The Pennsylvania State University
Health and Human Development Building

Christopher Graziani

Construction

Final Report

April 9, 2014

Advisor: Craig Dubler

Health and Human Development Building

The Pennsylvania State University - State College, Pennsylvania

Rendering courtesy of BCJ

Bohlin Cywinski Jackson
Architecture Planning Interior Design

Massaro
CM SERVICES, LLC

Project Team

Owner : The Pennsylvania State University
Construction Manager: Massaro CMS
Architect: Bohlin Cywinski Jackson
General Contractor : Leonard S. Fiore
Landscape Architect: Michael Vergason Landscape Architects
Civil Engineer: Gannett Fleming, Inc.
Structural Engineer: Robert Silman Associates
MEP/FP Engineer: Bruce E. Brooks

Building Statistics

Size : 150,000 GSF
Number of Stories: 4 + Mech. Penthouse
Dates of Construction: February 2013 to June 2015
Cost: Building Cost = $45 Million
Delivery Method: Design – Bid – Build

Structure

- Steel frame with shear wall bracing
- Spread footings
- Slab on composite metal deck

Mechanical

- Steam and chilled water loops run through campus
- Air is cooled and heated using VAV boxes

Lighting and Electrical

- Distribution Switchgear -1600 A, 480/277V, 3 Phase Power

Architecture

- Façade designed to match the Georgian style architecture of the surrounding buildings (hand-placed brick and limestone).
- Large atrium facing College Avenue with elaborate stair design.
- Architectural screen wall runs the entire height of the building in the atrium.

Christopher Graziani
Construction Management Option
http://www.engr.psu.edu/ae/thesis/portfolios/2014/cmg5359/index.html

Executive Summary

The following thesis report analyzes four different topics that were seen as problematic areas in the Penn State Health and Human Development Building. Each analysis studies how the project could be impacted from the standpoints of cost, schedule, and quality. This thesis report will focus on the construction of the concrete stair tower, re-sequencing of the atrium system, a return air plenum, and alternative excavation options. Analyses of mechanical and structural breadths will offer support to finalize results and conclusions.

Analysis 1: Stair Tower Redesign

The current design of the structure is a steel braced frame with concrete shear walls in the stair towers and elevator shaft. This design caused many issues on this project as it took 1 week per level to construct and resulted in a very low quality product. The delay to the project schedule was increased as the concrete couldn't be poured during the winter months of the project. This analysis will look at changing this concrete structure into a steel braced frame in order to accelerate the schedule and improve quality. A structural breadth will be utilized in order to size the steel members. The cost and schedule implications associated with this change will be analyzed to determine which system would provide the best product for the project.

Analysis 2: Re-Sequencing of Atrium Systems

The project will contain a large atrium space which will include an elaborate stair system, an architectural screen wall, and a scaffolding system to install this work. The coordination of these trades is a major challenge for the project team. This analysis will study different options for sequencing this work and the speed, safety, and coordination implications associated with each. The goal of the analysis is to select the best option for the project sequencing plan.

Analysis 3: Return Air Plenum

The complexity of the ceiling spaces in the building bring forth an issue of schedule and coordination concern. In order to address this concern, the implementation of a return air plenum will be explored. This analysis will study the logistics of how the system works as well as the cost and schedule implications associated with the installation.

Analysis 4: Alternative Excavation Methods

The final analysis will examine alternative means of excavation. The project utilized rock excavation blasting as opposed to the traditional rock excavation method. This analysis will study the similarities and differences of the two methods as well as research alternative methods to perform rock excavation blasting.

Academic Acknowledgements

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Dr. Craig Dubler (Advisor)

PENNSTATE
Department of
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Massaro
CM SERVICES, LLC

Bohlin Cywinski Jackson
Architecture Planning Interior Design

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Tim Jones, Kevin Nestor, Keith Smith, and Massaro's Project Team

Geoff Measel of G.E.M. Construction

David Walenga of Ruby + Associates

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Project Introduction

The Pennsylvania State University has hired Massaro Construction Management Services to act as the construction manager for The Health and Human Development Building as phase 2 of the Henderson South Project. This includes the demolition and renovation of existing buildings that make up the Health and Human Development College, as well as constructing new buildings. This project is a direct result of the university's push to improve the image of the campus from College Avenue. The Health and Human Development Building will be composed of the demolition of a section of the existing building, renovation of that building, and the construction of a new building. The 150,000 GSF building will reach a height of 5 stories and will include lab spaces, classrooms, and office spaces to allow students and faculty to utilize the space for learning and research opportunities.

The goal of the project is to improve the image of the campus from College Avenue and to provide the necessary amenities for the students and faculty of the Health and Human Development College. Building costs for the project are estimated to be $45 Million. The project began in February of 2013 and is to be completed for occupant move-in during the month of June in 2015. The project finish time is very important as it must give enough time for the building occupants to move in before the school semester begins.

This project is very unique in that it includes demolition, renovation of existing structures, and new construction. The building that stood before was first built in the 1950s and renovated multiple times on top of that structure. The university decided to keep part of the existing building because it contained a large amount of lab space and a large lecture hall, as well as the fact that it was in good shape. As was seen during the construction process, anytime you deal with a building as old as this one, problems will occur and adjustments will need to be made. The façade of the existing structure will be removed and replaced in order to match the façade of the surrounding buildings. The structural steel frame will be braced through concrete shear walls in the stair towers and elevator shaft walls. Many unique features are seen on this project including a curtain wall and an architectural screen wall in the large atrium space. As with all Penn State projects, this project is aiming to achieve a minimum of LEED certified.

Figure 1 Health and Human Development Building Rendering Image courtesy of Bohlin Cywinski Jackson

Existing Conditions

The Health and Human Development Building is located on the campus of The Pennsylvania State University in State College, Pennsylvania. The entrance to the site is off of one of the busiest streets in the State College area. College Avenue is a one-way street that is the main form of pedestrian and automobile traffic for the Penn State campus. The site is located between two heavily traveled areas on the Penn State campus: Old Main lawn and the HUB lawn. The figures below show the location of the site in relation to the campus.

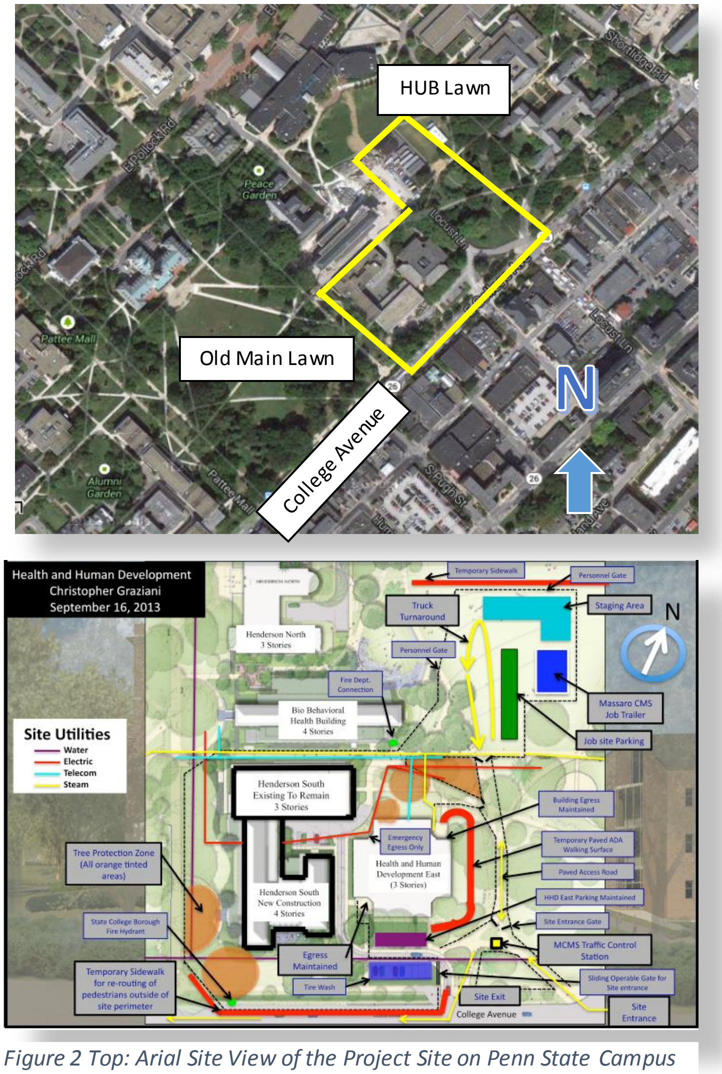


Figure 2 Top: Arial Site View of the Project Site on Penn State Campus Bottom: Site Logistics Plan

Project Delivery System

The Penn State Health and Human Development Building utilizes a multiple prime contract with a CM agent. Massaro CMS acted as the CM agent who would represent the owner (Penn State) in order to handle the multiple prime set up that was established for the project. Therefore, Massaro CMS was did not take on any risk for the project. A design-bid-build method was utilized as the project was a DGS (Department of General Services) funded project. There are 16 different primes on this project, hence why a CM agent was hired for the project. In order to choose these primes, the owner went through a prequalification phase to establish which primes could bid on the project. Once this was completed, the lowest bidder was chosen for each bid package. Once the prime was selected, a descope meeting was completed to ensure that the prime understood what they were responsible for and they were not excessively low on their bid. Each of the primes reports directly to the owner. All contracts held between the parties are lump sum. Performance and payment bonds are required from all primes on the project.

Utilizing a multiple prime contract with a CM agent could be very affective, however, it is very important that collaboration is stressed. Massaro worked closely with the owner to establish how the collaborative effort will be managed. They established that rather than having each prime bring in their own trailer to the site and working out of that, they would have one double-wide trailer that all of the primes would work out of so that a collaborative effort could be effective. The design of this trailer was carefully thought out as to have each prime with their own room, but utilizing an open door policy. This cut down on the countless amount of emails that would have gone back and forth between the primes. Utilizing a double-wide trailer as opposed to separate trailers for the different primes not only increased collaboration for the project, but it also made sense from a site logistics standpoint. The double-wide trailer also allows for daily collaboration of trades through a “white board process” shown below.

Project Organization Chart

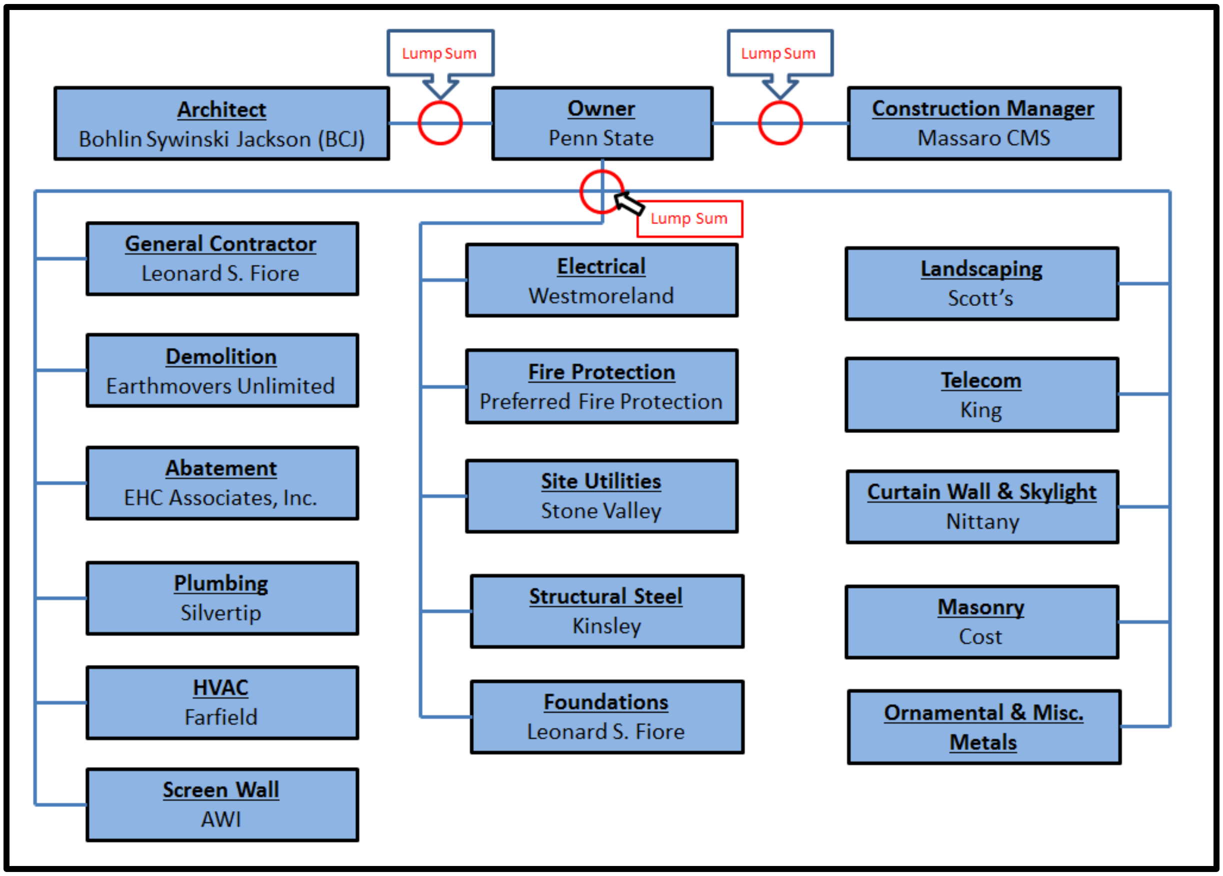


Figure 3 HHD Project Organizational Chart Showing the Multi-Prime Contract with CM Agent

Client Information

The Pennsylvania State University is beginning to invest greatly in the renovation and construction of buildings to show its supremacy compared to other college campuses. Penn State strives to build buildings of the highest quality. The owner prides itself on building “100 year” buildings. The main focus of the campus at this point in time is the image of the campus from College Avenue. Penn State had already began improving this face of the campus by renovating South Halls, a dormitory complex located very close to this project. This building is another piece of that process.

This project can be related very closely to the construction triangle. The construction triangle is made of three main points: Schedule, Quality, and Cost. These three items need to be balanced in order for the project to be successful. The major focus on nearly every project is safety, which is usually placed in the center of the triangle. However, with the three main points, normally only two of the three items can be utilized. Relating the Health and Human Development Building to the construction triangle, it is apparent that Penn State finds schedule and quality to be the most important. From a schedule standpoint, the project is projected to finish in June of 2015. Hence, it is important to maintain a constant schedule to sustain that date. The owner had established this period as a completion date so as to provide the building occupants enough time to be able to move in and prepare for the fall semester. If the project were to finish earlier, the building would likely not be fully occupied as many of the occupants would need to finish the spring semester in their current location before moving to the new building. If the project were to finish later, there would not be enough time for the occupants to prepare for the fall semester and it would likely result in the lack of utilization of the building until the spring semester. This is why it is important that the schedule be maintained.

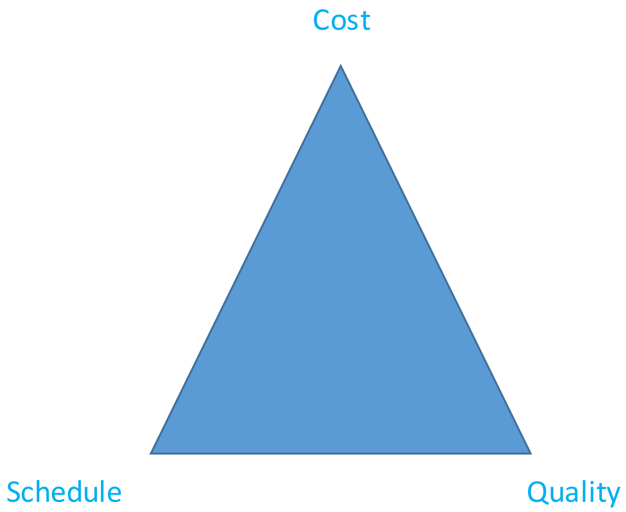


Figure 4 Construction Triangle Made up of Schedule, Quality, and Cost with a Constant Focus on Safety

In accordance to the quality of the project, Penn State and Massaro have taken large strides to make sure that the product at turnover is of the highest quality. Massaro utilizes iPads daily to perform QA/QC checklists to ensure that the materials are being installed correctly. Also, Massaro utilizes a traffic control manager at the entrance of the site. One of the major responsibilities of the traffic control manager is supervising all traffic entering and exiting the site. This is very important from a site logistics standpoint making sure that there is not a pile up of trucks or traffic. Also, this person stops every truck delivery that enters the site and makes sure that the materials meet the materials that were submitted. If the materials do not match, then the truck is sent away and the material does not even get on site. This saves from any type of controversy that could occur between the primes and the owner. Also, it ensures that the correct materials will be used.

The occupants of the building are made up of a variety of people. The college of Health and Human Development will be the main occupants of the building. This college is made up of a wide range of different college majors. These include 8 different academic units:

- Biobehavioral Health
- Communication Sciences and Disorders
- Health Policy and Administration
- Hospitality Management
- Human Development and Family Studies
- Kinesiology
- Nutritional Sciences
- Recreation, Park and Tourism Management

Each of these academic units has an impact on the design of the project. The college was consulted throughout the project in order to ensure that all needs were met.

Staffing Plan

Massaro CMS is acting as the CM agent for The Pennsylvania State University. The project team is comprised of a senior project manager, which is in charge of the overall project management. The site manager acts as a superintendent and is in charge of all site management responsibilities. The project engineers are in charge of documentation, submittal registration, and RFI communication. A BIM manager is on site to hold BIM coordination meetings, to answer any questions regarding coordination, and to act as a fourth project engineer. The project staffing plan is provided below.

Staffing Plan

Massaro CM SERVICES, LLC

Senior Project Manager
Kevin Nestor

Project Manager
Tim Jones

Site Manager
Jim Kephart

Project Engineers
Paroma Saha
Michael Clements
Jonathan Joseph

BIM Manager
Ryan Cole

Safety Officer
Crystal Shafer

Assistant Site Manager
Keith Smith

Intern
Christopher Graziani

Intern
Rebecca Bires

Traffic Control Personnel
Jodi McCullough

QA/QC Consultant
Scott Snelick

Figure 5 HHD Staffing Plan for Massaro CM Services

Project Schedule

With the Penn State Health and Human Development Building, it is important to create a schedule that creates a smooth flow to the project, as well as maintaining the utmost safety measures. The project began February 4, 2013 and is scheduled to have owner occupancy by June 30, 2015. The project is composed of two separate buildings: an existing to remain renovation and new construction. The existing to remain (E.T.R.) is a three level building with a mechanical penthouse that will require a complete shell demolition and renovation, abatement, and interior renovation. The new construction consists of 5 levels and a mechanical penthouse. According to the schedule, the project planning phase consists of submittal processes, BIM coordination, and the building mockup. These activities have long durations because they go throughout multiple tasks and activities throughout the project. The building mockup is for the foundation wall with an exposed finish. A summary of the major phases of the construction sequence is displayed in the table below.

Table 1 Project Schedule Summary Depicting the Major Tasks of the Project

Project Schedule Summary	
Activity	Duration (days)
Project Planning	233
Sitework	75
E.T.R. Shell	124
E.T.R. Interior Renovation	405
New Construction Shell	127
New Construction Structural Steel	80
New Construction Concrete Slabs	142
New Construction Building Envelope	228
New Construction Roof	171
New Construction Interior	174

Existing To Remain Shell and Interior Renovation

Based on logistical planning of other work that will be ongoing, it was found that the best sequence for the shell reconstruction was north, east, south, west, and then penthouse. The shell reconstruction includes the demolition of the existing shell, structural steel, concrete foundations (where necessary), structural metal steel, windows installation, limestone, and brick veneer. For the interior, it was found that working from the ground floor to the top floor would be the most efficient. This was because the ground floor consisted of classrooms and labs, so a learning curve would be able to be achieved for the second and third floors. The abatement is an activity that could fluctuate with the amount of days due to the unknown conditions inside the renovation. The duration that is estimated is something that could easily fluctuate with the amount of abatement that is required. The interior renovation also includes demolition, framing layout, HVAC demo, MEP rough-in, MEP install and insulate, MEP finishes, and interior finishes. A renovation project can cause many constructability concerns due to unforeseen conditions. For this reason, the way that the ETR renovation is scheduled allows for more time because it is started in the beginning of the project and could potentially extend further into the project. The figure here shows an elevation of the ETR that depicts the sequencing order with the mechanical penthouse on top which will only receive the shell facelift. One benefit of having this renovation along with the new construction is the fact that the work can be done at the same time. A benefit of this project is that the construction of the new building could be performed while the ETR is being renovated.

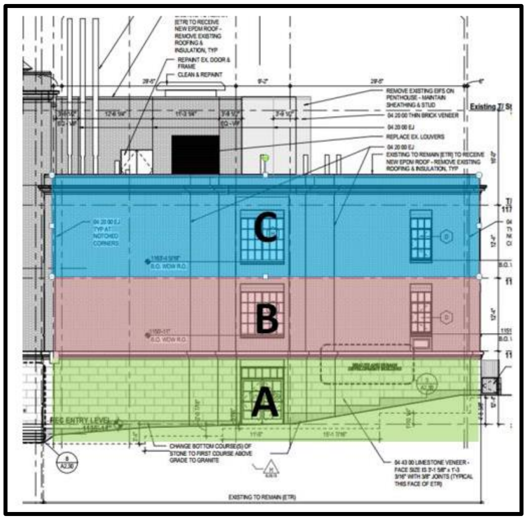


Figure 6 Vertical Sequencing Plan of Existing to Remain Structure

New Construction

The new building construction has a sequencing scheduled differently from the ETR section. As opposed to the vertical sequencing pattern that the ETR is scheduled with, the new construction is scheduled in a horizontal fashion. The new construction will be done in 3 areas. The sequencing pattern will begin with area A in the northwest area of the site and move to area B in the southwest area. The sequencing will finish with area C in the southeast section of the site. This sequencing plan was used due to site restrictions. The horizontal plan is shown in the figure below.

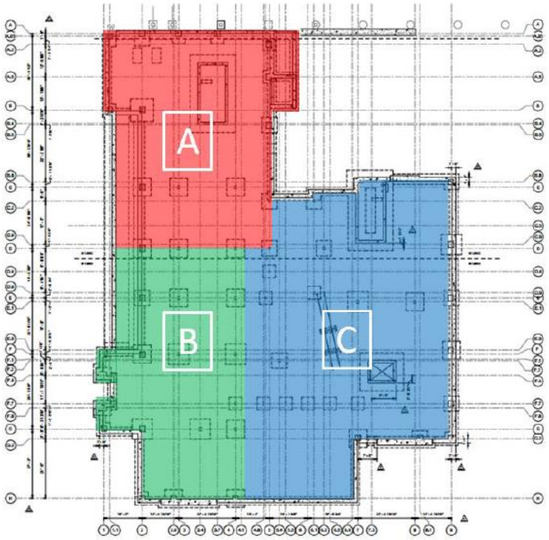


Figure 7 Horizontal Sequencing Plan of New Building Construction

New Construction Shell

For the shell section of the schedule, there are components that are broken down within the subsequent area. Area A consists of the soil nail wall installation. It is important to begin the soil nail wall excavation first due to the logistical implications that it carries. Concrete trucks need to come on the site and work to install the soil nail wall will be going on while excavation will begin elsewhere. The foundation of the area in A will consist of excavation, foundation walls and footings, and backfill. The structure of the building is steel framing with shear walls in the stair and elevator towers. For this reason, it is important to have the stair towers complete and cured before structural steel appears on site. So, areas A and C consist of some type of foundation work and stair or elevator tower concrete pouring.

New Construction Structural Steel and Concrete Slabs

The structural steel erection sequence will be performed with the same horizontal movement. It will begin in area A, then move to B, and end at C. The sequencing within these areas consists of the erection of steel, detailing, and the installation of the deck. The decking will be placed every two floors in order to meet safety requirements instilled by Massaro CMS. This is done as a fall protection standard and also so the concrete slabs can be poured whenever the steel erection in that area is completed. A simple lift plan is shown in the figure here. The major takeaway is that one crane will be used and will begin in area C in order to work in area A and it will back itself out of the site as it moves towards area C. Safety of steel erection will be critical and it will be important to make sure that the crane swing radius does not go over the HHD East building as it will be occupied with students and faculty throughout the steel erection sequence. The shakeout area will be in area B. So, as mentioned previously, the concrete slabs will follow the steel erection with the exception of the slab-on-grade which will be poured prior to steel erection. The concrete slab pour sequence will be performed in the order of the areas in the same fashion as the steel erection. Once the frame is in place and the deck is erected, the concrete slab will be poured. The concrete slab sequence consists of rough-in, prep work, and the physical pour. It will be important to monitor concrete placement and curing times for these slabs as it will be difficult to tear out and re-pour.

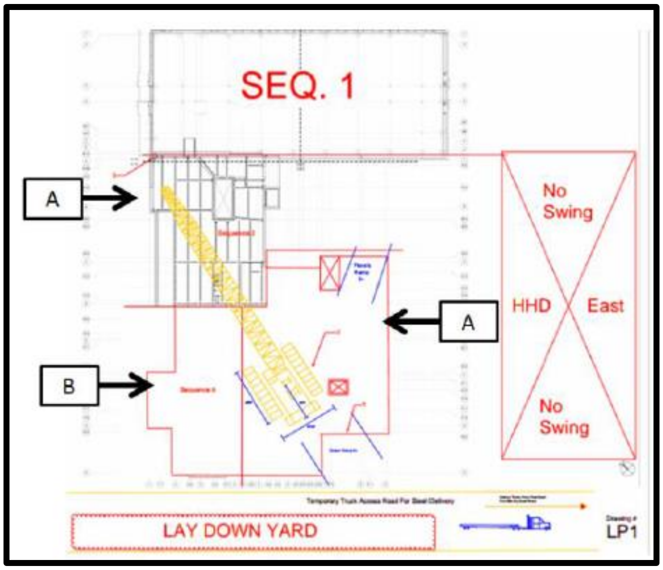


Figure 8 Steel Sequencing Plan Courtesy of RNR Construcion

Building Envelope

The next item for the schedule is the construction of the building envelope. With Massaro working on this project as Phase II of the Henderson South renovation, they have developed a learning curve from Phase I with the Biobehavioral Health Building. Since the Health and Human Development Building has been designed to match the façade of that building, they will be able to understand the difficulties and work around any issues that resulted from Phase I. This should result in a reduction of duration required for the HHD Building. The building envelope construction consists of CMU walls, rough-in, window blocking, window installation, veneer, and scaffolding removal. On the south elevation of the site, there is also a curtain wall for the atrium. This is a lot of on-site work from scaffolding equipment which could be a safety issue. One way of cutting down on schedule time as well as reducing safety concerns would be prefabricated wall panels. This is a leading industry trend that we are seeing more and more of now today.

Roof

The roof is divided into three sections: the west wing slate, the east wing slate, and the EPDM roofs. The west wing slate will take a good period of time due to the installation of the chimney. The chimney installation will consist of a rough-in, installation, and demobilization. Installation of the slate roof will also be made up of rough-in, install, and demobilization. EPDM roofs are different and consist of metal framing, a skylight, and the roof system. It is critical that the roofs are installed and the building is enclosed on time. For the interior work to begin, the building needs to be watertight so that finishes can be protected and a tempered environment can be established. So, roof installation is on the critical path of the project in order to ensure that interior work can begin and get completed on time with the quality that is expected.

Interior

The interior of the building will be done in three sections: the central commons areas, the west wing, and the east wing. The central commons area will be the most difficult as it will require intense coordination of trades. The atrium area will contain a very detailed stair C as well as an architectural screen wall which will consist of a large amount of scaffolding that will need to be worked around. The figure shown here shows how congested this space will be with the scaffolding as well as the installation of stair C and the architectural screen wall. The constructability concerns of this area are a reason why it will be discussed further through an analysis later in the report. For the schedule derived here, it was decided

Figure 9 Atrium Space Showing Congestion of Scaffolding, Stair C, and Screen Wall Installation

that stair C be installed first and the scaffolding for the architectural screen wall work around the installation of stair C. This area will begin with MEP rough-in and install in order to establish a tempered environment for finishes preservation. Framing layout, installation, insulation, and interior finishes will also be completed in this area. This area is scheduled as one floor because it is a big open space with features that extend to the top. The east and west wings will be completed in a vertical fashion from the ground level up to the top level. Each level will consist of MEP rough-in, MEP installation, framing layout, install, insulation, and interior finishes.

Closeout

The closeout stage will consist of a final cleaning and punch lists. Substantial completion is estimated to be May 21, 2015 with owner occupancy and project completion being June 30, 2015.

Project Cost Overview

When evaluating the costs associated with the construction of the Health and Human Development Building, it is important to breakdown the costs into smaller categories. In this case, it would make sense to break the cost down into the cost of the renovation and the new construction. However, the cost of the two facilities was not broken out separately in the information that was provided. Instead, the cost was broken down by the actual building cost and the total cost of the project. The results of this information are found below. A breakdown of the building systems is very difficult to create because the project includes two different types of spaces: office and laboratory. Also, this is difficult to create because the project is made up of both new construction and renovation.

Actual Building Costs

Total Area:	**150,000 GSF**
Building Construction Cost:	**$45 Million**
Building Construction Cost per SF:	**$300 per SF**

Total Project Costs

Total Area:	**150,000 GSF**
Total Project Cost:	**$59 Million**
Total Project Cost per SF:	**$393.33 per SF**

Building Systems Summary

Demolition

Demolition is seen in many different ways on this project. The existing structure consisting of a day care center and classrooms was initially demolished as well as the foundation system associated with it. This foundation system was a remnant of mining school constructed over 60 years ago. Additionally, asbestos abatement was required in the existing to remain section of the project as well as in the building that was demolished. Asbestos abatement was required before the building could be torn down for the safety of the workers and the environment. Lastly, demolition was required for the existing brick façade of the ETR. The brick façade was demolished and a new façade will be put in place in order to match that of the surrounding buildings.

Structural Steel Frame

The bracing of the building is done through concrete shear walls in the stair towers and elevator tower walls. The superstructure includes typical girders spans that vary from 16' to 30', and beams spans that vary between 21' and 30'. The slabs are composite with concrete on metal decking. In order to install the steel, one mobile crane will be used. The steel will be sequenced in three sections so as to allow for proper site logistics. The figure shown here depicts the concrete shear wall incorporated with a steel structure.

Figure 10 Concrete Stair Tower Shear Wall with Steel Structure

Cast in Place Concrete

The project utilizes a cast in place elevator shaft and stair towers. These will be constructed using rebar and formwork. The formwork is composed of wood and prefabricated forms including steel forms and glass fiber reinforced plastic forms. Concrete will be placed for these areas through a concrete pump truck. Cast in place concrete will also be applied to a soil nail wall that is being put in place to stabilize the existing to remain building. This concrete will be placed utilizing the shotcrete method.

Mechanical System

The mechanical system will utilize the campus utilities. The campus steam loop passes through an existing tunnel beneath the sidewalk adjacent to the north edge of the existing to remain structure. Campus chilled water will be extended into the building and utilized to serve the existing to remain and new building structures. The building will have secondary chilled water pumps with variable frequency drives. HVAC systems will generally consist of central system variable air volume air handling units located in the mechanical rooms of the new building. These VAV boxes will cool and heat the air that will be transported throughout the building. Fire suppression will be completed through a sprinkler system and spray on fire proofing on the structure.

Electrical System

Similar to the mechanical system, the electrical system is also tied into the campus power. The main distribution switchgear is a 1600 A, 480/277, 3-phase, 4-wire switchgear. This is then distributed to two switchboards, which stem out to sub-distribution panels. The HHD building lighting plan consists of both fluorescent and LED lighting fixtures. Occupancy sensors are used throughout the building in order to control the lighting and reduce energy usage.

Masonry

The stone masonry is designed to withstand gravity, wind, and seismic loads. Stone anchorage systems are used to attach to the existing back up wall. The typical exterior masonry wall will be a cavity wall design comprised of face brick, an exterior air cavity with rigid insulation, and a sheet membrane air/vapor barrier, dens-glass gypsum sheathing, galvanized metal studs and abuse resistant gypsum wallboard. The brick to be used on this building will be a molded colonial brick that will complement the brick used on the Phase One building. The image shown to the left shows the west façade of the building. Limestone trim will also be utilized. Standard scaffolding will be used around the exterior of the building.

Figure 11 HHD Building Facing West. Exterior Masonry Designed to Match That of Surrounding Buildings

Curtain Wall

The curtain wall will be a major feature for the building from an aesthetic standpoint. The goal of the project is to improve the view of the campus from College Avenue, and this feature will be the face of the building. The curtain wall is made up of aluminum framing members, steel reinforcement, anchors, fasteners, flashing, and glazing. The glazed wall will have a powdercoated finish and will be 1" thick insulated glass units. The constructability of the wall will comply with the manufacturer's submittal. A testing agency will be hired separately to perform tests and inspections.

Support of Excavation

The excavation was a very challenging area for the project team. The ground was made up of solid rock so rock excavation blasting was utilized. The excavation was sloped and the rock sheared off so a support system was not required. A dewatering plan was created in order to ensure that the removal of water from the excavation is done in a matter that does not harm the public health, property, and portions of work under construction. All excavation is permanent and will be backfilled once the structure is completed.

LEED Certification

As part of Penn State's University-wide Environmental Stewardship Initiative, the HHD Building will be designed to meet the U.S. Green Building Council's LEED Green Building Rating System. The University wishes for the project to meet the requirements for LEED certified at minimum. To meet the required level of certification, the design team focused on the following features:

1. Energy Conservation
2. Natural Resources Conservation
3. Prevention of Environmental Degradation
4. Occupant's Health, Well-being, and Comfort
5. Total Cost of Ownership

General Conditions

The general conditions estimate was developed from a series of values established from Massaro CMS pricing standards. The first item analyzed was the project management. This section contained all of the staffing for the Health and Human Development Building. In order to establish a quantity on the number of hours that each staff member has on the project, a takeoff was done for every month with the amount of hours per month estimated for each person. Full-time employees on the project have the highest number of hours, followed by the BIM Coordinator who is only working on the project part of the month, then interns who have less due to part time hours during the school year, and the safety coordinator having the least amount. This takeoff can be found in the appendix. The hourly rates for this staffing plan were taken from Massaro CMS. Items included in these general conditions, but not in the project general conditions, include construction equipment (crane, forklifts, hoists, and lifts) as well as temporary utilities. So, the general conditions that were created were higher than the general conditions on the project.

The next section analyzed was the temporary utilities on the project. The project site will be utilized for 29 months with requirements for phone/data, electric, temporary heat, water, generators, and porta johns necessary throughout the project. The material costs are at a cost per month rate and are taken from the actual prices paid by Massaro CMS.

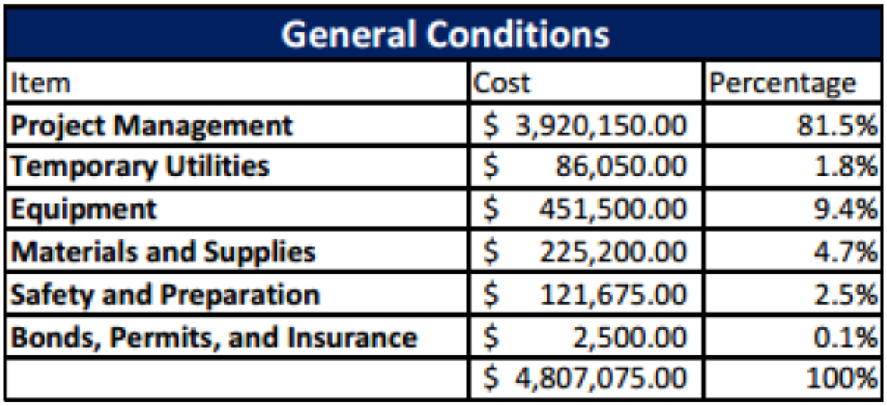
The project consists of 17 primes who are working in a collaborative effort with each other in one double-wide trailer. So, the equipment section includes trailer costs for 29 months of the project. This section also includes the mobile crane which is used for the steel erection, 4 forklifts, hoists, and 12 lifts. The durations of these pieces of equipment have been estimated based on schedule durations for what they are being used for.

This general conditions estimate also includes materials and supplies as well as safety and preparation. The materials and supplies include items in the trailer such as computers, cell phones, PPE, printing, fire extinguishers, BIM management, and drinking water/coffee. The BIM management is priced at a lump sum cost as an estimate for items such as meetings, programs, and model creation. The safety and preparation section includes items like temporary fencing, tree protection, temporary roads, signs, dumpsters, trash removal, and a truck tire wash station. The truck tire wash station cost is a lump sum that is taken directly from Massaro CMS.

Bonds, permits, and insurance make up the back end of the general conditions estimate. These are lump sum costs for the construction management agent. As an agent, bonds and insurance will not need to be purchased.

A breakdown of the general conditions is shown in the table on the following page:

Table 2 General Conditions Estimate for Construction Management Team



General Conditions		
Item	Cost	Percentage
Project Management	$ 3,920,150.00	81.5%
Temporary Utilities	$ 86,050.00	1.8%
Equipment	$ 451,500.00	9.4%
Materials and Supplies	$ 225,200.00	4.7%
Safety and Preparation	$ 121,675.00	2.5%
Bonds, Permits, and Insurance	$ 2,500.00	0.1%
	$ 4,807,075.00	100%

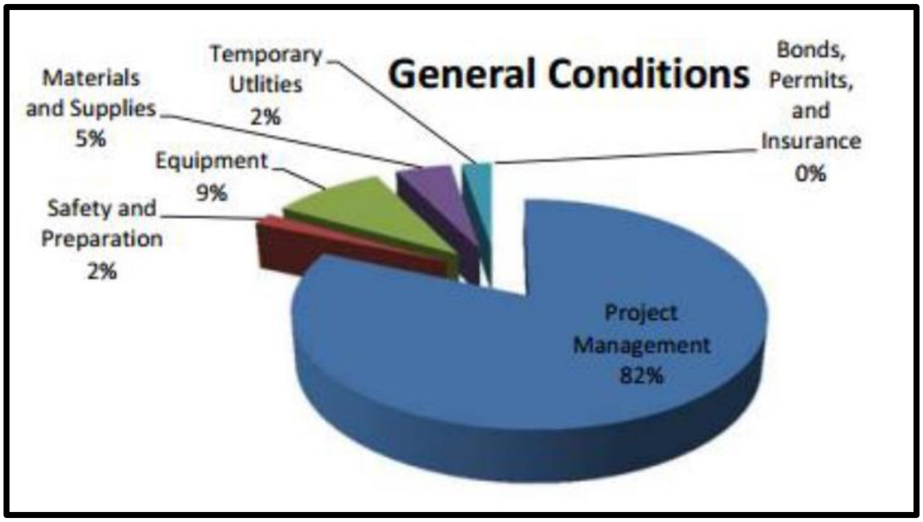


Figure 12 General Conditions Breakdown of Cost Distribution

Analysis 1 - Stair Tower Redesign

Problem Identification

Project schedule and quality of the product are the major driving factors for The Health and Human Development Building and its owner. For this reason, it is important to analyze areas in which the schedule could be jeopardized or that the quality of the product may not match what is expected of the owner. One of the major problematic areas on this project was the construction of stair tower A. This is a full cast-in-place concrete stair tower that is acting as a shear wall for the structural steel system. Figure 12 shows stair tower A installed with the steel members attached.

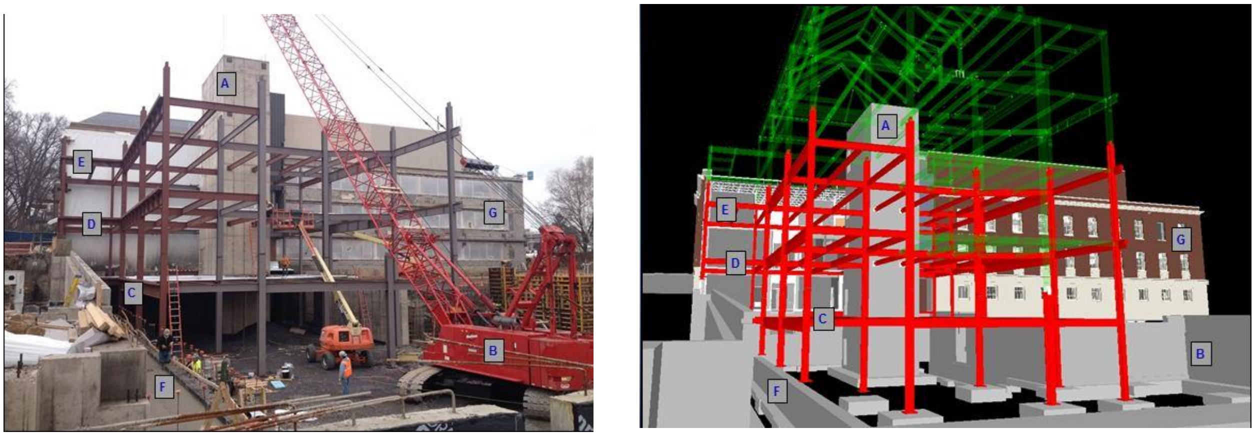


Figure 13 Stair A Installation with Steel Members Compared to BIM Model

The installation of this stair tower was very tedious and was a major schedule concern. It required strip forms, the placement of rebar, and the use of a concrete pump truck. On site, the process required to have the pump truck, a crane, and a JLG lift in order to raise the forms and make the pour. Not only does this require a large amount of coordination on site, but it also causes a major safety concern for construction. Once the forms were put in place and the rebar was being installed, it was important to ensure that the personnel were properly tied off and standards were met for the guardrail restrictions. However, with the strip forms, a 42” guardrail requirement could not be met due to the height of the stair tower forms at the concrete placement height. This was a major safety concern that had to be monitored throughout the installation and additional restrictions were required. Also, there is always a concern with site congestion where there are so many pieces of heavy equipment. These safety measures were the first topic of consideration when analyzing the problematic aspects of this area.

Schedule impacts were seen immediately on the first level construction of the stair tower. The construction of the stair tower took long periods of time as the forms needed to be put in place, rebar needed to be installed, and a pump truck needed to be brought to the site to pour the cast in place concrete. This process for installation of the cast in place concrete took about 1 week per level to construct. Figure 12 shows the process in which this structure was built. It is assumed that a learning curve would be achieved as more levels were installed; however the process became more difficult as the height increased. The pump truck needed to reach higher points and the workers needed to be transported up and down with the JLG lift. The amount of time taken for the installation of stair tower A caused for a later start to the steel sequencing. Also, with the concrete structure, weather is a strong restriction. The way that the schedule was created, the stair tower was installed on the edge of the winter season. Hence, weather restrictions were seen and delays were imminent.

Figure 14 Installation Process for Stair Tower A. (From Left to Right) Installation of Interior Formwork, Installation of Rebar, and Installation of Exterior Formwork. This process is concluded with the concrete pour.

The main focus of the owner on this project is the quality of the building at the turnover. The architect designed the stair towers as to have the concrete be architecturally exposed. This requires for the concrete to be poured and finished perfectly so as to not have any type of honeycombing or holes that may result during the installation process. The specifications call for any honeycombing, rock pockets, voids over 1/4” in any dimension, and holes to be cut out and repaired. Once stair tower A was completed, issues were found with the installation process. The first problem was noticed during a survey which was completed by the steel contractor. When the steel arrived on site, a survey was completed to make sure that the stair tower was installed correctly and that the steel would fit in properly. After the survey was completed, it was found that the tower had twisting as it grew in height. From the top of the tower to the bottom, the tower had twisted enough that the location was off by roughly 3 inches in some areas. This led to incorrect matching of steel beams. Some pieces were too short and some were too long, which led to beams needing to be cut and added delays to the schedule. The second problem was noticed when the architect did a walk-through of the site. Upon visitation to the stair tower, it was found that the look of the architectural exposed concrete did not meet the requirements provided by the specifications. This caused for the contractor to provide repair work on the areas to the satisfaction of the architect. Overall, this lead to a lower quality product and additional time added to the schedule.

Goal

After analyzing the issues of schedule, quality, and safety that are associated with the construction of the concrete stair tower, it was important to seek an alternative that would be safer, decrease schedule time, and improve quality. In order to do this, a steel braced frame will be analyzed. This analysis will investigate the cost and schedule implications, fireproofing requirements, and the quality of the finished product compared to the current concrete shear wall design.

Process

In order to compare these two systems, it is important to break the categories into smaller, more detailed items. The first category that will be analyzed is cost. The current design will be examined for material, labor, and equipment. Takeoffs were completed based on information provided from Massaro CMS, Leonard S. Fiore, and observations completed while on site. The proposed design will analyze the same items for cost. However, there will be differences in material, method of placement, and the manpower associated with installing this system.

From a schedule standpoint, the current design was observed as the task was being completed. The proposed design is expected to take much shorter time and provide a higher quality product. The design will consist of a steel braced frame with a drywall finish on both sides. When designing the steel structure, it will be important to account for openings that are designed in the stair tower. For stair A, there are openings on the west side of the tower for entrance into the stair area. Figure 13 shows a plan view of the stair tower and its dimensions. Per requested by the project specifications, a 2 hour fire rating will be required in the stair tower. The concrete cores do not require any additional fire proofing over and above what the concrete itself provides. However, with the steel, fireproofing will be needed on the members as well as the finished walls that will be installed. Another issue that will need to be studied is the amount of space that the steel will take up into the stair towers. Seeing that the steel enclosure thickness could potentially be larger than the 12" concrete thickness in the current design, it will be important to ensure that additional space is not required in the stair tower to have compliant stair widths. The study will attempt to maintain the same thickness as the concrete, or at least try to be very close.

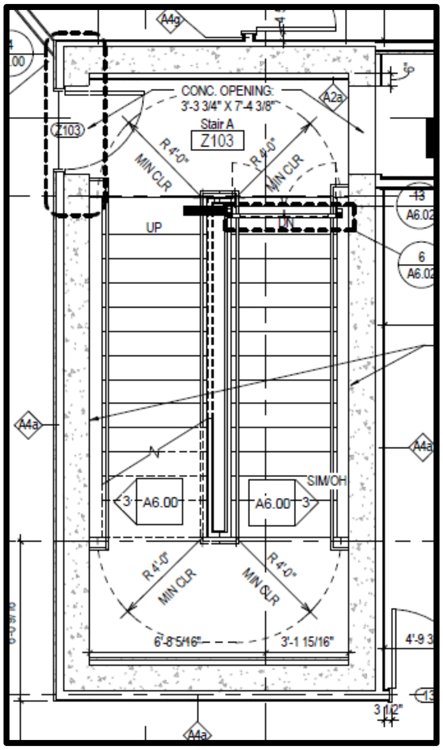


Figure 15 Plan View of Stair A

The design of the steel braced stair tower will be completed using a structural breadth. The sizing of the columns and beams will be done through the utilization of a structural computer program. One hand-calculated brace will be designed to ensure that the sizing process is understood and accounts for lateral loads from wind. Then, the fireproofing of the structure will be analyzed for cost and schedule. Lastly, the material required for the fill in between the steel structure. In order to achieve the required 2 hour fire rating and meet aesthetic standards, a drywall structure will be installed on both sides of the steel.

This analysis will strictly analyze the cost of materials, labor and equipment. There are many items that would need to be analyzed for this to be a full takeoff for the conversion from concrete to steel. One of these items is the connections required for the concrete to the steel and the steel to the steel. This would require a structural depth which is out of the scope of this analysis. Another item is the stair installation within the stair tower. With a concrete stair tower, connection points can be created and the stair tower can be erected once the entire stair tower is complete. One major benefit of having the cores done ahead of the steel floor framing is you have safe permanent stairs ready for your iron workers and other trades to use immediately. With steel however, steel stairs can be erected along with the steel framing to provide the same access. This is a coordination issue that requires upfront efforts. Another area that will be out of the scope of this analysis are the foundations. When replacing concrete walls with columns, the foundations will be affected. However, for this project, a 2 foot thick mat slab is used for this area. This item is not going to be studied for this analysis because the assumption is made that the concrete will weigh more than the steel, therefore it will be able to support the steel members that will be put in place. Lastly, one area that is understood, but is not in the scope of this analysis, is the LEED advantages of steel as opposed to the concrete. Steel is much “greener” than concrete. Steel generates more recycled materials than concrete.

Results

Current Design

Analyzing the current design, there are many different items that need to be estimated in order to get an accurate material cost. These items include concrete, rebar, forming, and rubbing. These items are analyzed for stair A, which is 12” thick and covers 4,690 square feet. The forming and rubbing takeoffs were completed for this amount of square footage but the total is doubled because they are placed on both sides of the concrete wall. The cost per unit was provided by Massaro CMS. This takeoff is shown in the table below. As is seen, the stair tower cost $147,032 for strictly material.

Table 3 Current Design of Concrete Stair Tower Material Takeoff

STAIR A: LEVEL 1 - TOP OF STRUCTURE							**Unit**	**$ per unit**	**Total $**
				12	" THICK	**4,690**	**SF**		
	CONCRETE - BUY					182	CY	125.00	$22,799
	REBAR			**50**	#/CY	9,119	LBS	2.00	$18,239
	FORMING					9,380	SF	10.00	$93,800
	RUBBING					9,380	SF	1.30	$12,194
	Stair A			- COST PER CUBIC YARD			$806	/CY	
	Stair A			- COST PER SQUARE FOOT			$31	/SF	
CIP WALL @ STAIR A				**-SUBTOTAL**		**$147,032**			

The installation of the concrete shear wall was a very tedious process. When this system was installed, it took 1 week per level to put the rebar in place, form the wall, and pump the concrete into the forms. With this being such a long process, it will require many hours of manpower. In order to complete this work, it was found that there would need to be 2 iron workers, 3 carpenters, 3 laborers, 1 crane operator, and 1 pump operator. The number of hours were tallied for each level and multiplied by the number of levels. The labor rates were taken from the project specification section D which provides prevailing wages based on the Pennsylvania Department of Labor & Industry. The rates provided include both labor rates and fringe benefits. The table below shows the manpower takeoff for the installation of the concrete stair tower.

Table 4 Current Design of Concrete Stair Tower Manpower Takeoff

Manpower Takeoff for Current Design						
Type of laborer	**Number of Workers**	**Hours Per Worker Per Level**	**# of Levels**	**Total Number of Hours**	**Cost/Hour**	**Total Cost**
Iron Workers	2	12	5	120	$ 49.63	$ 5,955.60
Carpenter	3	40	5	600	$ 38.60	$ 23,160.00
Laborer	3	40	5	600	$ 29.14	$ 17,484.00
Crane Operator	1	40	5	200	$ 43.54	$ 8,708.00
Pump Operator	1	8	5	40	$ 43.04	$ 1,721.60
						$ 57,029.20

The numbers for this estimate were arrived from daily reports provided by Massaro CMS. The reports were studied for how many workers were working on the stair tower during the installation process for one level. Then, the number of hours per level was multiplied by the total number of levels in order to arrive at the total number of hours to construct the stair tower. Typically, with any form of repetitive construction process, a learning curve would be developed. However, with the installation of this stair tower, the learning curve would be difficult to generate any type of schedule advancement because as the stair tower rises, it takes longer periods of time to transport manpower and materials up and down to perform the work. Also, it is more difficult for workers to complete the work from inside of a lift than it would be for them to complete the work on the ground.

The last area to analyze for the current design is the equipment that will be needed to complete the work. As was previously mentioned, the workers will need some type of lift (JLG) in order to put the rebar in place and lift the forms into place. Slip forms were utilized to speed up the process, but they require a crane to be lifted from level to level. Lastly, in order to pour the concrete at the higher levels, a concrete pump truck will be needed. The table below shows the takeoff for the equipment utilization.

Table 5 Current Design of Concrete Stair Tower Equipment Takeoff

Equipment Takeoff for Current Design					
Type of Equipment	**Days/Level**	**# of Levels**	**Total Number of Days**	**Cost/Day**	**Total Cost**
Crane	5	5	25	$ 1,250.00	$ 31,250.00
Lift	5	5	25	$ 180.00	$ 4,500.00
Pump Truck	1	5	5	$ 1,000.00	$ 5,000.00
					$ 40,750.00

As was mentioned in the problem identification section, the concrete stair tower had many issues associated with it in the construction process. One of these issues was the fact that it was 3 inches out of plumb in many areas. Additional cost and schedule will be associated with this constructability issue. The steel beams that will be connected to the concrete stair tower needed to be lengthened in some areas and cut in other areas. The amount of additional costs associated with this is very difficult to quantify. Also, the concrete finish was not installed to the specification required by the architect. The figure here shows the interior finish of the concrete shear wall. As can be seen, the finish is not what would be typically seen as an interior finish of a Penn State building. The decision has not been made yet, but it is likely that the concrete shear wall will require a drywall finish. This will likely be done with furring strips and drywall connections. Due to the fact that the concrete wall will be behind this finished material, there will be no additional fireproofing required. The cost and schedule takeoff for this amount of work will not be in the scope of this analysis. However, it is understood that additional time and cost will be required.

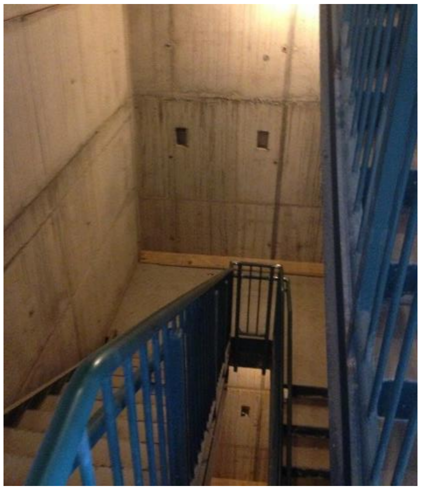


Figure 16 Concrete Shear Wall Interior Finish

To summarize the current design, it is found that the concrete shear wall will cost an utmost of $250,000 for material, equipment, and manpower. As was observed, the installation of this structure required 5 weeks of schedule time. This information is summarized in the table below.

Table 6 Summary of Concrete Shear Wall Cost Takeoff and Schedule Information

Summary for Current Design	
Material	$ 147,031.50
Equipment	$ 40,750.00
Manpower	$ 57,029.20
Total	$ 244,810.70
Schedule Time	5 Weeks

Steel Braced Frame Design

In order to design the steel braced frame, it is important to begin with the design of the braced frame. Due to the fact that the stair tower will need to resist lateral loads, some type of bracing will be needed to support these loads. There are many different options for bracing this frame. These options include, but are not limited to the design types shown in the figure below.

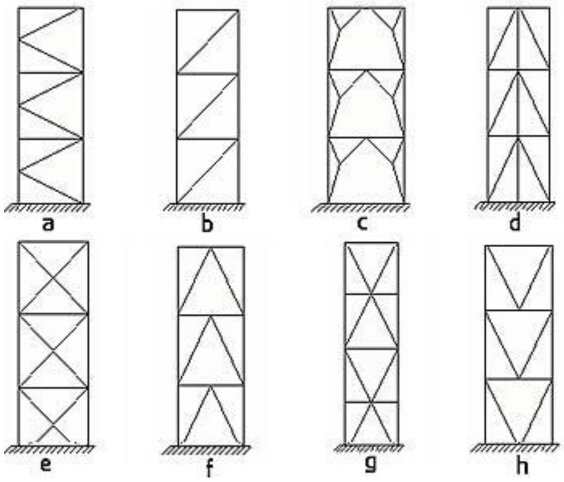


Figure 17 Steel Tower Bracing Design Types Courtesy of Google Image Search

From an architectural standpoint, it is important to ensure that the door locations are able to be maintained with the redesign of the bracing. Because the doors to enter the stair tower are located on the west side of the building at the location of where the landings would be, brace design type b from Figure 17 would be the ideal type. Therefore, the stair tower redesign will take on the braced framing style b shown in the figure above.

The stair tower will act similarly to the way that the concrete shear wall acts in the current design. It will not only support the dead and live loads of the area, but also resist lateral loads from wind. For this analysis, the cross brace member size will be calculated based on the lateral loads acting on the structure. The wind load will be calculated and will control (over seismic loading) due to the fact that it is located in the State College Area. The process for calculating the wind loads was taken from the MWFRS (envelope) procedure. The steps taken to solve this are described in the following section.

Step 1: Determine the risk category of building or other structure.

