Analysis of a Severely Skewed Prestressed Concrete Beam Bridge

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MIDAS Special Elite Engineers Webinar - An Insider's Perspective

Agenda

1. Introduction
2. Proposed Bridge Configuration
3. Preliminary Design
4. Refined Analysis Model
5. Results
6. Conclusions

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1. **Introduction**
2. Proposed Bridge Configuration
3. Preliminary Design
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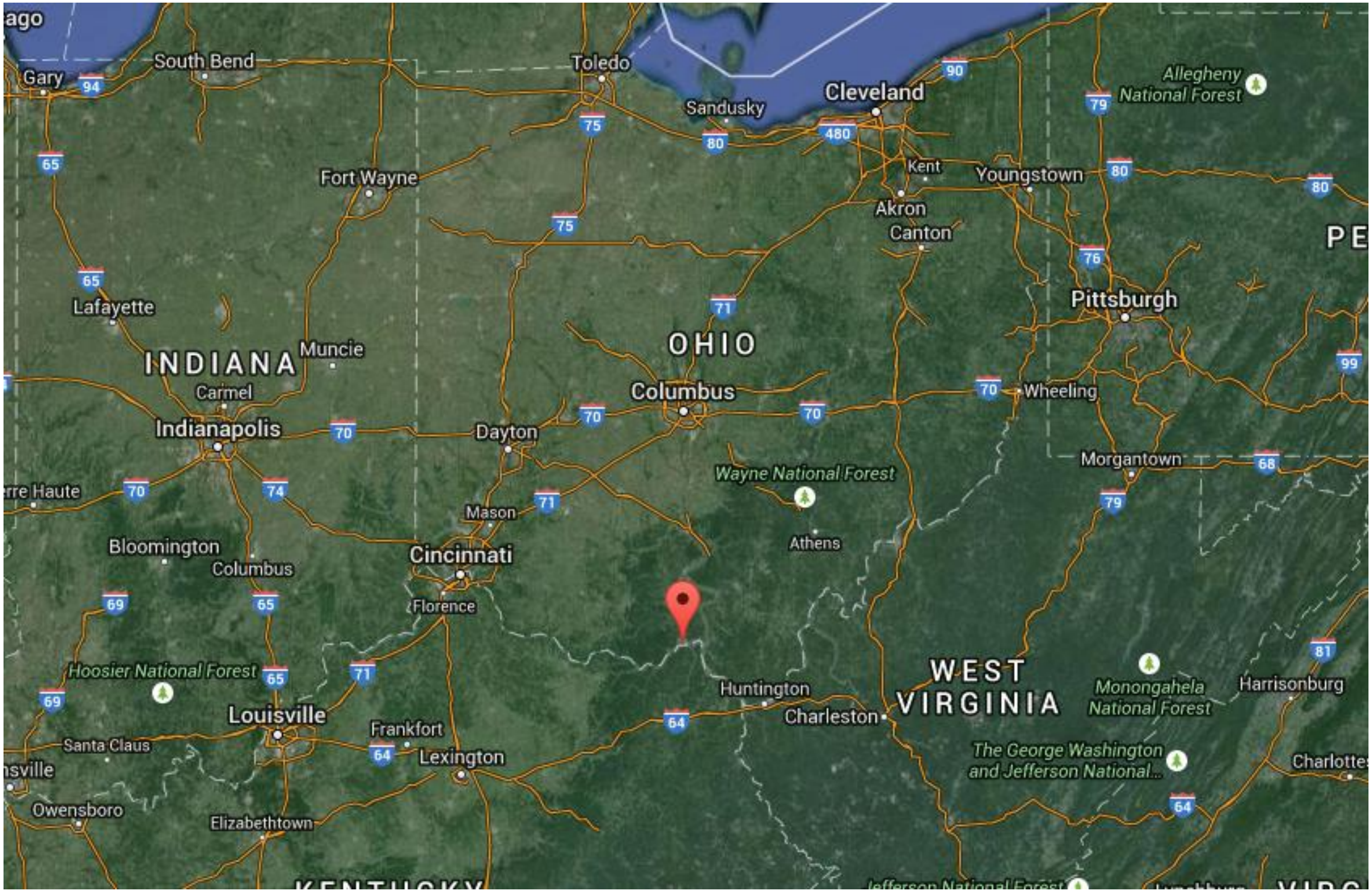
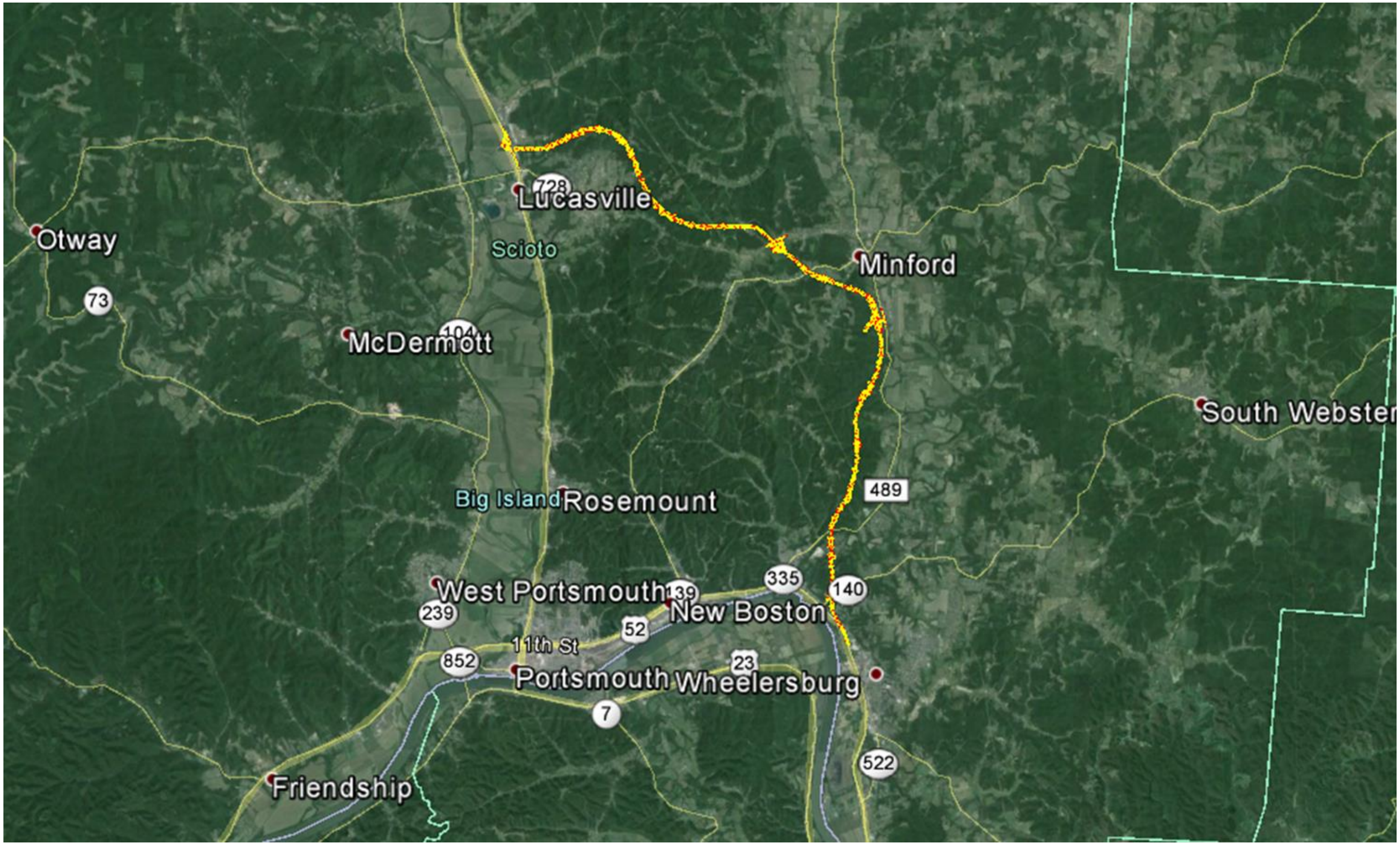
5. Results
6. Conclusions

- **Project Location**



1. Introduction

- **Portsmouth Bypass Project**



1. Introduction

- Project Facts
  - 16 miles long
  - 4-lane divided, limited access highway
  - Bypasses 23 miles of U.S. 23 and U.S. 52
  - Four interchanges
  - >25 Million CY Excavation
  - >20 Million CY Embankment
  - 85% of excavation is rock
  - Cuts & embankments up to 200 ft high
  - 21 bridges

1. Introduction

- Project Procurement
  - Portsmouth Bypass is Ohio first PPP
  - Design-Build-Finance-Operate-Maintain
  - ODOT to make annual availability payments for 35-year maintenance period
  - Project to be Delivered 8 years earlier than originally planned
  - Project Awarded in December 2014 after approximately 1 year bid process

1. Introduction

- Bid Process
  - 3 teams selected to bid, lowest annual availability payment selected
    - Portsmouth Gateway Group
      $25,884,800 per year (-$50,590)
    - PWP Portsmouth, LLC
      $25,935,390 per year
    - Portsmouth Bypass Development Partners
      $26,229,590 per year

Estimated Cost to Construct: $429,000,000

1. Introduction

- **Developer**
  - **ACS Infrastructure Development, Inc.**
  - **Infrared Capital Partners, Limited**
  - **Star America**
- **Construction Contractor**
  - **Dragados USA, Inc.**
  - **The Beaver Excavating Company**
  - **John R. Jurgensen Co., Inc.**
- **Lead Design Engineer**
  - **ms consultants, inc.**
- **Independent Quality Firm**
  - **HDR, Inc.**

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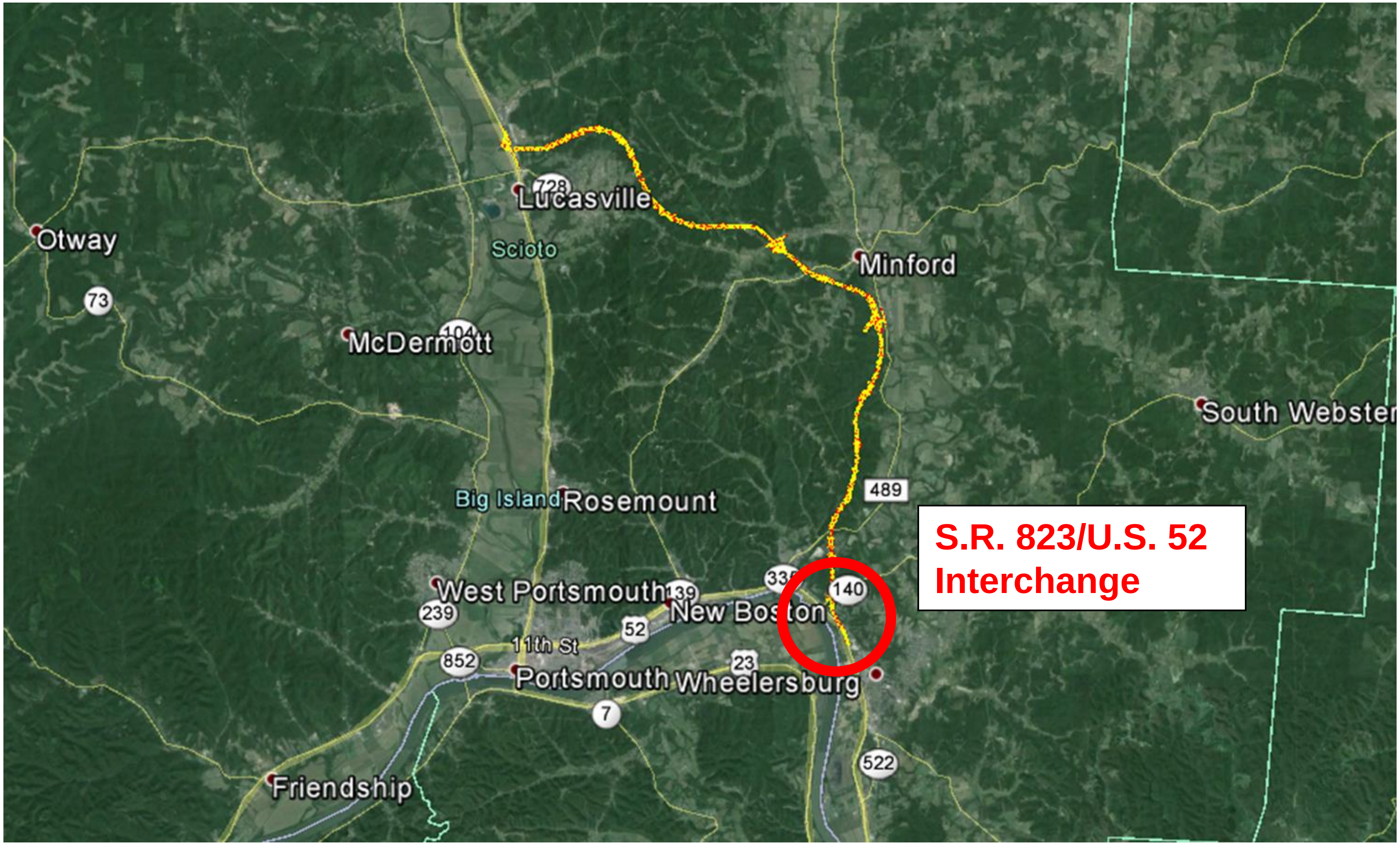
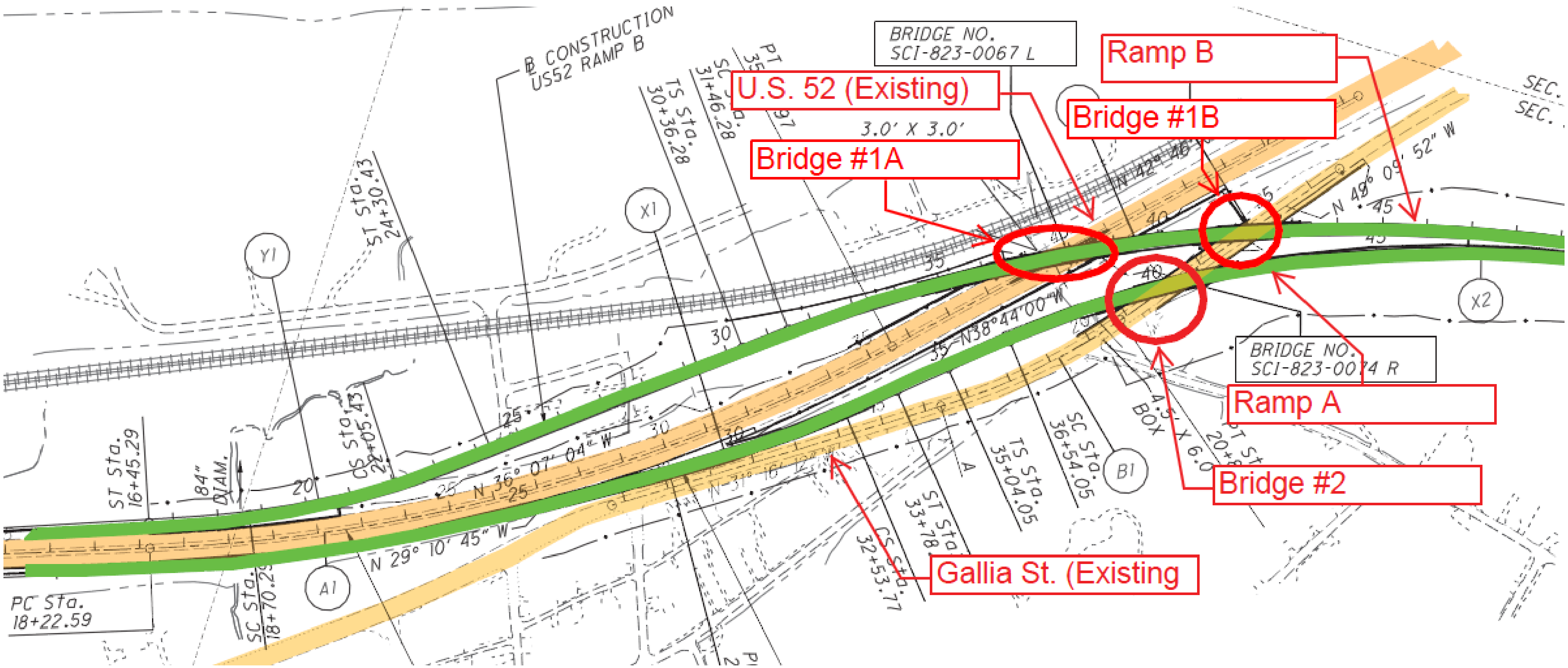
2. Proposed Bridge Configuration

- **Bridge Location**



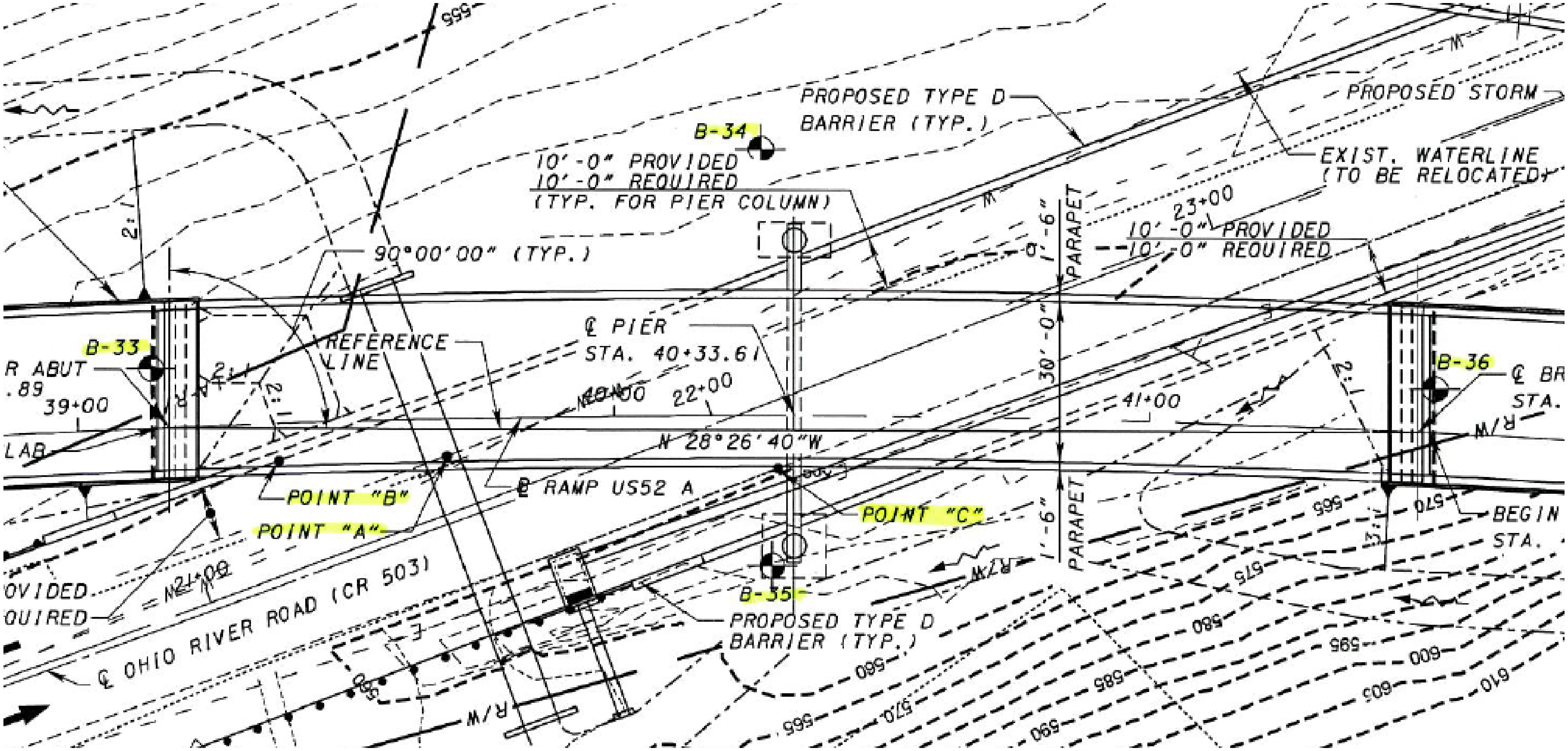
2. Proposed Bridge Configuration

- S.R. 823/U.S. 52 Interchange Plan



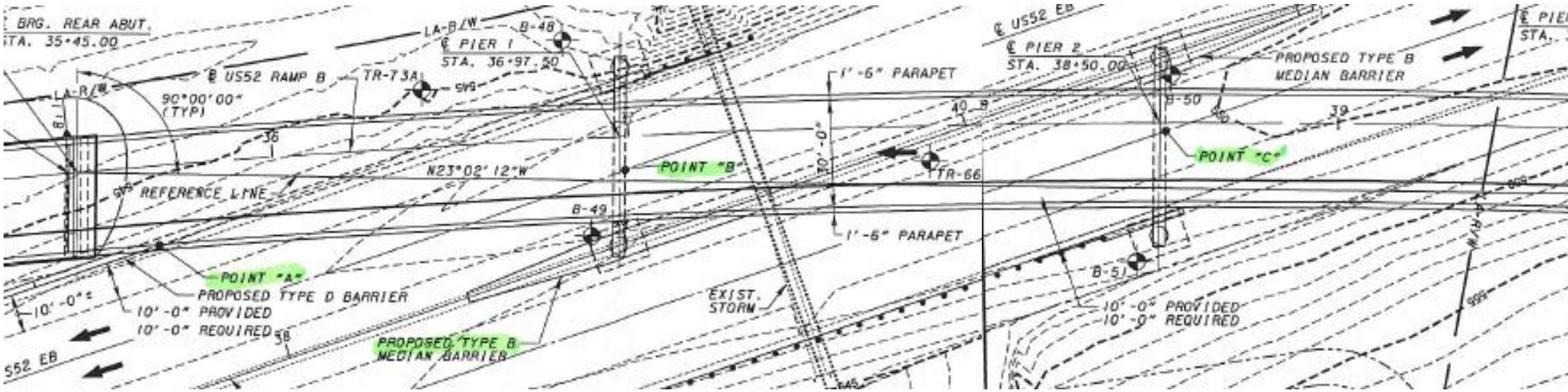
2. Proposed Bridge Configuration

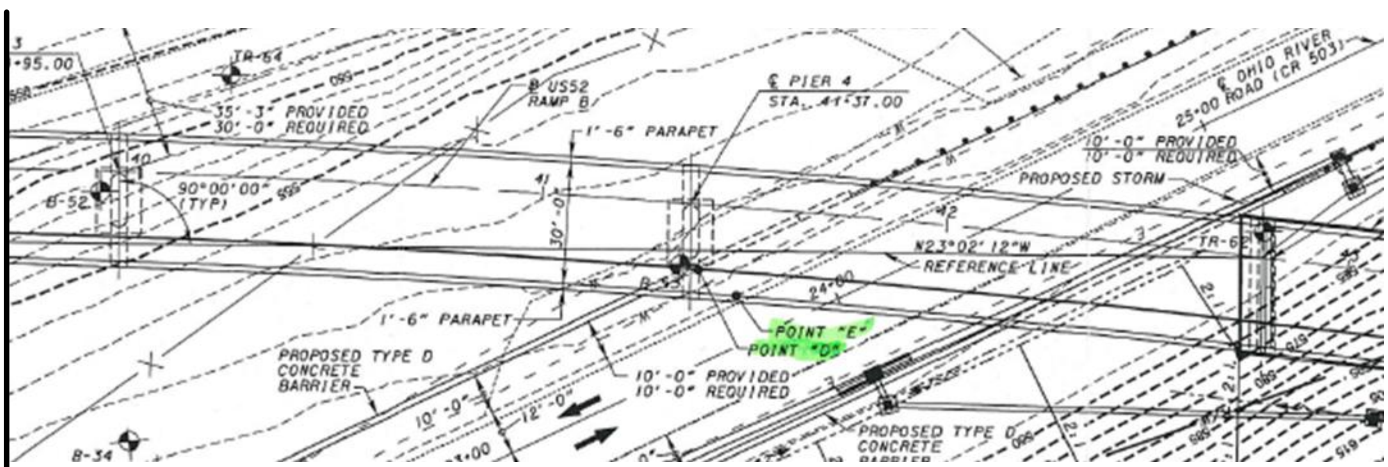
- **Bridge #2 – Reference Design Option**
  - **2-Span Steel Bridge with Straddle Bent**



2. Proposed Bridge Configuration

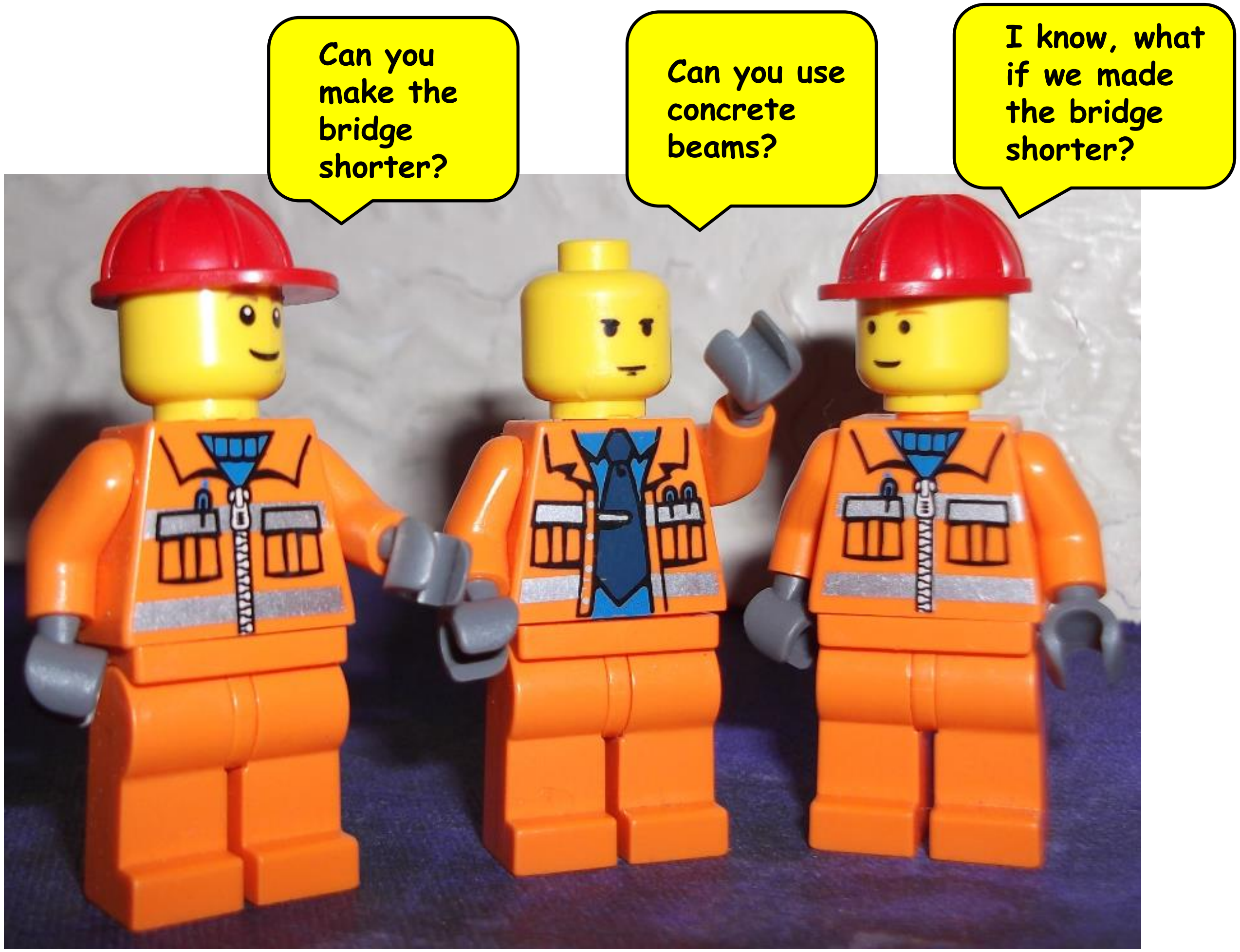
- **Bridge #1A & #1B – Reference Design Option**
  - **5-Span Steel Bridge with 2 Straddle Bents**





