# Computer Analysis Verification/Validation

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# “Design First, Then Compute”

“If you are not able to roughly design your structure by hand, you certainly have no business relying on your computer to do so.” – Stan Caldwell, P.E. *Structure Magazine*, Jul 2016

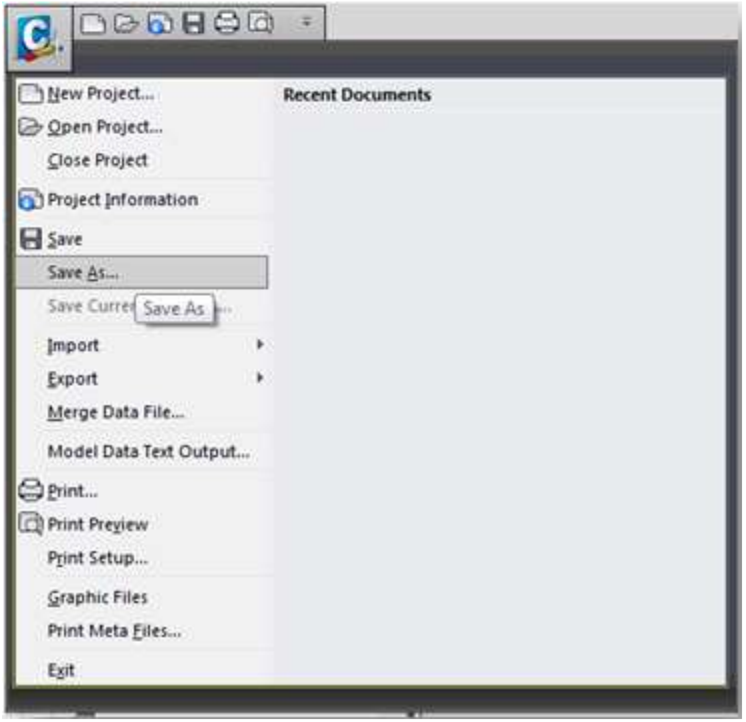
# Overview

- Model Setup
- Debugging
- Validation Process
- Troubleshooting
- Best Practices

# Model setup

# Getting Started - Tips

- Name your model and associated spread based on:
  - Date created
  - Model description
- Create a “save-as” of your model often, specifically when major changes are made.
- Computer memory is cheap, you aren’t!
- Easy to go back if needed (i.e. file becomes corrupt)



# Getting Started - Tips

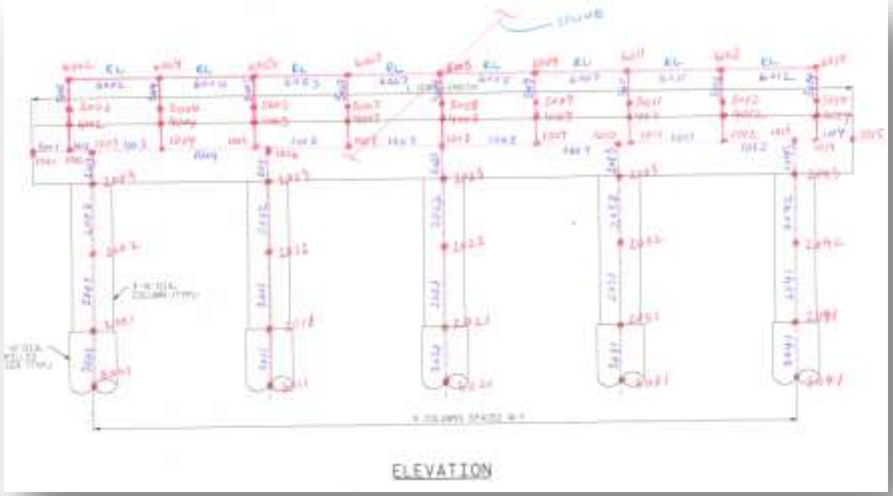
- Work from your local (C:\) drive and backup to your network daily at a minimum.
- Faster on local drive.
- Keep a master version including all analysis
  - DL
  - Wind
  - Moving Load
  - Seismic
- Break the model out for more time consuming analysis:
  - Moving load
  - Seismic

# Getting Started

- Keep your format as simple as possible
- Get your thought process on paper
- Begin documenting
- Establish a node/member/section property numbering system

# Model Setup

- Minimize extraneous joints/members BUT keep in mind what sections will be required for design (i.e. location of $M_{max}^{+}$, $M_{max}^{-}$)
- Use plan drawing or hand sketch to layout typical sections (i.e., typical pier numbering)



# Model Setup

- In almost every situation, geometry or loading will change.
- Using a spreadsheet for a base is helpful.
- Different situations warrant different methodology
  - Spreadsheet input
  - DXF file import
  - User interface
- Future proof your work!

# Model Setup

- Thoroughly document loading within spreadsheet or hand calculations.
- Break out each load type so future results can be easily identified. (i.e. barrier load, FWS, counterweight, etc.)

**Span 1**

Loads to be applied to the model:

| | | Type | p | w | P |
|---|---|---|---|---|---|
| | | | psf | k/ft | k |
| 1 | Connections | DC1 | EGs = 120%, FBs - 115% | | |
| 2 | Splices | DC1 | | 1.219 | |
| 3 | Stringers | DC1 | SEE BELOW | | |
| 4 | Utilities | DW | 5.56 | | |
| 5 | Sub stringers | DC1 | 1.97 | | |
| 6 | Haunches | DC1 | 1.34 | | |
| 7 | Overlay | DW | 11.64 | | |
| 8 | FWS | DW | 25.86 | | |
| 9 | Add'l deck | DC1 | 4.48 | | |
| 10 | Barriers | DC2 | 13.33 | | |
| 11 | Pedestrian Rail and Fence | DC2 | Applied as line loads | | |
| 12 | Concrete fill | DC1 | SEE TABLE | | |
| 13 | Pier Cap | DC1 | | 3.12 | |
| 14 | Footings | DC1 | | | 2278.5 |

# Model Setup

<u>Bridge Model:</u>

- Spreadsheet created for nodes, members, plates, section properties.
- Spreadsheet name associated with date and model
- Horizontal curves, Vertical profile and superelevations/cross-slopes developed from civil data.
- Simple input, flexible for the possibility of future change (it will happen).