- The risk category for this building falls under category II. Category II consists of all buildings and other structures except those located in Risk Categories I, III, and IV. This information is taken from Table 1.5-1 in the MWFRS method, Chapter 28 in the Steel Manual.

Step 2: Determine the basic wind speed, V, for applicable risk category.

- The basic wind speed for occupancy category II buildings can be found on Figure 26.5-1A. Analyzing the map shown, it can be found that the State College area requires a minimum design load of 115 mph for the wind speed, V.

Step 3: Determine wind load parameters:

Exposure category B, C, or D

Topographic Factor, K_{zt}

- Based on Section 26.7, the exposure category for the Health and Human Development Building is category B. This is because it is located in a suburban, urban area. The topographic factor is taken to be 1.0 because there are no hills around the area.

Step 4: Enter figure to determine wind pressures for h = 30 ft, p_{S30}

- Looking at Figure 28.6-1, the Basic Wind Speed (mph) is taken to be 115. Analyzing this column, a roof angle of 20^o is assumed to be taken for horizontal pressure in zone C. Zone C is used because the stair tower is not within 10% of the horizontal distance or 40 % of the building height. Also, there are only horizontal pressures on that corner. Looking at the chart, the p_{S30} value for zone C is 19.4.

Step 5: Enter figure to determine adjustment for building height and exposure, λ.

- Looking at figure 28.6-1, the mean roof height of the building is required. The Health and Human Development Building is actually out of the range for the mean roof heights listed in the table as it is listed as 70 feet tall. However, it is assumed to be able to take the numbers for the 60 feet mean roof height. Then, for exposure category B, the adjustment factor is 1.22.

Step 6: Determine adjusted wind pressures, $p_{s'}$

- Using equation 28.6-1, the wind load can be calculated with the following data:
  Wind load = 19.4 x 1 x 1.22 = 23.668 psf

One assumption made in this analysis is that Stair A only takes the load from the westernmost rectangle shape of the building as shown in the figure below.

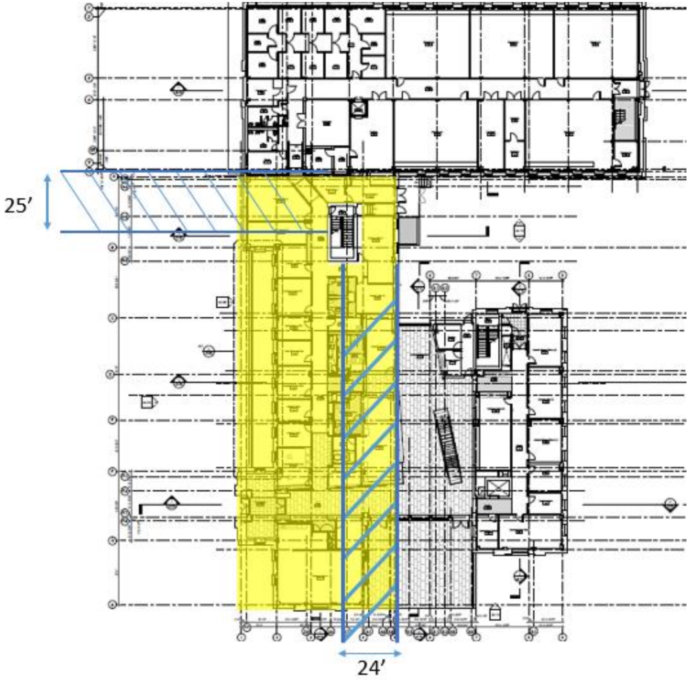


Figure 18 Stair A Tributary Area Dimensions

The figure shows in yellow the rectangular area in which the stair tower will absorb loads. The lines and dimensions show the tributary area in which the loads act on the stair tower. Next, the force acting on each level of the braced frame will be determined. The 23.668 psf that was determined for the wind load will be multiplied by the dimensions for the tributary areas in order to determine the loads on two of the four ends of the frame. These ends will then be mirrored to get the sizes of the other two ends. The calculations are listed below.

23.668 psf x 25’ = 591.7 plf
23.668 psf x 24’ = 568.032 plf

The stair tower has dimensions of 26’ in the long direction and 14’ in the short direction. The first end that will be studied is the 14’ side. The figure below shows the results of the calculation.

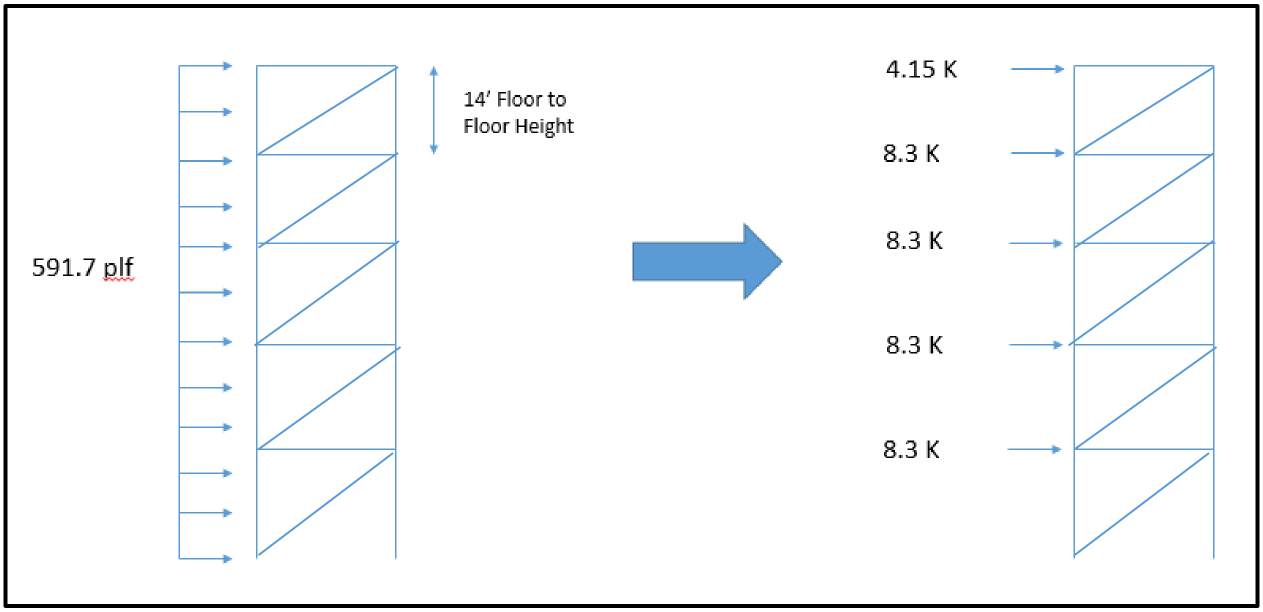


Figure 19 Lateral Load Calculations at Each Level of Stair Tower A

The load at the top floor is smaller than the rest because it only takes on the load from half of the floor below. The rest of the loads are equal because they absorb the lateral force for half of the floor below and half of the floor above. The next step in the process is calculating how much of this force will be resisted by the diagonal cross brace. This can be done by a simple method of joints calculation. The pinned connection is shown in the figure below to symbolize how the calculation will be performed.

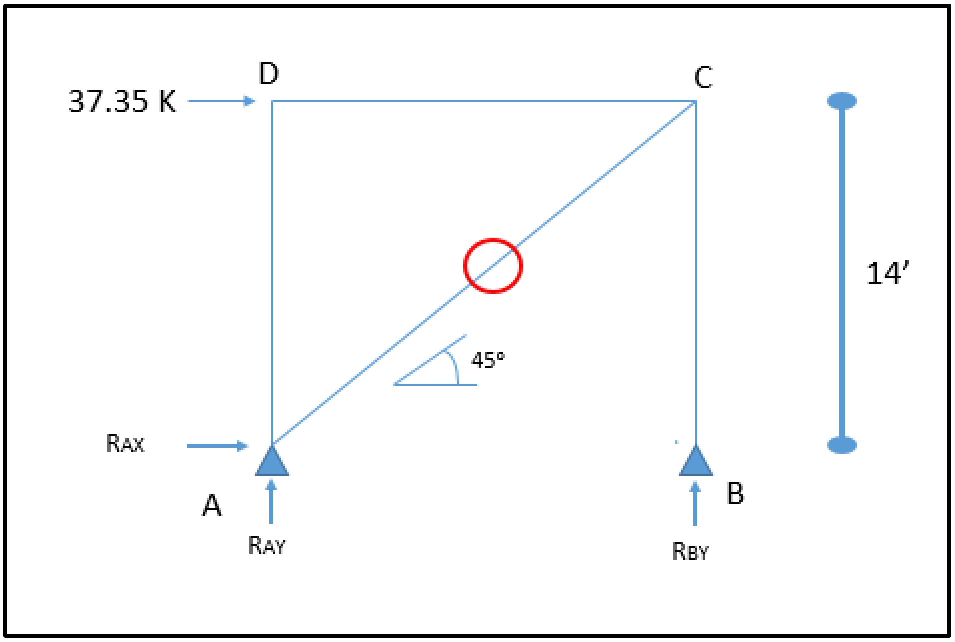
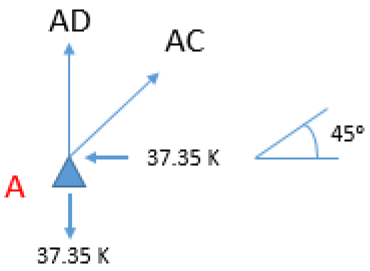


Figure 20 Bottom Frame in the Elevation View Depicting the Frame that will be Sized

The reactions were solved for at points A and B and were found to be the following values:
R_{AX} = 37.35 K ←
R_{AY} = 37.35 K ↓
R_{BY} = 37.35 K ↑

Then, the joint at point A will be analyzed in order to get the axial force for member AC. This will be the cross brace that will be designed for resistance of lateral loading. This area is shown with the red circle in the figure above.



$$\sum F_y = -37.35\text{ K} + AD_Y + AC\sin(45) = 0$$
$$\sum F_X = -37.35\text{ K} + AC\cos(45) = 0$$
$$\boxed{AC = 53\text{ Kips}}$$

Typically, a cross brace such as the one being analyzed here is made up of HSS steel. In order to size the HSS steel, it is important to check both tension and compression. For simplicity, a square piece of HSS steel will be utilized. Compression will control in this case as the force will be acting on the beam in a "pushing" manner rather than a pulling (tension). In the steel manual, compression is based on length of the member. So, the length of one of the cross braces was found to be 19.8 feet. Then, the manual was referenced and it was found that an HSS 4 ½ x 4 ½ x 3/8 piece of HSS steel would resist 59.9 Kips of compressive force which is greater than the 53 Kip force that was found from the previous joint analysis. Then, the piece needs to be checked in tension. It was found that an HSS 4 ½ x 4 ½ x 3/8 piece would hold 227 Kip of yielding strength and 179 kips of rupture strength. These numbers are drastically larger than the 53 kips of force required so it is concluded that a HSS 4 ½ x 4 ½ x 3/8 piece of steel should be used for all cross braces on the 14' wide section of the stair tower.

Next, vertical loads must be accounted for. In the case of a stair tower, the live load can be assumed to be 70 psf. Due to the fact that the steel has not been sized yet, the dead load of the steel is assumed to be 30 psf. Then, on each member of the stair tower, there will be point loads from the beams that are being loaded on and supported by the steel in the stair tower. Rather than calculating the point loads of each of these beams, the assumption was made to say that the load of the beams to be supported by the stair tower will apply a 50 psf distributed force on the beams of the stair tower. The result of these vertical loads is a 150 psf load that will be applied to each level of the stair tower. This 150 psf load will be distributed over the span of the beam that it is acting on. In this case, the beam spans 14' therefore applying a 2.1 kip/foot distributed force on this member. This is shown in the figure below.

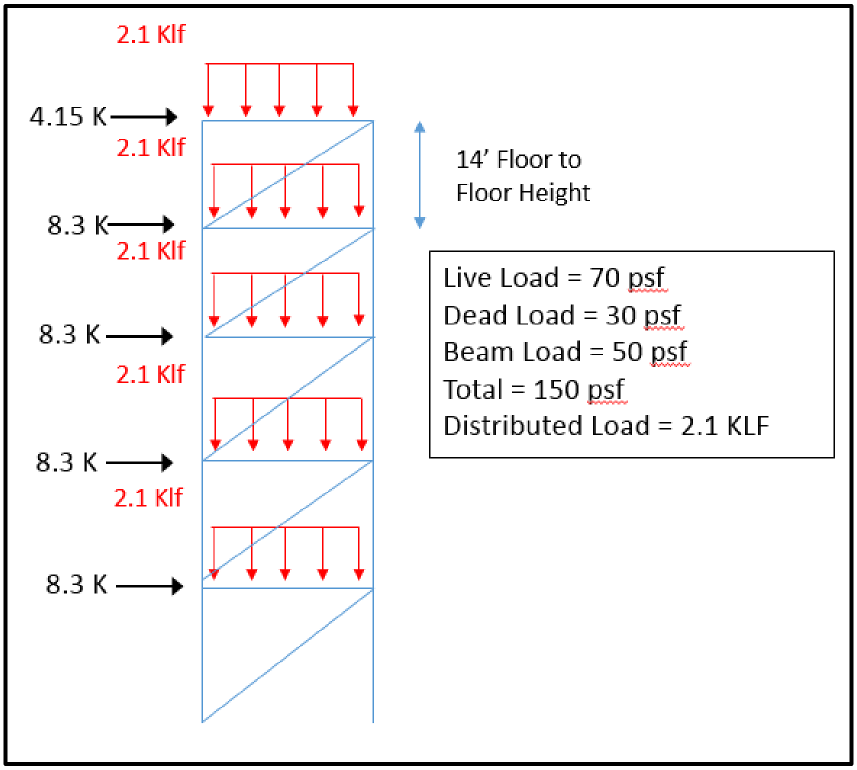


Figure 21 Load Calculations for 14' Wide Area of Stair Tower

These load values were then put into a structural design program called RISA. RISA technologies are a structural design firm which strives to provide the best structural design software in the industry. For this analysis, a simple 2D software program was needed. For this structure, all joints were considered pinned-pinned and the balance joints at the bottom of the structure were also pinned-pinned. The loads are added as shown for the entire structure, and the program provides the axial forces on each member of the structure. Now, in the case of this structure, the largest axial forces are seen on the lowest floor as these members are taking on the most amount of force due to the weight of the floors above.

When selecting a column size, there is a general common practice that is used in the industry today. Again, tension and compression will both need to be checked. In the case of the columns, it will be important to decide how tall the columns will be between splices. Typically, column splices are common every two to four floors, with two and four preferred over three. This is because OSHA limits the maximum elevation above a work platform to 30 feet. In a two-floor tier, the raising gang will erect the framing and the decking crew will deck the top level first. That will permit the raising gang to erect the next tier while the decking crew decks the intermediate floor. In a four-floor tier, it is somewhat similar. The raising gang will erect the first two levels of framing, and the decking crew will then deck the second level. The raising gang then continues with the third and fourth levels as the decking crew decks the first level. After that the decking crew decks the fourth level. As the raising gang continues with the next tier, the decking crew finishes by decking the third level. With these two options in mind, the two-floor tier system was chosen for this area. This is done due to the delivery of pieces of steel to the site. With a column splice on every two floors, 28' long pieces of steel will be brought to the site. This is a manageable delivery, but will still allow for a quick erection process. From a constructability standpoint, it is also good practice to have the same size columns the whole way up a building, especially a building of this size. This is to eliminate any type of confusion from the steel erector during the installation process. From a practical standpoint, the minimum column size is 8x31. This is governed by room for connections to beams and girders. Typically for a column, a W14 sized member is used. This is because W14 pieces splice well together. So, based on RISA model, the largest axial force acting on this column would be 177.2. In order to check for compression, the 28' length that was previously chosen will be used for the maximum length. Based on the steel manual, a 14x61 size wide flange would provide 215 kips of compressive strength. Testing for tension, this piece would provide 806 kips of yielding strength and 653 kips of rupture strength. So, the column will be split into 3 pieces (two 28' length and one 14' piece). This will require 3 splice plates similar to the ones shown in the figure below.

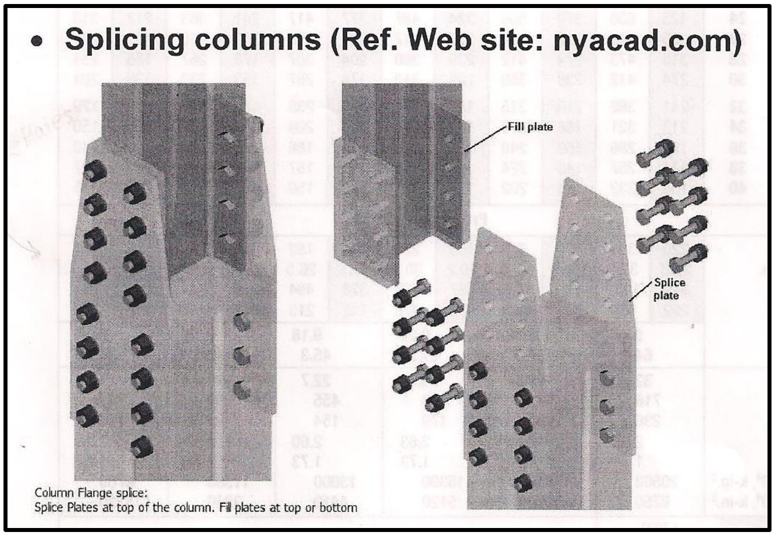


Figure 22 Colum Splice Plates Required

The next step is to size the horizontal beams between the columns. In the case of this structure, these beams are not very large due to the fact that the cross brace will help to take on the load that is applied laterally. Based on the RISA analysis, the largest axial force applied to the beams is 37.3 kips. With the reference of the steel manual, a W10x17 size member could be utilized as it will resist a maximum load of 40.1 kips. Hence, every horizontal member on the 14' side of the stair tower will be a W10x17 size beam.

The next step is to repeat this process for the 26 foot long side of the stair tower. Based on the wind load calculations, the stair tower's lateral forces include a 4 kip force on the top floor and 8 kips of force on each floor below that. This will result in a 36 kip resultant force to be used to analyze the cross braces. The same analysis shown in figure 20 will be used to find the axial force in the cross brace. This was found to be 40.89 kips. Then, utilizing the same process to check tension and compression, it was found that an HSS6x6x1/4 should be used for the cross braces of the 26 foot long side of the stair tower.

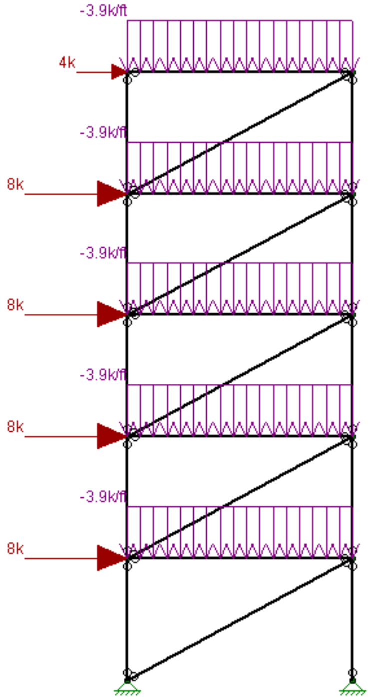


Figure 23 Stair Tower on 26' Long Side with Loads Shown (Generated from RISA program)

Next, the vertical loads will be accounted for the longer side of the stair tower. The same process was utilized in order to derive the loads. Each floor will have a 70 psf distributed live load, a 30 psf distributed dead load (assumed), and a 50 psf distributed load to account for the beams that it will support. When these loads are tabulated and multiplied by the span in which they act, it is found that a 3.9 plf distributed force will act on each floor. The figure here shows an image from the RISA program depicting the loads acting on each floor of the stair tower. Once the program was initiated, the axial loads on each member were derived in order to size the members. For the vertical columns, the largest axial force was found to be 307.3 kips. Based on the ideas that 28 feet is the maximum length to be used for the columns and structural columns are to have a steel member of W14 in order to easily splice, a W14x90 sized column is to be used. Checking for compression, this size member will resist a compressive force of 653 kips. Analyzing the member in tension, the piece will resist 1190 kips of yielding force and 970 kips of rupture strength. This means that the W14x90 sized column checks out with compressive and tensile forces and can be utilized for this system. Due to the fact that this column is sized to be larger than the columns designed for the shorter side of the stair tower, the W14x90 column will make up all four corner columns of the system. This is purely logical from a constructability concern and adds additional safety factors to the design. It is important for the erection crew to have some form of consistency when erecting the pieces. Having all 4 columns in this area the same makes their job easier and reduces the amount of mistakes that will be seen.

The next step will be to analyze the beams. The beams on this side of the stair tower span much further distances (26 feet). The larges axial force on these horizontal members was found to be 36 kips. Referencing the beam tables in the steel manual, it was found that a W10x30 would be able to be utilized for this member. The maximum load for a W10x30 is 42.2 kips.

One factor that would need to be diagnosed for the design of a steel braced frame is that of deflection. With a concrete stair tower, this analysis would not be necessary because concrete is so bulky and stiff that it is unlikely that the tower will deflect in any way. However, steel is different. The way that steel acts would cause the tower to lean in a certain direction. This is due to a process called building drift. This is shown in the figure here. The design of steel framed buildings must take into consideration the lateral drift of the structure due to wind loading. However, the scope of this analysis does not cover the deflection of this structure. However, it is understood that it would need to be taken into consideration. Due to the fact that the columns and beams were sized with a significant safety factor, the structure is assumed to have minimal deflection. Also, because the connections are to have shear plates, they will likely prevent a significant amount of deflection.

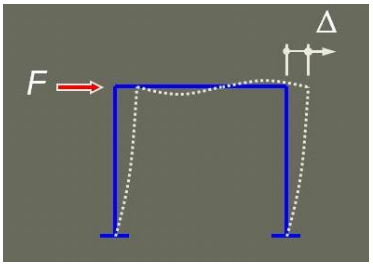


Figure 24 Building Drift (Image Courtesy of Google Image Search)

In summary, the columns will be sized at W14x90 at a maximum length of 28’. The horizontal beams on the short side of the stair tower will be sized at W10x17 with a span of 14 feet. The cross brace on the short side of the stair tower will be sized at a HSS 4 ½ x 4 ½ x 3/8 for all of the braces up the short side of the stair tower. The horizontal beams for the long side of the stair tower will be sized at W10x30. The cross braces will be sized at HSS 6 x 6 x ¼. The horizontal beams and the cross braces will be mirrored to their similar sides of the stair tower. This information, as well as lengths, is summarized in the table below.

Table 7 Steel Structure Summary of Members to be Utilized per the Design

Steel Design Summary		
Size	**Quantity**	**Length (ft)**
HSS 4-1/2 x 4-1/2 x 3/8	10	19.8
HSS 6 x 6 x 1/4	10	29.5
W14x90	8	28
W14x90	4	14
W10x30	10	26
W10x17	10	14

In order for this system to be designed properly, there are many different items that need to be considered. One of these items is whether the door can fit into the areas that the stair landings sit. This can be confirmed with a simple calculation of similar triangles. This calculation can be found in the figure below.

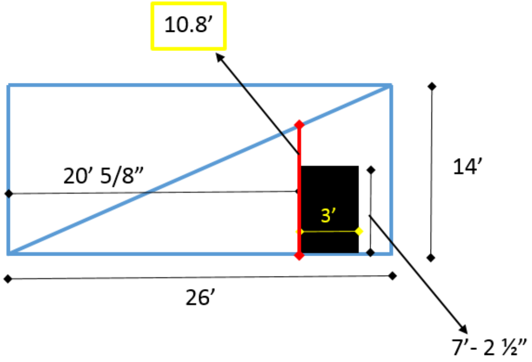


Figure 25 Dimensions to Ensure That the Door (Shown in Black) Will Fit With the Cross Brace in Place

As is shown in the figure, the door will fit and will actually have more than 3’ of room between the top of the door and the cross brace. The brace will have a maximum dimension of 6 inches, then accounting for the studs that will be placed in between for fill; there will still be plenty of room for the door to be put in place.

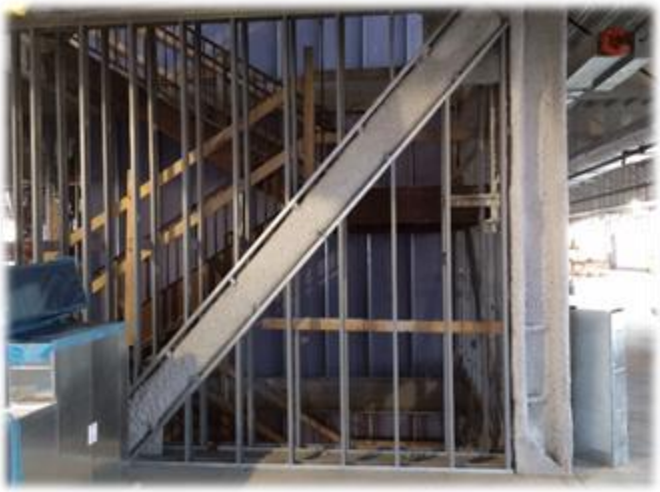


Figure 26 Stud Framing for Drywall Placement (Image Courtesy of David Walenga)

Another item that will need to be considered is the dimensions of the stairs. According to code, the width of the stairs shall not be less than 44”. The stair tower as designed has a stair width of 48”. This means that there is 4 inches of freedom on each side of the tower. Also, the landing must reach a minimum of 44”. As designed for the current system, the landing has a dimension of 48” as well. So, in every direction, the steel has an extra 4” of tolerance. The concrete in the current system has a thickness of 12 inches. Based on the steel that will be utilized in this system, the largest dimension of the steel is 14.52 inches in the flange for the 14x90 columns. This means that there will be an additional 2.52 inches in every direction compared to the concrete shear wall design. Even if a 5/8” piece of drywall were to be used on each side, the stairs would still be able to meet the code requirement. The last item that will need to be analyzed is the fill that will be associated with the steel design as compared to the concrete. With the concrete system, the concrete will be the final finish on the interior of the longer sides of the stair tower. As was previously mentioned, the finish of this concrete was a strong concern for the architect of the project. The concrete face turned out to have many different sized holes as well as honeycombing in certain areas. This has led to countless discussions of potentially putting up drywall around the stair tower or even painting the concrete to hide these marks. In fact, it was decided that the interior of the shorter side (aka where the landings are in place) will have a layer of drywall put in place. Also, the design calls for drywall to be placed around the entire perimeter of the stair tower. So, the only areas of concern would be the longer edges of the stair tower. With the steel design, the installation of the drywall will be done around the beams and columns. In order to place the track and studs into place, the floor slab will be extended out (minor change so very little cost additions). This idea can be seen in the figure shown here. As is shown, the floor slab is extended so as to allow for the stud track to be laid down and put into place. Also, the track is able to be attached directly to the fireproofed cross beam. The framing is done on both sides of the steel so as to allow for the drywall to be properly mounted on the stud framing. According to the USG Fire Resistant Assemblies manual, in order to achieve a two hour fire rating, the following structure will be needed with these requirements:

- ½" sheetrock fire code C core gypsum panels
- 2-1/2" 25 gauge steel studs 24" on center
- 1" Thermafiber SAFB
- RC-1 channel or equivalent on one side, spaced 24" on center
- Double layer gypsum panels screw-attached to channel, two layers screw-attached to steel studs
- Face layer joints finished

This structure has a thickness of 5", which can be tucked into the steel beams similar to the image shown in figure 25. Lastly, in order to provide proper fire proofing requirements, all beams and columns in the stair tower will include spray on fireproofing.

In order for this to be a proper analysis to benefit this project, cost and schedule will need to be analyzed. A takeoff was completed in order to estimate these values. For the steel braced frame design, there were three different items that were taken into account. The first item was estimated was the steel material. The estimate took into account the tonnage of the HSS steel due to the fact that the HSS steel was not found in the R.S. Means takeoff book. The cost per ton was provided by Massaro CMS and was estimated to be $3,000 per ton. The wide flange steel members were taken off by their lengths. A cost per lineal foot was provided by R.S. Means for each member. The W14x90 members were taken off as columns while the W10x30 and W10x17 were taken off as beams. With the labor and equipment included in the takeoff, a total cost for the steel installation was found. R.S. Means claims to have a taken into account the cost of installation of these pieces. However, it is safe to assume that the connections required at these pieces are not included. So, in order to account for the connections, 10% will be added to the takeoff. With this additional 10% added to the total cost of the steel installation, it was found that the steel would cost $75,965.44.

Table 8 Steel Design Cost Takeoff Based on R.S. Means and MCMS Data

Steel Design Summary												
Size	**Quantity**	**Length (ft)**	**Sum of Lengths**	**LB/LF**	**Lbs**	**Tons**	**Material Cost/LF**	**Labor Cost/ LF**	**Equipment Cost/ LF**	**Total/ LF**	**Cost/Ton**	**Total Cost**
HSS 4-1/2 x 4-1/2 x 3/8	10	19.8	198	19.82	3924.36	1.96					$ 3,000.00	$ 5,886.54
HSS 6 x 6 x 1/4	10	29.5	295	19.02	5610.9	2.81					$ 3,000.00	$ 8,416.35
W14x90	8	28	224	90	20160	10.08	$ 172.00	$ 2.86	1.59	$ 176.45		$ 39,524.80
W14x90	4	14	56	90	5040	2.52	$ 172.00	$ 2.86	1.59	$ 176.45		$ 9,881.20
W10x30	10	26	260	30	7800	3.9	$ 47.00	$ 4.99	2.77	$ 54.76		$ 14,237.60
W10x17	10	14	140	17	2380	1.19	$ 31.50	$ 4.58	2.54	$ 38.62		$ 5,406.80
												$ 69,050.40
											Add 10%	$ 6,905.04
												$ 75,955.44

The next item that was estimated was the fireproofing for the steel structure. As was previously mentioned, it was assumed that every piece of steel in the system needed to be fireproofed. R.S. Means estimates fireproofing based on a cost per square foot. In order to find the square footage, the steel members were assumed to be rectangular rather than the shape of the flange. This allowed for a surface area to be easily determined based on the sum of the lengths of the members of steel. The material, labor, and equipment costs per square foot were per inch of fireproofing that was applied. Based on the specifications of the project, two inches of fireproofing are required on the structure throughout the building. With these factors in place, a takeoff was completed and found that the fireproofing of the system would cost $7,939.27. This takeoff can be seen in the table below.

Table 9 Fireproofing Takeoff Based on R.S. Means Data

Fireproofing											
Size	**Quantity**	**Length (ft)**	**Sum of Lengths**	**Surface Length**	**Square Footage**	**Material**	**Labor**	**Equipment**	**Total**	**Inches**	**Total Cost**
HSS 4-1/2 x 4-1/2 x 3/8	10	19.8	198	1.5	297	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 724.68
HSS 6 x 6 x 1/4	10	29.5	295	2	590	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 1,439.60
W14x90	8	28	224	4.8	1065.49	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 2,599.80
W14x90	4	14	56	4.8	266.37	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 649.95
W10x30	10	26	260	2.7	705.47	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 1,721.34
W10x17	10	14	140	2.4	329.47	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 803.90
											$ 7,939.27

The final item that was estimated is the wall system that will act as the fill between the steel members. As was previously mentioned, the system will consist of a metal stud wall with a drywall finish. The system will obtain a 2 hour fire rating. In order to perform the takeoff, the lineal footage that the wall system will enclose will be estimated. The concrete system included the drywall finish already in the stair landing spaces and around the exterior of the stair tower. So the estimate for these areas is not included in this estimate. It was found that the 6" studs at 16" on center would make up 400 lineal feet of space. The drywall will be estimated at a square footage. With the fire rating requiring 2 sheets of 5/8" drywall taped and finished, it was found that the drywall that would need to be placed would take up 11,200 square feet of space. The last items to be estimated are the joint sealant and sound attenuation blanket. The joint sealant has the same lineal footage as the studs for the takeoff purposes. The sound attenuation blanket would only make up 4000 square feet of area. These items were then taken off by R.S. Means data as shown in the table below.

Table 10 Wall System Material Takeoff Based on R.S. Means Data

Material				
Description	**Quantity**	**Unit**	**Material Unit Cost**	**Total Cost**
6" Studs @ 16" O.C.	400	LF	30	$ 12,000.00
5/8" Drywall - Taped and Finsihed	11200	SF	1.52	$ 17,024.00
Joint Sealant	400	LF	0.3	$ 120.00
Sound Attenuation Blanket	4000	SF	0.44	$ 1,760.00
				$ 30,904.00

The labor for this system was taken off based on the number of days that it took to perform the work. As will be seen in the schedule takeoff later in the report, it was found that the installation of this system would require 20 days. With this in mind, the cost per day for the carpenter and taper and laborer was provided by MCMS. The cost of the labor for stocking the materials was based on the square footage of material that will be installed. This number was taken to be the largest square footage of material to be installed in the area: 11200 square feet. The estimate for the labor of the wall system is shown in the table below.

Table 11 Wall System Labor Takeoff Based on MCMS Data

Labor				
Type of Manpower	**Quantity**	**Unit**	**Cost per Unit**	**Total Cost**
Carpenter & Taper	20	MD	357.04	$ 7,143.02
Laborer	3.3	MD	273.12	$ 910.68
Laborer (stocking)	11200	SF	0.05	$ 560.00
				$ 8,613.70

In summary from a cost standpoint, the steel braced frame design of the stair tower cost significantly lower based on the estimates that were completed. In total, it was found that the steel braced frame system would cost $123,412.41 to install. This is summarized in the table below.

Table 12 Steel Braced Frame System Cost Summary

Summary for New Design	
Steel	$ 75,955.44
Fireproofing	$ 7,939.27
Fill (Framed Drywall)	$ 39,517.70
	$ 123,412.41

The main reason that the analysis was considered was because of the time that the concrete stair tower took to construct and the delays associated with not being able to pour concrete during the winter months of the project. So, an estimate needed to be performed to determine how much time would be saved if a steel braced frame was utilized as opposed to the concrete structure. The first item that was analyzed was the steel members. The HSS steel members were taken off based on the idea that the erector could install 30 tons per day. This number was provided by MCMS as R.S. Means did not provide information on hollow structural steel members. The wide flange members were taken off by the lineal footage that could be erected per size each day. This estimate fond that it would take 1.16 days to erect (about a day and 5 hours). The fireproofing schedule takeoff was determined based on the square footage that could be sprayed per day per inch. Based on R.S. Means, fireproofing for beams could be sprayed at 1500 square feet per day per inch. Based on the total square footage that would require fire proofing and the 2 inch fireproofing requirement, it was found that the fireproofing would require 4 and a half days. The 6" gypsum wall board partition wall was found to take 20 days to install. A summary of these items is shown in the table below. The full takeoff can be found in the appendix of the report.

Table 13 Steel Braced Frame Design Schedule Summary

Schedule Summary	
Item	**Duration (Days)**
Steel Members	1.16
Fireproofing	4.34
6" GWB Partition	20

Conclusion

The concrete stair tower was an item that needed to be addressed for this project for many reasons. Installation of this concrete system was a major schedule concern as it took over 5 weeks to construct and ran into delays due to the inability to pour concrete during the winter months. From a quality standpoint, the stair tower did not provide the type of finish that was required by the architect and the owner of the project. Lastly, the concrete structure caused many issues from a coordination standpoint. A survey was completed that showed that the concrete stair tower was not constructed plumb. In fact, it actually twisted 3 inches in some areas. This caused major constructability concerns for the steel erector. The steel erector needed to cut pieces in some areas and extend pieces of steel in other areas. Overall, the steel braced frame would solve these issues and would provide a better quality product at the turnover of the project. From a schedule standpoint, the steel braced frame will require a little over 1 day to lift the members into place. Although R.S. Means claims that this number would include the time required to bolt the members together as well, it is safe to assume that it would take longer than 1 day. However, it would not be much more than 2 days maximum for the bracing of this structure. This would improve the project schedule because it will allow for the remaining of the steel structure to be put in place. Although the rest of the items (fireproofing and wall fill) will sum to equate the amount of time for the concrete structure, these items are not critical to the project schedule. From a quality standpoint, the structure will be filled with drywall as opposed to the concrete face finish. Therefore, it will have an improved appearance. From a coordination standpoint, the steel erector will be installing all of this work, so there will not be any concern with the cutting or extending of pieces. Lastly, the cost estimate proved that the steel structure was significantly cheaper than the concrete structure. In fact, the steel structure cost $121,398.29 less than the concrete stair tower. This is a significant cost saving for the project. With all of these items considered, it is safe to say that this analysis proved that the stair tower with the steel structure would be the best system to build for this project.

Analysis 2 – Re-Sequencing of Atrium Systems

Problem Identification

A major constructability concern for the project is seen in the atrium of the building. The major issue in the area is the concern for the material finishes being installed. In the atrium, there will be a very elaborate staircase put into place as well as an architectural screen wall. The staircase, also known as stair C, will be finished with slate treads and will have elaborate glass features. The architectural screen wall system will be finished with wood panels. The problem lies in the fact that these finishes from both systems required a tempered environment. This means that the building would need to be entirely enclosed. This presents an issue with the constructability of these systems. Typically, a crane would be brought in and the prefabricated pieces will be raised into position. However, if the building is completely enclosed, the pieces for the screen wall and stair C will not be able to be lifted into place by crane. Rather, lifts and scaffolding will need to be used to put the pieces into place. Coordinating where these lifts can be placed in between the scaffolding will be a challenge.

Another problem with this area is the fact that there will be a large amount of work being performed in a small area between many different trades. As is shown in the figure here, the architectural screen wall contractor has elected to use its means of placing the work as scaffolding. According to the project schedule, the stair will be put in place without its finishes, then the scaffolding will be erected and the screen wall will be installed. While the scaffolding is erected and the screen wall installation is going on, the slate treads will be in place and will need to be maintained throughout the process of other work being completed in the atrium space. This creates major concerns from a schedule standpoint and a quality standpoint. With the amount of work being completed in a small space, congestion will occur. It is assumed that this will cause schedule delay due to coordination concerns. From a quality standpoint, it will be important to carefully monitor the ongoing overhead work. With the finishes being installed in place with large amounts of work being done and with scaffolding being erected, it will be very difficult to keep the finishes clean and unharmed.

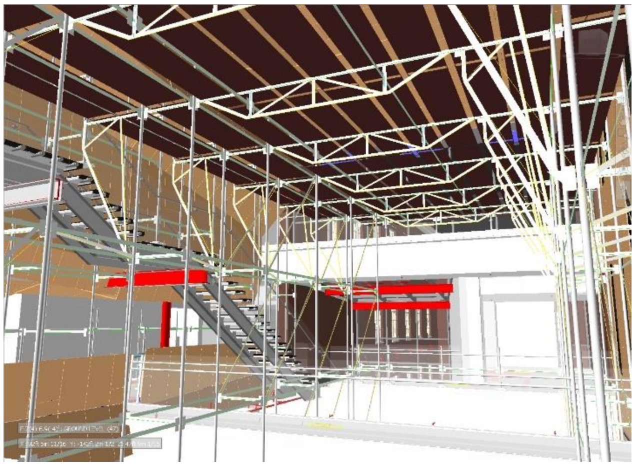


Figure 27 Atrium Space Depicting Congestion of Scaffolding, Stair Installation, and Architectural Screen Wall

The last issue regarding this space is safety. When working with large pre-fabricated pieces, it is important to establish a system that works in an efficient manner and is safe for employees to install. The scaffolding equipment will be a major safety concern as workers will be at the top of the scaffolding while other work will be going on underneath them. Also, where the scaffolding will be installed, workers will be installing the wood panels from an overhead position that would be difficult to reach without any type of ladder. This would then mean that a ladder would be required on top of scaffolding planks, requiring larger safety coordination tactics. Also, the maneuvering of the scissor lift within the scaffolding equipment will need to be carefully monitored to ensure that it does not disturb the scaffolding in any way.

Goal

This analysis will explore the different options for sequencing the work being completed in the atrium space. Each option will be analyzed for safety, schedule, and quality of work being installed. This will relate to the construction triangle that was discussed earlier in the report and will coordinate directly with the owner's needs and requirements. The goal will be to establish the safest, most efficient method of installation for both the stair and the screen wall.

Process

In order to perform this analysis, there are many factors that need to be considered. The atrium space will have many activities ongoing at the same time. However, for this analysis, the main focuses will be stair C, the architectural screen wall, and the scaffolding. This will simplify the sequencing process and will provide a better visual through the 4D schedule.

Creating a 4D schedule can be very challenging for a project. However, implementing the use of a 4D schedule has many benefits for the project team. 4D modeling combines 3D computer-aided design with time. The process is shown in the figure below.

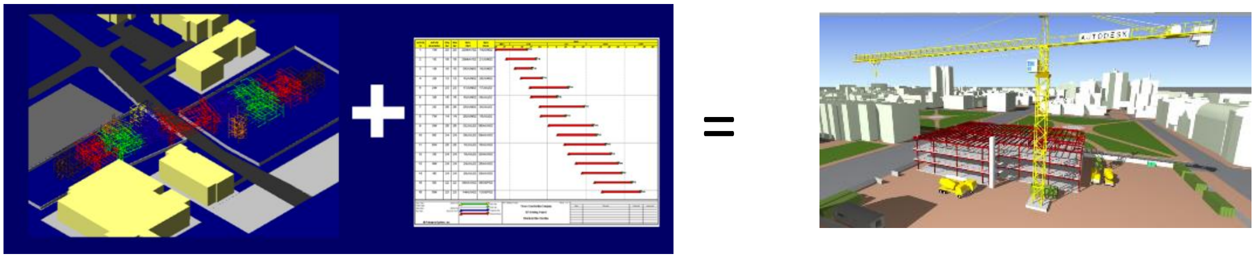


Figure 28 4D Scheduling Combines 3D Model with a Schedule

Different ways it can be used are as followed:

- Equipment and Crew Planning
- Temporary Facilities Planning
- Work Flow Planning
- Steel Sequencing

- Façade Sequencing

It has already been seen how BIM models can provide benefits for visualizing how the project will look and coordination of items. However, 4D scheduling is improving construction technology even further. 4D modeling allows project teams to visualize construction plans, identify construction consequences and space conflicts, identify safety issues, and improve communication of the project team members. This new technology has even been seen to go as far as to provide general contractors with information to assert detailed quantity takeoffs, location-based quantities, resources, productivity rates, and labor rates into the Building Information Model. Integrating human resources, equipment, and material resources with the BIM model, 4D scheduling helps to better schedule and estimate costs of the project. 4D BIM can also assist in monitoring procurement status of project materials. Although BIM can have a remarkable impact to a project, it is important to ensure that time will not be wasted. With BIM coordination, there are many high level people gathered in a room over a long period of time. Meetings could take many hours and it is important that time is utilized correctly so as to not waste time and money.

Before developing the 4D schedule, it is important to determine which areas will need to be studied. The analysis will take a look at how the materials can be brought in. Then, the sequencing of stair C, the scaffolding, and the architectural screen wall will be studied. In order to do this, a schedule will need to be created. The schedule will need to be developed based on the activities provided by the project schedule. From the main tasks of stair C installation, scaffold erection, and screen wall installation, the activities are broken down into more detailed tasks. This is because these processes are very complex. The figure shown here shows the arrangement of the screen wall in relation to the stairs and as can be seen, it will be very difficult to place this work if proper planning is not done.

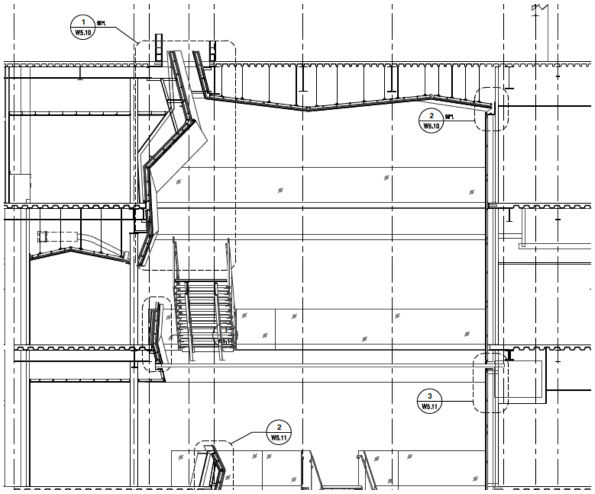


Figure 29 Section Cut through Atrium Space Showing the Architectural Screen Wall Flow and Locations

The first breakdown will be done for the activities involved with the installation of stair C. This process is made up of 4 different tasks. In order to complete the installation of stair C, the project team has scheduled out 4 main activities. These activities include the physical installation of the stair, painting the stairs, installing the slate treads, and installing the glass handrail. Slate tread installation is the longest duration activity in the process. The table below shows the activities for the installation of stair C with their durations.

Table 14 List of Stair C Schedule Activities

Stair C Schedule Acivities	
Activity	**Duration (Days)**
Stair C Install Level 1-2	10
Stair C Install Level 2-3	10
Stair C Install Level 3-4	10
Stair C: Paint Levels 1-2	4
Stair C: Paint Levels 2-3	4
Stair C: Paint Levels 3-4	4
Stair C: Slate Treads 1-2	12
Stair C: Slate Treads 2-3	12
Stair C: Slate Treads 3-4	12
Stair C: Glass Handrail 1-2	5
Stair C: Glass Handrail 2-3	5
Stair C: Glass Handrail 3-4	5

Next, the scaffolding activities will be analyzed. In this area, the erection of the scaffolding will be a very complex task and will require a large amount of coordination. The way that the scaffolding could be erected is an item that will be analyzed immensely in this analyses. However, from a schedule standpoint, this is a very simple task. Really, there are only two items that are necessary for the sequencing of scaffolding. These two items are: erect scaffolding and tear down scaffolding. Based on the project schedule, all of the scaffolding is put up at once and all of the scaffolding is torn down at once. This is an item that will be looked at and different options will be proposed. However, based on the information that is provided, the activities and durations are shown in full and that information is shown in the table below.

Table 15 List of Scaffolding Schedule Activities

Scaffolding Schedule Activities	
Activity	**Duration (Days)**
Erect Scaffolding	10
Tear Down Scaffolding	5

The last set of activities that will be studied is the architectural screen wall activities. These activities are very complex as they require a significant amount of work. The figure here shows a detail of one of the connections for the architectural screen wall with the wood finish. As can be seen, there is a significant amount of work that will need to be completed before the actual installation of the panels can begin. The drawing shows that this work will be completed by a separate contractor than the one installing the screen wall itself. This information was ignored for this analysis because the work does not need to be completed in a tempered environment, meaning that the work can be installed by any means necessary (crane, lift etc.). Also, because the work is being completed by a separate contractor, there should not be any type of schedule concern as far as man power required by the architectural screen wall contractor. However, it will be important that the contractor installing the framing behind the screen wall coordinate with the screen wall contractor to ensure that the schedule is not delayed due to the framing not being completed. Now, with the installation of the screen wall itself, there are really only two activities: Framing for the panels and the installation of the wood panels to the framing. The process for the installation of the screen wall is as followed:

1. 2 ½" metal stud framing at 16" on center is attached to the structural steel put in place.
2. Maple veneer over ¾" thick framed wood panels with built-up edging are tied into the stud framing.

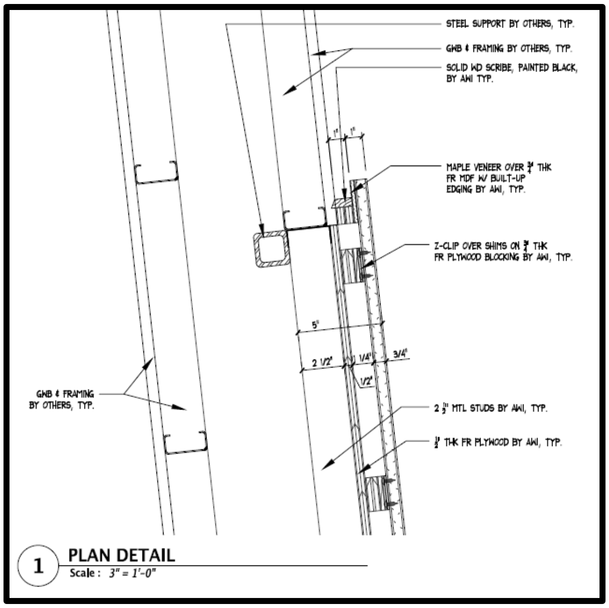


Figure 30 Detail of Architectural Screen Wall showing how the Screen Wall is attached to Stud Framing

The way that the screen wall is installed is fairly simple process, but it requires different contractors. This means that strong coordination efforts will be required. Structural steel is installed by Kinsley Construction, the steel erection contractor. The floor assembly is installed by Leonard S. Fiore, the general contractor. The stairs are installed by Cohen. The stair contractor needed to be hired as an independent contractor strictly for the installation of the stairs due to their complexity. A.W.I. is the screen wall contractor and will install the maple veneer and metal stud framing that will be tied into the structural steel. As the schedule suggests, the structural steel and floor assemblies will be complete far before the time any work in the atrium space is performed. So the only activities required for this analysis are the installation of the metal stud framing and the installation of the wood panels. These are summarized in the table below.

There are 4 steps required to develop a 4D model. The first step is (1.) develop/obtain a 3D CAD model. Fortunately, for this analysis, a 3D model was provided by the project team. The second step is (2.) develop/obtain a construction schedule. The analysis will reference the project schedule while creating activities specific to the area that is being studied in the atrium. The third step is to (3.) use 4D CAD software to link #D objects to schedule activities. In this case, the program that will be used is called Navisworks. The last step is (4.) perform analysis and develop presentations. The software will be used to compare speed, safety, and coordination. An animation will be developed to clearly visualize the sequencing work flow.

The activities will be imported into Microsoft Project to create a schedule based on the option selected. Once the schedule is complete, the schedule will be linked into the Navisworks model. Within Navisworks, different sections will be grouped into construction sets based on the sequencing plan established. From here, each task on the schedule will be assigned to a particular construction set from the model. Once these items are linked, the model will be created to construct the sets in accordance with the Microsoft Project file that was linked in. Then, an animation file can be created in order to provide a proper visual of how the atrium area will be sequenced. The Navisworks model provided by the project team will be analyzed. Within Navisworks, different sections will be grouped based on the sequence selected. Once the sequences are completed, the options will be analyzed for speed, safety, and coordination.

The last area that will be analyzed is how the items will be brought in to the atrium space to be lifted into place. The idea of bringing the items through the curtain wall systems or through the skylight will be analyzed. In order to do this, the items will be measured for size to ensure that they will fit into the areas and the schedule sequencing will be affected by this.

Results

There will be three options that will need to be analyzed. The first area that will be analyzed is how the materials will be brought into the atrium space. The curtain wall is the ideal area in which the pieces could be brought in. The south curtain wall is 45' long and is broken up into 5 sections as shown in the figure below.

Figure 31 Atrium South Curtain Wall with a Width of 45 feet

Now, in order to ensure that this option would be a possibility, it will be important to understand which items will need to be imported into the curtain wall system. There will be 3 main material systems that will need to be brought into the area. These systems are the stairs, the curtain wall, and the scaffolding. These systems are then broken up into their components and studied based on their size and when they are to be installed based on the schedule. Analyzing the schedule, it is found that the stringers of the stairs for level 1-2 and for level 3-4 will be brought into the atrium space before the curtain walls are done. This means that these pieces will be able to come into the atrium through the curtain wall. Based on the design, there will be more room provided on the south side of the curtain wall. The stringers will need to be brought into the space in sections. The steel members of the curtain wall (spaced every 9') will already be in place so it will be critical to prefabricate the stringers so that they can be brought into this space through the south curtain wall and lifted into place. Because this area will be open up to the skylight, a small crane will be able to be utilized in order to lift these pieces into place. It is likely that these pieces will be spliced at the landings similar to those shown in the figure here. These pieces are estimated to be about 12 feet in length. This should easily be able to be brought into this section as the floor to floor heights are 14 feet.

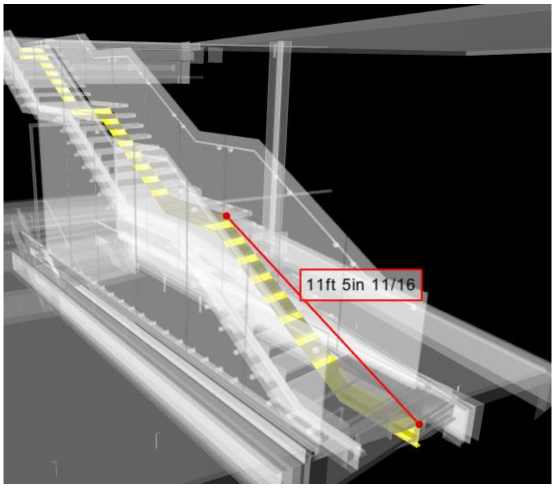


Figure 32 Atrium Stair Stringers Projected Distance Between Splices

Once the stringers from L1-2 and L3-4 are put into place, the curtain walls on the north and south end are put into place. Also, the skylight on the roof of the building will already be in place. So, the question becomes how to bring in the stairs from L2-3. One option would be to bring the stringers into the atrium space before the curtain walls are enclosed and staging them somewhere in the space until they are ready to be placed. However, the erection of the scaffolding will be done before it is installed so the area will be very congested. The option that will be utilized is that the stringers for this section will be brought into the space in small pieces through a set of double wide doors in the west side of the building. These sections are estimated to be about 12' long. This could be a challenging item to manage and the options will be analyzed in order to derive the best option. The stair treads will also need to be brought in, but they are small enough that they can be transported through a door either in the atrium space or on the west side of the building.

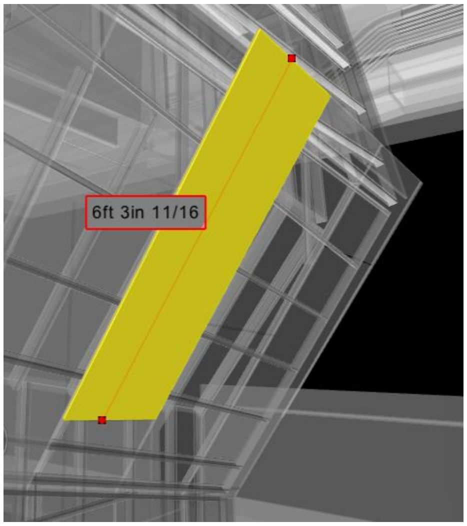


Figure 33 Architectural Screen Wall Wood Panel Dimensions

The other items that will be analyzed will be the wood panels for the screen wall, the studs for these sections, and the scaffolding. All of these activities will also be put into place after the curtain wall is put into place. The sizes of these items were analyzed, and it was found that it would be possible for these materials to be brought in through the same set of double doors that the stairs will be brought in through. The wood panels, as shown in the figure shown here, have a maximum length of a little more than 6 feet. This is presented in the image shown here. They have a typical width of about 2 feet. So, these are small enough to be brought in with a dolly through a set of double doors. The stud framing that they will be placed on can be brought into the area with several different methods. The studs can be brought in on a pallet before the curtain wall is closed and stored in a distant location. A room could be designated for prefabricated framing sections. However, it will be important to ensure that these sections can be transported from the room back to the atrium area. Also, it will be important that the prefabricated sections could be lifted into place with some type of machinery. The last item that will need to be analyzed is the scaffolding. The scaffolding will be brought into the area through the double doors as well. It would make sense to bring in the large pieces through a loading dock of some sort, but due to the tempered space requirements for the high-end finishes, this is not feasible and they need to be brought in through a door that is placed in some location. The figure shown here displays a rendering of how the atrium space will appear once the finishes are in place. The next sections will examine the three different options that could be utilized for the sequencing of these materials for installation in order to analyze the speed, safety, and coordination of this space. Each category will be rated on a scale of 1 to 3, with 1 being the lowest grade and 3 being the highest grade. This will help to put a quantifying number to a qualitative analysis.

