(Preliminary) Thesis Proposal
Increased Seismic Load: Lateral System Analysis and Redesign

Life Sciences Building
The Pennsylvania State University, University Park, Pennsylvania

Executive Summary|

This report is a proposal to analyze and redesign the lateral force resisting systems for the Life Sciences Building at The Pennsylvania State University, University Park, Pennsylvania. The building was designed starting in 1999 and was completed in 2004. The building is 'L' shaped, has 6 floors (97' total height) and a mechanical penthouse level, and totals 154,000 GSF.

The gravity framing system consists of concrete slabs on composite steel deck. The composite steel deck is supported by composite steel beams and composite steel girders which frame into steel columns. The building lateral system consists of moment resisting frames, concentrically braced frames, eccentrically braced frames, and frames that are hybrid combinations of moment and braced frames. In the east – west direction there are three moment frames and three hybrid frames that are combinations of moment and eccentrically braced frames. In the north – south direction there are three concentrically braced frames, two eccentrically braced frames, and two hybrid moment / concentrically braced frames.

Previous assignments and experience have shown that the existing composite steel gravity framing system is the best suited of all alternatives to handle the varying spans, varying loads, irregular column placement, and the need to integrate complex lateral systems into the structure. However, Technical Assignment III revealed that the lateral system could be redesigned to be more efficient. Ideas for improving the lateral system include the elimination of and redesign of lateral force resisting frames. In addition, the building was in Seismic Design Category "A" which gave little experience using the seismic loading provisions of ASCE 7-05.

The proposal is to analyze the building lateral system for a location that results in a SDC of "D" and use this seismic loading to investigate the complex lateral system in more detail than was done in Technical Assignment III. The lateral system will then be redesigned to resist lateral forces more efficiently while studies are concurrently undertaken to examine the effects of the redesign on the building architecture and construction costs.

Table of Contents

Building Description|

The Life Sciences Building at The Pennsylvania State University, University Park Campus, University Park, Pennsylvania is a six story steel framed structure that is roughly shaped like an "L".

The building can be conveniently broken down into three sections. The first section – referred to herein as "the long leg of the 'L'" – is the part of the building running east – west along the northern edge of the site occurring to the east of column line C. The long leg of the 'L' contains the bulk of the labs, offices and classrooms. The second section – referred to herein as "the knuckle" – is the part of the building that runs east – west along the northern edge of the site and occurs to the west of column line C. "The knuckle" is the part of the building where the above grade connection to the Chemistry Building ties into the Life Sciences Building. The third and final section – referred to herein as "the short leg of the 'L'" – is the part of the building that runs north – south along the western portion of the site and ties into the knuckle at its northern end. Only the long leg and short leg of the "L" and the area where they intersect will be analyzed.

There are several accessory structures connected to the Life Sciences Building – most of which will not be analyzed. One of the most notable features of the Life Sciences Building is the two story above grade connection to the adjacent Chemistry Building which occurs on the third and fourth floors. An expansion joint between the above grade connection and the Life Sciences Building allows the connection to be neglected in the analysis of the Life Sciences Building. A one level mechanical vault was constructed along with the building at its lowest level and is located on the tip of the long leg of the "L" (far east side of building). This mechanical vault is constructed entirely of reinforced concrete and its roof is used as a loading dock / truck parking area for the Life Sciences Building. It can be ignored in the analysis of the Life Sciences Building because its structure is a totally separate entity. Another part of the Life Sciences Building that stands out is a greenhouse located on the rooftop of the short leg of the "L". The greenhouse is located on the fourth floor of the overall building; however, this is the rooftop for the short leg of the "L" portion of the structure. The long leg of the "L" extends two more stories vertically.

Floors of the Life Sciences Building will be referred to in this and all subsequent reports by using the following convention:

B	Basement	1150'-0"
G	Ground Floor	1166'-8"
1	First Floor	1180'-8"
2	Second Floor	1194'-8"
3	Third Floor	1208'-8"
4	Fourth Floor	1222'-8"
P	Penthouse	1236'-8"
R	Roof	1263'-0"

Existing Structural System Summary|

Foundation|

The Life Sciences Building uses a combination of several foundation types to adapt to several different base slab elevations and varying subsurface conditions.

