9. Analysis 1 – Window Wall Attachment with Reinforced Concrete
(Structural Breadth)

9.1 Introduction

Turnberry Tower Arlington's exterior skin is made up of both curtain wall and window wall. When the general contractor was given the contract documents during bidding, it was noted that the exterior skin system did not have a design in place showing how to connect it to the structure of the building. Because the building structure is post tension concrete, not having a design for the connections made it very difficult for a connection to be designed in the existing conditions. Any connection design could have had a large impact on the structure design and may have caused a redesign of the post tension slabs.

9.2 Problem Statement

As a result of not having the detail for the window wall connection design, drilling into the cured post tension decks had to occur to attach the window and curtain wall. This led to having more than 20 tendons hit and fail during the window wall installation process. After this had occurred, the exterior skin installer was forced to use a Ferroscan unit to scan the post tension decks before every bolt was installed. The result of the busted post tension tendons can be seen below in *Figure 9.1*.

Figure 9.1 - Failed Post Tension Tendons

9.3 Goal

The goal of this analysis to act as the general contractor during the preconstruction process and suggest the post tension concrete slabs be replaced with reinforced concrete decks. This will allow for more design flexibility in connecting the exterior skin to the building. Once redesigned, a cost and schedule analysis will be performed to see which design would be better taking in to account all of the problems that occurred from the post tension tendon blow outs. I will also find out why post tension concrete was used on this building.

9.4 Research Steps

1. Investigate why post tension concrete was used by talking to the architect, structural engineer, and developer and ask if reinforced concrete could have been an option.
2. Use the direct design method and the CRSI handbook to design the building using normal concrete (structural breadth).
3. Consult with the scheduler to determine the correct durations for the use of reinforced concrete construction on this project and see what other activities this may impact.
4. Price the project using reinforced concrete.
5. Compare both the schedule and cost for the two different structural systems
6. Conclusion & Recommendation

9.5 Tools

1. CRSI Handbook
2. ACI Handbook
3. Direct Design Method
4. Architectural Engineering Professors
5. General Contractor and Design Team
6. R.S. Means Cost Analysis
7. Primavera / Microsoft Project
8. Microsoft Excel

9.6 Expected Outcome

When this project was designed and given to the general contractor, certain subcontractors were not yet onboard, including the exterior skin subcontractor. By the time the package was picked up and all of the submittals were approved by the architect, there was not time to place an embed into the post tension decks that would support the window wall. This led to the problems of ruptured post tension tendons and having to x-ray all future window wall installations. All of these additional costs to the project should show that if a suggestion was made to use reinforced concrete instead of post tension concrete then time and money would have been saved.

9.7 Use of Post Tension Concrete

The first step in the research process was to investigate why post tension concrete was used for this project. While going through documents that were available during the preconstruction process, many design details, including the window wall supports, were not yet supported so it seemed like a good time to go ahead and use post tension concrete which would cause more of a problem than reinforced concrete.

The post tension concrete allowed the slab thickness on the typical residential levels 2 through 26 to be 7 inches. With the parking garage below the structure, the 10 foot ceilings in some of the units as desired by the owner, and the sunshade on the roof, the final height of the building is at elevation 409.70. The building is located in Arlington, Virginia in the Rosslyn District. This site is in close proximity to Reagan National Airport which gives the Federal Aviation Administration the final approval on how high the building can be. The FAA says the elevation of the building is within 1/8 of an inch of the allowable height.

With the elevation requirement that needed to be met, and with the County of Arlington requiring that the building meet the zoning requirements of the "C-O District," the only way for the building to get an extra floor with the desired floor heights would be to use post tension concrete. This extra floor that was able to be incorporated into the design allows the owner to gain $17.6 million of sales from the residential units. If the height of the building from the reinforced concrete becomes an issue, the option for taking out one floor of the building becomes very unlikely based on this price.