# Model Setup

| | | | | | | |
|---|---|---|---|---|---|---|
| **Structure Weight Check:** | | | | | | |
| Superstructure: | | | | | | |
| | | | | Factor | W (kips) | |
| Girders | 1971 | kips | | 1.2 | 2,365 | |
| Floorbeams: | 2288 | kips | | 1.15 | 2,631 | |
| Deck: | 11084 | kips | | 1 | 11,084 | |
| Lateral Bracing: | 41.85 | kips | | 1 | 42 | |
| | | | | Subtotal: | 16,122 | kips |
| Substructure: | | | | | | |
| Pier 1 | | | | Factor | W (kips) | |
| Cap: | 1804.2 | kips | | 1 | 1,804 | |
| Column 1: | 375.92 | kips | | 1 | 376 | |
| Column 2: | 384.41 | kips | | 1 | 384 | |
| Pier 2 | | | | Factor | W (kips) | |
| Cap: | 1804.2 | kips | | 1 | 1,804 | |
| Column 1: | 317.02827 | kips | | 1 | 317 | |
| Column 2: | 335.82477 | kips | | 1 | 336 | |
| | | | | Subtotal: | 5,022 | kips |
| | | | | **Total Structure Weight:** | **33,658** | **kips** |
| | | | | **MIDAS Total SW Reaction:** | **34,511** | **kips** |
| | | | | **% Diff:** | **2.54%** | |

Bridge Model:

- Spreadsheet is linked throughout so that future changes are automatic.
- Consistency will help with a repetitive model.
- Add a check of geometry/loads in parallel of input section.

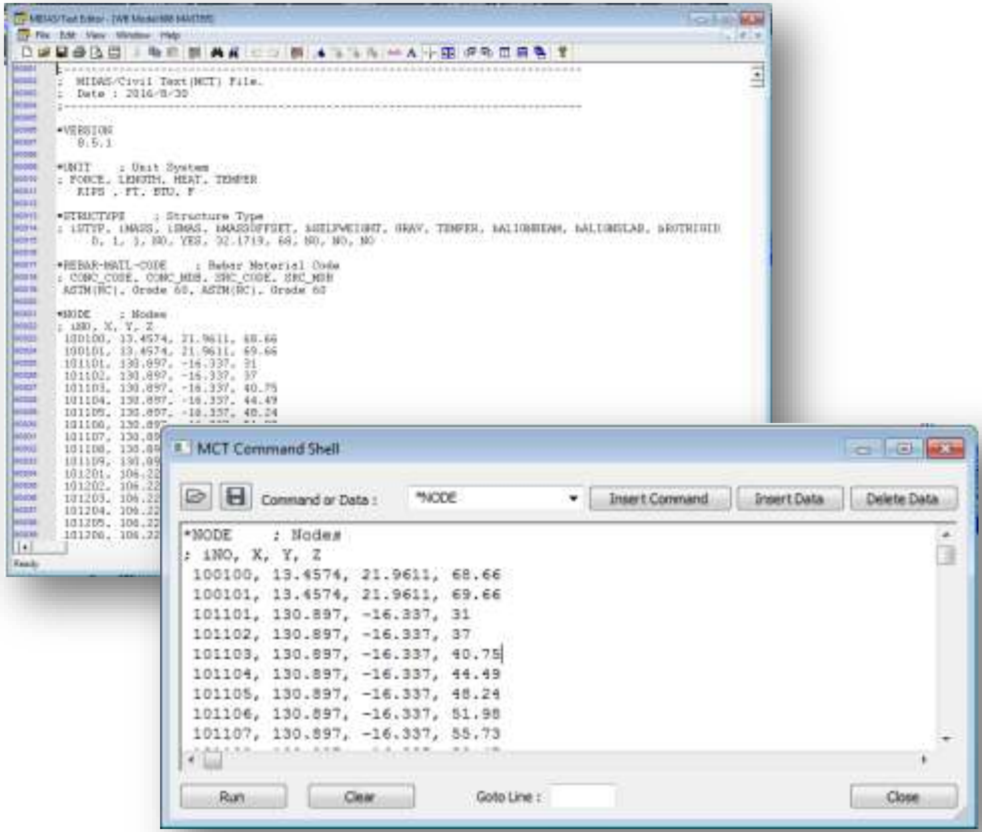
# Model Setup

.mcb file:

<u>Bridge Model:</u>

Spreadsheet data may be input using:

- MCB file or
- Piece by piece using “MCT Command Shell”

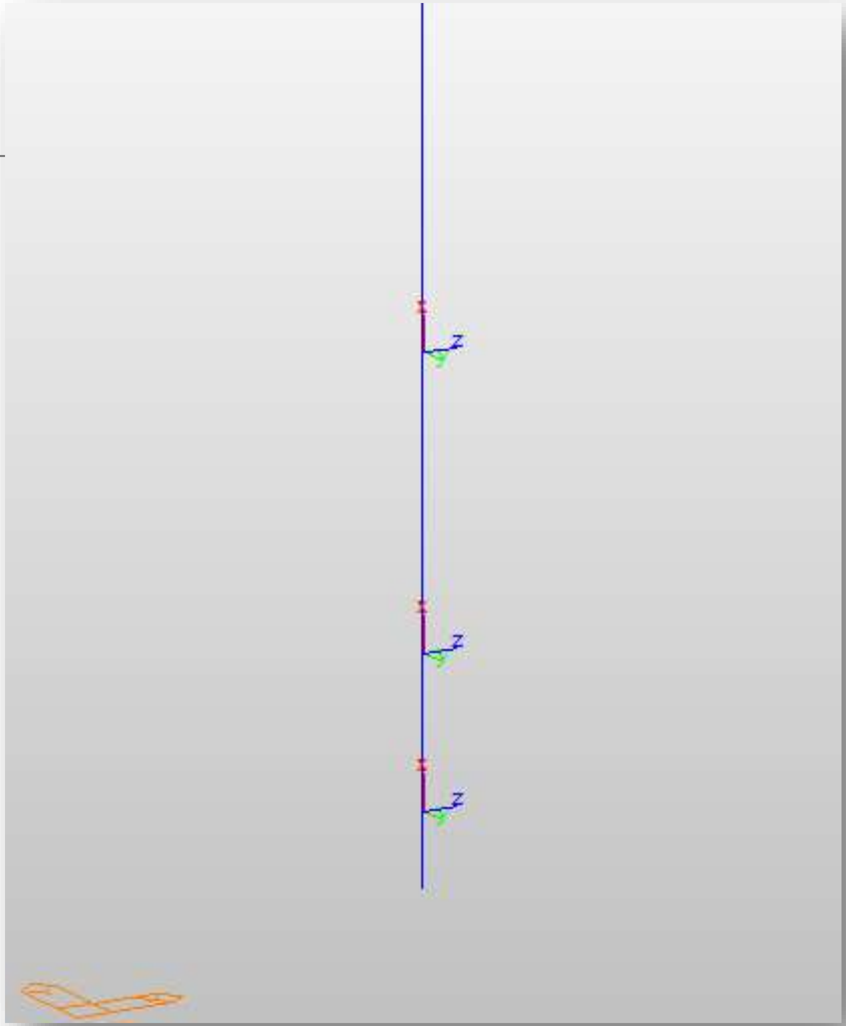



MCT Command Shell

# Model Setup

Bridge Model:

