OHIO DEPARTMENT OF TRANSPORTATION

COUNTY ENGINEERS ASSOCIATION OF OHIO
"ALL TRAVEL STARTS AND ENDS ON A LOCAL ROAD"

Fracture Critical Analyses of Pony-Truss Bridges

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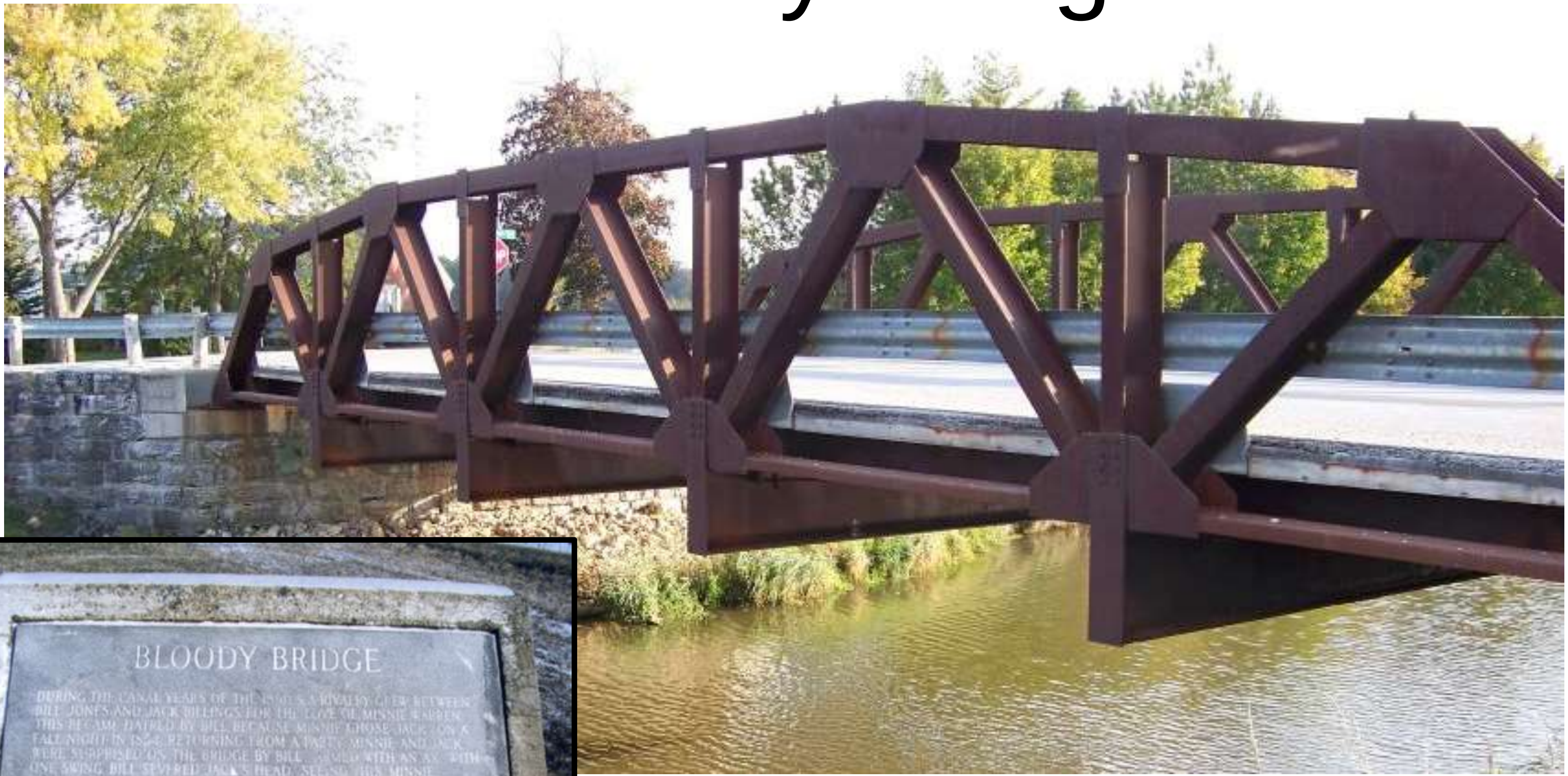
Background