9.8 Redesigning the Floor Slabs Using Direct Design Method

To see if was even possible to use reinforced concrete on this project, first I needed to redesign the slabs to see what the impact there would be on the cost and schedule. I started out by taking a typical floor and dividing a section into typical bays that would give me a general representation. I used the following general assumptions:

- 20" x 20" columns
- Per ASCE 7-05 Table 4.1, Live Load = 40 psf
- Dead Load (Concrete Self Weight) = 137.5 psf
- The whole deck would be #6 Rebar at 60 ksi

The general bay that was used for this analysis is show in *Figure 9.2*:

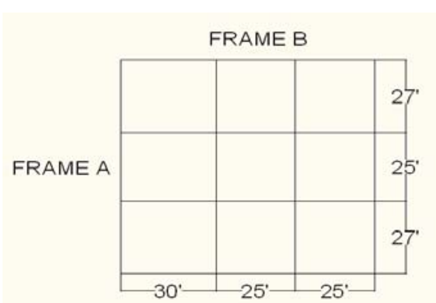

Figure 9.2 - Bay

To come up with the thickness of the slab, I used an equation from ACI 318 Building Code Chapter 9 Table 9.5c 2008, *Table 9.1* below.

fy, psi	Without Drop Panels			With Drop Panels		
	Exterior Panels		Interior Panels	Exterior Panels		Interior Panels
	Without Edge Beams	With Edge Beams		Without Edge Beams	With Edge Beams	
40,000	ln/33	ln/36	ln/36	ln/36	ln/40	ln/40
60,000	**ln/33**	ln/33	ln/33	ln/33	ln/36	ln/36
75,000	ln/28	ln/31	ln/31	ln/31	ln/34	ln/34

Table 9.1 – ACI Table 9.5c

Using the exterior panels without drop panels and without drop beams, the equation to use is ln/33. To be conservative, the largest bay size of 30 feet was chosen from the above *Table 9.1*. When the calculation is done, the thickness of the slab will be 11 inches.

The rest of the Direct Design Method helps to find the amount of steel and where it needs to be placed in the concrete slabs. The factored moment was found for both frames both within the column strip and in the middle strip. The steel was then divided between the positive and negative moments in both the column strips and middle strips. *Table 9.2 and Table 9.3* below summarize the results of the moments on the structure and *Table 9.4* shows the amount of steel that will be needed in each slab. The full structural analysis can be found in Appendix C including verification of the calculations.

Moments on Each Slab

FRAME A		
	+ Moment	- Moment
Column Strip	92 ft-k	214 ft-k
Middle Strip	62 ft-k	72 ft-k

Table 9.2- Moments in Frame A

FRAME B		
	+ Moment	- Moment
Column Strip	87 ft-k	201 ft-k
Middle Strip	58 ft-k	67 ft-k

Table 9.3 – Moments in Frame B

Amount of #6 Rebar per foot				
	FRAME A		FRAME B	
	+ Moment (Bottom Bars)	- Moment (Top Bars)	+ Moment (Bottom Bars)	- Moment (Top Bars)
Column Strip	8	13	8	12
Middle Strip	8	8	8	8

Table 9.4 – Rebar Required

9.9 Scheduling the Project: Post Tension Concrete vs. Reinforced Concrete

When observing the problems with post tension blowouts on this project, the first question that comes to mind is how many days were wasted on the schedule having to fix those decks? Upon further investigation of the schedule, this project was very fortunate that all of the repairs that needed to be done to the floor slabs did not affect the concrete work going on above and did not delay the interior trades on the SIP Schedule.

Next I wanted to look at was the formwork itself. The project was using a flying form system called the Peri Girder Truss Tables. These flying tables helped to speed up the erection of the tower, but they were designed for the post tension slabs that weigh less than the proposed reinforced concrete slabs. After talking to the concrete subcontractor, it was determined that the same formwork could handle the extra weight. That meant that there would be no delay in the construction from being forced to use other formwork or needing to move around more reshores.

After that I needed to investigate how the pour schedule for the reinforced concrete would compare to the pour schedule of the post tension concrete. To keep consistency between the two different types of decks, three zones were used to complete the pours. Each zone would take one day to pour. The post tension slabs utilized a 5 hour pour day and took between 10-11 days to complete. The reinforced concrete decks would need to use 8 hour pour days because of the thicker slabs and would need 12 days to complete (4 days for each zone). Below in *Table 9.5* is an abridged schedule that compares the pour schedules of post tension concrete slabs to the reinforced concrete slabs. The full schedule can be found in Appendix D.

