

Building Analysis of the Hershey Academic Support Center

Hershey, PA

Shawn Jones
Structural Option
Spring 2006 Senior Thesis



Presentation Outline

- » Introduction
- » Project Proposal
- » Structural Analysis
- » Cost Comparison
- » Fire System Study
- » Conclusions

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Introduction

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Building Stats



- » Owner: Penn State University
- » Construction Dates: March 1999 – August 2000
- » Overall Project Cost: \$16,900,000
- » Building Size: 150,000 ft²
- » Total Height: 5 stories at 56'-0" with the Mechanical Penthouse at 69'-0"
- » Project Delivery Method: GMP

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Primary Design Team

- » Architect: WTW Architects
- » Structural: Whitney, Bailey, Cox, & Magnani, LLP
- » Construction Manager: Barclay White Skanska
- » MEP & Lighting: Brinjac, Kambic, & Assoc.
- » Geotechnical: Schnabel Engineering & Assoc.

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Architecture

- » Precast Concrete Panels
- » Repeating Window Pattern



- » Jutting Stairwells on Sides
- » Membrane Roofing System

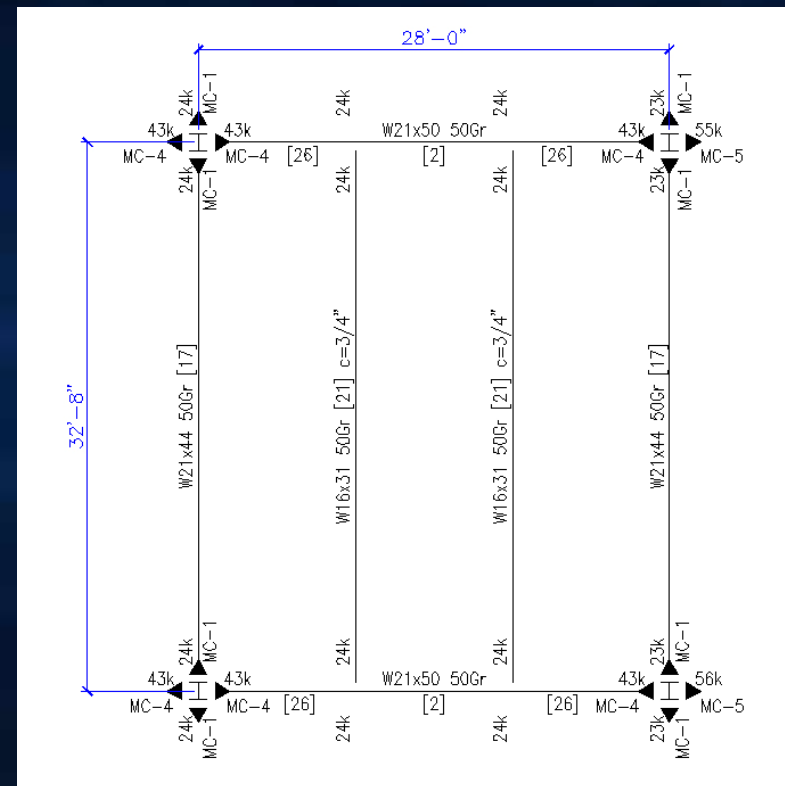
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Structural System Information

- » Composite Beam Floor Framing
- » 3" 20-Gauge Decking
- » 2.5" Lightweight Concrete Slab
- » W21x44 & W21x50 Standard Girders
- » Moment Connections located at columns