Spencerville, OH

"During the canal years of the 1850s a rivalry grew between Bill Jones and Jack Billings for the love of Minnie Warren. There became hatred by Bill because Minnie chose Jack. On a fall night in 1854, returning from a party, Minnie and Jack were surprised on the bridge by Bill, armed with an axe. With one swing, Bill severed Jack's head. Seeing this, Minnie screamed and fell into a watery grave. Bill disappeared, and when a skeleton was found years later in a nearby well, people asked was it suicide or justice."

http://www.ghostsofohio.org/

The Bloody Bridge



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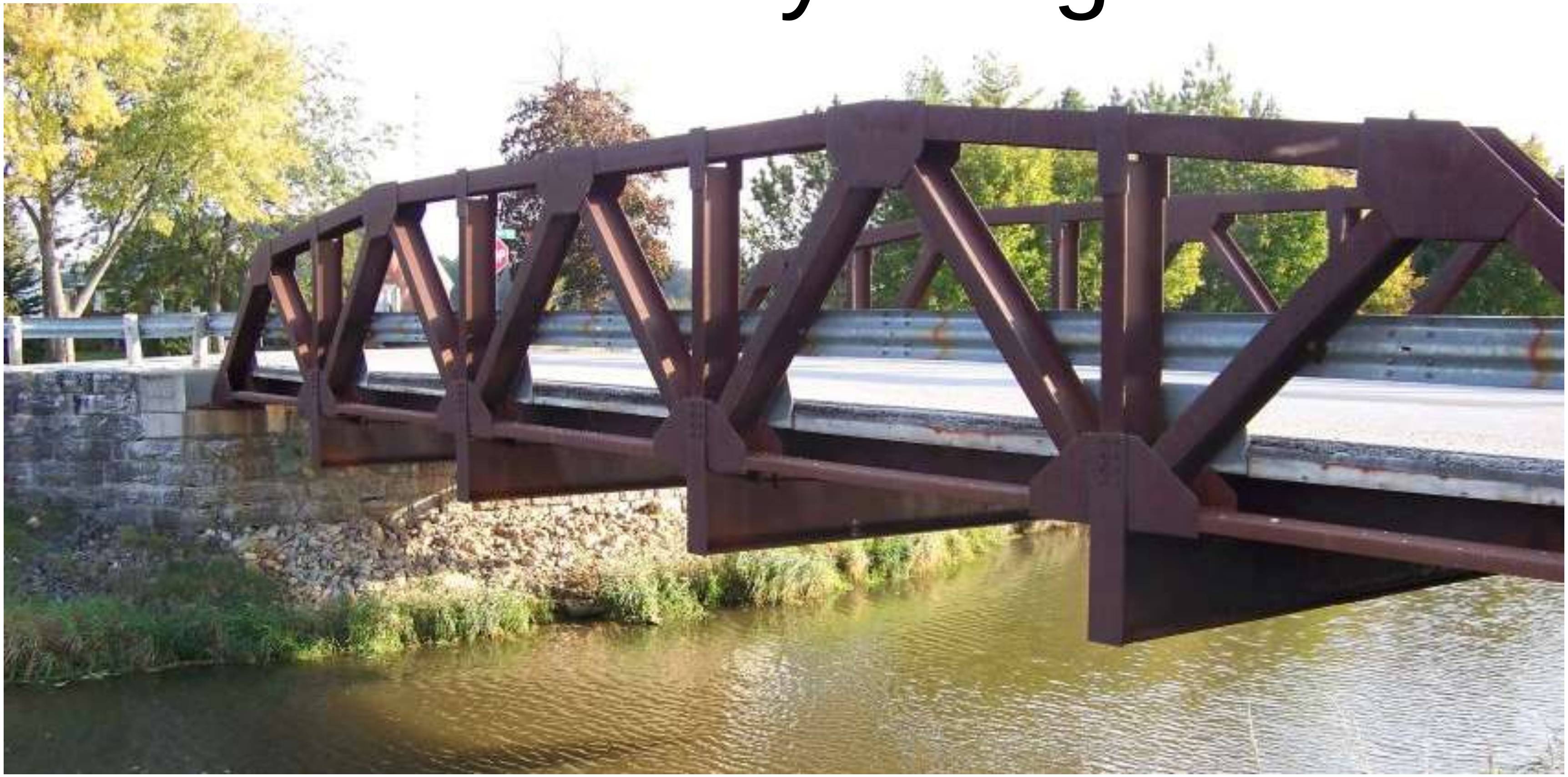


Fracture Critical = More Complex Inspections = Higher Costs

"Fracture Critical Member"

- NBIS Definition: A steel member in tension, or a member with a tension element, whose failure would probably cause a portion of, or the entire bridge to collapse.

