Executive Summary

This report is the culmination of a yearlong study on the Trump Taj Mahal Hotel tower, a 40 story luxury hotel located on the 1000 block of the boardwalk in Atlantic City, New Jersey. Given the architectural layout of the guest room spaces, a core only lateral force resisting system and flat slab concrete floor system were designed to accommodate the architectural requirements of the project. With only the core resisting the lateral forces acting on the tower, reinforced concrete shear walls with coupling beams were designed to in such a way as to limit the wind drift and effectively dissipate the hurricane force winds of Atlantic City. A concrete shear wall core of this nature was found to be extremely stiff and rigid. These properties will eliminate any torsional flexibility issues that usually result from a slender core only system.

The purpose of this study is to determine why a concrete shear wall core and filigree flat slab floor system were selected as the structural system of the tower. The proposed lateral force resisting system redesign consists of a core of steel braced frames, the majority of which will be concentric inverted "V" braces. Eccentric braced frames will be avoided as much as possible in order to benefit from the greater stiffness provided by concentric braced frames. The proposed gravity system redesign consists of a non-composite steel frame and precast concrete plank floor system; this floor system offers the key benefit of fast erection. Both systems were chosen on a basis to determine why a steel structural system was not chosen, given its superior erection time compared to that of a concrete system. With a steel system, the construction cost and erection time can be reduced; the hotel can open at an earlier date, thereby generating revenue sooner.

The braced frames in the core of the tower were designed to effectively limit the building drift to H/400, while providing enough strength capacity to meet the requirements of AISC LRFD 3rd Edition. To meet the recommended drift limitation of H/400, large built-up column sections were required at the lower levels of the tower. These built-up sections were pivotal in reducing the overall building drift because column axial deformations had the greatest effect on overall drift.

Minor architectural impacts resulted from this structural redesign. The elevator/service core at the center of the tower required redesigning in order to allow for more flexibility while determining the geometry of the braced frames. The core redesign involved the relocation of openings, elevators, and spaces. The floor to floor height of the tower was increase by 10 inches in order to accommodate the deeper steel structure; this 10 inch increase has many cost implications. Soffits are required in order to conceal the steel frame, particularly the spandrel beams and columns. These soffits will be visible in various guest rooms throughout the hotel. As these architectural impacts seem minor in the grand scheme of things, it is at the owner's discretion to determine the acceptability of such changes. However, for the purposes of this study these changes were deemed acceptable

With all of the architectural impacts, construction management breadth studies left me with the conclusion that the cost of the steel structure is $3.5 million more than the concrete/filigree system. However, it was also found that the steel structure would top out almost a month before the concrete schedule. Will this justify the substitution of the redesigned steel structure over a concrete structure?

However, drift and strength are not the only issues that need to be addressed in the preliminary design of a high-rise lateral force resisting system. Motion perception of building occupants can sometimes control the design of a structural system. In order to fully understand the structural dynamics of a building, complex wind tunnel studies must be performed.

For the purposes of this study, a parametric RMS acceleration study was performed in order to determine whether or not accelerations due to wind would be an issue. To better grasp the effects of accelerations due to wind, the concrete shear wall core was analyzed as a way of comparing the two systems. The concrete shear wall core was found to be an acceptable design based on this parametric study. However, the steel braced frame core RMS resultant accelerations at the top floor of the hotel were found to exceed the acceptable limit by a factor of 2.0. As the steel member sizes are already large, increasing the sizes of columns, braces, and girders is not an option and will not be a viable enough solution to the acceleration issue. Although nothing can truly be determined unless wind tunnel studies are performed, this still indicates the presence of acceleration issues.

Therefore, the proposed solution of replacing the concrete shear wall core with a core of steel braced frames is not directly feasible. Only with further investigations involving complex wind tunnel studies, the acceleration problem may be solved utilizing a liquid-tuned column damper or tuned mass damper. Keep in mind that such a solution will add upwards of $2 to $3 million to the project cost and will cause the steel structural redesign to cost more than the current concrete and filigree system by about $6 million. Therefore, for the purposes of this study the reinforced concrete shear wall core will be the accepted structural system of the Trump Taj Mahal Hotel.

It is important to keep in mind that high-rise design involves many factors that are best solved by that of a design professional with years of experience. This study has served more as a learning experience to the student and may shed some light on the advanced design topics of high-rise design.

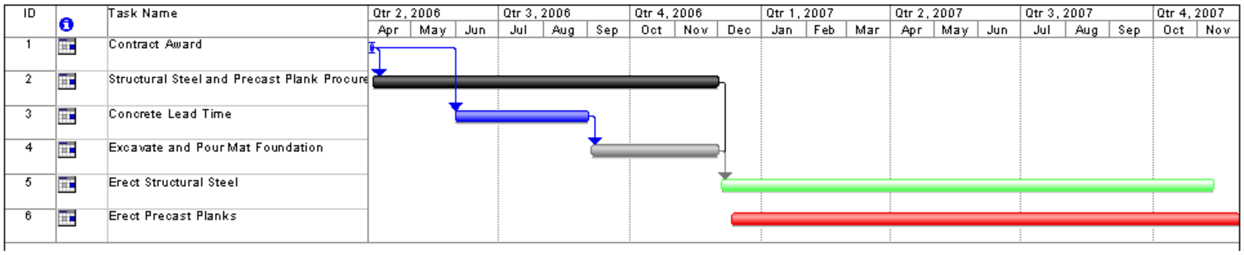

Figure 58: Summary of Steel Shear Wall Core and Precast Plank Floor System Schedule