Task Name	Duration	Start	Finish
Structure Tower Floor 2	32 days	Fri 12/28/07	Mon 2/11/08
Floor 2 - Reinforced Concrete	38 days	Fri 12/28/07	Tue 2/19/08
Structure Tower Floor 3	14 days	Wed 1/30/08	Mon 2/18/08
Floor 3 - Reinforced Concrete	16 days	Mon 2/4/08	Mon 2/25/08
Structure Tower Floor 4	11 days	Thu 2/14/08	Thu 2/28/08
Floor 4 - Reinforced Concrete	14 days	Thu 2/14/08	Tue 3/4/08
Structure Tower Floor 5	11 days	Wed 2/20/08	Wed 3/5/08
Floor 5 - Reinforced Concrete	13 days	Mon 2/25/08	Wed 3/12/08
Structure Tower Floor 6	10 days	Mon 3/3/08	Fri 3/14/08
Floor 6 - Reinforced Concrete	14 days	Mon 3/10/08	Thu 3/27/08
Structure Tower Floor 7	15 days	Mon 3/10/08	Fri 3/28/08
Floor 7 - Reinforced Concrete	14 days	Wed 3/19/08	Mon 4/7/08
Structure Tower Floor 8	15 days	Mon 3/17/08	Fri 4/4/08
Floor 8 - Reinforced Concrete	13 days	Thu 3/27/08	Mon 4/14/08
Structure Tower Floor 9	12 days	Mon 3/31/08	Tue 4/15/08
Floor 9 - Reinforced Concrete	12 days	Fri 4/4/08	Mon 4/21/08
Floors 10-17	52 days	Tue 4/8/08	Wed 6/18/08
Structure Tower Floor 18	8 days	Fri 6/13/08	Tue 6/24/08
Floor 18 - Reinforced Concrete	12 days	Wed 6/11/08	Thu 6/26/08
Structure Tower Floor 19	8 days	Fri 6/20/08	Tue 7/1/08
Floor 19 - Reinforced Concrete	12 days	Thu 6/19/08	Fri 7/4/08
Structure Tower Floor 20	8 days	Mon 6/30/08	Wed 7/9/08
Floor 20 - Reinforced Concrete	12 days	Fri 6/27/08	Mon 7/14/08
Structure Tower Floor 21	8 days	Wed 7/9/08	Fri 7/18/08
Floor 21 - Reinforced Concrete	12 days	Mon 7/7/08	Tue 7/22/08
Structure Tower Floor 22	10 days	Wed 7/16/08	Tue 7/29/08
Floor 22 - Reinforced Concrete	12 days	Tue 7/15/08	Wed 7/30/08
Structure Tower Floor 23	7 days	Mon 7/28/08	Tue 8/5/08
Floor 23 - Reinforced Concrete	12 days	Wed 7/23/08	Thu 8/7/08
Structure Tower Floor 24	7 days	Mon 8/4/08	Tue 8/12/08
Floor 24 - Reinforced Concrete	12 days	Thu 7/31/08	Fri 8/15/08
Structure Tower Floor 25	12 days	Mon 8/11/08	Tue 8/26/08
Floor 25 - Reinforced Concrete	12 days	Fri 8/8/08	Mon 8/25/08
Structure Tower Floor 26	12 days	Fri 8/22/08	Mon 9/8/08
Floor 26 - Reinforced Concrete	12 days	Mon 8/18/08	Tue 9/2/08