- AASHTO-MBE: A steel tension member or tension component of a steel member whose failure would be expected to result in a partial or full collapse of the bridge.

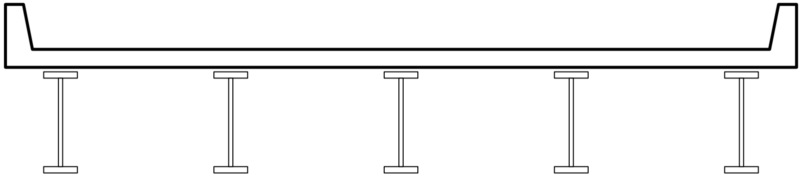
- AASHTO-LRFD: A component in tension whose failure is expected to result in the collapse of the bridge or the inability of the bridge to perform its function.

Structural Redundancy

- Load-Path Redundancy
- Structural Redundancy
- Internal Member Redundancy
- System Redundancy

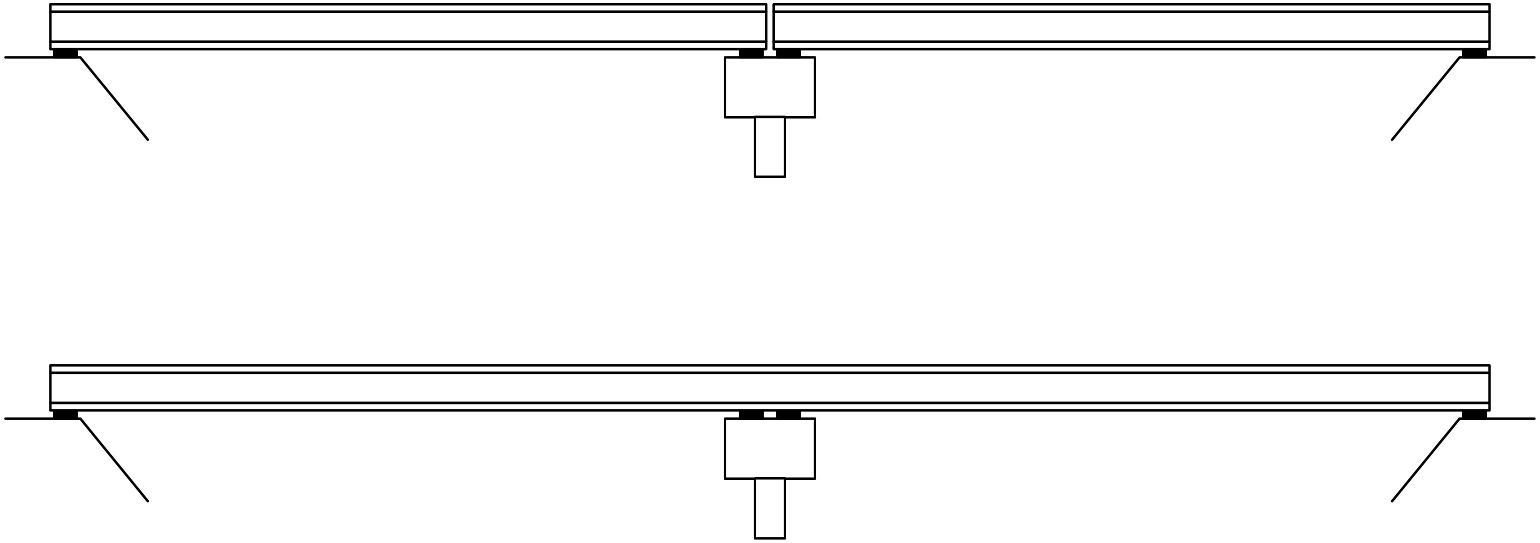
Structural Redundancy

- Load-Path Redundancy



Structural Redundancy

- Structural Redundancy



Structural Redundancy

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Structural Redundancy

- System Redundancy

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The Problem...

