Quality Assurance for Structural Engineering Firms

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DVASE | Delaware Valley Association of Structural Engineers
Eastern Chapter of the Structural Engineers Association of Pennsylvania

Learning Objectives

1. Discuss the importance of structural engineering Quality Assurance
2. Review the components of a Quality Assurance program
3. Review tips for performing QA reviews

What is a Structural Engineering QA program?

A system of procedures and processes used to facilitate efficient production of high-quality structural design and high-quality contract documents for that design.

Why is a QA program important?

- The pressure to get more done, faster, and better for less (no “simmer time”)
- Complex codes and design standards
- Complex analysis and design software – and blind reliance (by some) on that software
- Building Information Modeling
- Less experienced engineers taking on more responsibility earlier in their careers
- The lost art of structural drafting
- Communication challenges

Why is QA important?

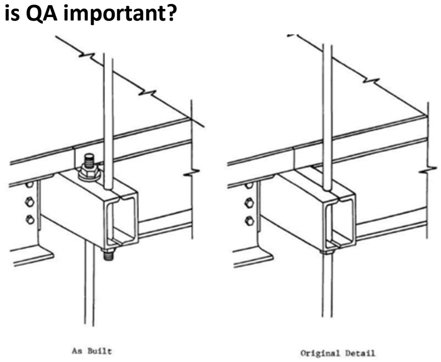
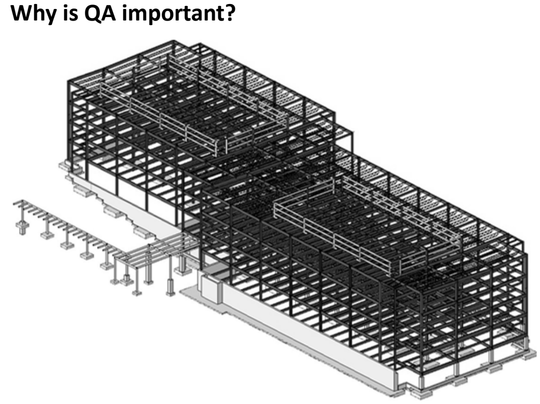


Figure 10.2 Comparison of interrupted and continuous hanger rod details.

Why is QA important?



Advantages of a QA program

- Better design
- Better drawings & models
- More efficient design process
- Better working environment for young engineers – and everyone else
- Fewer mistakes
- Fewer RFI's & change orders
- Increased profit
- Enhanced reputation

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The QA program manages:

- Design standards
- Drafting, detailing, and modeling standards
- Training
- Documentation of design
- Ongoing quality assurance reviews

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The QA program 30 years ago

- QA manager available to answer questions
- A single QA review at the end of design

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QA today

- Formal processes and procedures
- "Ongoing Quality Assurance"

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Who is responsible for Quality Assurance?

- Everyone
- Teamwork and communication
- Everyone should be able to contribute to the QA program
- Everyone must "buy in" to the program
- Willingness to accept constructive criticism

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"I don't want anyone looking at my design."

12

Quebec Bridge, August 1907

13

75 deaths; 18,000 tons of steel in the St. Lawrence River

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The Quality Assurance Program

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A useful publication

CASE Document 962 D, **"A Guideline Addressing Coordination and Completeness of Structural Construction Documents",** 2013, Council of American Structural Engineers.

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Components of a QA Program

1. QA manager
2. Training
3. Design standards
4. CAD & BIM standards – focus on drawing quality
5. Project Delivery System
6. Knowledge Base
7. Multiple QA reviews **("Ongoing QA")**

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1. QA Manager: Requirements

- 15 years experience (minimum)
- Knows the codes and design standards
- Detail oriented
- Problem solver
- A (balanced) nit-picker
- Flexible (willing to consider options)
- Practical (not overly theoretical)
- Enjoys working with others
- Doesn't shy from confrontation

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1. QA Manager: Responsibilities

- Establish / maintain office design standards
- Answer technical questions
- Train staff
- Review framing plans & details before going to CAD
- Maintain involvement & familiarity on projects
- Perform multiple QA reviews throughout design

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2. Training

You can't grow a tomato in a week.

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2. Training

- Formal training seminars on topics required to for engineers the to become more productive.
- "Boot camp" training for new hires
- Lunch and learn seminars for everyone
- TEK notes
- Interaction between new engineers and senior engineers

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2. Training: New Engineers

Topics:

- Shop drawing review
- How buildings go together (design, details, documentation of the design and details)
- Structural "drafting" and detailing
- AISC 360
- Structural steel connection design
- Constructability / connection "designability"
- ACI 318

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2. Training: Lunchtime Seminars

Topics:

- IBC & ASCE 7
- Lateral analysis
- Validating computer analysis
- Strut and tie design
- Cold-formed steel design
- Wood design
- Concrete mix design
- Braced frame connections
- Webinars, manufacturer lunch and learns
- And more….