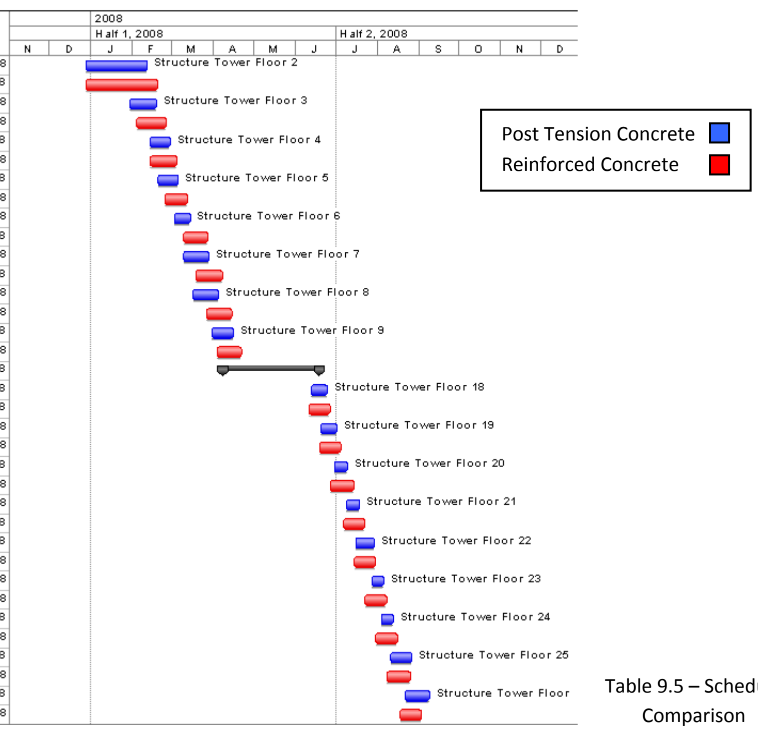

Table 9.5 – Schedule Comparison

9.10 Schedule Comparison

Taking a closer look at the schedules from *Section 1.9*, both the post tension concrete construction and the reinforced concrete construction would begin the erection of floor 2 on December 28th, 2007.

The post tension concrete will be a few days shorter for each floor in the beginning of the project than the reinforced concrete. The workers for the post tension concrete would need to get used to the layout of the post tension tendons and rebar, and how to stress the post tension tendons correctly. The reinforced concrete would have similar time adjustments needed for a learning curve by the workers, but the main factor they need to adjust to is the volume of concrete and rebar. Both structural systems would have a learning curve due to moving and setting up formwork, setting embeds, and getting use to the working conditions on the project.

The advantage that the reinforced concrete system has on the schedule is that workers will be able to accelerate the construction of those decks faster than the post tension decks. More workers could be put on to help move the formwork, set up rebar, and place concrete. The post tension is limited to how fast it can move because of the inspectors. The inspectors would have to approve the concrete to be tensioned and then again approve that the tensioning is satisfactory before the workers could move the formwork up to the next level. In the abridged schedule in *Table 9.5* and full schedule in Appendix D, it is noticeable at certain floors were additional days were required for post tension slabs.

In the end, the post tension concrete construction tops out at floor 26 on September 8th, 2008 and the reinforced concrete construction tops out at floor 26 on September 2nd, 2008. The difference is only 4 work days.

9.11 Cost Comparison between Post Tension Concrete Slabs and Reinforced Concrete Slabs

To compare the costs of the different structural systems, takeoffs were completed on three different options. The first option is what was actually done on the project and shows the cost for the post tension concrete. The next option shows the cost for reinforced concrete if one floor of the building is removed to meet the height requirements. The last option shows the cost for reinforced concrete if all the floors are built but the height of each floor is reduced to meet the building height requirement.

All of the estimates used R.S. Means 2008 Building Construction to find the average price of labor and materials and can be found below in *Table 9.6*.

Average Labor and Equipment			
Description	Labor	Equipment	Unit
Footings	$54.50	$0.33	CY
Columns	$435.00	$42.50	CY
Slab on Grade	$55.00	$0.41	CY
Slabs	$207.00	$19.60	CY
Beams	$490.00	$48.50	CY
Shear Walls	$430.00	$42.50	CY
Curbs, Pads, Toppings	$129.00	$1.78	CY
Average per CY	**$257.21**	**$22.23**	**CY**

Table 9.6 – Average labor and Equipment Costs

Prices for concrete per cubic yard, rebar per ton, and PT cable cost per pound were obtained directly from the subcontractor. Prices that were given included:

Concrete = $125 / cubic yard
Rebar = $1000 / ton
PT Cable = $1.15 / pound

9.11.1 Post Tension Concrete

The estimate for the post tension concrete system can be found below in *Table 9.7 through Table 9.10.* All of the takeoff notes can be found in Appendix B.

