Written By: Brenton Decker
Option: Construction management
Faculty Advisor: Chimay Anumba
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Thesis Final Report

George Mason University PE Building

Renovation & Expansion

Fairfax, Virginia

Fairfax, VA

Brenton Decker

CM Option

Project Team

Owner: George Mason University

Architect/Structural/MEP engineers: Ewing Cole

CM: Gilbane Building Co.

Landscape Consultant: Lewis Scully Gionet

Civil Engineer: Christopher Consultants

Audio Visual Consultant: PMK Consultants

Statistics

Location: GMU Fairfax Campus

Levels: 2 above grade

Size: 116,530 Sq. Ft.

Total Cost: 29 million

Construction Dates: Oct. 2007 – Apr. 2009

Delivery Method: CM at Risk

Structural

- Pour concrete foundations
- Strip and Spread footings
- Structural Steel Braced Frame
- Composite Metal Decking
- Light Gage Steel Studs
- Load Bearing CMU Walls
- Masonry Walls
- Site Retaining Walls
- Steel Roof Trusses

Mechanical

- 6 – VAV rooftop AHU's
- 6 – Split system ACU's
- 3 – 59HP Boilers
- 2 – 320 Ton Centrifugal Chillers
- 1920 GPM Induced Draft Cooling Tower
- Unit Heaters

Lighting/Electrical

- 2500A, 480/277V Main Switchboard
- 600A, 480/277V Motor Control Center
- Set of 100KW, 200A, 480V Emergency Generators
- 36 Different Luminaire Types

Architecture

- Multi-functional recreational facility
- Scenic woodland setting
- 3 Gymnasiums
- Raquetball/squash courts
- State of the art strength-training facility
- Juice bar & lounge area
- 2-story glass curtain wall enclosing fitness center
- Brick, metal paneling, glass facades
- EPDM roof system

hthttp://www.engr.psu.edu/ae/thesis/portfolios/2009/bkd5002/

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Executive Summary

The following document is a senior thesis report on the in-depth study of The George Mason University PE Building project which took place over the fall semester of 2008 and the spring semester of 2009 at the Pennsylvania State University in the Architectural Engineering Program. The main focus of this report is the analyses from the spring 2009 semester.

Analysis One – Implementing an alternate delivery method is the main focus of this analysis. The alternate method chosen was an enhanced CM @ risk method. A CM @ risk method was selected in the first place because of the need for preconstruction services, so the choice to just tweak the original method was the best one instead of changing it to another method. This enhanced method adds security to the owner by added provisions and bridging documents.

Analysis Two – Schedule acceleration by simultaneously erecting the two steel sequences is the focus of this analysis. This analysis led to analyzing how this acceleration impacted the schedule as well as other trades. In order to pull off the acceleration successfully, the underground work for the New East Wing had to be accelerated as well. The end result after implementing this acceleration was a cost and schedule savings. The money saved from implementing this turned out to be **$478,093**. It also saved **9 days** of construction time.

Analysis Three – Alternate ductwork for the New Venue Gym is the focus of this analysis. A Ductsox fabric system was chosen to replace the 24 gage galvanized steel supply duct. The fabric system turned out to be a **54”** diameter cylinder with **size 15** L-vents running the lengths of duct. Changing from the metal to fabric resulted in both a cost and schedule savings for the project. The cost savings was in the amount of **$14,607**. It also saved **5.5 days** of construction time.

Analysis Four – Reducing the size of several roof beams is the focus of this analysis. This was able to be done due to the fact that the roof was overdesigned for mechanical loads. The particular section of the roof being analyzed was made up of W12x19 and W14x22 roof beams. These were able to be reduced to all **W12x14** beams. This reduction resulted in a cost savings in the amount of **$15,585**.

Industry Research – The implementation of BIM for façade construction was the focus of this research. GMU’s façade caused many problems for field crews from unclear drawings and complex connection details. To implement BIM on this project would have cost **$120,000**. This is a small investment compared to the benefits that can be gained from it. Why BIM is not widely used in the industry was also researched. It was found that this is partly due to the conflict of deciding who should have to pay for the BIM implementation. The suggestion was made that all parties that benefit from using BIM should pay an equal portion of the cost. This way no one feels cheated and it will result in better collaboration between parties.

Project Background – The George Mason PE Building is a multi-functional recreational facility housing three gymnasiums, a state of the art strength-training and fitness center, racquetball/squash courts, as well as admin. offices and lounge areas for the students. It will be under construction for approximately a year and a half before being completed in the summer of 2009 at the George Mason University Fairfax campus in Virginia. It lies in the midst of a wooded area on the western part of campus. There are no adjacent buildings surrounding the site. The only surrounding structures are tennis courts and a football field to the North. The blue "E" in the image below marks the building site on campus.

Photo: Aerial View of George Mason PE Building Site on Campus

Building Systems Summary

<u>Structural Steel Frame</u>

The steel frame for this building consists of a series of braced bays with moment connections. The typical beam size is a W21 X 62. Columns are encased in 8in. X 8in. X 4in. CMU blocks. Steel members were erected using a 70 ton hydraulic truck crane.

Cast in Place Concrete

No horizontal formwork was required for this project due to all elevated slabs being poured on metal decking. The vertical formwork was mostly constructed of plywood/rough carpentry. However, in the mechanical courtyard area, west of the new Venue Gym, large metal forms with an expansive shoring system were used. Curved sections were used as well to construct the South side of the large retaining wall. As previously mentioned, all concrete was poured into place.

Mechanical System

The mechanical plant is located in the Southwest corner of the site, adjacent to the Venue Gym. It is home to (3) 59 HP boilers and (2) 320 ton centrifugal chillers. The air is distributed by (6) VAV Air Handlers located on the roof. The main fire protection system consists of a 500 gpm pump with a dry-pipe sprinkler system. The backup protection is provided by a 20 gpm jockey pump.

Electrical System

The electrical system consists of a 1200A, 480/277 V Main Service Switchboard. Power is supplied by the campus utilities, and comes into the transformers at 75 KVA where it is reduced to 480/277 V and 208/120 V respectively. The emergency backup system consists of an emergency generator set that is 100KW, 200A, and 480 V.

Masonry

The majority of the brick masonry is used as a veneer. It is connected by using a shelf angle and masonry ties at 16” O.C. to the bond beam behind. Scaffolding was erected and used to place the brick around the Venue Gym.

Curtain Wall

A large glass curtain wall makes up almost the entire East façade. This façade encloses the new strength-training and fitness center. The glass for the curtain walls consist of a combination of insulated and spandrel glass. These glass panels are being constructed using a man and material hoist.

Support of Excavation

Excavation support was only required at the North wall of the mechanical room. Soldier piles and wood lagging were used at this location. They were left in place to ensure the integrity of the Cage Gym. Dewatering systems were not used at all on this project.

Client Information – George Mason University's two most important ideals are freedom and learning. The PE Building is being renovated and expanded to bring it up to date with modern society and technology. This building is meant to accommodate the future demands for recreational opportunities for students, and will ultimately become the main recreation center on campus.

GMU's cost, quality, schedule, and safety expectations for this project are very high. The PE Building is meant to be somewhat of a signature building to the campus, so ensuring that it is completed at the highest level of quality is crucial. Cost, schedule, and safety expectations are typically high on any construction project. The owner always wants their building turned over on time and within the budget. To put this into perspective, they started organizing closeout procedures and requiring mock-up documents from the subcontractors approximately halfway through the project to help accelerate this process in the end. GMU promotes safety on the job everyday with making daily/weekly safety toolbox talks mandatory, as they do not want any accidents to occur.

Depth 1: Alternative Delivery Method

Background – This topic came about from the CM stating that the chosen method created an "interesting relationship" between them and the owner. The details of this "interesting relationship" were never explained, but the assumption was made that there was tension between parties or possibly control issues. GMU typical works with general contractors instead of construction managers, so they were not used to the CM @ Risk delivery method and the GMP. I suspect there were issues with the GMP in that the price was not so guaranteed due to change orders and other unsuspected things that possibly drove up the price a bit.

Proposal – In this analysis, I am proposing that a different delivery method should have been selected. Relationships play a key role in the success of a project and these can sometimes be dictated by the delivery method. The goal of this proposal is to select a different delivery method that makes the GMP more dependable and promotes better relationships and cooperation between all parties.

Methodology

- The first step was to research several other delivery method options that could have been used and compare the pros and cons of each
- Next, I made a survey and sent it out to industry members to get there input on delivery methods for university projects
- Last, I studied all the data collected and made an informed decision for an alternate delivery method.

Comparison of Multiple Delivery Methods – While researching this topic, a few different delivery methods were compared. These include CM Agency, Design-Build, the traditional GC method, CM @ Risk, and Enhanced CM @ Risk. The focus of this research was on how these methods fostered relationships between parties and who assumed control of construction and other aspects via contractual agreements. Another tool used in the research was a survey sent out to about twenty practitioners. This survey can be seen in Appendix A. While only about six of these surveys got answered and returned, the results were still helpful.