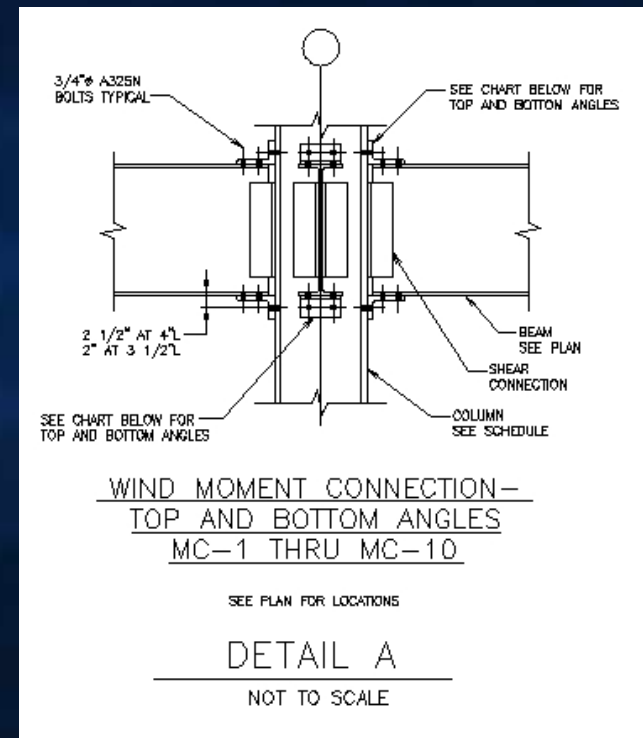
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Lateral System Information

- » 617 Moment Connections
- » 3 Main Types and 16 Subtypes
- » Typical Connection:
L6 x 4 x 7/8 x 0'7" with
4 Bolts to a Girder and
2 Bolts to a Column
- » Typical Detail Shown



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Project Proposal

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Problem Statement

- » At full restraint, the lateral system seemed over designed and removing moment connections would create a significant savings.
- » Design the lateral system to it's actual capacity and check the affects on both the lateral system as well as the floor system using "Type 2 with Wind" analysis.
- » Examine Cost Analysis & the Fire Protection System in detail

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Solution Method

- » Find the actual partial fixity of the different moment connections.
- » Apply to the building and compare results.
- » Check for floor system effects due to “Type 2 with Wind” design.
- » Compare connection prices and choose the most efficient connection type.
- » Examine the current spray-on fireproofing versus a 2 hour fire rated slab.

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Design Goals

- » Don't adversely affect the Architecture both inside and outside.
- » Do not exceed $H/400$ in terms of story drift in any moment frame.
- » Use up to date code values for design and analysis.

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Design Criteria

- » The original building code was BOCA 1996 but was changed to ASCE 7-02
- » Gravity Loads
 - Roof Dead Load = 30psf
 - Penthouse Dead Load = 125psf
 - Office Dead Load = 70psf
 - Main Floor Live Load = 100psf
- » Lateral Loads
 - Controlling Case: $0.9D + 1.6W$

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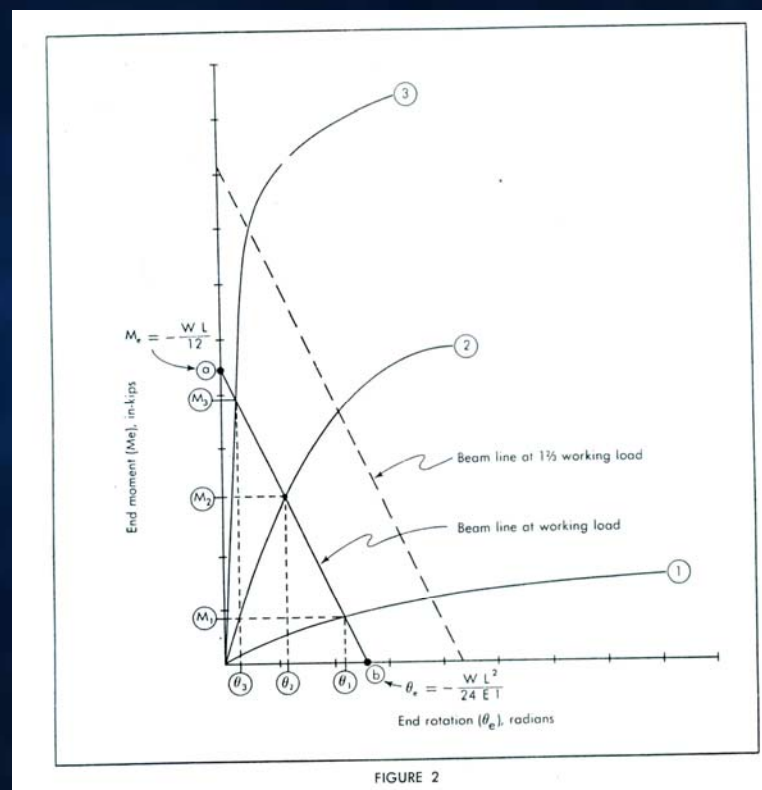
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Connection Restraint