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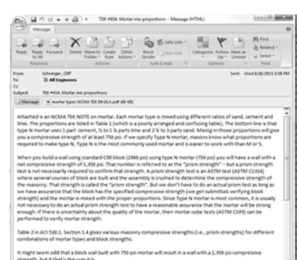
2. Training: TEK Notes



TEK #454: Mortar mix proportions - Message (HTML)

From: Schwinger, Cliff Sent: Wed 8/26/2015 3:59 PM
To: All Engineers
Cc:
Subject: TEK #454: Mortar mix proportions
Message | mortar types NCMA TEK 09-01A.pdf (48 KB)

Attached is an NCMA TEK NOTE on mortar. Each mortar type is mixed using different ratios of sand, cement and lime. The proportions are listed in Table 1 (which is a poorly arranged and confusing table). The bottom line is that type N mortar uses 1 part cement, ½ to 1 ¼ parts lime and 2 ¼ to 3 parts sand. Mixing in those proportions will give you a compressive strength of at least 750 psi. If we specify Type N mortar, masons know what proportions are required to make type N. Type N is the most commonly used mortar and is easier to work with than M or S.

When you build a wall using standard C90 block (1900 psi) using type N mortar (750 psi) you will have a wall with a net compressive strength of 1,350 psi. That number is referred to as the "prism strength" – but a prism strength test is not necessarily required to confirm that strength. A prism strength test is an ASTM test (ASTM C1314) where several courses of block are built and the assembly is crushed to determine the compressive strength of the masonry. That strength is called the "prism strength". But we don't have to do an actual prism test as long as we have assurance that the block has the specified compressive strength (we get submittals verifying block strength) and the mortar is mixed with the proper proportions. Since Type N mortar is most common, it is usually not necessary to do an actual prism strength test to have a reasonable assurance that the mortar will be strong enough. If there is uncertainty about the quality of the mortar, then mortar cube tests (ASTM C109) can be performed to verify mortar strength.

Table 2 in ACI 530.1, Section 1.4 gives various masonry compressive strengths (i.e., prism strengths) for different combinations of mortar types and block strengths.

It might seem odd that a block wall built with 750 psi mortar will result in a wall with a 1,350 psi compressive strength, but it that's the way it is.

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3. Design Standards

- In-house design guides
- Office procedures (modeling, drafting, LRFD vs ASD, etc.)
- Checklists

Must be office-wide consistency.

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4. CAD & BIM Standards / Drawing Quality

- CAD / BIM / drafting / detailing procedures
- Training on structural "drafting" for engineers
- Training on structural drafting for CAD personnel
- Typical details
- "Go-by" drawings
- BIM procedures and standards
- Pre-detailing CAD sign-off

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4. Drawing Quality

High-quality drawing presentation is essential

- It is easy to spot errors on good drawings
- Bad drawings can hide errors
- Bad drawings can be misunderstood
- Good drawings enhance safety
- Good drawings reduce confusion, RFI's and change orders

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4. Drawing Quality

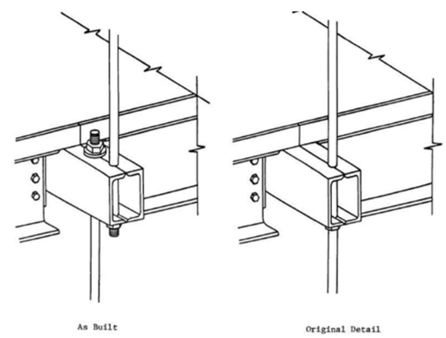

Figure 10.2 Comparison of interrupted and continuous hanger rod details.

