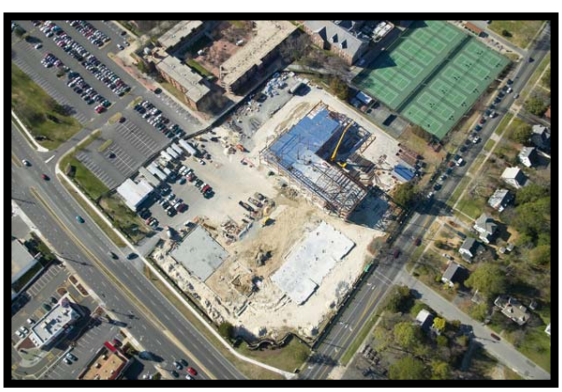
Teacher's Education and Technology Center
Salisbury University
Salisbury, MD

Senior Thesis Final Report 2006-07

Josh Thompson
Construction Management

Advisor: Dr. Hormam



Department of Architectural Engineering
The Pennsylvania State University

Teacher Education and Technology Center at Salisbury University

Salisbury, Maryland

Project Team

- Owner: The University of Maryland
- Architect: Ayers/Saint/Gross
- Structural: Hope Furrer Associates, Inc
- Electrical: Paulco Engineering, Inc.
- General Contractor: Holder Construction Company
- Mechanical & Plumbing: Mueller Assoc.
- Civil: Constellation Design Group

Project Overview

- Three Story Higher Education Building
- 165,00 square feet
- Overall Project Cost: $48 million
- Under construction from July 2006 until October 2008
- Project Delivery Method: Construction Management at Risk
- Project Develeloped for Extensive Number of New Teachers Projected Due to Regional Population Growth

Architectural

- Brick and Pre-cast Concrete Panel Exterior Facade
- Curved Corner Links Two Buildings and Provides Study Space
- Lab, Classroom,Technology, and Office Space
- Standing Seam Metal Roof

Structural

- Braced Structural Steel Frame on Concrete Piers
- Auger Cast Grout Piles with 55 Ton Capacity
- Pile Caps Ranging in Depth from 36”-46”
- Structural Lightweight Concrete Composite Slabs on Metal Decking
- Steel Deck Roof w/ Insulation Board/ High Temp. Water Proofing

Electrical/Lighting

- 4000 amp, 480Y/277V, 3 PH, 4 Wire Main Service
- 3000 kW Emergency Generator
- 24 Transformers Ranging from 9 to 112.5 KVA
- Flourescent, Incandescent, & HID Lighting: Both 277/120 Systems

Mechanical

- (2) 350 Ton Chillers with (1) Cooling Towers Each
- (8) Various Sized Attic AHU’s
- (2) 3000 MBH Boilers

Joshua Thompson Construction Management

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Table of Contents

Executive Summary

Set to be completed in the late spring of 2008, The Teachers Education and Technology Center at Salisbury University will serve as an important facility for developing the future Educators of Maryland. This 165,000 square foot, $45 million facility will house instructional, laboratory, lecture, & office spaces for the Salisbury University College of Education. The three main buildings of the facility are connected with spaces excellent for studying or impromptu meetings with professors. The courtyard created by the "S" shape of the building provides an ample green space for student interaction.

The construction research portion of this report focuses on the implementation of Building Information Modeling (BIM) for Construction Coordination. This research unveils the proper approach to utilizing BIM at the construction phase. This analysis provides information on BIM development, contractual Issues, coordination meeting impacts, and project team responsibilities. A strong focus was placed on the on-site construction coordination process and how a BIM geared approach differs from a traditional approach. A BIM powered coordination meeting is much more efficient because time is spent evaluating solutions to problems versus identifying the problems.

The second analysis of this report weighs the benefits and impacts of a panelized façade compared to a stick built façade. It was found that a panelized façade can cut schedule time nearly in half and reduced the loads on structural steel framing due to less dead weight. Structural steel spandrel beams were downsized in this analysis and cost impacts were calculated. The only negative note of this analysis was an increased façade cost of 30%.

Early stages of building projects can be critical to the schedule. If delays occur early, they can be hard to overcome. The analysis of the grade beam placement method was addressed for this reason. The proposed placement method eliminates wood formwork and uses earth forms in the form of excavated trenches. Savings in formwork material and labor was the impact and overall grade beam costs were reduced by 64%. The excavation schedule was accelerated by 4 days and the formwork schedule was accelerated by 15.

Finally, interior partitions were analyzed for acoustical performance. Acoustics are vital to learning especially in environments where verbal communication is relied upon. Sound transmissions to classroom spaces from mechanical, bathroom, & other classroom spaces were addressed in this analysis. Three partitions were found to have low Sound Transmission Class values and were improved upon by adding addition gypsum wall board material.

Project Background

The construction of The Teachers Education and Technology Center (TETC) at Salisbury University has been sparked by growing need for a significant number of new Elementary and Secondary school teachers. Upon completion, the TETC hopes to provide the skills to Elementary and Secondary Education students to teach other young people. This unique 165,000 square foot, $ 45 million project combines a multitude of spaces for instruction and learning. The project is being delivered using a CM at risk approach with Holder Construction Company as the General Contractor.

Owner Information

The owner of this project is the University of Maryland. The University of Maryland Architecture, Engineering, and Construction Department (UMAEC), a subdivision of the owner, directly works to manage the design and construction teams. The State of Maryland has determined that the population growth in the area is going to require a large number of teachers in Elementary and Secondary Education over the next few years. The Teachers Education and Technology Center will be used to instruct college students how to teach Elementary and Secondary students and help meet the demand for teachers. The University of Maryland looked at placing the building on several different campuses within their school system, but Salisbury ended up being the best logistical and financial fit. The building will house teaching spaces for the liberal arts, technology, and lab space for teaching the sciences.

The schedule for this project is the most important factor. Holder Construction Company is working to complete the building ahead of schedule for the Fall Semester of 2008. The current schedule will allow a move-in date at the end of July with substantial completion slated for July 23rd. The building needs to be substantially complete by June 1st to allow enough set up time to hold classes in September 2008.

The budget for the Education and Technology Center is not as critical, but the UMAEC is still working to obtain additional funding for the project. UMAEC is also considering alternatives such as millwork, roofing, and the hardscape/landscape that would be possible with the extra funding. Holder Construction hopes to free some extra money for this work by trying to manage their contingency as effectively as possible. Holder Construction has also performed

several value engineering analyses for cost savings. Analyses presented in this report could also produce additional funding.

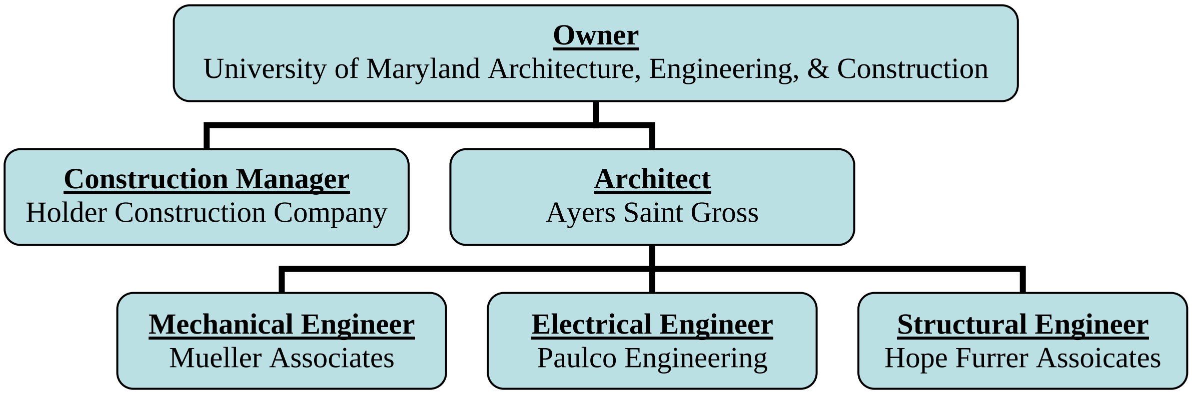
Project Delivery System

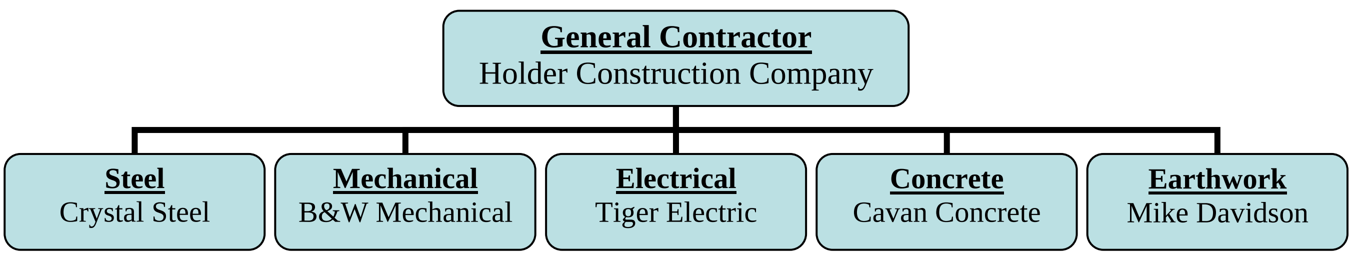
The Teachers Education and Technology Center is being delivered using a Construction Management at risk method. The University of Maryland has used Holder Construction Company is many past projects. Holder will be under a GMP contract with the University of Maryland. The use of the CM at Risk method allows UMAEC to bring Holder into the project very early to advise the owner. The project was awarded to Holder in 2004 and went through the pre-construction phase for two years before breaking ground. The long pre-construction phase creates a team environment very early that ensures the level of quality needed. During pre-construction Holder provided consultations in design, constructability, value analyses, and pricing for the owner. All contracts for Design work will be a lump sump.

Holder requires that all subcontractors have $5 million of insurance coverage. Subcontractors with a contract exceeding $50,000 were required to be bonded. Holder holds general and builder's risk insurance and was required to be bonded with the owner. The owner allowed Holder to hold only a 5% retainage for bonded subcontractors while a 10% retainage was used for non bonded subcontractors. All subcontractors were selected on a low bid basis.

An item of interest of the project is the Center for Conflict Resolution. The UMAEC set up a partnership to help discuss expectations, challenges, and goals during both pre-construction and construction. The partnership helped better define the lines of communication throughout the construction team, design team, consultants, and the owner. The meetings helped make clear how goals would be met and challenges would be faced. These sessions served as team building and developing a level of commitment and vision for the project.

Organizational Chart





Holder Construction Company Staffing Plan

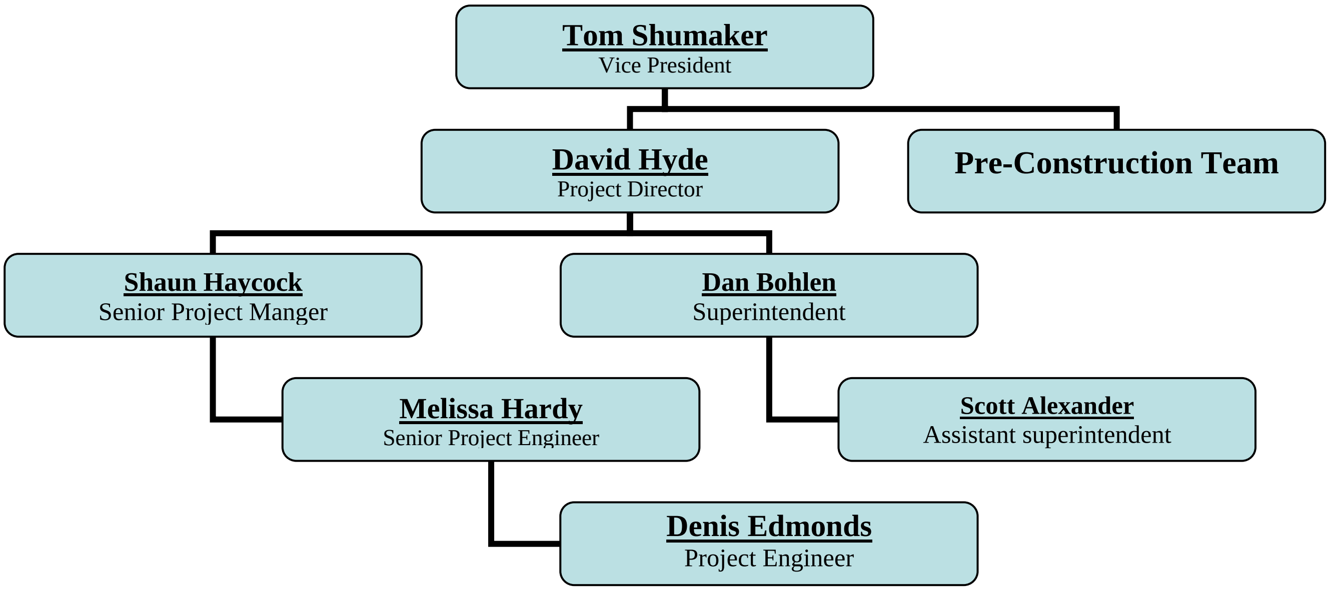
Holder Construction Company split their staff between the pre-construction and operations teams. The pre-construction team was responsible for the two year period prior to breaking ground and the operations team will take care of onsite duties during construction.

The pre-construction team initially worked to contact subcontractors to obtain bids for each of the trades on the project. The team reviewed each bid for compliance with the construction documents and for bid price to determine the best subcontractor to use on the

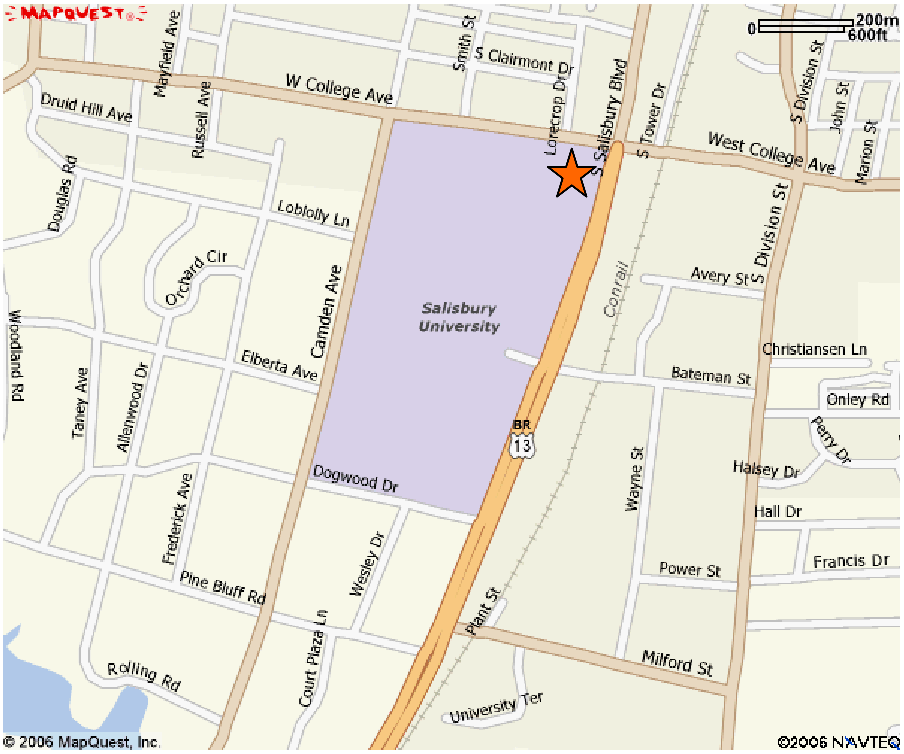
project. A site logistics plan and project schedule was also developed during preconstruction. The final task of the team was to perform value engineering analyses to cut cost from the project budget. As the pre-construction phase got closer to the beginning of construction the team worked with the operations team to revise the schedule and site plan to best fit the construction plan developed by the superintendents.

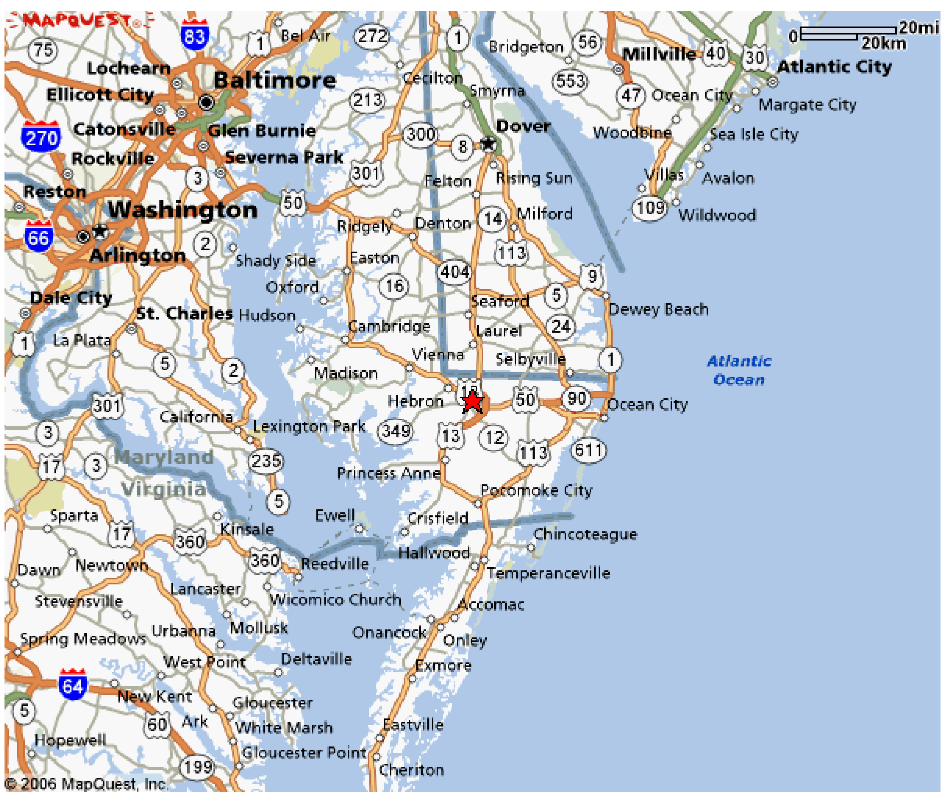
The operations group consists of a vice president, project director, superintendent, assistant superintendent, senior project manager, senior project engineer, and project engineer. Tom Shumaker, vice president, deals with staffing the job, corresponding with the owner, and resolving any subcontractor or budget issues. The Project Director, David Hyde, overees multiple University of Maryland projects that Holder is building, ensuring consistency throughout the projects, and also corresponding with the owner. The Senior Project Manager, Shaun Haycock, has duties that involve cost projections, owner billing, cost loading schedules, owner correspondence, etc. Under Shaun Haycock a Senior Project Engineer, Melissa Hardy, manages the MEP and exterior skin trades. She is also involved in the Project Managers duties such as cost projections and cost loading schedules. Dennis Edmonds, the Project Engineer on site, manages the remaining trades. He reviews submittals, shop drawings, and answers RFI’s for all trades. The Superintendent, Dan Bohlen, is responsible for the overall site coordination, the construction plan, updating the schedule, etc. Scott Alexander, the Assistant Superintendent, coordinates day to day field operations, maintains quality control, safety and safety orientations, and erosion

control.


