Technical Analysis #2

Cast-in-place caissons vs. Pre-cast concrete piles

Problem

The tower had a difficult schedule to adhere to from the start of the project. The foundation system used did not get the project started on a positive note. The pre-cast piles used brought about multiple issues throughout the foundation construction that could have been avoided. Issues ranging from barge deliveries to driving to engineered depth not only frustrated the team, but also put them behind schedule from the beginning. The Central Plant located across the street used a cast-in-place caisson foundation system. The construction process of this foundation went smooth, with only minor issues arising. Furthermore, the Central Plant's soil conditions, site logistics, construction crew, etc. are all identical to that of the tower. With these details known, the foundation system used on the Central Plant, at least initially, seems as though it would have been a better choice for that of the tower.

Goal

The goal of this technical analysis is to evaluate using the cast-in-place caissons as the tower's foundation system; the team would have saved not only time but money as well. The research will primarily be focused on the schedule impact the alternate system will have, but the cost issue will also be addressed. The added costs that occurred from unforeseen developments during the pre-cast pile construction will also be factored into the research.

Analysis Techniques

1. Determine all of the loads from the building that are acting at the base of each column. Loads values used are given by the designers on the drawings.
2. Once load calculations are completed caisson sizes and quantities can be determined.
3. All relevant information from the tower's foundation construction, original budget, actual cost, actual schedule dates, etc will be compiled and reviewed.
4. The actual construction details were retrieved from the Central Plant team. This information, such as caissons/day, cost/caisson, etc. allowed for a very accurate estimate for the tower. Also, a RS Means estimate comparison was shown for clarification.
5. Analyze any structural issues that will change due to the analysis.
6. Create a schedule and budget for the alternate system on the tower.
7. Compare the actual costs and duration dates of the existing schedule to the results from the alternate system.

Tools

1. Architectural Engineering Faculty (Parfitt, Schneider, Hanagan)
2. Gilbane Building Company Canton Crossing Tower/Central Plant Construction Team
3. Microsoft Excel
4. Soil Safe, Inc. , Maryland

Column Load Determinations

The start of the redesign process was calculating the tributary area for each of the columns. From there each of the twenty floors was added onto that value. The design value for dead loads was 57 psf and live loads 100 psf. The next step was to incorporate the roof loads and wind loads, which were also given by the designer. An estimated value for each column load was giving in the geotechnical report, but for accuracy reasons the loads were calculated by hand and then compared to the estimates. Shown below are sample calculations for final loads on columns A-2 and B-3 to illustrate the formulas used for wind loaded and non-wind loaded columns.

Sample Load Calculations

A-2 (Non-wind loaded column)

1.2(D) + 1.6(L)

1.2(298,576) + 1.6(521,600) = ***1,193 kips***

B-3(Wind loaded column)

1.6(W) + 1.2(D) + 1.0(L)

1.6(600) + 1.2(957,992) + 1.0(1,663,280) = ***2,814 kips***

In the Appendix section on pages 38-39 a table is provided showing all of the calculations used for each of the 49 caissons.

Caisson Design Calculations

The previously calculated loads at the column bases were then used to design each of the 49 caissons needed in the structural system. Various critical numbers came from the geotechnical report for the foundation. *Table TA2.1* below shows of all of these values is shown below.

Table TA2.1

Stratum	Top of Stratum Elevation	Ultimate Skin Friction	Factor of Safety / New Ultimate	Ultimate End Bearing	Factor of Safety / New Ultimate
Recent Alluvial	EL 0	1.0 ksf	FS= 2.5 *0.4 ksf*	N/A	FS= 2.0 ~~
Upper Potomac	EL -25	3.0 ksf	FS= 2.5 *1.2 ksf*	20 ksf	FS= 2.0 *10 ksf*
Lower Potomac	**EL -50**	**4.0 ksf**	**FS= 2.5** ***1.6 ksf***	**60 ksf**	**FS= 2.0** ***30 ksf***

To begin the design I decided to use the Lower Potomac soil level values because I was estimating a depth of 70'-80' from historical data. The next step was to calculate how much load caissons of varying diameters would hold at various depths. The compression loads were all calculated with the factor of safety of 2.0. I then added on the value of skin friction for each of the caissons, while also checking the uplift loads. This calculation was simply the surface area of the caisson times the ultimate skin friction value shown in the table above. The final value calculated was the weight of the shaft using the effective weight of concrete as 85 pcf, this value was then subtracted from uplift load. The final check was to be sure the new value of skin friction minus the self-weight was greater than the target value of 1900 kips given in the geotechnical report. The extra values in skin friction and self-weight exceeding the 1900 kips of uplift were then added to the final load calculation.

