Tips for Validating the Results of Structural Engineering Software

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Seminar goal

To review philosophy and procedures for validating the accuracy of structural analysis models for,

- Building structures
- Non-building structures
Two important points

This *is not* a discussion on limitations of specific software, nor is it a criticism of any software.

We will review shortcuts and approximate procedures for validating computer analysis. These shortcuts *are not* a substitute for meticulous adherence to the requirements of the building code.

To be discussed

1. Philosophy
2. Types of errors
3. Understanding the software
4. The infinitely rigid diaphragm
5. Load combinations
6. Building structures
   - Gravity framing
   - LLRS
7. Non-building structures
Simple tools can be used to provide important information

Simple checks can be used to validate a complex structural analysis performed with a computer.

Philosophy & mindset

Use the computer as a tool – not a crutch

Validation of computer models requires understanding the minutia of the codes and specifications

- IBC
- ASCE 7
- AISC 360
- ACI 318
Philosophy & mindset

Never stop thinking about,

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

There are important aspects of each that computer models will not consider
Philosophy & mindset

- Don’t assume the computer knows more than you
- Don’t assume the computer checks everything – it doesn’t
- 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 good to be true – there’s a mistake
- Don’t be blinded by pre-conceived notions
- Never get complacent – question everything
- Watch the flow of the load
- “The map is not the territory.”
Philosophy & mindset
Types of errors

1. Missing information errors
2. Default errors
3. Code check errors
4. Input errors
5. Errors in understanding software
6. Software limitations
7. Software errors
8. Constructability errors
9. Translation errors
Understanding the software

…and limitations

Create simple models to check your assumptions of how the software works
How are wind loads computed?

Does computer model consider additional MWFRS wind loads due to irregular geometry?

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?
Understanding the software

Load path issues - are drag struts analyzed?

- What is load path for load transfer between braced frames?
- Where did the drag strut force go?

Understanding the software

Are load paths realistic?

- Why did the forces get smaller on this lower level?
- Where did the lateral load go?

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, $N_i$

![Snow vs Roof Live Load](image)

Understanding the software

What does the software not check?

Are girt wind loads computed?

![Diagram](image)
Understanding the software

What does the software not check?

Slabs on metal deck:
- Deck capacity for support of wet concrete during slab pour
- Slab capacity for support of superimposed loads
- Span direction (What happens when the slab is spanning in the wrong 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?
How are beam deflections computed?

Are any floor areas disconnected from the LLRS? If so, how are the columns designed?
Understanding the software

Diaphragm issues:

Are floor diaphragms infinitely rigid? Are there any unrealistic analysis results from this assumption?

Does the software design the diaphragm? (Probably not.)

The Infinitely Rigid Floor Diaphragm
Diaphragms

- Rigid, flexible or semi-rigid?
- Strength and stiffness
- Was the diaphragm designed?
- Are lateral loads properly distributed to BF’s & MF’s?
- Are diaphragms pulling loads out of BF’s?
- Are diaphragms hiding drag strut forces?
- Are diaphragms stiff enough to brace 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?

Assumption of infinitely rigid diaphragm can distort lateral load distribution to the LLRS

Stiff walls + infinitely rigid floor diaphragm = torsionally stiff structure. (unrealistically stiff)
Assumptions of infinitely rigid diaphragms can (incorrectly) pull loads out of a braced frames & moment frames.

Are the diaphragms stiff & strong enough to brace the columns?
Diaphragms

Sloped columns need braces at each end and a load path to the LLRS.

Did the computer design the struts?

Did the computer design the diaphragm?

Diaphragms

Horizontal out-of-plane offset

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

In-plane offset in braced frame

Did the computer design the drag strut?

Diaphragms

Is there a load path to the LLRS? Are there adequate diaphragm connections to the LLRS?

How do the loads get into this braced frame?
Load combinations

There are many load combinations. Understand & check the important ones (simplified),

1.2D+1.6L (or 1.4D)
1.2D+1.6W+L
1.2D+E+L
0.9D+1.6W
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 that are 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

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
- Skewed beams w/ large reactions
- Translation errors – drawings do not match model

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

Validation of the gravity load framing is exact

Validation of the LLRS is less precise – but manual calculations should be within 20% of the computer analysis

Validating the LLRS

Wind

- Look at wind in each orthogonal direction
- Compute average wind pressure
- Compute base shear in each direction & 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 & compare with computer
Validating the LLRS

Common errors / problems,

– Parapets, roof screens and penthouses missing from model
– Software incorrectly considering shielding for irregular-shaped buildings
– Infinitely rigid diaphragms distorting load distribution to the braced frames and moment frames.

Validating the LLRS

Seismic (for R=3)

– Look at loads in each orthogonal direction
– Compute $T_a$ & $C_u T_a$
– Compare $C_u T_a$ with exact period, $T$ (from computer)
– Use appropriate period
– Compute $C_s$
– 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 BF’s and MF’s w/ computer
Validating the LLRS

Unusual load distributions within the LLRS are usually related to rigid diaphragm issues.

Infinitely rigid diaphragms can cause loads to move in and out of BF’s and MF’s in the model.

Non - Building Structures
Reactions and behavior of complex non-building structures is not always intuitive due to,

- Unusual geometry
- Many load combinations

Monumental stair
Non-building structures

Storage bin

Non-building structures

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
– 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

Verify that loads are there and are pointing the right direction
Non-building structures

Verify that members are oriented correctly

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

Understand the various bracing constraints in the software and make sure they match the actual constraints
Summary

- Understand ASCE 7, AISC 360, ACI 318, IBC, NWS, 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
- Verify that there are continuous & legitimate load paths
- Never get complacent
- Get a second set of eyes on all models
- “The map is not the territory.”


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.

Don’t view your computer model as a “source of wonder”. Understand and validate the results.
Thank you!
Questions?
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