- » End Moment vs. Rotation Graph
- » Curve 1 represents fully flexible
- » Curve 2 represents partially restrained
- » Curve 3 represents fully restrained



Connection Checks

» Fracture

$$\phi F_u A_n = (0.75) * (58 \text{ksi}) * A_n = 43.5 \text{ksi} * (A_n)$$

» Rupture

$$\phi F_n A_w = (0.75) * (0.6) * (70) * A_w = 31.5 * A_w$$

» Yield

$$\phi F_y A_g = (0.9) * (36 \text{ksi}) * A_g = 32.4 \text{ksi} * (A_g)$$

» All 16 Connections Yielded before Fracture and Rupture Occurred.



Relative Stiffness

$$\alpha_i = \frac{EI}{R_{ki}d}$$

Connection	Connection Size	Stiffness (R_{ki})
MC-1	L6 X 4 X 7/8 X 0'-7"	101,549
MC-2	L6 X 4 X 7/8 X 0'-6"	97,589
MC-3	L3-1/2 X 3-1/2 X 5/8 X 0'-6 1/2"	79,203
MC-4	L6 X 4 X 3/4 X 0'-7"	87,551
MC-5	L6 X 4 X 3/4 X 0'-8"	88,380
MC-6	L4 X 4 X 5/8 X 0'-10"	79,417
MC-7	L6 X 4 X 3/4 X 0'-9"	92,323
MC-8	L3-1/2 X 3-1/2 X 1/2 X 0'-6 1/2"	68,596
MC-9	L3-1/2 X 3-1/2 X 9/16 X 0'-5"	68,830
MC-10	L3-1/2 X 3-1/2 X 1/2 X 0'-10"	73,001
MC-11	PL4 X 5/8 X 1'-2"	262,300
	PL8 X 3/8 X 2'-0	241,000
		251,650