Option 1

The first option that will be analyzed is the current design of the project. The current design utilizes a sequencing scheme to save time by performing multiple activities concurrently. The first items that will be performed is work on the stairs on the south side of the atrium space. The stringers for the stairs from levels 1-2 and 3-4 will be done first. Then, the treads will be put on both of these areas. These treads will be made of slate and will need to be protected throughout the project. Scaffolding will then be put in place on the north and south sides of the atrium. Planks will be put on the top level of this scaffolding and workers will be supported by these planks as they work overhead. Once the scaffolding is in place, the north stair from level 2-3 will constructed. The screen wall will be built by utilizing a top-down method. This means that the screen wall contractor will erect the screen wall at the ceiling and work down the sides of the atrium with the panels. In order to construct the panels, stud framing is attached to steel that is already put in place in the building. Then, the wood panels are attached to the stud framing. With the top down method, the screen wall contractor will get to the top of the scaffolding and work off of the planks to erect the screen wall located on the ceiling. This area can be visualized in the figure shown here. As is seen, the planks will support the workers that will be utilizing the space to put the framing and wood panels into place. However, the way that this scaffolding is designed, the workers will need to use some type of ladder on top of the planks. This will be a major safety concern. Another way to perform this work will be to utilize lifts that will extend all the way up to the ceiling space (close to 60 feet). This would require for parts of the planking to

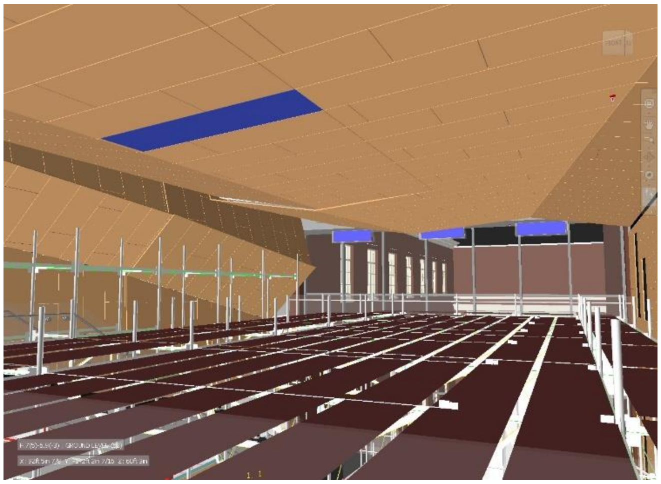


Figure 34 Planks Shown on the Top Level of the Scaffolding

be left out so that the lift can fit through the area. This will require a significant amount of coordination between the trades on the project. Once the ceiling area east of the skylight is completed, the stair contractor will install the north stair treads from levels 2-3. As was previously mentioned, bringing these stairs into the atrium will be a challenging process for the project team because the curtain wall will be constructed and the area will be entirely enclosed. Once these stairs are brought in, it will be a challenge to erect them with the scaffolding in place. The scaffolding would need to be erected so that there will be room to erect the stringers for stair C. With the scaffolding still erected, the screen wall west of the skylight will be constructed. The schedule shown here depicts the areas in which the screen wall is broken up. Due to the complexity of this screen wall, it needed to be broken down into smaller sections. The schedule shows all screen wall activities in green with the sections divided into their locations from a vertical standpoint as well as their orientation as north or south. The north stair treads will be installed as the screen wall is being constructed and while the scaffolding is still in place. With the wood panels and slate stair treads installed with such construction congestion, it is going to be very difficult to maintain a quality product throughout installation. Once the scaffolding is removed, the glass handrail will be installed for the stairs. The glass handrail will be in place while additional screen wall is performed. Constructing the screen wall should be a very clean process. However, with any overhead work, there are safety concerns. Also, the studs will need to be cut so they can be put into place.

Table 16 Option 1 Atrium Sequencing Plan

Current Design (Option 1)	
Activity	**Duration**
South Stair 1-2	10
South Stair 3-4	10
South Stair Treads 1-2 and South Stair Treads 3-4	17
Scaffolding North and Scaffolding South	8
Plank North and Plank South	2
North Stair 2-3	10
Screen Wall South Ceiling Framing and Screen Wall North Ceiling Frame and Screen Wall South Ceiling Framing 2	10
Screen Wall North Ceiling and Screen Wall South Ceiling	21
Screen Wall East of Skylight South Framing and Screen Wall East of Skylight North Framing	4
Screen Wall East of Skylight South and Screen Wall East of Skylight North	7
North Stair Treads 2-3	12
Screen Wall West of Skylight South Framing and Screen Wall West of Skylight North Framing	5
Screen Wall West of Skylight South and Screen Wall West of Skylight North	8
Screen Wall West Upper Middle South Framing and Screen Wall West Upper Middle North Framing	5
Screen Wall West Upper Middle South and Screen Wall West Upper Middle North	8
Remove Scaffolding	5
Glass Handrail 1-2.5 and Glass Handrail 2.5-4	16
Screen Wall West Lower Middle South Framing and Screen Wall West Lower Middle North Framing	3
Screen Wall West Lower Middle South and Screen Wall West Lower Middle North	5
Screen Wall East Middle South Framing	2
Screen Wall East Middle South	4
Screen Wall West Lower Framing	3
Screen Wall West Lower	5

Based on this analysis, the schedule, safety, and coordination assessment can be completed. The project team decided to utilize this option in order to save time on the schedule. They were able to accelerate the schedule by performing multiple activities concurrently. For example, the north stairs were to be installed as the screen wall was erected. However, with this procedure, there are many concerns from a coordination standpoint. With these activities being performed simultaneously, it will be difficult for the contractors to not be “stepping on each other’s toes”. With the scaffolding taking up the entire atrium space, there will not be any open space for the stair contractor to have work space and staging space. So, from a coordination standpoint, this is a difficult option to utilize for contractors performing the work. From a safety standpoint, the scaffolding workers will have a significant amount of room to work off of to safely complete the overhead work. However, the workers below the scaffolding will be performing their work with scaffolding set up above them. This is similar to having steel lifted overhead while work is being performed. This could be a major safety concern. So, based on the 1-3 scale of grading the options, the following grades were given to option 1.

Table 17 Grading Scale Given to Option 1 of Atrium Sequencing

Option 1	
Category	**Grading**
Safety	2
Coordination	1
Speed	3

Option 2

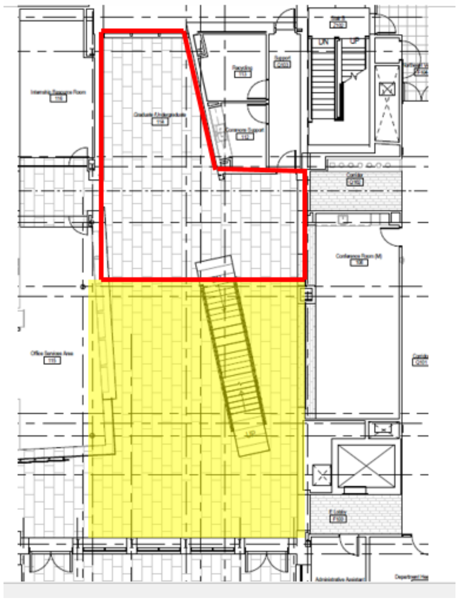


Figure 35 Option 2 Atrium Sequencing Plan Layout

The second option for the sequencing of this area will analyze the possibility of splitting the atrium space in half and performing the work separately as opposed to concurrently. This option will add additional time to the schedule, but it will provide a higher level of safety as opposed to option 1. Also, the amount of coordination required between trades will be decreased significantly as everyone will have their own separate space. Due to the need for the south stair stringers to be brought in through the atrium, they need to still go in place first. The stairs and treads will be put on sequentially. Once the south stairs are put in place, the curtain wall will be enclosed so that the space can be tempered. Then, the scaffolding will be erected on just the south side of the area. This would typically be assumed to take half the time that it would be required if the full scaffolding set was put in place, however, the 8 day duration that was associated with the scaffolding erection in option 1 includes a learning curve that would be associated with the continuous process. So, in this situation a 5 day duration would be sufficient to erect the south area scaffolding equipment. The planks would then be put up on top of this section. With the scaffolding in place on the west side of the atrium space, the workers will then be able to put up the framing for the ceiling screen wall on the south side. With the planks and scaffolding only set up on the south side, lifts will easily be able to transport materials up to the planks on the top of the scaffolding. This is shown in the figure here. The yellow space displays the area that will be occupied by scaffolding equipment. The stairs will be in place as shown. The area outlined in red shows the area that will be unoccupied. With this layout, the north stair stringers could actually be brought in prior to the curtain wall being enclosed in. This will cut down on the headaches that would occur from having to bring these large pieces of steel in through a set of double doors. As is shown, there will be plenty of space to stage the stair stringers in the outlined area as work is being performed on the south side of the area. In fact, the stairs could actually be put in place as well so that all of the stairs are put in place. This could be done while the architectural screen wall work is being performed with the scaffolding equipment on the south side. Once all of the work on the south side that requires the scaffolding equipment is completed, the scaffolding will be taken down. Then, the scaffolding equipment will be erected on the north side of the atrium space. The scaffolding in this space will allow all of the work in the north area of the atrium to be completed with the scaffolding. The treads will still need to be protected in the north and south areas of the atrium, but more space will be provided for materials to be transported up and down in the space. Also, coordination of trades will be less of an issue as the items will be put in place separately. Although this will provide a better quality product and create less headaches for the coordination of trades. The full schedule for this option is shown below.

Table 18 Atrium Coordination Option 2

Option 2	
Activity	**Duration**
South Stair 1-2	10
South Stair 3-4	10
South Stair Treads 1-2 and South Stair Treads 3-4	17
Scaffolding South	5
Plank South	1
North Stair 2-3	10
Screen Wall South Ceiling Framing	6
Screen Wall South Ceiling	11
Screen Wall East of Skylight South Framing	2
Screen Wall East of Skylight South	4
North Stair Treads 2-3	12
Screen Wall West of Skylight South Framing	3
Screen Wall West of Skylight South	5
Screen Wall West Upper Middle South Framing	3
Screen Wall West Upper Middle South	5
Remove Scaffolding South	3
Glass Handrail 1-2.5 and Glass Handrail 2.5-4	16
Screen Wall West Lower Middle South Framing	2
Screen Wall West Lower Middle South	3
Screen Wall East Middle South Framing	2
Screen Wall East Middle South	4
Scaffolding North	5
Plank North	1
Screen Wall North Ceiling Framing	6
Screen Wall North Ceiling	11
Screen Wall East of Skylight North Framing	2
Screen Wall East of Skylight North	4
Screen Wall West of Skylight North Framing	3
Screen Wall West of Skylight North	5
Screen Wall West Upper Middle North Framing	3
Screen Wall West Upper Middle North Framing	5
Remove Scaffolding North	3
Screen Wall West Lower Middle North Framing	2
Screen Wall West Lower Middle North	3
Screen Wall West Lower Framing	3
Screen Wall West Lower	5

As is seen, this option will add significant time to the schedule, but this may be the best option from the owner's perspective. Penn State strives to build buildings that are of the highest quality. They pride themselves on building structures that will last 100 years. In order to construct a set of items such as these, it is important that they be installed correctly. This option was given a set of grading criteria in order to compare it to option 1. This grading system is shown below.

Table 19 Grading System Given to Option 2 of the Atrium Sequencing

Option 2	
Category	**Grading**
Safety	3
Coordination	3
Speed	1

Option 3

The last option that will be analyzed includes a change in sequencing for the curtain wall. In the case of the previous options, the curtain wall on the south wall will be finished once the stairs are put in place. In option 1, the wall is put up once the stringers of stair C for levels 1-2 and 3-4 are put in place. However, the area of stair C from level 2-3 will need to be brought in through an exterior door and brought into the area. Option 2 shows that the section of stair C from 2-3 can actually be staged inside the area until it is time to be erected into place. Option 3 will utilize the idea of installing all of the stair areas first. This includes installing the levels in order from 1-4. In fact, the option of prefabricating the entire stair could be utilized to be brought into the space without impacting the critical path of the space. The big impact here is that the finishes of the area would not be able to be put in place into the area is tempered. Enclosing the building would be the next item on the critical path. With the stairs in place, scaffolding can be erected as the other options suggest and items can be brought into the space and staged before the building is enclosed. The scaffolding will need additional coordination in the space as it will need to be erected around the stairs that will be in place. Also, the lifts will need to have designated areas where they can go up and down to avoid the scaffolding and stair areas. This idea can be seen in the figure here. This image is a view of the top floor plan of the atrium space with stair C finishing at the 4th floor. The areas marked in blue are the areas in which scaffolding can be erected with planks on top. The area marked in red is a potential area for the lift to be put so that materials can be delivered up to the planked section of the scaffolding. Safety requirements will be needed (i.e. guardrail preventing a 200 pound force) around the area. The remaining items in the schedule will be performed in the same fashion (top-down method). A schedule was created for this option and can be seen in the table below.

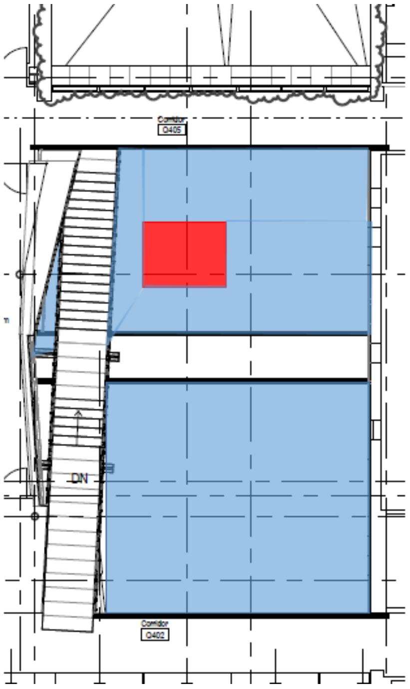


Figure 36 Atrium Space Showing in Blue Where Planks can be Placed for Scaffolding and Where Lifts can Transport Materials in Red

Table 20 Atrium Coordination Option 3

Option 3	
Activity	**Duration**
South Stair 1-2	8
North Stair 2-3	8
South Stair 3-4	8
Scaffolding North and Scaffolding South	8
Plank North and Plank South	2
Enclose Curtain Wall	
Screen Wall South Ceiling Framing and Screen Wall North Ceiling Frame and Screen Wall South Ceiling Framing 2	10
Screen Wall North Ceiling and Screen Wall South Ceiling	21
Screen Wall East of Skylight South Framing and Screen Wall East of Skylight North Framing	4
Screen Wall East of Skylight South and Screen Wall East of Skylight North	7
Screen Wall West of Skylight South Framing and Screen Wall West of Skylight North Framing	5
Screen Wall West of Skylight South and Screen Wall West of Skylight North	8
Screen Wall West Upper Middle South Framing and Screen Wall West Upper Middle North Framing	5
Screen Wall West Upper Middle South and Screen Wall West Upper Middle North	8
Remove Scaffolding	5
Screen Wall West Lower Middle South Framing and Screen Wall West Lower Middle North Framing	3
Screen Wall West Lower Middle South and Screen Wall West Lower Middle North	5
Screen Wall East Middle South Framing	2
Screen Wall East Middle South	4
Screen Wall West Lower Framing	3
Screen Wall West Lower	5
South Stair Treads 1-2 and South Stair Treads 3-4	17
North Stair Treads 2-3	12
Glass Handrail 1-2.5 and Glass Handrail 2.5-4	16

This option would ensure that the stair treads on the stairs were not harmed in any way during the construction of the project as well as allow the stair contractor to install the stairs right away and be out of the area. However, there are many other items that will provide difficulties in this space. The first of which is that the curtain wall will now be thrown into the mix as construction for that space will be ongoing. Also, the coordination of the trades to erect the scaffolding with the stairs in place will be a challenge. With the stair stringers in place early, the stair contractor is then stuck waiting until the space is done to come in and put the treads on. These are all items that pose a challenge with this option. Although the schedule could be accelerated in the beginning by installing all 3 sections of the stair at first, enclosing the curtain wall needs to be done before any other work can begin. A grading scale was given to this option and can be seen below.

Table 21 Grading System Given to Option 3 of the Atrium Sequencing

Option 3	
Category	**Grading**
Safety	2
Coordination	2
Speed	2

4D Simulation

Each option was analyzed to determine the implications of safety, coordination, and speed. These items were able to be quantified into a grading system in order to provide some type of data information that could be analyzed. However, these were very difficult to visualize aside from the schedule provided for each option. So, a 4D simulation was performed in order to provide a better picture of how the sequencing of the atrium area would be performed. The simulation was performed for option 1 due to the fact that the project team wanted to also have this information for the sequencing plan that they had decided to utilize. As was noted, option 1 utilizes a plan in which the schedule can be accelerated so as to save time. However, the plan would require a significant amount of coordination among trades. Hence, it is beneficial to see when the items are to be put in place and what will already be in place when the construction begins. The 4D simulation was set up in the same fashion as the schedule was organized. The simulation focuses strictly on the major items that were discussed in this analysis and hides everything else in the building. Due to the fact that a video simulation can not be put into this document, snap shots of each major phase are shown with the item installation listed below. This process is shown here:

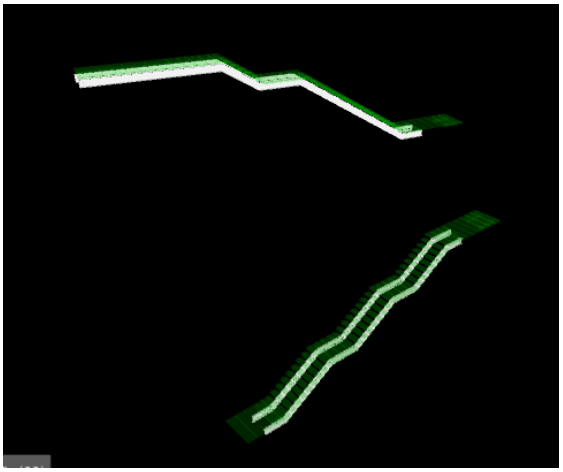


Figure 38 Installation of Stair Treads Levels 1-2 and 3-4

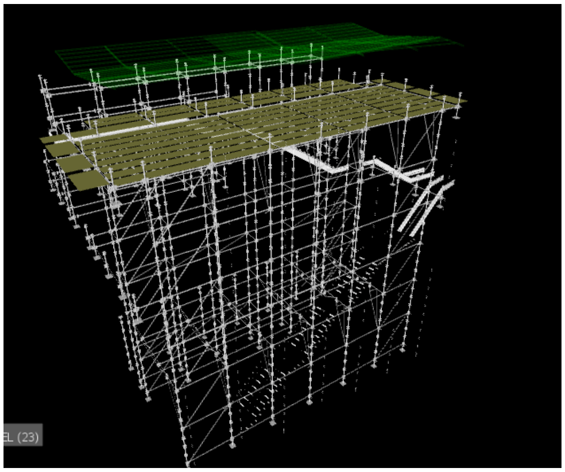


Figure 37 Scaffold Erected with Planks and Ceiling Framing to Begin

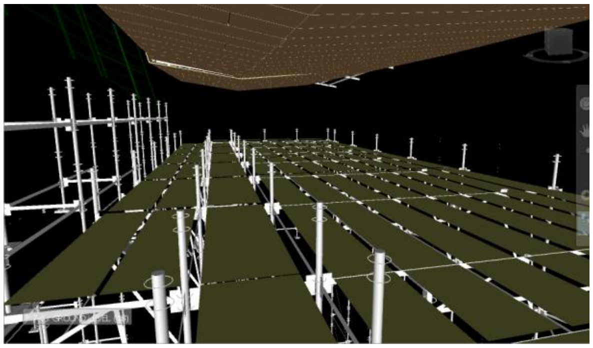


Figure 39 View from on top of the scaffolding where wood panels will be installed. Framing west of the skylight is started

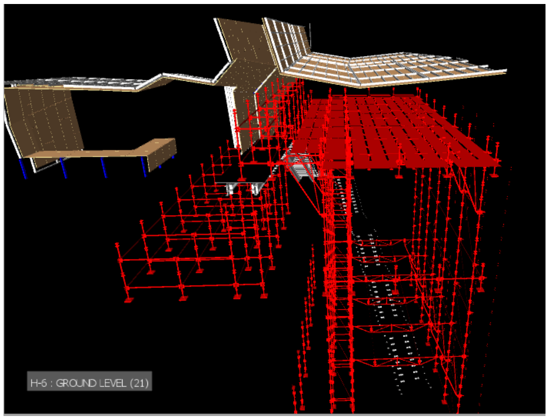


Figure 40 Start of scaffolding demolition. Screen wall west of skylight being turned into table space

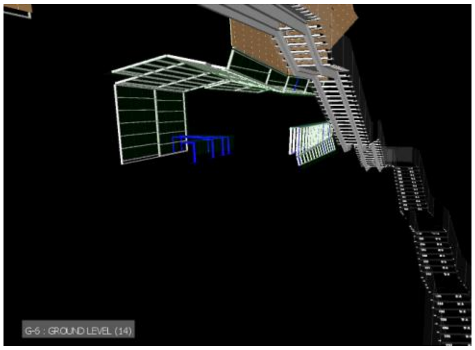


Figure 41 Screen Wall Framing on Lower Middle Section of the Atrium Space

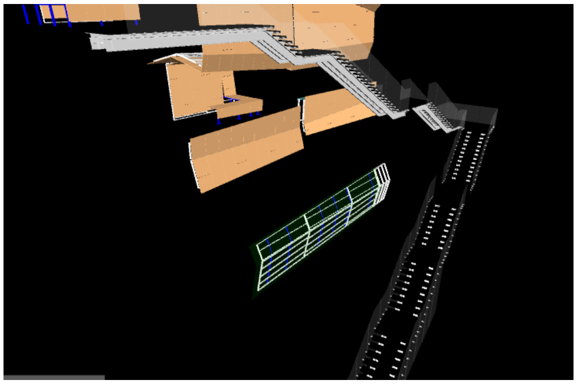


Figure 43 Framing for the Screen Wall on the Lower Section of the Atrium Space

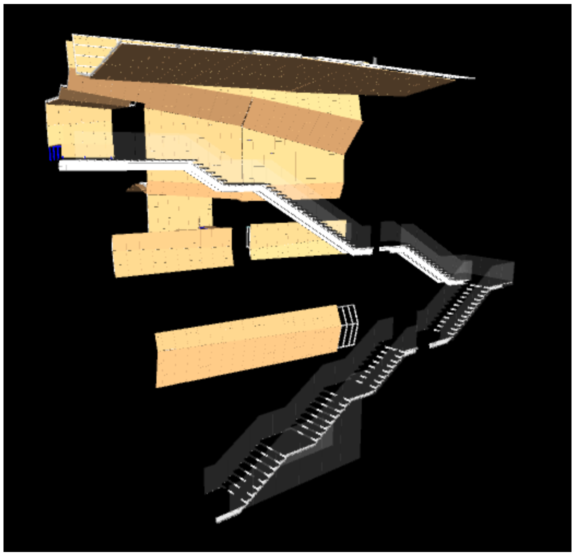


Figure 42 Atrium Space upon Completion of Systems in this Analysis

Conclusion

Although the coordination in this atrium space are a major challenge for the construction manager and the rest of the project team, the space will be one of the major features of the university. As is shown by the figure here, the space will allow for students to congregate and provide a large, welcoming space to the college of Health and Human Development. This is a reason why the quality of the materials to be installed in the space needs to be maintained at a high level. The analysis shows that each option has its own benefits. However, in many cases, the benefits are not able to outweigh the consequences. Based on the grading system established in this analysis, it is safe to say that option 2 is the best way to sequence these items in this space. Option 2 contains areas in which the schedule can be accelerated if necessary and maintains safety and quality requirements that are desired on this project. This option also minimizes the amount of coordination required among trades in the area. Although option 1 was chosen to be utilized on the project in order to accelerate the schedule, it is going to be a challenge for the project team to coordinate the trades in order to maximize efficiency and maintain the finishes of the materials in the space. With all of the options mentioned for the sequencing, communication between the contractors will be critical. Although option 2 says that minimum coordination will be needed, the contractors will need to communicate their plan of the day with the construction management team as well as the other trades working in the space. This will help to resolve any coordination issues that could be seen throughout the process.

Figure 44 Atrium Space Depicting Architectural Screen Wall and Stair C Features

Analysis 3 – Return Air Plenum [Mechanical Breadth]

Problem Identification

Another major concern for the Health and Human Development Building is the complex MEP design in the ceiling spaces. This is a major reason why BIM was implemented for coordination. Figure 45 depicts an area next to a mechanical room, which contains heavy congestion in the ceiling space. With any high-tech building, there is always a concern with fitting all of the equipment into the space that is available. The Health and Human Development Building is no different. With this complexity of design in a small space, it is important to get all trades involved early in the project and for the equipment sizing to be known prior to installation. As previously mentioned, this is a multiple prime contract. So, there will be multiple contractors working in this tight ceiling space to make sure that all of the materials are put in place correctly. The major concern with the ceiling space is trade coordination. With this, comes a potential schedule drawback. All materials arriving on site need to be sized to the exact dimensions as on the BIM model with a very small tolerance to ensure that all pieces fit. The image below shows the BIM model in an area directly off of a mechanical room on the first floor of the building. As is shown, this is a very congested area with many different materials in the small ceiling space.

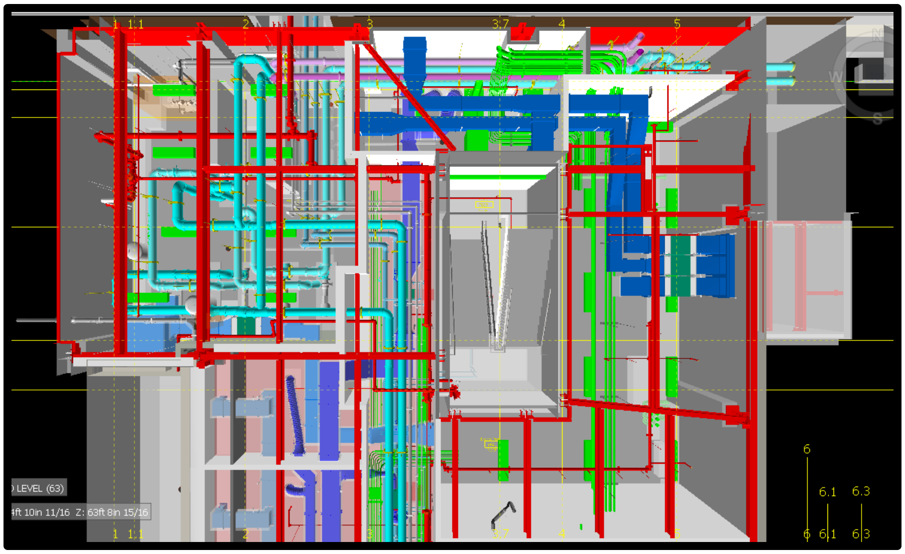


Figure 45 BIM Model Showing the Congestion in the Ceiling Spaces

Goal

When dealing with a tight ceiling space, the major concern is the potential for schedule delays. The concern of putting in materials in such a congested area is the sequencing order of the items and ensuring that all systems installed are the exact size as designed. There are many different alternatives to increase the amount of space in the ceiling plenum. One way to account for this problem is to eliminate the return air ductwork and implement a return air plenum.

What is a Return Air Plenum?

A return air plenum is a system in which air return is forced into the ceiling plenum space and circulated back into the return air chases and recycled through the air handling units. The major advantages of using this system is that it would eliminate a large piece of ductwork and save space inside the ceiling to allow the contractors to have more room to work with. The figure below shows a comparison of a return air plenum and a typical return air piece of ductwork. As is shown, the ceiling space is much more open due to the loss of the return air ductwork.

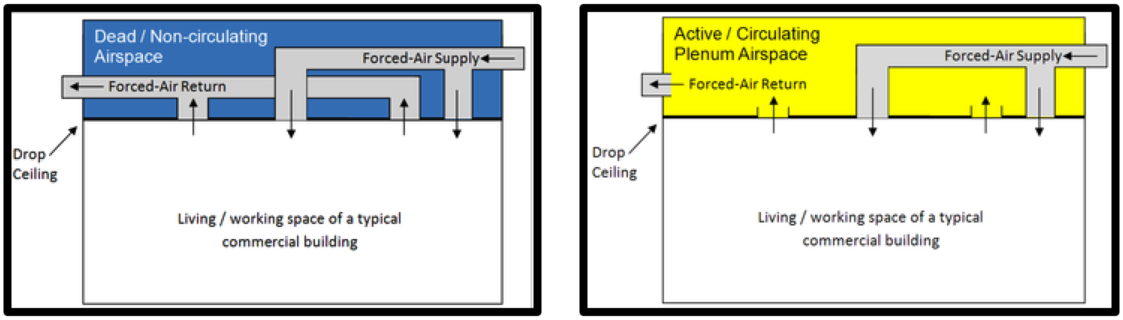


Figure 46 Left: Traditional Return Air Ductwork System
Right: Return Air Plenum System

A plenum return system recycles air in the building back to the air handling unit. In the case of this building, the AHU is located on the roof. Plenum return is often used for buildings with offices, classrooms, and other areas that do not deal with chemicals or any other form of exhaust that would be harmful to others. Plenum return is used in these areas because that air is returned back into the AHU and is mixed with the outside air that comes into the building. The new mixture is redistributed back in to the building. This system can be very energy effective because return air that circulates through the ceiling will be drawn to the VAVs that are located in the ceiling and the warm air can be recirculated back into the system as opposed to going through the AHU.

As with any type of HVAC system, there are limitations to utilizing a return air plenum system. The major problem with this system is sound transmission above the ceiling into the rooms below it. Another problem, from a privacy sense, is that people do not typically want to have their conversations heard by people in other rooms. Another issue is the potential for the infiltration of chemical, biological, and radiological agents. If these agents are introduced into the plenum space, they will likely filtrate back to the air handling unit. This is the reason why the rooms that produce these agents have direct exhaust systems. One major construction issue that is typically seen from this system is that the area is not properly balanced. If the system is incorrectly balanced, ceiling tiles could start to pull up or doors could close on people due to negative or positive pressurization of the room.

Process

Before any form of analysis can be completed, it is important to choose an area in which the return air plenum will be put in place. For the Health and Human Development Building, it was found that the first floor through air handling unit 8 would be the most efficient area to analyze. The analysis will require an estimate for the return air ductwork that is currently in place, a schedule takeoff to complete this work, a fire/smoke damper takeoff, and a cost estimate for materials that need to be plenum rated in the ceiling. When a return air plenum is utilized, fire and smoke are allowed to travel quickly. By using plenum-rated materials levels of toxicity in smoke are lowered. Cable is plenum-rated by using a jacket coating made of flame-resistant materials. Other items such as insulation need to be wrapped so that there are not any “free” materials flying through the plenum space. As is seen, the insulation is wrapped inside the wall studs. Also, the wire is all encapsulated inside rigid conduit, and there are no other items floating inside the space. For this project, items that will need to be analyzed include the steel fireproofing, electrical conduit, cables, supply air ductwork, the sprinkler system, and hot/chilled water systems. The analysis will further look at the CFM requirements for this space. This would be performed by analyzing the supply and return air on each level and ensuring that the air handling unit could handle the CFM requirement. Then, a duct calculator will be utilized in order to determine the size of ductwork necessary for the air going into the chase.

Figure 47 Return Air Plenum Space Utilized in a Wall at the Biobehavioral Health Building on Penn State's Campus

Results

In order to properly install a return air plenum, there are many factors that need to be taken into consideration. The area in which the system will be implemented needs to be properly analyzed and be an efficient area to perform an analysis. Analyzing an entire floor area would be very complex as it would require an analysis of multiple air handling units. Also, in this building, the hallways and spaces outside of the mechanical rooms are the most congested ceiling spaces in the building. Performing the work in these areas would make the most sense as more space would be needed in these areas. However, due to the complexity of these areas and different air handling units feeding different areas, it was not very logical to utilize these spaces. This analysis will look at conference room 101 and kitchen/support area 101A on the first floor of the Health and Human Development Building. The image below shows the area in which will be analyzed. The supply air ductwork is highlighted with different colors depicting the different sizes.

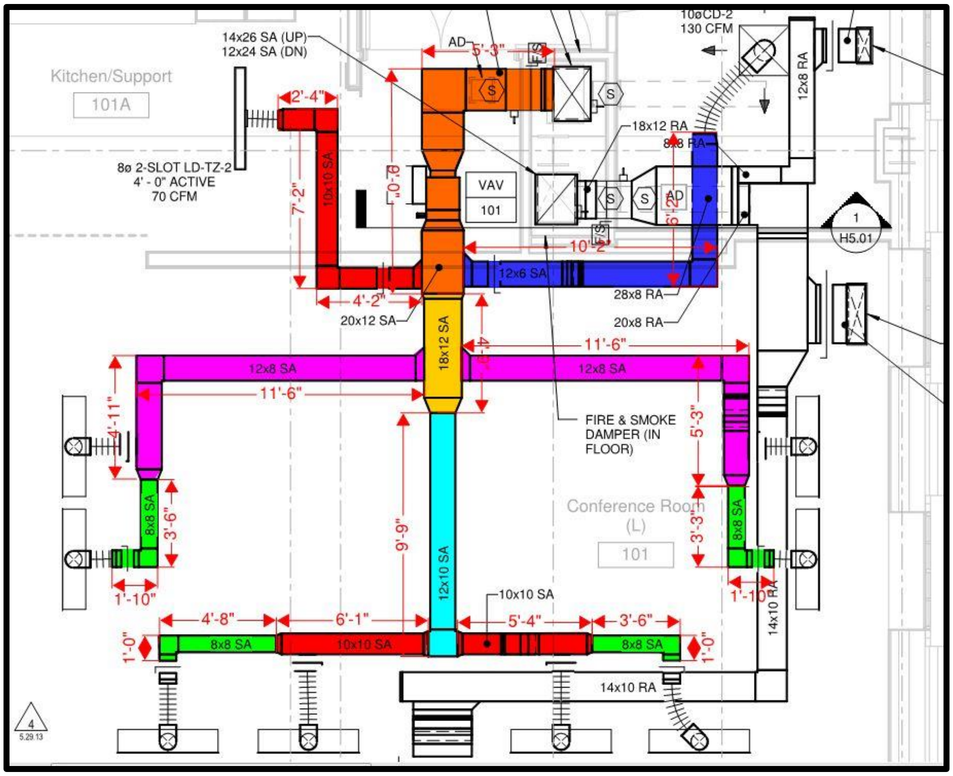


Figure 48 Analysis Area of Return Air Plenum Space. Supply Air Ductwork is highlighted.

The first items that were considered for the analysis were the cost and schedule takeoffs for the return air ductwork that is in the current design. In order to perform a ductwork takeoff, the sizes of the ductwork need to be separated and the gage must be determined. In this situation, there are 7 different sizes of return air ductwork and they are all 24 gage. In order to account for scrap or any additional materials needed for the process, 5% was added to all of the lengths. It was found that the return air ductwork totaled to weigh 345 pounds. Massaro CMS provided a cost per pound that they utilized on the project for 24 gage ductwork of $8.50 per pound. This cost included the labor required to place the ductwork. It was also assumed that all the seams and seals are included in prefabrication costs. For all of the ductwork in this area, it was found that the total cost of fabricating and placing the ductwork to be $2,085.70. A table summarizing this information is shown below.

Table 22 Estimate Takeoff Showing Return Air Ductwork That Will be Removed for Return Air Plenum Design

RA Ductwork Takeoffs

Size	Sum of the two sides	Max Dimension	Gage	lb/ft	Length (ft)	Pounds	SF	Cost/pound	Cost
18x12	30	18 -> 30	24	6.5	3	19.50	13.86913	$ 8.50	$ 117.89
28x8	36	28 -> 30	24	7.8	7	54.60	38.83357	$ 8.50	$ 330.09
8X8	16	8 -> 30	24	3.4	3	10.20	7.254623	$ 8.50	$ 61.66
12X8	20	12 -> 30	24	4.3	7	30.10	21.40825	$ 8.50	$ 181.97
16X6	22	16 -> 30	24	4.7	2	9.40	6.685633	$ 8.50	$ 56.83
20X8	28	20 -> 30	24	6	10	60.00	42.67425	$ 8.50	$ 362.73
14X10	24	14 -> 30	24	5.2	31	161.20	114.6515	$ 8.50	$ 974.54
		TOTALS				345.00	245.377		$ 2,085.70

Whenever ductwork is installed, fire and smoke dampers are put in place between rooms for fire code requirements. These are passive fire protection products used in heating, ventilation, and air conditioning (HVAC) ducts to prevent fire and smoke from spreading inside of a piece of ductwork through walls and floors. When a rise in temperature is seen, the damper closes shut so as to not allow anything to pass through it. The figure here shows what a typical fire/smoke damper looks like. As is seen, the louver screens will close whenever a certain temperature is reached or smoke is noticed. However, with a return air plenum, the entire space is plenum rated so fire and smoke dampers are not required. In the current design, there is only one area where the ductwork passes between rooms. Therefore, the plenum design will save cost for the installation of that fire and smoke damper. A return air plenum system will not need fire/smoke dampers because there will not be any form of ductwork installed. The estimated cost of the fire and smoke damper is $350. With the ductwork and fire/smoke damper costs totaled up, the return air plenum design would save $2,435.70.

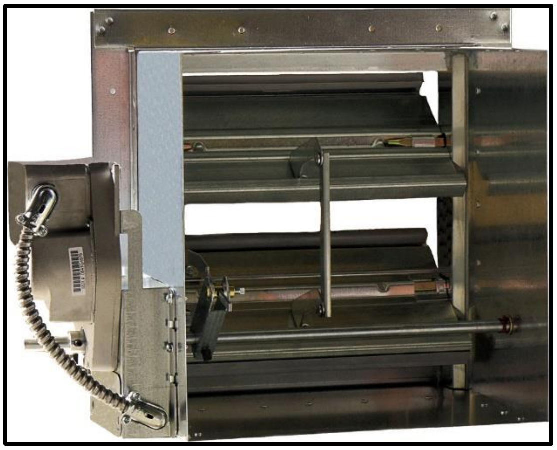


Figure 49 Fire and Smoke Damper Courtesy of Google Image Search

Based on the previous numbers, it would seem obvious that a return air plenum should be utilized in every situation. However, installing a return air plenum could add cost and time. As was previously mentioned, all items in the ceiling need to be plenum rated due to fire restrictions. So, when determining which materials need to be plenum rated, it is important to first determine what materials are in the ceiling. Upon review of the drawings, it was found that there was steel, electrical conduit, cables, supply air ductwork, and a sprinkler system inside the plenum space. The first item analyzed is the steel. It would be expected that some type of action would be needed due to the spray on fireproofing on the steel beams and columns. One would think that the SOFP would blow around in the plenum space and be recycled into the air. However, it was found that the steel would not need to have any additional requirements. The fireproofing on the steel would be okay as it would be dried before the return air plenum system was installed. Next, it was found that the electrical conduit would need to be plenum rated. This means that it would have to be rigid conduit only. In the case of this building, the specifications read that all electrical conduit will be rigid only. After back-checking the submittals provided by the electrical contractor, it was confirmed that all conduit that will be installed in the building will be plenum rated (rigid only). So, no additional costs will be added to what is designed for the building. Next, the cables were analyzed. It was found that they would also need to be plenum rated. After review of the submittals for the project, it was found that all cables that would be used would be plenum rated. Again, this would mean that there would be no additional cost to the project. Electrical and Telecommunication contractors were consulted on this topic and it was established that it is the industry trend now to have materials be plenum rated in order to add an extra level of safety. However, there is one item in this space that would add additional time and cost. The supply air ductwork would have insulation placed around it. In order for it to be properly utilized in a plenum space, the insulation would need to be wrapped so as to not allow the insulation to be free floating around the plenum space. In order to determine the cost implications of wrapping this insulation, a ductwork takeoff would need to be completed for the supply air ductwork. The takeoff for the ductwork is shown below.

Table 23 Supply Air Ductwork Takeoff for Insulation Wrap Estimate

Supply Air Takeoff							
Size	**Sum of the two sides**	**Max Dimension**	**Gage**	**lb/ft**	**Length (ft)**	**Pounds**	**SF**
20x12	32	20 --> 30	24	6.9	14	98.325	85.05623
10x10	20	10 --> 30	24	4.3	25	107.858	93.30306
12x6	18	12 --> 30	24	3.9	16	63.7	55.10381
18x12	30	18 --> 30	24	6.5	5	30.875	26.70848
12x8	20	12 --> 30	24	4.3	33	142.617	123.3708
8x8	16	8 --> 30	24	3.4	21	69.9833	60.53922
12x10	22	12 --> 30	24	4.7	10	45.825	39.641
							483.7226

As is seen, there is about 484 square feet of supply air ductwork. Requirements state that the insulation wrap needs to be ½ inch thick. So, for this estimate, 1" vapor barrier wrap was assumed to be used. According to R.S. Means, 1" vapor barrier wrap cost $1.96 per SF. This would mean that it would cost $948.10. The figure to the right shows fiber wrap that would typically be used for ductwork insulation. Lastly, the sprinkler system needed to be analyzed. After review, it was found that the sprinkler system would not need to be plenum rated because the pipe would be metal and the sprinkler heads would simply sit in the ceiling openings. So, for all of the items that needed to be plenum rated, the only additional cost would come from the insulation wrap that would be needed.

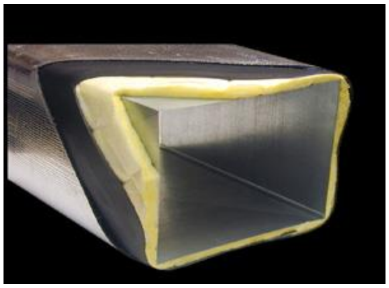


Figure 50 Fiber Wrap Insulation for Supply Air Ductwork Courtesy of Google Image Search

With this information accounted for, the current design and the plenum design can be compared. From a cost standpoint, it is seen that the plenum design would be more effective from a cost standpoint. The table below shows the comparison of the two systems from a cost standpoint.

Table 24 Cost Comparison of Current Return Air Ductwork Design and Return Air Plenum System

Current Design	
Item	**Cost**
Ductwork	$ 2,085.70
Fire Dampers (1)	$ 350.00
	$ 2,435.70
PLENUM DESIGN	
Item	**Additional Cost**
Ductwork Insulation Wrap	$ 948.10

Based on this information, it is found that the plenum design will save an estimated $1,487.61 if implemented. This number is only this high because most of the materials installed in the system are already plenum rated. In many buildings, the materials are not plenum rated so installing a return air plenum may not be cost effective. This analysis looks at one area that is made up of 1250 square feet with a cost savings of $1,487.61. If this idea was interpolated throughout the building so that a return air plenum was the only form of returning air to the air handling units, a total savings could be interpolated. Understanding that this would not be logical, this is simply a theory based interpolation. Obviously some areas will be more expensive and others will be less expensive due to the materials located in the areas. However, the space that was analyzed was taken to be a typical room area that would act as an average room so the interpolation could be accurate. The table below shows how this number can be interpolated throughout the project.

Table 25 Return Air Plenum Interpolated Cost Savings for the Entire Building

Savings in Area	**SF of Area**	**Savings/SF**
$ 1,487.61	1250	$ 1.19
Total Area of Building	**Savings/SF**	**Total Savings**
150000	$ 1.19	$ 178,512.94

Removing this ductwork from the design has advantages from a schedule standpoint. Takeoff information was taken from Penn State professor, Rob Leicht's AE476 practicum for ductwork takeoffs. Based on this information, it was found that prefabrication takes 1 hour of labor per 200 pounds of sheetmetal. For this reason, it was found that it would take 2 hours total to perform this process. To raise and hang one rectangular piece of ductwork, it is estimated to take 15 minutes. Based on the plan shown above, it is estimated that there are 13 pieces in this section. This means that it would take 195 minutes to raise and hang the ductwork. 15 minutes are added for install time for a piece of duct which penetrates a wall. In this area, there are two instances in which a piece of duct penetrates the wall. This will add a half hour to the schedule total. Additionally, 1 minute is added to seal 24 linear inches of duct flange between pieces. For the 13 pieces, 13 minutes are added to the total. Lastly, it takes 10 minutes to insulate 10 linear feet of ductwork. Based on the takeoff, there are 63 linear feet of return air ductwork in this section, meaning that 63 minutes will be added. Lastly, a fire/smoke damper will only require 10 minutes to install. This is because the piece comes to the site already put together so it just has to be lifted into place. This entire process totals 431 minutes, which is about 7 hours to install the return air ductwork. The schedule activities for the return air ductwork are summarized in the table below.

Table 26 Traditional Return Air Ductwork System Schedule Summary

Schedule Information For Current Design	
Activity	**Duration**
Prefabrication	2 hours
Raise and Hang	195 minutes
Install Piece that Penetrates Wall	30 minutes
Seal Duct Flange Between Pieces	13 minutes
Insulate Ductwork	63 minutes
Install Fire/Smoke Damper	10 minutes
Total	7 hours

Utilizing a return air plenum system does add some time to the schedule however. It takes time to wrap the insulation of the supply air ductwork. Based on numbers provided by the subcontractor, it will take about 73 minutes to wrap the insulation surrounding the supply air ductwork. This is an item that could be prefabricated in the shop so that it does not add more time to the project schedule. Also, it is important to understand that in order for a return air plenum system to be efficient, the ceiling space needs to be completely sealed. This may require additional time and money; however it is assumed that it is a very minor addition. Based on these numbers, utilizing a return air plenum in this space would save 6 hours of time. In order to be conservative to account for any additional requirements for this system, it would be safe to say that 5 hours of time would be saved. However, the best cast scenario would be to prefabricate the fiber wrap and save an hour of project schedule time. This can also be interpolated for the entirety of the project. This can be summarized in the table below.

Table 27 Interpolation of Schedule Savings for Entire Building

Savings in Area (Hours)	**SF of Area**	**Savings/SF**
6	1250	0.0048
Total Area of Building	**Savings/SF**	**Total Savings**
150000	0.0048	720.00

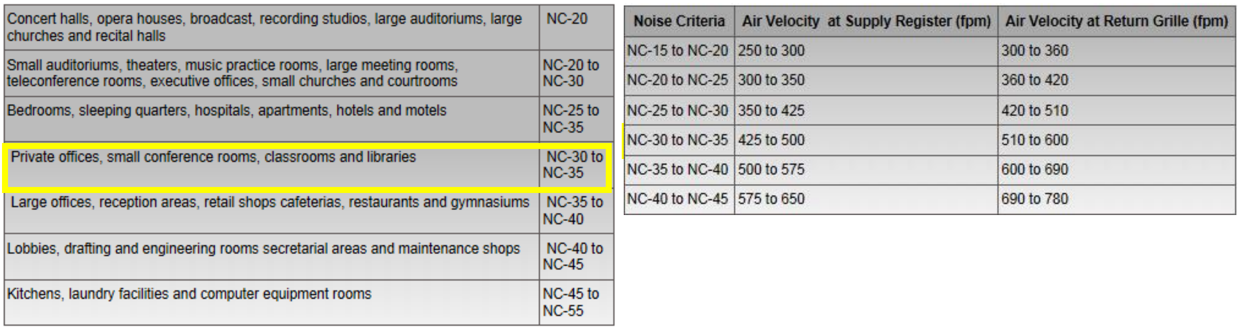
With 720 hours of schedule saving for the project, it would be seen that the return air plenum would save 9 days of schedule time for the return air system installation. Again, this would not be a realistic interpolation but it gives an idea of time savings that could be seen.

Next, it is important to make sure that the return air plenum system will work in the space. Based on the idea that the plenum space is larger than what the size of the ductwork would be, it is assumed that there is enough space in the plenum for the air to circulate. This means that the floor to floor heights would not need to be increased. Next, the amount of air that is supplied and returned in the space was analyzed. It was found that the area is equally pressured meaning that the amount of air supplied to the space is equal to the amount of air returned. The ductwork in this space is connected to an air handling unit (AHU 8) that is located on the roof of the building. This air handling unit serves the southwest area of the building on every floor. The takeoff depicting the CFM requirements on every floor is shown in the table below.

Table 28 Hair Handling Unit 8 Supply and Return Airflow Takeoff

	ACF 8	
Level	**Supply Air Provided (CFM)**	**Return Air (CFM)**
3	2700	3000
3.1	1440	1440
3.2	740	740
3.3	960	960
3.4	1390	1390
	7230	7530

When the return air ductwork is removed from the system, the air needs some way to return to the air handling unit. With the current design, the air in the room leaves the room through grilles in the ceiling. The air is then circulated through the ductwork and into the chase which carries the air back to the AHU where it is circulated and recycled back into the sytem. With a return air plenum, a piece of ductwork will be placed branching off of the chase so that air can be sucked up through the chase and recycle back through the AHU. In order to size this piece of ductwork, a duct calculator was used from KLING STUBBINS. With this duct calculator, airflow (CFM) and velocity (FPM) are entered and a duct size is calculated. For the space that is being analyzed, an airflow of 1440 CFM was entered as it was the amount of supply air that was being provided. The velocity that needed to be entered was based on the acoustical requirements of the space. The requirements for a conference room can be seen in the tables below.

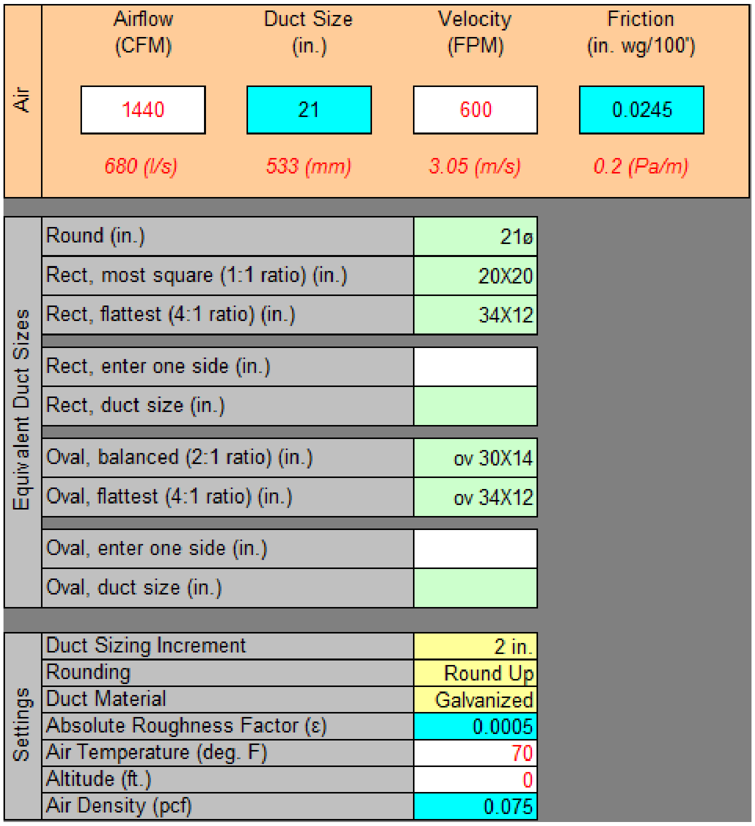


Concert halls, opera houses, broadcast, recording studios, large auditoriums, large churches and recital halls	NC-20
Small auditoriums, theaters, music practice rooms, large meeting rooms, teleconference rooms, executive offices, small churches and courtrooms	NC-20 to NC-30
Bedrooms, sleeping quarters, hospitals, apartments, hotels and motels	NC-25 to NC-35
Private offices, small conference rooms, classrooms and libraries	NC-30 to NC-35
Large offices, reception areas, retail shops cafeterias, restaurants and gymnasiums	NC-35 to NC-40
Lobbies, drafting and engineering rooms secretarial areas and maintenance shops	NC-40 to NC-45
Kitchens, laundry facilities and computer equipment rooms	NC-45 to NC-55

Noise Criteria	Air Velocity at Supply Register (fpm)	Air Velocity at Return Grille (fpm)
NC-15 to NC-20	250 to 300	300 to 360
NC-20 to NC-25	300 to 350	360 to 420
NC-25 to NC-30	350 to 425	420 to 510
NC-30 to NC-35	425 to 500	510 to 600
NC-35 to NC-40	500 to 575	600 to 690
NC-40 to NC-45	575 to 650	690 to 780

Figure 51 NC Requirements Courtesy of Acoustical Solutions, Inc.

Based on these tables, the conference room that is being analyzed will fall under the NC-30 to NC-35 range with an air velocity at return grille of 510 to 600. These numbers were then placed into the excel sheet for the duct calculator to determine the duct size. This can be shown in the figure below.



	Airflow (CFM)	Duct Size (in.)	Velocity (FPM)	Friction (in. wg/100’)
Air	1440	21	600	0.0245
	680 (l/s)	533 (mm)	3.05 (m/s)	0.2 (Pa/m)

Equivalent Duct Sizes	Round (in.)	21ø
	Rect, most square (1:1 ratio) (in.)	20X20
	Rect, flattest (4:1 ratio) (in.)	34X12
	Rect, enter one side (in.)	
	Rect, duct size (in.)	
	Oval, balanced (2:1 ratio) (in.)	ov 30X14
	Oval, flattest (4:1 ratio) (in.)	ov 34X12
	Oval, enter one side (in.)	
	Oval, duct size (in.)	
Settings	Duct Sizing Increment	2 in.
	Rounding	Round Up
	Duct Material	Galvanized
	Absolute Roughness Factor (ε)	0.0005
	Air Temperature (deg. F)	70
	Altitude (ft.)	0
	Air Density (pcf)	0.075

Figure 52 Duct Calculator Results Taken from KLING STUBBINS

As is shown, the most square piece of ductwork that could be used is a 20x20 piece and the flattest piece that can be utilized is a 34x12. The amount of space in the plenum is 2’7-3/4”.

This is equivalent 31-3/4”. Even with insulation wrapped around this piece of ductwork, a square 20x20 piece will have more than enough space in the plenum to fit.

Conclusion

Upon review of this analysis, it is found that a return air plenum space would be the most efficient system to use. The return air plenum is the most logical from both a cost and schedule perspective. The return air plenum system made the most sense for this building mostly because most of the materials in the ceiling space are already plenum rated. If these materials needed to be changed to become plenum rated, additional cost and time would have been needed. Installation of this system will also reduce the amount of headaches that would come about due to coordination issues within the tight ceiling space. With the removal of such a large piece of ductwork, a large amount of space is freed up. This would be beneficial to the contractors placing the work and will allow for a larger tolerance on other material placement based on the BIM models.

Analysis 4 – Alternative Excavation Options

Problem Identification

A major challenge on this project was found in the very early stages of the project. When the geotechnical report was done for this project, it was found that the soil was composed of solid rock. Then, when initial excavation began, it was confirmed that the traditional method of excavating solid rock using a hammer would take an extended period of time. With the phasing for the excavation process occurring during the summer months, it would have been okay to have constant hammering and not disturb any classes. However, the idea of rock excavation blasting was proposed as a method of reducing schedule time and decreasing the amount of noise that would occur from long periods of rock hammering.

Rock excavation blasting is done by drilling holes roughly 15 feet down in the ground, filling them with explosives, and setting off charges to break up the rock and allow for easier excavation. This process requires a significant amount of planning and coordination of everyone on site as well as the people from the surrounding buildings. During the initial planning phase, it was important to analyze the entire site and how the blasting would affect the surrounding areas. For this project, it was established that a 300-foot safety radius would be needed for a complete automobile and pedestrian shutdown. This requires a huge effort from a management standpoint. In order to establish a safety barrier, it is important to ensure that a proper staff will be provided.

A professional traffic control team was hired in order to handle all automobile and pedestrian traffic on the very busy College Avenue. Hiring a professional traffic control company not only ensured a professional group of people, but also helped to establish traffic control based on PENNDOT standards. There were roughly 30 people involved in the day-to-day activities of the rock excavation blasting. With this amount of activity and the idea of explosives being used, it is imperative to notify students and faculty in the surrounding buildings. This is a large effort, with potentially major results in schedule acceleration.

Goal

This analysis is an opportunity to investigate the different methods of excavation, and compare the advantages and disadvantages of both. Rock excavation blasting and traditional excavation measures are challenges on a job site in their own way. This analysis will discuss the requirements necessary for both methods as well as the cost and schedule implications. The goal is to provide insight on which method would be most efficient to use on a job site

Traditional excavation and rock excavation blasting are the two most common excavation methods utilized in the construction industry today. In other fields and in other areas of the world, there are other methods of excavation. This analysis will also research these additional methods and determine the necessary requirements that would be necessary to perform those activities on this jobsite.

Process

Excavation is a very tricky aspect of any construction job. It is very difficult to estimate a cost and a schedule period because there is always the unknown factor of what will be discovered during the digging process. In many instances, the geotechnical report will provide enough information so that the contractor performing the work has some type of idea for estimating, scheduling, and means and methods. When it comes to rock excavation, traditionally there has always been just one way of doing it: rock hammering through heavy machinery. This is a very tedious process which requires a long period of time and is very disturbing to the surrounding public. An alternative to this traditional method has surfaced over the past years when it comes to rock excavation for building purposes. This alternative is called rock excavation blasting. Both of these methods have their own advantages and disadvantages.