Once each diameter of caisson at all five trial depths had a final load capacity value, the column loads were analyzed to decide what size caissons at which depth would be most efficient. The tables for the load capacities are shown in the Appendix at the end of the report. The two depths that I decided for were 70' and 80', and after a comparison of the excavated materials between the two I chose 80'. The comparison is shown below in *Table TA2.3* For construction simplicity I chose to use only six different size caissons and to keep all of the depths consistent at 80'.

In the Appendix section pages 40-41, tables are shown for every depth that was considered for caissons (50'-90'). Once again, it should be noted that 80' was chosen for the depth of all 49 caissons.

Table TA2.3

Excavation Comparison for 70' & 80' Depths						
Excavation Details for 70' Depth				**Excavation Details for 80' Depth**		
Volume (cy)	# of Ciassons	CY of Caissons		Volume (cy)	# of Ciassons	CY of Caissons
20.94				20.94		
28.51				28.51		
37.23				37.23		
47.12				47.12		
58.18				58.18	8	465.42
70.40	8	563.16		70.40	10	703.95
83.78	10	837.76		83.78		
98.32				98.32		
114.03				114.03	7	798.20
130.90	7	916.30		130.90	15	1,963.50
148.94	15	2,234.03		148.94	2	297.87
168.13	2	336.27		168.13		
188.50				188.50		
210.02				210.02	6	1,260.13
232.71	6	1,396.27		232.71		
256.56				256.56		
281.58				281.58		
307.76				307.76		
335.10				335.10		
363.61				363.61		
393.28				393.28		
424.12				424.12		
	TOTAL CY	**6,283.78**			**TOTAL CY**	**5,489.07**

Shown below are the caisson sizing calculations for a caisson with a 96" diameter at 80' depth. On the following page *Table TA2.4* shows all of the calculations for the 80' deep caissons. It is important to note that the actual elevation of the caissons are EL = -95' due to the basement that was added in the other Technical Analysis.

Sample Caisson Sizing Calculations (96"diamter @ 80' depth)

L_{eb} = Ultimate End Bearing * πr^2

L_{eb} = 30 ksf * π (4 ft)^2

L_{eb} = *1,508 kips*

L_{sf} = Ultimate Skin Friction * SA

$L_{sf} = 1.6\text{ ksf} * [(2\,\pi)\,(4\text{ ft})^2 + (2\,\pi)\,(4\text{ ft})\,(80\text{ ft})]$

L_{sf} = *3,378 kips – 1900 kips = 1478 kips added to load*

Self-Wt = $\pi\, r^2$ * depth * 85 pcf

$SW = \pi\,(4\text{ ft})^2 * 80\text{ ft} * 85\text{ pcf}$

SW = 342 kips

Final Load Calculation = $L_{eb} + (L_{sf} - \text{Uplift}) + SW$

FL = 1,508 + (3,378-1900) + 342

FL = ***<u>3328 kips</u>***

Table TA2.4

Sizing Index @ 80' Depth								
Diameter (in)	Diameter (ft)	Kips	S A @ 80'	Skin Friction	Added KIPS	Total w/ SF	SW	**Final Kips**
36	3	212	768	1229	-671	-459	48	**-411**
42	3.5	289	899	1438	-462	-173	65	**-108**
48	4	377	1030	1649	-251	126	85	**211**
54	4.5	477	1163	1860	-40	438	108	**546**
60	5	589	1296	2073	173	763	134	**896**
66	5.5	713	1430	2288	388	1100	162	**1262**
72	6	848	1565	2503	603	1451	192	**1644**
78	6.5	995	1700	2720	820	1815	226	**2041**
84	7	1155	1836	2938	1038	2193	262	**2454**
90	7.5	1325	1973	3157	1257	2583	300	**2883**
96	8	1508	2111	3378	1478	2986	342	**3328**
102	8.5	1702	2250	3600	1700	3402	386	**3788**
108	9	1909	2389	3823	1923	3831	433	**4264**
114	9.5	2126	2529	4047	2147	4273	482	**4755**
120	10	2356	2670	4273	2373	4729	534	**5263**
126	10.5	2598	2812	4499	2599	5197	589	**5786**
132	11	2851	2955	4727	2827	5678	646	**6325**
138	11.5	3116	3098	4957	3057	6173	706	**6879**
144	12	3393	3242	5187	3287	6680	769	**7449**
150	12.5	3682	3387	5419	3519	7201	834	**8035**
156	13	3982	3533	5652	3752	7734	903	**8637**
162	13.5	4294	3679	5887	3987	8281	973	**9254**

Caisson Reinforcement Sizing

The reinforcing for the caissons was designed assuming that the area of the steel would be 1% of the gross cross-sectional area of the caisson, as shown below in *Table TA2.5*. The size of the reinforcing rebar was simplified for construction to two different sizes for the whole building, #11's & #14's. The rebar cages are to extend to at least EL = -50 due to soil conditions through the top layers. Additionally, ties will be used at 18" o.c.