Pony Truss Bridges = Fracture Critical

Pony Truss Bridges

Design Assumptions:

- Trusses Designed as 2D Determinate Systems
- Very Little System Behavior is Assumed

Possible Secondary Load Paths:

- Internal Member Redundancy
- Axial Continuity of Stringers / Longitudinal Deck Continuity
- Flexural Continuity of the Stringers
- Participation of Secondary and Nonstructural Elements
- Indeterminate Support Conditions

2012 FHWA Memorandum

Federal Highway Administration

Memorandum

Subject: <u>**ACTION:**</u> Clarification of Requirements for Fracture Critical Members
/s/ original Signed by

Date: June 20, 2012

From: M. Myint Lwin, P.E., S.E.
Director, Office of Bridge Technology

In Reply Refer To: HIBT-10

To: Directors of Field Services
Federal Lands Highway Division Engineers
Division Administrators

The purpose of this memo is to provide clarification of the FHWA policy for the classification of Fracture Critical Members. For design and fabrication, only Load Path Redundancy may be considered. For in-service inspection protocol, Structural Redundancy demonstrated by refined analysis is now formally recognized and may also be considered. Internal member redundancy is currently not recognized in the classification of Fracture Critical Members for either design and fabrication or in-service inspection. Finally, this memo introduces a new member classification, a System Redundant Member (SRM), which is a non-load-path-redundant member that gains its redundancy by system behavior.

Several States and FHWA Division Bridge Engineers have requested that we clarify our policy regarding the classification of Fracture Critical Members (FCMs). There are two primary implications related to identifying FCMs in bridges: 1) specification of proper materials and testing for design and fabrication, and 2) establishment of proper in-service inspection protocol. Clarification of our current policy and future direction is provided herein.

Definitions
The current National Bridge Inspection Standards (NBIS) definition for a FCM is ***"a steel member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse."***

The AASHTO *Manual for Bridge Evaluation* (MBE), 2nd Edition, defines a FCM as ***"steel tension members or steel tension components of members whose failure would be expected to result in a partial or full collapse of the bridge."***

The AASHTO *LRFD Bridge Design Specifications* (LRFD), 6th Edition, defines a FCM as a ***"component in tension whose failure is expected to result in the collapse of the bridge or the inability of the bridge to perform its function."***

Date: June 20, 2012

Subject: Clarification of Requirements for Fracture Critical Members

From: M. Myint Lwin
Director, Office of Bridge Tech

To: Directors of Field Services

2012 FHWA Memorandum

The Memo States:

- “If a refined analysis demonstrates that a structure has adequate strength and stability sufficient to avoid partial or total collapse and carry traffic in the presence of a totally fractured member (by structural redundancy), the member does not need to be considered fracture critical for in-service inspection protocol.”

- “The assumptions and analyses conducted to support this determination need to become part of the permanent inspection records or bridge file so that it can be revisited and adjusted as necessary to reflect changes in bridge conditions or loadings.”

2012 FHWA Memorandum

So what's an "Refined Analysis?"

What's a Refined Analysis

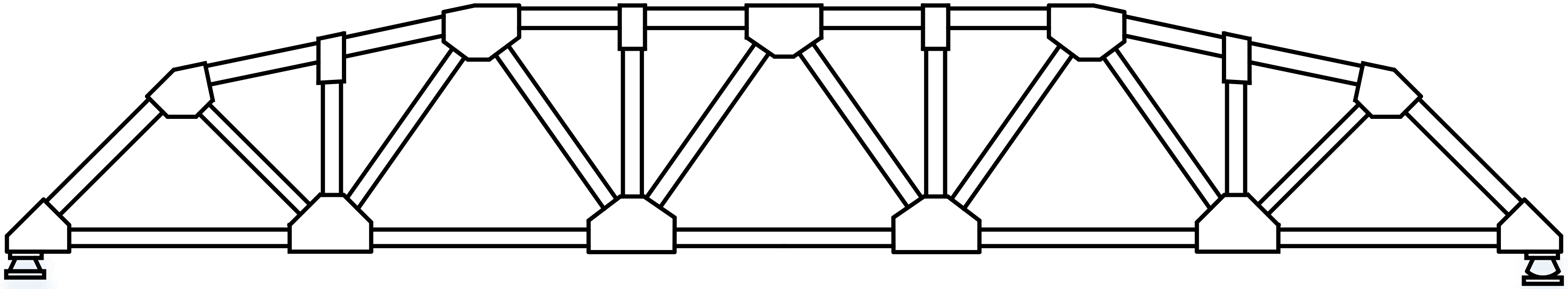
What Type of Loading do we use?

