VII CONGRESO INTERNACIONAL DE LA CONSTRUCCIÓN CON ACERO

2019 Medellín, *Centro de Eventos El Tesoro*
Junio 19, 20 y 21

ICCA
INSTITUTO COLOMBIANO DE LA CONSTRUCCIÓN CON ACERO

Tips for Validating the Results of Structural Engineering Software

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THE HARMAN GROUP
structural engineering
parking planning and design

PHILADELPHIA | NEW YORK

CONGRESO INTERNACIONAL DE LA CONSTRUCCIÓN CON ACERO

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- We invite you to set your cell phones in silence mode.

Thanks!

Seminar Objective

Review methods for validating the accuracy of structural analysis models for:

- Building structures
- Non-building structures

Two points…

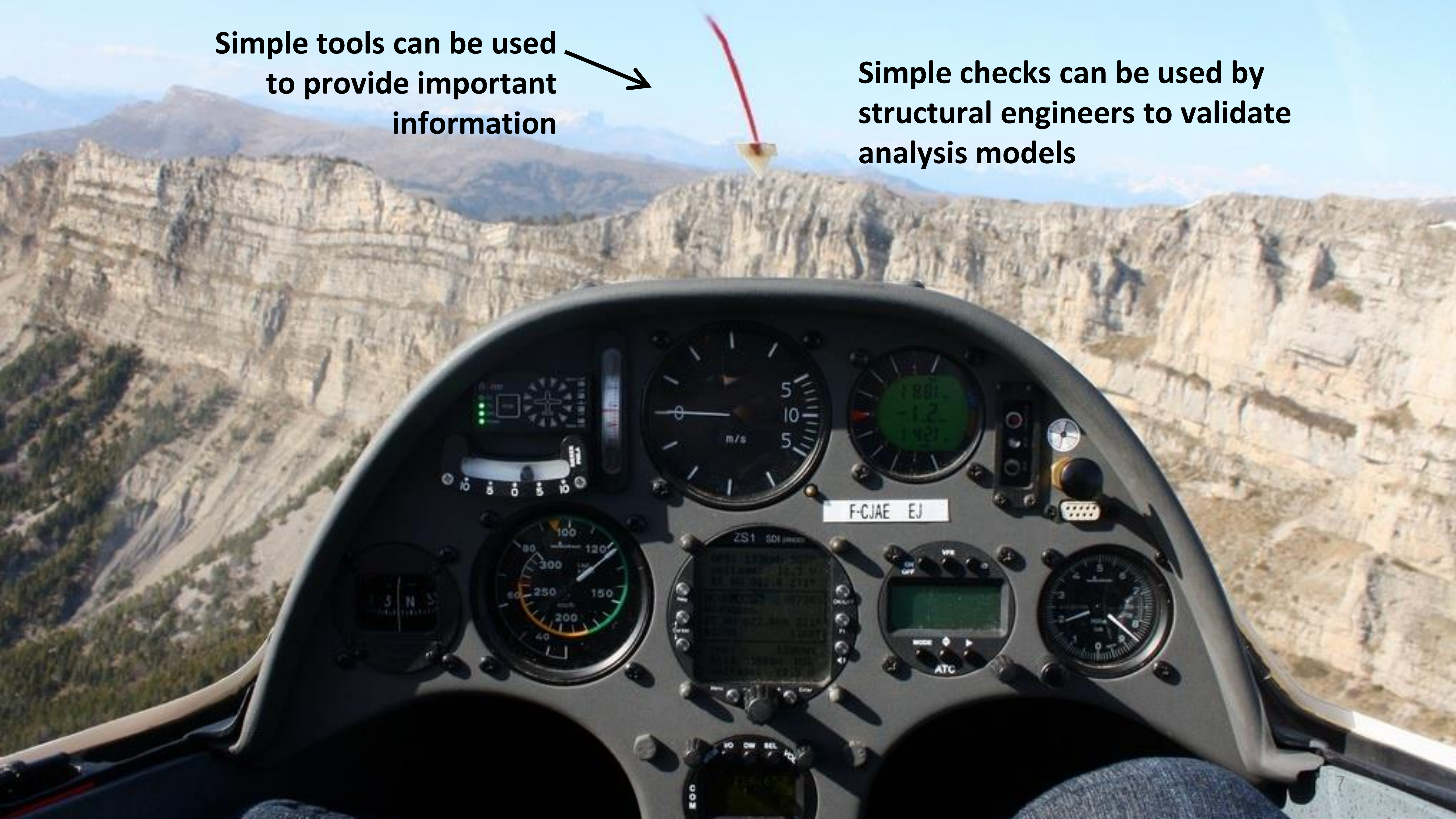
- This is *not* a discussion on limitations of any software.
- We will review shortcuts and approximate procedures for validating computer analysis; however, shortcuts ***are not*** a substitute for meticulous adherance to the requirements of the building code

To be discussed

1. Philosophy of model validation
2. Types of errors
3. Understanding the software
4. Infinitely rigid diaphragms
5. Load combinations
6. Building structures
    - Gravity framing
    - Lateral load resisting system
7. Non-building structures

Simple tools can be used to provide important information

Simple checks can be used by structural engineers to validate analysis models




Nazarene

Philosophy and mindset

- Use the computer as a tool – not a crutch.
- Do not assume that computer analysis is correct until you manually validate the results.
- Validation of computer models requires understanding the of the codes and design standards.
  - IBC
  - ASCE 7
  - AISC 360

Do not blindly rely on the computer

Philosophy and mindset

Do not blindly rely on the computer

future tense

Dumbing It Down in the Cockpit

As automation gets sharper, pilots' thinking skills are getting duller.

By STEVE CASNER

DEC 12, 2014 • 7:47 AM

BUSINESS INSIDER

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The Boeing 737 Max crashes show that 'deteriorating pilot skills' may push airlines to favor Airbus

Jim Edwards Apr. 28, 2019, 4:09 AM

Philosophy and mindset

Never stop thinking about:

1. Strength
2. Stability
3. Load paths
4. Bracing
5. Connections
6. Serviceability
7. Redundancy
8. Constructability

There are aspects of each that computer models will not consider.

Philosophy and mindset

- If the framing in the model does not look right, then there is probably a problem.
- Do not rely on the computer model to tell you that a suspect design works. (Trust your instinct.)
- Question everything
- Be cautious
- Be skeptical

Philosophy and mindset

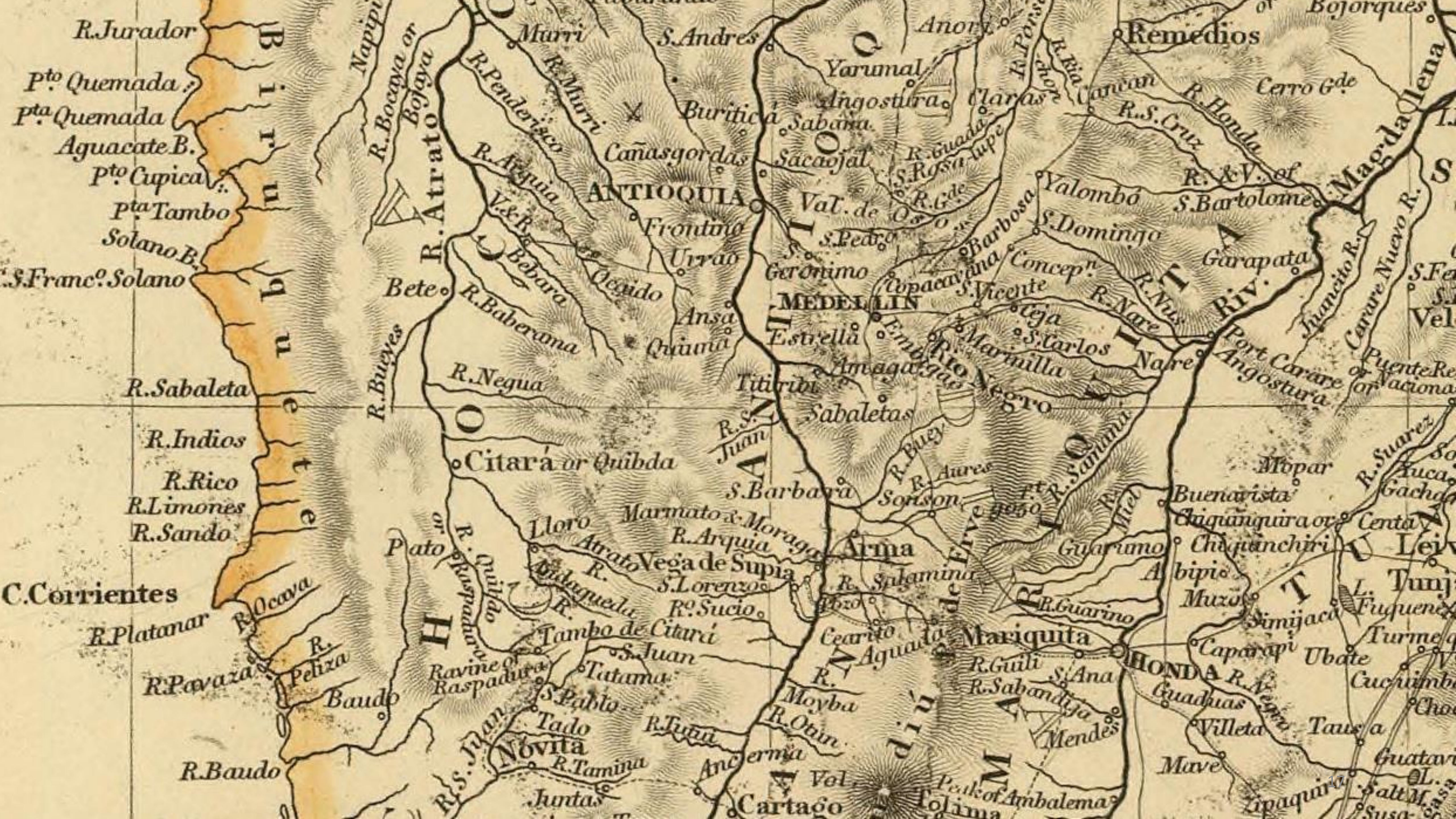
- Do not assume the computer knows more than you
- Do not assume the computer checks everything
- Design assumptions don’t become valid solely by putting them in the analysis model
- A model that runs with no errors does not mean the design is a good one – or safe one
- If the results seem too good to be true – there’s a mistake
- Do not let the computer think for you

Philosophy and mindset

- Do not be blinded by pre-conceived notions
- Never get complacent – question everything
- Watch the flow of the load
- “The map is not the territory.”
  - A map is a model of the land.
  - A computer model of a structure is not the structure.
  - Both are models. Both are approximations.


COLOMBIA,
DEDICATED TO
J. ARROWSMITH
C A R I B B E A N S E A
Portuguese Guayana
B R A Z I L

1834 map



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Pto Quemada
Pta Quemada
Aguacate B.
Pto Cupica
Pta Tambo
Solano B.
S.Franco Solano
R.Sabaleta
R.Indios
R.Rico
R.Limones
R.Sando
C.Corrientes
R.Platanar
R.Ocava
R.Peliza
R.Pavaza
Baudo
R.Baudo
Bay of Biruquete
R.Bocaya or Bojaya
Napipi
R.Atrato
R.Bueyes
Bete
Citará or Quibda
Pato
R.Raspadura
R.Quito
Lloro
Atrato R.
Andagueda R.
Tambo de Citará
Ravine of Raspadura
S.Juan
Tatama
S.Pablo
Tado
Novita
R.Tamina
R.S.Juan
Juntas
R.Penderisco
R.Murri
Murri
R.Arquia
V.&R.
Bebara
Ocaido
R.Baberama
R.Negua
CHOCO
S.Andres
Buriticá
Cañasgordas
ANTIOQUIA
Frontino
Urrao
Ansa
Quiuna
Titiribi
R.S.Juan
S.Barbara
Marmato & Moraga
R.Arquia
Vega de Supia
S.Lorenzo
Ro.Sucio
Arma
R.Moyba
R.Otun
R.Tuna
Ancerma
Vol.
Cartago
Yarumal
Angostura
Sabana
Sacaojal
Val. de Osos
S.Pedro
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R.Samana
Anori
R.Porse
Claras
Remedios
R.Ria
Cancan
R.S.Cruz
R.Honda
Cerro Gde
Yalombo
S.Domingo
R.Nare
R.Nus
Nare
Port Carare
Angostura
R.&V. of S.Bartolome
Garapata
Magdalena Riv.
Juancito R.
Carare Nuevo R.
Puente Real or Nacional
MARIQUITA
Mariquita
R.Guarino
Guarumo
Buenavista
Chiquinquira or Chiquinchiri
Albipio
Muzo
Mopar
R.Miel
HONDA
R.Guali
R.Sabandija
S.Ana
Mendes
Guaduas
R.Negro
Villeta
Mave
Caparapi
Simijaca
L.Fuquene
Ubate
Tausa
Zipaquira
Peak of Ambalema
Tolima
Quindiu
R.Suarez
Centa
Leiva
Tunja
Turmeque
Guatavita
Bojorques
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Velez
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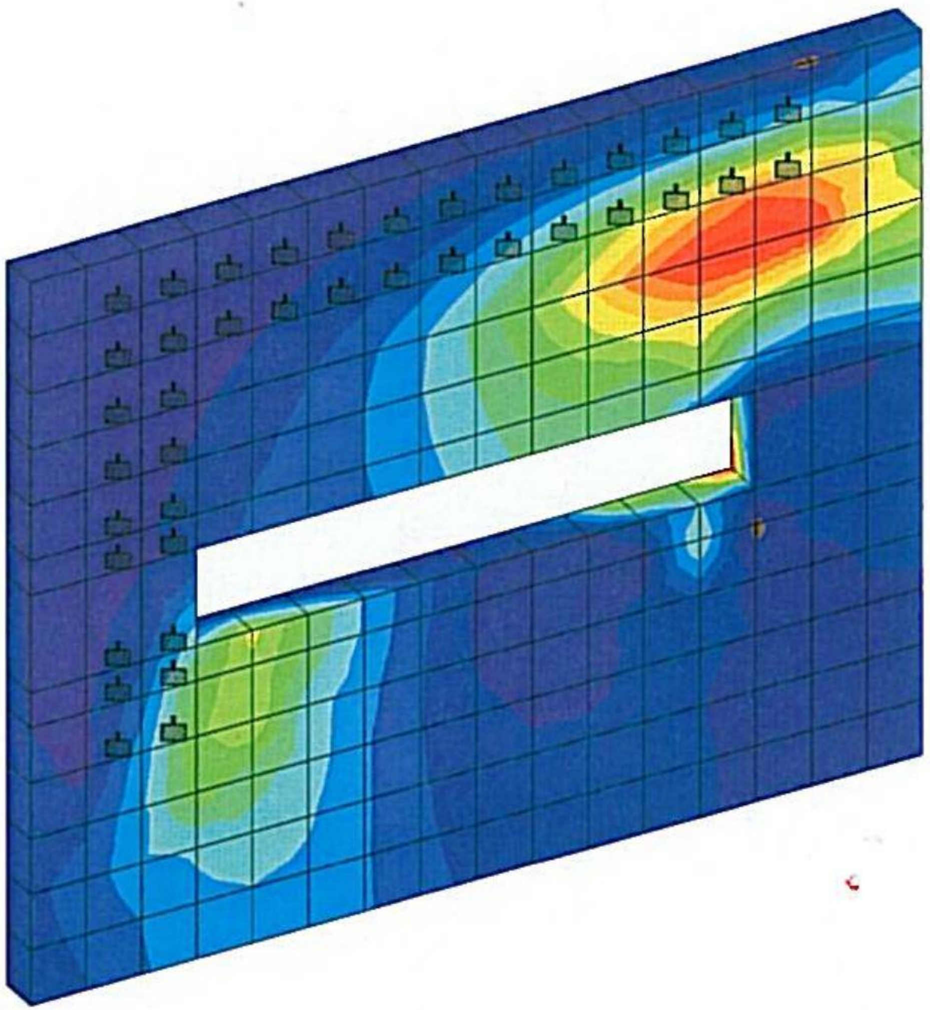
Philosophy and mindset

We see what we want to see.

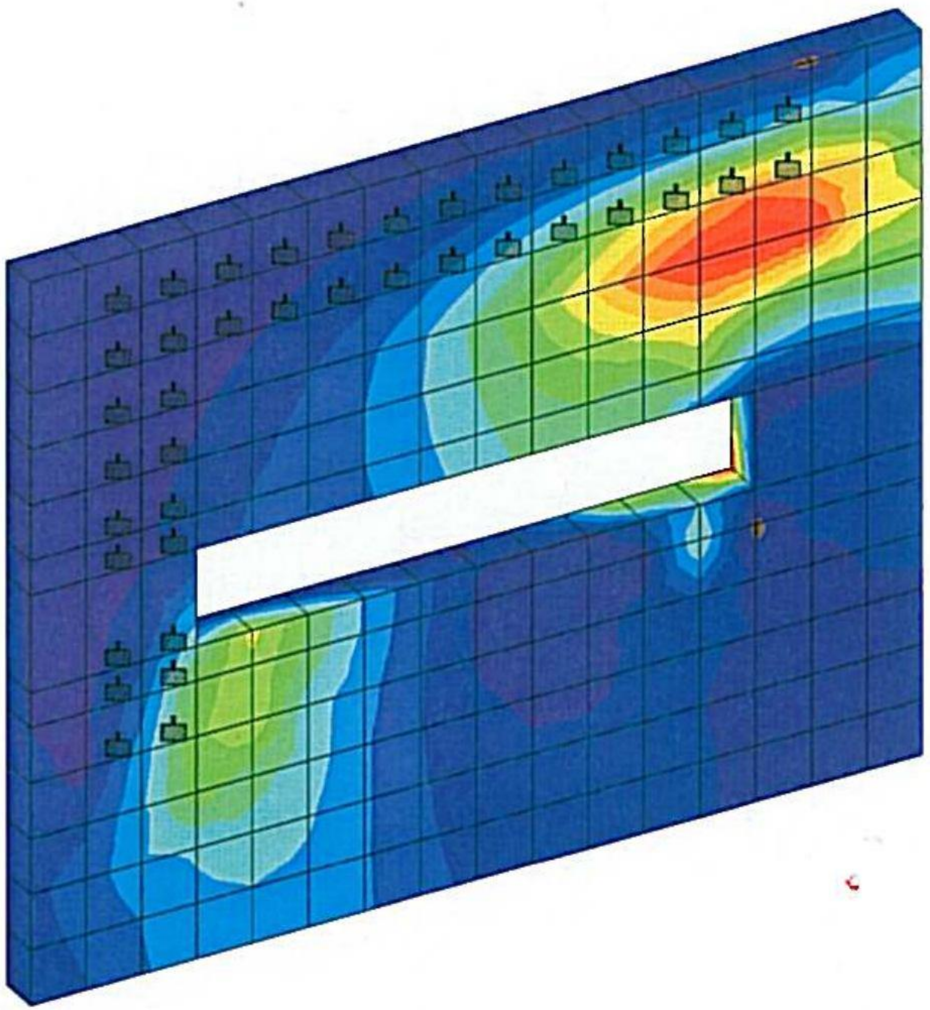
The way we hope a structure works influences the way we model it and the way we interpret the results.



