Rutgers University Law School

Building Addition and Renovation

Camden, NJ

Final Report

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Structural Option
AE 481W Senior Thesis
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Rutgers Law School

Camden, New Jersey

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Senior Thesis Website: http://www.engr.psu.edu/ae/thesis/portfolios/2008/ner116

Project Team:

- Owner: Rutgers University
- Architect: Ayers/Saint/Gross Architects and Planners
- Structural Engineer: Christakis VanOcker Morrison
- MEP Engineer: Mueller Associates
- Civil Engineer: Remington & Vernick Engineers
- Roofing Consultant: Wiss, Janney, Elstner Associates
- Hardware Consultant: John P. Jester Associates, Inc.
- Audiovisual Consultant: Shen Milsom & Wilke, Inc.
- Cost Estimator: International Consultants, Inc.

General Building Information:

- Size: 66,800 GSF addition
- Height: 6 stories plus penthouse, 85'-0"
- Dates for Construction: May 2006 – August 2008
- Project Cost Information: $25,900,000
- Project Delivery Method: CM at Risk

Architecture:

- Expansion and renovation of 1970's-era law building
- Create space for classrooms, seminar rooms, student organizations, and faculty offices
- Create a bridge over 5th Street to connect the existing building to the new addition
- Develop a roof terrace above existing building

Lighting/Electrical System:

- 480Y/277V Secondary, 3PH, 4W Supply to Building
- (2) Main Switchboards (2500A East Building, 1200A West Building)
- 100KW Natural Gas Back-up Generator

Structural System:

- (6) Moment Resisting Steel Frame to resist lateral loads
- 20'-0" x 46'-8" Typical Bay Spacing
- Combination Typical Shallow Strip and Moment Footings with Drilled Piles
- Steel W-Shapes Forming Bridge over Fifth Street

Mechanical System:

- Water HVAC System Located in Penthouse
  - (3) 1020MBH Boilers
  - (1) 250 Ton Screw Type Chiller
  - (1) 250 Ton Cooling Tower

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TABLE OF CONTENTS

EXECUTIVE SUMMARY **1**

INTRODUCTION **2**

BUILDING BACKGROUND **3**

STRUCTURAL SYSTEM 3
FIRE PROTECTION SYSTEM 3
ARCHITECTURE 3
CONSTRUCTION SYSTEMS 4
BUILDING ENVELOPE 4
MECHANICAL SYSTEM 4
ELECTRICAL SYSTEM 5
LIGHTING SYSTEM 5
TELECOMMUNICATION SYSTEM 5
TRANSPORTATION SYSTEM 5

EXISTING STRUCTURAL SYSTEM **6**

FOUNDATION SYSTEM 6
COLUMNS 6
FLOOR SYSTEMS 6
LATERAL FORCE RESISTING SYSTEM 7
ROOF FRAMING SYSTEM 7

PROBLEM STATEMENT **8**

DESIGN CONSTRAINTS **9**

DEPTH STUDY: ALTERNATIVE STRUCTURAL SYSTEM **11**

COMPOSITE JOIST FLOOR SYSTEM DESIGN 11
PROPOSED LATERAL SYSTEM REDESIGN 16
PROPOSED LATERAL SYSTEM REDESIGN 16

BREADTH STUDY #1: ARCHITECTURAL IMPACT **24**

BREADTH STUDY #2: COST AND SCHEDULE EVALUATION **29**

SUMMARY AND CONCLUSION **33**

APPENDIX A: BUILDING LOADS **35**

APPENDIX B: COMPOSITE JOIST DESIGN **38**

APPENDIX C: LATERAL SYSTEM DESIGN **45**

RAM STRUCTURAL SYSTEM ANALYSIS 46
EAST-WEST LATERAL SYSTEM 48
NORTH-SOUTH LATERAL SYSTEM 50

APPENDIX D: CONNECTION DESIGN **52**

APPENDIX E: REVISED ARCHITECTURAL PLANS **55**

APPENDIX F: CONSTRUCTION SCHEDULE MODIFICATIONS **64**

TABLE OF FIGURES

FIGURE 1: KEY PLAN FOR BUILDING REFERENCE 2
FIGURE 2: EXISTING MOMENT FRAME FLOOR PLAN (LATERAL ELEMENTS SHOWN IN RED) 7
FIGURE 3: TYPICAL FLOOR SYSTEM DETAILS (EXISTING V. PROPOSED) 12
FIGURE 4: TYPICAL STRUCTURAL SYSTEM FRAMING 13
FIGURE 5: PROPOSED LATERAL FORCE SYSTEM (LATERAL ELEMENTS IN RED) 17
FIGURE 6: PROPOSED LATERAL FORCE SYSTEM AS STRESSED BY SERVICE LOADS 17
FIGURE 7: NORTH-SOUTH ECCENTRIC BRACED FRAME 18
FIGURE 8: TYPICAL PROPOSED EAST-WEST FRAME 19
FIGURE 9: PROPOSED COLUMN STRESSES DUE TO GRAVITY LOADING 21
FIGURE 10: TYPICAL PROPOSED MID-SPAN CONNECTION FOR CHEVRON BRACES 22
FIGURE 11: TYPICAL PROPOSED COLUMN/BEAM BRACE CONNECTION 22
FIGURE 12: TYPICAL PROPOSED BRACE DETAIL 23
FIGURE 13: PROPOSED FIRST FLOOR PLAN 25
FIGURE 14: PROPOSED CLASSROOM REDESIGN 26
FIGURE 15: PROPOSED SOUTH ELEVATION 27
FIGURE 16: PROPOSED NORTH ELEVATION 28
FIGURE 17: EXISTING BEAM/GIRDER AND BEAM/COLUMN CONNECTION 31
FIGURE 18: OVERALL PROJECT SCHEDULE FOR RUTGERS UNIVERSITY LAW SCHOOL 31
FIGURE 19: EXISTING V. PROPOSED STRUCTURAL SYSTEM SCHEDULE 32

LIST OF TABLES

TABLE 1: FLOOR VIBRATION CALCULATION SUMMARY, PRIMARY EAST ADDITION 13
TABLE 2: FLOOR VIBRATION CALCULATION SUMMARY, SECONDARY EAST ADDITION 14
TABLE 3: GRAVITY COLUMN LOAD TABLE.. 20
TABLE 4: LATERAL SYSTEM COLUMN LOAD 20
TABLE 5: EXISTING STRUCTURAL SYSTEM COST ESTIMATE.. 29
TABLE 6: PROPOSED STRUCTURAL SYSTEM COST ESTIMATE 30
TABLE 7: STRUCTURAL SYSTEM COMPARISON.. 34

Executive Summary

This report examines the structural system of the Rutgers University Law School Building Addition and Renovation project in Camden, New Jersey. The project was analyzed in depth in previous Technical Reports produced in the Fall semester of 2007. Resulting from those reports, an alternative floor system and lateral force resisting system were analyzed for feasibility and economy in this project.

The existing floor framing system was compared to the composite joist floor framing system. The proposed system was then designed for strength and serviceability requirements necessary for an office building, including vibration and fire protection analysis. Due to vibration analysis, a CJ26 1600/775/270 joist was chosen for the typical floor system spanning 47-feet, a design driven by serviceability criteria rather than strength. This design size was also chosen to maintain the existing floor system depth, maintaining the intended architectural experience.

In connection to the floor system, a braced frame lateral system was analyzed in comparison to the existing moment frame construction. A preliminary virtual work analysis was performed and then evaluated using RAM Structural System to determine required member sizes. The introduction of braced frames changed member size determination from serviceability criteria to strength requirements. The modified lateral system experiences significantly less drift than the existing moment frame construction. Three braced frames were designed for the North-South direction of the Primary East Addition with two frames in the East-West direction.

The architecture was reviewed and modified to maintain existing architectural spaces while permitting lateral braces to be placed within the wall construction. Upper floors were able to be maintained; however, the first floor required a shift of classroom spaces and the development of 20-foot modules for ease of implementing the braces. Additionally, the introduction of braced frames alters several window locations in the existing elevations; therefore a study of the elevations was also performed. Revised floor plans and elevations have been attached to illustrate an efficient method of integrating the structural system with the architecture.

Finally, a cost estimate and detailed schedule analysis was performed to determine the potential cost and time savings from the modified structure. Cost information was researched from industry professionals and R.S. Means to evaluate overall cost of both floor systems and lateral systems. Overall schedule was then developed through the use of information found in R.S. Means. It was determined that an overall project cost savings of $100,000 could be saved through the new lateral system and approximately one week of schedule time. The proposed floor system was determined to be virtually equal to the existing system in cost and schedule.

Through the analysis, it was determined the modification to the lateral system would be beneficial to the overall building if the structural engineer were brought into the design process at a time where plans were still able to be modified. The modification to the lateral system did not positively impact the construction cost or schedule, and therefore is not recommended for use in this project.

Introduction

The Rutgers University Law School Building Addition, located in Camden, New Jersey, is a five story university building including a bridge joining the addition to the existing law school. The overall building height of the 66,800 GSF East Addition is 84'-4", just beneath the 85'-0" maximum height restriction. The first floor will be used as classroom space with a moot court to simulate legal proceedings, while the upper floors will be used as office space, including a law clinic in which students are encouraged to participate. The Law School addition was designed to the standards of the 2000 International Building Code and ASCE 7-98; however, the analysis for this project has been performed with the 2006 International Building Code as well as ASCE 7-05. The existing conditions were analyzed through various hand calculations and verified with RAM Structural System for lateral simulation.

Throughout this report, the building addition will reference several different key components: the Primary East Addition, the Secondary East Addition, and the Bridge. Each of these separate components has been labeled in Figure 1: Key Plan below. This thesis report will examine the structure, architecture, and construction management associated with the East Additions.

As this building is designed as an addition to an existing 1970's era law school, there was an emphasis in relating the new architecture to the predefined building. Also, due to space constraints, this addition is on the opposite side of Fifth Street, requiring the development of a bridge structure to join the two buildings. Within the new space, there is a much larger, more open feel, floor to ceiling heights of approximately 15 feet have been reached on the first floor with upper floors enjoying 12 foot heights—this height creates a difference between the two portions of the building making the second floor of the east addition correspond with the third floor of the existing building.

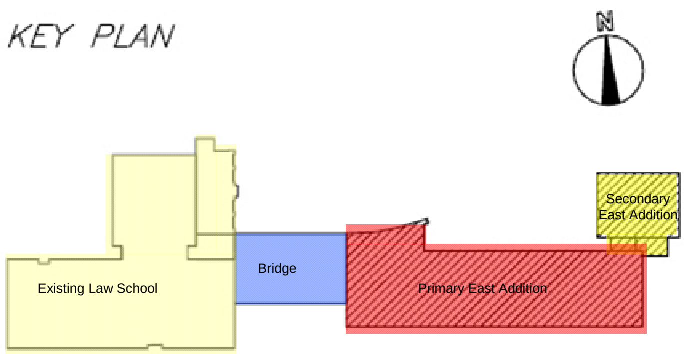

Figure 1: Key Plan for Building Reference

Building Background

The following sections will overview the systems designed for the Rutgers University Law School Building Addition and Renovation project.

Structural System

The foundation system for the Rutgers University Law School Building Addition incorporates the use of drilled piles with pile caps used to support the loads associated with the bridge spanning Fifth Street, a grade beam connecting the pile caps located along the roadway, moment resisting foundations on geo-piers supporting the moment resisting frames, and typical strip footings used for the exterior façade walls.

The framing system used in the building is a typical moment frame steel construction with a composite floor system on metal decking. The steel system is used as the only lateral force resisting system in the building, increasing the typical member sizes. The roof framing system also consists of metal deck on smaller steel framing.

Fire Protection System

The Law School Building is protected by a new hydraulically designed automatic wet pipe sprinkler system throughout the entire building. The structural system (bearing walls, columns, and floor system) has been designed for a two hour fire resistance level as required by the International Building Code, with a one hour resistance rating for the roof structure. The designed floor slab, 4.5 inches of normal weight concrete eliminates the need for fireproofing of the deck. In addition, a Siamese connection has been installed on the exterior of the East Addition, the second connection on the building; this was permitted by New Jersey Building Code as the building was too large for one to adequately supply the full structure. These connections serve the standpipes which have been designed for 750 GPM each. Also, two 500 GPM fire pumps have been installed, this lower rating has been chosen as NFPA 14 allows fire pumps to act at 150% of their full capacity and Camden, New Jersey experiences low water pressure in the water mains supplying the building.

Architecture

The expansion and renovation of the 1970-era law building is designed to relieve crowded conditions and provide much-needed space for classrooms, seminar rooms, student organization space, and faculty offices. A bridge connection over 5th Street will formally link the addition to the existing building and will provide the law school with student lounge space. The student lockers and café will be relocated from the basement to a more

dignified position adjacent to this new lounge. A new entrance lobby resolves accessibility and security needs and provides a footprint for expanding the library circulation desk above. The new entrance, together with the bridge connection and addition, provides the law school with a new image on campus.

Construction Systems

The Rutgers University Law School is designed to be constructed in four phases. These phases include demolition of parts of the existing building, renovation of the existing building, and new building construction. Due to minimal storage space on site, interior finish materials have been permitted to be stored in existing rooms of the Law School slated for renovation, and contractor offices have been located in a building off site.

Building Envelope:

The building envelope of the Rutgers Law School consists of a running bond brick façade curtain wall, 8" CMU back-up wall for the east addition, with aluminum window punch-out windows and cast stone sills, and a Type 1 random ashlar brick curtain wall on the west addition. The Law Clinic Student Work Area is enclosed by 8" CMU back-up wall with a Type 1 masonry façade, random ashlar brick. The bridge crossing Fifth Street is a Type 1 masonry curtain wall with decorative steel fascia forming the underside facing the street.

There are several different roofing systems used on the addition. The first of which is an 8" concrete on metal deck, with 3" thick extruded polystyrene over drainage mat, loose laid under a 2-ply heat welded smooth surface modified waterproofing material. In addition, 2" x 24" x 24" adjustable pavers are to be installed for a decorative finish. The next system, also concrete on metal deck system, with 1-ply heat welded waterproofing, with ¼ in/ft tapered isocyanurate insulation covered by ½" thick gypsum coverboard and fully adhered 0.060 reinforced FR EPDM roofing. This system is used at locations surrounding roof access points. The primary roofing system is a standing seam metal roofing, with ¼ in/ft isocyanurate insulation protected by ½" gypsum coverboard and fully adhered 0.060 reinforced FR EPDM roofing.

Mechanical System

The mechanical system provided for the building is a water and air system using steam to heat the entire building and is located in the penthouse. The system designed for the building addition is completely separated from the existing system and consists of three 1020 MBH boilers and a 250 ton screw type chiller and cooling tower. The decision to utilize three smaller boilers for the building rather than one large one was a clear choice, as the larger boiler would require the employment of a full time operating engineer. In addition, the current construction of the building retains enough heat that the building is currently cooled until into December. This system provides flexibility for the heating needs and efficiency of output.

Electrical System

The electrical system in the Rutgers University Law School is moderately complex. As the building and addition are considered one building according to New Jersey Building Code, only one point of electrical service is permitted to the building. Resulting from this requirement, the existing main distribution panel has been relocated to the east building addition, creating additional panel boards and more complexity in the system.

The building is supplied with 480Y/277V 3 Phase/4 wire power from the electric company. This power is then delivered to the main 2500A switchboard in the East Addition, and directed to a sub main switchboard, 1200A located in the existing electrical room of the existing west building.

The emergency backup power supply designed for the building is a 100KW natural gas backup generator.

Lighting System

The lighting system designed for the Rutgers University Law School primarily consists of recessed parabolic troffers; however, direct, indirect, direct-indirect lighting methods are also implemented at various locations within the building. Almost every fixture in the building includes a fluorescent lamp with an electronic ballast, ranging in types from wall washers to recessed or semi-recessed troffers to wall sconces and downlights.

Telecommunication System

The Law School Building is equipped with data connection to each of the fixed seats in the lecture halls. Each room is equipped with internet/data connections and digital voice recorders and video players to enable the recording of lectures for later reference. All the cables for this system are routed through the ceiling with access panels in each room to provide adequate ability to service any problems that may occur in the audio/visual components.

Transportation System

In the East Addition of the Rutgers University Law School only one elevator has been provided for vertical transportation within the building. There is also an ornamental stair case provided near the law offices and another stair located adjoining the bridge connecting the two buildings. The existing building consists of one central elevator lobby with two elevators and three stairwells, one at each entrance.

Existing Structural System

The following information represents a brief overview of the existing structural system designed for the Rutgers University Law School Building Addition.

Foundation System

The foundation system utilized to support the east building addition incorporates moment-resisting spread footings, concrete pad foundations, and typical wall footing foundations. The typical foundations used to resist the lateral loads of the primary east addition are 11'-0" x 11'-0" x 2'6" spread footings with a 40" square reinforced concrete pier. The secondary east addition uses a smaller version, 7'-0" x 7'-0" x 2'-0", of the same concrete foundation. All spread footings for the building are supplemented with a displacement geopier system provided by Geostructures, Inc. to achieve an allowable bearing capacity of 5000 psf.

The foundation system supporting the bridge designed to cross Fifth Street incorporates drilled piles with pile caps along with a typical wall footing. A series of (24) 14" diameter piers are drilled to a depth of 65'-70' below grade, as required by the geotechnical report. In the east addition, the piles are capped with (4) 48" pile caps covering (6) piles each. To top off the pile caps, a grade beam, 2'-0" x 2'-0", has been designed to create a wall footing under the bridge addition.

Columns

The typical framing system used in the Rutgers University Law School is steel moment frame construction. Typical columns fixed to the foundations are A992 Grade 50 W14X159 for the primary east addition creating typical bays of 20'-0" by 46'-8", and A992 Grade 50 W14X82 for the secondary east addition which create 41'0" by 22'8" typical bays. Optional column splices have been located above the third floor for value engineering alternatives.

Floor Systems

The typical floor system developed for the Law School Building is composite beam framing. Each system incorporates a mildly reinforced composite floor slab (3/4" X 5" shear studs) with typical A992 Grade 50 steel framing systems. While there are several different slab thicknesses, the framing consists of 24" W-shaped beams spaced at 10'-0" on center framing into 24" W-shaped girders.

Lateral Force Resisting System

The lateral support for the entire east building addition is developed through the use of moment-resisting frames, as an open plan was critical in the architectural design of the building. There are (10) frames spaced at 20’-0” on center for the primary east addition, and (4) frames spaced at 11’-4” on center for the secondary east addition. For the bridge addition, (2) lateral wind resisting frames are required to withstand the load, these frames are spaced at 67’-4” on center. Each of the lateral support frames are created through beam-column moment connections.

Roof Framing System

The roof framing system designed for the entire east building addition and bridge section of the Rutgers University Law School consists of W18 beams spaced at 10’-0” or less on center framing into W18 girders with 3”-18ga galvanized roof decking.

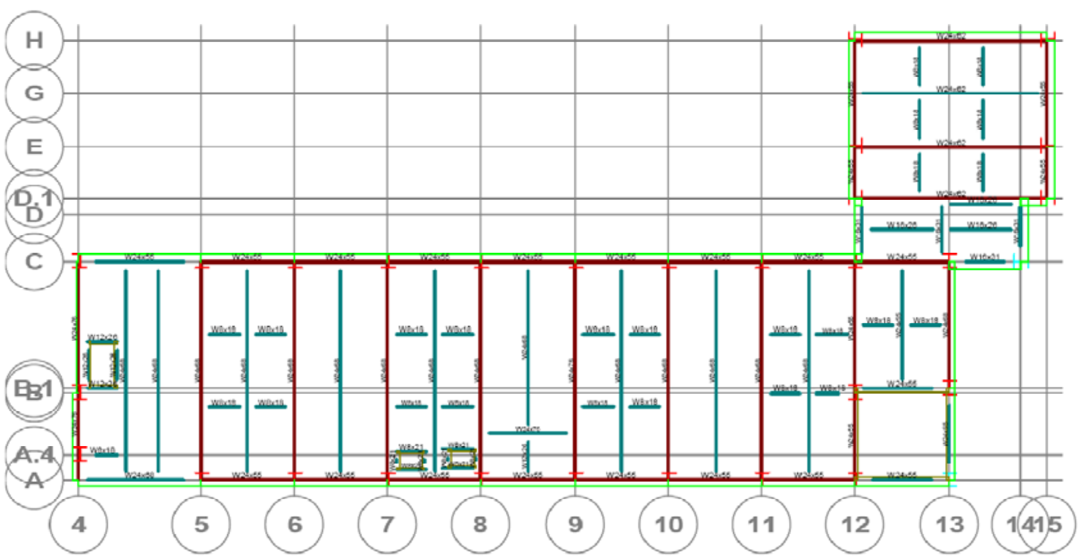

Figure 2: Existing Moment Frame Floor Plan (Lateral Elements shown in Red)

Problem Statement

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The architectural features and layout of the Rutgers University Law School Building Addition require an open plan, leading to the selection of steel moment frame construction as the existing framing system. The height limitation of 85'-0" has eliminated several alternative framing systems. Following an analysis of this structure, it has been determined that the framing system utilized has been sized for serviceability criteria due to wind drift rather than material strength. The models generated by RAM Structural System and STAAD Pro 2006 have verified the drift requirements and sizes chosen in the design; however, these members are loaded to approximately 50 percent of their available strength capacity.

