Thesis Proposal

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Revised: January 9, 2013

Office Building

Sayre, PA

Seth M. Moyer | Structural

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Executive Summary

The Office Building is being constructed as part of an office complex development project located in Sayre, PA. The building is five stories tall (all above grade), extending up to 67'-0" at the mean roof height (top of parapet elevation = 74'-5"), and has 85,075 ft^2 of total floor area. The floor structure is made up of 4" thick concrete slabs on composite steel deck (4" total combined depth). The slab is carried by open web steel joists which are supported by wide flange steel beams. The beams carry the gravity loads to wide flange steel columns that distribute the loads down to the foundation. The lateral system of the Office Building consists of 16 double angle braced frames (8 in each the N-S and E-W directions).

The purpose of this report is to provide an introduction and outline of the depth and breadth studies proposed for the spring semester senior thesis work. The proposal includes a thorough discussion of the structural depth, which is a redesign of the lateral system from braced to moment frames. Two breadth studies will also be detailed and include a redesign of the building enclosure (Breadth One) and a hygrothermal analysis with an assessment of the impact of the enclosure redesign on the building's mechanical systems (Breadth Two).

An ETABS structural computer model will be developed from an existing model, created for Technical Report 3, to investigate different moment frame layouts and varying numbers of rigid frames for the structural depth study proposed. Controlling moments and other joint reactions will be determined from the ETABS output, based on the critical loading found to control the design of the lateral system in Technical Report 3. Once reactions are determined, the beam-to-column connections will be designed to transfer the full moment being applied. The columns will be checked for strength and stiffening elements will be designed where required. Where necessary, beam and column sizes will be adjusted to meet strength requirements.

Breadth One will include research and analysis of potential glazing system options to replace the existing insulated metal panels. Enclosure performance will consider resistance to heat, moisture and air transfer through the envelope barriers. Once an enclosure is chosen, an effective and constructible layout will be determined and connection and installation details will be developed.

Breadth Two will include an assessment of the hygrothermal performance of the proposed and existing enclosures. In comparing the two systems, the effects of the redesign on the heating and cooling loads of the building will be quantified. Finally, the potential impact on the building's mechanical systems will be addressed.

Building Introduction

The Office Building is being constructed as part of a multi-phase office complex development project in Sayre, PA. Upon completion, currently slated for April 2013, the building will provide office and meeting space. On the second floor, it will also feature a fitness wing and locker rooms for employees. With five stories (all above grade) extending up to 67'-0" at the mean roof height (top of parapet elevation = 74'-5"), the 85,075 sq ft Office Building has been designed for a total occupancy load of 1134.

The footprint of the Office Building is laid out in an off-centered "H" configuration (See Figure 1). The façade enclosing the east and west wings is primarily made up of insulated metal panels on 6" cold formed metal studs. Horizontal glazing strips, 6' in height, break up the exterior at each story. The portion of the building that connects the two wings is enclosed with a curtain wall glazing system. Figure 2 shows an elevation of the south-facing (main entrance) side of the building, which shows both the wings and connecting portion. The parapet extends past the roof to a maximum height of 74'-5" along both the east and west facades. The parapet then tapers down to a height of 68'-2 1/2" at the interior edge of the wings and continues at that elevation across the connecting segment.

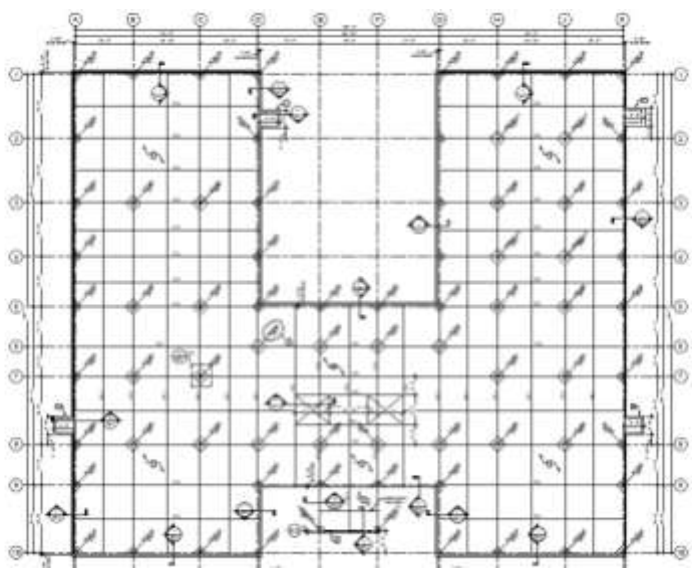


Figure 1: First Floor Slab Plan
(Image Credit: Larson Design Group)