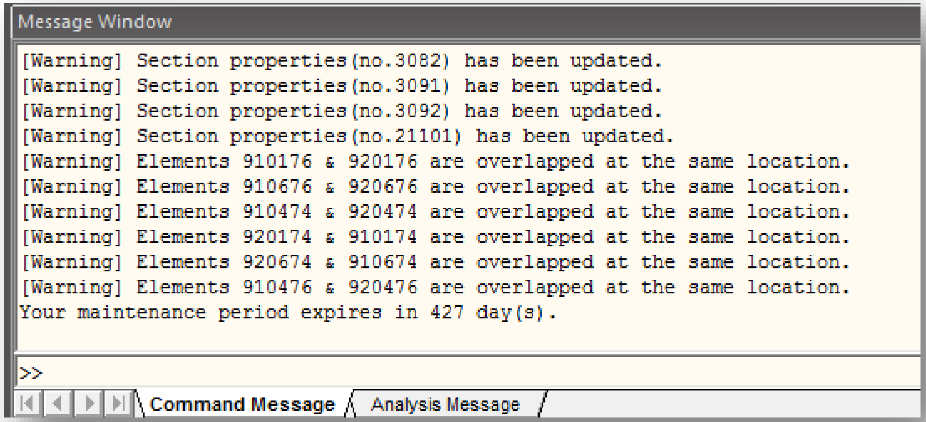
- Majority of data input using text
- Member orientations and geometry verified in user interface.
- Consistent member orientation is important.



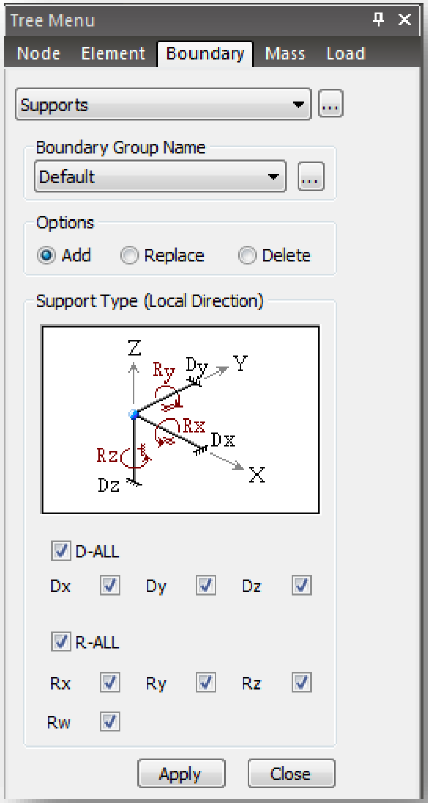
# Debugging

# Debugging

- Even the most carefully set up model can have errors or warnings.
- Error or warning message often further downstream from the problem.
- Errors must be resolved.
- Warnings don't always need to be addressed.



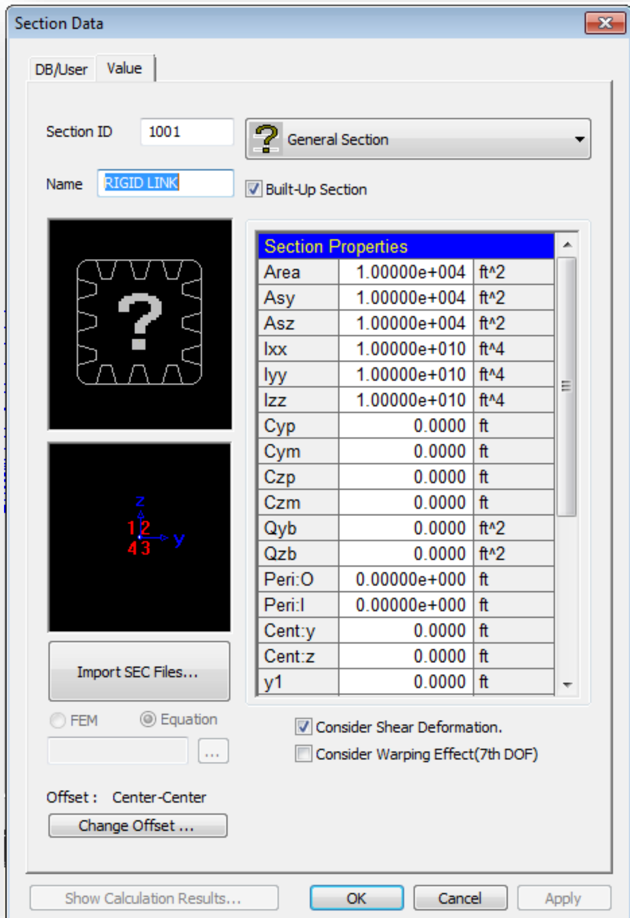
# Debugging




Common Sources of Error:

- Boundary Conditions
  - Effects the structure stability
- Members incorrectly defined.
  - Double check spreadsheet, make changes within spreadsheet.
  - Make sure this problem isn't repetitive.
- Changes made directly in .mcb file or MCT Command Shell
- Tapered section groups.