Reinforcing Steel			
Area	Amount (Ton)	Cost per Ton	Total Cost
Columns	916	$1,000	$916,000
Shear Walls	1402	$1,000	$1,402,000
Slabs	753	$1,000	$753,000
TOTAL	**3071**		**$3,071,000**

Table 9.7 – Rebar for Post Tension Concrete Slab

Miscellaneous Items			
Item	Amount	Cost per	Total Cost
Post Tension Cables	626,999 LBS	$1.15 / lbs	$721,049
Grout PT Ends	14,456 EA	$0.50 EA	$7,228
WWF 6x6 W1.4/W1.4	19,312 SF	$18.05 / CSF	$348,582
WWF 6x6 W2.1/W2.1	53,001 SF	$26.50 / CSF	$1,404,527
TOTAL			**$2,481,385**

Table 9.8 – Miscellaneous Items for Post Tension Concrete Slab

Total Material Cost		
Item	Amount	Total Cost
Concrete	37,351 CY	$4,668,875
Reinforcing Steel	3071 Tons	$3,071,000
Miscellaneous Items		$2,481,385
TOTAL		**$10,221,260**
TOTAL PER CY		**$273.65**

Table 9.9 – Total Material Cost

Construction Cost of Post Tension Concrete System						
Description	Qty	Unit	Material	Labor	Equipment	Total Cost
Cast In Place Concrete including placing and stripping formwork, placing rebar, placing concrete, and finishing concrete	37351	CY	$273.65	$257.21	$22.23	$20,658,837
				TOTAL	**$27.55**	**per SF**

Table 9.10 – Construction Cost of Post Tension Structural System

The prices obtained for concrete per cubic yard, rebar per ton, and post tension tendons per pound were multiplied by the amount of these materials on the project and a total material price of $10,221,260 was calculated. When this number is divided by the number of cubic yards of concrete on the job you obtain $273.65 per cubic yard. This number was added to the average costs of labor and equipment and the total cost of $20,658,837 was obtained for the construction of the concrete structural system. This number when divided by the projects 750,000 square feet yields $27.55 per square foot (as seen in *Table 9.10* above).

Figure 9.3 shows a typical tower level with rebar cages for shear walls and columns, part of a concrete deck poured, and exposed PT cables laid out and ready for a concrete pour. *Figure 9.4* shows the use of the Automatic Climbing System (ACS) for the core of the building.

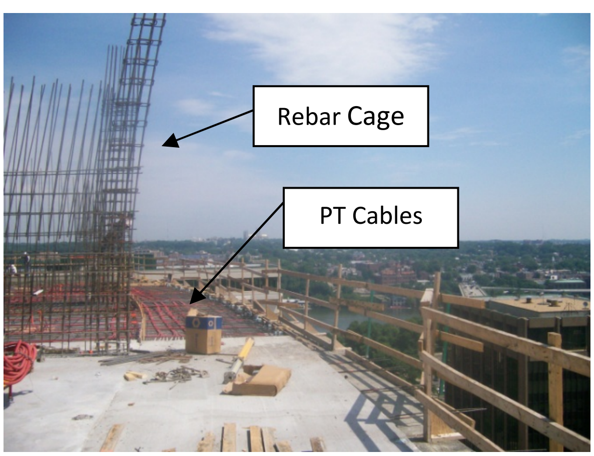

Figure 9.3 – Working Deck

Figure 9.4 – ACS Formwork for Core

9.11.2 Reinforced Concrete Removing One Story

The estimate for the first reinforced concrete system, which includes the removal of one story of the building, can be found below in *Table 9.11 through Table 9.14.* All of the takeoff notes can be found in Appendix D.