Philosophy and mindset

There is nothing inherent in a finite element model that makes it correct.

Look at models objectively. Do not be lulled into complacency.



Types of Errors

Types of errors

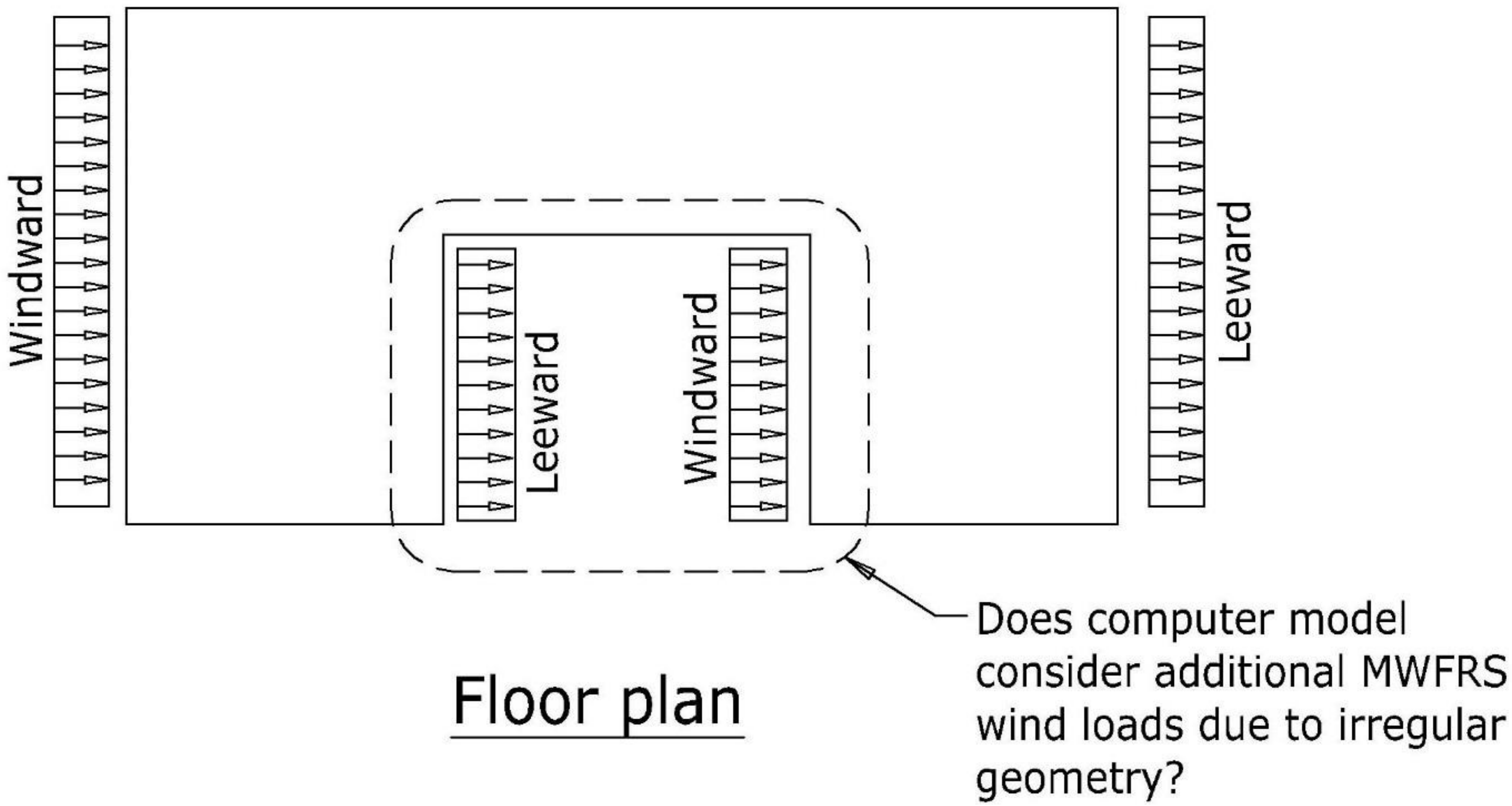
1. Missing information errors
2. Global errors
3. Default errors
4. Code check errors
5. Input errors (modeling errors)
6. Errors in understanding software
7. Software limitations
8. Software errors
9. Constructability errors
10. Translation errors

Understanding the Software … and Software Limitations

Create simple models to check your assumptions of how the software works.

Understanding the software

How are wind loads computed?

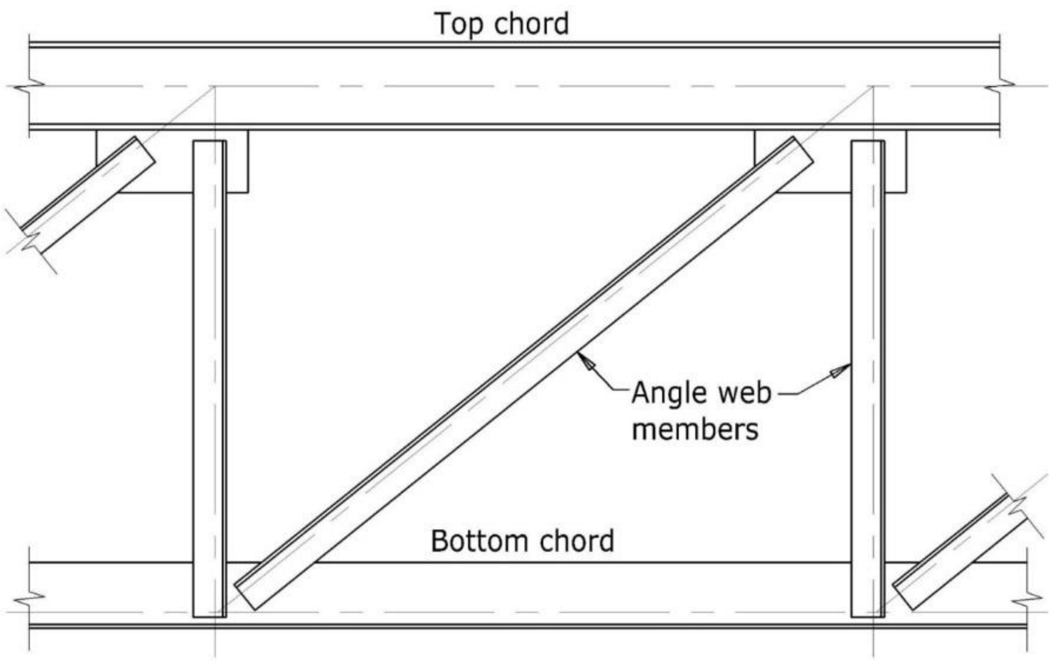


Understanding the software

How are the 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?

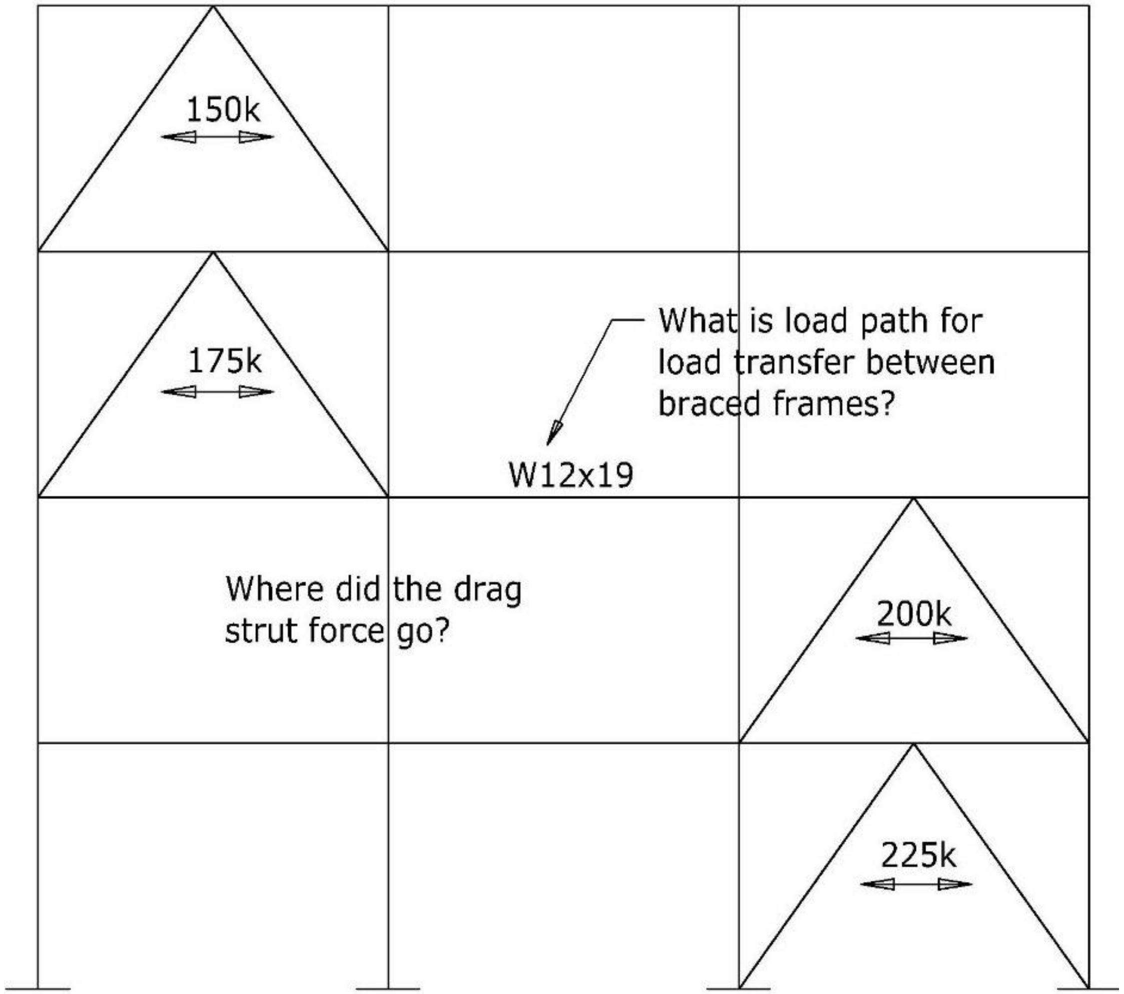


How did the computer design the web members?

Understanding the software

Load path issues:

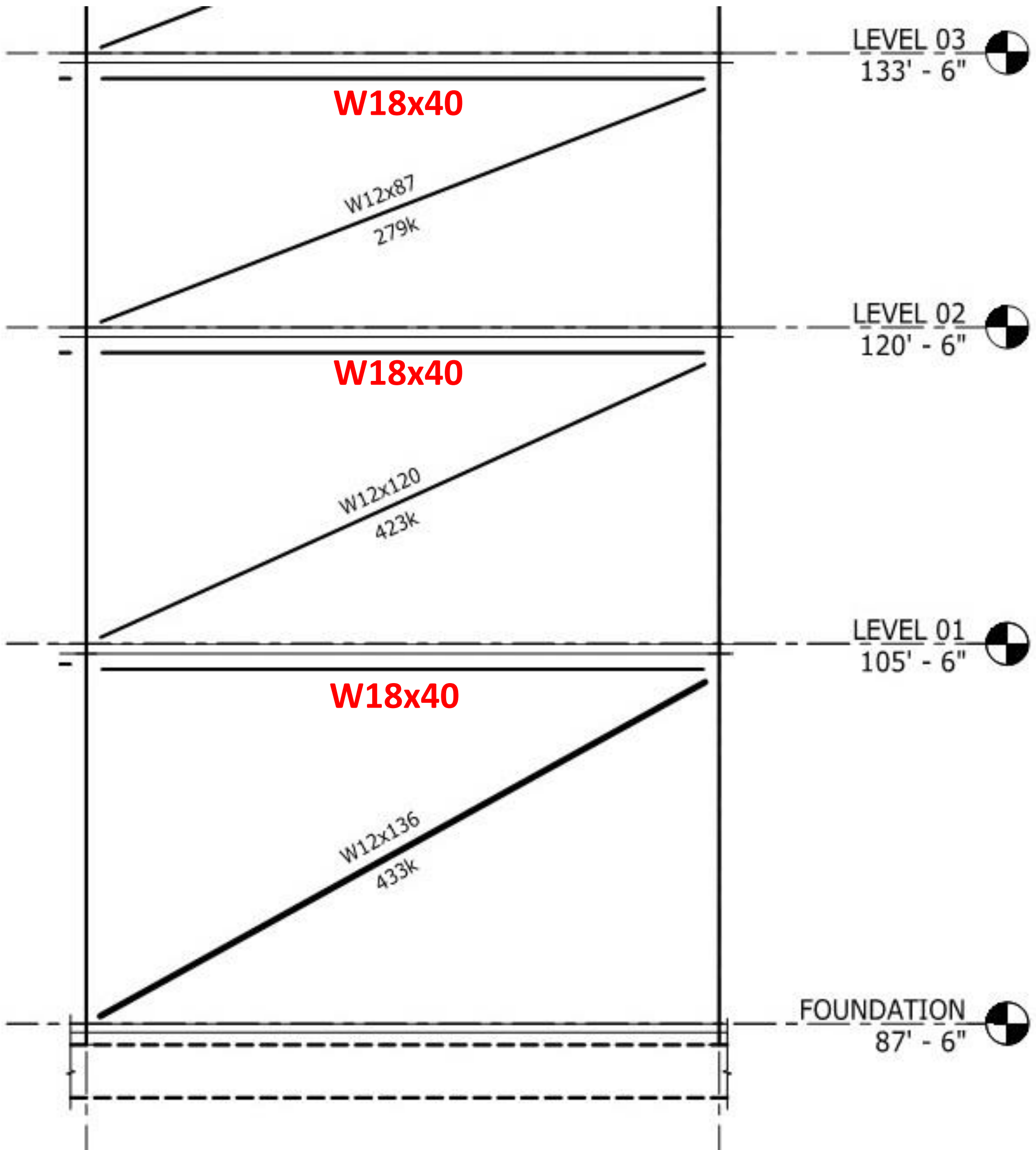
Are drag struts recognized by the model and properly analyzed?



Understanding the software

Load path issues:

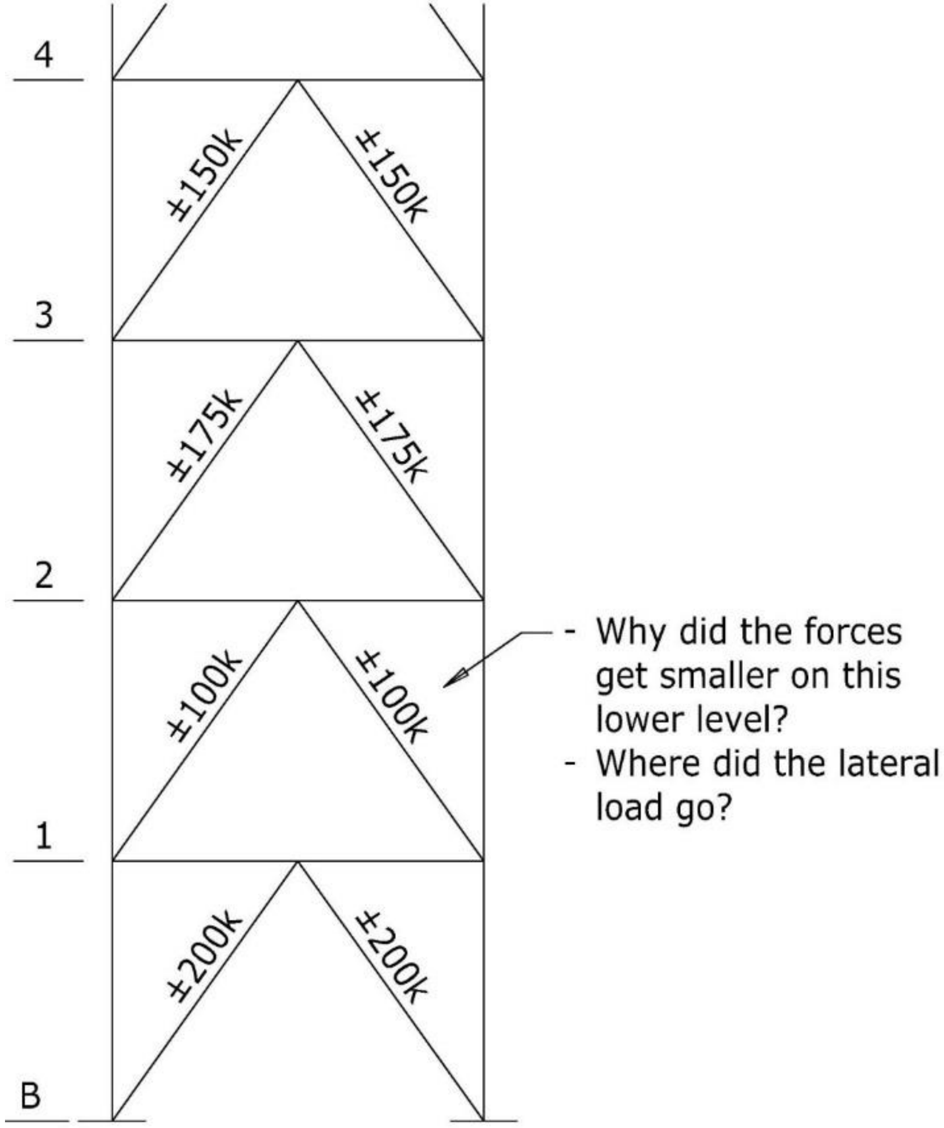
Do loads "disappear" out of the braced frames as they travel down the structure?