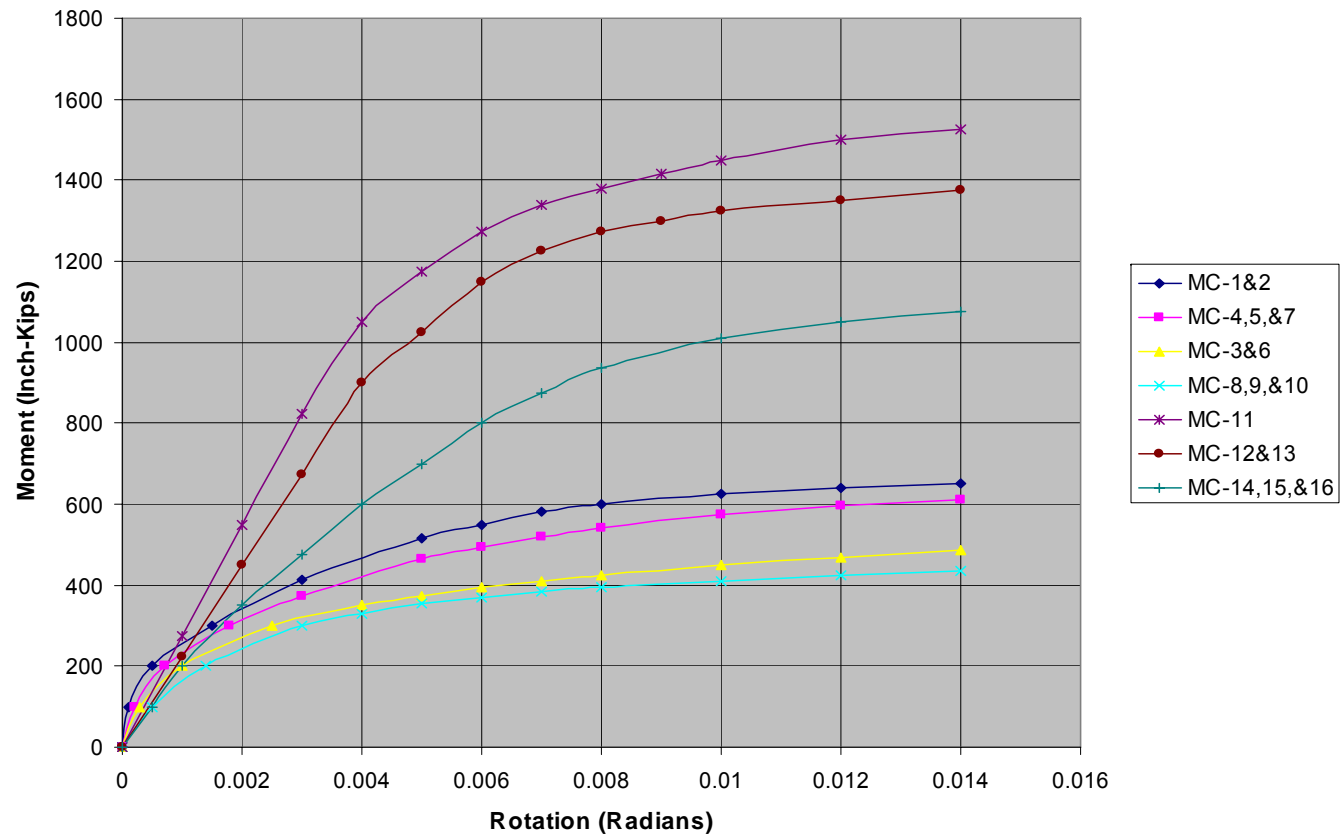
Connection	Connection Size	Stiffness (R_{ki})
MC-12	PL7 X 1/2 X 1'-8"	248,100
	PL12 X 3/8 X 2'-10"	212,700
		230,400
MC-13	PL8 X 3/8 X 1'-8"	236,600
	P12 X 5/16 X 2'-8"	214,000
		225,300
MC-14	PL4 X 3/8 X 1'-6"	256,000
	L3-1/2 X 3-1/2 X 1/2 X 0'-6 1/2"	68,596
		162,298
MC-15	PL5 X 3/8 X 1'10"	238,700
	L3-1/2 X 3-1/2 X 5/8 X 0'-6 1/2"	79,203
		158,952
MC-16	PL4 X 3/8 X 1'-6"	256,000
	L3-1/2 X 3-1/2 X 1/2 X 0'-10"	73,001
		164,501

