FINAL THESIS REPORT:

"OPTIMIZATION OF BUILDING SYSTEMS"

BRIDGESIDE POINT II

PITTSBURGH, PA

Antonio DeSantis Verne

Structural Option

Advisor: M. K. Parfitt

4/9/2008

BRIDGESIDE POINT II

PITTSBURGH, PA

PROJECT TEAM

OWNER :	THE FERCHILL GROUP
ARCHITECT :	STRADA, LLC
STRUCTURAL :	ATLANTIC ENGINEERING SERVICES
CIVIL :	GATEWAY ENGINEERS, INC.
MEP :	ALLEN & SHARIFF ENGINEERING
CONSTUCTION :	TURNER CONSTRUCTION

BUILDING STATISTICS

SIZE :	180,000 SQ. FT.
HEIGHT :	5 LEVELS - 74'-6" T/STEEL
OCCUPANCY :	OFFICE & LABORATORY
BUILD DATES :	SEPTEMBER 2007 - TBD
COST :	$18 MILLION (GMP)
DELIVERY METHOD :	DESIGN-BID-BUILD

STRUCTURAL

STRUCTURAL STEEL FRAMING WITH 3" COMPOSITE STEEL DECK & 3" CONCRETE SLAB

TYPICAL BAY SIZE IS 30'-0" x 32'-0"

LARGE, EXPOSED BRACED FRAMES RESIST LATERAL LOADS

4" SLAB ON GRADE AND PILE FOUNDATION SYSTEM

ARCHITECTURE

BUILT IN 48-ACRE PITTSBURGH TECHNOLOGY CENTER

PRECAST STONE PANELS ACCENTED BY PROFILED METAL PANELS AND EXPANSIVE GLASS CURTAIN WALLS

OPEN FLOOR PLAN

FLOOR TO FLOOR HEIGHT = 15'-0"

MEP

A LABORATORY AHU PROVIDES 100% OUTDOOR AIR AT 40,000 CFM WHILE TWO OTHER AHU'S EQUIPPED WITH ENERGY RECOVERY WHEELS PROVIDE 150,000 CFM AND SERVE SPACES WITH VAV AND PFP UNITS

SEVEN - 532 GPM BOILERS SERVE THE HEATING ASPECTS OF THE BUILDING

BUILDING POWER AT 480Y/277V -- FLOOR POWER AT 208/120V VIA 30kVA TRANSFORMERS

ANTONIO DeSANTIS VERNE
STRUCTURAL OPTION

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EXECUTIVE SUMMARY

This thesis evaluates an optimization of building systems performed on Bridgeside Point II. Previous analysis reveals a potential exists to optimize the lateral system, as well as the verticality of the building. Lateral analysis indicates that the first floor behaves similar to a soft story, which results in non-uniform drift. Further research shows that the building tops off approximately 15 feet below the maximum zoning height, meaning extra revenue could be generated with a taller building. The depth study of this paper focuses on the structural issues presented by optimizing the drift and height of the building, while breadth studies focus on optimization of the façade and relocation of the current rooftop penthouse.

The lateral system is retooled by replacing knee braces with chevron braces. This change allows for the beams to be braced at mid-span and facilitates equal member stiffness contribution. An inefficient two-bay frame is condensed into a single bay. The optimized system costs less because of smaller members and a more efficient brace layout. The vertical optimization study shows that adding a floor and moving the penthouse to the ground floor creates approximately 30,000 square feet of new leasable space. The bracing scheme used in the lateral study is also used as part of the vertical optimization study. The extra space and reduced lateral members easily offset the additional upfront costs. If fully occupied, this new building design will pay off faster than the current building design.

The architecture breadth focuses on the façade of the building, as well as, some aspects of the ground floor. The north façade is completely reworked so it can expose the lateral bracing. Other facades underwent similar modifications to expose the bracing on the ground floor. Thus, a sense of load progression from the roof to the foundations is created. What results is a more homogenous façade that accents the structure of the building. The acoustics breadth study focuses on the reduction of noise propagation. By placing the mechanical room on the ground floor, a new space is designed to help minimize the effects of equipment vibration and noise. A thick barrier wall provides ample noise reduction characteristics, and an inertia pad helps rid any structural borne vibrations.

The goals of this thesis are to create an economic and efficient building. Based on the results, these goals are clearly achieved. From a feasibility standpoint, each proposed topic of study positively impacted the structure. It is the recommendation of the author to implement all changes addressed in this thesis.

ACKNOWLEDGMENTS

The author wishes to extend acknowledgments and thanks to the following individuals, faculty, professionals, and firms for their generous aid with this thesis:

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A special thanks to my friends and peers.

A very special thanks to my family, especially my mom and dad for the countless pep-talks and their endless support over the past half decade.
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INTRODUCTION: BRIDGESIDE POINT II

The Bridgeside Point II project consists of five above grade stories with a combination of office and laboratory space. It is located in the Pittsburgh Technology Center, which is just east of downtown Pittsburgh, Pennsylvania. The building conveys a feeling of progression from a historic steel mill town to a fast-paced, innovation driven city through its use of clean lines, visible lateral system, and open plan. A glass curtain wall lends itself for a feeling of transparency on the upper floors, while dense, pre-cast panels wrap the ground floor.

The building is approximately 160,000 square feet and reaches a height of 75 feet above grade. The building floor template is an open plan with a design core capable of housing office and laboratory spaces as each floor is roughly 15 feet floor to floor. A typical bay is 30 feet by 32 feet, and is comprised of composite steel with a concrete slab on deck (Figure 1). The lateral system is a series of braced frames, two in the east – west building direction and three in the north – south building direction. The foundation system is a driven pile system. A typical pile cap hosts between three and seven piles and has a thickness of 3’-6” to 4’-6”. The ground floor is a reinforced slab on grade with grade beams around the perimeter.

Flexibility is the main concept this building expresses. At the time of design, no definite tenant was indentified; however, the intended client is thought to be “high tech”. Therefore, this required the design to be extremely flexible, and distribution of systems to be more critical. In order to create this flexibility two things are directly affected. The desired large bays require a heavy uniform live load, thus larger structural members. Also placement of the lateral system is limited. The lateral system is placed roughly at the building side’s midpoints.

This report reviews and discusses the results of an optimization thesis of Bridgeside Point II. Lateral analysis took advantage of RAM Structural System and SAP 2000 as well as hand calculations as noted in their respective sections. Spot checks were performed on several members to ensure the computer designed members were accurate for both strength and drift control.

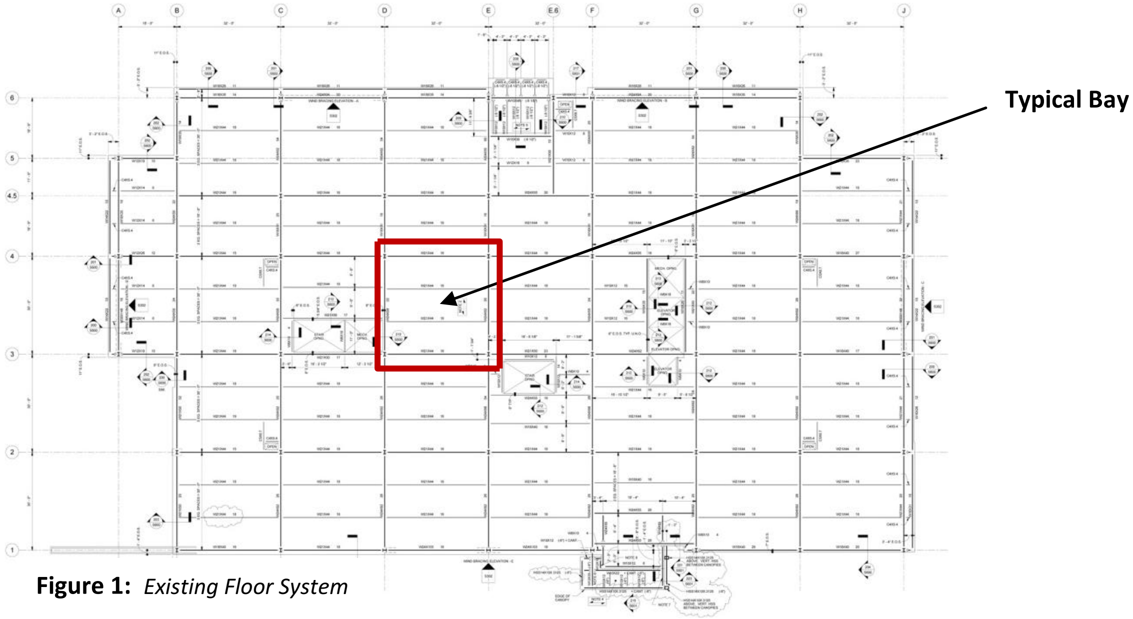

Figure 1: *Existing Floor System*

EXISTING COMPOSITE STEEL SYSTEM

Floor System

The floor system of Bridgeside Point II is a composite system with a typical bay size of 30’-0” by 32’-0”. A 3” concrete slab rests on 3” composite steel decking. Shear studs ¾” diameter (5 ½” long) are used to create composite action. This assembly provides a 1.5 to 2 hour fire rating which meets IBC requirements. Infill beams are W21x44 spaced at 10’-0” center to center which frame into W24x62 girders.