Understanding the software

Load path issues:

Are load paths realistic?



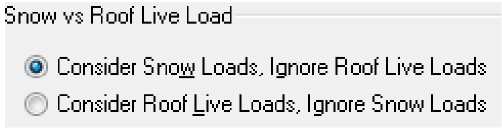
Braced frame elevation

Understanding the software

What are the defaults?

Some examples:

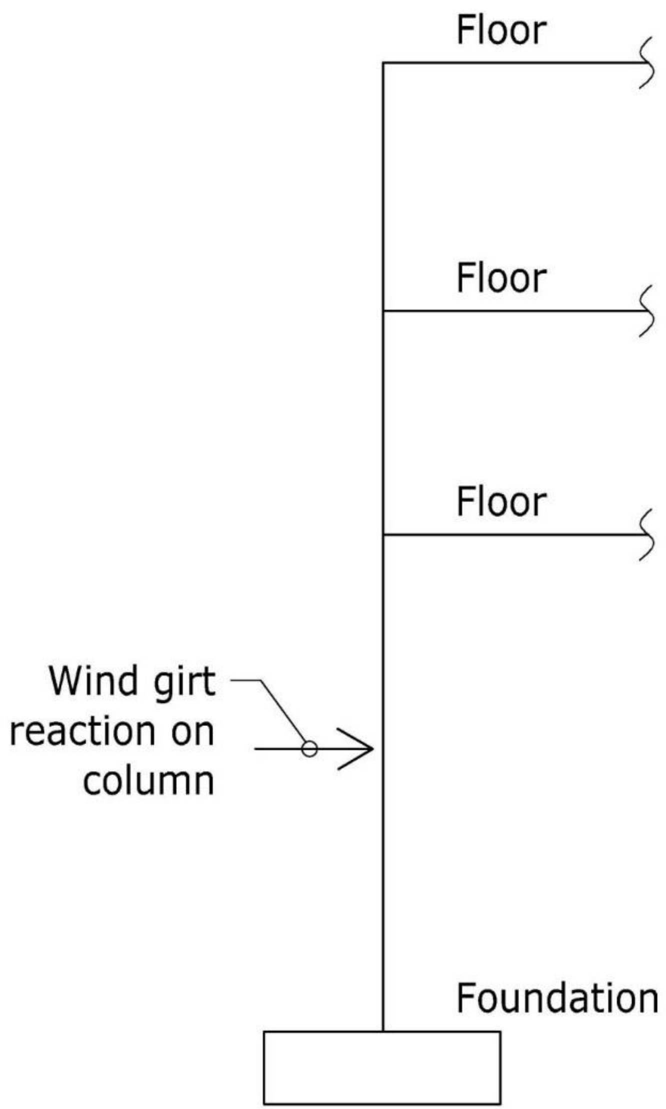
- Structure self-weight
- Roof snow or roof live (can computer deal with both?)
- Unit weight & f’c of concrete (slab-on-metal deck)
- R_g and R_p values for headed studs on composite beams
- Minimum “studdable” beam size
- Bracing constraints
- Second-order analysis (on or off?)
- Notional load, Ni



Understanding the software

What does the software not check?

Are wind girt loads considered?



Understanding the software

What does the software not check?

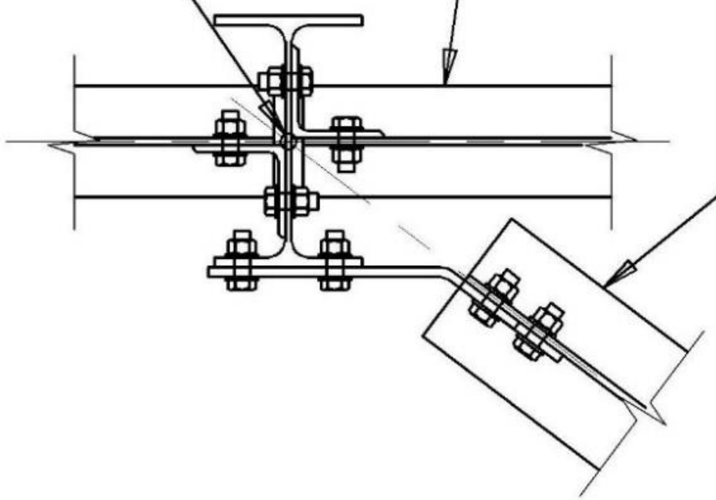
Slabs on metal deck:

- Can deck support wet weight of concrete?
- Any single span conditions?
- Can slab support superimposed loads?
- Is slab spanning in the correct direction?

Understanding the software

How does the model differ from the real structure?

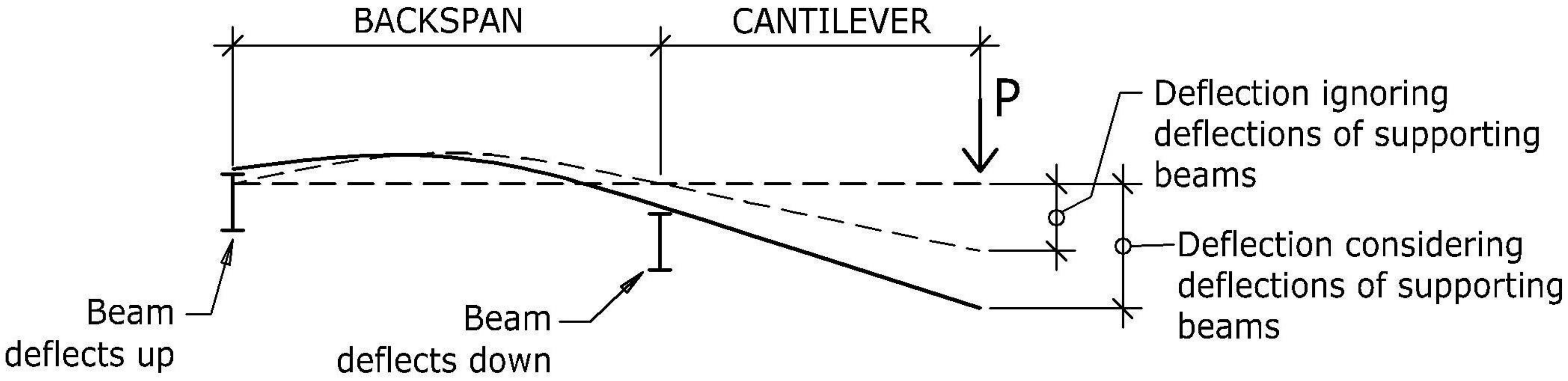
Eccentric loads on the tips of columns



Did computer assume girder framing to workpoint with little or no connection eccentricity?

Understanding the software

How are beam deflections computed?



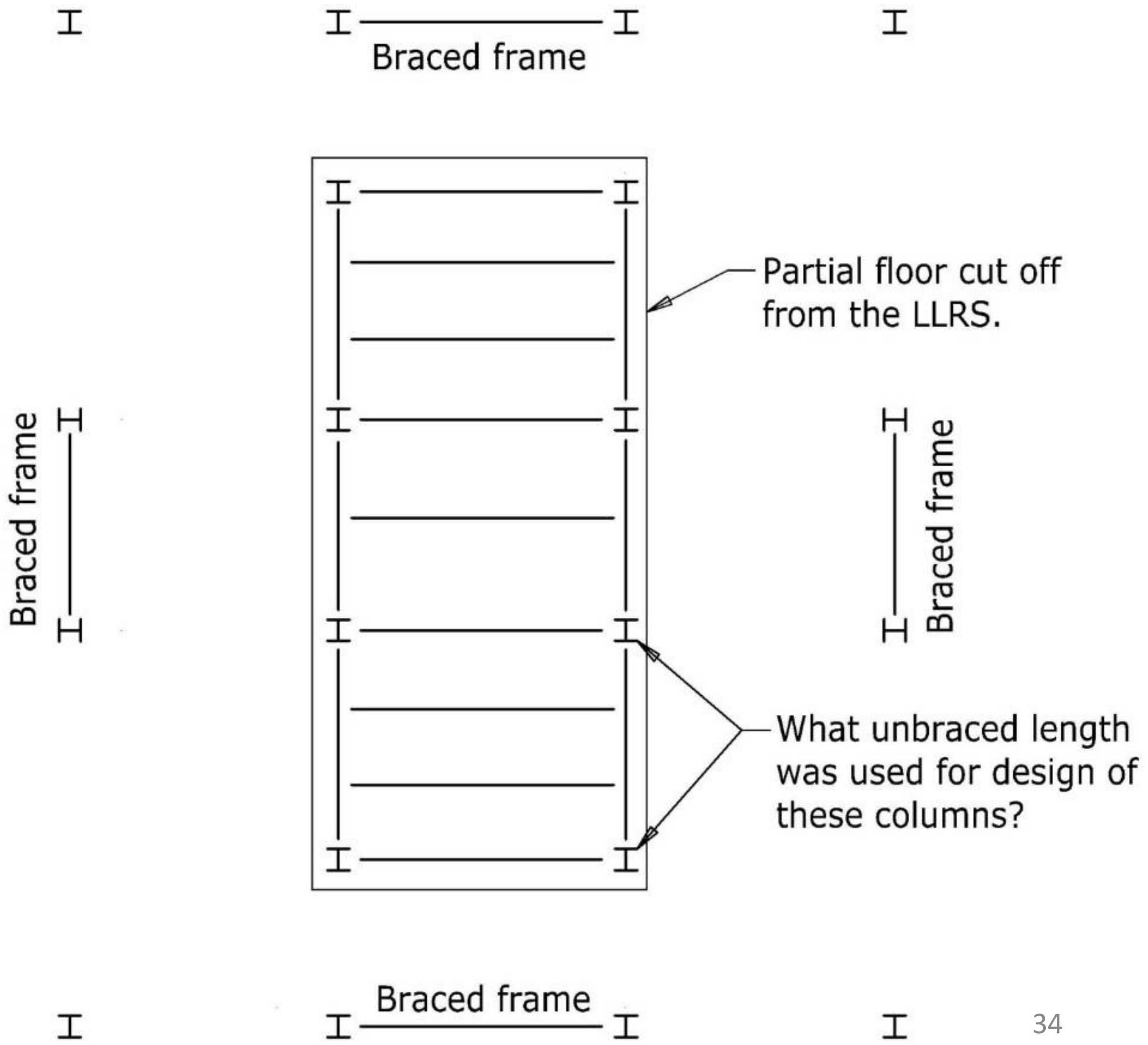
Does software consider deflections of beams supporting cantilevered beams?

Understanding the software

Are any floor areas disconnected from the lateral load resisting system?

If so:

- How are the columns designed?
- Is the structure stable?



Understanding the software

Diaphragm issues:

- Rigid diaphragms? Are there any unrealistic analysis results from the assumption of a rigid diaphragms?
- Did the software design the diaphragm? (Probably not)

Rigid Floor Diaphragms

Infinitely Rigid Floor Diaphragms

Diaphragms

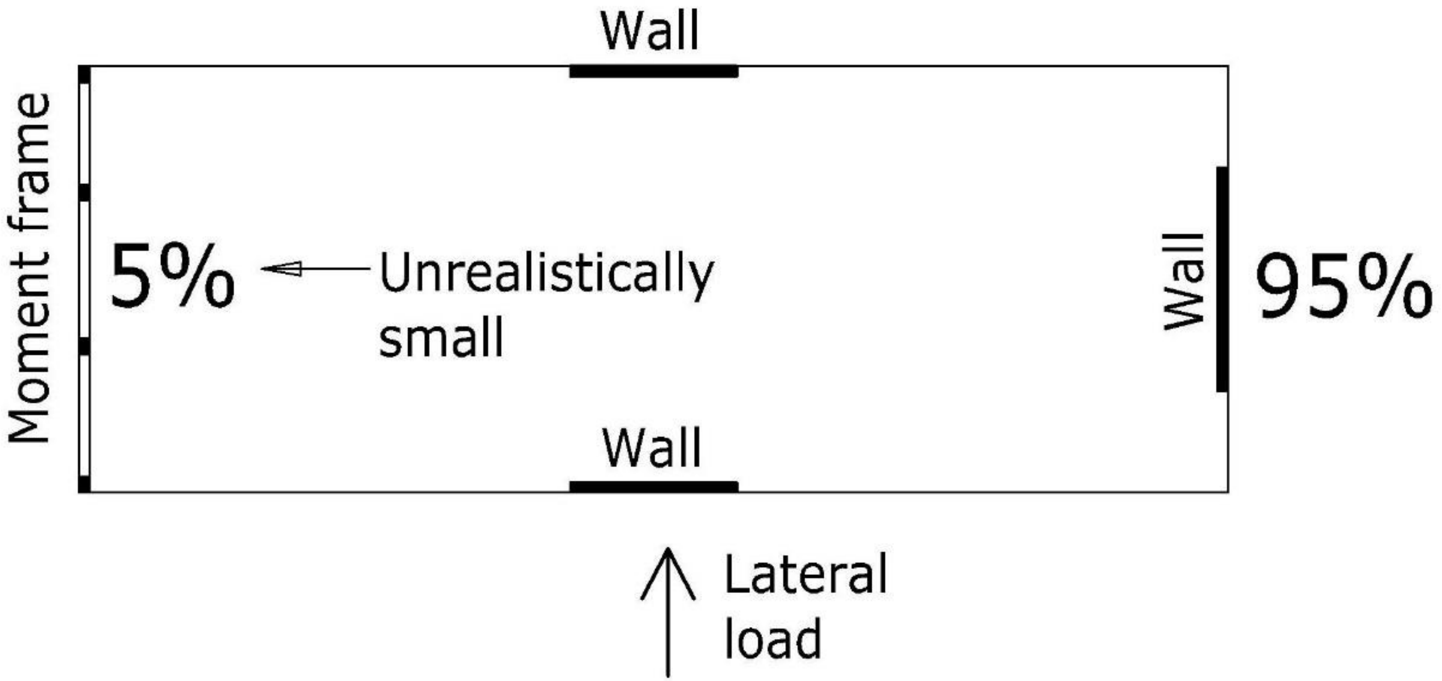
- Rigid, flexible or semi-rigid?
- Strength and stiffness
- Were the diaphragms designed?
- Are lateral loads properly distributed to the braced frames and moment frames
- Are diaphragms pulling loads out of the braced frames?
- Are diaphragms hiding drag strut forces?

Diaphragms

- Are diaphragms stiff enough to brace the columns?
- Any sloping columns? If so, are there brace struts?
- Is there a load path from the diaphragms to the LLRS?
- Was the diaphragm load path detailed on the drawings?
- Are drag strut connections defined?

Diaphragms

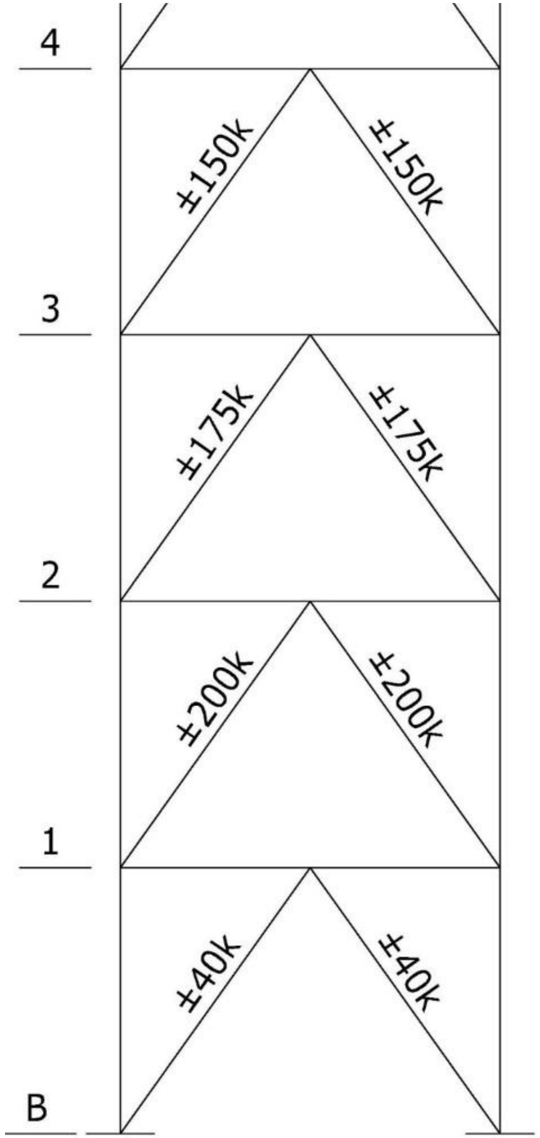
Distribution of lateral loads based rigid diaphragm assumption can distort distribution of loads to the lateral load resisting system.



