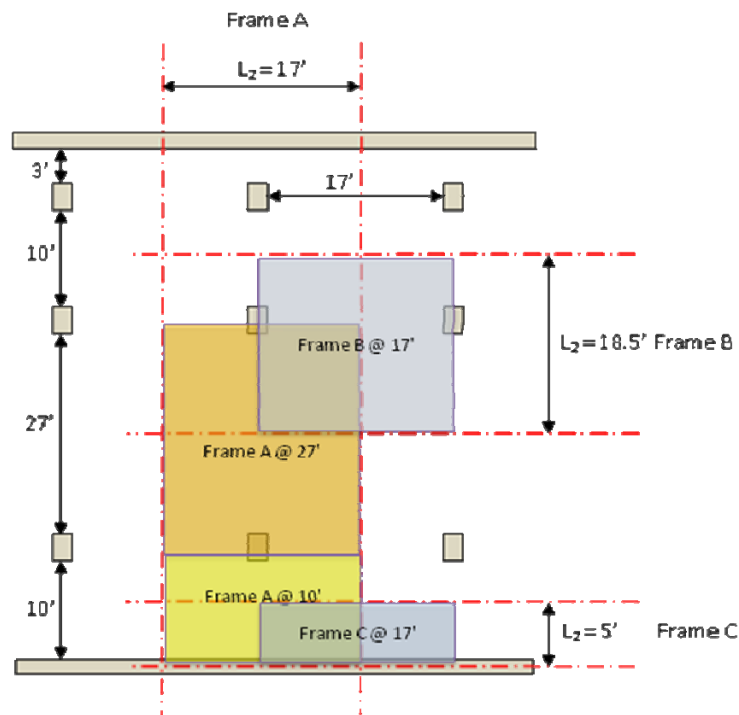


Figure 9: Averaged Column Grid and Frame Locations

❖ Step 4: Filigree Design

- Gene McDermott at Midstate Filigree Systems was contacted to aid in the re-design.
- Original drawings and load cases were sent for the analysis.
- A slab and beam system was chosen for the Filigree design because it requires less steel and concrete; it also has a smaller total floor depth.
- Through Gene, Mike Jevin at Healy Long & Jevin, Inc. was contacted for an estimate and schedule data.

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- An estimate was performed for the new slab and beam Filigree system and for the original system with drop panels; which was very similar in quantities to the structural take off performed in Technical Report 2 and could be compared to the Filigree system.
 - The estimates performed by Healy Long & Jevin, Inc were averaged from a previous job, Wilmington High-Rises, and then adjusted for this project. This explains why the square footages in their estimate are 36,000 when the actual total is 44,100. Because of this difference, the SF prices from the estimates were applied to the true SF of 44,100.
 - The formwork SF cost, from Healy Long & Jevin, Inc, was taken directly from the Filigree estimate and applied to the total square footage. The Miller & Long formwork SF cost was applied to the calculated total square footage of the original system and the flat plate system. The estimate was done in this manner because of the different types of formwork used in the Filigree system compared to both cast in place systems.
 - Based on the tonnage and cubic yard quantities of steel and concrete, respectively I used RSMeans 2008 to find the total cost including labor and materials for the original system and the flat plate system.

Analysis Results

Please refer to Appendix D for calculations and comparisons.

❖ *Stud Rail Design*

- As described earlier the stud rails were not necessary to accommodate shear forces.
- The total factored load equaled 214 PSF and the total distributed load equaled 3.745 kips.
- Based on the factored load and distributed load the tributary load at the column face was found, the shear equaled 68.35 kips.
- Using the common column size of 18" x 30" the effective width, b_o , was found to be 130 inches.
- From this data the shear strength at critical section $d/2$ from the column face was found to be 234.41 kips.
- 234.41 kips is significantly greater than 68.35 kip load.
- Stud rails were not required.

❖ *Flat Plate Design*

- Using a 10" slab and the averaged column grid described earlier, four critical frames were analyzed at the column strips and middle strips to determine what rebar was required to satisfy the moments on those frames. The frames analyzed can be seen in Figure 9 on page 28.

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- From this detailed analysis the total lengths, pounds, and tonnage of steel were calculated, as well as the total cubic yards of concrete. Then those numbers were multiplied by a unit cost per ton and a labor cost taken from RSMMeans 2008.
- The total quantities equal 42.1 tons and 1361.11 cubic yard, and costs equal \$59,144.32 and \$596,575.00 respectively.
- Formwork cost was calculated based on total square footage multiplied by the square footage cost of \$5.50/SF, supplied by Miller & Long, the concrete contractor.
 - This square footage cost was used because of the methods used for typical cast in place concrete; the formwork is usually stick built forms of plywood.
- The total formwork square footage equaled 44,100.00, and cost \$242,550.00.
- This system has a duration of 27 days as determined by Healy Long & Jevin, Inc.