Lateral System

Large braced frames make up the building’s lateral load resisting system. In order to increase the flexibility of the building plan, the perimeter was chosen for the bracing (Figure 3). Four of the five bracing frames are exposed via windows. In these bays, large HSS8x8x3/8 and HSS10x10x1/2 provide the bracing at the second through fifth floors and are Chevron Braces, which create a two story “X” in the window (Figure 2). On the first floor these four frames have an eccentric brace, whereas the large fifth frame is two bays wide and is comprised of all W-shape eccentric braces.

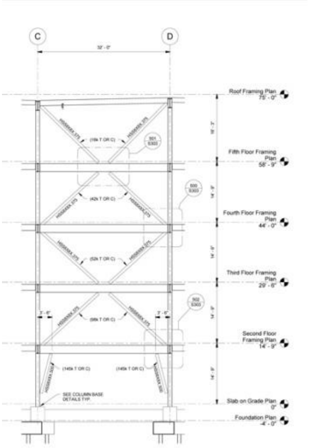

Figure 2: *Typical Lateral Frame*

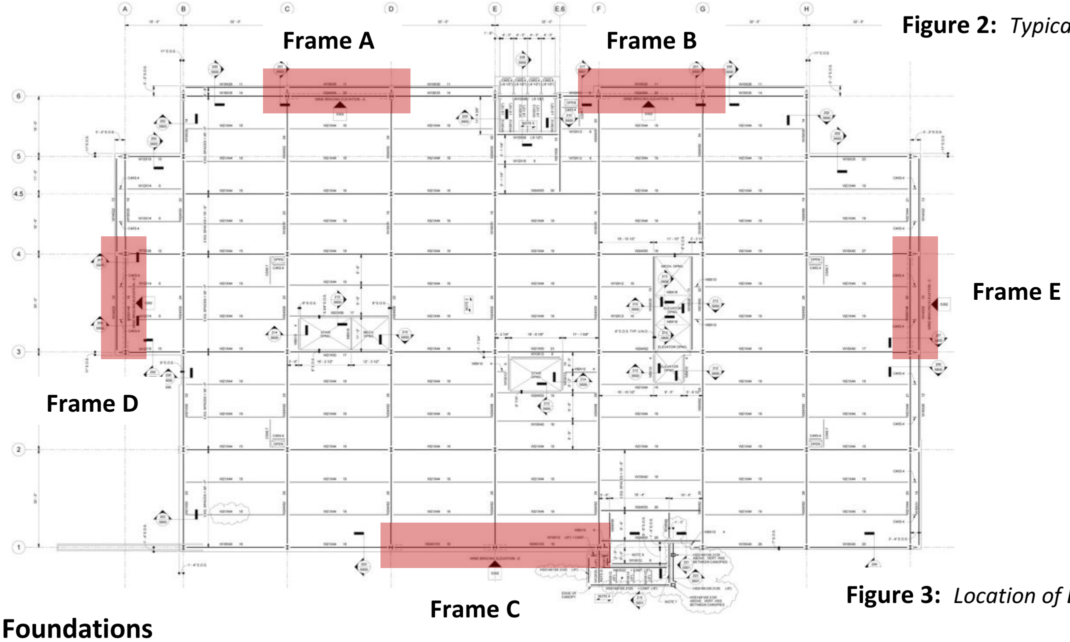

Figure 3: *Location of Lateral Bracing*

Foundations

A driven pile system with pile caps containing between two and nine piles provides the foundation system for the building with an end bearing capacity of 105 to 130 tons per pile. The pile caps vary in thickness from 3’-6” to 4’-6” and have between 9 and 12 No. 9 reinforcing bars. Depending on their location within the site, they are driven to a depth of 45 to 55 feet. These piles support the framing system as well as 12” thick grade beams. The ground floor is a 4” concrete slab on grade. Soil conditions are from the geotechnical report provided by Professional Service Industries, Inc. dated May 2007.

CODES AND LOAD COMBINATIONS

Codes and References

The 2006 International Building Code as amended by the City of Pittsburgh.

The Building Code Requirements for Structural Concrete (ACI 318-05), American Concrete Institute.

Steel Construction Manual, Thirteenth Edition, American Institute of Steel Construction.

Minimum Design Loads for Buildings and Other Structures (ASCE 7-05), American Society of Civil Engineers.

This report will use Load and Resistance Factor Design for all steel design checks.

Deflection Criteria per 2006 International Building Code

Δ_{WIND} = H/400 Allowable Building Drift

$\Delta_{SEISMIC} = 0.025h_{SX}$ Allowable Story Drift

Load Cases and Combinations per 2006 International Building Code

The following are the load cases considered for this analysis per 2006 IBC, Section 1605:

1.4(Dead)
1.2(Dead) + 1.6(Live) + 0.5(Roof Live)
1.2(Dead) + 1.6(Roof Live) + (1.0 Live or 0.8 Wind)
1.2(Dead) + 1.6(Wind) + 1.0(Live) + 0.5(Roof Live)
1.2(Dead) + 1.0(Seismic) + 1.0(Live)
0.9(Dead) + 1.6(Wind)
0.9(Dead) + 1.0(Seismic)

Different load cases and combinations were applied in various directions and with varying eccentricities to the wind and seismic loads in the computer analysis. The total combinations generated for LRFD were 313. It should be noted that snow loads were not included in this analysis. A detailed listing of the load cases and combinations used are available upon request.

Wind Criteria

Wind loads were analyzed using Section 6.5 of ASCE 7-05. Below are the assumptions used to aide in the determination of the Main Wind-Force Resisting System. For a detailed layout of the corrected calculations, please refer to Appendix B.

Basic Wind Speed ***V***……………………………………………… 90 mph
Exposure Category……………………………………………… C
Importance Factor……………………………………………… 1.0
Building Category……………………………………………… II
Internal Pressure Coefficient ***GCpi***……………………… +/- 0.18

Seismic Criteria

Seismic loads were analyzed using chapters 11 and 12 of ASCE 7-05. Below are the assumptions used to aide in the determination of the Seismic Force Resisting System. For a detailed layout of the corrected calculations, please refer to Appendix B.

Seismic Use Group……………………………………………… II
Importance Factor……………………………………………… 1.0
Spectral Response Accelerations
  S_s……………………………………………………………… 0.125
  S_1……………………………………………………………… 0.049
Site Class………………………………………………………… D
Site Class Factors
  F_a……………………………………………………………… 1.6
  F_v……………………………………………………………… 2.4
S_{MS}…………………………………………………………… 0.20
S_{M1}…………………………………………………………… 0.1176
S_{DS}…………………………………………………………… 0.133
S_{D1}…………………………………………………………… 0.078
Seismic Design Category………………………………… B
Response Modification Factor…………………………… 3.0
  (Ordinary Composite Steel & Concrete Braced Frame)
Seismic Period Coefficient (C_t)…………………………… 0.03
Seismic Period Coefficient (C_s)…………………………… 0.02
Period Coefficient (x)…………………………………………… 0.75

-End of Section-

PROBLEM BACKGROUND

Problem Statement

The present design of Bridgeside Point II utilizes a braced frame for the lateral forces experienced on site. Lateral analysis performed in technical report three indicated that the opportunity exists to study and optimize building and story drift, particularly at the second story level. The upper stories exhibit a very rigid behavior, while the second story is quite flexible in comparison. While this is not a strength issue, it is a potential serviceability concern. The current story drift could present a problem for the façade at the second and third story interface. If the façade is not designed and fastened properly, the precast and metal panels could experience performance problems.

The building also tops off 15 feet under the maximum zoning height of 90 feet (not including the mechanical space). With an ever increasing demand for real estate, building vertically is a common solution. However, adding an additional floor to Bridgeside Point II poses several challenges both structurally and architecturally. If an extra floor is feasible, more revenue could be generated for the owner. Even with the possibility of increased marketability and revenue, several of the major problems would be the higher upfront cost needed to cover the new floor, and the impact on schedule like completion date. Adding a floor could increase the existing column and footing sizes, as well as, alter the lateral system considerably; and, in the case of the current design, would require relocation of the penthouse and possibly more driven piles. The existing heating, cooling, and lighting systems would need to be re-evaluated for the new demand loads and redistributed due to the relocated mechanical room. The relocated mechanical room poses the concern of noise and vibration intrusion to the adjacent lab and office spaces; therefore, special consideration should be given to the shared wall.

Problem Solution

Optimization of the story drift presents an opportunity for thesis study, especially if an additional floor is added. A completely new braced system will be implemented. A moment-frame system will not be considered because of the higher costs for connections and its inefficiency compared to a braced frame system. The braced system will reflect the client's initial idea of structural elements exposure via powerful diagonals; however, the mixture of eccentric and concentric braces will be eliminated. The new system will be comprised only of concentric bracing, as that will afford the most rigidity, and the greatest chance for cost reduction. The original and new systems will be compared and analyzed based on drift, cost, and feasibility. Along with this, one breadth study focusing on the building architecture will be examined. The north façade will be revisited for the purposes of exposing the lateral bracing. If the drift optimization proves to be uneconomical and inefficient, further façade studies will be performed to validate the connection's and material's performance.