Tom Shumaker
Vice President
David Hyde
Project Director
Pre-Construction Team
Shaun Haycock
Senior Project Manger
Dan Bohlen
Superintendent
Melissa Hardy
Senior Project Engineer
Scott Alexander
Assistant superintendent
Denis Edmonds
Project Engineer

Project Location





Local Conditions

The Teachers Education and Technology Center is located on the eastern shore of southern Maryland on Salisbury University's campus. The building structure is steel with a brick façade to match the brick of the buildings throughout the University of Maryland School System. Two mobile cranes will be utilized to set structural steel starting from the back most corner of the site working towards the intersection of West College Ave. and U.S. 13.

The project site is not constricted by surrounding buildings and there is ample space for lay down areas, parking, and the trailer compound (Refer to Site Plan in Appendix C). The site also has necessary dumpster space for recycling and waste management. Holder Construction will be recycling concrete, steel, drywall, and paper for the project. The owner was considering a LEED certification, but financial constraints did not allow it. The specifications associated with LEED certification that do not increase the project cost are still being used. Additional dumpsters for each type of material being recycled will be placed on site. Waste and recycled material will be hauled off site by the same waste management company.

The Test Borings found that the surface soil to be Silty Sand Fill with layers of various grades of sands and clayey sands below. In general the subsurface layers were found to be alternating layers of poorly graded and well graded sands. The sandy soils of the project site require the use of auger cast piles for the foundation system. Driven piles were considered but the noise was not acceptable with dormitories in the area. During Test Borings groundwater was encountered. The water table should be assumed to be at or below the caved depths for borings where groundwater was not found. The water table was estimated to be between 10 to 14 feet below the surface and the auger cast piles are estimated to be drilled to approximately 20 feet below grade. Therefore some type of site dewatering will be required. The Auger Cast Piles are specified to carry of a maximum load of 55 tons.

Site Layout Planning

Layout & Access

Main access to the site can be found off U.S. Route 13 to the east. Dumpsters for the recycling steel, drywall, and concrete are located inside the construction entrance for haul service. The construction trailers were also placed near the entrance for deliveries, on site meetings, and to better control the site.

Steel Phasing & Crane Locations

Two mobile cranes will be necessary to erect the steel and their locations show on the site plans found in Appendix C. The 2^{nd} of the mobile cranes will be removed on February 15^{th}, 2007 when Building A is complete. Steel will be staged in two major areas that will allow on site unloading of members and no traffic interruptions. As mentioned above, structural steel erection and placement of elevated slabs will begin with sequence 1 at Building A. The relevant sequences to Building are A, B, & C are as following:

- Building A: Sequences 1-12
- Building B: Sequences 13-20
- Building C: Sequences 21-31

Project Schedule Summary- *See Schedule Following Page*

Schedule Notes - Key Elements to Sequences

- **Foundations**
  - Drill and Place Concrete for Piles
  - Placement of Reinforcing Steel and Formwork for Pile Caps, Piers, Grade Beams to Follow
  - 4” of Granular Base, Reinforcing Steel, and Formwork Prepped for SOG
- **Structure**
  - Structural Steel Columns, Beams, and Roof Trusses
  - Metal Floor and Roof Decking

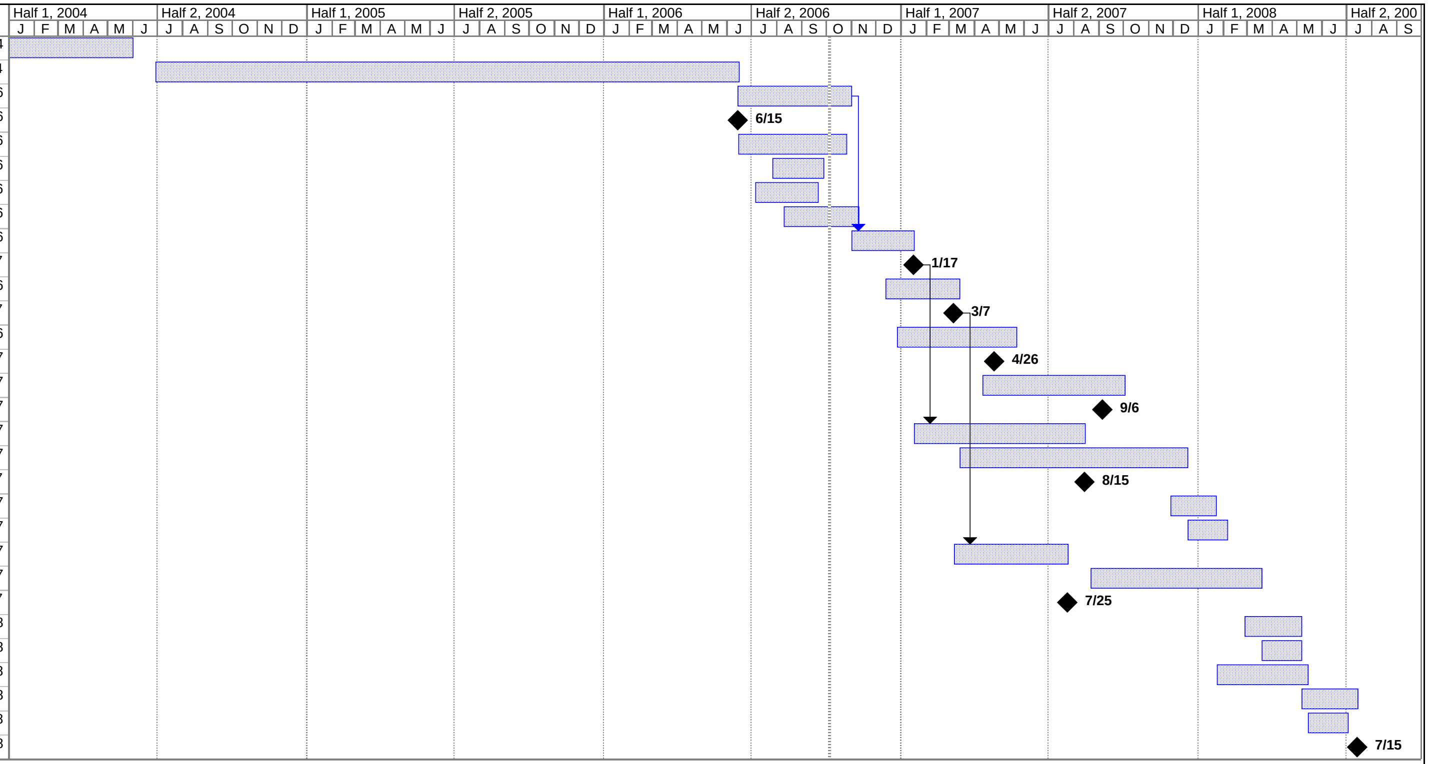
- Installation of Elevated Concrete Composite Slabs

- **Finishes**
  - Drywall
  - Paint
  - Acoustical and Hardboard Ceilings
  - Flooring
  - Millwork and Casework

MEP

- Underground Electrical & Plumbing
- MEP overhead and in slab rough-in
- MEP Terminations
- Setting of Equipment
- Commissioning

ID	Task Name	Duration	Start
1	Design Services	109 days	Thu 1/1/04
2	Pre-Construction	513 days	Wed 6/30/04
3	Steel Lead Time	100 days	Thu 6/15/06
4	Notice to Proceed	1 day	Thu 6/15/06
5	Site Work	95 days	Fri 6/16/06
6	MEP Underground	45 days	Fri 7/28/06
7	Foundations Building A	55 days	Fri 7/7/06
8	Foundations Building B& C	66 days	Fri 8/11/06
9	Superstructure Building A	55 days	Thu 11/2/06
10	Structure Top Out Bldg A	1 day	Wed 1/17/07
11	Superstructure Building B & C	65 days	Thu 12/14/06
12	Structure Top Out Bldg B&C	1 day	Wed 3/7/07
13	Exterior Skin Building A	105 days	Thu 12/28/06
14	Dry-In Date Building A	1 day	Thu 4/26/07
15	Exterior Skin Building B & C	125 days	Thu 4/12/07
16	Dry-In Date Building B&C	1 day	Thu 9/6/07
17	MEP Systems Building A	150 days	Thu 1/18/07
18	Interior Finishes Building A	200 days	Thu 3/15/07
19	AHU Start Up Building A	1 day	Wed 8/15/07
20	Data/Telecom/AV Install Bldg A	40 days	Thu 11/29/07
21	Commissioning Bldg A	35 days	Thu 12/20/07
22	MEP Systems Building B&C	100 days	Thu 3/8/07
23	Interior Finishes Building B&C	150 days	Thu 8/23/07
24	AHU Start Up Building B&C	1 day	Wed 7/25/07
25	Data/Telecom/AV Install Bldg B&C	50 days	Thu 2/28/08
26	Commissioning Bldg B & C	35 days	Thu 3/20/08
27	Lanscaping/Irrigation/Final Grading	80 days	Fri 1/25/08
28	Punchlist	49 days	Thu 5/8/08
29	Owner Training/ O&M Manuals	35 days	Fri 5/16/08
30	Substantial Completetion	1 day	Tue 7/15/08



Project: Salisbury
Date: Wed 10/4/06

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Architecture

The Teacher Education and Technology Center consists of three levels of lecture/classroom spaces, faculty offices, and laboratory spaces. The main architectural feature of the building is the curved corner colonnade, mimicking the curve of the street corner the building sits on. The "S" shaped building footprint creates a large courtyard space shielded from the busy street. A stairwell tower located on the southwest corner of the building is an added feature to the back of the building. The facility is broken down into three separate buildings, all interconnecting. These connection spaces allow for study and impromptu meeting spaces.

The exterior façade of the building features 4" hand-laid brick, vertically & horizontally running architectural pre-cast concrete bands, and punch out windows. The gabled roof is covered with a standing seam aluminum roof.

Building Systems

Building Envelope

The Teacher Education and Technology Center roofing system consists of a combination of an interior flat roof and a perimeter gable roof. The entire systems utilizes "W" shape steel framing and trusses with metal decking. A standing seam aluminum roof covers the roof gables and a rubber roofing membrane covers the interior flat roof.

The building exterior walls consist of both brick and architectural pre-cast concrete panels. 4" Nominal brick is used and pre-cast panels range in depth from 4"-9". The exterior masonry back-up consists of 8" cold formed metal framing, 1" rigid cavity board, 2" air space and an air barrier. The façade system rests on foundation concrete at the ground floor and is supported using 6" x 6" shelf angles at the floor levels.

The majority of the building utilizes "punch-out" windows with the exception of the corner colonnade, back side stairwell tower, and courtyard "porch". These areas of the building utilize full height windows, broken by pre-cast concrete panels that increase the amount of natural daylight in the building.

Superstructure & Foundation

The building rests on Auger Cast Piles with an average depth of -20'. Pile Caps, Ranging from 36"-46", and Piers ranging from 24"x24" to 30"x30"support steel columns/base plates. Grade beams are utilized between columns to help lateral force resisting. Slab-on-grades consist of 5" of concrete with 6"x6" Welded Wire Fabric reinforcing.

The building is comprised of a braced structural steel frame with bolted/welded moment & shear connections. A 6.25" composite metal deck and concrete floor system is used with light weight concrete. Foundation and elevated slab concrete was placed using a concrete pump.

Mechanical

Eight Air Handling Units ranging from 3,000 to 34,000 CFM utilizing Variable Air Volume Boxes service the building. Two 350 Ton Chillers and Boilers servicing the AHU's are contained in the ground floor mechanical room with two equal capacity cooling towers located in the adjacent mechanical yard.

Electrical

A 4000 amp, 480/277 V, 3 Phase, 4 Wire feed services the building's main distribution. This service is manipulated using a series of transformers ranging from 9 to 112.5 KVA. A3000 KVA, 480/277 V diesel powered emergency generator is located at the ground floor mechanical yard for back-up power. A buried diesel fuel oil system is adjacent.

Project Cost Background

	Total Cost	**Cost per SF (165,000)**
Construction Cost	$45,060,520	$273.09
Total Construction Cost	$47,222,372	$286.20
Building Systems Cost		
Mechanical (HVAC, Plumbing, Fire Protection)	**$11,000,322**	**$66.67**
Electrical (Including Telecommunications)	**$ 4, 718,350**	**$ 28.59**
Structural		
• Concrete	**$2,019,110**	
• Steel	**$ 5,316,274**	
• Total Structure	**$7,335,384**	**$44.46**
Masonry & Pre-cast	**$4,012,837**	**$24.32**

Analysis 1

Construction Research: Implementation of Building Information Modeling at the Construction Phase

Background

During the 2006 PACE Seminar, it was obvious there was a high level of uncertainty from industry members regarding Building Information Modeling (BIM) implementation. Industry members struggled to answer the question of how a BIM should be used during the construction phase of the project. Other topics that didn't have clear cut answers were how risk and contractual relationships are affected using a BIM and how a BIM affects project teams. After visiting the TETC project site and observing the very inefficient approach being used for coordination review, it became obvious that BIM coordination would be an excellent topic of investigation.

Building Information Modeling is such a new topic that it has forced construction companies to develop their own implementation approaches with some trial and error. Contractors in the beginning stages of BIM, have a lot of questions with regards to legal, risk, and responsibility issues. Many contractors do no understand that BIM risk can be dealt with in a very simple manner and that BIM doesn't have to mean throwing out all of your old coordination processes. The goal of this research is to gain feedback from construction companies successfully using BIM at the construction stage and be able to write some guidelines for other construction companies.

The end goal of this research is to provide construction companies with a clear implementation plan that presents some options that could be tailored to their company or project. To achieve this goal, interviews will be conducted of multiple BIM experienced General Contractors and Penn State faculty acting as a consultant to a General Contractor. The results of these interviews will be used to compare and contrast implementation strategies.

On the following pages several typical interview questions and the answers are listed.

Research Method

The Associated General Contractors of America has formed an initiative to write a guide for Building Information Modeling to contractors. This guide defines BIM, gives an overview of tools, the process, and addresses risk. After reading this guide, it was determined that specifics of

BIM use for construction coordination were lacking. Specific information on dealing with subcontractors and the coordination process needed to be elaborated on more.

To develop more detailed guidelines, General Contractors with BIM implementation experience were targeted. Interview questions were drafted for both phone and personal interviews. The use of the interview process versus a survey allowed the interviewee to elaborate more on the processes.

In addition to the interview process, research into necessary contract literature was carried out. Examples of this language are included in this report for the reader's reference.

Interview Sources		
Name	**Company**	**Role**
David Epps	Holder Construction Company	BIM Champion
Mike Lefevre	Holder Construction Company	BIM Implementation Leader
Mike Kenig	Holder Construction Company	Vice President
Brian Horn	Gilbane Building Company	BIM Coordinator
Dr. John Messner	Penn State	Faculty
Jake Hawes	Clark Construction Group	BIM Implementation Leader
David Hyde	Holder Construction Company	Sr. Project Manager
Don Miller	Holder Construction Company	Sr. Project Manager

Research Interview Questions/Results

Building Information Modeling Implementation at the Construction Phase

1. From a contractual standpoint, how are you requiring subcontractors to use BIM while still considering legal implications?
    - Specific language is being written into Request for Proposals
    - Specific language is being written into subcontracts
    - 2D drawings still dictate legal responsibility
        - 2D shop drawings and 3D BIM's are required by General Contractor
        - Changes and updates must be carried through both media

2. In general, what are the varying levels of modeling capabilities of subcontractors? Is one particular trade more advanced that another?
    - Mechanical, Plumbing, and Structural subcontractors are very advanced with 3D modeling
        - These trades have already been drawing in 3D
        - Many subcontractors are using this process for fabrication
    - Electrical and Fire Protection trades are lagging with modeling efforts
    - Mechanical, Plumbing, and Structural are the most critical for trade coordination so this is not a major issue

3. E-mail has difficulties with large file transfers. What options are you using for file transfers between subcontractors?
    - File transfer can be done via E-mail, but subcontractors are using compact disks for file submission
    - For the Public (FTP) sites are also used for file swapping
        - General Contractors can give subcontractors access to FTP sites to retrieve and submit files
4. How does using a BIM impact typical weekly on site coordination meetings?

- On site meetings are carried out in a very similar matter but with the use of technology
- BIM is used for visualization and 2D shops drawings can be utilized at the same time to make notes for both model and 2D shop drawing updates later
- The use of BIM allows issues to be identified prior to meetings and solutions prepared ahead of time

5. Specifically, how do you utilize a BIM for weekly coordination meetings? Are there any additional tools needed?
    - Additional hardware and software is necessary
        - Wall projectors and/or "White Boards" are needed for group meetings
        - Laptops can be linked to projectors/whiteboards to complete model manipulation
        - Universal model viewing software is needed such as Navisworks to accommodate many model file formats
        - Clash detection reports distributed prior to meetings so team members can bring proposed solutions
6. When an architect does not provide an architectural model, is your company using outsourcing or In-House modeling to develop it?
    - Both outsourcing and In-House modeling are utilized and this depends on company preference
    - Outsourcing and In-House modeling have advantages and disadvantages
        - Outsourcing eliminates time dedicated to using an associate for modeling effort, however outsourcing tends to have a higher cost
        - Outsourcing puts a general contractor in a model management role, similar to everyday management tasks, versus a technical modeling role
        - In-House modeling eliminates a 3rd party and forces company associates to know the project inside and out
        - In-House modeling reduces time. Outsourcing requires transmission of information and wait time until a new model is issued

    - For successful Outsourcing, the 3rd party must be very involved and frequent site meetings may be necessary
    - Outsourcing can lead to a conflict of interests. Modeling approaches/quality level may differ requiring re-work

7. Does the delivery method dictate whether a BIM can be utilized for a project? Which delivery method is preferred?
    - In general, the delivery method doesn't necessarily dictate if a BIM can be used because the shop drawing process still exists
    - The Construction Management at Risk approach tends to be most successful
        - This arrangement eliminates the hard bid approach and introduces a team approach the strengthens a modeling effort
        - The preconstruction stage often is longer and trades can be bought out earlier allowing additional time to coordinate models

8. From an organizational standpoint, how do you deal with coordinating all the modeling efforts from various team members?
    - Whether using Outsourcing or In-House modeling the general contractor needs to identify a model manager
        - Referred to as a "BIM Coordinator" or "BIM Champion"
        - Typically a young associate familiar with software applications
        - Responsible for coordinating subcontractors models with architectural models
            - File formats
            - Resolving coordinate issues (X,Y,Z)
            - Tracking updates/changes

9. What are some technical issues that need to be looked out for?
    - Some subcontractors have little understanding of what a BIM entails

- Subcontractors need to model using a file format that can be viewed in a program such as Navisworks
- Most models are submitted with major coordinate issues that have to be resolved by BIM Coordinators or Modelers
- Because of the new nature of BIM, IT departments can be of little help to BIM Coordinators/Modelers with software issues

Model Development

General Contractors using BIM are typically relying on subcontractors for model development of technical trades such as mechanical, electrical, and plumbing, however in some cases General Contractors are developing these as well. If not provided by the Architect, the General Contractor's model responsibility mainly lies with architectural aspects of the project. There are two approaches to the architectural modeling effort; In-House Modeling or Outsourcing.