In an attempt to reduce overall project cost, the lateral system will be designed as a braced frame, reducing the amount of required field welding on the project. In addition, an alternative floor framing system, composite steel joists, will be examined for efficiency as well as ease of construction. The effects of vibration created with such a large span joist will also be examined to determine feasibility of this alternative. Beyond vibration analysis, the new floor system will be studied for other serviceability criteria such as deflection and fire proofing.

The introduction of steel cross bracing will significantly impact the layout of the architecture; therefore an architectural breadth study will be performed to analyze the results of this structural revision—making great attempts to maintain the current architectural experience. The building façade will be reviewed as will the overall layout of classrooms and offices to determine the most desirable alternative to accommodate the need for a new lateral force resisting system.

As the modification of the framing system will eliminate a large amount of wind clips—reducing the amount of steel and bolts required, a construction management study will be performed to examine the potential cost savings and schedule improvements. The overall project schedule will be examined to determine the duration of the floor system construction and the lateral force resisting system to evaluate the impact of modifying this aspect of the structure. In addition, a more detailed analysis of the floor and lateral system schedules will be reviewed for more explicit information. Each system will then be reviewed for overall cost of materials and construction to determine the most efficient method. This project is state funded; therefore, the ability to save on construction costs will allow money to be reallocated to improved features within the building itself.

Design Constraints

The following sections detail the special requirements which need to be addressed within each floor framing system examined. Each of these requirements will help narrow the scope of research performed in this report.

Architectural Requirements

There are several architectural requirements in the design of the Rutgers University Law School Building; however, the constraint most influenced by the floor system is the clear span across the North-South direction of the primary east addition. This section includes two classrooms with a dividing corridor. Although a column could be placed on the sides of the hallway, the ability to clear span this distance provides the most flexibility in the building.

This requirement has driven the design parameters to a steel building. Through analysis in Technical Report #2, a typical mild-steel reinforced section was determined to be unfeasible. Also, the post-tensioned system was determined to be inefficient because there is only one bay, reducing the effectiveness of the design. Therefore, only steel structural systems were considered in the redesign of the floor system.

Fire Rating Requirements

This building has been designed for Type IB construction, requiring fire resistance ratings of two hours on the floor system. This will need to be taken into consideration with the use of steel members and decking as fire proofing will need to be applied.

The composite joist floor system being examined will require fireproofing on the underside of the decking, a process not necessary for the existing structural system because the depth of slab provided the 2 hour rating on its own. This will need to be examined in more detail to determine the benefits of modifying the structural system.

Foundation Requirements

The subgrade material located onsite has been determined to have relatively low bearing capacity and requires geopier stabilization to support the loads being applied. As a result, the superstructure weight should be minimized so as to avoid the need of additional stabilization.

Cost Analysis

As with many projects, cost is a major factor in the choice of system design for the Rutgers University Law School Addition. Because this project is financed by the state university of New Jersey, there is not a large budget to design and develop a top of the line law school building which will attract students to attend the university. Both systems will be analyzed through a detailed structural estimate to determine the most efficient.

Vibration Requirements

Vibration, although prevalent in the mechanical equipment located in the penthouse (boilers, pumps, and fans) move while in operation. This movement, however, will be absorbed by vibration isolators and inertia pads attached to the equipment. The primary focus of the vibration effects occurs from walking effects due to the large spans. The existing system will then be compared to the proposed floor system for effectiveness in mitigating the vibration effects.

Acoustic Requirements

As this is a classroom building as well as a law office, the need for acoustic privacy is essential. There must be sufficient isolation of rooms through the walls as well as through the floor system. This requirement, while important to the building design, has limited impact to the structural study of this report. The architectural study will consider sound isolation in the design review and necessary modifications.

Depth Study: Alternative Structural System

The alternative structural floor and lateral force resisting systems are described in detail in the following two sections. Methods of analysis, research performed, and final results are described and illustrated in each section.

Composite Joist Floor System Design

An alternative floor system was examined for use in the Rutgers University Law School Building Addition. The proposed system is a composite joist (CJ Series) system to replace the existing composite beam system in the current design. This system is proposed to reduce floor system cost and improve schedule while maintaining the same floor system depth. The connection of the joists to the girders will reduce the amount of time to erect the structure.

Typical floor joists were designed for the Primary East Addition and the Secondary East Addition. The methods described in the Steel Joist Institute's (SJI) Standard Specifications for Composite Steel Joists and Code of Standard Practice, First Edition were used for preliminary joist design. Following the determination of the uniformly distributed load, a joist was selected from the weight tables based on total load, compared to the allowable factored live load, and finally examined for total deflection. As the joist tables are based on total load, live load and load prior to composite action have a significant effect on joist selection.

Following strength analysis of the joists, an initial analysis following the SJI Technical Digest #5, Vibrations of Steel Joist-Concrete Slab Floors was performed. This analysis produced very favorable results; however, these results were then compared with the values obtained using the American Institute of Steel Construction's (AISC) Design Guide 11. As Design Guide 11 is the most recent accepted method for analyzing floor vibrations, it was used as a final criterion for joist selection. Through research in the Design Guide, a value of 0.03 was assumed for the modal damping ratio as a conservative value because the first floor provides a very open plan; however, the upper floors provide significant partitions making the damping ratio extra conservative. Also, from the Design Guide, the acceptable value for classroom/office space was found to be 0.005g due to walking vibrations—the only anticipated type of vibration problem for this project. The initial results from Technical Digest #5, through comparison with Design Guide 11 and information researched on vibration analysis, were not included in this report due to the incompleteness and inconsistency of the method.

Primary East Addition

The joists for the Primary East Addition were initially chosen to be 26CJ 1150/600/270 which requires a 26" CJ-Series joist with 1400 pounds/foot (plf) capacity for strength requirements. The 1200plf capacity does not provide adequate live load capacity for the office/classroom loading typical to the building. This joist is spaced at 5'-0" on-center with a 1.5" B composite steel decking and 2.5" of 4000psi concrete. In order to achieve the composite strength required of this section, (50) 5/8" shear studs are required to be installed on the system, assumed to be located in the weak position.

After a preliminary analysis of the composite system, the AISC's Design Guide 11 was used to determine potential vibration issues on the floor system. Typically with K-Series joists, large spans create significant vibration issues, requiring additional mass for appropriate damping issues—although CJ-Series Joists are being used for this project, no data was available for their predicted behavior. Therefore, a very detailed analysis was performed for this system. Due to live load reductions associated with vibration analysis, the initial joist selection proved to be inadequate to comfortably damp vibrations caused by walking in an office environment. Through interpretation of the results, the deflection of the joist was found to generate the largest portion of the vibration problem; therefore, the joist size was increased to effectively increase the moment of inertia. Through use of the CJ-Series Weight Tables, the effective moment of inertia of the joist is more readily available as it is required for the calculation of the composite joist strength.

Through examination of the system, it was determined that the CJ-Series joists provide a much more rigid system than the K-Series joists; however, the large spans still require additional sizes to eliminate vibration issues. The CJ-Series joists provide much larger non-composite moments of inertia, permitting for smaller members in the design, while retaining a very large composite moment of inertia. The depth of the joists was chosen to maintain approximately the same size floor system associated with the existing system. This reduced the ability to improve vibration with a lighter, deeper member and required a heavier, shallow member—reducing the effectiveness of the additional structure weight.

Below is a comparison of the typical floor systems, the existing composite beam design and the composite joist design. This illustration provides information regarding the overall depth and member spacing—the chosen CJ series joist produces a thinner floor system than the existing system, but requires additional members. This design permits the overall architectural experience to remain unchanged with modification to the structure.

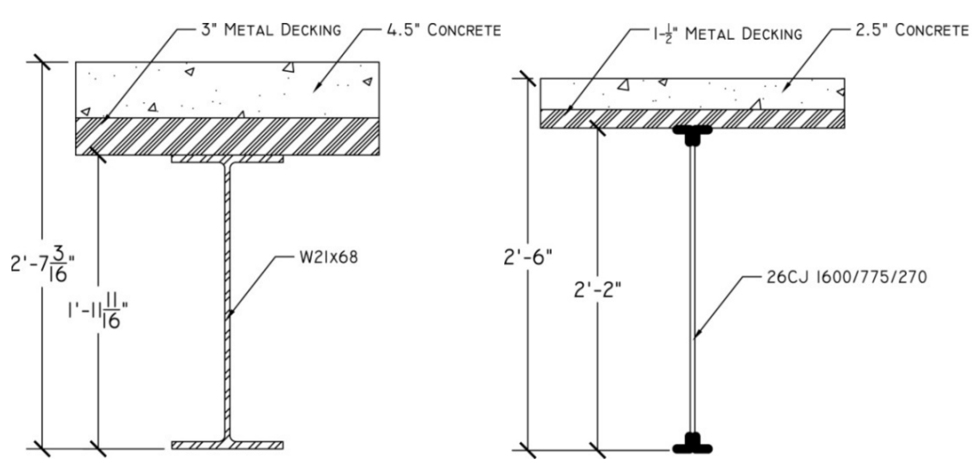

Figure 3: Typical Floor System Details (Existing v. Proposed)

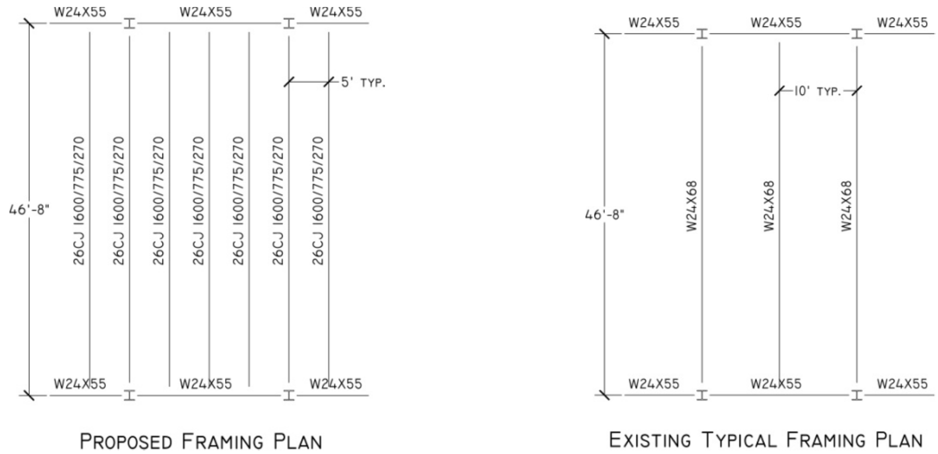

Figure 4: Typical Structural System Framing

The final design for the typical joist in the Primary East Addition is a 26CJ 1600/775/270 designed for 1150plf. The original steel deck and concrete thickness design will be used with (46) ¾" shear studs rather than (50) 5/8" studs. The table below outlines the results of the Design Guide 11 vibration analysis and denotes the selected joist for the typical plan in the Primary East Addition. As illustrated by the joist strength capacities, listed by parentheses in the table, the selected members are significantly larger than is required for standard loading characteristics. A more detailed sample calculation is available for review in Appendix B.

Table 1: Floor Vibration Calculation Summary, Primary East Addition

Composite Joist Properties			
1)	Designation	26CJ 1150(1600)/600(775)/270	
2)	Joist Span	47	ft
3)	Joist Spacing	5	ft
4)	Effective Moment of Inertia (I_j)	2260	in^4
5)	Uniformly Distributed Load	411	plf
6)	Deflection from Uniform Load (Δ_j)	0.69	in
7)	Effective Panel Weight	154,583	lbs
Girder Properties			
1)	Designation	W24x55	
2)	Girder Span	20	ft
3)	Effective Moment of Inertia (I_g)	4898	in^4
4)	Uniformly Distributed Load	1987	plf
5)	Deflection from Uniform Load (Δ_g)	0.11	in4
6)	Effective Panel Weight	52,994	lbs
Panel Properties			
1)	Total Panel Weight	140,561	lbs
2)	Natural Frequency (f_n)	3.96	Hz
3)	Modal Damping Ratio (β)	0.03	
4)	Allowable Acceleration Limit	0.005	g
5)	Estimated Peak Acceleration	0.004	g

Secondary East Addition

The study for the Secondary East Addition resulted in similar conclusions; the required joist sizes were significantly larger than required for strength in order to control vibration requirements. The baseline design for the much smaller 35 foot span in this addition was a 20CJ 1030(1200)/480(614)/270 steel joist. This would require (34) ½" shear studs to be placed in the weak position for capacity. The table below shows the chosen joist designation was a 26CJ 1030(1600)/480(1199)/270 with (28) 5/8" shear studs in the weak position. This is a very substantial modification to the original design; however, the selected joist maintains the same floor system as is implemented in the Primary East Addition, making the construction process identical. Through analysis, it was determined that although joists can be spaced further in small span applications, these shorter spans, in connection with shorter girders produce vibration problems due to a significantly lighter slab/joist combinations.

Table 2: Floor Vibration Calculation Summary, Secondary East Addition

Composite Joist Properties			
1)	Designation	26CJ 1030(1600)/480(1199)/270	
2)	Joist Span	35	ft
3)	Joist Spacing	5	ft
4)	Effective Moment of Inertia (I_j)	1200	in^4
5)	Uniformly Distributed Load	381	plf
6)	Deflection from Uniform Load (Δ_j)	0.37	in
7)	Effective Panel Weight	60,223	lbs
Girder Properties			
1)	Designation	W24x55	
2)	Girder Span	11.3	ft
3)	Effective Moment of Inertia (I_g)	2096	in^4
4)	Uniformly Distributed Load	1987	plf
5)	Deflection from Uniform Load (Δ_g)	0.01	in
6)	Effective Panel Weight	20,903	lbs
Panel Properties			
1)	Total Panel Weight	59,351	lbs
2)	Natural Frequency (f_n)	5.75	Hz
3)	Modal Damping Ratio (β)	0.03	
4)	Allowable Acceleration Limit	0.005	g
5)	Estimated Peak Acceleration	0.005	g

Roof Framing System

The roof system was also designed with this system; however, it was not analyzed for vibration affects as it is not an occupiable space. While no sample calculations are included in this report for the roof design, the final system chosen is 20CJ 311/144/35.

Additional Serviceability Criteria

The fireproofing system necessary for the composite joist floor system is outlined in the Code of Standard Practice published by the SJI. Two viable solutions were presented to provide 2-hour protection, a ceiling membrane protection or spray applied fire resistive materials (SAFRM). Through contact with industry professionals, the membrane protection system was disregarded due to limited number of floor penetrations and general overall cost associated with the system. There are several SAFRM systems capable of providing the 2 hour rated assembly—an acceptable method shall be chosen by the contractor. An analysis of the required fireproofing system will be further conducted in the Construction Management breadth in respect to overall cost and schedule impact.

Proposed Lateral System Redesign

An alternative lateral framing system has been researched for the Rutgers University Law School Building Addition and Renovation project. Through contact with industry professionals and building system research, the potential to mix concrete and steel trades in the Camden, New Jersey area was not considered. As a result, diagonal braced frames, chevron braces, and eccentric chevron braces were examined as feasible alternate systems. These frames were determined to exclude the composite joist sections utilized for the floor system. This permits simpler and more economical connections of the HSS braces to the beam-column interface. A new system was examined to reduce the schedule required to complete the project and reduce overall cost of welding.

An initial investigation into member forces was performed using STAAD Pro 2006 to determine the most efficient method of bracing the frames and to aid in the virtual work calculations for preliminary member sizing. Additionally, calculations performed for Technical Assignment #1 were used in the preliminary sizing of the columns for the new lateral system and verified using the final floor system loadings. By removing the moment frames from the building, column sizes no longer needed to be sized to prevent drift—permitting significantly smaller members. The beams used in the bracing system were also reanalyzed because the existing structural system carries a tributary with of twice that necessary for the new floor system design. Several different models were developed for both the East-West building direction as well as the North-South frames. The following sections will describe the alternatives examined and illustrate the final bracing layouts for each direction. The final analysis performed in RAM Structural System does not reflect the proposed floor joist system as this model was only generated for lateral system analysis and the modification of the floor system has no significant impact on the braced frames.

Further, typical connection designs have been examined and designed for a cost and schedule comparison on the project. While only one connection has been designed, the remaining connections appear to have very similar loading characteristics and should provide adequate information for comparison. These connections have been described in detail following the frame analysis sections.

Finally, the proposed lateral system will eliminate the moment from being introduced from the columns into the column foundations. The foundations will be redesigned to reduce the required size and overall project cost. While geotechnical data was not available for review, the existing foundations have been designed with a displacement geopier system creating a bearing capacity of 5000psf. An analysis of the foundations with this capacity was performed and an alternate analysis of allowable foundation pressure of 1500psf was performed as permitted by the International Building Code 2006. More information regarding the proposed foundation designs are described after the frame and connection details.

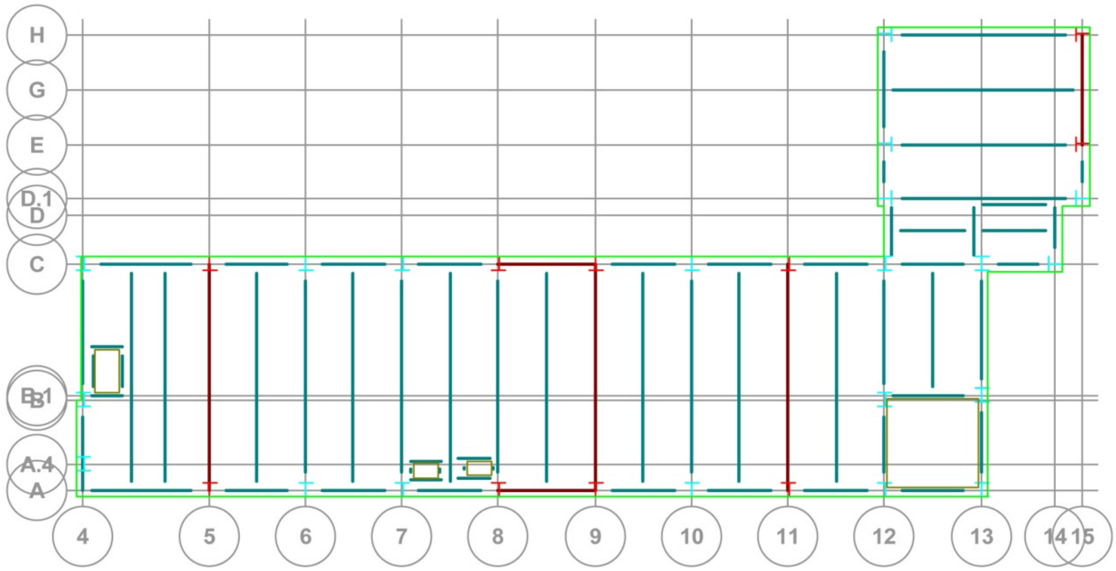

Figure 5: Proposed Lateral Force System (Lateral Elements in Red)

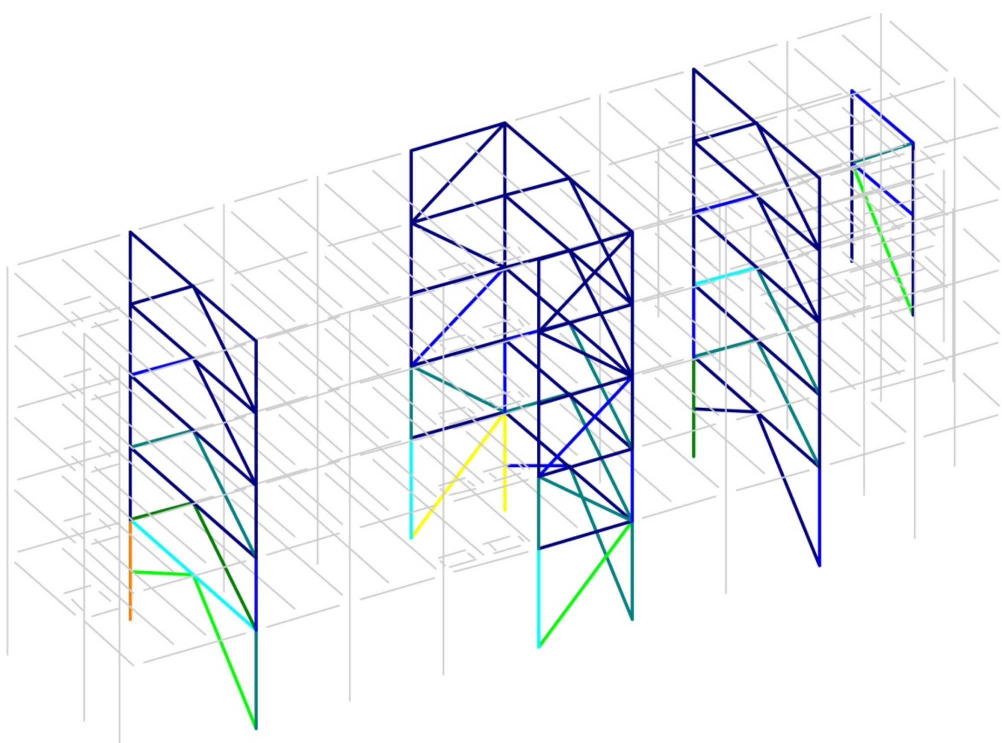

Figure 6: Proposed Lateral Force System as Stressed by Service Loads

North-South Building Frame

In the North-South direction, an eccentrically braced frame was found to be the most feasible alternative to the moment frames utilized in the existing design. The 47-foot span combined with the 21-foot floor to ceiling height eliminates the potential for diagonal bracing. Also, the architectural style chosen does not permit the standard chevron braces; an exterior hallway runs along the length of the building. Thus, the exterior brace connects to the column at 10-feet above the floor level to reduce architectural impact on the hallway. The other alternate bracing system considered was knee braces on the first floor with chevron braces on all other floors—this alternative was eliminated after STAAD analysis provided data representing large first floor drifts and very rigid upper floors. These results in connection with architectural requirements led the design to the eccentric braced frames. The existing architecture includes classroom spaces interfering with the proposed bracing solutions. As a result, an architectural study was performed to determine the most feasible solution to this issue and can be found in the Architectural breadth study of this report.