What's a Refined Analysis

What Type of Loading do we use?

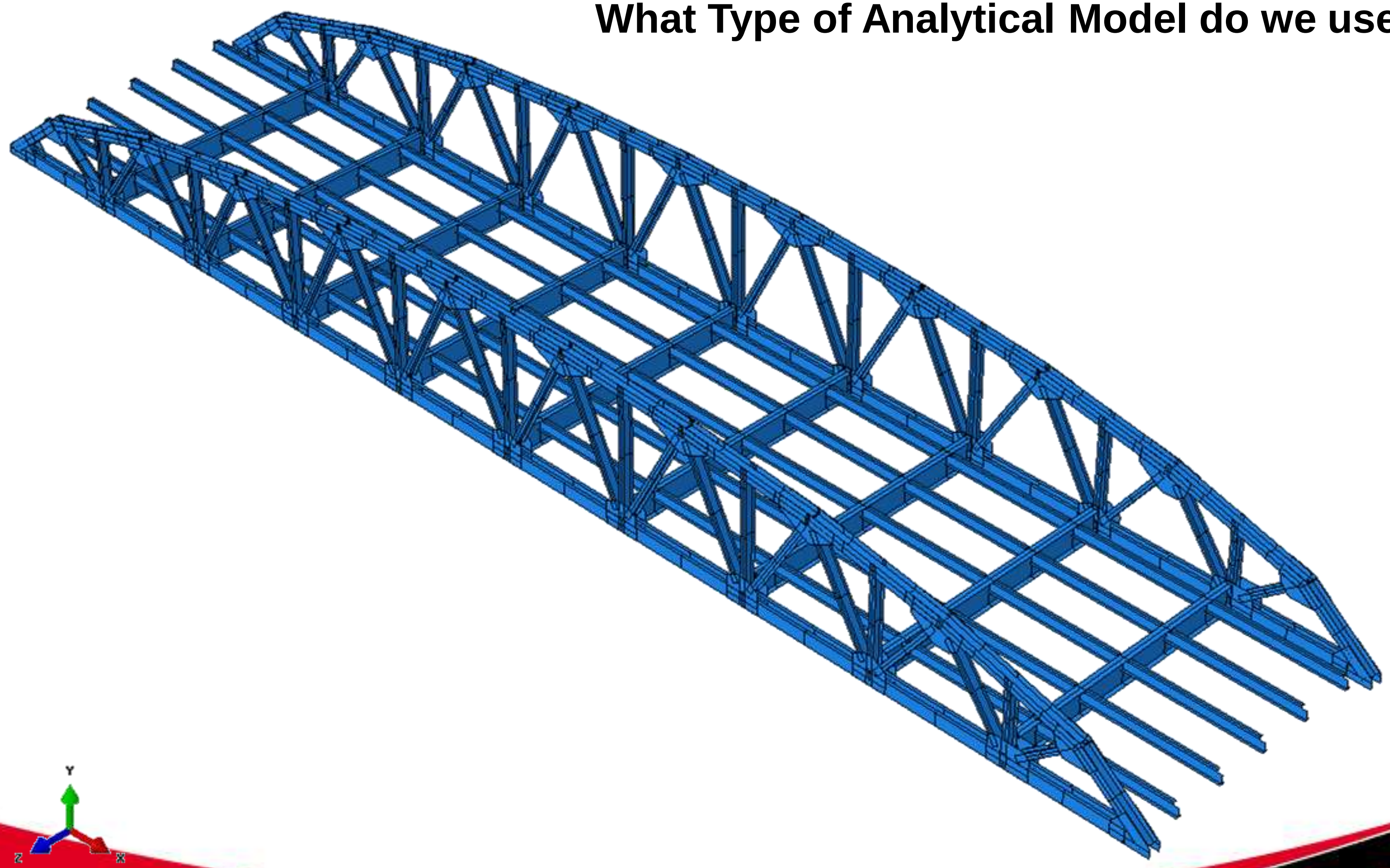
What's a Refined Analysis

What Type of Analytical Model do we use?