Marketability will be addressed next. A study will be conducted on adding an addition floor to the current structure, and look at the projected value of the current five story building and its upfront cost, versus the projected value of the proposed six story building and its upfront cost. The initial expectation is that the six story building bears the potential to dramatically increase building revenue while minimally impacting upfront costs. The additional floor will allow for a complete redesign of the lateral system, in order to optimize drift. Along with this, a breadth study will encompass the relocation of the penthouse equipment, as well as, a detailed analysis of sound isolation for the mechanical room and the impacts this additional floor will create for the mechanical and electrical systems. The result will be a complete cost comparison between the current cost and the "new" proposed cost.

SOLUTION METHODS

Structural Analysis

For drift optimization, different bracing schemes will be investigated (Figure 4). The most economical brace pattern for both drift *and* cost will be designed in accordance with the gravity and lateral loads from ASCE 7-05 and methods from the thirteenth edition steel manual. Computer models generated with SAP and RAM Structural System will be completed for the existing building and the alternate lateral system(s). Through a comparison of the two models, it will be determined how to optimize the lateral system in the most economical and least intrusive way relative to the function of the floor plan and building architecture.

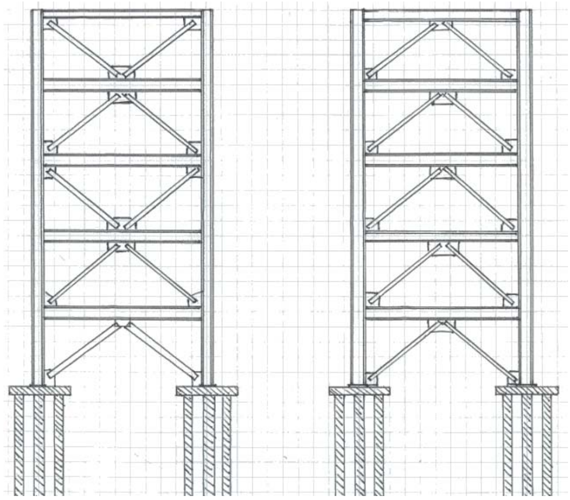

Figure 4: *Possible Lateral Framing Solutions*

For increased marketability, Bridgeside Point II will be given an additional floor for leasing. Pittsburgh Zoning Code allows for a maximum height of 90 feet, unless the building is unique in nature, therefore 90 feet will be the benchmark for new building height. This will not compromise the current floor to floor heights because of the penthouse relocation (Figure 5). In order to accommodate this increased height, RAM Structural System will be used to design all gravity members with the loads given by ASCE 7-05. This includes, but is not limited to, the new floor's beams, girders, and columns, as well as, the existing columns and footings. The foundations will be resized as needed. This additional floor will require a new lateral system. Optimization will be the cornerstone of the design governed by ASCE 7-05 and modeled in RAM and SAP. Once complete, a very detailed analysis involving cost, drift, and feasibility will be done using RS Means and Engineering Economics for costs, ASCE 7-05 for drift. This analysis will determine the viability of adding a floor and any implications it presents.

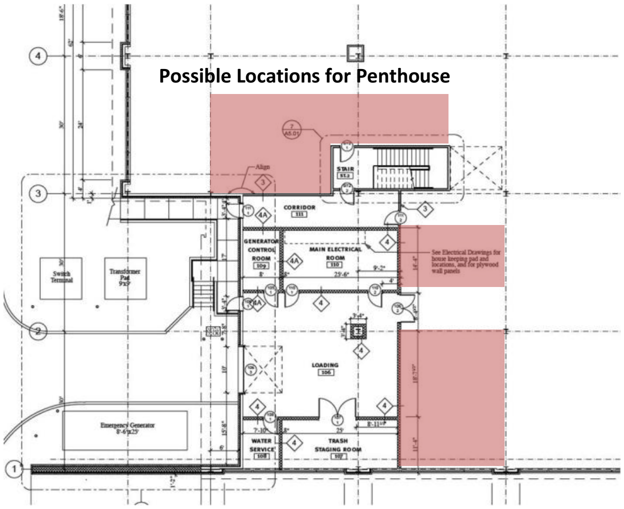

Figure 5: *First Floor - Options for Existing Penthouse*

Breadth Analysis

Along with the main structural study, a minimum of two breadth studies will also be performed. The first study will look at Bridgeside Point II's exterior architecture given the altered lateral bracing system. It will also look whether a revision to the cladding system is necessary based on its behavior under the current building drift conditions. This study will emphasize performance and optimization. The second study will focus on the implications of adding an additional floor to the structure. This will include an analysis of sound isolation for new mechanical room now located within the building as well as the implications to the existing mechanical and electrical systems.

The façade study will focus on the aesthetics of the new bracing scheme. Several rendered elevations will be provided to express the changes in the façade. In the event that lateral optimization proves uneconomical, an alternate façade study will be performed to determine if the existing connections and materials meet the new standard put forth by AISC for 2008, Façade Attachments to Steel Buildings to ensure that connections and materials are designed and installed properly. Upon conclusion, recommendations will be presented.

The second breadth study will focus mainly on sound isolation; however, if time permits, calculation and design of new heating/cooling and lighting systems will be performed. This study will look at reducing noise transmission from the mechanical room to the rest of the building, as well as, ensuring the building is not experiencing any unwanted vibrations from said room.

- End Section -

DEPTH STUDY: BUILDING OPTIMIZATION

The purpose of this thesis is to optimize lateral and vertical structural components of Bridgeside Point II through various analytical methods. Lateral optimization will focus on drift and brace efficiency and economy. Vertical optimization will focus on adding an additional floor while taking advantage of the new lateral system. The desire for optimization stems from previous investigation that indicated the building's braced frames were not homogenous in rigidity top to bottom. Studies based on Pittsburgh zoning, showed the building topped off 15 feet below the permitted maximum height. By optimizing the building, the result should be a more cost-effective building that increases the revenue stream.

Lateral Optimization

The goal of this study is to create a consistent bracing scheme, while eliminating the soft story. Disconnect in rigidity from the first to second floor is classified as soft story, which is defined as a story that has a considerable less amount of stiffness than the stories above or below it. Typical it has inadequate energy absorption capacity to resist laterally induced building forces.[1] In order to compensate for the lack of rigidity, additional frames were required to limit the drift to code specifications. This also required much larger members, which could be viewed as inefficient and costly. As discussed in the introduction to this paper, the frames are located around the perimeter and use a combination of bracing schemes (Figure 6). From stiffness analysis, the two-bay frame exhibits the least amount of rigidity. The results also indicated that the first floor acted as a soft story, and minimizing or eliminating this irregularity would give the building a more uniform drift.

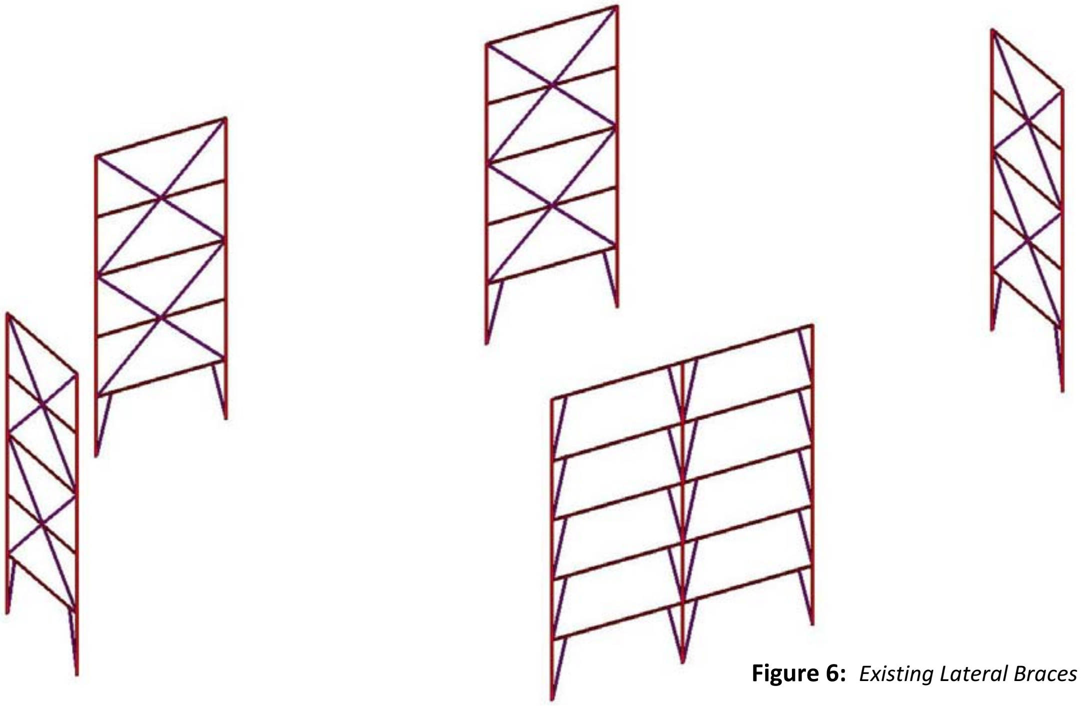

Figure 6: *Existing Lateral Braces*

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[1] Day, Robert W. "Geotechnical Earthquake Engineering Handbook." McGraw-Hill. 2002. pp. 4.6

The first objective is the soft story. Continuity needs to be present in the lateral system. Creation of this can be done by various moment frames and braced frame schemes. However, the initial design has exposed bracing, so switching to moment frames would not fit this concept, and would also prove to be very costly. After several schematics with alternate bracing, it was determined that simply removing the knee brace and replacing it with a chevron brace could be a viable solution. That also generated that idea to completely remove the two-story "X" and use chevron braces from top to bottom, creating a triangle (Figure 7).