In order to compare the two methods, it will be important to analyze the problems associated with each. For the analysis, the project team was consulted in order to define the implications associated with rock excavation blasting. As was seen, the rock excavation blasting process was a very complex process which requires a lot of coordination between all members on site. One of these coordination issues is the amount of space the process requires on site. The image here gives an idea of the equipment and area required for the blasting to be performed safely and correctly. These coordination items will be discussed in detail in the next section of

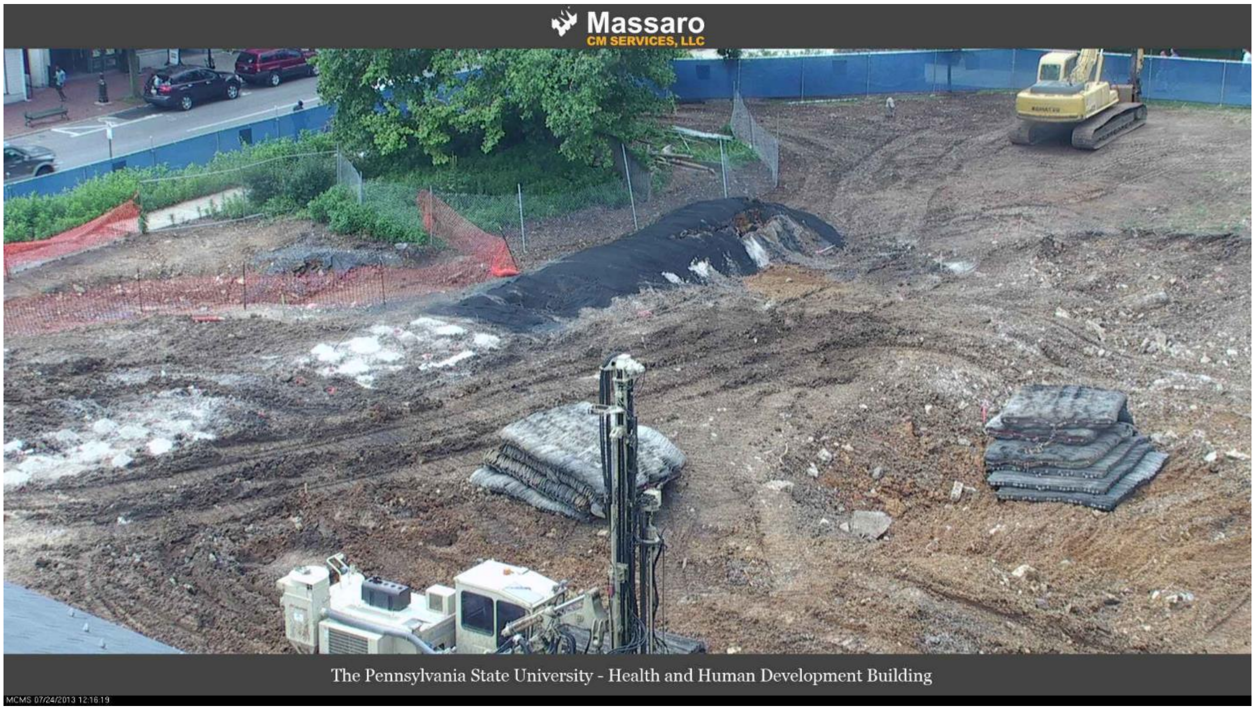


Figure 53 Rock Excavation Blasting Site Overview Photo Courtesy of Massaro CMS Webcam

the analysis. An estimate will be completed that will look at the cost of blasting, a pre blast survey, blast monitors, blasting mats, stone, mobilization, excavation, and the manpower associated with rock excavation blasting.

For the traditional method of excavation, an estimate will be completed that will analyze the amount of rock that will need to be excavated by rock hammering and what can be excavated cleanly with a basic excavator bucket. In order to estimate this total, the geotechnical report was analyzed and it was found that the soil was mostly made of dolomite rock. Dolomite rock usually works like a sin graph, so it is assumed that the soil is made up of half unrippable material and half rippable material. A schedule estimate was then completed in order to determine the amount of time saved due to the utilization of blasting. The amount of saved time will then be incorporated into the general conditions cost which is assumed to be $1000 per day. For these estimates, it is assumed that the truck hauling is the same for both methods.

In order to research alternative rock excavation methods, internet research is required in order to analyze what other members in the industry are experimenting with in order to excavate solid rock. Also, excavation in fields outside of construction will be researched. Alternative uses of Royex technology and the Rock Hawg will be analyzed. The advantages and disadvantages of each will be described.

Results

As was previously mentioned, the rock excavation blasting was utilized on this project in order to cut down on the amount of time required to break up the rock. This was also done to decrease the amount of disruption that would have resulted from the constant hammering that would have been done every day for a significant period of time. Based on prior experience with Penn State jobs, Douglas Explosives was hired as the blasting contractor. As soon as the contractor was hired, a blasting plan needed to be submitted regarding qualifications, storage of explosives, blast loading procedure, safety signals and safety programs, danger area clearance, vibration monitoring, and a cost breakdown. Based on the blasting plan, it was apparent that a significant effort would be necessary in order to do this process safely and efficiently.

Before any blasting could be performed, many safety measures had to be put into place. The difficulty of utilizing this type of excavation method on this site is the proximity to surrounding buildings. Blasting is typically performed on a site that is very open and isolated from any other structures. Not only is there a concern for the surrounding buildings, but the pedestrians that are traveling through these areas need to be safe. The first task that needed to be completed was to determine the perimeter safety radius of the blast. The blasting contractor makes the decision on what type of radius that needs to be clear of any pedestrians in case of any type of rock shearing off and shooting out of the site perimeter. For this particular project, a 300 foot radius was required. All areas inside this perimeter would require personnel so that traffic could be stopped. This lead to the next step which was determining the amount of personnel required. It was found that a professional traffic control team would be needed Hiring this team not only ensured a professional group of people, but also helped to establish traffic control based on PENNDOT standards. It was established that 10 people was necessary from the traffic control team as well as an additional 12 people that would be made up of members from the project team. In order to coordinate this large amount of personnel that would be required for this effort, it was important to ensure that the same personnel was used every day and daily meetings took place to make sure everyone was in place. The figure below shows a view of the site with the amount of manpower necessary to perform the activity shown with stars.

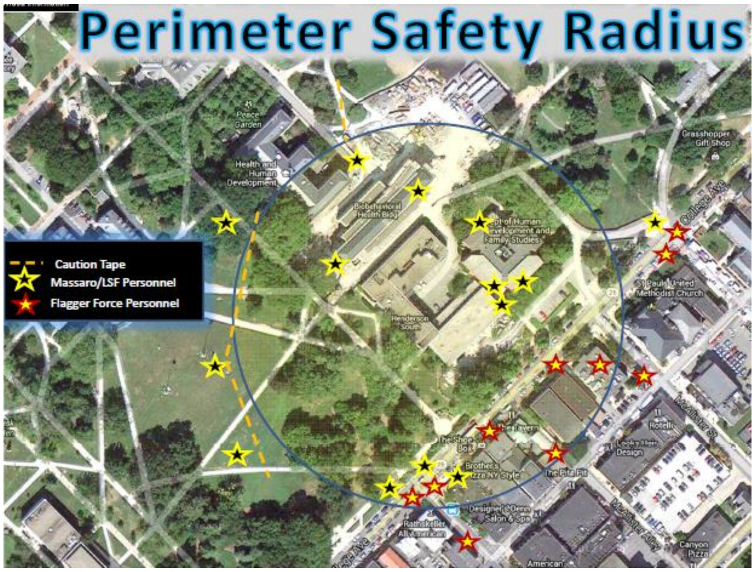


Figure 54 Three Hundred Foot Perimeter Safety Radius

The benefit of the way the schedule turned out was that this process would be completed during the summer months. This was crucial in that the students of the Penn State campus would not be there. If it was during one of the semesters, it would have required a much larger effort and the rock excavation would probably not have been utilized. However, any time that explosives are being mentioned, people will get nervous. On this project, an article went out about the possibility of blasting being used on the site and there were immediate questions and concerns. In order to calm the concerns of the people, additional measures needed to be taken. An email was created to send out to the employees of surrounding buildings and postcards were made to pass out to pedestrians on the busy street of College Avenue. Another major concern was the condition of surrounding buildings. A surveying company was hired to perform walk-through surveys of the surrounding buildings to check for visible cracking, water damage, etc. This was done so that evidence could be provided in case anyone tried to use the blasting as an insurance measure. Also, the surveying company was able to set up seismograph tests to track vibration levels. These monitors contained a series of vibration limits that were established by the blast operator and were recorded to ensure that the blasts were not creating large vibration effects.

The next step in the process was to determine a proper blast time. In order to establish two proper blast times, many items were analyzed. These items included the openings of adjacent stores, outdoor area lunch times, class schedules, pedestrian traffic, bus schedules, orientation schedules, and community activities. One of the most important items was the class schedules. Although the blasting would occur during the summer months, it was important to ensure that the traffic control personnel would not be trying to hold up large groups of people for a period of time so that a blast could be performed. Once all of the items were analyzed, blast times were established and the procedure would occur twice a day.

All of these measures require time and money. Once all of these items are completed, blasting can begin. The procedure necessary to perform a blast is as followed (developed by Douglas):

1) The blast hole will be measured with a loading tape for proper depth and monitored for the amount of rock which is logged on a hole plug placed in the hole immediately after drilling.
2) One blast cap will be placed in a cast booster and placed at the bottom of each hole.
3) The hole will be loaded with a calculated amount of blasting agent determined by the blaster. Depending on the scaled distance formula and the amount of rock in each hole, the amount of blasting agent will vary from 2 to 12 pounds per hole.
4) The type of blasting agent loaded will depend on whether the hole contains water or is dry. Wet holes will be loaded with manufactured 2 ½ inch sticks of waterproof emulsion. Dry holes will be loaded with ANFO.
5) The remainder of the hole will be stemmed with crushed stone.

Blasting mats will be provided in order to control the rock from leaving the site. Once the blaster in charge sees that the area is clear, he sets off his charges. The blasts are completed in patterns to break up the rock. Then, the excavator is brought in to remove the loose rock and put it in trucks to be hauled off site. With all of these items in mind, it is obvious that rock excavation blasting is a very complex process and requires a large effort from a safety standpoint.

Although blasting saved time, it was more expensive to complete the work. Douglas Explosives performed the blasting, a pre blast survey, placed monitors, utilized blasting mats, placed stone, and mobilized for $95,000. This estimate is seen below.

Table 29 Estimate for Blasting Excluding Manpower and Excavation

Blasting Estimate	
Blasting	$ 55,000.00
Pre Blast Survey	$ 20,000.00
Monitors	$ 6,000.00
Blasting Mats	$ 6,000.00
Stone	$ 1,000.00
Mobilization	$ 7,000.00
Total	$ 95,000.00

The amount of manpower utilized for this activity was extremely large. Manpower takeoffs were completed based on the assumption that there are two blasts performed each day for 14 days. Massaro used 11 people for this effort, LSF used 6, Douglas Explosives used 3, and Flagger Force (professional traffic control team) used 10 people. Two excavation operators are assumed to be utilized in order to excavate the material at 8 hours a day for 17 days. The labor rates associated with this manpower estimate were taken from the labor and industry section from the project specifications. Flagger Force has their own set of requirements for the operations that they perform. The team members from the company are required to work a minimum of 4.5 hours per day on a single job, regardless of the amount of time they are needed. For this project, they were only needed for 2 hours maximum. That meant that they were being paid to be on site doing nothing for 2.5 hours every day for 14 days. This was a very large cost implication for the blasting method. The following table shows the estimate for manpower takeoffs. It was found that the total cost for manpower is estimated to be about $80,000.

Table 30 Manpower Takeoff for Rock Excavation Blasting

Manpower Takeoffs

Type of Personnel	Hours/day	Number of days	Total Number of Hours	Cost per Hour	Total Cost
Project Manager	2	14	28	$ 95.00	$ 2,660.00
Site Managers (3)	6	14	84	$ 85.00	$ 7,140.00
Superintendent	2	14	28	$ 100.00	$ 2,800.00
Senior PM	2	14	28	$ 100.00	$ 2,800.00
Intern (2)	4	14	56	$ 35.00	$ 1,960.00
Project Engineer (3)	6	14	84	$ 75.00	$ 6,300.00
LSF Laborers (6)	12	14	168	$ 29.14	$ 4,895.52
Douglas Blaster In Charge	8	14	112	$ 45.19	$ 5,061.28
Douglas Personnel	8	14	112	$ 45.19	$ 5,061.28
Flagger Force (10)	45	14	630	$ 39.00	$ 24,570.00
Excavation Operators (2)	16	17	272	$ 43.04	$ 11,706.88
TOTAL					$ 74,954.96

With the blasting and manpower aspects estimated, the next item to analyze is the physical excavation side of the process. This would be the excavator coming to the site, using a bucket, and putting the blasted material in a truck. The estimate for this process was completed by using the total cubic yardage of rock that needed to be excavated and the cost per cubic yard for well blasted rock. The cost of this excavation totaled to $186,825.

Table 31 Excavation Takeoff For Rock Excavation Blasting

Excavation Takeoff For Blasting		
CY needed to be Excavated	Cost/ CY	Total Cost
7473	$ 25.00	$ 186,825.00

The rock excavation blasting process was tracked throughout the process for schedule days. For the physical blasting stage, it took 14 days to complete this process. While this process was finishing up, the excavators were able to come onto the site and begin excavating the blasted material. The excavation time was derived from the schedule for the truck drivers that were used to haul away the material. This number was found to be 17 days in order to excavate the blasted material. Later in the report, the amount of money saved from this schedule advancement will be analyzed.

Traditional excavation is not as complex. The traditional method of completing rock excavation includes utilizing excavators. The excavators have a bucket and a jackhammer attachment that they are able to switch back and forth. The process begins with the excavator using the jackhammer to break up the rock. Jackhammering this rock is a very tedious process and causes a large amount of disruption to people in surrounding areas. The figure here shows how the process would typically work. Once a significant amount of rock is hammered out, the excavator will then switch to the bucket, remove the rock, put it in a truck, and it will be hauled off. This process is very unpredictable. The most significant concern with the traditional excavation method is the fear of the unknown. Whenever you are dealing with a demolition project with excavation, you never really know what is going to be found underground. With this project, the building that was demolished was built on top of a mining school. So, not only was the soil made up of solid rock, but the concrete foundations were in the ground and needed to be removed. This uncertainty is one of the major drawbacks to traditional excavation. The geotechnical report can only provide so much information and it is very difficult for the contractor that is to perform this work to estimate cost and schedule to complete the task.

Figure 55 Traditional Rock Excavation Utilizing a Hammer Attachment

Estimating traditional excavation begins with what is in the soil. The geotechnical report showed that the soil was made of dolomite rock. As was previously mentioned, dolomite rock typically runs like a sin graph. This means that the rock could be very deep in some areas and close to the surface in other areas. For this reason, it was estimated that the dolomite rock made up half of the soil that needed to be excavated. With this in mind, it can be said that the soil is made up of half rippable material and half unrippable material. The amount of soil that needed to be removed was 7473 cubic yards. The estimate for rippable and unrippable material showed that this process would cost $280,237.50. This takeoff is shown in the table below.

Traditional Excavation Takeoff		
Unrippable Soil		
Cubic Yardage to Excavate	**Cost Per Cubic Yard**	**Total Cost**
3736.5	$ 50.00	$ 186,825.00
Rippable Soil		
Cubic Yardage to Excavate	**Cost Per Cubic Yard**	**Total Cost**
3736.5	$ 25.00	$ 93,412.50
Total		**$ 280,237.50**

The estimated cost includes the equipment and manpower necessary to perform the work. However, this process takes more time than what was required for rock excavation blasting. Additional time costs money as it requires general conditions. The amount of time for the traditional excavation method is very difficult to estimate. In order to perform a takeoff for the amount of time to excavate rippable and unrippable materials, excavation estimate standards were consulted. In general, it was found that unrippable materials could be excavated at 315 cubic yards per day and rippable materials could be excavated at 500 cubic yards per day to excavate and haul off the materials. With these numbers, it was found that it would take 27 days to excavate the material and haul the material off site. This would be an additional 5 days compared to the rock excavation blasting. These 5 days not only save time, but it saves money. General conditions are typically estimated at $30,000 per month, which in turn is estimated at $1000 per day. With these 5 days of savings, the rock excavation blasting saved an estimated $5,000 from general conditions because it finished earlier. This information is summarized in the table below.

Table 32 Estimated Cost Savings Due to Schedule Acceleration

Cost Savings Due to Schedule Acceleration			
Schedule Saving	**General Conditions Estimated Per Month**	**General Condtions Per Day**	**Total Savings From Schedule Advancement**
5 Days	$30,000	$1,000	$5,000

The general contractor on the project found another way to save a large amount of money for the project. When dolomite rock is blasted, the rock shears off and becomes stable and strong. This is easily seen in the figure shown to the right. For this project, the general contractor hired an engineer to approve of the conditions so that shoring would not be required. Additionally the soil was excavated so that it sloped back in order to reiterate the lack of shoring equipment required. This saved an estimated $400,000 according to Massaro. It is not certain that this would not have been needed for the traditional excavation method, but there is a very high possibility that shoring would have been required.

Figure 56 Sheared off Rock due to Blasting Utilization

Conclusions

Rock excavation blasting has made a huge impact on the construction industry. On this project in particular, it made a major impact to the schedule as it saved an estimated 5 days in the schedule. This number would probably have been much higher as the estimate does not take into consideration the amount of time necessary to continuously switch out the hammer and bucket on the excavator for the traditional method. Also, the estimate does not take into consideration weather, machinery problems, and the unknown aspect of excavation. The rock excavation blasting method removed many of these concerns. From a cost standpoint, the two methods are very difficult to compare from a general, every day project, point of view. On this particular site, the rock excavation blasting actually reduced schedule and cost. The table below shows a cost comparison of the two methods of excavation.

Table 33 Cost Comparison of Blasting Totals and Traditional Excavation Totals

Blasting Totals	
Blasting Estimate	$ 95,000.00
Manpower Takeoffs	$ 74,954.96
Excavation	$186,825.00
	$356,779.96

Traditional Excavation Totals	
Excavation	$280,237.50
General Conditions	$ 5,000.00
Shoring Requirements	$400,000.00
	$685,237.50

The blasting process actually saved an estimated $328,457.54. As shown in the table, this price includes the shoring requirements that would have been needed for the traditional excavation method. This may not have been necessary. If the shoring requirements were not needed, the traditional excavation method would have been significantly less expensive. However, it would have caused a constant amount of noise throughout the day as opposed to the rock excavation blasting method. For this project, the rock excavation blasting method was the more efficient and cost effective method to use. This happened mostly due to the timing in which the excavation process fell in the project. The process began in the summer months where there were not as many students on campus. This allowed for the blasting method to be done in a controlled environment. If the excavation process fell in the project schedule to a time during the school year, it would have been likely that the traditional excavation method would have been required. So, from an industry standpoint, it will depend on the type of project and when the excavation process falls in the project schedule to determine which method should be utilized.

Research

In other parts of the world, other methods are being used in order to excavate solid rock. One of these methods is Royex rock breaking technology. Royex is a company based in Sweden that specializes in the use of miniature explosives to break rock. Advantages of using Royex technology include that it is environmentally safe, operationally effective, and cost effective. Royex explains that the technology has minimal fly rock, minimal rock vibrations, substantially lower noise levels compared to conventional explosives, and substantially lower gas emissions compared to conventional explosives. From an operational standpoint, Royex is significantly faster due to lighter drill equipment, requires minimal amounts of personnel for clearance, and is safer to transport and store. As far as cost, no heavy equipment is necessary, significantly lower lead times for coverage and area clearing are required, costs for transport and storage are lowered, and personnel training is much faster. This technology seems very similar to the rock excavation blasting method that was utilized on this project. According to Thomas Gustavsson of Royex, there are many differences between the two systems. The most impactful difference is that the burn speed and as such, the gas expansion generated, is proportional to confinement pressure and heat. If initiated in atmospheric pressure, the propellant burns with about a half foot a second (compare to dynamite burn rate which is about 6000 m/s in the same pressure). This means that when encapsulated in a drill hole, the propellant will build pressure until the rock breaks or the stemming is shot out of the hole. When either occurs, pressure will drop rapidly and the process stops. Conventional explosives explode or detonate in their original state if initiated. Royex cartridges will only burn if initiated freely or in its original package. Without coverage, the Royex system causes minimal fly rock compared

Figure 57 Royex Technology for Rock Excavation Blasting Courtesy of http://royexsystem.com/rock-breaking-gallery.html

to the large amount of fly rock that would be produced from traditional explosives if not covered. An image depicting the Royex technology is shown below.

Another alternative that is being used elsewhere is a type of equipment called a Rock Hawg. This piece of equipment originated in the U.K. and Irish markets. This machine was initially released as a 55 ton, 440hp machine that was created for construction of haul roads in quarries, ultra wide trenches for large pipe installation, and large scale excavation for chlorination tanks in water treatment works. With the success of these projects, a new 110 ton, 630hp version of the rock hawg has been created. This was created to take on larger challenges to increase productivity and efficiency in existing sites. Rock hawg implements top down cutting technology. This allows the teeth to gain greater rock penetration. As soon as contact is made with the teeth, the rock is instantly cut. The machine cuts the rock in place instead of fracturing it on a seam. This enables it to cut very accurately if needed as well as having the capability to cut flat rock faces. The rock hawg has been used on construction sites so large areas of rock can be excavated both efficiently and cost effectively. Material produced eliminates the need to import material as backfill. Rock can be excavated quickly which can reduce site working time and the impact on the local community. This would be very helpful for a site such as this on a college campus. This type of work is a very slow process and strictly breaks up the rock as shown in the figure below. The material would still need excavated upon cutting the rock. This type of machinery would provide several benefits, however the schedule would likely not provide enough time for the equipment to be used.

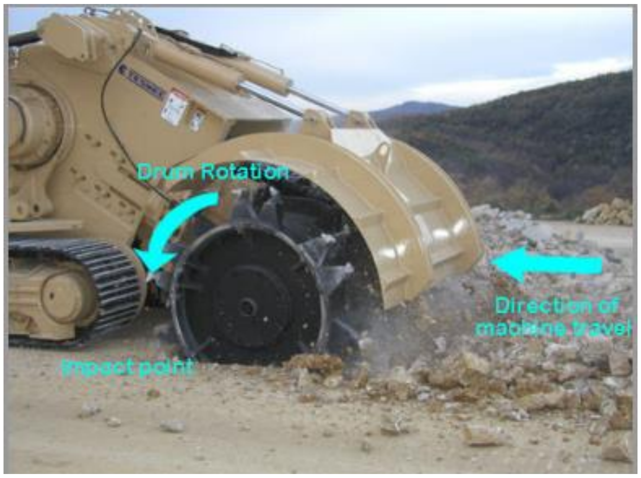


Figure 58 Rock Hawg Equipment Utilized for Solid Rock Excavation

The Rock Hawg and the Royex Technology are two innovative ways of excavating solid rock from a site. Based on the research that was performed, it seemed that the Royex Technology required similar procedures as the rock excavation blasting, but to a smaller scale. The Rock Hawg however, created large amounts of noise and appeared to take a significant period of time. As of now, the Rock Hawg makes more sense to be utilized for excavating small areas like roadways or landscaping areas. Although this is an incredible machine, it does not make sense for use on a construction project at this point in time.

Appendix A

General Conditions Estimate

General Conditions Estimate

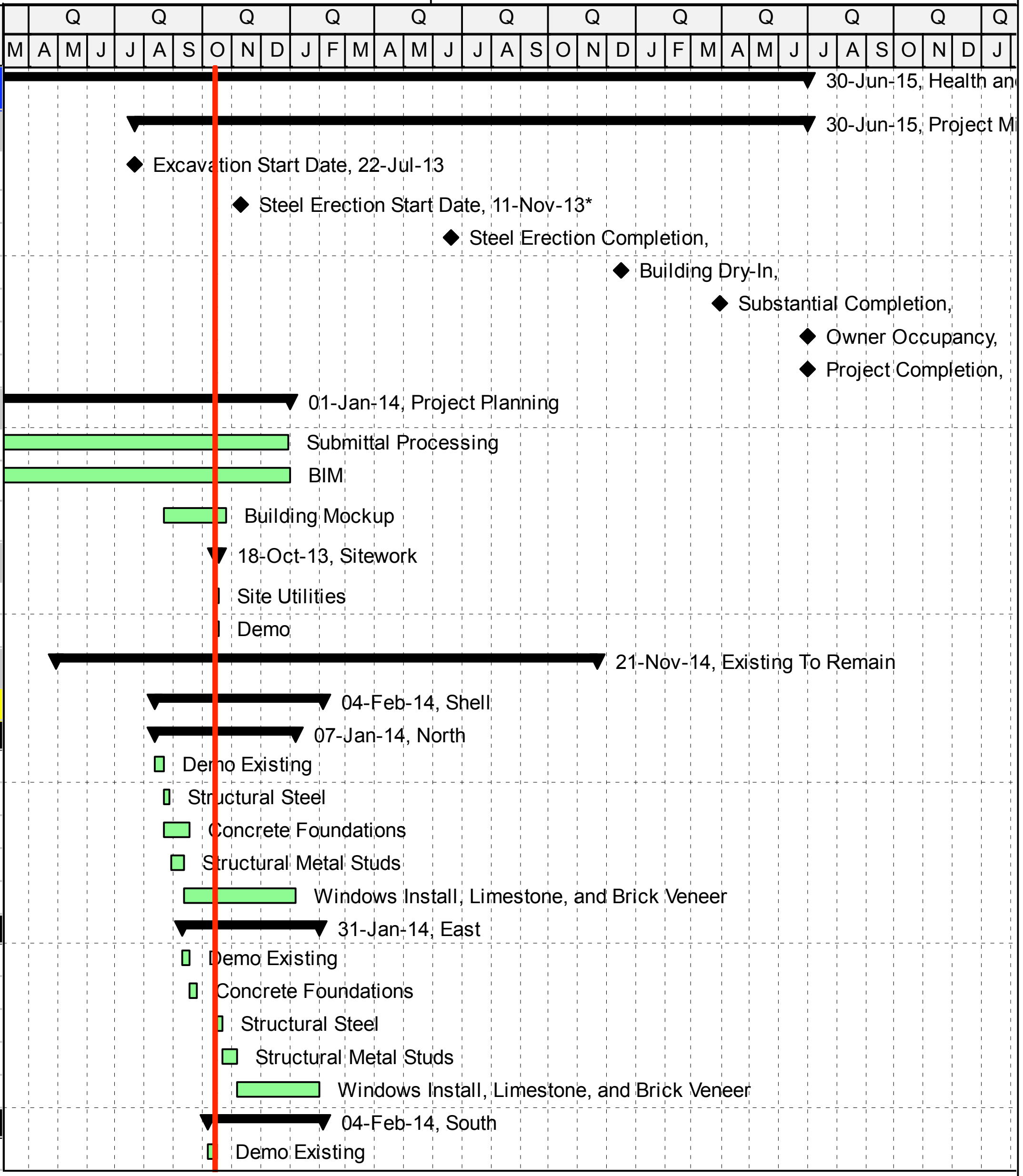
Code	Description	Quantity	Unit	Material $/Unit	Labor $/Unit	Lump Sum/Unit	Total $
Project Management							
PM001	Senior PM	4640	hr	0	100	0	$464,000.00
PM002	Asst. PM	4640	hr	0	95	0	$440,800.00
PM003	BIM Coord.	2900	hr	0	80	0	$232,000.00
PM004	Superintendent	4640	hr	0	100	0	$464,000.00
PM005	Project Engineer (1)	4640	hr	0	75	0	$348,000.00
PM006	Project Engineer (2)	4640	hr	0	75	0	$348,000.00
PM007	Project Engineer (3)	4640	hr	0	75	0	$348,000.00
PM008	Assistant Site Manager	4640	hr	0	85	0	$394,400.00
PM009	QA/QC Consultant	4640	hr	0	85	0	$394,400.00
PM010	Project Intern (1)	2000	hr	0	35	0	$70,000.00
PM011	Project Intern (2)	2000	hr	0	35	0	$70,000.00
PM012	Traffic Control Personnel	4640	hr	0	70	0	$324,800.00
PM013	Safety Coordinator	290	hr	0	75	0	$21,750.00
	Total						$3,920,150.00
Temporary Utilities							
T001	Phone/Data	29	mo	100	0	0	$2,900.00
T002	Electric	29	mo	250	0	0	$7,250.00
T003	Temporary Heat	12	mo	1250	0	0	$15,000.00
T004	Water	29	mo	100	0	0	$2,900.00
T005	Temporary Generators	29	mo	1200	0	0	$34,800.00
T006	Porta Johns	29	mo	800	0	0	$23,200.00
	Total						$86,050.00
Equipment							
E001	Office Trailers (2)	29	mo	2500	0	0	$72,500.00
E002	Mobile Crane	9	mo	25000	0	0	$225,000.00
E003	Forklifts (4)	29	mo	2000	0	0	$58,000.00
E004	Hoist	16	mo	1500	0	0	$24,000.00
E005	Lifts (12)	20	mo	3600	0	0	$72,000.00
	Total						$451,500.00
Materials and Supplies							
M001	Computers	29	mo	5000	0	0	$145,000.00
M002	Cell Phones (10)	29	mo	400	0	0	$11,600.00
M003	PPE	20	LS	0	0	100	$2,000.00
M004	Printing	29	mo	1200	0	0	$34,800.00
M005	Portable Toilet (5)	29	mo	85	0	0	$2,465.00
M006	Fire Extinguishers	10	LS	0	0	100	$1,000.00
M007	BIM Management (Programs/Meetings)	1	LS			25000	$25,000.00
M008	Drinking Wate/Coffee	29	mo	200	0	0	$5,800.00
	Total						$227,665.00
Safety and Preparation							
S001	Temporary Fence and Tree Protection	4300	LF	2	12	0	$60,200.00
S002	Temporary Road	4000	SY	1.2	4	0	$20,800.00
S003	Signs	15	EA	200	100	0	$4,500.00
S004	Dumpsters (4)	29	mo	1,000	0	0	$29,000.00
S005	Trash Removal	29	mo	75	0	0	$2,175.00
S006	Truck Wash Station	1	LS	0	0	5000	$5,000.00
	Total						$121,675.00
Bonds, Permits, and Insurance							
B001	Occupancy Permit	1	LS	0	0	1000	$1,000.00
B002	Land Permit	1	LS	0	0	1500	$1,500.00
B003	Bonds	N/A	N/A	N/A	N/A	N/A	N/A
B004	Insurance	N/A	N/A	N/A	N/A	N/A	N/A
	Total						$2,500.00
	Grand Total						$4,809,540.00

Appendix B

Detailed Project Schedule

Health and Human Development Building | Classic Schedule Layout | 15-Oct-13 03:55

Activity Name	Original Duration	Start	Finish
Health and Humar	622	04-Feb-13	30-Jun-15
Project Milestones	504	22-Jul-13	30-Jun-15
Excavation Start Date	0	22-Jul-13	
Steel Erection Start Date	0	11-Nov-13*	
Steel Erection Completi	0		20-Jun-14
Building Dry-In	0		16-Dec-14
Substantial Completion	0		31-Mar-15
Owner Occupancy	0		30-Jun-15
Project Completion	0		30-Jun-15
Project Planning	233	04-Feb-13	01-Jan-14
Submittal Processing	231	04-Feb-13	30-Dec-13
BIM	233	04-Feb-13	01-Jan-14
Building Mockup	47	21-Aug-13	25-Oct-13
Sitework	5	14-Oct-13	18-Oct-13
Site Utilities	5	14-Oct-13	18-Oct-13
Demo	5	14-Oct-13	18-Oct-13
Existing To Remain	405	29-Apr-13	21-Nov-14
Shell	124	12-Aug-13	04-Feb-14
North	104	12-Aug-13	07-Jan-14
Demo Existing	7	12-Aug-13	20-Aug-13
Structural Steel	5	21-Aug-13	27-Aug-13
Concrete Foundat	19	21-Aug-13	17-Sep-13
Structural Metal S	9	28-Aug-13	10-Sep-13
Windows Install, L	83	11-Sep-13	07-Jan-14
East	103	09-Sep-13	31-Jan-14
Demo Existing	7	09-Sep-13	17-Sep-13
Concrete Foundat	5	18-Sep-13	24-Sep-13
Structural Steel	5	16-Oct-13*	22-Oct-13
Structural Metal S	11	22-Oct-13*	05-Nov-13
Windows Install, L	61	06-Nov-13*	31-Jan-14
South	85	07-Oct-13	04-Feb-14
Demo Existing	7	07-Oct-13	15-Oct-13



▬ Actual Level of Effort	🟩 Remaining Work
🟦 Actual Work	🟥 Critical Remain...

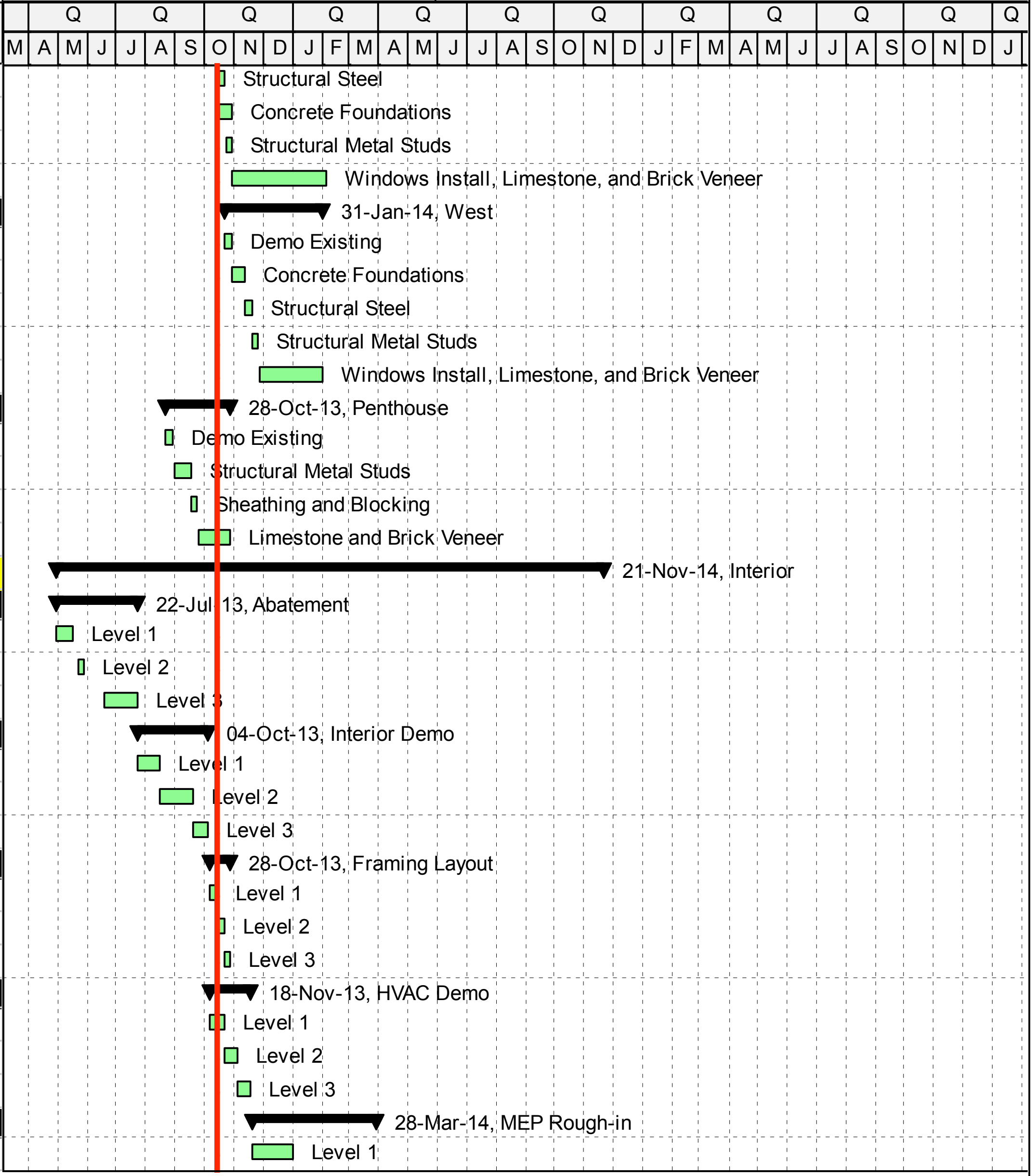
TASK filter: All Activities

Health and Human Development Building

Classic Schedule Layout

15-Oct-13 03:55

Activity Name	Original Duration	Start	Finish
Structural Steel	5	16-Oct-13*	22-Oct-13
Concrete Foundat	10	16-Oct-13*	29-Oct-13
Structural Metal S	5	23-Oct-13*	29-Oct-13
Windows Install, L	68	30-Oct-13*	04-Feb-14
West	**73**	**21-Oct-13**	**31-Jan-14**
Demo Existing	7	21-Oct-13*	29-Oct-13
Concrete Foundat	10	30-Oct-13*	12-Nov-13
Structural Steel	5	13-Nov-13*	19-Nov-13
Structural Metal S	5	20-Nov-13*	26-Nov-13
Windows Install, L	46	27-Nov-13*	31-Jan-14
Penthouse	**48**	**21-Aug-13**	**28-Oct-13**
Demo Existing	7	21-Aug-13	29-Aug-13
Structural Metal S	11	30-Aug-13	16-Sep-13
Sheathing and Blo	5	17-Sep-13	23-Sep-13
Limestone and Bri	25	24-Sep-13*	28-Oct-13
Interior	**405**	**29-Apr-13**	**21-Nov-14**
Abatement	**59**	**29-Apr-13**	**22-Jul-13**
Level 1	15	29-Apr-13	17-May-13
Level 2	4	22-May-13	28-May-13
Level 3	23	19-Jun-13	22-Jul-13
Interior Demo	**53**	**23-Jul-13**	**04-Oct-13**
Level 1	17	23-Jul-13	14-Aug-13
Level 2	24	15-Aug-13	18-Sep-13
Level 3	12	19-Sep-13	04-Oct-13
Framing Layout	**16**	**07-Oct-13**	**28-Oct-13**
Level 1	6	07-Oct-13	14-Oct-13
Level 2	5	15-Oct-13*	21-Oct-13
Level 3	5	22-Oct-13*	28-Oct-13
HVAC Demo	**31**	**07-Oct-13**	**18-Nov-13**
Level 1	11	07-Oct-13	21-Oct-13
Level 2	10	22-Oct-13*	04-Nov-13
Level 3	10	05-Nov-13*	18-Nov-13
MEP Rough-in	**92**	**19-Nov-13**	**28-Mar-14**
Level 1	30	19-Nov-13*	01-Jan-14

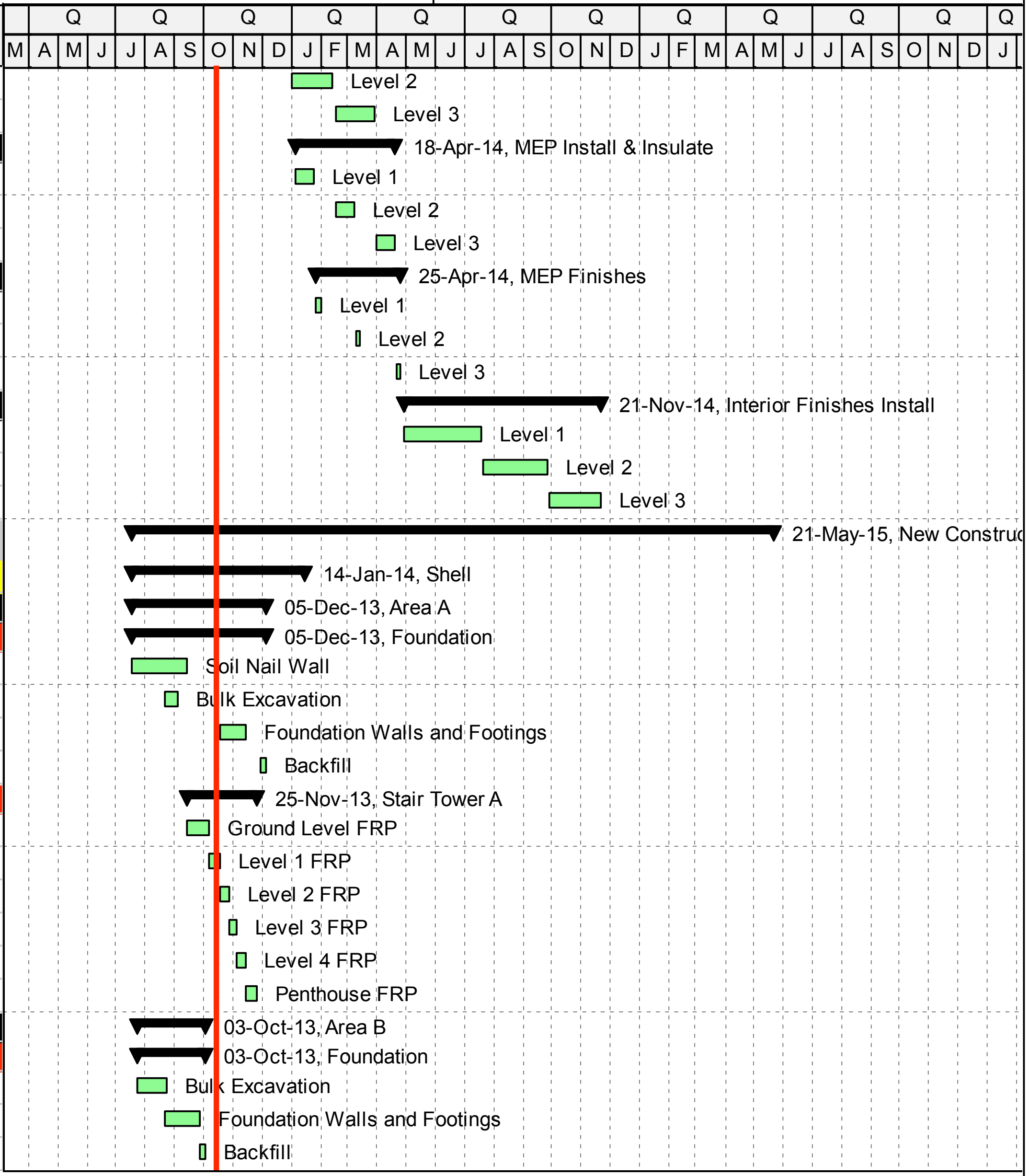


▬	Actual Level of Effort	🟩	Remaining Work
🟦	Actual Work	🟥	Critical Remain...

TASK filter: All Activities

Health and Human Development Building | Classic Schedule Layout | 15-Oct-13 03:55

Activity Name	Original Duration	Start	Finish
Level 2	30	02-Jan-14*	12-Feb-14
Level 3	30	17-Feb-14*	28-Mar-14
MEP Install & Insula	**75**	**06-Jan-14**	**18-Apr-14**
Level 1	15	06-Jan-14*	24-Jan-14
Level 2	15	17-Feb-14*	07-Mar-14
Level 3	15	31-Mar-14*	18-Apr-14
MEP Finishes	**65**	**27-Jan-14**	**25-Apr-14**
Level 1	5	27-Jan-14	31-Jan-14
Level 2	5	10-Mar-14*	14-Mar-14
Level 3	5	21-Apr-14*	25-Apr-14
Interior Finishes Ins	**150**	**28-Apr-14**	**21-Nov-14**
Level 1	60	28-Apr-14*	18-Jul-14
Level 2	50	21-Jul-14*	26-Sep-14
Level 3	40	29-Sep-14*	21-Nov-14
New Construction	479	17-Jul-13	21-May-15
Shell	127	17-Jul-13	14-Jan-14
Area A	**100**	**17-Jul-13**	**05-Dec-13**
Foundation	**100**	**17-Jul-13**	**05-Dec-13**
Soil Nail Wall	41	17-Jul-13	12-Sep-13
Bulk Excavation	10	21-Aug-13	04-Sep-13
Foundation Wa	20	17-Oct-13*	13-Nov-13
Backfill	5	29-Nov-13*	05-Dec-13
Stair Tower A	**52**	**13-Sep-13**	**25-Nov-13**
Ground Level F	17	13-Sep-13	07-Oct-13
Level 1 FRP	9	07-Oct-13	17-Oct-13
Level 2 FRP	8	17-Oct-13*	28-Oct-13
Level 3 FRP	6	28-Oct-13*	04-Nov-13
Level 4 FRP	9	04-Nov-13*	14-Nov-13
Penthouse FRP	8	14-Nov-13*	25-Nov-13
Area B	**51**	**24-Jul-13**	**03-Oct-13**
Foundation	**51**	**24-Jul-13**	**03-Oct-13**
Bulk Excavation	22	24-Jul-13	22-Aug-13
Foundation Wa	25	22-Aug-13	26-Sep-13
Backfill	6	26-Sep-13	03-Oct-13

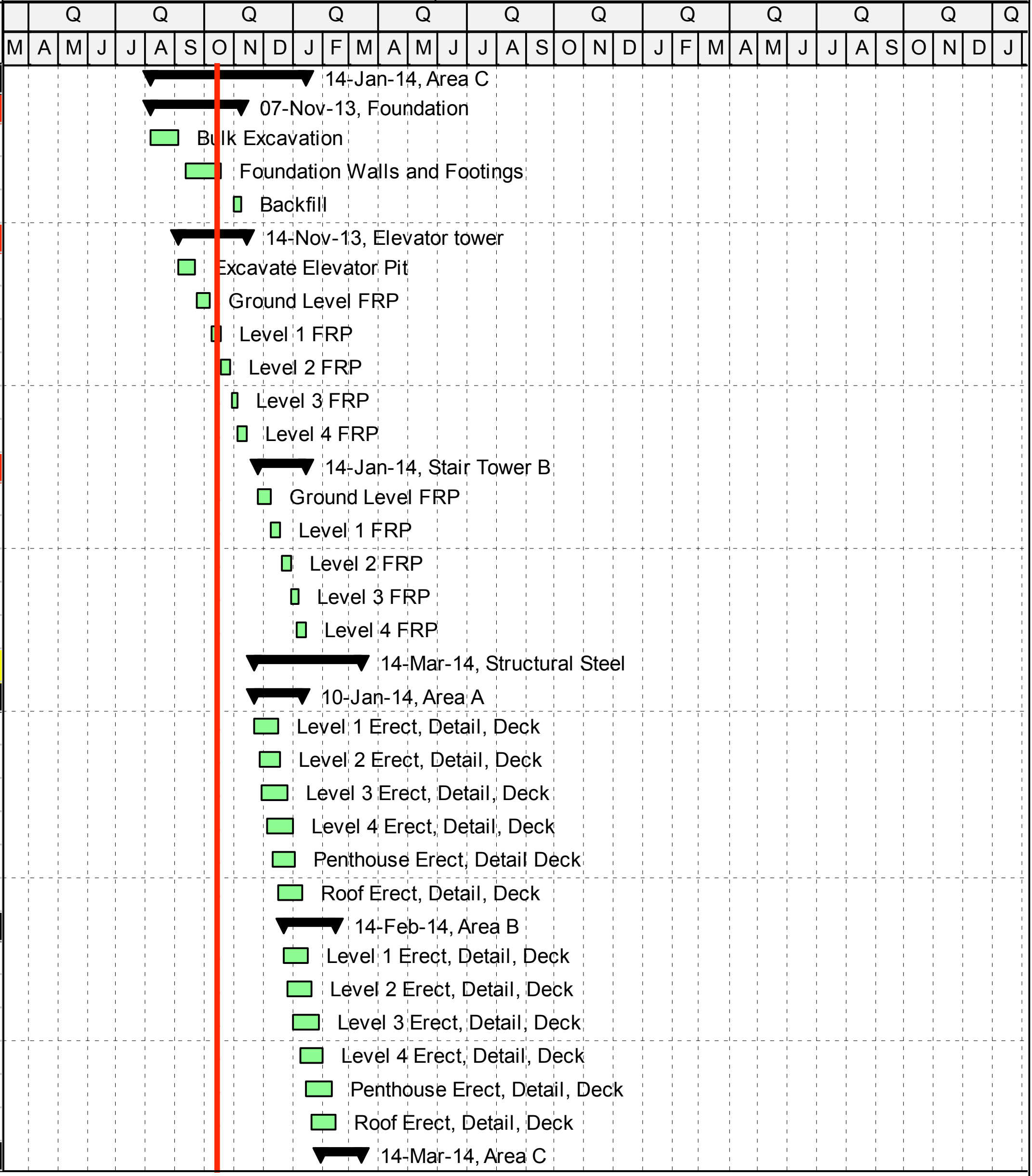


🟦	Actual Level of Effort	🟩	Remaining Work
🟦	Actual Work	🟥	Critical Remain...

TASK filter: All Activities

Health and Human Development Building | Classic Schedule Layout | 15-Oct-13 03:55

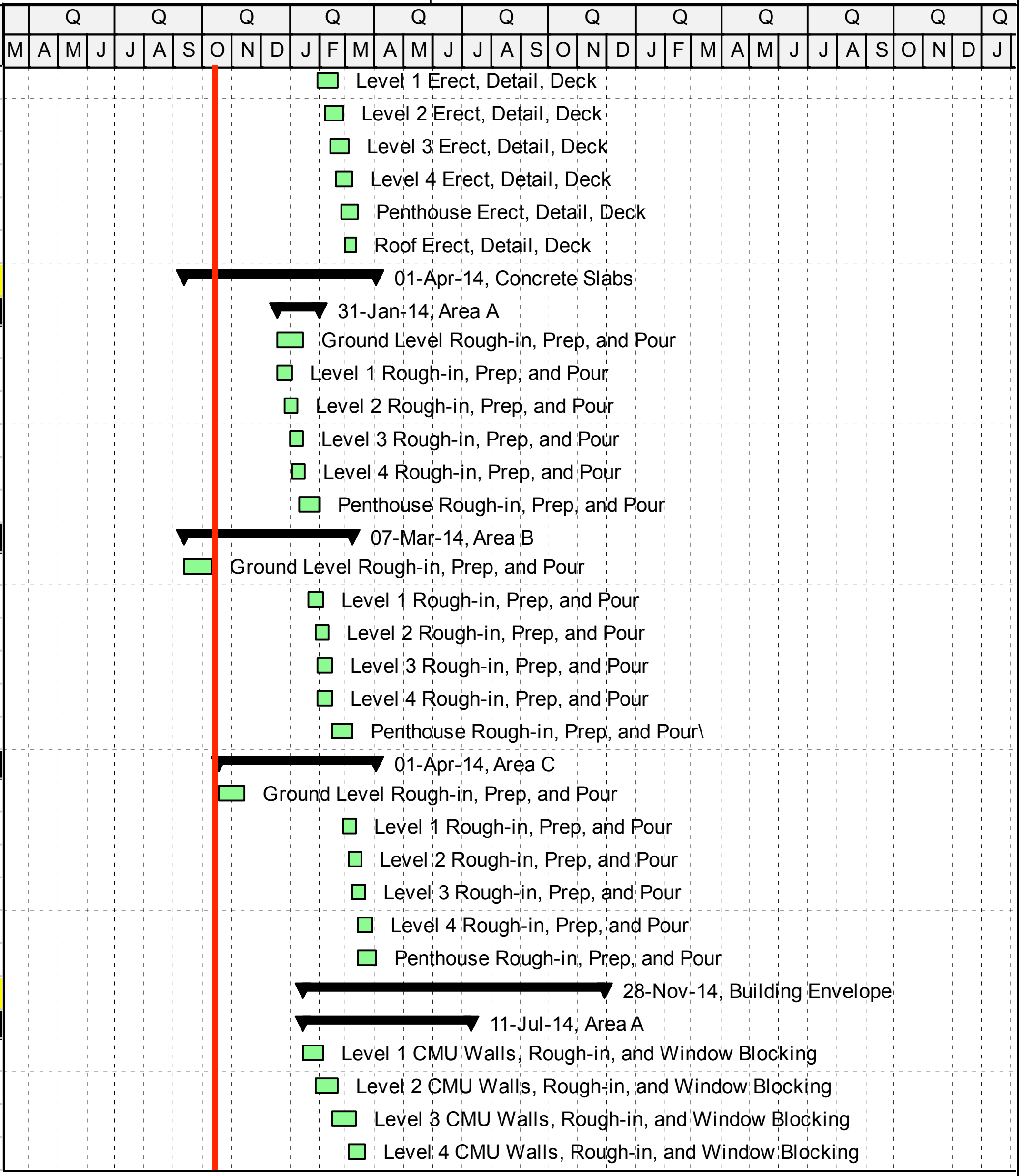
Activity Name	Original Duration	Start	Finish
Area C	114	05-Aug-13	14-Jan-14
Foundation	68	05-Aug-13	07-Nov-13
Bulk Excavation	21	05-Aug-13	03-Sep-13
Foundation Wa	26	12-Sep-13	17-Oct-13
Backfill	6	31-Oct-13*	07-Nov-13
Elevator tower	53	03-Sep-13	14-Nov-13
Excavate Eleva	14	03-Sep-13	20-Sep-13
Ground Level F	11	23-Sep-13	07-Oct-13
Level 1 FRP	8	08-Oct-13	17-Oct-13
Level 2 FRP	7	18-Oct-13*	28-Oct-13
Level 3 FRP	5	29-Oct-13*	04-Nov-13
Level 4 FRP	8	05-Nov-13*	14-Nov-13
Stair Tower B	35	25-Nov-13	14-Jan-14
Ground Level F	10	25-Nov-13*	09-Dec-13
Level 1 FRP	9	09-Dec-13*	19-Dec-13
Level 2 FRP	6	20-Dec-13*	30-Dec-13
Level 3 FRP	6	30-Dec-13*	06-Jan-14
Level 4 FRP	7	06-Jan-14*	14-Jan-14
Structural Steel	80	21-Nov-13	14-Mar-14
Area A	35	21-Nov-13	10-Jan-14
Level 1 Erect, Det	18	21-Nov-13*	17-Dec-13
Level 2 Erect, Det	16	27-Nov-13*	19-Dec-13
Level 3 Erect, Det	19	29-Nov-13*	26-Dec-13
Level 4 Erect, Det	19	05-Dec-13*	01-Jan-14
Penthouse Erect, I	17	11-Dec-13*	03-Jan-14
Roof Erect, Detail	18	17-Dec-13*	10-Jan-14
Area B	39	23-Dec-13	14-Feb-14
Level 1 Erect, Det	18	23-Dec-13*	16-Jan-14
Level 2 Erect, Det	18	27-Dec-13*	21-Jan-14
Level 3 Erect, Det	19	02-Jan-14*	28-Jan-14
Level 4 Erect, Det	18	08-Jan-14*	31-Jan-14
Penthouse Erect, I	20	14-Jan-14*	10-Feb-14
Roof Erect, Detail	20	20-Jan-14*	14-Feb-14
Area C	31	31-Jan-14	14-Mar-14



▬ Actual Level of Effort	🟩 Remaining Work
🟦 Actual Work	🟥 Critical Remain...