The foundation of the long leg of the "L" will consist primarily of reinforced concrete spread footings. The maximum allowed bearing pressure on the soil underneath the spread footings is 6 ksf. Underneath walls the foundation ranges from 1'-6" to 2'-3" thick and from 5'-6" to 10'-2" wide. To support columns the spread footings range from 1'-7" to 4'-0" thick and from 5'-6" to 17'-4" wide.

To support the rest of the building, including the knuckle and short leg of the "L", footings are supported on driven steel H – piles. The soil bearing capacity is considered to be 6 ksi on the gross section area of the steel H – pile (the skin friction value is unknown). The piles used are HP10x57 and HP12x74 sections with allowable working loads of 100 k and 130 k respectively. Piles are driven in groups to an average depth of 25' and capped. Piles are driven vertically in the center of pile caps and battered outward on the perimeter of pile caps on a 1:6 (H:V) batter. The piles are arranged in groups of 2,3,4,5,6,8,11, and 16. The pile caps are reinforced concrete and range in thickness from 3'-0" to 5'-0" deep. Grade beams span between pile caps to support the brick exterior walls.

Floor Framing|

The typical basement slab on grade is 6" of 4000 psi concrete on 6" of PennDOT 2A aggregate reinforced with WWF6x6 – W4xW4. The typical ground level slab on grade is 5" of 4000 psi concrete reinforced with WWF6x6 – W2.9x2.9. The typical floor deck is composite 18 gage, 2" thick fluted with 4-1/2" of concrete cover for a total thickness of 6-1/2". The concrete on composite deck is normal weight, 4000 psi with one layer of WWF4x4 – W5.5xW5.5. All beams and girders are composite steel wide flange sections using typical 5" long, ¾" diameter shear studs welded directly to the beam. The typical shear studs have a shear transfer capacity of 13.3 k/stud.

The basement level of the Life Sciences Building only occurs underneath the long leg of the "L". The basement level of the long leg of the "L" and ground floor level of the short leg of the "L" and knuckle are slabs on grade (constructed as specified above). Slabs on grade in the basement are typically 6" concrete reinforced with one layer of welded wire fabric. Slabs on grade at ground level are typically 5" thick.

Existing Structural System Summary (continued)|

Floor Framing (continued)|

Beginning with the ground floor level the floor framing system of the long leg of the "L" takes on a repeating layout. This framing system is typical and occurs on the ground through fourth floors. The floor system uses the typical composite deck / slab as described above. Infill beams for the ground through fourth floors are typically composite W16x26 (spaced 8'-0" o.c.) and composite W16x31 (spaced 8'-8" o.c.) with a built in camber and span of 31'-0". The girders supporting the W16x26 infill beams are composite W24x68 and span 31'-0". The girders supporting the W16x26 infill beams are composite W30x99 and span 41'-0".

The gravity framing of the short leg of the "L" is typical on the second through fourth floors, but becomes quite complex on the ground floor to accommodate an auditorium with a sloped floor. The floor framing system for the second through fourth floors of the short leg consists of the typical composite floor system bearing on composite W14x22 infill beams. The W14x22 infill beams are spaced at 8'-8" o.c. and span 20'-8". They are supported by W21x57 composite girders which span 26'-0". Each girder supports two infill beams at third points.

The mechanical penthouse level occurs at the top of the long leg of the "L". The interior of the penthouse houses air handlers and various other pieces of mechanical and electrical equipment. There are also cooling towers located outdoors on the roof at the penthouse level. The penthouse was designed for comparatively heavy live and dead loads so the beams and girders are much larger than the typical floor framing for the long leg of the "L". The penthouse floor structure begins with the typical composite floor deck and slab that can be found throughout the rest of the building. This slab bears into various W18 infill beams ranging from composite W18x40 to W18x97 (used to frame around openings in the slab). The most typical infill beams are W18x46 and W18x50 but larger sizes are also common where slab openings exist or support structures for the mechanical equipment bear down on the infill beam. The typical span of the beams and girders is 31'. The girders are most typically composite steel W33x141 and W33x201.