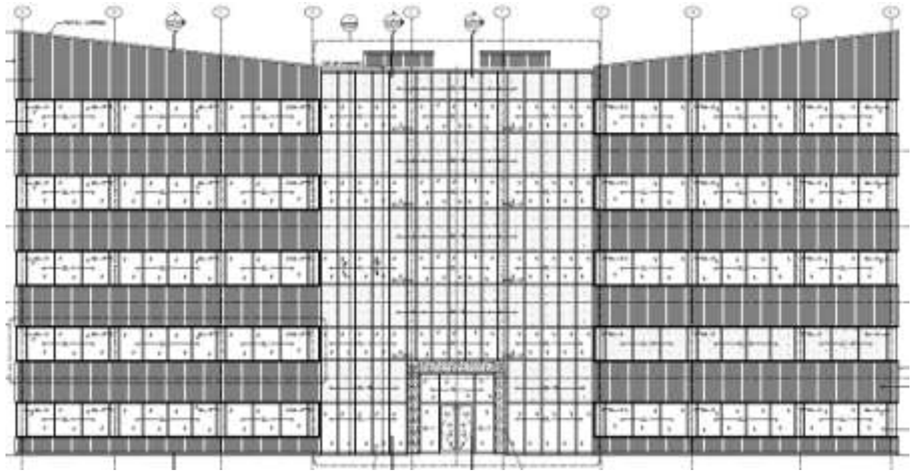


Figure 2: South Elevation
(Image Credit: Silling Associates, Inc.)

Structural Overview

The Office Building structure is founded on spread, combined and strip footings which support the concrete piers, pier walls, foundation walls and columns directly to transfer the loads from the superstructure to the soil they bear upon. The floor system is made up of 4” thick (total) composite deck floor slabs on open web steel joists (non-composite for joists/beams). The joists frame into wide flange steel beams, which transfer the loads to wide flange steel columns. The lateral system consists of braced frames in both the N-S and E-W directions, which all extend up to the roof.

Foundations

The geotechnical report conducted by CME Associates, Inc. for the Office Building site subsurface conditions indicates that spread and continuous footing foundations may be designed for an allowable soil bearing pressure of 4,000 psf. The report also specifies that spread footings should not be less than 3’-3” square and continuous strip footings should not be less than 2’-3” wide to prevent excessive settlements.

Typical interior columns are supported directly by spread footings just under the slab-on-grade. Typical perimeter columns sit on concrete piers that extend down to the spread footings. To protect against frost heave, perimeter footings have a minimum of 4’-0” of soil above their bearing elevation, measured from the bottom of the footing to finish grade. Both 8” and 12” thick concrete foundation walls run continuously along the outside perimeter of the building footprint, centered on 2’-3” strip footings, between the perimeter piers and footings.

At the braced frame locations outlined in Figure 3, 28” thick pier walls extend between the individual column piers. Combined footings also extend from pier to pier. The combined footings help to resist the overturning moments that result from lateral loading along their longitudinal axis. They also help to prevent differential settlement of the individual columns that form the braced frame.

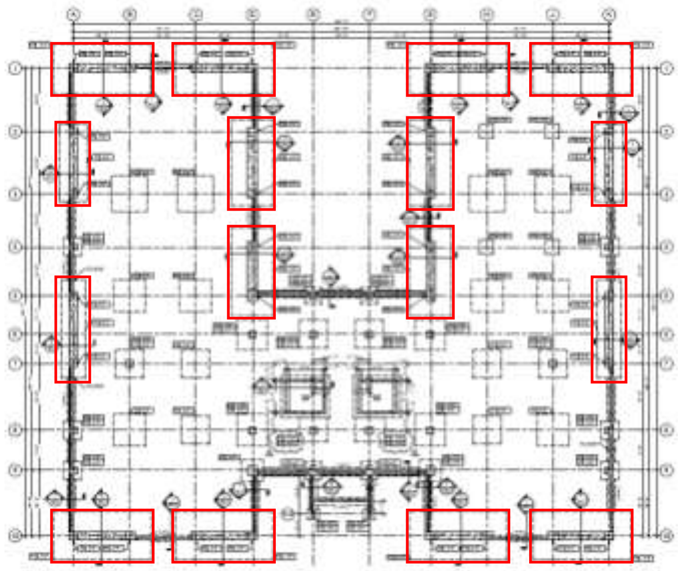


Figure 3: Braced Frames/Combined Footing Locations
(Image Credit: Larson Design Group)

Floor and Framing System

The first floor is a 4" thick slab-on-grade with WWF 6x6 – W2.9xW2.9 at mid-depth. Floors 2-5 consist of 2 1/2" thick normal weight concrete on 20 gauge 1 1/2" composite deck with WWF 6x6 – W4.0xW4.0 at mid-depth (4" total slab thickness). The composite deck slab is supported by open web steel joists (typically 16K2 up to 16K4) spaced at 3'-0" on center, maximum. The floor joists distribute the gravity loads to the wide flange beams (interior beams are typically W24s and the exterior beams range from W12 to W16). The maximum beam span is 36', between grid lines 1 and 3, for the W24x76 interior beams along grid lines B, C, H and J.

The beams carry the loads to wide flange columns to then be dispersed to the foundation. Typical column sizes include W12x53, W12x65, W12x79 and W12x106. All typical columns are spliced at 30'-8" above first floor (4' above the third floor). Where the fitness room is located in the east wing on level 2, HSS6x6x1/4 columns run up to the bottom of the W24x55 and W24x76 beams at grid points H2, H4, J2 and J4. The primary purpose of these one story columns is to reduce vibrations in the bays supporting the fitness center activities, which might otherwise create a serviceability issue with the light system of framing being utilized.