What's a Refined Analysis

What Type of Analytical Model do we use?



What's a Refined Analysis

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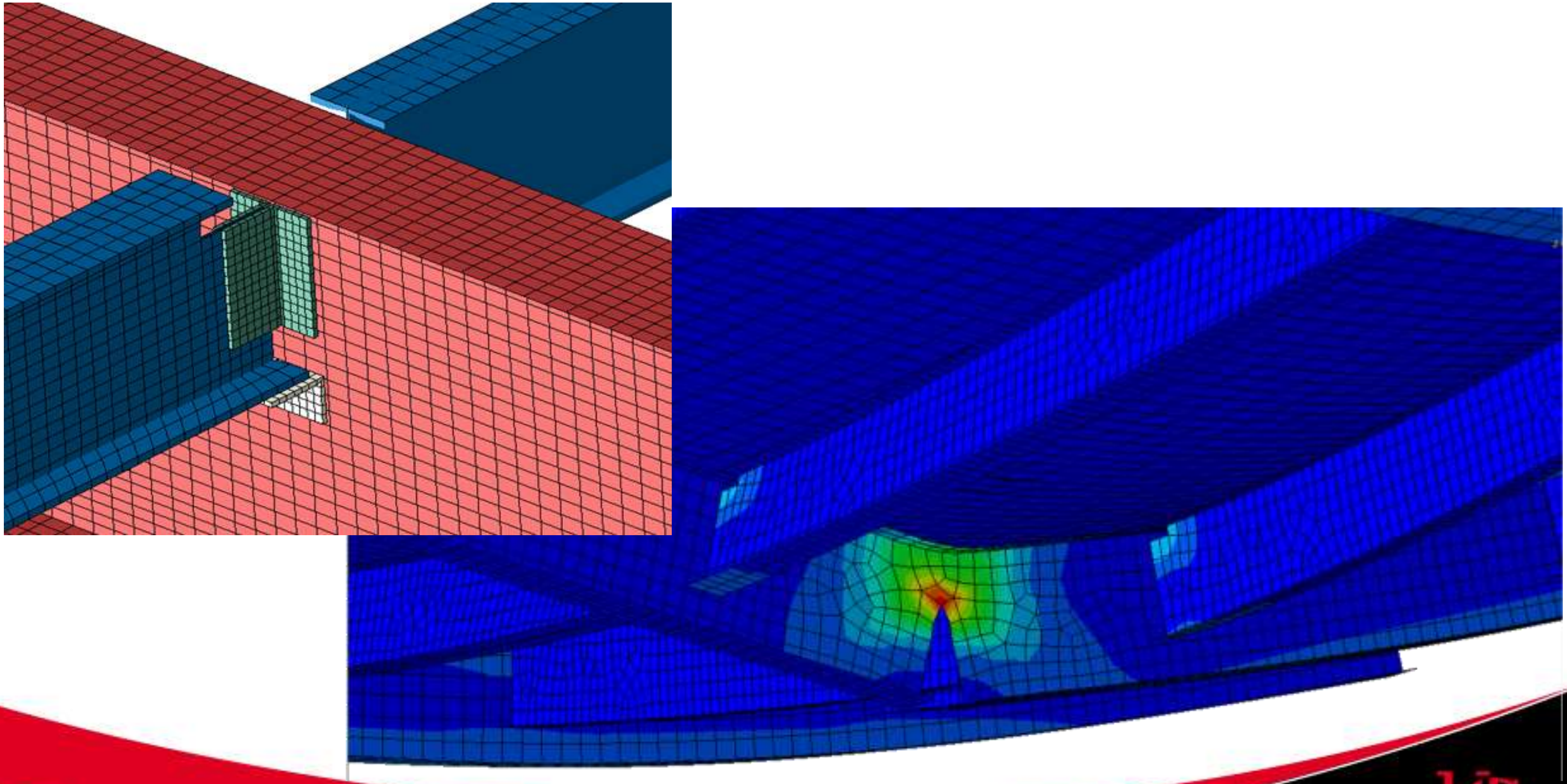