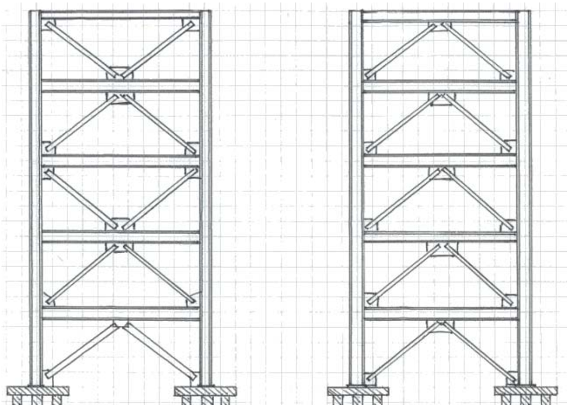


Figure 7: *Modified "X" brace (left) & Chevron brace (right)*

The next objective was the two-bay frame. The current design required this frame for drift control. However, with the new schemes the opportunity exists to reduce the two-bay frame to one bay. Should this be a viable solution, the braces should be made visible on the north façade (see Architecture Breadth, page 22).

The new bracing schemes were constructed in SAP and RAM Structural System. RAM would perform the lateral analysis, while SAP would be used to verify the results of a virtually work analysis. The new lateral systems would be checked against drift, as well as member economy and participation. The modified "X" brace system will be presented first (Figure 8). This design closely mimics the initial layout, however, it is clearly seen how the second floor beam is braced at mid-span. This affords for a much smaller beam, and increased the rigidity significantly. However, from analysis it is shown that several of the beams take little or no lateral load. Their size, while originally determined for gravity loads, is much larger in order to achieve greater rigidity. The tables below show the contribution (in percent) of each member with regards to stiffness, as well as, the drift experienced by using this system. It should be noted that all the systems presented significantly reduce the amount of drift compared to the existing lateral system.

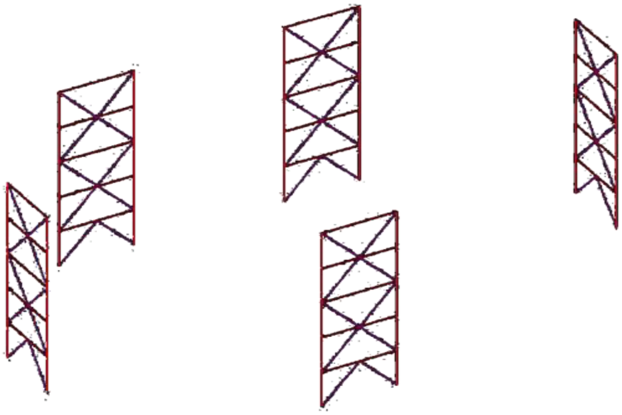


Figure 8: *Modified "X" brace*

East - West Direction

Beams	7.75%
West Columns	23.38%
East Columns	22.19%
West Braces	23.58%
East Braces	23.10%

	Story Drift		Structure Drift		
	Actual	Allowable	Actual	Allowable	
Roof	0.116	0.450	0.659	2.220	OK
5th Floor	0.136	0.443	0.542	1.770	OK
4th Floor	0.149	0.443	0.406	1.328	OK
3rd Floor	0.114	0.443	0.257	0.885	OK
2nd Floor	0.143	0.443	0.143	0.443	OK

North - South Direction

Beams	6.92%
West Columns	18.37%
East Columns	17.63%
West Braces	28.85%
East Braces	28.22%

	Story Drift		Structure Drift		
	Actual	Allowable	Actual	Allowable	
Roof	0.038	0.450	0.287	2.220	OK
5th Floor	0.050	0.443	0.249	1.770	OK
4th Floor	0.063	0.443	0.200	1.328	OK
3rd Floor	0.060	0.443	0.137	0.885	OK
2nd Floor	0.077	0.443	0.077	0.443	OK

This system performs very well under the drift criterion. The soft story irregularity is eliminated. Drift is more uniform, and the building does not drift anywhere near the allowable, even with one less bay of bracing.

The chevron-brace system will be presented next (Figure 9). This design seems to be the most homogenous scheme because each beam is braced at mid-span. This will aid in reducing beam sizes, while at the same time increasing their contribution in the lateral load participation. With beam participation increasing, it should be expected that the column participation will decrease. The intent is purposeful. The columns are much larger in terms of weight (W14x90 – W14x132) and span upwards of 75 feet, while the beams are W18x40 and only span up to 32 feet. By reducing the column size, the amount steel required drops considerably when spread out over five frames. The tables below show the contribution (in percent) of each member with regards to stiffness, as well as, the drift experienced by using this system.

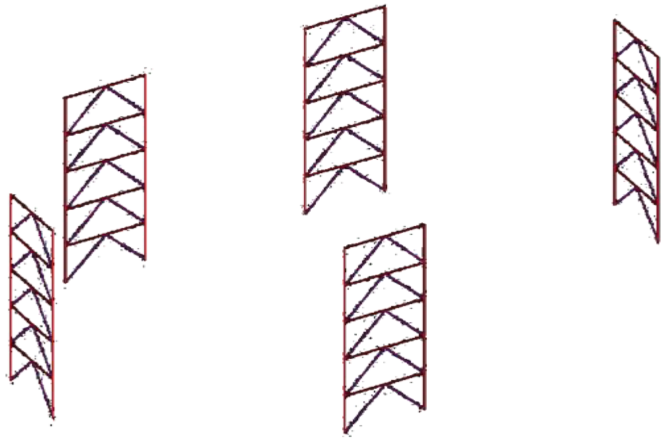


Figure 9: *Chevron brace*

East - West Direction

Beams	29.61%
West Columns	11.99%
East Columns	12.02%
West Braces	23.15%
East Braces	23.23%

	Story Drift		Structure Drift		
	Actual	Allowable	Actual	Allowable	
Roof	0.117	0.450	0.731	2.220	OK
5th Floor	0.121	0.443	0.615	1.770	OK
4th Floor	0.211	0.443	0.493	1.328	OK
3rd Floor	0.132	0.443	0.283	0.885	OK
2nd Floor	0.151	0.443	0.151	0.443	OK

North - South Direction

Beams	31.39%
West Columns	11.25%
East Columns	11.23%
West Braces	23.03%
East Braces	23.11%

	Story Drift		Structure Drift		
	Actual	Allowable	Actual	Allowable	
Roof	0.039	0.450	0.296	2.220	OK
5th Floor	0.047	0.443	0.257	1.770	OK
4th Floor	0.069	0.443	0.211	1.328	OK
3rd Floor	0.064	0.443	0.141	0.885	OK
2nd Floor	0.077	0.443	0.077	0.443	OK

With this system the soft story is eliminated once again. This system drifts a slight amount more than the modified "X" system; however, the sizes used with the chevron frame are smaller. Since both systems are well under the maximum allowable story drift, the most economical and efficient braced system would be the chevron system.

The goal of this study was to create a consistent scheme and address the soft story. This goal was clearly met, and the result is a very homogenous lateral system. All the members have been streamlined to meet the gravity and lateral loads. The reduction of the two-bay frame results in fewer braced members. The next criterion to check is cost. The table below shows the relative costs and the expected payback time (in years).

Building System	**Total Cost (Including MEP Alterations)**	**Cost Difference**	**Payback (Years)**	**Recommend**
Existing Structure	$19,126,000	$0	8.38	-
Modified "X"-Brace	$19,054,746	-$71,254	8.35	Yes
*Modified Chevron Brace	$19,040,189	-$85,811	8.34	Yes

**Optimal choice*

Both bracing schemes reduce the cost of the building, with the edge going to the chevron system. Since the cost reduction is relatively small in relation to the total building cost, it is easy to see why different bracing schemes were overlooked. By the time the engineer performed all the analysis, drafted the design, and presented it to the owner, those cost savings could have been swallowed up. Nonetheless, the chevron braces add value to the project. This study does provided very valuable information to younger engineers, even seasoned engineers. Just because a system works, does not necessarily mean it is the optimal choice. Dialog amongst architects and engineers about design should exist at all levels of design, but the schematic level is where the real savings and important decisions occur. A soft story in Pittsburgh really is not a big issue; however, knowledge of the building's behavior is very important. Extreme loads could ultimately damage the façade and induce massive P-delta effects into the structure. With the redesign presented, these possibilities are significantly reduced; therefore, a façade investigation dealing with connection detailing will not need to be performed. The redesign meets and exceeds the goals set forth, it is thereby recommended for implementation.