An enlarged portion of the typical floor framing plan can be seen in Figure 4 below.

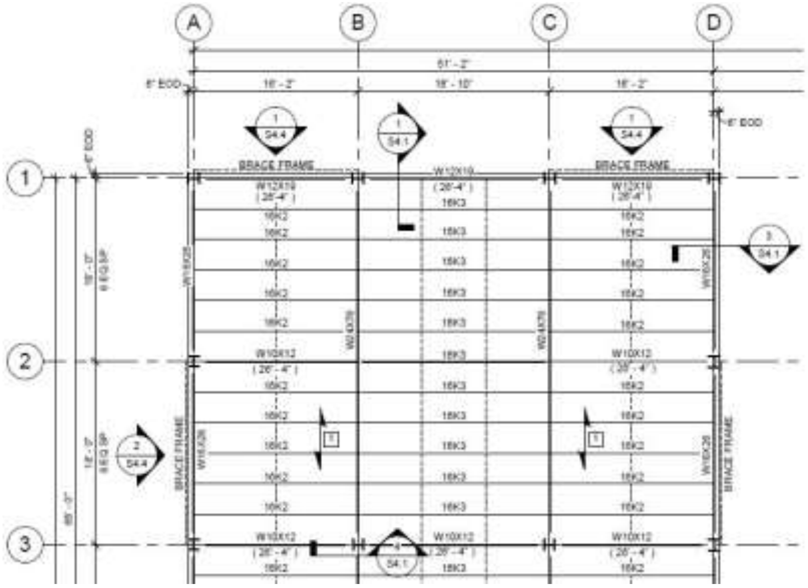


Figure 4: Typical Floor Framing Plan (Enlarged)
(Image Credit: Larson Design Group)

<u>Roof and Framing System</u>

The roof structure is made up of 1 1/2" Type B 20 gauge wide rib roof deck. A maximum thickness of 4" of rigid insulation is laid on top of the deck and is covered with fully adhered EPDM roof membrane. The deck is typically supported by 16KCS2 and 24K4 open web steel joists spaced at 6'-0" on center, maximum. The joists then rest on W21x44 interior beams and either W12x19 or W14x22 exterior beams, sloping down from the perimeter to the interior support members. All gravity loads are then transferred to the wide flange columns. An enlarged portion of the typical roof framing plan can be seen in Figure 5 below.

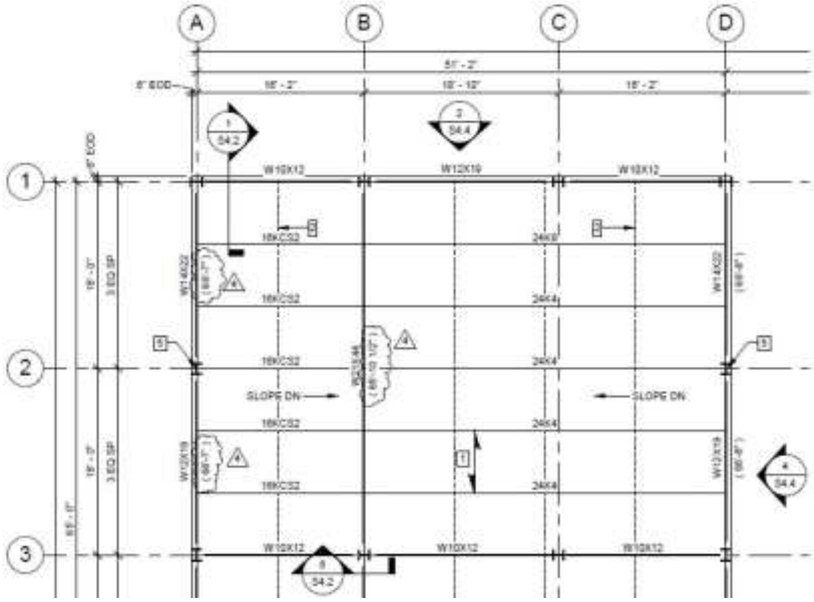


Figure 5: Typical Roof Framing Plan (Enlarged)
(Image Credit: Larson Design Group)