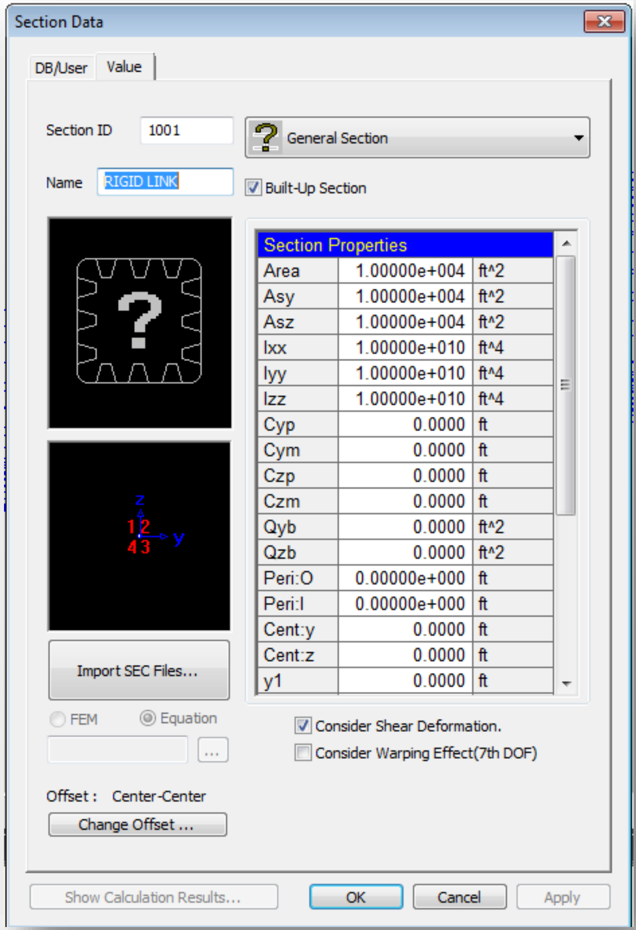
# Debugging




<u>Common Sources of Error:</u>

- Rigid links too stiff.
  - User defined Rigid links should have stiffness $10^3$ times as the stiffest member it is connected to.
- Rigid links too soft.
  - May not be flagged as an error by the program.

# Debugging




Rigid Links:

- Beyond runtime errors, improperly defined rigid links may cause incorrect results.
- Rigid links must be calibrated. (iterative)

# Validation Process

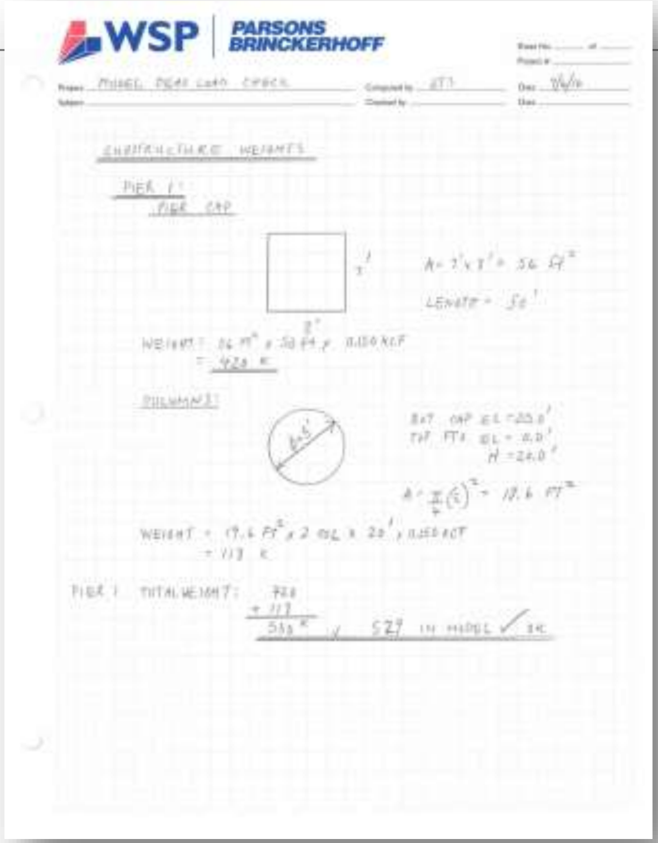
# Model Validation

- You should have an idea of how you expect your model to behave.
- Computer model is a tool, not the end-all, be-all.
- Are you results making sense?
- Garbage-in, Garbage-out

# Model Validation

<u>Dead Loads:</u>

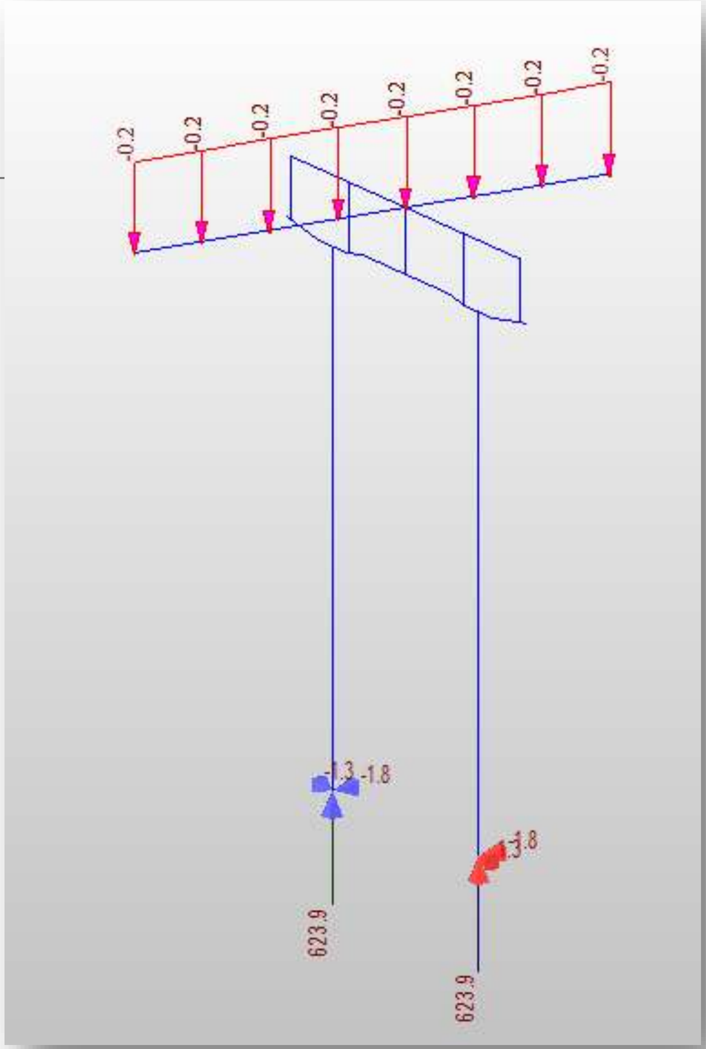
- After basic model setup and dead loads have been added.
- Hand calculate (or in Excel):
  - Reactions
  - Overall model weight
- Compare to model results.
- May also add temporary test loads to simply verify that load path is as expected and 100% of the loads are accounted for.