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4. Drawing Quality

Establish written standards for drafting

Sections and details (general)

85. What is the purpose of the section or detail? Every section or detail must have a purpose and must convey information that would otherwise be missing or unclear. (No need to always show everything – particularly if specific things are not related to the purpose of the detail.)
86. Every section must have text. (No purpose for a section if there is no text. It is just a "picture".)
87. Organize details in logical format. Foundation, concrete, steel, masonry, etc.
88. Do not draw more than necessary in sections and details (i.e., walls, beams, etc)
89. Do not detail things that are not in our scope of work (architectural details, etc.)
90. Do not refer to waterproofing, flashing, and other things that are not in our scope of work in structural sections and details
91. Draw details to scale
92. Left justify text on the right side of the details; right justify text on the left side of the detail
93. Strive for photo-quality details
94. Sections versus details: sections occur for distance, details occur at one spot
95. Don't cut sections every which way
96. No titles on details (unless they are typical details)
97. Don't refer to a detail that refers back to the same detail
98. Combine similar sections to a single detail (section 1, 1A, 1B,…)
99. It is ok to refer to other details for additional information, but don't refer to another detail that refers to another detail
100. Avoid orphan details (every detail other than typical details must be referenced)
101. Don't state the obvious (BEAM, SEE PLAN; SLAB, SEE PLAN FOR THICKNESS; COLUMN, SEE SCHEDULE….)
102. Mega-sections (sections encompassing two or more floors) are ok, however if conditions change along the length of the mega-section, then the section must reflect that. When cutting a mega-section on two floors (top and bottom of mega-section), cut the section in the same spot.
103. Do not "half detail" sections.
104. Extent arrows: generally not needed. If section is typical say "TYP". If section applies along full length of wall, then extent along full length is implied.

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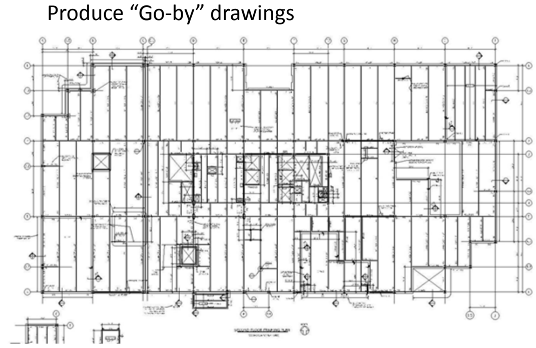
4. Drawing Quality

Produce "Go-by" drawings



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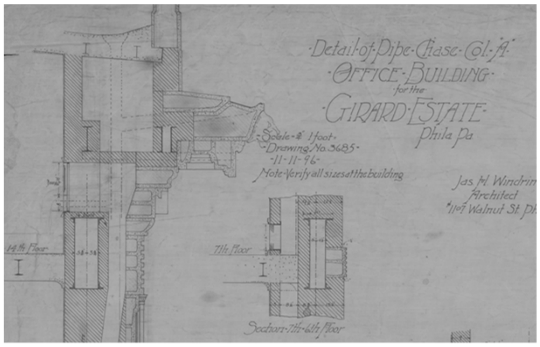
4. Drawing Quality (1896)



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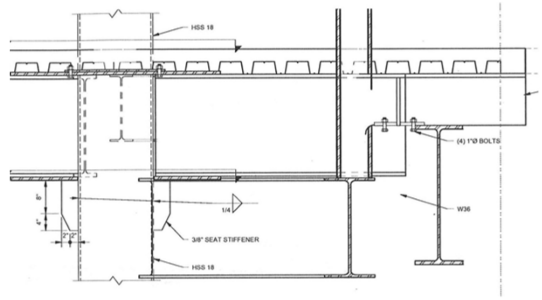
4. Drawing Quality (2017)



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5. Project Delivery System

Checklists and procedures for:
- Project startup
- Schematic design
- Design development
- Contract documents
- Construction Administration

The PDS is:
- A road map
- Eliminates re-invention of the wheel
- Fosters uniformity and consistency

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6. Knowledge Base

- Server-based database of structural engineering knowledge
- Similar to Wikipedia
- Contains checklists, design guides, seminar notes, TEK notes, etc.

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7. QA reviews

- Ongoing QA (multiple QA reviews)
- QA manager maintains familiarity with all projects as they progress through design
- Ongoing QA will catch problems early (when they are easy to fix).
- Ongoing QA improves productivity

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The Quality Assurance Review

(the "in-house" peer review)

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Quality Assurance Reviews

In-house reviews conducted to verify that design and documentation is in conformance with procedures, practices and standards mandated by the QA program.

This discussion is applicable to ***all*** engineers – not just those performing QA reviews. All engineers are responsible for performing their own "self – QA review"*.

*The "self-QA review" is not a substitute for an independent QA review by someone else.

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Why a "self-QA" review is not enough

Black holes stand at the very edge of scientific theory. Most scientists believe they exist, although many of of their theories break down under the extreme conditions within. But Professor Cornelius Van Bockstein of of the University of Ushuaia says he knows what you would find inside, and challenges the traditional idea that gravity would cause you death by "spaghettification".

Count the number of F's in the text above.