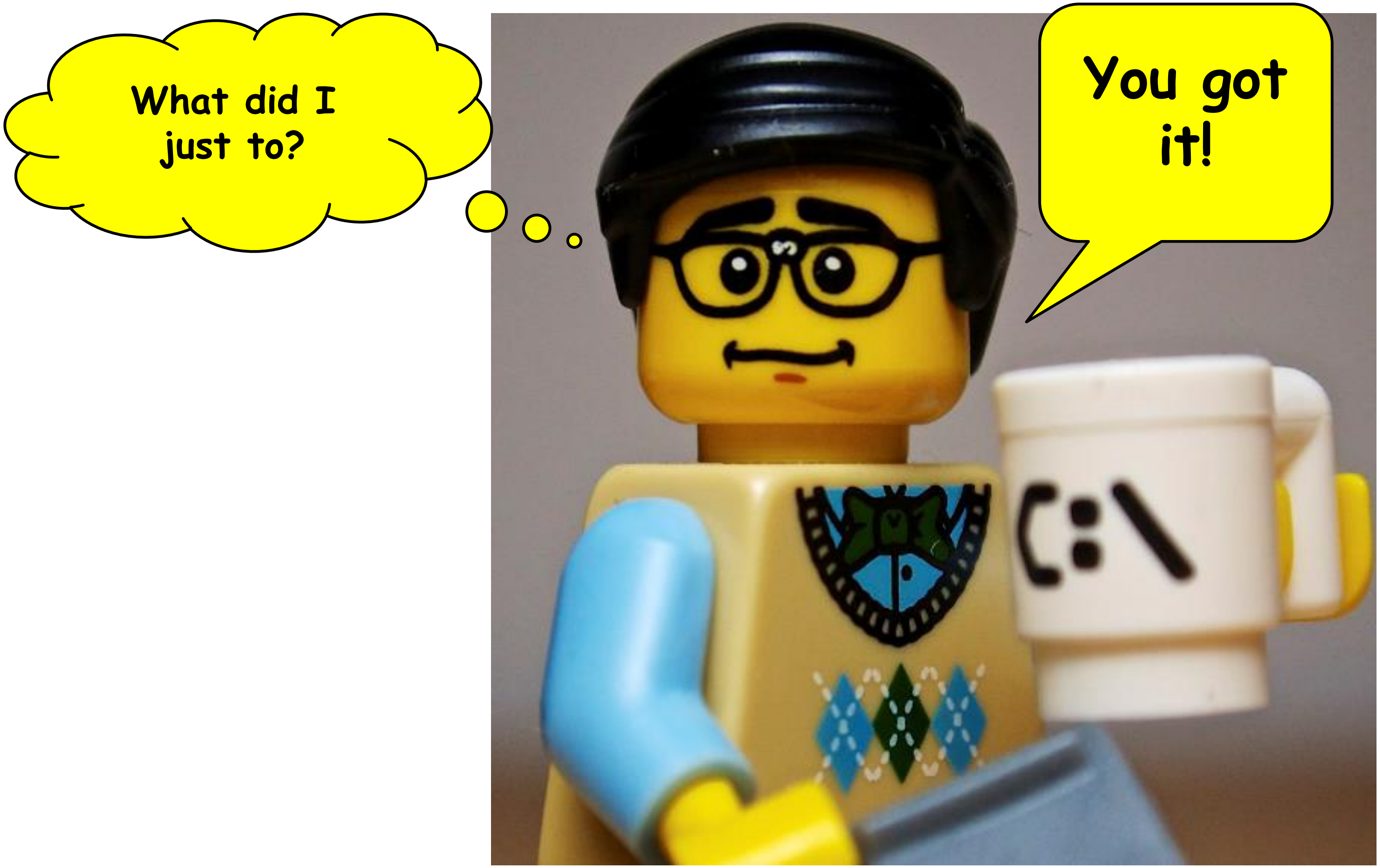
2. Proposed Bridge Configuration

- **PGG Revised Design – How the D/B Process Works**



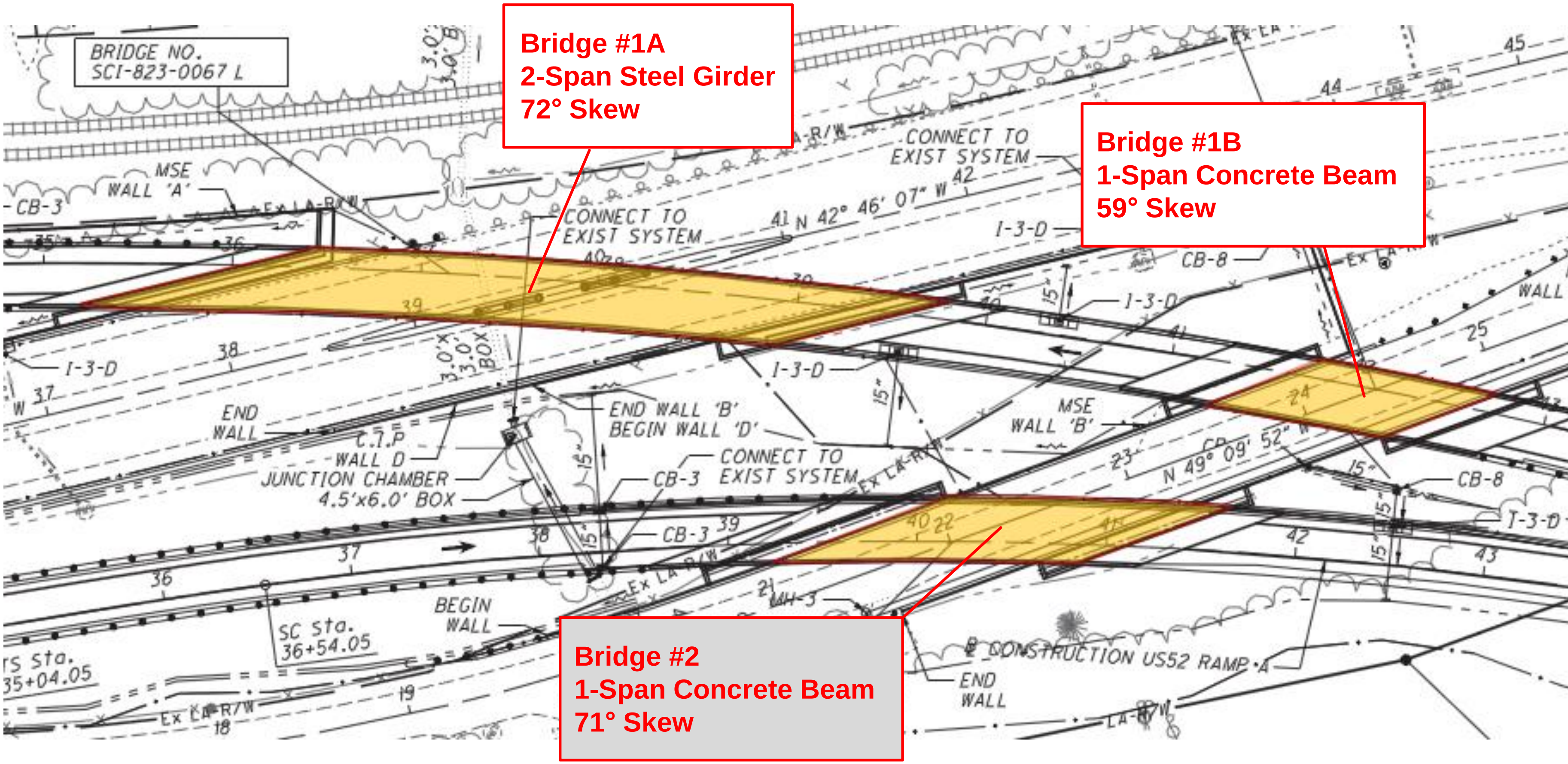
2. Proposed Bridge Configuration

- **PGG Revised Design – How the D/B Process Works**



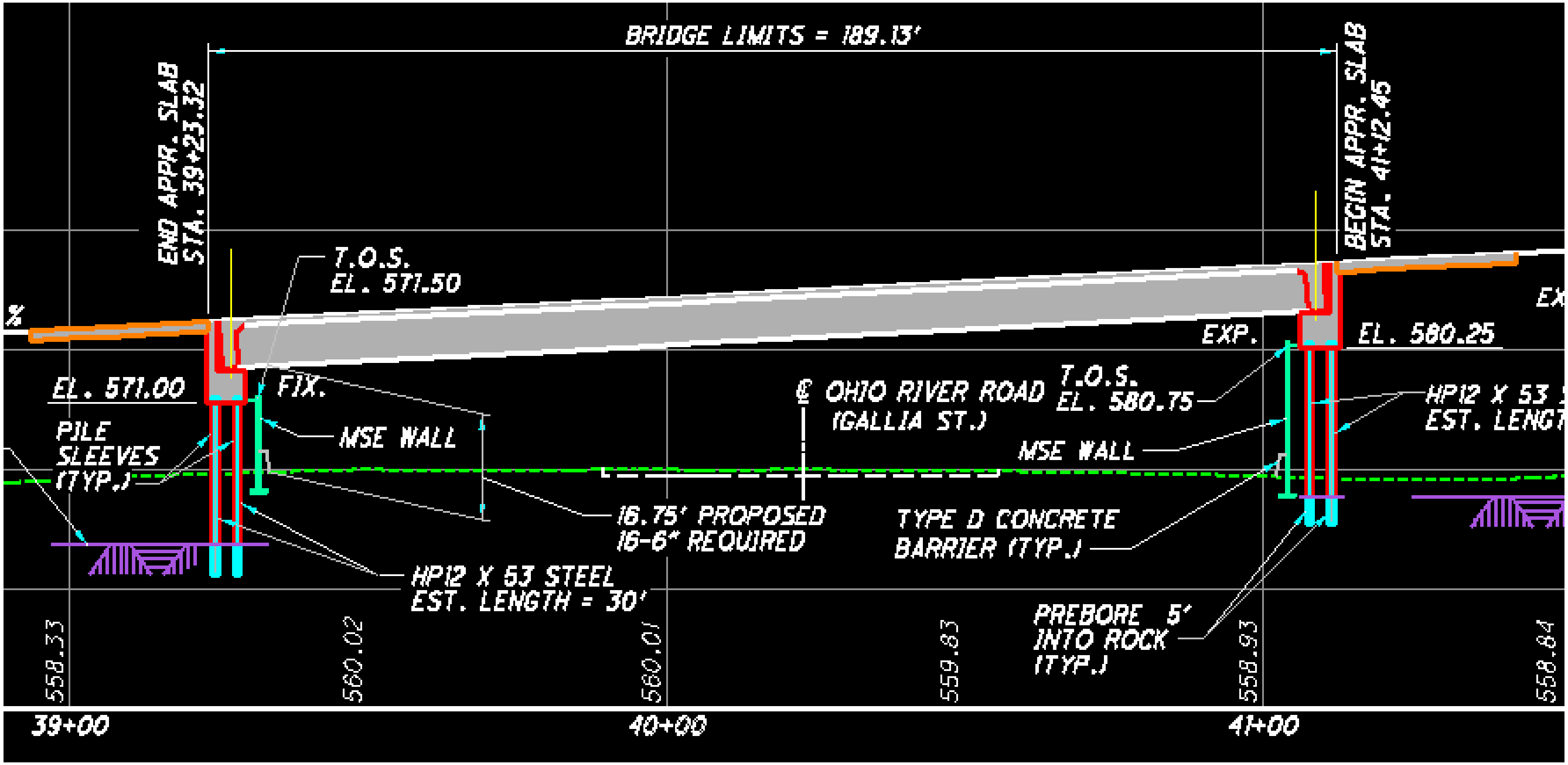
2. Proposed Bridge Configuration

- **PGG Revised Design – Bridge Schematic**



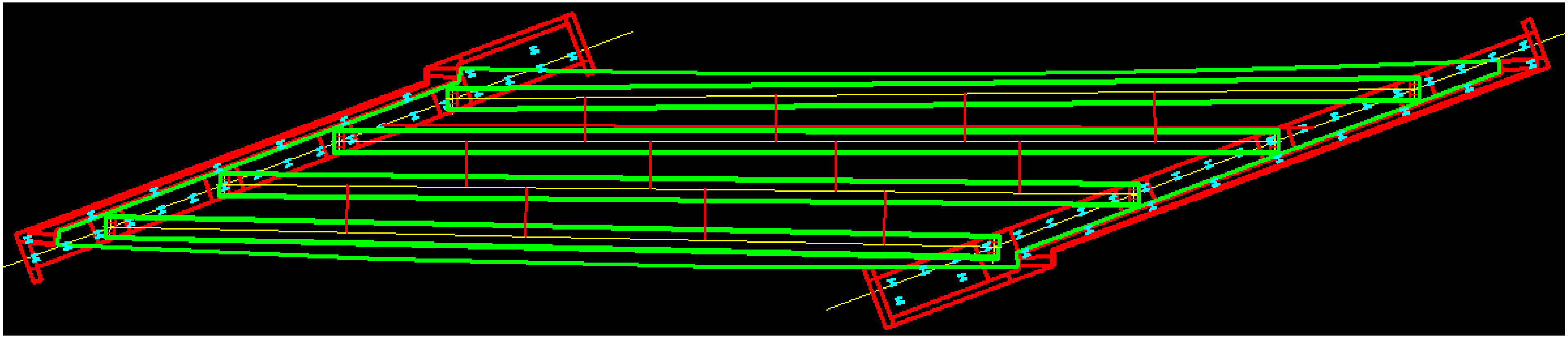
2. Proposed Bridge Configuration

- Proposed Bridge #2 Profile



2. Proposed Bridge Configuration

- Proposed Bridge Framing and Deck Plan



- Girder Span Varies 158.84’ to 173.76’
- All Bays Flared – Vary from 7.58’ to 9.60’
- Deck Overhangs Curved – Vary 3.54’ to 5.20’
- Staggered diaphragm arrangement

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3. Preliminary Design

- **Preliminary Design Approach**

- Preliminary Design Approach
  - Don't be ashamed

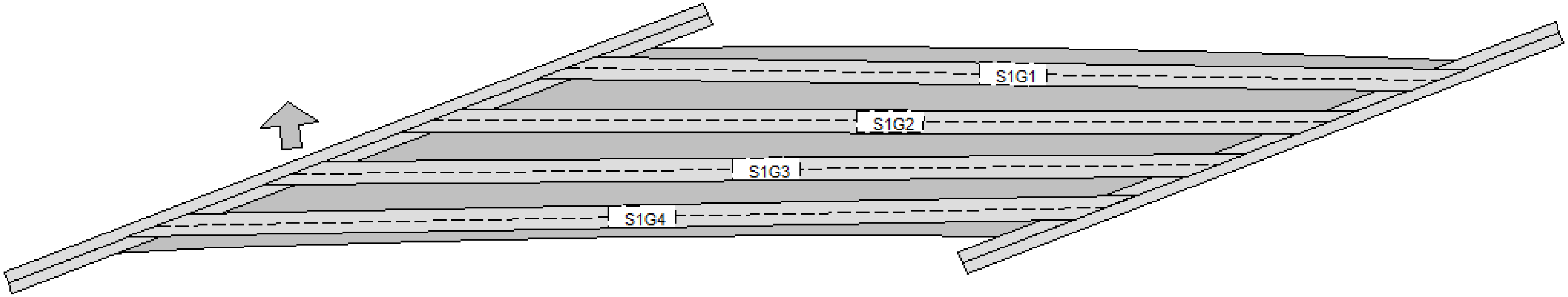
3. Preliminary Design

- **Preliminary Design Approach**
  - Don’t be ashamed
  - **Just know the limitations**

3. Preliminary Design

Know the Limitations

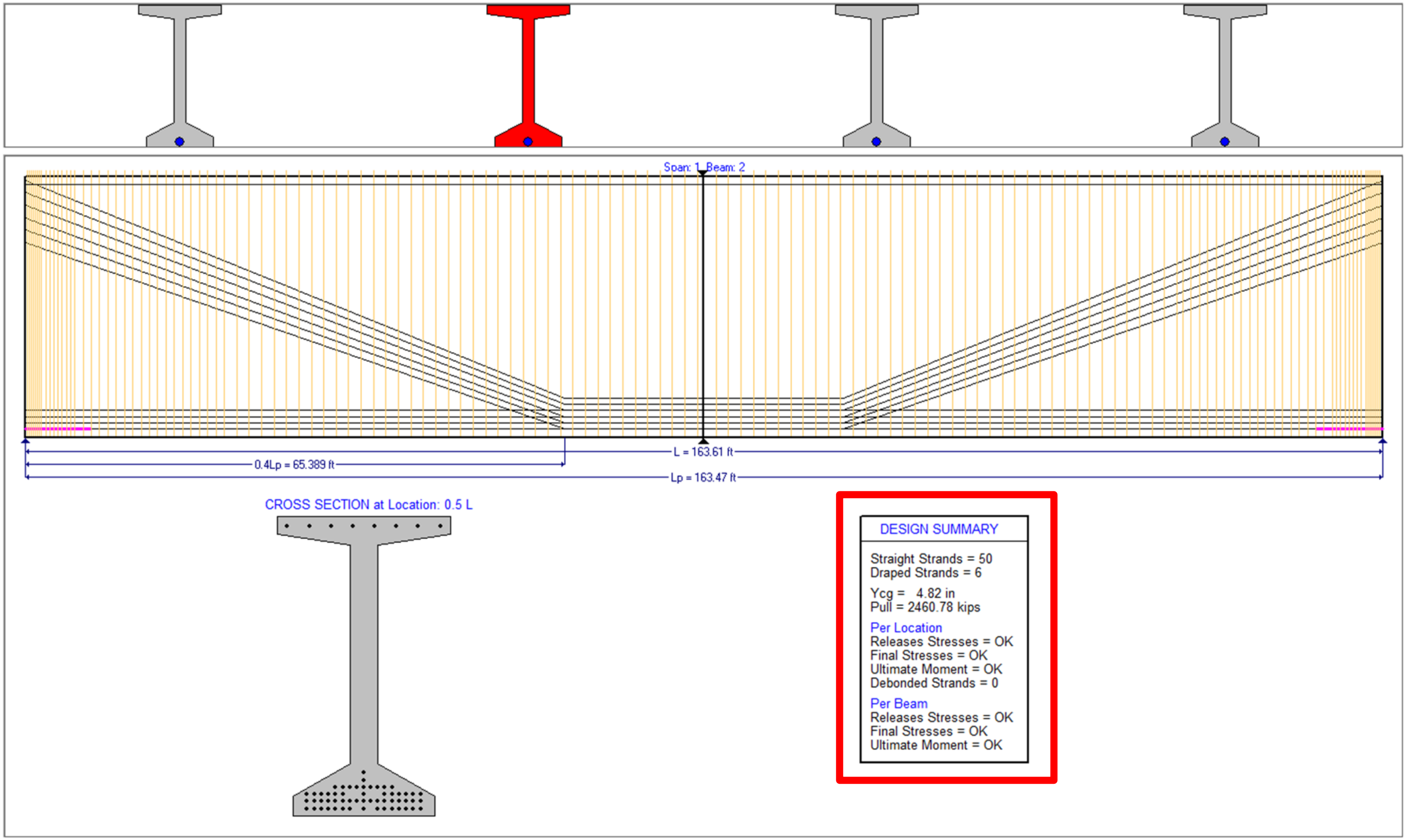
- **Plan view shows all skew, spans, and flare correctly**



3. Preliminary Design

Know the Limitations

- **Design Summary says it's all OK! However…**



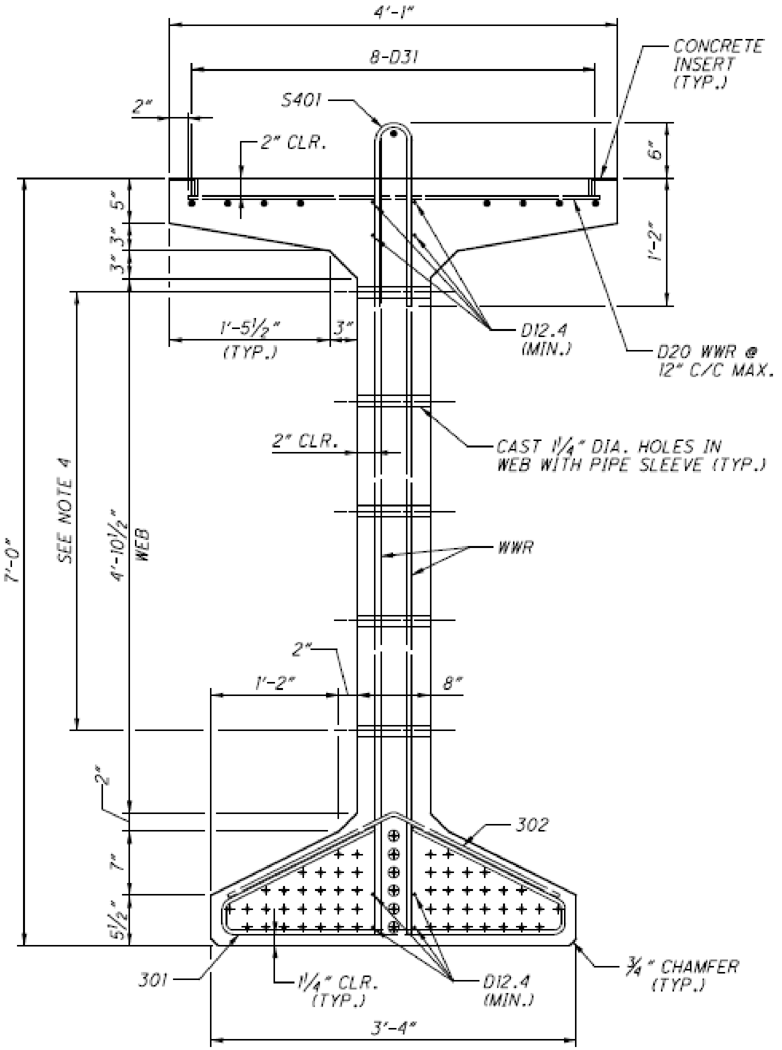
3. Preliminary Design

Know the Limitations

- Four girders designed independently as line girders
  - No consideration of:
    - Skew effects (except AASHTO skew factors)
    - Grade effect on axial load
    - Intermediate diaphragm forces
    - Lateral bending/torsion effects
    - Effects of bearing restraint
    - Actual live load distribution
    - Effect of end diaphragm restraint
    - Deck construction loads

3. Preliminary Design

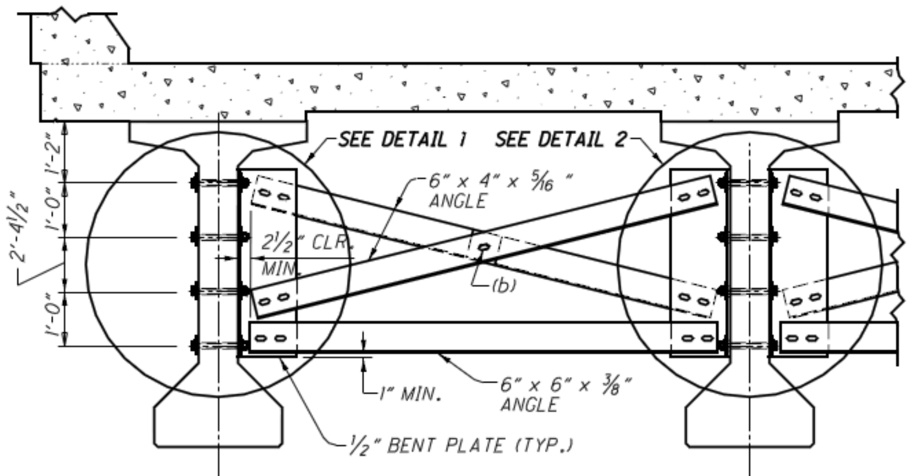
- Results of Preliminary Design
  - ODOT WF84-49
    - varying strand pattern
    - Modified standard ODOT WF72-49
    - 6 to 8 draped strands per beam
  - Lightweight concrete
    - w_c = 120 pcf
    - Recommended by precaster for shipping
  - High-strength concrete
    - f'_{ci} = 6 ksi
    - f'_c = 9 ksi



SECTION B-B
WF84-49

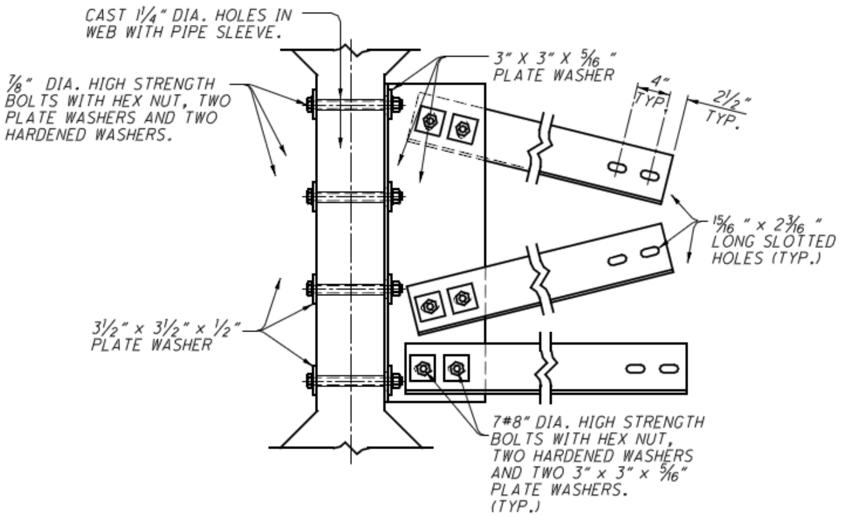
3. Preliminary Design

- **Results of Preliminary Design**
  - **Intermediate steel diaphragms modified from ODOT PSID-1-13**



STEEL INTERMEDIATE DIAPHRAGM

(FOR 84" BEAM)

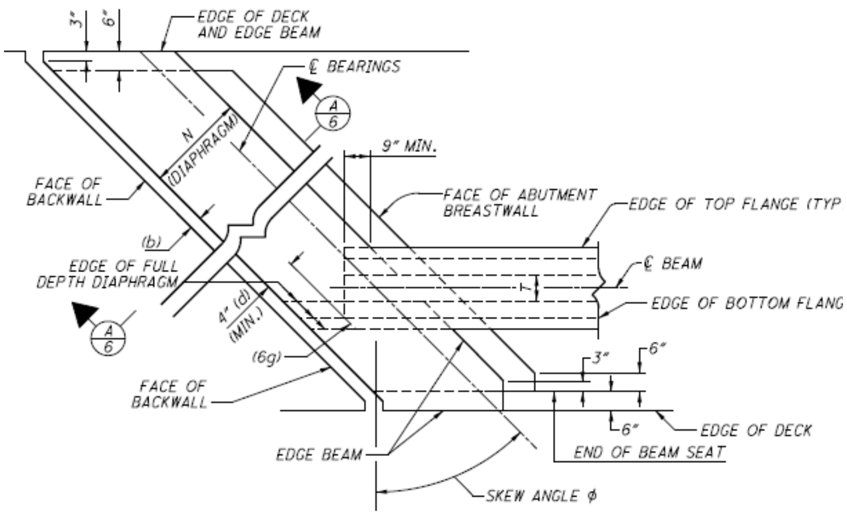


DETAIL 1

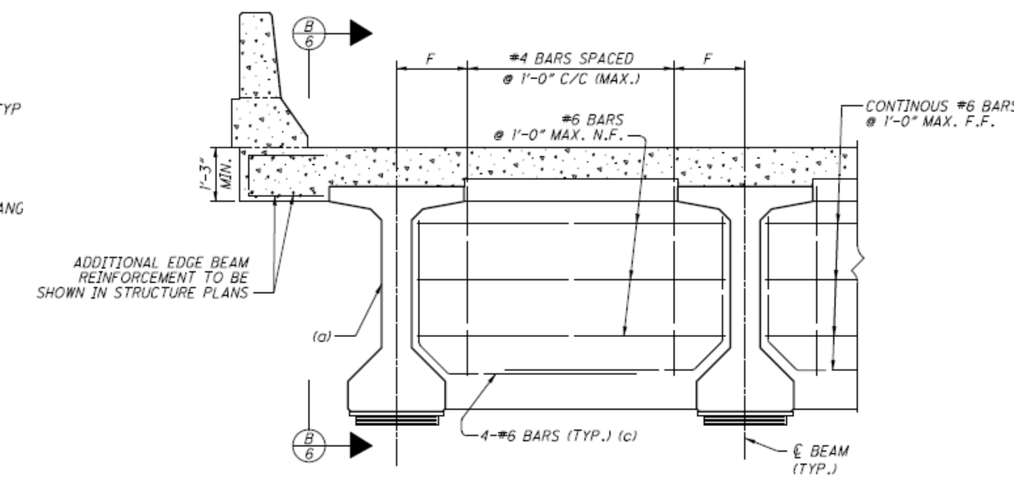
DETAIL 1 SHALL BE USED AT THE FASCIA BEAM AND ALL INTERIOR BEAMS WHEN THE SKEW ANGLE EXCEEDS 10°.