Both approaches have strong points, but it should be noted that for successful outsourcing there needs to be a strong relationship with the consultant. The 3rd party consultant must be very involved in the project and frequent site meetings may be necessary. Outsourcing requires strong information transmission between the consultant and the contractor. Every time there are design or coordination changes, these changes must be communicated to the consultant for revisions to the model

In contrast, an In-House modeling effort eliminates the 3rd party and the information transmission. In-House modeling efforts allow the project team to model the project to their own predetermined standards and also greatly increase overall knowledge of the building and project. However, Contractors who prefer In-House modeling find it necessary to Outsource from time to time when the project size makes an In-House effort unfeasible.

When subcontractors develop models for the coordination/shop drawing submission process, General Contractors need the ability to incorporate these models with the Architectural model. A composite model or multiple composite models must then be created for coordination purposes. A composite model entails combining Architectural models with trade contractor

models. Several models may be created combing all trades or particular trades depending on the coordination goal.

This process requires an associate with a working knowledge of BIM file formats, software applications, and the models themselves. Associates such as these often work directly on site in the construction office and are referred to as BIM Coordinators. These associates manage the model submission process, the construction of composite models, and are involved in the trade coordination/shop drawing review process.

Contractual Language

Simple provisions can be made to already existing subcontracts and Request for Proposals. For the time being the question of accountability for Building Information Model files is till unclear, however a BIM can still be a powerful coordination tool.

In the future, 2D Shop Drawings may no longer be required, but for the time being Subcontracts and Requests for Proposals (RFP) can be tailored to still allocate responsibility using a BIM for construction coordination. Including this information into a RFP will guarantee that bidding subcontractors are qualified and have the ability to produce Building Information Models. These documents are written to call for subcontractors to submit 2D drawings <u>*AND*</u> a Building Information Model. The language makes it clear which media are primary, requirements for submissions, requirements of models, and how coordination meetings will occur.

For comparison, two examples of language are below. The language from the Request for Proposal and Subcontract shows two different approaches.

Sample Language

From a Request for Proposal

Example to an Electrical Subcontractor

> "It is agreed and understood that the Subcontractor shall prepare a complete set of 2D construction coordination drawings and 3D model utilizing a Building Information Modeling Software package per Specification 16010 1.12 for the coordination of all electrical work with the Architectural, Structural, and Mechanical Drawings to minimize conflicts during the design and construction process. Electrical Subcontractor shall provide the 3D model & 2D drawings to the Mechanical

Subcontractor, who will create one composite drawing with the mechanical, fire protection and electrical systems coordinated with the architectural and structural systems.

Subcontractor acknowledges that the HVAC ductwork drawings are the base for the Contractor's Coordination Drawings and the HVAC contractor will be in the leadership position Subcontractor acknowledges that 2D construction coordination drawings will dictate all legal responsibility .”

General Requirements from a Subcontract

1. In general, the goal of the BIM scope of work is to create a technically accurate and detailed 3D computer model of the architectural, structural, mechanical, plumbing, and electrical systems.

2. The level of detail defined in the Specific Scope Requirements is the minimum level of detail required in the model. Greater detail than the minimum should be incorporated into the model where important details are necessary for communicating information about a system.

3. The Trade Contractor shall provide shop drawings in both 2D and 3D model format. 2D drawings will be primary for legal responsibility.

4. The 3D model shall be located and oriented to the predetermined world coordinates for the project to allow easy integration into the BIM for the project.

5. The 3D model shall be constructed in a manner such that all elements of the model can be converted into a 2D dimensioned drawing for use in the field.

6. In addition to the native file format, the Trade Contractor shall provide translation of the 3D model into a .DWG, CIS/2, or other agreed upon file format that can be viewed using Navisworks JetStream v5.

7. The following changes shall be incorporated into the drawings and model:

- RFIs, ASIs, and Owner changes
- Changes in the sequence of work
- Field modifications
- Shop drawing review comments
- Changes requested by the Construction Manager

8. All revised 3D model or 2D drawing submittals shall have a written narrative to define changes from previous submittals. Typical

drafting techniques such as 'clouds' or 'bubbles' are acceptable means of tracking changes on the 2D drawings. Layer control shall be used to define changes in the 3D model. All revisions shall be shown in both 2D and 3D formats.

9. The working 3D model will be shared with the Trade Contractors and design team at least once every two weeks. This will be performed by posting the model to the project FTP site. The Trade Contractor will post the native file format and an agreed upon file format as defined above.

10. The 3D modeling conventions will be established at a pre-detailing meeting to be attended by:

- Concrete Contractor and detailer
- Steel Fabricator and detailer
- Mechanical/Electrical/Plumbing Contractors and detailers

11. The Trade Contractor will submit its 3D modeling software and proposed file format(s) for approval prior to proceeding with detailing.

12. The Trade Contractors are advised that the model shall be shared among all trades and shall be the basis of coordination and fabrication. Costs incurred for post-coordination changes caused by unauthorized deviations from the model shall be borne by the Trade Contractor that initially deviated from the model. This determination is at the sole discretion of the Construction Manager.

13. The base architectural BIM will be created using AutoDesk's Revit Building.

14. The 3D modeling effort is intended to augment and assist in the MEP coordination process outlined in the Bid Documents. Before first submission shop drawings the elements shall be first pass coordinated in the 3D model. The model is intended to find conflicts before shop drawings are reviewed and approved.

On Site Coordination Meetings

BIM brings a completely new approach to coordination meetings. Typically, coordination meetings use a team approach to identifying problem areas on the drawings. Problems are identified during the meetings, a proposed solution is agreed upon, and the subcontractor will

incorporate these revisions for the following meeting. This style tends to be very time consuming.

In contrast, a BIM coordination meeting allows for problems to be addressed prior to these meetings and the proposed solutions to be discussed during the meeting itself. General Contractors using BIM for coordination will require subcontractors to submit models well in advance to a coordination meeting being held. In between meetings, the General Contractor's 'BIM Coordinator' will run clash detection reports on their own or in junction with subcontractors. These reports are then distributed to all team members. This increases collaboration between Subcontractors, Designers, & the Construction Team.

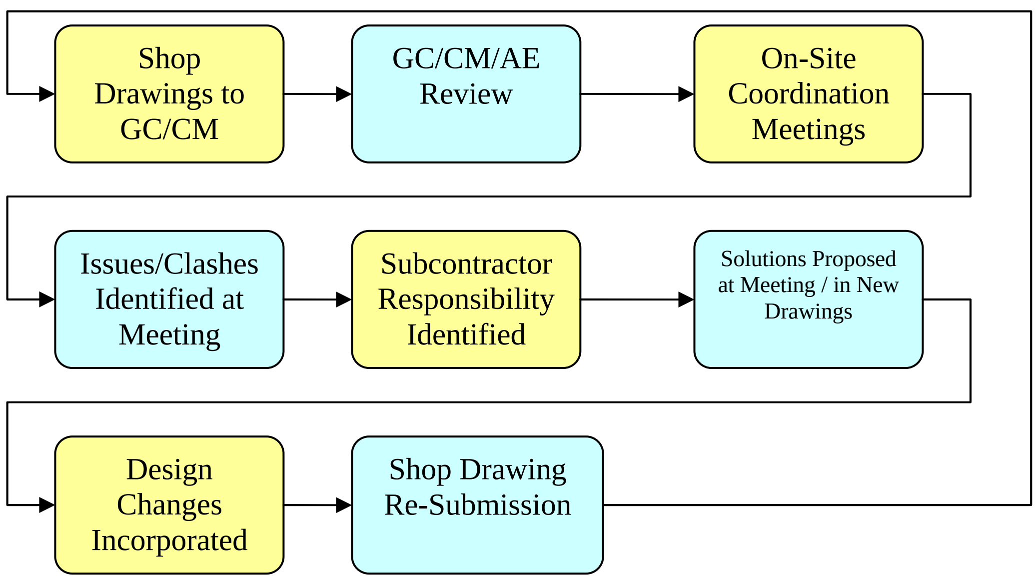
This approach allows a subcontractor or designer to propose a solution or multiple solutions to an issue at the next meeting. The meeting time can be used to discuss options and finalize a solution instead of spending time just identifying problem areas. Although many clash detection issues can be caught in between meetings, model review is still performed during meetings. Model review is performed to confirm incorporated design/coordination changes and to pin point any new issues. Examples of clash detection reports that would be distributed to the construction team and flow charts of the coordination process can be seen below.

An interesting, underlying theme found here were different perspectives of BIM implementation and the elimination of "finger pointing". The perspective of BIM implementation between GC's/CM's and Subcontractors was very different. Subcontractors tend to be very willing and excited about the idea of using BIM for coordination. Many subcontractors are already using BIM for their own in-house benefits. GC's & CM's can tend to have a very timid, unsure attitude towards implementing BIM and seem like they could be hindering the implementation. The other item of interest, "finger pointing", deals with Subcontractors coming to traditional coordination meetings and individuals not wanting to take responsibility for a coordination issue or trying to steer blame to another party. The use of BIM for coordination forces the Subcontractor to draft solutions to issues prior to meetings and this eliminates "finger pointing".

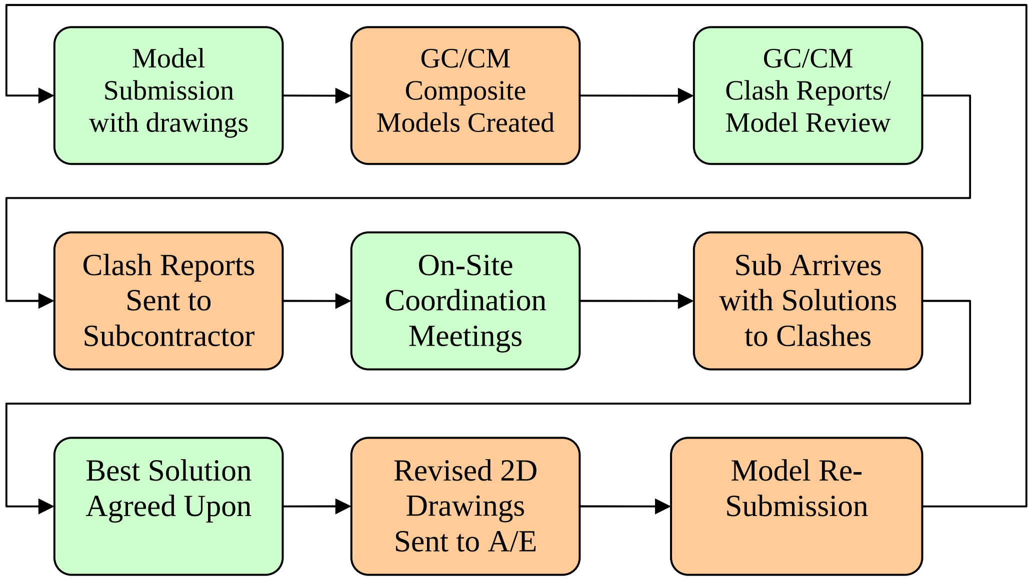
To perform these on-site coordination meetings some small additions must be made when using BIM. The most commonly used coordination strategy is the use of computer projectors and laptops for model review. Models can be projected onto screens or trailer walls, and then

manipulated for visualization purposes. Projectors such as these can be purchased for as little as $500.

Another common strategy is the use of 2D paper drawings in junction with the 3D models. This approach allows team members to make notes for model updates on the fly and helps relate 3D visualization to the 2D drawings. 2D drawings are necessary due to the inability of software applications to implement specification data, notes, and dimensions when viewed in 3D. Subcontractors will be required to make coordination and design changes addressed in these meetings to 3D models and 2D drawings to be submitted per the General Contractor's schedule.



Traditional Coordination Process



Coordination Using Building Information Modeling

Example Clash Detection Reports

Clash detection reports can be filtered to include only pertinent information to the trade contractor receiving the report. An example of this would be sending an HVAC/Plumbing contractor a report detailing ductwork and overhead piping interferences with structural steel. NavisWorks prepares clash detection reports, in HTML format, that detail the two items (or more) that have interferences issues, with the distance of interference, and a small thumbnail rendering of the trouble area. This allows for interferences to be identified and corrected quickly without presenting any more information than what is needed. An example of a NavisWorks clash detection report of Structural Framing vs. Plumbing can be seen in Figure 1 below.

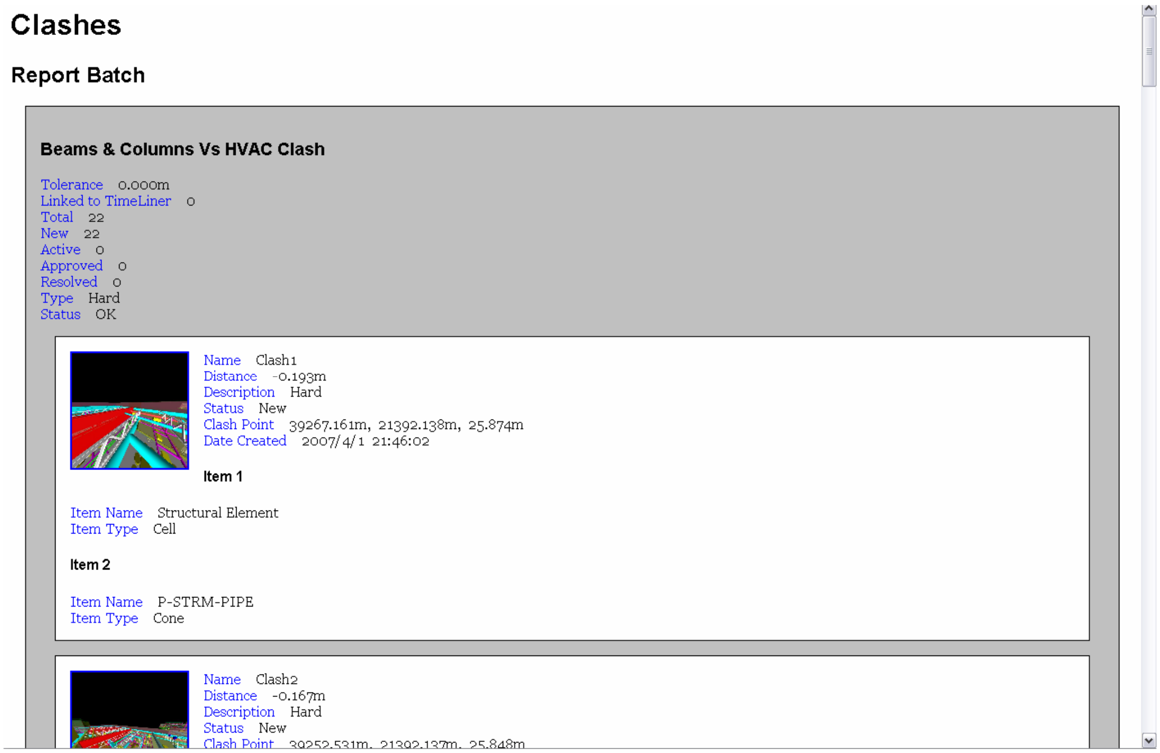


Figure 1- Example Clash Detection Report

Request for Information (RFI) Impact

One of the biggest benefits of a BIM and using a BIM for coordination is reducing the number of RFI's. RFI's are often populated due to missing dimensions, unclear documents, or coordination problems. BIM can often reduce the number of RFI's for a typical project to fewer than 100. The use of this tool helps to communicate the design and construction plan to subcontractors more clearly than 2D drawings and therefore reducing questions. When RFI's do occur a BIM is a useful tool for visualization. The General Contractor or Designer can include a JPEG image of the area in question for clarity purposes in the answer.

Model Updates and Shop Drawing Submissions

Although the BIM is used as the basis for coordination between MEP, Structural, and Architectural trades, revisions and submissions of 2D drawings still need to be performed. BIM software packages are tailored to combine model and 2D revisions into a single process. Typically, the 2D submission will follow the digital model submission to a FTP site.

Similar to the existing shop drawing process, some type of written submission noting design and coordination revisions is typically required. Revisions to 2D drawings can be easily communicated using normally accepted conventions such as clouding or text, but communicating changes through a BIM could be harder. Modelers are using two approaches for communication. Layering applications in BIM software is common but experienced contractors are also submitting text documents in digital formats. Written documents allow information such as specification data and exact dimensional changes to be clearly communicated quickly with little model manipulation.

Application to the Teachers Education & Technology Center (TETC) at Salisbury University

TETC is not a highly complex project with respect to MEP coordination; however, BIM could have benefited the project. Although not required, the structural steel contractor modeled the project for their own purposes. An addition of an MEP model would have been a big addition. To date the project has over 200 answered RFI's from subcontractors. BIM could have reduced this number greatly.

Many of these RFI's dealt with overhead coordination of MEP trades with Structural Steel. The high level of Audio Visual equipment in the building added coordination problems with floor penetrations, structural framing, and interior wall partitions. RFI's and Change Orders had to be written for relocating interior partitions and un-planned penetrations to structural framing. Building Information Modeling could have eliminated theses costly Change Orders and RFI's.

Conclusion

Building Information Modeling is a powerful tool that more construction companies need to utilize. The implementation of BIM at the construction phase of a project does not have to involve more risk or cost to a company. Construction companies need to become more informed about the process of BIM Implementation and form company specific master plans for implementation. A greater understanding of BIM as a construction tool, and less perception of BIM as a completely new construction approach will strengthen BIM Implementation. As more General Contractors and Subcontractors implement BIM, the push for and pressure will become greater for Design Professionals to design buildings using intelligent, 3D models.