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Purpose of the QA Review

A second set of eyes will find:

- Mistakes
- Confusion
- Missing information
- Constructability problems

The QA review:

- Provides a level of redundancy to the design process
- Monitors the effectiveness of the QA program

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Primary Goal of a QA Review

To verify that structures are properly designed

Look at:

- Big picture – load paths / framing efficiency
- Member sizes
- Critical connection details
- Constructability
- Glaring errors

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Secondary Goal

To verify that drawings are complete, coordinated and correct. Look at the drawings through the eyes of the,

- Architect
- Contractor
- Steel fabricator
- Detailer
- Inspector
- Peer reviewer
- Building Official
- Detailer
- Young engineer reviewing shop drawings
- Lawyer

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QA Review Checklist

1. Big picture
2. Load paths
3. Stability & redundancy
4. Framing sizes
5. Strength & stiffness
6. Validate analysis model
7. Connections
8. Details
9. Constructability
10. Look for mistakes
11. Design creep
12. Look for subtleties
13. Look at drawings through the eyes of others
14. Clarity & consistency (poor drafting)
15. Omissions
16. "Little" little things
17. "Big" little things
18. Coordination with others
19. Other things…

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1. Look at the big picture

- Load paths
- Global stability issues (and subtleties)
- Local stability and bracing subtleties
- Connections
- Inefficient framing
- Design loads
- Problems with model (what did model miss?)

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2. Verify Load Paths

- Any unrealistic load paths?
- Are all load paths complete and continuous?
- Any loads jumping in & out of braced frames, moment frames and shear walls?
- Problems related to “infinitely rigid” diaphragms?

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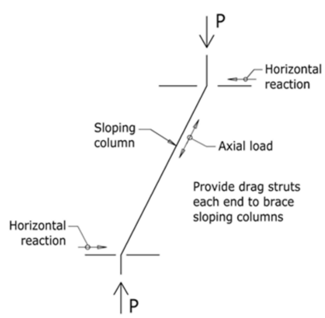
2. Verify Load Paths



Do the forces resolve?

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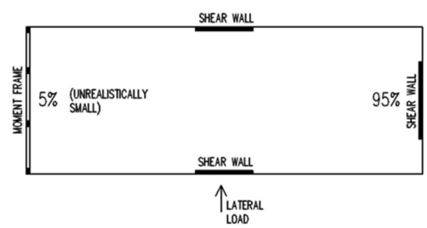
2. Verify Load Paths



Any unrealistic distributions of lateral loads between lateral load resisting elements?

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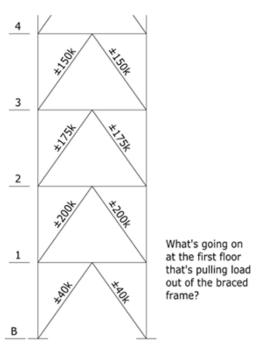
2. Verify Load Paths

Any questionable braced frame forces from computer analysis?



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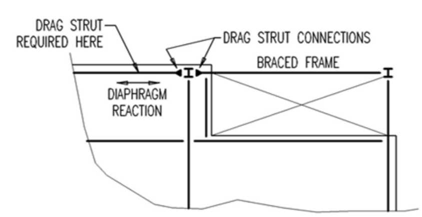
2. Verify Load Paths



Did the computer analysis consider load path issues if the floor diaphragm is not connected to the braced frame? (Probably not?)

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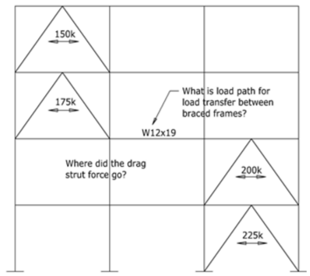
2. Verify Load Paths



Did the computer analysis consider drag strut forces?

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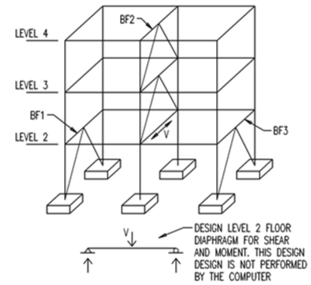
2. Verify Load Paths

Did the computer analyze and design the diaphragm? (Probably not)



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3. Stability & Redundancy

- Are there enough braced frames, moment frames and shear walls?
- Are they properly sized and located?
- Are any columns braced in the computer model – but not in reality?
- Is there sufficient redundancy?
- Any “islands of instability”?