Existing Structural System Summary (continued)|

Roof Framing|

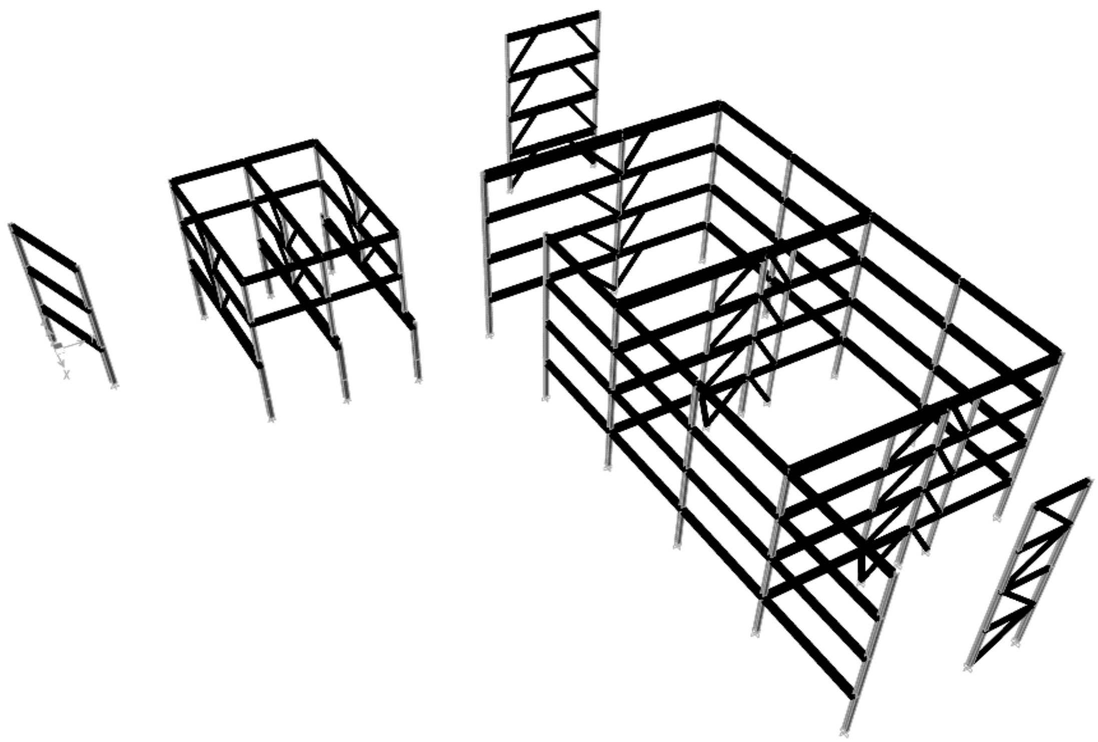
The typical roof deck is 20 gage, 1-1/2" deep, wide rib steel roof decking. The roof consists of low roofs that are framed as part of the mechanical penthouse floor system. From the low roof, set back in from the building perimeter, a sharply angled roof / wall goes up to form the enclosure of the mechanical penthouse. On the top of the space created by the angled roof / walls there is another flat roof to completely enclose the mechanical penthouse. As stated previously the low roof is framed as part of the mechanical penthouse floor system. The sharply angled roof is framed by noncomposite W18x60 girders running at an angle that is more vertical than horizontal (78 degrees). These girders run from the low roof to the top of the mechanical penthouse enclosure and act as beams / columns by forming the walls and supporting the higher flat roof. The girders are spaced at 31'-0". W12x26 infill beams then span horizontally in between the W18x60 girders. The infill beams span the entire 31'-0" space between the girders and are spaced with three equal spaces measured from the low flat roof to the top of the high flat roof. Finally, the top of the mechanical penthouse covered by the high flat roof is framed by W16x40, W16x31, and W16x26 beams in various configurations that allow large openings for the vent stacks that ventilate the laboratories. The flat roofs are both covered with the typical roof deck. The sloped roof / walls are infilled between the girders with light gauge steel framing and plywood sheathing.