Reinforcing Steel			
Area	Amount (Ton)	Cost per Ton	Total Cost
Columns	354	$1,000	$354,200
Shear Walls	1944	$1,000	$1,944,000
Slabs	1065	$1,000	$1,065,000
TOTAL	**3363**		**$3,363,200**

Table 9.11 - Rebar for Reinforced Concrete Slab Removing One Story

Miscellaneous Items			
Item	Amount	Cost per	Total Cost
WWF 6x6 W1.4/W1.4	19,312 SF	$18.05 / CSF	$348,582
WWF 6x6 W2.1/W2.1	53,001 SF	$26.50 / CSF	$1,404,527
TOTAL			**$1,753,108**

Table 9.12 – Miscellaneous Items for Reinforced Concrete Slab Removing One Story

Total Material Cost		
Item	Amount	Total Cost
Concrete	43355 CY	$5,419,369
Reinforcing Steel	3363 Tons	$3,363,200
Miscellaneous Items		$1,753,108
TOTAL		**$10,535,677**
TOTAL PER CY		**$243.01**

Table 9.13 – Total Material Cost

Construction Cost of Reinforced Concrete System (Removing One Floor)						
Description	Qty	Unit	Material	Labor	Equipment	Total Cost
Cast In Place Concrete including placing and stripping formwork, placing rebar, placing concrete, and finishing concrete	43355	CY	$243.01	$257.21	$22.23	$22,651,046
				TOTAL	**$30.20**	**per SF**

Table 9.14 – Construction Cost for Reinforced Concrete Slab Removing One Story

The prices obtained for concrete per cubic yard, rebar per ton, and post tension tendons per pound were multiplied by the amount of these materials on the project and a total material price of $10,535,677 was calculated. When this number is divided by the number of cubic yards of concrete on the job you obtain $243.01 per cubic yard. This number was added to the average costs of labor and equipment and the total cost of $22,651,046 was obtained for the construction of the concrete structural system. This number when divided by the projects 750,000 square feet yields $30.20 per square foot (as seen in *Table 9.14* above).

9.11.3 Reinforced Concrete Adjusting Story Heights

The estimate for the second reinforced concrete system, which includes the adjustment of story heights, can be found below in *Table 9.15 through Table 9.18.* All of the takeoff notes can be found in Appendix D.

Reinforcing Steel			
Area	Amount (Ton)	Cost per Ton	Total Cost
Columns	354	$1,000	$354,200
Shear Walls	1944	$1,000	$1,944,000
Slabs	1100	$1,000	$1,100,000
TOTAL	**3398**		**$3,398,200**

Table 9.15 - Rebar for Reinforced Concrete Slab Adjusting Story Height

Miscellaneous Items			
Item	Amount	Cost per	Total Cost
WWF 6x6 W1.4/W1.4	19,312 SF	$18.05 / CSF	$348,582
WWF 6x6 W2.1/W2.1	53,001 SF	$26.50 / CSF	$1,404,527
TOTAL			**$1,753,108**

Table 9.16 - Miscellaneous for Reinforced Concrete Slab Adjusting Story Height

Total Material Cost		
Item	Amount	Total Cost
Concrete	44072 CY	$5,508,994
Reinforcing Steel	3983 Tons	$3,398,200
Miscellaneous Items		$1,753,108
TOTAL		**$10,660,302**
TOTAL PER CY		**$241.88**

Table 9.17 – Total Material Cost

Construction Cost of Reinforced Concrete System (Adjusting Story Height)						
Description	Qty	Unit	Material	Labor	Equipment	Total Cost
Cast In Place Concrete including placing and stripping formwork, placing rebar, placing concrete, and finishing concrete	44072	CY	$241.88	$257.21	$22.23	$22,975,867
				TOTAL	**$30.63**	**per SF**

Table 9.18 – Construction Cost for Reinforced Concrete Slab Adjusting Story Height

The prices obtained for concrete per cubic yard, rebar per ton, and post tension tendons per pound were multiplied by the amount of these materials on the project and a total material price of $10,660,302 was calculated. When this number is divided by the number of cubic yards of concrete on the job you obtain $241.88 per cubic yard. This number was added to the average costs of labor and equipment and the total cost of $22,975,867 was obtained for the construction of the concrete structural system. This number when divided by the projects 750,000 square feet yields $30.63 per square foot (as seen in *Table 1.18* above).

After calculating the cost differences in the systems, below in *Table 1.19* is a summary of the final cost for each structural system (both as a total cost and a cost per square foot). The table also lists how many units each structural system would allow to be built based on the total height restriction of the building.