# Model Validation

Dead Loads:

- Check magnitudes and directions of forces and reactions are as expected.
  - Forces are applied are vertical, are the reactions?
  - Are forces following the expect load path from the applied load.

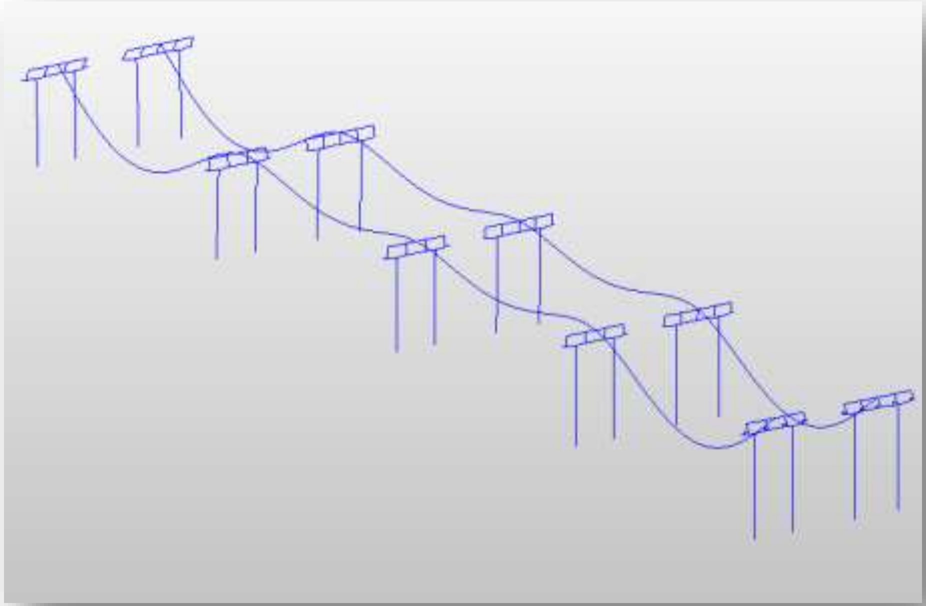


# Model Validation

Dead Loads:

Deflected shape

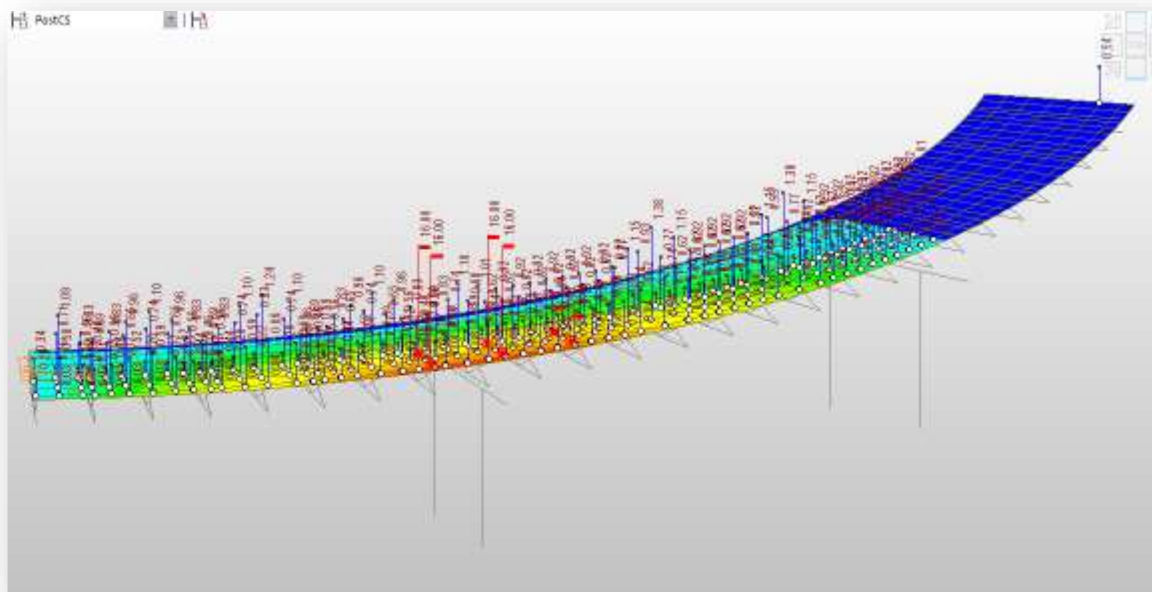
- Is the model superstructure/substructure deflecting as expected?
- Are the magnitudes reasonable?
- Look at the deflected shape for each of the broken out load types and compare.
- Deflections may be plotted in Excel to compare magnitudes from each contributing load



# Model Validation

<u>Live loads:</u>

- Applied loading and moving load cases should be documented externally.
- Look at each case using:
  - Moving load tracer
  - Influence Surface/Lines
- Check key locations:
  - Max reaction at a pier
  - Girder $M_{max}^{-}$
  - Girder $M_{max}^{+}$
  - Etc.