Several options were examined for determining the number of braced frames required for the building considering strength criteria along with service drift limits. Through the approximate method of virtual work, it was found that three braced frames in the Primary East Addition are necessary to maintain a manageable HSS bracing size. The braces were controlled by strength criteria—the length of the members created buckling problems in the members. As a result, the drift for the frame is 0.88 inches which is much less than the allowable 2.5 inches determined from the H/400 criterion. The first floor utilizes HSS9x7x1/2” members while the remaining braces are HSS8x6x1/2”.

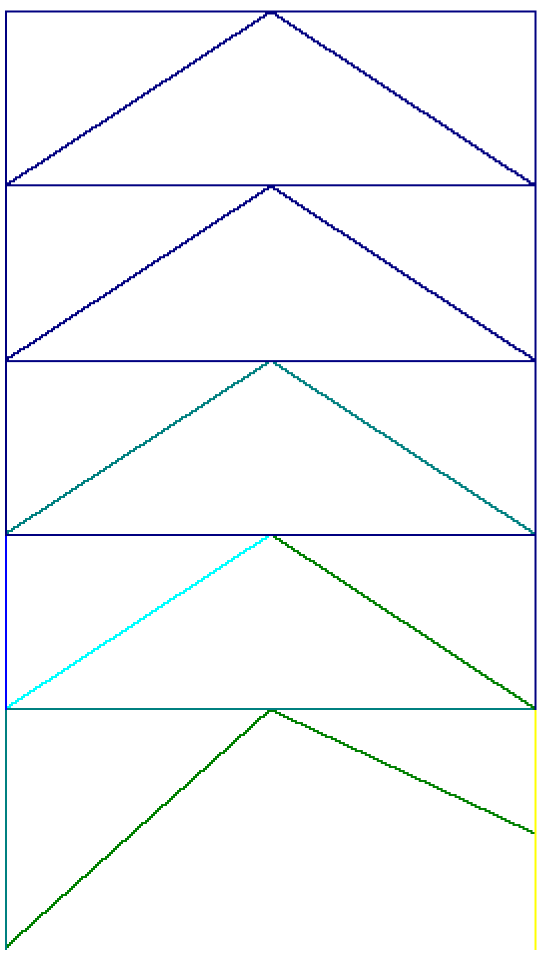

Figure 7: North-South Eccentric Braced Frame

The column sizes required for the North-South braced frame are larger than the gravity loaded columns due to wind load impacts. Additionally, the eccentric bracing introduces additional moment to the column at the base of the structure, increasing the column size from a W14x82 to a W14x99. The larger columns will be spliced at the third floor level and reduced to the typical W14x82. The preliminary design for this frame can be found in Appendix C of the report. A support was added at the location of the eccentric brace and the reactions were applied to the designated column. The preliminary design predicted 0.63 inches of drift at the roof level, determined reasonable due to the shortening of the column.

East-West Building Frame

The East-West braced frame was determined to be a diagonal brace to reduce the number of connections required. This type of bracing created a minimal problem with the architecture, as these frames are located on the exterior of the building, an architectural impact was required to be examined. The result, an architectural breadth was performed to determine whether to arrange the existing building façade to minimize the impact of the braces or to expose the structural system through a glass curtain wall—this analysis can be found in the Architectural breadth study in this report. Additionally, the diagonal braces were selected for architectural aesthetics for exposure in the North building elevation as can be seen in the architecture section of this report.

These frames span 20 feet and are able to support the lateral system with only two bays of bracing. Therefore, one bay of bracing is located on either side of the Primary East Addition to reduce the effect of torsion on the building. Through a virtual work analysis and with the use of STAAD Pro 2006, general member sizes were determined for these frames. As HSS8x6x1/2" bracing was utilized in the North-South frame, the same section was used for the diagonal braces in the East-West frame. The increased column size required for the North-South frames were also required for this design—the W14x99 columns are also spliced down to W14x82 columns at the third floor level.

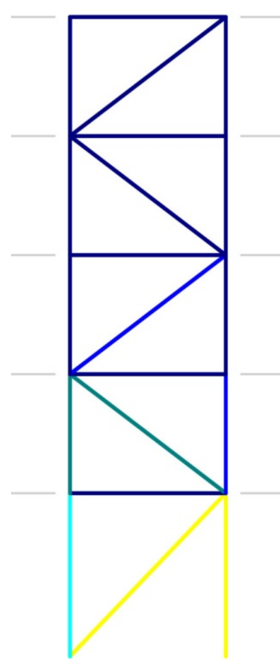

Figure 8: Typical Proposed East-West Frame

Proposed Column Design

A result of the removal of moment frames as the lateral system was the ability to reduce the typical column size. After assessing the new loads generated by the proposed composite joist floor system, the dead load of the structure remains very similar to the dead load assumed with the existing structure. Therefore, the gravity load analysis performed in Technical Assignment #1 was used as a basis for generating the preliminary sizes for columns in the final design. The table below displays the column loading used to appropriately size the columns for the project—this load was used to determine required footing sizes.

Table 3: Gravity Column Load Table

Gravity Column Loads (kips)				
Level	Dead Load	Live Load	Snow Load	1.2D + 1.6L + 0.5S
Roof	17.4	0.0	10.9	26.3
3rd Floor	43.2	70.5	0.0	164.6
4th Floor	43.2	14.1	0.0	74.4
3rd Floor	43.2	14.1	0.0	74.4
2nd Floor	43.2	14.1	0.0	74.4
Total	190.3	112.8	10.9	414.3

From the loads in the above table, columns were sized to be W14x82 members at all gravity only locations. These columns were based on a 21 foot first floor effective height and are permitted to be reduced in size at the third floor if desired; however, a column reduction was not designed as this was a value engineering alternative for the existing design and was not implemented. The following table represents the load carried by the North-South chevron braced frame columns. A W14x99 was chosen to support these loads, and was reduced to a W14x82 at the third floor level.

Table 4: Lateral System Column Load

Lateral System Column Loads (kips)					
Level	Dead Load	Live Load	Wind Load	Roof Live Load	1.2D + 1.6W + 1.0L + 0.5L_r
2nd Floor	190.3	112.8	237.0	6.9	723.8

The figure below represents the loading stresses of the columns under gravity load; the image depicts the columns being loaded from 80-95 percent of allowable load from the second floor to the foundation. The lateral force resisting system does not show equal stresses, as this loading depicts only the effect of gravity loading.

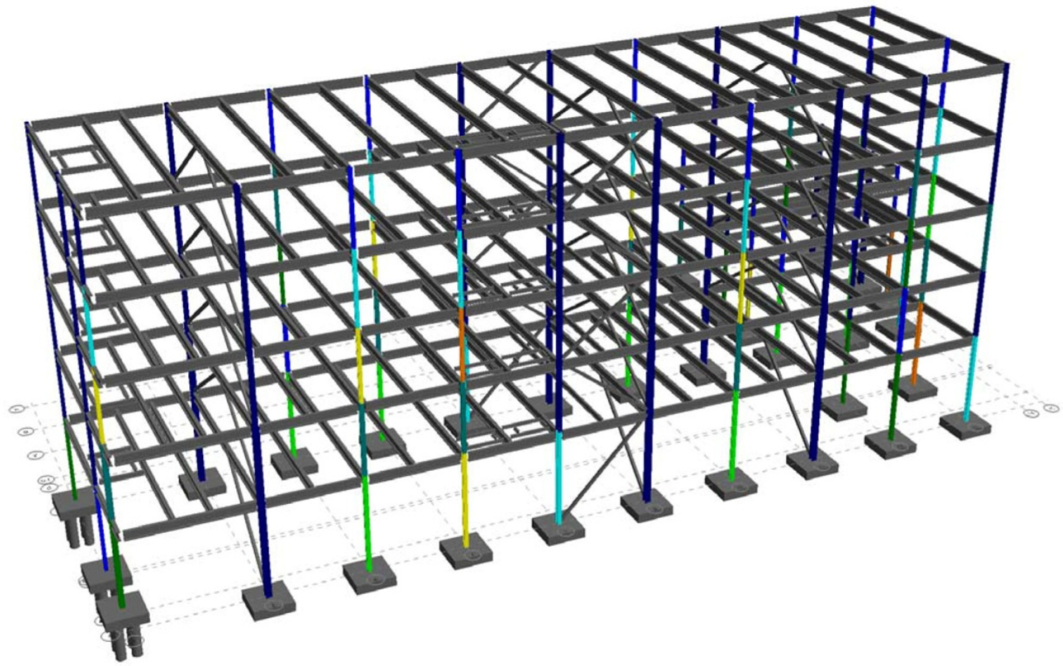

Figure 9: Proposed Column Stresses due to Gravity Loading

Proposed Beam Design

The proposed floor system reduces the spacing of floor members from 10-feet on center to 5-feet on center; as a result, smaller beams can be utilized for the braced frames. This analysis and design very closely mirrors the analysis performed in Technical Report #1 when the existing system was examined. The beam size required for the lateral system designed is a W21x50 with (44) ¾" shear studs along the beam length. This configuration of shear studs was chosen for efficiency as well as for repetition with the composite joist system which requires (46) ¾" shear studs along the length.

This beam was also designed for composite action because the current floor system utilizes shear studs; it seemed most practical to maintain a similar quality. These beams will only be placed at locations where the lateral braced frame is used; the remainder of the floor system will be composed of composite steel joists as designed in the previous section. These beams are used to provide for a more simple connection of the HSS bracing members with the column/beam connection. In the North-South direction, the chevron bracing is impractical with the composite joist design, as framing into the bottom chord of the truss is not common practice, nor would it make sense to load a joist in that manner.

Proposed Connection Design

A general connection design for the lateral bracing was designed for an overall system cost analysis. A typical connection was selected from the chevron braced frame; a midpoint connection was chosen as well as a connection of the HSS to the beams and girders in the system. The details below illustrate the types of connections designed for this project.

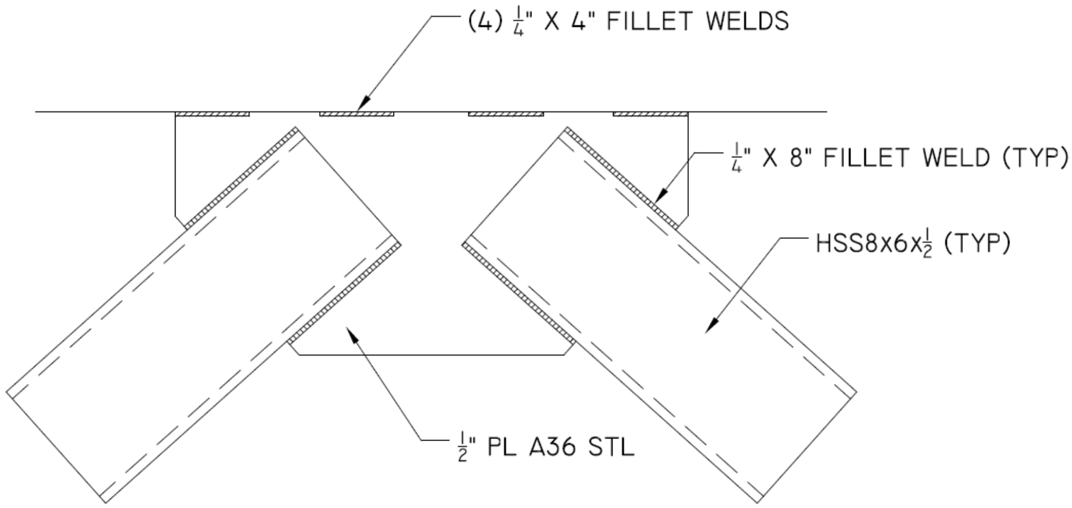

Figure 10: Typical Proposed Mid-span Connection for Chevron Braces

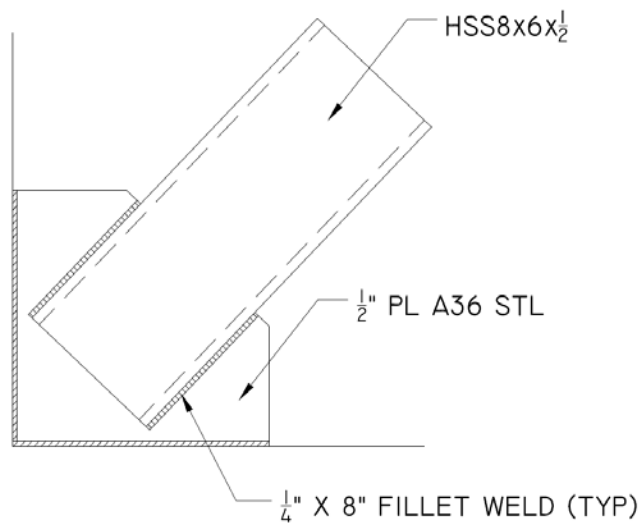

Figure 11: Typical Proposed Column/Beam Brace Connection

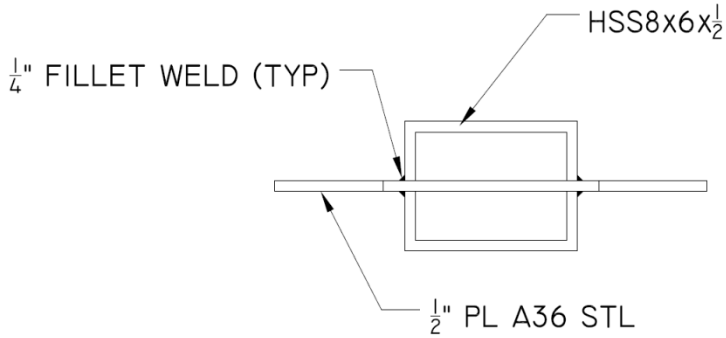

Figure 12: Typical Proposed Brace Detail

The connection plate was welded to the HSS and the girder to provide a simpler connection—rather than connecting these members with bolts. These connections are only necessary at the braced frame locations, as opposed to the wind clips necessary at each beam/girder interface. This system of connections was used in an attempt to minimize overall building cost for the project.

The overall cost of each connection is approximately $600 each. Although this cost per connection is similar to the bolted moment connections created in the existing design, the quantity of connections required is able to reduce the total project cost. A more detailed cost analysis is provided in the Construction Management breadth study of this report.

Proposed Foundation Redesign

The utilization of an alternative lateral system is expected to permit the foundation system to be modified. The braced frames allow for pinned column bases, eliminating the moment transfer from the column into the footing, thereby reducing the required bearing area. The load required for the ground floor columns was transferred into the foundation system for determining an alternative design. An allowable bearing capacity of 5000psf is provided by the displacement geopier system; however, an analysis of required foundation sizes with 1500psf bearing capacity was also considered (the estimated bearing capacity of silty/sandy soil characteristics provided by the IBC 2006).

An analysis of required bearing area for the loads generated through the columns failed to permit significantly smaller foundation requirements. The loads generated by both floor systems are very similar; therefore, an equal bearing capacity is required for the soil capacity. Through this study, it was determined that the necessary

As a result, the cost savings expected through the redesign of the lateral system has been neglected. The same foundation design provided for the initial building lateral system will be required for the proposed lateral and gravity system. This will be reflected in the cost analysis of these foundations found in the Construction Management breadth study included in this report.

Breadth Study #1: Architectural Impact

The architectural style of the Rutgers University Law School incorporates new building construction with the existing 1970's era building. The structural study of this report involved the redesign of the lateral system for the project—changing the system from moment frames to braced frames. Moment frames generate large open plans, necessary for the architectural layout designed for this project. Unfortunately, braced frames fail to permit equally large spaces, even the eccentric chevron braces create the need for breaks in the floor plan. As a result, the floor plan was investigated as part of this report.

Additionally, a direct result of the braced frames was a need to consider the impact on the building façade. While great care was taken to reduce the amount impact of the new framing, as this building is a single bay, the framing in the East-West direction will require exterior bracing. This section of the report will examine what required changes need to be made to the building to permit the alternative structural system.

The drawings referenced within this section of the report, as well as the existing conditions, can be found in larger scale in Appendix E of this report.

First Floor Redesign

The floor plan for the first floor of the Rutgers University Law School consists of three classroom spaces, several service locations, and a moot court. The existing structural system permits for large open spaces, leading to the existing architectural layout.

By redesigning the existing structural system from moment frame construction to braced frame construction, the open plan system is compromised. Though great care was taken to reduce the architectural impact through strategically placed braces, the initial design will require several modifications to adapt. As a result, several different building layouts have been analyzed; the plan below, also displayed in Appendix E, depicts the revised first floor plan chosen to suit the needs of the client. A comparison to the existing floor plan can also be found in Appendix E of this report.

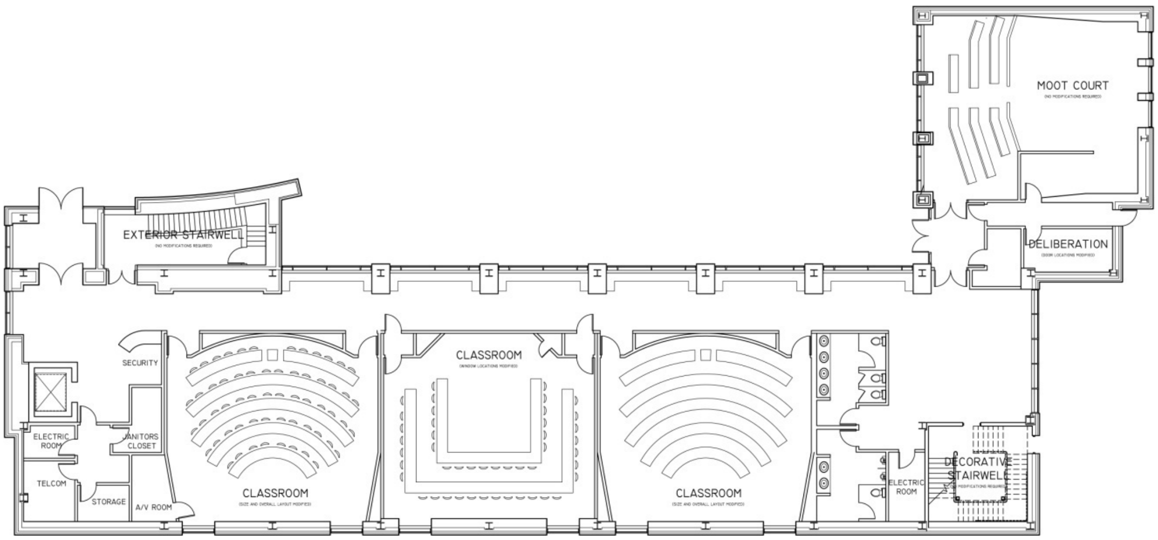

Figure 13: Proposed First Floor Plan

The revised floor plan will be analyzed and described from the western ground floor entrance to the secondary addition on the eastern side of the project.