Stiff walls + infinitely rigid floor diaphragm = torsionally stiff structure. (unrealistically stiff)

Diaphragms

An assumption of rigid diaphragms can (incorrectly) pull loads out of a braced frames and moment frames.

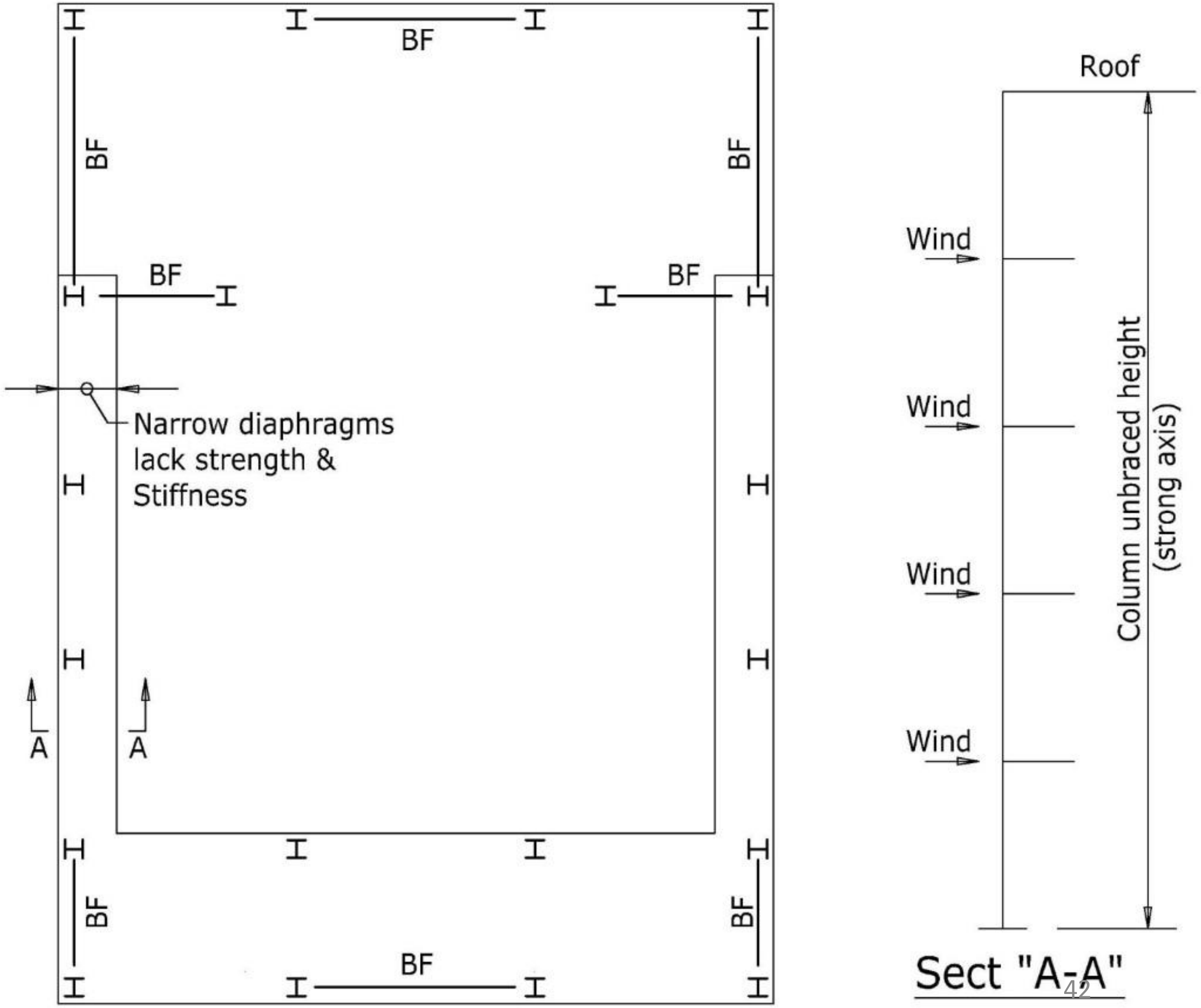


Braced frame elevation

What's going on at the first floor that's pulling load out of the braced frame?

Diaphragms

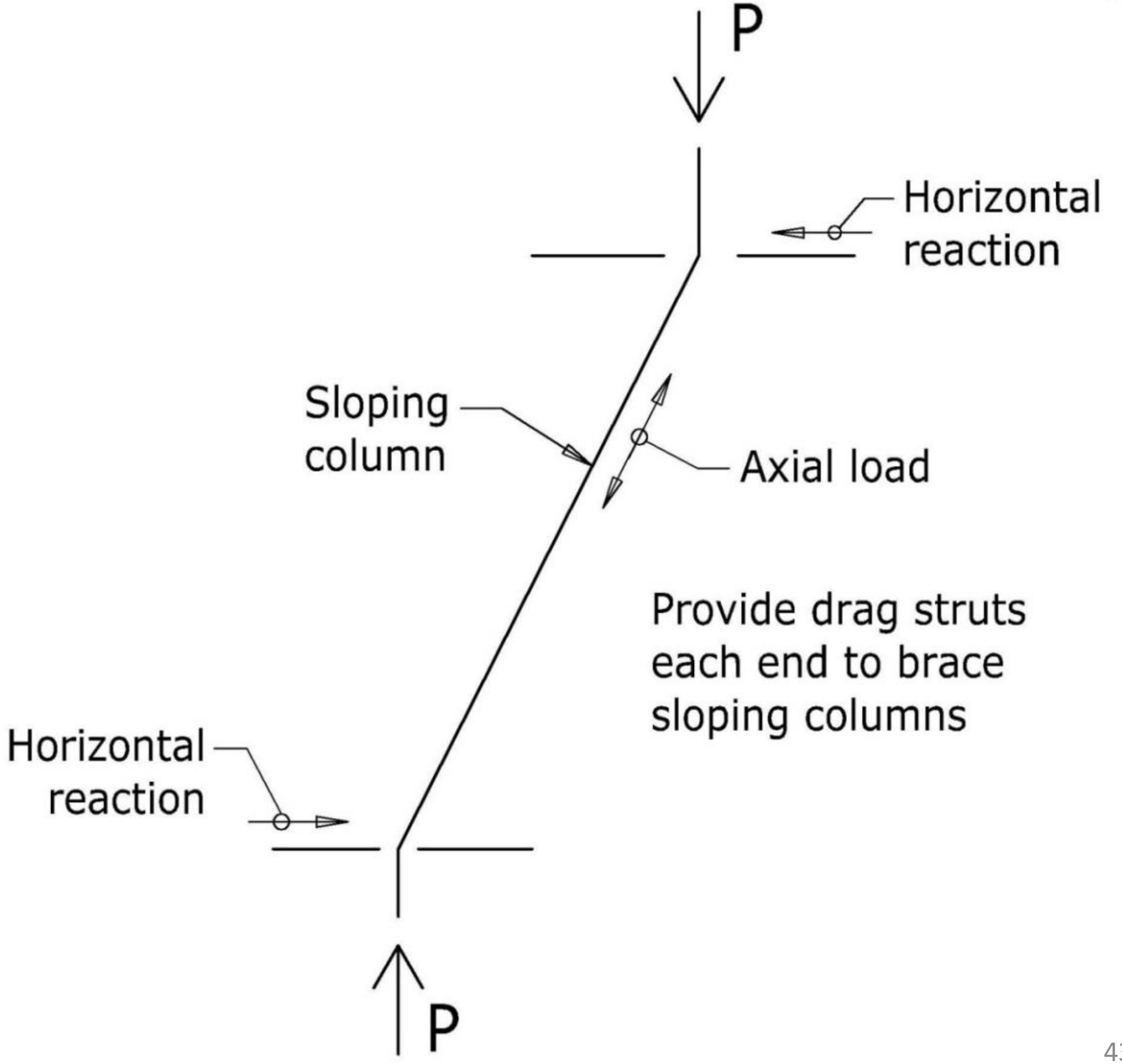
Are the diaphragms stiff enough and strong enough to brace the columns?



Diaphragms

Sloping columns require braces at each end and they require a load path to the lateral load resisting system.

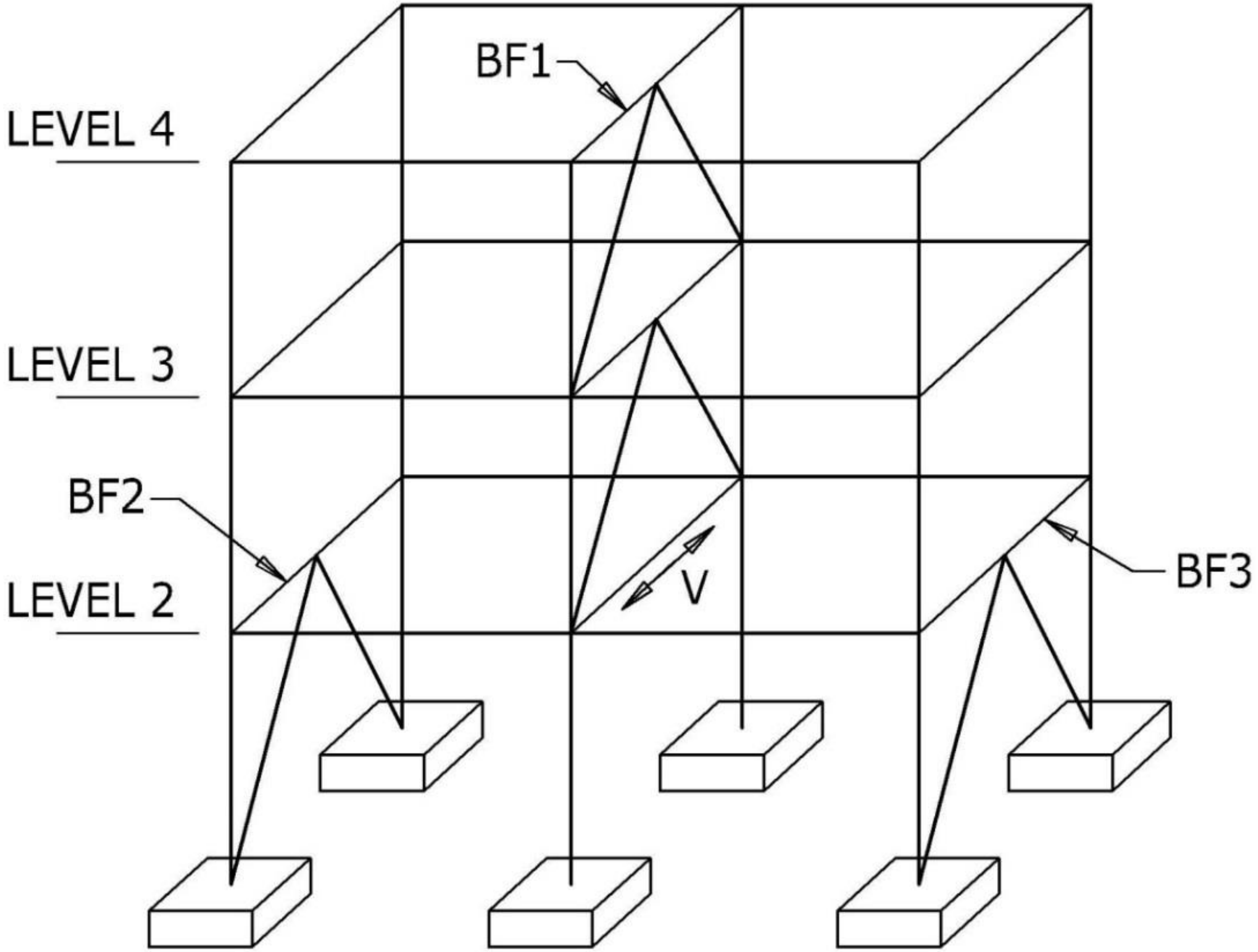
Did the computer design the struts?



Diaphragms

Horizontal out-of-plane offset

Did the computer
design the diaphragm?



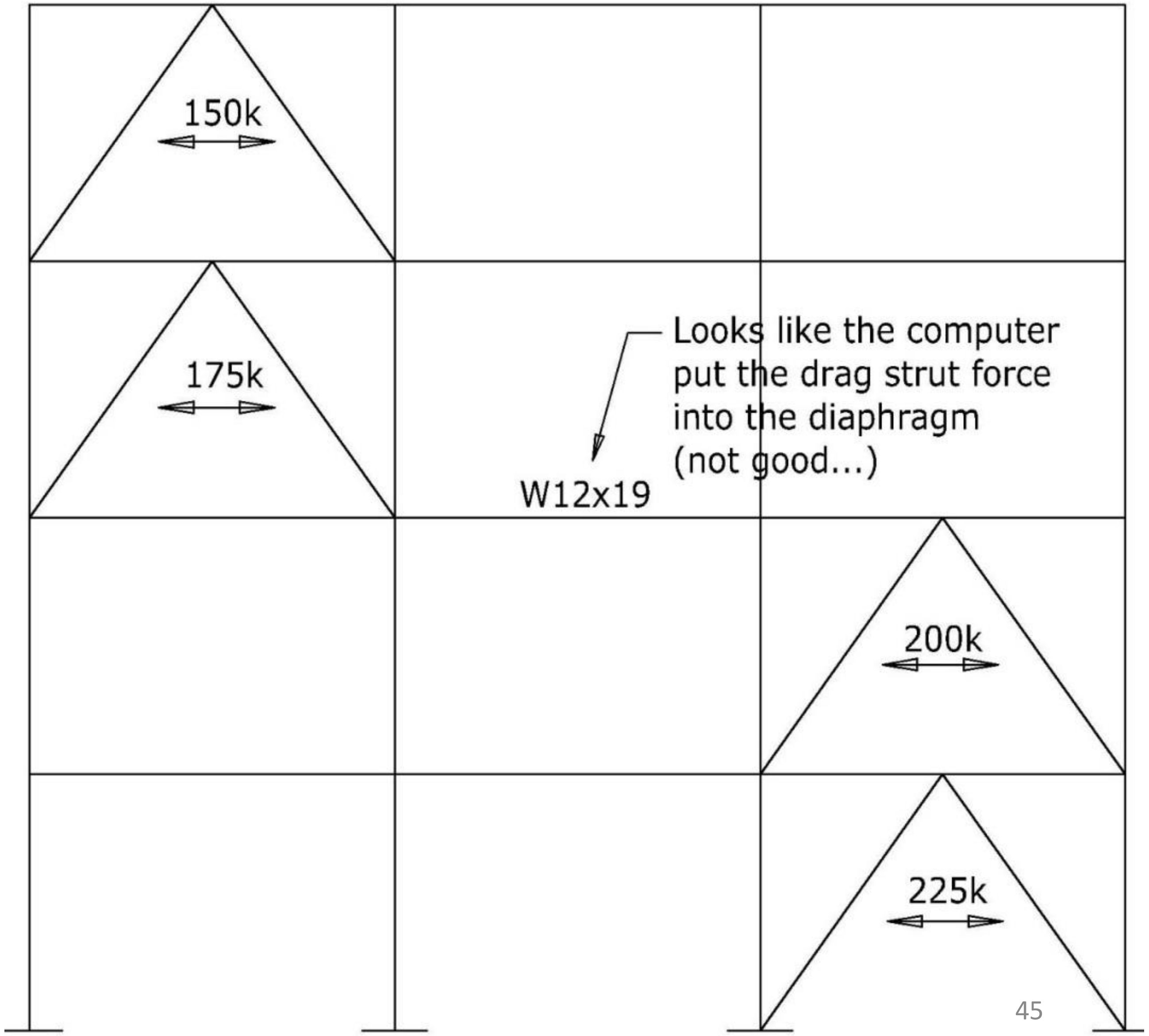
Design level 2 slab to transfer horizontal
forces from BF1 to BF2 & BF3

Diaphragms

In-plane offset in braced frame

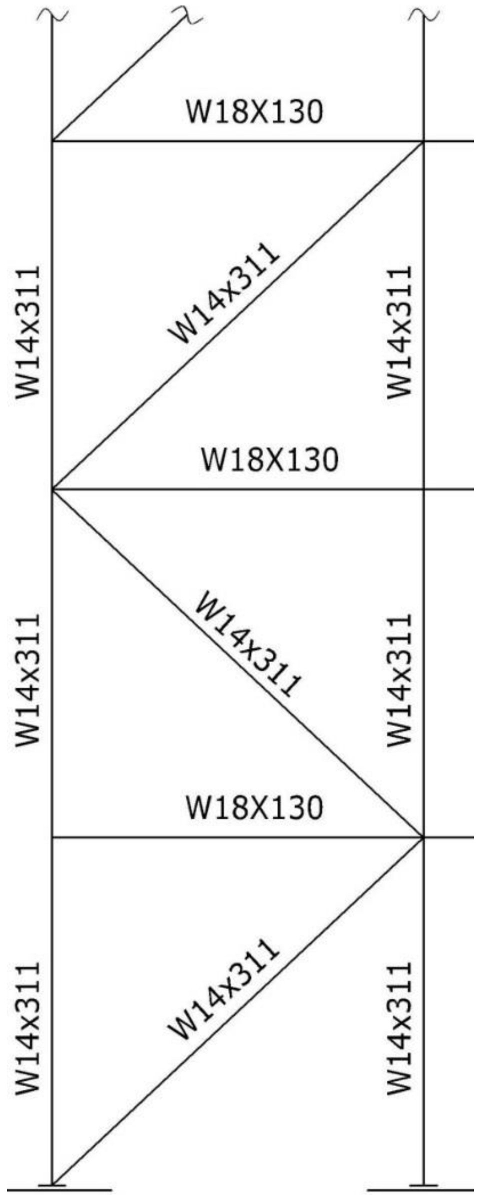
Did computer design drag strut?

Rigid diaphragm assumptions can hide axial forces in braced frame beams.