3. Preliminary Design

- Results of Preliminary Design
  - Concrete end diaphragms modified from ODOT PSID-1-13



EXPANSION ABUTMENT PARTIAL PLAN



EXPANSION JOINT END DIAPHRAGM

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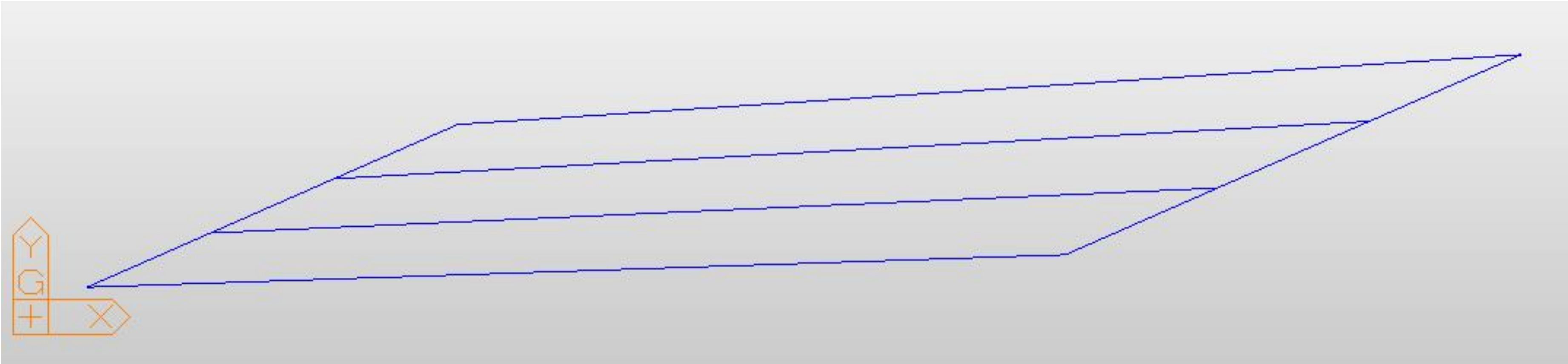
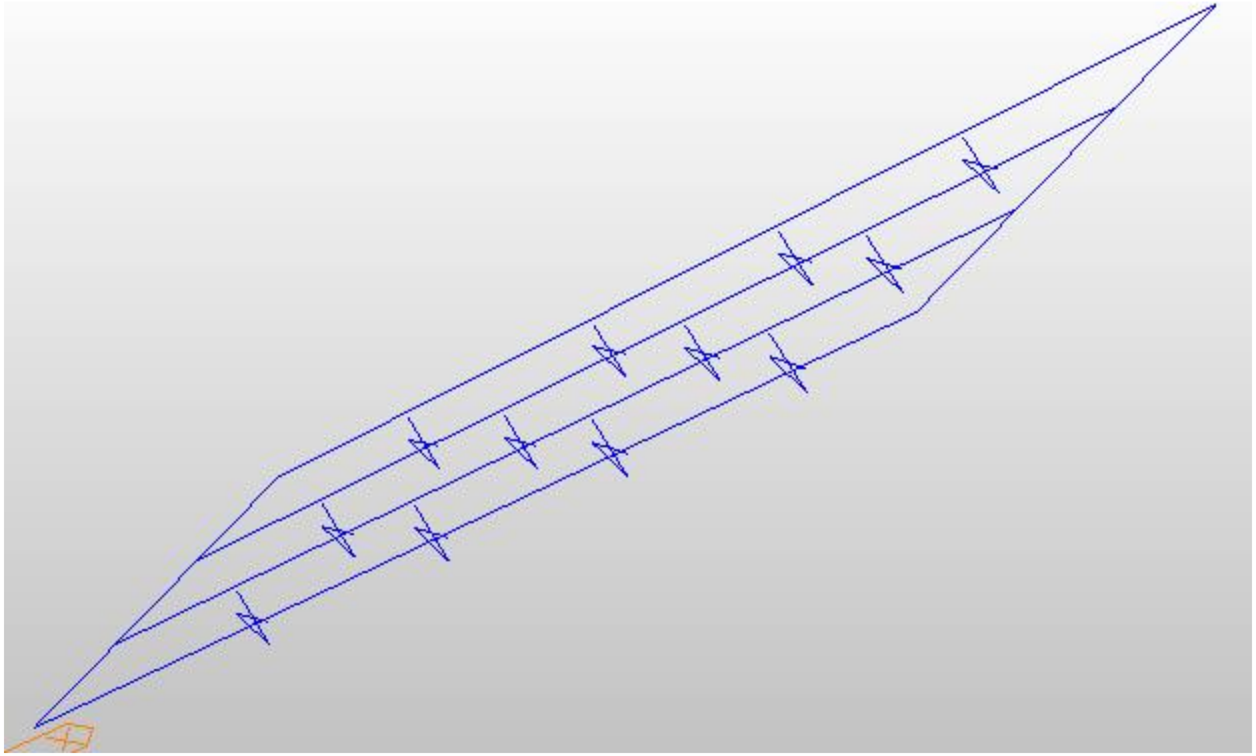
4. Refined Analysis Model

- Modeling Approach
  - Detailed grillage model
    - Beam elements for concrete beams, end diaphragms



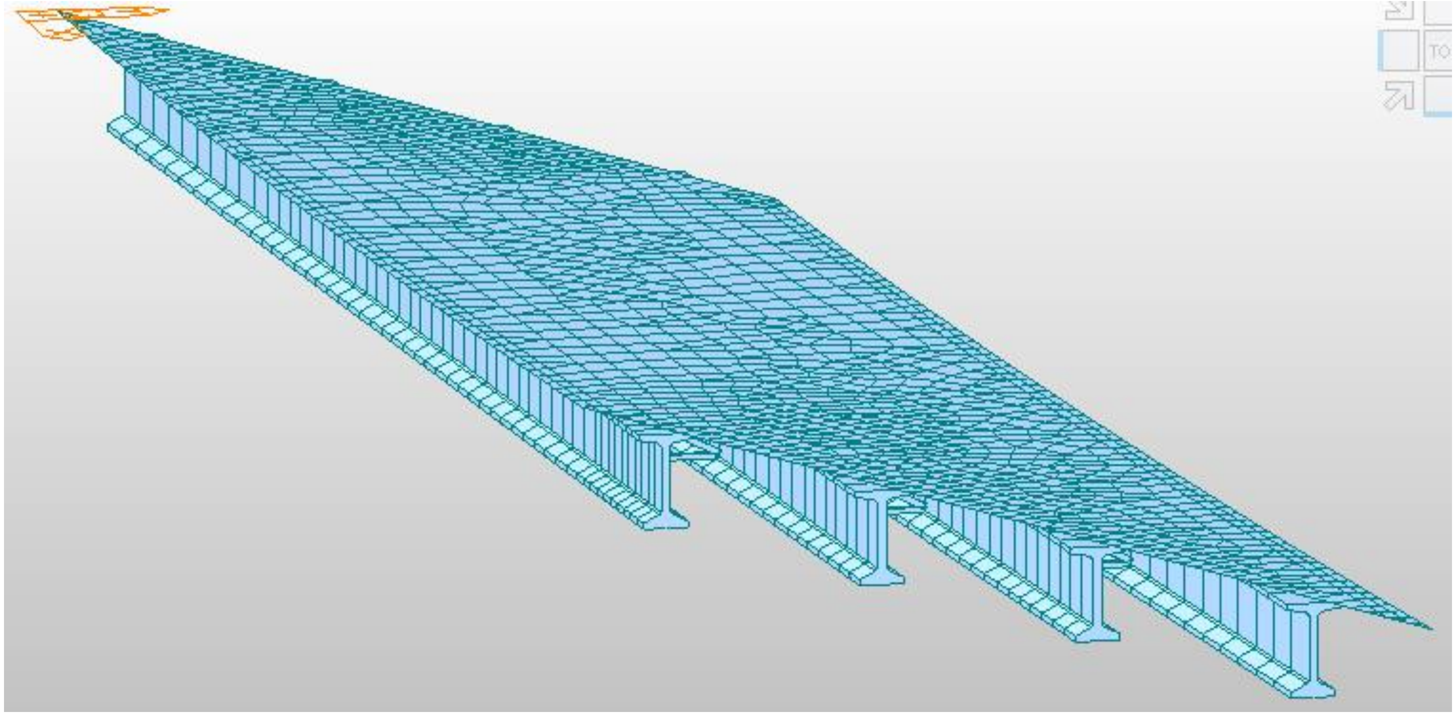
4. Refined Analysis Model

- **Modeling Approach**
  - **Detailed grillage model**
    - Beam elements for concrete beams, end diaphragms
    - **Truss elements for intermediate steel diaphragms**



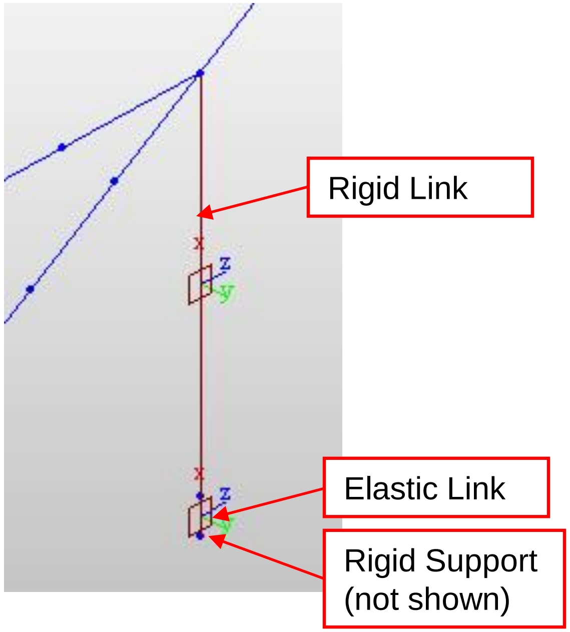
4. Refined Analysis Model

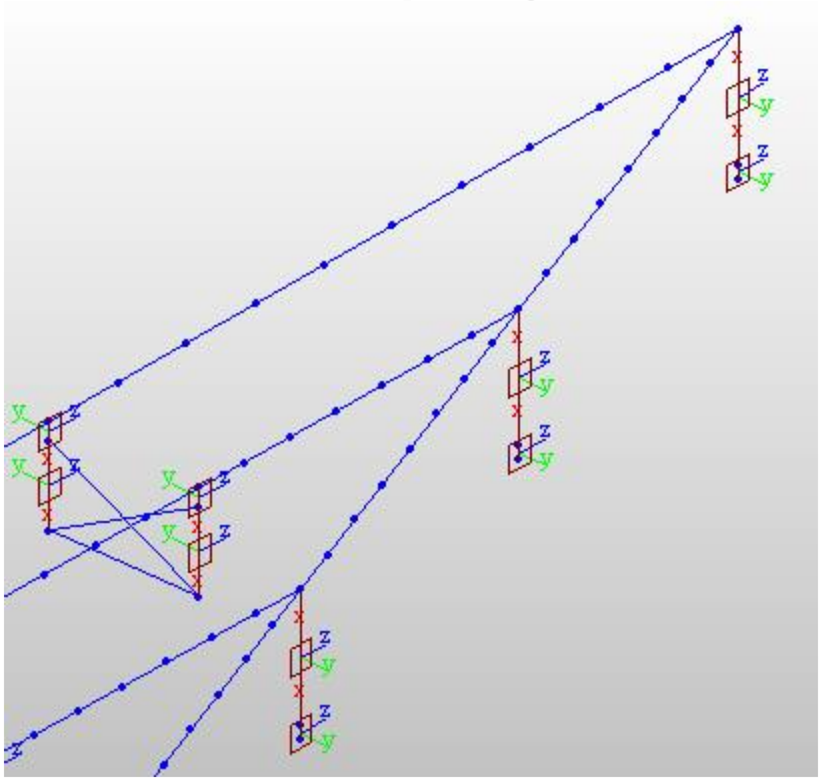
- **Modeling Approach**
  - **Detailed grillage model**
    - Beam elements for concrete beams, end diaphragms
    - Truss elements for intermediate steel diaphragms
    - **Plate elements for deck**



4. Refined Analysis Model

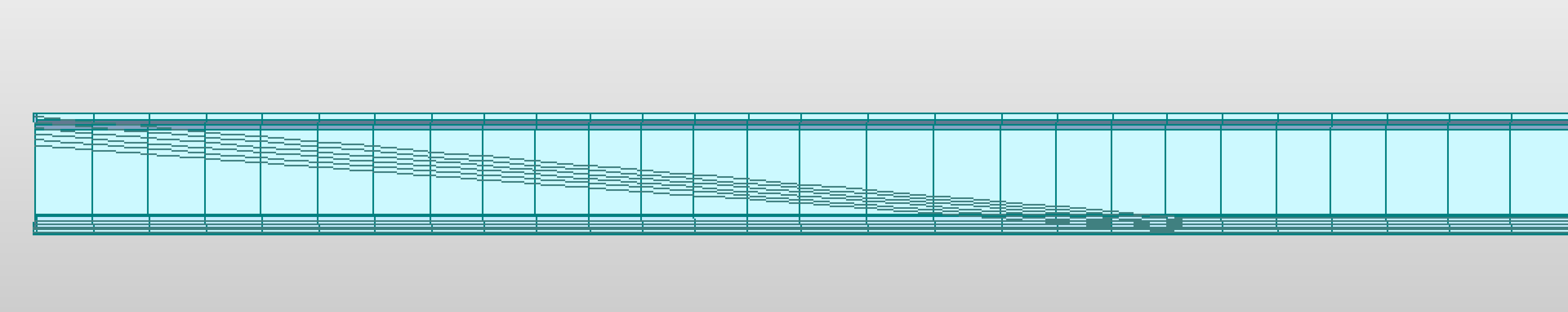
- Modeling Approach Using MIDAS
  - Detailed grillage model
    - Beam elements for concrete beams, end diaphragms
    - Truss elements for intermediate steel diaphragms
    - Plate elements for deck
    - **Elastic links for bearings**





4. Refined Analysis Model

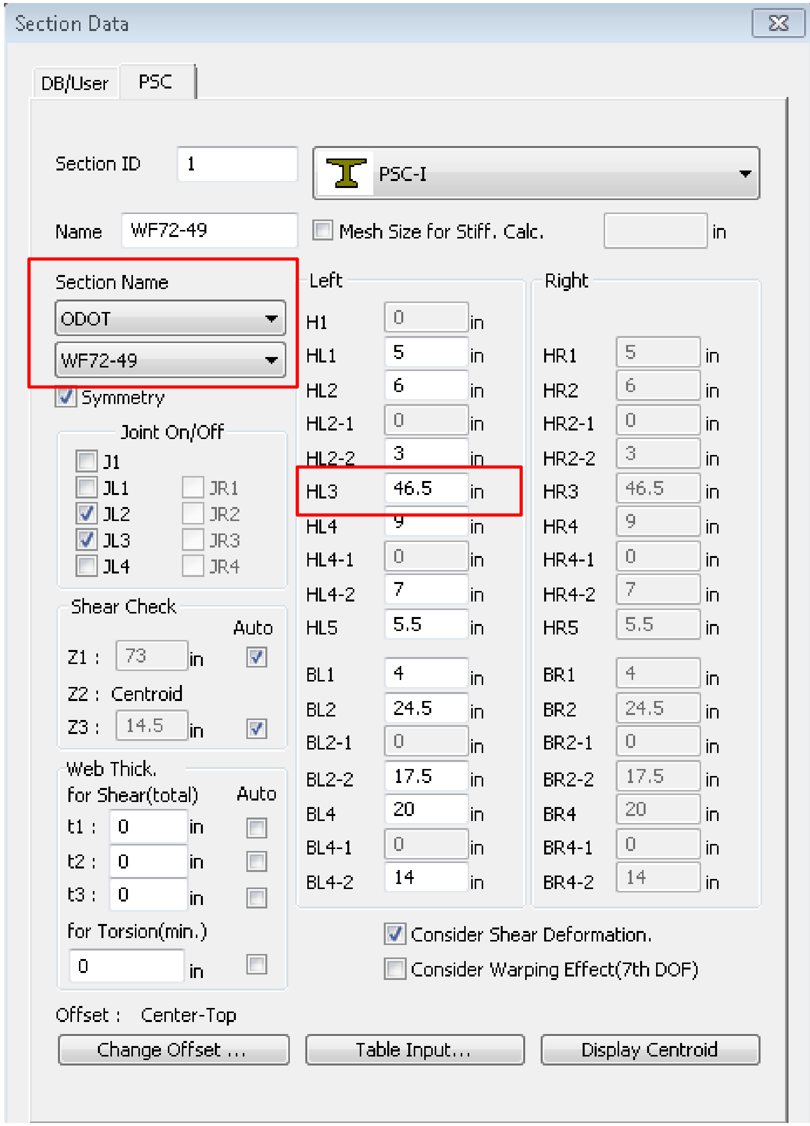
- Modeling Approach Using MIDAS
  - Detailed grillage model
    - Beam elements for concrete beams, end diaphragms
    - Truss elements for intermediate steel diaphragms
    - Plate elements for deck
    - Elastic links for bearings
    - Strands modeled with tendon template

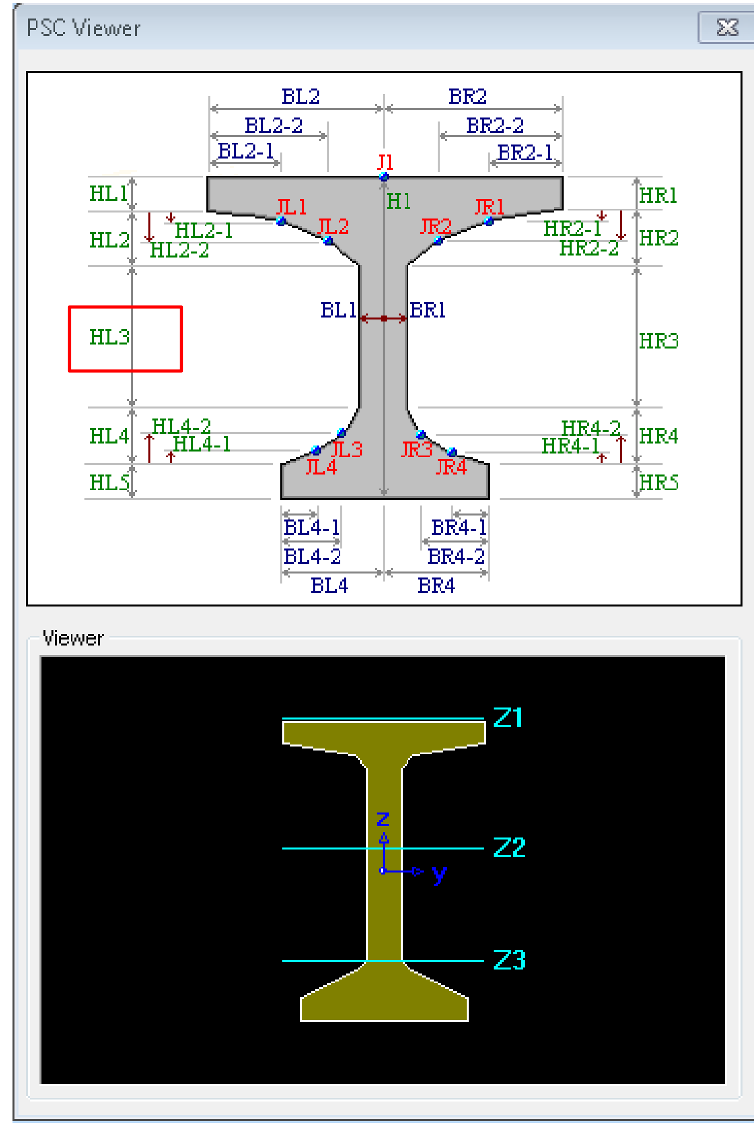


4. Refined Analysis Model

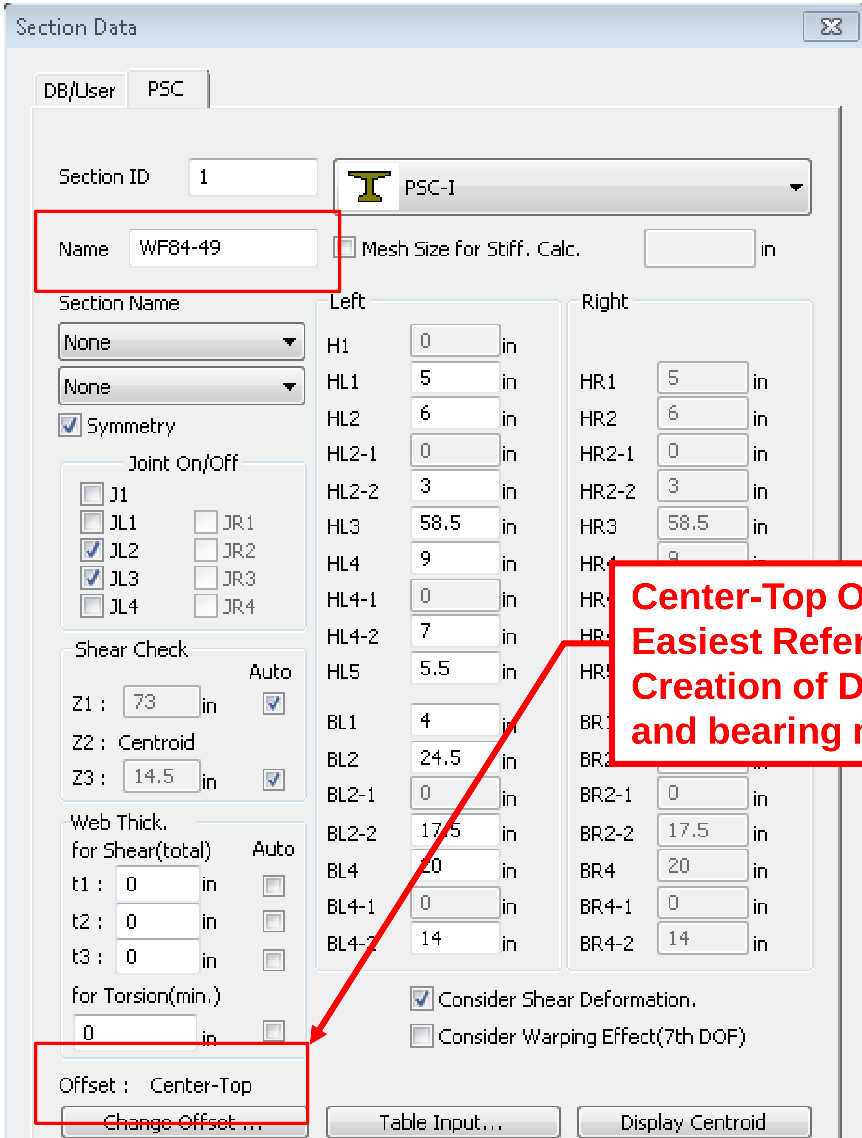
- Create Sections
  - Non-standard WF84-49 Concrete Beams
    - Easily created by modifying predefined ODOT WF72-49

4. Refined Analysis Model

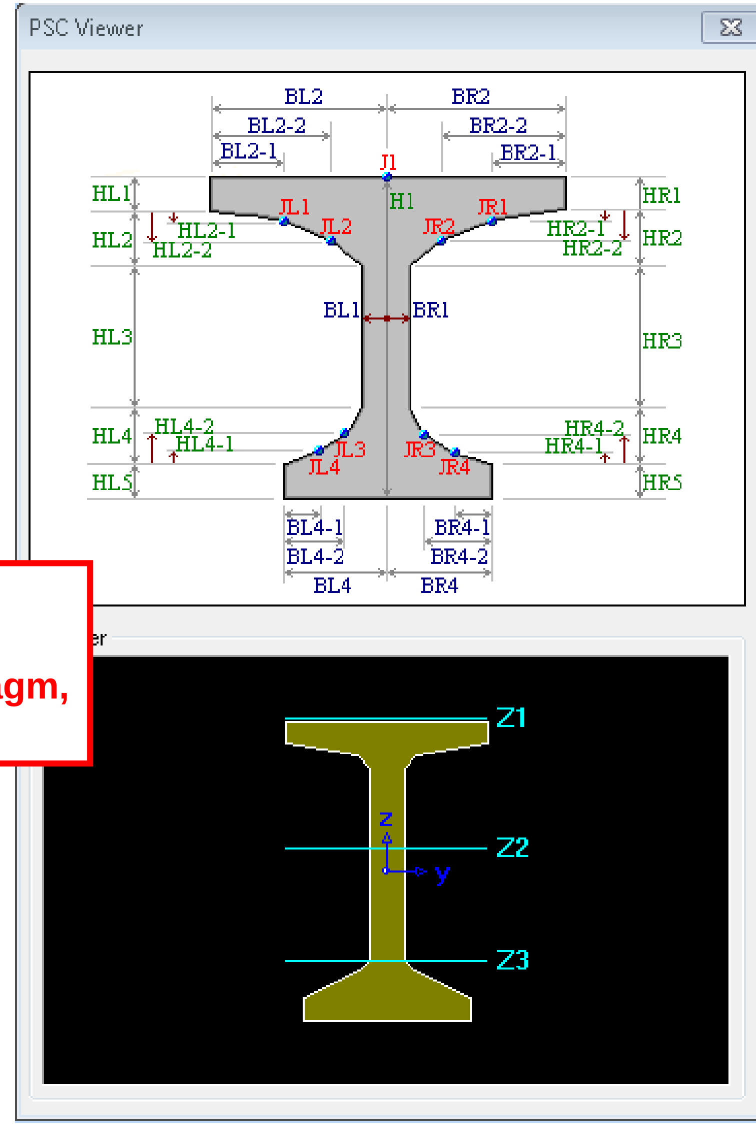




4. Refined Analysis Model

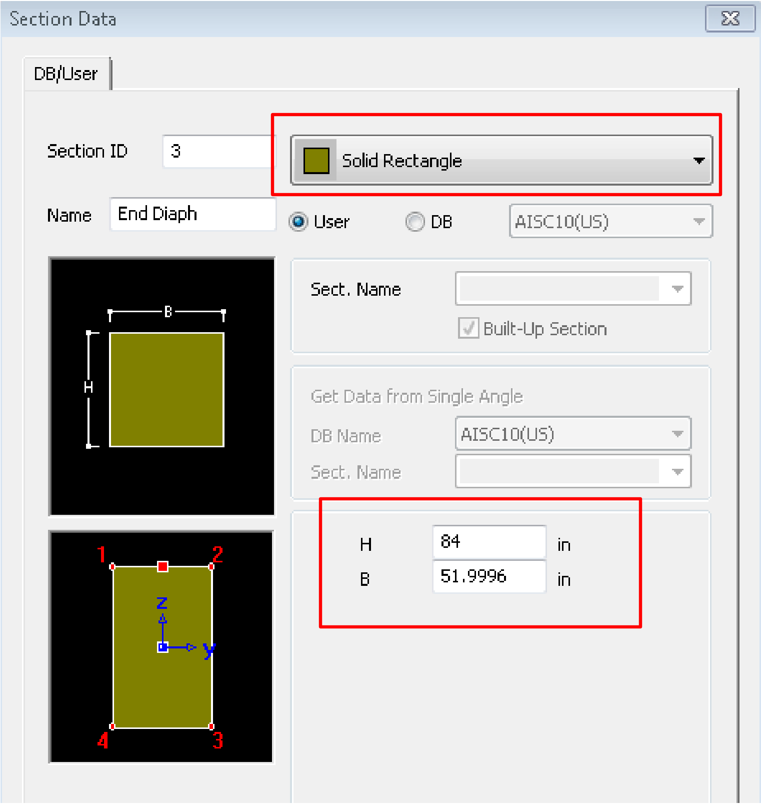


Center-Top Offset – Easiest Reference for Creation of Deck, Diaphragm, and bearing nodes