The floor plan has been broken into 20-foot components, permitting for the braced frames to be hidden inside the wall structure. Much care was taken to ensure the existing exterior hallway, following the North curtain wall façade of the building, was maintained—retaining the architectural experience for students on the first floor. This decision retains the bench seating along the large curtain wall windows and ensures code egress requirements are met for this space.

Upon entering the building, the security checkpoint has been maintained to ensure safety on campus. This section of the building has been modified to contain the service areas necessary to run the building. The telecommunications room and custodial closets have been relocated to a remote area behind the security desk.

The classrooms have been arranged in the same manner as the existing design; however, the first classroom has been condensed to a 40-foot module. This presented several challenges to the architectural room layout. Prior to redesigning the classroom space, the amount of desk space permitted for each student was analyzed and recorded to ensure equal classroom performance of the new design. To retain an equal student capacity in the classrooms while maintaining the existing room depth, an additional row of student seating was created by eliminating the projector cubicle and replacing it with a projector unit in the middle of the back row desk space. This provided 2.49 linear feet of desk space as compared to 2.47 linear feet of desk space by the original design. While the classroom space was narrowed by a few feet, and the overall depth maintained, the wall space generated in the rear of the room retains the required square footage for instruction. Additionally, the vestibule designed for the classroom entrance was modified to create a recessed entrance; however, the door opening into the hallway was removed—a potentially hazardous door. The required egress clear space was maintained in the classroom spaces to ensure a safe learning environment. These modifications allow the classroom space to be utilized in the same manner as the original design but also allow for the revised structural system to go virtually unnoticed in the building. The modified classroom can be seen in the plan below and can be compared to the existing design in Appendix E of this report.

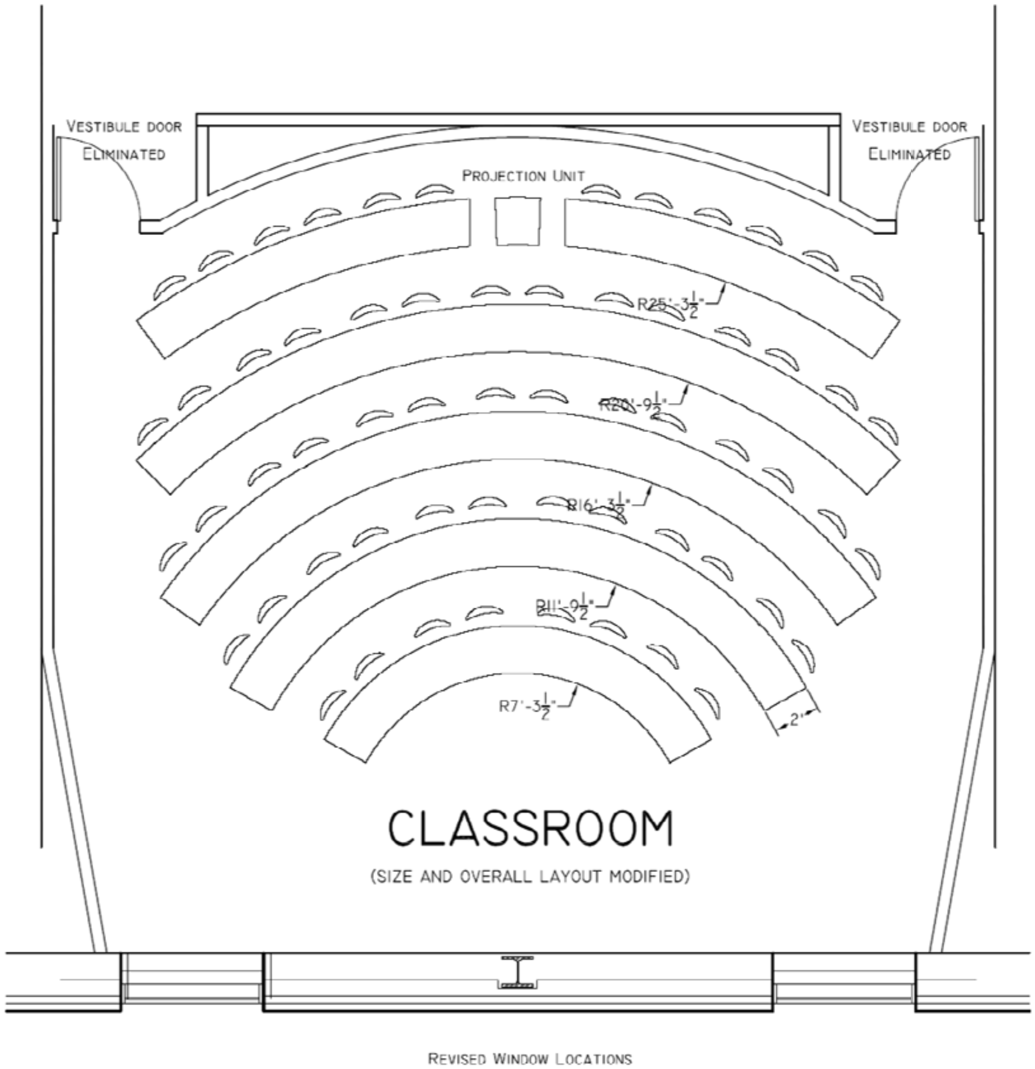

Figure 14: Proposed Classroom Redesign

Finally, the restrooms have been altered to a 20-foot wide module and relocated from the western side of the building to the easternmost side of the primary east addition next to the stairs. This location was chosen to retain the current electric room location to minimize impact to other floors. As the plan illustrates, the restrooms permit an extra room to be created, a room used to provide the continuous electric service through the building. In general, the restroom layout has been kept, only moved to the opposite side of the building.

Upper Floor Design Considerations

The ground floor electric room was not relocated to reduce impact on the upper levels—minimizing the effect of the braced frames on the architecture. As the upper level floor plans are currently designed on a 10-foot system, the large open plan is not necessary for the architectural experience. This type of floor plan permits the installation of braces between office spaces. As a result, the upper floor plans have not been redesigned; ensuring the architectural experience initially created for this space can be maintained.

Elevation Considerations and Modifications

By adding braced frames to the exterior of the North and South elevations of the Rutgers University Law School Addition, the architectural impact needed to be investigated. The south wall of the Primary East Addition was modified only slightly by the moving of windows on the first floor. This modification can be seen highlighted in yellow on the South Elevation displayed below.

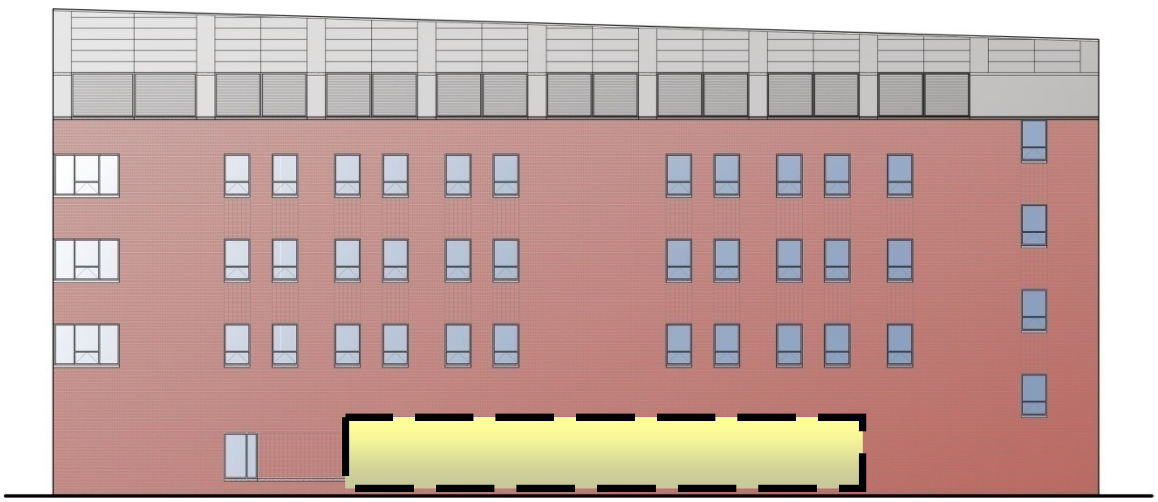

Figure 15: Proposed South Elevation

The modification required is from the movement of the classrooms on the ground floor only. The large portion of wall not occupied by windows corresponds to the mechanical chase running down the exterior wall in the existing drawings. The addition of a braced frame in that bay of the structure does little to impact the architectural experience of the building.

However, the use of a braced frame in the North façade creates a great deal of issues. Several alternatives were considered: removing the windows, installing much smaller windows, and exposing the structural system. In the end, the decision to expose the braced frame was made to permit light to penetrate the offices and reception areas located in that portion of the building. A curtain wall was designed for the bay requiring the braced frame; the architectural style was considered when implementing the curtain wall glass design. As the current design utilizes stack bond between the windows, the mullions of the curtain wall form a more vertical component on the façade where the stack bond masonry would belong. Another concern to this design is the floor system located behind the glass. This problem was resolved through the use of spandrel glass at all floor level locations to improve the aesthetic appeal. Finally, the exposed structural system will be coated with intumescent paint; thus providing the required fire resistance. Overall, the addition of glass to the façade, with mullions utilized to incorporate the typical building features enhances the building image while showcasing the structure.

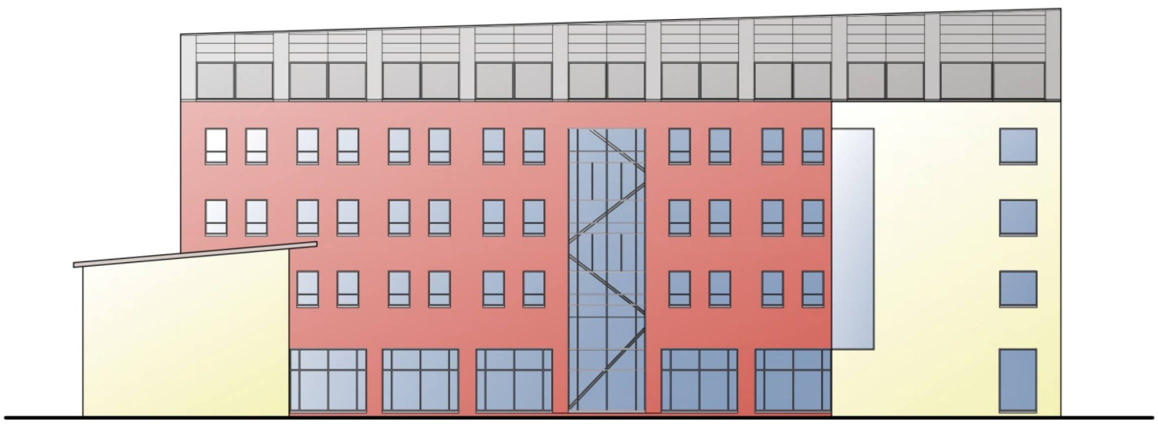

Figure 16: Proposed North Elevation

The elevations shown above can be found in Appendix E of this report and can be examined against the existing building elevations.

Breadth Study #2: Cost and Schedule Evaluation

The modification of the structural system of the Rutgers University Law School Addition creates several cost and schedule implications. This section of the report will examine the overall structural cost of each system and determine any schedule changes due to the modifications.

The cost estimates and schedule information can be found in full size in Appendix F of this report.

Cost Estimates

A detailed structural estimate was prepared for the existing structural system using R.S. Means Building Systems information. Additionally, information regarding connection materials and costs were developed through the help of industry professionals to determine an approximate cost and schedule duration. The system take off is listed in the table below, producing a structural system cost of $1.44 million, approximately 6.5 percent of the total building cost. This estimate reflects the structural cost of materials and labor which will be modified in the redesign. Members remaining the same were not included in this estimate as no savings or additional expense will be generated from these components: bridge section, west building addition, exterior stairwell, and foundations.

Table 5: Existing Structural System Cost Estimate

Description	Crew	Daily Output	Units	Material	Labor	Equipment	Total	Total O&P	Required Output	Total Cost
Steel Shapes										
W8x18	E-2	600	L.F.	$25.50	$3.91	$2.61	$32.02	$37.50	1000	$37,500.00
W14x159	E-2	720	L.F.	$145.00	$3.26	$2.18	$150.44	$173.01	1870	$323,521.22
W14x90	E-2	740	L.F.	$109.00	$3.17	$2.12	$114.29	$131.43	245	$32,201.21
W16x26	E-2	1000	L.F.	$31.50	$2.34	$1.57	$35.41	$40.72	105	$4,275.76
W24x55	E-2	1110	L.F.	$66.50	$3.06	$1.53	$71.09	$81.75	1256	$102,682.40
W24x62	E-2	1110	L.F.	$75.00	$3.06	$1.53	$79.59	$91.53	140	$12,813.99
W24x68	E-2	1110	L.F.	$82.50	$3.06	$1.53	$87.09	$100.15	1974	$197,703.01
W24x76	E-2	1110	L.F.	$92.00	$3.06	$1.53	$96.59	$111.08	282	$31,324.14
W27x84	E-2	1190	L.F.	$102.00	$2.85	$1.43	$106.28	$122.22	1159	$141,655.30
										$883,677.02
Misc. Steel										
3"-16 ga. Metal Decking	E-4	3400	S.F.	$3.16	$0.41	$0.04	$3.61	$4.15	59620	$247,512.43
3/4" x 5" Shear Studs		975	Ea	$0.84	$0.72	$0.37	$1.93	$2.62	4890	$12,811.80
L7x4x7/8 Connection Material		440	Lb	$0.64	$2.38	$0.30	$3.32	$3.82	7074	$27,008.53
7/8" Connection Bolts		110	Ea	$1.52	$3.13		$4.65	$7.30	1620	$11,826.00
3/4" Shear Connection Bolts		115		$1.04	$2.99		$4.03	$6.55	2128	$13,938.40
Concrete										
6x6 W2.9xW2.9 WWF		29	C.S.F.	$20.00	$23.50	$0.00	$43.50	$61.50	596	$36,654.00
4.5" Concrete		2585	S.F.	$2.02	$0.73	$0.28	$3.03	$3.48	59620	$207,745.89
										$244,399.89
Total Cost		$1,441,174.07								

The proposed structural system was analyzed in a similar manner to the existing system, and the material take off is displayed below. The information regarding HSS bracing and connections was determined through the help of industry professional "rules of thumb" and therefore is listed as a unit item. Overall, the construction cost of the revised structural system totals $1.31 million, a $100,000 savings from the initial design. While this is not a large savings, it totals 7 percent of the total structural system cost. As this project is a state funded project, additional funds will increase the budget permitted to be spent on enhancing the building features.

Table 6: Proposed Structural System Cost Estimate

Description	Crew	Daily Output	Units	Material	Labor	Equipment	Total	Total O&P	Required Output	Total Cost
Steel Shapes										
W14x82	E-2	600	L.F.	$25.50	$3.91	$2.61	$32.02	$37.50	1945	$72,937.50
W14x90	E-2	740	L.F.	$109.00	$3.17	$2.12	$114.29	$131.43	255	$33,515.54
W24x55	E-2	1110	L.F.	$66.50	$3.06	$1.53	$71.09	$81.75	1256	$102,682.40
W27x84	E-2	1190	L.F.	$102.00	$2.85	$1.43	$106.28	$122.22	1159	$141,655.30
										$350,790.74
Composite Joist System										
CJ Series System		15	Tons	1400	226	122	1748	2050	142.7	$292,625.20
3/4" x 5" Shear Studs		975	Ea	$0.84	$0.72	$0.37	$1.93	$2.62	7200	$18,864.00
Bracing (including connections)			Ton	$980.00				$3,630	22.00	$79,861.83
Spray Applied Fire Proofing								$2.00	59620	$119,240.00
										$510,591.03
Misc. Steel										
3"-16 ga. Metal Decking	E-4	3400	S.F.	$3.16	$0.41	$0.04	$3.61	$4.15	59620	$247,512.43
										$247,512.43
Concrete										
6x6 W2.9xW2.9 WWF		29	C.S.F.	$20.00	$23.50	$0.00	$43.50	$61.50	596	$36,654.00
4.5" Concrete		2585	S.F.	$1.36	$0.73	$0.28	$2.37	$2.73	59620	$162,494.31
										$199,148.31
Total Cost	$1,308,042.51									

A primary modification to the structural system is a change to the lateral force resisting system. The new connection consists of welded plates joining the HSS members with the wide flanged beams and columns, eliminating the wind moment connections installed at nearly every column beam interface. These connections were estimated from information provided by industry professionals, creating approximately $32,000 of connection materials for the new design compared with approximately $40,000 of connections created by the original design. Although this produces a very limited cost savings in the reduced number of connections helps reduce overall project schedule. The design required for the moment connections require bolted angles on the top and bottom flange of each beam/column interface. While the cost per connection of the moment connections is lower than the necessary welded connections for the braced frame, the number of connections is greatly reduced, reducing the overall connection cost of the project.

The existing connection detail creating a moment connection at each beam/column location is shown below as represented in the structural detail drawings. The proposed connections for the braced frames has been illustrated and described in the lateral force resisting system redesign section of the structural depth in this report. The proposed system incorporates the beam/column connection with double angle shear connections at braced frame locations; however, it eliminates the need for the additional angles on the top and bottom flanges of the beam connections. The composite joist floor system removes connection bolts at theses connections and therefore reduces cost and overall schedule time required for detailing these locations.

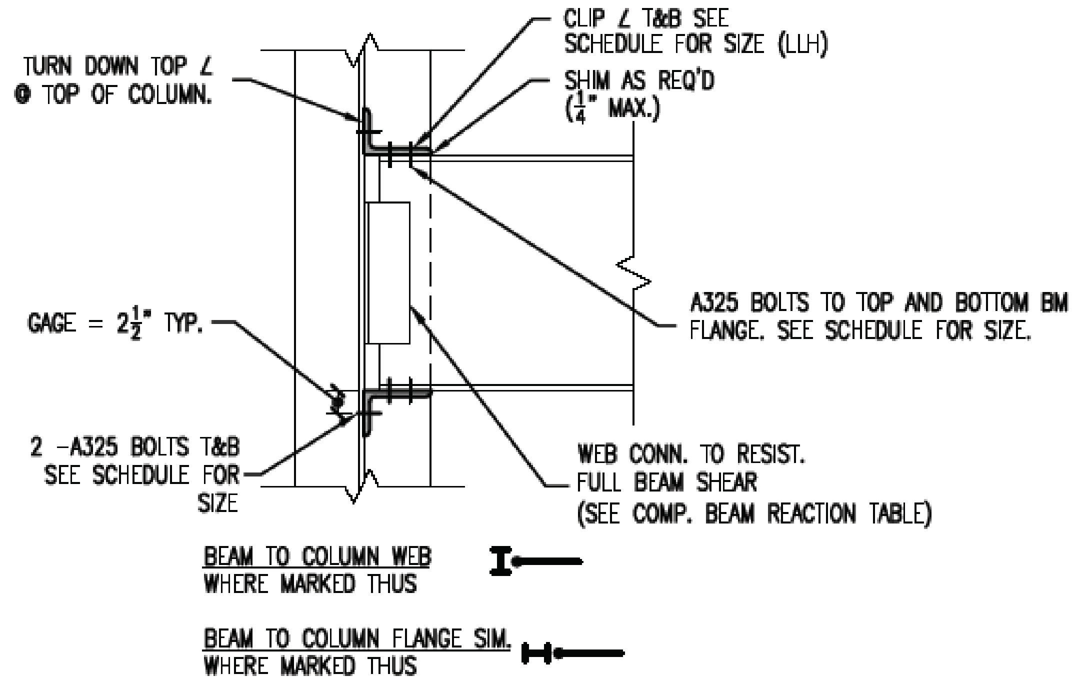

Figure 17: Existing Beam/Girder and Beam/Column Connection

Schedule Implications

An analysis of the schedule for the Rutgers University Law School Addition has been performed and illustrated in the overall schedule listed below. This project has been designed to be constructed in several phases to minimize impact on classroom activities during typical Fall and Spring semesters. The first schedule is a breakdown of each phase of construction depicting the amount of time scheduled for each portion.