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Moment vs. Rotation



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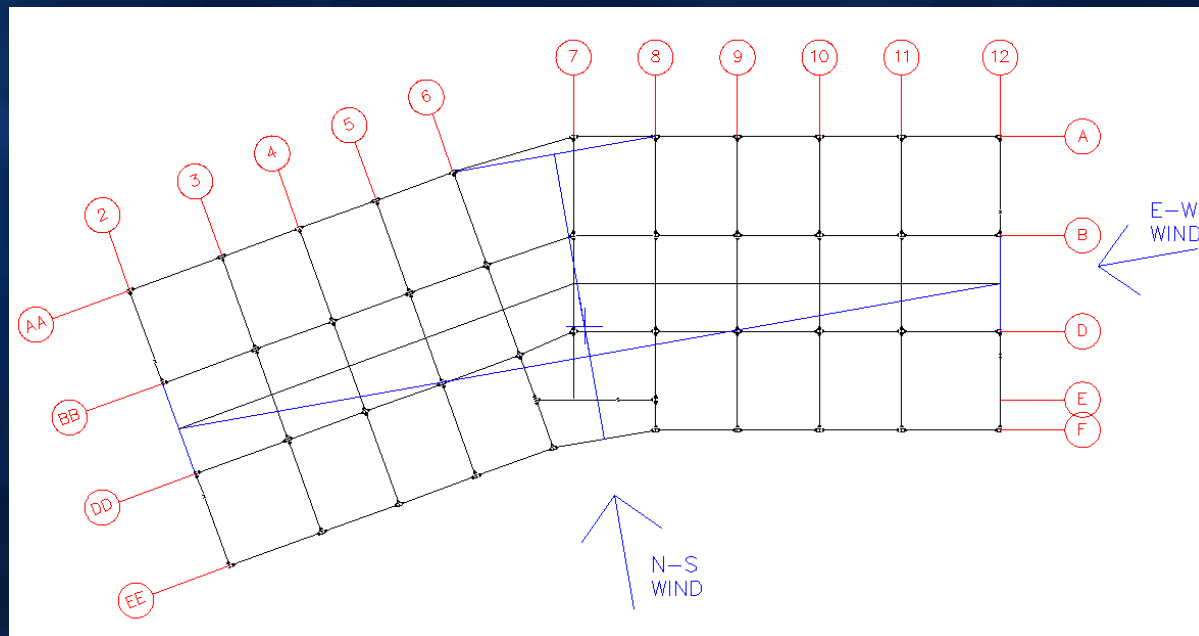
- » Thicker angles allow less rotation
- » Smaller, stiff plates allow less rotation
- » Using R_{ki} and the graph, percent restraint was calculated
- » Typical R values range from 20-90%

Moment Connection	Restraint Value (R)
MC-1	34%
MC-2	33%
MC-3	27%
MC-4	30%
MC-5	30%
MC-6	27%
MC-7	31%
MC-8	23%
MC-9	23%
MC-10	25%
MC-11	85%
MC-12	78%
MC-13	76%
MC-14	55%
MC-15	54%
MC-16	56%



Story Drift

- Deflection Calculation $H/400$: $((69') * (12\text{in}/\text{ft})) / 400 = 2.07\text{in}$
- » East Section Frame #C: Story Drift = 1.5in < 2.07in ALLOW
 - » West Section Frame #B: Story Drift = 1.47in < 2.07in ALLOW
 - » $H/400$ was considered the acceptable value of drift
 - Center Section Frame #D: Story Drift = 1.87in < 2.07in ALLOW



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Story Drift

» Removed 2 E-W Roof Moment Connections

Deflection Calculation H/400: $((69') * (12\text{in}/\text{ft})) / 400 = 2.07\text{in}$
East Section Frame #12: Story Drift = $1.85\text{in} < 2.07\text{in}$ ALLOW
West Section Frame #2: Story Drift = $1.76\text{in} < 2.07\text{in}$ ALLOW
Center Section Frame #D: Story Drift = $2.23\text{in} < 2.07\text{in}$ FAIL

» Removed all E-W Roof Moment Connections

Deflection Calculation H/400: $((69') * (12\text{in}/\text{ft})) / 400 = 2.07\text{in}$
East Section Frame #12: Story Drift = $2.28\text{in} < 2.07\text{in}$ FAIL
West Section Frame #2: Story Drift = $2.19\text{in} < 2.07\text{in}$ FAIL



Story Drift

- » Removed 2 Roof E-W Moment Connections from every other frame

Deflection Calculation H/400: $((69') * (12\text{in}/\text{ft})) / 400 = 2.07\text{in}$
East Section Frame #12: Story Drift = 2.03in < 2.07in ALLOW
West Section Frame #2: Story Drift = 1.94in < 2.07in ALLOW
Center Section Frame #D: Story Drift = 1.96in < 2.07in ALLOW

- » The drift passes and a total of 24 moment connections are removed, valued at about \$4000 total

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Floor System

- » Floor system uses “Type 2 with Wind” design
- » Negative wind moment controls lateral member design at columns
- » Interior beams are controlled by gravity loads
- » Creates varied floor member sizes
- » With composite action, shear studs are used to balance out the center positive moment with the negative end moments