TASK filter: All Activities

Activity Name	Original Duration	Start	Finish
Level 1 Erect, Det	15	31-Jan-14*	20-Feb-14
Level 2 Erect, Det	15	06-Feb-14*	26-Feb-14
Level 3 Erect, Det	15	12-Feb-14*	04-Mar-14
Level 4 Erect, Det	14	18-Feb-14*	07-Mar-14
Penthouse Erect,	15	24-Feb-14*	14-Mar-14
Roof Erect, Detail	8	28-Feb-14*	11-Mar-14
Concrete Slabs	**142**	**12-Sep-13**	**01-Apr-14**
Area A	**31**	**19-Dec-13**	**31-Jan-14**
Ground Level Rou	19	19-Dec-13*	15-Jan-14
Level 1 Rough-in,	10	19-Dec-13*	02-Jan-14
Level 2 Rough-in,	11	26-Dec-13*	09-Jan-14
Level 3 Rough-in,	11	01-Jan-14*	15-Jan-14
Level 4 Rough-in,	11	03-Jan-14*	17-Jan-14
Penthouse Rough	16	10-Jan-14*	31-Jan-14
Area B	**125**	**12-Sep-13**	**07-Mar-14**
Ground Level Rou	20	12-Sep-13	09-Oct-13
Level 1 Rough-in,	11	21-Jan-14*	04-Feb-14
Level 2 Rough-in,	11	28-Jan-14*	11-Feb-14
Level 3 Rough-in,	11	31-Jan-14*	14-Feb-14
Level 4 Rough-in,	11	31-Jan-14*	14-Feb-14
Penthouse Rough	16	14-Feb-14*	07-Mar-14
Area C	**117**	**17-Oct-13**	**01-Apr-14**
Ground Level Rou	20	17-Oct-13*	13-Nov-13
Level 1 Rough-in,	11	26-Feb-14*	12-Mar-14
Level 2 Rough-in,	11	04-Mar-14*	18-Mar-14
Level 3 Rough-in,	11	07-Mar-14*	21-Mar-14
Level 4 Rough-in,	11	14-Mar-14*	28-Mar-14
Penthouse Rough	13	14-Mar-14*	01-Apr-14
Building Envelope	**228**	**15-Jan-14**	**28-Nov-14**
Area A	**128**	**15-Jan-14**	**11-Jul-14**
Level 1 CMU Wall	16	15-Jan-14*	05-Feb-14
Level 2 CMU Wall	18	29-Jan-14*	21-Feb-14
Level 3 CMU Wall	18	14-Feb-14*	11-Mar-14
Level 4 CMU Wall	14	04-Mar-14*	21-Mar-14

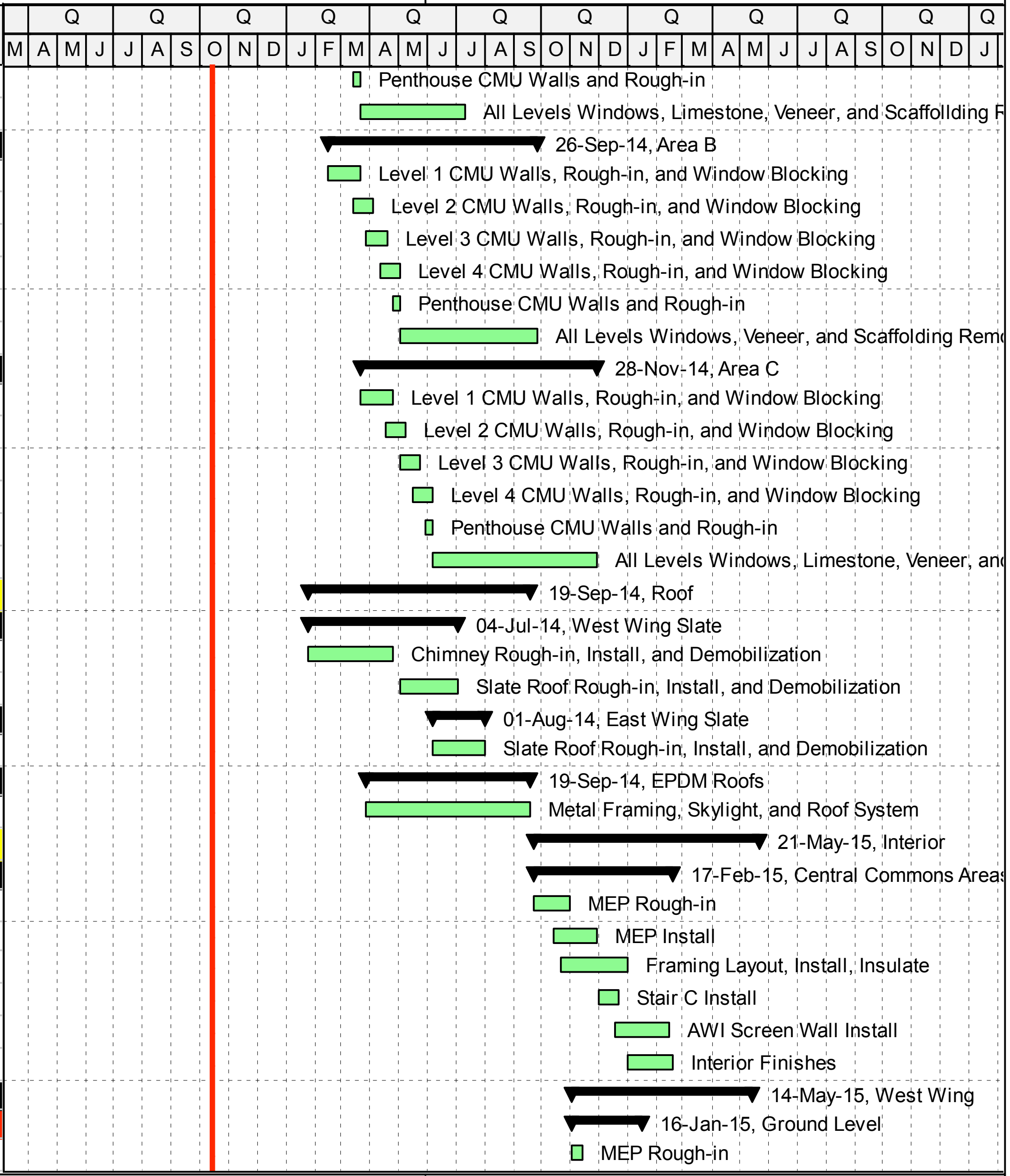


▬	Actual Level of Effort	🟩	Remaining Work
▬	Actual Work	🟥	Critical Remain...

TASK filter: All Activities

Health and Human Development Building | Classic Schedule Layout | 15-Oct-13 03:55

Activity Name	Original Duration	Start	Finish
Penthouse CMU V	6	14-Mar-14*	21-Mar-14
All Levels Windov	81	21-Mar-14*	11-Jul-14
Area B	**161**	**14-Feb-14**	**26-Sep-14**
Level 1 CMU Wall	26	14-Feb-14*	21-Mar-14
Level 2 CMU Wall	16	14-Mar-14*	04-Apr-14
Level 3 CMU Wall	16	28-Mar-14*	18-Apr-14
Level 4 CMU Wall	16	11-Apr-14*	02-May-14
Penthouse CMU V	6	25-Apr-14*	02-May-14
All Levels Windov	106	02-May-14*	26-Sep-14
Area C	**181**	**21-Mar-14**	**28-Nov-14**
Level 1 CMU Wall	26	21-Mar-14*	25-Apr-14
Level 2 CMU Wall	16	18-Apr-14*	09-May-14
Level 3 CMU Wall	16	02-May-14*	23-May-14
Level 4 CMU Wall	16	16-May-14*	06-Jun-14
Penthouse CMU V	6	30-May-14*	06-Jun-14
All Levels Windov	126	06-Jun-14*	28-Nov-14
Roof	**171**	**24-Jan-14**	**19-Sep-14**
West Wing Slate	**116**	**24-Jan-14**	**04-Jul-14**
Chimney Rough-ir	66	24-Jan-14*	25-Apr-14
Slate Roof Rough-	46	02-May-14*	04-Jul-14
East Wing Slate	**41**	**06-Jun-14**	**01-Aug-14**
Slate Roof Rough-	41	06-Jun-14*	01-Aug-14
EPDM Roofs	**126**	**28-Mar-14**	**19-Sep-14**
Metal Framing, Sk	126	28-Mar-14*	19-Sep-14
Interior	**174**	**22-Sep-14**	**21-May-15**
Central Commons /	**107**	**22-Sep-14**	**17-Feb-15**
MEP Rough-in	30	22-Sep-14*	31-Oct-14
MEP Install	34	14-Oct-14*	28-Nov-14
Framing Layout, Ir	51	22-Oct-14*	31-Dec-14
Stair C Install	16	01-Dec-14*	22-Dec-14
AWI Screen Wall	42	18-Dec-14*	13-Feb-15
Interior Finishes	34	01-Jan-15*	17-Feb-15
West Wing	**139**	**03-Nov-14**	**14-May-15**
Ground Level	**55**	**03-Nov-14**	**16-Jan-15**
MEP Rough-in	10	03-Nov-14*	14-Nov-14



🟦 Actual Level of Effort	🟩 Remaining Work
🟦 Actual Work	🟥 Critical Remain...

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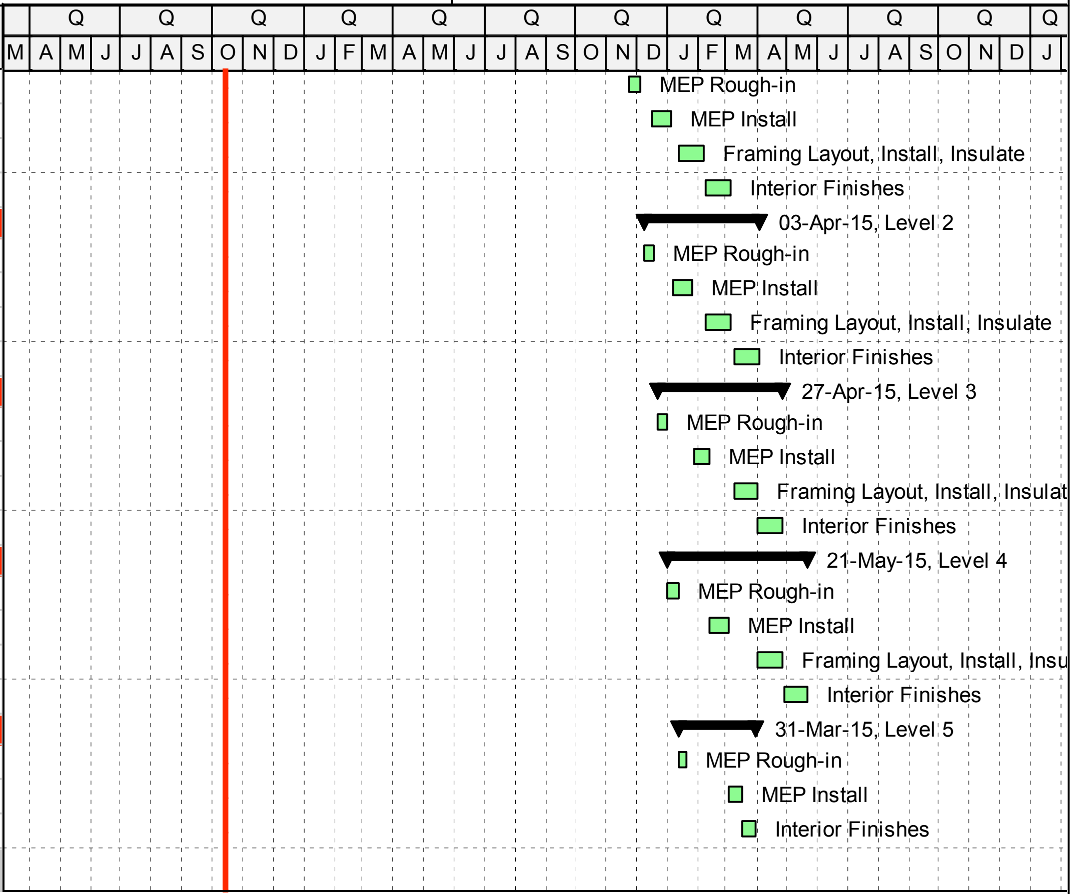
TASK filter: All Activities

Activity Name	Original Duration	Start	Finish
MEP Install	15	17-Nov-14*	05-Dec-14
Framing Layout	20	24-Nov-14*	19-Dec-14
Interior Finishes	20	22-Dec-14*	16-Jan-15
Level 1	**65**	**17-Nov-14**	**13-Feb-15**
MEP Rough-in	10	17-Nov-14*	28-Nov-14
MEP Install	15	08-Dec-14*	26-Dec-14
Framing Layout	20	19-Dec-14*	15-Jan-15
Interior Finishes	20	19-Jan-15*	13-Feb-15
Level 2	**73**	**01-Dec-14**	**11-Mar-15**
MEP Rough-in	8	01-Dec-14*	10-Dec-14
MEP Install	13	29-Dec-14*	14-Jan-15
Framing Layout	18	16-Jan-15*	10-Feb-15
Interior Finishes	18	16-Feb-15*	11-Mar-15
Level 3	**83**	**11-Dec-14**	**06-Apr-15**
MEP Rough-in	8	11-Dec-14*	22-Dec-14
MEP Install	13	15-Jan-15*	02-Feb-15
Framing Layout	18	11-Feb-15*	06-Mar-15
Interior Finishes	18	12-Mar-15*	06-Apr-15
Level 4	**93**	**23-Dec-14**	**30-Apr-15**
MEP Rough-in	8	23-Dec-14*	01-Jan-15
MEP Install	13	03-Feb-15*	19-Feb-15
Framing Layout	18	09-Mar-15*	01-Apr-15
Interior Finishes	18	07-Apr-15*	30-Apr-15
Level 5	**95**	**02-Jan-15**	**14-May-15**
MEP Rough-in	5	02-Jan-15*	08-Jan-15
MEP Install	10	20-Feb-15*	05-Mar-15
Interior Finishes	10	01-May-15*	14-May-15
East Wing	**139**	**10-Nov-14**	**21-May-15**
Ground Level	**65**	**10-Nov-14**	**06-Feb-15**
MEP Rough-in	10	10-Nov-14*	21-Nov-14
MEP Install	15	25-Nov-14*	15-Dec-14
Framing Layout	20	15-Dec-14*	09-Jan-15
Interior Finishes	20	12-Jan-15*	06-Feb-15
Level 1	**75**	**24-Nov-14**	**06-Mar-15**

▬ Actual Level of Effort	🟩 Remaining Work
🟦 Actual Work	🟥 Critical Remain...

TASK filter: All Activities

Activity Name	Original Duration	Start	Finish
MEP Rough-in	10	24-Nov-14*	05-Dec-14
MEP Install	15	16-Dec-14*	05-Jan-15
Framing Layout	20	12-Jan-15*	06-Feb-15
Interior Finishes	20	09-Feb-15*	06-Mar-15
Level 2	85	08-Dec-14	03-Apr-15
MEP Rough-in	10	08-Dec-14*	19-Dec-14
MEP Install	15	06-Jan-15*	26-Jan-15
Framing Layout	20	09-Feb-15*	06-Mar-15
Interior Finishes	20	09-Mar-15*	03-Apr-15
Level 3	91	22-Dec-14	27-Apr-15
MEP Rough-in	8	22-Dec-14*	31-Dec-14
MEP Install	13	27-Jan-15*	12-Feb-15
Framing Layout	18	09-Mar-15*	01-Apr-15
Interior Finishes	18	02-Apr-15*	27-Apr-15
Level 4	101	01-Jan-15	21-May-15
MEP Rough-in	8	01-Jan-15*	12-Jan-15
MEP Install	13	13-Feb-15*	03-Mar-15
Framing Layout	18	02-Apr-15*	27-Apr-15
Interior Finishes	18	28-Apr-15*	21-May-15
Level 5	56	13-Jan-15	31-Mar-15
MEP Rough-in	5	13-Jan-15*	19-Jan-15
MEP Install	10	04-Mar-15*	17-Mar-15
Interior Finishes	10	18-Mar-15*	31-Mar-15
Closeout	0		



▬	Actual Level of Effort	🟩	Remaining Work
🟦	Actual Work	🟥	Critical Remain...

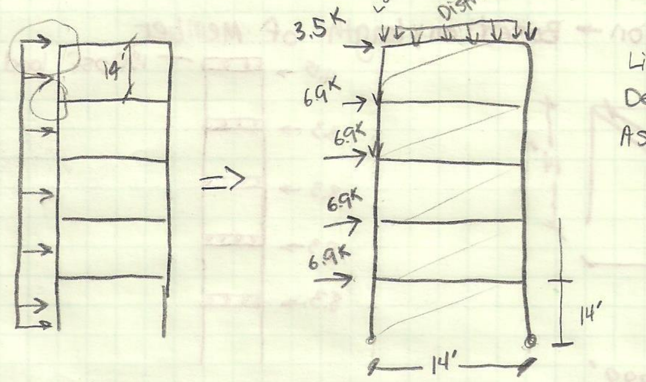
TASK filter: All Activities

Appendix C

Structural Breadth Calculations

19.642 psf × 26' = 491.05 plf

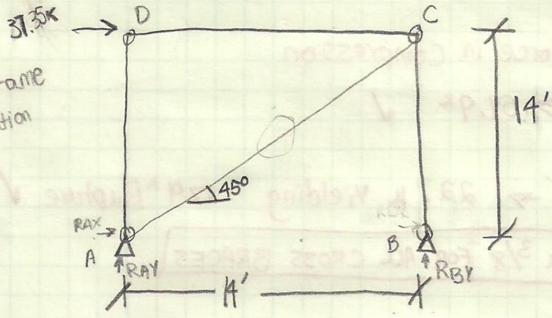
19.642 psf × 24' = 471.408 plf



Live Load = 70 psf

Dead Load = Assumed 30psf

Assume Load of beams = 50psf



Bottom Frame in Elevation view

$\Sigma F_x = 0 = 37.35 + R_{Ax} = 0$

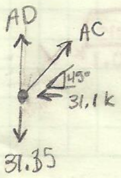
$R_{Ax} = -37.35$ $\boxed{R_{Ax} = 37.35 \leftarrow}$

$\Sigma F_Y = 0 = R_{AY} + R_{BY} = 0$

$R_{AY} = -37.35$ $\boxed{R_{AY} = 37.35 \downarrow}$

$\Sigma M_A = 0 \Rightarrow R_{BY}(14') = 37.35(14')$

$\boxed{R_{BY} = 37.35 \uparrow}$



$\Sigma F_Y = -37.35 + AD_Y + AC\sin(45) = 0$

$\Sigma F_x = -37.35 + AC\cos(45) = 0$

$AC\cos(45) = 37.35$

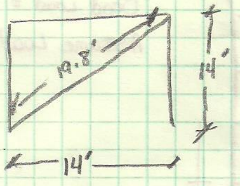
$\boxed{AC = 53K}$

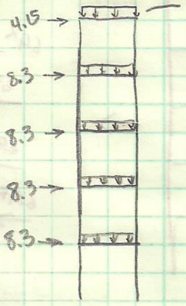
Don't account for Dead & live load for this b/c it only resists lateral

→ HSS Steel

Check Steel Manual

- → Tension →
- → Compression → Based on length of Member





190 psf load → Multiply it by the span (14') Divided by 1000 → = 2.1 k/ft

19.799'

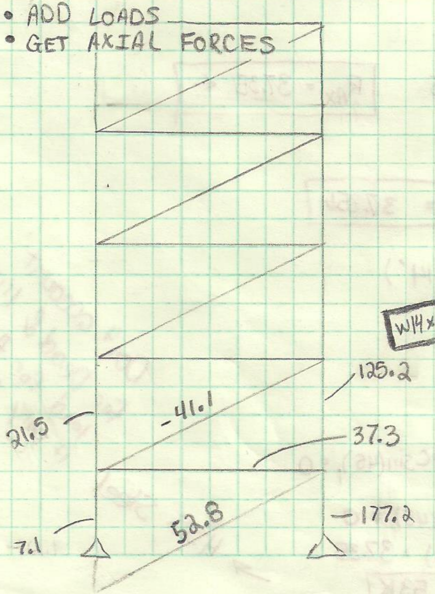
Check the 53k Axial Force in Compression

HSS 4½ x 4½ x ⅜ → 59.9k ✓

CHECK IN TENSION → 227k Yielding 179k Rupture ✓

Use HSS 4½x4½ x ⅜ FOR ALL CROSS BRACES

- Put the Model into Risa
- ADD LOADS
- GET AXIAL FORCES



✱ USE THE LARGEST SIZE THE WHOLE WAY UP. LARGEST MEMBERS ON THE BOTTOM

* use 28' Long For Columns as Maximum length

* WANT TO USE W14 for Column Sizing because they splice well together.

W14x61

Compression → 215 kips ✓

Tension → 806 Yielding ✓

653 Rupture ✓

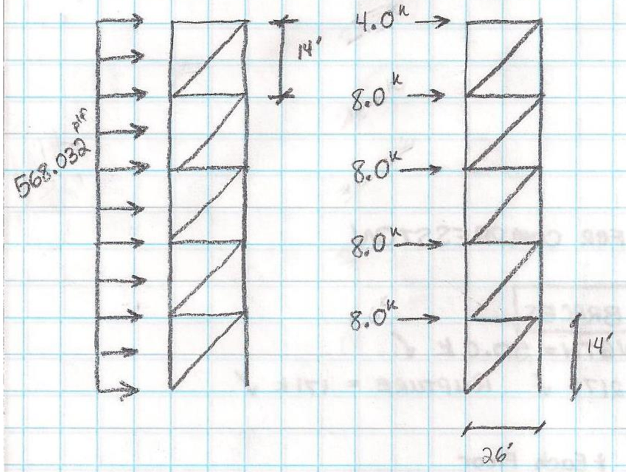
Use W10x17 For Beams

↳ Max load = 40.1k ✓

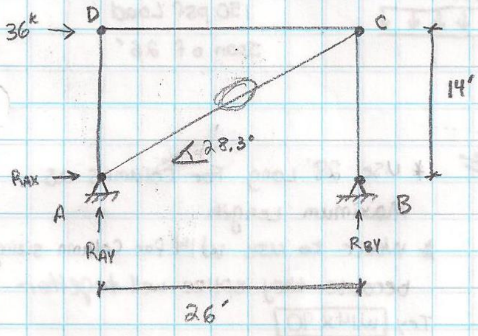
Other Side of Stair Tower

Wind Load = 23.668 psf

23.668 psf × 24' = 568.032 plf



Σ Horizontal Forces = 36.0k



Angle : Tan (Angle) = $\frac{14}{26}$

Angle = 28.3°

$\Sigma F_x = 0 = 36 + R_{AX} = 0$

$R_{AX} = -36^k$

$\boxed{R_{AX} = 36^k \leftarrow}$

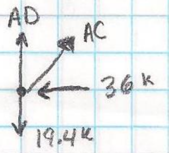
$\Sigma F_y = 0 = R_{AY} + R_{BY} = 0$

$R_{AY} = -19.4^k$

$\boxed{R_{AY} = 19.4^k \downarrow}$

$\Sigma M_A = 0 \Rightarrow R_{BY}(26') = 36(14')$

$\boxed{R_{BY} = 19.4K \uparrow}$



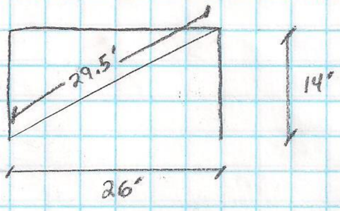
$\Sigma F_y = -19.4K + AD_y + AC \sin(28.3) = 0$

$\Sigma F_x = -36 + AC \cos(28.3) = 0$

$AC \cos(28.3) = 36 \rightarrow \boxed{AC = 40.89K}$

CHECK STEEL MANUAL

- IDEAL FROM A CONSTRUCTION STANDPOINT TO USE SAME SIZE
  - ↳ CHECK COMPRESSION FIRST SINCE IT CONTROLS

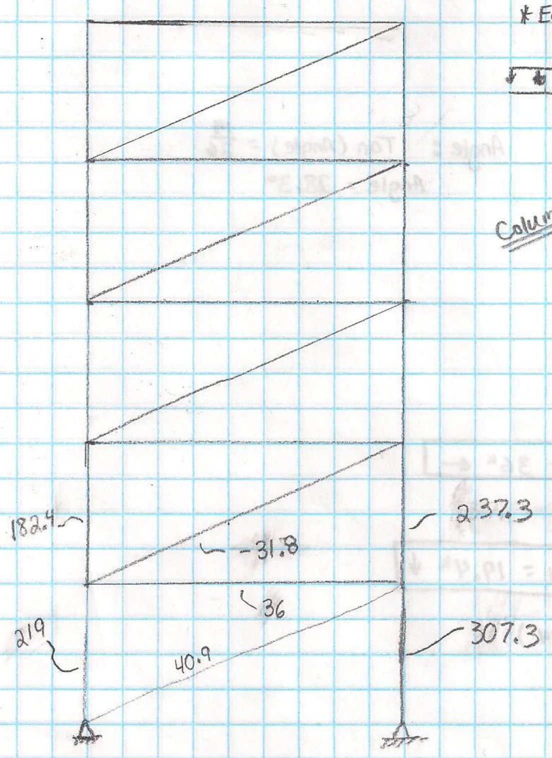


SAME SIZE WILL NOT WORK FOR COMPRESSION

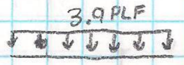
$\boxed{\text{USE HSS } 6\times6\times1/4 \text{ FOR CROSS BRACES}}$

↳ COMPRESSION FOR 30' LENGTH = 50.0 K ✓

↳ TENSION → YIELDING = 217ᵏ ✓ RUPTURE = 171 k ✓



* Each Floor



150 psf Load

Span of 26'

Columns

* Use 28' Long For Columns as Maximum Length

* Want to use W14 for Column sizing because they splice well together

Try $\boxed{\text{W14} \times 90}$

Compression → 653 kips ✓

Tension → 1190 Yielding ✓

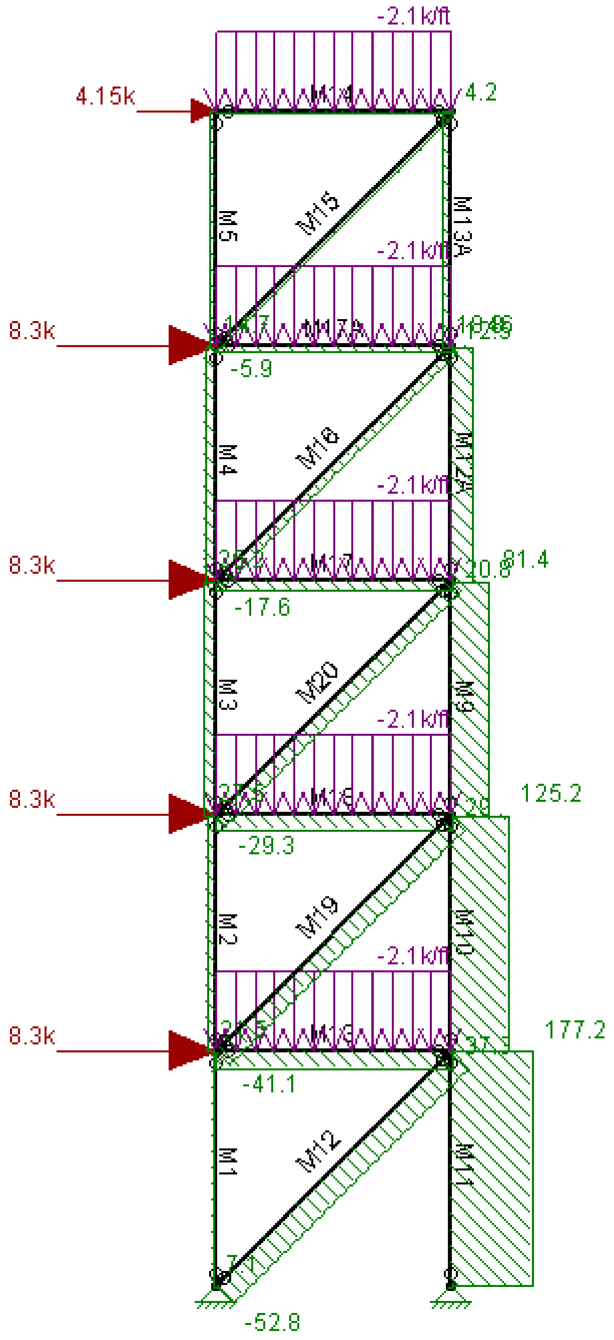
970 Rupture ✓

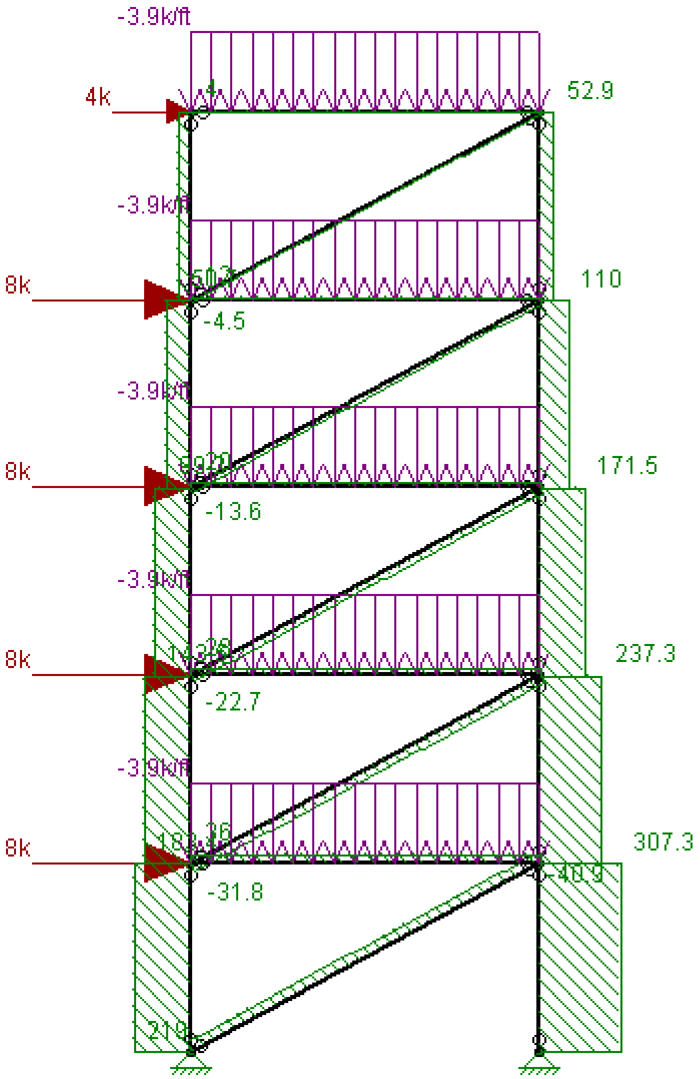
Beams

Span = 26'

can use a $\boxed{\text{W10} \times 30}$

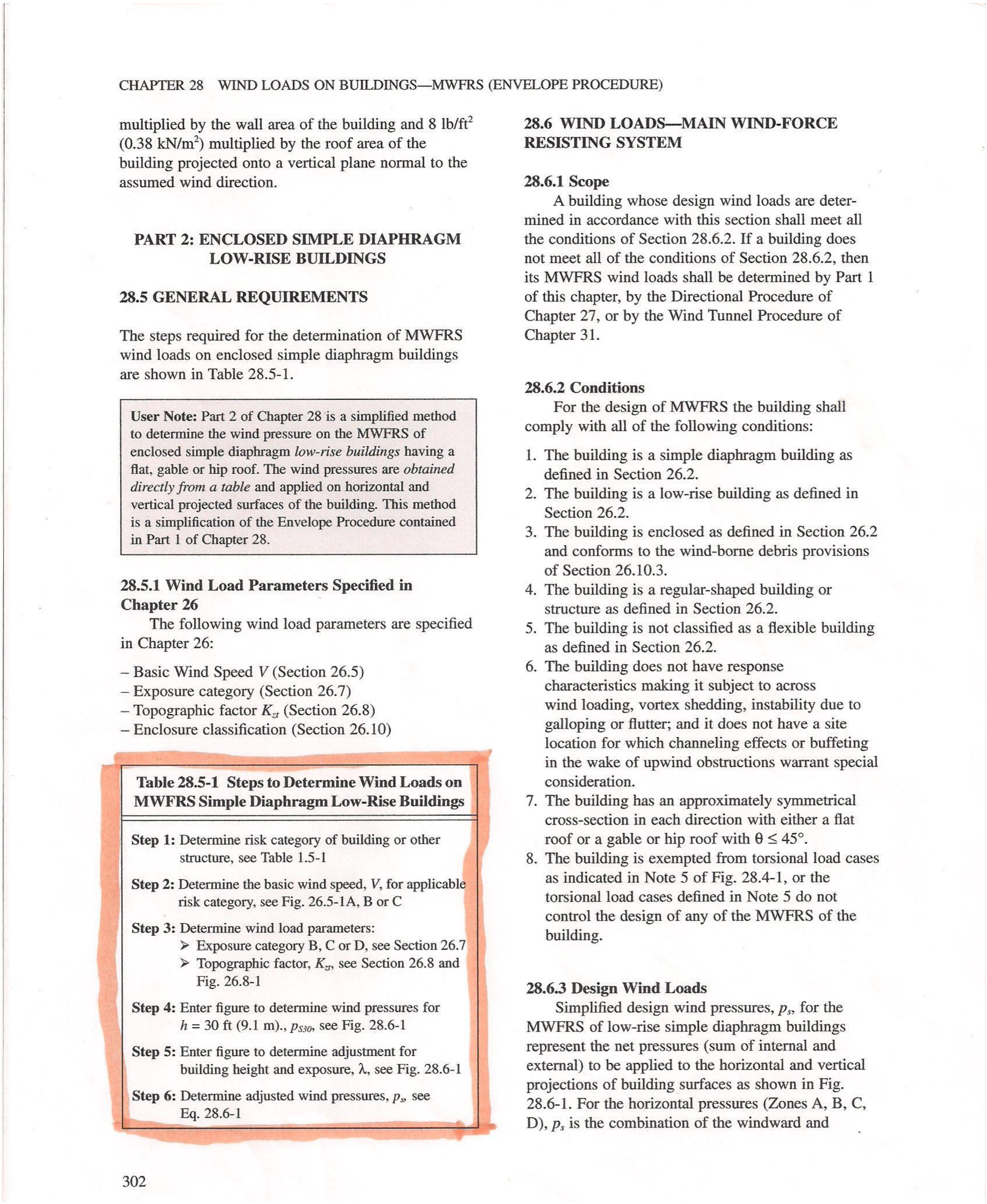
↳ Max Load = 42.2


-2.1k/ft
4.15k
M14
4.2
M15
M5
M13A
-2.1k/ft
8.3k
M17A
-5.9
M4
M18
M12A
-2.1k/ft
8.3k
M17
20.8
81.4
-17.6
M3
M20
M9
-2.1k/ft
8.3k
M18
125.2
-29.3
M2
M19
M10
-2.1k/ft
8.3k
M16
177.2
-41.1
M1
M12
M11
-52.8


-3.9k/ft
4k
4
52.9
-3.9k/ft
8k
50.3
110
-4.5
-3.9k/ft
8k
171.5
-13.6
-3.9k/ft
8k
237.3
-22.7
-3.9k/ft
8k
307.3
-31.8
-40.9
219

Appendix D

Structural Breadth References



multiplied by the wall area of the building and 8 lb/ft^2 (0.38 kN/m^2) multiplied by the roof area of the building projected onto a vertical plane normal to the assumed wind direction.

PART 2: ENCLOSED SIMPLE DIAPHRAGM LOW-RISE BUILDINGS

28.5 GENERAL REQUIREMENTS

The steps required for the determination of MWFRS wind loads on enclosed simple diaphragm buildings are shown in Table 28.5-1.

> **User Note:** Part 2 of Chapter 28 is a simplified method to determine the wind pressure on the MWFRS of enclosed simple diaphragm *low-rise buildings* having a flat, gable or hip roof. The wind pressures are *obtained directly from a table* and applied on horizontal and vertical projected surfaces of the building. This method is a simplification of the Envelope Procedure contained in Part 1 of Chapter 28.

28.5.1 Wind Load Parameters Specified in Chapter 26

The following wind load parameters are specified in Chapter 26:

– Basic Wind Speed *V* (Section 26.5)
– Exposure category (Section 26.7)
– Topographic factor K_{zt} (Section 26.8)
– Enclosure classification (Section 26.10)

Table 28.5-1 Steps to Determine Wind Loads on MWFRS Simple Diaphragm Low-Rise Buildings

Step 1: Determine risk category of building or other structure, see Table 1.5-1

Step 2: Determine the basic wind speed, *V*, for applicable risk category, see Fig. 26.5-1A, B or C

Step 3: Determine wind load parameters:
- Exposure category B, C or D, see Section 26.7
- Topographic factor, K_{zt}, see Section 26.8 and Fig. 26.8-1

Step 4: Enter figure to determine wind pressures for h = 30 ft (9.1 m)., p_{S30}, see Fig. 28.6-1

Step 5: Enter figure to determine adjustment for building height and exposure, λ, see Fig. 28.6-1

Step 6: Determine adjusted wind pressures, p_s, see Eq. 28.6-1

28.6 WIND LOADS—MAIN WIND-FORCE RESISTING SYSTEM

28.6.1 Scope

A building whose design wind loads are determined in accordance with this section shall meet all the conditions of Section 28.6.2. If a building does not meet all of the conditions of Section 28.6.2, then its MWFRS wind loads shall be determined by Part 1 of this chapter, by the Directional Procedure of Chapter 27, or by the Wind Tunnel Procedure of Chapter 31.

28.6.2 Conditions

For the design of MWFRS the building shall comply with all of the following conditions:

1. The building is a simple diaphragm building as defined in Section 26.2.
2. The building is a low-rise building as defined in Section 26.2.
3. The building is enclosed as defined in Section 26.2 and conforms to the wind-borne debris provisions of Section 26.10.3.
4. The building is a regular-shaped building or structure as defined in Section 26.2.
5. The building is not classified as a flexible building as defined in Section 26.2.
6. The building does not have response characteristics making it subject to across wind loading, vortex shedding, instability due to galloping or flutter; and it does not have a site location for which channeling effects or buffeting in the wake of upwind obstructions warrant special consideration.
7. The building has an approximately symmetrical cross-section in each direction with either a flat roof or a gable or hip roof with $\theta \le 45°$.
8. The building is exempted from torsional load cases as indicated in Note 5 of Fig. 28.4-1, or the torsional load cases defined in Note 5 do not control the design of any of the MWFRS of the building.

28.6.3 Design Wind Loads

Simplified design wind pressures, p_s, for the MWFRS of low-rise simple diaphragm buildings represent the net pressures (sum of internal and external) to be applied to the horizontal and vertical projections of building surfaces as shown in Fig. 28.6-1. For the horizontal pressures (Zones A, B, C, D), p_s is the combination of the windward and

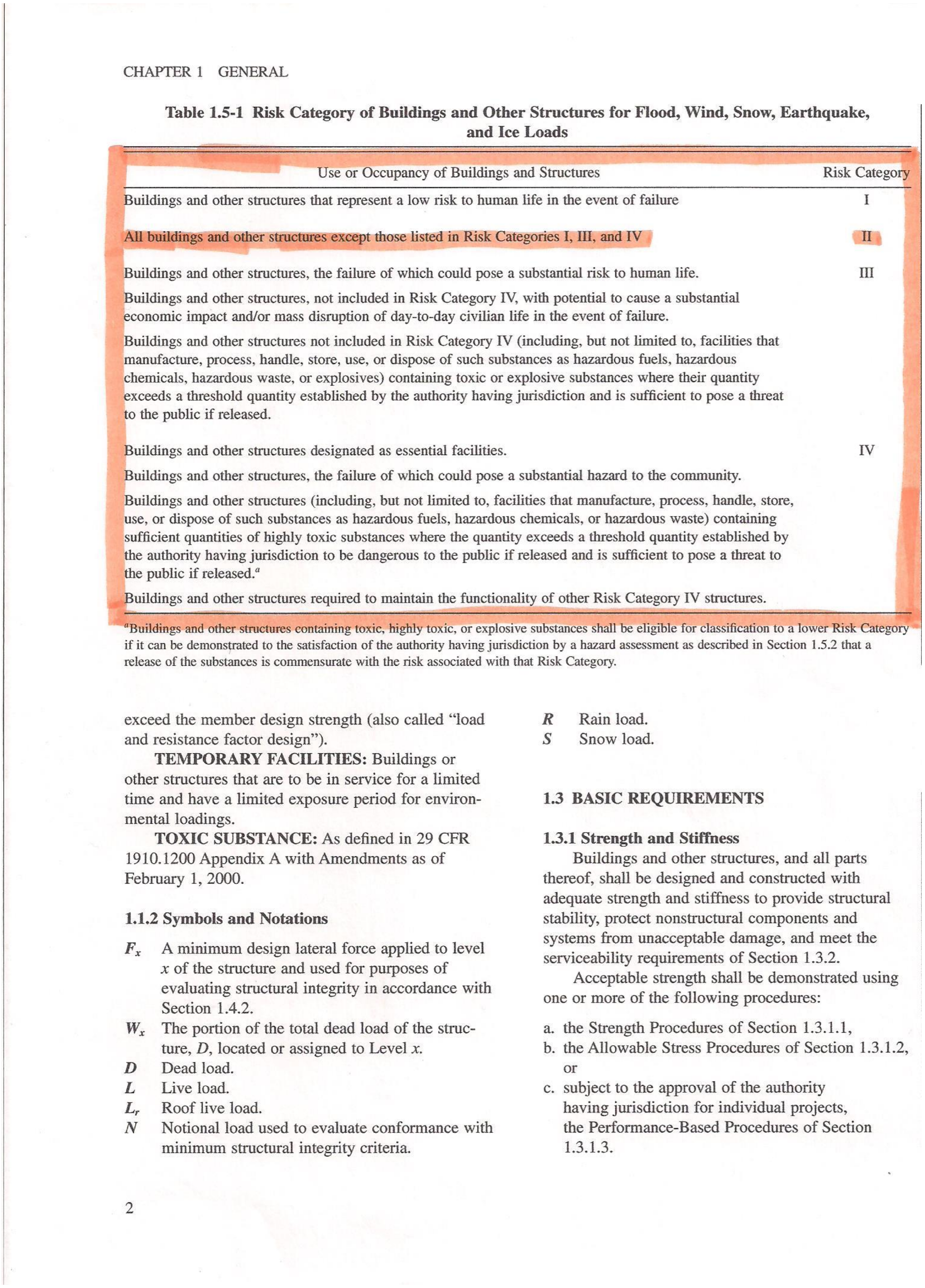


Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV

[a] Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.

exceed the member design strength (also called "load and resistance factor design").

TEMPORARY FACILITIES: Buildings or other structures that are to be in service for a limited time and have a limited exposure period for environmental loadings.

TOXIC SUBSTANCE: As defined in 29 CFR 1910.1200 Appendix A with Amendments as of February 1, 2000.

1.1.2 Symbols and Notations

F_x	A minimum design lateral force applied to level x of the structure and used for purposes of evaluating structural integrity in accordance with Section 1.4.2.
W_x	The portion of the total dead load of the structure, D, located or assigned to Level x.
D	Dead load.
L	Live load.
L_r	Roof live load.
N	Notional load used to evaluate conformance with minimum structural integrity criteria.
R	Rain load.
S	Snow load.

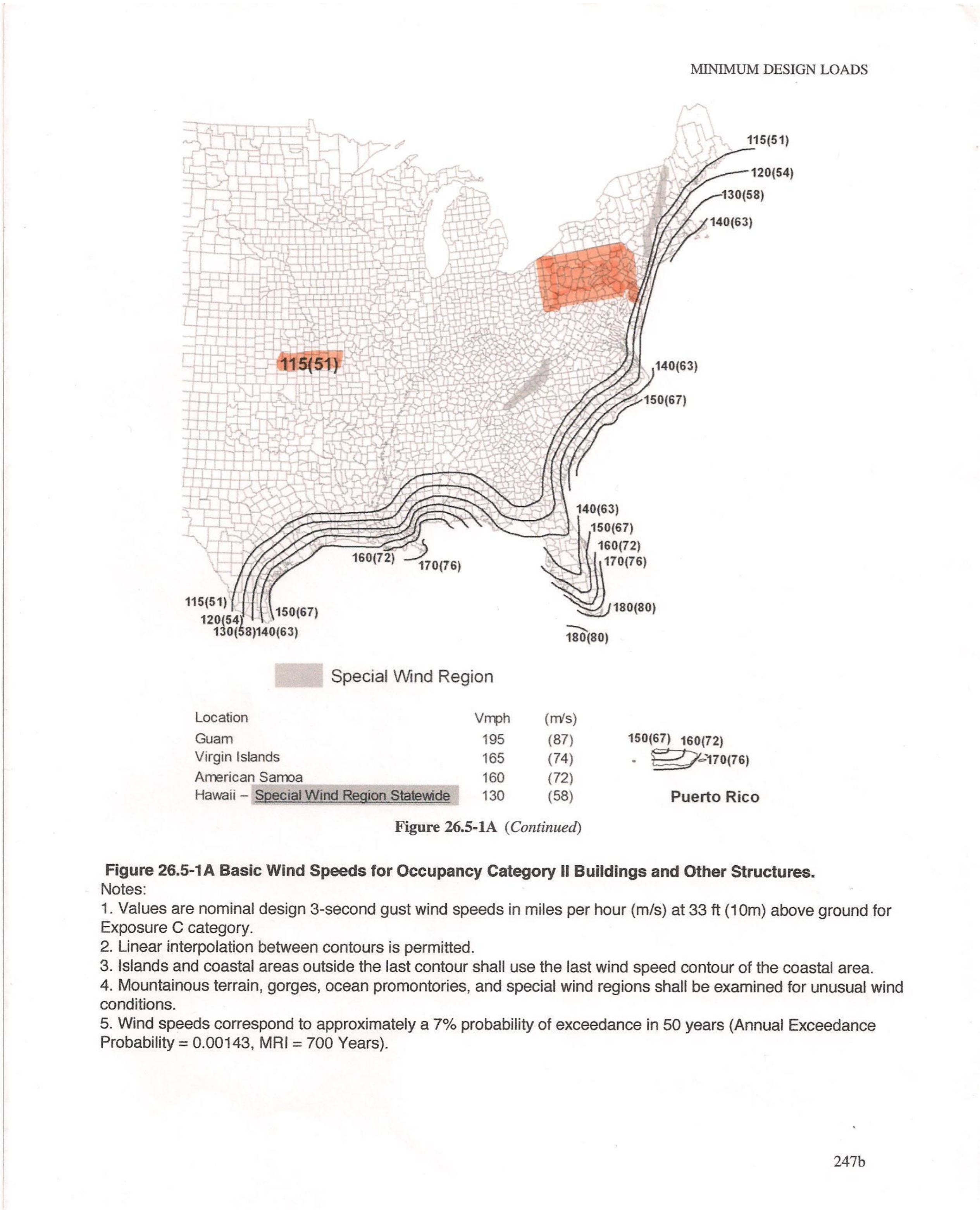
1.3 BASIC REQUIREMENTS

1.3.1 Strength and Stiffness

Buildings and other structures, and all parts thereof, shall be designed and constructed with adequate strength and stiffness to provide structural stability, protect nonstructural components and systems from unacceptable damage, and meet the serviceability requirements of Section 1.3.2.

Acceptable strength shall be demonstrated using one or more of the following procedures:

a. the Strength Procedures of Section 1.3.1.1,
b. the Allowable Stress Procedures of Section 1.3.1.2, or
c. subject to the approval of the authority having jurisdiction for individual projects, the Performance-Based Procedures of Section 1.3.1.3.



MINIMUM DESIGN LOADS

▨ Special Wind Region

Location	Vmph	(m/s)
Guam	195	(87)
Virgin Islands	165	(74)
American Samoa	160	(72)
Hawaii – Special Wind Region Statewide	130	(58)

Figure 26.5-1A *(Continued)*

Figure 26.5-1A Basic Wind Speeds for Occupancy Category II Buildings and Other Structures.

Notes:

1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 Years).

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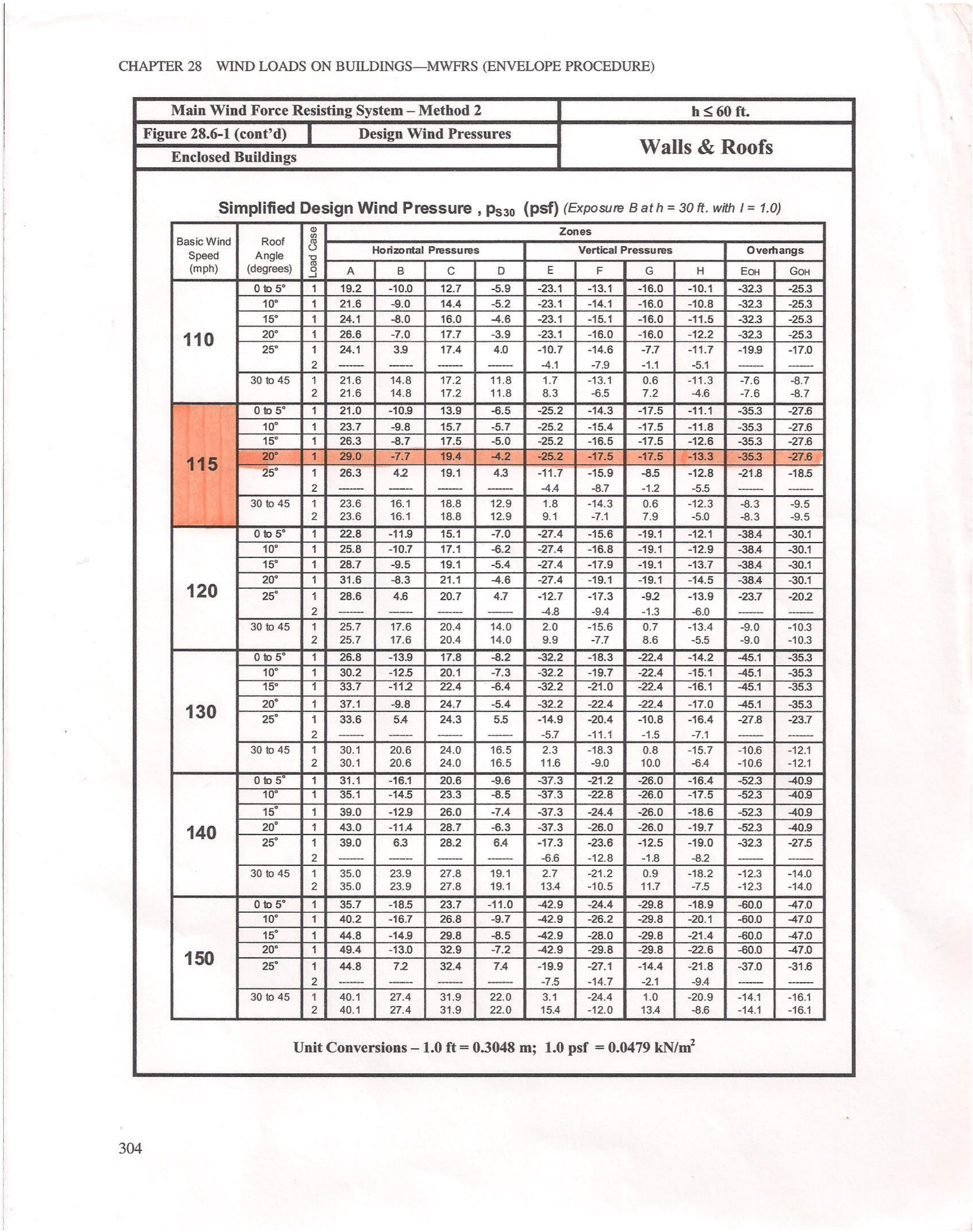


Main Wind Force Resisting System – Method 2 | **h ≤ 60 ft.**

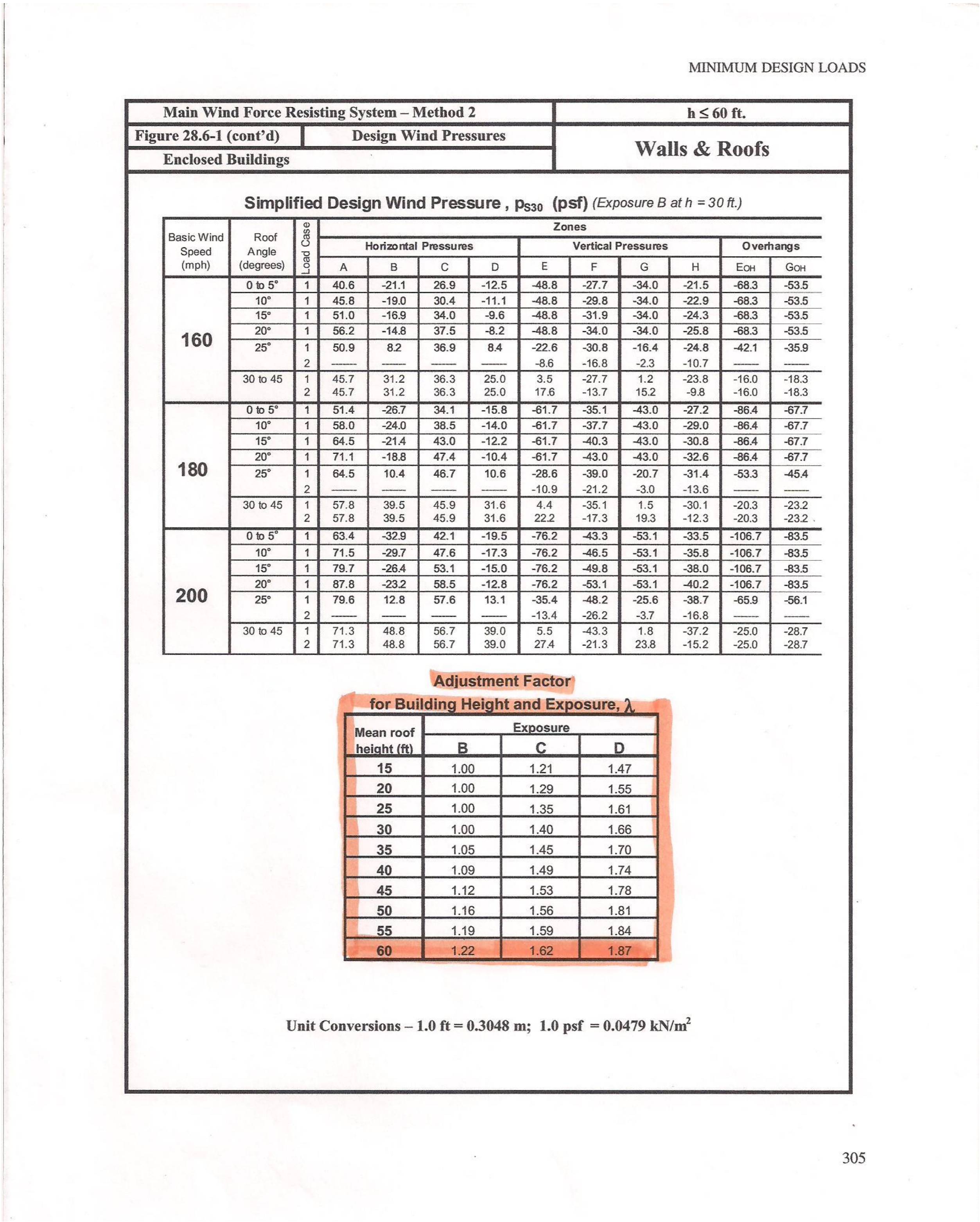
Figure 28.6-1 (cont'd) | **Design Wind Pressures** | **Walls & Roofs**

Enclosed Buildings

Simplified Design Wind Pressure , p_{S30} (psf) *(Exposure B at h = 30 ft. with I = 1.0)*