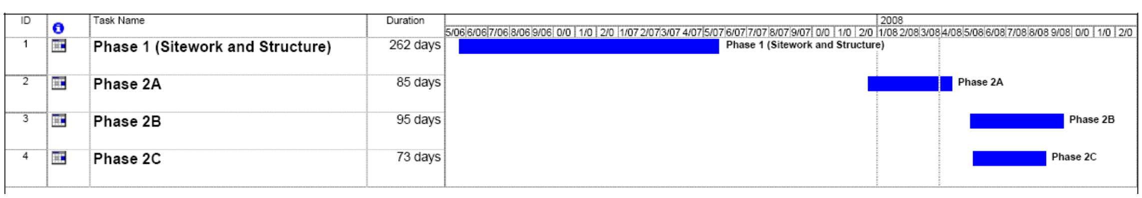

Figure 18: Overall Project Schedule for Rutgers University Law School

The phase of interest to this report is Phase 1 (Site Work and Structure). Therefore, a detailed breakdown of the existing schedule is included for comparison to the proposed schedule revisions resulting from the proposed structural system. It was determined the critical path includes the erection of the column line and beam/girder system, as well as the floor slab construction and detailing of each floor. The two schedules listed below represent the existing structural system and the proposed structural system respectively.

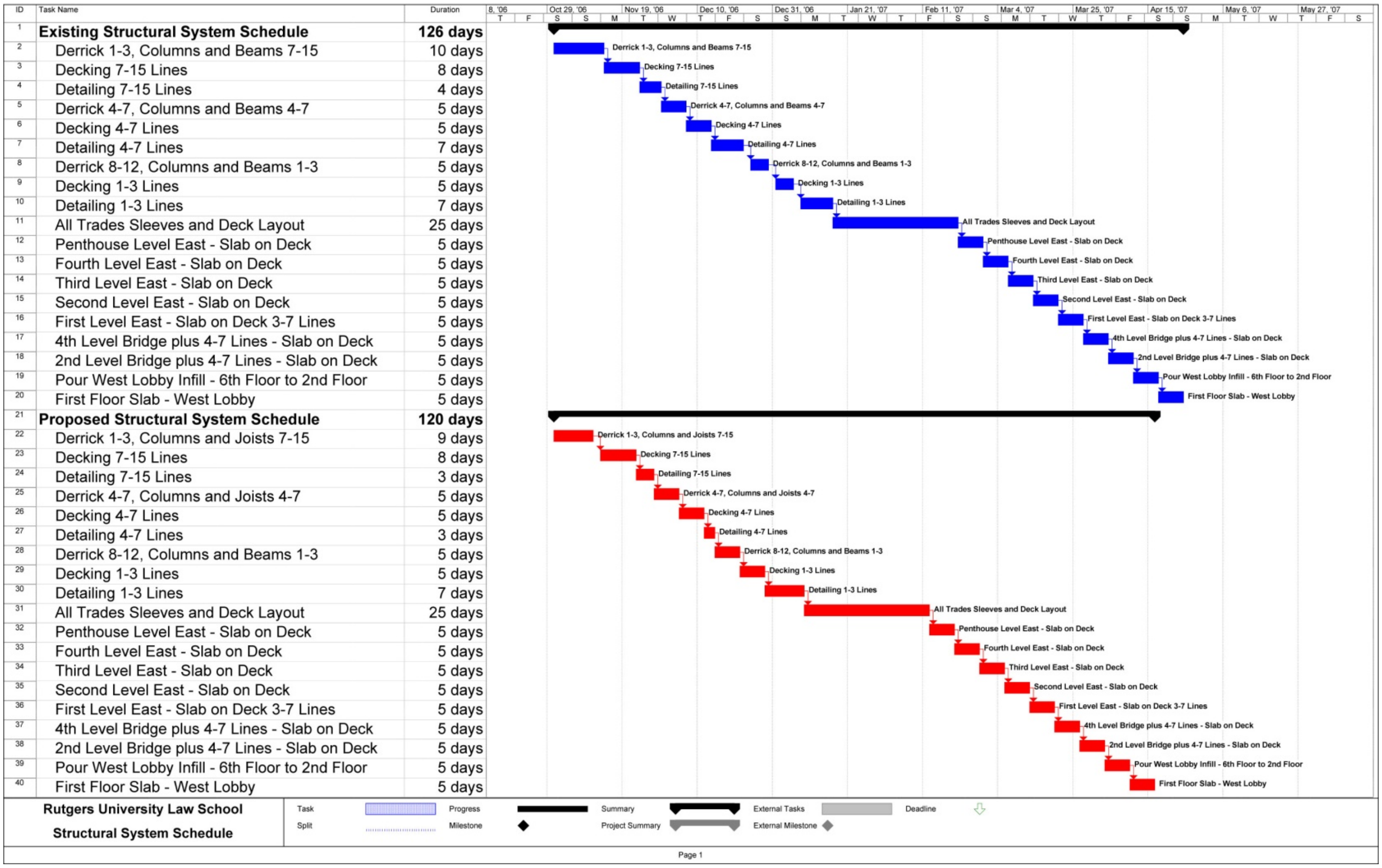

Figure 19: Existing v. Proposed Structural System Schedule

The schedules illustrate the critical path of erecting the steel and placing the deck and concrete; however, the spray on fireproofing has also been included in the schedule found in Appendix F to represent the additional time necessary for completion. The fireproofing does not fall on the critical path, and thus the additional required fireproofing does not have a negative impact on the schedule. There was no modification to steel and deck erection on column lines 1 through 3 as these lines represent to locations found on the bridge portion of the project. The only column lines modified due to the structural redesign are column lines 4 through 15, the primary east addition and the secondary east addition. Members falling on the bridge addition or the west building renovation were not considered as part of this report.

The modification of the schedule for the proposed schedule provides data for the reduction of the project schedule by one week. The time savings results from reduced time detailing the floors—representing the connection requirements of each system. The braced frame requires a significantly reduced number of bolts and members, permitting the construction process to advance significantly more rapidly.

While the additional fireproofing will require extended schedule time, it is not on the critical path, reducing its effect on the building process.

Summary and Conclusion

In conclusion, the Rutgers University Law School Building Addition and Renovation project is most feasible to be a steel framed building. Through previous analysis, concrete members were decided to be uneconomical for a one bay, large span frame generated by the architecture.

The floor system was analyzed as a composite joist floor system and evaluated for all typical serviceability criteria, including deflection, vibration, and fireproofing. In order to meet vibration criteria, the required joist was sized significantly larger than the required load; however, the chosen joist a 26CJ 1600/775/270. This size joist permits a floor system equal to the existing floor-ceiling sandwich.

In connection with an alternative floor system, the lateral framing system was analyzed to determine the effectiveness of a braced frame system compared to the moment frame system designed for the project. Braced frames were analyzed to reduce the necessary moment connections at each beam/column interface. Through several iterations, the use of three braced frames in the North-South direction was found necessary to utilize manageable HSS bracing members on the lower floors. This system, even with architectural interest in mind, and eccentric chevron braces designed to reduce impact, requires modification to the building architecture—both interior and exterior changes. The architecture was analyzed and a solution with the least possible impact on the existing style was selected as the most feasible solution, hiding most braces within existing walls; however, the bracing on the North elevation was exposed as part of the architecture.

Finally, the modified structural system was analyzed for overall cost and schedule requirements. Through a detailed takeoff, the composite joist floor system with braced frame lateral force resisting system was found to save $100,000 from the existing moment frame steel construction. Additionally, the reduced number of connections was able to reduce the total schedule duration by one week over a four month steel erection schedule.

In conclusion, the proposed structural system incorporating composite steel joists and braced lateral force resisting frames reduce the total project cost. The proposed floor system maintains an equal floor-ceiling sandwich, provides adequate vibration control, and meets all other required criteria. The proposed lateral system reduces construction time, helping reduce the amount of time necessary to work on the project during typical semester dates. The proposed lateral system is recommended for this project as it will slightly reduce overall building cost and improve the project schedule. The floor system modification produced similar results and therefore no significant benefits. The table below provides a summary of the report and displays the overall benefits associated with each system. The chart provides information proving each system is very similar; however, the reduced cost makes the proposed system more desirable.

Table 7: Structural System Comparison

	Existing System	Proposed System
Architecture	+	Revised Plan Required
Fireproofing	+	- (Deck Fireproofing Required)
Foundation	=	No Significant Modification Required
Cost	- Slightly More Expensive Construction	+
Vibration	= Acceptable for Walking Vibrations (0.04g)	= Acceptable for Walking Vibrations (0.041g)

Appendix A: Building Loads

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Building Material Dead Loads:

Typical Floor System

	Unit Weight (psf/in)	Total Weight (psf)
16 Ga. Metal Floor Decking	N/A	3.50
4-1/2" Concrete	12.50	75.00
Finish Material Surcharge	10.00	10.00
		88.50

Roofing System

	Unit Weight (psf/in)	Total Weight (psf)
18 Ga. Roof Decking	N/A	3.00
5/8" Gypsum Board	4.40	2.75
2" Thick Isocyanurate	1.50	3.00
1/2" Gypsum Cover Board	4.40	2.20
0.060 Reinforced FR EPDM	N/A	1.00
		11.95

Wall Systems
(Assume 30% of wall weight from window)

	Unit Weight (psf/in)	Total Weight (psf)
8" CMU Wall	N/A	47.00
4" Brick Veneer	N/A	32.00
Glass and Window Openings	N/A	10.00
		55.60

Miscellaneous Loads

	Unit Weight (psf/in)	Total Weight (psf)
M/E/P Surcharge	N/A	10.00
		10.00

Roof Live Load:

	Design	IBC 2006
Flat roof:	30 psf	20 psf

Floor Live Load:

	Design	IBC 2006
Typical Room/Office:	60 psf	60 psf
Corridors:	100 psf	100 psf
Corridors above first floor:	100 psf	80 psf
Lobbies:	100 psf	100 psf
Stairwells and exit ways:	100 psf	100 psf
Mechanical Penthouse	150 psf	150 psf

Snow Load:

(Values Calculated from ASCE 7-05)

Ground Snow Load, p_g	30	psf	Fig. 7-1
Flat Roof Snow Load, p_f	**23.1**	psf	Eq. 7-1
Minimum p_f per ASCE 7-05	22.0	psf	
Exposure Factor, C_e	1.0		Table 7-2
Thermal Factor, C_t	1.0		Table 7-3
Importance Factor, I	1.1		Table 7-4

Note: Value in bold represents controlling snow load

North-South Wind Forces

Floor	h (ft)	Floor Height	T_{width}	p (psf)	F (k)
2	21.0	21	20.0	21.93	8.25
3	36.3	15.333	20.0	23.75	7.49
4	51.7	15.333	20.0	25.08	7.86
Penthouse	67.0	15.333	20.0	26.15	8.16
Roof	82.3	15.333	20.0	27.06	4.15

East-West Wind Forces

Floor	h (ft)	Floor Height	T_{width}	p (psf)	F (k)
2	21.0	21	23.5	19.84	8.80
3	36.3	15.333	23.5	21.68	8.06
4	51.7	15.333	23.5	23.03	8.49
Penthouse	67.0	15.333	23.5	24.12	8.86
Roof	82.3	15.333	23.5	25.04	4.51

Appendix B: Composite Joist Design

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Rutgers University Law School

Floor System Redesign

Typical Floor Joist Strength Design

Design by: Nathan E. Reynolds

Date: 3/5/08

Joist Geometry:

1)	Depth	26	in
2)	Span	47	ft
3)	Adjacent Member Spacing (left)	5	ft
4)	Adjacent Member Spacing (right)	5	ft

Concrete and Deck:

1)	Type of Floor Deck		
2)	Depth of Floor Deck	1.5	in
3)	Slab Thickness Above Deck	2.5	in
4)	Concrete Unit Weight	145	pcf
5)	Concrete Compressive Strength	4	ksi

Nominal Loads:

1)	Non-Composite Construction Dead Load			
	a)	Concrete	41	psf
	b)	Joist and Bridging (Estimated)	4	psf
	c)	Deck	2	psf
	d)	**Total**	**47**	psf
			233	plf
2)	Construction Live Load			
	a)	During Concrete Placement	40	psf
			200	plf
3)	Composite Dead Load			
	a)	Fixed Partitions	20	psf
	b)	Mechanical	5	psf
	c)	Electrical	2	psf
	d)	Fireproofing	2	psf
	e)	Floor Covering and Ceiling	16	psf
	f)	Miscellaneous Dead Loads	0	psf
	g)	**Total**	**45**	psf
			225	plf

Rutgers University Law School

Floor System Redesign
Typical Floor Joist Strength Design (Con't)

Design by: Nathan E. Reynolds
Date: 3/5/08

4)		Composite Live Load			
	a)	Live Load (Reduced as Applicable)	75	psf	*Calculated as*
	b)	Moveable Partitions	0	psf	*average of actual*
	c)	**Total**	75	psf	*live load applied*
			375	plf	
5)		Total Factored Non-Composite Dead Load, 1.2 x (1d)	56	psf	
			280	plf	
6)		Total Factored Composite Dead Load, 1.2 x (3g)	54	psf	
			270	plf	
7)		Total Factored Composite Design Load, 1.6 x (4c)	120	psf	
			600	plf	
8)		Total Factored Composite Design Load (5) + (6) + (7)	230	psf	
		(Concentrated Dead Load Not Included)	1150	plf	
Additional Concentrated Dead Load, P, at Top Chord			0	kips	
	Distance from Left		0	ft	
Total Factored Composite Dead Load			0	kips	

Camber and Deflection (Unfactored Load):

1)		Loads to Camber For			
	a)	Percent of Non-Composite DL, (1d) x 100%	46.625	psf	
	b)	Percent of Composite DL, (3g) x 50%	22.5	psf	
	c)	Percent of Composite LL, (4c) x 20%	15	psf	
2)		Maximum Allowable Live Load Deflection, Span/360	1.57	in	
3)		Maximum Deflection, Span/240	2.35	in	

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Floor System Redesign
Composite Joist Selection and Deflection

Design by: Nathan E. Reynolds
Date: 3/5/08

Joist Specification: 26CJ 1150(1600)/600(775)/270

Height of Deck Ribs
h_r = 1.5 in

Thickness of Concrete
t_c = 2.5 in

Joist Spacing
J_c = 5 ft

1) Self Weight of Joist
Wt_{joist} = 28

2) Allowable Composite Live Load
w_{360} = 775 plf

3) Number of Shear Studs/Diameter
N-ds = 46-3/4

4) Composite Moment of Inertia
I_{eff} = 2260 in^4

5) Type of Bridging Required
(3) L1.25x0.109H

6) Non-Composite Moment of Inertia
$I_{n\text{-}c,\ eff}$ = 855 in^4

Deflection and Camber:

1) Deflection Prior to Composite Action

Δ = 1.003 in or L / 562

A) Design Length 46.67 ft
B) E_s (psi) 2.9E+07 psi

2) Deflection Due to Composite Dead Load

Δ = 0.366 in or L / 1540

4) Deflection Due to Live Load

Δ = 0.611 in or L / 924

5) Total Deflection

Δ = 1.98 in or L / 285

6) Camber

Joist Camber = 1.31 in

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Floor System Redesign
Design Guide 11 Vibration Analysis

Design by: Nathan E. Reynolds
Date: 3/5/08

Joist Properties

1)	Designation	1150(1600)/600(775)	
2)	Span	47	ft
3)	Depth	26	in
4)	Self Weight	28	plf
5)	Load Capacity	775	plf

Determine Joist Moment of Inertia, I_j

1) Effective Moment of Inertia

I_{eff} = 2260 in^4

Determine Deflection of the Joist

1) Uniformly Distributed Load on Joist

w = 411 plf

2) Deflection due to Uniform Load

Δ_j = 0.69 in

Determine the Effective Joist Panel Weight

1)	Effective Depth of Slab				
	d_e	=	3.25	in	
2)	Joist Spacing				
	J_s	=	5	ft	
3)	Stiffness of the Joist				
	D_j	=	452.00		
4)	Stiffness of the Slab				
	D_s	=	69.13		
5)	Modulus of Elasticity of the Concrete				
	E_c	=	3605	ksi	
6)	Dynamic Modular Ratio				
	n	=	6.0		
7)	Width of Effective Panel				
	C_j	=	2.0		
	B_j	=	58.8	ft	
	B_j	=	40.0	ft	Controls
8)	Effective Panel Weight				
	W_j	=	154583	lbs	

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Floor System Redesign

Design Guide 11 Vibration Analysis (Con't)

Design by: Nathan E. Reynolds

Date: 3/5/08

Determine Girder Properties

1)	Girder Specification		W24x55	
2)	Girder Span		20	ft
3)	Self Weight		55	plf
4)	Girder Depth		24	in
5)	Effective Width		8	ft
	A)	b =	47	ft
	B)	b =	8	ft Controls
6)	Concrete Area			
	A_c	=	52.4	in^2
7)	Steel Properties			
	A_s	=	16.2	in^2
	I_{xx}	=	1350	in^4
8)	Composite Neutral Axis			
	y	=	5.68	in
9)	Composite Moment of Inertia			
	I_{comp}	=	4898	in^4
10)	Girder Moment of Inertia			
	I_g	=	2237	in^4

Determine Deflection of Girder

1)	Uniformly Distributed Load on Girder			
	w	=	1987	plf
2)	Deflection due to Uniform Load			
	Δ_g	=	0.11	in

Determine the Effective Girder Panel Weight

1)	Stiffness of Girder			
	D_g	=	47.59	
2)	Width of Effective Panel			
	C_g	=	1.6	
	B_g	=	31.3	ft
3)	Effective Panel Weight			
	W_g	=	52994	lb

Determine the Effective Panel Weight

W	=	140561	lb

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Floor System Redesign
Design Guide 11 Vibration Analysis (Con't)

Design by: Nathan E. Reynolds
Date: 3/5/08

Determine the Natural Frequency

f_n	=	**3.96**	Hz

Evaluate Vibration Criterion

1)	Constant Force			
	P_o	=	65	lb
2)	Modal Damping Ratio			
	β	=	0.03	
3)	Acceleration Limit			
	a_o/g	=	0.005	g
4)	Estimated Peak Acceleration			
	a_p/g	=	**0.004**	g