CM Agency

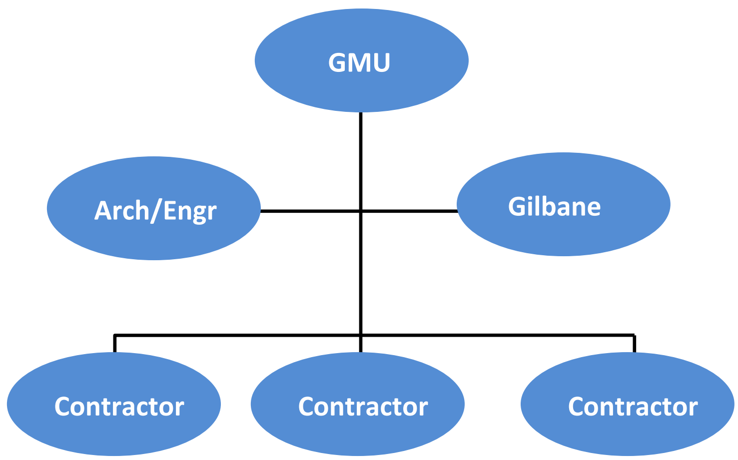


Figure 1. CM Agency Chart

Figure 1 shows the organizational chart for the GMU project using the CM Agency approach. In researching this approach, it was found that the CM Agency method is not a true delivery method. It is a management tool and can be used with any other delivery method if desired. The lines shown represent the contractual agreements between parties. Using this approach, the owner holds all of the contracts. This differs from the selected approach where Gilbane holds the subcontracts. The owner assumes most of the risk in this approach. Some pros of the CM Agency method are as follows:

- Ability to use Multiple Delivery Methods
- Ability to fast track construction
- Competitive pricing on smaller packages
- Facilitator
- All savings to owner

Some of the cons of this approach include

- Conflict from AE and GC's who feel CM is interfering with their relationship with the owner
- Upfront costs may appear high
- Misunderstanding of roles/responsibilities

Design-Build

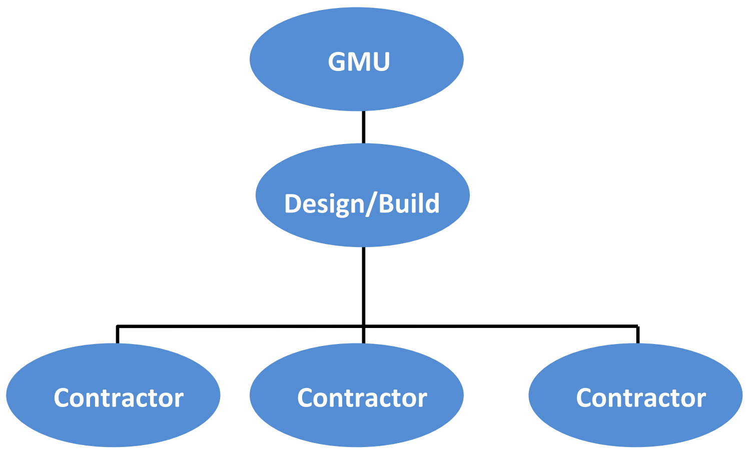


Figure 2. Design-Build Chart

Figure 2 shows the organizational chart of the GMU project implementing the design-build delivery method. Using this method, the design-build firm holds the subcontracts and assumes most of the risk. They are also responsible for the design of the building as well. If this method would have been chosen, Gilbane would not have been awarded this job since they are a construction management firm. Some of the pros that go along with this delivery method are as follows:

- Single responsible entity for design and construction
- Minimizes design – construction risk
- Potentially fast track project/earlier knowledge of cost
- Reduction in disputes
- Potential for construction methods integrated into design – creative solutions through collaboration

Some of the cons that go along with the design-build method include:

- Owner must carefully define program (bridging documents)
- Contractor control may impact quality level
- Changes due to late program alterations
- Changes can happen without owner involvement that owner may not desire
- No checks/balances between architect and contractor

Traditional GC Method

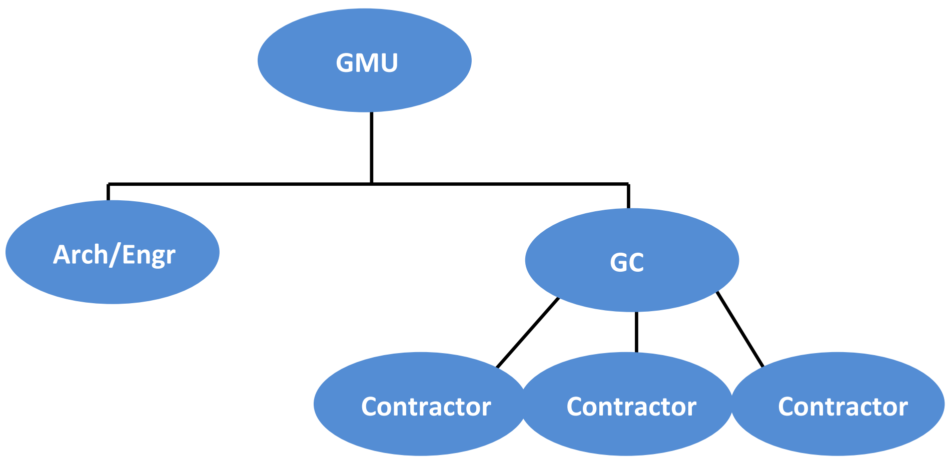


Figure 3. Traditional GC Method Chart

Figure 3 shows the organizational chart for the GMU project implementing the traditional GC delivery method. If this method would have been implemented, Gilbane would not have been on the job since they are a construction management firm and not a general contractor. This is probably the most commonly used and accepted delivery method in the industry. Some pros of this method are as follows:

- Widely understood and legally accepted method
- Owner's control/input over project
- Completed set of documents when bid
- Competitive pricing

Some of the cons include:

- Don’t know price until bid day
- Additional design time
- Owner liable for design errors & omissions
- Can create adversarial relationships
- No contractor input during design

CM @ Risk

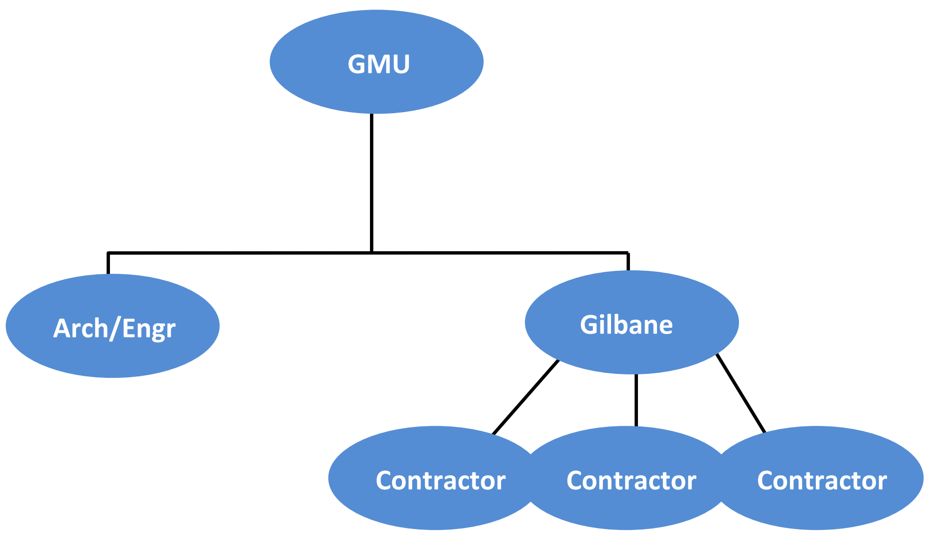


Figure 4. CM @ Risk Organizational Chart

Figure 4 shows the organizational chart for the selected CM @ Risk delivery method. Comparing this method to the previous traditional GC method, their organizational charts look identical. The slight differences between the two are that an owner would select a CM if they needed some extent of preconstruction services for the project. A GC usually just builds the project and oversees the subcontractors. Some of the pros for the CM @ Risk method are as follows:

- Qualifications based selections
- Ability to fast track construction
- One point of responsibility for project delivery
- Advanced input of constructability and cost
- Budgeting control with CM's input
- Opportunities for minority participation enhanced

Some of the cons that come along with this method include:

- CM acting as contractor
- Importance of selecting right CM – must be good at pre-con and build
- No contract between AE and CM
- Changes come from owner's or CM's contingency

Enhanced CM @ Risk Method

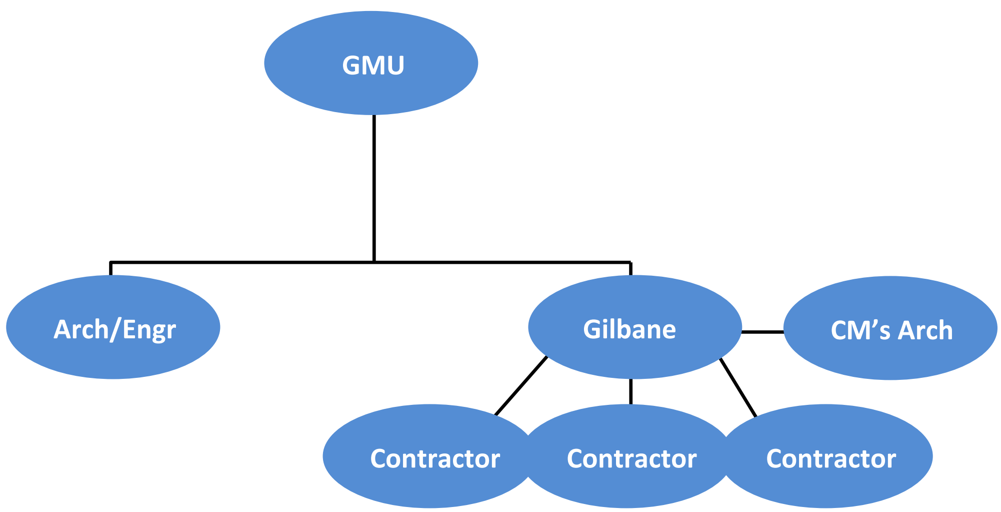


Figure 5. Enhanced CM @ Risk Method

Figure 5 shows the organizational chart for the enhanced CM at Risk delivery method. This method provides additional safety to the owner and makes the GMP contract more reliable. The difference between the two organizational charts is that in this method the CM has their own AE. The owner increases their protection by adding additional provisions to the contract, giving the CM more responsibility, and utilizing aspects of bridging. To learn more about these items that increase the owner's protection refer to the article in appendix B.

Results & Recommendations – After researching these various delivery methods, it appears that a better approach to delivering this project would have been to use a combination of two methods. Since GMU is used to working with general contractor's, implementing the traditional GC method and having a CM agency on board would have been a better approach. However, the downfall to going this route is that it would lengthen the project time and add cost since there would be a CM and GC. With this in mind, tweaking the chosen CM at risk method would probably be the overall best choice. It's called the enhanced CM at risk method.