Cost Analysis

Concrete and Filigree Structural System Cost

The structural cost breakdown, as obtained from Bovis Lend Lease, of the concrete and filigree structural system is as follows:

Foundations Cost……………………………………………………………………...$3.3 mil
Superstructure Cost…………………………………………………………………..$41.5 mil
Misc. Structural Steel……………………………………………………………….. $3.5 mil
Metal Stairs……………………………………………………………………………$1.4 mil

TOTAL………...………………………………………………………………….**$49.7mil**

Steel Structural System Cost with Additional Cost

By interviewing various construction professionals and also utilizing R.S. Means 2008, the following data was compiled for use in determining the cost estimate of the steel structural system (15% overhead and profit is included):

Structural Steel………………………………..……………………………………$3,800.00/ton

Beam Connection Allowance………………………………………..5.00%
Column Splice Allowance……………………………………........7.00%
Brace Connection Allowance…………………………..….…….15.00%

10” Precast Concrete Planks……………………..……………………………………$15.00/SF
3000 psi 2 inch Topping Slab………………………………………...………………$3.75/SF
Shear Studs……………………………………………………………………...……$5.75/EA

A 10% premium was added to the cost of built-up column sections and atypical precast concrete planks.

By speaking with the lead estimator on the Trump Taj Mahal Hotel project, John Adams of Bovis Lend Lease, the following data was compiled for use in determining the additional cost of the structural steel system (15% overhead and profit is included):

Sotawall Hybrid Curtain Wall……..……………………………………………..$85.00/SF
Otis Elevator…………………………………………………………………...$260,000.00
Mechanical Piping……………………………………………………………..$500,000.00
Sanitary System………………………………………………………………..$250,000.00
Domestic Water………………………………………………………………..$250,000.00
Bathroom Exhaust……………………………………………………………..$250,000.00
Busduct……………………………………………………………………..…$50,000.00

Additional costs of beam and column soffits, fireproofing, and fire-rated partitions reflect those costs recorded in Table 7 of the architectural breadth studies. Again, these costs were obtained using R.S. Means 2008.

A summary of the costs of the steel and precast plank structural system is as follows:

Foundations Cost………………………………………………………………...$3.3 mil
Superstructure Cost……………………………………………………......…..$39.2 mil
Additional Cost…………………………………………………………………..$5.9 mil
Misc. Structural Steel………………………………………………………... $3.5 mil
Metal Stairs……………………………………………………………………….$1.4 mil

TOTAL……….....………………………………………………………………….**$53.3mil**

All detailed cost calculations including takeoff can be found in Appendix H.

Construction Management Studies Conclusions

The following table compares both the cost (including additional costs) and schedule of the steel and concrete structural systems:

	Steel and Precast Plank System	Concrete/Filigree System
Total Structural Schedule (Weeks)	**88**	**92**
Superstructure Schedule (Weeks)	52	65
Cycle Time per Typical Floor	6 ½ days	8 days
Cost of Construction (Total)	**$53.3million**	**$49.7million**
Cost of Construction/SF	$73.00/SF	$67.50/SF

Table 8: Cost and Schedule Comparison

As it can be seen by Table 8, the cost and schedule of both systems is very similar. The steel structural system cost approximately $3.5 million more than the concrete/filigree system. The steel structural system will top out 4 weeks earlier than the concrete/filigree system; requiring approximately 13 less weeks for superstructure erection (cost savings are also reflected by this). However, this does not include any additional cost and schedule time reflected by the requirement of a tuned mass damper. The impact of such additional items was also not taken into consideration in the total schedule. This will be discussed further in the final conclusions and recommendations part of this report.

Structural steel and precast concrete systems require much more area for staging and storage, however the 25,000 square feet of provided space on-site should suffice. A tower crane will able to lift the large built-up steel column sections without the use of a supplemental mobile crane. Steel columns of precast plank systems are fabricated in larger lengths (more than 40 feet lengths) and are erected prior to the planks. This means that the tower crane operator will have to be careful to avoid hitting an erected steel column with a precast concrete plank. A tower crane with a luffing boom will help alleviate this issue.

On-site quality control of a cast-in-place concrete system is always a concern of the structural engineer of record and the construction manager. For this particular project, The Harman Group has provided an on-site field inspector. As precast planks are fabricated in a controlled environment, a higher quality product is obtained. This may eliminate the need for the on-site presence of a field inspector.

Final Conclusions and Recommendations

Limiting the drift of a tall building does not guarantee satisfactory motion perception performance due the accelerations caused by wind. The high wind velocities of the Atlantic Ocean shore line cause high along-wind, across-wind, and torsional accelerations on the upper levels of the Trump Taj Mahal Hotel. These accelerations are much higher on the lighter and more flexible steel braced frame core as compared to the rigid and heavy concrete shear wall core.