Analysis 2

Pre-fabricated Metal Stud Crete® Panels-Structural Breadth

Background

The current façade design calls for stick built 3-5/8" masonry on a 7-5/8" metal stud back-up with exterior sheathing board, 1" cavity board insulation and sheet membrane air barrier. Masonry is attached to the structure using 6"x6" continuous clip angles welded to pour stops which are attached to spandrel beams. 4"-9" Architectural Pre-Cast Concrete spandrels are featured at each floor level and rest on the 6"x 6" angles as well. Due to owner delays, completion of the façade has dictated the start of interior partitions due to dry-in issues.

Methods

- Perform Quantity Take-Off of Existing Façade
- Complete Cost & Schedule Comparison of Two Systems
- Analyze Attachment Detail
- Perform Structural Analysis of Spandrel Beams to Determine If Downsizing Is Feasible

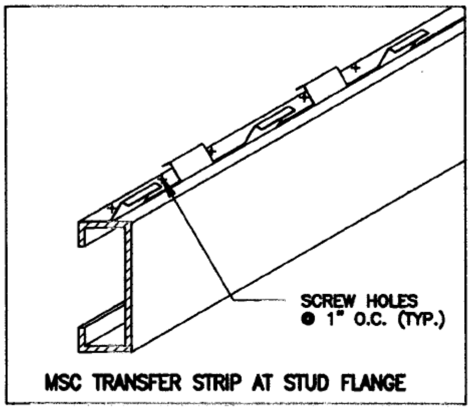
Resources

- Holder Construction Company
- Metal Stud Crete® Panel Company
- Architectural Engineering Faculty
- Endicott Clay Products Company
- AISC Steel Design Guide 22
    - Façade Attachments to Steel-Framed Buildings

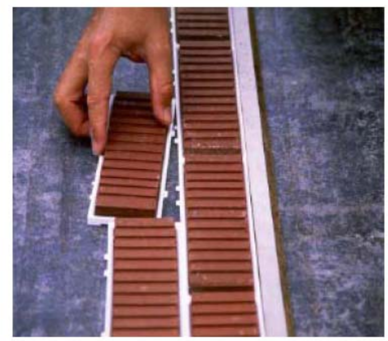
Proposed System

The proposed façade system is a pre-fabricated panel system called the Metal Stud Crete® system. The Metal Stud Crete® system consists of light-gauge metal framing, shear-transfer strips, 2.5" of reinforced pre-cast concrete, and a thin-brick facing. The shear-transfer strips create a composite system between the concrete and metal studs. Various manufacturers of thin brick can be used such as the Endicott or Scott Systems. Panels can also be sandblasted for a limestone like finish.

To fabricate the Metal Stud Crete® lanels large fiberglass casting tables with rollers are used. Cold formed metal framing is fabricated into the correct panel sizes then the "Y" shaped shear strips are screwed to the front of the panels. Thin brick, any necessary molds, and reinforcing are placed in the bottom on the casting forms. The panels are then placed in the casting forms and secured for the proper concrete thickness. Concrete is then poured into the forms, cured, and forms are striped. The panels can be fabricated up to 16' tall and 40' wide. Typical panels for the TETC project will be approximately 15'x15'.



Scott Systems & Endicott Brick both fabricate thin brick for casting into pre-cast concrete panels. The use of thin brick on the Metal Stud Crete® system requires more labor because each brick has to be hand laid into the forms and snapped together using the thin brick gaskets provided. After casting these gaskets must be removed by hand.



For the TETC project, Panels spanning one floor vertically and 15' in width will be used. The panels will be approximately 9" thick consisting of 5-5/8" of stud back up with 2.5" of concrete with a 0.5" brick facing. The Architectural Pre-Cast spandrels will be incorporated into the top of these panels.

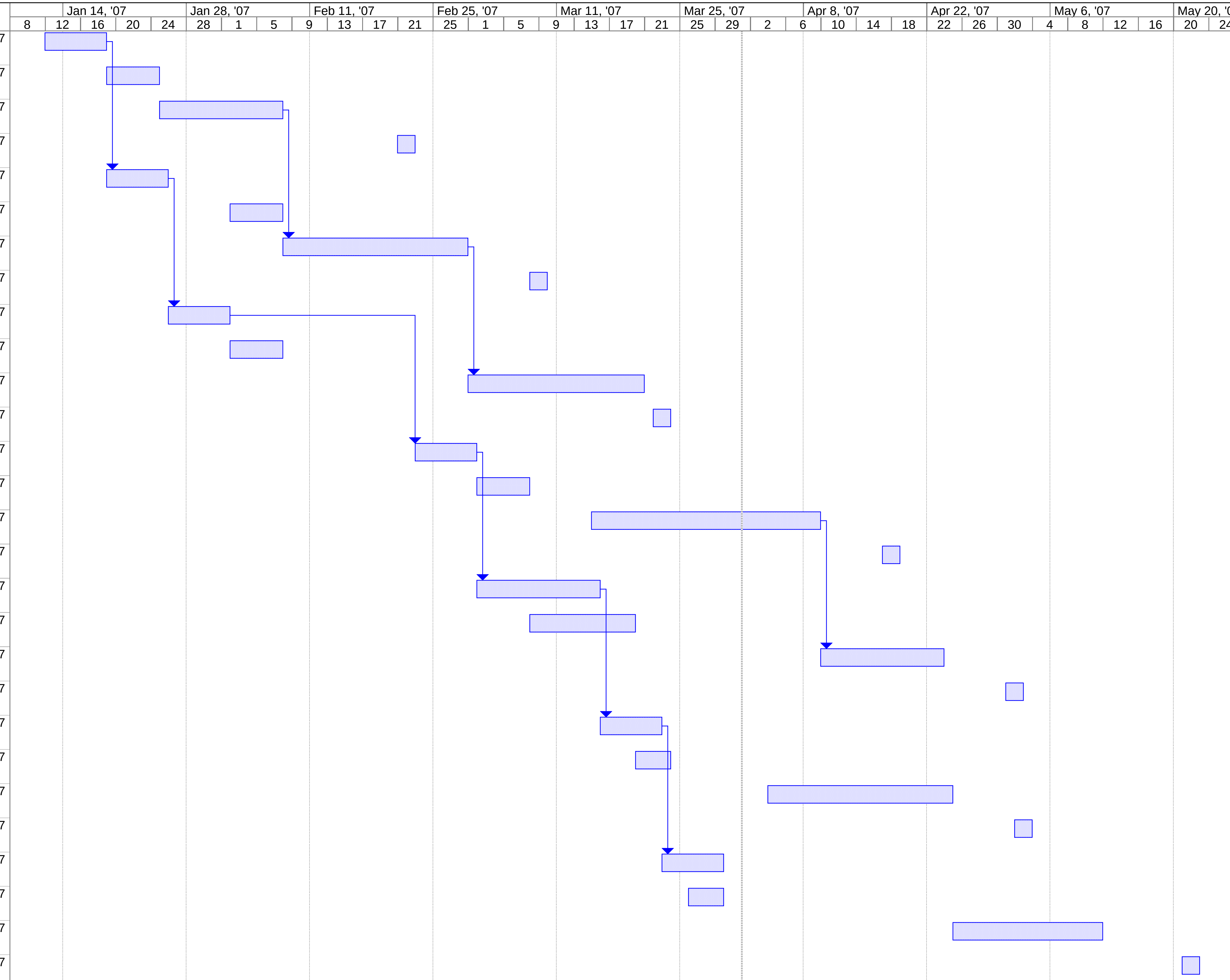
Panels will be attached to the existing steel spandrel beams using angle clips running continuously at 4' O.C spacing. After erection, all panel joints and perimeters must be caulked for moisture control. The use of this system allows for grade beam shelves to be eliminated for masonry bearing at the ground floor. This makes formwork unnecessary and allows an accelerated grade beam placement method that is analyzed in the following analysis

Schedule Comparison

The Metal Stud Crete® system provides very significant schedule savings in erection time. The panelized system reduces schedule time by 51% from 91 to 45 day durations. The schedule acceleration allows interior finishes to begin nearly 8 weeks early. A production rate of 12 panels per day was used to calculate the schedule.

Both the panelized and stick built systems construct one elevation of the building at a time, following the structural steel sequence. One negative impact of the panelized system is increase durations for caulking panels. The 15’ x 15’ panels increase the number of construction/control joints by a factor of 3. However, quick erection of panels allows a caulking crew to closely following the completed panel erection. The use of these panels also eliminates the need for hoisting of Architectural Pre-Cast Spandrels. Summary schedules of the existing façade system and the proposed system can be found on the following 2 pages for comparison.

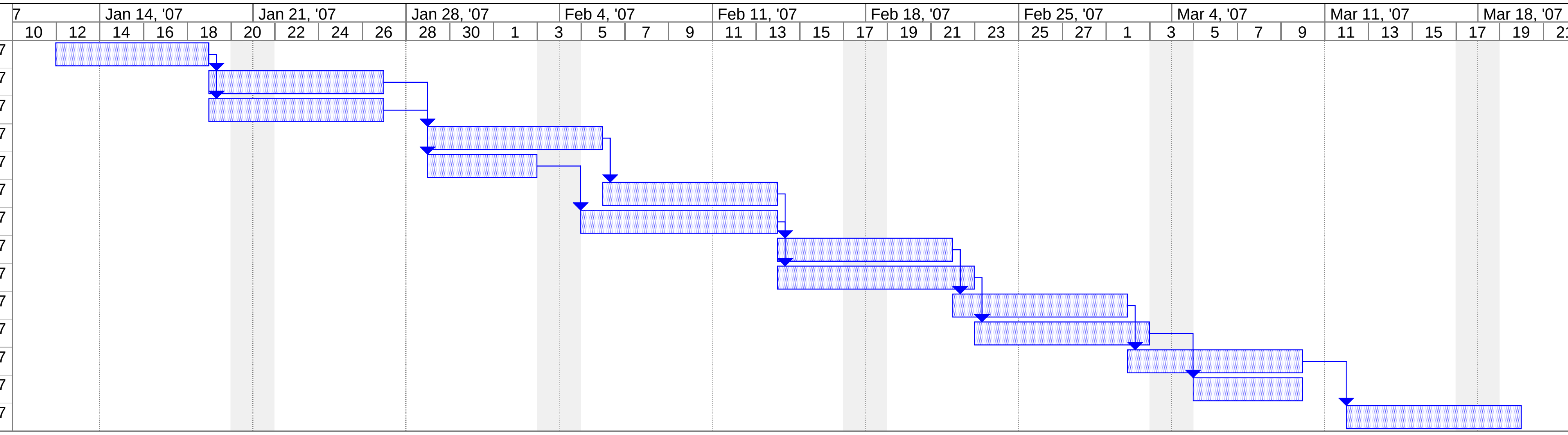
ID	Task Name	Duration	Start	Finish
1	Exterior Studs & Sheating Elevation 1	5 days	Fri 1/12/07	Thu 1/18/07
2	Air Barrier Elevation 1	4 days	Fri 1/19/07	Wed 1/24/07
3	Brick Masonry Elevation 1	10 days	Thu 1/25/07	Wed 2/7/07
4	Caulking Elevation 2	2 days	Wed 2/21/07	Thu 2/22/07
5	Exterior Studs & Sheating Elevation 2	5 days	Fri 1/19/07	Thu 1/25/07
6	Air Barrier Elevation 2	4 days	Fri 2/2/07	Wed 2/7/07
7	Brick Masonry Elevation 2	15 days	Thu 2/8/07	Wed 2/28/07
8	Caulking Elevation 2	2 days	Thu 3/8/07	Fri 3/9/07
9	Exterior Studs & Sheating Elevation 3	5 days	Fri 1/26/07	Thu 2/1/07
10	Air Barrier Elevation 3	4 days	Fri 2/2/07	Wed 2/7/07
11	Brick Masonry Elevation 3	14 days	Thu 3/1/07	Tue 3/20/07
12	Caulking Elevation	2 days	Thu 3/22/07	Fri 3/23/07
13	Exterior Studs & Sheating Elevation 4	5 days	Fri 2/23/07	Thu 3/1/07
14	Air Barrier Elevation 4	4 days	Fri 3/2/07	Wed 3/7/07
15	Brick Masonry Elevation 4	18 days	Thu 3/15/07	Mon 4/9/07
16	Caulking Elevation 4	2 days	Tue 4/17/07	Wed 4/18/07
17	Exterior Studs & Sheating Elevation 5	10 days	Fri 3/2/07	Thu 3/15/07
18	Air Barrier Elevation 5	8 days	Thu 3/8/07	Mon 3/19/07
19	Brick Masonry Elevation 5	10 days	Tue 4/10/07	Mon 4/23/07
20	Caulking Elevation 5	2 days	Tue 5/1/07	Wed 5/2/07
21	Exterior Studs & Sheating Elevation 6	5 days	Fri 3/16/07	Thu 3/22/07
22	Air Barrier Elevation 6	4 days	Tue 3/20/07	Fri 3/23/07
23	Brick Masonry Elevation 6	15 days	Wed 4/4/07	Tue 4/24/07
24	Caulking Elevation 6	2 days	Wed 5/2/07	Thu 5/3/07
25	Exterior Studs & Sheating Elevation 7	5 days	Fri 3/23/07	Thu 3/29/07
26	Air Barrier Elevation 7	4 days	Mon 3/26/07	Thu 3/29/07
27	Brick Masonry Elevation 7	13 days	Wed 4/25/07	Fri 5/11/07
28	Caulking Elevation 7	2 days	Mon 5/21/07	Tue 5/22/07



Project: Masonry Schedule
Date: Sun 4/1/07

Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			

ID	Task Name	Duration	Start	Finish
1	Erect Wall Panels Elevation 1	5 days	Fri 1/12/07	Thu 1/18/07
2	Caulk Wall Panels Elevation 1	6 days	Fri 1/19/07	Fri 1/26/07
3	Erect Wall Panels Elevation 2	6 days	Fri 1/19/07	Fri 1/26/07
4	Caulk Wall Panels Elevation 2	6 days	Mon 1/29/07	Mon 2/5/07
5	Erect Wall Panels Elevation 3	5 days	Mon 1/29/07	Fri 2/2/07
6	Caulk Wall Panels Elevation 3	6 days	Tue 2/6/07	Tue 2/13/07
7	Erect Wall Panels Elevation 4	7 days	Mon 2/5/07	Tue 2/13/07
8	Caulk Wall Panels Elevation 4	6 days	Wed 2/14/07	Wed 2/21/07
9	Erect Wall Panels Elevation 5	7 days	Wed 2/14/07	Thu 2/22/07
10	Caulk Wall Panels Elevation 5	6 days	Thu 2/22/07	Thu 3/1/07
11	Erect Wall Panels Elevation 6	6 days	Fri 2/23/07	Fri 3/2/07
12	Caulk Wall Panels Elevation 6	6 days	Fri 3/2/07	Fri 3/9/07
13	Erect Wall Panels Elevation 7	5 days	Mon 3/5/07	Fri 3/9/07
14	Caulk Wall Panels Elevation 7	6 days	Mon 3/12/07	Mon 3/19/07



Project: Wall Panel Schedule
Date: Sun 4/1/07

Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			

Cost Comparison

The only negative impact of the pre-fabricated Metal Stud Crete® panels is an increase in cost. The Metal Stud Crete® panels result in a 29% increase of approximately $820,000 in the façade system cost. These costs are likely a result of the fabrication and shipping process. Typical panels would be used throughout the building, but many panels will be unique to coordinate with the architecture of the façade. The 15' x 15' panels also have to be transported to site via truck. A cost comparison of the two systems can be seen below in Table 1-Façade Cost Summary Comparison.

Metal Stud Crete ® Panels		
Pre-Cast Panels with Stud Back-up		
Façade Area (SF)	Unit Price ($/SF)	Total Cost ($)
107,137	$28.00	$2,999,836.00
Endicott® Thin Brick		
107,137	$6.00	$642,822.00
	Total Cost	**$3,642,658.00**
Conventional 4" Hand-Layed Brick		
Façade Area (SF)	Unit Price ($/SF)	Total Cost ($)
107,137	$26.32	$2,819,845.84
	Total Cost	**$2,819,845.84**
	Difference	**$822,812.16**

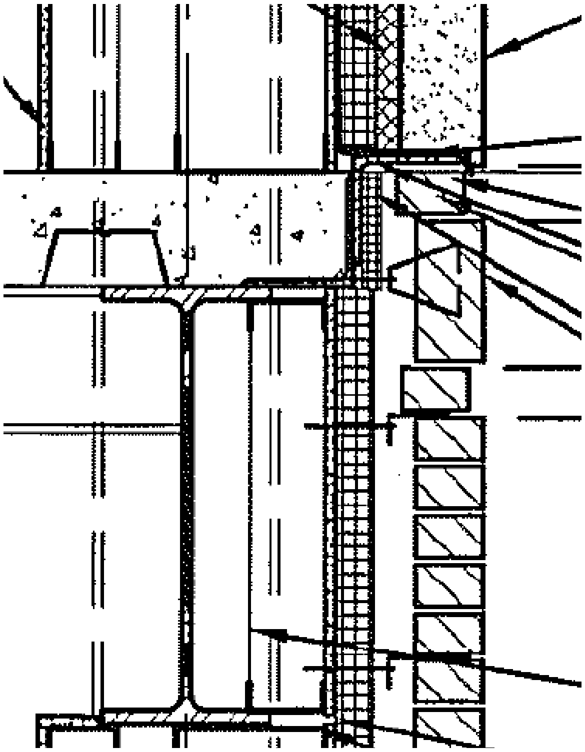
Table 1- Facade Cost Summary Comparison

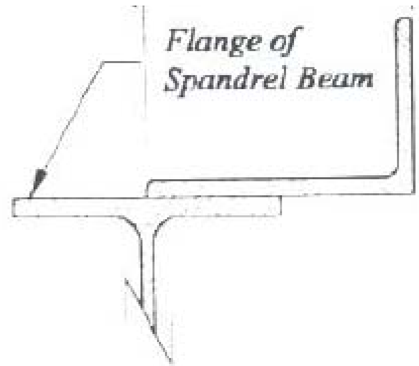
* Unit Prices obtained from Holder Construction Companpy & The Metal Stud Crete® Companyy

Connection Details

Small modifications to the masonry connection details must be made in order to utilize the Metal Stud Crete® panels. Currently, the masonry assembly rests on 6"x 6x 1/2" continuous angles welded to the pour stops. The proposed connection detail uses 6"x 6x 1/2" continuous angles attached to the concrete pour stops and a bolt connection to the metal framing of the panel.

At the base of the panels connection is made from the bottom track metal framing to the grade beam/ SOG concrete using ½" wedge anchors. Vertical panel-to-panel connections are made using self taping screws between metal framing. Theses joints are then caulked after completed erection. These connection details can be seen below in Figures 2-5.