Basic Wind Speed (mph)	Roof Angle (degrees)	Load Case	Zones									
			Horizontal Pressures				Vertical Pressures				Overhangs	
			A	B	C	D	E	F	G	H	E_{OH}	G_{OH}
110	0 to 5°	1	19.2	-10.0	12.7	-5.9	-23.1	-13.1	-16.0	-10.1	-32.3	-25.3
	10°	1	21.6	-9.0	14.4	-5.2	-23.1	-14.1	-16.0	-10.8	-32.3	-25.3
	15°	1	24.1	-8.0	16.0	-4.6	-23.1	-15.1	-16.0	-11.5	-32.3	-25.3
	20°	1	26.6	-7.0	17.7	-3.9	-23.1	-16.0	-16.0	-12.2	-32.3	-25.3
	25°	1	24.1	3.9	17.4	4.0	-10.7	-14.6	-7.7	-11.7	-19.9	-17.0
		2	-------	-------	-------	-------	-4.1	-7.9	-1.1	-5.1	-------	-------
	30 to 45	1	21.6	14.8	17.2	11.8	1.7	-13.1	0.6	-11.3	-7.6	-8.7
		2	21.6	14.8	17.2	11.8	8.3	-6.5	7.2	-4.6	-7.6	-8.7
115	0 to 5°	1	21.0	-10.9	13.9	-6.5	-25.2	-14.3	-17.5	-11.1	-35.3	-27.6
	10°	1	23.7	-9.8	15.7	-5.7	-25.2	-15.4	-17.5	-11.8	-35.3	-27.6
	15°	1	26.3	-8.7	17.5	-5.0	-25.2	-16.5	-17.5	-12.6	-35.3	-27.6
	20°	1	29.0	-7.7	19.4	-4.2	-25.2	-17.5	-17.5	-13.3	-35.3	-27.6
	25°	1	26.3	4.2	19.1	4.3	-11.7	-15.9	-8.5	-12.8	-21.8	-18.5
		2	-------	-------	-------	-------	-4.4	-8.7	-1.2	-5.5	-------	-------
	30 to 45	1	23.6	16.1	18.8	12.9	1.8	-14.3	0.6	-12.3	-8.3	-9.5
		2	23.6	16.1	18.8	12.9	9.1	-7.1	7.9	-5.0	-8.3	-9.5
120	0 to 5°	1	22.8	-11.9	15.1	-7.0	-27.4	-15.6	-19.1	-12.1	-38.4	-30.1
	10°	1	25.8	-10.7	17.1	-6.2	-27.4	-16.8	-19.1	-12.9	-38.4	-30.1
	15°	1	28.7	-9.5	19.1	-5.4	-27.4	-17.9	-19.1	-13.7	-38.4	-30.1
	20°	1	31.6	-8.3	21.1	-4.6	-27.4	-19.1	-19.1	-14.5	-38.4	-30.1
	25°	1	28.6	4.6	20.7	4.7	-12.7	-17.3	-9.2	-13.9	-23.7	-20.2
		2	-------	-------	-------	-------	-4.8	-9.4	-1.3	-6.0	-------	-------
	30 to 45	1	25.7	17.6	20.4	14.0	2.0	-15.6	0.7	-13.4	-9.0	-10.3
		2	25.7	17.6	20.4	14.0	9.9	-7.7	8.6	-5.5	-9.0	-10.3
130	0 to 5°	1	26.8	-13.9	17.8	-8.2	-32.2	-18.3	-22.4	-14.2	-45.1	-35.3
	10°	1	30.2	-12.5	20.1	-7.3	-32.2	-19.7	-22.4	-15.1	-45.1	-35.3
	15°	1	33.7	-11.2	22.4	-6.4	-32.2	-21.0	-22.4	-16.1	-45.1	-35.3
	20°	1	37.1	-9.8	24.7	-5.4	-32.2	-22.4	-22.4	-17.0	-45.1	-35.3
	25°	1	33.6	5.4	24.3	5.5	-14.9	-20.4	-10.8	-16.4	-27.8	-23.7
		2	-------	-------	-------	-------	-5.7	-11.1	-1.5	-7.1	-------	-------
	30 to 45	1	30.1	20.6	24.0	16.5	2.3	-18.3	0.8	-15.7	-10.6	-12.1
		2	30.1	20.6	24.0	16.5	11.6	-9.0	10.0	-6.4	-10.6	-12.1
140	0 to 5°	1	31.1	-16.1	20.6	-9.6	-37.3	-21.2	-26.0	-16.4	-52.3	-40.9
	10°	1	35.1	-14.5	23.3	-8.5	-37.3	-22.8	-26.0	-17.5	-52.3	-40.9
	15°	1	39.0	-12.9	26.0	-7.4	-37.3	-24.4	-26.0	-18.6	-52.3	-40.9
	20°	1	43.0	-11.4	28.7	-6.3	-37.3	-26.0	-26.0	-19.7	-52.3	-40.9
	25°	1	39.0	6.3	28.2	6.4	-17.3	-23.6	-12.5	-19.0	-32.3	-27.5
		2	-------	-------	-------	-------	-6.6	-12.8	-1.8	-8.2	-------	-------
	30 to 45	1	35.0	23.9	27.8	19.1	2.7	-21.2	0.9	-18.2	-12.3	-14.0
		2	35.0	23.9	27.8	19.1	13.4	-10.5	11.7	-7.5	-12.3	-14.0
150	0 to 5°	1	35.7	-18.5	23.7	-11.0	-42.9	-24.4	-29.8	-18.9	-60.0	-47.0
	10°	1	40.2	-16.7	26.8	-9.7	-42.9	-26.2	-29.8	-20.1	-60.0	-47.0
	15°	1	44.8	-14.9	29.8	-8.5	-42.9	-28.0	-29.8	-21.4	-60.0	-47.0
	20°	1	49.4	-13.0	32.9	-7.2	-42.9	-29.8	-29.8	-22.6	-60.0	-47.0
	25°	1	44.8	7.2	32.4	7.4	-19.9	-27.1	-14.4	-21.8	-37.0	-31.6
		2	-------	-------	-------	-------	-7.5	-14.7	-2.1	-9.4	-------	-------
	30 to 45	1	40.1	27.4	31.9	22.0	3.1	-24.4	1.0	-20.9	-14.1	-16.1
		2	40.1	27.4	31.9	22.0	15.4	-12.0	13.4	-8.6	-14.1	-16.1

Unit Conversions – 1.0 ft = 0.3048 m; 1.0 psf = 0.0479 kN/m^2



Main Wind Force Resisting System – Method 2		h ≤ 60 ft.
Figure 28.6-1 (cont'd)	Design Wind Pressures	Walls & Roofs
Enclosed Buildings		

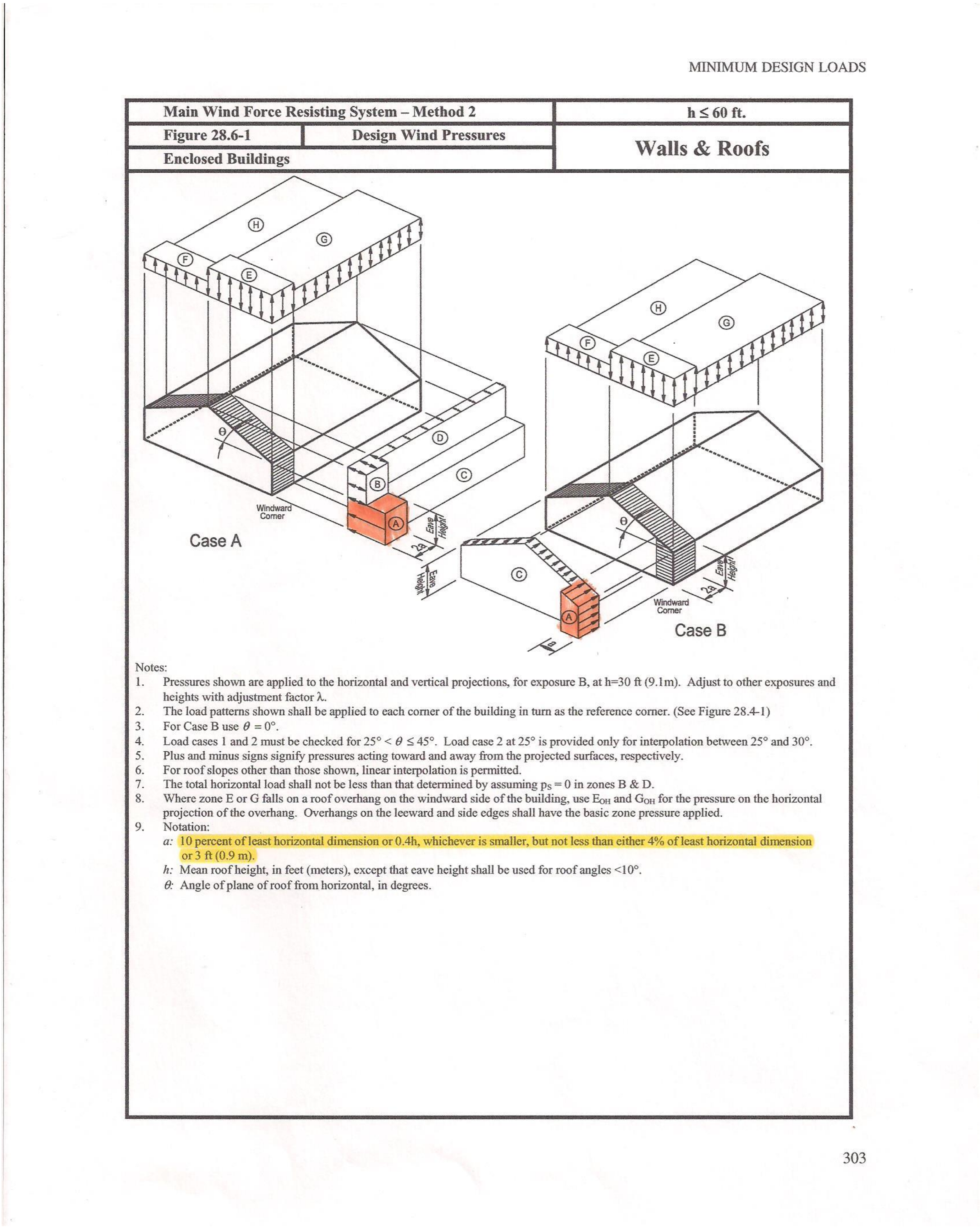
Simplified Design Wind Pressure , p_{S30} (psf) *(Exposure B at h = 30 ft.)*

Basic Wind Speed (mph)	Roof Angle (degrees)	Load Case	Zones									
			Horizontal Pressures				Vertical Pressures				Overhangs	
			A	B	C	D	E	F	G	H	E_{OH}	G_{OH}
160	0 to 5°	1	40.6	-21.1	26.9	-12.5	-48.8	-27.7	-34.0	-21.5	-68.3	-53.5
	10°	1	45.8	-19.0	30.4	-11.1	-48.8	-29.8	-34.0	-22.9	-68.3	-53.5
	15°	1	51.0	-16.9	34.0	-9.6	-48.8	-31.9	-34.0	-24.3	-68.3	-53.5
	20°	1	56.2	-14.8	37.5	-8.2	-48.8	-34.0	-34.0	-25.8	-68.3	-53.5
	25°	1	50.9	8.2	36.9	8.4	-22.6	-30.8	-16.4	-24.8	-42.1	-35.9
		2	------	------	------	------	-8.6	-16.8	-2.3	-10.7	------	------
	30 to 45	1	45.7	31.2	36.3	25.0	3.5	-27.7	1.2	-23.8	-16.0	-18.3
		2	45.7	31.2	36.3	25.0	17.6	-13.7	15.2	-9.8	-16.0	-18.3
180	0 to 5°	1	51.4	-26.7	34.1	-15.8	-61.7	-35.1	-43.0	-27.2	-86.4	-67.7
	10°	1	58.0	-24.0	38.5	-14.0	-61.7	-37.7	-43.0	-29.0	-86.4	-67.7
	15°	1	64.5	-21.4	43.0	-12.2	-61.7	-40.3	-43.0	-30.8	-86.4	-67.7
	20°	1	71.1	-18.8	47.4	-10.4	-61.7	-43.0	-43.0	-32.6	-86.4	-67.7
	25°	1	64.5	10.4	46.7	10.6	-28.6	-39.0	-20.7	-31.4	-53.3	-45.4
		2	------	------	------	------	-10.9	-21.2	-3.0	-13.6	------	------
	30 to 45	1	57.8	39.5	45.9	31.6	4.4	-35.1	1.5	-30.1	-20.3	-23.2
		2	57.8	39.5	45.9	31.6	22.2	-17.3	19.3	-12.3	-20.3	-23.2
200	0 to 5°	1	63.4	-32.9	42.1	-19.5	-76.2	-43.3	-53.1	-33.5	-106.7	-83.5
	10°	1	71.5	-29.7	47.6	-17.3	-76.2	-46.5	-53.1	-35.8	-106.7	-83.5
	15°	1	79.7	-26.4	53.1	-15.0	-76.2	-49.8	-53.1	-38.0	-106.7	-83.5
	20°	1	87.8	-23.2	58.5	-12.8	-76.2	-53.1	-53.1	-40.2	-106.7	-83.5
	25°	1	79.6	12.8	57.6	13.1	-35.4	-48.2	-25.6	-38.7	-65.9	-56.1
		2	------	------	------	------	-13.4	-26.2	-3.7	-16.8	------	------
	30 to 45	1	71.3	48.8	56.7	39.0	5.5	-43.3	1.8	-37.2	-25.0	-28.7
		2	71.3	48.8	56.7	39.0	27.4	-21.3	23.8	-15.2	-25.0	-28.7

Adjustment Factor
for Building Height and Exposure, λ

Mean roof height (ft)	Exposure		
	B	C	D
15	1.00	1.21	1.47
20	1.00	1.29	1.55
25	1.00	1.35	1.61
30	1.00	1.40	1.66
35	1.05	1.45	1.70
40	1.09	1.49	1.74
45	1.12	1.53	1.78
50	1.16	1.56	1.81
55	1.19	1.59	1.84
60	1.22	1.62	1.87

Unit Conversions – 1.0 ft = 0.3048 m; 1.0 psf = 0.0479 kN/m^2



Main Wind Force Resisting System – Method 2 | **h ≤ 60 ft.**

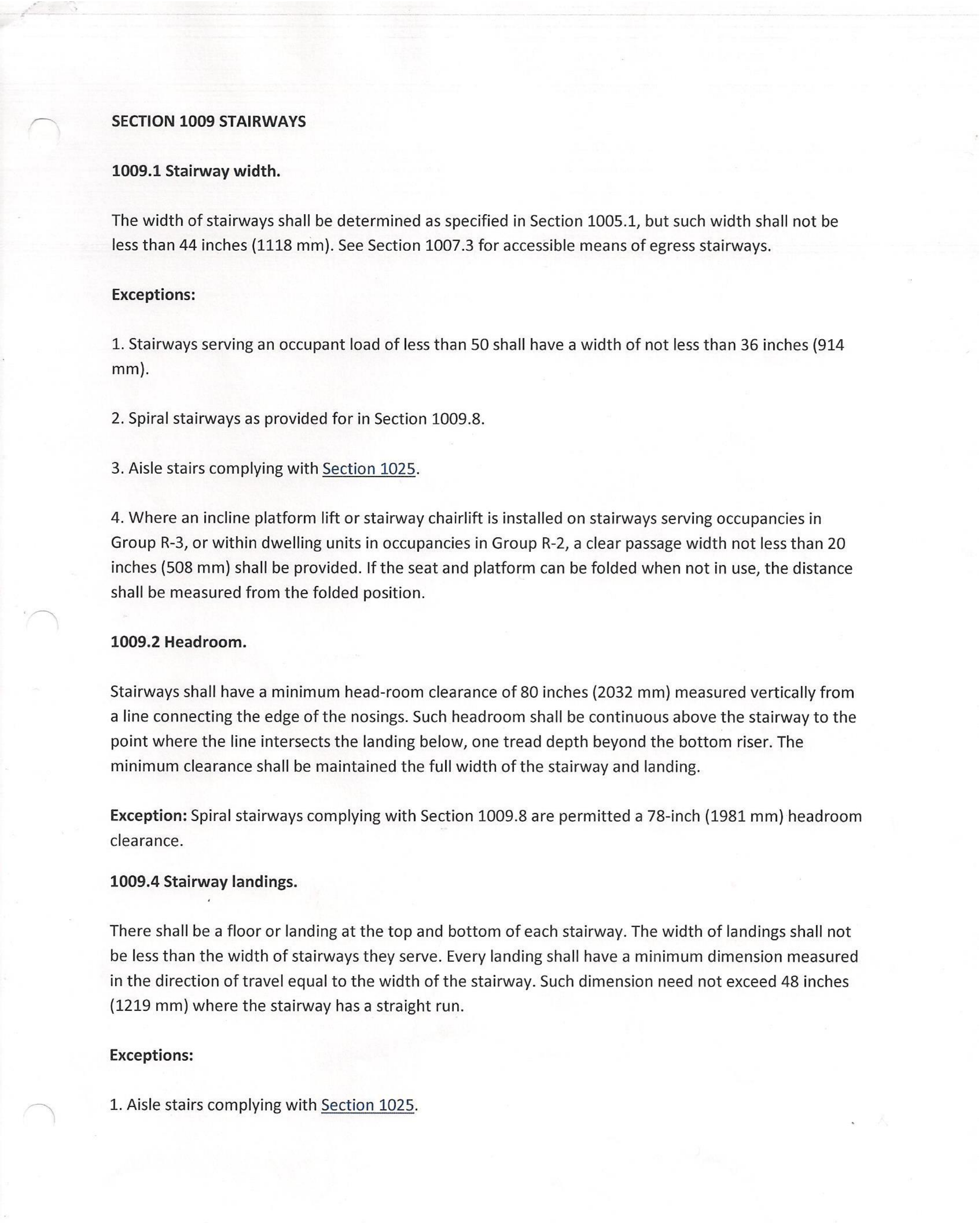
Figure 28.6-1 | **Design Wind Pressures**

Enclosed Buildings

Walls & Roofs

Notes:

1. Pressures shown are applied to the horizontal and vertical projections, for exposure B, at h=30 ft (9.1m). Adjust to other exposures and heights with adjustment factor λ.
2. The load patterns shown shall be applied to each corner of the building in turn as the reference corner. (See Figure 28.4-1)
3. For Case B use $\theta = 0°$.
4. Load cases 1 and 2 must be checked for $25° < \theta \leq 45°$. Load case 2 at 25° is provided only for interpolation between 25° and 30°.
5. Plus and minus signs signify pressures acting toward and away from the projected surfaces, respectively.
6. For roof slopes other than those shown, linear interpolation is permitted.
7. The total horizontal load shall not be less than that determined by assuming $p_S = 0$ in zones B & D.
8. Where zone E or G falls on a roof overhang on the windward side of the building, use E_{OH} and G_{OH} for the pressure on the horizontal projection of the overhang. Overhangs on the leeward and side edges shall have the basic zone pressure applied.
9. Notation:
   - *a:* 10 percent of least horizontal dimension or 0.4h, whichever is smaller, but not less than either 4% of least horizontal dimension or 3 ft (0.9 m).
   - *h:* Mean roof height, in feet (meters), except that eave height shall be used for roof angles <10°.
   - *θ:* Angle of plane of roof from horizontal, in degrees.



SECTION 1009 STAIRWAYS

1009.1 Stairway width.

The width of stairways shall be determined as specified in Section 1005.1, but such width shall not be less than 44 inches (1118 mm). See Section 1007.3 for accessible means of egress stairways.

Exceptions:

1. Stairways serving an occupant load of less than 50 shall have a width of not less than 36 inches (914 mm).

2. Spiral stairways as provided for in Section 1009.8.

3. Aisle stairs complying with Section 1025.

4. Where an incline platform lift or stairway chairlift is installed on stairways serving occupancies in Group R-3, or within dwelling units in occupancies in Group R-2, a clear passage width not less than 20 inches (508 mm) shall be provided. If the seat and platform can be folded when not in use, the distance shall be measured from the folded position.

1009.2 Headroom.

Stairways shall have a minimum head-room clearance of 80 inches (2032 mm) measured vertically from a line connecting the edge of the nosings. Such headroom shall be continuous above the stairway to the point where the line intersects the landing below, one tread depth beyond the bottom riser. The minimum clearance shall be maintained the full width of the stairway and landing.

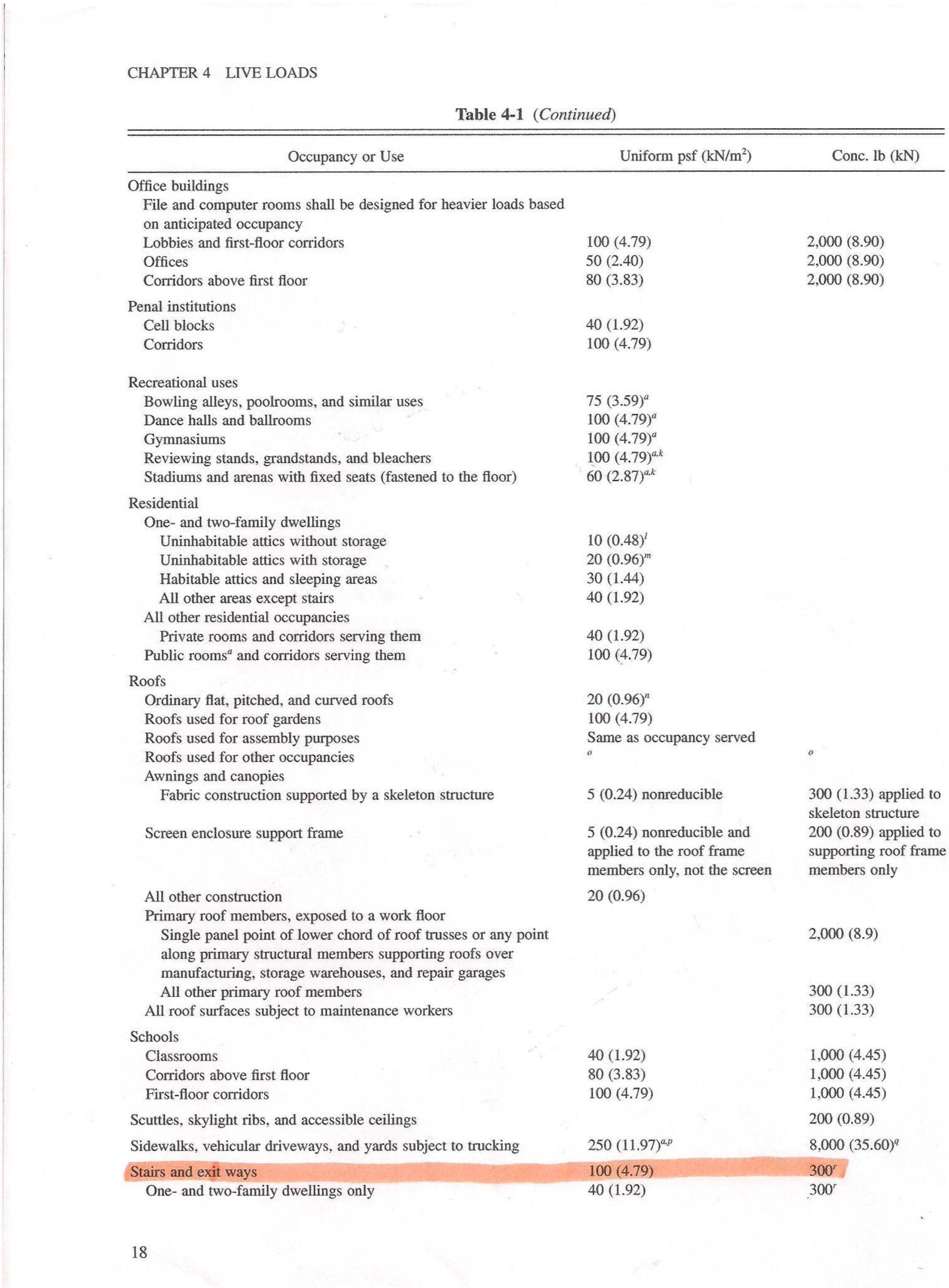
Exception: Spiral stairways complying with Section 1009.8 are permitted a 78-inch (1981 mm) headroom clearance.

1009.4 Stairway landings.

There shall be a floor or landing at the top and bottom of each stairway. The width of landings shall not be less than the width of stairways they serve. Every landing shall have a minimum dimension measured in the direction of travel equal to the width of the stairway. Such dimension need not exceed 48 inches (1219 mm) where the stairway has a straight run.

Exceptions:

1. Aisle stairs complying with Section 1025.

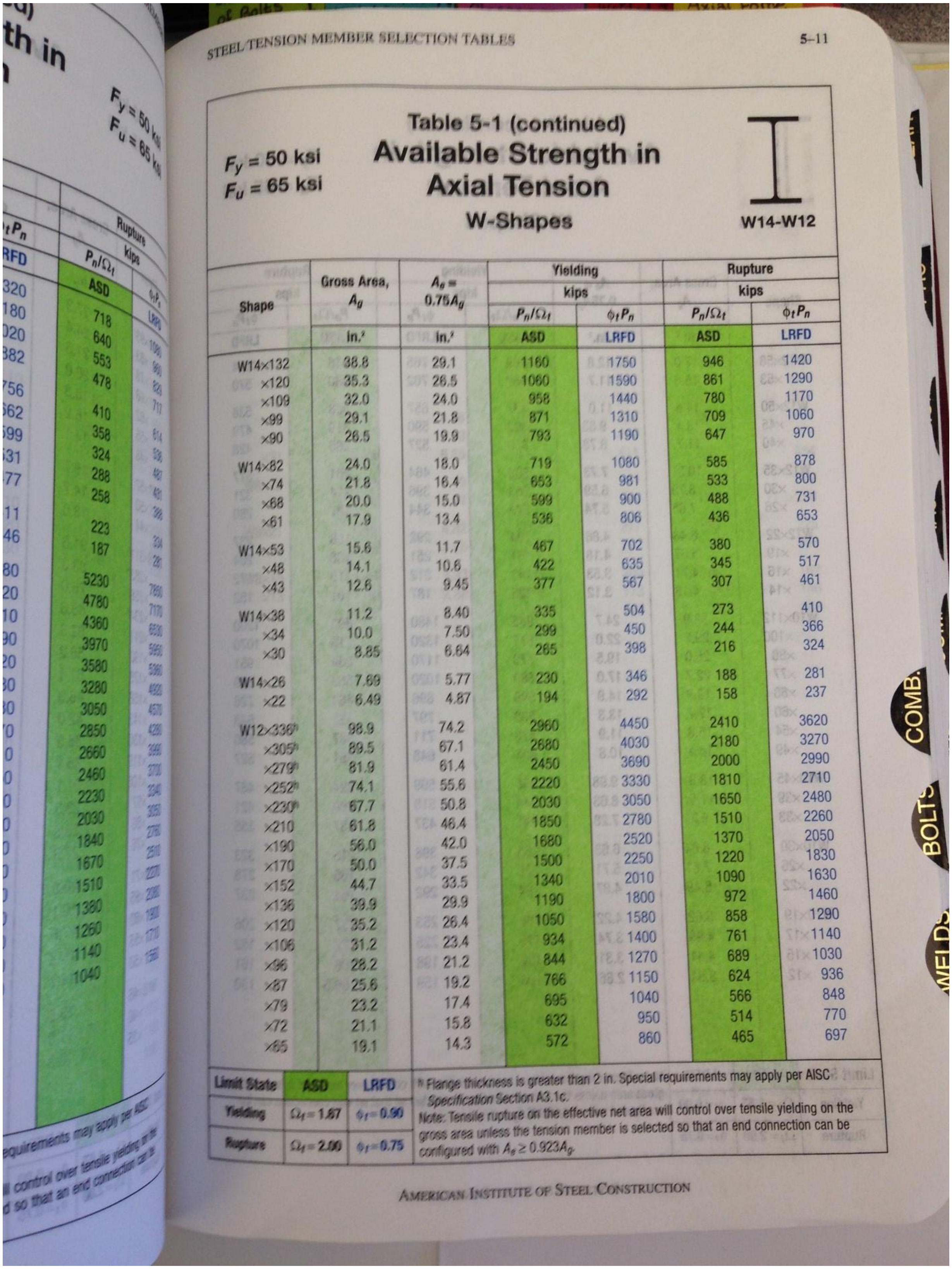


CHAPTER 4 LIVE LOADS

Table 4-1 *(Continued)*

Occupancy or Use	Uniform psf (kN/m²)	Conc. lb (kN)
Office buildings		
File and computer rooms shall be designed for heavier loads based on anticipated occupancy		
Lobbies and first-floor corridors	100 (4.79)	2,000 (8.90)
Offices	50 (2.40)	2,000 (8.90)
Corridors above first floor	80 (3.83)	2,000 (8.90)
Penal institutions		
Cell blocks	40 (1.92)	
Corridors	100 (4.79)	
Recreational uses		
Bowling alleys, poolrooms, and similar uses	75 (3.59)[a]	
Dance halls and ballrooms	100 (4.79)[a]	
Gymnasiums	100 (4.79)[a]	
Reviewing stands, grandstands, and bleachers	100 (4.79)[a,k]	
Stadiums and arenas with fixed seats (fastened to the floor)	60 (2.87)[a,k]	
Residential		
One- and two-family dwellings		
Uninhabitable attics without storage	10 (0.48)[l]	
Uninhabitable attics with storage	20 (0.96)[m]	
Habitable attics and sleeping areas	30 (1.44)	
All other areas except stairs	40 (1.92)	
All other residential occupancies		
Private rooms and corridors serving them	40 (1.92)	
Public rooms[a] and corridors serving them	100 (4.79)	
Roofs		
Ordinary flat, pitched, and curved roofs	20 (0.96)[n]	
Roofs used for roof gardens	100 (4.79)	
Roofs used for assembly purposes	Same as occupancy served	
Roofs used for other occupancies	[o]	[o]
Awnings and canopies		
Fabric construction supported by a skeleton structure	5 (0.24) nonreducible	300 (1.33) applied to skeleton structure
Screen enclosure support frame	5 (0.24) nonreducible and applied to the roof frame members only, not the screen	200 (0.89) applied to supporting roof frame members only
All other construction	20 (0.96)	
Primary roof members, exposed to a work floor		
Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs over manufacturing, storage warehouses, and repair garages		2,000 (8.9)
All other primary roof members		300 (1.33)
All roof surfaces subject to maintenance workers		300 (1.33)
Schools		
Classrooms	40 (1.92)	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
First-floor corridors	100 (4.79)	1,000 (4.45)
Scuttles, skylight ribs, and accessible ceilings		200 (0.89)
Sidewalks, vehicular driveways, and yards subject to trucking	250 (11.97)[a,p]	8,000 (35.60)[q]
Stairs and exit ways	100 (4.79)	300[r]
One- and two-family dwellings only	40 (1.92)	300[r]

18



F_y = 50 ksi
F_u = 65 ksi

Table 5-1 (continued)
Available Strength in Axial Tension
W-Shapes

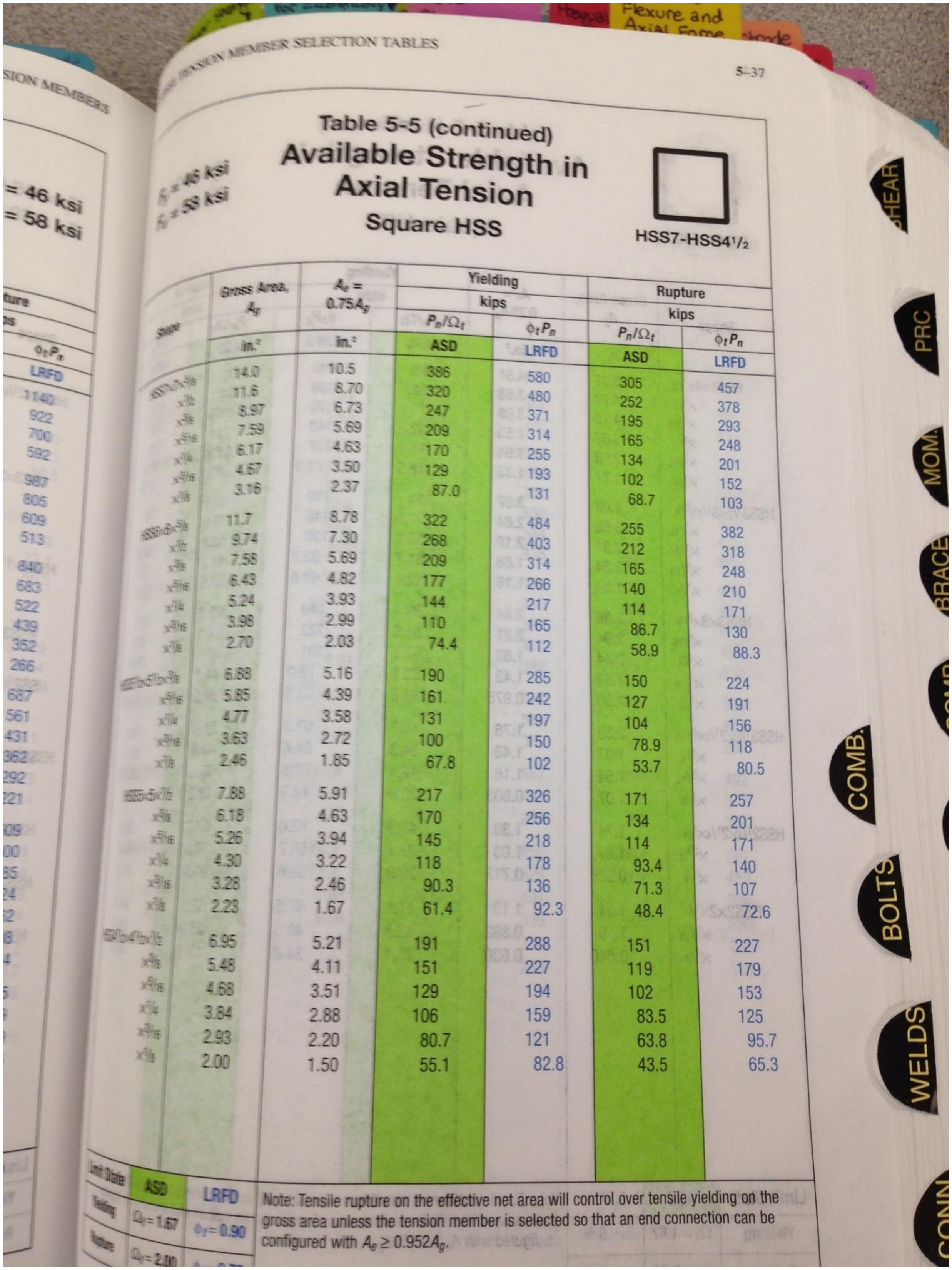
W14-W12

Shape	Gross Area, A_g	$A_e = 0.75A_g$	Yielding kips		Rupture kips	
			P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$
	in.²	in.²	ASD	LRFD	ASD	LRFD
W14×132	38.8	29.1	1160	1750	946	1420
×120	35.3	26.5	1060	1590	861	1290
×109	32.0	24.0	958	1440	780	1170
×99	29.1	21.8	871	1310	709	1060
×90	26.5	19.9	793	1190	647	970
W14×82	24.0	18.0	719	1080	585	878
×74	21.8	16.4	653	981	533	800
×68	20.0	15.0	599	900	488	731
×61	17.9	13.4	536	806	436	653
W14×53	15.6	11.7	467	702	380	570
×48	14.1	10.6	422	635	345	517
×43	12.6	9.45	377	567	307	461
W14×38	11.2	8.40	335	504	273	410
×34	10.0	7.50	299	450	244	366
×30	8.85	6.64	265	398	216	324
W14×26	7.69	5.77	230	346	188	281
×22	6.49	4.87	194	292	158	237
W12×336[h]	98.9	74.2	2960	4450	2410	3620
×305[h]	89.5	67.1	2680	4030	2180	3270
×279[h]	81.9	61.4	2450	3690	2000	2990
×252[h]	74.1	55.6	2220	3330	1810	2710
×230[h]	67.7	50.8	2030	3050	1650	2480
×210	61.8	46.4	1850	2780	1510	2260
×190	56.0	42.0	1680	2520	1370	2050
×170	50.0	37.5	1500	2250	1220	1830
×152	44.7	33.5	1340	2010	1090	1630
×136	39.9	29.9	1190	1800	972	1460
×120	35.2	26.4	1050	1580	858	1290
×106	31.2	23.4	934	1400	761	1140
×96	28.2	21.2	844	1270	689	1030
×87	25.6	19.2	766	1150	624	936
×79	23.2	17.4	695	1040	566	848
×72	21.1	15.8	632	950	514	770
×65	19.1	14.3	572	860	465	697

Limit State	ASD	LRFD
Yielding	$\Omega_t = 1.67$	$\phi_t = 0.90$
Rupture	$\Omega_t = 2.00$	$\phi_t = 0.75$

[h] Flange thickness is greater than 2 in. Special requirements may apply per AISC Specification Section A3.1c.

Note: Tensile rupture on the effective net area will control over tensile yielding on the gross area unless the tension member is selected so that an end connection can be configured with $A_e \geq 0.923A_g$.



TENSION MEMBER SELECTION TABLES

5-37

Table 5-5 (continued)
Available Strength in Axial Tension
Square HSS

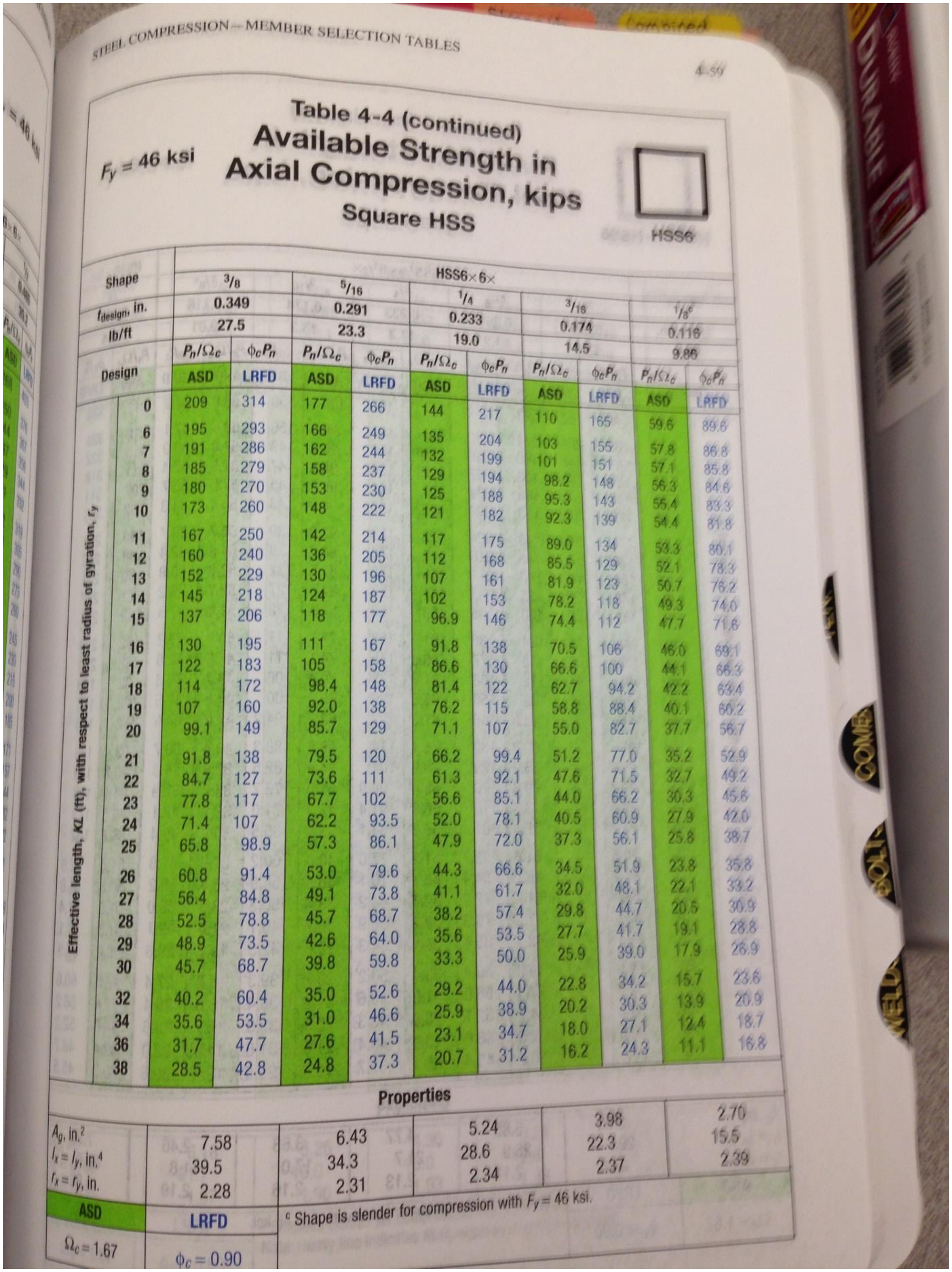
F_y = 46 ksi
F_u = 58 ksi

HSS7-HSS4$^1/_2$

Shape	Gross Area, A_g	$A_e = 0.75A_g$	Yielding kips		Rupture kips	
			P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$
	in.²	in.²	ASD	LRFD	ASD	LRFD
HSS7×7×5/8	14.0	10.5	386	580	305	457
×1/2	11.6	8.70	320	480	252	378
×3/8	8.97	6.73	247	371	195	293
×5/16	7.59	5.69	209	314	165	248
×1/4	6.17	4.63	170	255	134	201
×3/16	4.67	3.50	129	193	102	152
×1/8	3.16	2.37	87.0	131	68.7	103
HSS6×6×5/8	11.7	8.78	322	484	255	382
×1/2	9.74	7.30	268	403	212	318
×3/8	7.58	5.69	209	314	165	248
×5/16	6.43	4.82	177	266	140	210
×1/4	5.24	3.93	144	217	114	171
×3/16	3.98	2.99	110	165	86.7	130
×1/8	2.70	2.03	74.4	112	58.9	88.3
HSS5$^1/_2$×5$^1/_2$×3/8	6.88	5.16	190	285	150	224
×5/16	5.85	4.39	161	242	127	191
×1/4	4.77	3.58	131	197	104	156
×3/16	3.63	2.72	100	150	78.9	118
×1/8	2.46	1.85	67.8	102	53.7	80.5
HSS5×5×1/2	7.88	5.91	217	326	171	257
×3/8	6.18	4.63	170	256	134	201
×5/16	5.26	3.94	145	218	114	171
×1/4	4.30	3.22	118	178	93.4	140
×3/16	3.28	2.46	90.3	136	71.3	107
×1/8	2.23	1.67	61.4	92.3	48.4	72.6
HSS4$^1/_2$×4$^1/_2$×1/2	6.95	5.21	191	288	151	227
×3/8	5.48	4.11	151	227	119	179
×5/16	4.68	3.51	129	194	102	153
×1/4	3.84	2.88	106	159	83.5	125
×3/16	2.93	2.20	80.7	121	63.8	95.7
×1/8	2.00	1.50	55.1	82.8	43.5	65.3

Limit State	ASD	LRFD
Yielding	$\Omega_t = 1.67$	$\phi_t = 0.90$
Rupture	$\Omega_t = 2.00$	

Note: Tensile rupture on the effective net area will control over tensile yielding on the gross area unless the tension member is selected so that an end connection can be configured with $A_e \geq 0.952A_g$.



STEEL COMPRESSION—MEMBER SELECTION TABLES

4-59

$F_y = 46$ ksi

Table 4-4 (continued)
Available Strength in Axial Compression, kips
Square HSS

HSS6

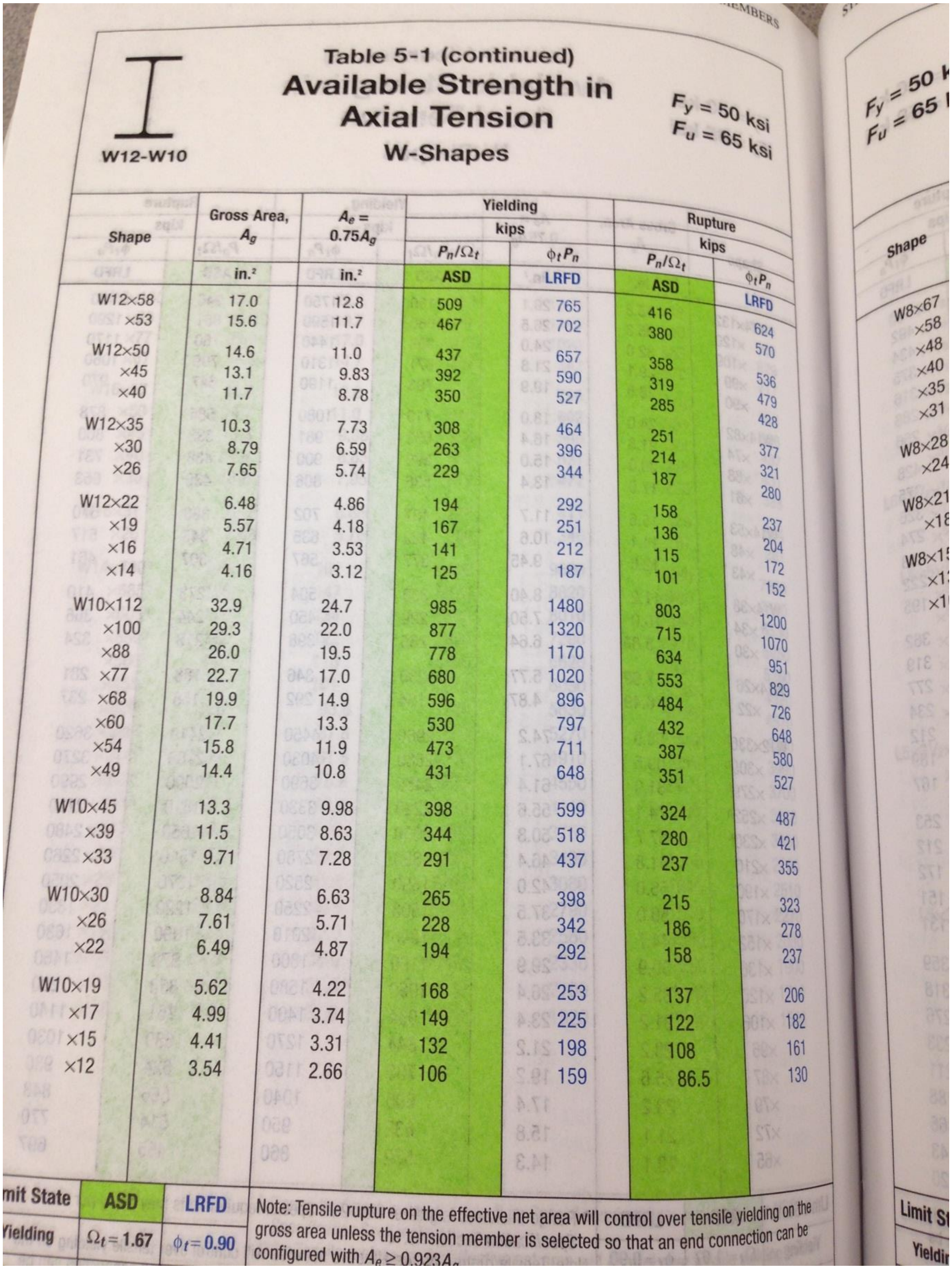
Shape		HSS6×6×									
		3/8		5/16		1/4		3/16		$1/8^c$	
t_{design}, in.		0.349		0.291		0.233		0.174		0.116	
lb/ft		27.5		23.3		19.0		14.5		9.86	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, r_y	0	209	314	177	266	144	217	110	165	59.6	89.6
	6	195	293	166	249	135	204	103	155	57.8	86.8
	7	191	286	162	244	132	199	101	151	57.1	85.8
	8	185	279	158	237	129	194	98.2	148	56.3	84.6
	9	180	270	153	230	125	188	95.3	143	55.4	83.3
	10	173	260	148	222	121	182	92.3	139	54.4	81.8
	11	167	250	142	214	117	175	89.0	134	53.3	80.1
	12	160	240	136	205	112	168	85.5	129	52.1	78.3
	13	152	229	130	196	107	161	81.9	123	50.7	76.2
	14	145	218	124	187	102	153	78.2	118	49.3	74.0
	15	137	206	118	177	96.9	146	74.4	112	47.7	71.6
	16	130	195	111	167	91.8	138	70.5	106	46.0	69.1
	17	122	183	105	158	86.6	130	66.6	100	44.1	66.3
	18	114	172	98.4	148	81.4	122	62.7	94.2	42.2	63.4
	19	107	160	92.0	138	76.2	115	58.8	88.4	40.1	60.2
	20	99.1	149	85.7	129	71.1	107	55.0	82.7	37.7	56.7
	21	91.8	138	79.5	120	66.2	99.4	51.2	77.0	35.2	52.9
	22	84.7	127	73.6	111	61.3	92.1	47.6	71.5	32.7	49.2
	23	77.8	117	67.7	102	56.6	85.1	44.0	66.2	30.3	45.6
	24	71.4	107	62.2	93.5	52.0	78.1	40.5	60.9	27.9	42.0
	25	65.8	98.9	57.3	86.1	47.9	72.0	37.3	56.1	25.8	38.7
	26	60.8	91.4	53.0	79.6	44.3	66.6	34.5	51.9	23.8	35.8
	27	56.4	84.8	49.1	73.8	41.1	61.7	32.0	48.1	22.1	33.2
	28	52.5	78.8	45.7	68.7	38.2	57.4	29.8	44.7	20.5	30.9
	29	48.9	73.5	42.6	64.0	35.6	53.5	27.7	41.7	19.1	28.8
	30	45.7	68.7	39.8	59.8	33.3	50.0	25.9	39.0	17.9	26.9
	32	40.2	60.4	35.0	52.6	29.2	44.0	22.8	34.2	15.7	23.6
	34	35.6	53.5	31.0	46.6	25.9	38.9	20.2	30.3	13.9	20.9
	36	31.7	47.7	27.6	41.5	23.1	34.7	18.0	27.1	12.4	18.7
	38	28.5	42.8	24.8	37.3	20.7	31.2	16.2	24.3	11.1	16.8

Properties

	3/8	5/16	1/4	3/16	$1/8^c$
A_g, in.^{2}	7.58	6.43	5.24	3.98	2.70
$I_x = I_y$, in.^{4}	39.5	34.3	28.6	22.3	15.5
$r_x = r_y$, in.	2.28	2.31	2.34	2.37	2.39

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

^{c} Shape is slender for compression with $F_y = 46$ ksi.



EMBERS

W12-W10

Table 5-1 (continued)
Available Strength in Axial Tension
W-Shapes

F_y = 50 ksi
F_u = 65 ksi

Shape	Gross Area, A_g	$A_e = 0.75A_g$	Yielding kips		Rupture kips	
			P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$
	in.²	in.²	ASD	LRFD	ASD	LRFD
W12×58	17.0	12.8	509	765	416	624
×53	15.6	11.7	467	702	380	570
W12×50	14.6	11.0	437	657	358	536
×45	13.1	9.83	392	590	319	479
×40	11.7	8.78	350	527	285	428
W12×35	10.3	7.73	308	464	251	377
×30	8.79	6.59	263	396	214	321
×26	7.65	5.74	229	344	187	280
W12×22	6.48	4.86	194	292	158	237
×19	5.57	4.18	167	251	136	204
×16	4.71	3.53	141	212	115	172
×14	4.16	3.12	125	187	101	152
W10×112	32.9	24.7	985	1480	803	1200
×100	29.3	22.0	877	1320	715	1070
×88	26.0	19.5	778	1170	634	951
×77	22.7	17.0	680	1020	553	829
×68	19.9	14.9	596	896	484	726
×60	17.7	13.3	530	797	432	648
×54	15.8	11.9	473	711	387	580
×49	14.4	10.8	431	648	351	527
W10×45	13.3	9.98	398	599	324	487
×39	11.5	8.63	344	518	280	421
×33	9.71	7.28	291	437	237	355
W10×30	8.84	6.63	265	398	215	323
×26	7.61	5.71	228	342	186	278
×22	6.49	4.87	194	292	158	237
W10×19	5.62	4.22	168	253	137	206
×17	4.99	3.74	149	225	122	182
×15	4.41	3.31	132	198	108	161
×12	3.54	2.66	106	159	86.5	130

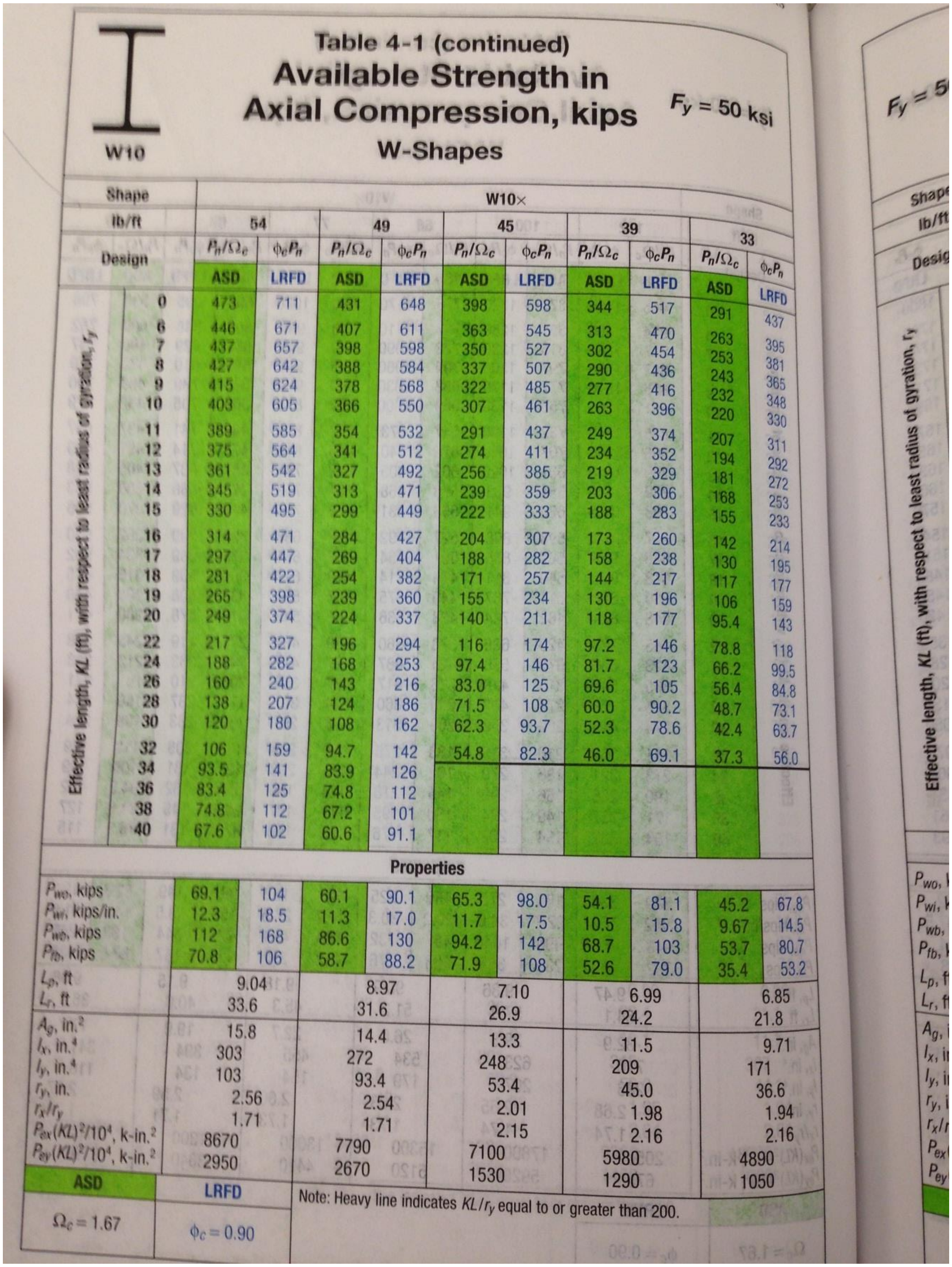
mit State	ASD	LRFD
Yielding	$\Omega_t = 1.67$	$\phi_t = 0.90$

Note: Tensile rupture on the effective net area will control over tensile yielding on the gross area unless the tension member is selected so that an end connection can be configured with $A_e \geq 0.923A_g$.