Because of its behavior to the high velocity wind of Atlantic City, the steel braced frame core designed in this study may require supplementary mass and damping in the form of a liquid-tuned column damper or a tuned mass damper. These devices can add substantial costs to the project; in the realm of $2 to $3 million. However, only parametric RMS acceleration calculations were performed in this study to determine the dynamic response of the steel braced frame core. In order to absolutely verify that a tuned mass damper will be required, complex wind tunnel studies must be performed.

Other costs are incurred when converting a concrete system to a steel system. Because of the 10 inch floor to floor height increase, additional costs were incurred due to increased runs of elevators, MEP equipment, and curtain wall glass and framing; as well as steel fireproofing and the addition of fire-rated partitions. The wind tunnel loads used in this report were determined for a tower that was 30 feet lower than the redesigned steel tower. This will impact the wind loads in such a way as to increase the magnitude, and thus, the strength and drift requirements. This could result in a more costly braced frame core. However for the purposes of this study, the increase was neglected (the height increase is only 6%).

The overall cost of the redesigned steel structure is in the realm of $5.5 to $6.5 million more than the concrete shear wall and filigree system if a tuned mass damper is required. Even if the steel structural frame and precast floor is completed approximately 1 month prior to the concrete frame, the additional time required to install the tuned mass damper and all required additional architectural and MEP components (curtain wall, partitions, fireproofing, soffits, etc.) will negate some of the time saved during erection. This indicates that the redesigned steel structure may top out at approximately the same time as the concrete system and may cost more overall as well.

The final conclusion and recommendation is to keep the existing concrete shear wall core and filigree flat plate system. A braced frame core was found to limit the drift of the building within an acceptable range; however the dynamic behavior may prove to cause building occupants to experience motion perception in the form of accelerations. The filigree flat plate system accommodates the architecture of a hotel tower without any negative ramifications. It is concluded that a project of this size requires years of professional design experience to fully understand the behavior and design considerations. However, results of this study do shed light on advanced high-rise design topics which can be used for further study.

Cost and Schedule Takeoff

Structure

Description	Quantity	Unit	Daily Output	Labor Hours	Material	Labor	Equipment	Total	Total 15% O&P	Total Hours	10 hr Days	Total Cost
4000psi Topping Slab	682570	S.F.						$3.25	$3.75			$2,559,637.50
10" Precast Hollowcore Planks	682570	S.F.	3600	0.002	$11.05	$1.21	$0.75	$13.01	$14.97	1517	152	$10,215,759.75
Structural Steel - Beams	1608	Tons			$892.17	$1,982.61	$429.57	$3,304.35	$3,800.00			$6,108,959.23
Structural Steel - Columns	2629	Tons			$892.17	$1,982.61	$429.57	$3,304.35	$3,800.00			$9,991,972.32
Structural Steel - Braces	819.621	Tons			$892.17	$1,982.61	$429.57	$3,304.35	$3,800.00			$3,114,559.80
Structural Steel - Labor Output	5007	Each	40	0.25						1252	126	
Additional for Beam Connections	$26,316,691.30	Cost							5.00%			$1,315,834.56
Additional for Column Splices	$26,316,691.30	Cost							7.00%			$1,842,168.39
Additional for Brace Connections	$26,316,691.30	Cost							15.00%			$3,947,503.69
Shear Studs	16000	Each						$5.00	$5.75			$92,000.00
Tower Crane Jumps	3									120	15	
Plumbing and Bolting										120	15	
									Total	3009	308	$39,188,395.25

Note: Shear studs taken at one stud per foot for transfer of lateral forces from diaphragm to braced frame.

Cost/SF	$54.50

Additional

Description	Quantity	Unit	Material	Labor	Misc	Total	Total O&P	Total Cost
Curtain Wall	15600	SF					$85.00	$1,326,000.00
Elevators	1.06	% Incr.				$4,500,000.00		$258,620.69
MEP Increase	1.06	% Incr.						$1,300,000.00
Fire Rated Gypsum Board Partitions								
ANSI/UL 263 Design No. U411	186667	SF	$1.35	$3.04		$4.49	$5.16	$963,200.00
Additional Shaft Wall Assembly	16667	SF	$1.18	$2.77		$3.95	$4.54	$75,708.33
Gypsum Board Soffit - Beams ANSI/UL 263 Design No. N501	213760.00	SF	$1.16	$3.60		$4.76	$5.47	$1,170,122.24
Gypsum Board Soffit - Columns ANSI/UL 263 Design No. X518 ANSI/UL 263 Design No. X521	82800	SF	$1.16	$3.60		$4.76	$5.71	$472,953.60
Fire Resistant Drop Ceiling ANSI/UL 263 Design No. D502	90800	SF	$1.12	$1.36	.	$2.48	$3.36	$305,088.00
								$5,871,692.86

Cost Breakdown	
Structural	$39,188,395.25
Additional	$5,871,692.86
Total	**$45,060,088.11**