Structural Systems Cost Comparison for Turnberry Tower Arlington			
Structural System	Residential Units	Total Structural Cost	Cost per SF
Post Tension Concrete	247	$20,658,837	$27.55
Reinforced Concrete (Removing 1 Story)	235	$22,651,046	$30.20
Reinforced Concrete (Adjusting Story Height)	247	$22,975,867	$30.63

Table 9.19 – Comparison of Costs for Structural Systems

Note: The cost per square foot is a bit higher than expected for this building (average is around $25/SF). This may be caused to the rise in prices for steel and material transportation to the site. The formwork used on this project is also more expensive than typical formwork.

9.12 Conclusion & Recommendation

From the schedule analysis, it was seen that all of the systems were basically identical and took the same amount of time to construct. Not enough time would be saved to come up with a definitive reason to use one system over another.

The post tension concrete option gives the best cost result. It will cost approximately $20.7 million and will provide the owner with all of the desired units at their desired heights. The next best option is the reinforced concrete option with removing one story. This option will cost $22.7 million. Unfortunately this option has to cut 12 units out of the building. The most costly option will be the reinforced concrete with adjusting the story heights. This option will cost approximately $23 million and will provide all of the units desired by the owner, but at a reduced floor to ceiling height.

The more important items to compare are how much the reinforced concrete systems would cost compared to the post tension system, and the problems associated with its construction. The post tension concrete system cost approximately $20.7 million to construct, which includes $100,000 to fix and remediate the damage done by broken tendons. This is far less than the other systems proposed.

The other costs that go along with a tendon failure are not able to have a cost associated. Inspectors may feel obligated or pressured from local building officials to inspect the building more thoroughly. This could delay the construction schedule a few days. Broken tendons can lead to bad publicity in the construction industry. If a developer is thinking about putting up a new post tension building, and they have heard about the company's poor reputation in managing these types of buildings in the past, it could be the reason not to hire that company.

Luckily for Turnberry Tower Arlington, the local building officials did not delay the schedule significantly so no time was lost on construction. To make sure that the window wall subcontractor did not hit any more post tension tendons, they started to use a Ferroscan unit. This unit would tell the user precisely where all of the tendons and rebar were located in the slab. Everyone that was drilling into the slab was required to attend a training session on post tension tendons and how to properly use the Ferroscan unit.

If the decision was made to change to one of the reinforced concrete systems, the problem of the overall building height would need to be addressed. Because the reinforced concrete slabs would add 4 inches per floor to the building, the additional 9 feet would need to be taken into account. Presently with the post tension concrete design, the final building height would be at 409.70 feet, which is within 1/8 of an inch of the allowable height in the area.

The first thought is to attempt to make up the 9 feet by squeezing more space out of the plenum area. Unfortunately for this project, most of the space has vaulted ceilings that extend all the way to the slab above. That would mean that either of the scenarios would need to take place to use reinforced concrete; change the floor to ceiling heights in the units to make up the additional 9 feet, or take out one floor to make up the 9 feet.