Depth 2: Schedule Acceleration & Site Layout

Background – This analysis came about due to the GMU project being about a month behind its original intended completion date. The delays were due to weather and extreme mud problems in the mechanical courtyard. Many activities were affected by this and Gilbane had to change their sequence of work to minimize lost time. To try and make up some of the lost time, I saw the opportunity to possibly accelerate the steel construction. The original schedule split the steel erection in two sequences, but the possibility for simultaneous erection of the sequences was there.

Proposal – I am proposing that the two steel sequences be erected simultaneously to make up some of the lost time from delays. This requires the addition and costs of an extra crane and crew. The ultimate goal of this analysis is to hopefully show that there would be an overall cost and schedule savings from implementing this idea.

Methodology

- The first step was to analyze the schedule and determine how much it could be accelerated
- The next step was to figure out what extra manpower and equipment would be needed and use RS Means to find the costs of these
- Next, I analyzed the impact the acceleration had on other trades and what needed to be done to smooth the process
- I then calculated the extra costs associated with the acceleration from the RS Means data collected
- I compared the added costs to an average cost per day of construction for the project to determine if the end result was a savings
- Last, I analyzed what impact the acceleration would have on site logistics

Simultaneous Erection of Steel Sequences – As previously mentioned, the steel erection was split into two sequences. The first sequence includes the Mechanical Room steel and New Venue Gym steel. The second sequence consists of the entire New East Wing. With these two sequences combined, there are 839 pieces of steel to erect. The original timeframe for sequence one to be erected was from the beginning of April thru the end of May 2008. Sequence two's timeframe was from mid May thru early July 2008. This makes the total original erection time over a span of about four months utilizing 65 workdays. Figure 6 below depicts the original steel erection using one crane.

Steel Erection	
Cranes	Original Duration
1	65 days

Figure 6. Original Steel Erection

By adding another crane and erecting the two sequences simultaneously, the schedule gets accelerated. In particular, the construction of the New East Wing is where the acceleration occurs. The addition of the extra crane cuts the duration to erect the steel by nine days. Figure 7 and 7a below show the chart for the accelerated steel erection and the schedules of the basic construction sequence, both original and accelerated respectively.

Steel Erection Acceleration	
Cranes	New Duration
2	59 days

Figure 7. Accelerated Steel Erection

Original Schedule	86 days	Tue 3/11/08	Tue 7/8/08
New Gym Underground	8 days	Tue 3/11/08	Thu 3/20/08
Mech. Underground	15 days	Mon 3/17/08	Fri 4/4/08
New Gym SOG	5 days	Tue 3/25/08	Mon 3/31/08
East Wing Underground	20 days	Mon 3/31/08	Fri 4/25/08
New Gym Steel	25 days	Fri 4/4/08	Thu 5/8/08
Mech. Steel	15 days	Thu 4/17/08	Wed 5/7/08
East Wing SOG	15 days	Fri 4/18/08	Thu 5/8/08
East Wing Steel	40 days	Wed 5/14/08	Tue 7/8/08

Accelerated Schedule	77 days	Tue 3/11/08	Wed 6/25/08
New Gym Underground	8 days	Tue 3/11/08	Thu 3/20/08
Mech. Underground	15 days	Mon 3/17/08	Fri 4/4/08
New Gym SOG	5 days	Fri 3/21/08	Thu 3/27/08
East Wing Underground	10 days	Mon 3/31/08	Fri 4/11/08
New Gym Steel	25 days	Fri 4/4/08	Thu 5/8/08
Mech. Steel	15 days	Thu 4/17/08	Wed 5/7/08
East Wing SOG	15 days	Fri 4/4/08	Thu 4/24/08
East Wing Steel	40 days	Thu 5/1/08	Wed 6/25/08

Figure 7a. Basic sequence of work original (left) & accelerated (right)

How acceleration affects other trades – The ideal scenario would have been to be able to erect sequence two at the exact same time as sequence one. However, since the steel erection sequences are on the critical path and being accelerated, this means that several trades in front of the steel erection will be affected. In particular, this acceleration affects the concrete slab on grade and some of the underground work. To allow the steel erection to be accelerated, the East Wing underground work needs to be accelerated as well. This is accomplished by adding an extra crew to cut the time in half. The two schedules above reflect the required accelerations of this activity. The underground work is accelerated by about two weeks. The costs of adding the additional manpower will be analyzed in the next section. The East Wing slab on grade is moved up and scheduled to start a week after the East Wing underground work gets underway. No additional manpower is needed for moving this activity.

This acceleration would be an inconvenience to Gilbane as well. Originally, their office was located inside the building for the first half of the construction. This allowed them to only have to rent a construction trailer for several months while the New East Wing was being constructed. Implementing this acceleration would require Gilbane to have there office located in a trailer for the entire length of the project. This adds additional costs to the project that will be taken into account in the following section as well.

Cost Analysis of Acceleration – The added costs to the project from implementing this acceleration include an additional 70 ton hydraulic truck crane, an additional steel erection crew, and an additional crew for the underground work. Figure 8 below shows the RS Means 2009 data for these additional items.

Steel Erection Crew		
Crew E-7	**Hr.**	**Daily**
1 Structural Steel Foreman	$46.70	$373.60
4 Struc. Steel Workers	$44.70	$1,430.40
1 Equip. Operator	$42.55	$340.40
1 Equip. Operator Oiler	$36.80	$294.40
1 Welder Foreman	$46.70	$373.60
2 Welders	$44.70	$715.20
1 hydraulic Truck Crane, 80 Ton		$1,296.00
2 Welders, gas engine, 300 Amp		$268.40
80 L.H., Daily Totals		$5,092.00

Underground Work Crew		
Crew B-17A	**Hr.**	**Daily**
2 Laborer Foremen	$33.60	$537.60
6 Laborers	$31.60	$1,516.80
1 Skilled Worker Foreman	$42.85	$342.80
1 Skilled Worker Foreman	$40.85	$326.80
80 L.H., Daily Totals		$2,724.00

Figure 8. RS Means Crew Data

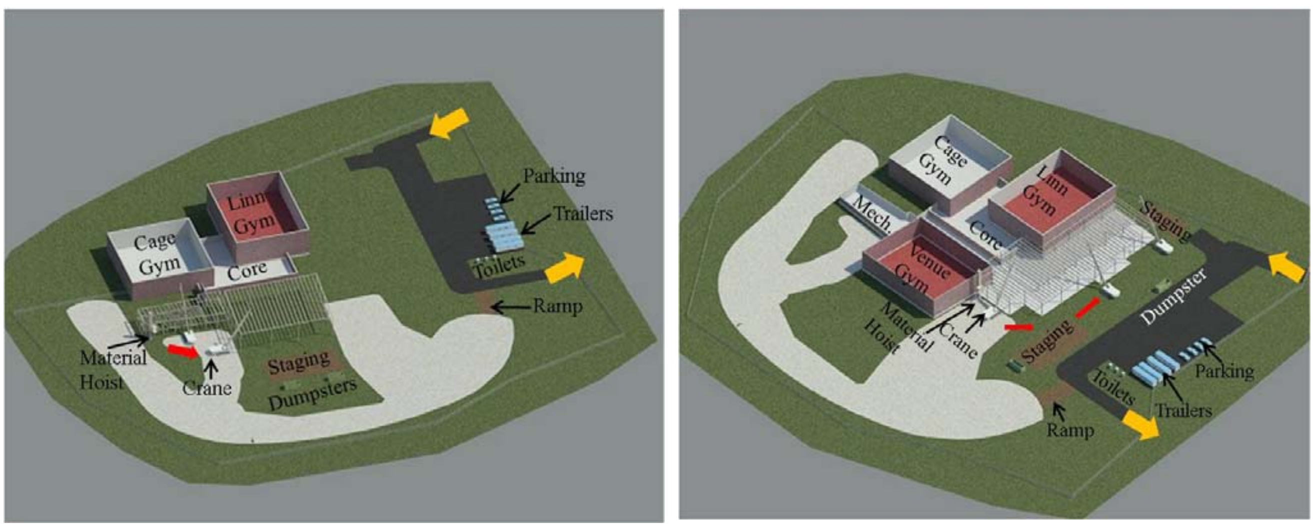
The underground work crew is needed for ten days and the steel erection crew is needed for 40 days. Gilbane's construction trailer would now be needed for the entire length of the project. These additional items bring the final additional cost to **$212,000**.

This seems like a high additional cost, but there is also a cost savings from the accelerated schedule when looking at the average construction cost per day of the project. The total construction cost for the PE Building is $24 million. The total number of work days for the project is 313 days. This gives the following cost per day for the project:

$$\frac{\$24 million}{313 days} = \$76,677\, per day$$

Knowing that the acceleration saves nine days of construction time, the cost savings from that is then **$690,093**. Finally, when the savings is compared to the additional cost to implement the acceleration a substantial savings is still the end result. The final amount of the savings is **$478,093**.

Site Logistics – The site logistics for implementing the acceleration would be slightly more congested but still manageable. Since the site is relatively small to begin with, most materials are shipped for just in time delivery instead of being stored on site. The only materials that room is really made for to store on site is the steel and curtain wall. The staging areas on the site are limited to the South and East portions. This can be seen in the images below. The congestion comes in from the added crane.



Rendered Images of the Site Layout for Steel Sequence 1(left) & Sequence 2(right)

Results & Recommendations – While the steel acceleration would create added site congestion, it should be implemented and managed properly due to the significant cost savings it creates. It also helps make up about two weeks of the lost time from delays. Site coordination between trades would be crucial to ensure they do not interfere with each others activities.

Breadth 1: Alternate Duct System in New Gym (mechanical breadth)

Background – Part of GMU's PE Building Renovation and Expansion project is renovating the duct systems in each gymnasium and the addition of the New Venue Gym. The new ductwork being installed is constructed using 24ga. galvanized steel. Metal ductwork has been used for many years, but a rising trend in the industry is the use of fabric ductwork. While this trend is on the up rise, many benefits are being realized from using a fabric system over a metal system.

Proposal – In this analysis, I am proposing to switch the mechanical supply ductwork in the New Venue Gym from the 24ga. galvanized steel to a Ductsox fabric system. The ultimate goal of this proposal is to showcase the eco-friendliness of the fabric duct as well as show that implementing this change would result in a cost and schedule savings.