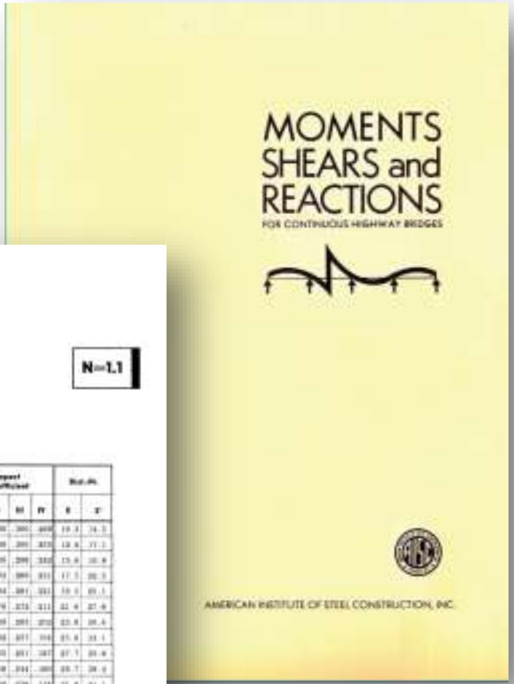


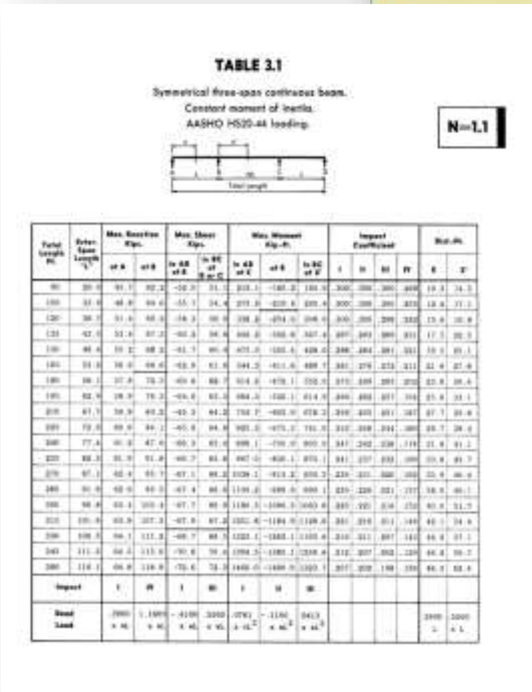
# Model Validation

<u>Live loads:</u>

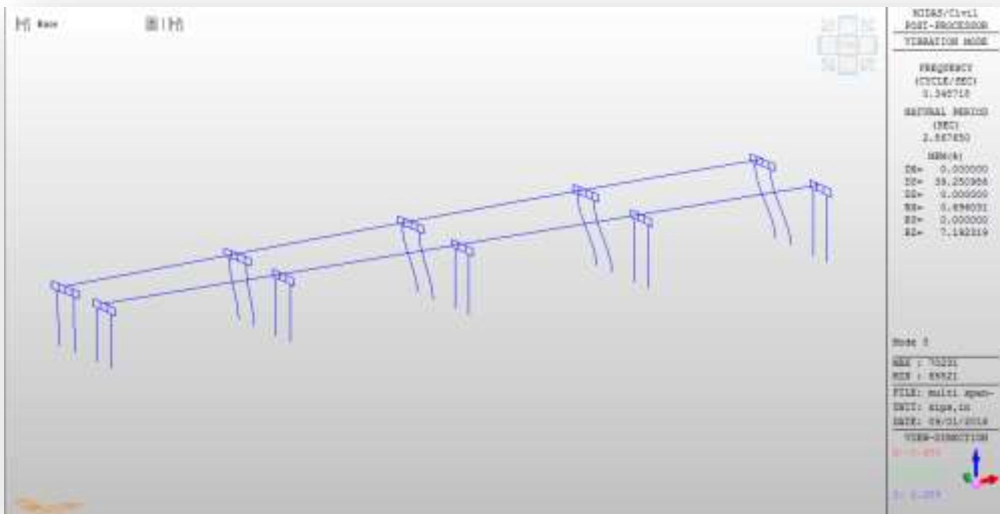
Spot check using hand calculations.

- *AISC Manual of Steel Construction* continuous beam tables
- *AISC Moments, Shears and Reactions for Continuous Highway Bridges*



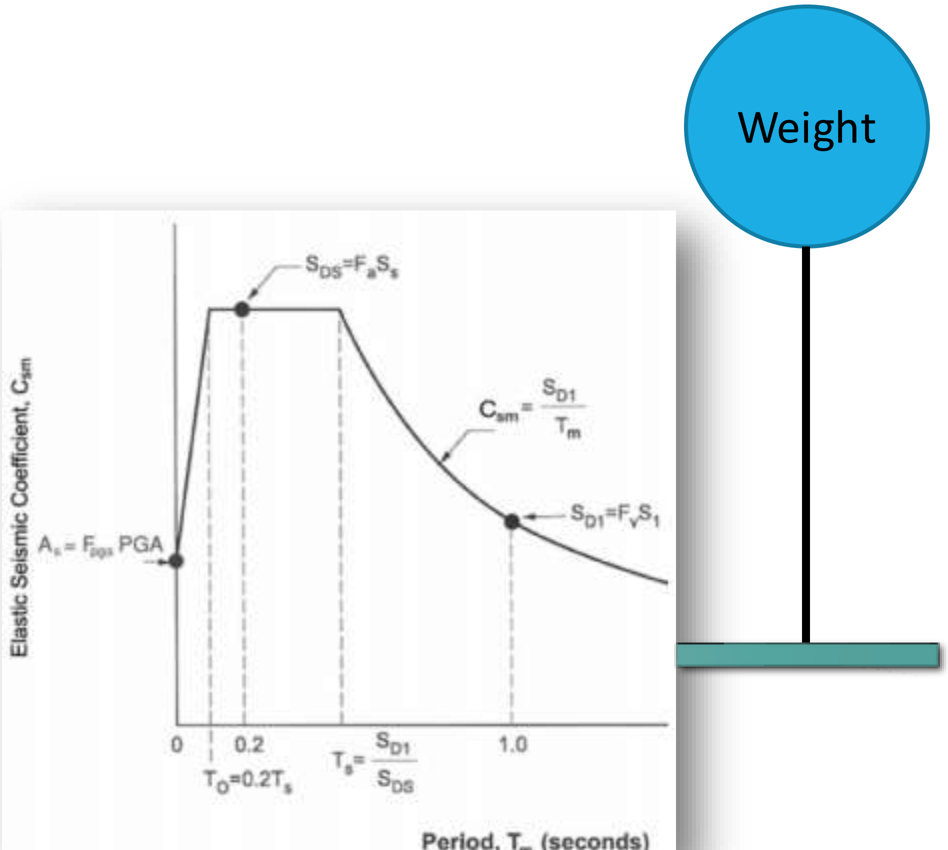
# Model Validation




Seismic Loading:

- Look at your mode shapes. (At least first 10)
- Fundamental frequency/period
- Mass Participation
- % Mass Participation
  - > 90% in horizontal directions
  - > 80 % in vertical direction