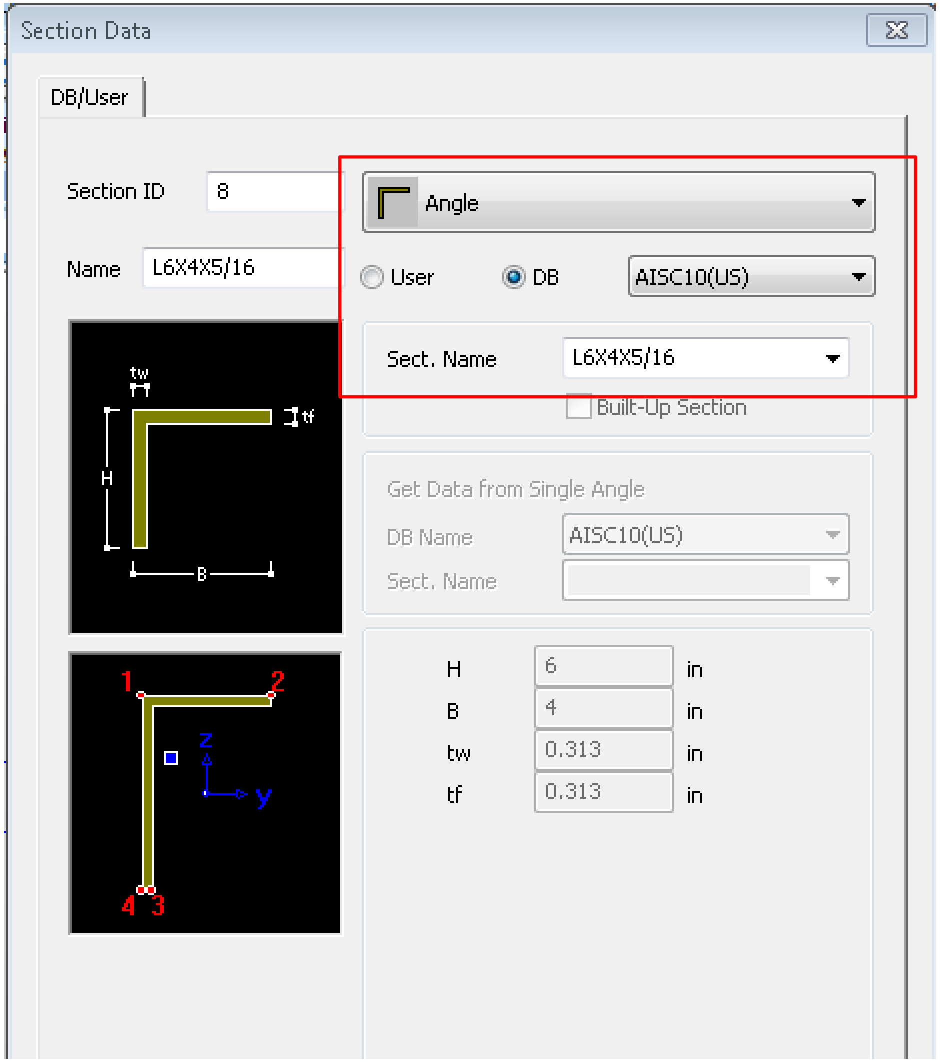
4. Refined Analysis Model

- **Create Sections**
  - Non-standard WF84-49 Concrete Beams
    - Easily created by modifying predefined ODOT WF72-49
  - **End Diaphragm**
    - **Solid Rectangle**



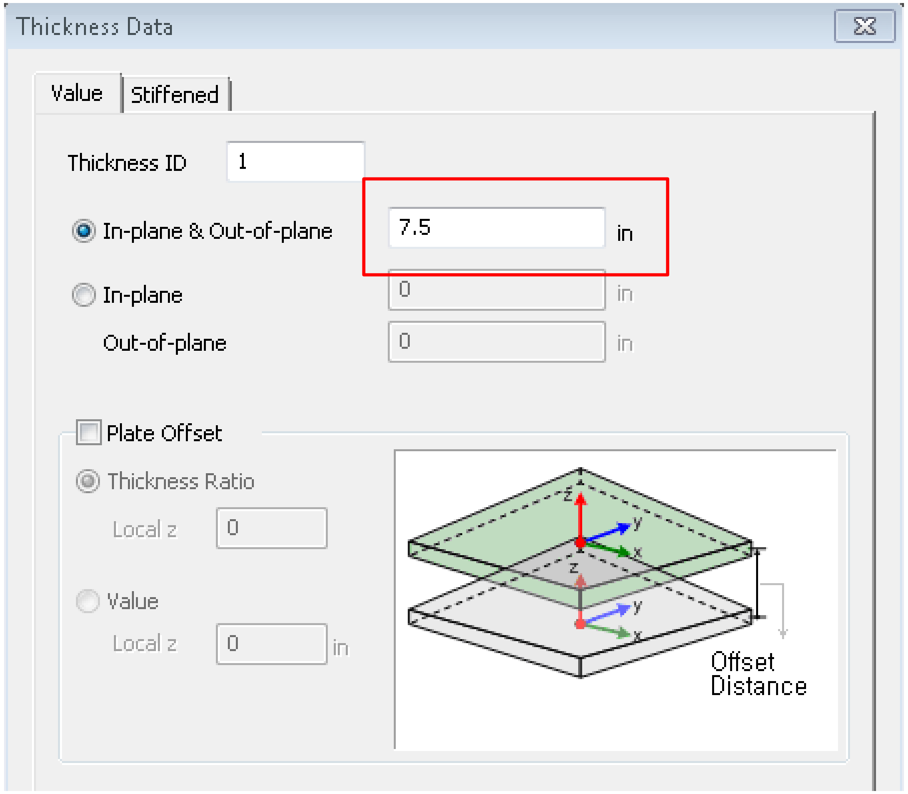
4. Refined Analysis Model

- **Create Sections**
  - Non-standard WF84-49 Concrete Beams
    - Easily created by modifying predefined ODOT WF72-49
  - End Diaphragm
    - Solid Rectangle
  - **Intermediate Diaphragm Members**
    - **Predefined AISC Steel Sections**



4. Refined Analysis Model

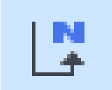
- Create Sections
  - Non-standard WF84-49 Concrete Beams
    - Easily created by modifying predefined ODOT WF72-49
  - End Diaphragm
    - Solid Rectangle
  - Intermediate Diaphragm Members
    - Predefined AISC Steel Sections
  - **Deck Plates**
    - **Properties-> Thickness->Add**



4. Refined Analysis Model

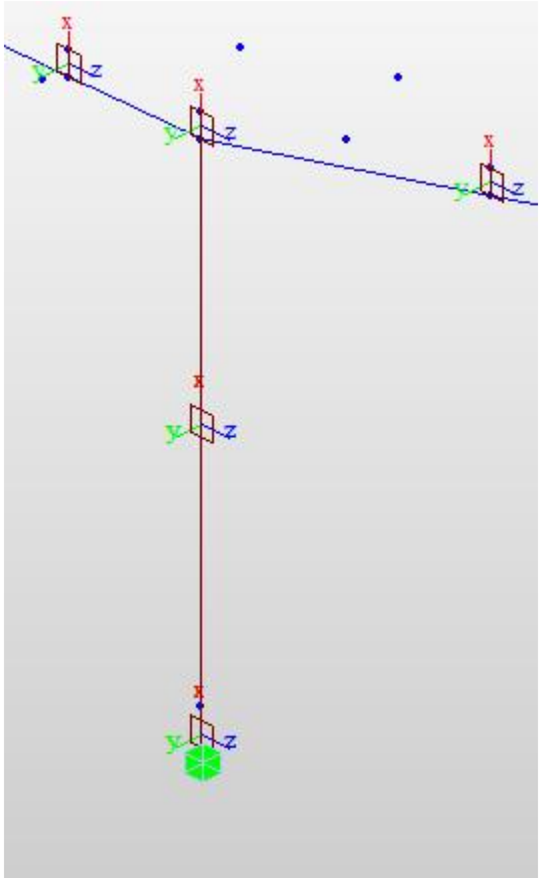
- Create Materials
  - Properties -> Material Properties -> Add
  - All materials created from MIDAS predefined materials with default properties except as noted
    - Steel – ASTM A572-50
    - Tendon Steel – ASTM A416-270 (Low Relaxation)
    - Lightweight Precast Beams – ASTM(RC) C9000
      - Adjusted density and elastic modulus
    - Concrete for End Diaphragms – ASTM(RC) C4500
    - Deck Concrete – ASTM(RC) C4500
      - Density set to zero so wet concrete loads can be applied to beam in construction stage analysis
  - Time Dependent Properties to be added later

4. Refined Analysis Model

- Create Nodes and Elements
  - Many ways to do this, many references available from MIDAS
  - The following extra steps now will help later on:
    - Use GROUPS liberally as nodes/elements are defined (used extensively in construction stage analysis)
    - Node and element renumbering  (helpful for defining live load, specifying output points)
  - Plate elements for deck were created with auto-mesh tool
    - Translate girder nodes upward with rigid links and automesh will find these nodes on the deck plane

4. Refined Analysis Model

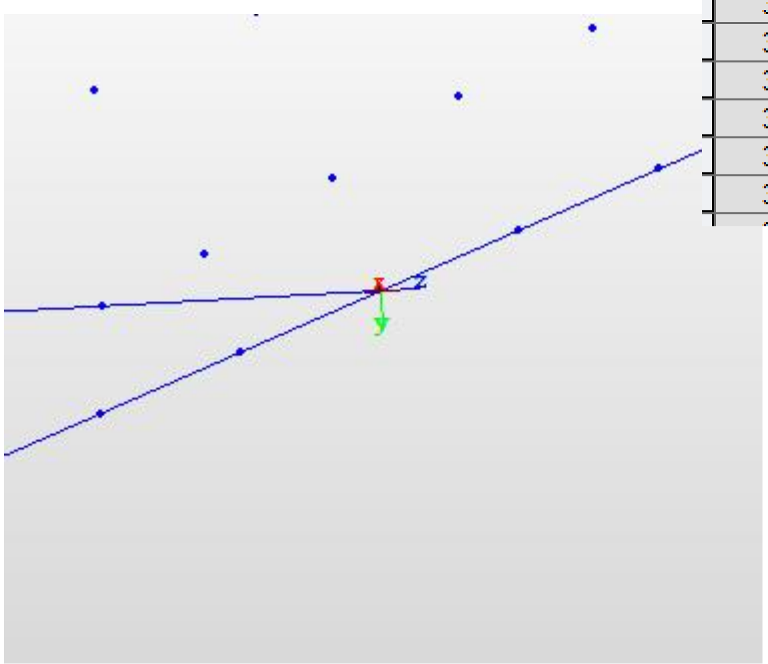
- Boundary Conditions
  - Rigid links used to connect:
    - Top of beam to deck
    - Beam to intermediate diaphragms
    - End of beam to bearing
  - Bearing elastic links
    - Offset bottom of beam node downward by bearing height
    - Add ground support with 6 DOF restrained
    - Add elastic link between bottom of girder and ground support for full control of restraint conditions in all DOF



4. Refined Analysis Model

- **Modeling Bearings**
  - **Rotate bearing parallel to beam (defaults to GCS)**

No	Node1	Node2	Type	B Angle ([deg])	SDx (kips/in)	SDy (kips/in)	SDz (kips/in)
329	4061	4053	GEN	1.90	10000.000	19.0000	19.0000
330	4062	4054	GEN	2.55	10000.000	19.0000	19.0000
331	4063	4055	GEN	3.17	10000.000	10000.000	10000.000
332	4064	4056	GEN	3.75	10000.000	19.0000	19.0000
333	4057	246	GEN	1.90	10000.000	19.0000	19.0000
334	4058	248	GEN	2.55	10000.000	19.0000	19.0000
335	4059	4051	GEN	3.17	10000.000	19.0000	19.0000
336	4060	4052	GEN	3.75	10000.000	19.0000	19.0000



4. Refined Analysis Model

- **Modeling Bearings**
  - Rotate bearing parallel to beam
  - **Enter accurate stiffness of bearing into table**

No	Node1	Node2	Type	B Angle ([deg])	SDx (kips/in)	SDy (kips/in)	SDz (kips/in)
329	4061	4053	GEN	1.90	10000.000	19.0000	19.0000
330	4062	4054	GEN	2.55	10000.000	19.0000	19.0000
331	4063	4055	GEN	3.17	10000.000	10000.000	10000.000
332	4064	4056	GEN	3.75	10000.000	19.0000	19.0000
333	4057	246	GEN	1.90	10000.000	19.0000	19.0000
334	4058	248	GEN	2.55	10000.000	19.0000	19.0000
335	4059	4051	GEN	3.17	10000.000	19.0000	19.0000
336	4060	4052	GEN	3.75	10000.000	19.0000	19.0000

“Fixed” End – load plate has oversize holes, assume only one set of anchor bolts engaged

Expansion End – estimated elastomeric bearing stiffness based on assumed size

Vertical Support – essentially rigid (1000 kip = 0.1” deflection)

4. Refined Analysis Model

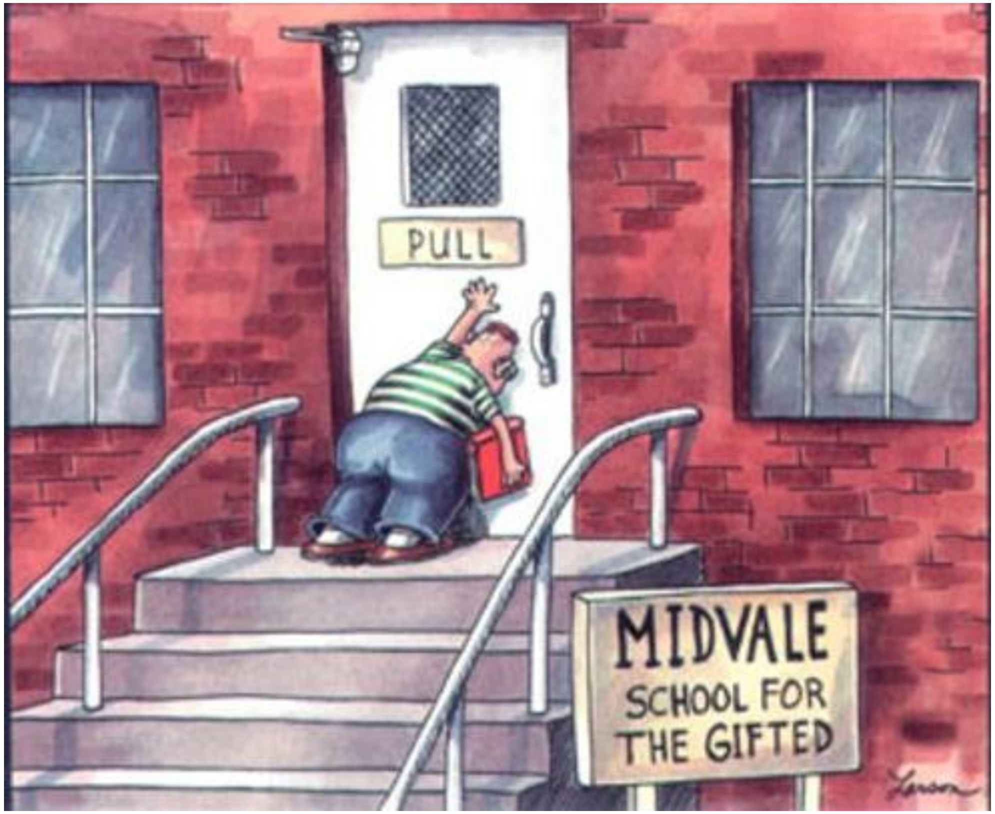
- **Modeling Bearings**
  - Rotate bearing parallel to beam
  - Enter accurate stiffness of bearing into table
  - **Consider changes in BC during construction**
    - **Example: End of beam needs torsional restraint until diaphragms are installed (ie. temporary A-frame brace)**
    - **Model multiple bearings, divide into groups**

No	Node1	Node2	Type	B Angle ([deg])	SDx (kips/in)	SDy (kips/in)	SDz (kips/in)	SRx (in*kips/[rad])	SRy (in*kips/[rad])	SRz (in*kips/[rad])	Shear Spring Location	Distance Ratio SDy	Distance Ratio SDz	Group
257	4061	4053	GEN	1.90	10000.000	10000.000	10000.000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports
258	4062	4054	GEN	2.55	10000.000	10000.000	10000.000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports
259	4063	4055	GEN	3.17	10000.000	10000.000	10000.000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports
260	4064	4056	GEN	3.75	10000.000	10000.000	10000.000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports
261	4057	246	GEN	1.90	10000.000	10000.000	0.0000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports
262	4058	248	GEN	2.55	10000.000	10000.000	0.0000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports
263	4059	4051	GEN	3.17	10000.000	10000.000	0.0000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports
264	4060	4052	GEN	3.75	10000.000	10000.000	0.0000	0.00	0.00	83333333.33	☐	0.50	0.50	BC Group 1 Initial Supports

No	Node1	Node2	Type	B Angle ([deg])	SDx (kips/in)	SDy (kips/in)	SDz (kips/in)	SRx (in*kips/[rad])	SRy (in*kips/[rad])	SRz (in*kips/[rad])	Shear Spring Location	Distance Ratio SDy	Distance Ratio SDz	Group
329	4061	4053	GEN	1.90	10000.000	19.0000	19.0000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia
330	4062	4054	GEN	2.55	10000.000	19.0000	19.0000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia
331	4063	4055	GEN	3.17	10000.000	10000.000	10000.000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia
332	4064	4056	GEN	3.75	10000.000	19.0000	19.0000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia
333	4057	246	GEN	1.90	10000.000	19.0000	19.0000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia
334	4058	248	GEN	2.55	10000.000	19.0000	19.0000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia
335	4059	4051	GEN	3.17	10000.000	19.0000	19.0000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia
336	4060	4052	GEN	3.75	10000.000	19.0000	19.0000	0.00	0.00	0.00	☐	0.50	0.50	BC Group 5 Release Fascia

4. Refined Analysis Model

- **Don’t underestimate the importance of accurate BC’s!**



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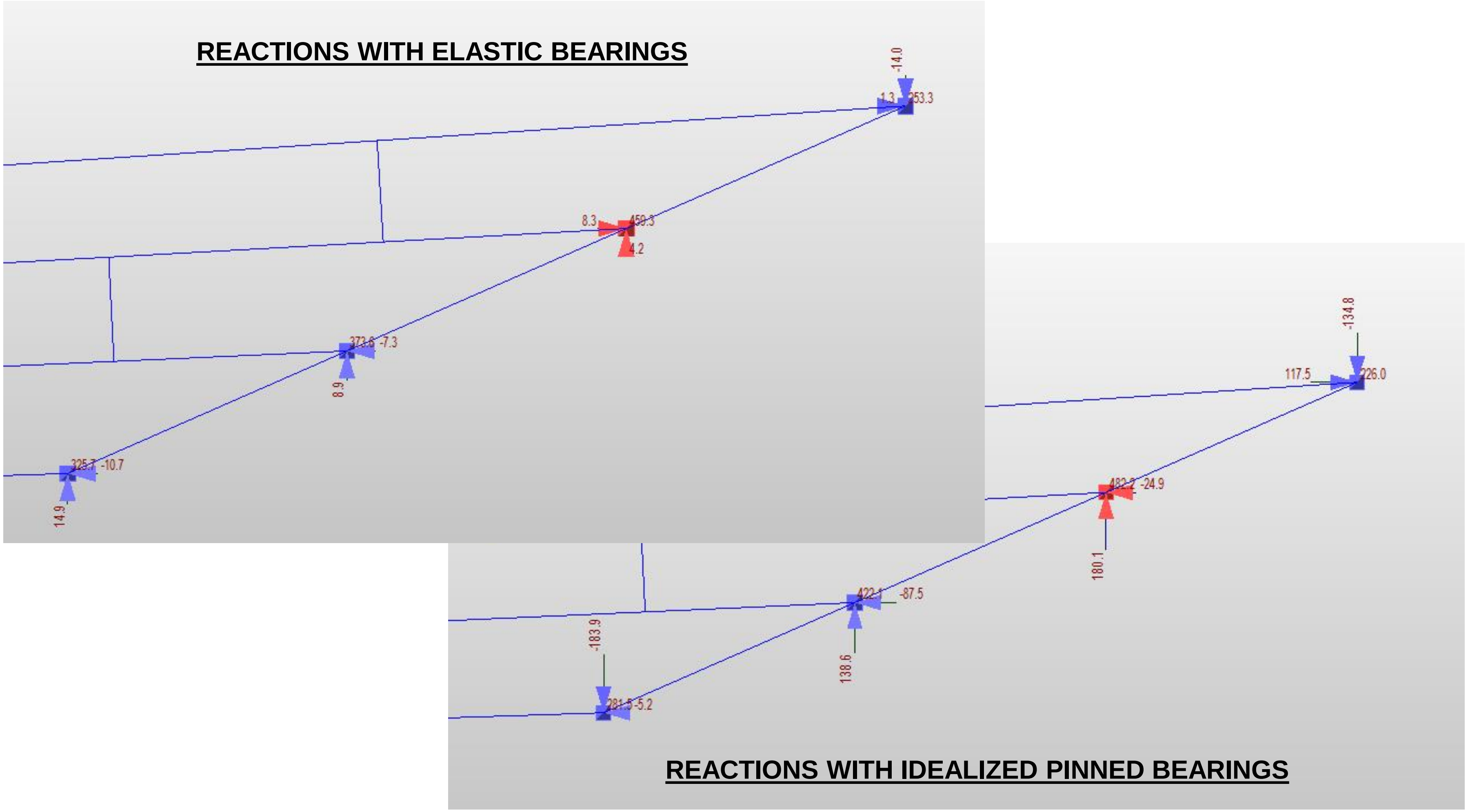
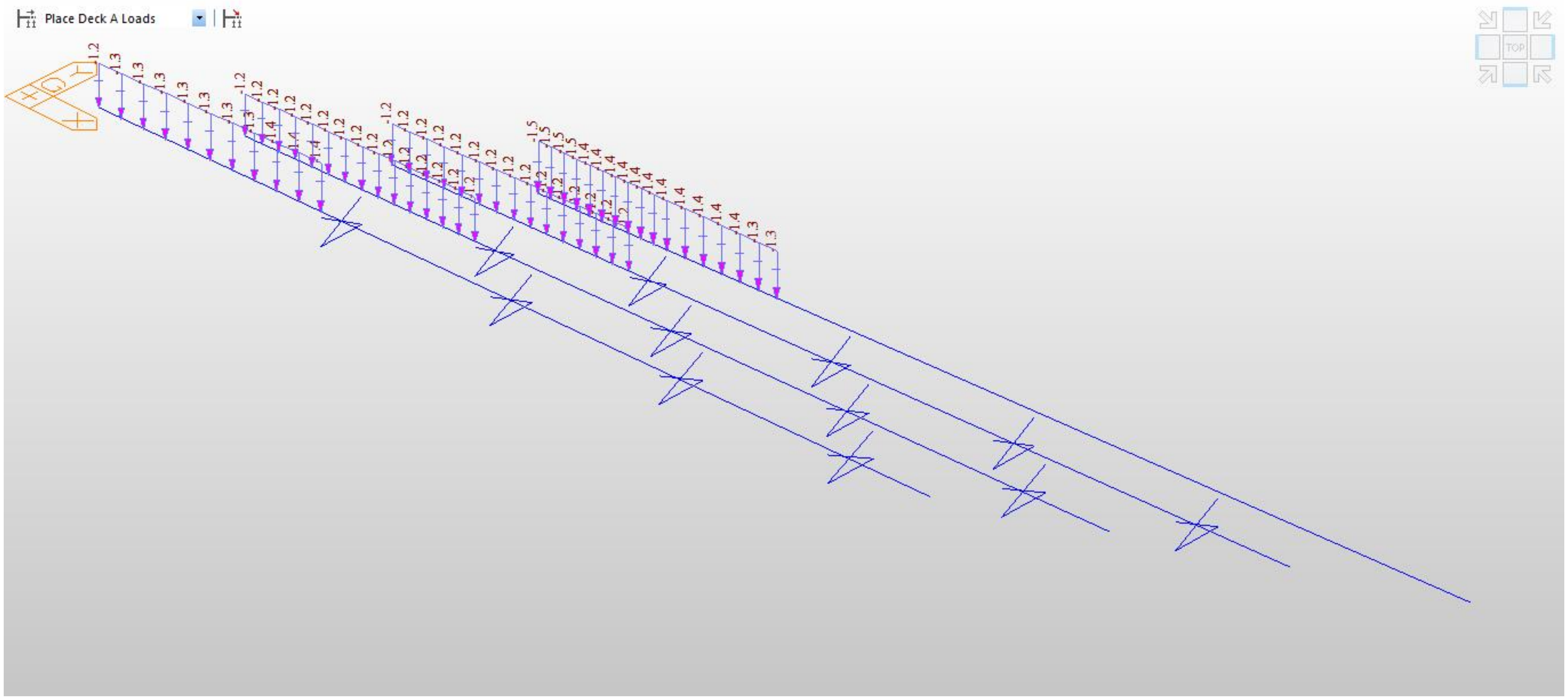


4. Refined Analysis Model

- **Dead Loads**
  - **Beam and diaphragm loads - self-weight**
  - **Deck and haunch - trapezoidal line load to top of beam**
    - **Divided into five separate zones to simulate deck placement sequence**



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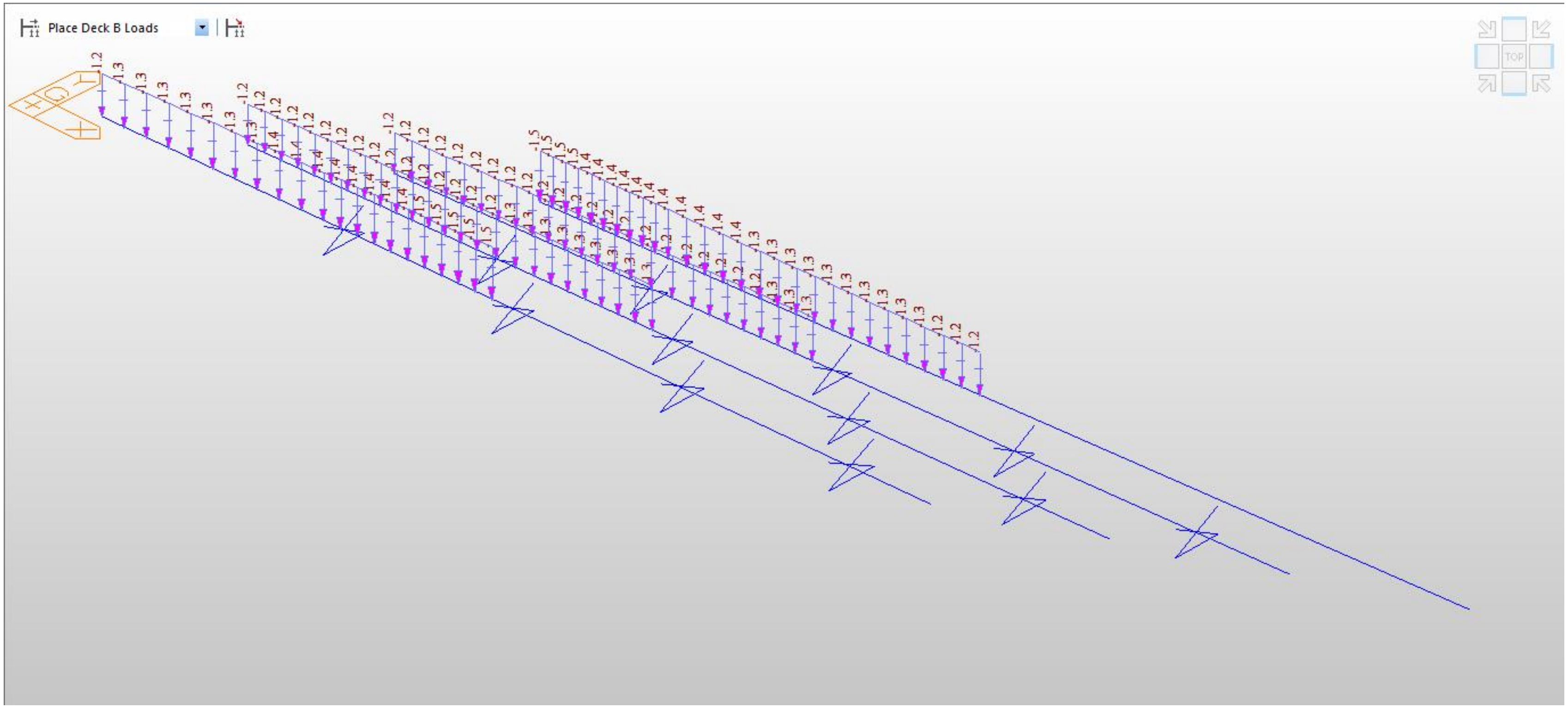