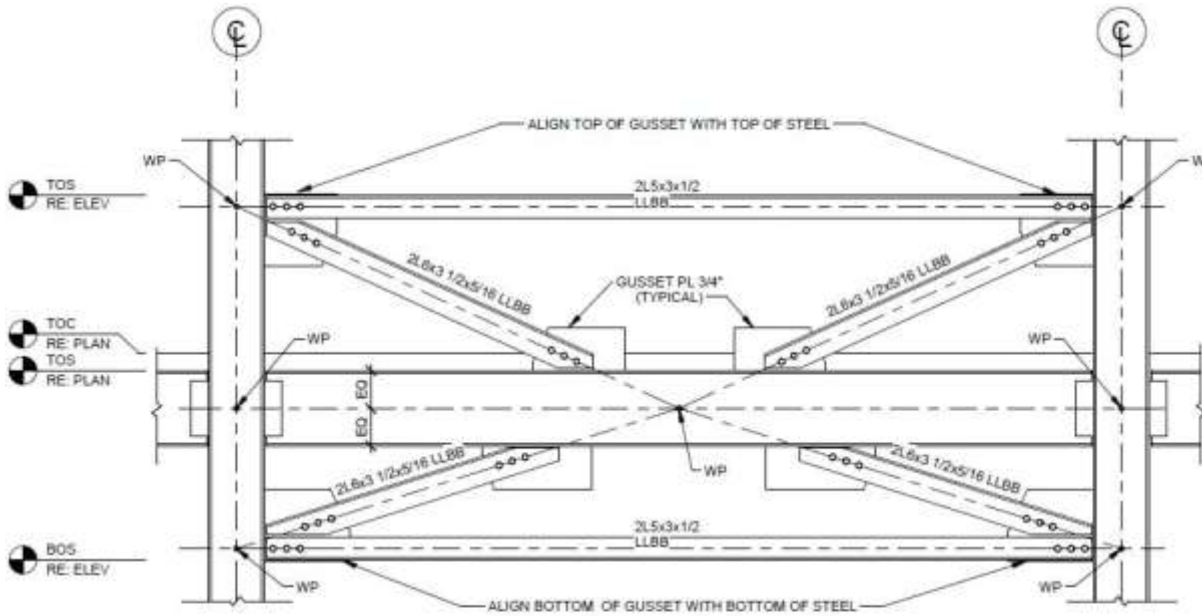
Lateral System

The lateral force resisting system of the Office Building is made up of 16 “K” braced frames (8 in each the N-S and E-W directions) (See Figure 3 for plan locations). The double angles brace the center work point of the perimeter beam at each floor down to the horizontal double angle-to-column intersection points above the windows of the floor below and up to the horizontal double angle-to-column intersection points below the windows of the floor above (double angles brace the base of the columns to the center work point of the horizontal wide flange beam below the windows at level 1). Figure 6 below shows typical bracing details and a typical braced frame.

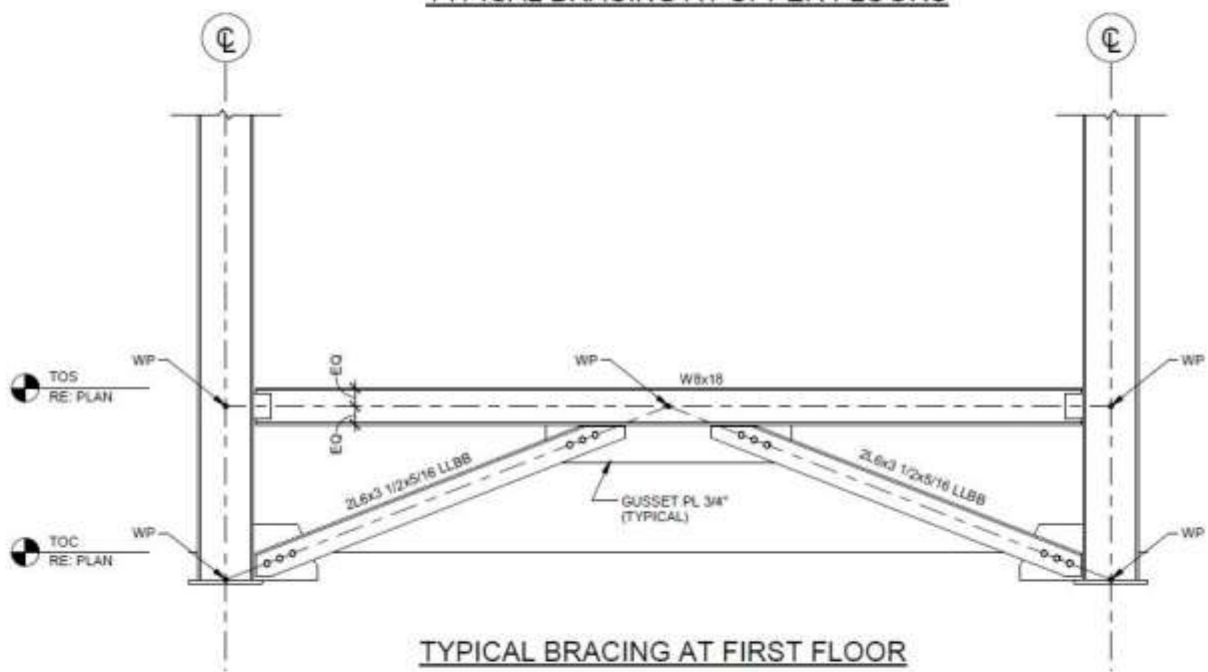
Wind pressures on the exterior of the building are collected by the façade and the resultant forces are transferred into the floor/roof diaphragms. The diaphragms at each story act rigidly and transfer the story shear forces to the braced frames that run parallel to the direction of the loading (the roof diaphragm has been treated as rigid for simplification of modeling and analysis, although it will likely behave as flexible since it is constructed of untopped steel decking). The braced frames resist the lateral loads based on the proportion of their relative stiffness. These story forces accumulate at each floor, moving down through the building until the total base shear is transferred into the ground via the foundation.

Similarly, for seismic loads induced by the building’s response to ground motion/acceleration, the total base shear is distributed to the diaphragms at each story as a function of the respective heights and weights attributed to each level. Once distributed, the seismic forces are transmitted through the diaphragms and into the braced frames based on relative stiffness.