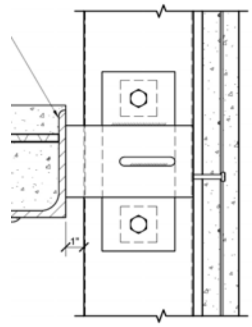


Figure 2- Existing Masonry Connection

Figure 3- Metal Stud Crete Connection to Angle/ Pour Stop

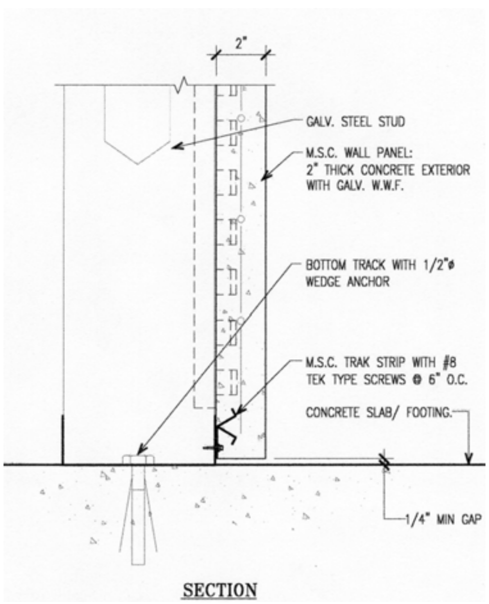


Figure 4-Slab/ Foundation Base Connection

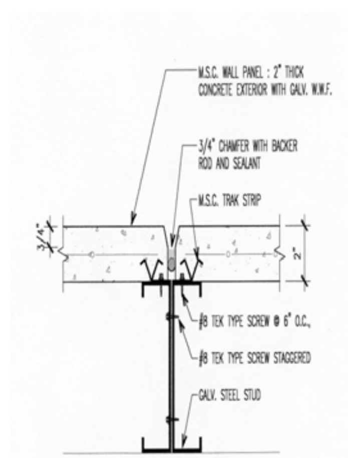


Figure 5- Panel-to Panel Connection

Structural Impact

The largest benefit of the Metal Stud Crete ® system is the reduction in load from 45 PSF for brick to 36 PSF for the panel system. As can be seen above in the connection details, both systems are supported by angle supports connected to wide flange spandrel beams. The nature of the connection creates an eccentric, torsional load on the spandrel beams. Regardless of the façade system, the torsional load must be accounted for in the beam design. Comparison of loads and member sizes can be seen below in Table 2- Spandrel Beam Analysis.

The AISC Façade Attachments to Steel-Framed Buildings Guide was used to perform a structural analysis of the existing spandrel beams and to determine if downsizing these members was feasible. This guide defines steps to analyze a steel spandrel beam for torsional effects due to a façade attachment. This process checks beams for shear, flexure, deflection and rotation. Deflections and rotations of both the spandrel beam and roll beams framing into the spandrel beam are calculated to determine capacity.

Three typical spandrel beams were checked in this analysis and each beam was evaluated for downsizing the member. A W30 x 90, W27 x 94, and W21 x 44 were checked. All three beams were able to be downsized, but only the larger two members were chosen for downsizing. The W21 x 44 member was not downsized to keep more members typical. Adjacent framing to the W21 x 44 was of the same size. Additionally, downsizing of the W21 x 44 would introduce a more shallow shape than the roll beams framing into the spandrel beam and this would increase the possibility for shear failure in the connection due to coping. The W30 x 90 and W27 x 94 members were both downsized to W24 x 76 to introduce more typical members. Detailed calculations of this process can be found in Appendix A.

Spandrel Beam Analysis		
	Metal Stud Crete ®	**Traditional Brick Façade**
Unit Weight (PSF)	36	45
Member Size	W 24 x 76	W 30 x 90
	W 24 x 76	W 27 x 94
	W 21 x 44	W 21 x 44

Table 2- Spandrel Beam Analysis

Cost Impact of Downsizing Beams

The cost savings of downsizing spandrel beams for all the W30 x 90 and W27 x 94 members in the building. Continuing the structural analysis for the remaining spandrel beams would increase the number of beams to be downsized and increase cost savings. The results of the cost impact are seen below in Table 3- Spandrel Beam Steel Savings.

Spandrel Beam Steel Savings						
Qty.	**Shape**	**lb/ft**	**Length (LF)**	**Tons**	**Unit Price ($/Ton)**	**Total Cost**
17	W30 x 90	90	30	23	$3,000.00	$68,850.00
10	W 27 x 94	94	30	14	$3,000.00	$42,300.00
27	W 24 x 76	76	30	31	$3,000.00	$92,340.00
					Cost Savings	**$18,810.00**

Table 3- Spandrel Beam Steel Savings

* Unit price obtained from Holder Construction Company. Price accounts for fabrication and installation

Conclusion

Although the Metal Stud Crete® system introduces a higher first cost, it produces significant schedule acceleration and a positive impact on the foundation system. The 29% increase in cost is offset by cutting schedule time nearly in half, eliminating the need for cold weather protection, and scaffolding. The panelized system also eliminated the need for a grade beam self for masonry bearing and reduced structural framing costs by downsizing members.

Panelized façade systems should be considered more often for the structural impacts as well. To further this investigation, the façade attachment could be analyzed with support conditions at the columns. Due to time, this analysis could not be performed. Spanning the façade panels the width of the column bay would greatly reduce the spandrel beam sizes and eliminate the torsional effect. The columns support the torsional load much better. In this case, the Metal Stud Crete ® panels could span from column to column with a maximum span of 33'.

Analysis 3

Alternative Grade Beam Placement Method

Background

The general contractor originally proposed that all grade beams be excavated and formed using stick built forms. After concrete placement, the forms were to be stripped and the grade beams were to be backfilled. This method requires more labor and material cost for excavation and added costs and schedule time for formwork. An excavated trench for a grade beam to be formed in can be seen in the photo to the right.

Goal

The goal of this analysis is to determine if placing concrete into excavated trenches can significantly reduce schedule time, labor, and material costs. The proposed placement method eliminates the need for formwork and decreases the volume of excavation. It is important to note that although very little excavated material will be hauled off site, this method could reduce the need for backfill when formwork is stripped.

Methods

- Concrete Quantity Take-Off
  - Determine the quantity of concrete in Cubic Yards
  - Apply waste factor for waste concrete
- Estimate Formwork Savings
  - Labor & Material
- Calculate Schedule Reduction

Resources

- Holder Construction Company
- R.S. Means Cost Works 2005

Results

Upon completing this analysis, it can be determined that placing concrete into excavated trenches is a more efficient method. Although there is minimal impact on the excavation costs, the schedule and formwork savings are significant. The cost, schedule, & material analyses can be seen in detail in the following sections.

Cost Analysis

To complete this analysis, soil excavation and concrete quantities had to be determined using the structural foundation plans and values obtained from the General Contractor, Holder Construction Company. Actual widths of excavation for formed grade beams were obtained from Holder Construction Company. A detailed quantity take-off of concrete material and proposed soil excavation were carried out. Excavation quantities were calculated using a depth from grade (30’-6”) to bottom of grade beam elevation. Formwork quantities were calculated from the structural foundation plans using total contact area of formwork.

The expected outcome of a reduction in formwork costs and slight increase in concrete material costs were confirmed. As can be seen below in Table 4-Grade Beam Cost Comparison, the proposed placement method introduces a savings of approximately 64% to the foundation budget. Due to little to no excavated material being hauled off site there is very little impact to excavation costs. A 15% waste factor was applied to the concrete quantities due to placing concrete directly into trenches. Labor and Material Savings for eliminated formwork far out weigh the additional cost of concrete. Depending on trench location, concrete placement will still be directly out of chute or from concrete pump. A detailed copy of the of the material cost estimate can be found on the following two pages in Tables 5-8.

Overal Cost Comparision		
	Formed Grade Beams	**Excavated Trenches**
Formwork	$81,274.58	-
Concrete	$36,800.00	$42,550.00
Excavation	$4,416.03	$1,681.30
Total Cost	**$122,490.61**	**$44,231.30**

Table 4- Grade Beam Cost Comparison

Concrete Cost Impact						
Grade Beam	**Width (ft.)**	**Length (ft.)**	**Depth (ft)**	**CY**	**Unit Price ($/CY)**	**Total Cost ($)**
1' W x 2' D	1	10	2	1	$115.00	$85.19
1.5' W x 2' D	1.5	525.83	2	58	$115.00	$6,718.94
1.5' W x 2.5' D	1.5	104.09	2.5	14	$115.00	$1,662.55
2' W x 2' D	2	353.84	2	52	$115.00	$6,028.39
2' W x 2.5' D	2	583.25	2.5	108	$115.00	$12,421.06
2' W x 3' D	2	118	3	26	$115.00	$3,015.56
2' W x 3'-6" D	2	61	3.5	16	$115.00	$1,818.70
2'-2" W x 2' D	2.17	30	2	5	$115.00	$554.56
2'-2" W x 3' D	2.17	72	2	12	$115.00	$1,330.93
3' W x 2' D	3	94.67	2	21	$115.00	$2,419.34
3'-6" W x 2' D	3.5	14	2	4	$115.00	$417.41
3'-8"x2'	3.67	10.67	2	3	$115.00	$333.58

Original Cubic Yards			320
Original Total Cost			**$36,800.00**
15% Waste Factor Increase			48
Total Cubic Yards			368
Increased Cost ($115/CY)			**$5,635.00**
Total Cost			**$42,550.00**

Table 5- Concrete Cost Impact

* 15% Waste factor assumed for placing concrete directly into excavated trenches

** Concrete Unit prices obtained from Holder Construction Company. Excluding reinforcing cost

Formwork Material Savings					
Grade Beam	**Length (ft.)**	**Depth (ft)**	**Contact Area (SF)**	**Unit Price ($/SF)**	**Total Material ($/SF)**
1' W x 2' D	10	2	40	$7.00	$280.00
1.5' W x 2' D	525.83	2	2103.32	$7.00	$14,723.24
1.5' W x 2.5' D	104.09	2.5	520.45	$7.00	$3,643.15
2' W x 2' D	353.84	2	1415.36	$7.00	$9,907.52
2' W x 2.5' D	583.25	2.5	2916.25	$7.00	$20,413.75
2' W x 3' D	118	3	708	$7.00	$4,956.00
2' W x 3'-6" D	61	3.5	427	$7.00	$2,989.00
2'-2" W x 2' D	30	2	120	$7.00	$840.00
2'-2" W x 3' D	72	2	288	$7.00	$2,016.00
3' W x 2' D	94.67	2	378.68	$7.00	$2,650.76
3'-6" W x 2' D	14	2	56	$7.00	$392.00
3'-8"x2'	10.67	2	42.68	$7.00	$298.76
		Total Contact Area (SF)	**9015.74**		
		Total Formwork ($)			**$63,110.18**

Table 6- Formwork Material Savings

* Formwork Unit prices obtained from Holder Construction Company

Labor & Schedule Savings

The proposed placement method produced labor savings in formwork and excavation of approximately $18,000 and $3,000 respectively. Both excavation and concrete placement can be accelerated by 4 and 15 days respectively. This allows column piers and erection of steel columns to begin earlier. It is noted that the acceleration in excavation schedule could be impacted by reduced productivity due to exact excavations for grade beam trenches needed. The results of the labor and schedule savings can be seen below in Tables 7-10.

Original Excavation						
Grade Beam	**Width of Excavation (ft.)**	**Length (ft.)**	**Depth to Bottom GBM (ft)**	**BCY**	**Labor & Equipment ($/BCY)**	**Total Cost**
1' W x 2' D	5	10	2	4	$5.20	$19.26
1.5' W x 2' D	5	525.83	2	195	$5.20	$1,012.71
1.5' W x 2.5' D	5	104.09	2.5	48	$5.20	$250.59
2' W x 2' D	5	353.84	2	131	$5.20	$681.47
2' W x 2.5' D	5	583.25	2.5	270	$5.20	$1,404.12
2' W x 3' D	5	118	3	66	$5.20	$340.89
2' W x 3'-6" D	5	61	3.5	40	$5.20	$205.59
2'-2" W x 2' D	5.5	30	2	12	$5.20	$63.56
2'-2" W x 3' D	5.5	72	2	29	$5.20	$152.53
3' W x 2' D	6	94.67	2	42	$5.20	$218.79
3'-6" W x 2' D	7	14	2	7	$5.20	$37.75
3'-8"x2'	7	10.67	2	6	$5.20	$28.77
				849	**Total Cost**	**$4,416.03**

Table 7- Original Excavation Costs

Proposed Excavation						
Grade Beam	**Width of Excavation (ft.)**	**Length (ft.)**	**Depth to Bottom GBM (ft)**	**BCY**	**Labor & Equipment ($/BCY)**	Total Material Cost
1' W x 2' D	1	10	2	1	$5.20	$3.85
1.5' W x 2' D	1.5	525.83	2	58	$5.20	$303.81
1.5' W x 2.5' D	1.5	104.09	2.5	14	$5.20	$75.18
2' W x 2' D	2	353.84	2	52	$5.20	$272.59
2' W x 2.5' D	2	583.25	2.5	108	$5.20	$561.65
2' W x 3' D	2	118	3	26	$5.20	$136.36
2' W x 3'-6" D	2	61	3.5	16	$5.20	$82.24
2'-2" W x 2' D	2.5	30	2	6	$5.20	$28.89
2'-2" W x 3' D	2.5	72	2	13	$5.20	$69.33
3' W x 2' D	3	94.67	2	21	$5.20	$109.40
3'-6" W x 2' D	4	14	2	4	$5.20	$21.57
3'-8"x2'	4	10.67	2	3	$5.20	$16.44
				323	**Total Cost**	**$1,681.30**

Table 8- Proposed Excavation Costs

** Labor and cost data obtained from R.S. Means Cost Works 2005.
(Labor= $3.58/ BCY, Equip.= $1.62/ BCY)

*** 8 hour work days assumed

Labor Savings			
Labor			
Crew	Unit Price ($/HR)	Duration (Hrs)	Total Cost ($)
1 Foreman	$56.47	120	$6,776.40
4 Carpenters	$53.35	120	$6,402.00
1 Laborer	$41.55	120	$4,986.00
		Total Labor Cost ($)	**$18,164.40**

Table 9- Labor Savings

Schedule Impact			
Item	**BCY**	**BCY/Day**	**Days**
Formed Grade Beam Excavation	850	150	6
Trench Grade Beam Excavation	323	150	2
		Difference	**4 Days**
Formwork			
Contact Area (SF)	Daily Output (SF/Day)	Schedule Acceleration	
9016	600	**15 Days**	

Table 10- Schedule Impact

* Grade Beam excavation unit prices & formwork labor rates taken from R.S. Means Cost Works 2005

** Formwork schedule durations obtained from Holder Construction Company

*** Formwork crew includes 5 carpenters and 1 Laborer

Conclusion

The major time and material savings found through this analysis make it obvious that an excavated trench method is very feasible and proficient method for foundation concrete placement. It was learned that this placement method is mostly helpful for formwork cost and time savings. A further analysis of this method could look at the space planning and layout issues of using excavated trenches for grade beams. To make this method efficient the trenches must be excavated rather precisely to avoid too much concrete waste. Additionally, quality control/assurance comparisons could be completed for the two methods.

Analysis 4

Acoustical Analysis of Interior Partitions- Breadth

Background

Good classroom acoustics are vital when the teaching and learning process relies strongly on verbal communication. Transmission of noise from one learning environment to another can hinder learning when speech communication from an instructor is difficult to understand. When concentration on speaking and listening can be removed teaching tends to be more effective. Good classroom acoustics can reduce repetition by instructors and reduce the number of questions by students. Classroom acoustics have an impact on typical students' ability to learn and especially on students with disabilities.

The American National Standards Institute has written the standard for Acoustical Performance in School Buildings. This standard defines acceptable Sound Transmission Class (STC), Impact Isolation Class, and Reverberation Time values for school buildings. Table 11 below includes STC values for three school spaces. STC, evaluated in this analysis, is a single number rating for sound transmission loss through construction assemblies. The goal of this analysis is to calculate the required STC & Transmission Loss values for four receiving spaces, compare the values to the existing wall assemblies, and make appropriate recommendations.

American National Standards Institute Acoustical Peformance Criteria for Schools(ANSI Standard S12.60)		
Receiving Space	**Adjacent Space**	**STC Required**
Classroom	Bathroom	53
Classroom	Mechanical Room	60
Classroom	Classroom	50

Table 11- ANSI STC Criteria for Schools

Resources

- Penn State Architectural Engineering Faculty
- Textbook: Architectural Acoustics by M. David Egan
- Acoustical Society of America: American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools-ANSI S12.60
- Textbook: Architectural Acoustics by Marshall Long
- National Concrete Masonry Association TEK Note 13-1A

Methods

- Determine Noise Criteria Values for Critical Receiving Space
- Determine Absorption Coefficients of Floor, Wall, Ceiling, & Materials
- Calculate the Following

- Floor, Wall, & Ceiling Area of Critical Receiving Space
- Total Acoustical Absorption of Critical Noise Receiving Space
- Required Noise Reduction & Transmission Loss Values

- Compare Existing to Required Transmission Loss Values
- Compare ANSI S12.60 Required Sound Transmission Class Values to Existing Values
- Make Recommendations for Improvement If Necessary

Results

This analysis evaluated the Transmission Loss and Sound Transmission Class criteria for three different classroom spaces, all with different adjacent spaces. Adjacent bathroom, mechanical, and classroom spaces were chosen for analysis. Required Noise Reduction and Transmission Loss values were calculated using receiving room absorption values, transmitting room sound levels, and receiving room ambient sound levels.

Required Transmission Loss Values, calculated in decibels at 6 frequency bands, were determined for 4 classroom receiving spaces. The Transmission Loss values and the STC rating of the wall assemblies were then determined using tables in M. David Egan's Architectural Acoustics book. The calculated and existing values were then compared. The results of these calculations and comparisons can be seen in Tables 12-16 at the end of this section. The full length acoustical calculations can be found in the Appendix B of this report.

The expected outcome of this analysis was that the existing STC values of the partitions might be improved upon. The STC value of 52 for the spaces divided by only metal stud partitions fell just below the specified standard of 53 by ANSI S12.60. The ANSI Standard S12.60 of 53 is a minimum value for a classroom space. To improve on this rating, an additional layer of 5/8" gypsum wall board is recommended. This material addition will increase the STC Rating from 52 to 57. The cost of the material addition can be seen below in Table 12.