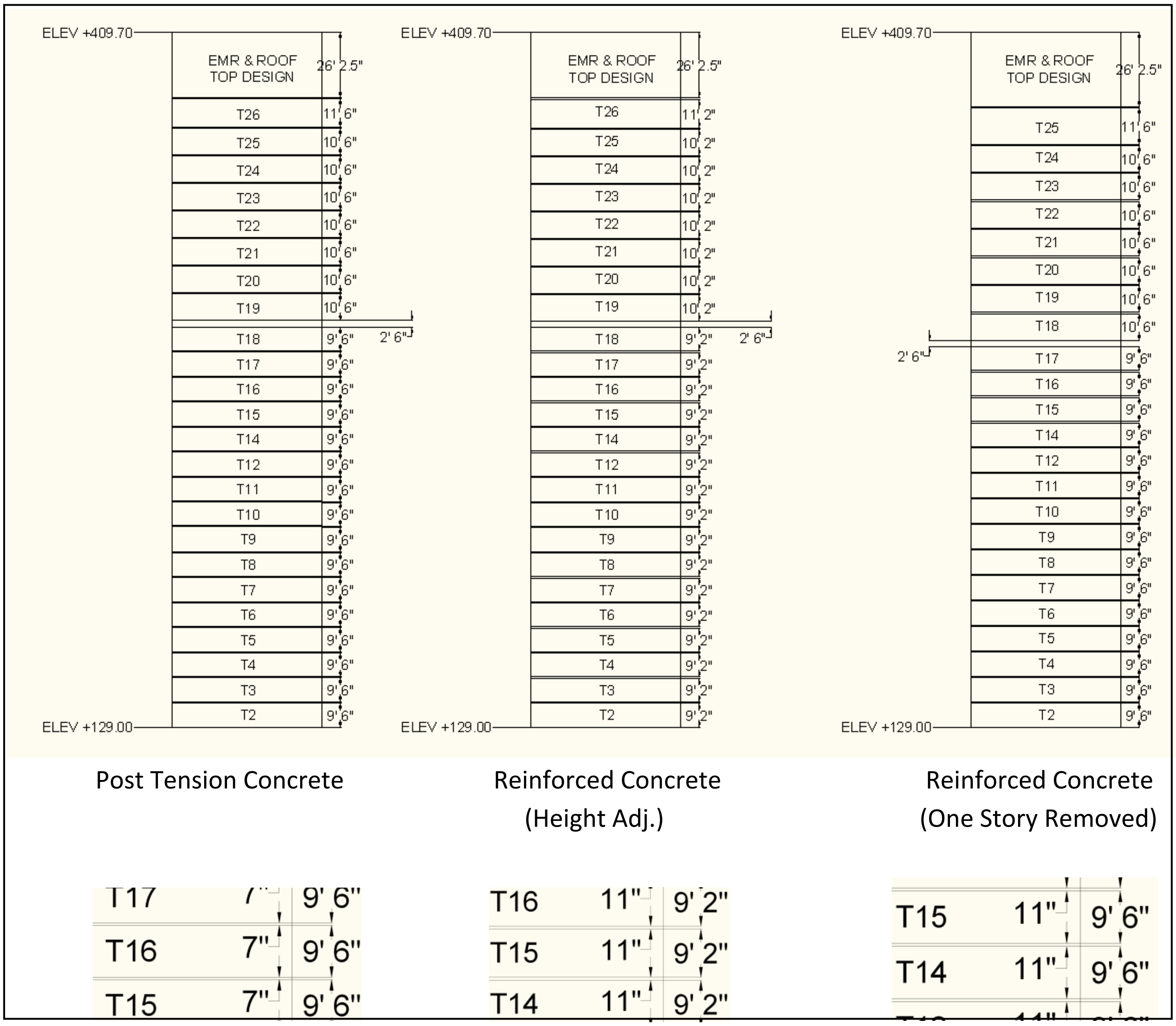

Figure 9.5 – Comparing Structural Systems

The above *Figure 9.5* compares the three different systems visually. The left structure is the tower erected in the post tension concrete with a floor to ceiling height of 9’6” with a 7” slab. This tower has 25 floors. The middle structure is the tower erected in reinforced concrete with a floor to ceiling height of 9’2” with an 11” slab. This tower has 25 floors. The structure on the right is the tower erected in reinforced concrete with a floor to ceiling height of 9’6” with an 11” slab. This tower has 24 floors. All three towers start at elevation +129.00 and end at +409.70 which is within the allowable limits.

If the structure in the middle is used, the cost will be greater and the owner will not get the desired ceiling to floor heights, which is a selling point for these units. If the tower on the right is used the owner will achieve the desired floor to ceiling heights, but will lose 1 level of rentable units will decrease their profits by $17.6 million.

After reviewing the results for both the schedule and the cost for all of the proposed alternative options (reinforced concrete), I believe that the best option is post tension concrete system, which is the system that was used. If the ceiling to floor height on each level is reduced, the owner will not be as happy because a major selling point of the building is the above average height in each apartment. This method will also add approximately $2.2 million to the building. This cost is more than the mistakes caused by the post tension blowouts. If one floor is removed from the building, all of the floor to ceiling heights will remain, but the owner will lose $17.6 million. This method also costs $2 million more than the post tension system.

Using the post tension system is the cheapest and most efficient way to gain the desired floor to ceiling heights and get the maximum amount of rentable units in the building.