Goals of UC/ODOT Study

Develop a Protocol for the “Refined Analysis”

- Straightforward 3D Model
- Fairly Standard Analysis Software
- Implementable by Consultants or County Engineers

Possibly Develop Blanket Conclusions for Pony Truss Bridges

- Floor Beams Spaced at 14’-0” or Greater
- Certain PTB Topologies or Deck Types
- Built-Up Tension Members

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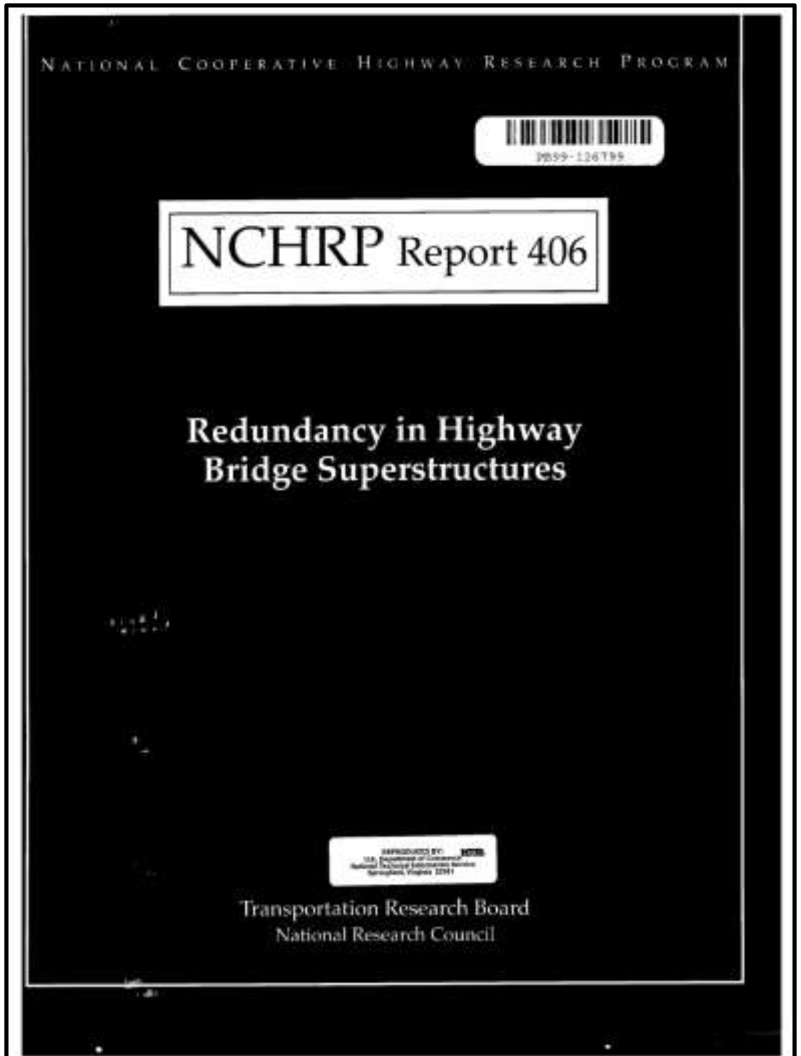

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 406

Redundancy in Highway Bridge Superstructures

Transportation Research Board
National Research Council

NCHRP 406

The Main Objective of NCHRP 406 Is:

- ...to define methods of quantitatively assessing structural redundancy in highway bridges.

Four Limit States are Considered:

- Member Failure LF_1
- Ultimate Capacity LF_u
- Functionality LF_f
- Damaged Capacity LF_d