Appendix C: Lateral System Design

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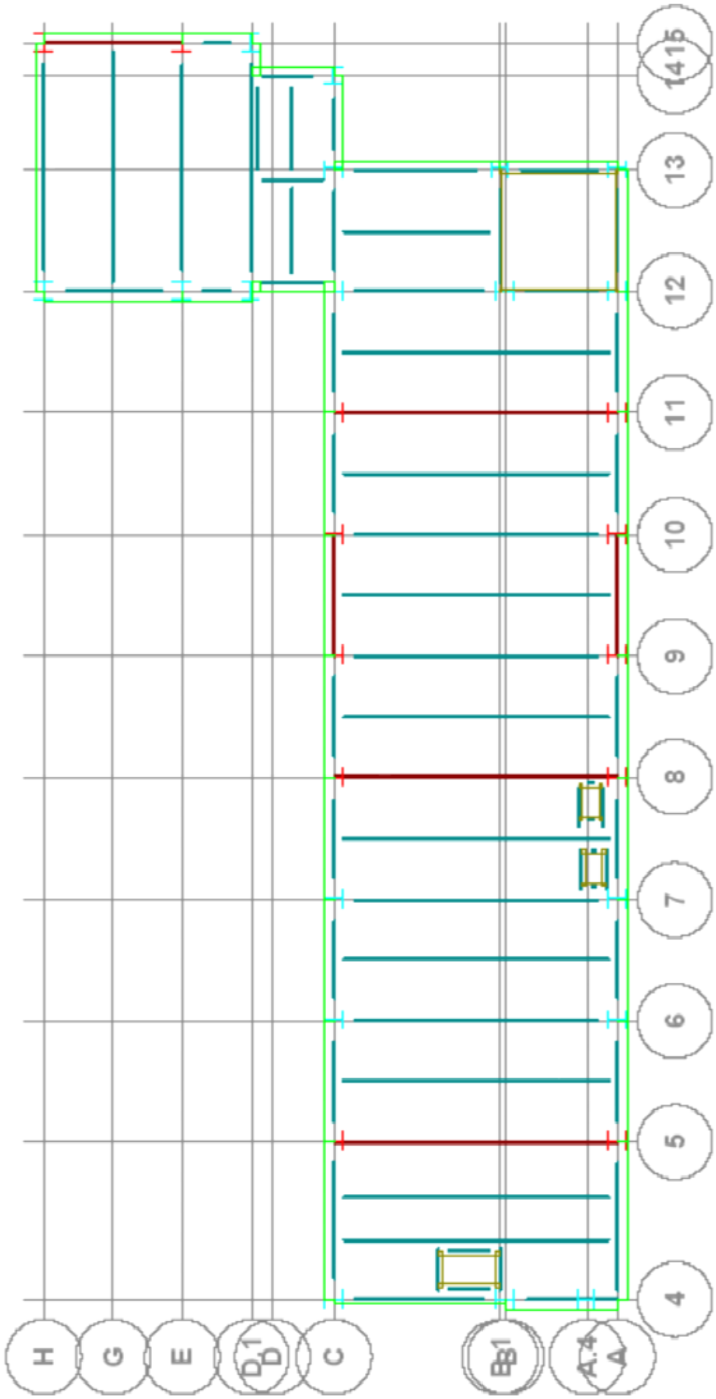
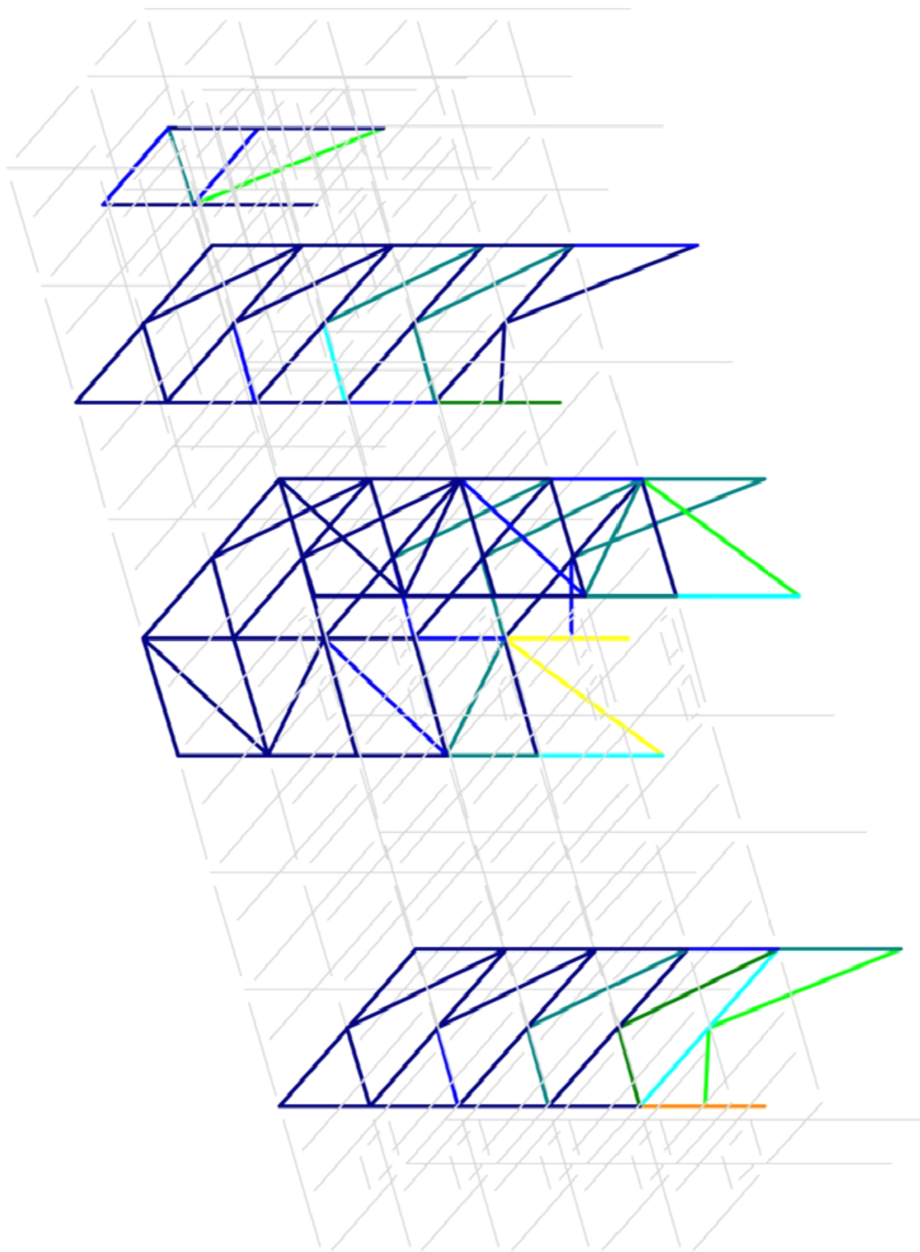
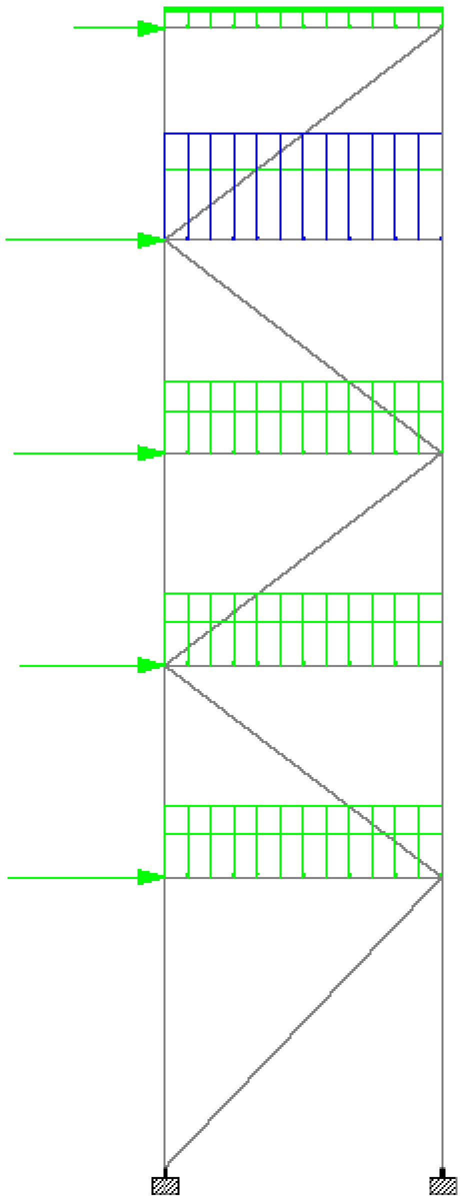
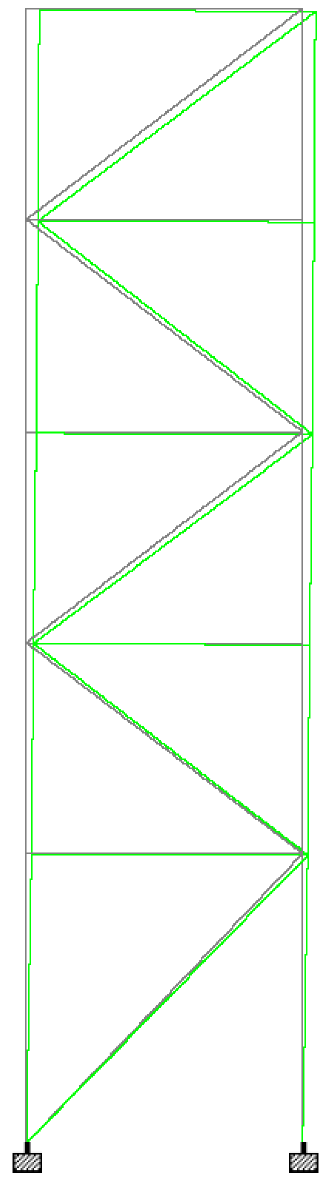
RAM Structural System Analysis





East-West Lateral System





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Lateral System Redesign
Virtual Work Analysis for Preliminary Member Sizing

Frame Direction: East-West
Frame Designation: Diagonal Bracing

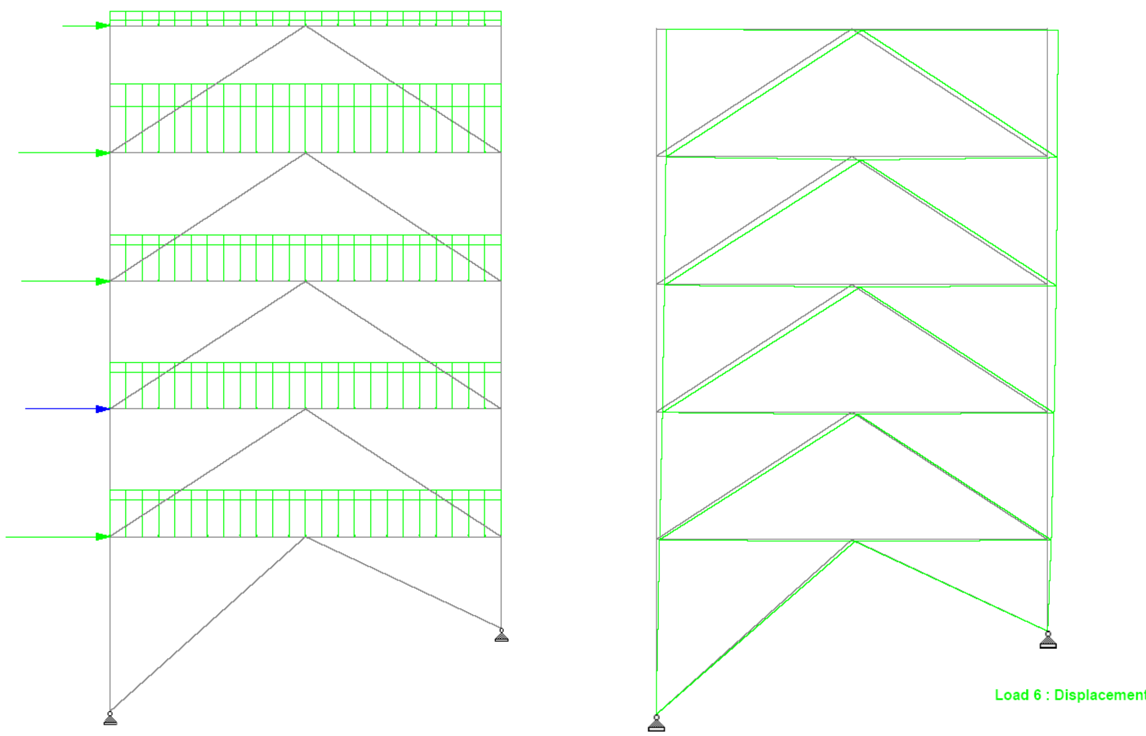
Design by: Nathan E. Reynolds
Date: 2/25/08

Member	F (k)	f (k)	ℓ (in)	A (in^2)	E (ksi)	Ffℓ/AE (in)
1	134.00	-3.070	252	26.5	29000	-0.13490
2	286.00	4.120	252	26.5	29000	0.38638
3	96.90	-3.070	184	26.5	29000	-0.07123
4	184.00	2.300	184	26.5	29000	0.10133
5	99.90	-1.540	184	24	29000	-0.04067
6	146.00	2.300	184	24	29000	0.08877
7	62.30	-1.540	184	24	29000	-0.02536
8	80.90	0.765	184	24	29000	0.01636
9	18.50	0.000	184	24	29000	0.00000
10	22.40	0.765	184	24	29000	0.00453
11	8.80	0.000	282	20	29000	0.00000
12	0.00	0.000	282	20	29000	0.00000
13	8.50	0.000	282	20	29000	0.00000
14	0.00	0.000	282	20	29000	0.00000
15	5.10	1.000	282	20	29000	0.00248
16	-57.10	-1.450	348	11.6	29000	0.08565
17	38.50	1.260	302	11.6	29000	0.04355
18	-28.30	-1.260	302	11.6	29000	0.03201
19	17.70	1.260	302	11.6	29000	0.02002
20	-6.42	-1.260	302	11.6	29000	0.00726
						0.51619

Percent of Total Drift		
Columns	=	63.0%
Beams	=	0.5%
Bracing	=	36.5%

Members controlled by strength requirements rather than drift requirements

North-South Lateral System



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Lateral System Redesign
Virtual Work Analysis for Preliminary Member Sizing

Frame Direction: North-South
Frame Description: Eccentric Chevron Bracing (3 Frames)

Design by: Nathan E. Reynolds
Date: 2/19/08

Member	F (k)	f (k)	ℓ(in)	A (in^2)	E (ksi)	Ffℓ/AE (in)
1	80.00	-1.300	252	46.7	29000	-0.01935
2	0.00	1.300	120	46.7	29000	0.00000
3	269.00	1.300	132	46.7	29000	0.03408
4	78.20	-0.979	184	46.7	29000	-0.01040
5	186.00	0.979	184	46.7	29000	0.02474
6	65.50	-0.654	184	46.7	29000	-0.00582
7	114.00	0.654	184	46.7	29000	0.01013
8	33.10	-0.326	184	46.7	29000	-0.00147
9	45.30	0.326	184	46.7	29000	0.00201
10	4.93	0.000	184	46.7	29000	0.00000
11	4.93	0.000	184	46.7	29000	0.00000
12	71.50	0.500	282	20	29000	0.01738
13	-94.70	-0.500	282	20	29000	0.02302
14	46.60	0.500	282	20	29000	0.01133
15	-77.90	-0.500	282	20	29000	0.01894
16	18.30	0.500	282	20	29000	0.00445
17	-72.60	-0.500	282	20	29000	0.01765
18	38.50	0.500	282	24.8	29000	0.00755
19	-17.00	-0.500	282	24.8	29000	0.00333
20	18.80	0.000	282	20	29000	0.00000
21	0.00	-1.000	282	20	29000	0.00000
22	-35.00	-0.461	378	7.84	29000	0.06168
23	155.00	0.725	312	7.84	29000	0.22546
24	-35.50	-0.597	337	7.84	29000	0.04441
25	113.00	0.597	337	7.84	29000	0.14136
26	-15.40	-0.597	337	7.84	29000	0.01171
27	92.90	0.597	337	7.84	29000	0.07064
28	20.40	-0.598	337	7.84	29000	-0.01808
29	86.70	0.598	337	7.84	29000	0.07685
30	-2.14	-0.597	337	7.84	29000	0.00189
31	20.20	0.597	337	7.84	29000	0.01787
						0.77137

Appendix D: Connection Design

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Rutgers University Law School

Floor System Redesign
Braced Frame Connections

Design by: Nathan E. Reynolds
Date: 3/4/08

Connection Requirements:

1)	Plate Thickness	0.5	in	
2)	Required Force	80	k	
3)	Yield Strength	36	ksi	
4)	Rupture Strength	58	ksi	

Check Weld Rupture

1)	Plate to HSS Weld Connection				
	A)	Size of Weld	0.25	in	
	B)	Number of Welds	4		
	C)	Minimum Weld Length	8	in	Controls
	D)	Required Weld Length	4.79	in	
2)	Plate to Girder Connection				
	A)	Vertical Component of Connection	60	k	
	B)	Size of Weld	0.25	in	
	C)	Number of Welds	2		
	D)	Minimum Weld Length	8	in	Controls
	E)	Required Weld Length	7.18	in	
3)	Plate to Girder Connection				
	A)	Horizontal Component of Connection	60	k	
	B)	Size of Weld	0.25	in	
	C)	Number of Welds	2		
	D)	Minimum Weld Length	8	in	Controls
	E)	Required Weld Length	7.18	in	

Failure Modes

1)	Tension Yielding				
	A)	Effective Length of Connection	10	in	
	B)	Allowable Force	162	k	OK
2)	Tension Rupture				
	A)	Effective Length of Connection	10	in	
	B)	Allowable Force	218	k	OK
3)	Block Shear				
	A)	Gross Shear Area	8	in^2	
	B)	Net Tension Area	4	in^2	
	C)	Uniform Tension Stress Distribution	0.75		
	D)	Allowable Force	339.3	k	OK

Rutgers University Law School

Floor System Redesign
Braced Frame Connections

Design by: Nathan E. Reynolds
Date: 3/4/08

Connection Requirements:

1)	Plate Thickness	0.5	in	
2)	Required Force	120	k	
3)	Yield Strength	36	ksi	
4)	Rupture Strength	58	ksi	

Check Weld Rupture

1)	Plate to HSS Weld Connection				
	A)	Size of Weld	0.25	in	
	B)	Number of Welds	2		
	C)	Minimum Weld Length	8	in	
	D)	Required Weld Length	**14.37**	in	Controls
	E)	Maximum Weld Length	**17.50**	in	OK

Failure Modes

1)	Tension Yielding				
	A)	Effective Length of Connection	10	in	
	B)	Allowable Force	**162**	k	OK
2)	Tension Rupture				
	A)	Effective Length of Connection	10	in	
	B)	Allowable Force	**218**	k	OK
3)	Block Shear				
	A)	Gross Shear Area	8	in^2	
	B)	Net Tension Area	4	in^2	
	C)	Uniform Tension Stress Distribution	0.75		
	D)	Allowable Force	**339.3**	k	OK