Columns|

The system of columns and lateral force resisting system is designed so that very few columns aren't involved in a moment frame or braced frame. Most column loading depends on many more factors than just the accumulation of gravity loads. The columns range in size from W10 up to W14. The weights generally vary from 33 lbs/ft to 311 lbs/ft. Estimated column loads vary from 60 k to 1100 k, with the vast majority of column loads in the range of 200 k to 800 k.

Detailed Existing Lateral System Description|

Lateral System Diagram (from ETABS)|



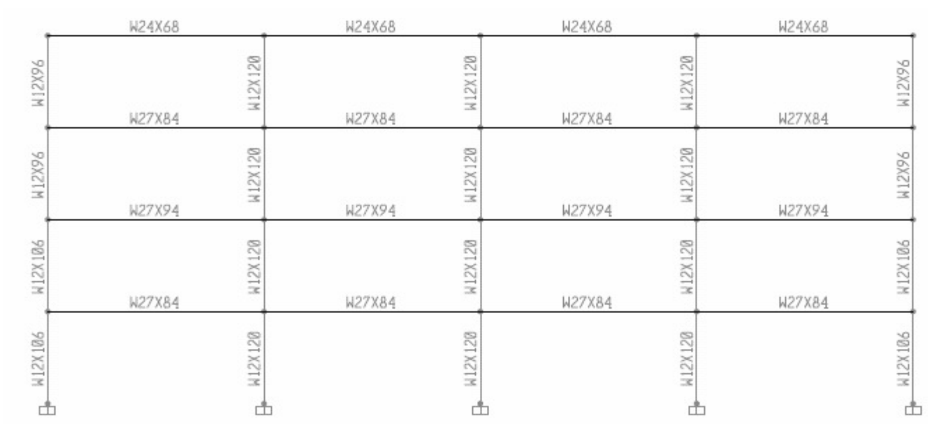
Detailed Lateral System Description|

The building lateral system consists of moment resisting frames, concentrically braced frames, eccentrically braced frames, and frames that are hybrid combinations of moment and braced frames. In the east – west direction there are three moment frames, and three hybrid frames that are combinations of moment and eccentrically braced frames. In the north – south direction there are three concentrically braced frames, two eccentrically braced frames, and two hybrid moment / concentrically braced frames. The system is further complicated by the fact that although most of the frames are on two orthogonal axes – there are three lateral resisting frames that are rotated at various angles from the orthogonal axes due to architectural constraints. Nearly all of the lateral force resisting frames are tied into frames in the orthogonal direction with moment connections. The lateral frame illustrations shown in this section have their bases at the first floor level but many extend down to the ground and basement floor levels.

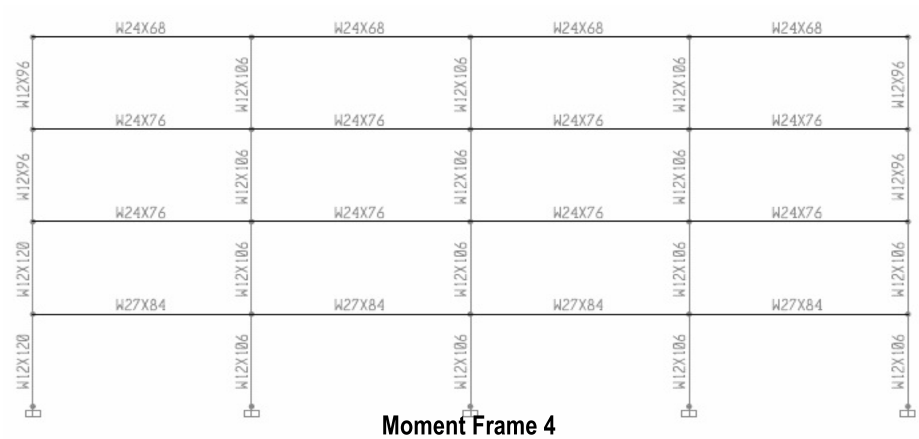
Detailed Existing Lateral System Description (continued)|

East – West Direction Lateral System Description|

The lateral system in the east – west direction as stated above consists of three moment frames and three hybrid frames that combine both moment resisting and concentrically braced elements. Two of the moment frames, Moment Frame 1 and Moment Frame 4 occur along the exterior wall of the long leg of the "L". Moment Frame 1 and Moment Frame 4 are illustrated below:



Moment Frame 1

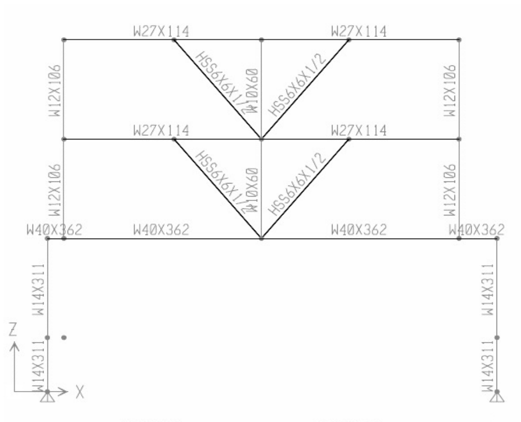


Moment Frame 4

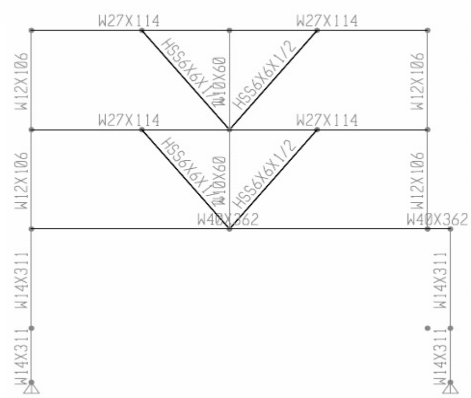
Detailed Existing Lateral System Description (continued)|

East – West Direction Lateral System Description (continued)|

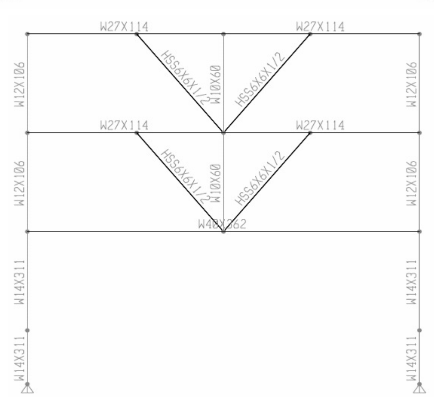
The only other moment frame running in the east – west direction is Moment Frame 9. It runs angled at twenty degrees from the east – west axis at the very end of the short leg of the "L". It is illustrated at the far left of the three dimensional view of the lateral force resisting system shown at the beginning of this section of the proposal. The three hybrid moment / eccentrically braced frames that take east – west lateral loading are all very similar with slight changes in each frame to adapt to the architectural restrictions of the building. Views of all three hybrid frames are shown below – note the large clear span moment frame on the lowest level. The clear span is needed to allow for an auditorium to be located on the first floor of the building, convenient to the major entrances and exits. These three hybrid frames occur in the short leg of the "L".



Hybrid Frame 5.3



Hybrid Frame 6

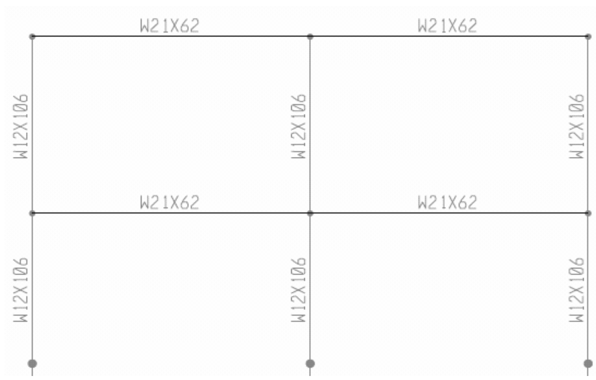


Hybrid Frame 7

Detailed Existing Lateral System Description (continued)|

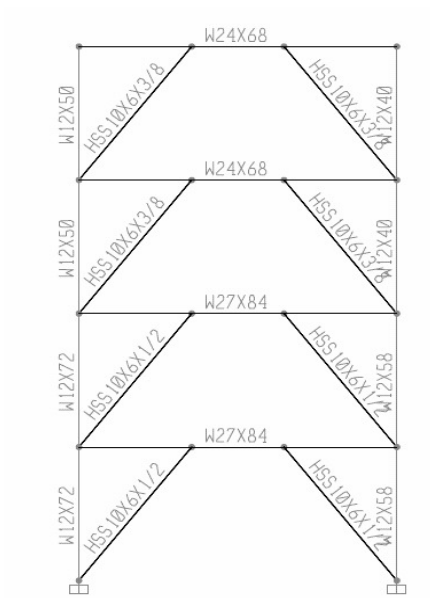
North – South Direction Lateral System Description|