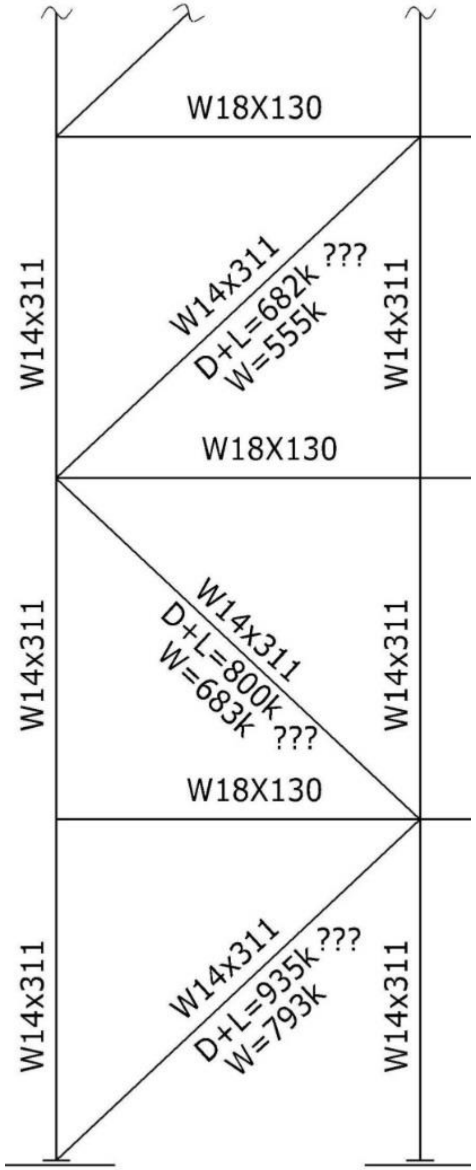


Diaphragms

Rigid diaphragm assumptions can lead to improper analysis of braced frames.



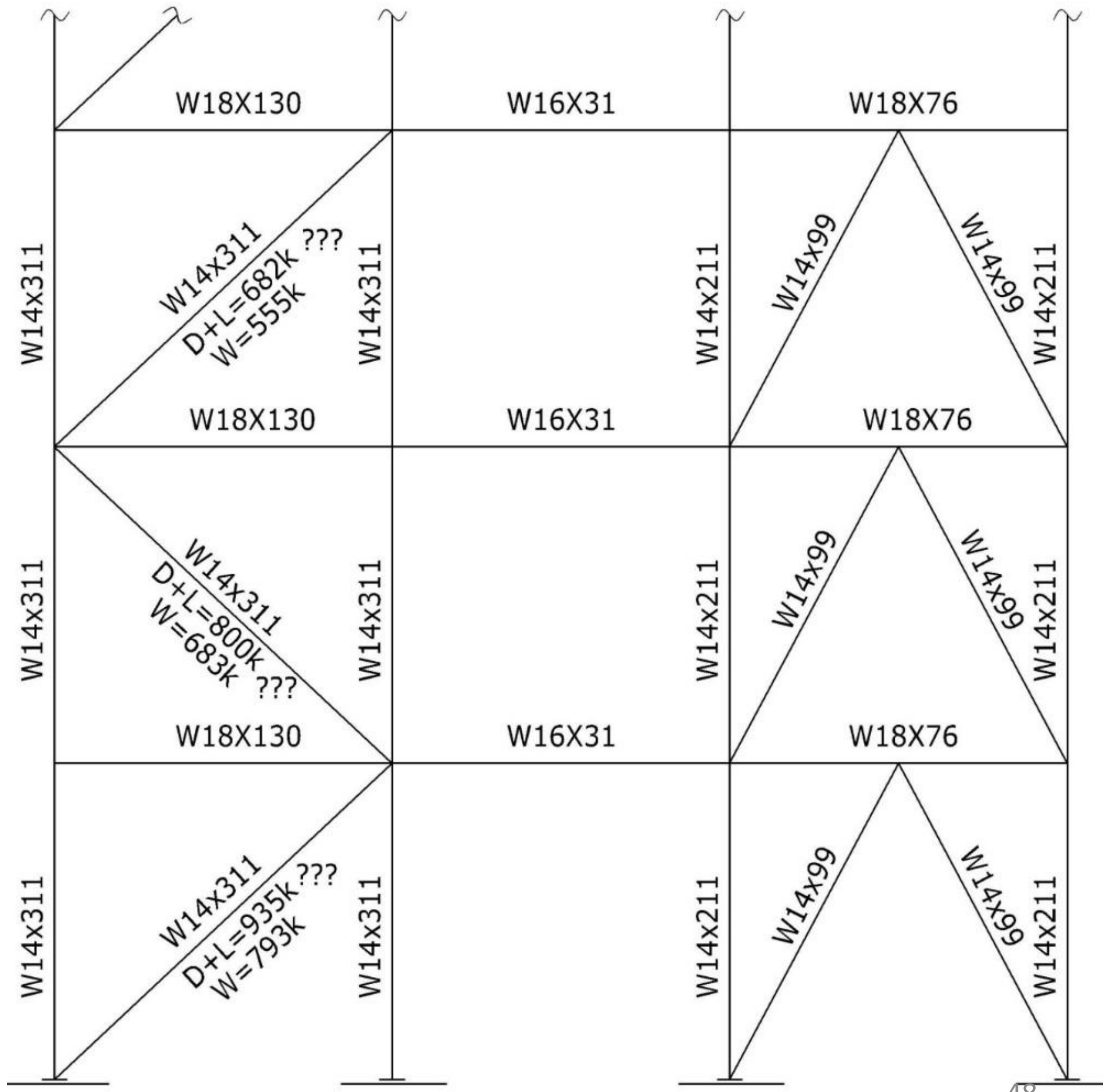
Diaphragms


W18X130
W14x311
W14x311
D+L=682k ???
W=555k
W14x311
W18X130
W14x311
W14x311
D+L=800k
W=683k ???
W14x311
W18X130
W14x311
W14x311
D+L=935k ???
W=793k
W14x311

Diaphragms

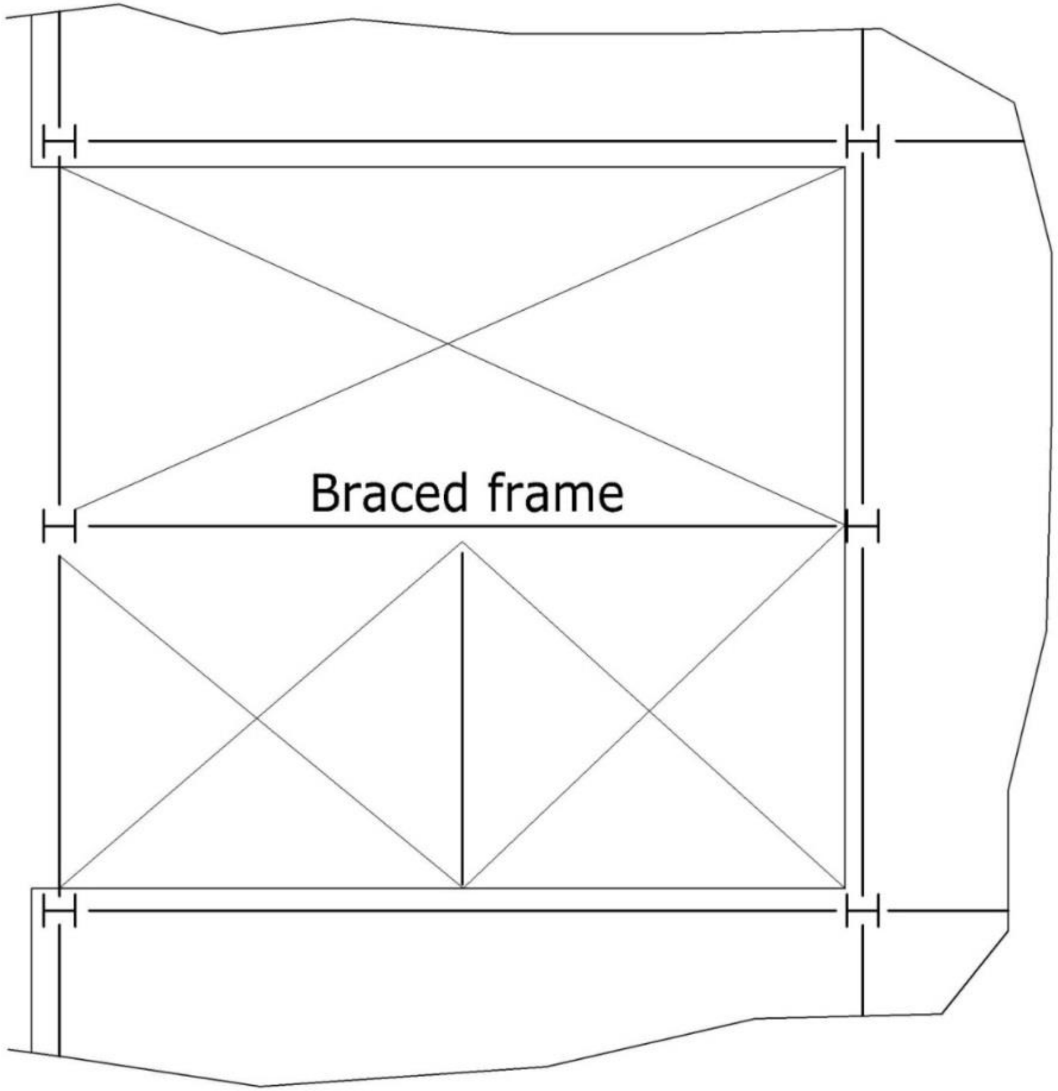
Infinitely rigid diaphragm assumption causes diagonal braces to resist gravity load - taking load off the columns.

Serious error!



Diaphragms

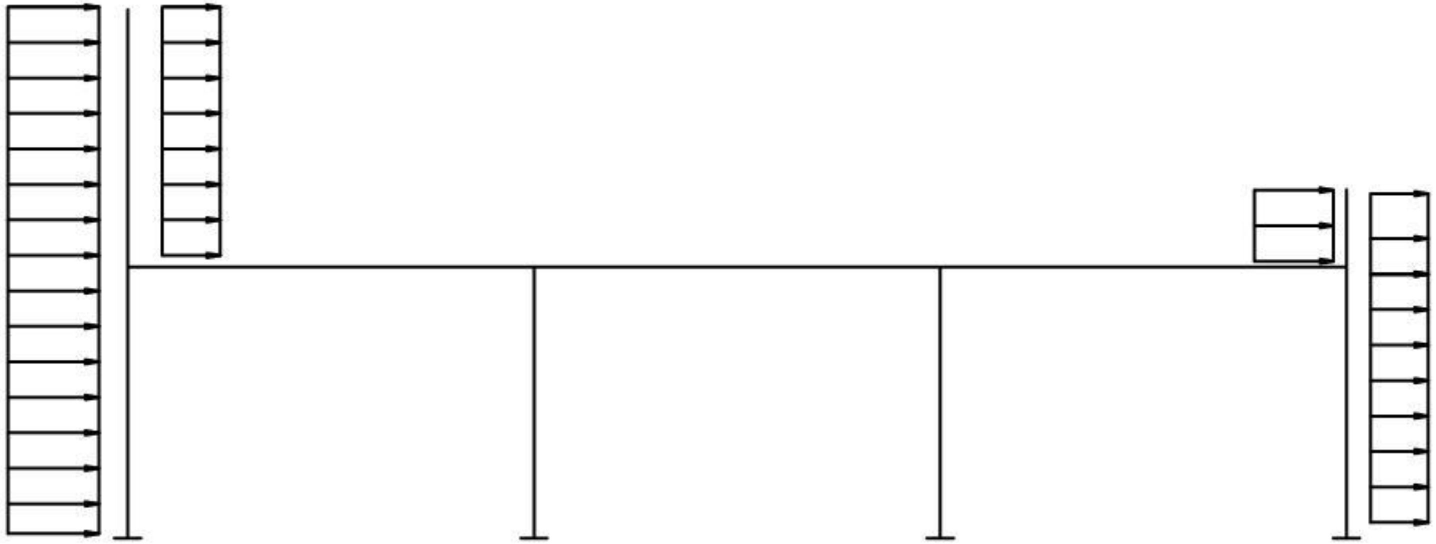
Is there a load path to the braced frame? Are there adequate diaphragm connections to the braced frame? (No.)



How do the loads get into this braced frame?

Diaphragms

What does the software not check?



Are wind loads on roof parapets and screens considered?

Load Combinations

Load combinations

There are many load combinations.

Manually check the "important" ones (ASCE 7-10 simplified):

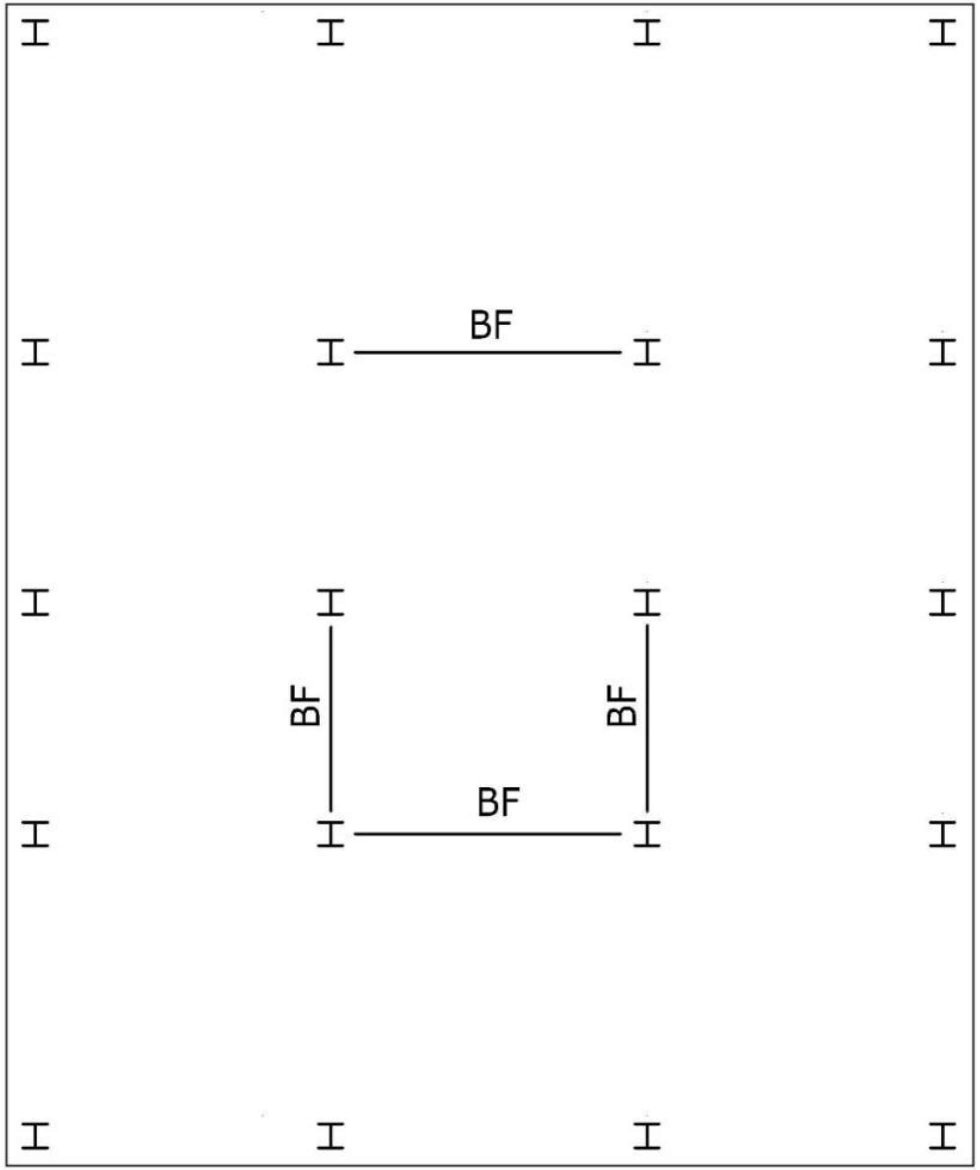
1.2D+1.6L (or 1.4D)

1.2D+W+L
1.2D+E+L

0.9D+W
0.9D+E

Load combinations

When orthogonal braced frames share common columns, consider diagonal wind loading (ASCE 7, wind load Case 3)



Building Structures

Validating floor framing (gravity)

Look for things missing in the model

- Geometry
- Framing
- Loads from:
  - Elevators
  - Escalators
  - Stairs
  - Folding partitions
  - Mechanical shafts
  - Heavy runs of suspended piping
  - Dense files
  - Rooftop mechanical equipment
  - Roof screens
  - Parapets (snow drifts)
  - Facade loads
  - Window washing davits

Validating floor framing (gravity)

Three steps:

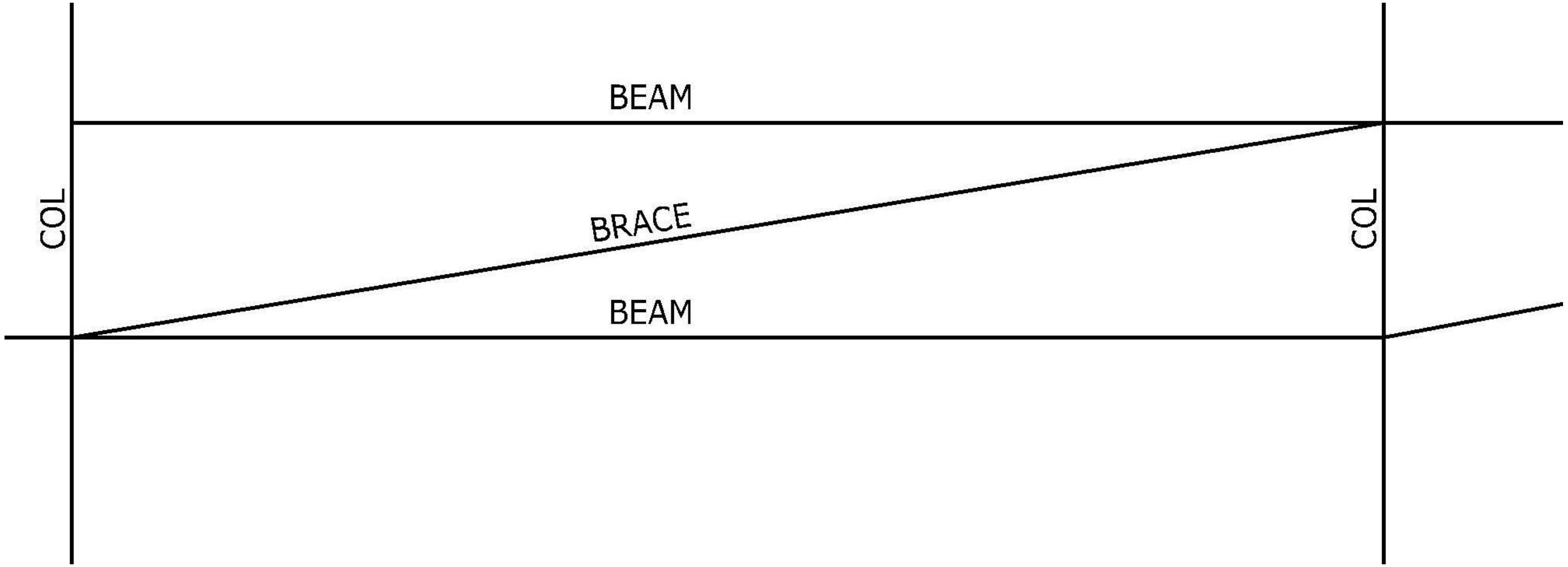
1. **Show reactions and member forces on the drawings.**
2. Manually design a typical beam and girder. Repeat where loads change.
3. Manually design a typical column.