# Model Validation




<u>Seismic Loading:</u>

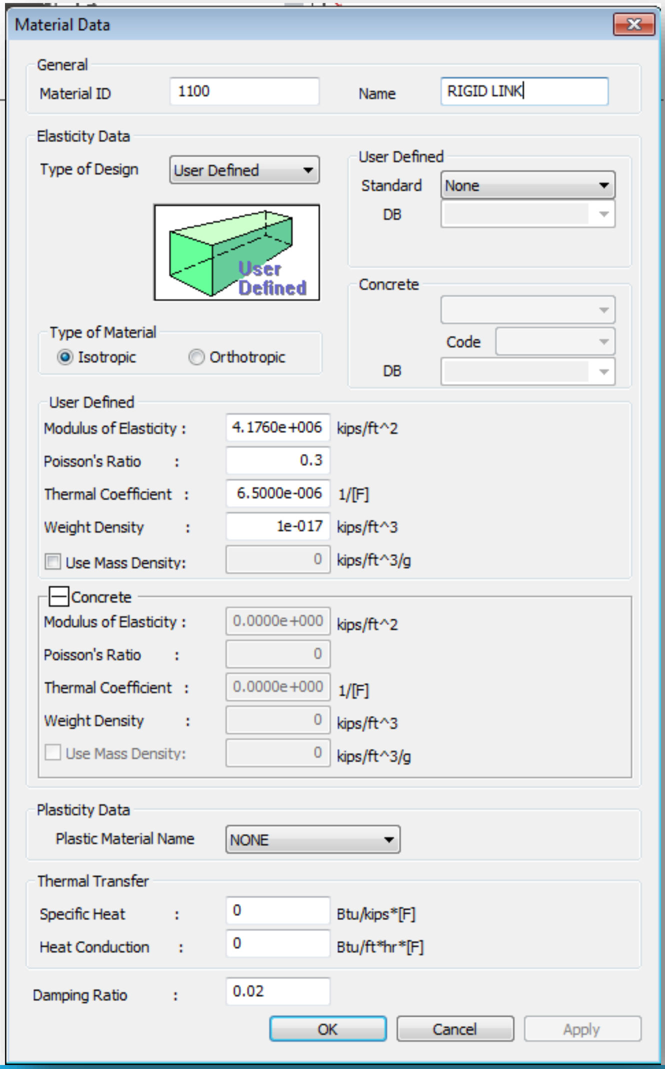
- Spot check and hand calculations can be done using the Single-Mode Spectral Method.
- Using fundamental period

# Troubleshooting

# Troubleshooting

## Dead Load

- Weight does not match hand calculation
  - Verify weight is accounted for in either "self weight" or applied loads
  - Verify material densities (check the "automatic properties" are correct)
- Very large deflections
  - Check that rigid links defined properly.
  - Check member releases

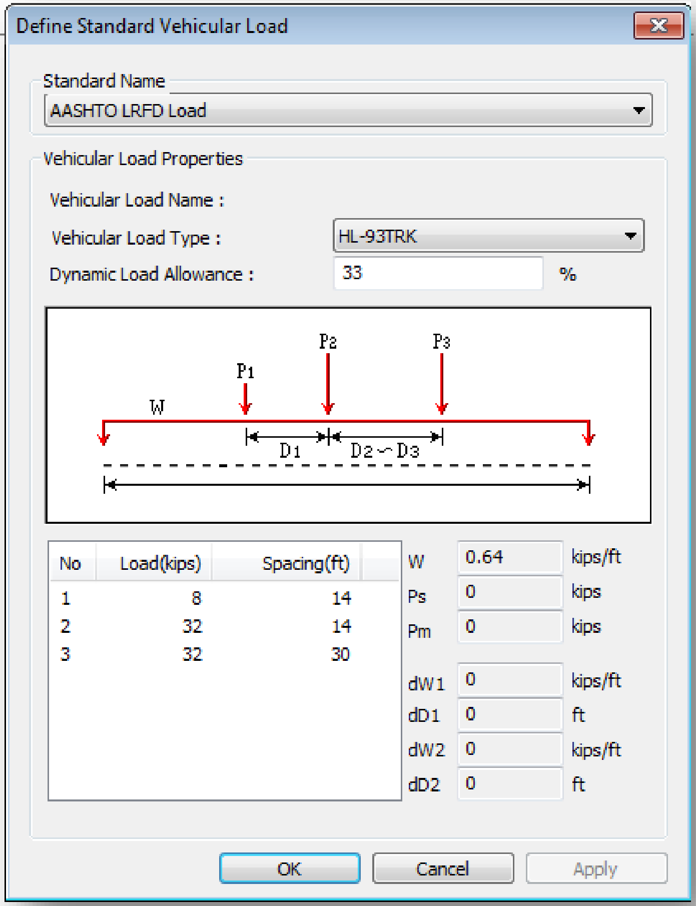


# Troubleshooting

Live Load

Resulting loads/forces are off

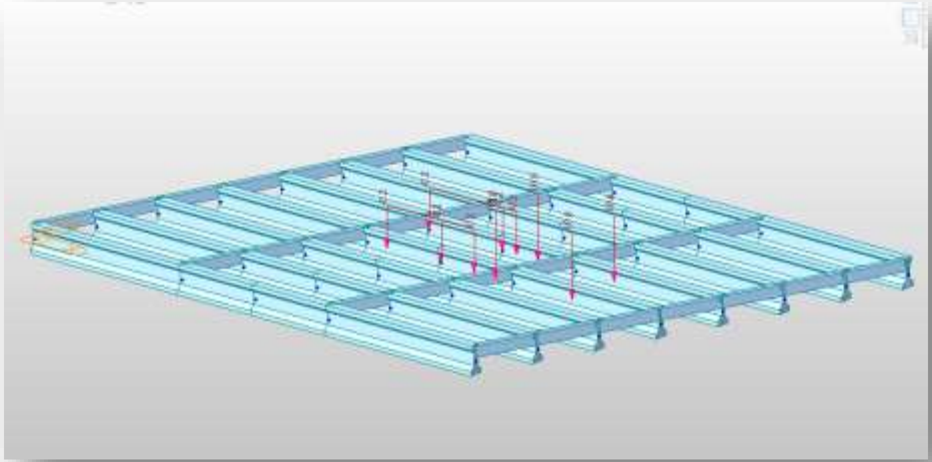
- Is multiple presence properly defined?
- Is impact included?
- Are combination of trucks/lanes defined properly?
- Look at moving load tracer



# Troubleshooting

Live Load

- Create static load simulating Live Load case, compare to moving load
- Move to key locations to verify expected results by hand calculation