Appendix E: Revised Architectural Plans

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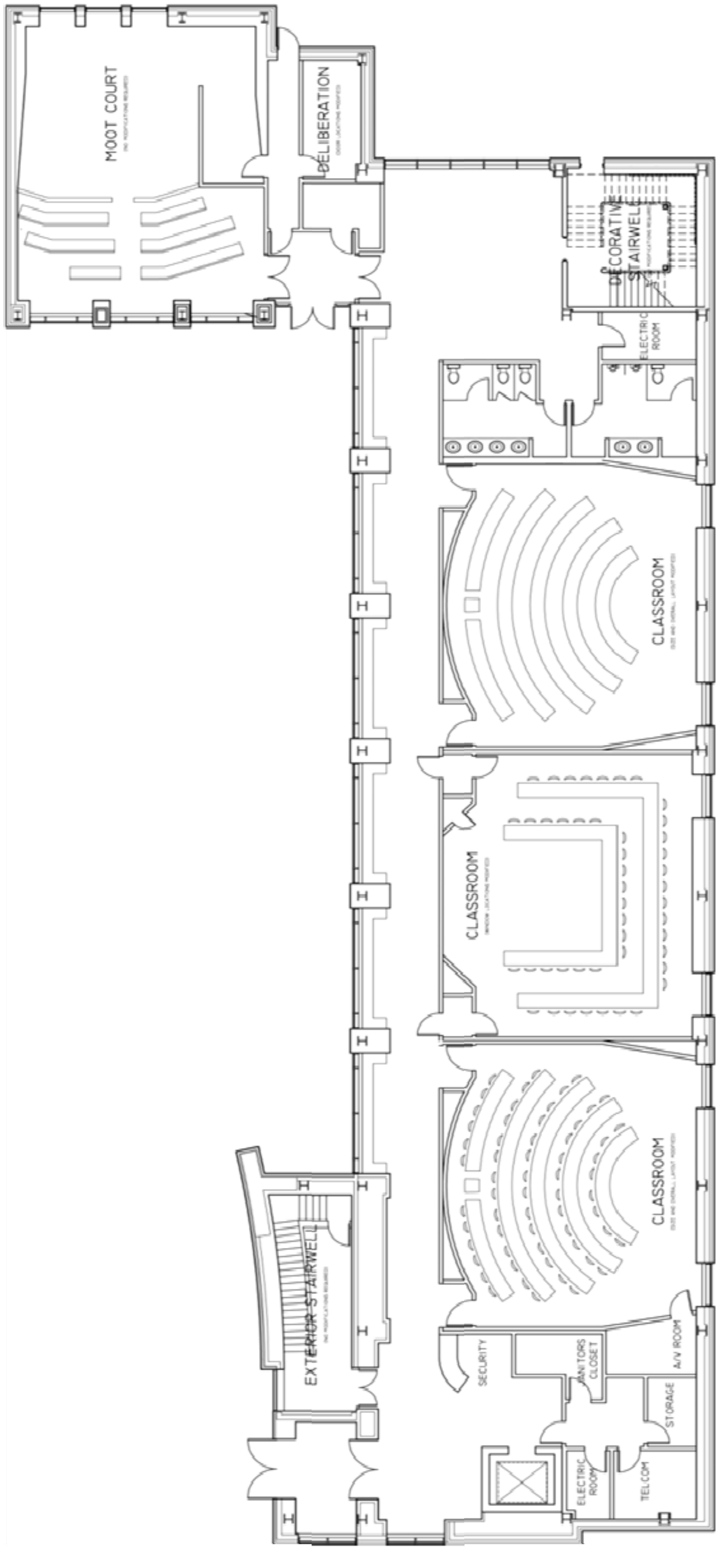
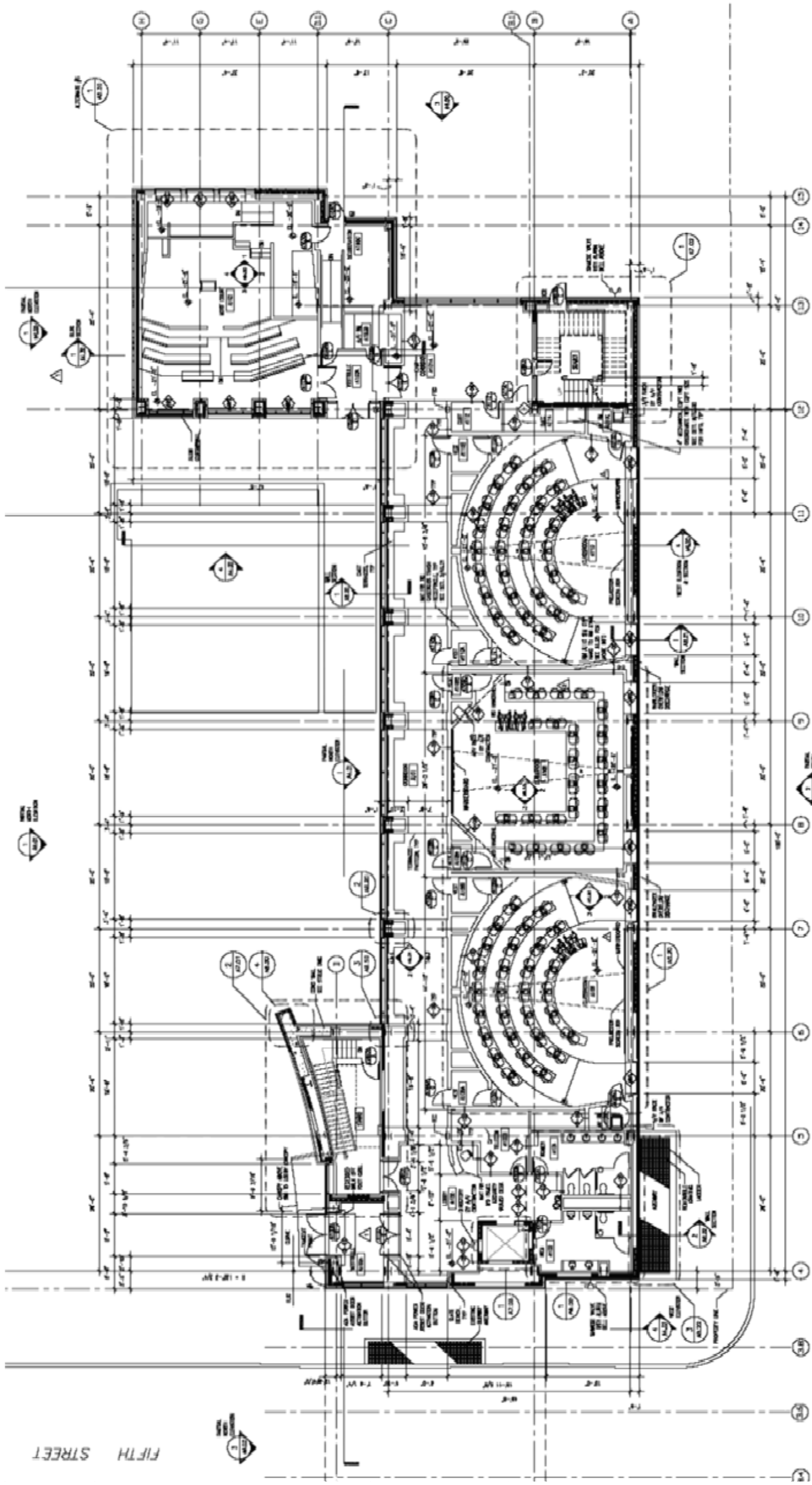
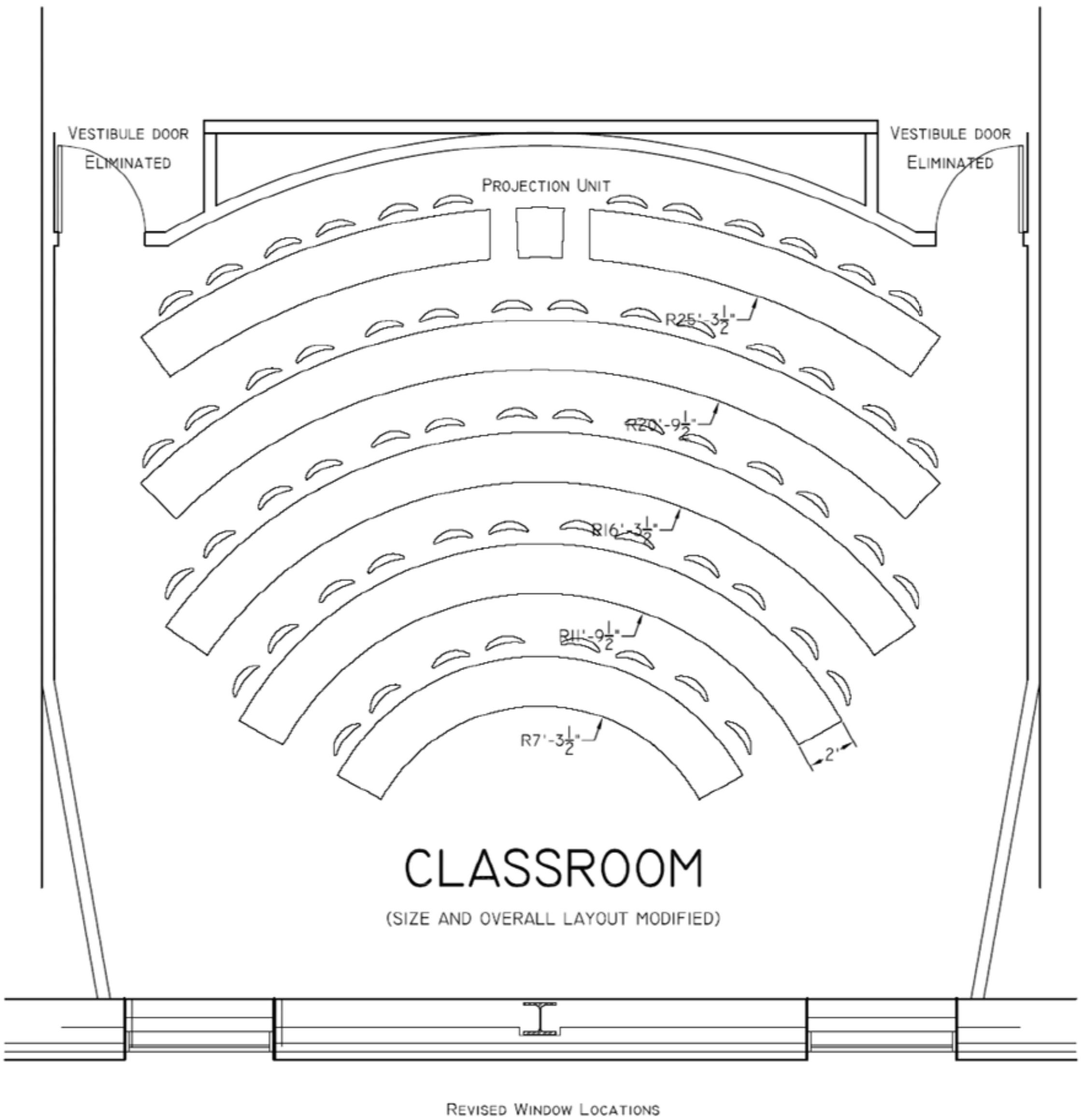