Vertical Optimization

The goal of this study is to utilize as much vertical space on the site as possible to generate more revenue. The Pittsburgh zoning code for this site allows for a maximum building height of 90 feet unless the building is very iconic in nature. For the purpose of this thesis, Bridgeside Point II is going to be treated as non-iconic. The building tops off at 75 feet plus a roof top mechanical room; therefore, vertical optimization would permit one additional floor, so long as the mechanical room is relocated. The most logical location for the mechanical room is the first (ground) floor, which is discussed further in the Acoustics Breadth (page 27). The additional floor design was done preliminary by hand for rough sizing, and then implemented into a RAM model. The roof was also redesign to reflect the removal of the mechanical room. The following design loads were considered:

Dead Loads					
Typical Floor Loads (psf)		Roof Loads (psf)		Penthouse Loads (psf)	
Partitions	10	M.E.P.	5	M.E.P.	5
Finishes	3	Slab & Deck	50	Slab & Deck	25
M.E.P.	5	Structural Steel	10	Structural Steel	10
Slab & Deck	57	Misc.	5	Misc.	5
Structural Steel	15	--	-	--	-
Total	**90**	**Total**	**70**	**Total**	**45**

Live Loads	
Building Space	Load (psf)
Public Areas	100
Lobbies	100
First Floor Corridors	100
Corridors Above First Floor	80
Office	50
Light Storage	125
Mechanical	150
Stairs	100

The additional floor was design in accordance with these loads and applicable codes such as IBC 2006 and ASCE 7-05. The floor itself matched the other existing floors in the building (Figure 10); the main difference was on the roof (Figure 11). The roof no longer required a composite steel portion to meet the penthouse demand loads. This reduced the amount of concrete and steel needed at this level.

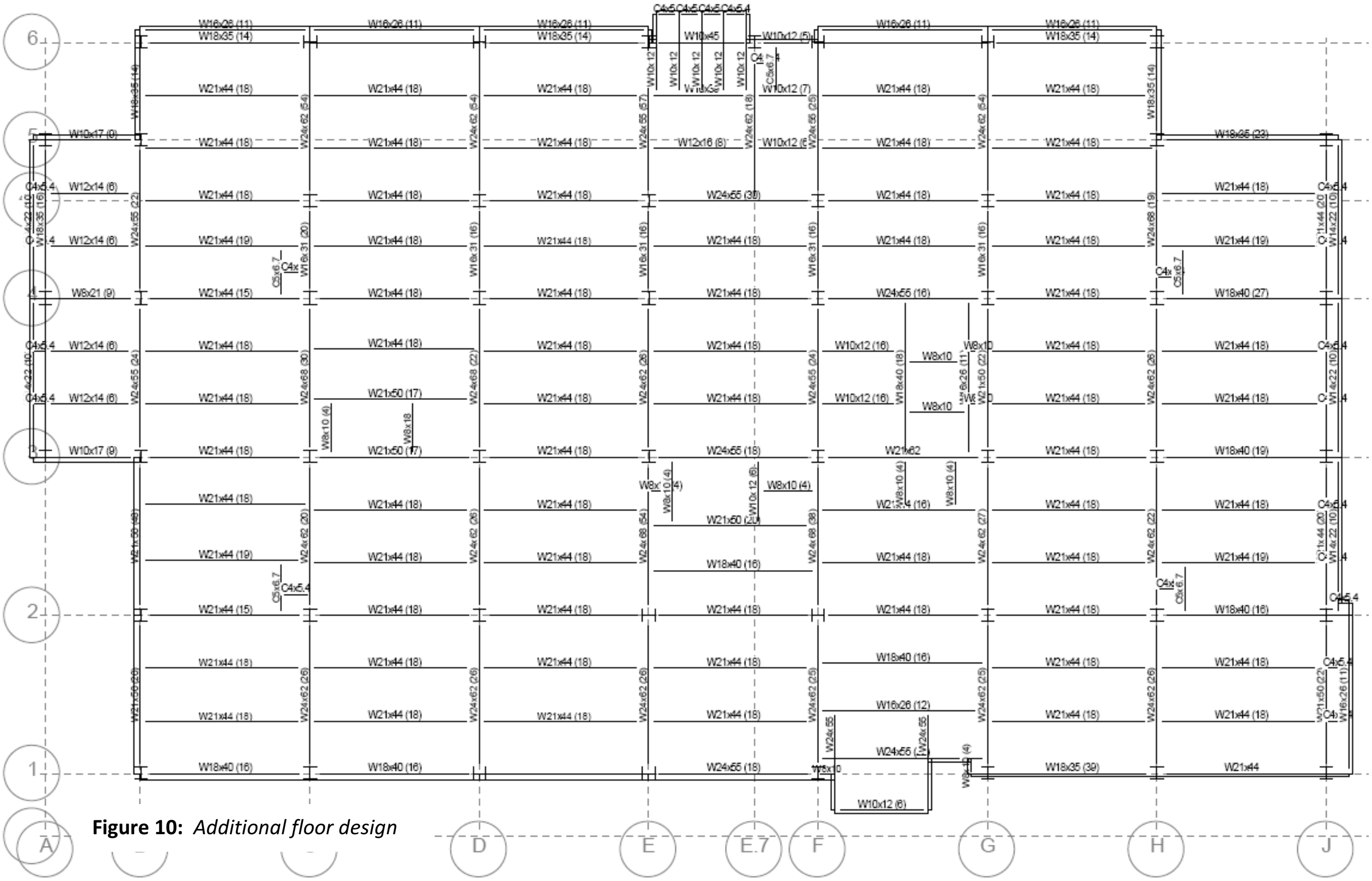


Figure 10: *Additional floor design*

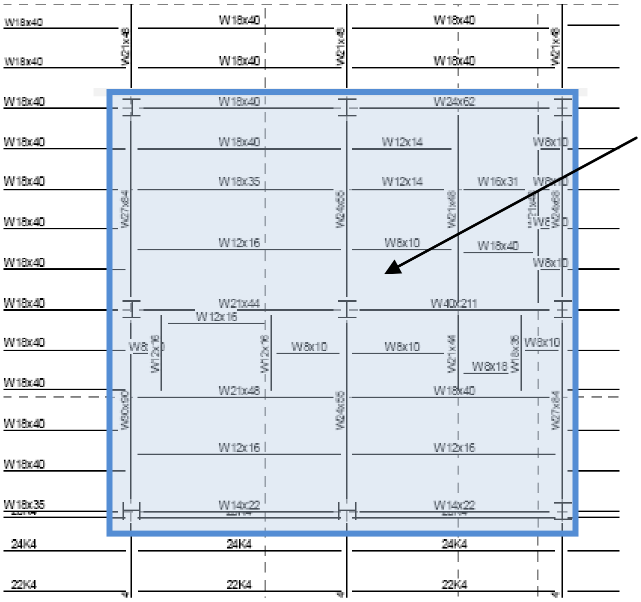


Figure 11: *Redesigned roof structure*

Following the load path down to the ground, the foundation load carrying capacities were checked for adequacy in handling the new loads. In-depth calculation was not used; rather, the existing base plates were checked for their maximum load capacities. These loads were then compared against the actual loads they experienced. Only in a few circumstances were base plates and foundations found to be inadequate for the new loads (Figure 10, see Appendix D for Foundation Plan).

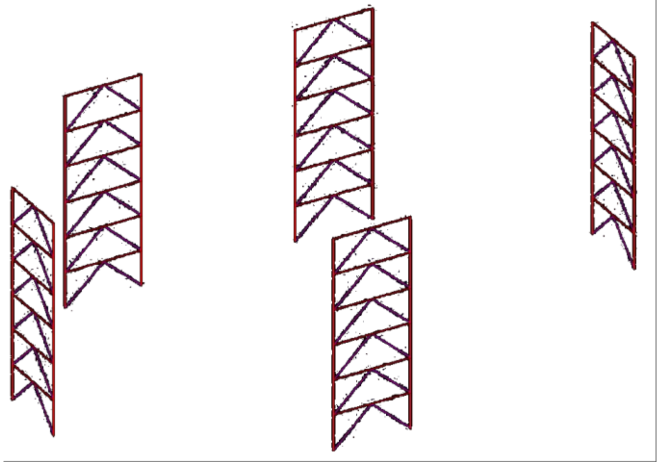
	Max Load	**Actual Load with Addition**	**System Impact**	**Required Foundation Changes**	**Required Base Plate Changes**
2 Pile Cap	410	411	Requires foundation change	Change Pier H5 to a 3 Pile Cap	Alter base plate on H5
3 Pile Cap	630	644	Requires foundation change	Change Pier E2 to a 4 Pile Cap	Alter base plates on 2, 4, and 4.5 Lines
4 Pile Cap	805	805	No change to foundation system	None	None
9 Pile Cap	730	370	No change to foundation system	None	None

Figure 12: *Foundation system impact to addition loads and the resulting implications*

Only two pile caps and 15 base plates needed to be redesigned. For the purpose of this thesis, actual sizes were not calculated; instead, inadequate pile caps and base plates were increased in size to match similar sections that were rated for the load.