Methodology

- First, I had to determine what the existing duct system was constructed of as well as determine the size of the air handler that serves the space
- I then searched for an applicable fabric duct system to replace the existing one
- The next step was to design the fabric supply duct system based on the size of the air handler and the layout of the ductwork in the space
- Next, I used MC^2 estimating software to determine the cost of the metal duct in the gymnasium
- I then contacted a Ductsox supplier to get pricing for the designed fabric duct system
- I compared the cost of the two systems and calculated the savings
- Last, I calculated the installation time of the fabric system and compared it to that of the metal system to show that the installation time is reduced

Why Use a Fabric Duct System

There are many advantages to using a fabric duct system over a metal system.

- Aesthetics
- Superior Air Dispersion
- Simplified Design
- Lower Costs
- Easy Installation

- Little Balancing
- Hygienic
- Cleanable

Unlike metal duct, a fabric duct system can discharge air more uniformly along the entire length of the duct. These systems also provide consistent and uniform air dispersion to the occupied space. Figure 9 below shows the air dispersion of metal vs. fabric duct systems.

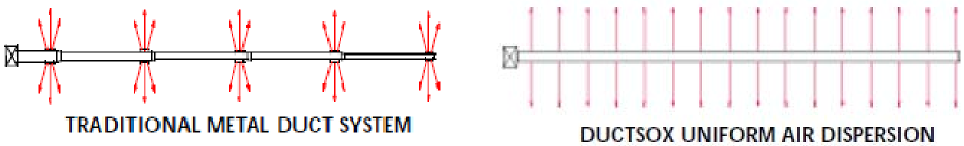


Figure 9. Air dispersion of metal vs. fabric duct

Fabric duct can be 20-80% less expensive than metal duct. Not only is it much lighter which can result in lower material costs, but it is much easier to install as well. A large diameter fabric system takes about the same amount of labor time to install as a small diameter one. This is not the case with metal duct. Shipping costs are also cheaper since the fabric can be put in smaller boxes and shipped easily with a low risk of getting damaged.

Fabric is a much cleaner and more hygienic material than metal. The air porous fabric eliminates the risk of condensation and stops dust from settling. This fabric does not absorb moisture either, which can be a source for bacteria and mold. Runs of fabric duct are constructed together with the use of zippers. This allows them to be taken down easily and washed periodically. Metal duct is much harder and expensive to clean. This causes it not to be done as often as it should be and can lead to causing sick building syndrome.

Fabric Duct Design – The fabric duct system chosen for this analysis is a product from DuctSox. The suggested fabric system for a commercial gymnasium project is the cylindrical Verona fabric for the supply duct. The comfort flow option is also chosen for this application. Product data for this can be seen in Appendix C.

Air is supplied to the new gymnasium via a VAV air handler located on the roof. This unit has a volume flow rate of **23,000 cfm**. Given that the air handler is located at the North side of the gymnasium, the main supply and return duct runs are located on that side of the space as well. There are four branches off of the main supply run that distribute air throughout the space. The return duct has two branches that are centrally located within the gymnasium. An image of the duct layout can be seen on the next page.

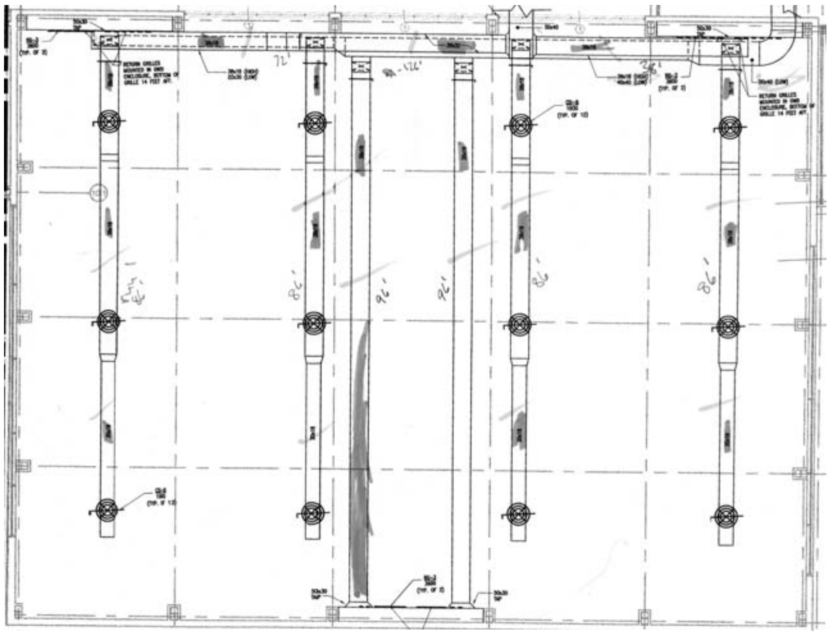


Photo: New Venue Gym Duct Layout

For ease of design and even air distribution, this same layout was kept for the fabric system. The 23, 000 cfm flow rate of air yields a **54"** diameter for the cylindrical fabric with an inlet velocity of **1,400 fpm**. The supply duct fabric is porous making each run of duct act as a giant diffuser. Being that the duct is hung at a height of 30 feet above the finished floor, the porous fabric alone does not provide the required throw needed for the space. This requires a series of **size 15** L-vents to be used as well. These vents are a series of holes placed at **3&9** o'clock and **4&8** o'clock along the length of the fabric to direct air outward and downward into the space. Figure 11 below shows a detail of the vents. The detailed mechanical calculations can be seen in Appendix C.

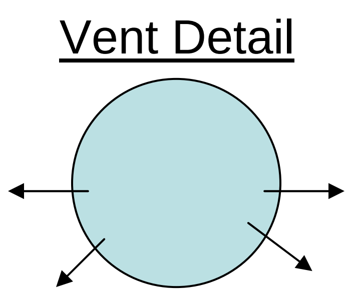


Figure 11. Supply Duct Vent Detail

Cost & Schedule Savings from Alternate Duct System

The cost difference and schedule time saved are analyzed from switching the metal duct system in the New Venue Gym to a fabric duct system. These savings come from differences in material costs, labor costs, and installation times.

When comparing material costs of the metal and fabric duct systems, fabric duct can be much cheaper. Steel prices are still rather high throughout the industry, and when large size ducts are needed the cost escalates. This is not the case with fabric. Fabric is quite cheap in comparison no matter what size ducts are needed. Shipping costs for fabric are lower as well. This is due to the fact that it can be packaged in smaller boxes and the risk of damaging it is minimal. The difference in costs between the two systems can be seen in figure 12 below. Detailed estimates of the metal duct system can be seen in Appendix D.

Metal Duct	Cost	Fabric Duct	Cost
Supply	$35,990.47	Supply	$21,383.20
Return	$27,234.40	Return	$27,234.40
Total Cost	$63,224.87		$48,617.60
Savings			**$14,607.27**

Figure 12. Duct System Costs

The main area where fabric becomes cheaper than metal duct is the labor costs and installation times. Installing large, heavy metal ducts requires significant manpower and time. A fabric system has a huge advantage in this area in that it takes approximately the same amount of time and manpower to install a small diameter duct as it does a large diameter duct. This is not the case with metal duct. The larger the duct, the longer it takes to install. Figure 13 below shows a detailed breakdown of how the installation time for the fabric duct was calculated. The overall schedule savings from the fabric duct system can be seen in figure 14.

Fabric Duct Installation	
Activity	**Time (hrs)**
Inlet connection	1
Cable Suspension & hang duct	42.16
Add 20% for diameter 41-60"	8.43
Total	51

* Note installation time based on 2 man crew

Figure 13. Fabric Duct installation Breakdown

Duct Installation Time	
Metal Supply Duct	12 days
Fabric Supply Duct	6.5 days
Savings	**5.5 days**

Figure 14. Duct installation times

Results & Recommendation – The change from the metal supply duct to the fabric supply duct should be implemented due to its many benefits that make it worthwhile. As seen, it saves a decent amount of money and a little over a week of construction time. It also promotes a healthier and cleaner environment for the students and faculty. Fabric systems can be used in offices and other applications as well, and I believe the entire supply system in the PE Building should be switched to this because it is a much better product.

Tools Used

- Mechanical Drawings
- MC^2 Estimating Software
- Microsoft Excel
- H&H Associates
- Project Specifications
- Ductsox Design Manual

<u>Breadth 2: Reducing Roof Beam Sizes</u> (structural breadth)

Background – The initial intent of this breadth was to try and relate it to my mechanical breadth by reducing the roof truss size in the New Gym due to lighter loads from the fabric duct. After researching this a bit, I found there was not much difference in the loads after spreading them out over the roof area. This led me to switch my breadth to reducing roof beam sizes from overdesign of mechanical loads. By overdesign, I mean that the roof is typically designed before the mechanical equipment and locations it will be placed on the roof are well known, which leads to an overdesigned roof system. This is not necessarily bad, but money could have been saved. In this case, the roof design load for mechanical equipment is **75 psf**. This turns out to be much higher than what is actually needed for some areas.

Proposal – In researching and analyzing this problem, I am attempting to reduce the size of the roof beams that run along the corridor between the New Venue Gym and the Cage Gym. I hope to be able to show a cost savings from the reduction in beam sizes.

Methodology

- The first step I had to do was look at the equipment specifications for the air handlers that are located on this section of the roof to determine how much they weighed
- Next, I had to search through my drawings to find the roof construction materials and ceiling finishes
- I then went to ASCE 7-05 to find the proper weights of these materials to use in calculating my roof loads
- I then calculated my total loadings and used the steel manual to find an adequate beam size
- Next, I checked to make sure the beam size met all required design calculations
- Lastly, I used MC^2 software to estimate the difference in costs of the beam sizes

Original Roof Structure – The corridor's original roof structure seen in the image below is made up of wide flange beams and columns, with 3 ply built up roof on rigid insulation, on 1-1/2" 20ga. metal deck. The ceiling is acoustical tile. The roof supports two 8,000lb air handlers that service two of the gymnasiums. When spreading the weight of these air handlers across the area of the roof, the actual mechanical loading from these units only reaches around **8 psf**. This is much less than the designed 75 psf loading, which does allow for reduction in beam sizes.