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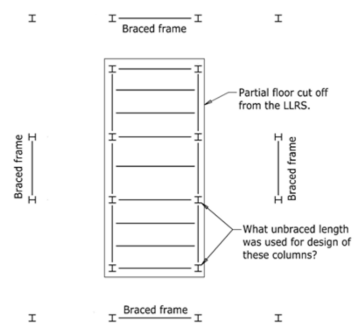
3. Stability & Redundancy



“Island of instability”

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4. Check framing (gravity & lateral)

Check:

- Typical framing to verify the analysis model
- Every major load-carrying member
- Wind and seismic loads
- Unique framing and loads that may not be in the computer model

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Show reactions

- Showing reactions makes the QA review easier
- Load paths are easier to follow
- Mistakes are easier to find (modeling mistakes)
- Forces designer to think about the connections
- Reduces cost (allowing fabricator to detail connections for actual reactions).

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Things requiring special attention

Elevators	Folding partitions
Escalators	Special hang points
Facades	Rooftop MEP loads
Davits	Heavy hung piping
Stairs	Special loads on joists
Monumental stairs	Horizontal loads from rigging
Hangers	Catwalks
Theater rigging	Unusual framing

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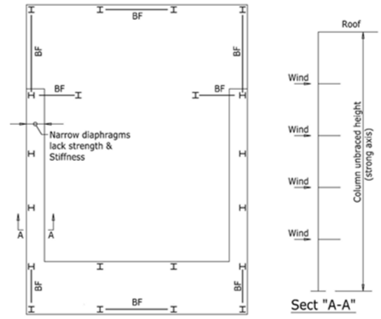
5. Strength and stiffness



The model assumed a diaphragm with infinite strength and stiffness.

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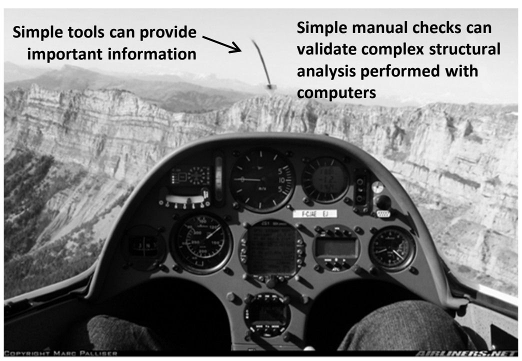
6. Validate the analysis model



Don't get lost in the model

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6. Validate the analysis model

Simple tools provide valuable information

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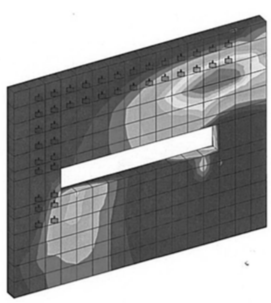
6. Validate the analysis model

We see what we want to see.

The way we hope a structure works influences the way we model it - and the way we interpret the results.



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6. Validate the analysis model

Understand the software:

- What are the flaws and simplified assumptions made by the software programmers?
- What are the variables?
- What are the defaults?
- What are the prejudices (invalid assumptions) that we put into our models?

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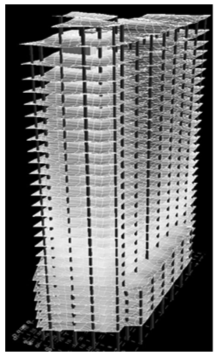
6. Validate the analysis model

There is nothing inherent about finite element analysis modeling that makes it correct.

View all models with suspicion.

Never get complacent with the computer analysis.



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6. Validate the analysis model

What did the computer not check?

- Framing through steps in floor slabs
- "Infinitely rigid" diaphragm issues
- Incorrect assumptions made in model
- What was not checked? (wind shielding)
- Global stability ("islands of instability")
- Load path subtleties (drag struts, girt loads)
- What is not in the model? (missing loads, etc.)
- What changed since the model was first created? (roof screens, slab openings, rooftop MEP units, steps in floor slabs, revised slab edge locations, etc.)
- Struts and strut load paths at each end of sloping columns

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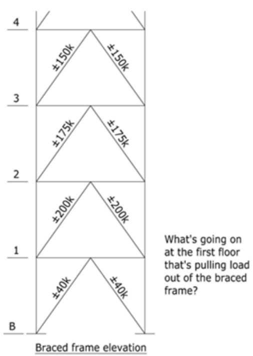
6. Validate the analysis model



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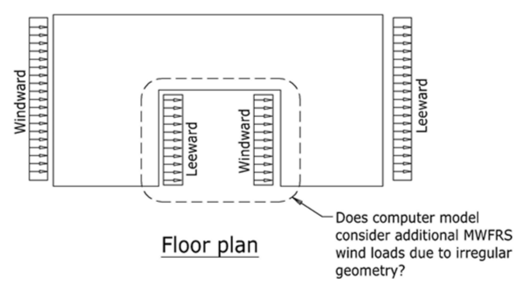
Understanding the software

How are wind loads computed?