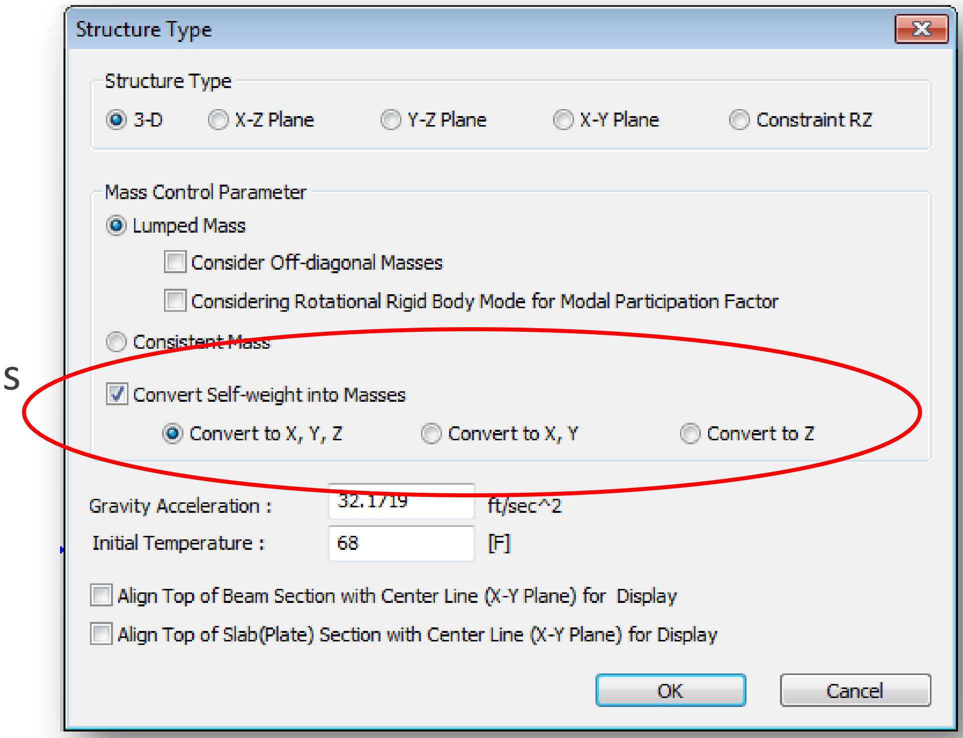


# Troubleshooting

## Seismic

Mass Participation is low.

- Increase the number of modes.
- Verify that option to convert self weight to mass is checked.
- Verify "Loads to Mass" function has accounted for all mass.

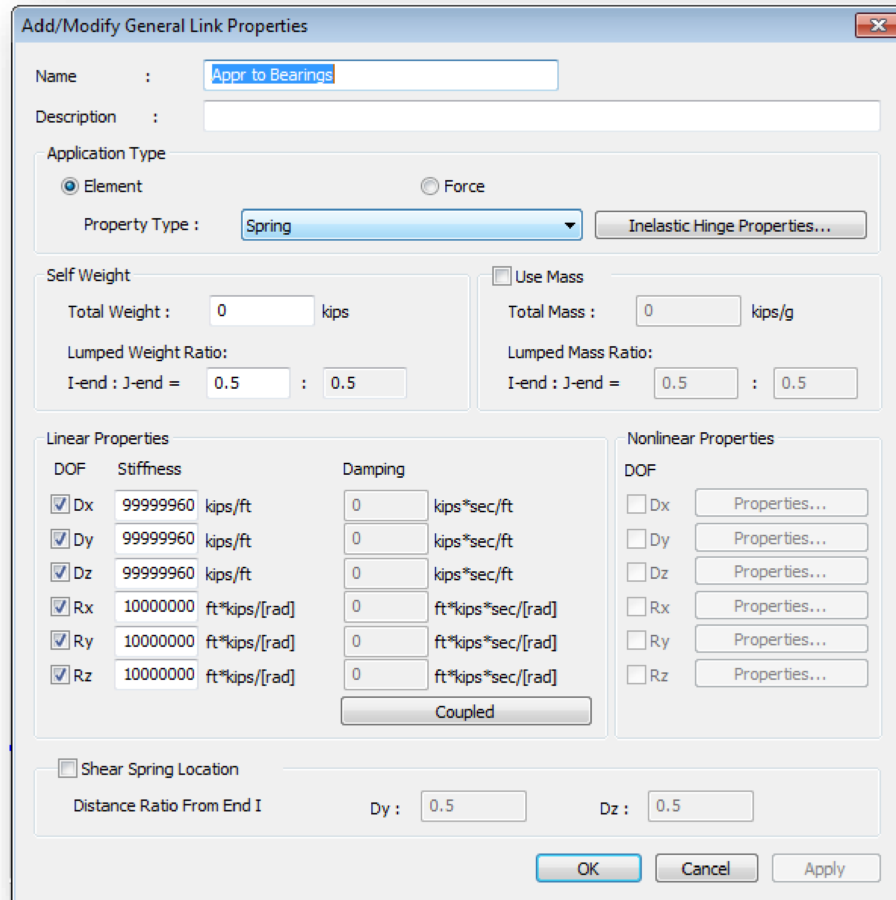


# Troubleshooting

## Seismic

Fundamental Period is unreasonably high, check:

- Member connectivity
- Support definitions
- Member releases
- Rigid link or general link stiffness.



# Troubleshooting

Do a “save as” of your model

<u>Break it down</u> piece-by-piece

<u>Simplify</u> in order to pinpoint problem & speed up run time

Back of the envelope <u>hand calculations</u>

# Best Practices

# Best Practices

1. **Documentation**
   - Before you start your model
   - Step-by-step along the way
   - Include notes, methodology, model associated with spreadsheet
   - Model screenshots with results
2. **Backup your work**
   - Save a version every time a major change is made
   - Save as on a routine basis
3. **Descriptive naming and methodology**
   - Date
   - Simple description
4. **Future proof your work**
   - Easy to modify spreadsheets

# Best Practices

5. **Expected results**
   - Understand the problem you are solving.
   - Think about what results you expect.
   - Look at the big picture
6. **Hand check your work**
   - Back-of-the-envelope calculations
7. **Validate model after major changes**
   - Mode shapes
   - Fundamental period
   - Reactions
   - Deformed shapes

# Thank You

# References

*1. AASHTO. 2014. AASHTO LRFD Bridge Design Specifications, 7th Edition, 2015 and 2016 Interim. American Association of State Highway and Transportation Officials, Washington, DC.*

*2.* Adams, Scott. "Dilbert." N.p.: n.p., n.d. Print.