Similarly, the story forces accumulate and are eventually transferred down to the bearing soils through the foundation.



TYPICAL BRACING AT UPPER FLOORS



TYPICAL BRACING AT FIRST FLOOR

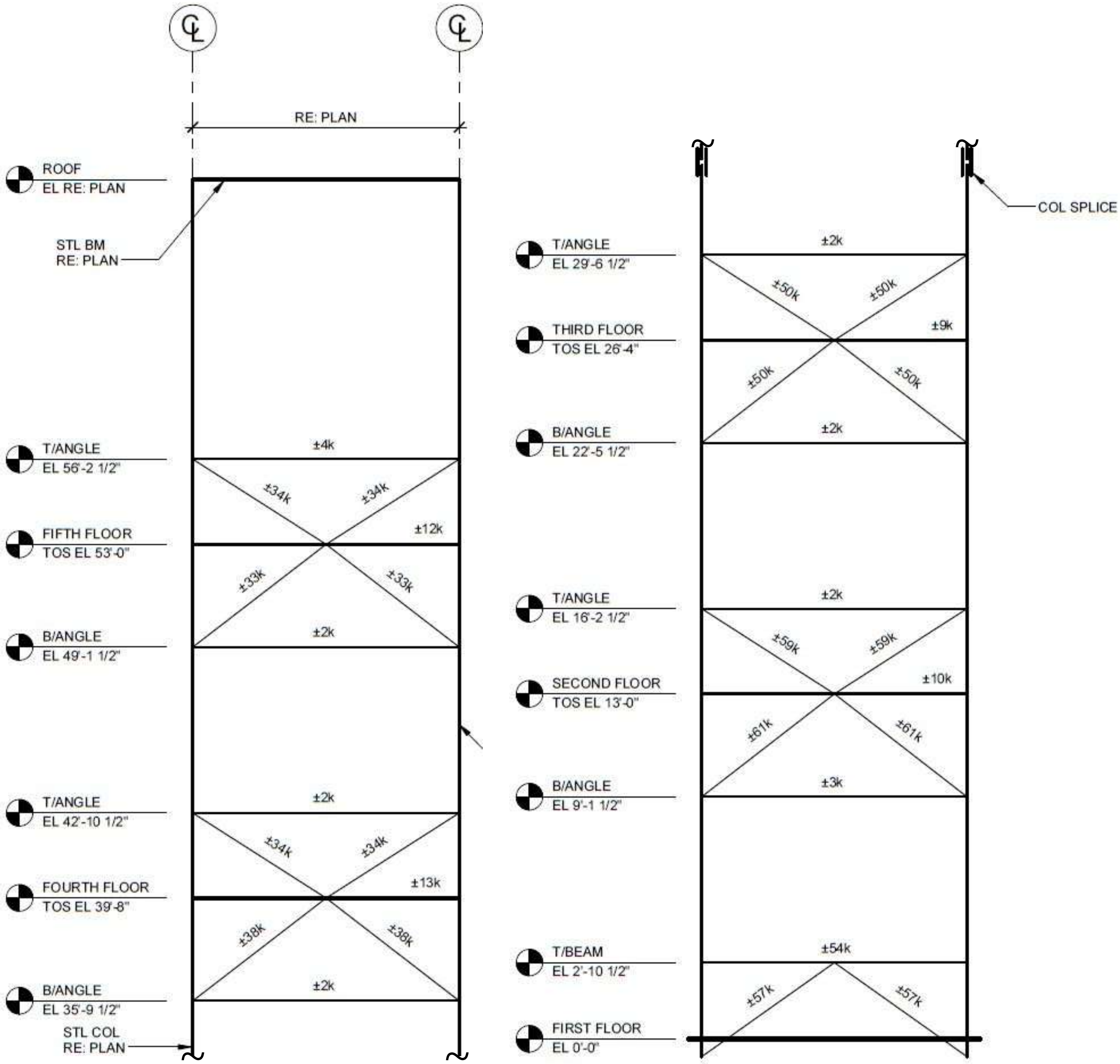


Figure 6: Typical Braced Frame and Bracing Details
(Image Credit: Larson Design Group)

Design Codes

The major model and design codes and standards used in the design of the Office Building:

- Pennsylvania Uniform Construction Code (PAUCC)
- International Building Code 2009 (IBC 2009) (as adopted and modified by the PAUCC)
- Minimum Design Loads for Buildings and Other Structures (ASCE 7-05)
- Specification for Structural Concrete (ACI 301-05)
- Building Code Requirements for Structural Concrete (ACI 318-08)
- Specification for Structural Steel Buildings (AISC 360-05)
- Standard Specifications for Open Web Steel Joists, K-Series (SJI-K-1.1 05)
- Design Manual for Composite Decks, Form Decks, Roof Decks and Cellular Metal Floor Deck with Electrical Distribution, SDI Pub. No. 29

The same codes and standards are being referenced for use in this technical report with the following exceptions:

- ASCE 7-10
- AISC Steel Construction Manual, 14th Edition, LRFD
- Specification for Structural Steel Buildings (AISC 360-10)
- Building Code Requirements for Structural Concrete (ACI 318-11)

Materials Used

Materials were referenced from Sheets S0.1 and S0.2 and are summarized below in Figure 7.