In the north – south direction lateral forces are resisted by a total of seven frames. Two of these frames – Hybrid Frame C.2 and Hybrid Frame D.8 – are hybrid frames combining concentrically braced elements with moment resisting elements. These two hybrid frames occur on the outside walls of the short leg of the "L". The upper two stories of each three story frame is illustrated below (bracing in the lowest level of the frame is not visible due to the limitations of ETABS).



Hybrid Frame C.2
Hybrid Frame D.8 (identical)
(first floor braced level not shown)

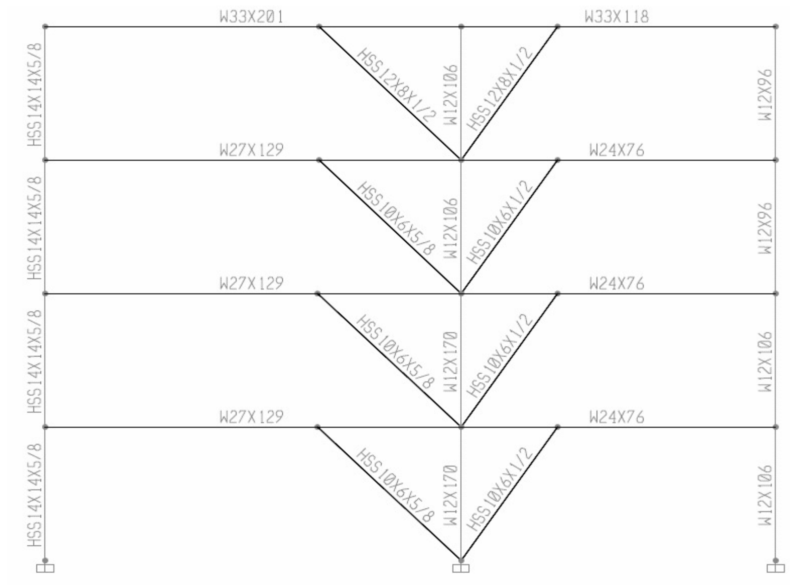
Two eccentrically braced frames are utilized to resist lateral forces on the building in the north – south direction. They are located in the "knuckle" where the long leg and short leg of the "L" meet. The first eccentrically braced frame – Braced Frame C – is one bay wide and is located at the outside corner of the "L". The second eccentrically braced frame – Braced Frame E – is located internally where the long and short legs meet and is roughly in line with the exterior wall of the short leg of the "L". The eccentrically braced moment frames that occur in the "knuckle" of the "L" are shown below.



Braced Frame C

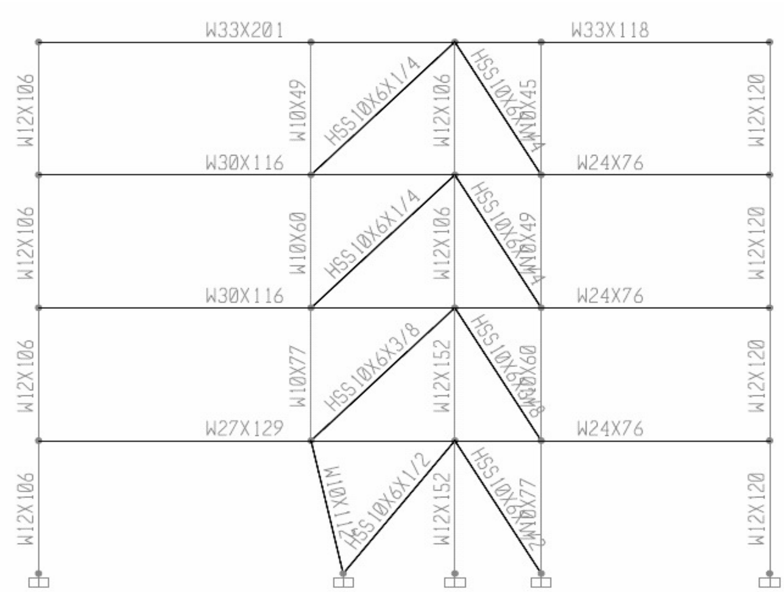
Detailed Existing Lateral System Description (continued)|