With the additional floor designed and the foundations revised, the next step is designing the lateral system. Based on the findings from the lateral optimization study, a chevron brace scheme is used (Figure 13). Once again the two-bay frame is eliminated because as with the previous study, the drift was not remotely close to the limits imposed by ASCE 7. For thoroughness, the modified "X" brace system is also checked. Even though the chevron brace is a more efficient choice, the "X" brace mimics the original design and may be preferred by the owner. By increasing the total building height, the lateral forces also increased (See Appendix XX). The new load does not dramatically affect the member sizes; but it does have a big enough impact to require detailed analysis. The frames are designed in such a manner that the interaction equation is as close to 1.0 as possible. Typically, the beams would start to fail under the gravity load when optimized; rather than the lateral load, which is why the resulting drift is so minimal. The results for the chevron brace will be presented next (See Appendix A for the Modified "X" – Brace results). The tables on the next page show the contribution (in percent) of each member with regards to stiffness, as well as, the drift experienced by using this system.

Figure 13: *Additional floor with chevron frame*



East - West Direction

Beams	21.91%
West Columns	18.13%
East Columns	18.14%
West Braces	20.88%
East Braces	20.94%

	Story Drift		Structure Drift		
	Actual	Allowable	Actual	Allowable	
Roof	0.162	0.450	1.252	2.663	OK
6th Floor	0.194	0.443	1.090	2.220	OK
5th Floor	0.246	0.443	0.895	1.770	OK
4th Floor	0.247	0.443	0.649	1.328	OK
3rd Floor	0.212	0.443	0.403	0.885	OK
2nd Floor	0.191	0.443	0.191	0.443	OK

North - South Direction

Beams	19.48%
West Columns	18.10%
East Columns	18.09%
West Braces	22.14%
East Braces	22.18%

	Story Drift		Structure Drift		
	Actual	Allowable	Actual	Allowable	
Roof	0.063	0.450	0.559	2.663	OK
6th Floor	0.078	0.443	0.496	2.220	OK
5th Floor	0.098	0.443	0.417	1.770	OK
4th Floor	0.108	0.443	0.319	1.328	OK
3rd Floor	0.108	0.443	0.211	0.885	OK
2nd Floor	0.103	0.443	0.103	0.443	OK

These results are nearly perfect because each member group is contributing very similar amounts. It is clear that the lateral frames are as efficient as possible. The drift amounts are very reasonable and because they are less than half of the allowable, P-Delta effects will be neglected.

The goal of this study was to maximize the building space and generate extra revenue while staying within all site constraints, and not altering the existing footprint. The additional floor creates approximately 30,000 square feet of new leasable space. Using the results from the lateral optimization, the building's lateral system was streamlined, which reduced drift and member size. In terms of efficiency, the goal was reached. The next criterion to check is cost. The table below shows the relative costs and the expected payback time (in years).

Building System	**Total Cost (Including MEP Alterations)**	**Cost Difference**	**Payback (Years)**	**Recommend**
Existing Structure	$19,126,000	$0	8.38	-
Addition with "X"- Brace	$21,496,806	$2,370,806	7.85	Yes
*Addition with Chevron Brace	$21,477,402	$2,351,402	7.84	Yes

**Optimal choice*

This additional floor does increase the upfront cost by approximately 12%. The extra money necessary to create such an addition could present a financing problem. However, the additional floor creates an opportunity from which revenue can be generated. As determined from analysis, the increased revenue offsets the upfront costs. It should be noted that the payback did not include interest, inflation, or lease increases as this was not a breadth topic, rather, a simple comparison to prove the feasibility of the design. These results are somewhat stunning; but when considered further, they are easily justifiable.

The five story structure already fronted much of the cost. The additional floor required a few more tons of steel; however, the columns only needed minimal alterations. The remaining systems could be estimated as a cost per square foot (See Appendix C for in-depth calculations). Essentially all the necessary components are there, the additional floor is just fractionally increasing the total cost, while dramatically increasing the revenue stream. This comparison proves that the additional floor is not only efficient but very economical. The building with the addition would pay itself faster because of the increased rentable space. It would be worth presenting this claim in the schematic phase of development because it may have been overlooked due to the rooftop penthouse. By simply relocating the penthouse to the ground floor, 15 feet of vertical space are freed and the amount of leasable space (even by excluding the space occupied by the mechanical room) is increased by nearly 30,000 square feet.

Depth Study Summary

The intent of this depth work was to optimize Bridgeside Point II from a lateral and vertical standpoint. Lateral analysis proved that replacing the knee brace with a brace that spanned to the beam mid-span eliminated the soft story and reduced drift. The reduction of the two-bay frame also proved to be beneficial and more efficient. Vertical analysis proved that adding a floor, it is very feasible. The lateral system performed well under the new design loads and only minimally impacted the gravity structure. Both analysis studies indicated that an alternate bracing system saved money. The vertical analysis proved that it could actually generate more revenue and easily pay off the increased cost *before* the original cost would be paid off. Overall, utilization of both optimizations is recommended.

-End Section-

ARCHITECTURE BREADTH: FAÇADE OPTIMIZATION

The purpose of the study is to investigate the impacts of the lateral and vertical structural optimization performed in the depth coverage. Currently, Bridgeside Point II utilizes materials to emphasize the progression of the site from an old steel mill to a cutting edge research park. The bottom floor is clad in precast panels, while the second through fifth floors have a combination of glass and metal panels. The expansive use of glass and metal paneling lends itself well to a more modern structure by exposing the lateral system, which makes the building look and feel transparent. For this study, existing elevations and plans are presented and compared to the structure developed in the optimization study.

Lateral Impacts to Architecture

The existing lateral system created powerful symbols, “X’s,” which are visible on 3 sides of the building (Figure 14 below). Those not in engineering can still relate to this symbol and understand the strength and stability it provides to various structures. However, there is a discontinuity with the bracing from the first to second floor. The bracing seems to disappear behind the precast panels, and conveys that the top of the precast column is the foundation for the bracing. However, while still aesthetically pleasing, it does in fact confuse the onlooker to what is really happening structurally. The knee brace, which is not visible, actually completes the frame and transfers the load to foundation. The optimized structure utilizes chevron braces, and these braces span the entire height of the building (Figure 15).

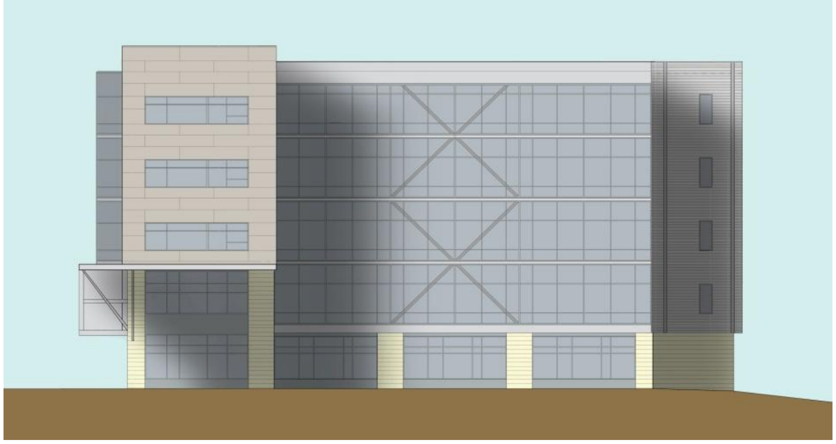


Figure 14: *Existing West Elevation*

Figure 15: *Revised West Elevation*

Now the building shows the true story of the lateral structure. It is clear that bracing terminates at the ground, which could be misinterpreted with the existing structure. For this new bracing scheme to work architecturally, modifications have to be made at the ground level. As the building currently exists, the bottom floor is set back approximately three feet from the upper floors. While this adds character and depth to the building, it does not afford bracing to continue to the base in an unobtrusive manner with respect to the floor plan. Rectification for this problem comes by merely pushing the walls at the bracing locations out three feet to match the upper floors (Figure 16).

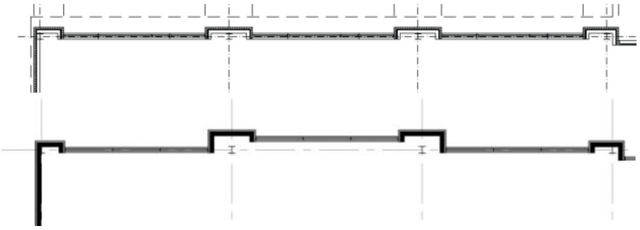


Figure 16: *This shows the existing floor plan (top left) versus the modified floor plan (bottom left) and the proximity of the columns and beams to the exterior walls.*

Several other details were enhanced or added to further accent the structure of the building. The most significant changes came to the north elevation. Currently the bracing is not exposed because ribbon windows were used versus glass panels, and the ground floor window scheme as seen in the previous figures (Figure 17). No reasons to these decisions could be obtained, but several theories exist. Being the north side of the building, direct sunlight is very limited, so fewer windows provide less heat loss/gain; furthermore, it is the side that faces the very crowded and noisy Interstate 376. These are all possibilities that could have fueled the design to its current state. However, be that as it may, the north façade is the front facing façade of the building, meaning this is the side that greets occupants and visitors. Therefore, a very powerful and homogenous façade should be presented to the user rather than an atypical façade. The new façade (Figure 18) borrows the same schemes and materials from the other elevations to create a very homogenous look and comes across as powerful but not overbearing.