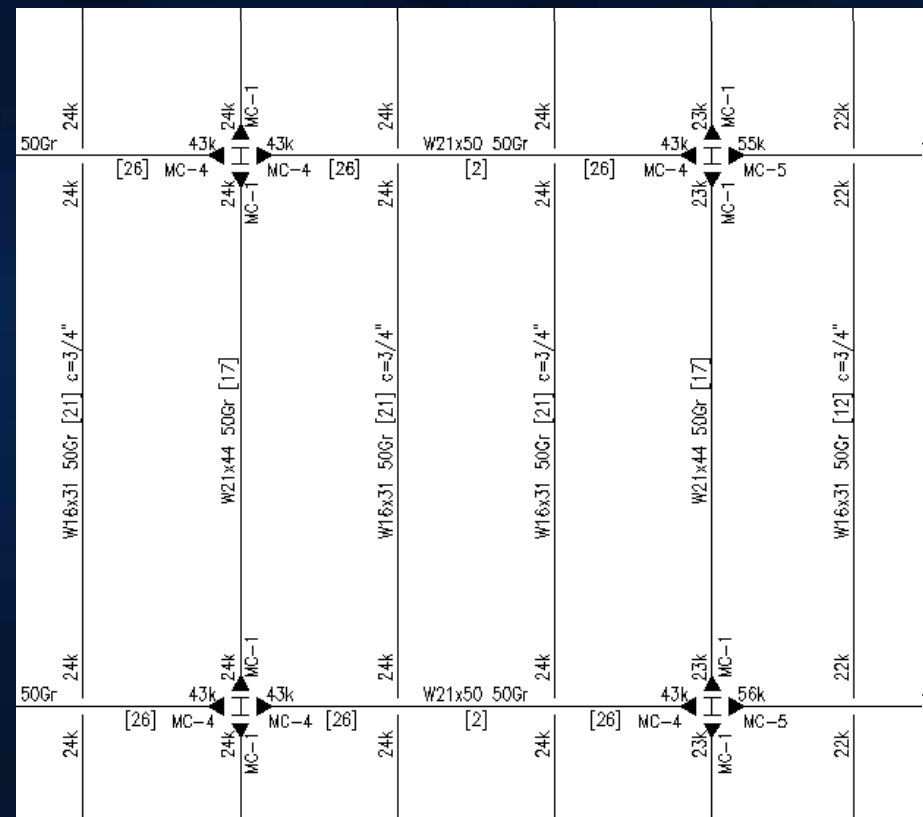
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Floor System

- » When North was fit to be replaced with a 2000 average used from North with R/A Meter check the W18x40 which sizes.
- » shear studs on the first two floors
- » #10 members size as ~~sub~~ changed at a savings of \$12,320



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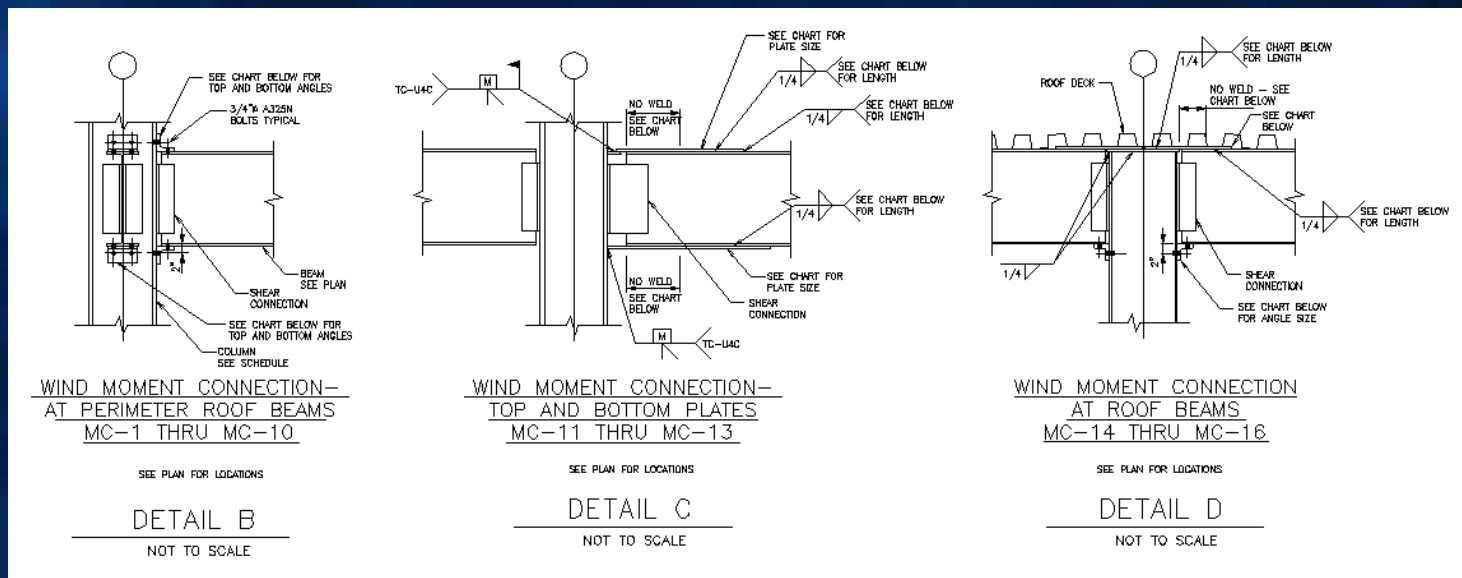
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Overview