❖ *Filigree Design*

- The structural design for the Filigree system was performed by Gene McDermott of Midstate Filigree Systems.
- The slab and beam system was chosen because it was more efficient for the floor plan than a flat plate system; the slab being 6” and the beam being 11.5”. A structural plan of the slab and beam Filigree system can be found in Appendix D.
- Based on the design and estimate provided by Healy Long & Jevin, Inc the quantities of steel, concrete and formwork were tallied. The costs of steel and concrete were calculated using RSMMeans 2008 to maintain consistency, and were comparable to the actual estimate.
- The formwork cost was taken directly from the estimate because of the scaffolding type of formwork used compared to the stick built plywood system of the cast in place slabs.
- The total quantities of steel, concrete, and formwork equal 48 tons, 816.67 cubic yards, and 44,100 and cost \$67,440.00, \$357,945.00, and \$142,575.30 respectively.
- This system has a duration of 21 days as determined by Healy Long & Jevin, Inc.

System Comparison

A system comparison can be found on the following page and in Appendix D.

Site delivery expenses were not included in this estimate.

As shown on the following RSM page, the 10” cast in place slab system saves \$27,952.49 in steel costs, \$10,493.74 in formwork costs and 17 schedule days for only the slab work. However, the re-designed cast in place system requires 14.53 more cubic yards of concrete which costs \$6,367.53. Despite the greater amount of concrete required the re-designed cast in place system saves a total of \$30,153.98 compared to the original system with the adjusted location factor.



The slab and beam Filigree system saves \$19,656.81 in steel cost, \$232,262.44 in concrete cost, \$110,468.44 in formwork cost, and 23 schedule days for only the slab work. This system saves in all categories analyzed totaling a savings of \$340,644.45 as compared to the original system with the adjusted location factor. This savings is due to the minimal amounts of steel, concrete, and formwork required in the pre-stressed pre-cast panels that form the structure. These panels are used as formwork in conjunction with the scaffold system.

Structural System Comparison Summary			
Analysis Description	Existing CIP Slab with Drop Panels	Re-Designed CIP Slab without Drop Panels	Filigree Slab and Beam System
Steel Cost	\$87,096.81	\$59,144.32	\$67,440.00
Concrete (CY)	1346.58	1361.11	816.67
Concrete Cost	\$590,207.48	\$596,575.00	\$357,945.00
Formwork Cost	\$253,043.74	\$242,550.00	\$142,575.30
Slab Duration (Days)	44	27	21
Adjusted Total Cost	\$874,527.14	\$844,373.16	\$533,882.68
Savings Analysis			
Steel Cost	n/a	\$27,952.49	\$19,656.81
Concrete (CY)	n/a	-14.53	303.81
Concrete Cost	n/a	-\$6,367.53	\$232,262.48
Formwork Cost	n/a	\$10,493.74	\$110,468.44
Slab Duration (Days)	n/a	17	23
Adjusted Total Cost Savings	n/a	\$30,153.98	\$340,644.45

Figure 10: Structural System Comparison Summary

Schedule Reduction Analysis

A detailed structural schedule can be found in Appendix D and on the following page.

The original garage system was scheduled to be completed in three phases of each level working from the mat slab up through the building. The schedule includes pouring the columns, walls, and slabs of each level together before moving to the next level. The schedule also includes the reshore being stripped at the full 28 day strength. The original system was started on 6/20/07 and completed on 11/5/07 taking 98 schedule days (weekends not included).

The re-designed cast in place system utilizing a flat plate 10” slab is also scheduled in a similar fashion. The construction progresses floor by floor, including pouring the columns, walls, and slabs before moving to the next floor. The schedule also includes stripping the reshore at only 75% of the full strength as determined by Healy Long & Jevin, Inc. The flat plate system beginning on the same start date, 6/20/07 would finish on 9/27/07 taking 71 schedule days to complete; saving 27 schedule days.

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The Filigree system is scheduled beginning on the same start date due to the same foundation system and crane set date. This system also progresses floor by floor including the columns, walls, and slabs being constructed before moving to the next floor. The Filigree shoring can also be used as the reshore system because it is a scaffolding type system. The shoring does need to be cracked from the concrete at 75% strength to avoid buckling or bending of the system. The Filigree is scheduled to start on 6/20/07 and would finish on 9/19/07 taking 65 schedule days to complete; saving 33 schedule days.