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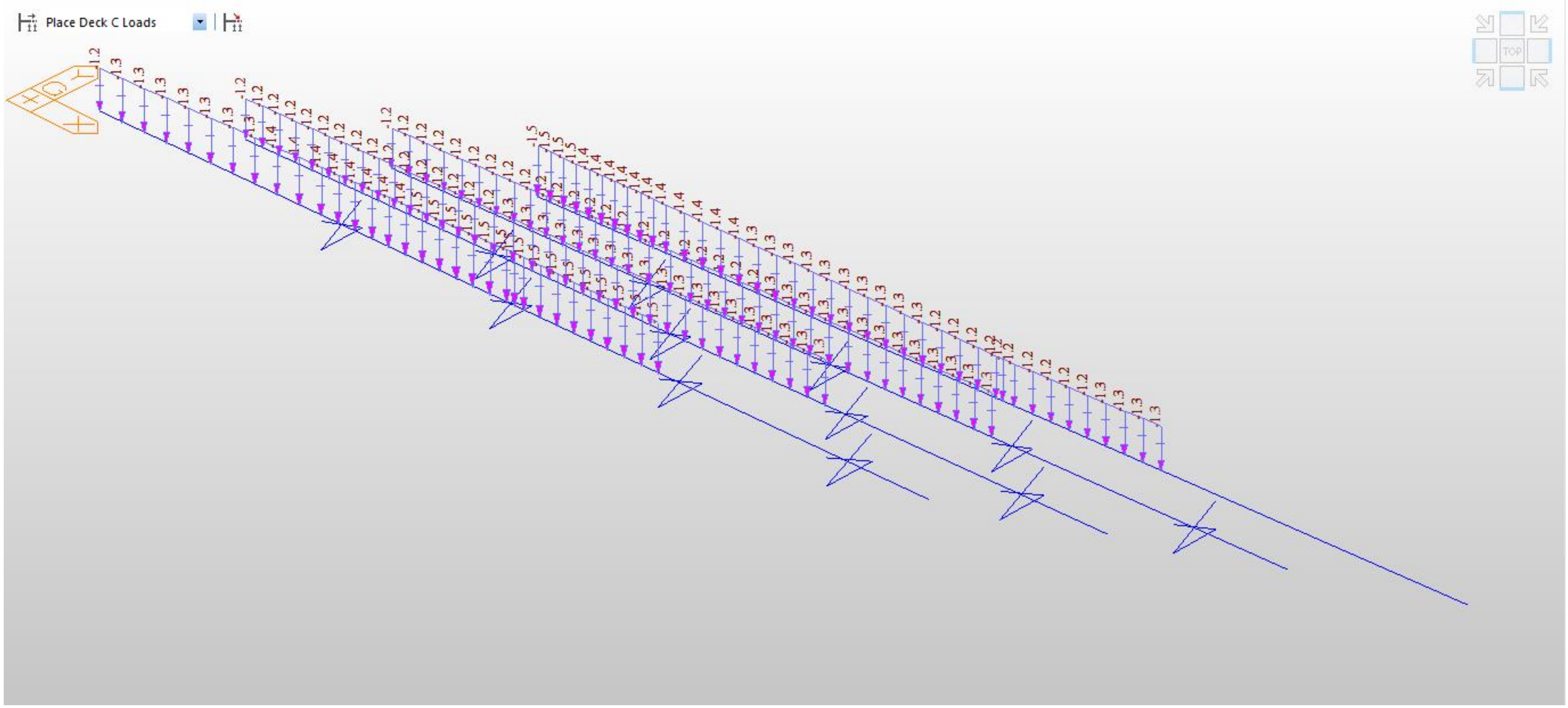

4. Refined Analysis Model

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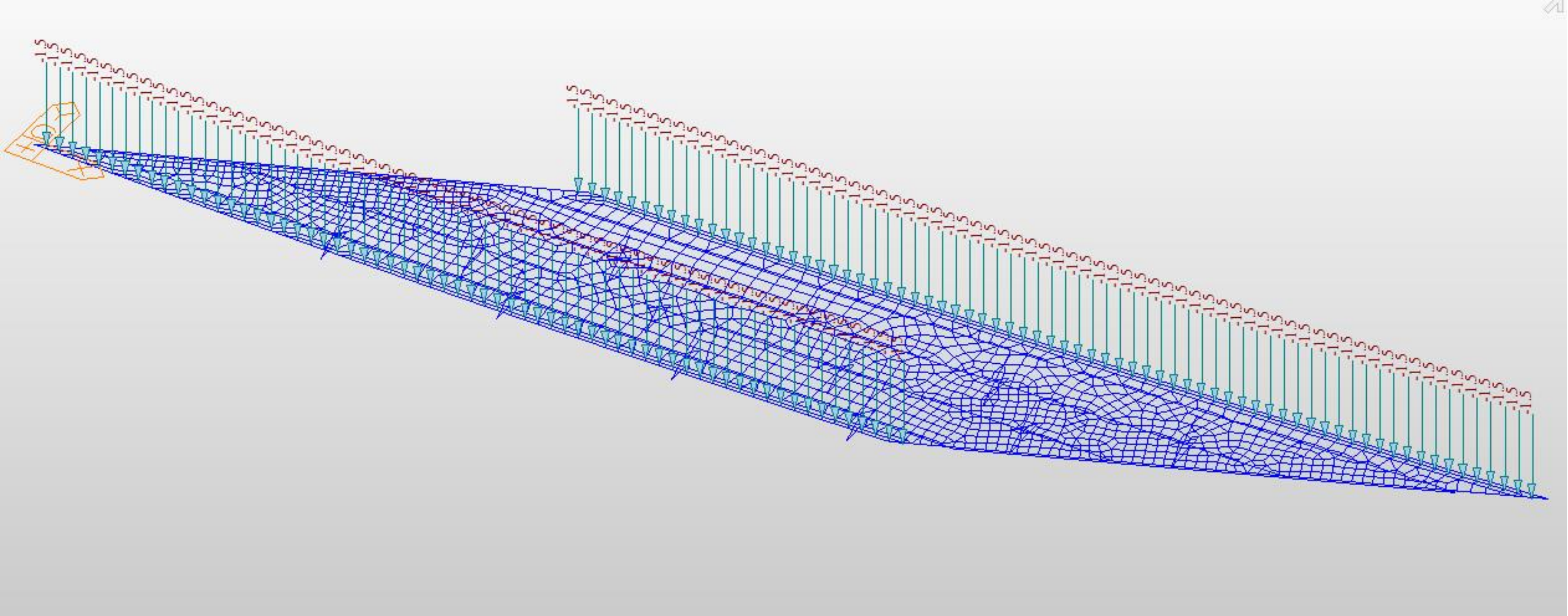
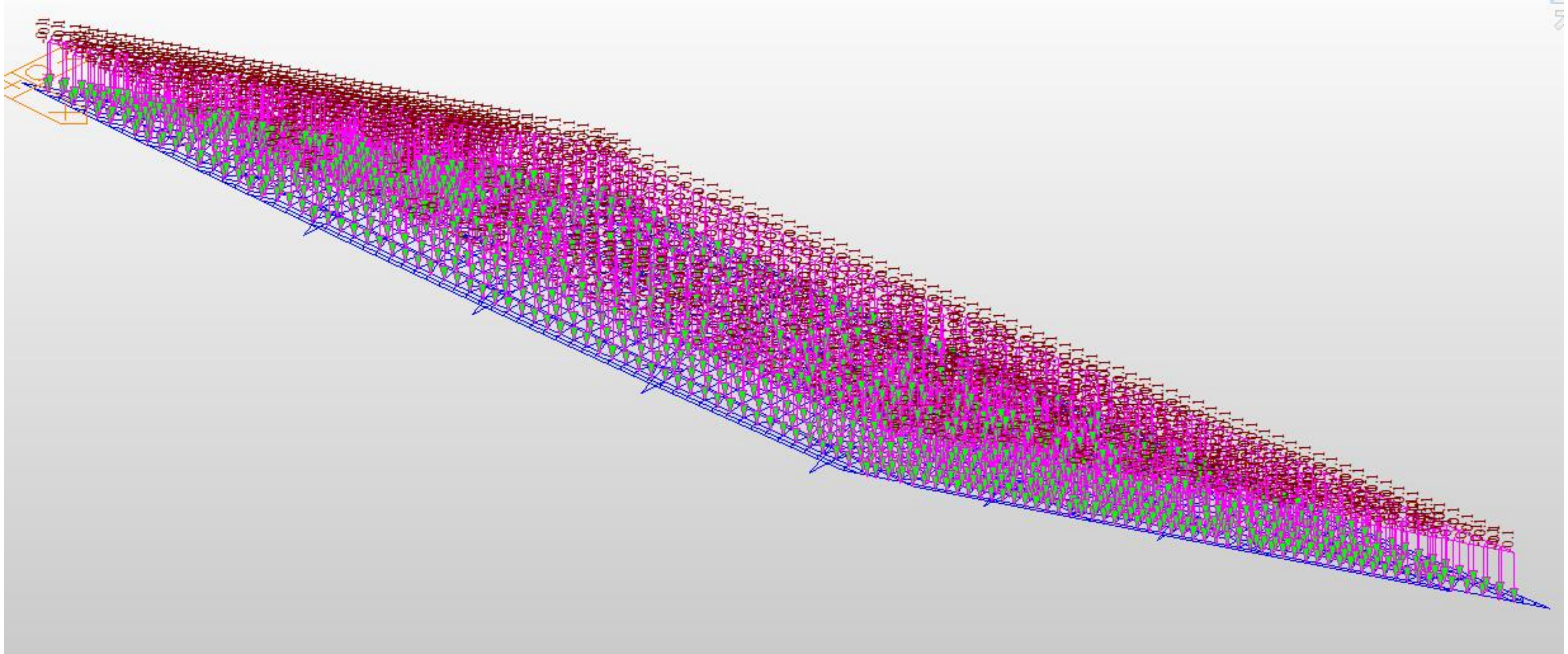
  - Deck and haunch - trapezoidal line load to top of beam
  - **Parapet load - nodal loads to the deck nodes**



4. Refined Analysis Model

- **Dead Loads**
  - Beam and diaphragm loads - self-weight
  - Deck and haunch - trapezoidal line load to top of beam
  - Parapet load - nodal loads to the deck nodes
  - **Wearing surface - pressure load on deck plates**

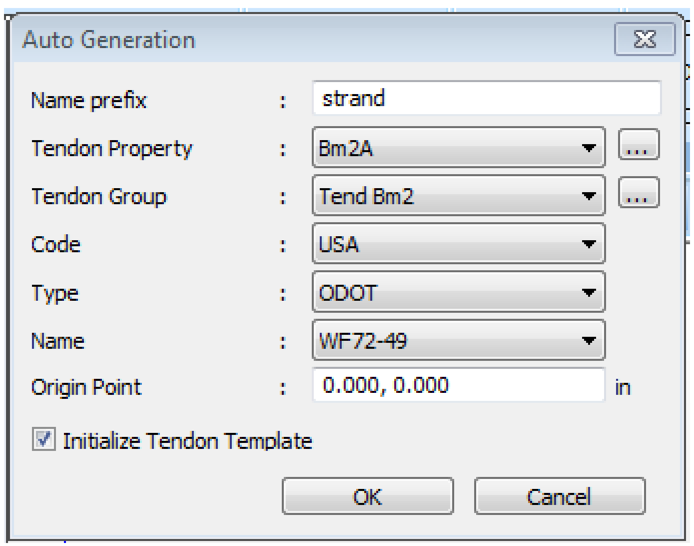


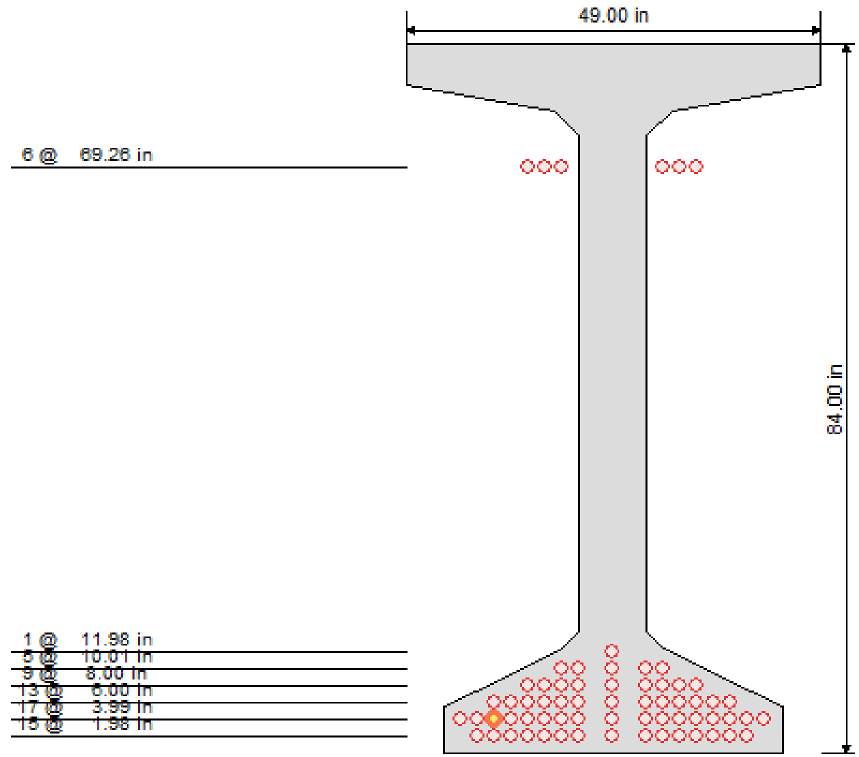
4. Refined Analysis Model

- **Prestress Loads**
  - Beam and diaphragm loads - self-weight
  - Deck and haunch - trapezoidal line load to top of beam
  - Parapet load - nodal loads to the deck nodes
  - Wearing surface - pressure load on deck plates
  - **Create a load case for prestress, will be filled in when tendon information is defined**

4. Refined Analysis Model

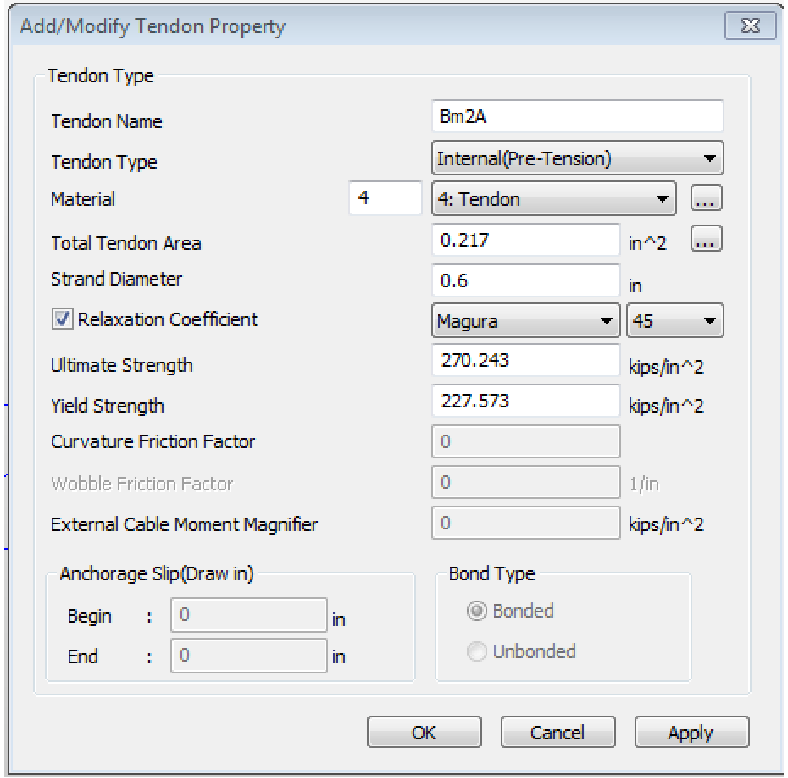
- **Defining Tendons**
  - **Modified from auto-generated template for ODOT WF72-49**
    - **Structure->Wizard->PSC Bridge->Tendon Template**
    - **Edit coordinates of top strands**





4. Refined Analysis Model

- Tendon Properties
  - Define tendon properties, profile and load from:
    - Loads->Load Type->Temp/Prestress->Prestress Loads->…

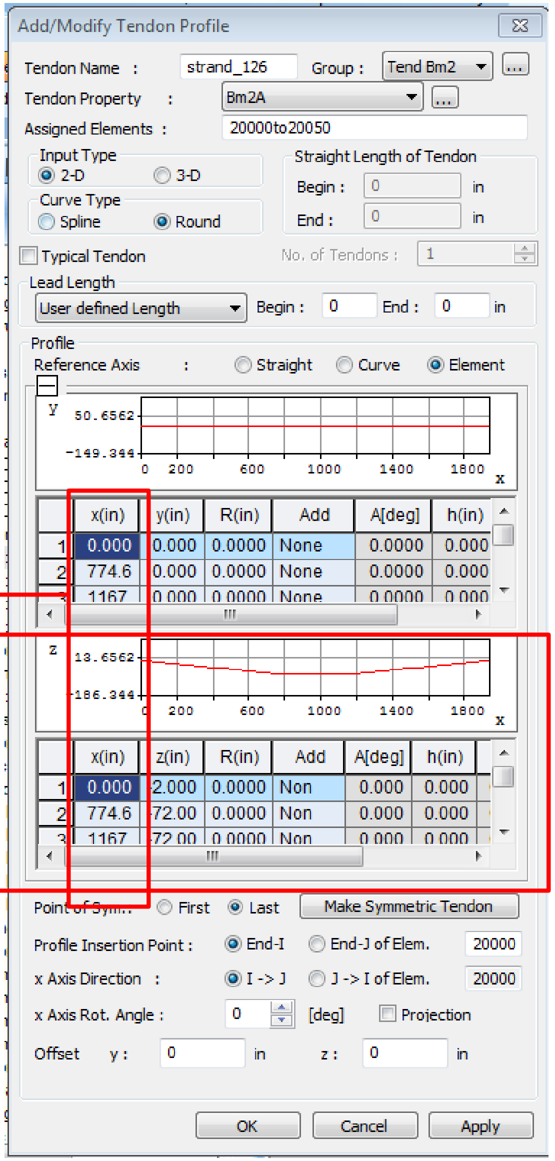


4. Refined Analysis Model

- **Tendon Profile**
  - **All straight tendons already have correct profile information from the tendon template**
  - **Edit profile of draped tendons only**
  - **Adjust x coordinate for debonded strands**

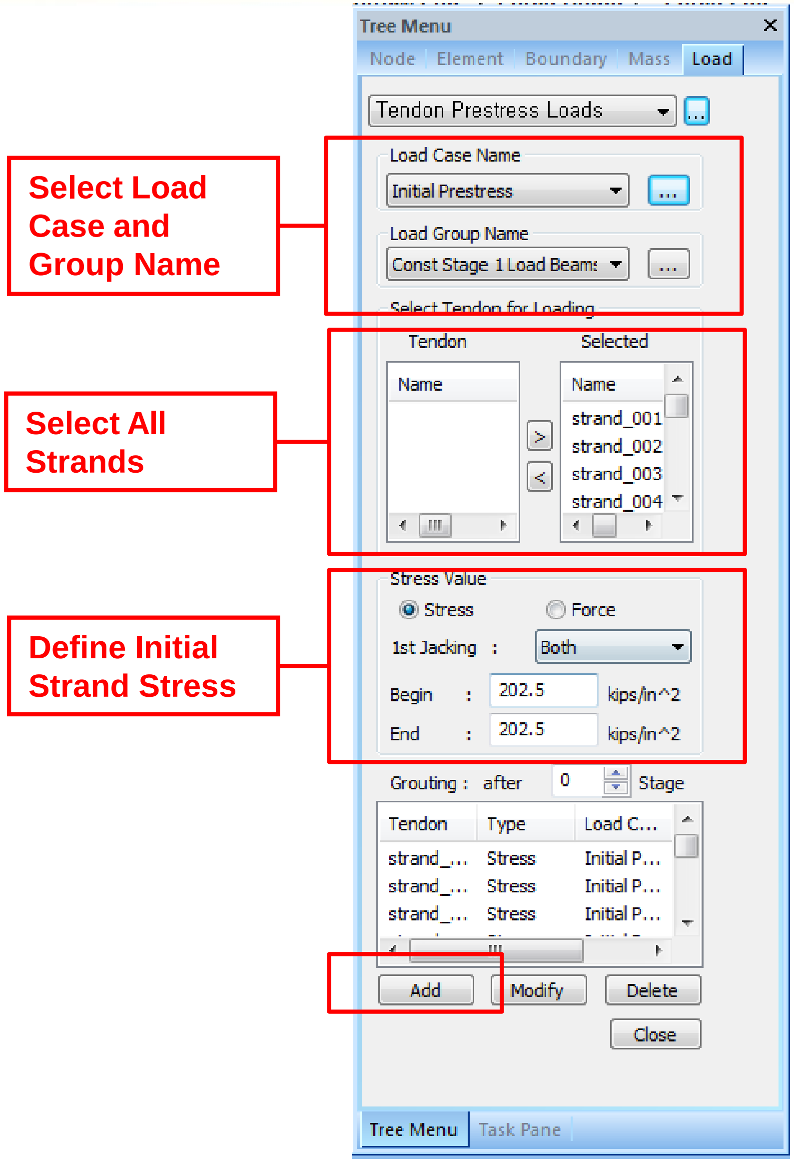
Adjust start and end coordinates for debonding

Define coordinates of drape points



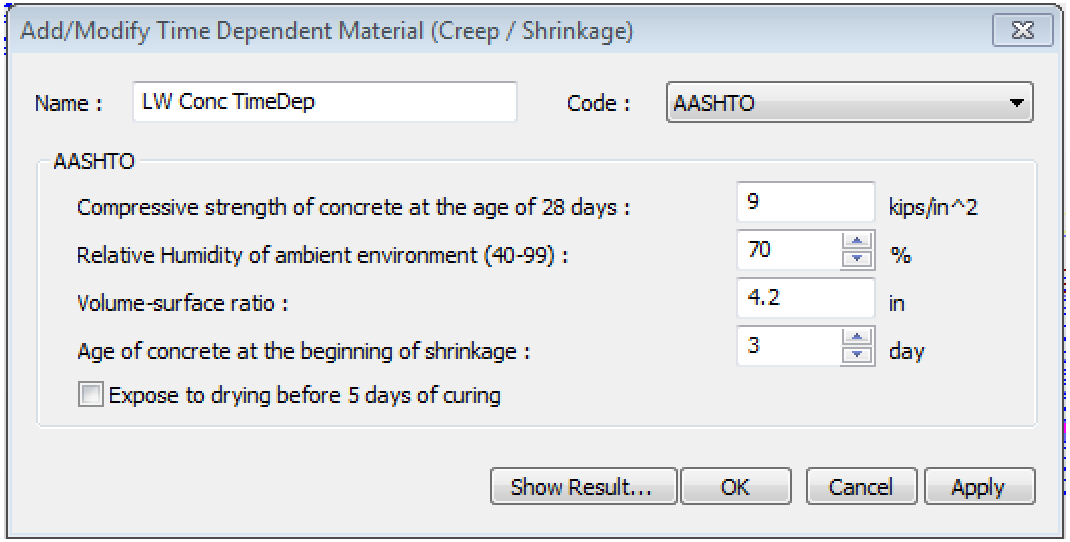
4. Refined Analysis Model

- **Tendon Prestress**
  - **All tendons prestressed to 75% of ultimate strength**



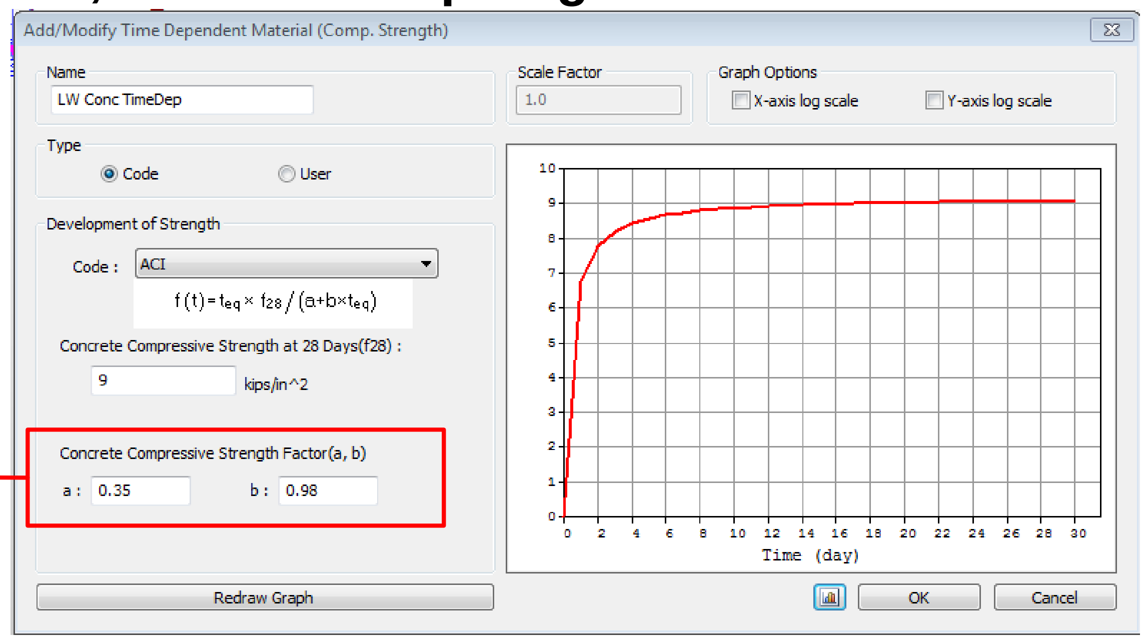
4. Refined Analysis Model

- Time Dependent Materials
  - Each time dependent material needs:
    - Creep/Shrinkage properties
    - Compressive strength gain curve
  - Properties->Time Dep. Matl.->Creep/Shrinkage->Add
    - PS beam shown, deck and diaphragm also defined



4. Refined Analysis Model

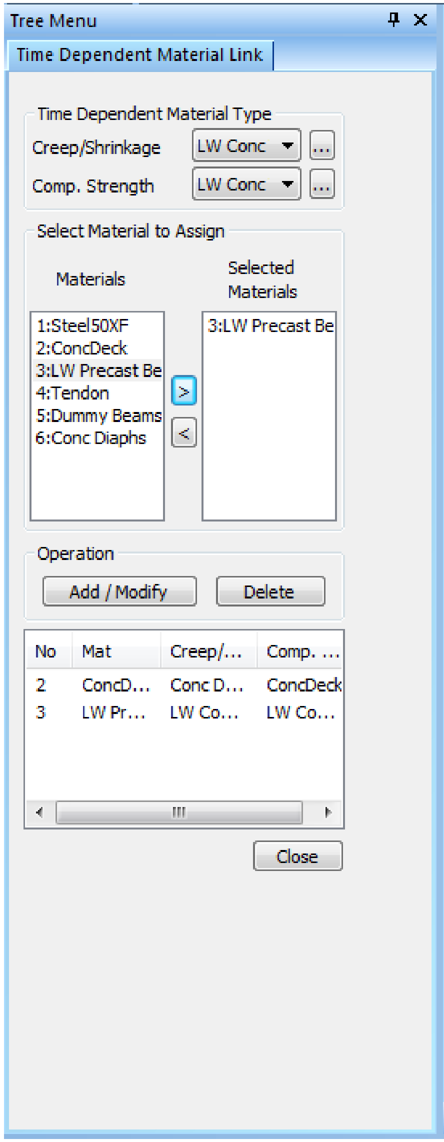
- Time Dependent Materials
  - Each time dependent material needs:
    - Creep/Shrinkage properties
    - Compressive strength gain curve
  - Properties->Time Dep. Matl.->Comp. Strength->Add
    - PS beam shown, deck and diaphragm also defined



ACI a,b factors "fudged" based on knowns: 6 ksi release strength at 1 day and 9 ksi strength at 28 days