Validating floor framing (gravity)

Possible errors/problems:

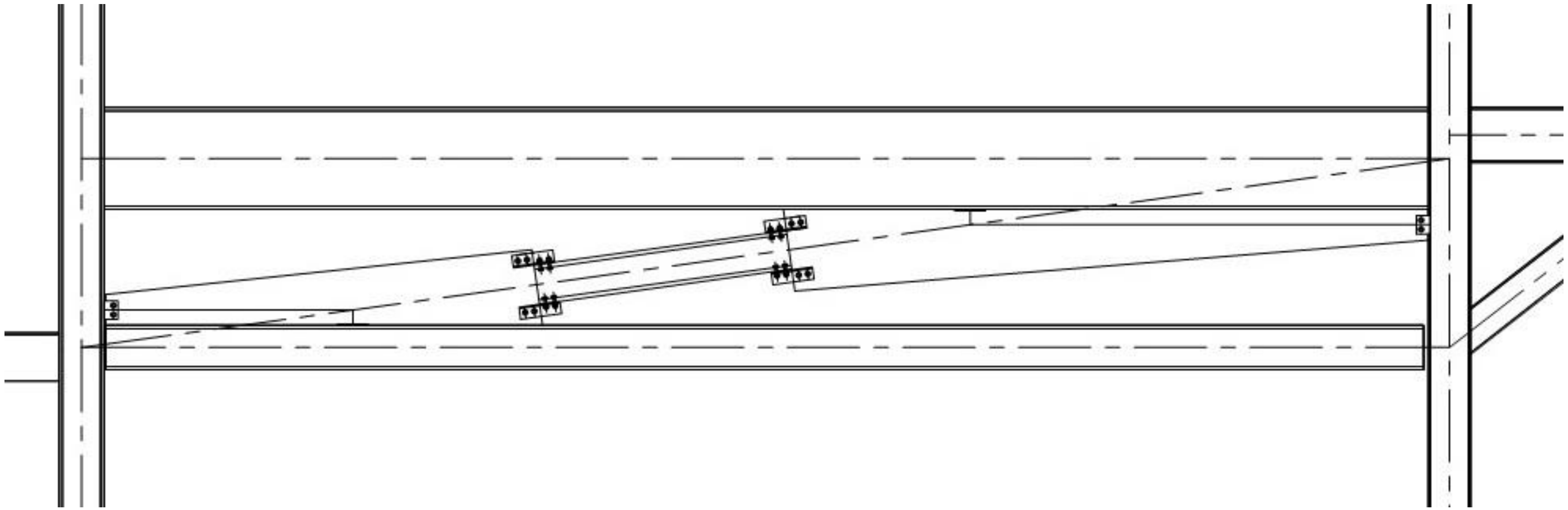
- Double counting or missing structure self-weight
- Slab-on-metal-deck turned in wrong direction
- Improper live load reduction
- Incorrect or missing loads
- Unconstructable framing
- Translation errors – drawings do not match model

Constructability



Is the design constructable?

Constructability



These brace connections are neither constructable nor designable.

Validating the Lateral Load Resisting System

- Validation of the gravity load framing is exact
- Validation of the lateral load resisting system is less precise – however manual calculations should be within 20% of the computer analysis.

Validating the Lateral Load Resisting System

Wind

- Look at wind in each orthogonal direction
- Compute average wind pressure
- Compute base shear in each direction and compare with computer
- Distribute loads to LLRS in proportion to the tributary area (modify where stiffness's vary significantly or where diaphragm issues dictate), envelope and compare with computer

Validating the Lateral Load Resisting System

Common errors/problems

- Parapets, roof screens and penthouses missing from the model
- Software incorrectly considering shielding for irregular- shaped buildings
- Rigid diaphragms distorting load distribution to the BF’s & MF’s

Validating the Lateral Load Resisting System

Seismic (for R=3 structural steel buildings)

- Look at loads in each orthogonal direction
- Compute T_a & C_uT_a
- Compare C_u T_a with exact period, T (from computer)
- Use appropriate period
- Compute C_s

Validating the Lateral Load Resisting System

Seismic (for R=3 structural steel buildings)

- Compute seismic weight, W
- Compute base shear, $V = C_s W$
- Compare base shear with computer analysis
- Distribute V within the LLRS in proportion to tributary mass
- Compare loads in Braced Frames and Moment Frames w/ computer results

Validating the Lateral Load Resisting System

Unusual load distributions in the Lateral Load Resisting System are usually related to rigid diaphragm issues. Look for these unusual load distributions.

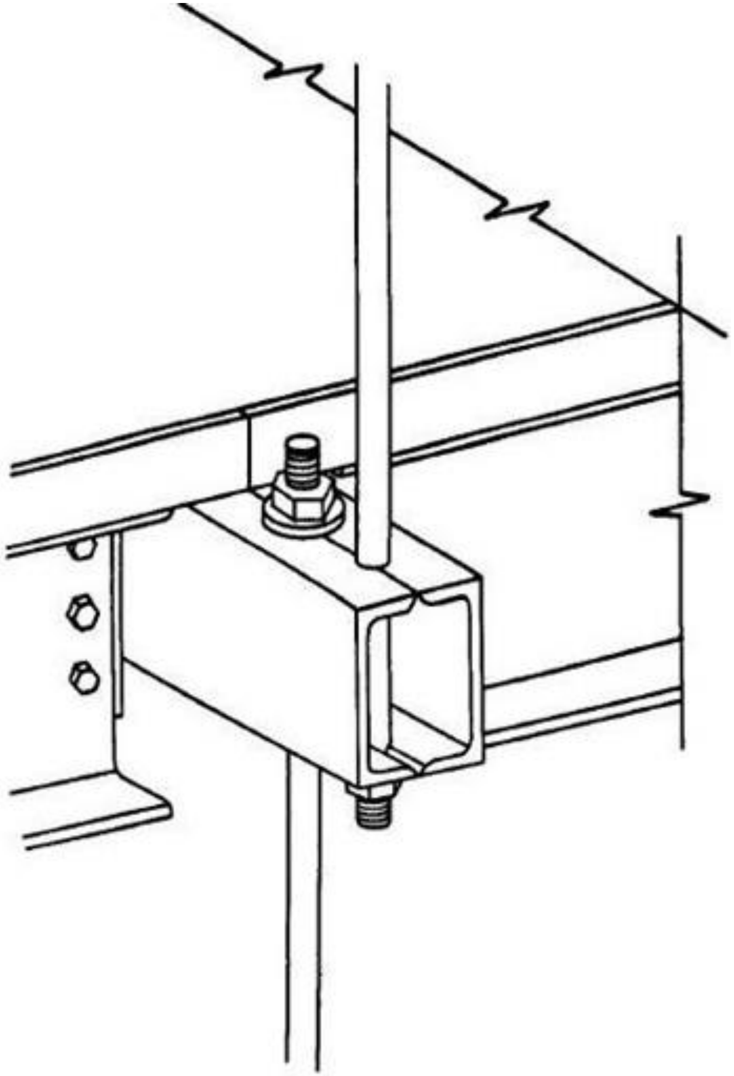
Look for unusual framing or connections

- Pay attention to unusual framing configurations that cannot be precisely modeled, and conditions that will not be flagged by the software such as “kinked connections”.
- Does your software design connections?

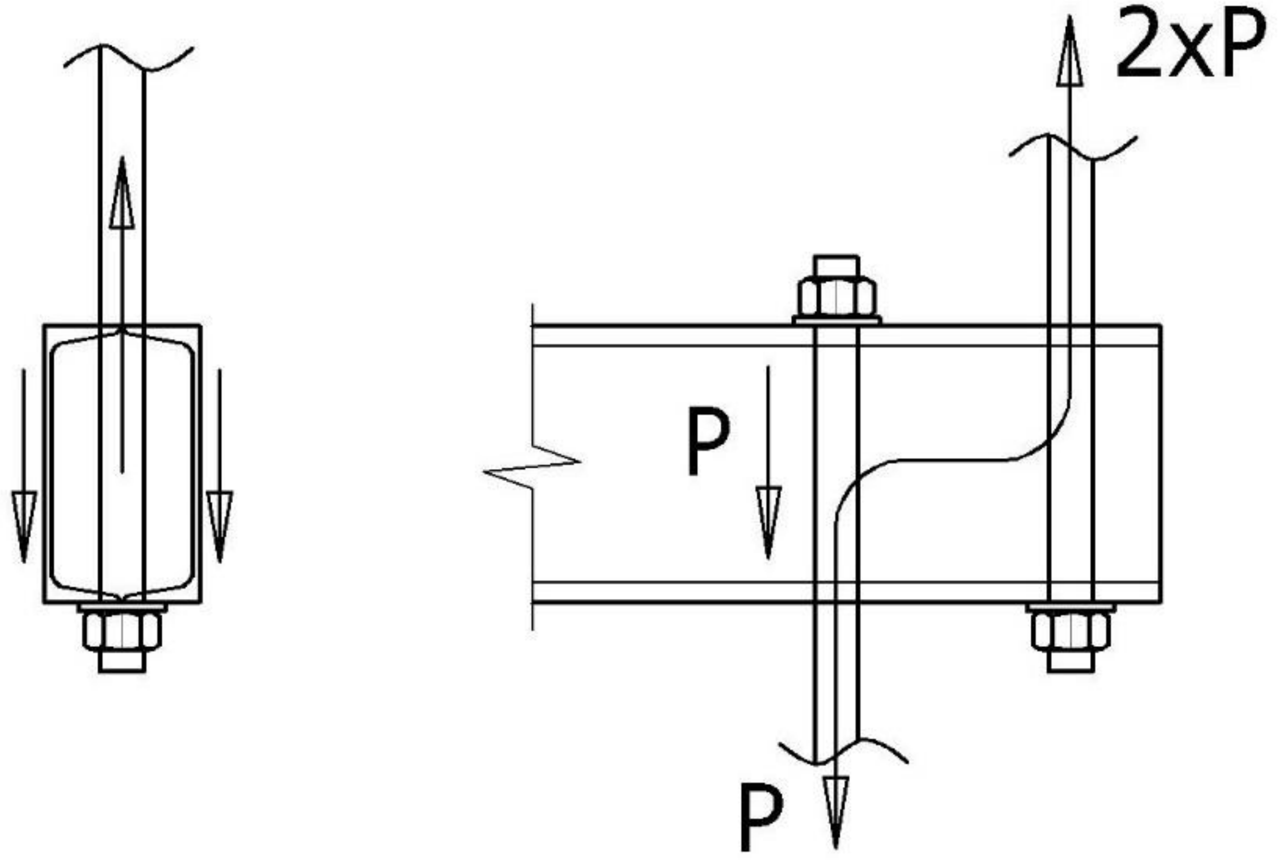
Look for things that were not designed by the computer

- Where the connections analyzed and designed by the software?
- Any unusual connections?
- Any undesignable connections?
- Any unconstructable connections?
- Any“kinked connections”?

Look for unusual connections not analyzed by the software



Look for unusual connections not analyzed by the software

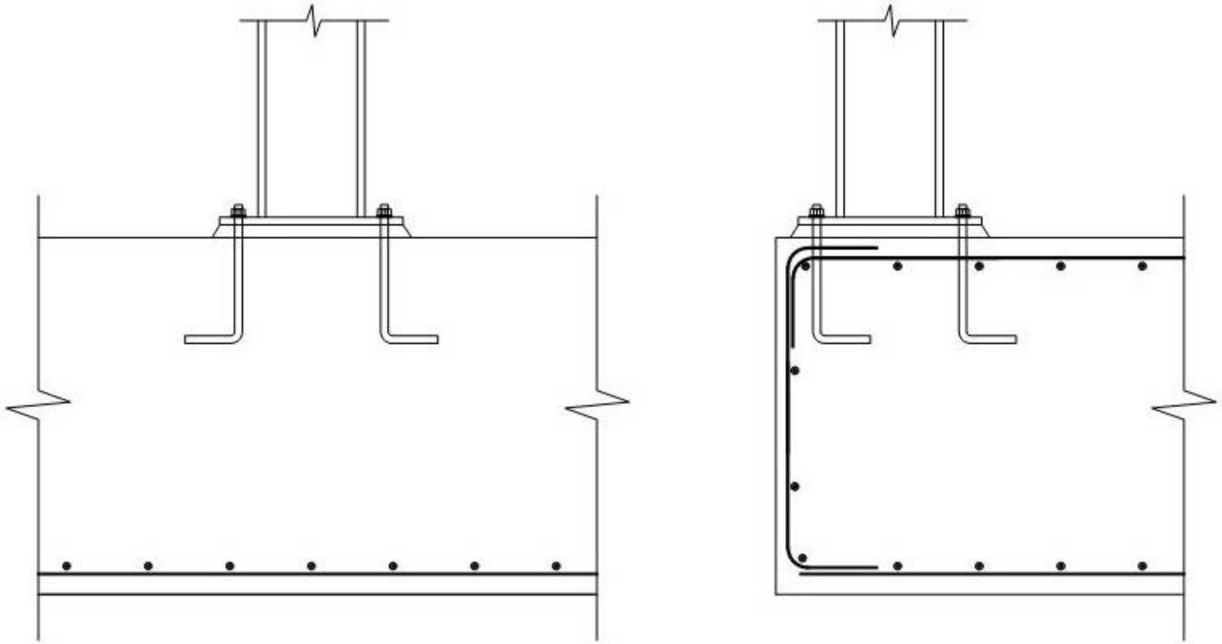


Look for subtle differences between the model and the actual structure

Are there any framing conditions not reflected in the model?

- Kinked connections?
- Offset footings
- Heavy column loads bearing on mat foundations at edges of elevator pits or bearing on basement walls

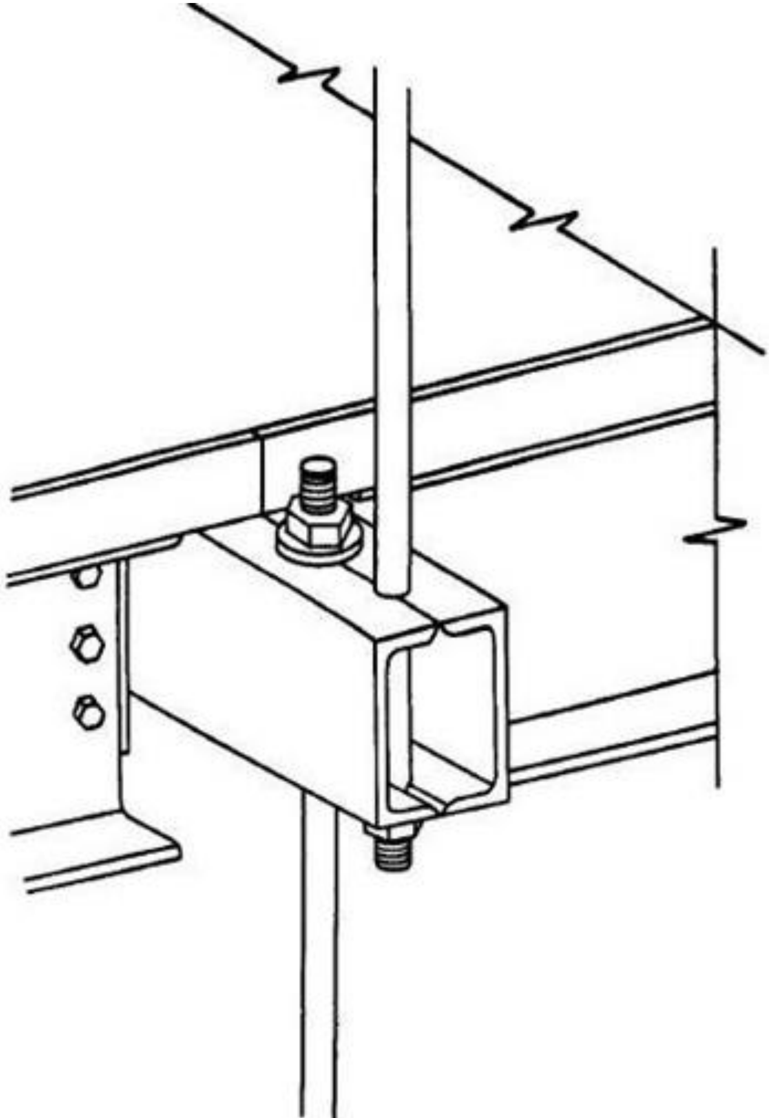
Look for subtle differences between the model and the actual structure (Things not considered by the computer.)