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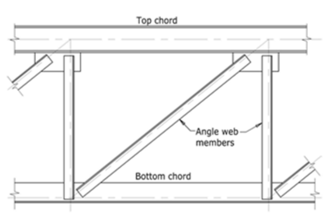
Understanding the software

How are members designed?



Compression: Were angles designed as concentrically loaded (Table 4-11), eccentrically loaded (Table 4-12) or per Section E5 "Single Angle Compression Members"?

Tension: was shear lag factor, "U" considered?

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7. Check the connections

- Critical connections
- Unusual connections (slide bearings, etc.)
- Connections with complex geometry
- "Kinked Connections" – connections with jogs in the load path through the connection
- Hangers
- Truss connections, braced frame connections
- Connections with large reactions
- Are all connections "designable" (review even when delegating connection design)
- Look for problems due to revised framing configurations

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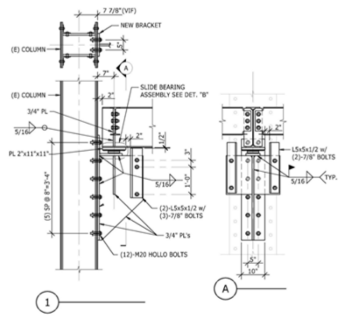
8. Think through & document all of the details



How did you want that slide bearing to the existing column detailed?

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Mindset to foster good design

- If you don't understand the details, you can't do good design.
- Think about the details first, then design
- Think about "connection designability" (even when delegating connection design)
- Provide connection concept details – even when delegating connection design. (Conceptual connection details are specifically required by the 2016 AISC Code of Standard Practice)

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Failure to think details through during design can lead to unanticipated changes during construction

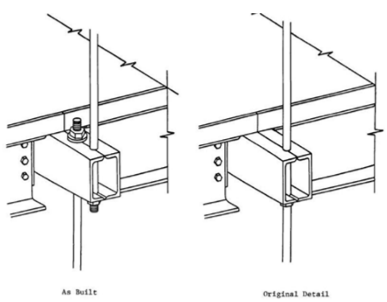

Figure 10.2 Comparison of interrupted and continuous hanger rod details.

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9. Constructability

Steel buildings:

- Will the pieces fit together?
- Are the connections designable?

Concrete buildings:

- Is the formwork economical and repetitive?
- Can the reinforcing steel be easily installed?
- Just because the computer analysis says the design works does not mean that it can be built – or even that it works.

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9. Constructability

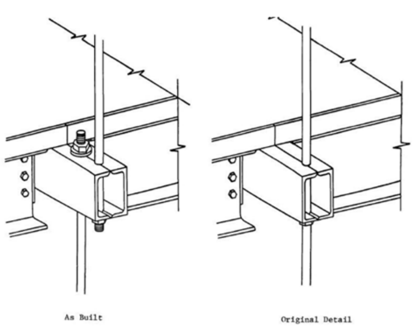

Figure 10.2 Comparison of interrupted and continuous hanger rod details.

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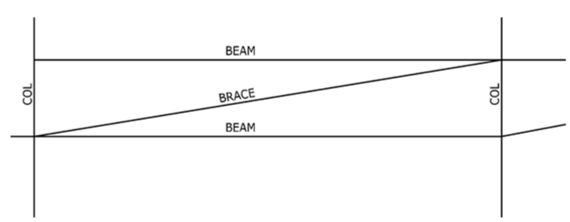
9. Constructability



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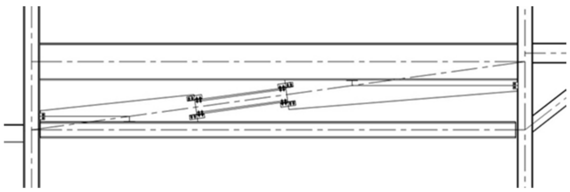
9. Constructability



These connections are neither constructable nor designable

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10. Look for mistakes

- Wrong reactions
- Members too small
- Improper framing configurations
- Insufficient or missing reinforcing steel
- Punching shear problems
- Missing structural integrity reinforcing steel
- Missing sections and details
- Mistakes in sections and details
- Mistakes in computer model
- Invalid assumptions made in computer model
- Insufficient diaphragm strength/missing diaphragm connections