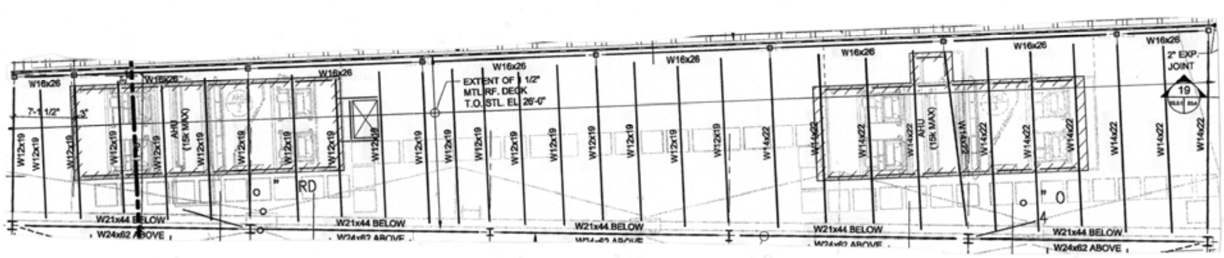


Photo: Corridor Original Roof Structure

Reduction in Beam Sizes – The beams under analysis are the W14x22's and the W12x19's shown in the image below. The circled beam in the image is the W14x22 that was selected for the first analysis.

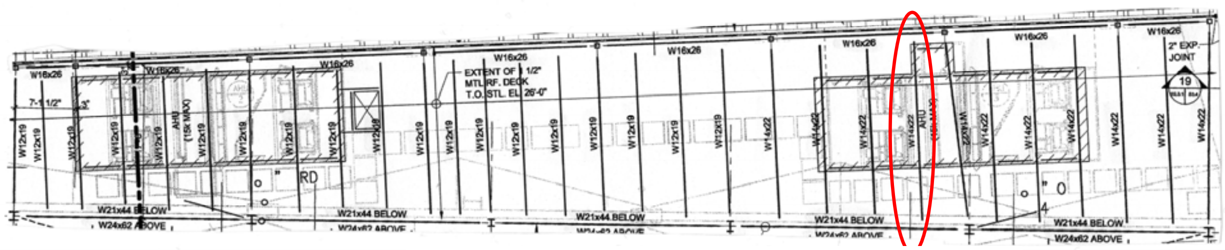


Photo: Beam used for first structural analysis

To start this analysis, the applied loads to this area were calculated. Figure 15 below is a chart showing all of the loads considered in calculating a new beam size.

Dead Loads	Weight (psf)	Snow Loads	Weight (psf)
Misc. dead load	15	Snow load	30
AHU	6.4	Snow drift load	65
3-ply roofing	1		
Rigid Insulation	0.75		
20 ga. Metal deck	2.5		
ACT ceiling tile	1		

Figure 15. Beam loading considerations

These loads yielded a **915 plf** uniformly distributed load over the span of the beam. Knowing that the beam has fixed connections at both ends, the max shear and moments were calculated.

$$\mathbf{Vu_{max} = 11.5\ kips}$$

$$\mathbf{Mu_{max} = 48.6\ ft\text{-}kips}$$

Using these calculated values, a W12x14 beam was selected from the steel manual to replace the original W14x22's. Compact section criteria and Shear strength were evaluated to make sure the beam met proper requirements. These calculations along with the entire beam analysis calculations can be seen in Appendix E.

A second beam that supports the other air handler at the opposite end of the corridor was analyzed as well. The beam analyzed is circled in the image below.

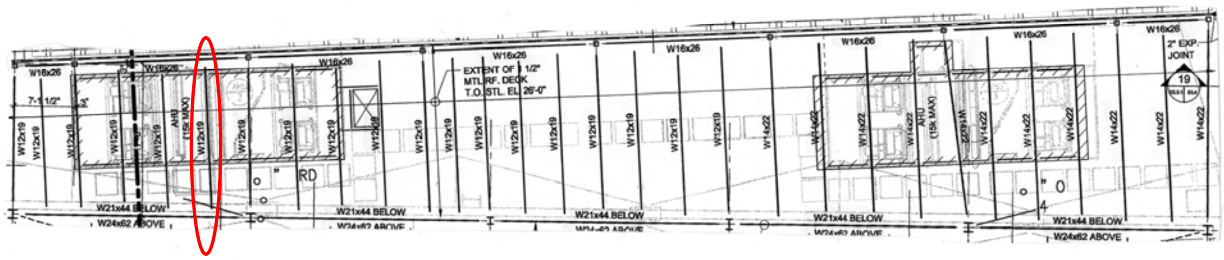


Photo: Beam used in second structural analysis

Again, the applied loads to this area were calculated. Figure 16 below is a chart showing all of the applied loads considered for this beam analysis.

Dead Loads	Weight (psf)	Snow Loads	Weight (psf)
Misc. dead load	15	Snow load	30
AHU	8.6	Snow drift load	65
3-ply roofing	1		
Rigid Insulation	0.75		
20 ga. Metal deck	2.5		
ACT ceiling tile	1		

Figure 16. Beam load considerations

These loads yielded a **925 plf** uniformly distributed load spanning the length of the beam. Knowing the beam has fixed connections, the max shear and moments were calculated.

$\mathbf{Vu_{max} = 9.25\ kips}$

$\mathbf{Mu_{max} = 30.8\ ft\text{-}kips}$

From inspection, these loads are smaller than the loads in the first beam analysis so W12x14's can be used here as well.

Cost Comparison – By reducing the roof beams in the respected corridor, a cost savings is realized. There are 30 beams total that were able to be reduced. Estimates were done in MC^2 to determine the cost of the original roof members and the reduced size members. Figure 17 below shows the cost for each and the total savings. Detailed estimates of the two can be seen in Appendix E.

Roof Beams	Cost
Original Roof Members	$70,071.69
Reduced Members	$54,486.42
Savings	**$15,585.27**

Figure 17. Roof beam costs

Constructability Benefits

- Ceiling plenum – the reduced depth allows for more space in the ceiling plenum to run pipes and wires
- Repetition – identical steel members accelerates connection time due to learning curve
- Lighter picks – slightly lighter picks for crane from smaller beam sizes

Results & Recommendations – Implementing the size reduction in the roof beams to all W12x14's saves a fair amount of money for the steel package. This analysis was only done on a small portion of the roof, but reductions could probably be made elsewhere as well saving even more money. Added space in the ceiling plenum is another good reason this switch is recommended. Congestion is usually a problem in that area and any extra space to work is a bonus.

Tools Used

- Structural Drawings
- AE 404 Notes
- Steel Manual
- ASCE 7-05
- MC^2 Estimating Software
- Microsoft Excel

Industry Research: Implementing BIM for Façade Construction

Background – A reoccurring issue during the construction of the GMU PE Building was problems with the façade construction. Coordination meetings were held once a week and problems regarding this issue came up every time. Even after the meetings were over, the subcontractors working on the facades stayed after to try and work out their problems with each other and the CM.

Research – BIM was researched in this analysis to determine its benefits and costs. BIM is slowly catching on in the industry, but a lot of owners and contractors are hesitant to use it. This research was also aimed at uncovering why that is the case since it is such a powerful tool.

Methodology

- First, I researched BIM to find out what benefits can come from it
- I then researched how much BIM costs to implement it
- Lastly, I researched why it is not used as much in the industry

BIM implementation on GMU – BIM should have been implemented on GMU's PE Building for the façade construction due to it's' complexity. At first glance, the façade seems quite normal in that its construction materials are glass, brick, and metal paneling. These materials are used routinely in most modern buildings, so the complexity is masked. However, when closer inspection is done, there are actually nine different façade types that wrap the building. These nine façade types include:

- 5 types of metal paneling
- 3 types of glass
- Brick

These façade types are all intertwined together around the building. The complexity comes from how the facades connect to each other. As mentioned in the background, Gilbane held weekly coordination meetings with subcontractors and these issues came up almost every time. The subcontractors performing this work even stayed after the general meeting was over to discuss who was responsible for certain work related to connecting various façade types as well as how it was supposed to be done. Several change orders came about from this complexity and misunderstanding as well. All of this creates hours of unproductive work, delays, and added costs to the project.

Benefits of BIM – BIM can provide many benefits to the construction of a building if implemented early and managed properly. It provides the ability to see how a certain scope of work will be built in the field before the work is actually done. This is a much more effective way of managing complex scopes of work than the overlaying and comparing drawings to find errors which was used on the GMU project. BIM reduces the amount of change orders due to its ability to find clashes and allow the proper adjustments to be made before the construction work is done in the field. It also provides greater collaboration between trades, which in turn provides a better and more productive work environment.

Costs of Implementing BIM – BIM is perceived as being very expensive. This is one of the main reasons many owners and contractors choose not to use it. However, when looked at in terms of overall construction costs of a project, BIM only accounts for about **.5%** of the overall cost. This means that the cost of implementing BIM on GMU's PE Building would have been **$120,000**. This is a significant upfront cost to pay, but it should be looked at as a worthy investment that will ultimately probably pay for itself from the savings it creates over the course of the project.

Why BIM is "under used" in the industry – As previously mentioned, one of the main reasons BIM is not used as frequently in the construction industry is because of the relatively high upfront cost associated with it. When deciding whether or not to implement BIM on a project, the problem comes in when deciding who should pay for it. Industry members argue that the person who benefits most from it should pay for it. This person is the owner the majority of the time. However, I believe that the cost should be split evenly between all parties involved in using BIM since the owner is not the sole beneficiary of BIM's benefits. In doing this, implementing BIM would become a more affordable and attractive option.