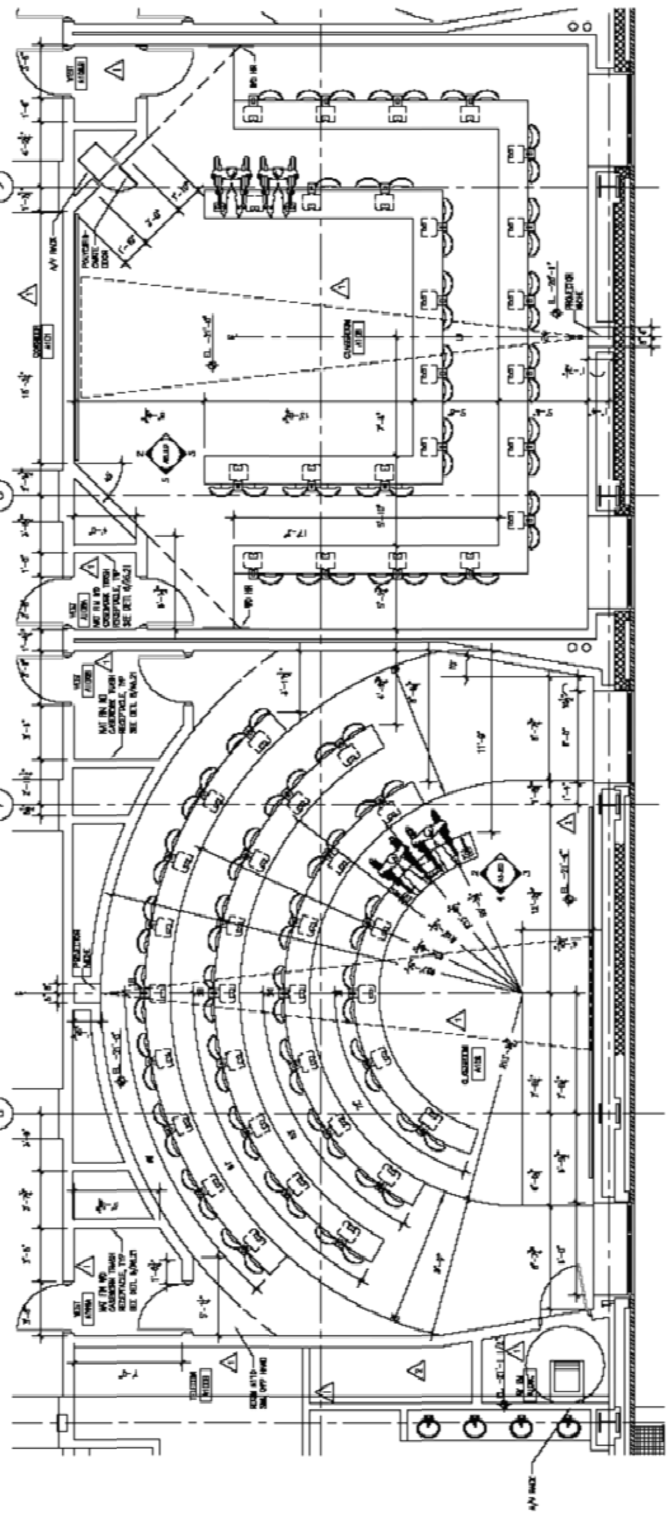
Proposed First Floor Plan



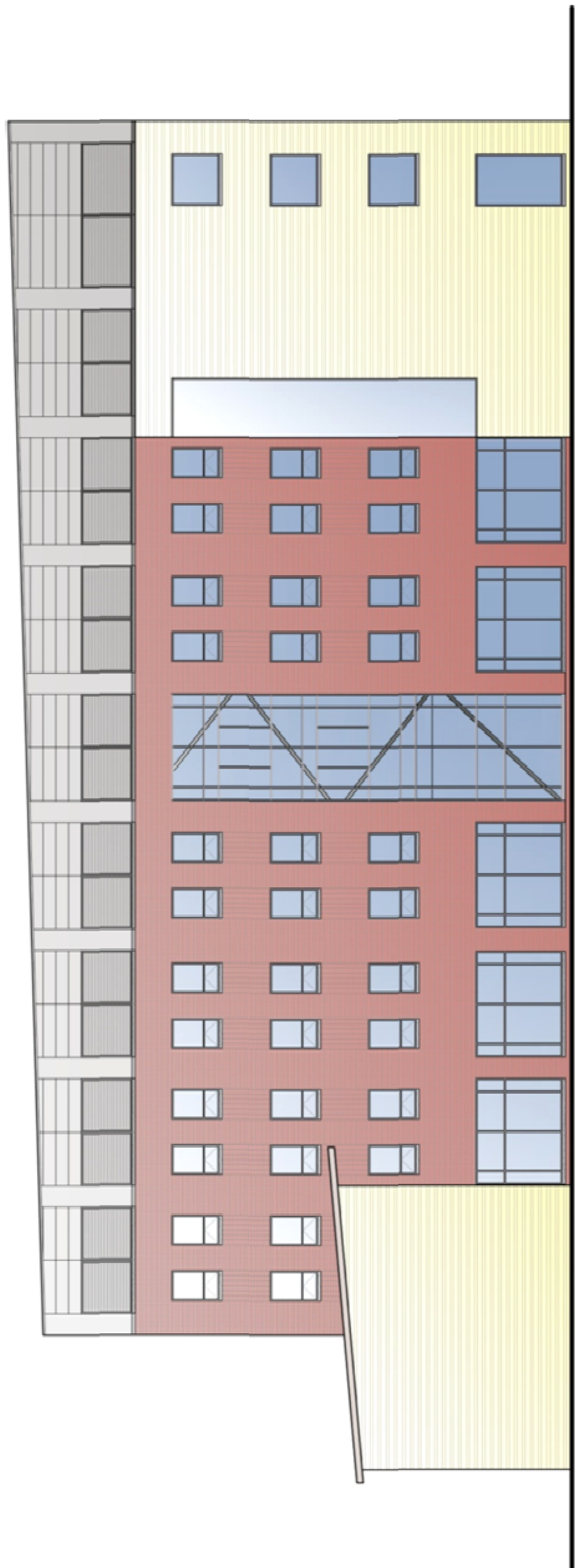
Existing First Floor Plan



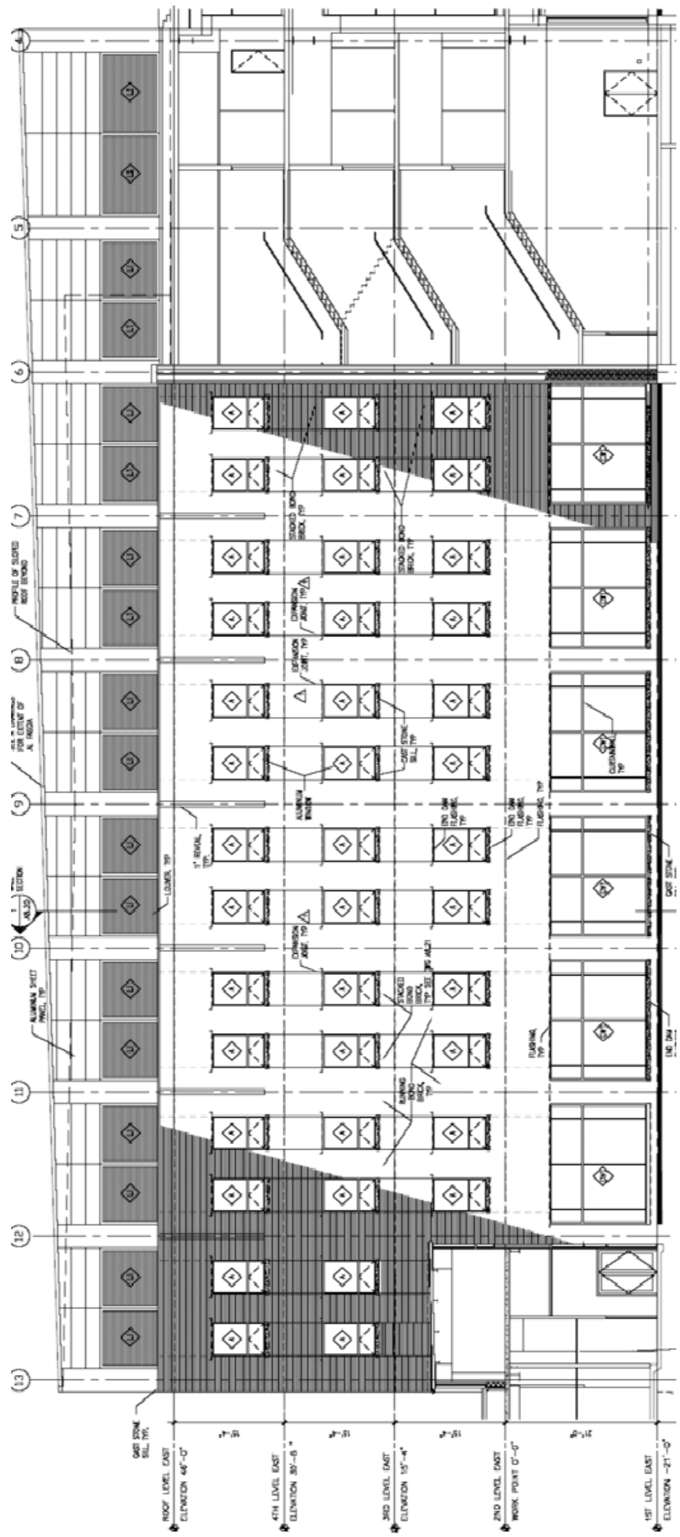
Proposed Classroom Design



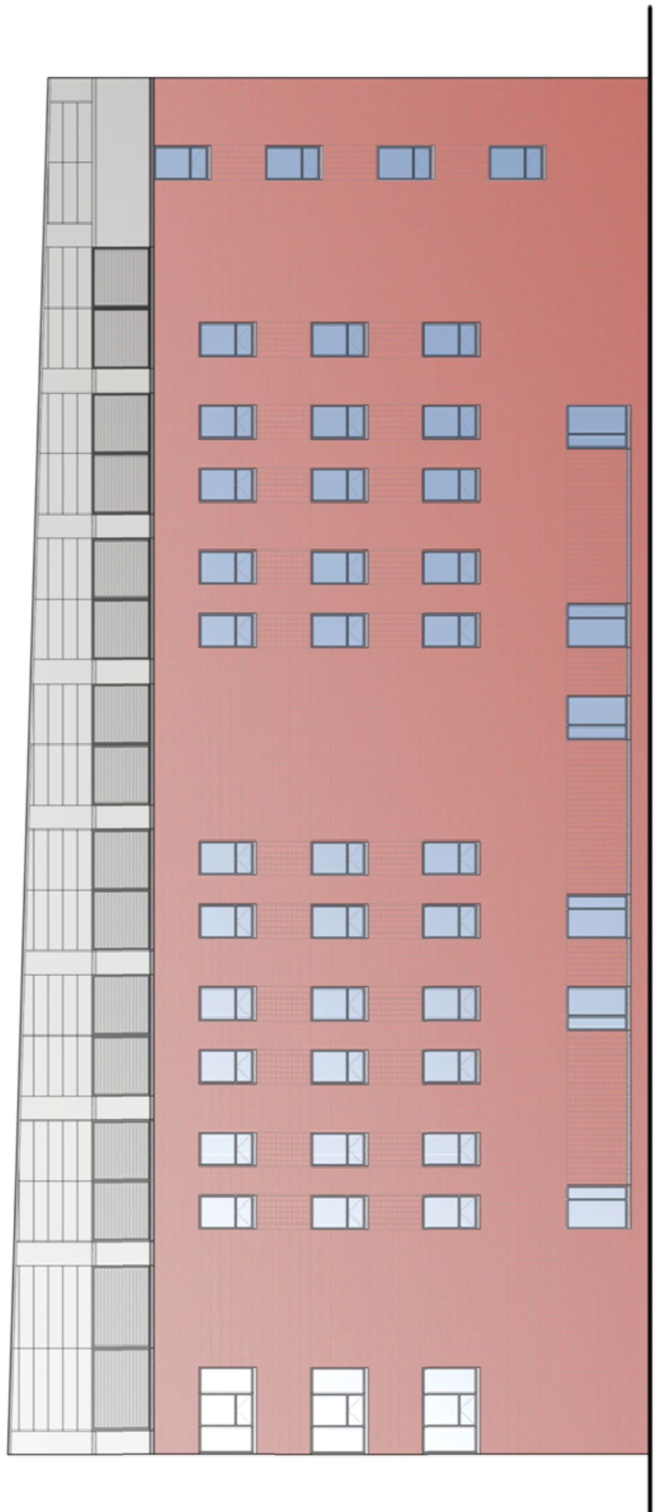
Existing Classroom Details



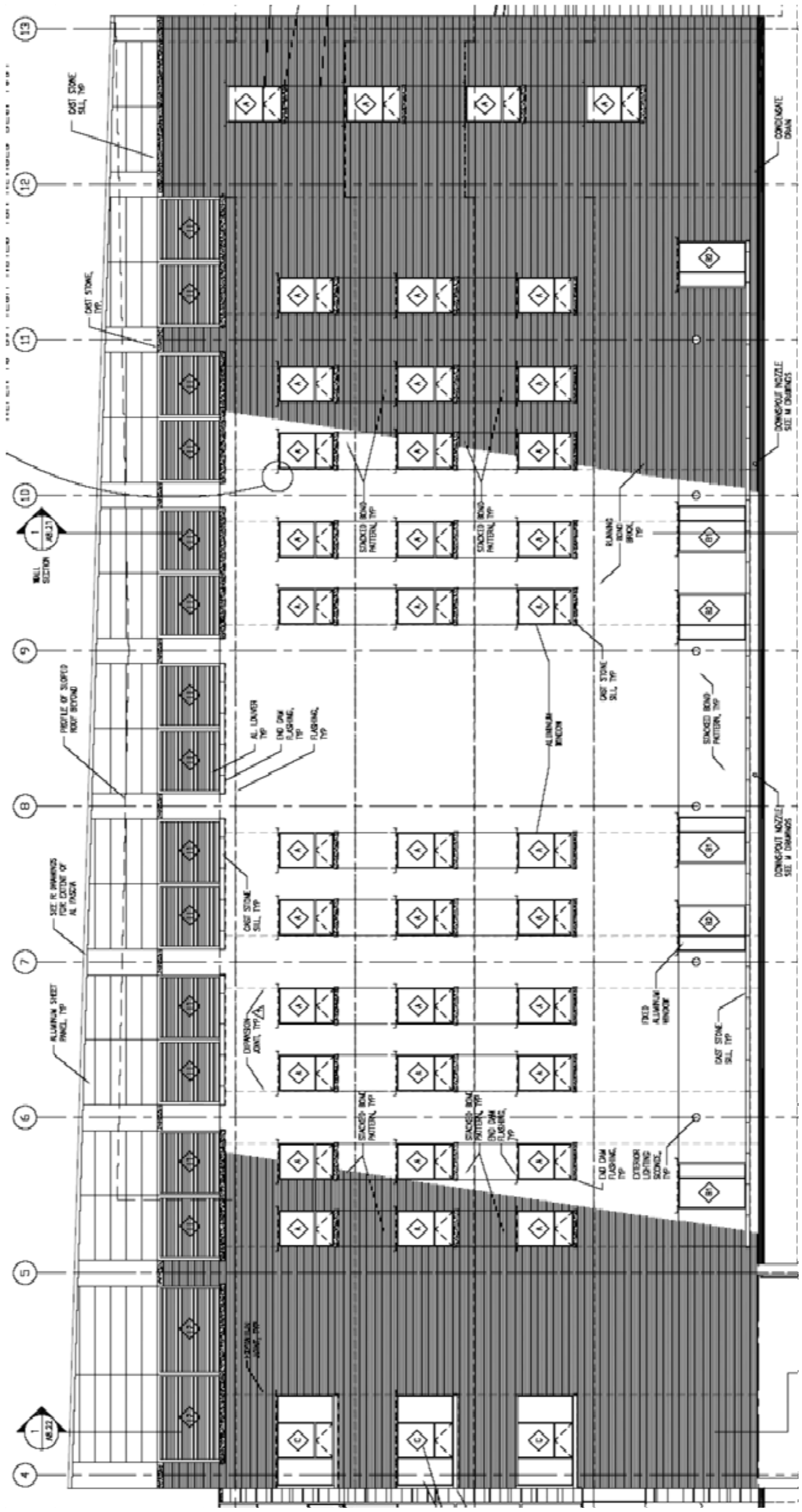
Proposed South Elevation



Existing North Elevation



Proposed South Elevation



Existing South Elevation

Appendix F: Construction Schedule Modifications

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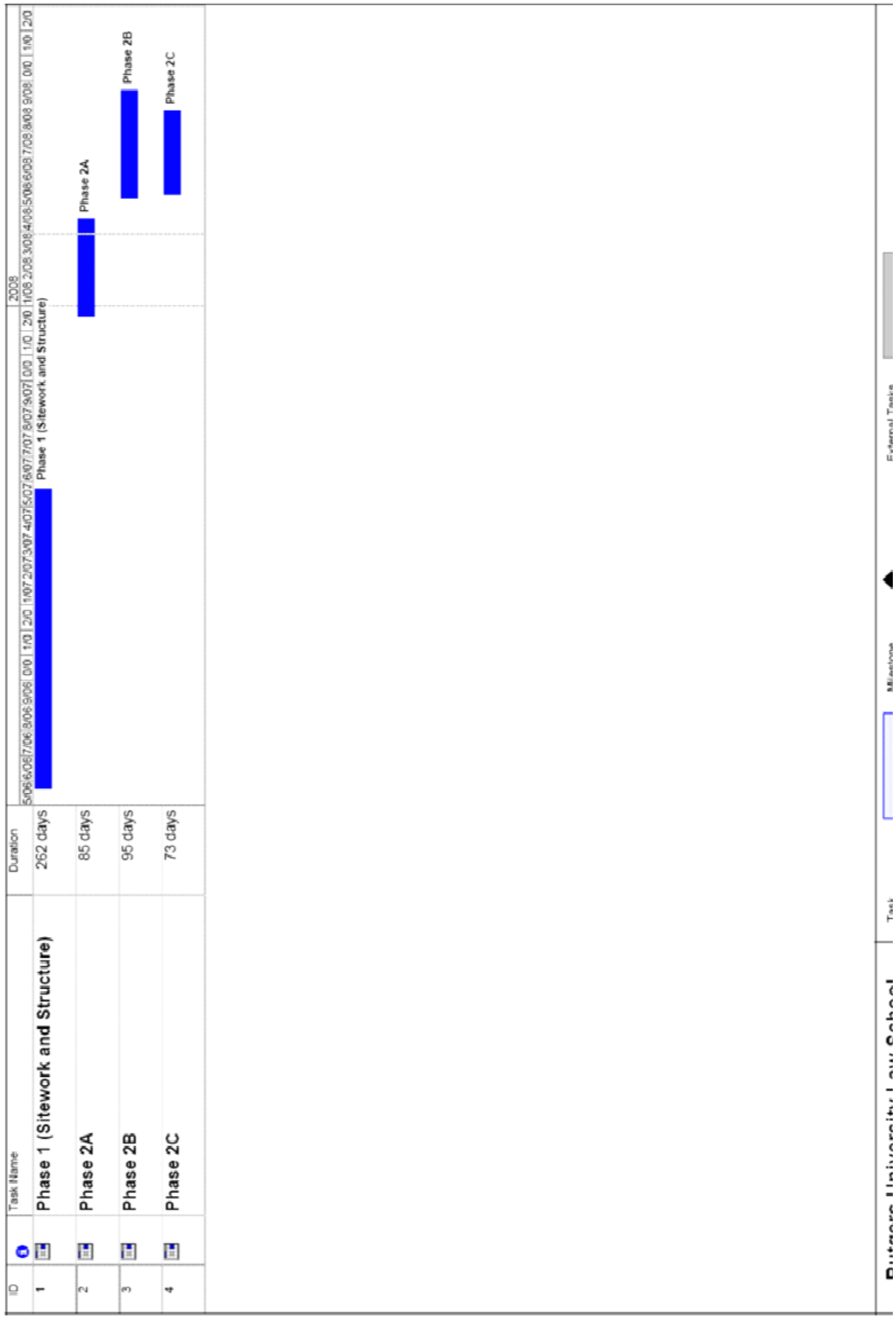
Description	Crew	Daily Output	Units	Material	Labor	Equipment	Total	Total O&P	Required Output	Total Cost
Steel Shapes										
W8x18	**E-2**	**600**	**L.F.**	**$25.50**	**$3.91**	**$2.61**	**$32.02**	**$37.50**	**1000**	**$37,500.00**
W14x159	E-2	720	L.F.	$145.00	$3.26	$2.18	$150.44	$173.01	1870	$323,521.22
W14x90	**E-2**	**740**	**L.F.**	**$109.00**	**$3.17**	**$2.12**	**$114.29**	**$131.43**	**245**	**$32,201.21**
W16x26	E-2	1000	L.F.	$31.50	$2.34	$1.57	$35.41	$40.72	105	$4,275.76
W24x55	**E-2**	**1110**	**L.F.**	**$66.50**	**$3.06**	**$1.53**	**$71.09**	**$81.75**	**1256**	**$102,682.40**
W24x62	E-2	1110	L.F.	$75.00	$3.06	$1.53	$79.59	$91.53	140	$12,813.99
W24x68	**E-2**	**1110**	**L.F.**	**$82.50**	**$3.06**	**$1.53**	**$87.09**	**$100.15**	**1974**	**$197,703.01**
W24x76	E-2	1110	L.F.	$92.00	$3.06	$1.53	$96.59	$111.08	282	$31,324.14
W27x84	**E-2**	**1190**	**L.F.**	**$102.00**	**$2.85**	**$1.43**	**$106.28**	**$122.22**	**1159**	**$141,655.30**
										$883,677.02
Misc. Steel										
3"-16 ga. Metal Decking	E-4	3400	S.F.	$3.16	$0.41	$0.04	$3.61	$4.15	59620	$247,512.43
3/4" x 5" Shear Studs		**975**	**Ea**	**$0.84**	**$0.72**	**$0.37**	**$1.93**	**$2.62**	**4890**	**$12,811.80**
L7x4x7/8 Connection Material		440	Lb	$0.64	$2.38	$0.30	$3.32	$3.82	7074	$27,008.53
7/8" Connection Bolts		**110**	**Ea**	**$1.52**	**$3.13**		**$4.65**	**$7.30**	**1620**	**$11,826.00**
3/4" Shear Connection Bolts		115		$1.04	$2.99		$4.03	$6.55	2128	$13,938.40
										$313,097.16
Concrete										
6x6 W2.9xW2.9 WWF		**29**	**C.S.F.**	**$20.00**	**$23.50**	**$0.00**	**$43.50**	**$61.50**	**596**	**$36,654.00**
4.5" Concrete		2585	S.F.	$2.02	$0.73	$0.28	$3.03	$3.48	59620	$207,745.89
										$244,399.89
Total Cost		$1,441,174.07								

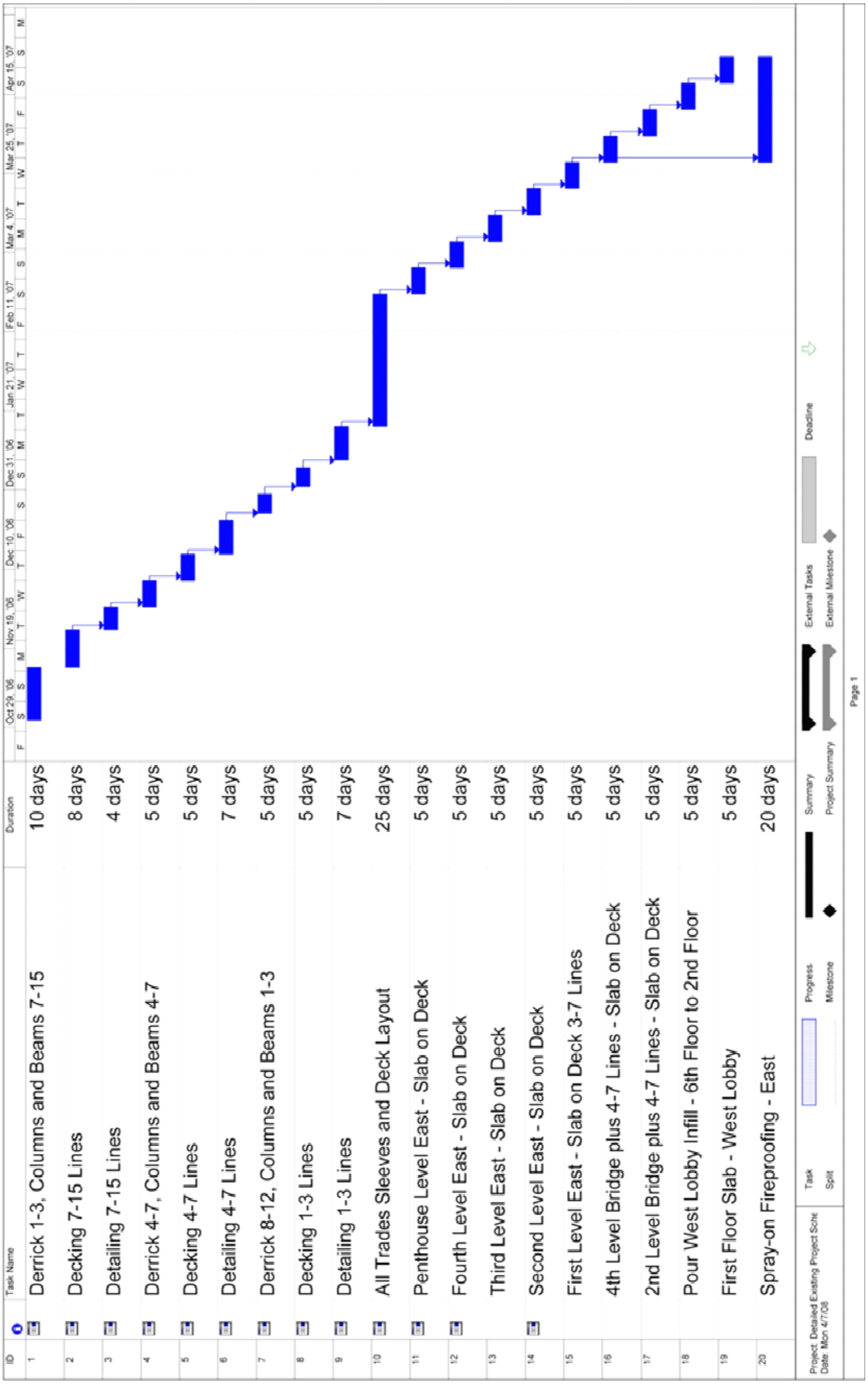
Existing Structural System Cost Estimate

Description	Crew	Daily Output	Units	Material	Labor	Equipment	Total	Total O&P	Required Output	Total Cost
Steel Shapes										
W14x82	**E-2**	**600**	**L.F.**	**$25.50**	**$3.91**	**$2.61**	**$32.02**	**$37.50**	**1945**	**$72,937.50**
W14x90	E-2	740	L.F.	$109.00	$3.17	$2.12	$114.29	$131.43	255	$33,515.54
W24x55	**E-2**	**1110**	**L.F.**	**$66.50**	**$3.06**	**$1.53**	**$71.09**	**$81.75**	**1256**	**$102,682.40**
W27x84	E-2	1190	L.F.	$102.00	$2.85	$1.43	$106.28	$122.22	1159	$141,655.30
										$350,790.74
Composite Joist System										
CJ Series System		**15**	**Tons**	**1400**	**226**	**122**	**1748**	**2050**	**142.7**	**$292,625.20**
3/4" x 5" Shear Studs		975	Ea	$0.84	$0.72	$0.37	$1.93	$2.62	7200	$18,864.00
Bracing (Including connections)			**Ton**	**$980.00**				**$3,630**	**22.00**	**$79,861.83**
Spray Applied Fire Proofing								$2.00	59620	$119,240.00
										$510,591.03
Misc. Steel										
3"-16 ga. Metal Decking	**E-4**	**3400**	**S.F.**	**$3.16**	**$0.41**	**$0.04**	**$3.61**	**$4.15**	**59620**	**$247,512.43**
										$247,512.43
Concrete										
6x6 W2.9xW2.9 WWF		29	C.S.F.	$20.00	$23.50	$0.00	$43.50	$61.50	596	$36,654.00
4.5" Concrete		**2585**	**S.F.**	**$1.36**	**$0.73**	**$0.28**	**$2.37**	**$2.73**	**59620**	**$162,494.31**
										$199,148.31
Total Cost	**$1,308,042.51**									

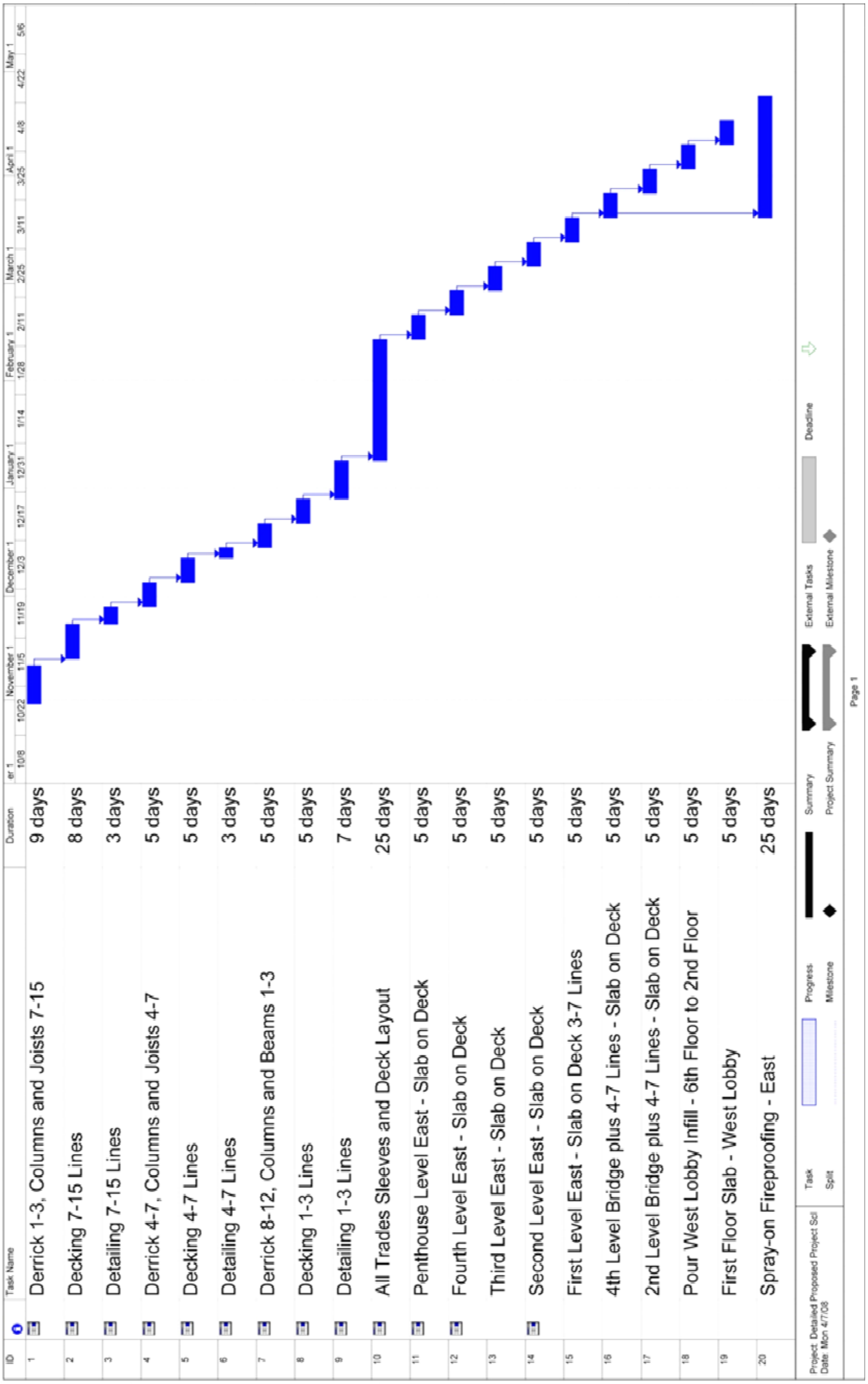
Proposed Structural System Cost Estimate



Existing Project Phase Schedule



Detailed Existing Project Schedule



Detailed Proposed Project Schedule