	Gypsum Board Cost		
Room	**Quantity**	**Unit Price ($/SF)**	**Total Cost ($)**
156	438	$0.89	$389.82
151	258	$0.89	$229.62
184	294	$0.89	$261.66
		Total Cost	**$881.10**

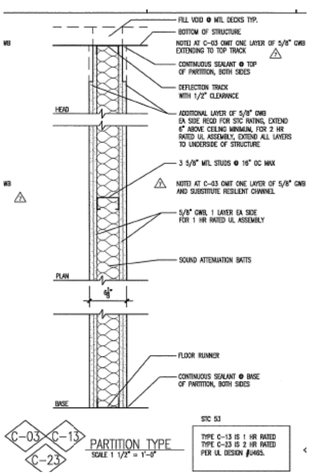
Table 12- Gypsum Board Material Cost

Currently, the partitions do not run entirely from floor to bottom of structure. Gypsum wall board is extended 6" above the acoustical ceiling panels. To further improve upon the room acoustics, the wall board could be extended to the bottom of the metal decking where the top track of the stud wall is attached.

Additionally, the acoustics of water flow through piping in the bathroom partition wall was checked. For 2" supply lines a value of 40 GPM was used to determine a water velocity of 4 ft/s. This value meets the maximum requirement for of 4 ft/s for 2" pipe specified in M. David Egan's Architectural Acoustics Text Book. This calculation can be seen below.

$$\mathbf{V = 0.4\ (Q/d^2) = 0.4\ [40gpm\ /\ (2")^{2}] = 4\ ft/s \leq 4\ ft/s\ OK}$$

Partition Acoustics Results



- Interior partition for Receiving Classrooms 151,156, & 184.
- 3 5/8" Metal Stud Wall
- 2 Layers 5/8" Gypsum Wall Board Each Side
- 3" Sound Attenuation Batt in Cavity
- STC Rated 52

Receiving Classroom 156	Area (SF)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Ambient Classroom Noise (NC-30)		52	45	40	36	34	33
Required Transmission Loss (dB)		**29**	**30**	**33**	**37**	**34**	**29**
Existing Construction TL (STC-52)		**38**	**52**	**59**	**60**	**56**	**62**
			ANSI Standard S12.60 STC				**53**
			Existing Partition STC				**52**
			STC Increase (1 Layer 5/8"GWB)				**5**
			Improved STC Rating				**57**
			STC+NC=82 ≥ 75 OK				

Table 13- Bathroom Space Transmitted to Tiered Lecture Space

Receiving Classroom 151	Area (SF)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Ambient Classroom Noise (NC-30)		52	45	40	36	34	33
Required Transmission Loss (dB)		**9**	**22**	**32**	**33**	**29**	**22**
Existing Construction TL (STC-52)		**38**	**52**	**59**	**60**	**56**	**62**

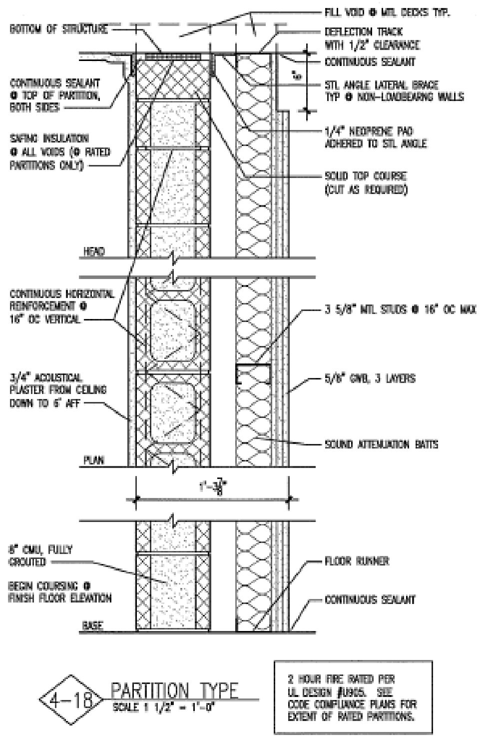
ANSI Standard S12.60 STC	**50**
Existing Partition STC	**52**
STC Increase (1 Layer 5/8"GWB)	**5**
Improved STC Rating	**57**
STC+NC=82 ≥ 75 OK	

Table 14- Tiered Lecture Space Transmitted to a 44 Seat Classroom

Receiving Classroom 184	Area (SF)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Ambient Classroom Noise (NC-30)		52	45	40	36	34	33
Required Transmission Loss (dB)		**13**	**23**	**30**	**31**	**30**	**27**
Existing Construction TL (STC-52)		**38**	**52**	**59**	**60**	**56**	**62**

ANSI Standard S12.60 STC	**50**
Existing Partition STC	**52**
STC Increase (1 Layer 5/8"GWB)	**5**
Improved STC Rating	**57**
STC+NC=82 ≥ 75 OK	

Table 15- Methods Laboratory Transmitted to a 44 Seat Classroom



- Interior Partition for Receiving Classroom 129
- 8" Reinforced, Fully Grouted CMU Wall
- 2" Air Space
- 3 5/8" Metal Stud Wall
- 3 Layers 5/8" Gypsum Wall Board
- 3" Sound Attenuation Batt in Cavity
- STC Rated 79

Receiving Classroom 129	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Classroom Noise (NC-30)	52	45	40	36	34	33
Required Transmission Loss (dB)	**29**	**35**	**39**	**42**	**43**	**42**
Equivalent STC Rating	**79**					
	ANSI Standard S12.60 STC					**60**
	Existing Partition STC					**79**
	STC+NC= ≥ 75 OK					

Table 16- Mechanical Equipment Room Transmitted to a 44 Seat Classroom

Conclusion

To ensure acoustically sound learning spaces, some of the analyzed partitions in the TETC building need to be slightly improved upon. The existing metal stud partitions fall slightly under the acceptable STC ratings in the America National Standards Institute specification for acoustical performance of learning spaces. For most sound transmissions, the partitions would likely be sufficient but additional layers of Gypsum Wall Board would make the learning spaces acoustically sound at wall times. The 8" CMU/Stud Wall partition was found to be far more

adequate than the ANSI specified standard. It can be concluded that designers often put too much emphasis on isolating noisy spaces such as mechanical rooms and not as much emphasis on other spaces. Sound isolation between two adjacent classrooms can be just as important for a good learning environment.

Technical Analyses Conclusions

The impacts of using a panelized façade provide benefits for many systems of the building. The panelized façade does have an increased cost of $800,000, but the system reduces schedule time by approximately 2 months. The smaller structural member sizes, due to lower dead weight, would allow some offsetting cost savings. An owner would need to evaluate positives and negatives of a building being completed more quickly, architectural aesthetics, and cost. For a critical schedule this system is a good solution.

The use of a panelized façade system eliminates the need for a grade beam shelf for first floor masonry load bearing. Without a masonry bearing shelf, the use of earth forms for grade beam concrete can be used to reduce grade beam costs by approximately $80,000 and accelerate the schedule by approximately 2-3 weeks. This savings helps to offset the increased façade cost also. This solution helps to accelerate the schedule out of the ground when delay can be the most critical.

Although acoustics are very important for learning spaces, I would not recommend the owner adding wall board material to partitions. The STC values are below the acceptable standards but not low enough that they would be critical. The additional cost of approximately $900 for adding wall board for only 3 walls could turn into a sizeable amount of money if the acoustical analysis was completed for the entire building. The acoustical improvements would be a good consideration if additional budget money became available.

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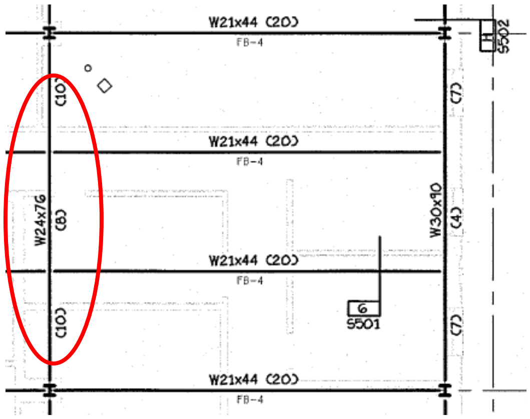
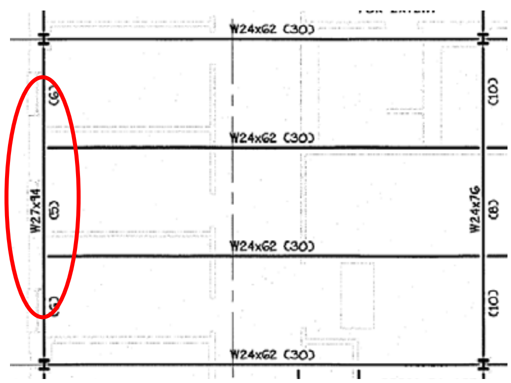
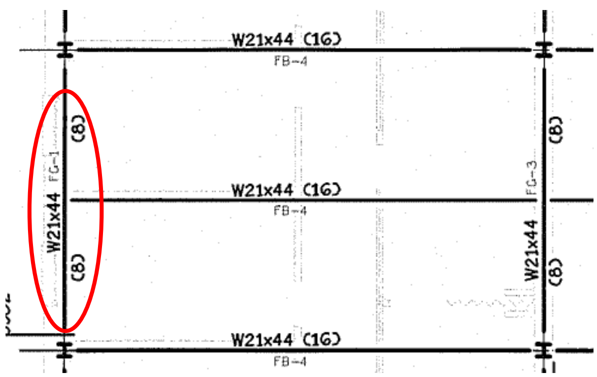
Appendix A
Spandrel Beam Calculations



Framing Plan for W30 x 90



Framing Plan for W27 x 94



Framing Plan for W21 x 44

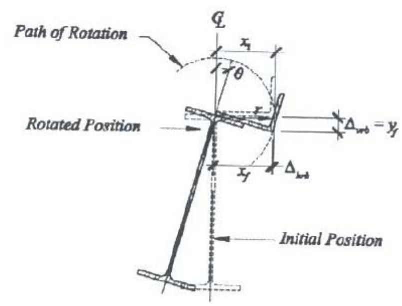


Fig. 6-19. Rigid body rotation about center of top flange.

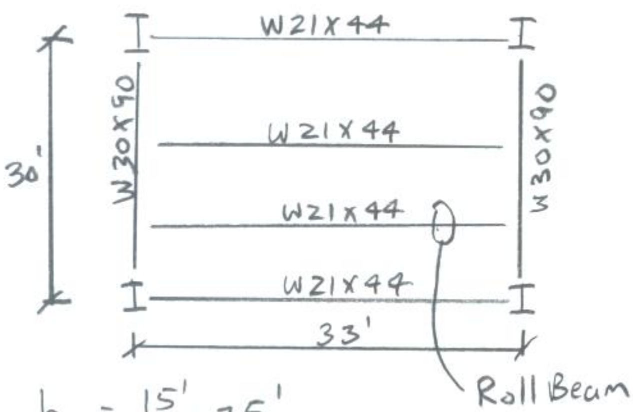
Beam Rotation Diagram

Josh Thompson

PENN STATE UNIVERSITY

CLASS: Senior Thesis
DATE: 4/6/07
ASSIGNMENT:

Spandrel Beam Analysis W30x90



$L = 30'$ $L_{T \text{ (Beam spacing)}} = 10'$

$S_{deck} = 10'$ (deck spacing) $L_{RB} = 33'$ (Roll Beam Length)

$e_h = 2''$ (angle vertical cantilever) $\ell_{eoD} = 6''$ (edge of deck dimension)

$h = 15'$ (Story ht) $h_c = 15'$ (ht. cladding hung)

$h_s = \frac{15'}{2} = 7.5'$ (Spandrel trib width for wind)

$S_c = 4'$ (facade connection spacing)

$e_{cw} = 10.5''$ (eccentricity of curtain wall)

$t_r = \frac{S_{deck}}{2} + \ell_{eoD} = 5.5'$ (trib. width for spandrel beam)

W30x90 Properties

$S_x = 245 \text{ in}^3$

$J = 2.84 \text{ in}^2$

$W_{no} = 75.2$ (normalized warping constant)

$d = 29.5''$

$t_w = 0.47''$

$I_x = 3610 \text{ in}^4$

W21X44 properties (Roll Beam)

$I_x = 843 \text{ in}^4$

Loads

$W_{dead} = 54$ psf

$W_{live} = 100$ psf

$W_{cw} = 36$ psf

$W_{wind} = 30$ psf

$W_{Dead} = 90 \frac{lb}{ft} + 54 \frac{lb}{ft^2}(5.5') = 387 \frac{lb}{ft}$

$W_{live} = 100 \text{ psf} \times 5.5' = 550 \frac{lb}{ft}$

$P_{cw} = 36 \text{ psf} \times 15' \times 4' = 2.16^k$

$W_u = 1.2(387) + 1.6(550) = 1.34 \frac{k}{ft}$

$P_u = 1.2(2.16) = 2.60^k$

$W_{wind} = 30 \text{ psf} \times \frac{15'}{2} = 225 \frac{lb}{ft}$

$t_{wind\,(torsion)} = 225 \frac{lb}{ft} \times \frac{2''}{12} = 38 \frac{ft\text{-}lb}{ft}$

$W_{cw} = 36 \text{ psf} \times 15' = 540 \text{ lb/ft}$

$t_{curtainwall} = 540 \frac{lb}{ft}\left(\frac{10.5''}{12}\right) = 473 \frac{ft\text{-}lb}{ft}$

$t_{total} = t_{cw} + t_{wind} = 473 \frac{ft\text{-}lb}{ft} + 38 \frac{ft\text{-}lb}{ft} = 511 \frac{ft\text{-}lb}{ft}$

(Uniform torsional moment)

$T = t_{total}\left(\frac{L_T}{2}\right) = 511\left(\frac{10'}{2}\right) = 2.66$ ft-k

(torsion @ each side of roll beam)

$R_T = \frac{2T}{L_{RB}} = \frac{2(2.66)}{33'} = 0.155^k$ (spandrel rx. due to roll beam moment)

$R_{RB} = W_{RB}\left(\frac{L_{RB}}{2}\right) = 44\frac{lb}{ft}\left(\frac{33'}{2}\right) = 0.726^k$ (spandrel rx. due to roll beam selfwt.)

$P_{RB} = R_T + R_{RB} = 0.881^k$ (point Load on spandrel due to roll beam)

$t_u = 1.2\, t_{cw} + 0.8\, t_{wind} = 0.598 \frac{ft\text{-}k}{ft}$ (Uniform torsional moment)

$T_u = t_u\left(\frac{L_T}{2}\right) = 0.598\left(\frac{10'}{2}\right) = 2.99$ ft-k (torsion @ spandrel ends)

$R_{Tu} = \frac{2T_u}{L_{RB}} = \frac{2(2.99)}{33'} = 0.18^k$ (factored Vert. rx due to roll beam end moment)

$R_{RBu} = 1.2\, W_{RB} \frac{L_{RB}}{2} = 1.2(44)\left(\frac{33'}{2}\right) = 0.87^k$ (factored rx. due to roll beam)

$P_{RBu} = R_{Tu} + R_{RBu} = 0.18 + 0.87 = 1.05^k$ (total factored point Load on spandrel)

Shear + Moment

$V_u = \frac{W_u L}{2} + 3P_u + P_{RBu} = \frac{1.34\frac{k}{ft}(30')}{2} + 3(2.6^k) + 1.05^k = 29^k$

$M_u = \frac{W_u L^2}{8} + P_u\left[\frac{S_c}{2} + \frac{3S_c}{2} + \frac{5S_c}{2}\right] + P_{RBu}(S_{RB})$

$M_u = \frac{1.34(30^2)}{8} + 2.6\left[\frac{4'}{2} + \frac{12'}{2} + \frac{20'}{2}\right] + 1.05^k(10') = 208$ ft-k

$\phi M_n = 0.9 F_y S = \frac{0.9(50)(245\, in^3)}{12 \frac{in}{ft}} = 919$ ft-k

a, $F\Theta$, $F\Theta'$, $F\Theta''$ are torsion constants looked up for this loading condition. $F\Theta = 0.037$, $F\Theta' = 0$, $F\Theta'' = 0.24$
$a = 67.8$

Rotation of spandrel (mid span)

$$\Theta = \frac{2 F\Theta \, t_{total} \, a^2}{GJ} = \frac{2(0.037)(0.511 \frac{ft\text{-}k}{ft})(67.8^2)}{11{,}200 (2.84 in^2)} = 0.00546 \text{ rad}$$

$$\Theta = 0.00546 \text{ rad} \left(\frac{360}{2\pi}\right) = 3.17^\circ$$

$$\Theta'' = \frac{F\Theta'' t_u}{GJ} = \frac{0.24(0.598 \frac{ft\text{-}k}{ft})}{11{,}200 (2.84)} = 4.51 e^{-6} \text{ rad/in}^2$$

Warping Normal stress (mid span)

$$\sigma_{wsu} = E \, W_{No} \, \Theta''$$

W_{No} → Normalized warping constant

$$\Theta_{wsu} = 29{,}000 (75.2 in^2)(4.51e^{-6}) = 9.84 \text{ ksi}$$

Combined stresses

$$\frac{M_u}{\phi M_n} + \frac{\sigma_{wsu}}{\phi F_y} = \frac{208 \text{ ft-k}}{919 \text{ ft-k}} + \frac{9.84 \text{ ksi}}{0.9(50 \text{ ksi})} = 0.45 \leq 1.0$$ ✓

OK for flexure

Shear Strength

$$\Theta' = \frac{F\Theta' t_u 10 a^2}{GJL} = 0 \qquad \Theta'' = 0$$

shear stress in web (torsion)

$$\tau_t = G t_w \Theta' = 0$$

total shear stress in web

$$f_{uv} = \tau_t + \frac{V_u}{d t_w} = 0 + \frac{29^k}{29.5''(0.47'')} = 2.1 \text{ ksi}$$

$$V_n = 0.6 F_y = 30 \text{ ksi}$$

$$\frac{f_{uv}}{\phi V_n} = \frac{2.1 \text{ ksi}}{1.0(30)} = 0.07 \leq 1.0$$

OK for shear ✓

Deflection $w = w_D + w_L = 0.937 \frac{k}{ft}$

mid span → $\Delta_w = \frac{5wl^4}{384EI} = \frac{5(0.937)(30)^4(1728)}{384(29{,}000)(3610)} = 0.163''$

@ 2.5' → $\Delta_{P_1} = \frac{P_{cw}(a_1)}{12EI}\left[0.75L^2 - a_1^2\right]$

$\Delta_{P_1} = \frac{2.16(2.5')(1728)}{12(29{,}000)(3610)}\left[0.75(30)^2 - 2.5^2\right] = 0.00687'$

@ 7.5' → $\Delta_{P_2} = \frac{2.16(7.5')(1728)}{12(29{,}000)(3610)}\left[0.75(30)^2 - 7.5^2\right] = 0.0138$

@ 12.5' → $\Delta_{P_3} = \frac{2.16(12.5)(1728)}{12(29{,}000)(3610)}\left[0.75(30)^2 - 12.5^2\right] = 0.0193$

Δ due to Roll beam → $\Delta_{RB} = \frac{P_{RB}(a_{RB})}{12EI}\left[0.75L^2 - a_{RB}^2\right]$

$a_{RB} = 10'$

$\Delta_{RB} = \frac{0.881^k(10')(1728)}{12(29{,}000)(3610)}\left(0.75(30)^2 - 10^2\right) = 0.007''$

total deflection

$\Delta_{total} = \Delta_w + 2(\Delta_{P_1} + \Delta_{P_2} + \Delta_{P_3} + \Delta_{RB}) = 0.257''$

Roll Beam Rotation

$\Theta_{RB} = \frac{2TL_{RB}}{3EI_{RB}} = \frac{2(2.66\ ft\text{-}k)(33')(144)}{3(29{,}000)\ 843 in^4} = 3.45e^{-4}$

$\Theta_{RB} = 3.45e^{-4}\left(\frac{360}{2\pi}\right) = 0.19°$

$\Theta_{total} = 3.17° + 0.19° = 3.36°$

PENN STATE UNIVERSITY

CLASS: Senior Thesis
DATE: 4/6/07
ASSIGNMENT:

Vert./Horizontal Distance from Spandrel centroid to Curtain wall support $y_i = 0 \quad x_i = 6''$

Dist. b/w spandrel centroid + curtain wall support

$$r = \sqrt{0^2 + 6^2} = 6''$$

Initial Curtain wall angle $\alpha = \tan^{-1}\left(\frac{0}{6}\right) = 0$

Final angle after rotation $\beta = \alpha - \theta_{total} = -3.36°$

Final Curtain wall dist. after rotation $y_f = 6\sin(-3.36) = -0.35''$

$x_f = 6\cos(-3.36) = 5.99''$

Curtain wall translation due to spandrel rotation

$$\Delta_{cw} = y_i - y_f = 0.35''$$

angle support translation due to spandrel rotation

$$\Delta = x_f - x_i = 0''$$

Total vertical Deflection

$$\Delta = \Delta_{total} + \Delta_{cw} = 0.257'' + 0.35'' = 0.607''$$

Deflection limited to $\frac{l}{360} = \frac{30' \times 12''}{360} = 1.0''$

$0.607'' < 1.0''$ (ok) ✓ for deflection

W 30x90 adequate in flexure, shear, + deflection

Down size of W 30 x 90 to W 24 x 76 for decrease in facade load.