- » 617 Total Moment Connections, 2,329 bolts, and 318.6 linear feet of weld
- » 3 Main Types: Top and Bottom Angle, Top and Bottom Plate, and Top Plate with Bottom Angle



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Moment Connection Cost

- » A combination of RS Means and data from Chris Holcombe of Milton Steel was used to price the varying connection types.
- » The three common connection type prices from Milton Steel are listed in bold along with the rest.

MC-1 = \$165
MC-2 = \$165
MC-3 = \$103
MC-4 = \$160
MC-5 = \$160
MC-6 = \$107
MC-7 = \$160
MC-8 = \$99
MC-9 = \$101
MC-10 = \$99
MC-11 = \$268
MC-12 = \$328
MC-13 = \$352
MC-14 = \$145
MC-15 = \$157
MC-16 = \$145

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Duration Data

- » Welded connections take about twice as long to erect as bolted connections.
- » RS Means has output at 105 high strength bolts per day versus 50 linear feet of weld per day.
- » The average angled connection has 4-6 bolts and the average welded connection has 3-4 linear feet of weld.

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Fire System Study

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Existing System

- » Designed by the PA Department of Labor and Industry's Fire and Panic Code for 2 hour fire rating.
- » Hydraulic sprinkler system with smoke detectors in all major areas
- » 2.5" Lightweight Concrete slab with cementitious spray on fireproofing



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Proposal

- » Increase the slab thickness by 1" to meet the 2 hour fire rating for the slab.
- » Potentially saves cost of spray on fireproofing which covers the slab, beams, and columns.
- » Fireproofing must remain in the stairwells
- » RS Means was used to obtain cost data

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Calculations

» Concrete

- 30,000 ft² area per floor at \$91.00 per yd³
- Assume 10% Waste
- Total cost = \$50,977

» Fireproofing

- 30,000 ft² of deck area per floor at \$1.29 per ft³
- 225 columns at 101 ft² per floor per column at \$1.23 per ft³
- 620 beams at 156 ft² per floor per beam at \$0.98 per ft³
- Deck = \$16,925, Columns = \$12,102, Beams = \$41,227
- Total cost = \$70,254
- Total Savings = \$19,277

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Recommendations

- » Calculating partial fixity of the connections lead to a savings in price of \$16,320, but compared to the nearly \$17 million dollar project, this savings is minimal.
- » The time needed to run all the calculations could be better spent saving money elsewhere, so I recommend to use the current flat fixity system.
- » For connection types, bolted connections are definitely recommended wherever they can be used since welded connections are more expensive and take longer to make.
- » An extra inch of concrete over spray on fireproofing saves about \$20,000, but it does add some weight to the structure, so either system is a plausible choice.

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Acknowledgements

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Questions?



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