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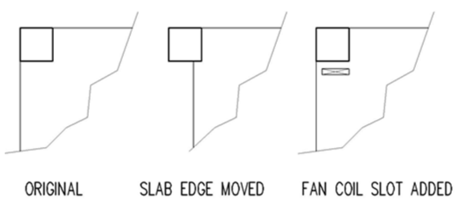
11. Design Creep

Small changes in slab edge locations can drastically affect punching shear capacity in flat plates



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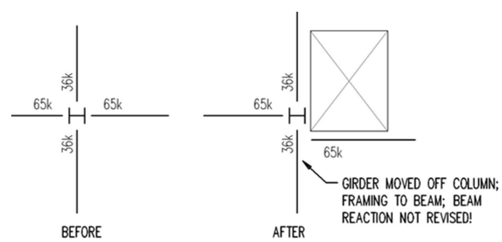
11. Design Creep

Example: Slab opening added near column; girder shifted to avoid opening; girder now connecting to beam but beam and beam reaction not revised.



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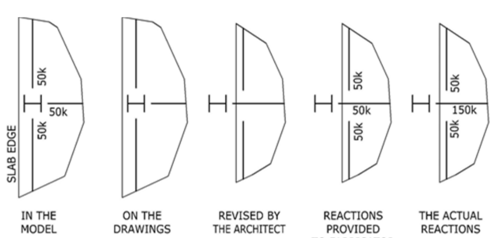
11. Design Creep

Missing reactions, design creep and a translation error can cause a structural failure



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11. Design creep during construction

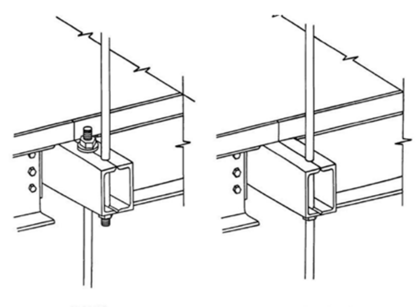

Figure 10.2 Comparison of interrupted and continuous hanger rod details.

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12. Look for subtleties

- Column splices at inappropriate locations (mid-height of 100’ unbraced height)
- Framing through steps in floor slabs
- Diaphragm issues
- Incorrect assumptions made in computer model
- Things not checked in the computer analysis
- Stability subtleties (“islands of instability”)
- Double-height columns taking wind load
- Load path subtleties (circular framing)

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12. Look for subtleties

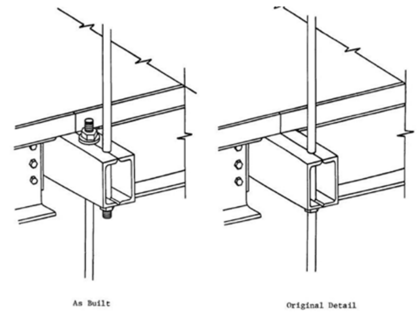
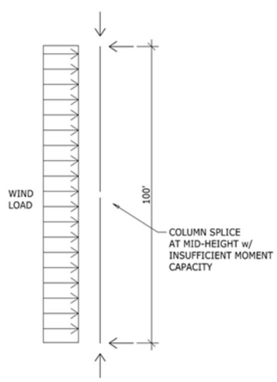


Figure 10.2 Comparison of interrupted and continuous hanger rod details.

80

12. Look for subtleties

Special column splices required in tall unbraced columns



81

13. Look at the drawings through the eyes others

- Look at the drawings from the perspective of someone who’s not an engineer
- Is everything shown that will allow contractor to build structure without having to guess or issue RFI’s?
- Is every foot of the building perimeter covered by a section?
- Is everything clearly indicated?
- Is bad drafting obscuring important information?
- Anything missing?
- Are all details provided?
- Any conflicting information?
- Can the drawings be interpreted by someone who’s not an engineer?
- Search drawings for potential change orders

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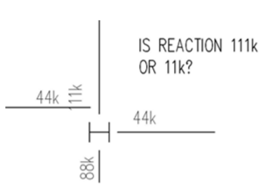
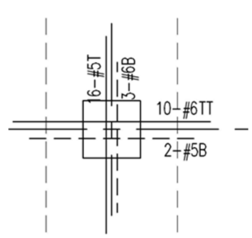
14. Clarity & Consistency (Poor Drafting)

Sloppy drafting can cause structural failures





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14. Clarity & Consistency (Poor Drafting)

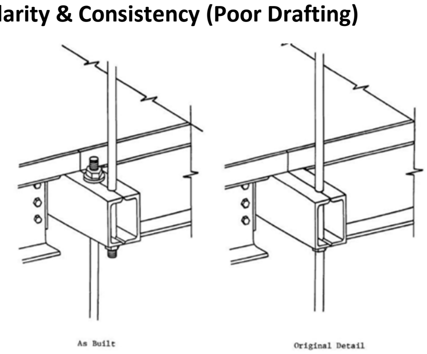

Figure 10.2 Comparison of interrupted and continuous hanger rod details.