Steel		
Type	ASTM Standard	Grade
W and WT Shapes	A992	50
Standard Shapes	A36	N/A
Angles, Channels and Plates	A36	N/A
HSS	A500	B
Pipe	A53, E or S	B
Anchor Rods	F1554	N/A
Shear/Anchor Studs	A108	N/A
Deformed Anchors	A496	N/A
Bolts (Plain)	A307	N/A
Bolts (High Strength)	A325	N/A
Nuts	A563	C
Hardened Washers	F436	N/A
Plate Washers	A36	N/A
Deformed and Plain Bars	A615	60
Welded Wire Reinforcement	A185	N/A
Steel Deck	A611	C,D,E
or Steel Deck	A653-94	33
Zinc Coated Steel Sheet	A1003	N/A
Hot Dipped, Galvanized Finish	A123	N/A
Load-Bearing Cold-Formed	C955-07	N/A
SS Pipes and Tubes	A312	N/A
SS Bars and Fittings	A582	N/A
Alum. Pipes and Tubes	B429	N/A
Alum. Bars and Fittings	B221	N/A
SS Fasteners	A240/A666	N/A

Concrete		
Usage	Weight	f'c (psi)
Foundation Walls	Normal	4500
Column Piers	Normal	4500
Combined Footings	Normal	4500
Exterior Slabs-on-Grade	Normal	4500
Specified Column Piers	Normal	5500
Elements Not Specified	Normal	3000

Miscellaneous	
Type	Standard
Grout (6000 psi)	ASTM C1107
Weld Electrodes	AWS Class E7018

Figure 7: Materials Summary

Proposal

Structural Depth

Through the analyses performed for previous technical reports, the existing structural system of the Office Building was determined to be sufficient for both strength and serviceability requirements. The only exceptions were several story drifts, found in Technical Report 3, which exceeded allowable drift limitations under wind loading. Of the alternate floor systems considered in Technical Report 2, only composite steel was considered to be a viable option, and it was found to have similar properties and performance to the original floor. The composite design was found to weigh about 12 psf less, and cost around 6% less ($/sf) than the existing floor design. However, the major advantage offered by composite steel is improved vibration control, and the existing floor system of composite deck slabs on open web steel joists was specifically designed to limit vibrations in accordance with AISC Design Guide 11. For these reasons, the focus of the structural depth was placed on a redesign of the lateral system.

Although the existing lateral force resisting system is made up of double angle braced frames, it acts, effectively, much as a moment frame system. The bracing configuration in place below and above the windows at each story (bracing is only below, not above, the windows at level 5) has the double angle braces extending up/down to connection points at the top and bottom corners of the windows at each level. Therefore, the bracing connections to the columns, via gusset plates, are occurring at effectively unbraced locations along the height of the columns (at points several feet above and below the perimeter beam and floor diaphragm elevations, at which the columns are fully braced). Because of the brace termination points, bending moments are introduced into the columns. This configuration necessitates the columns to resist interactive axial and flexural forces, creating a significantly less efficient bracing arrangement than fully triangulated braces would offer. Therefore, the braced frames in place are not fully taking advantage of the benefits that a braced frame system is capable of achieving in terms of efficiency.

Moment frames will be investigated and used to replace the existing braced frames as the lateral force resisting system for the Office Building. Fully restrained moment connections will be used for the rigid frames in which the lateral support, through resistance of sway in the frames, will be provided by maintaining the right angles between connected members (beam-to-column connections) through sufficient connection rigidity/stiffness. The connections will be designed to provide a full transfer of moment with negligible relative rotation between the members making up each joint, in accordance with the controlling wind loading case and applicable load combinations of ASCE 7-10 as determined in Technical Report 3.

In order to optimize the redesign of the lateral system, the moment frames will, ideally, be located at or near the perimeter of the Office Building, as the existing braced frames are currently. Columns that are part of moment connections will be assessed for strength and, where required, member sizes will either be changed or stiffening elements and/or doubler plates will be provided. Existing beams in the moment frames will also be checked for strength and sizes will be changed where necessary.

Breadth One

The existing bracing configuration was designed for the locations above and below the windows so that the horizontal glazing strips could continue around the perimeter of the building, uninterrupted by the structure. This then allowed the lateral resistance to be placed primarily around the building's perimeter where it would be most effective and efficient while preserving the strong horizontal features that define the architecture of the building. Insulated metal panels spanning above and below the glazing effectively hide the double angle braces.

With the proposed structural redesign of the Office Building's lateral system, the bracing members will be replaced by moment frames, primarily along the exterior grid lines. As a result, the enclosure of the east and west wings will be redesigned with a glazing system to replace the current insulated metal panels. The glazing will be similar to the system used to enclose the central portion of the building, between the east and west wings, where no braced frames are located in the original design layout. The new enclosure will provide more natural light to the interior office and meeting spaces throughout the building, similar to that already provided for the circulation core of the building.