W 24x76

$S_x = 176\ in^3$

$J = 2.68\ in^4$

$W_{no} = 52.2\ in^2$

$I = 2100\ in^4$

$W_{Dead} = 373\ \frac{lb}{ft}$

↳ reduces M_u to 207 ft-k

reduces $\phi M_N = 0.9(176 in^3) 50 ksi$

$\phi M_N = 660$ ft-k

V_u remains the same

Check flexure

$$\Theta = \frac{2(0.037)(0.511 \frac{ft\text{-}k}{ft})(67.8^2)}{11{,}200\ (2.68\ in^4)} = 3.27^\circ$$

$$\Theta_u'' = \frac{0.24(0.598 \frac{ft\text{-}k}{ft})}{11{,}200\ (2.68\ in^4)} = 4.78e^{-6}$$

$$\sigma_{wsu} = 29{,}000(52.2\ in^2)(4.78e^{-6}) = 7.24\ ksi$$

$$\frac{207\ ft\text{-}k}{660\ ft\text{-}k} + \frac{7.24\ ksi}{0.9(50\ ksi)} = 0.475 \leq 1.0$$ (OK) ✓ for flexure

Shear

$$f_{uv} = \tau_t + \frac{V_u}{d t_w} = 0 + \frac{29^k}{23.9''(0.44'')} = 2.75\ ksi$$

$$\frac{f_{uv}}{\phi V_N} = \frac{2.75\ ksi}{30\ ksi} = 0.092 \leq 1.0$$ (OK) ✓ for shear

Deflection

$$W = 373\ \frac{lb}{ft} + 550\ \frac{lb}{ft} = 923\ \frac{lb}{ft}$$

$$\Delta_w = \frac{5(0.923 \frac{K}{ft})(30'^4)(1728)}{384(29{,}000)(2100\ in^4)} = 0.28''$$

Deflection (cont.)

$$\Delta_{P_1} = \frac{2.16(2.5')(1728)}{12(29{,}000)(2100)}\left[0.75(30^2) - 2.5^2\right] = 0.00854''$$

$$\Delta_{P_2} = \frac{2.16(7.5')(1728)}{12(29000)(2100)}\left[0.75(30^2) - 7.5^2\right] = 0.0237''$$

$$\Delta_{P_3} = \frac{2.16(12.5')(1728)}{12(29{,}000)(2100)}\left[0.75(30^2) - 12.5^2\right] = 0.0331''$$

$$\Delta_{RB} = \frac{0.881(10')(1728)}{12(29000)(2100)}\left[0.75(30^2) - 10^2\right] = 0.0119''$$

$$\Delta_{total} = 0.43''$$

$$\Theta_{RB} = \frac{2(2.66)(33')(144)}{3(29{,}000)(843 in^4)} = 3.45e^{-4}\left(\frac{360}{2\pi}\right) = 0.19^\circ$$

$$\Theta_{total} = 3.46^\circ$$

$$y_f = 6 \sin(-3.46) = -0.36$$

$$x_f = 6 \cos(-3.46) = 5.99$$

$$\Delta_{cw} = 0.36''$$

$$\Delta_{angle} = 0$$

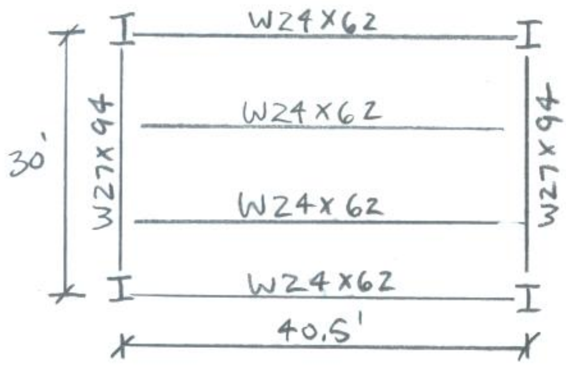
$$\Delta_{total} = 0.43 + 0.36 = 0.79''$$

$0.75'' < 1.0''$ ok. ✓

Beam can be downsized from

W30x90 to W24x76

Spandrel Beam Analysis   W 27x94



$L = 30'$ $L_T = 10'$ $S_{deck} = 10'$

$L_{RB} = 40.5'$ $S_{RB} = 10'$ $e_h = 2''$

$l_{eod} = 6''$ $h = 15'$ $h_c = 15'$

$S_c = 4'$ $e_{cw} = 10.5''$ $t_r = 5.5'$

W27x94

$S_x = 243\ in^3$

$J = 4.03\ in^2$

$I_x = 3270\ in^4$

$t_w = 0.49''$

$d = 26.9''$

$W_{No} = 65.4\ in^2$

W24x62

$I_x = 1550\ in^4$

$W_D = 391\ \frac{lb}{ft}$ $W_{wind} = 225\ \frac{lb}{ft}$

$W_{live} = 550\ \frac{lb}{ft}$ $t_{wind} = 38\ \frac{ft\text{-}lb}{ft}$

$W_u = 1.35\ ^k/_{ft}$ $W_{cw} = 540\ \frac{lb}{ft}$

$P_u = 2.6^k$ $t_{cw} = 473\ \frac{ft\text{-}lb}{ft}$

$t_{total} = 511\ \frac{ft\text{-}lb}{ft}$

$T = 511\left(\frac{10}{2}\right) = 2.66\ ft\text{-}k$ $R_{RB} = 62\left(\frac{40.5}{2}\right) = 1.26^k$

$R_T = 0.131^k$ $P_{RB} = 1.39^k$

$t_u = 0.598\ \frac{ft\text{-}k}{ft}$ $T_u = 2.99\ ft\text{-}k$ $R_{Tu} = 0.15^k$

$R_{RBu} = 1.5^k$ $P_{RBu} = 1.65^k$

Shear + Moment

$$V_u = \frac{1.35(30)}{2} + 3(2.6) + 1.65 = 30^k$$

$$M_u = \frac{1.35(30^2)}{8} + 2.6\left[\frac{4}{2} + \frac{12}{2} + \frac{20}{2}\right] + 1.65(10') = 216\ ft\text{-}k$$

$$\phi M_n = 0.9(50)(243\ in^3) = 911\ ft\text{-}k$$

$$\Theta = \frac{2(0.037)(0.511)(67.8^2)}{11,200(4.03)}\left(\frac{360}{2\pi}\right) = 2.18^\circ$$

$$\Theta'' = \frac{0.24(0.598)}{11,200(4.03)} = 0.000003$$

$$\sigma_{wsu} = 29,000(65.4 in^2)(0.000003) = 6.03 \text{ ksi}$$

$$\frac{216 \text{ ft-k}}{911 \text{ ft-k}} + \frac{6.03 \text{ ksi}}{45 \text{ ksi}} = 0.37 \le 1.0$$ OK ✓ for flexure

Shear

$$f_{uv} = 0 + \frac{30^k}{26.9''(0.49'')} = 2.28 \text{ ksi} \qquad V_N = 0.6(50) = 30$$

$$\frac{f_{uv}}{\phi V_N} = \frac{2.28 \text{ ksi}}{1.0(30)} = 0.076 \le 1.0$$ OK ✓ for shear

Deflection

$$W = 391 + 550 = 0.941 \text{ k/ft}$$

$$\Delta_w = \frac{5(0.941)(30^4)(1728)}{384(29000)(3270)} = 0.181''$$

$$\Delta_{P1} = \frac{2.16(2.5')(1728)}{12(29000)(3270)}\left[0.75(30^2) - 2.5^2\right] = 0.00548''$$

$$\Delta_{P2} = \frac{2.16(7.5')(1728)}{12(29000)(3270)}\left[0.75(30^2) - 7.5^2\right] = 0.0152$$

$$\Delta_{P3} = \frac{2.16(12.5')(1728)}{12(29,000)(3270)}\left[0.75(30)^2 - 12.5^2\right] = 0.0213''$$

$$\Delta_{RB} = \frac{1.39^k(10')(1728)}{12(29,000)(3270)}\left[0.75(30^2) - 10^2\right] = 0.0121''$$

$$\Delta_{total} = 0.289''$$

$$\Theta_{RB} = \frac{2(2.66)(40.5')(144)}{3(29{,}000)(1550\ in^4)} \times \frac{360}{2\pi} = 0.11^\circ$$

$$\Theta_{total} = 2.18^\circ + 0.11^\circ = 2.29^\circ \qquad \Delta_{cw} = 0.24''$$

$$\Delta_{angle} = 0''$$

$$y_f = 6\sin(-2.29) = -0.24$$

$$x_f = 6\cos(-2.29) = 5.99''$$

$$\Delta_{total} = 0.289 + 0.24'' = 0.529'' \leq 1.0''$$ ok ✓ for deflection

---

Downsize W 27x94 to W 24x76 for decrease in facade load

$W_D = 373\ \frac{lb}{ft}$ ok for Shear/Flexure by inspection

$$\Delta_{RB} = \frac{1.39^k(10')(1728)}{12(29{,}000)(2100\ in^4)}\left[0.75(30^2) - 10^2\right] = 0.0189''$$

$$\Delta_{total} = 0.28 + 2(0.00854 + 0.0237 + 0.0331 + 0.0189) = 0.45''$$

W24x76
$I_x = 2100\ in^4$
$J = 2.68\ in^2$

$$\Theta_{RB} = \frac{2(2.66)(40.5')(144)}{3(29{,}000)(1550)} \times \frac{360}{2\pi} = 0.11^\circ$$

$$\Theta = \frac{2(0.037)(0.511)(67.8^2)}{(11{,}200)(2.68} \times \frac{360}{2\pi} = 3.27^\circ$$

$$\Theta_{total} = 3.38^\circ$$

$$y_f = 6\sin(-3.38) = -0.35$$

$$x_f = 6\cos(-3.38) = 5.99$$

$$\Delta_{cw} = 0.35''$$

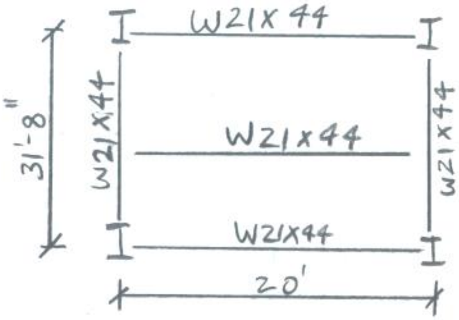
$$\Delta_{angle} = 0$$

$$\Delta_{total} = 0.45 + 0.35 = 0.8''$$

$0.8'' < 1.0''$ ✓ OK

Beam can be downsized from W27x94 to W24x76

Spandrel Beam Analysis W 21X 44



$L = 20'$ $L_T = 10'$ $S_{deck} = 10'$ $L_{RB} = 31.67'$

$S_{RB} = 10'$ $e_h = 3''$ $l_{eod} = 6''$ $h = 15'$

$h_c = 15'$ $S_c = 4'$ $e_{cw} = 10.5''$ $t_r = 5.5'$

W 21X44

$S_x = 81.6\ in^3$

$J = 0.77\ in^2$

$W_{no} = 32.8\ in^2$

$d = 20.7''$

$t_w = 0.35''$

$I_x = 843\ in^4$

$W_D = 341\ \frac{lb}{ft}$ $W_{Live} = 550\ \frac{lb}{ft}$

$P_{cw} = 2.16^k$ $W_u = 1.29^k$

$P_u = 2.60^k$ $W_{wind} = 225\ \frac{lb}{ft}$

$t_{wind} = 38\ \frac{lb}{ft}$ $W_{cw} = 540\ lb/ft$

$t_{cw} = 473\ \frac{lb}{ft}$ $t_{total} = 511\ \frac{lb}{ft}$

$T = 511\left(\frac{10}{2}\right) = 2.56\ ft\text{-}k$ $R_{RB} = 44\left(\frac{31.67}{2}\right) = 0.697^k$

$R_T = 0.16^k$ $P_{RB} = 0.86^k$

$t_u = 0.64\ \frac{ft\text{-}k}{ft}$ $T_u = 3.2\ ft\text{-}k$

$R_{Tu} = 0.2^k$ $R_{RBu} = 0.836^k$ $P_{RBu} = 1.04^k$

Shear + Moment

$$V_u = \frac{1.29(20')}{2} + 3(2.16) + 1.04 = 20^k$$

$$M_u = \frac{1.29(20)^2}{8} + 2.16\left[2+6+10\right] + 1.04(10) = 114\ ft\text{-}k$$

$$\phi M_n = 0.9(50)(81.6) = 306\ ft\text{-}K$$

$$\Theta = \frac{2(0.037)(0.511)(67.8)^2}{11{,}200(0.77)} \times \frac{360}{2\pi} = 0.17^\circ$$

$$\Theta'' = \frac{0.24(0.64)}{11{,}200(0.77)} = 1.78e^{-5}$$

$\sigma_{wsu} = 1.78e^{-5}(29{,}000)(32.8) = 16.9 \text{ ksi}$

$\frac{114}{306} + \frac{16.9}{0.9(50)} = 0.75 \leq 1.0$ ok ✓ for flexure

Shear

$f_{uv} = 0 + \frac{20^k}{20.7(0.35)} = 2.76 \text{ ksi}$

$\frac{f_{uv}}{\phi V_n} = \frac{2.76}{0.6(50)} = 0.092 \leq 1.0$ ok ✓ for shear

Deflection

$w = 341 + 550 = 0.891 \frac{k}{ft}$

$\Delta_w = \frac{5(0.891)(20^4)\,1728}{384(29000)(843)} = 0.131''$

$\Delta_{p1} = \frac{2.16(2.5')(1728)}{12(29000)(843)}\left[0.75(20)^2 - 2.5^2\right] = 0.0213''$

$\Delta_{p2} = \frac{2.16(7.5)(1728)}{12(29{,}000)(843)}\left[0.75(20^2) - 7.5^2\right] = 0.0590$

$\Delta_{p3} = \frac{2.16(12.5)(1728)}{12(29000)(843}\left[0.75(20^2) - 12.5^2\right] = 0.0825$

$\Delta_{RB} = \frac{0.86(10')(1728)}{12(29{,}000)(843)}\left[0.75(20)^2 - 10^2\right] = 0.0291''$

$\Delta_{total} = 0.52''$

$\Theta_{RB} = \frac{2(2.56)(31.67)(144)}{3(29{,}000)(843)} \times \frac{360}{2\pi} = 0.18^\circ$

$\Theta_{total} = 0.35^\circ$

$y_f = 6 \sin(-0.35) = -0.0367$

$x_f = 6 \cos(-0.35) = 5.99$

$\Delta_{cw} = 0.0367$

$\Delta_{angle} = 0$

$\Delta_{total} = 0.52'' + 0.0367'' = 0.56'' \leq 1.0''$ (ok) for deflection

All adjacent framing is W21x44's, This Beam is Not downsized to keep typical members and the downsize would introduce a more shallow shape, increasing shear failure in the connection due to coping.