F_y = 50 k
F_u = 65 k

Shape
W8×67
×58
×48
×40
×35
×31
W8×28
×24
W8×21
×18
W8×15
×1
×1

Limit St
Yieldi



W10

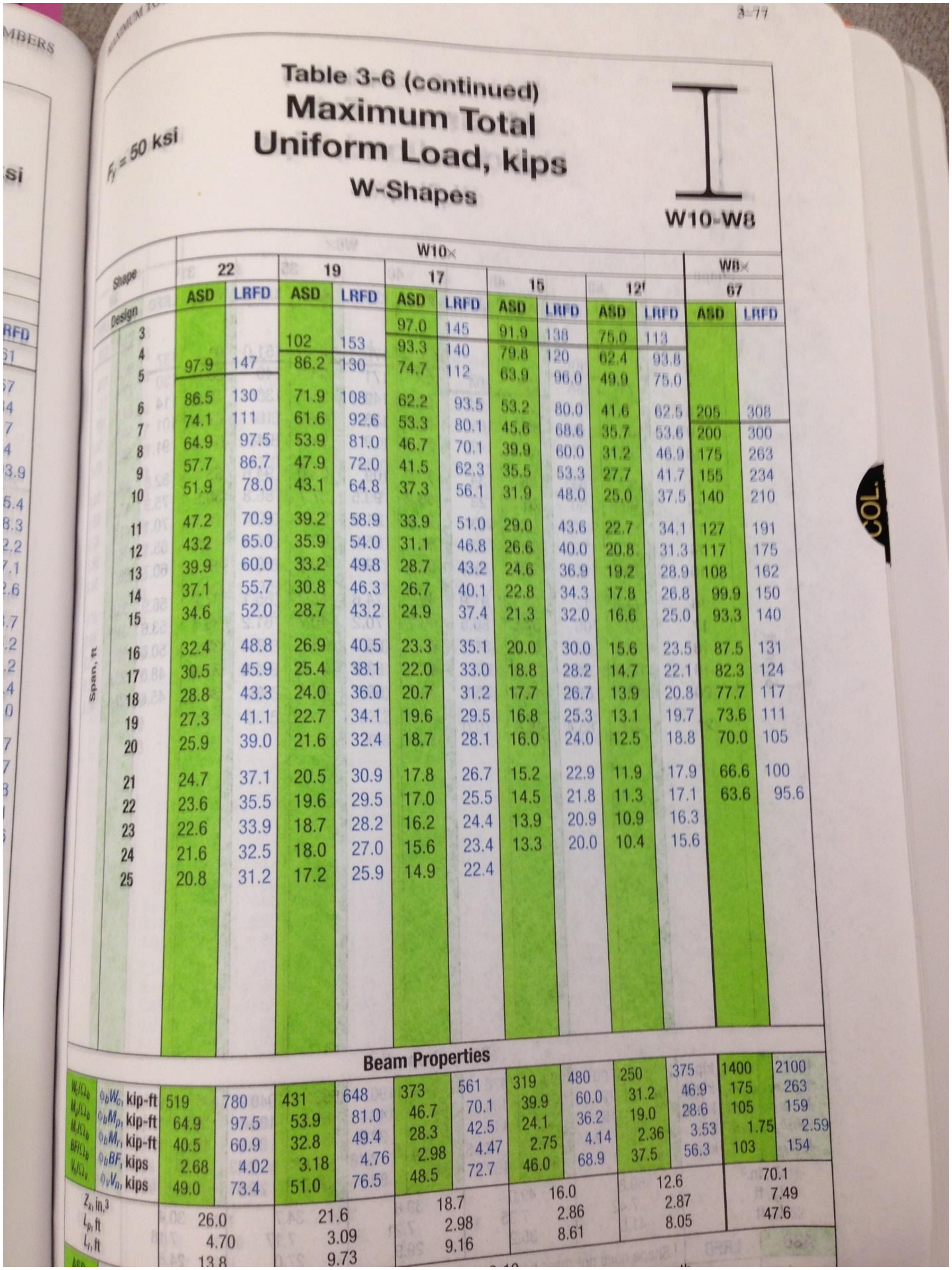
Table 4-1 (continued)
Available Strength in Axial Compression, kips
W-Shapes

$F_y = 50$ ksi

Shape		W10×									
lb/ft		54		49		45		39		33	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, r_y	0	473	711	431	648	398	598	344	517	291	437
	6	446	671	407	611	363	545	313	470	263	395
	7	437	657	398	598	350	527	302	454	253	381
	8	427	642	388	584	337	507	290	436	243	365
	9	415	624	378	568	322	485	277	416	232	348
	10	403	605	366	550	307	461	263	396	220	330
	11	389	585	354	532	291	437	249	374	207	311
	12	375	564	341	512	274	411	234	352	194	292
	13	361	542	327	492	256	385	219	329	181	272
	14	345	519	313	471	239	359	203	306	168	253
	15	330	495	299	449	222	333	188	283	155	233
	16	314	471	284	427	204	307	173	260	142	214
	17	297	447	269	404	188	282	158	238	130	195
	18	281	422	254	382	171	257	144	217	117	177
	19	265	398	239	360	155	234	130	196	106	159
	20	249	374	224	337	140	211	118	177	95.4	143
	22	217	327	196	294	116	174	97.2	146	78.8	118
	24	188	282	168	253	97.4	146	81.7	123	66.2	99.5
	26	160	240	143	216	83.0	125	69.6	105	56.4	84.8
	28	138	207	124	186	71.5	108	60.0	90.2	48.7	73.1
	30	120	180	108	162	62.3	93.7	52.3	78.6	42.4	63.7
	32	106	159	94.7	142	54.8	82.3	46.0	69.1	37.3	56.0
	34	93.5	141	83.9	126						
	36	83.4	125	74.8	112						
	38	74.8	112	67.2	101						
	40	67.6	102	60.6	91.1						
Properties											
P_{wo}, kips		69.1	104	60.1	90.1	65.3	98.0	54.1	81.1	45.2	67.8
P_{wi}, kips/in.		12.3	18.5	11.3	17.0	11.7	17.5	10.5	15.8	9.67	14.5
P_{wb}, kips		112	168	86.6	130	94.2	142	68.7	103	53.7	80.7
P_{fb}, kips		70.8	106	58.7	88.2	71.9	108	52.6	79.0	35.4	53.2
L_p, ft		9.04		8.97		7.10		6.99		6.85	
L_r, ft		33.6		31.6		26.9		24.2		21.8	
A_g, in.^{2}		15.8		14.4		13.3		11.5		9.71	
I_x, in.^{4}		303		272		248		209		171	
I_y, in.^{4}		103		93.4		53.4		45.0		36.6	
r_y, in.		2.56		2.54		2.01		1.98		1.94	
r_x/r_y		1.71		1.71		2.15		2.16		2.16	
$P_{ex}(KL)^2/10^4$, k-in.^{2}		8670		7790		7100		5980		4890	
$P_{ey}(KL)^2/10^4$, k-in.^{2}		2950		2670		1530		1290		1050	

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

Note: Heavy line indicates KL/r_y equal to or greater than 200.



3-77

Table 3-6 (continued)
Maximum Total Uniform Load, kips
W-Shapes

F_y = 50 ksi

W10-W8

Shape		W10× 22		W10× 19		W10× 17		W10× 15		W10× 12^f		W8× 67	
Design		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Span, ft	3					97.0	145	91.9	138	75.0	113		
	4			102	153	93.3	140	79.8	120	62.4	93.8		
	5	97.9	147	86.2	130	74.7	112	63.9	96.0	49.9	75.0		
	6	86.5	130	71.9	108	62.2	93.5	53.2	80.0	41.6	62.5	205	308
	7	74.1	111	61.6	92.6	53.3	80.1	45.6	68.6	35.7	53.6	200	300
	8	64.9	97.5	53.9	81.0	46.7	70.1	39.9	60.0	31.2	46.9	175	263
	9	57.7	86.7	47.9	72.0	41.5	62.3	35.5	53.3	27.7	41.7	155	234
	10	51.9	78.0	43.1	64.8	37.3	56.1	31.9	48.0	25.0	37.5	140	210
	11	47.2	70.9	39.2	58.9	33.9	51.0	29.0	43.6	22.7	34.1	127	191
	12	43.2	65.0	35.9	54.0	31.1	46.8	26.6	40.0	20.8	31.3	117	175
	13	39.9	60.0	33.2	49.8	28.7	43.2	24.6	36.9	19.2	28.9	108	162
	14	37.1	55.7	30.8	46.3	26.7	40.1	22.8	34.3	17.8	26.8	99.9	150
	15	34.6	52.0	28.7	43.2	24.9	37.4	21.3	32.0	16.6	25.0	93.3	140
	16	32.4	48.8	26.9	40.5	23.3	35.1	20.0	30.0	15.6	23.5	87.5	131
	17	30.5	45.9	25.4	38.1	22.0	33.0	18.8	28.2	14.7	22.1	82.3	124
	18	28.8	43.3	24.0	36.0	20.7	31.2	17.7	26.7	13.9	20.8	77.7	117
	19	27.3	41.1	22.7	34.1	19.6	29.5	16.8	25.3	13.1	19.7	73.6	111
	20	25.9	39.0	21.6	32.4	18.7	28.1	16.0	24.0	12.5	18.8	70.0	105
	21	24.7	37.1	20.5	30.9	17.8	26.7	15.2	22.9	11.9	17.9	66.6	100
	22	23.6	35.5	19.6	29.5	17.0	25.5	14.5	21.8	11.3	17.1	63.6	95.6
	23	22.6	33.9	18.7	28.2	16.2	24.4	13.9	20.9	10.9	16.3		
	24	21.6	32.5	18.0	27.0	15.6	23.4	13.3	20.0	10.4	15.6		
	25	20.8	31.2	17.2	25.9	14.9	22.4						
Beam Properties													
W_c/Ω_b	$\phi_b W_c$, kip-ft	519	780	431	648	373	561	319	480	250	375	1400	2100
M_p/Ω_b	$\phi_b M_p$, kip-ft	64.9	97.5	53.9	81.0	46.7	70.1	39.9	60.0	31.2	46.9	175	263
M_r/Ω_b	$\phi_b M_r$, kip-ft	40.5	60.9	32.8	49.4	28.3	42.5	24.1	36.2	19.0	28.6	105	159
BF/Ω_b	$\phi_b BF$, kips	2.68	4.02	3.18	4.76	2.98	4.47	2.75	4.14	2.36	3.53	1.75	2.59
V_n/Ω_v	$\phi_v V_n$, kips	49.0	73.4	51.0	76.5	48.5	72.7	46.0	68.9	37.5	56.3	103	154
Z_x, in.^{3}		26.0		21.6		18.7		16.0		12.6		70.1	
L_p, ft		4.70		3.09		2.98		2.86		2.87		7.49	
L_r, ft		13.8		9.73		9.16		8.61		8.05		47.6	

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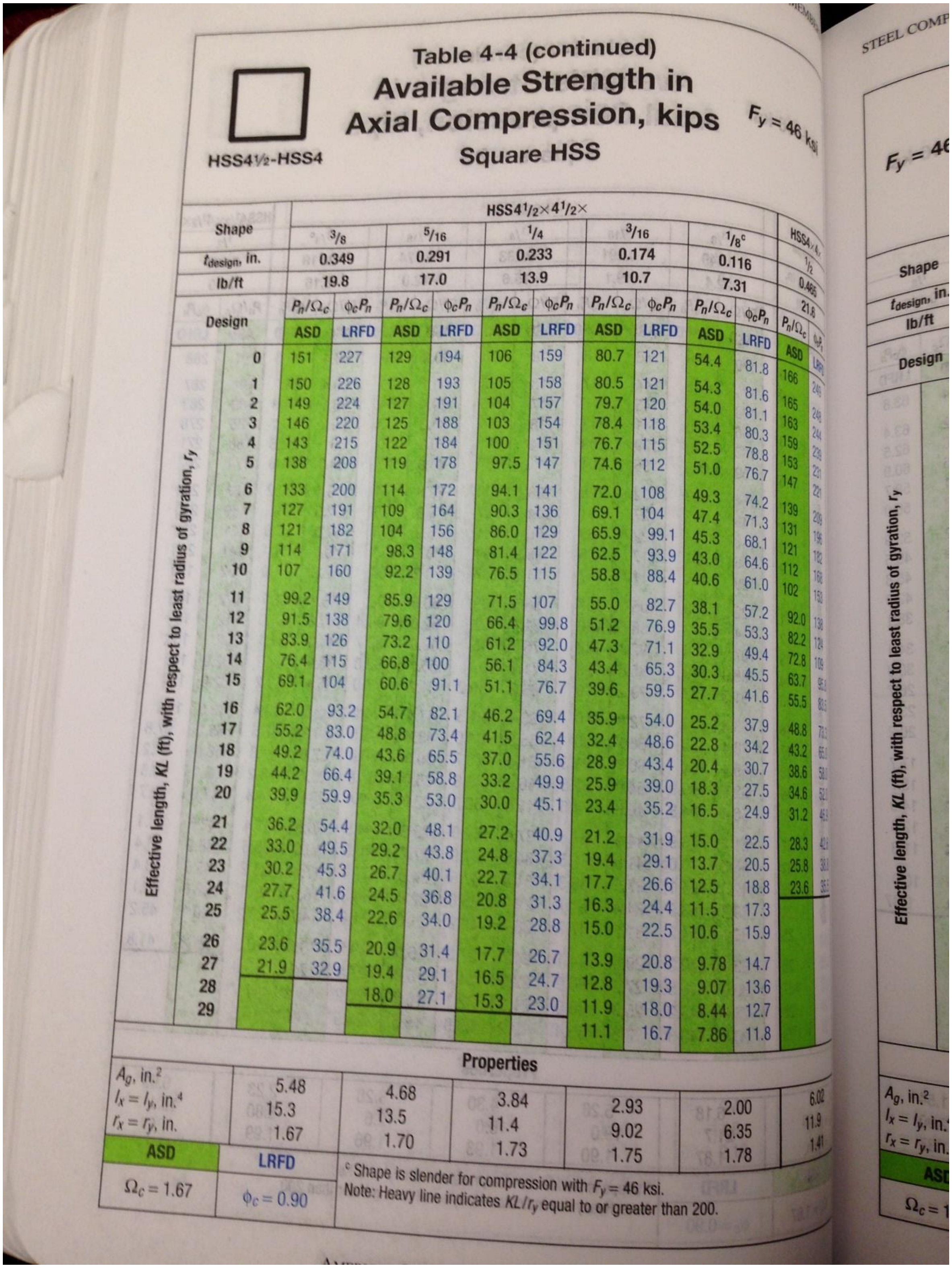


HSS4½-HSS4

Table 4-4 (continued)
Available Strength in Axial Compression, kips
Square HSS

$F_y = 46$ ksi

	Shape	HSS4½×4½×										HSS4×4×
		3/8		5/16		1/4		3/16		$1/8^c$		1/2
	t_{design}, in.	0.349		0.291		0.233		0.174		0.116		0.465
	lb/ft	19.8		17.0		13.9		10.7		7.31		21.6
	Design	P_n/Ω_c	ϕ_cP_n	P_n/Ω_c	ϕ_cP_n	P_n/Ω_c	ϕ_cP_n	P_n/Ω_c	ϕ_cP_n	P_n/Ω_c	ϕ_cP_n	P_n/Ω_c
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD
Effective length, KL (ft), with respect to least radius of gyration, r_y	0	151	227	129	194	106	159	80.7	121	54.4	81.8	166
	1	150	226	128	193	105	158	80.5	121	54.3	81.6	165
	2	149	224	127	191	104	157	79.7	120	54.0	81.1	163
	3	146	220	125	188	103	154	78.4	118	53.4	80.3	159
	4	143	215	122	184	100	151	76.7	115	52.5	78.8	153
	5	138	208	119	178	97.5	147	74.6	112	51.0	76.7	147
	6	133	200	114	172	94.1	141	72.0	108	49.3	74.2	139
	7	127	191	109	164	90.3	136	69.1	104	47.4	71.3	131
	8	121	182	104	156	86.0	129	65.9	99.1	45.3	68.1	121
	9	114	171	98.3	148	81.4	122	62.5	93.9	43.0	64.6	112
	10	107	160	92.2	139	76.5	115	58.8	88.4	40.6	61.0	102
	11	99.2	149	85.9	129	71.5	107	55.0	82.7	38.1	57.2	92.0
	12	91.5	138	79.6	120	66.4	99.8	51.2	76.9	35.5	53.3	82.2
	13	83.9	126	73.2	110	61.2	92.0	47.3	71.1	32.9	49.4	72.8
	14	76.4	115	66.8	100	56.1	84.3	43.4	65.3	30.3	45.5	63.7
	15	69.1	104	60.6	91.1	51.1	76.7	39.6	59.5	27.7	41.6	55.5
	16	62.0	93.2	54.7	82.1	46.2	69.4	35.9	54.0	25.2	37.9	48.8
	17	55.2	83.0	48.8	73.4	41.5	62.4	32.4	48.6	22.8	34.2	43.2
	18	49.2	74.0	43.6	65.5	37.0	55.6	28.9	43.4	20.4	30.7	38.6
	19	44.2	66.4	39.1	58.8	33.2	49.9	25.9	39.0	18.3	27.5	34.6
	20	39.9	59.9	35.3	53.0	30.0	45.1	23.4	35.2	16.5	24.9	31.2
	21	36.2	54.4	32.0	48.1	27.2	40.9	21.2	31.9	15.0	22.5	28.3
	22	33.0	49.5	29.2	43.8	24.8	37.3	19.4	29.1	13.7	20.5	25.8
	23	30.2	45.3	26.7	40.1	22.7	34.1	17.7	26.6	12.5	18.8	23.6
	24	27.7	41.6	24.5	36.8	20.8	31.3	16.3	24.4	11.5	17.3	
	25	25.5	38.4	22.6	34.0	19.2	28.8	15.0	22.5	10.6	15.9	
	26	23.6	35.5	20.9	31.4	17.7	26.7	13.9	20.8	9.78	14.7	
	27	21.9	32.9	19.4	29.1	16.5	24.7	12.8	19.3	9.07	13.6	
	28			18.0	27.1	15.3	23.0	11.9	18.0	8.44	12.7	
	29							11.1	16.7	7.86	11.8	

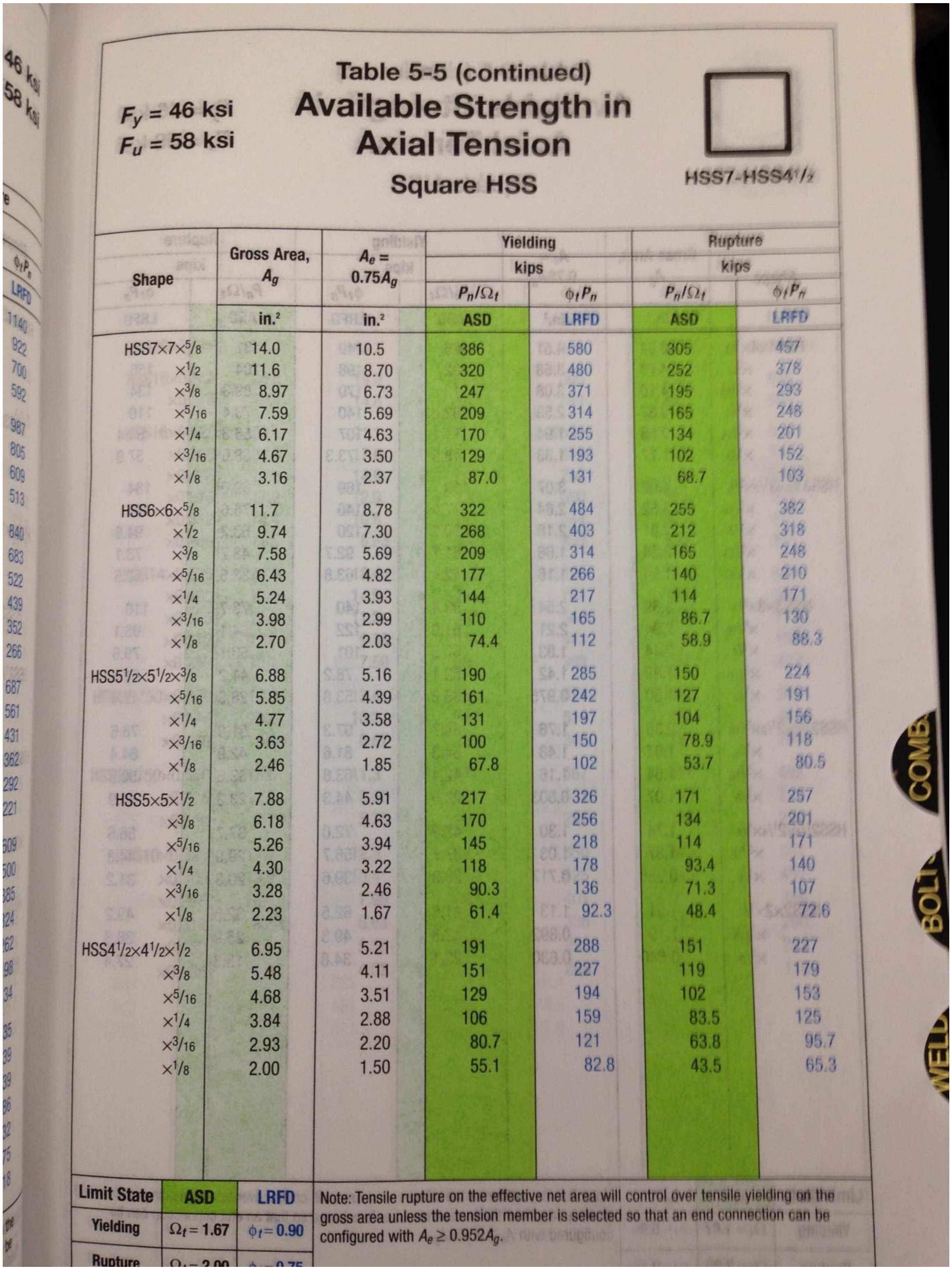
Properties

A_g, in.^{2}	5.48	4.68	3.84	2.93	2.00	6.02
$I_x = I_y$, in.^{4}	15.3	13.5	11.4	9.02	6.35	11.9
$r_x = r_y$, in.	1.67	1.70	1.73	1.75	1.78	1.41

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

^{c} Shape is slender for compression with $F_y = 46$ ksi.

Note: Heavy line indicates KL/r_y equal to or greater than 200.



F_y = 46 ksi
F_u = 58 ksi

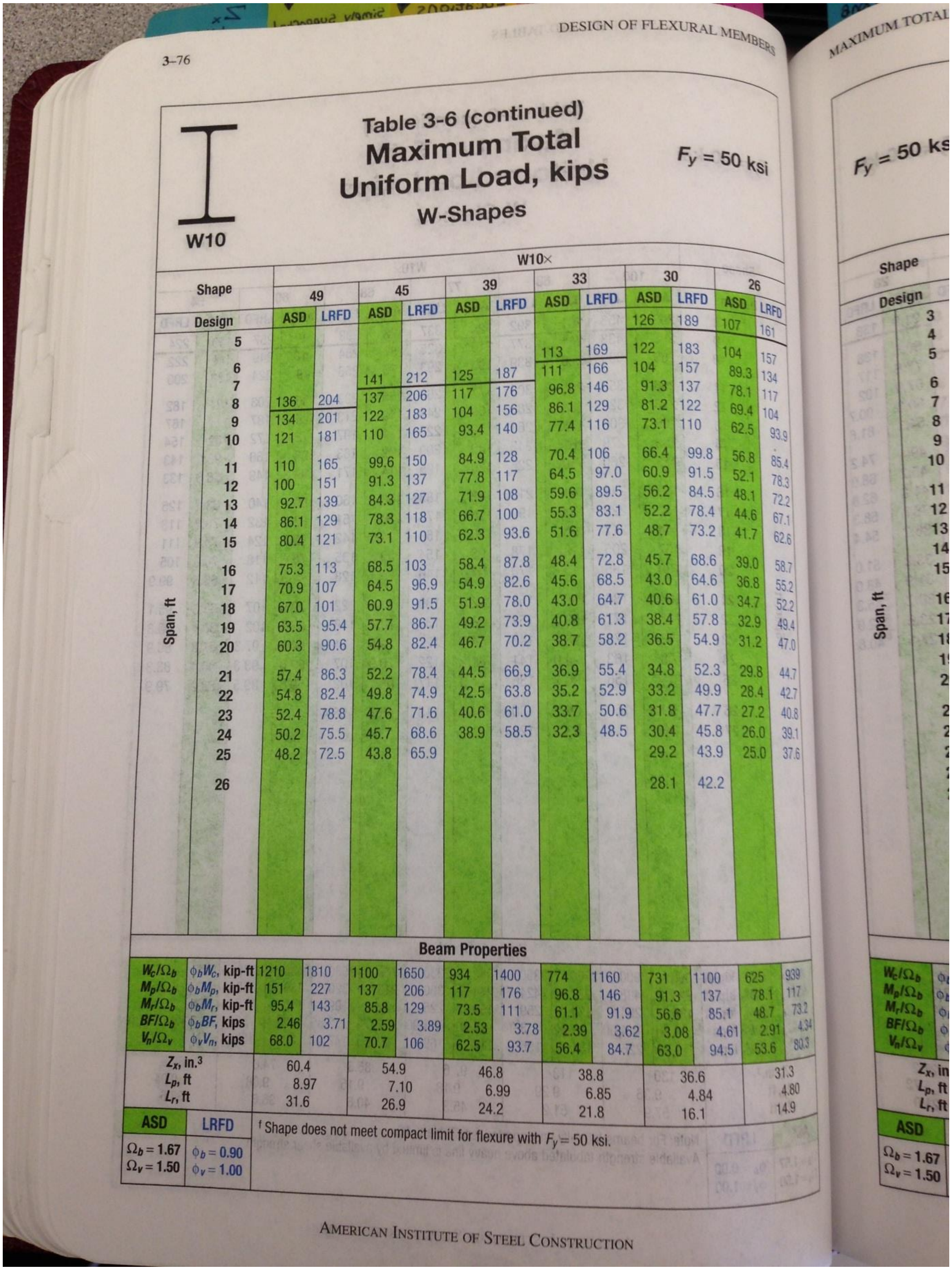
Table 5-5 (continued)
Available Strength in Axial Tension
Square HSS

HSS7-HSS4$\frac{1}{2}$

Shape	Gross Area, A_g	$A_e = 0.75A_g$	Yielding kips		Rupture kips	
			P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$
	in.^{2}	in.^{2}	ASD	LRFD	ASD	LRFD
HSS7×7×5/8	14.0	10.5	386	580	305	457
×1/2	11.6	8.70	320	480	252	378
×3/8	8.97	6.73	247	371	195	293
×5/16	7.59	5.69	209	314	165	248
×1/4	6.17	4.63	170	255	134	201
×3/16	4.67	3.50	129	193	102	152
×1/8	3.16	2.37	87.0	131	68.7	103
HSS6×6×5/8	11.7	8.78	322	484	255	382
×1/2	9.74	7.30	268	403	212	318
×3/8	7.58	5.69	209	314	165	248
×5/16	6.43	4.82	177	266	140	210
×1/4	5.24	3.93	144	217	114	171
×3/16	3.98	2.99	110	165	86.7	130
×1/8	2.70	2.03	74.4	112	58.9	88.3
HSS5 1/2×5 1/2×3/8	6.88	5.16	190	285	150	224
×5/16	5.85	4.39	161	242	127	191
×1/4	4.77	3.58	131	197	104	156
×3/16	3.63	2.72	100	150	78.9	118
×1/8	2.46	1.85	67.8	102	53.7	80.5
HSS5×5×1/2	7.88	5.91	217	326	171	257
×3/8	6.18	4.63	170	256	134	201
×5/16	5.26	3.94	145	218	114	171
×1/4	4.30	3.22	118	178	93.4	140
×3/16	3.28	2.46	90.3	136	71.3	107
×1/8	2.23	1.67	61.4	92.3	48.4	72.6
HSS4 1/2×4 1/2×1/2	6.95	5.21	191	288	151	227
×3/8	5.48	4.11	151	227	119	179
×5/16	4.68	3.51	129	194	102	153
×1/4	3.84	2.88	106	159	83.5	125
×3/16	2.93	2.20	80.7	121	63.8	95.7
×1/8	2.00	1.50	55.1	82.8	43.5	65.3

Limit State	ASD	LRFD
Yielding	$\Omega_t = 1.67$	$\phi_t = 0.90$
Rupture	$\Omega_t = 2.00$	$\phi_t = 0.75$

Note: Tensile rupture on the effective net area will control over tensile yielding on the gross area unless the tension member is selected so that an end connection can be configured with $A_e \geq 0.952A_g$.



W10

Table 3-6 (continued)
Maximum Total Uniform Load, kips
W-Shapes

$F_y = 50$ ksi

Shape	W10×											
	49		45		39		33		30		26	
Design	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Span, ft 5									126	189	107	161
6							113	169	122	183	104	157
7			141	212	125	187	111	166	104	157	89.3	134
8	136	204	137	206	117	176	96.8	146	91.3	137	78.1	117
9	134	201	122	183	104	156	86.1	129	81.2	122	69.4	104
10	121	181	110	165	93.4	140	77.4	116	73.1	110	62.5	93.9
11	110	165	99.6	150	84.9	128	70.4	106	66.4	99.8	56.8	85.4
12	100	151	91.3	137	77.8	117	64.5	97.0	60.9	91.5	52.1	78.3
13	92.7	139	84.3	127	71.9	108	59.6	89.5	56.2	84.5	48.1	72.2
14	86.1	129	78.3	118	66.7	100	55.3	83.1	52.2	78.4	44.6	67.1
15	80.4	121	73.1	110	62.3	93.6	51.6	77.6	48.7	73.2	41.7	62.6
16	75.3	113	68.5	103	58.4	87.8	48.4	72.8	45.7	68.6	39.0	58.7
17	70.9	107	64.5	96.9	54.9	82.6	45.6	68.5	43.0	64.6	36.8	55.2
18	67.0	101	60.9	91.5	51.9	78.0	43.0	64.7	40.6	61.0	34.7	52.2
19	63.5	95.4	57.7	86.7	49.2	73.9	40.8	61.3	38.4	57.8	32.9	49.4
20	60.3	90.6	54.8	82.4	46.7	70.2	38.7	58.2	36.5	54.9	31.2	47.0
21	57.4	86.3	52.2	78.4	44.5	66.9	36.9	55.4	34.8	52.3	29.8	44.7
22	54.8	82.4	49.8	74.9	42.5	63.8	35.2	52.9	33.2	49.9	28.4	42.7
23	52.4	78.8	47.6	71.6	40.6	61.0	33.7	50.6	31.8	47.7	27.2	40.8
24	50.2	75.5	45.7	68.6	38.9	58.5	32.3	48.5	30.4	45.8	26.0	39.1
25	48.2	72.5	43.8	65.9					29.2	43.9	25.0	37.6
26									28.1	42.2		

Beam Properties

W_c/Ω_b	$\phi_b W_c$, kip-ft	1210	1810	1100	1650	934	1400	774	1160	731	1100	625	939
M_p/Ω_b	$\phi_b M_p$, kip-ft	151	227	137	206	117	176	96.8	146	91.3	137	78.1	117
M_r/Ω_b	$\phi_b M_r$, kip-ft	95.4	143	85.8	129	73.5	111	61.1	91.9	56.6	85.1	48.7	73.2
BF/Ω_b	$\phi_b BF$, kips	2.46	3.71	2.59	3.89	2.53	3.78	2.39	3.62	3.08	4.61	2.91	4.34
V_n/Ω_v	$\phi_v V_n$, kips	68.0	102	70.7	106	62.5	93.7	56.4	84.7	63.0	94.5	53.6	80.3
Z_x, in.^{3}		60.4		54.9		46.8		38.8		36.6		31.3	
L_p, ft		8.97		7.10		6.99		6.85		4.84		4.80	
L_r, ft		31.6		26.9		24.2		21.8		16.1		14.9	

ASD	LRFD
$\Omega_b = 1.67$ $\Omega_v = 1.50$	$\phi_b = 0.90$ $\phi_v = 1.00$

[f] Shape does not meet compact limit for flexure with $F_y = 50$ ksi.

American Institute of Steel Construction

Appendix E

Stair Tower Takeoffs

STAIR A: LEVEL 1 - TOP OF STRUCTURE							Unit	$ per unit	Total $
				12	" THICK	**4,690**	**SF**		
	CONCRETE - BUY					182	CY	125.00	$22,799
	REBAR			**50**	#/CY	9,119	LBS	2.00	$18,239
	FORMING					9,380	SF	10.00	$93,800
	RUBBING					9,380	SF	1.30	$12,194
	Stair A			- COST PER CUBIC YARD			$806	/CY	
	Stair A			- COST PER SQUARE FOOT			$31	/SF	
CIP WALL @ STAIR A				**-SUBTOTAL**		**$147,032**			

Manpower Takeoff for Current Design

Type of laborer	Number of Workers	Hours Per Worker Per Level	# of Levels	Total Number of Hours	Cost/Hour	Total Cost
Iron Workers	2	12	5	120	$ 49.63	$ 5,955.60
Carpenter	3	40	5	600	$ 38.60	$ 23,160.00
Laborer	3	40	5	600	$ 29.14	$ 17,484.00
Crane Operator	1	40	5	200	$ 43.54	$ 8,708.00
Pump Operator	1	8	5	40	$ 43.04	$ 1,721.60
						$57,029.20

Equipment Takeoff for Current Design

Type of Equipment	Days/Level	# of Levels	Total Number of Days	Cost/Day	Total Cost
Crane	5	5	25	$ 1,250.00	$ 31,250.00
Lift	5	5	25	$ 180.00	$ 4,500.00
Pump Truck	1	5	5	$ 1,000.00	$ 5,000.00
					$ 40,750.00

Steel Design Summary

Size	Quantity	Length (ft)	Sum of Lengths	LB/LF	Lbs	Tons	Material Cost/LF	Labor Cost/ LF	Equipment Cost/ LF	Total/ LF	Cost/Ton	Total Cost
HSS 4-1/2 x 4-1/2 x 3/8	10	19.8	198	19.8	3924.4	1.96					$ 3,000.00	$ 5,886.54
HSS 6 x 6 x 1/4	10	29.5	295	19	5610.9	2.81					$ 3,000.00	$ 8,416.35
W14x90	8	28	224	90	20160	10.08	$ 172.00	$ 2.86	1.59	$ 176.45		$ 39,524.80
W14x90	4	14	56	90	5040	2.52	$ 172.00	$ 2.86	1.59	$ 176.45		$ 9,881.20
W10x30	10	26	260	30	7800	3.9	$ 47.00	$ 4.99	2.77	$ 54.76		$ 14,237.60
W10x17	10	14	140	17	2380	1.19	$ 31.50	$ 4.58	2.54	$ 38.62		$ 5,406.80
												$ 69,050.40
											Add 10%	$ 6,905.04
												$ 75,955.44

Fireproofing

Size	Quantity	Length (ft)	Sum of Lengths	Surface Length	Square Footage	Material	Labor	Equipment	Total	Inches	Total Cost
HSS 4-1/2 x 4-1/2 x 3/8	10	19.8	198	1.5	297	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 724.68
HSS 6 x 6 x 1/4	10	29.5	295	2	590	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 1,439.60
W14x90	8	28	224	4.8	1065.49	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 2,599.80
W14x90	4	14	56	4.8	266.37	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 649.95
W10x30	10	26	260	2.7	705.47	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 1,721.34
W10x17	10	14	140	2.4	329.47	$ 0.53	$ 0.60	$ 0.09	$ 1.22	2.00	$ 803.90
											$ 7,939.27

Fill = Estimated to be 6" GWB Partition

Material							
Description	**Quantity**	**Unit**	**Material Unit Cost**	**Total Cost**	**Production Rate Per day**	**Unit**	**Total Time Needed (Days)**
6" Studs @ 16" O.C.	400	LF	30	$ 12,000.00	100	LF	4
5/8" Drywall - Taped and Finsihed	11200	SF	1.52	$ 17,024.00	965	SF	11.6
Joint Sealant	400	LF	0.3	$ 120.00	1000	LF	0.4
Sound Attenuation Blanket	4000	SF	0.44	$ 1,760.00	1000	SF	4
				$ 30,904.00			20

Labor				
Type of Manpower	**Quantity**	**Unit**	**Cost per Unit**	**Total Cost**
Carpenter & Taper	20	MD	357.04	$ 7,143.02
Laborer	3.3	MD	273.12	$ 910.68
Laborer (stocking)	11200	SF	0.05	$ 560.00
				$ 8,613.70

Stud Height	**14.00**	LF
Ceiling Height	**10.00**	AFF
Sheets	**2**	EA

Schedule

Steel Members

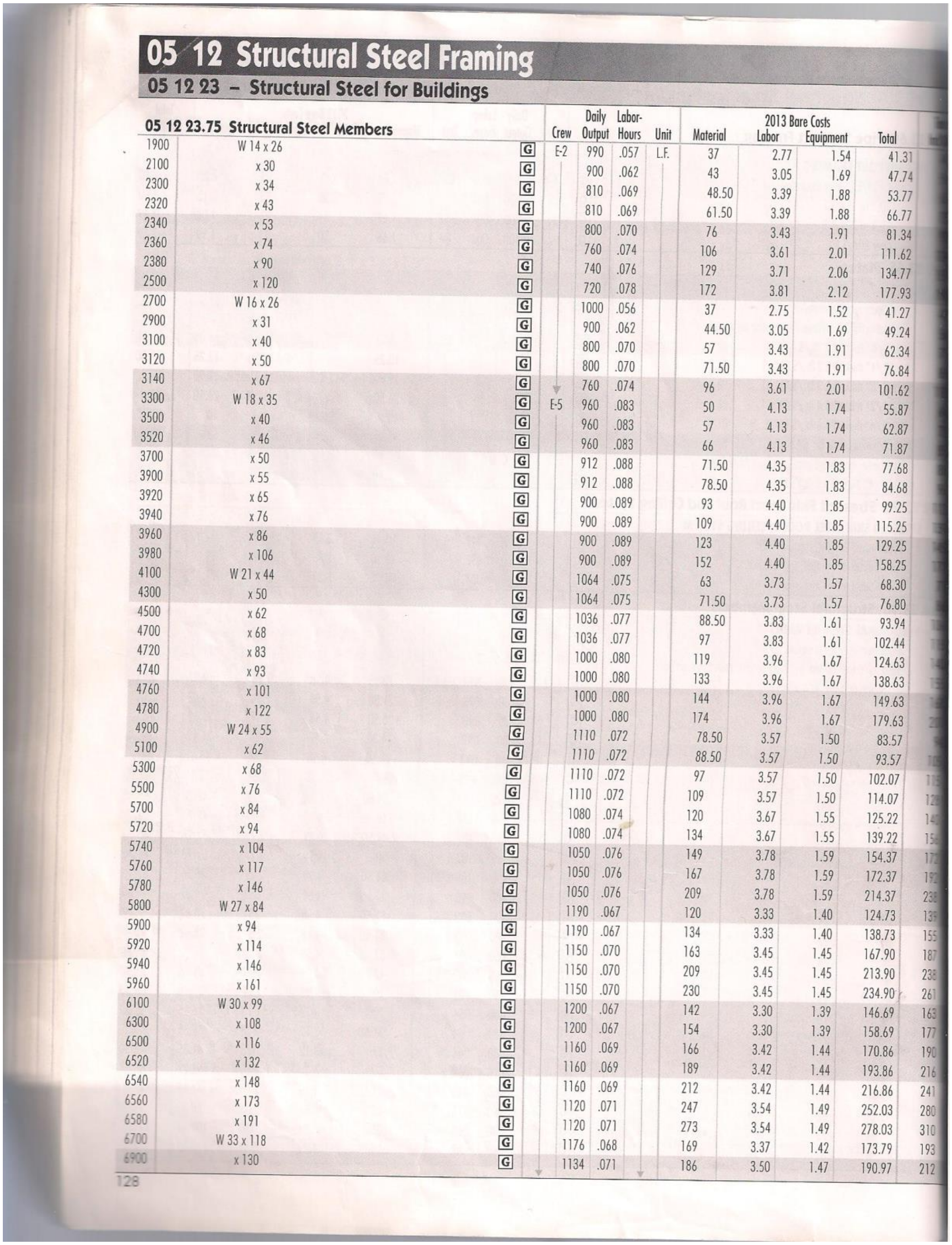
Size	Quantity	Length (ft)	Sum of Lengths	Tons	Tons/Day	Daily Output/LF	Days
HSS 4-1/2 x 4-1/2 x 3/8	10	19.8	198	1.96	30		0.07
HSS 6 x 6 x 1/4	10	29.5	295	2.81	30		0.09
W14x90	8	28	224	10.08		960	0.23
W14x90	4	14	56	2.52		960	0.06
W10x30	10	26	260	3.9		550	0.47
W10x17	10	14	140	1.19		600	0.23
							1.16

Fireproofing

Daily Output/SF	Total SF	Total Days
1500	3253.8	4.34

6" GWB Partition Material

Description	Quantity	Unit	Production Rate Per day	Unit	Total Time Needed (Days)
6" Studs @ 16" O.C.	400	LF	100	LF	4
5/8" Drywall - Taped and Finsihed	11200	SF	965	SF	11.61
Joint Sealant	400	LF	1000	LF	0.4
Sound Attenuation Blanket	4000	SF	1000	SF	4
					20



05 12 Structural Steel Framing

05 12 23 – Structural Steel for Buildings

05 12 23.75 Structural Steel Members			Crew	Daily Output	Labor-Hours	Unit	Material	2013 Bare Costs Labor	Equipment	Total
1900	W 14 x 26	G	E-2	990	.057	L.F.	37	2.77	1.54	41.31
2100	x 30	G		900	.062		43	3.05	1.69	47.74
2300	x 34	G		810	.069		48.50	3.39	1.88	53.77
2320	x 43	G		810	.069		61.50	3.39	1.88	66.77
2340	x 53	G		800	.070		76	3.43	1.91	81.34
2360	x 74	G		760	.074		106	3.61	2.01	111.62
2380	x 90	G		740	.076		129	3.71	2.06	134.77
2500	x 120	G		720	.078		172	3.81	2.12	177.93
2700	W 16 x 26	G		1000	.056		37	2.75	1.52	41.27
2900	x 31	G		900	.062		44.50	3.05	1.69	49.24
3100	x 40	G		800	.070		57	3.43	1.91	62.34
3120	x 50	G		800	.070		71.50	3.43	1.91	76.84
3140	x 67	G		760	.074		96	3.61	2.01	101.62
3300	W 18 x 35	G	E-5	960	.083		50	4.13	1.74	55.87
3500	x 40	G		960	.083		57	4.13	1.74	62.87
3520	x 46	G		960	.083		66	4.13	1.74	71.87
3700	x 50	G		912	.088		71.50	4.35	1.83	77.68
3900	x 55	G		912	.088		78.50	4.35	1.83	84.68
3920	x 65	G		900	.089		93	4.40	1.85	99.25
3940	x 76	G		900	.089		109	4.40	1.85	115.25
3960	x 86	G		900	.089		123	4.40	1.85	129.25
3980	x 106	G		900	.089		152	4.40	1.85	158.25
4100	W 21 x 44	G		1064	.075		63	3.73	1.57	68.30
4300	x 50	G		1064	.075		71.50	3.73	1.57	76.80
4500	x 62	G		1036	.077		88.50	3.83	1.61	93.94
4700	x 68	G		1036	.077		97	3.83	1.61	102.44
4720	x 83	G		1000	.080		119	3.96	1.67	124.63
4740	x 93	G		1000	.080		133	3.96	1.67	138.63
4760	x 101	G		1000	.080		144	3.96	1.67	149.63
4780	x 122	G		1000	.080		174	3.96	1.67	179.63
4900	W 24 x 55	G		1110	.072		78.50	3.57	1.50	83.57
5100	x 62	G		1110	.072		88.50	3.57	1.50	93.57
5300	x 68	G		1110	.072		97	3.57	1.50	102.07
5500	x 76	G		1110	.072		109	3.57	1.50	114.07
5700	x 84	G		1080	.074		120	3.67	1.55	125.22
5720	x 94	G		1080	.074		134	3.67	1.55	139.22
5740	x 104	G		1050	.076		149	3.78	1.59	154.37
5760	x 117	G		1050	.076		167	3.78	1.59	172.37
5780	x 146	G		1050	.076		209	3.78	1.59	214.37
5800	W 27 x 84	G		1190	.067		120	3.33	1.40	124.73
5900	x 94	G		1190	.067		134	3.33	1.40	138.73
5920	x 114	G		1150	.070		163	3.45	1.45	167.90
5940	x 146	G		1150	.070		209	3.45	1.45	213.90
5960	x 161	G		1150	.070		230	3.45	1.45	234.90
6100	W 30 x 99	G		1200	.067		142	3.30	1.39	146.69
6300	x 108	G		1200	.067		154	3.30	1.39	158.69
6500	x 116	G		1160	.069		166	3.42	1.44	170.86
6520	x 132	G		1160	.069		189	3.42	1.44	193.86
6540	x 148	G		1160	.069		212	3.42	1.44	216.86
6560	x 173	G		1120	.071		247	3.54	1.49	252.03
6580	x 191	G		1120	.071		273	3.54	1.49	278.03
6700	W 33 x 118	G		1176	.068		169	3.37	1.42	173.79
6900	x 130	G		1134	.071		186	3.50	1.47	190.97

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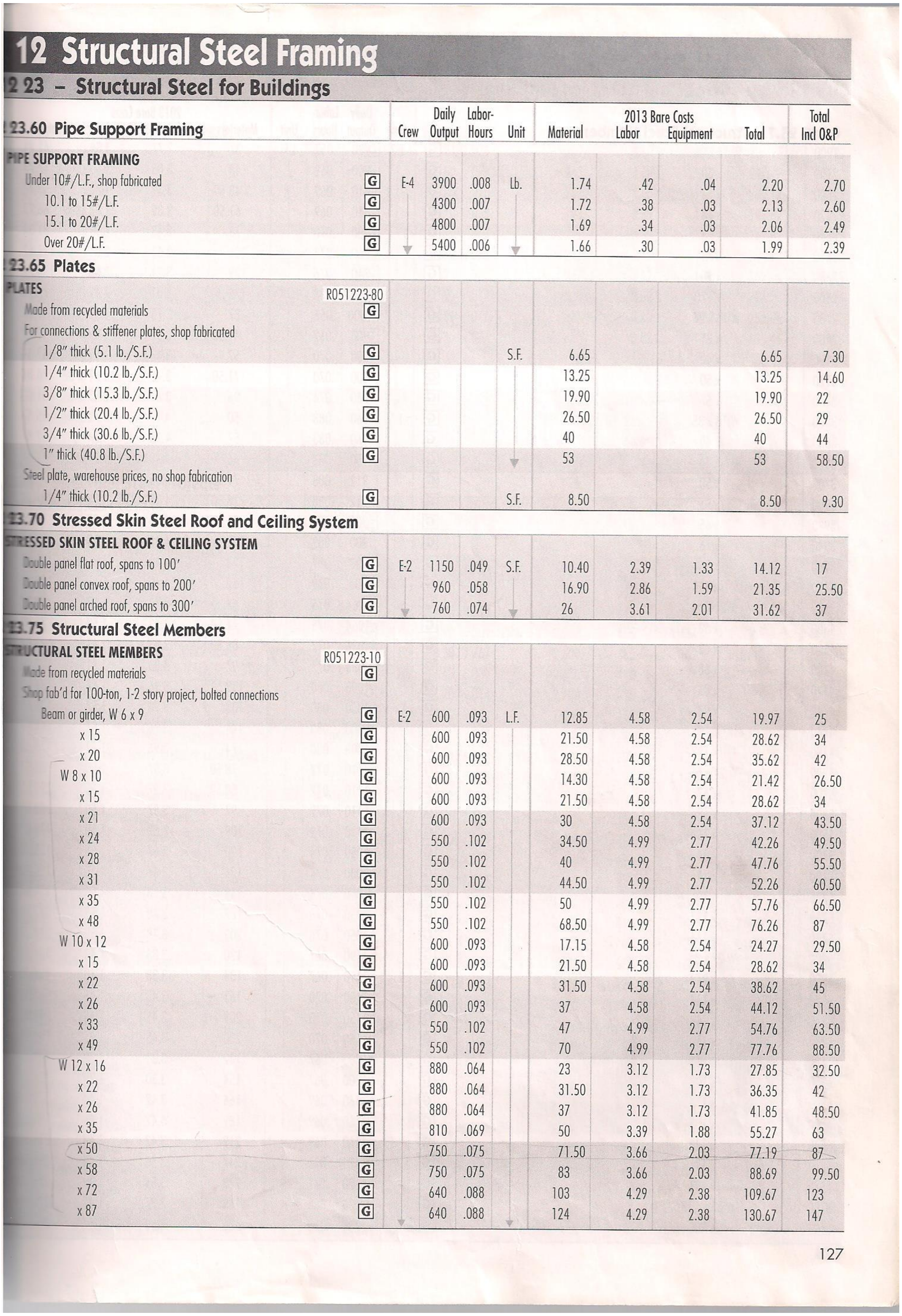

12 Structural Steel Framing

2 23 – Structural Steel for Buildings

23.60 Pipe Support Framing		Crew	Daily Output	Labor-Hours	Unit	Material	2013 Bare Costs Labor	Equipment	Total	Total Incl O&P
PIPE SUPPORT FRAMING										
Under 10#/L.F., shop fabricated	G	E-4	3900	.008	Lb.	1.74	.42	.04	2.20	2.70
10.1 to 15#/L.F.	G		4300	.007		1.72	.38	.03	2.13	2.60
15.1 to 20#/L.F.	G		4800	.007		1.69	.34	.03	2.06	2.49
Over 20#/L.F.	G		5400	.006		1.66	.30	.03	1.99	2.39
23.65 Plates										
PLATES R051223-80										
Made from recycled materials	G									
For connections & stiffener plates, shop fabricated										
1/8″ thick (5.1 lb./S.F.)	G				S.F.	6.65			6.65	7.30
1/4″ thick (10.2 lb./S.F.)	G					13.25			13.25	14.60
3/8″ thick (15.3 lb./S.F.)	G					19.90			19.90	22
1/2″ thick (20.4 lb./S.F.)	G					26.50			26.50	29
3/4″ thick (30.6 lb./S.F.)	G					40			40	44
1″ thick (40.8 lb./S.F.)	G					53			53	58.50
Steel plate, warehouse prices, no shop fabrication										
1/4″ thick (10.2 lb./S.F.)	G				S.F.	8.50			8.50	9.30
23.70 Stressed Skin Steel Roof and Ceiling System										
STRESSED SKIN STEEL ROOF & CEILING SYSTEM										
Double panel flat roof, spans to 100′	G	E-2	1150	.049	S.F.	10.40	2.39	1.33	14.12	17
Double panel convex roof, spans to 200′	G		960	.058		16.90	2.86	1.59	21.35	25.50
Double panel arched roof, spans to 300′	G		760	.074		26	3.61	2.01	31.62	37
23.75 Structural Steel Members										
STRUCTURAL STEEL MEMBERS R051223-10										
Made from recycled materials	G									
Shop fab'd for 100-ton, 1-2 story project, bolted connections										
Beam or girder, W 6 x 9	G	E-2	600	.093	L.F.	12.85	4.58	2.54	19.97	25
x 15	G		600	.093		21.50	4.58	2.54	28.62	34
x 20	G		600	.093		28.50	4.58	2.54	35.62	42
W 8 x 10	G		600	.093		14.30	4.58	2.54	21.42	26.50
x 15	G		600	.093		21.50	4.58	2.54	28.62	34
x 21	G		600	.093		30	4.58	2.54	37.12	43.50
x 24	G		550	.102		34.50	4.99	2.77	42.26	49.50
x 28	G		550	.102		40	4.99	2.77	47.76	55.50
x 31	G		550	.102		44.50	4.99	2.77	52.26	60.50
x 35	G		550	.102		50	4.99	2.77	57.76	66.50
x 48	G		550	.102		68.50	4.99	2.77	76.26	87
W 10 x 12	G		600	.093		17.15	4.58	2.54	24.27	29.50
x 15	G		600	.093		21.50	4.58	2.54	28.62	34
x 22	G		600	.093		31.50	4.58	2.54	38.62	45
x 26	G		600	.093		37	4.58	2.54	44.12	51.50
x 33	G		550	.102		47	4.99	2.77	54.76	63.50
x 49	G		550	.102		70	4.99	2.77	77.76	88.50
W 12 x 16	G		880	.064		23	3.12	1.73	27.85	32.50
x 22	G		880	.064		31.50	3.12	1.73	36.35	42
x 26	G		880	.064		37	3.12	1.73	41.85	48.50
x 35	G		810	.069		50	3.39	1.88	55.27	63
x 50	G		750	.075		71.50	3.66	2.03	77.19	87
x 58	G		750	.075		83	3.66	2.03	88.69	99.50
x 72	G		640	.088		103	4.29	2.38	109.67	123
x 87	G		640	.088		124	4.29	2.38	130.67	147

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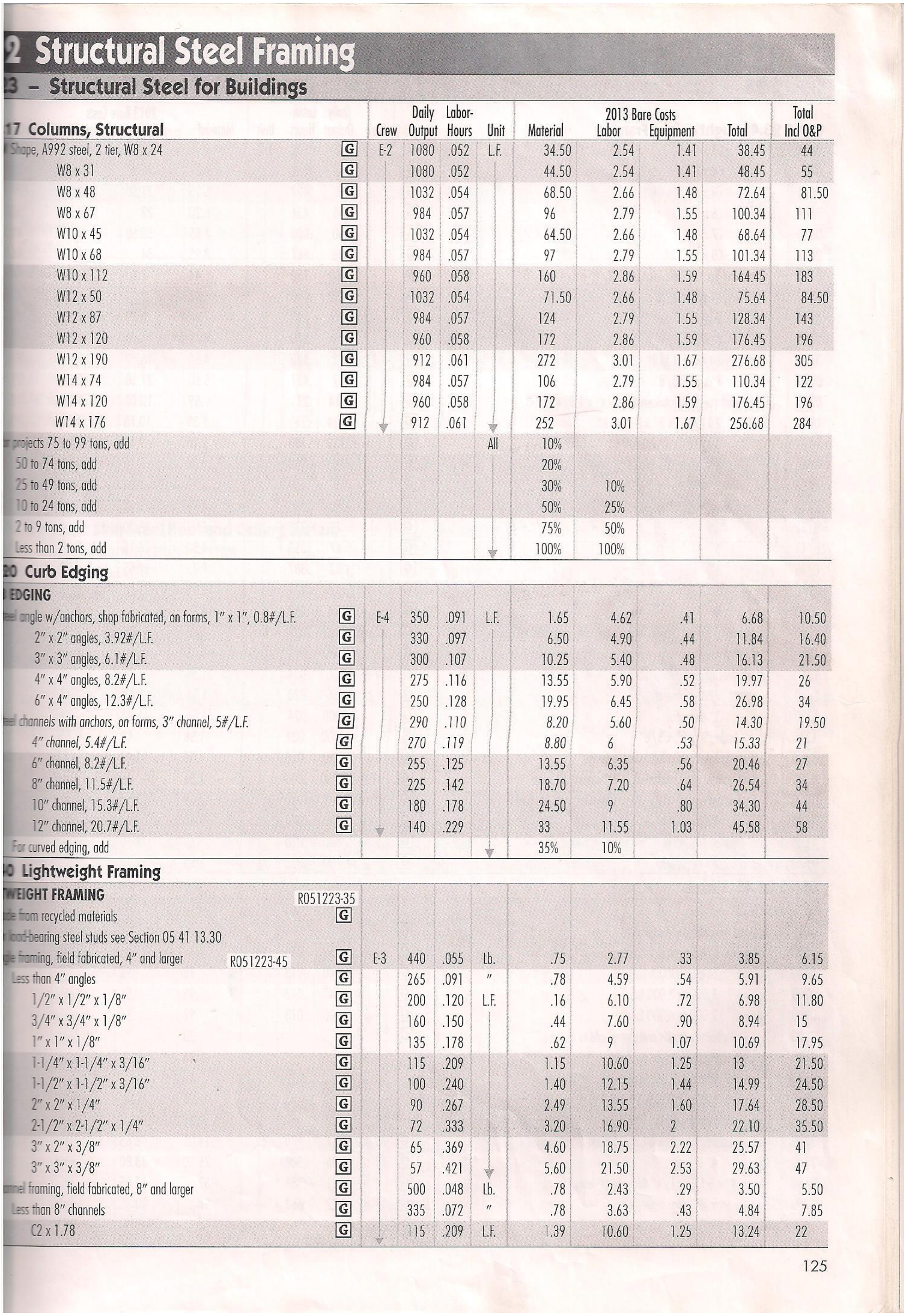