The proposed new glazing system will be researched and carefully assessed with respect to its overall performance as the building's primary enclosure as well as for the best installation configuration and proper detailing for an effective building envelope system. The performance will be investigated by looking into the behavior of the barrier and how it affects the movement of heat, moisture and air into, out of and through the building. The proposed layout and placement of the glazing units will consider both span distances and wind loading conditions. Special attention will also be given to the façade connections and joint detailing for proper installation to assure optimal performance.

Breadth Two

With the enclosure redesign proposed for Breadth One, a high percentage of the building's exterior envelope will be changed from insulated metal panels to a glazing system. Such a major change could potentially have a significant impact on the conditions and environment inside the Office Building. After researching and analyzing a new enclosure as a part of Breadth One, its overall hygrothermal performance will be assessed and compared to that of the insulated metal panels. Differences in performance will be used to assess the effects of this redesign on the heating and cooling loads of the building and the potential impact on its mechanical systems.

MAE Requirements

Means and methods from graduate level coursework will be used throughout the investigation, analysis and design of the depth and breadth work proposed for the senior thesis project in spring 2013. *AE 530 - Computer Modeling of Building Structures* has provided the base knowledge to effectively model and analyze the Office Building's structural system using ETABS analysis software. The depth study will rely heavily on the coursework from *AE 534 – Analysis and Design of Steel Connections* for the design and specification of the fully restrained moment connections forming the rigid moment frames. The breadth studies will both draw on the material covered in *AE 542 – Building Enclosure Science and Design* for the analysis, assessment and design of the proposed enclosure.

Tasks and Tools

Task 1 – Develop ETABS Structural Model

- Start with the ETABS model created for lateral analysis in Technical Report 3
- Remove double angle braces and reset applicable member end releases
- Model (centerline) beam-to-column rigid joints
- Explore various locations and number of moment frames to create an efficient layout
- Determine controlling moments and other reactions at moment frame joints, based on the critical load cases and combinations derived from ASCE 7-10 in Technical Report 3

Task 2 – Design Beam-to-Column Connections

- From the ETABS output, assess the strength of existing members for controlling load cases and adjust sizes as required
- Design shear tab connections between beam webs and columns
- Investigate/compare moment connection options with and without flange pates
- Design beam-to-column moment connections

Task 3 – Perform Check of Columns

- Check columns for all potential limit states, including web buckling and panel zone shear yielding where applicable
- Design stiffeners and/or panel zone doubler plates where required
- Determine if column member sizes can/should be increased versus adding stiffening