Figure 17: *Existing North Elevation*

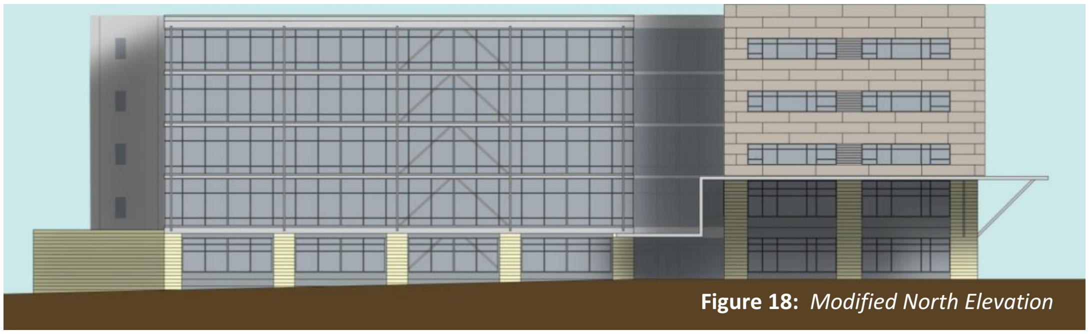


Figure 18: *Modified North Elevation*

Vertical Impacts to Architecture

Vertical optimization of the building's structure was also presented in the depth study; and it poses changes to the architecture of the building. While the new elevations differ considerably from the existing elevations, they do not differ much from the proposed changes made in the lateral portion of this breadth study as seen below (Figures 19 through 22). The same idea of bracing termination and homogenous facades can easily be seen.

North Elevations

Figure 19: *Existing North Elevation*

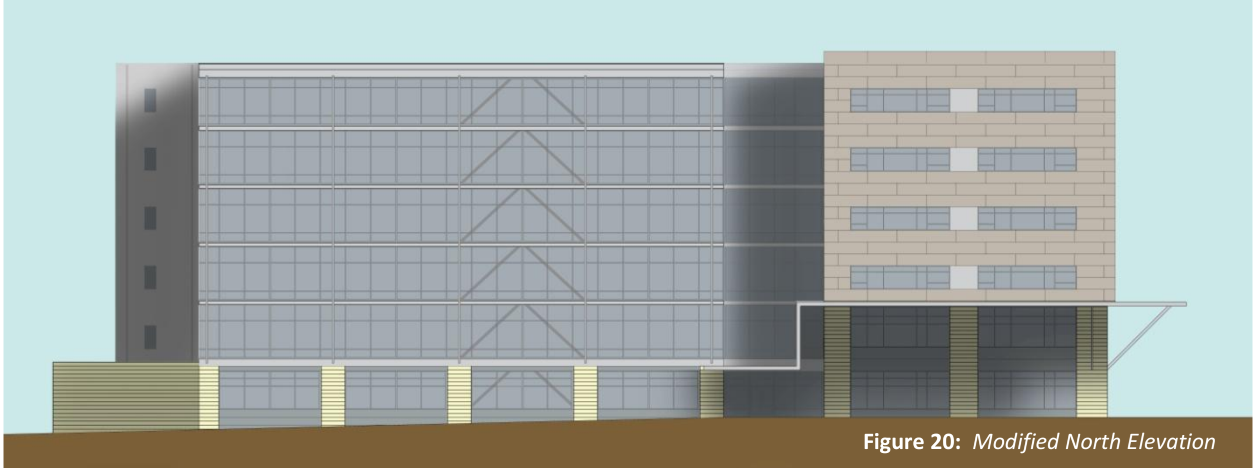


Figure 20: *Modified North Elevation*

West Elevations

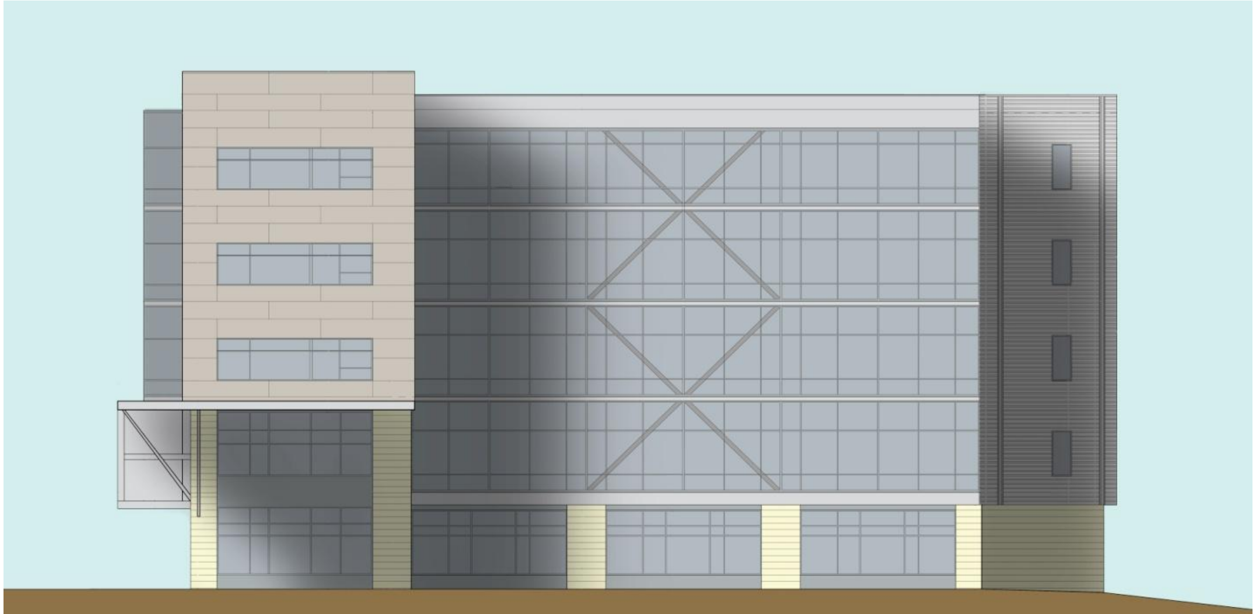


Figure 21: *Existing West Elevation*

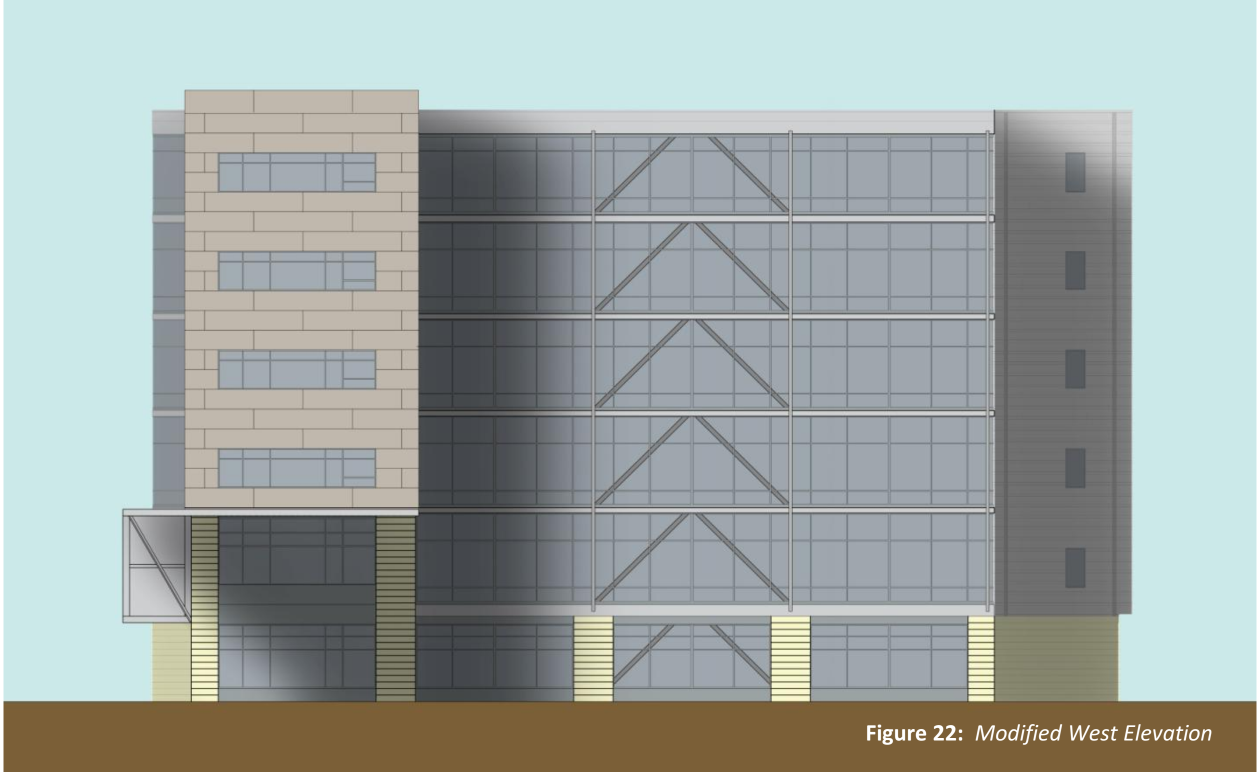


Figure 22: *Modified West Elevation*

Recommendations

The changes made to the architecture enhance the aesthetics of the building. A sense of progression is drawn by looking at the building and taking the site into consideration. The upward pointing braces represent the progression of an old steel mill site to a modern research park. The braces also show the progression of load as it works its way from the top of the building to the foundation. It should be noted, for this study to be complete, exhaustive research regarding the new thermal envelope and impact to the mechanical system should be considered; however, is not included in this thesis. Based on these results, the changes to the architecture are acceptable, and in practice should be presented in the schematic design phase.