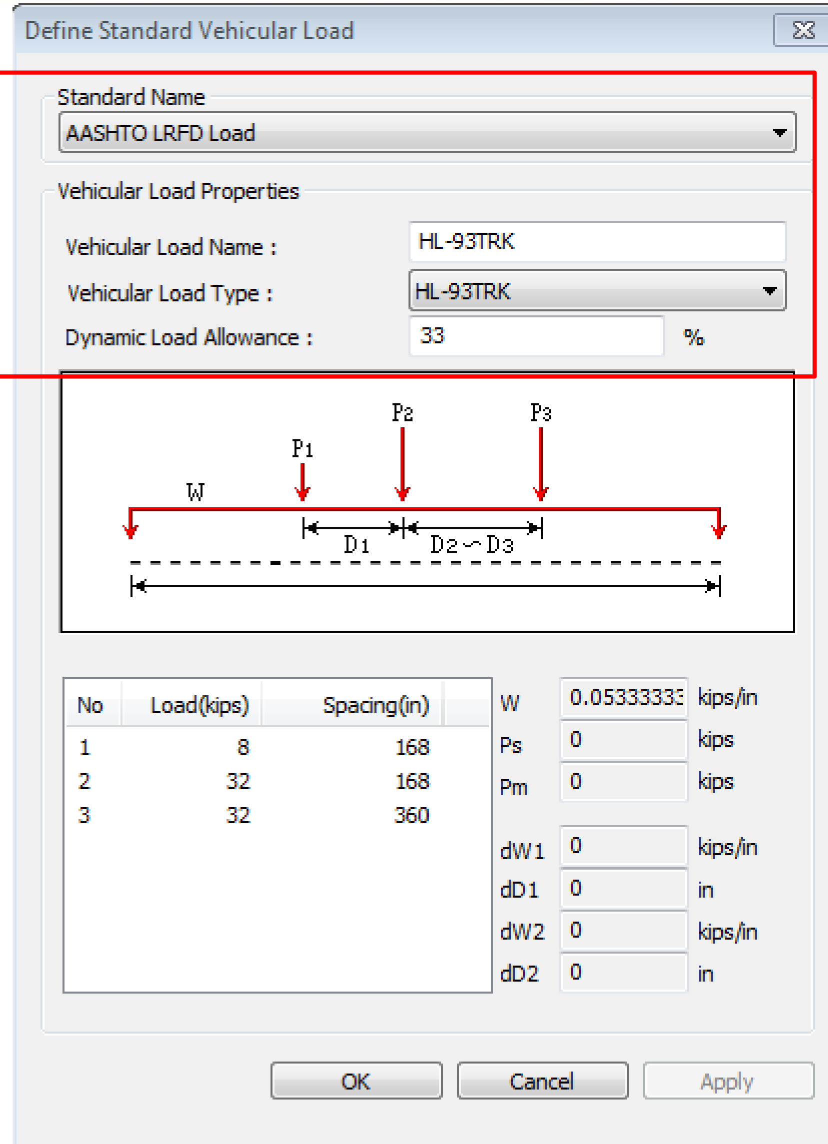
4. Refined Analysis Model

- **Time Dependent Materials**
  - **Link time dependent properties to materials**
  - **Properties->Time Dep. Matl.->Material Link**



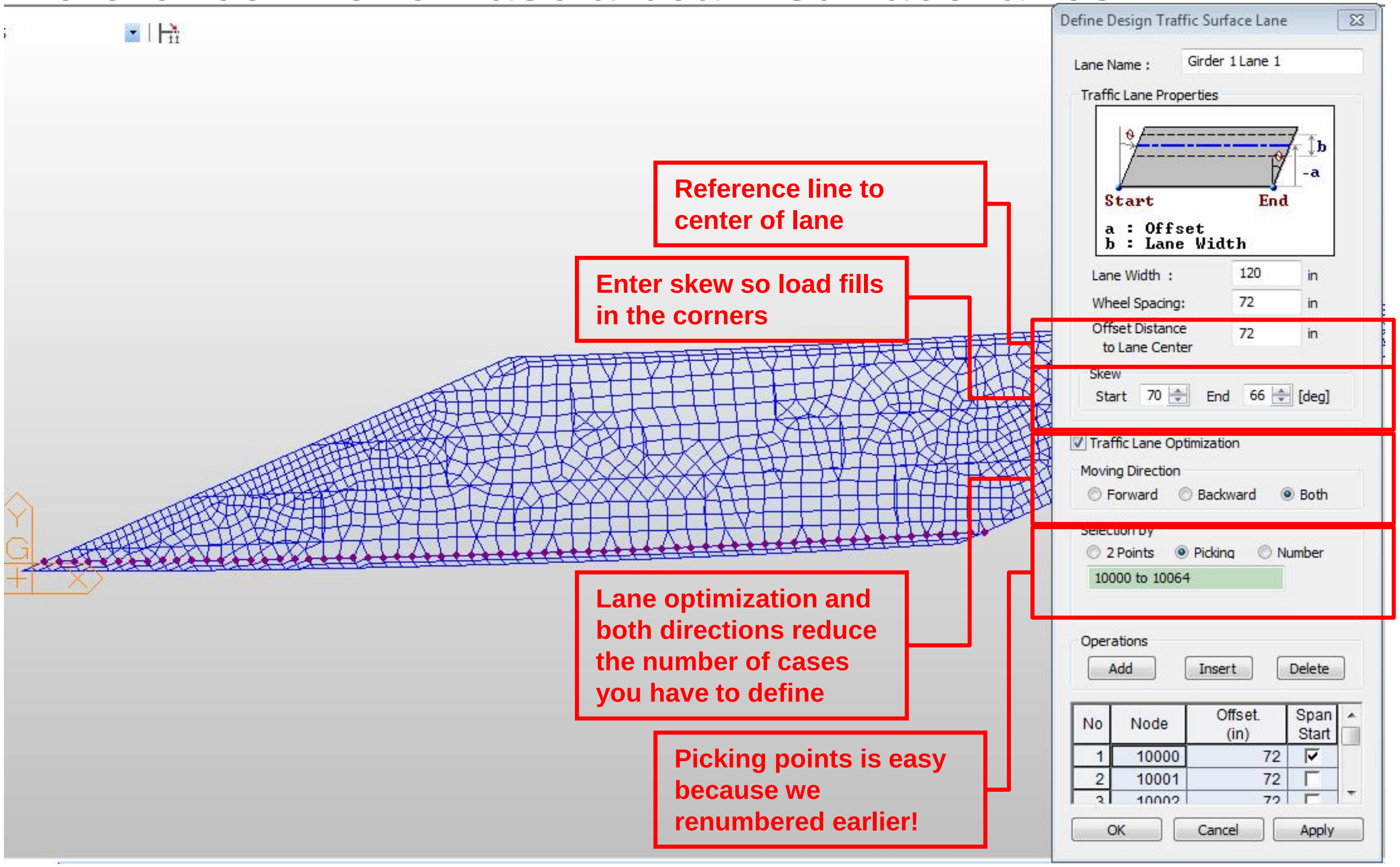
4. Refined Analysis Model

- **Moving Load**
  - **Select moving load code AASHTO LRFD**
  - **Select vehicles HL-93TRK and HL-93TDM**
  - **Set Dymanic Load Allowance to 33%**



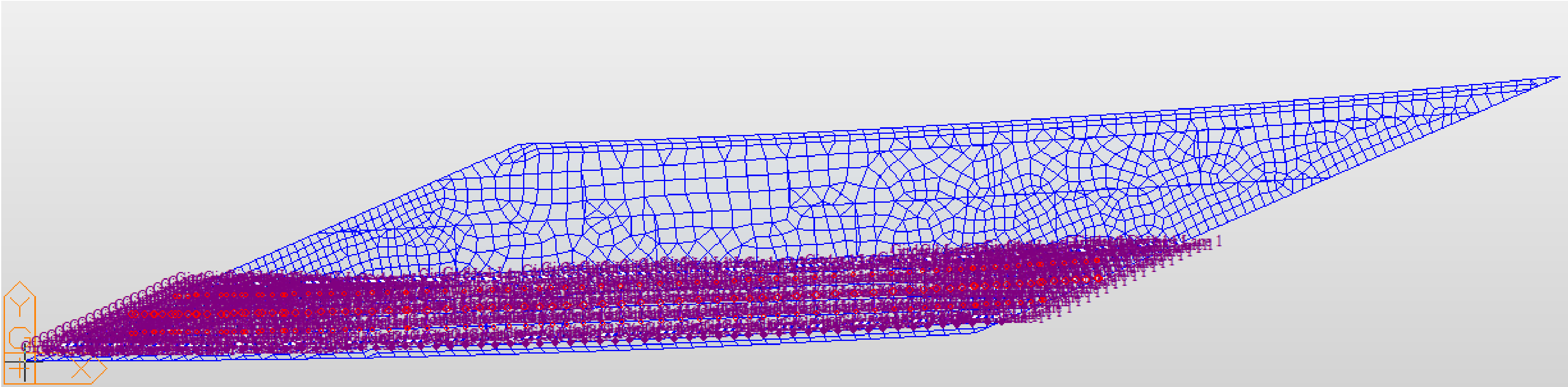
4. Refined Analysis Model

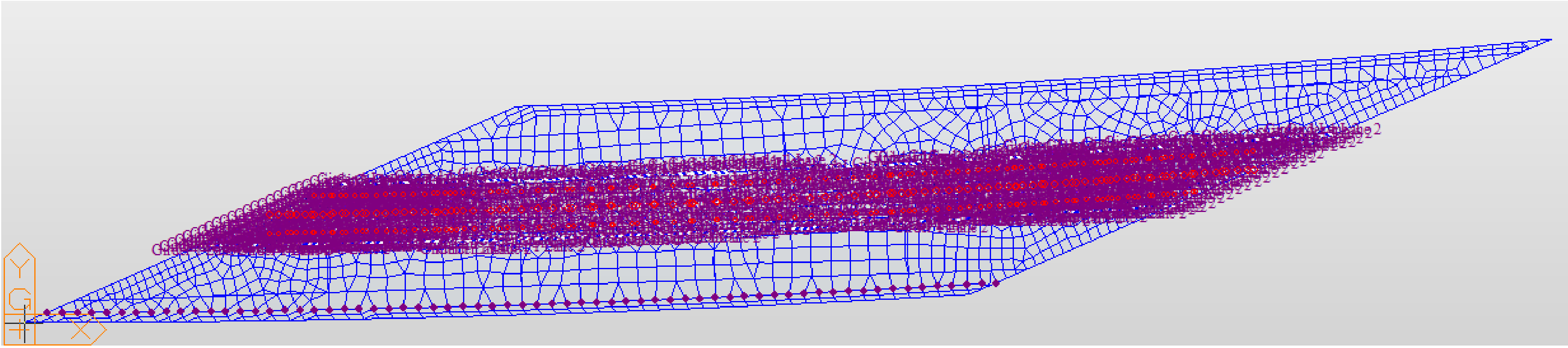
- **Traffic Surface Lanes – Fascia Beams**
  - **Curved deck on straight beams, therefore curb line used as reference line for fascia beam surface lanes**



4. Refined Analysis Model

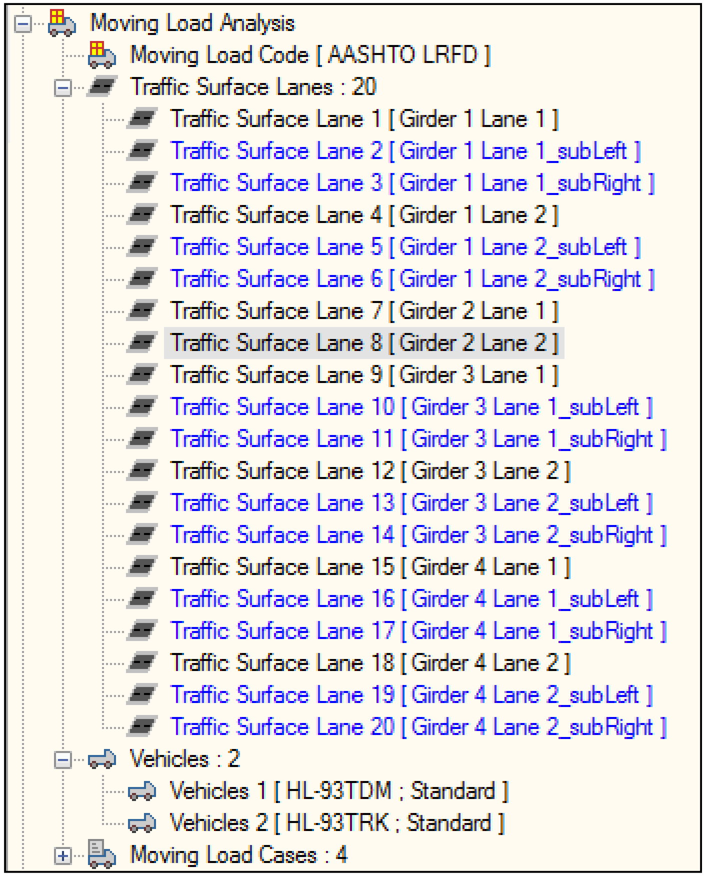
- Traffic Surface Lanes – Fascia Beams
  - Just change the offset for the second lane





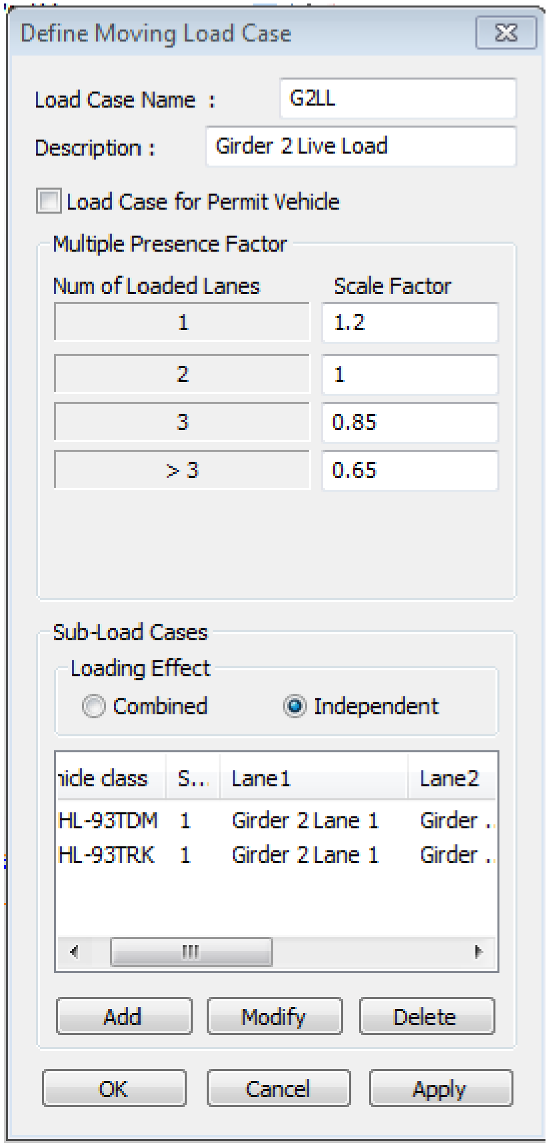
4. Refined Analysis Model

- **Traffic Surface Lanes – Interior Beams**
  - **Similar procedure as fascia beam, but use beam line nodes as reference instead of curb line**
  - **One set of 2 lane positions optimized for each beam**
    - **Total of 8 lanes defined**
    - **Using lane optimization, MIDAS creates the rest**



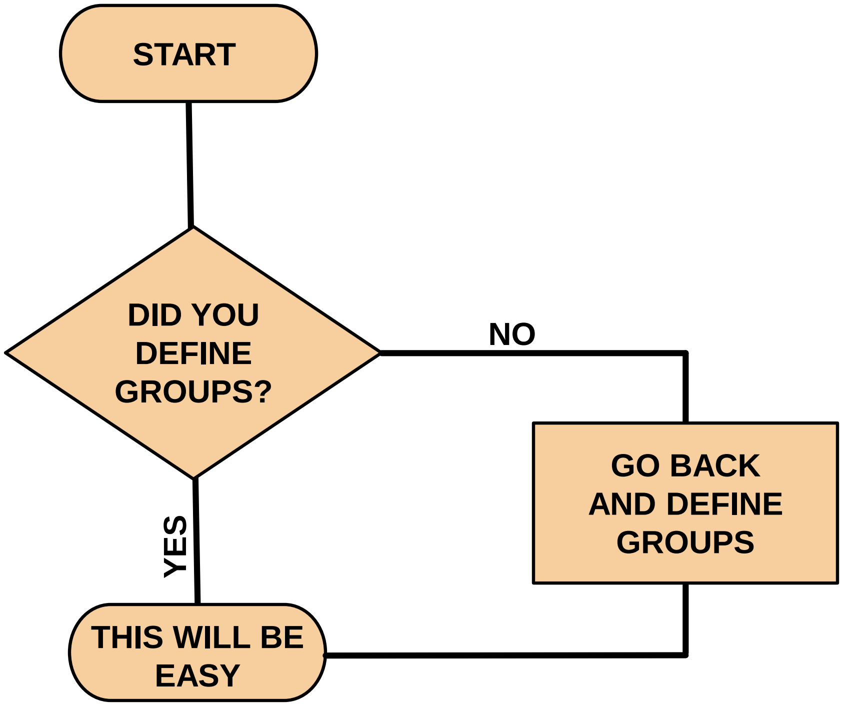
4. Refined Analysis Model

- Moving Load Cases (MLC)
  - Defines which lane loadings can occur simultaneously
  - Defines multiple presence factors
  - Create MLCs with optimum lanes for each beam
    - ie. Beam 1, Lane 1 with Beam 1, Lane 2
    - If using lane optimization, group similar shift directions



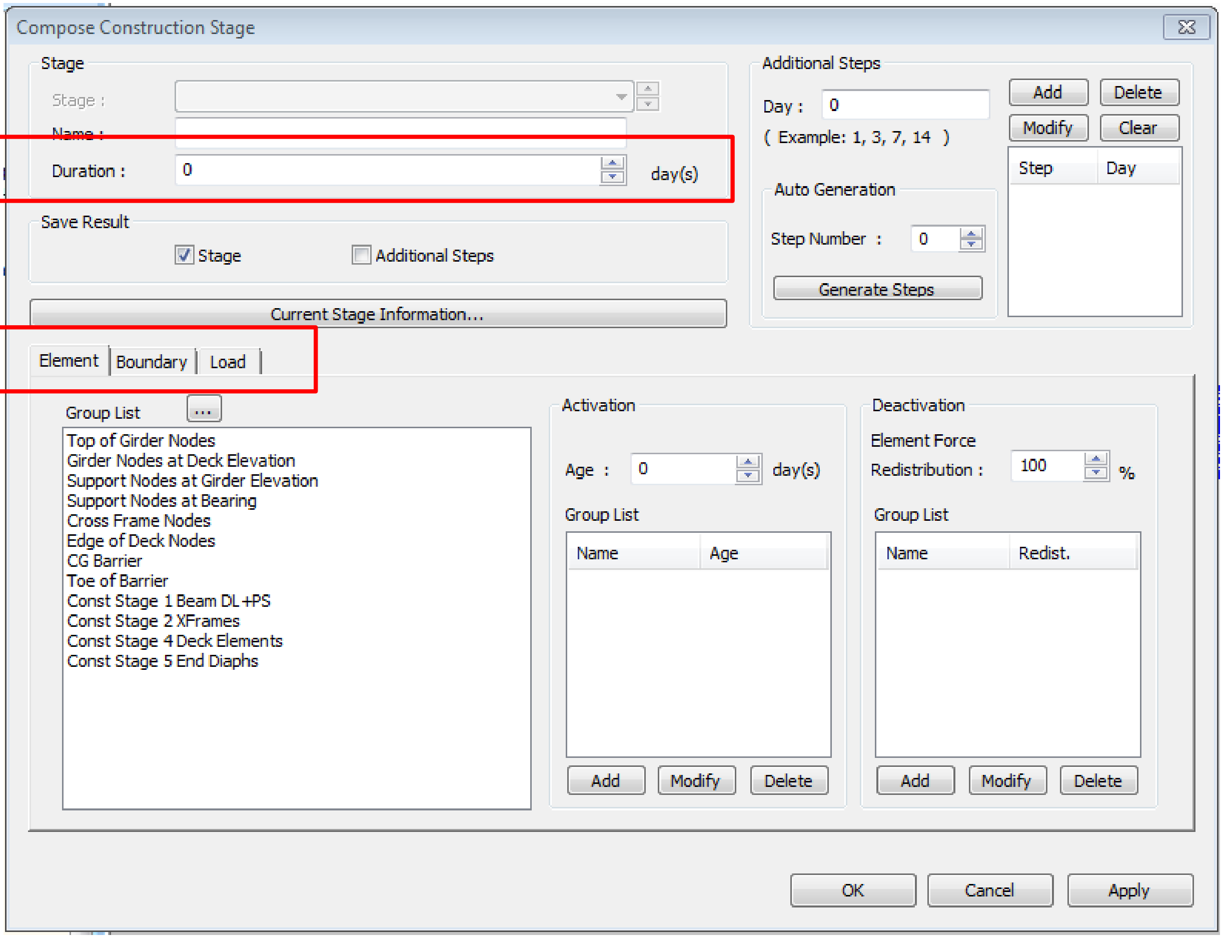
4. Refined Analysis Model

- **Construction Stage (CS) Analysis**



4. Refined Analysis Model

- **Construction Stage (CS) Analysis**
  - **Load->Load Type->Construction Stage->Define C.S.->Add**



4. Refined Analysis Model

- Construction Stage (CS) Analysis
  - The only things that can happen in a construction stage:
    - Elements change
    - Boundary conditions change
    - Loads change
    - Time passes

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  - The only things that can happen in a construction stage:
    - Elements change
    - Boundary conditions change
    - Loads change
    - Time passes

Must be result of activating or deactivating a group

Input as a duration

4. Refined Analysis Model

- Basic CS Analysis Stage Summary
  - Prestress the beams and erect
  - Erect steel diaphragms (zero force under beam self-weight)
  - Release temporary beam end supports
  - Place deck loading in 5 stages to simulate placement
  - Activate deck elements (makes bridge composite)
  - Place end diaphragms
  - Place Barrier
  - Open bridge to traffic
  - Place future wearing surface
  - “End” of time dependent effects

4. Refined Analysis Model

- **Basic CS Analysis Stage Summary (with wait time)**
  - Prestress the beams and erect
  - Wait
  - Erect steel diaphragms (zero force under beam self-weight)
  - Release temporary beam end supports
  - Wait
  - Place deck loading in 5 stages to simulate placement
  - Wait
  - Activate deck elements (makes bridge composite)
  - Wait
  - Place end diaphragms
  - Wait
  - Place Barrier
  - Wait
  - Open bridge to traffic
  - Wait
  - Place future wearing surface
  - Wait
  - “End” of time dependent effects

WAIT TIMES ARE CRITICAL TO ESTIMATING TIME DEPENDENT EFFECTS.

THIS MODEL APPLIES ALL LOADS ON THE 1ST DAY OF A STAGE AND THEN USES DEFINED “WAIT STAGES” WHERE NOTHING HAPPENS EXCEPT TIME PASSING.

THE USER CAN ALSO CHANGE WHETHER LOADS ARE APPLIED AT THE BEGINNING OR END OF A STAGE TO ELIMINATE ADDITIONAL STAGES. THIS IS A MATTER OF PREFERENCE.

4. Refined Analysis Model

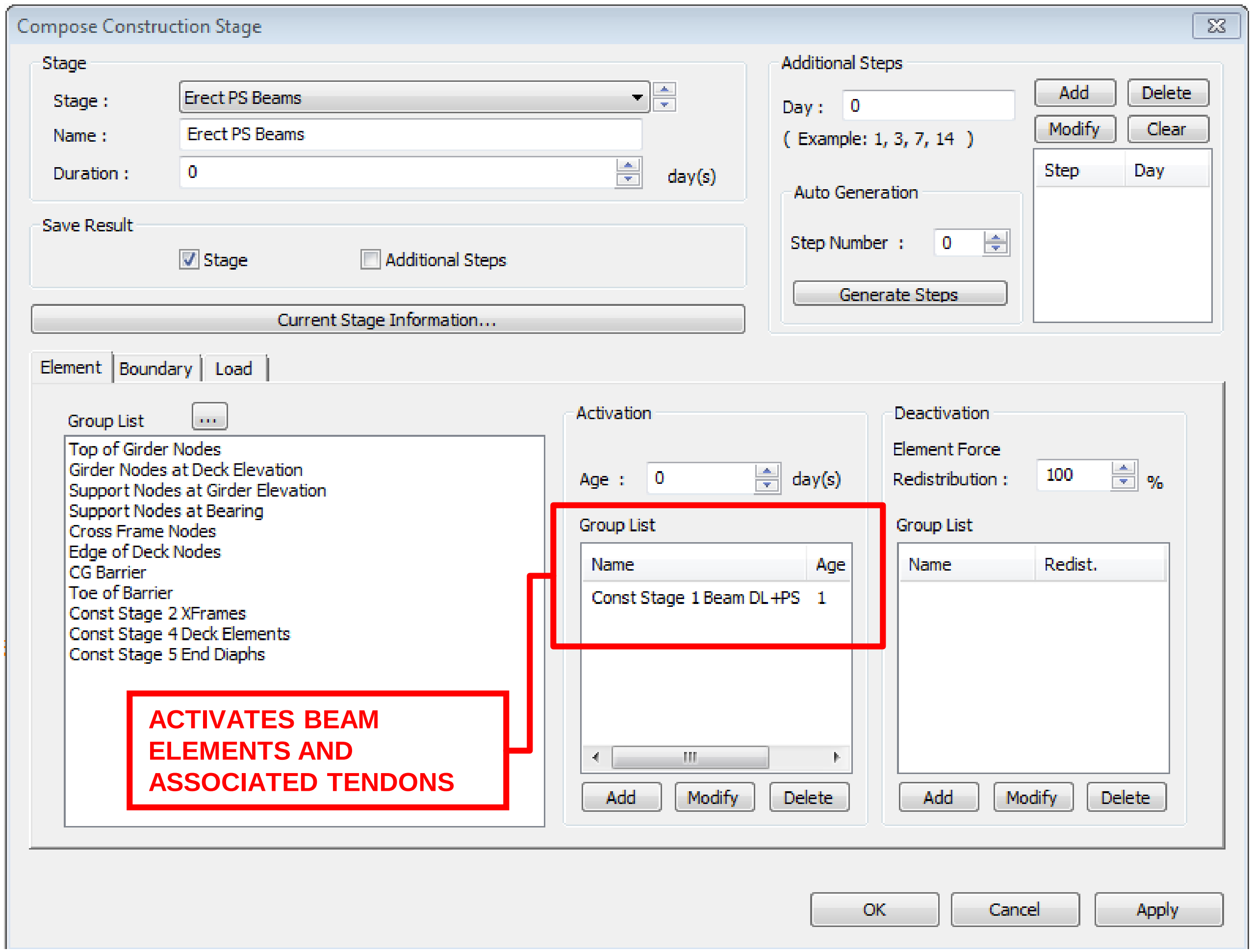
- **Basic CS Analysis Stage Summary – What Changes?**
  - Prestress the beams and erect
    - Add elements, add boundary conditions, add load
  - Erect steel diaphragms (zero force under beam self-weight) (#)
    - Add elements, add boundary conditions*
  - Release temporary beam end supports
    - Delete boundary conditions, add boundary conditions
  - Place deck loading in 5 stages to simulate placement
    - Add load
  - Activate deck elements (makes bridge composite)
    - Add elements, add boundary conditions*
  - Place end diaphragms (#)
    - Add elements
  - Place Barrier
    - Add load
  - Open bridge to traffic
  - Place future wearing surface
    - Add load
  - "End" of time dependent effects

* - BOUNDARY CONDITIONS ADDED AT THESE STAGES ARE RIGID LINKS

- ADDITIONAL LOAD AT THIS STAGE IS SELF-WEIGHT, WHICH IS AUTOMATICALLY ACTIVATED WHEN AN ELEMENT IS ACTIVATED (IF SELF-WEIGHT IS SELECTED IN A PREVIOUS STAGE)