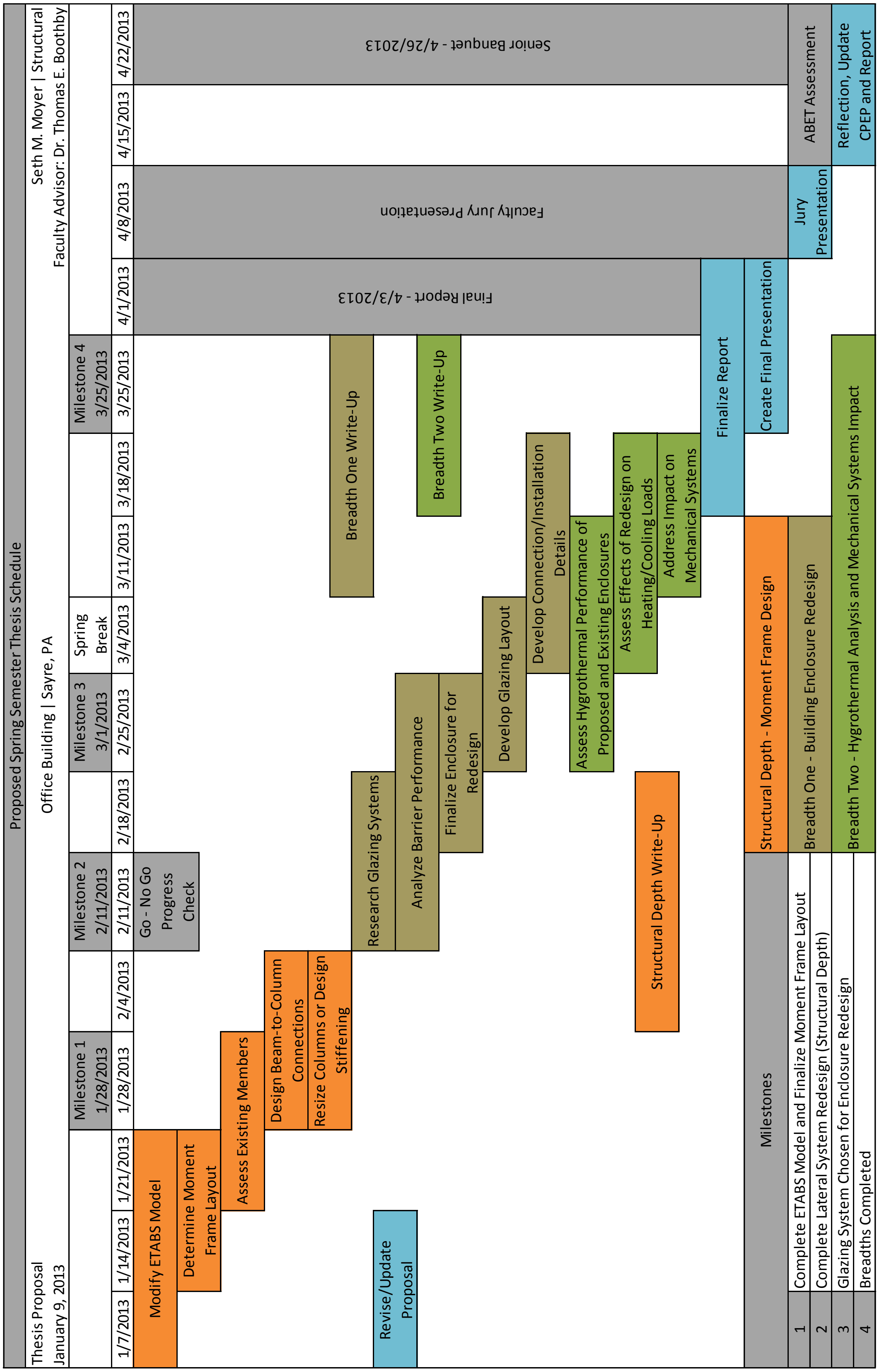
Task 4 – Breadth One

- Research potential glazing system options to replace the insulated metal panels, including the existing type already enclosing the central portion of the Office Building
- Analyze the properties and performance of the barrier, considering heat, moisture and air movement through it and the building
- Determine a constructible layout/configuration of the glazing, considering loading and span distances
- Develop details for façade connections, assembly joints and proper installation for optimal performance and an effective envelope

Task 5 – Breadth Two

- Assess the overall hygrothermal performance of the proposed glazing system based on research and analysis performed for Breadth One
- Investigate and assess the overall hygrothermal performance of the existing insulated metal panels
- Compare the results of the studies for the proposed and existing enclosures
- Quantify the differences in performance with respect to the transfer of heat and moisture to assess the effects of the redesign on the heating and cooling loads of the building
- Address the potential impact on the building's mechanical systems

Schedule


Proposed Spring Semester Thesis Schedule
Thesis Proposal
January 9, 2013
Office Building | Sayre, PA
Seth M. Moyer | Structural
Faculty Advisor: Dr. Thomas E. Boothby
Milestone 1
1/28/2013
Milestone 2
2/11/2013
Milestone 3
3/1/2013
Spring Break
Milestone 4
3/25/2013
1/7/2013
1/14/2013
1/21/2013
1/28/2013
2/4/2013
2/11/2013
2/18/2013
2/25/2013
3/4/2013
3/11/2013
3/18/2013
3/25/2013
4/1/2013
4/8/2013
4/15/2013
4/22/2013
Modify ETABS Model
Determine Moment Frame Layout
Assess Existing Members
Design Beam-to-Column Connections
Resize Columns or Design Stiffening
Go - No Go Progress Check
Revise/Update Proposal
Research Glazing Systems
Analyze Barrier Performance
Finalize Enclosure for Redesign
Develop Glazing Layout
Develop Connection/Installation Details
Assess Hygrothermal Performance of Proposed and Existing Enclosures
Assess Effects of Redesign on Heating/Cooling Loads
Address Impact on Mechanical Systems
Structural Depth Write-Up
Breadth One Write-Up
Breadth Two Write-Up
Finalize Report
Create Final Presentation
Final Report - 4/3/2013
Faculty Jury Presentation
Jury Presentation
Senior Banquet - 4/26/2013
ABET Assessment
Reflection, Update CPEP and Report
Milestones
Structural Depth - Moment Frame Design
Breadth One - Building Enclosure Redesign
Breadth Two - Hygrothermal Analysis and Mechanical Systems Impact
1 Complete ETABS Model and Finalize Moment Frame Layout
2 Complete Lateral System Redesign (Structural Depth)
3 Glazing System Chosen for Enclosure Redesign
4 Breadths Completed

Conclusion

This report has provided an overview of the depth and breadth studies proposed for the spring semester senior thesis work. The proposal offered a discussion of the structural depth, which is a redesign of the lateral system from braced to moment frames. Two breadth studies were also detailed, including a redesign of the building enclosure (Breadth One) and a hygrothermal analysis and impact assessment of the enclosure redesign on the building's mechanical systems (Breadth Two).

An ETABS structural computer model will be developed to investigate different moment frame layouts and varying numbers of rigid frames. Controlling moments and other joint reactions will be determined from the ETABS output, based on the critical loading found in Technical Report 3. Using the ETABS reported reactions, the beam-to-column connections will be designed to resist the applied forces. The columns will be checked for strength and stiffening elements will be designed where required. Beam and column sizes will also be adjusted as necessary to meet strength requirements.

Breadth One will include research and analysis of potential glazing system options to replace the existing insulated metal panels. Enclosure performance will consider resistance to heat, moisture and air transfer through the building envelope. Once an enclosure is chosen, an effective configuration will be determined and connection and installation details will be developed.

Breadth Two will include an assessment of the hygrothermal performance of the proposed and existing enclosures. Following the initial assessment and comparison, the effects of the redesign on the heating and cooling loads of the building will be quantified. Finally, the potential impact on the building's mechanical systems will be addressed.