Acknowledgments

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H&H Associates – Roger Bower

GMU – Chris Brooks

Appendix A

Appendix A – Industry Survey

Thesis Research Survey Questionnaire

Name (Optional):
Company:
Position:

1. **What are some of the university project(s) you have had experience working on?**

2. **What delivery methods (i.e. CM @ risk, Multiple Prime, etc.) were chosen for each of these projects? If these methods were chosen beforehand for a reason, please list the reasons.**

3. **In your opinion, what was the best thing about this delivery method for the project?**

4. **What was the worst thing about this delivery method for the project?**

5. **Did the delivery method prolong any activities (i.e. submittals, change orders, RFI's, etc.) in any way? If so, please explain.**

6. **How much of a role did the Owner (the university) play in the project?**

7. **If they played a large role, did you feel that they had too much control over the project? If so, please explain.**

8. **Do you think the delivery method (especially looking at relationships between the owner and other contractors) plays an important role in the success/efficiency of the project? (i.e. timely completion, within budget, quality/performance factors)**

9. **Looking back at this/these projects, do you feel the delivery method chosen was the best choice? If not, what method would have worked better and why?**

Appendix B

Enhanced CM-at-Risk

The Enhanced CM-at-Risk project delivery method provides much more safety for the Owner than the traditional version of CM-at-Risk. The enhancements which make the GMP more dependable can be accomplished in one of three ways:

1. Additional provisions in the Agreement between Owner and CM (Contractor).

The additional contract provisions in the Agreement would be accompanied by the attachment of a description of the complete project scope, any design documents produced to date, the Program of Requirements, and information about the site. The provision itself would state the maximum allowable amount of the GMP, a number probably taken from the Owner's authorized project budget. Further, subsequent issuances of the GMP would be classified as "GMP Confirmations". At each issuance, the GMP Confirmation would attach the most up-to-date drawings and specifications.

There would be a provision in the original agreement between the Owner and the CM that the GMP would be confirmed to be no higher than the previously approved GMP. If this could not be accomplished the CM would be required to submit proposals for changes that would be both acceptable to the Owner and in compliance with the program of requirements (unless the Owner has approved design/scope changes at approved price adjustments.)

There would be appropriate and protective termination rights for the Owner that would include repayment of any charges by the CM to date and possible reimbursement to the Owner for design costs to date. A number of other special provisions should be added with respect to subs, subs' prices and alternatives if subs' prices have had an unacceptable net increase.

An additional contractual responsibility of the CM would be continuous and thorough technical reviews of the drawings and specifications, both at the various stages of design as well as upon completion of the Construction Documents. The CM would be charged with the responsibility to confirm to the Owner that these documents are complete for the respective phase and that they are correct, fully coordinated, in full compliance with all applicable codes and laws, and that all constructability or logistical problems have been covered in the GMP.

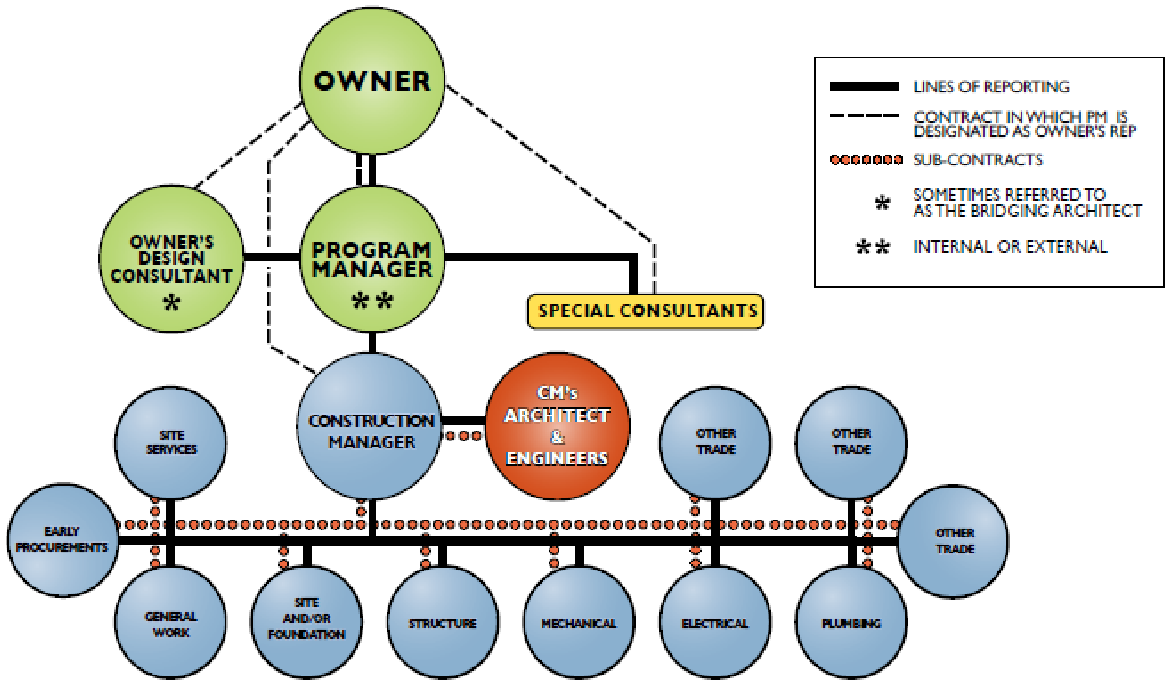
2. Expanding Responsibilities of the CM (Contractor)

By original agreement between the parties, at the end of a very full Design Development phase that is concluded with the production of documents equal to Bridging Contract Documents, (see back page) the Owner's AE would become a sub to the CM so that the CM then would have a design-build responsibility. In this approach the construction phase of the AE's services, under a contractual option retained for the Owner in the Owner-AE agreement, would be dropped and another entity retained by the Owner would act on behalf of the Owner in the administration of the design-build contract.

3. Utilizing Aspects of Bridging

In this form, sometimes called Bridging, the Owner's AE would remain in the employ of the Owner, with a reduced scope of services equivalent to the services of the Owner's Design Consultant ("ODC") services in a Bridging project. Separately, at the outset, the CM would have designated the "CM's AE". That AE would then produce the final architectural and engineering construction documents for review by the Owner's AE for compliance with the design documents prepared by the Owner's AE. The following chart shows how the procedures in this form are easily laid over the CM-at-Risk project delivery method. The CM with its separate AE comes on board early. Otherwise the project is managed as any other CM-at-Risk project would be managed. For more information on the Bridging method, go to **www.bridgingmethod.com**

Diagram of Project Organization for Form 3 of Enhanced CM-at-Risk

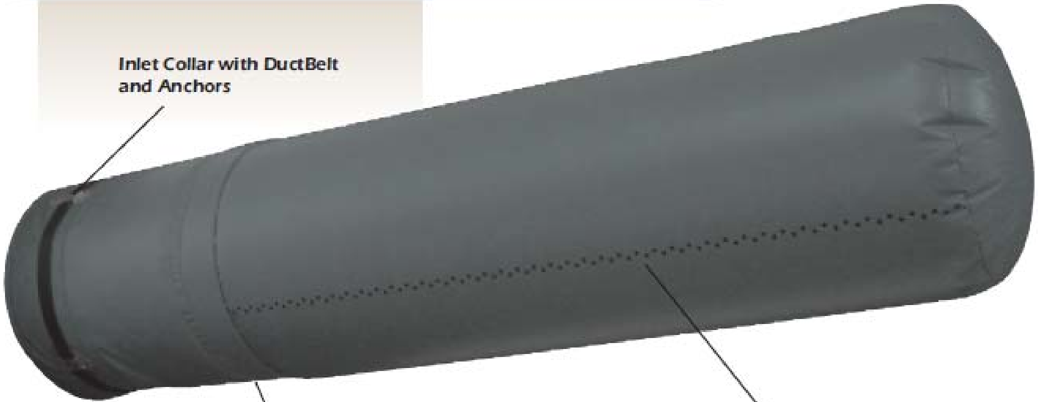


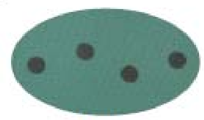
Appendix C

Appendix C – Verona Fabric Product Data

COMMERCIAL

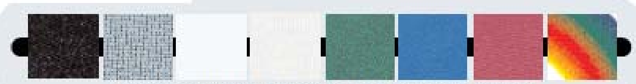
Verona™





L-Vent
(standard)

Fabric: The all purpose Verona™ is a woven air permeable commercial grade fabric that offers best-in-class performance and features. Features include finished seam construction, positive inlet anchoring system and a zippered inlet collar for the addition of DuctSox Final Filter or Adjustable Flow Device. Verona comes in seven popular colors; black, gray, white, tan, green, blue, red and custom colors. Verona is machine washable and available with all DuctSox suspension systems.



(Black, Gray, White, Tan, Green, Blue, Red, Custom Colors)

Application: Ideal for any aesthetically attractive environment. Common uses are in; retail, commercial, education, and community applications. Ideal if condensation is a concern.