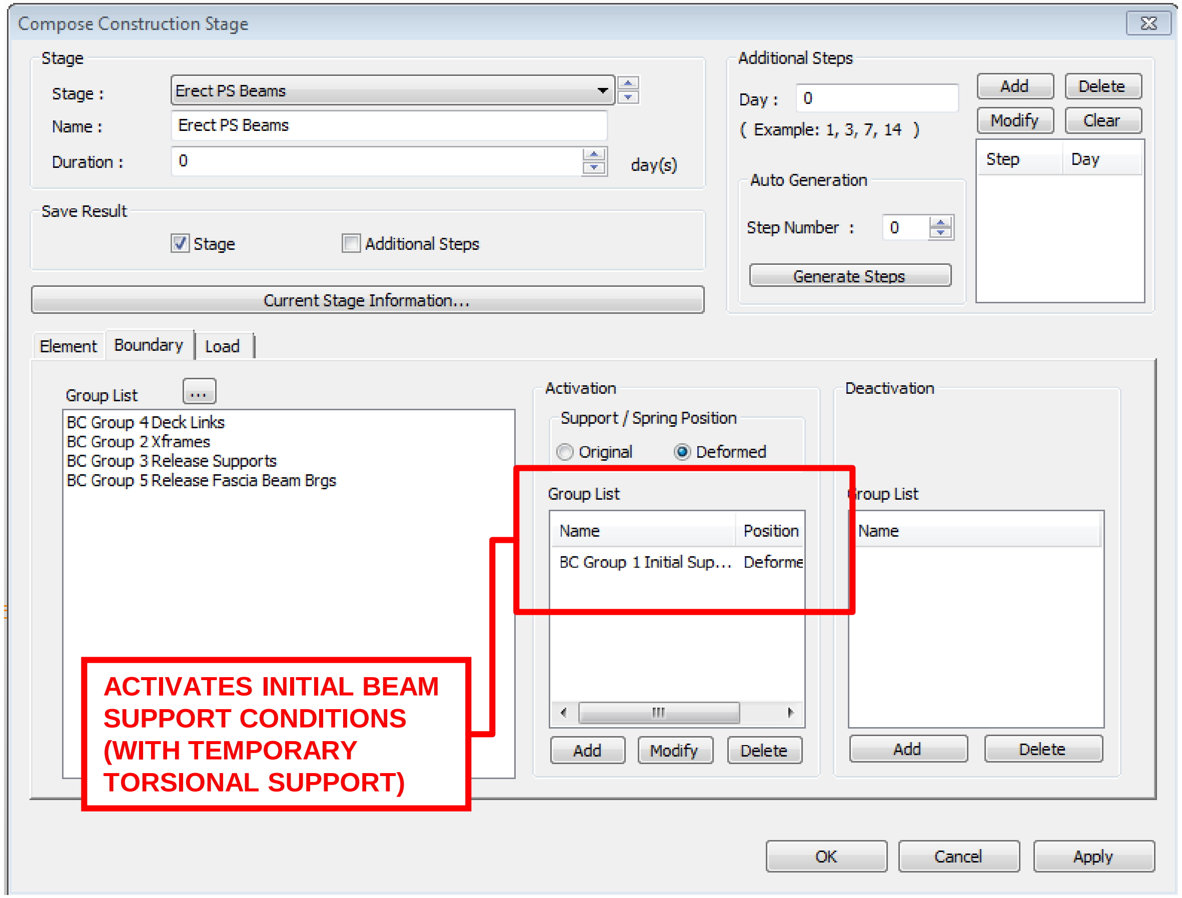
4. Refined Analysis Model

- Defining the First Stage – Need <u>Elements</u>, Boundaries, and Loads



4. Refined Analysis Model

- **Defining the First Stage - Need Elements, Boundaries, and Loads**



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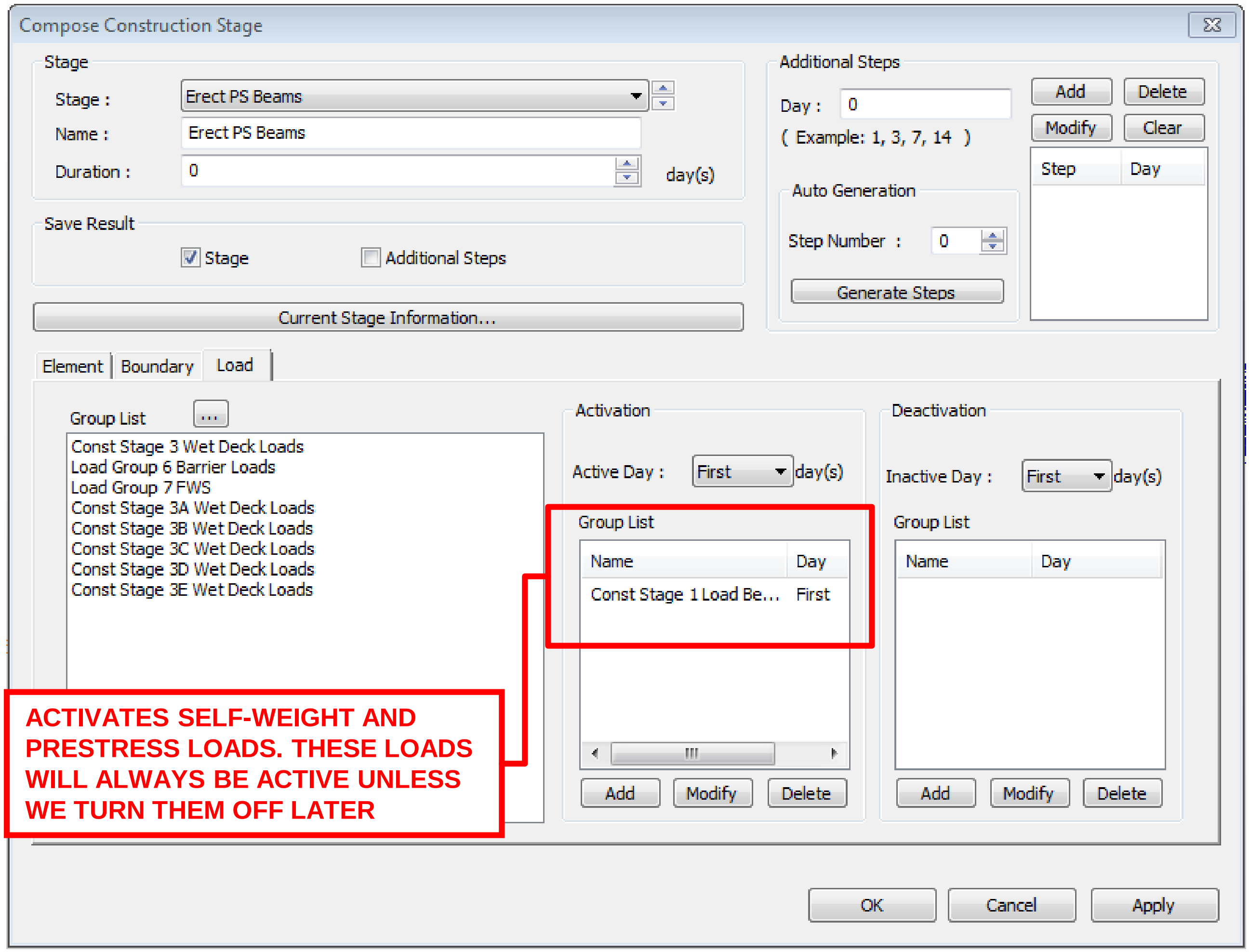
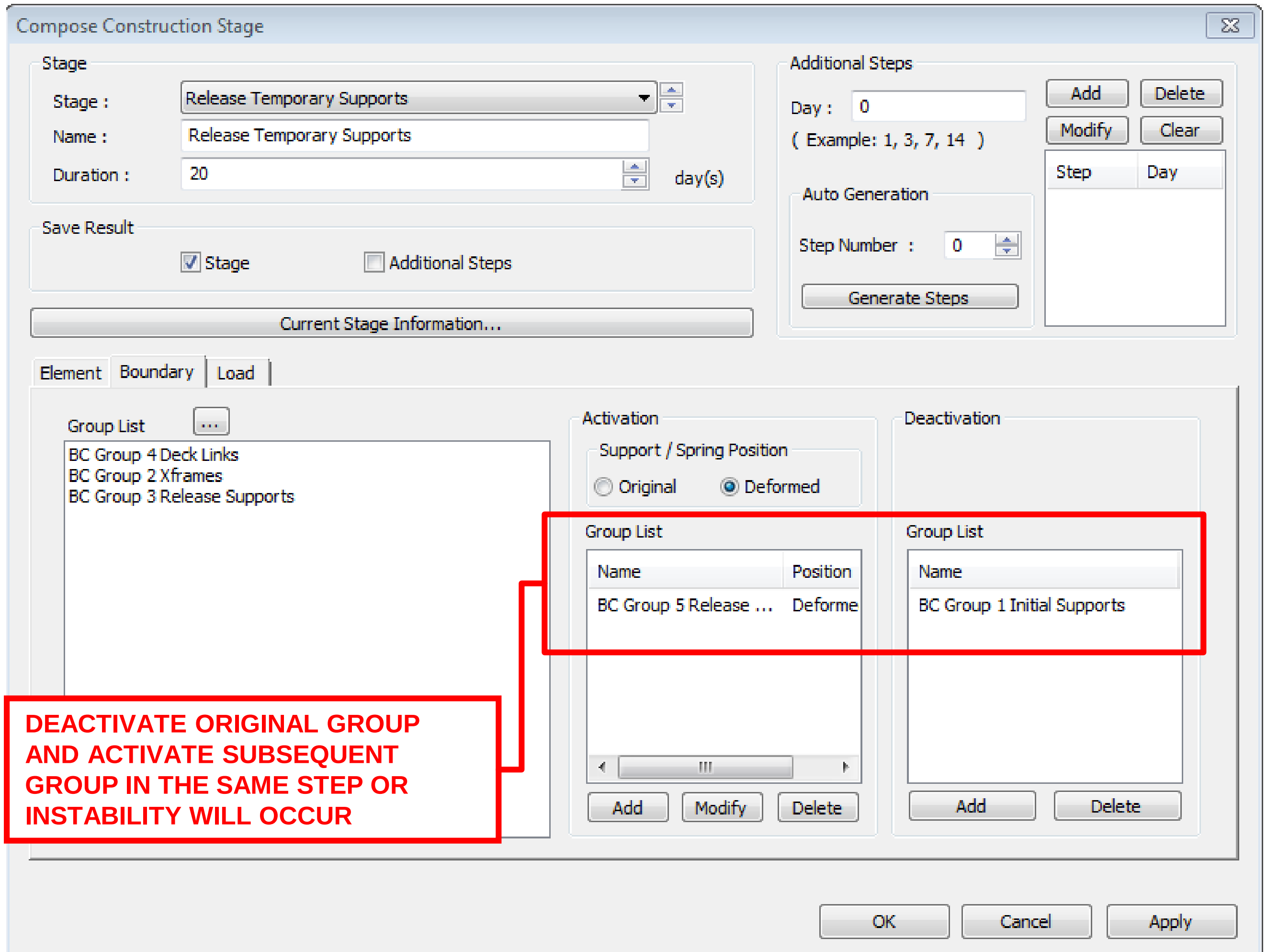
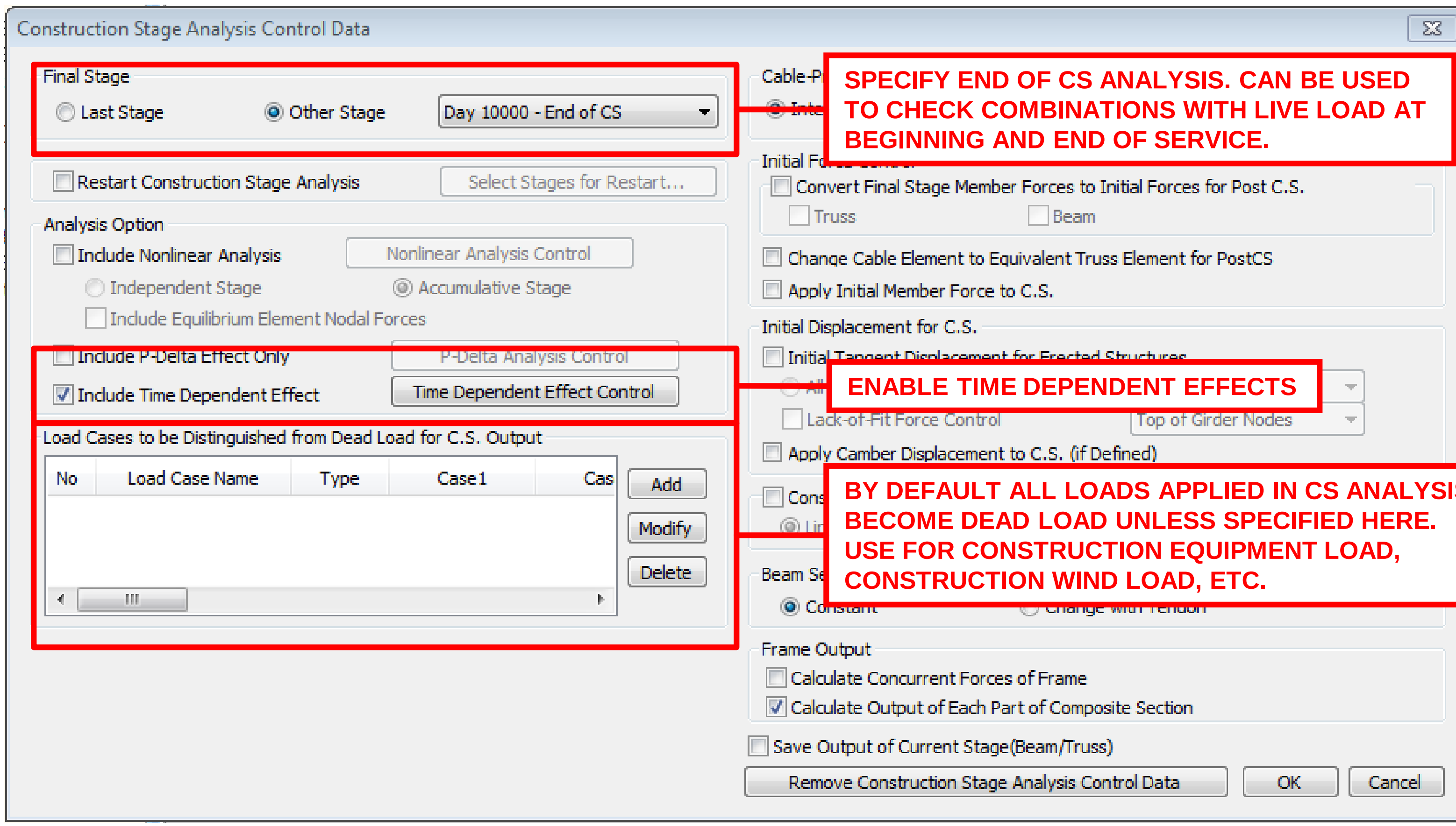


4. Refined Analysis Model

- **Activating/Deactivating Boundary Conditions**

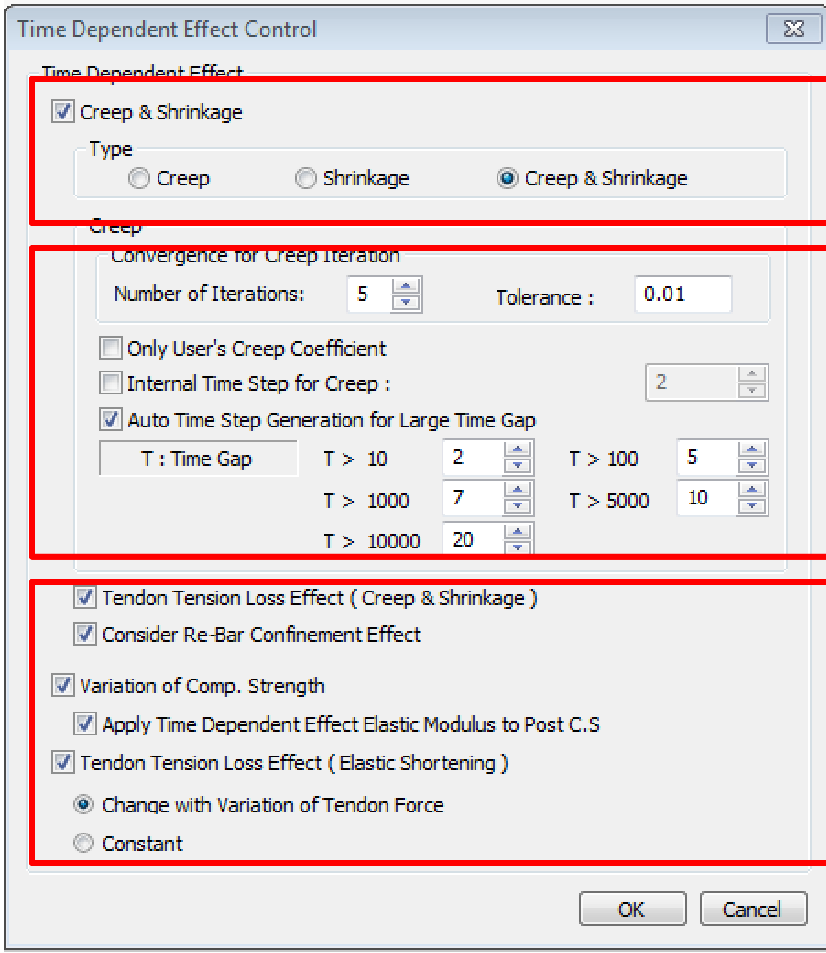


- **Construction Stage Analysis Control**
  - **Analysis->Construction Stage**



4. Refined Analysis Model

- **Construction Stage Analysis Control – Time Dependent Effects**
  - **Analysis->Construction Stage->Time Dependent Effect Control**



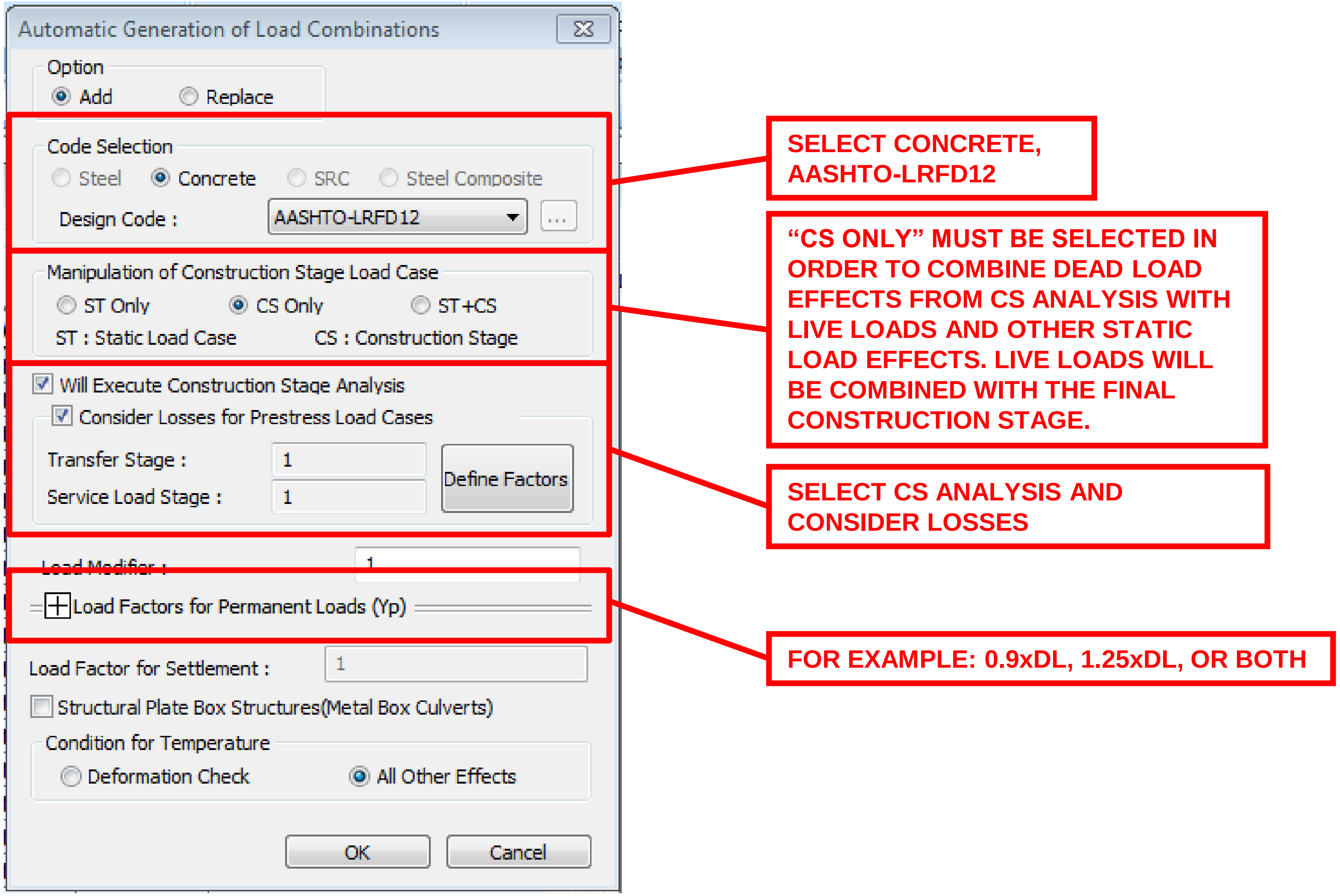
SELECT CREEP AND SHRINKAGE

AUTOMATIC CONTROL OF CONVERGENCE CRITERIA AND ADDITIONAL TIME STEPS FOR C&S

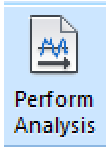
CONTROL OF TENDON ELASTIC LOSSES, ETC.

4. Refined Analysis Model

- **Load Combinations**
  - **Results->Load Combinations->Concrete Design->Auto Generation**



4. Refined Analysis Model



PERFORM ANALYSIS!

Agenda

1. Introduction
2. Proposed Bridge Configuration
3. Preliminary Design
4. Refined Analysis Model
5. **Results**
6. Conclusions

5. Results

- Results to be Considered
  - Load Combinations After All Losses
    - Service (I – Compression, III – Tension)
      (Typically governs design)
    - Strength I (Shear Only)
      - Strength for moment does not govern
  - Envelope of Stresses During Construction

5. Results

- Service III – Tension at Midspan
  - Axial Force and Vertical Bending Only
    - Additional stresses have transferred from interior to exterior beams, particularly Beam 1, the shortest beam

MIDSPAN TENSION STRESS (KSI)			
Beam	Preliminary Design	Refined Analysis	Allowable Stress
1	-0.172	-0.355	-0.284
2	-0.233	-0.072	-0.284
3	-0.227	-0.125	-0.284
4	-0.215	-0.272	-0.284

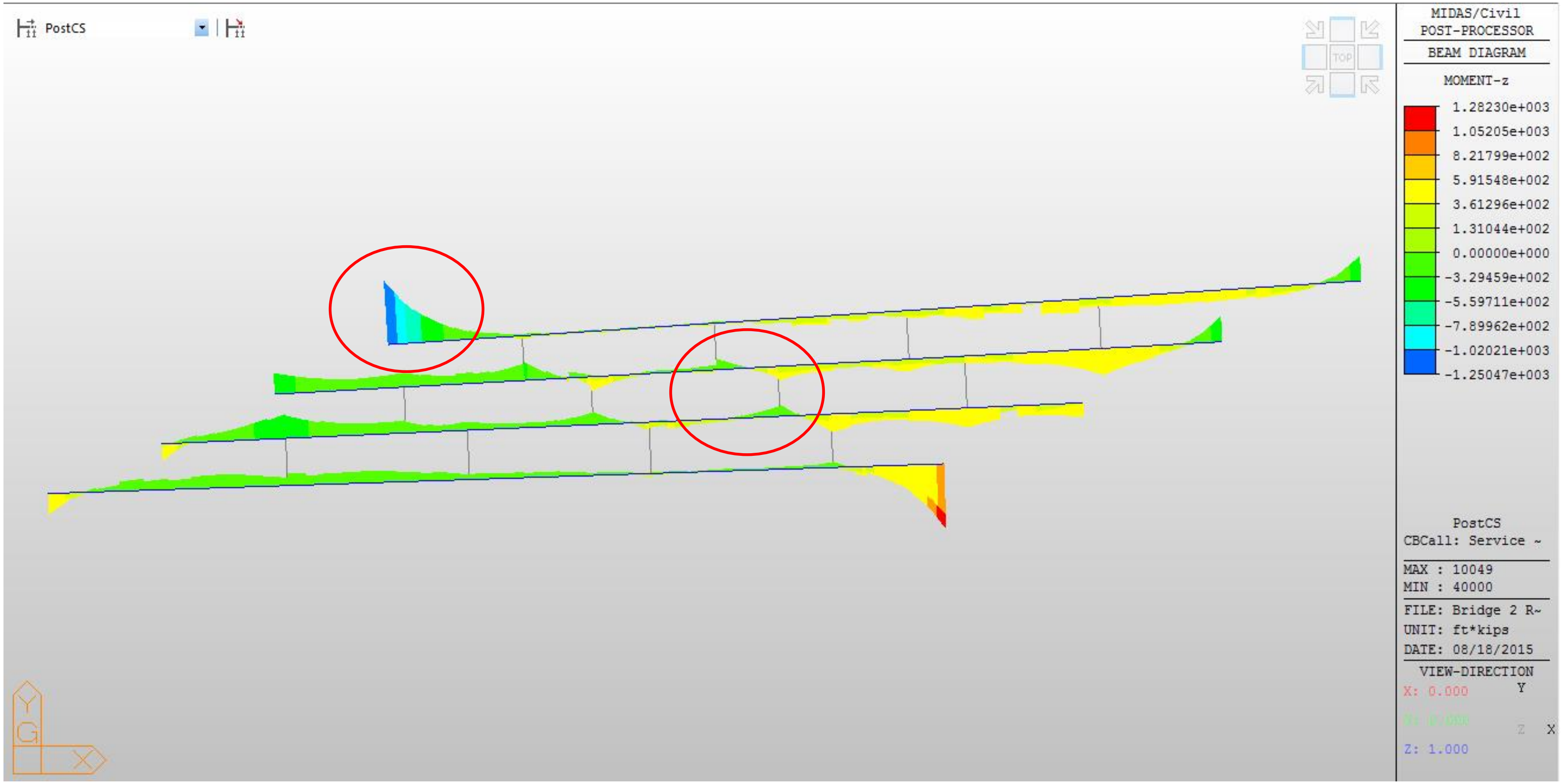
5. Results

- Service III – Tension at Midspan
  - Axial Force and Vertical Bending
  - Lateral Bending
    - Lateral bending effect adds tension stress to bottom flange

MIDSPAN TENSION STRESS (KSI) WITH LATERAL BENDING			
Beam	Preliminary Design	Refined Analysis	Allowable Stress
1	-0.172	-0.436	-0.284
2	-0.233	-0.314	-0.284
3	-0.227	-0.580	-0.284
4	-0.215	-0.481	-0.284