2 Structural Steel Framing

3 – Structural Steel for Buildings

17 Columns, Structural		Crew	Daily Output	Labor-Hours	Unit	Material	Labor	Equipment	Total	Total Incl O&P
						2013 Bare Costs				
Shape, A992 steel, 2 tier, W8 x 24	G	E-2	1080	.052	L.F.	34.50	2.54	1.41	38.45	44
W8 x 31	G		1080	.052		44.50	2.54	1.41	48.45	55
W8 x 48	G		1032	.054		68.50	2.66	1.48	72.64	81.50
W8 x 67	G		984	.057		96	2.79	1.55	100.34	111
W10 x 45	G		1032	.054		64.50	2.66	1.48	68.64	77
W10 x 68	G		984	.057		97	2.79	1.55	101.34	113
W10 x 112	G		960	.058		160	2.86	1.59	164.45	183
W12 x 50	G		1032	.054		71.50	2.66	1.48	75.64	84.50
W12 x 87	G		984	.057		124	2.79	1.55	128.34	143
W12 x 120	G		960	.058		172	2.86	1.59	176.45	196
W12 x 190	G		912	.061		272	3.01	1.67	276.68	305
W14 x 74	G		984	.057		106	2.79	1.55	110.34	122
W14 x 120	G		960	.058		172	2.86	1.59	176.45	196
W14 x 176	G		912	.061		252	3.01	1.67	256.68	284
projects 75 to 99 tons, add					All	10%				
50 to 74 tons, add						20%				
25 to 49 tons, add						30%	10%			
10 to 24 tons, add						50%	25%			
2 to 9 tons, add						75%	50%			
Less than 2 tons, add						100%	100%			
20 Curb Edging										
EDGING										
eel angle w/anchors, shop fabricated, on forms, 1" x 1", 0.8#/L.F.	G	E-4	350	.091	L.F.	1.65	4.62	.41	6.68	10.50
2" x 2" angles, 3.92#/L.F.	G		330	.097		6.50	4.90	.44	11.84	16.40
3" x 3" angles, 6.1#/L.F.	G		300	.107		10.25	5.40	.48	16.13	21.50
4" x 4" angles, 8.2#/L.F.	G		275	.116		13.55	5.90	.52	19.97	26
6" x 4" angles, 12.3#/L.F.	G		250	.128		19.95	6.45	.58	26.98	34
eel channels with anchors, on forms, 3" channel, 5#/L.F.	G		290	.110		8.20	5.60	.50	14.30	19.50
4" channel, 5.4#/L.F.	G		270	.119		8.80	6	.53	15.33	21
6" channel, 8.2#/L.F.	G		255	.125		13.55	6.35	.56	20.46	27
8" channel, 11.5#/L.F.	G		225	.142		18.70	7.20	.64	26.54	34
10" channel, 15.3#/L.F.	G		180	.178		24.50	9	.80	34.30	44
12" channel, 20.7#/L.F.	G		140	.229		33	11.55	1.03	45.58	58
For curved edging, add						35%	10%			
0 Lightweight Framing										
WEIGHT FRAMING R051223-35										
de from recycled materials	G									
load-bearing steel studs see Section 05 41 13.30										
le framing, field fabricated, 4" and larger R051223-45	G	E-3	440	.055	Lb.	.75	2.77	.33	3.85	6.15
Less than 4" angles	G		265	.091	"	.78	4.59	.54	5.91	9.65
1/2" x 1/2" x 1/8"	G		200	.120	L.F.	.16	6.10	.72	6.98	11.80
3/4" x 3/4" x 1/8"	G		160	.150		.44	7.60	.90	8.94	15
1" x 1" x 1/8"	G		135	.178		.62	9	1.07	10.69	17.95
1-1/4" x 1-1/4" x 3/16"	G		115	.209		1.15	10.60	1.25	13	21.50
1-1/2" x 1-1/2" x 3/16"	G		100	.240		1.40	12.15	1.44	14.99	24.50
2" x 2" x 1/4"	G		90	.267		2.49	13.55	1.60	17.64	28.50
2-1/2" x 2-1/2" x 1/4"	G		72	.333		3.20	16.90	2	22.10	35.50
3" x 2" x 3/8"	G		65	.369		4.60	18.75	2.22	25.57	41
3" x 3" x 3/8"	G		57	.421		5.60	21.50	2.53	29.63	47
nnel framing, field fabricated, 8" and larger	G		500	.048	Lb.	.78	2.43	.29	3.50	5.50
Less than 8" channels	G		335	.072	"	.78	3.63	.43	4.84	7.85
C2 x 1.78	G		115	.209	L.F.	1.39	10.60	1.25	13.24	22

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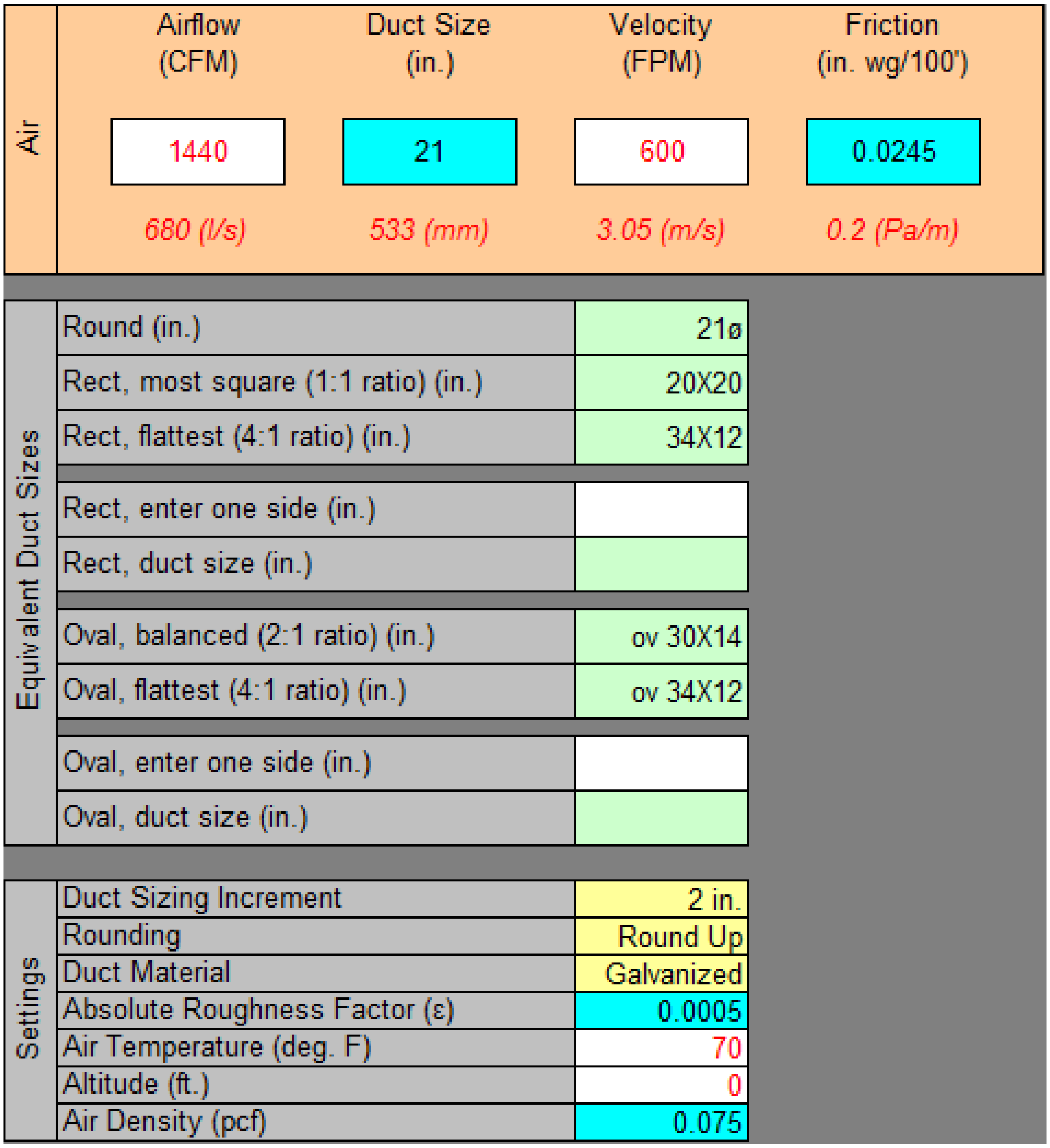
Appendix F

Mechanical Breadth Calculations

ACF 8 Air Supply Balance Checks		
Level	**Supply Air Provided (CFM)**	**Return Air (CFM)**
3	2700	3000
3.1	1440	1440
3.2	740	740
3.3	960	960
3.4	1390	1390
	7230	7530



Air	Airflow (CFM)	Duct Size (in.)	Velocity (FPM)	Friction (in. wg/100')
	1440	21	600	0.0245
	680 (l/s)	*533 (mm)*	*3.05 (m/s)*	*0.2 (Pa/m)*

Equivalent Duct Sizes	Round (in.)	21ø
	Rect, most square (1:1 ratio) (in.)	20X20
	Rect, flattest (4:1 ratio) (in.)	34X12
	Rect, enter one side (in.)	
	Rect, duct size (in.)	
	Oval, balanced (2:1 ratio) (in.)	ov 30X14
	Oval, flattest (4:1 ratio) (in.)	ov 34X12
	Oval, enter one side (in.)	
	Oval, duct size (in.)	

Settings	Duct Sizing Increment	2 in.
	Rounding	Round Up
	Duct Material	Galvanized
	Absolute Roughness Factor (ε)	0.0005
	Air Temperature (deg. F)	70
	Altitude (ft.)	0
	Air Density (pcf)	0.075

Appendix G

Return Air Plenum Takeoffs

RA Ductwork Takeoffs

Size	Sum of the two sides	Max Dimension	Gage	lb/ft	Length (ft)	Pounds	SF	Cost/pound	Cost
18x12	30	18 -> 30	24	6.5	3	19.50	13.86913	$ 8.50	$ 117.89
28x8	36	28 -> 30	24	7.8	7	54.60	38.83357	$ 8.50	$ 330.09
8X8	16	8 -> 30	24	3.4	3	10.20	7.254623	$ 8.50	$ 61.66
12X8	20	12 -> 30	24	4.3	7	30.10	21.40825	$ 8.50	$ 181.97
16X6	22	16 -> 30	24	4.7	2	9.40	6.685633	$ 8.50	$ 56.83
20X8	28	20 -> 30	24	6	10	60.00	42.67425	$ 8.50	$ 362.73
14X10	24	14 -> 30	24	5.2	31	161.20	114.6515	$ 8.50	$ 974.54
		TOTALS				345.00	245.377		$ 2,085.70

Supply Air Takeoff							
Size	Sum of the two sides	Max Dimension	Gage	lb/ft	Length (ft)	Pounds	SF
20x12	32	20 --> 30	24	6.9	14	98.3	85.1
10x10	20	10 --> 30	24	4.3	25	107.9	93.3
12x6	18	12 --> 30	24	3.9	16	63.7	55.1
18x12	30	18 --> 30	24	6.5	5	30.9	26.7
12x8	20	12 --> 30	24	4.3	33	142.6	123.4
8x8	16	8 --> 30	24	3.4	21	70.0	60.5
12x10	22	12 --> 30	24	4.7	10	45.8	39.6
							483.7

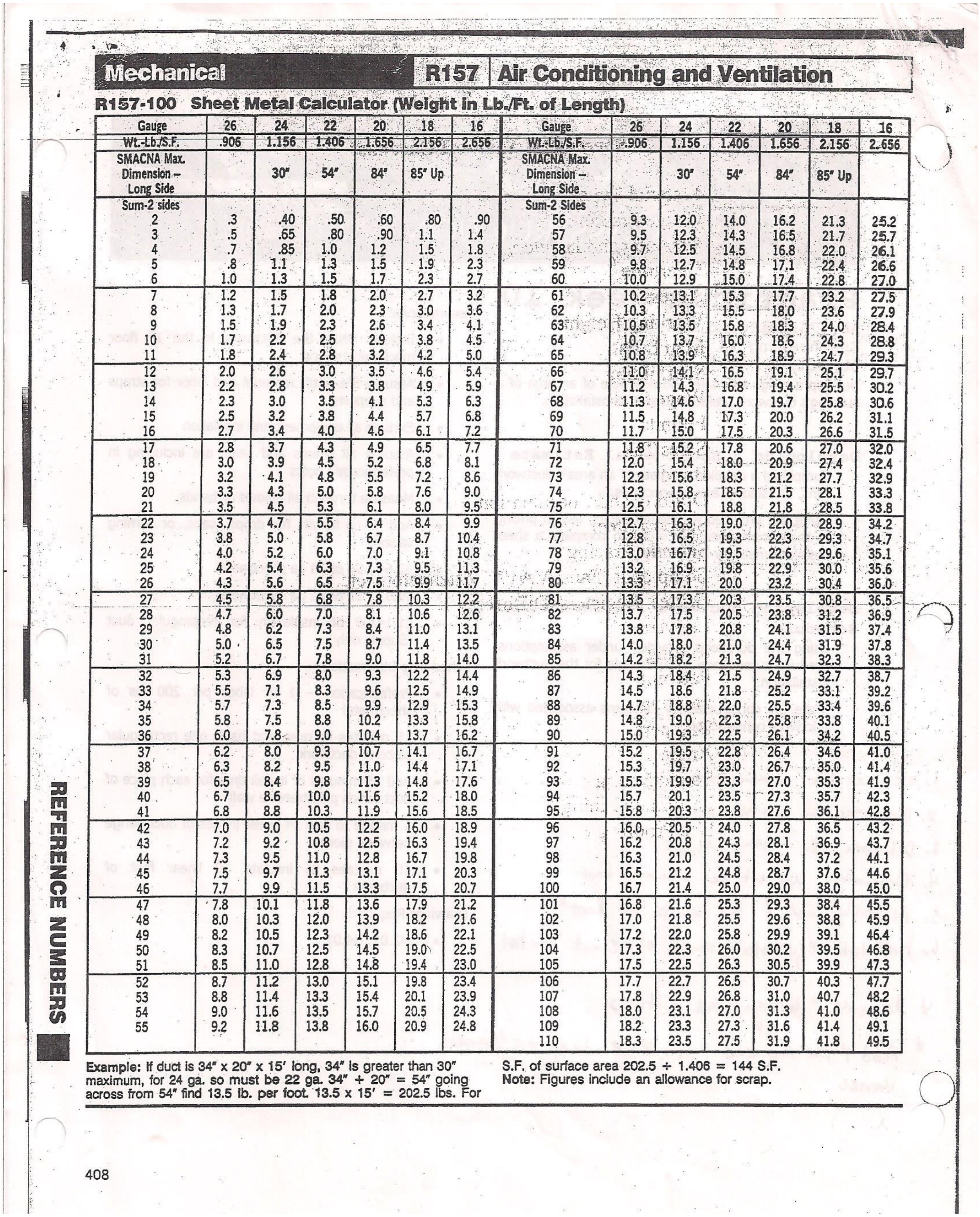
* Requirements say that the insulation wrap needs to be 1/2 inch thick						
According to Subcontractor	Cost per SF	SF	Total Cost	Minutes/SF	Minutes	
1" Vapor Barrier Wrap	1.96	484	$ 948.10	0.15	73	

SCHEDULE INFORMATION							
PREFABRICATION - 1 hr labor per 200 lbs of sheetmetal							
2	hrs total						
15 MINUTES TO RAISE AND HANG ONE RECTANGULAR PIECE OF DUCTWORK							
13	Pieces	15	minutes/piece	195			
ADD 15 MINUTES OF INSTALL TIME FOR EACH PIECE OF DUCT WHICH PENETRATES A WALL							
2	Pieces that Penetrate	15	minutes/piece	30			
1 MINUTE TO SEAL 24 LINEAR INCHES OF DUCT FLANGE BETWEEN PIECES							
13	Areas to sea	1	Minute/seal	13			
10 MINUTES TO INSULATE 10 LINEAR FEET OF DUCTWORK							
63	LF	10	Minutes/10 LF	63			
				404.5		6.7	Hours

Savings in Area	SF of Area	Savings/SF
$ 1,487.61	1250	$ 1.19
Total Area of Building	**Savings/SF**	**Total Savings**
150000	$ 1.19	$ 178,512.94

Appendix H

Mechanical Breadth References



Mechanical | **R157** | **Air Conditioning and Ventilation**

R157-100 Sheet Metal Calculator (Weight in Lb./Ft. of Length)

Gauge	26	24	22	20	18	16	Gauge	26	24	22	20	18	16
Wt.-Lb./S.F.	.906	1.156	1.406	1.656	2.156	2.656	Wt.-Lb./S.F.	.906	1.156	1.406	1.656	2.156	2.656
SMACNA Max. Dimension – Long Side		30″	54″	84″	85″ Up		SMACNA Max. Dimension – Long Side		30″	54″	84″	85″ Up	
Sum-2 sides							Sum-2 Sides						
2	.3	.40	.50	.60	.80	.90	56	9.3	12.0	14.0	16.2	21.3	25.2
3	.5	.65	.80	.90	1.1	1.4	57	9.5	12.3	14.3	16.5	21.7	25.7
4	.7	.85	1.0	1.2	1.5	1.8	58	9.7	12.5	14.5	16.8	22.0	26.1
5	.8	1.1	1.3	1.5	1.9	2.3	59	9.8	12.7	14.8	17.1	22.4	26.6
6	1.0	1.3	1.5	1.7	2.3	2.7	60	10.0	12.9	15.0	17.4	22.8	27.0
7	1.2	1.5	1.8	2.0	2.7	3.2	61	10.2	13.1	15.3	17.7	23.2	27.5
8	1.3	1.7	2.0	2.3	3.0	3.6	62	10.3	13.3	15.5	18.0	23.6	27.9
9	1.5	1.9	2.3	2.6	3.4	4.1	63	10.5	13.5	15.8	18.3	24.0	28.4
10	1.7	2.2	2.5	2.9	3.8	4.5	64	10.7	13.7	16.0	18.6	24.3	28.8
11	1.8	2.4	2.8	3.2	4.2	5.0	65	10.8	13.9	16.3	18.9	24.7	29.3
12	2.0	2.6	3.0	3.5	4.6	5.4	66	11.0	14.1	16.5	19.1	25.1	29.7
13	2.2	2.8	3.3	3.8	4.9	5.9	67	11.2	14.3	16.8	19.4	25.5	30.2
14	2.3	3.0	3.5	4.1	5.3	6.3	68	11.3	14.6	17.0	19.7	25.8	30.6
15	2.5	3.2	3.8	4.4	5.7	6.8	69	11.5	14.8	17.3	20.0	26.2	31.1
16	2.7	3.4	4.0	4.6	6.1	7.2	70	11.7	15.0	17.5	20.3	26.6	31.5
17	2.8	3.7	4.3	4.9	6.5	7.7	71	11.8	15.2	17.8	20.6	27.0	32.0
18	3.0	3.9	4.5	5.2	6.8	8.1	72	12.0	15.4	18.0	20.9	27.4	32.4
19	3.2	4.1	4.8	5.5	7.2	8.6	73	12.2	15.6	18.3	21.2	27.7	32.9
20	3.3	4.3	5.0	5.8	7.6	9.0	74	12.3	15.8	18.5	21.5	28.1	33.3
21	3.5	4.5	5.3	6.1	8.0	9.5	75	12.5	16.1	18.8	21.8	28.5	33.8
22	3.7	4.7	5.5	6.4	8.4	9.9	76	12.7	16.3	19.0	22.0	28.9	34.2
23	3.8	5.0	5.8	6.7	8.7	10.4	77	12.8	16.5	19.3	22.3	29.3	34.7
24	4.0	5.2	6.0	7.0	9.1	10.8	78	13.0	16.7	19.5	22.6	29.6	35.1
25	4.2	5.4	6.3	7.3	9.5	11.3	79	13.2	16.9	19.8	22.9	30.0	35.6
26	4.3	5.6	6.5	7.5	9.9	11.7	80	13.3	17.1	20.0	23.2	30.4	36.0
27	4.5	5.8	6.8	7.8	10.3	12.2	81	13.5	17.3	20.3	23.5	30.8	36.5
28	4.7	6.0	7.0	8.1	10.6	12.6	82	13.7	17.5	20.5	23.8	31.2	36.9
29	4.8	6.2	7.3	8.4	11.0	13.1	83	13.8	17.8	20.8	24.1	31.5	37.4
30	5.0	6.5	7.5	8.7	11.4	13.5	84	14.0	18.0	21.0	24.4	31.9	37.8
31	5.2	6.7	7.8	9.0	11.8	14.0	85	14.2	18.2	21.3	24.7	32.3	38.3
32	5.3	6.9	8.0	9.3	12.2	14.4	86	14.3	18.4	21.5	24.9	32.7	38.7
33	5.5	7.1	8.3	9.6	12.5	14.9	87	14.5	18.6	21.8	25.2	33.1	39.2
34	5.7	7.3	8.5	9.9	12.9	15.3	88	14.7	18.8	22.0	25.5	33.4	39.6
35	5.8	7.5	8.8	10.2	13.3	15.8	89	14.8	19.0	22.3	25.8	33.8	40.1
36	6.0	7.8	9.0	10.4	13.7	16.2	90	15.0	19.3	22.5	26.1	34.2	40.5
37	6.2	8.0	9.3	10.7	14.1	16.7	91	15.2	19.5	22.8	26.4	34.6	41.0
38	6.3	8.2	9.5	11.0	14.4	17.1	92	15.3	19.7	23.0	26.7	35.0	41.4
39	6.5	8.4	9.8	11.3	14.8	17.6	93	15.5	19.9	23.3	27.0	35.3	41.9
40	6.7	8.6	10.0	11.6	15.2	18.0	94	15.7	20.1	23.5	27.3	35.7	42.3
41	6.8	8.8	10.3	11.9	15.6	18.5	95	15.8	20.3	23.8	27.6	36.1	42.8
42	7.0	9.0	10.5	12.2	16.0	18.9	96	16.0	20.5	24.0	27.8	36.5	43.2
43	7.2	9.2	10.8	12.5	16.3	19.4	97	16.2	20.8	24.3	28.1	36.9	43.7
44	7.3	9.5	11.0	12.8	16.7	19.8	98	16.3	21.0	24.5	28.4	37.2	44.1
45	7.5	9.7	11.3	13.1	17.1	20.3	99	16.5	21.2	24.8	28.7	37.6	44.6
46	7.7	9.9	11.5	13.3	17.5	20.7	100	16.7	21.4	25.0	29.0	38.0	45.0
47	7.8	10.1	11.8	13.6	17.9	21.2	101	16.8	21.6	25.3	29.3	38.4	45.5
48	8.0	10.3	12.0	13.9	18.2	21.6	102	17.0	21.8	25.5	29.6	38.8	45.9
49	8.2	10.5	12.3	14.2	18.6	22.1	103	17.2	22.0	25.8	29.9	39.1	46.4
50	8.3	10.7	12.5	14.5	19.0	22.5	104	17.3	22.3	26.0	30.2	39.5	46.8
51	8.5	11.0	12.8	14.8	19.4	23.0	105	17.5	22.5	26.3	30.5	39.9	47.3
52	8.7	11.2	13.0	15.1	19.8	23.4	106	17.7	22.7	26.5	30.7	40.3	47.7
53	8.8	11.4	13.3	15.4	20.1	23.9	107	17.8	22.9	26.8	31.0	40.7	48.2
54	9.0	11.6	13.5	15.7	20.5	24.3	108	18.0	23.1	27.0	31.3	41.0	48.6
55	9.2	11.8	13.8	16.0	20.9	24.8	109	18.2	23.3	27.3	31.6	41.4	49.1
							110	18.3	23.5	27.5	31.9	41.8	49.5

Example: If duct is 34″ x 20″ x 15′ long, 34″ is greater than 30″ maximum, for 24 ga. so must be 22 ga. 34″ + 20″ = 54″ going across from 54″ find 13.5 lb. per foot. 13.5 x 15′ = 202.5 lbs. For S.F. of surface area 202.5 ÷ 1.406 = 144 S.F.

Note: Figures include an allowance for scrap.

REFERENCE NUMBERS

408

Appendix I

Rock Excavation Blasting Takeoffs

Blasting Estimate	
Blasting	$55,000.00
Pre Blast Survey	$20,000.00
Monitors	$ 6,000.00
Blasting Mats	$ 6,000.00
Stone	$ 1,000.00
Mobilization	$ 7,000.00
Total	$95,000.00

Manpower Takeoffs

Type of Personnel	Hours/day	Number of days	Total Number of Hours	Cost per Hour	Total Cost
Project Manager	2	14	28	$ 95.00	$ 2,660.00
Site Managers (3)	6	14	84	$ 85.00	$ 7,140.00
Superintendent	2	14	28	$ 100.00	$ 2,800.00
Senior PM	2	14	28	$ 100.00	$ 2,800.00
Intern (2)	4	14	56	$ 35.00	$ 1,960.00
Project Engineer (3)	6	14	84	$ 75.00	$ 6,300.00
LSF Laborers (6)	12	14	168	$ 29.14	$ 4,895.52
Douglas Blaster In Charge	8	14	112	$ 45.19	$ 5,061.28
Douglas Personnel	8	14	112	$ 45.19	$ 5,061.28
Flagger Force (10)	45	14	630	$ 39.00	$ 24,570.00
Excavation Operators (2)	16	17	272	$ 43.04	$ 11,706.88
					$ 74,954.96

Excavation Takeoff For Blasting		
CY needed to be Excavated	Cost/ CY	Total Cost
7473	$ 25.00	$186,825.00

Appendix J

Traditional Excavation Method Takeoff

Traditional Excavation Takeoff			
Assumed half unrippable material and half rippable because dolemite rock works like a sin graph			
Unrippable Soil			
Cost/CY	**Cost**	**cy/day**	**Days**
$ 50.00	$ 186,825.00	315	12
Rippable Soil			
Cost/Cy	Cost	CY/Day	Days
25	$ 93,412.50	500	15
Total	$ 280,237.50		27
Additional Costs			
General Conditions	$ 5,000.00		
Subtotal	$ 285,237.50		
Shoring Requirements	$ 400,000.00		
Total	$ 685,237.50		

Appendix K

Specification Based Labor Costs

pennsylvania
DEPARTMENT OF LABOR & INDUSTRY
BUREAU OF LABOR LAW COMPLIANCE

PREVAILING WAGES PROJECT RATES

Project Name: Henderson Addition - Health and Human Development Building
Awarding Agency: Penn State University
Contract Award Date: 2/5/2013
Serial Number: 13-01024
Project Classification: Building/Heavy/Highway
Determination Date: 2/25/2013
Assigned Field Office: Altoona
Field Office Phone Number: 814-940-6224
Toll Free Phone Number:

Centre County

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Asbestos & Insulation Workers	6/28/2010		$30.63	$20.13	$50.76
Asbestos & Insulation Workers	6/27/2011		$31.67	$21.09	$52.76
Asbestos & Insulation Workers	7/2/2012		$32.17	$21.59	$53.76
Asbestos & Insulation Workers	7/1/2013		$33.17	$21.59	$54.76
Asbestos & Insulation Workers	6/30/2014		$34.17	$21.59	$55.76
Boilermaker (Commercial, Institutional, and Minor Repair Work)	1/1/2010		$23.59	$15.15	$38.74
Boilermaker (Commercial, Institutional, and Minor Repair Work)	3/1/2011		$24.22	$16.02	$40.24
Boilermaker (Commercial, Institutional, and Minor Repair Work)	5/1/2012		$24.84	$16.90	$41.74
Boilermakers	1/1/2011		$37.35	$28.12	$65.47
Boilermakers	1/1/2012		$37.62	$29.85	$67.47
Boilermakers	1/1/2013		$38.69	$31.13	$69.82
Bricklayers, Stone Masons, Pointers, Caulkers, Cleaners	5/2/2011		$30.05	$14.45	$44.50
Bricklayers, Stone Masons, Pointers, Caulkers, Cleaners	4/29/2012		$30.55	$14.50	$45.05
Bricklayers, Stone Masons, Pointers, Caulkers, Cleaners	4/28/2013		$31.04	$14.71	$45.75
Bricklayers, Stone Masons, Pointers, Caulkers, Cleaners	5/4/2014		$31.62	$14.93	$46.55
Bricklayers, Stone Masons, Pointers, Caulkers, Cleaners	5/3/2015		$32.24	$15.16	$47.40

PREVAILING WAGES PROJECT RATES

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Bricklayers, Stone Masons, Pointers, Caulkers, Cleaners	5/1/2016		$32.90	$15.40	$48.30
Carpenters	6/1/2009		$24.79	$9.68	$34.47
Carpenters	6/1/2010		$25.33	$10.14	$35.47
Carpenters	6/1/2011		$25.85	$10.61	$36.46
Carpenters	6/1/2012		$25.98	$11.67	$37.65
Carpenters	6/1/2013		$26.09	$12.51	$38.60
Carpenters	6/1/2014		$26.21	$13.35	$39.56
Carpenters, Soft Floor Layers	6/1/2006		$23.70	$8.79	$32.49
Cement Finishers	5/3/2009		$26.55	$13.40	$39.95
Cement Finishers	5/2/2010		$26.53	$14.22	$40.75
Cement Finishers	5/1/2011		$27.23	$14.27	$41.50
Cement Finishers	4/30/2012		$27.93	$14.32	$42.25
Cement Masons	6/1/2010		$24.60	$11.99	$36.59
Cement Masons	7/1/2010		$24.60	$11.99	$36.59
Cement Masons	7/12/2011		$24.85	$12.59	$37.44
Cement Masons	6/1/2012		$25.15	$13.19	$38.34
Cement Masons	6/1/2013		$25.45	$13.84	$39.29
Dockbuilder, Pile Drivers	1/1/2010		$29.95	$12.25	$42.20
Dockbuilder, Pile Drivers	1/1/2011		$30.35	$13.10	$43.45
Dockbuilder, Pile Drivers	1/1/2012		$30.85	$13.70	$44.55
Dockbuilder, Pile Drivers	1/1/2013		$31.45	$14.20	$45.65
Drywall Finisher	6/1/2009		$24.45	$13.59	$38.04
Drywall Finisher	6/1/2010		$24.55	$14.49	$39.04
Drywall Finisher	6/1/2011		$25.00	$15.04	$40.04
Drywall Finisher	6/1/2012		$25.55	$15.49	$41.04
Drywall Finisher	6/1/2013		$26.15	$15.89	$42.04
Electric Lineman	5/1/2009		$39.54	$16.03	$55.57
Electric Lineman	5/31/2010		$38.00	$17.73	$55.73
Electric Lineman	5/30/2011		$38.88	$17.96	$56.84
Electric Lineman	11/28/2011		$39.78	$18.20	$57.98

PREVAILING WAGES PROJECT RATES

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Electric Lineman	5/28/2012		$40.70	$18.45	$59.15
Electric Lineman	11/26/2012		$41.63	$18.70	$60.33
Electricians & Telecommunications Installation Technician	12/26/2008		$33.11	$17.13	$50.24
Electricians & Telecommunications Installation Technician	12/25/2009		$35.61	$17.13	$52.74
Electricians & Telecommunications Installation Technician	12/24/2010		$38.01	$17.13	$55.14
Electricians & Telecommunications Installation Technician	12/23/2011		$35.76	$21.10	$56.86
Electricians & Telecommunications Installation Technician	12/21/2012		$37.71	$21.10	$58.81
Electricians & Telecommunications Installation Technician	12/21/2013		$39.71	$21.10	$60.81
Elevator Constructor	1/1/2009		$37.33	$21.20	$58.53
Elevator Constructor	1/1/2010		$38.84	$22.82	$61.66
Elevator Constructor	1/1/2011		$40.33	$24.44	$64.77
Elevator Constructor	1/1/2012		$41.84	$26.06	$67.90
Elevator Tender (Use Elevator Apprentice or Constructor)	1/1/2007		$0.00	$0.00	$0.00
Glazier	9/1/2010		$20.38	$14.82	$35.20
Glazier	9/1/2011		$20.88	$15.32	$36.20
Glazier	9/1/2012		$21.38	$15.82	$37.20
Glazier	9/1/2013		$21.88	$16.32	$38.20
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2009		$24.73	$20.10	$44.83
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2010		$25.11	$21.40	$46.51
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2011		$25.26	$23.02	$48.28
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2012		$26.28	$23.35	$49.63
Laborers (Class 01 - See notes)	7/1/2009		$18.05	$9.19	$27.24
Laborers (Class 01 - See notes)	7/1/2010		$18.27	$10.14	$28.41
Laborers (Class 01 - See notes)	7/1/2011		$18.27	$10.27	$28.54
Laborers (Class 01 - See notes)	1/1/2012		$18.27	$10.87	$29.14
Laborers (Class 02 - See notes)	7/1/2009		$18.20	$9.19	$27.39
Laborers (Class 02 - See notes)	7/1/2010		$18.42	$10.14	$28.56
Laborers (Class 02 - See notes)	7/1/2011		$18.42	$10.27	$28.69
Laborers (Class 02 - See notes)	1/1/2012		$18.42	$10.87	$29.29

PREVAILING WAGES PROJECT RATES

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Laborers (Class 03 - See notes)	7/1/2009		$18.30	$9.19	$27.49
Laborers (Class 03 - See notes)	7/1/2010		$18.52	$10.14	$28.66
Laborers (Class 03 - See notes)	7/1/2011		$18.52	$10.27	$28.79
Laborers (Class 03 - See notes)	1/1/2012		$18.52	$10.87	$29.39
Laborers (Class 04 - See notes)	7/1/2009		$17.05	$9.19	$26.24
Laborers (Class 04 - See notes)	7/1/2010		$17.27	$10.14	$27.41
Laborers (Class 04 - See notes)	7/1/2011		$17.61	$10.27	$27.88
Laborers (Class 04 - See notes)	1/1/2012		$17.61	$10.87	$28.48
Landscape Laborer	7/1/2009		$18.25	$9.05	$27.30
Landscape Laborer	7/1/2010		$18.25	$9.90	$28.15
Landscape Laborer (Skilled)	7/1/2009		$18.67	$9.05	$27.72
Landscape Laborer (Skilled)	7/1/2010		$18.67	$9.90	$28.57
Landscape Laborer (Tractor Operator)	7/1/2009		$18.97	$9.05	$28.02
Landscape Laborer (Tractor Operator)	7/1/2010		$18.97	$9.90	$28.87
Millwright	6/1/2011		$34.42	$15.08	$49.50
Millwright	6/1/2012		$35.89	$16.11	$52.00
Millwright	5/1/2013		$36.49	$16.76	$53.25
Millwright	6/1/2014		$37.35	$17.15	$54.50
Operators (Class 01 - see notes)	7/1/2009		$25.47	$12.63	$38.10
Operators (Class 01 - see notes)	7/1/2010		$26.37	$13.13	$39.50
Operators (Class 01 - see notes)	7/1/2011		$26.88	$13.96	$40.84
Operators (Class 01 - see notes)	8/28/2012		$27.37	$14.62	$41.99
Operators (Class 01 - see notes)	7/1/2013		$27.87	$15.17	$43.04
Operators (Class 01 - see notes)	7/1/2014		$28.37	$15.72	$44.09
Operators (Class 01 - see notes)	7/1/2015		$28.97	$16.22	$45.19
Operators (Class 01 - see notes)	7/1/2016		$29.57	$16.77	$46.34
Operators (Class 02 -see notes)	7/1/2009		$22.79	$12.63	$35.42
Operators (Class 02 -see notes)	7/1/2010		$23.69	$13.13	$36.82
Operators (Class 02 -see notes)	7/1/2011		$24.20	$13.96	$38.16
Operators (Class 02 -see notes)	8/28/2012		$24.50	$14.62	$39.12
Operators (Class 02 -see notes)	7/1/2013		$24.85	$15.17	$40.02

PREVAILING WAGES PROJECT RATES

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Operators (Class 02 -see notes)	7/1/2014		$25.20	$15.72	$40.92
Operators (Class 02 -see notes)	7/1/2015		$25.65	$16.22	$41.87
Operators (Class 02 -see notes)	7/1/2016		$26.10	$16.77	$42.87
Operators (Class 03 - see notes)	7/1/2009		$21.24	$12.63	$33.87
Operators (Class 03 - see notes)	7/1/2010		$22.14	$13.13	$35.27
Operators (Class 03 - See notes)	7/1/2011		$22.65	$13.96	$36.61
Operators (Class 03 - see notes)	8/28/2012		$22.85	$14.62	$37.47
Operators (Class 03 - see notes)	7/1/2013		$23.10	$15.17	$38.27
Operators (Class 03 - see notes)	7/1/2014		$23.35	$15.72	$39.07
Operators (Class 03 - see notes)	7/1/2015		$23.70	$16.22	$39.92
Operators (Class 03 - see notes)	7/1/2016		$24.05	$16.77	$40.82
Operators (Class 04 - Chief of Party (Surveying and Layout))	7/1/2009		$20.84	$12.63	$33.47
Operators (Class 04 - Chief of Party (Surveying and Layout))	7/1/2010		$21.74	$13.13	$34.87
Operators (Class 04 - Chief of Party (Surveying and Layout))	8/28/2012		$22.45	$14.62	$37.07
Operators (Class 04 - Chief of Party (Surveying and Layout))	7/1/2013		$22.70	$15.17	$37.87
Operators (Class 04 - Chief of Party (Surveying and Layout))	7/1/2014		$22.95	$15.72	$38.67
Operators (Class 04 - Chief of Party (Surveying and Layout))	7/1/2015		$23.30	$16.52	$39.82
Operators (Class 04 - Chief of Party (Surveying and Layout))	7/1/2016		$23.65	$16.77	$40.42
Operators (Class 04 - Instrument Person (Surveying & Layout))	7/1/2009		$19.84	$12.63	$32.47
Operators (Class 04 - Instrument Person (Surveying & Layout))	7/1/2010		$20.74	$13.13	$33.87
Operators (Class 04 - Instrument Person (Surveying & Layout))	8/28/2012		$21.45	$14.62	$36.07
Operators (Class 04 - Instrument Person (Surveying & Layout))	7/1/2013		$21.70	$15.17	$36.87
Operators (Class 04 - Instrument Person (Surveying & Layout))	7/1/2014		$21.95	$15.72	$37.67
Operators (Class 04 - Instrument Person (Surveying & Layout))	7/1/2015		$22.30	$16.22	$38.52
Operators (Class 04 - Instrument Person (Surveying & Layout))	7/1/2016		$22.65	$16.77	$39.42
Operators (Class 04 - Rodman/Chainman (Surveying and Layout))	7/1/2009		$19.39	$12.63	$32.02
Operators (Class 04 - Rodman/Chainman (Surveying and Layout))	7/1/2010		$20.29	$13.13	$33.42
Operators (Class 04 - Rodman/Chainman (Surveying and Layout))	8/28/2012		$21.00	$14.62	$35.62

PREVAILING WAGES PROJECT RATES

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Operators (Class 04 - Rodman/Chainman (Surveying and Layout))	7/1/2013		$21.25	$15.17	$36.42
Operators (Class 04 - Rodman/Chainman (Surveying and Layout))	7/1/2014		$21.50	$15.72	$37.22
Operators (Class 04 - Rodman/Chainman (Surveying and Layout))	7/1/2015		$21.85	$16.22	$38.07
Operators (Class 04 - Rodman/Chainman (Surveying and Layout))	7/1/2016		$22.20	$16.77	$38.97
Painters Class 6 (see notes)	6/1/2009		$24.77	$12.81	$37.58
Painters Class 6 (see notes)	6/1/2010		$25.28	$13.53	$38.81
Painters Class 6 (see notes)	6/1/2011		$25.72	$14.09	$39.81
Painters Class 6 (see notes)	6/1/2012		$26.25	$14.56	$40.81
Painters Class 6 (see notes)	6/1/2013		$26.78	$15.03	$41.81
Painters Class 6 (see notes)	6/1/2014		$27.28	$15.58	$42.86
Pile Driver Divers (Building, Heavy, Highway)	1/1/2009		$43.28	$12.00	$55.28
Pile Driver Divers (Building, Heavy, Highway)	1/1/2010		$44.39	$12.25	$56.64
Pile Driver Divers (Building, Heavy, Highway)	1/1/2010		$44.39	$12.25	$56.64
Pile Driver Divers (Building, Heavy, Highway)	1/1/2011		$45.53	$13.00	$58.53
Pile Driver Divers (Building, Heavy, Highway)	1/1/2012		$46.28	$13.60	$59.88
Pile Driver Divers (Building, Heavy, Highway)	1/1/2013		$47.18	$14.10	$61.28
Plasterers	6/1/2008		$20.97	$9.64	$30.61
Plasterers	6/1/2010		$20.97	$9.94	$30.91
Plasterers	6/1/2011		$21.57	$9.94	$31.51
Plasterers	6/1/2012		$24.00	$7.51	$31.51
Plumbers and Steamfitters	5/1/2009		$30.27	$18.16	$48.43
Plumbers and Steamfitters	5/1/2010		$31.07	$19.36	$50.43
Plumbers and Steamfitters	5/1/2011		$31.92	$20.56	$52.48
Plumbers and Steamfitters	5/1/2012		$32.67	$20.81	$53.48
Roofers (Composition)	5/1/2009		$30.00	$23.10	$53.10
Roofers (Composition)	5/1/2010		$30.75	$24.95	$55.70
Roofers (Composition)	5/1/2011		$30.75	$25.95	$56.70
Roofers (Composition)	5/1/2012		$31.05	$26.95	$58.00
Roofers (Shingle, Slate, Tile)	5/1/2011		$23.75	$15.62	$39.37

PREVAILING WAGES PROJECT RATES

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Roofers (Shingle, Slate, Tile)	5/1/2012		$24.00	$16.37	$40.37
Sheet Metal Workers	6/1/2009		$29.56	$29.12	$58.68
Sheet Metal Workers	6/1/2010		$29.59	$29.69	$59.28
Sheet Metal Workers	6/1/2011		$29.59	$30.44	$60.03
Sheet Metal Workers	6/1/2012		$30.61	$30.42	$61.03
Sign Makers and Hangars	7/1/2009		$24.17	$15.99	$40.16
Sign Makers and Hangars	5/21/2010		$24.33	$16.37	$40.70
Sprinklerfitters	1/1/2010		$33.85	$17.60	$51.45
Sprinklerfitters	1/1/2011		$33.35	$18.45	$51.80
Sprinklerfitters	4/1/2011		$34.18	$18.45	$52.63
Sprinklerfitters	1/1/2012		$34.18	$18.60	$52.78
Sprinklerfitters	4/1/2012		$35.21	$18.65	$53.86
Sprinklerfitters	1/1/2013		$35.21	$18.80	$54.01
Terrazzo Finisher	5/1/2009		$26.54	$14.37	$40.91
Terrazzo Finisher	5/1/2010		$27.89	$14.42	$42.31
Terrazzo Finisher	5/1/2011		$28.14	$14.42	$42.56
Terrazzo Finisher	5/1/2012		$28.57	$14.49	$43.06
Terrazzo Finisher	5/1/2013		$29.07	$14.64	$43.71
Terrazzo Finisher	5/1/2014		$29.66	$14.80	$44.46
Terrazzo Setter	5/1/2012		$27.16	$17.37	$44.53
Terrazzo Setter	5/1/2013		$27.60	$17.58	$45.18
Terrazzo Setter	5/1/2014		$28.13	$17.80	$45.93
Tile & Marble Finisher	5/1/2011		$23.18	$12.52	$35.70
Tile & Marble Finisher	5/1/2012		$24.18	$12.57	$36.75
Tile & Marble Finisher	5/1/2013		$24.63	$12.72	$37.35
Tile & Marble Finisher	5/1/2014		$25.17	$12.88	$38.05
Tile & Marble Finisher	5/1/2015		$25.81	$13.04	$38.85
Tile & Marble Finisher	5/1/2016		$26.54	$13.21	$39.75
Tile & Marble Layer	5/1/2011		$25.90	$13.81	$39.71
Tile & Marble Layer	5/1/2012		$26.90	$13.99	$40.89
Tile & Marble Layer	5/1/2013		$27.29	$14.20	$41.49

PREVAILING WAGES PROJECT RATES

Building	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Tile & Marble Layer	5/1/2014		$27.78	$14.41	$42.19
Tile & Marble Layer	5/1/2015		$28.36	$14.63	$42.99
Tile & Marble Layer	5/1/2016		$29.03	$14.86	$43.89
Tilesetters & Marble Masons	1/1/2012		$30.85	$13.60	$44.45
Tilesetters & Marble Masons	1/1/2012		$30.85	$13.60	$44.45
Tilesetters & Marble Masons	1/1/2013		$31.45	$14.10	$45.55
Tilesetters & Marble Masons	1/1/2013		$31.45	$14.10	$45.55
Truckdriver class 1(see notes)	1/1/2009		$24.23	$11.44	$35.67
Truckdriver class 1(see notes)	1/1/2010		$24.98	$12.04	$37.02
Truckdriver class 1(see notes)	1/1/2011		$25.48	$12.79	$38.27
Truckdriver class 1(see notes)	1/1/2012		$25.88	$13.49	$39.37
Truckdriver class 1(see notes)	1/1/2013		$26.25	$14.22	$40.47
Truckdriver class 2 (see notes)	1/1/2009		$24.38	$11.51	$35.89
Truckdriver class 2 (see notes)	1/1/2010		$25.13	$12.11	$37.24
Truckdriver class 2 (see notes)	1/1/2011		$25.64	$12.85	$38.49
Truckdriver class 2 (see notes)	1/1/2012		$26.02	$13.57	$39.59
Truckdriver class 2 (see notes)	1/1/2013		$26.40	$14.29	$40.69
Truckdriver class 3 (see notes)	1/1/2009		$24.91	$11.75	$36.66
Truckdriver class 3 (see notes)	1/1/2010		$25.64	$12.37	$38.01
Truckdriver class 3 (see notes)	1/1/2011		$26.15	$13.11	$39.26
Truckdriver class 3 (see notes)	1/1/2012		$26.53	$13.83	$40.36
Truckdriver class 3 (see notes)	1/1/2013		$26.90	$14.56	$41.46

PREVAILING WAGES PROJECT RATES

Heavy/Highway	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Carpenter Welder	1/1/2009		$28.23	$12.16	$40.39
Carpenter Welder	1/1/2010		$29.18	$12.56	$41.74
Carpenter Welder	1/1/2011		$29.18	$13.57	$42.75
Carpenter Welder	1/1/2012		$29.45	$14.40	$43.85
Carpenter Welder	1/1/2013		$29.83	$15.12	$44.95
Carpenters	1/1/2009		$27.53	$12.16	$39.69
Carpenters	1/1/2010		$28.48	$12.56	$41.04
Carpenters	1/1/2011		$28.47	$13.57	$42.04
Carpenters	1/1/2012		$28.74	$14.40	$43.14
Carpenters	1/1/2013		$29.12	$15.12	$44.24
Cement Finishers	1/1/2009		$26.72	$12.97	$39.69
Cement Finishers	1/1/2010		$27.62	$13.42	$41.04
Cement Finishers	1/1/2011		$28.02	$14.27	$42.29
Cement Finishers	1/1/2012		$28.22	$15.17	$43.39
Cement Finishers	1/1/2013		$28.60	$15.89	$44.49
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2009		$24.73	$20.10	$44.83
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2010		$25.11	$21.40	$46.51
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2011		$25.26	$23.02	$48.28
Iron Workers (Bridge, Structural Steel, Ornamental, Precast, Reinforcing)	6/1/2012		$26.28	$23.35	$49.63
Laborers (Class 01 - See notes)	1/1/2009		$23.20	$12.65	$35.85
Laborers (Class 01 - See notes)	1/1/2010		$23.65	$13.55	$37.20
Laborers (Class 01 - See notes)	1/1/2011		$23.89	$14.56	$38.45
Laborers (Class 01 - See notes)	1/1/2012		$23.97	$15.58	$39.55
Laborers (Class 01 - See notes)	1/1/2013		$24.03	$16.62	$40.65
Laborers (Class 02 - See notes)	1/1/2009		$23.36	$12.65	$36.01
Laborers (Class 02 - See notes)	1/1/2010		$23.81	$13.55	$37.36
Laborers (Class 02 - See notes)	1/1/2011		$24.05	$14.56	$38.61
Laborers (Class 02 - See notes)	1/1/2012		$24.13	$15.58	$39.71
Laborers (Class 02 - See notes)	1/1/2013		$24.19	$16.62	$40.81
Laborers (Class 03 - See notes)	1/1/2009		$23.85	$12.65	$36.50

PREVAILING WAGES PROJECT RATES

Heavy/Highway	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Laborers (Class 03 - See notes)	1/1/2010		$24.30	$13.55	$37.85
Laborers (Class 03 - See notes)	1/1/2011		$24.54	$14.56	$39.10
Laborers (Class 03 - See notes)	1/1/2012		$24.62	$15.58	$40.20
Laborers (Class 03 - See notes)	1/1/2013		$24.68	$16.62	$41.30
Laborers (Class 04 - See notes)	1/1/2009		$24.30	$12.65	$36.95
Laborers (Class 04 - See notes)	1/1/2010		$24.75	$13.55	$38.30
Laborers (Class 04 - See notes)	1/1/2011		$24.99	$14.56	$39.55
Laborers (Class 04 - See notes)	1/1/2012		$25.07	$15.58	$40.65
Laborers (Class 04 - See notes)	1/1/2013		$25.13	$16.62	$41.75
Laborers (Class 05 - See notes)	1/1/2009		$24.71	$12.65	$37.36
Laborers (Class 05 - See notes)	1/1/2010		$25.16	$13.55	$38.71
Laborers (Class 05 - See notes)	1/1/2011		$25.40	$14.56	$39.96
Laborers (Class 05 - See notes)	1/1/2012		$25.48	$15.58	$41.06
Laborers (Class 05 - See notes)	1/1/2013		$25.54	$16.62	$42.16
Laborers (Class 06 - See notes)	1/1/2009		$21.55	$12.65	$34.20
Laborers (Class 06 - See notes)	1/1/2010		$22.00	$13.55	$35.55
Laborers (Class 06 - See notes)	1/1/2011		$22.24	$14.56	$36.80
Laborers (Class 06 - See notes)	1/1/2012		$22.32	$15.58	$37.90
Laborers (Class 06 - See notes)	1/1/2013		$22.38	$16.62	$39.00
Laborers (Class 07 - See notes)	1/1/2009		$24.20	$12.65	$36.85
Laborers (Class 07 - See notes)	1/1/2010		$24.65	$13.55	$38.20
Laborers (Class 07 - See notes)	1/1/2011		$24.89	$14.56	$39.45
Laborers (Class 07 - See notes)	1/1/2012		$24.97	$15.58	$40.55
Laborers (Class 07 - See notes)	1/1/2013		$25.03	$16.62	$41.65
Laborers (Class 08 - See notes)	1/1/2009		$25.70	$12.65	$38.35
Laborers (Class 08 - See notes)	1/1/2010		$26.15	$13.55	$39.70
Laborers (Class 08 - See notes)	1/1/2011		$26.39	$14.56	$40.95
Laborers (Class 08 - See notes)	1/1/2012		$26.47	$15.58	$42.05
Laborers (Class 08 - See notes)	1/1/2013		$26.53	$16.62	$43.15
Operators (Class 01 - see notes)	1/1/2009		$26.38	$14.44	$40.82
Operators (Class 01 - see notes)	1/1/2010		$27.18	$14.99	$42.17

PREVAILING WAGES PROJECT RATES

Heavy/Highway	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Operators (Class 01 - see notes)	1/1/2011		$27.68	$15.74	$43.42
Operators (Class 01 - see notes)	1/1/2012		$28.08	$16.44	$44.52
Operators (Class 01 - see notes)	1/1/2013		$28.48	$17.14	$45.62
Operators (Class 02 -see notes)	1/1/2009		$26.12	$14.44	$40.56
Operators (Class 02 -see notes)	1/1/2010		$26.92	$14.99	$41.91
Operators (Class 02 -see notes)	1/1/2011		$27.42	$15.74	$43.16
Operators (Class 02 -see notes)	1/1/2012		$27.82	$16.44	$44.26
Operators (Class 02 -see notes)	1/1/2013		$28.22	$17.14	$45.36
Operators (Class 03 - See notes)	1/1/2009		$22.47	$14.44	$36.91
Operators (Class 03 - See notes)	1/1/2010		$23.27	$14.99	$38.26
Operators (Class 03 - See notes)	1/1/2011		$23.77	$15.74	$39.51
Operators (Class 03 - see notes)	1/1/2012		$24.17	$16.44	$40.61
Operators (Class 03 - See notes)	1/1/2013		$24.57	$17.14	$41.71
Operators (Class 03)	1/1/2011		$23.77	$15.74	$39.51
Operators (Class 04 - See notes)	1/1/2009		$22.01	$14.44	$36.45
Operators (Class 04 - See notes)	1/1/2010		$22.81	$14.99	$37.80
Operators (Class 04 - See notes)	1/1/2011		$23.31	$15.74	$39.05
Operators (Class 04 - See notes)	1/1/2012		$23.71	$16.44	$40.15
Operators (Class 04 - See notes)	1/1/2013		$24.11	$17.14	$41.25
Operators (Class 05 - See notes)	1/1/2009		$21.76	$14.44	$36.20
Operators (Class 05 - See notes)	1/1/2010		$22.56	$14.99	$37.55
Operators (Class 05 - See notes)	1/1/2011		$23.06	$15.74	$38.80
Operators (Class 05 - See notes)	1/1/2012		$23.46	$16.44	$39.90
Operators (Class 05 - See notes)	1/1/2013		$23.86	$17.14	$41.00
Painters Class 1 (see notes)	6/1/2009		$27.24	$12.81	$40.05
Painters Class 1 (see notes)	6/1/2010		$27.84	$13.53	$41.37
Painters Class 1 (see notes)	6/1/2011		$27.84	$15.03	$42.87
Painters Class 1 (see notes)	6/1/2012		$29.60	$14.56	$44.16
Painters Class 1 (see notes)	6/1/2013		$30.38	$15.03	$45.41
Painters Class 1 (see notes)	6/1/2014		$30.93	$15.58	$46.51
Painters Class 2 (see notes)	6/1/2009		$27.77	$12.81	$40.58

PREVAILING WAGES PROJECT RATES

Heavy/Highway	Effective Date	Expiration Date	Hourly Rate	Fringe Benefits	Total
Painters Class 2 (see notes)	6/1/2010		$28.38	$13.53	$41.91
Painters Class 2 (see notes)	6/1/2011		$28.38	$15.03	$43.41
Painters Class 2 (see notes)	6/1/2012		$29.60	$14.56	$44.16
Painters Class 2 (see notes)	6/1/2013		$30.38	$15.03	$45.41
Painters Class 2 (see notes)	6/1/2014		$30.93	$15.58	$46.51
Painters Class 3 (see notes)	6/1/2009		$29.81	$12.81	$42.62
Painters Class 3 (see notes)	6/1/2010		$30.48	$13.53	$44.01
Painters Class 3 (see notes)	6/1/2011		$30.48	$15.28	$45.76
Painters Class 3 (see notes)	6/1/2012		$31.70	$14.56	$46.26
Painters Class 3 (see notes)	6/1/2013		$32.48	$15.03	$47.51
Painters Class 3 (see notes)	6/1/2014		$33.03	$15.58	$48.61
Painters Class 4 (see notes)	6/1/2009		$23.79	$12.81	$36.60
Painters Class 4 (see notes)	6/1/2010		$24.38	$13.53	$37.91
Painters Class 4 (see notes)	6/1/2011		$24.38	$14.93	$39.31
Painters Class 4 (see notes)	6/1/2012		$25.36	$14.56	$39.92
Painters Class 4 (see notes)	6/1/2013		$25.98	$15.03	$41.01
Painters Class 4 (see notes)	6/1/2014		$26.42	$15.58	$42.00
Painters Class 5 (see notes)	6/1/2009		$19.28	$12.81	$32.09
Painters Class 5 (see notes)	6/1/2010		$19.81	$13.53	$33.34
Painters Class 5 (see notes)	6/1/2011		$19.81	$14.67	$34.48
Painters Class 5 (see notes)	6/1/2012		$20.61	$14.56	$35.17
Painters Class 5 (see notes)	6/1/2013		$21.11	$15.03	$36.14
Painters Class 5 (see notes)	6/1/2014		$21.47	$15.58	$37.05
Piledrivers	1/1/2009		$28.85	$12.00	$40.85
Piledrivers	1/1/2010		$29.95	$12.25	$42.20
Piledrivers	1/1/2011		$30.35	$13.10	$43.45
Piledrivers	1/1/2012		$30.85	$13.70	$44.55
Piledrivers	1/1/2013		$31.45	$14.20	$45.65
Steamfitters (Heavy and Highway - Gas Distribution)	5/1/2010		$30.27	$26.09	$56.36
Steamfitters (Heavy and Highway - Gas Distribution)	5/1/2012		$34.87	$26.86	$61.73

References

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David Walenga

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