Concrete under the baseplate on left has twice the bearing capacity as concrete under baseplate on the right. (Was edge condition considered by the analysis/design software?)

Differences between the model and the structure

- This was a seemingly small revision to the detail.
- Pay attention to the details.
- *Look* for problems.
- Don’t let the computer think for you.



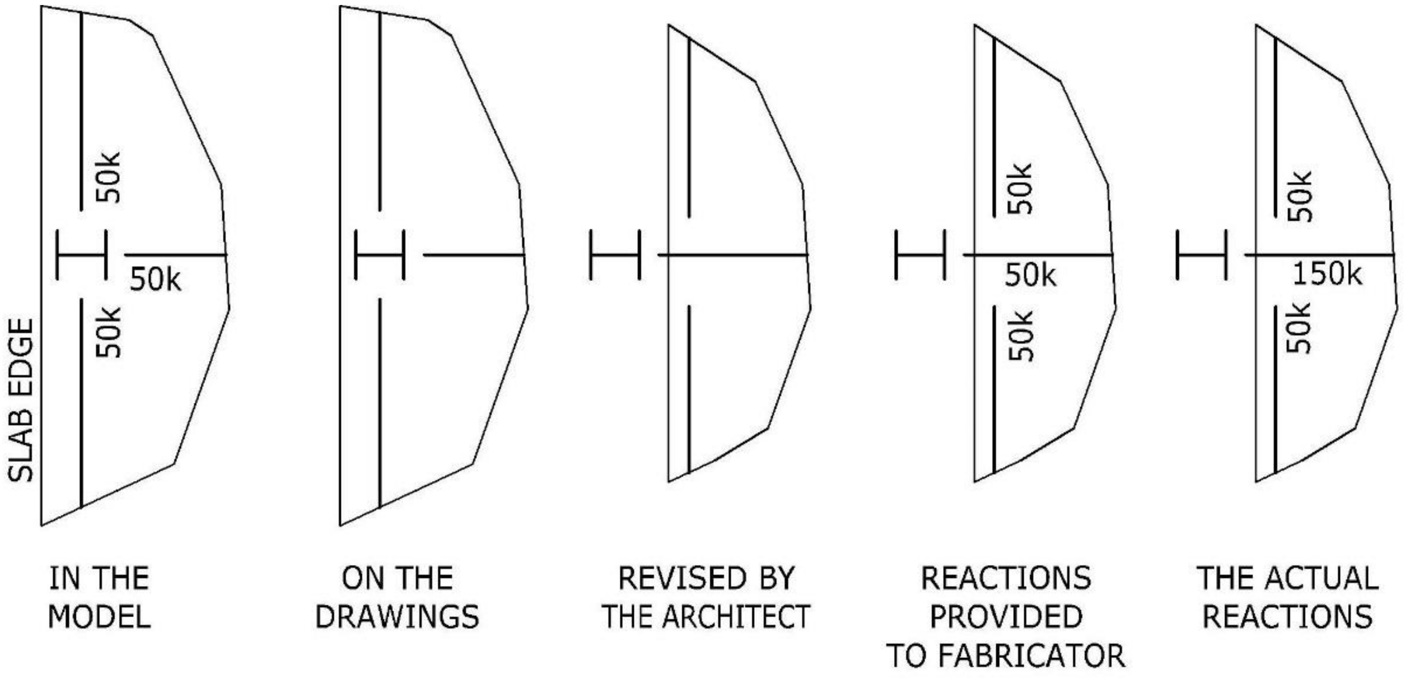
Look for changes that occurred after modeling

Look for changes in the framing that are not reflected in the model:

- Sloping columns
- Framing offset from columns
- Kinked connections
- Translation errors

Translation errors

Translation errors – subtle differences between the analysis model and what is on the drawings can cause structural failures



Model validation must continue throughout design.

Non-Building Structures

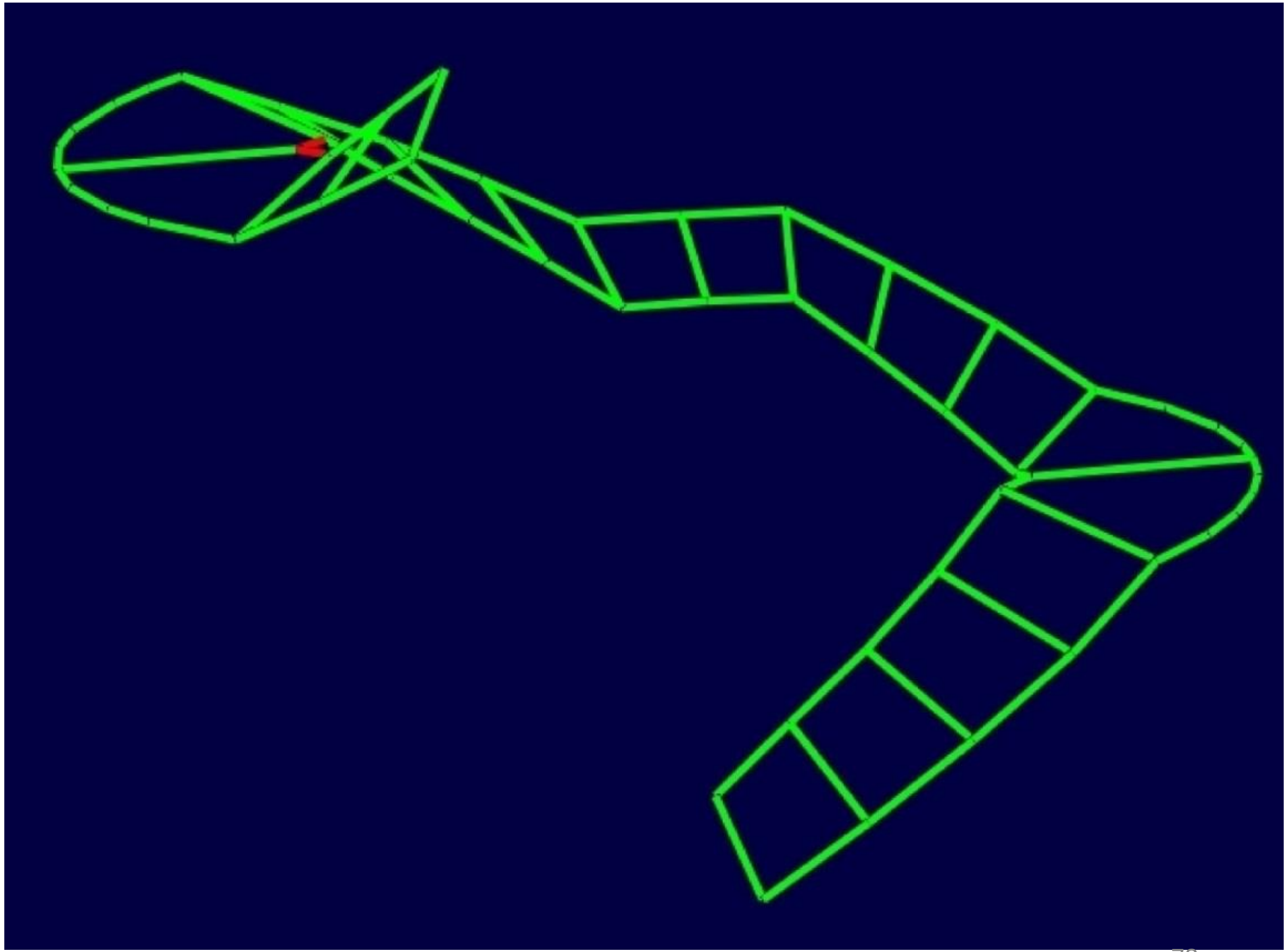
Non-building structures

Reactions and behavior of complex non-building structures is not always intuitive due to:

- Unusual geometry
- Many load combinations

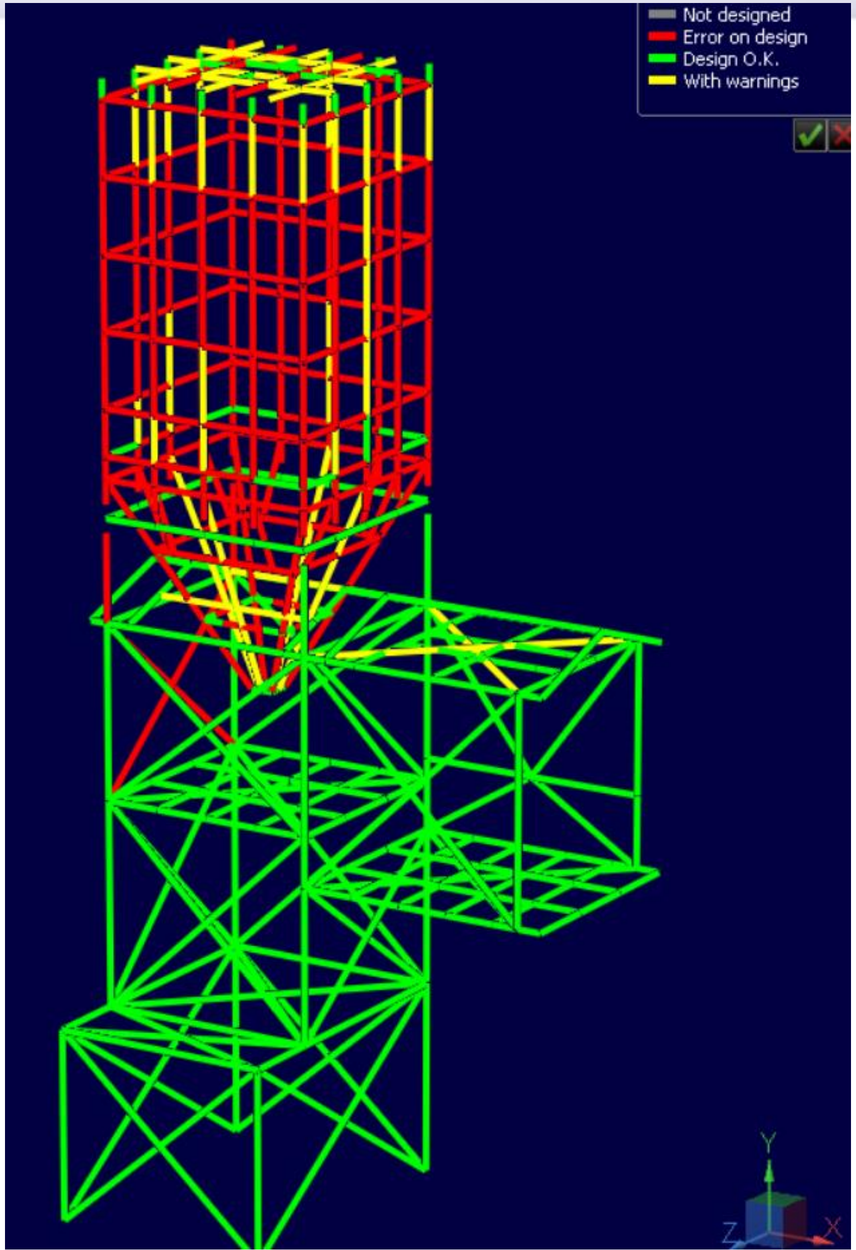
Non-building structures

Monumental stairs



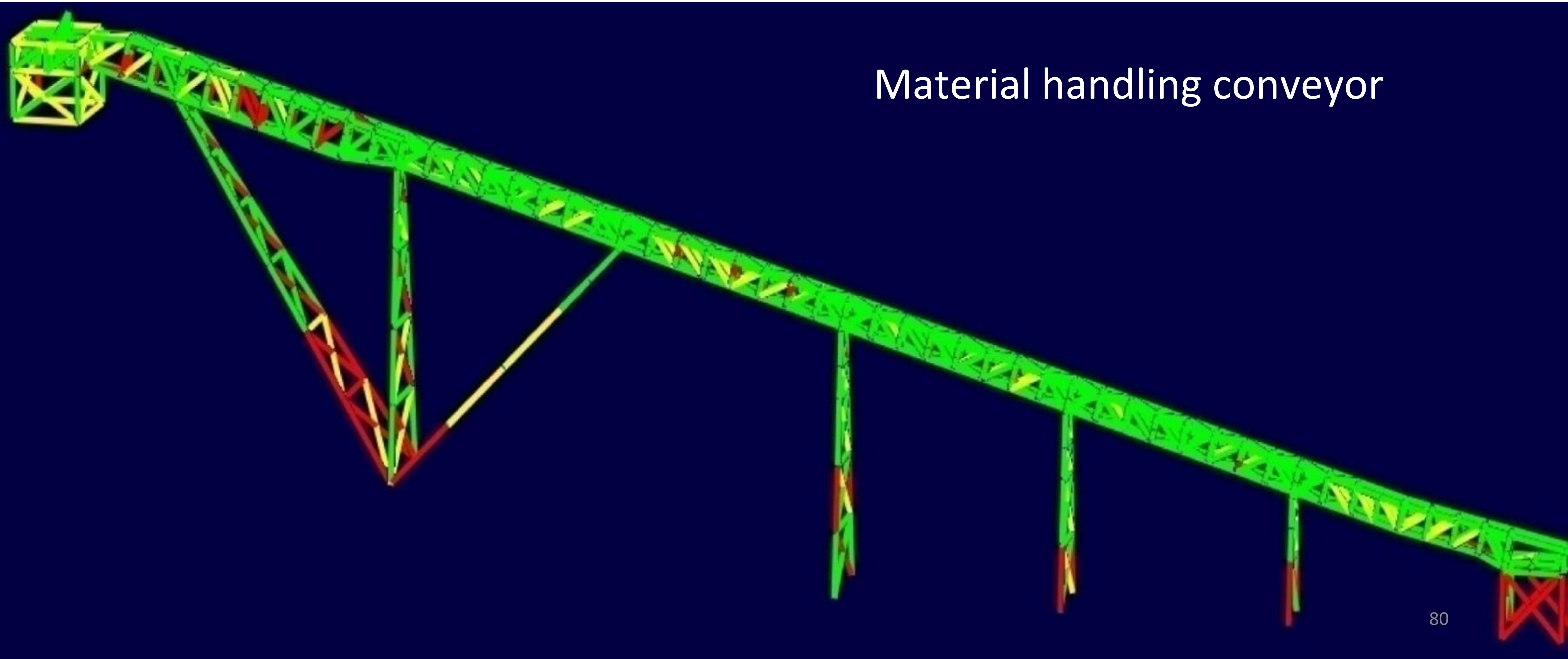
Non-building structures

Storage bin



Non-building structures

Material handling conveyor



Non-building structures

Tips for validating non-building structure models

- Look at the model in steps
- Verify reactions/member forces manually, one load at a time
- Look at the deflected shape for each load
- Isolate problem areas with temporary supports

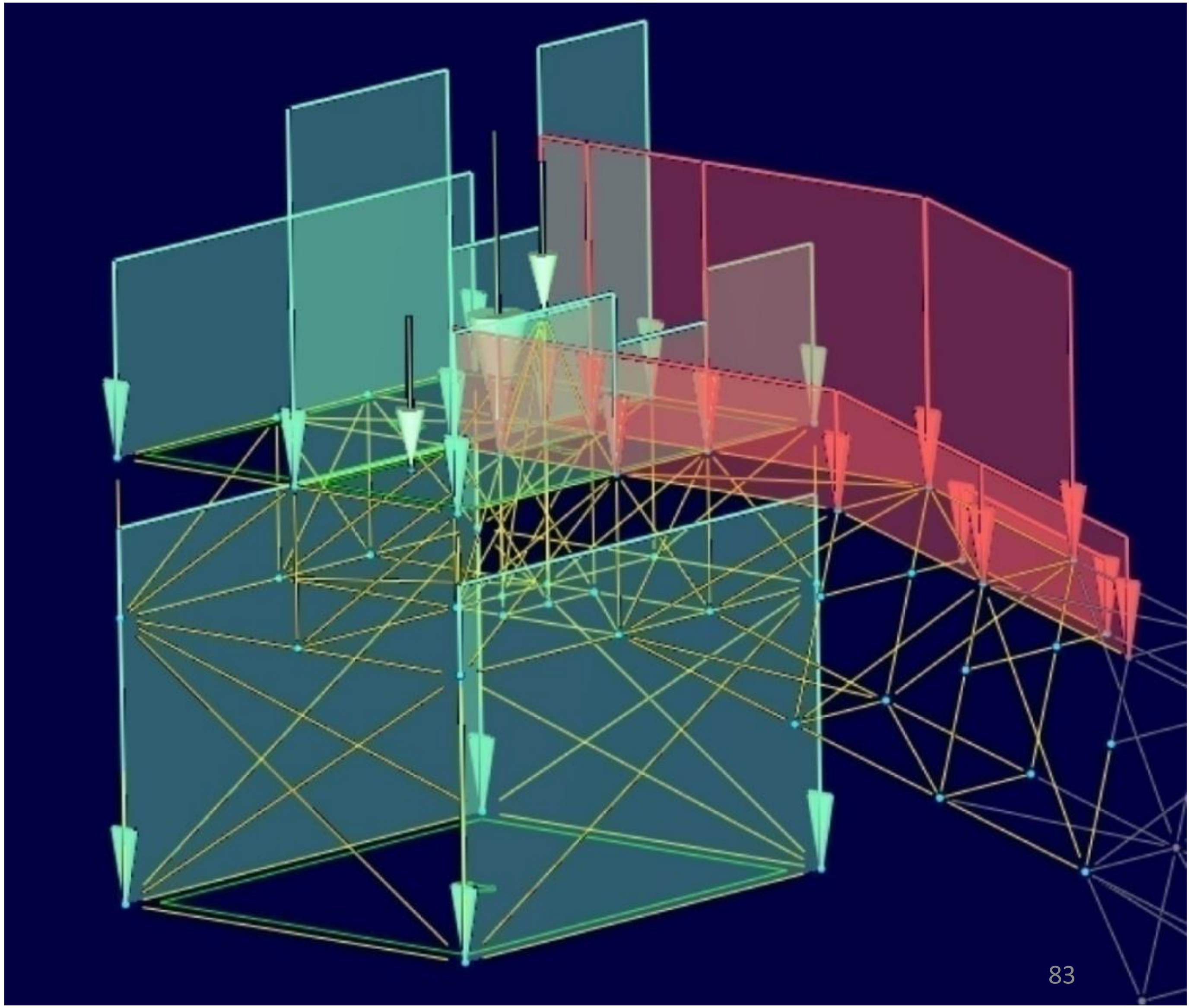
Non-building structures

Tips for validating non-building structure models

- Look at the extruded shape to verify member orientations
- Verify direction of loads
- Understand the defaults, including unbraced length variables
- Understand how software designs members