Comfort-Flow

Specifications:
Fabric: FR Polyester Twill
Weight: 5.2 oz/yd²
Porosity: 1.5 CFM/ft² @ 0.5" w.g.
Codes: UL Classified (ICC-AC167)

Appendix C – Mechanical Calculations

Air Handler – Volume flow rate = 23,000 cfm

From duct layout – Inlet velocity = 1,400 fpm

From Volume flow rate – Fabric diameter = 54”

Takeoff Tees

Placed 1.5 x diameter away from endcaps

$1.5 \times 54'' = 6'9''$ away from endcaps

Fabric Airflow

$$Q_{fabric} = FP \times SA \times (AP / .5)$$

where FP – fabric porosity, AP – Average Pressure, SA – Surface Area

$$Q_{fabric} = 1.5 \times 6579 \times (.5 / .5)$$

$$Q_{fabric} = 9868 cfm$$

Throw required for vent orientation

4&8 o’clock: $(Height - 6) \times 2.00 =$ throw required

$(30 - 6) \times 2.00 =$ throw required

48 *fpm* throw required

Vent Sizing

TVS – Total vent size

$$TVS = \left(\frac{Q_{vent}}{(Length) \times (AP / .5)} \right)$$

$$TVS = \left(\frac{5160 cfm}{(86') \times (.5 / .5)} \right) = 60$$

$60 / 4 vents = 15$, Use size 15 vents

Appendix D

Appendix D – Steel Duct Estimates

Steel Supply Duct Estimate - Standard Construction Project

Detail - Without Taxes and Insurance Indirect Costs are Spread

Estimator :
Project Size : sqft

ItemCode	Description	Quantity	UM	Lab.Unit	Mat.Unit	Eqp.Unit	Sub.Unit	Eqp.Rent.Unit	Temp.Mat.Unit	Other Unit	Tot.UnitCost	TotalCost
Air distribution												
15810.010	GALVANIZED ROUND-LOW PRESS		****									
15810.010	GALVANIZED ROUND-LOW PRESS		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.581	DUCT, STRAIGHT	1,483.53	LBS	2.5715							2.572	3,814.91
15810.581	DUCT, STRAIGHT	1,146.75	LBS	2.5715							2.572	2,948.87
15810.581	DUCT, STRAIGHT	2,244.18	LBS	2.5715							2.572	5,770.91
15810.581	DUCT, STRAIGHT	173.40	LBS	2.5715							2.572	445.90
15810.593	FTNGS-AVG LABOR	215.79	LBS	2.5715							2.572	554.90
15810.593	FTNGS-AVG LABOR	33.72	LBS	2.5715							2.572	86.70
15810.593	FTNGS-AVG LABOR	17.34	LBS	2.5715							2.572	44.59
15810.594	TOTAL LBS	1,146.75	LBS		0.435						0.435	499.07
15810.594	TOTAL LBS	190.74	LBS		0.435						0.435	83.01
15810.594	TOTAL LBS	1,517.25	LBS		0.435						0.435	660.31
15810.594	TOTAL LBS	2,459.97	LBS		0.435						0.435	1,070.58
15810.960	GALV DUCT CONNECTIONS		****									
15810.960	GALV DUCT CONNECTIONS		****									
15810.960	GALV DUCT CONNECTIONS		****									
15810.960	GALV DUCT CONNECTIONS		****									
15810.961	S-SLIP CONNECTOR	1,860.00	INCH	0.4883	0.026						0.514	955.85
15810.961	S-SLIP CONNECTOR	4,560.00	INCH	0.4883	0.026						0.514	2,343.38
15810.961	S-SLIP CONNECTOR	350.00	INCH	0.4883	0.026						0.514	179.87
15810.961	S-SLIP CONNECTOR	2,166.00	INCH	0.4883	0.026						0.514	1,113.11
15810.962	DRIVE SLIP CONNECTOR	1,116.00	INCH	0.4883	0.026						0.514	573.51
15810.962	DRIVE SLIP CONNECTOR	1,824.00	INCH	0.4883	0.026						0.514	937.35
15810.962	DRIVE SLIP CONNECTOR	2,160.00	INCH	0.4883	0.026						0.514	1,110.02
15810.962	DRIVE SLIP CONNECTOR	280.00	INCH	0.4883	0.026						0.514	143.89
15810.963	CLASS A TRANS JOINT REIN	2,016.00	INCH									
15810.963	CLASS A TRANS JOINT REIN	1,260.00	INCH									
15810.965	CLASS C TRANS JOINT REIN	2,100.00	INCH									
15810.966	CLASS D TRANS JOINT REIN	1,824.00	INCH									
15810.967	CLASS E TRANS JOINT REIN	280.00	INCH									
15810.967	CLASS E TRANS JOINT REIN	4,256.00	INCH									
15810.967	CLASS E TRANS JOINT REIN	2,166.00	INCH									
15810.970	CLASS H TRANS JOINT REIN	350.00	INCH									
15820.015	MANUAL DAMPERS		****									
15820.015	MANUAL DAMPERS		****									
15820.038	VOLUME, 24 GA	9.76	LBS	2.2460	0.435						2.681	26.17
15820.038	VOLUME, 24 GA	21.96	LBS	2.2460	0.435						2.681	58.89
15820.210	MISC DUCT ACCESSORIES		****									
15820.210	MISC DUCT ACCESSORIES		****									
15820.210	MISC DUCT ACCESSORIES		****									
15820.210	MISC DUCT ACCESSORIES		****									
15820.251	MASTIC SEALANT	22.40	GALS	81.3750	13.120						94.495	2,116.69
15820.251	MASTIC SEALANT	2.10	GALS	81.3750	13.120						94.495	198.44
15820.251	MASTIC SEALANT	9.92	GALS	81.3750	13.120						94.495	937.39
15820.251	MASTIC SEALANT	13.30	GALS	81.3750	13.120						94.495	1,256.78
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.318	THREADED ROD - 1/4"	468.00	LNFT	5.4684	0.870						6.339	2,966.56
15820.318	THREADED ROD - 1/4"	279.00	LNFT	5.4684	0.870						6.339	1,768.53
15820.318	THREADED ROD - 1/4"	31.67	LNFT	5.4684	0.870						6.339	200.73
15820.318	THREADED ROD - 1/4"	311.67	LNFT	5.4684	0.870						6.339	1,975.59
15820.321	ANGLE, 1" X 1" X 1/8"	103.33	LNFT	0.3906	0.430						0.821	84.81
15820.322	ANGLE, 1.5" X 1.5" X 1/8"	208.00	LNFT	0.3906	0.662						1.052	218.90
15820.322	ANGLE, 1.5" X 1.5" X 1/8"	12.50	LNFT	0.3906	0.662						1.052	13.16
15820.322	ANGLE, 1.5" X 1.5" X 1/8"	110.00	LNFT	0.3906	0.662						1.052	115.76
15851.010	SUPPLY AIR DIFFUSER		****									
15851.011	CLG MTD,ROUND LOUVER FACE		****									
15851.013	2 SQFT SURF AREA	12.00	EACH	24.4125	35.200						59.613	715.35
	*** Total Air distribution**											**35,990.47**
	Total Estimate											**35,990.47**

Steel Return Duct Estimate - Standard Construction Project

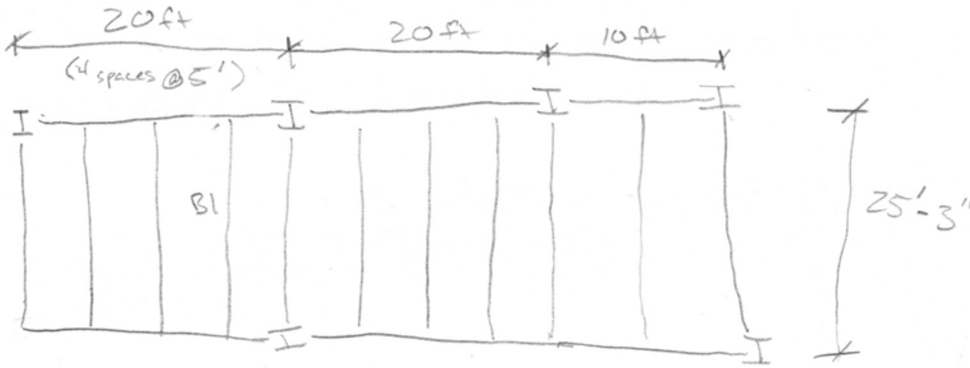
Detail - Without Taxes and Insurance Indirect Costs are Spread