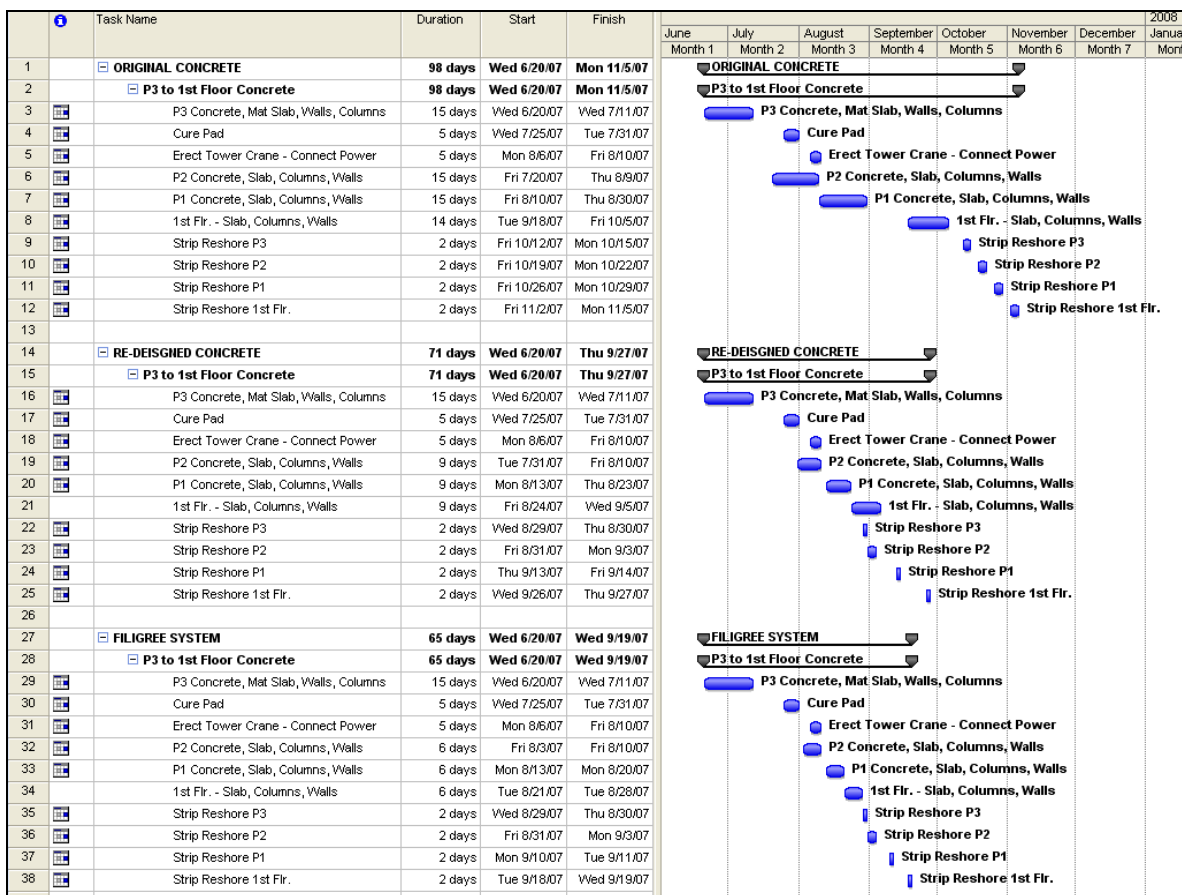


Figure 11: Detailed Structural Schedule, original provided by Balfour Beatty.

Both proposed systems would get the project out of the ground faster than the original which directly leads to an overall shorter project schedule. And in turn the Residence Inn would be able to open sooner than the current scheduled opening date of 9/12/08. The Figure 12 on the next page is an estimate of the revenue that could be made if the hotel was able to open earlier using either the 10" flat plate system or the Filigree system.

- The nights counted include the weekend time during the 27 schedule day improvement for the 10" flat plate system, and the 33 schedule day improvement for the Filigree system.

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- The Residence Inn is predicted to bring in approximately \$180 per room after three years, as provided by Don Nagl at Marriott.
- This estimate does not include operations costs.

System	Price/Unit	Units	Time	Revenue
10" CIP	\$180	147	37 Nights	\$979,020.00
Filigree	\$180	147	45 Nights	\$1,190,700.00

Figure 12: Revenue Summary

Constructability Review

For all three systems analyzed, the site would still be as constricted as it is currently. The original system and the 10" flat plate system use more concrete pumps than the crane, which can cause site congestion because the pump truck must be close to the footprint onsite. The Filigree system would also utilize pump trucks near the footprint to pour the topping slab. However, the Filigree system would utilize the crane more than the other two cast in place systems. This is because the pre-stressed pre-cast panels are too heavy to be set by hand; they must be set by the crane. Since the tower crane would be in place before the Filigree panels would arrive onsite, there would be no added cost for extra time with the crane.

Overall, all three systems would be constructed very similarly and would not pose anymore site congestion problems than already exist. The biggest advantage would be that the construction would take less schedule time which means less congested time onsite.

Conclusion & Recommendation

The benefits of the Filigree system far outweigh those of the 10" cast in place flat plate system as well as the original system.

- The Filigree system has a smaller overall depth which is key in designing clearance heights and piping and plumbing work.
- The construction is 33 days faster which can enable an early opening.
- This system also saves the owner approximately \$362,000.00 in construction cost and can possibly add additional revenue of \$1.2 million within the first 45 nights.

Based on this analysis of structural design, cost, schedule, and constructability the Filigree slab and beam system is the recommended system. It exceeds the original design and the flat plate re-designed system in every aspect. It is quicker, saves the owner money, and helps them bring in more revenue.