-End Section-

ACOUSTIC BREADTH: REDUCTION OF NOISE PROPAGATION

The purpose of the study is to investigate the relocation of the mechanical room and the corresponding noise propagation. As a five story building, the mechanical room sits atop the roof; however, when the building transforms into a six story building, vertical space is not available for the mechanical room on the roof. Now the most logical location for the room is on the ground floor. Moving the mechanical room to the ground floor provides easy access to the boilers; however, these same boilers have the potential to create unwanted noise propagation into the adjacent office/laboratory spaces. For this study, a revised plan is presented indicating the new location, as well as, calculations showing the noise level and effect on the spaces.

Occupants and equipment are sensitive to noise and vibration. This study focuses primarily on noise; however, measures were taken to prevent unwanted structural borne vibrations. Location of the mechanical room is very critical, especially in a spec office/laboratory. After careful consideration, the ground floor proved to be the most ideal. The ground floor is a slab on grade bearing on a deep foundation system, which dramatically reduces the effects of any structural vibrations. In addition to the slab on grade, the boilers will rest atop an inertia pad for further vibration mitigation. The east side of the ground floor already has a designed area for various maintenance rooms, as well as, a tractor-trailer dock. This side of the building is an optimal choice for the mechanical room. The main idea is to place the room in the least intrusive area. After several designs and schemes, locating the mechanical room above the existing east stairwell and maintenances areas proved most beneficial (Figure 23).

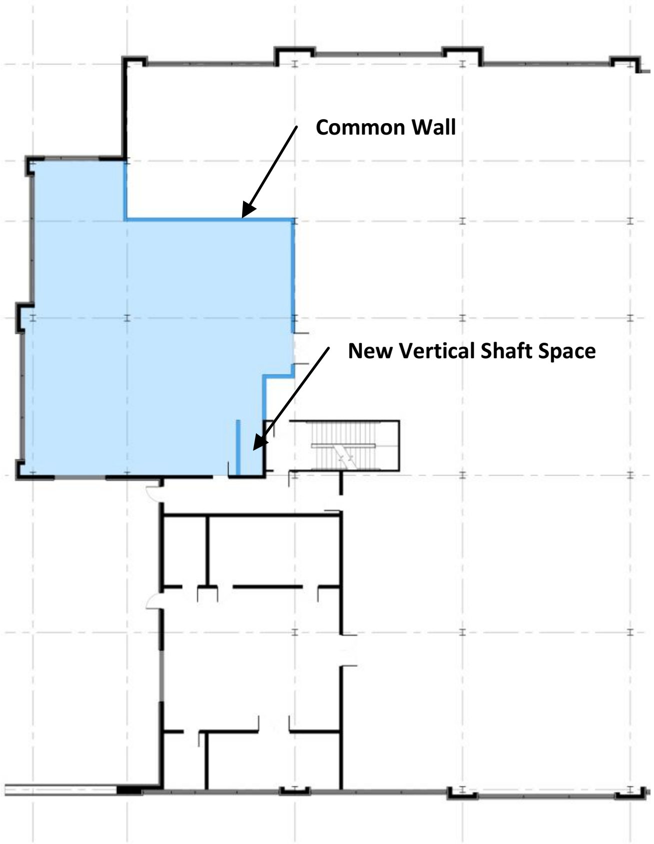


Figure 23: *New Mechanical Room Location (shaded area)*

This area takes advantage of the loading dock and affords a space to run piping from the ground to the roof without intruding on the surrounding spaces. However, office and laboratory spaces are adjacent to this space, and will inevitably share a wall. The design and construction is very important if noise propagation is to be reduced to such a level that it is undetectable. The wall itself is required to span from the floor to the underside of the floor above to reduce or eliminate the flanking effect. The type of wall chosen for this study is going to be fairly massive compared to the interior walls that will be located within the building. An 8 inch CMU wall set in a full mortar bed (the cells shall be filled with either sand or mortar) will be used. On either side of the wall, plaster will be used to add additional mass. Electrical outlets will be surface mounted on this wall. However, on the office/laboratory side, the tenant may elect to construct an ordinary stud wall on top of the plaster coated CMU wall. This may be done as long as the plaster is not removed and the electrical conduit is run within the stud wall. By adding an additional stud wall, the noise reducing characteristics will be greatly enhanced and will be conservative.

Calculations

The mechanical room will host between six and eight boilers, all of which could be operating simultaneously. It is necessary to determine the reverberation time in the room itself, so those working in the room are not experiencing unwanted echoes. For the size and use of the room the reverberation times are acceptable because they are in the range of a typical classroom (Figure 24).

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
$T_{60} = 0.05(V/a) = 0.05(V/\Sigma S\alpha)$	0.54	0.43	0.43	0.47	0.72	1.04

Figure 24: *Reverberation Times of Mechanical Room*

Since the mechanical room will share a wall with the adjacent office/laboratory spaces, noise reduction is very important. Typical office spaces have an average sound pressure level of 50 decibels (dB's); therefore, it would be used as a masking mechanism for the mechanical room noise. The idea behind masking is fairly simple. Masking makes use of background noise to cover up the unwanted noise (sometimes referred to as "white noise"). In the case of the office, this can be done in several ways. The easiest way utilizes bland and steady sounds that can be played over a speaker system. However, this study is going to rely on common noises found in offices to negate the intruding sounds. These sounds can be phones ringing, people talking, printers, etc. and cost nothing additional. The intent is that the wall will be constructed in such a way that it reduces the mechanical room's sound to a level that barely perceptible to the average human. The boiler used in Bridgeside Point II is also used at the Women's Resource Center in State College, PA. Using a decibel measuring device, the boiler's noise output was recorded. Since the boiler will be working in series with up to 7 additional boilers, 8 dB are added to the Women's Resource Center boiler. Figure 25 shows the acceptability of the wall system. Typically, 500 Hz to 1000 Hz are generally used for analysis, and the actual sound pressure level resembles the sound level of a very quiet home late at night.

	Sound Pressure Level (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sound in Source Room	78	73	63	58	53	48
Sound in Receiving Room	50	50	50	50	50	50
Required Noise Reduction	28	23	13	8	3	-
Provided Noise Reduction	28	37	42	47	50	52
Actual Sound Pressure Level	50	36	21	11	3	-
Acceptable	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Figure 25: *Acceptability of Wall System with Sound Pressure Levels Measured in Decibels*

Recommendations

Based on the calculations and research, the mechanical room would work without incident on the ground floor. The occupants of said floor should rarely hear the boilers unless the access doors are opened during office hours. The new location provides convenient access to the equipment in the event they need to be serviced or replaced. It also allows piping to be run vertically through the building with very minimal impact to the open plan. The additional costs for the wall and inertia pad were included in the cost summary presented in the depth of this paper. Referring back to page 20, the additional costs of this system are easily offset by the increased leasable space and are therefore negligible.

-End Section-

CONCLUSION

This report focuses on building optimization in a lateral and vertical sense of Bridgeside Point II. The existing design of Bridgeside Point II presents two great areas to focus thesis study. The lateral system currently exhibits a soft story effect, which causes non-uniform drift. While it does not present any problems structurally, it is definitely an area in need of optimization. The building is also 15 feet under the current maximum zoning height for a non-iconic building. The possibility of adding to the building vertically is definitely worth investigating, and by doing so could generate more revenue for the owner.

The lateral analysis proves that the reduction of the two-bay frame, and the alterations to the bracing at the first floor dramatically improve the efficiency and economy of the lateral system. Member sizes are streamlined, which lowers the cost of the structural system by a fair amount. Drift is dramatically reduced (nearly by a factor of three); moreover, the soft story effect is completely eliminated on the first floor. The vertical analysis proves that an additional floor would be feasible and would have minimal impact on the existing structural system. Utilizing the lateral system developed in the first analysis, the structure exhibits uniform drift, which is approximately a factor of two less than the code allowable. While the additional floor increases upfront building costs, the extra leasable space generates a much better revenue stream. This new revenue actually pays off the building seven months faster than the current building revenue.

The architecture breadth study, which focuses on optimizing the façade in lieu of structural changes, creates a better sense of load progression via exposed elements. The north façade is opened up to allow more natural light and exposure to the braces. Since drift is dramatically altered, for the better, no study on façade connections is required. The acoustics breadth study looks at moving the mechanical room to the ground floor since the new addition utilized the maximum height allowed by the zoning code. Analysis shows that with a fairly heavy wall the noise propagation could be controlled to an acceptable level. The location of the mechanical room is very desirable because it is now easy to access for equipment servicing. It also allows for creation of a vertical shaft along the stairwell for convenient access to the upper floors.

The goals of this thesis are to create an economic and efficient building. Based on the results, these goals are clearly met. From a feasibility standpoint, each proposed topic of study positively impacted the structure. It is the recommendation of the author to implement all changes addressed in this thesis.

All design values were done in accordance with the applicable codes. Detailed notes, tables, and figures are provided in the appendices for further review. Any questions and/or comments should be directed to Antonio Verne through email: adv118@psu.edu.