Estimator :
Project Size : sqft

ItemCode	Description	Quantity	UM	Lab.Unit	Mat.Unit	Eqp.Unit	Sub.Unit	Eqp.Rent.Unit	Temp.Mat.Unit	Other Unit	Tot.UnitCost	TotalCost
Air distribution												
15810.010	GALVANIZED ROUND-LOW PRESS		****									
15810.010	GALVANIZED ROUND-LOW PRESS		****									
15810.010	GALVANIZED ROUND-LOW PRESS		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.460	DUCTWORK-MATL & FIELD LAB		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.580	GALV RECT-24GA-MED PRESS		****									
15810.581	DUCT, STRAIGHT	173.40	LBS	2.5715							2.572	445.90
15810.581	DUCT, STRAIGHT	1,063.52	LBS	2.5715							2.572	2,734.84
15810.581	DUCT, STRAIGHT	410.77	LBS	2.5715							2.572	1,056.28
15810.581	DUCT, STRAIGHT	2,071.55	LBS	2.5715							2.572	5,327.00
15810.581	DUCT, STRAIGHT	138.72	LBS	2.5715							2.572	356.72
15810.593	FTNGS-AVG LABOR	25.05	LBS	2.5715							2.572	64.41
15810.593	FTNGS-AVG LABOR	43.16	LBS	2.5715							2.572	110.98
15810.593	FTNGS-AVG LABOR	38.53	LBS	2.5715							2.572	99.09
15810.593	FTNGS-AVG LABOR	78.61	LBS	2.5715							2.572	202.14
15810.594	TOTAL LBS	435.81	LBS		0.435						0.435	189.67
15810.594	TOTAL LBS	217.33	LBS		0.435						0.435	94.58
15810.594	TOTAL LBS	173.40	LBS		0.435						0.435	75.46
15810.594	TOTAL LBS	2,114.71	LBS		0.435						0.435	920.32
15810.594	TOTAL LBS	1,102.05	LBS		0.435						0.435	479.61
15810.960	GALV DUCT CONNECTIONS		****									
15810.960	GALV DUCT CONNECTIONS		****									
15810.960	GALV DUCT CONNECTIONS		****									
15810.960	GALV DUCT CONNECTIONS		****									
15810.960	GALV DUCT CONNECTIONS		****									
15810.961	S-SLIP CONNECTOR	3,952.00	INCH	0.4883	0.026						0.514	2,030.93
15810.961	S-SLIP CONNECTOR	250.00	INCH	0.4883	0.026						0.514	128.48
15810.961	S-SLIP CONNECTOR	323.00	INCH	0.4883	0.026						0.514	165.99
15810.961	S-SLIP CONNECTOR	495.00	INCH	0.4883	0.026						0.514	254.38
15810.961	S-SLIP CONNECTOR	1,460.00	INCH	0.4883	0.026						0.514	750.29
15810.962	DRIVE SLIP CONNECTOR	675.00	INCH	0.4883	0.026						0.514	346.88
15810.962	DRIVE SLIP CONNECTOR	1,872.00	INCH	0.4883	0.026						0.514	962.02
15810.962	DRIVE SLIP CONNECTOR	133.00	INCH	0.4883	0.026						0.514	68.35
15810.962	DRIVE SLIP CONNECTOR	1,460.00	INCH	0.4883	0.026						0.514	750.29
15810.962	DRIVE SLIP CONNECTOR	200.00	INCH	0.4883	0.026						0.514	102.78
15810.963	CLASS A TRANS JOINT REIN	1,800.00	INCH									
15810.963	CLASS A TRANS JOINT REIN	133.00	INCH									
15810.966	CLASS D TRANS JOINT REIN	323.00	INCH									
15810.967	CLASS E TRANS JOINT REIN	3,800.00	INCH									
15810.967	CLASS E TRANS JOINT REIN	2,920.00	INCH									
15810.967	CLASS E TRANS JOINT REIN	280.00	INCH									
15810.970	CLASS H TRANS JOINT REIN	350.00	INCH									
15820.010	GALV DUCT ACCESSORIES		****									
15820.011	VANES - TRACK	95.20	INCH	3.5805	0.019						3.600	342.69
15820.012	VANES - BLADES	380.80	INCH	0.3580	0.019						0.377	143.64
15820.015	MANUAL DAMPERS		****									
15820.038	VOLUME, 24 GA	21.96	LBS	2.2460	0.435						2.681	58.89
15820.210	MISC DUCT ACCESSORIES		****									
15820.210	MISC DUCT ACCESSORIES		****									
15820.210	MISC DUCT ACCESSORIES		****									
15820.210	MISC DUCT ACCESSORIES		****									
15820.210	MISC DUCT ACCESSORIES		****									
15820.251	MASTIC SEALANT	19.41	GALS	81.3750	13.120						94.495	1,834.46
15820.251	MASTIC SEALANT	1.52	GALS	81.3750	13.120						94.495	143.63
15820.251	MASTIC SEALANT	1.50	GALS	81.3750	13.120						94.495	141.74
15820.251	MASTIC SEALANT	3.90	GALS	81.3750	13.120						94.495	368.53
15820.251	MASTIC SEALANT	9.73	GALS	81.3750	13.120						94.495	919.75
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.310	DUCT HANGERS, GALVANIZED		****									
15820.318	THREADED ROD - 1/4"	31.25	LNFT	5.4684	0.870						6.339	198.09
15820.318	THREADED ROD - 1/4"	432.00	LNFT	5.4684	0.870						6.339	2,738.36
15820.318	THREADED ROD - 1/4"	218.50	LNFT	5.4684	0.870						6.339	1,385.03
15820.318	THREADED ROD - 1/4"	31.67	LNFT	5.4684	0.870						6.339	200.73
15820.318	THREADED ROD - 1/4"	112.75	LNFT	5.4684	0.870						6.339	714.70
15820.321	ANGLE, 1" X 1" X 1/8"	27.33	LNFT	0.3906	0.430						0.821	22.43
15820.322	ANGLE, 1.5" X 1.5" X 1/8"	13.75	LNFT	0.3906	0.662						1.052	14.47
15820.322	ANGLE, 1.5" X 1.5" X 1/8"	71.88	LNFT	0.3906	0.662						1.052	75.64
15820.322	ANGLE, 1.5" X 1.5" X 1/8"	192.00	LNFT	0.3906	0.662						1.052	202.06
15820.322	ANGLE, 1.5" X 1.5" X 1/8"	12.50	LNFT	0.3906	0.662						1.052	13.16
	*** Total Air distribution**											**27,235.40**
	Total Estimate											**27,235.40**

Appendix E

Appendix E – Structural Hand Calculations



B1 ⇒

mech + elec = 15 psf
ACT = 1 psf
20 ga Deck = 2.5 psf
Rigid Insulation = .75 psf
AHU = 6.4 psf

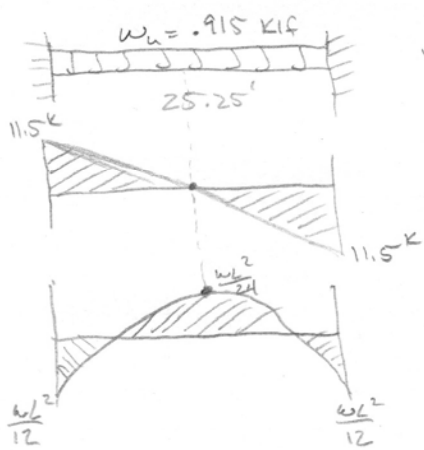
DL = 25.65 psf

Snow load = 30 psf + 65 max drift = 95 psf

$$W_u = 1.2(25.65) + 1.6(95) = 183 \text{ psf}$$

$$w_u = 183(5') = 915 \text{ plf} = .915 \text{ kpf}$$

(5' ↑ Tributary width)



$$V_{u\,max} = .915\left(\frac{25.25}{2}\right) = 11.5^k$$

$$M_{u\,max} = \frac{wL^2}{12} = \frac{.915(25.25')^2}{12} = 48.6 \text{ ft}\cdot\text{k}$$

A992 50 KSI Steel

$V_u = 11.5^k$ $M_u = 48.6$ ft.K

$L_b = 0$

Using Z_x tables (p.11 steel manual)

$M_u \leq \phi b M_{px}$

$48.6 \leq 65.2$

W12x14 – $\phi b M_{px} = 65.2$ ft.K

Compact section criteria

W12x14

$\frac{b_f}{2t_f} = 8.82 < 9.15 \therefore$ OK

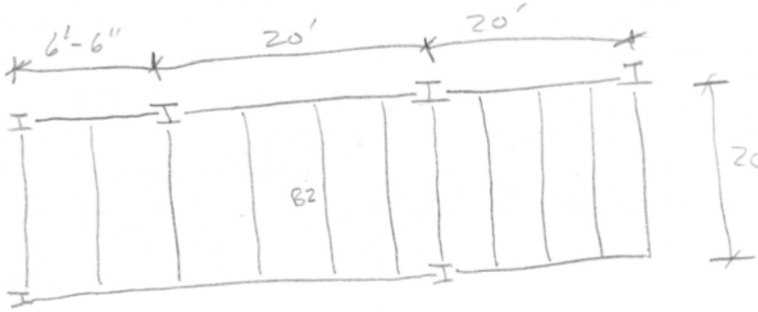
$\frac{h}{t_w} = 54.3 < 90.5 \therefore$ OK

Shear

$V_u \leq \phi V_n$

W12x14 – $\phi V V_{nx} = 64.3^k$

$11.5 \leq 64.3 \therefore$ OK



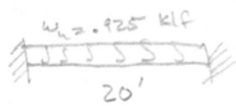
B2 – mech + elec = 15 psf
ACT = 1 psf
20 ga Deck = 2.5 psf
Rigid insulation = .75 psf
AHU = 8.6 psf

DL = 27.85 psf

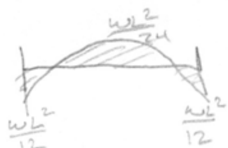
Snow load = 30 psf + 65 drift = 95 psf

$W_u = 1.2(27.85) + 1.6(95) = 185$ psf

$w_u = 185(5') = .925$ klf



$V_{u_{max}} = .925\left(\frac{20}{2}\right) = 9.25^{K}$



$M_{u_{max}} = \frac{.925(20)^2}{12} = 30.8$ ft.K

★ From Inspection, Loads are smaller than previous calculation So W12x14 can be used as well.

Appendix E – Original & Reduced Size Roof Beam Estimates

Original Steel Estimate - Standard Construction Project

Detail - Without Taxes and Insurance Indirect Costs are Spread

Estimator :
Project Size : sqft

ItemCode	Description	Quantity	UM	Lab.Unit	Mat.Unit	Eqp.Unit	Sub.Unit	Eqp.Rent.Unit	Temp.Mat.Unit	Other Unit	Tot UnitCost	TotalCost
Structural framing												
05129.101	STEEL BEAMS		****									
05129.101	STEEL BEAMS		****									
05129.102	I BEAMS	72.20	CWT	28.7300	35.000	5.000					68.730	4 962.31
05129.102	I BEAMS	61.11	CWT	28.7300	35.000	5.000					68.730	4 199.75
05129.990	* STRUCTURAL STEEL WEIGHT *	3.61	TONS									
05129.990	* STRUCTURAL STEEL WEIGHT *	3.06	TONS									
	*** Total Structural framing**											**9,162.05**
Fire and smoke protection												
07810.031	CEMENTITIOUS FIREPROOFING	807.50	BDFT	44.8066	0.448	0.080					45.335	36 607.69
07810.031	CEMENTITIOUS FIREPROOFING	536.06	BDFT	44.8066	0.448	0.080					45.335	24 301.95
	*** Total Fire and smoke protection**											**60,909.64**
	Total Estimate											**70,071.69**

New Steel Estimate - Standard Construction Project

Detail - Without Taxes and Insurance Indirect Costs are Spread

Estimator :
Project Size : sqft

ItemCode	Description	Quantity	UM	Lab.Unit	Mat.Unit	Eqp.Unit	Sub.Unit	Eqp.Rent.Unit	Temp.Mat.Unit	Other Unit	Tot.UnitCost	TotalCost
Structural framing												
05129.101	STEEL BEAMS		****									
05129.101	STEEL BEAMS		****									
05129.102	I BEAMS	53.20	CWT	28.7300	35.000	5.000					68.730	3,656.44
05129.102	I BEAMS	38.89	CWT	28.7300	35.000	5.000					68.730	2,672.57
05129.990	* STRUCTURAL STEEL WEIGHT *	2.66	TONS									
05129.990	* STRUCTURAL STEEL WEIGHT *	1.94	TONS									
	*** Total Structural framing**											**6,329.00**
Fire and smoke protection												
07810.031	CEMENTITIOUS FIREPROOFING	613.70	BDFT	44.8066	0.448	0.080					45.335	27,821.84
07810.031	CEMENTITIOUS FIREPROOFING	448.57	BDFT	44.8066	0.448	0.080					45.335	20,335.57
	*** Total Fire and smoke protection**											**48,157.42**
	Total Estimate											**54,486.42**