North – South Direction Lateral System Description (continued)|



Braced Frame E

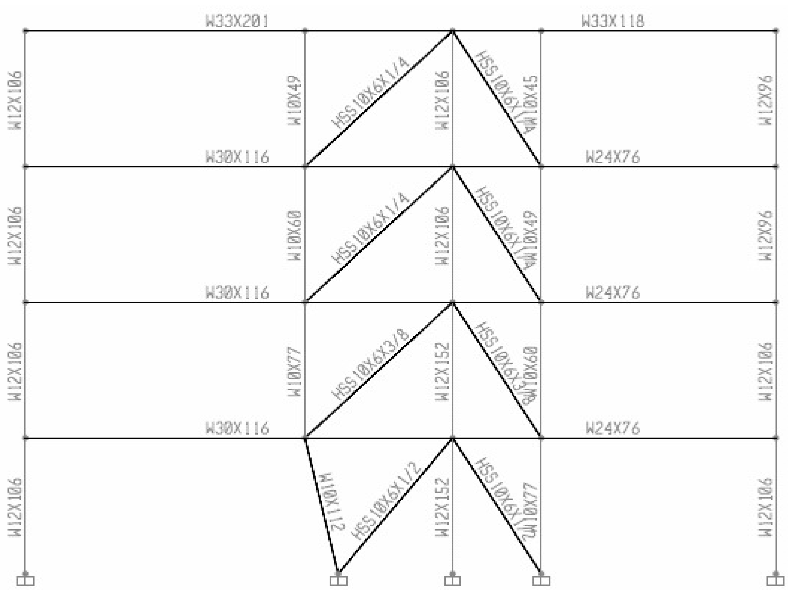
Finally, three concentrically braced frames provide lateral force resistance within the long leg of the “L”. Two north – south braced frames – Braced Frame G and Braced Frame J – span the entire orthogonal distance between east – west Moment Frame 1 and Moment Frame 4. The last lateral force resisting frame in the north – south direction – Braced Frame K – is located at the far east end of the building at the end of long leg of the “L”. These three frames are illustrated below.



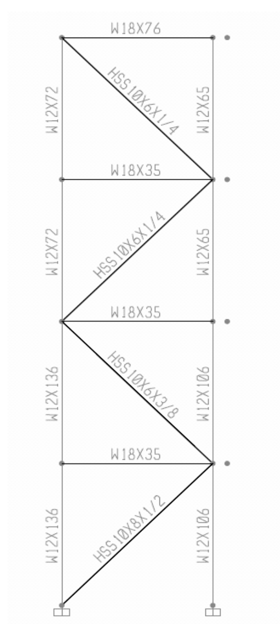
Braced Frame G

Detailed Lateral System Description and Diagrams (continued)|

North – South Direction Lateral System Description (continued)|



Braced Frame J



Braced Frame K

Problem Statement|

Analysis in Technical Assignment II confirmed that the existing composite steel deck on composite steel framing is probably the best gravity framing system to suit the varied span lengths and irregular framing plan of the Life Sciences Building.

However, the lateral force resisting system of the Life Sciences Building is very complicated. As stated previously, lateral forces are resisted through a combination of moment resisting frames, concentrically braced frames, eccentrically braced frames, and hybrid frames consisting of two or more types of lateral frames. Technical Assignment III showed that there is much room for improvement in the design of this system.

Analysis and understanding of the lateral force resisting system in Technical Assignment III was limited due to the complicated nature of the system. Analysis through ETABS did show that several of the many frames in the lateral force resisting system are taking very low portions of the total lateral load – some are taking almost none of the lateral load. Additionally, the Life Sciences Building happened to be in Seismic Design Category "A", so experience with seismic design provisions of ASCE 7 – 05 was very limited.