Table TA 2.5

Sizing Reinforcement as As=1% of Total Area				
Diameter (in)	Area (sq in)	As (sq in)	Bar Size	Total Area
36	1,018	10.18		
42	1,385	13.85		
48	1,810	18.10		
54	2,290	22.90		
60	2,827	28.27	20 - #11	31.20
66	3,421	34.21	24 - #11	37.44
72	4,072	40.72		
78	4,778	47.78		
84	5,542	55.42	36 #11	56.16
90	6,362	63.62	42 #11	65.52
96	7,238	72.38	32 #14	72.00
102	8,171	81.71		
108	9,161	91.61		
114	10,207	102.07	46 #14	103.50

Comparisons

The schedule breakdowns were calculated using actual data from the Central Plant contract and the subcontractors used on that job as well as the actual construction schedule from the tower. The caisson data will be more accurate this way than if collected from another source, for instance R.S. Means, because it takes into account location, soil conditions, subcontractors, etc. The tower's pile data is actual information since at the time of this report the construction had been completed. As shown below the caissons had a much shorter duration that the piles. Rounding off to account for any unforeseen issues with the caisson construction, they still are completed roughly a month before the piles. This month's worth of time will show up in the cost comparison shown in the next section of the report. A month's worth of time in a tenant fit-out building means extra income to the owner from leases.

Table TA2.6

Schedule Breakdowns		
Description	**Piles**	**Caissons**
Actual Rates	4/day	153.5 CY/day
# of Units	314	5489.07
Actual Duration	78.5 days	35.75 days

The cost comparison also used historical data from the contracts of the Central Plant and the tower for the most accurate reporting possible. The piles cost approximately $68/LF while the caissons were $443/CY. The differences between the two began with the pile caps. The original design required pile caps where as the redesign of caissons eliminated that, removing $122,705 from the contract. The caissons on the other hand required that nearly 2,225 tons of contaminated soils be removed from site and disposed of properly. This value came from the assumption in the geotechnical report that the soil was contaminated to EL = -20'. This value is accounted for in the previous Technical Analysis where the basement level was added to the tower. That excavation, if combined with this redesign, will already account for all of the contaminated soils. The big cost savings comes with the month that is saved from the shorter construction duration of the caissons. At $24 rent/sq ft a year (quoted from Gilbane Building Company's Project Executive, Mark Luria) the savings calculates to $1,000,000 for this 500,000 sq ft of commercial leasing space.

Table TA 2.7

Cost Breakdowns		
Description	Piles [=] LF	Caissons [=] CY
# of Piles/Caissons	314	49
Cost per Pile/Caisson	$5,941	$37,566
Unit Cost [=] LF/CY	$67.90	$442.98
# of Units	27,777 LF	5,489.07 CY
Pile Caps	$122,705	0
Removal of Contaminated Soils		$66,825[a]
1 Month Early Completion		($1,000,000)
Totals (basement added from Analysis #1)	***$2,008,762.13***	***$1,431,548.23***
Totals (no basement)		***$1,498,373.23***

[a] Value accounted for in Technical Analysis #1 for the basement addition.

Conclusion

After completing this analysis I conclude that the decision to use cast-in-place caissons is superior to that of precast, prestressed driven piles. The idea for the analysis came after issues arose during the construction of the piles, but the implementation of caissons was discussed during early design. The design team decided against the caissons, but as this analysis shows in hind sight the caissons were the better choice. The most important discovery during this analysis was the speed of the caissons duration compared to the piles. Any owner, especially a tenant fit-out owner, is going to want to reduce their schedule by a month if the situation arises. Not only did the caissons save nearly $1.5 million, but it allows the project's schedule to be on track from the start. Another notable advantage of the caissons is the delivery method that was used for the precast piles. The piles had to be barged in through the harbor for delivery. With the site located along the water this should not be an issue, but during construction one of the delivery barges tipped over losing roughly $150,000 worth of piles. This is an extreme occurrence that is out of the normal, but should be noted for comparison.