Appendix B

Acoustical Calculations

Receiving Classroom 156	Area (SF)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Ceiling, Acoustical Panels	1655	Absorption Coefficient (α)					
		0.76	0.93	0.83	0.99	0.94	0.95
		Absorption(sabins,a_2)					
		1257.8	1539.15	1373.65	1638.45	1555.7	1572.25
Floor, VCT	1655	Absorption Coefficient (α)					
		0.02	0.03	0.03	0.03	0.03	0.02
		Absorption(sabins,a_2)					
		33.1	49.65	49.65	49.65	49.65	33.1
Walls, GWB on Metal Studs	1467	Absorption Coefficient (α)					
		0.28	0.12	0.1	0.07	0.13	0.09
		Absorption(sabins,a_2)					
		410.76	176.04	146.7	102.69	190.71	132.03
Total Absorption (sabins)		1702	1765	1570	1791	1796	1737
Transmitted Noise from Bathroom		85	79	78	77	72	65
Ambient Classroom Noise (NC-30)		52	45	40	36	34	33
Required Noise Reduction		33	34	38	41	38	32
10 Log (a_2/S)		-4	-4	-5	-4	-4	-4
Required Transmission Loss (dB)		**29**	**30**	**33**	**37**	**34**	**28**
Existing Construction TL (STC-52)		**38**	**52**	**59**	**60**	**56**	**62**

Receiving Classroom 151	Area (SF)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Ceiling, Acoustical Panels	947	Absorption Coefficient (α)					
		0.76	0.93	0.83	0.99	0.94	0.95
		Absorption(sabins,a_2)					
		719.72	880.71	786.01	937.53	890.18	899.65
Floor, VCT	947	Absorption Coefficient (α)					
		0.02	0.03	0.03	0.03	0.03	0.02
		Absorption(sabins,a_2)					
		18.94	28.41	28.41	28.41	28.41	18.94
Walls, GWB on Metal Studs	1110	Absorption Coefficient (α)					
		0.28	0.12	0.1	0.07	0.13	0.09
		Absorption(sabins,a_2)					
		310.8	133.2	111	77.7	144.3	99.9
Total Absorption (sabins)		1049.46	1042.32	925.42	1043.64	1062.89	1018.49
Transmitted Noise from Classroom 152		66	72	77	74	68	60
Classroom Noise (Per ANSI Standard S12.60)		35	35	35	35	35	35
Required Noise Reduction		31	37	42	39	33	25
10 Log (a_2/S)		-5	-5	-5	-5	-5	-5
Required Transmission Loss (dB)		**26**	**32**	**37**	**34**	**28**	**20**
Existing Construction TL (STC-52)		**38**	**52**	**59**	**60**	**56**	**62**

Receiving Classroom 129	Area (SF)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Ceiling, Acoustical Panels	870	Absorption Coefficient (α)					
		0.76	0.93	0.83	0.99	0.94	0.95
		Absorption(sabins,a_2)					
		661.2	809.1	722.1	861.3	817.8	826.5
Floor, VCT	870	Absorption Coefficient (α)					
		0.02	0.03	0.03	0.03	0.03	0.02
		Absorption(sabins,a_2)					
		17.4	26.1	26.1	26.1	26.1	17.4
Walls, GWB on Metal Studs	1062	Absorption Coefficient (α)					
		0.28	0.12	0.1	0.07	0.13	0.09
		Absorption(sabins,a_2)					
		297.36	127.44	106.2	74.34	138.06	95.58
Total Absorption (sabins)		975.96	962.64	854.4	961.74	981.96	939.48
Transmitted Noise from Mech. Room		86	85	84	83	82	80
Classroom Noise (Per ANSI Standard S12.60)		35	35	35	35	35	35
Required Noise Reduction		51	50	49	48	47	45
10 Log (a_2/S)		-5	-5	-5	-5	-5	-5
Required Transmission Loss (dB)		**46**	**45**	**44**	**43**	**42**	**40**
Existing Construction (STC-)		**79**					

Receiving Classroom 184	Area (SF)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Ceiling, Acoustical Panels	822	Absorption Coefficient (α)					
		0.76	0.93	0.83	0.99	0.94	0.95
		Absorption(sabins,a_2)					
		624.72	764.46	682.26	813.78	772.68	780.9
Floor, VCT	822	Absorption Coefficient (α)					
		0.02	0.03	0.03	0.03	0.03	0.02
		Absorption(sabins,a_2)					
		16.44	24.66	24.66	24.66	24.66	16.44
Walls, GWB on Metal Studs	1017	Absorption Coefficient (α)					
		0.28	0.12	0.1	0.07	0.13	0.09
		Absorption(sabins,a_2)					
		284.76	122.04	101.7	71.19	132.21	91.53
Total Absorption (sabins)		925.92	911.16	808.62	909.63	929.55	888.87
Transmitted Noise from Labratory 185		70	73	75	72	69	65
Classroom Noise (Per ANSI Standard S12.60)		35	35	35	35	35	35
Required Noise Reduction		35	38	40	37	34	30
10 Log (a_2/S)		-5	-5	-5	-5	-5	-5
Required Transmission Loss (dB)		**30**	**33**	**35**	**32**	**29**	**25**
Existing Construction TL (STC-52)		**38**	**52**	**59**	**60**	**56**	**62**

Josh Thompson Senior Thesis 3/25/07

Acoustical Calculation Example

Receiving Classroom 156

Ceiling/Floor Area = 1655 SF
Wall Area = 1467 SF

Total absorption (sabins) = Σ(absorption coefficient)(Area)

$a_2 = \Sigma \alpha(S)$

Required Transmission Loss (TL) = Noise Reduction(NR) − $10\log\left(\frac{a_2}{S}\right)$

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Total absorption	1702	1765	1570	1791	1796	1737
Transmitted Noise	85	79	78	77	72	65
Ambient Noise (NC-30)	52	45	40	36	34	33
Required NR	33	34	38	41	38	32
$10\log\left(\frac{a_2}{S}\right)$	−4	−4	−5	−4	−4	−4
Required TL	29	30	33	37	34	28

→ Required NR = Transmitted Noise − Ambient Noise

$$10\log\left(\frac{a_2}{S}\right) = 10\log\frac{1702}{(1655+1655+1467)} = -4.4$$

Total absorption
At 125 Hz

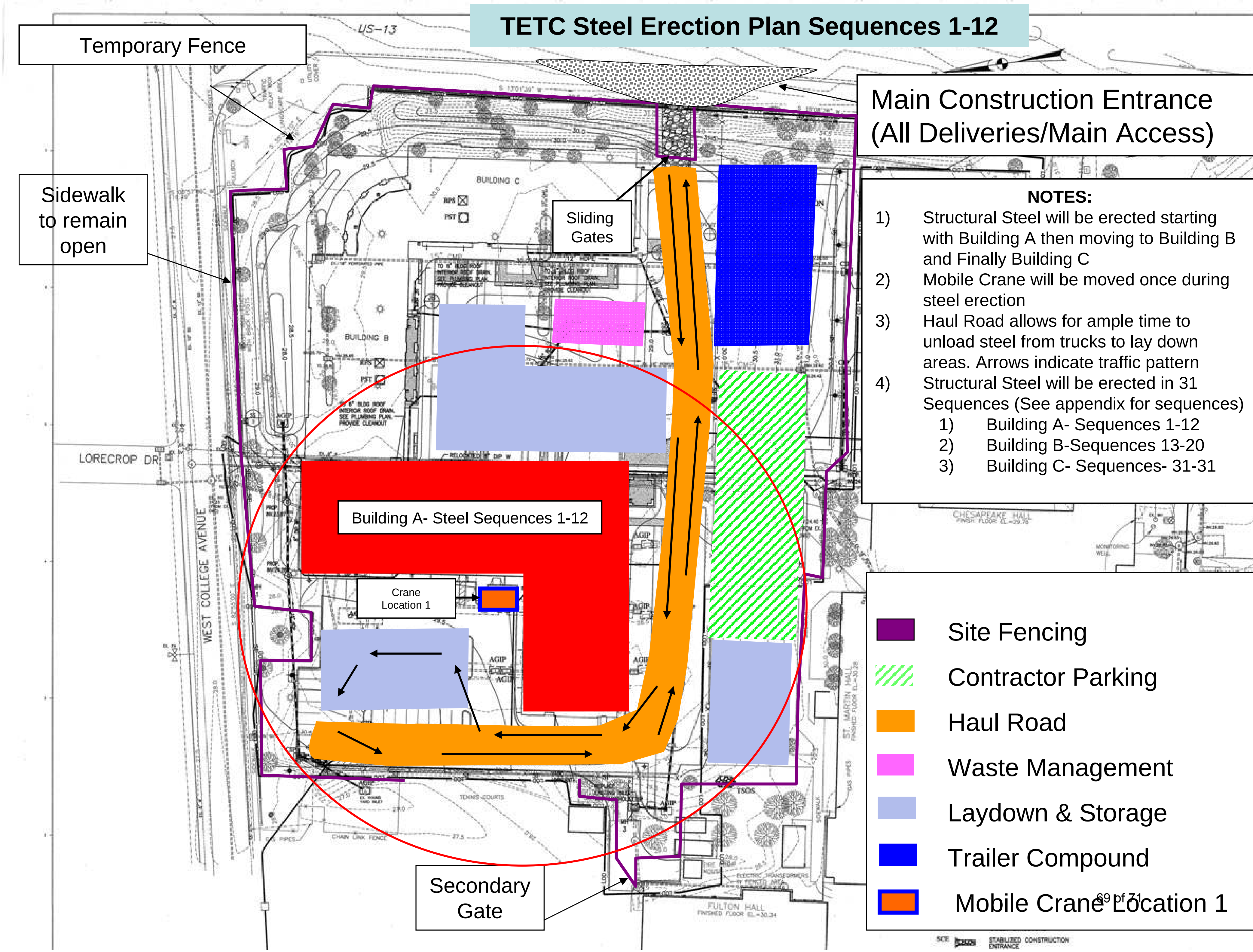
$\alpha_{ceiling} = 0.76$
$\alpha_{floor} = 0.02$
$\alpha_{wall} = 0.28$

$a_2 = 1655(0.76) + 1655(0.02) + 1467(0.28)$

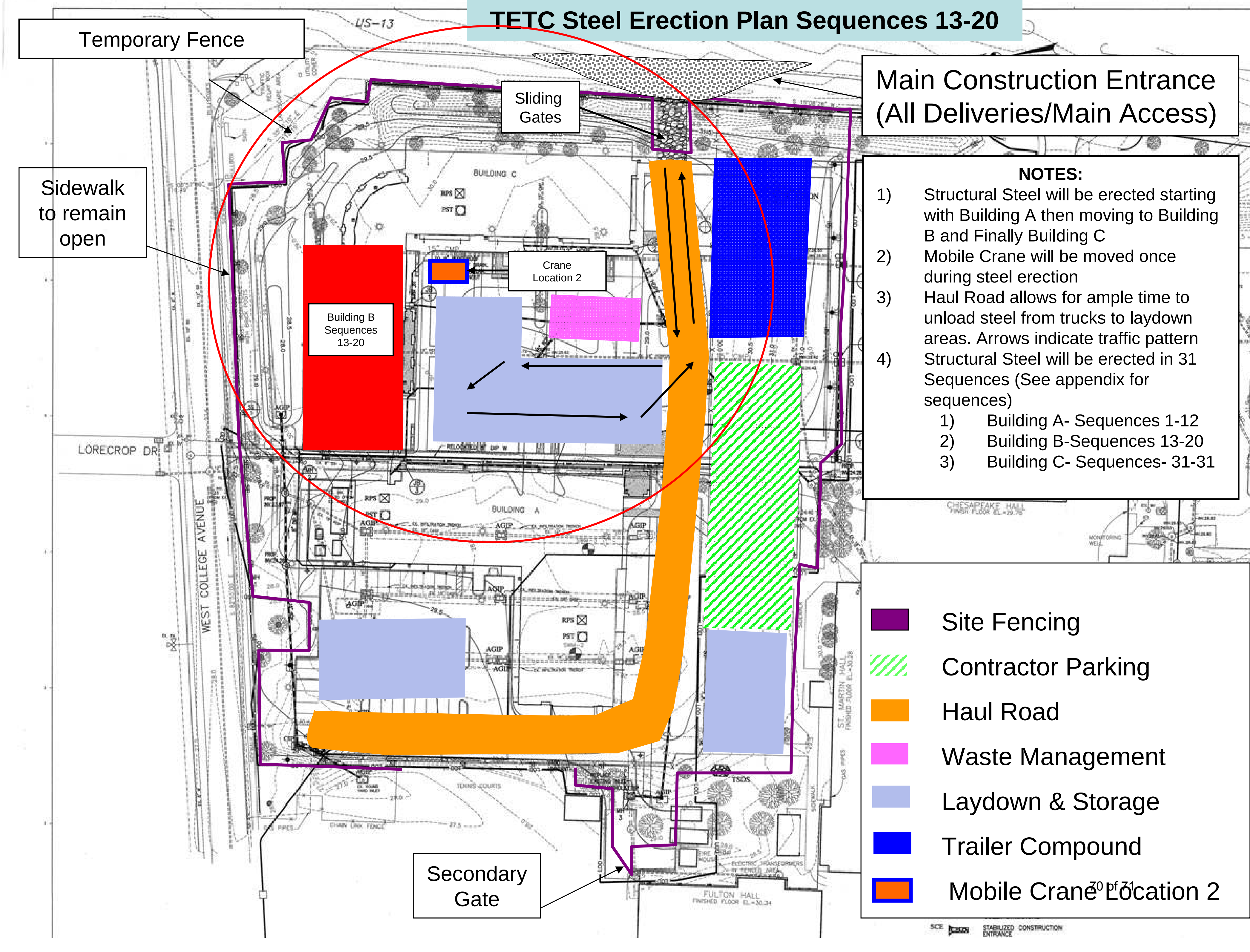
$a_2 = 1702$

Required TL @ 125 Hz = $33 + (-4) = 29$

Appendix C
Site/Sequencing Plans

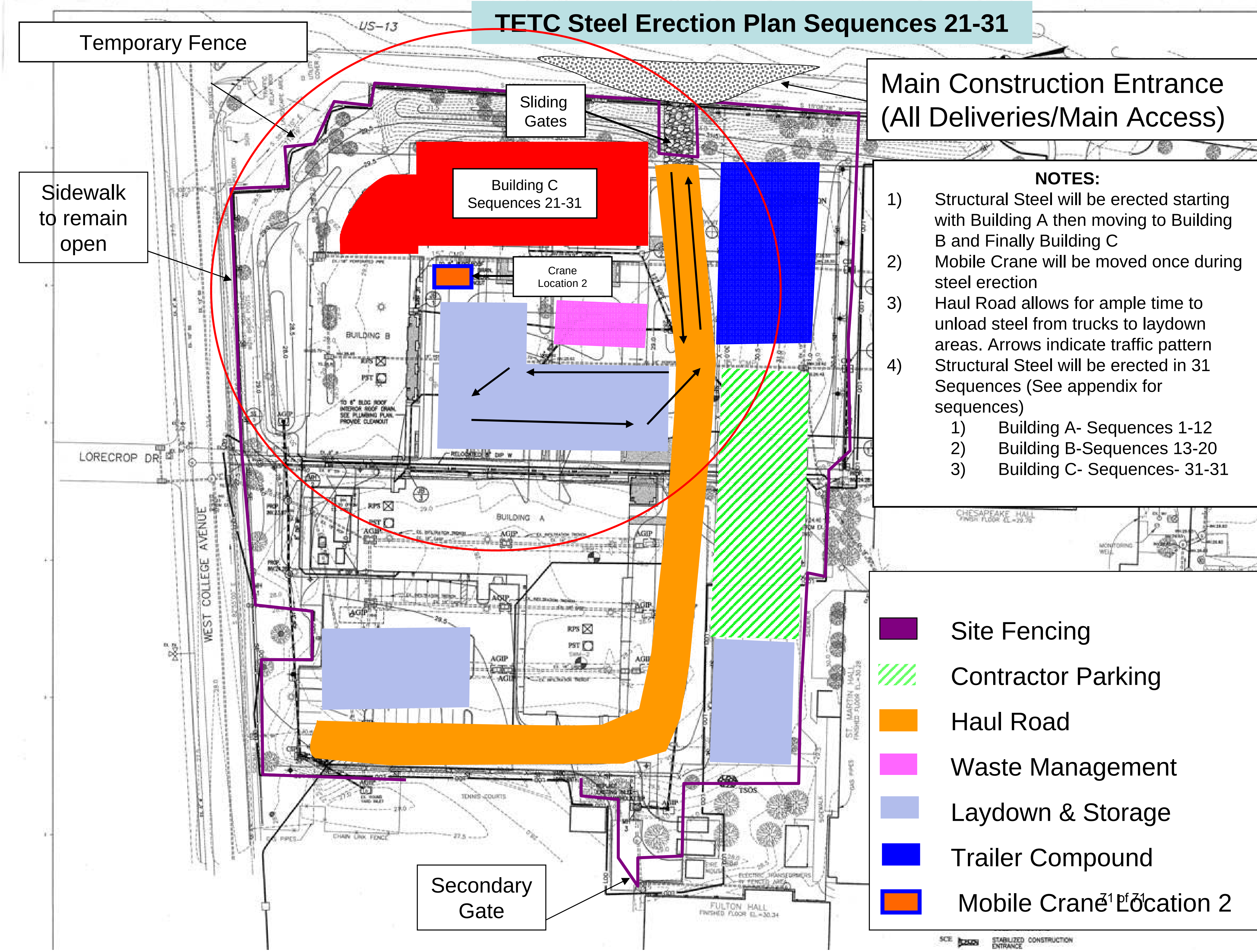

TETC Steel Erection Plan Sequences 1-12
Temporary Fence
Sidewalk to remain open
Main Construction Entrance (All Deliveries/Main Access)
Sliding Gates
NOTES:
1) Structural Steel will be erected starting with Building A then moving to Building B and Finally Building C
2) Mobile Crane will be moved once during steel erection
3) Haul Road allows for ample time to unload steel from trucks to lay down areas. Arrows indicate traffic pattern
4) Structural Steel will be erected in 31 Sequences (See appendix for sequences)
1) Building A- Sequences 1-12
2) Building B-Sequences 13-20
3) Building C- Sequences- 31-31
Building A- Steel Sequences 1-12
Crane Location 1
Secondary Gate
LORECROP DR
WEST COLLEGE AVENUE
BUILDING B
BUILDING C
CHESAPEAKE HALL
FULTON HALL
Site Fencing
Contractor Parking
Haul Road
Waste Management
Laydown & Storage
Trailer Compound
Mobile Crane Location 1

TETC Steel Erection Plan Sequences 13-20



NOTES:

1) Structural Steel will be erected starting with Building A then moving to Building B and Finally Building C
2) Mobile Crane will be moved once during steel erection
3) Haul Road allows for ample time to unload steel from trucks to laydown areas. Arrows indicate traffic pattern
4) Structural Steel will be erected in 31 Sequences (See appendix for sequences)
   1) Building A- Sequences 1-12
   2) Building B-Sequences 13-20
   3) Building C- Sequences- 31-31


TETC Steel Erection Plan Sequences 21-31
Temporary Fence
Sliding Gates
Main Construction Entrance (All Deliveries/Main Access)
Sidewalk to remain open
Building C Sequences 21-31
Crane Location 2
NOTES:
1) Structural Steel will be erected starting with Building A then moving to Building B and Finally Building C
2) Mobile Crane will be moved once during steel erection
3) Haul Road allows for ample time to unload steel from trucks to laydown areas. Arrows indicate traffic pattern
4) Structural Steel will be erected in 31 Sequences (See appendix for sequences)
1) Building A- Sequences 1-12
2) Building B-Sequences 13-20
3) Building C- Sequences- 31-31
Secondary Gate
Site Fencing
Contractor Parking
Haul Road
Waste Management
Laydown & Storage
Trailer Compound
Mobile Crane Location 2
US-13
LORECROP DR
WEST COLLEGE AVENUE
BUILDING B
BUILDING A
CHESAPEAKE HALL
ST. MARTIN HALL
FULTON HALL
TENNIS COURTS
TSOS