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14. Clarity & Consistency (Poor Drafting)

- Look for conflicts between framing plans and sections/details.
- Inconsistencies with framing
  - Group similar beams
  - Consistency = simplicity = economy
- Drafting inconsistencies
- Are sections and details cut in a uniform manner?
- Are the details well thought out, arranged in an organized manner and well-drawn?

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15. Look for Omissions

Look for the things that are not there.

Missing:

- Reactions
- Section/details
- Dimensions and elevations
- Sizes
- Reinforcing steel
- Beams
- Columns
- Expansion joints
- Slab openings
- Excessively long slab-on-metal-deck spans

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16. Look for "little" little things

- Spelling mistakes
- Sections cut the wrong way
- Improper dimensioning
- Text over text / text over lines / lines over lines
- Improper text font, size, justification, etc.

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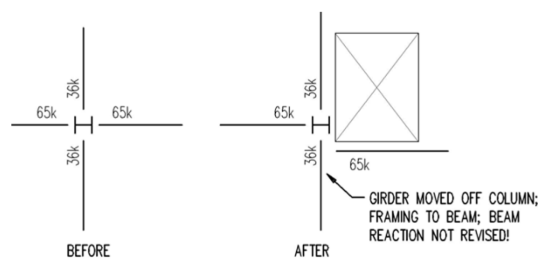
17. Look for "BIG" little things



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18. Coordination with Others

- Dimensions and slab edges
- Facade sections, details and support requirements
- Column locations
- Slab openings
- Headroom clearances
- Slab elevations, slopes, depressions and steps
- Floor plans (verify design loads)
- Stairs, elevators, escalators
- Rooftop screen walls, MEP penthouse, parapets…

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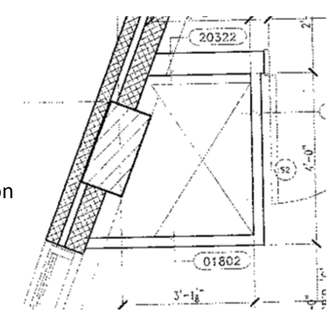
18. Coordination with Others

Slab opening cuts off load path to column.

Opening not shown on structural drawings.



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18. Coordination with Others

MEP Coordination

- Heavy piping & equipment loads
- Large ducts (headroom interference with framing)
- Beam web penetrations
- Slab embedded electrical conduit
- Below grade utilities

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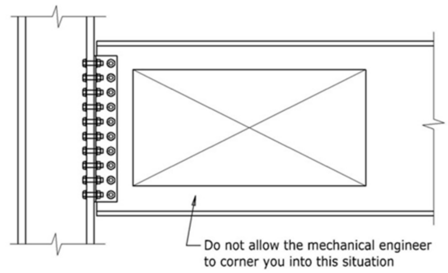
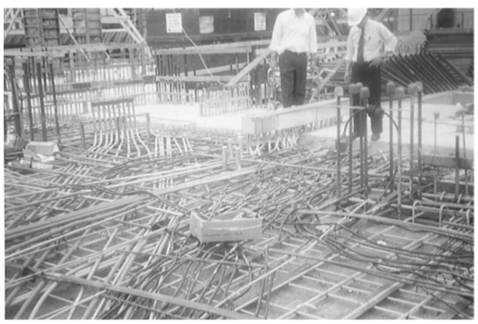
18. Coordination with Others



92

18. Coordination with Others



Slab-embedded electrical conduit.

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19. And many other things…

- Serviceability issues
- Foundations
- Wood framing
- Precast
- Window washing davits
- Roof screens
- Rooftop dunnage
- Facade connections
- Delegated design
- Elevators
- Escalators
- Stairs/monumental stairs
- Durability issues

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Things to remember

- Never get complacent
- Ongoing QA
- Few things are binary in structural engineering
- Good communication is essential
- Load paths, stability, reactions
- Understand software limitations
- Look for what is not there
- Changes after design can cause problems
- Drawings and design must be complete
- Seemingly small things can cause big problems
- Think through the details while designing

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Summary

QA program

1. QA manager
2. Training
3. Design standards
4. CAD/BIM Standards
5. Project Delivery System
6. Knowledge base
7. QA reviews / Ongoing QA

Teamwork, communication, and "Ongoing QA" are essential

Quality Assurance is everyone's responsibility

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Thank you

Questions?

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