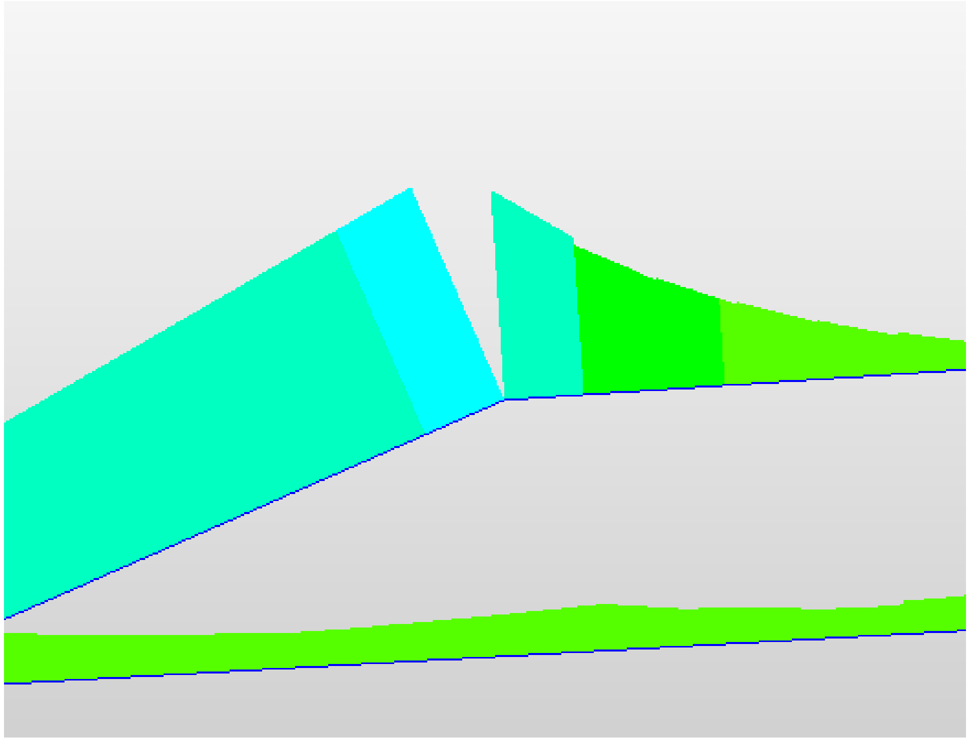
5. Results

- **Service III – Lateral Bending Moment**



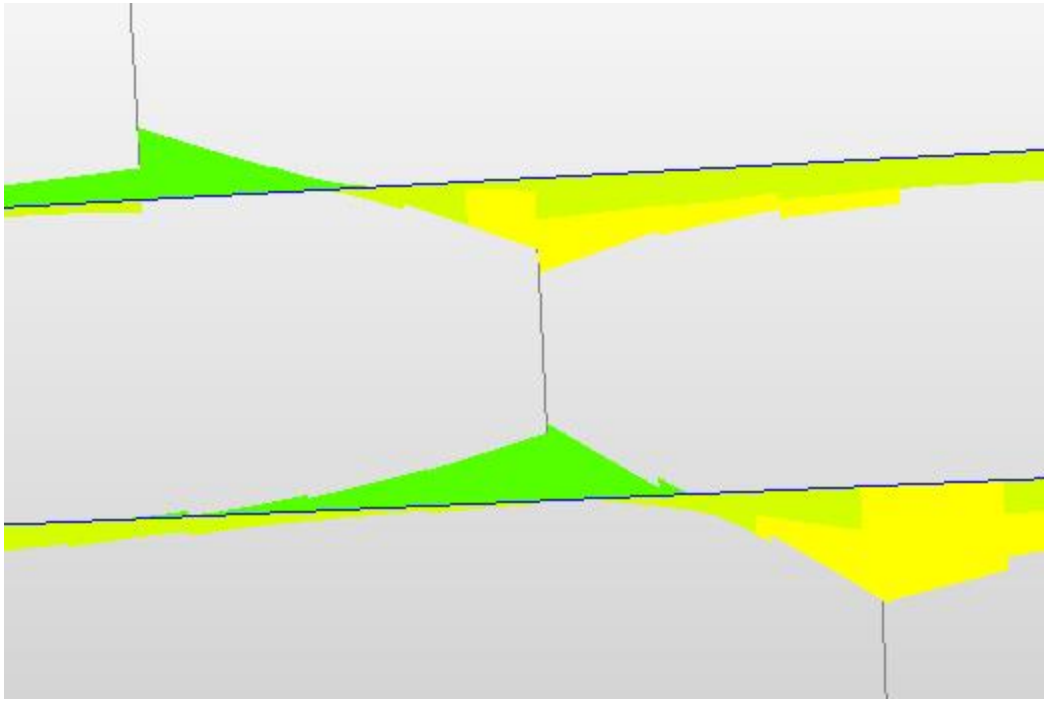
5. Results

- **Service III – Lateral Bending Moment**
  - **Highest moment at end diaphragm connection**
    - **In a heavily reinforced compression zone**
    - **Joint actually not fully restrained – opportunity for further refinement**



5. Results

- Service III – Lateral Bending Moment
  - Localized moments at intermediate diaphragm connections
    - Located in tensile zone – consider potential for additional cracking



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2	-0.233	-0.314	-0.284
3	-0.227	-0.580	-0.284
4	-0.215	-0.481	-0.284

MODULUS OF RUPTURE = -0.600 KSI

5. Results

- Service I – Compression at Midspan
  - Axial Force and Vertical Bending Only
    - Also indicates additional load to exterior beams

MIDSPAN COMPRESSION STRESS (KSI)				
Beam		Preliminary Design	Refined Analysis	Allowable Stress
1	w/ LL	2.862	3.280	5.400
2	w/ LL	2.838	2.812	5.400
3	w/ LL	2.973	2.955	5.400
4	w/ LL	3.176	3.518	5.400

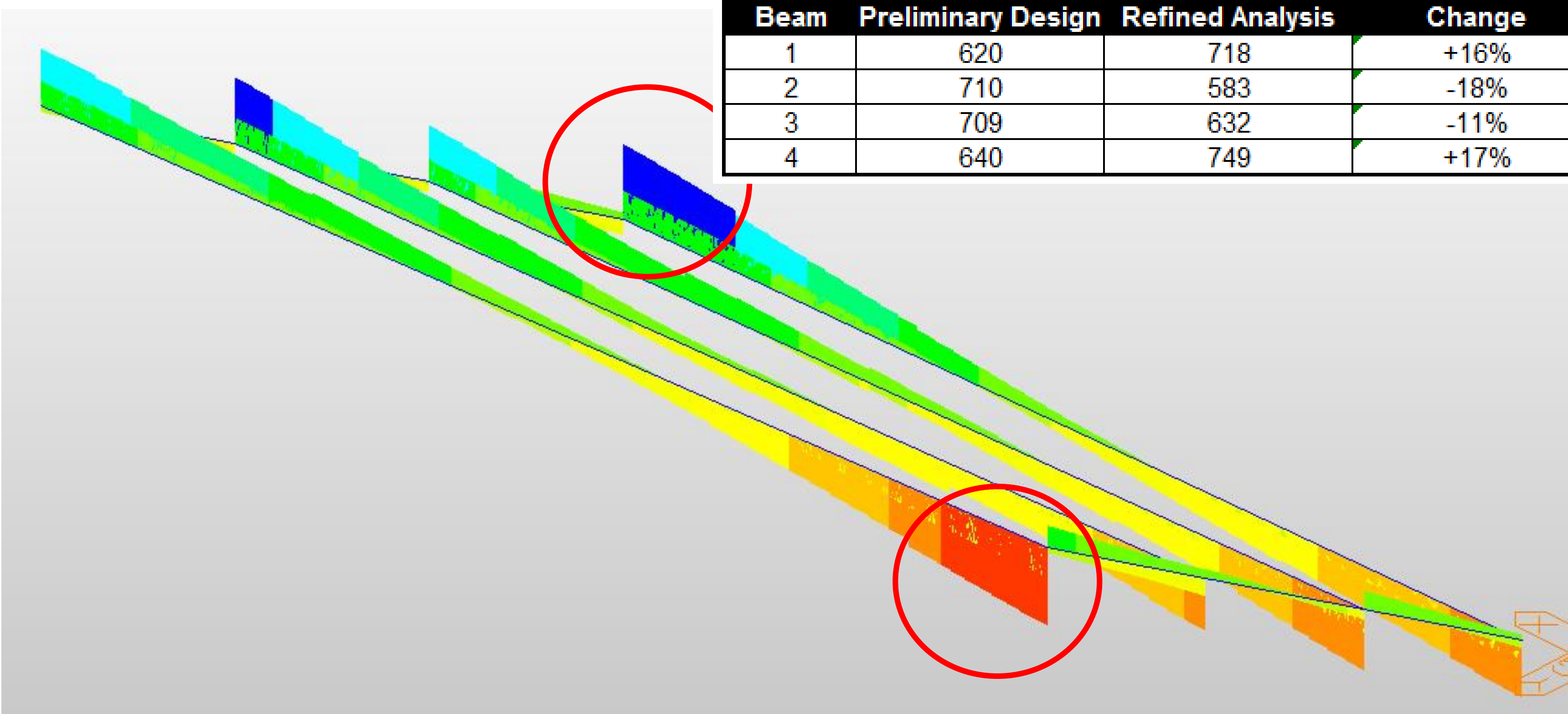
5. Results

- Service I – Compression at Midspan
  - Axial Force and Vertical Bending
  - Lateral Bending
    - Lateral bending effect adds to compressive stress
    - Less of a concern because compression does not often govern and because the top flange is fully restrained

MIDSPAN COMPRESSION STRESS (KSI) WITH LATERAL BENDING				
Beam		Preliminary Design	Refined Analysis	Allowable Stress
1	w/ LL	2.862	3.376	5.400
2	w/ LL	2.838	3.173	5.400
3	w/ LL	2.973	3.625	5.400
4	w/ LL	3.176	3.818	5.400

5. Results

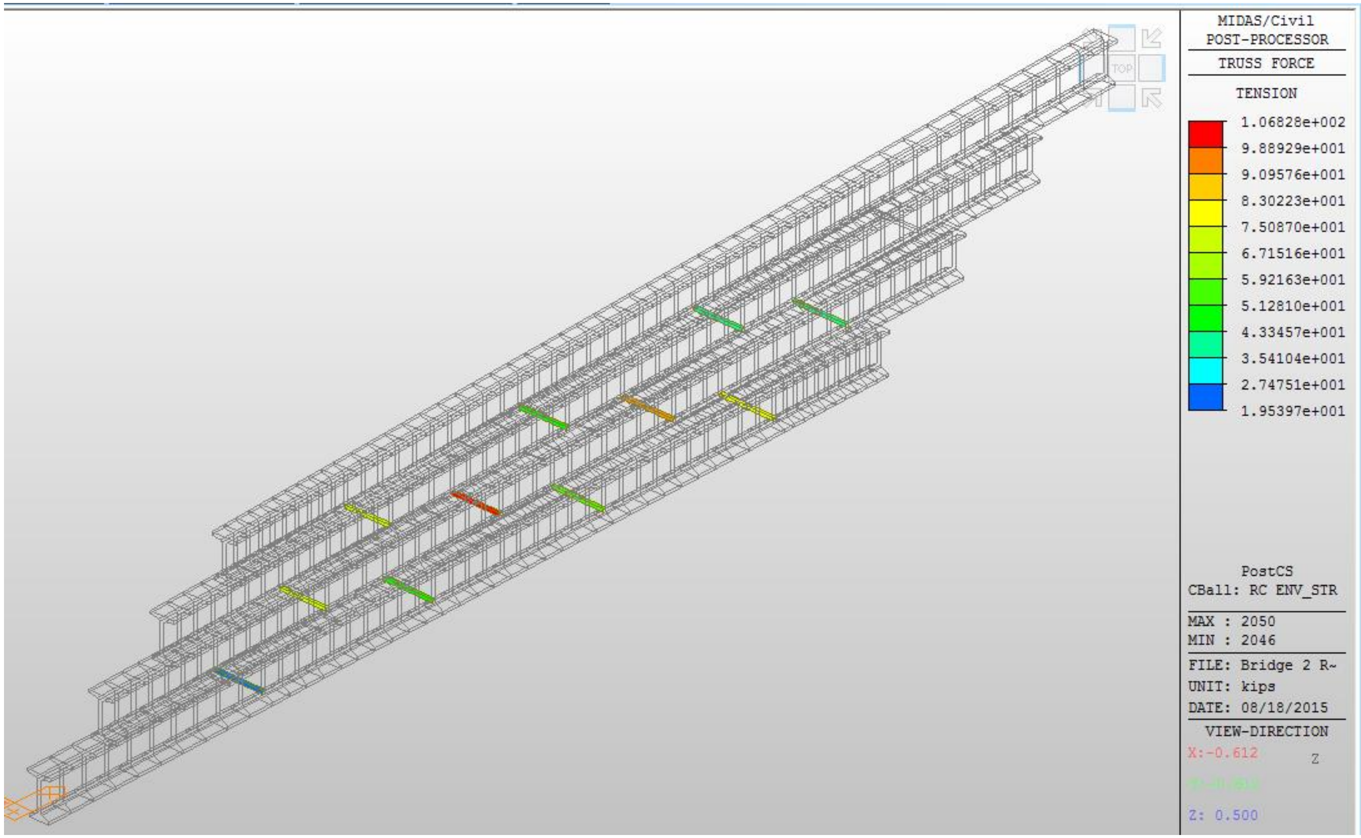
- **Strength Limit State – Shear**
  - **Increase in exterior beams**
  - **Increase at obtuse corners**



STRENGTH I SHEAR (KIPS)			
Beam	Preliminary Design	Refined Analysis	Change
1	620	718	+16%
2	710	583	-18%
3	709	632	-11%
4	640	749	+17%

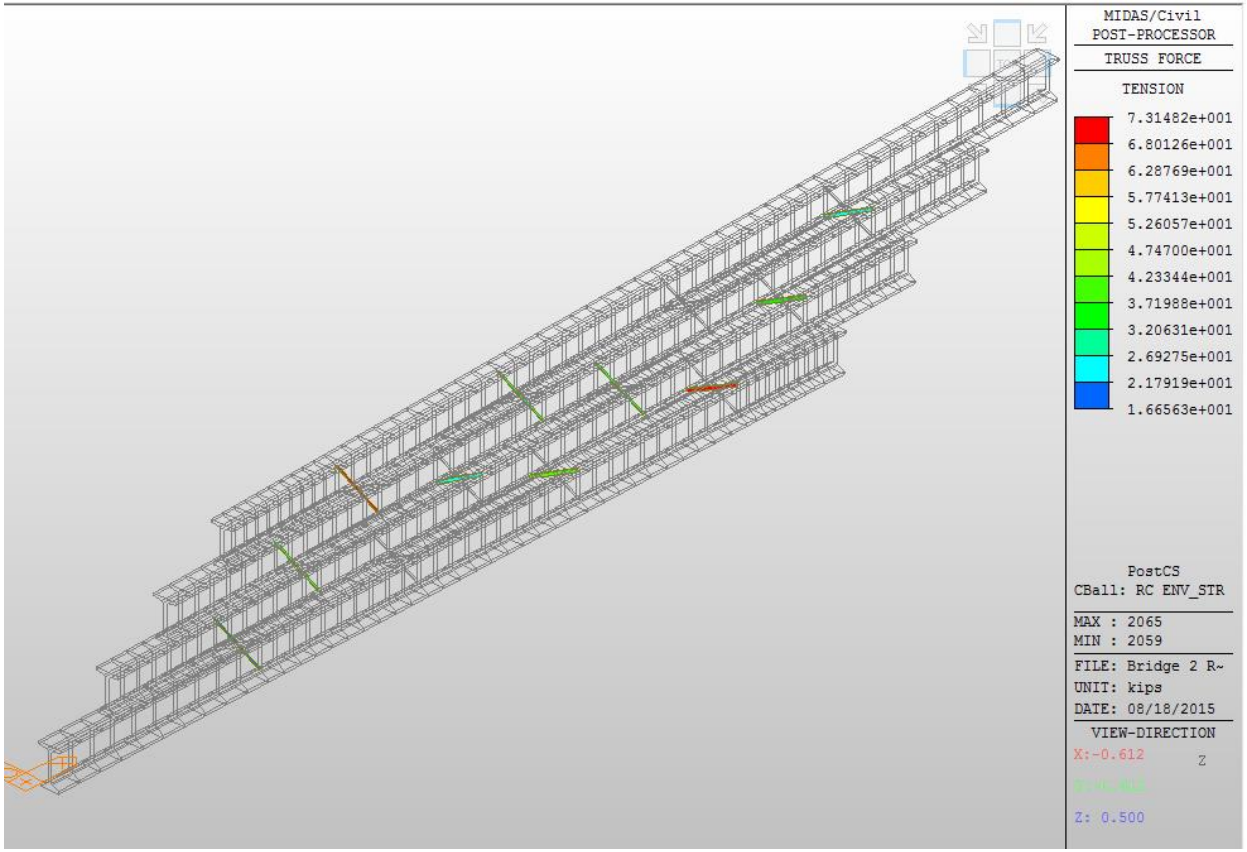
5. Results

- **Strength Limit State – Steel Diaphragm Force**
  - **Activate member size to be checked (L 6x6x3/8)**
  - **Filtering by tension and compression simplifies checking**
  - **107 kip maximum tension / 207 kip resistance (OK)**



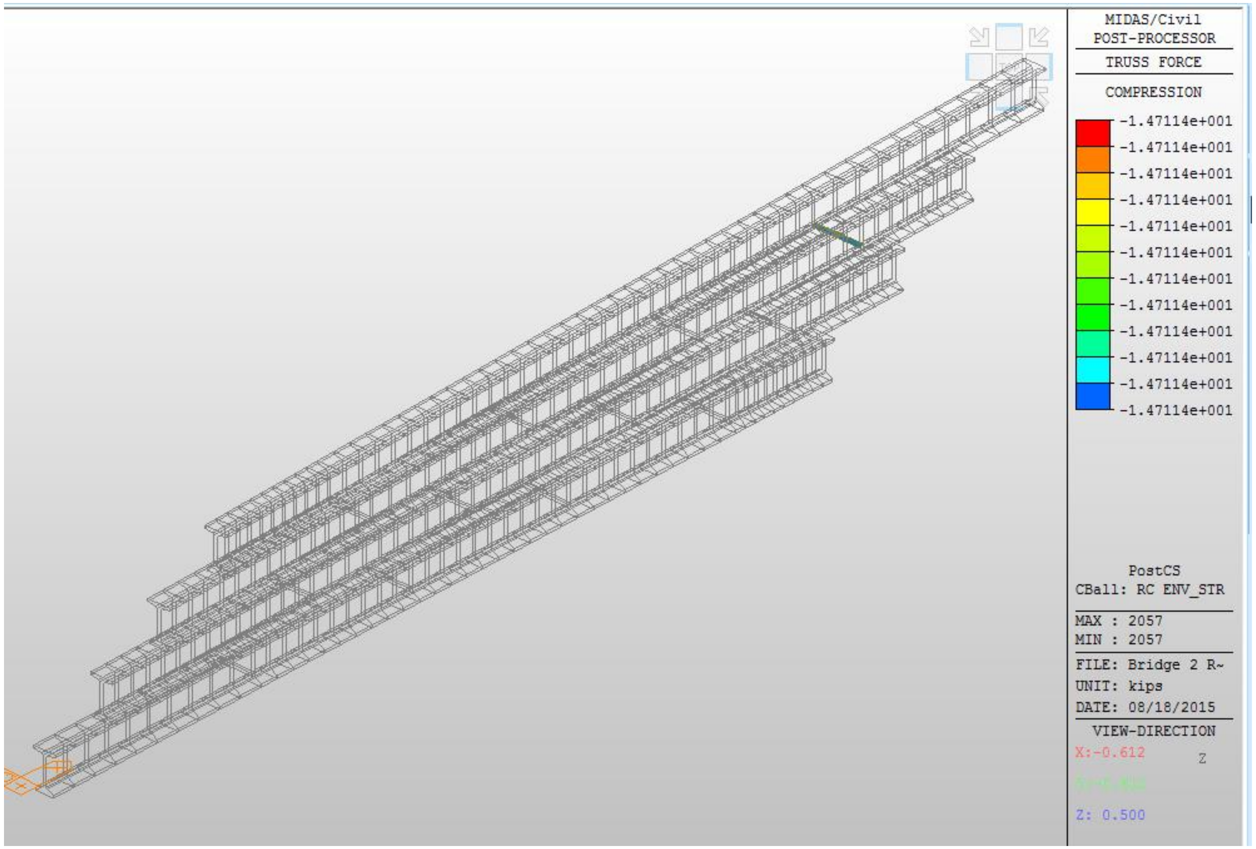
5. Results

- **Strength Limit State – Steel Diaphragm Force**
  - **Activate member size to be checked (L 6x4x5/16)**
  - **73 kip maximum tension / 144 kip resistance (OK)**



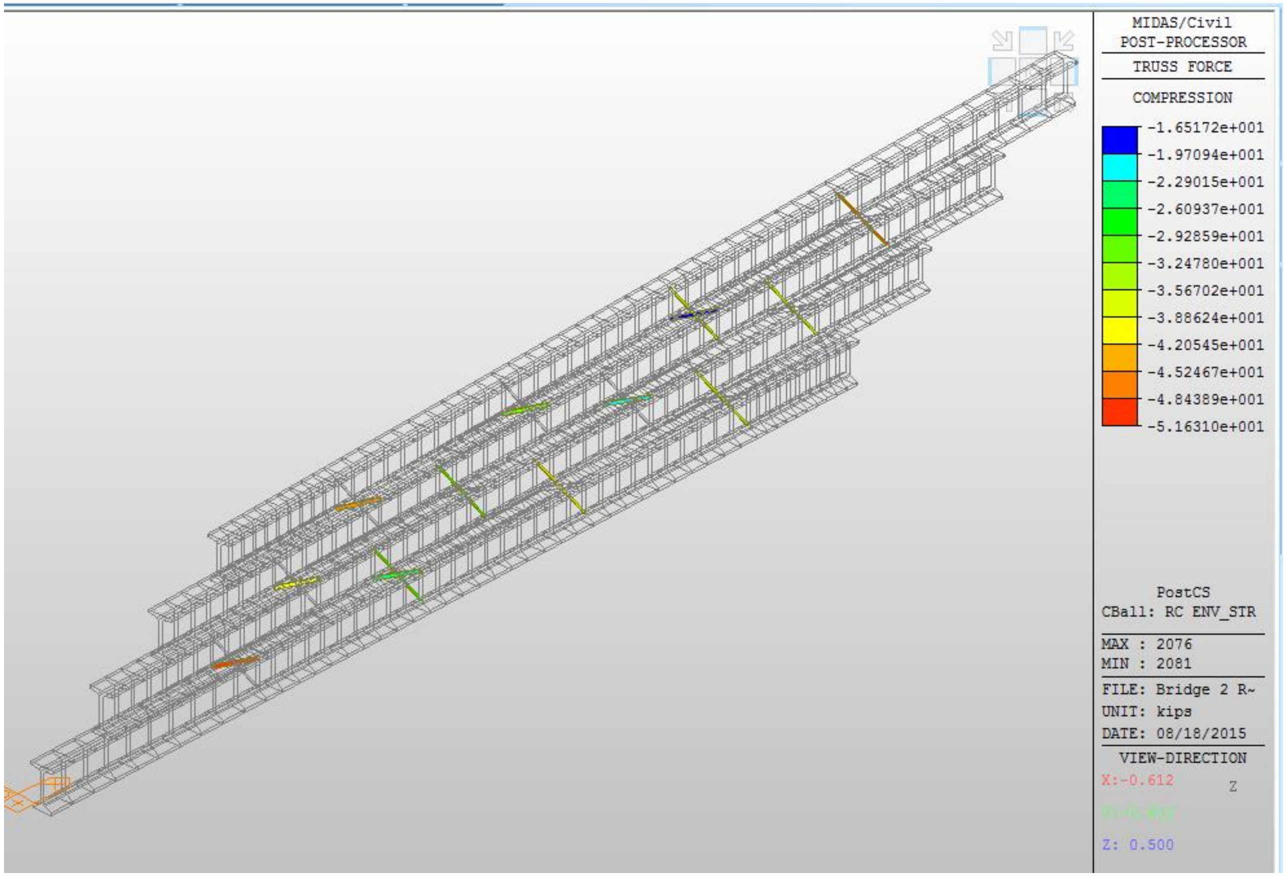
5. Results

- **Strength Limit State – Steel Diaphragm Force**
  - **Activate member size to be checked (L 6x6x3/8)**
  - **15 kip maximum compression / 102 kip resistance (OK)**



5. Results

- **Strength Limit State – Steel Diaphragm Force**
  - **Activate member size to be checked (L 6x4x5/16)**
  - **52 kip maximum compression / 66 kip resistance (OK)**

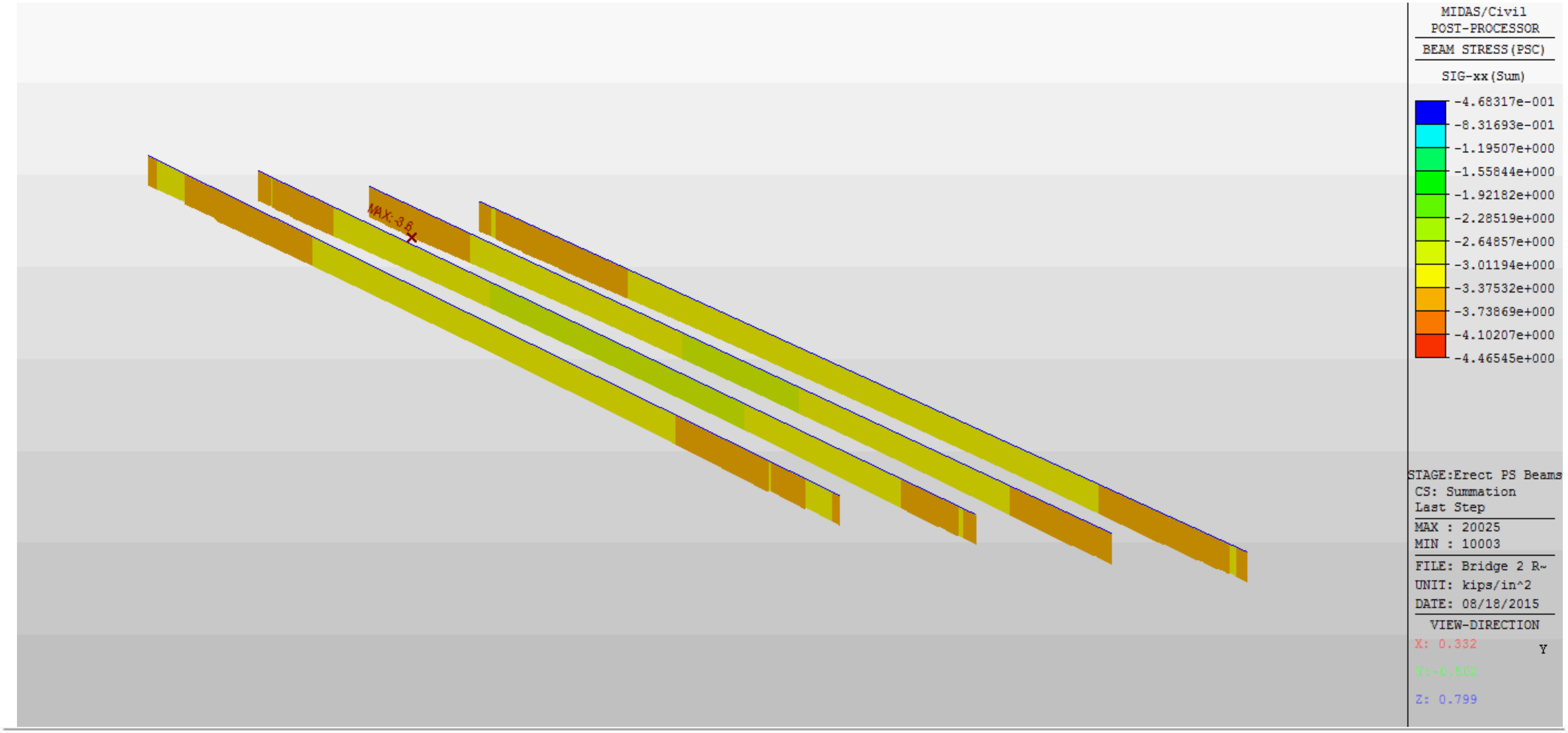


5. Results

- Construction Stage Analysis – Steel Diaphragm Force
  - During construction there are potentially large fluctuations in the diaphragm forces not evident from the final load conditions
  - Particular concern is during deck placement
  - MIDAS allows user to envelope Max/Min forces for all stages
  - For this bridge, the factored CS envelope diaphragm forces were:
    - 53 kips Compression
    - 55 kips Tension
  - Forces are equal to or less than the STR-I design forces and therefore do not govern

5. Results

- **Construction Stage Analysis – Beam Stresses**
  - **MIDAS provides CS beam stresses at each construction stage**
  - **Animation is a useful tool to visualize CS stage stress changes**
  - **CS stresses for this bridge were less than service loads**



Agenda

1. Introduction
2. Proposed Bridge Configuration
3. Preliminary Design
4. Refined Analysis Model
5. Results
6. **Conclusions**

6. Conclusions

- By comparing line girder analysis with refined analysis of this severely skewed prestressed bridge, the following was revealed:
  - Tensile stresses due to primary bending in the exterior beams was increased
  - Potentially significant tensile stresses due to lateral bending effects are present in interior and exterior beams alike
  - Compression stresses were increased in the exterior beams and due to lateral bending, but was not critical for this bridge
  - Shear at the obtuse bridge corners was increased
  - Significant restraint forces exist at the obtuse corner beam to diaphragm connection that merit further investigation
  - The assumed steel diaphragm sections checked out, but with refined analysis at least there is a basis for design
  - Stresses during construction stages were not critical for the beam, but should be checked for the assumed sequence

Acknowledgements

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