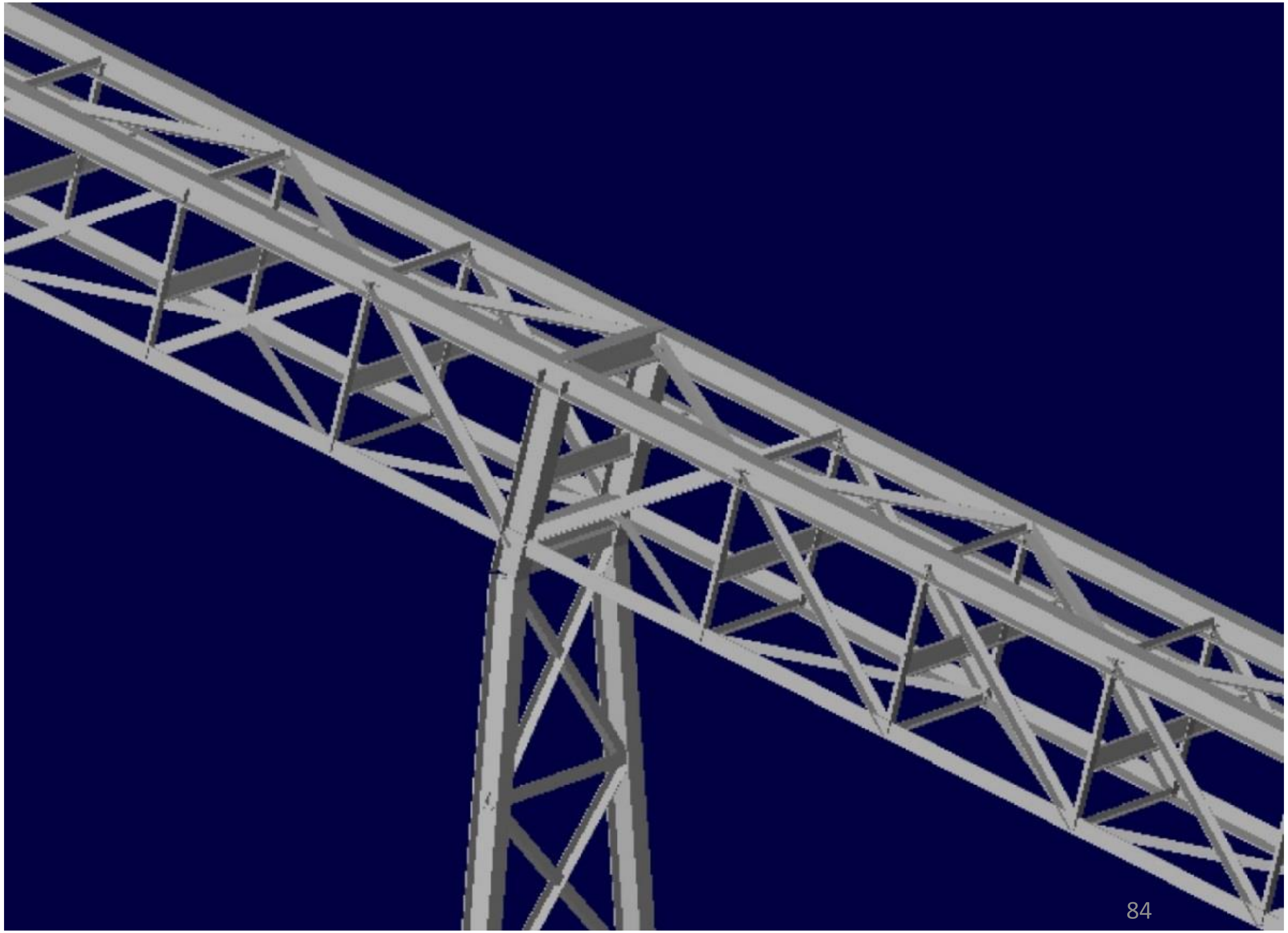
Non-building structures

Verify that loads are in the model, and are pointing the correct direction.



Non-building structures

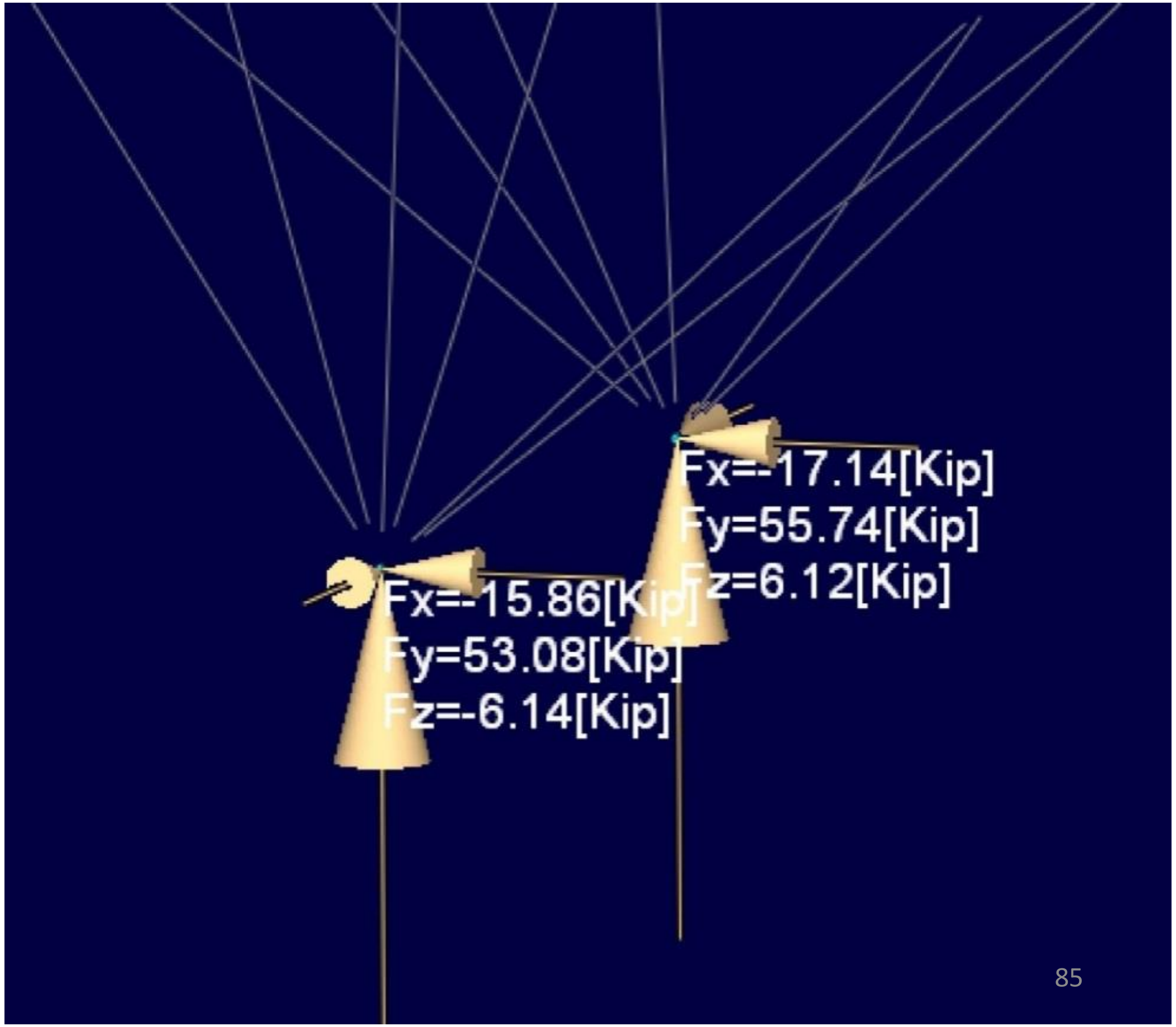
Verify member orientations



Non-building structures

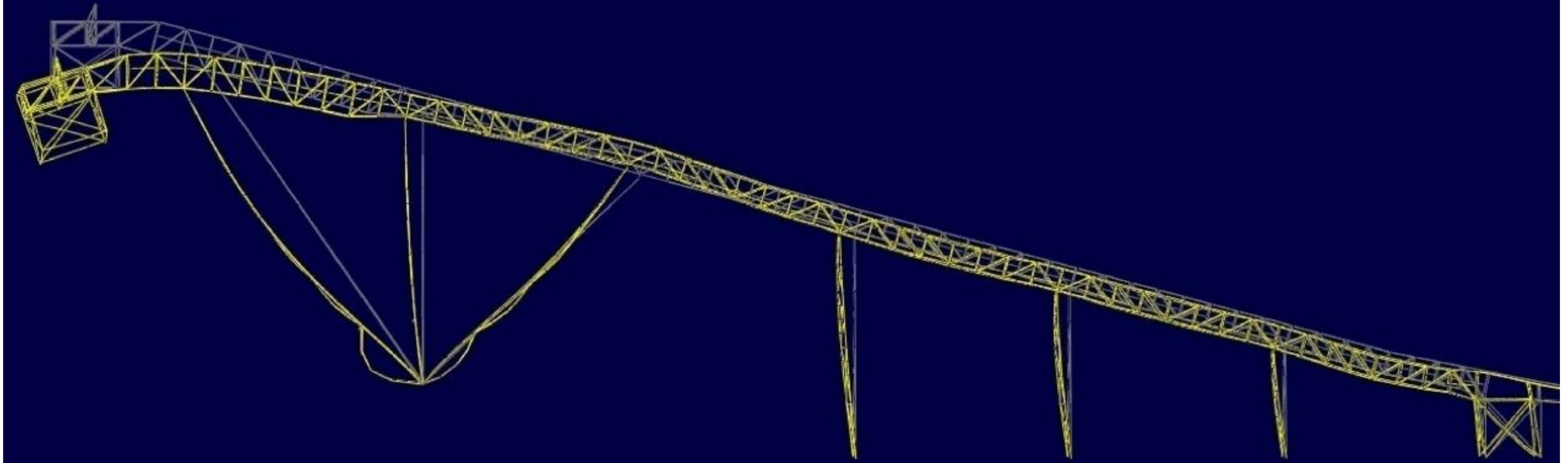
Check reactions one load at a time.

Do they make sense?



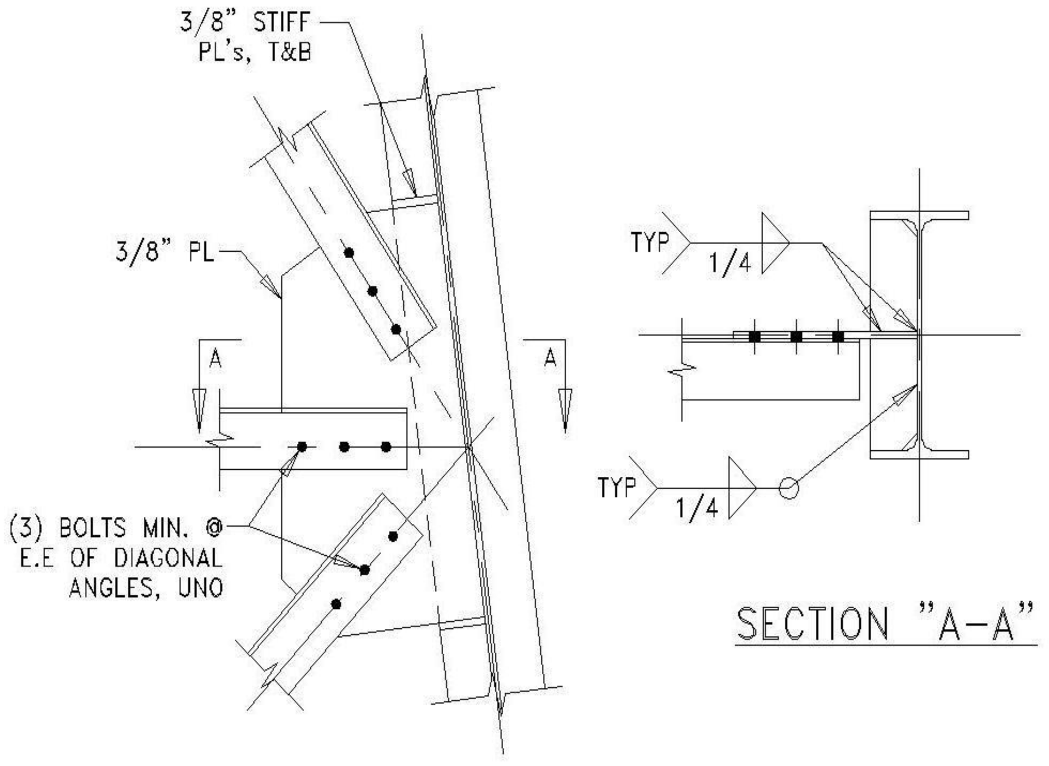
Non-building structures

Look for unusual deformations – one load at time

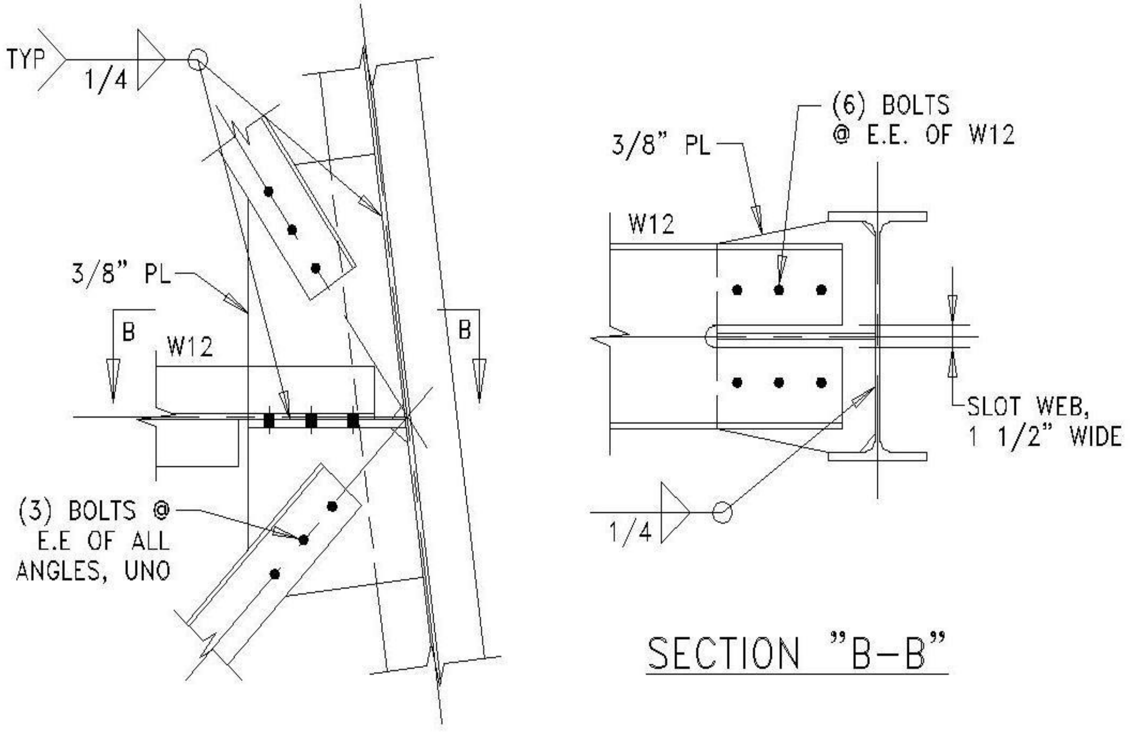


Non-building structures

Understand the various bracing constraints in the software and verify that they match actual constraints as detailed.



ANGLE BRACING



BRACING w/ HORIZONTAL W12

Summary

- Understand ASCE 7, AISC 360, IBC, etc.
- Understand the software limitations and defaults
- Follow the loads/show the reactions
- Floor framing: manually design a typical beam, girder & column
- LLRS: compute base shear w/ simplified lateral load calculations
- Rigid diaphragms in models can hide and distort load distribution
- Diaphragms require strength and stiffness
- Diaphragms must be connected to the LLRS
- Look at the deflected shapes

Summary

- Verify that there are continuous and legitimate load paths
- Pay attention to unusual framing
- Look for bracing issues not considered by the model
- Look for connection designability issues, kinked connections, etc.
- Look for differences between the model and the actual framing
- Never get complacent
- Get a second set of eyes on all models
- “The map is not the territory.”

From **"Architectural Engineering",** Joseph Kendall Freitag, **1895**, John Wiley & Sons, NY.

Many and many are the architects who have used cast-iron columns piled story on story, with tile partitions only as a wind-resisting medium, and their structures stand, to become a source of wonder to the engineering profession.

Do not view your computer model as a *"source of wonder".*

Understand and validate the results.

Thank you!

Questions?

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