Proposed Solution|

The existing gravity framing system of the Life Sciences Building is satisfactory and performs well under the loading conditions. No modifications to the gravity framing system will be made unless required by changes in the lateral force resisting system.

A more detailed analysis than was done in Technical Assignment III of the Life Science Building lateral force resisting system will be performed. Additionally, new lateral loads will be calculated by moving the building to a location (to be determined) that will result in the increase of seismic forces on the building. The goal is to find a site that will provide the equivalent of Seismic Design Category "D". A redesign of the lateral system to make it more efficient by the redesign and elimination of frames will be undertaken.

Solution Method|

The floor system and gravity framing system will be left largely unchanged unless changes to the lateral system require it.

First a new location for the building will have to be determined that will result in a Seismic Design Category of at least "D". Then the new lateral loads due to seismic loading will be computed using ASCE 7 – 05. The existing wind loading, which controls in State College, Pennsylvania, will be left unchanged and will provide a interesting comparison between the seismic lateral forces which tend to control on the west coast to the wind loading lateral forces that tend to control on the east coast.

Next, the ETABS model used in Technical Assignment III will be modified from its simplified state so that it accurately reflects the real construction of the building. The lateral loading that was previously calculated will be applied to the model. The model will be analyzed and the forces that each frame takes will be considered.

Finally, the lateral force resisting system will be optimized by redesigning frames and eliminating frames to achieve greater efficiency.

Additional topics relating to both the existing lateral force resisting system and the system that is used as a result of seismic loading and the redesign will be investigated and compared in order to give me a greater understanding of building lateral systems. These topics will be discussed and determined with a thesis faculty consultant upon completion of the redesign. This is expected to include some of the following: accidental torsion, hand distribution methods, redundancy factors, over strength factors, deflection and amplification factors, and vertical earthquake effects.

Breadth Studies|

Breadth studies will probably evolve as thesis work progresses, but will focus on two main areas.

Architecture|
Changes in the lateral system to make it more efficient will probably result in changes to the building layout. These changes will be studied and their pros and cons evaluated with a faculty consultant. The benefits of a more efficient lateral system will be compared against the drawbacks due to changes in the building architecture. This will provide good design experience – working with architects is part of a structural engineers career.

Construction|
Part of the change to a seismically controlled lateral system from a wind controlled lateral system will be cost issues. The change in cost resulting from the wind controlled lateral system in State College, PA being changed to a seismically controlled system will be investigated. Base costs will be compared to avoid location based cost differences (California is much more expensive than State College, PA). This will be interesting insight into how much more buildings will cost because they need to be designed for earthquakes.

Tasks / Tentative Schedule|

January 14	Find Site / Calculate Seismic Loading *Revise Proposal w/ Andres Lepage*
January 21	Build ETABS Model *Discuss Loading / Modeling w/ Andres Lepage*
January 28	Build ETABS Model *Verify Model w/ Andres Lepage*
February 4	Consider Alternative Lateral Systems *Discuss Options w/ Andres Lepage*
February 11	Choose Lateral System Redesign Breadth: Architectural Design Changes *Verify Final Design w/ Andres Lepage* *w/ Bob Holland*
February 18	Alter Gravity System to fit Lateral *Verify Architectural Changes w/ Bob Holland*
February 25	Refine Lateral System ***LATERAL/ARCHITECT DESIGN COMPLETE***
March 3	Finish Lateral Redesign Breadth: Construction Cost Comparison *Discuss Final Report w/ Andres Lepage*
March 10	Spring Break *Give Andres Lepage a Break*
March 17	St. Patrick's Day Week (Catch Up) *Give Andres Lepage another Break*
March 24	Start Final Report / Breadth Studies *Verify Construction Cost Comparison*
March 31	Finish Breadth Studies ***BREADTH STUDIES REPORTS COMPLETE***
April 7	Finish Report / Prepare Presentation *Present Final Report Draft to Andres Lepage*
April 14	Presentation Week ***FINAL REPORT/PRESENTATION COMPLETE***