NCHRP 406

- $(LF_1)\,(P_{LL}) + P_{DL} = P_n$

$$LF_1 = \frac{P_n - P_{DL}}{P_{LL}}$$

- $(LF_u)\,(LL) + DL$ = Collapse
- $(LF_f)\,(LL) + DL$ = Displacement Limit
- $(LF_d)\,(LL) + DL$ = Collapse

$$LF_d = \frac{TL_d - DL}{LL}$$

Damage Simulated by Removing a Member from the Structural Model

NCHRP 406

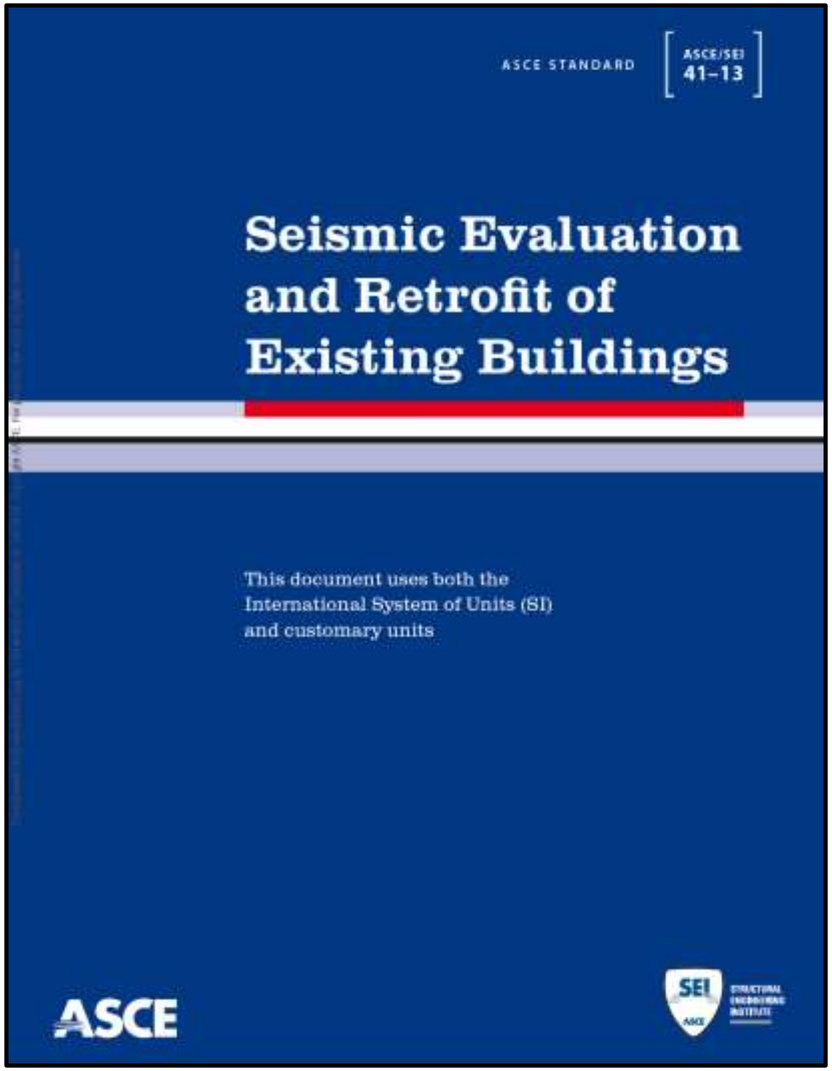
- Reserve Ratios for the Bridge are then Computed:

$$R_u = \frac{LF_u}{LF_1} \qquad R_f = \frac{LF_f}{LF_1} \qquad R_d = \frac{LF_d}{LF_1}$$

- Damaged Condition is Most Applicable to Fracture Critical Analyses:

$$R_d = \frac{LF_d}{LF_1} \square \frac{\text{Collapse Strength of the Damaged Bridge}}{\text{Design Strength of the Undamaged Bridge}}$$

- Criterion for Damaged Redundancy: $\boldsymbol{R_d \geq 0.50}$


ASCE STANDARD
ASCE/SEI 41-13
Seismic Evaluation and Retrofit of Existing Buildings
This document uses both the International System of Units (SI) and customary units
ASCE
SEI

ASCE 41-13

The Main Objective of ASCE 41-13 is:

- ... to provide engineers with methods of assessing the seismic integrity of structures that were designed to meet codes and standards that are not as rigorous as current codes.

The General Procedure for an ASCE 41 Evaluation is:

- Define Building Performance Levels
- Define Seismic Hazards and Levels of Seismicity
- Obtain As-Built Information
- Perform an Analysis of the Structure
- Evaluate the Structural Components
- Identify Deficiencies and Implement Retrofit Strategies

ASCE 41-13

Four Different Analysis Procedures are Defined in ASCE 41:

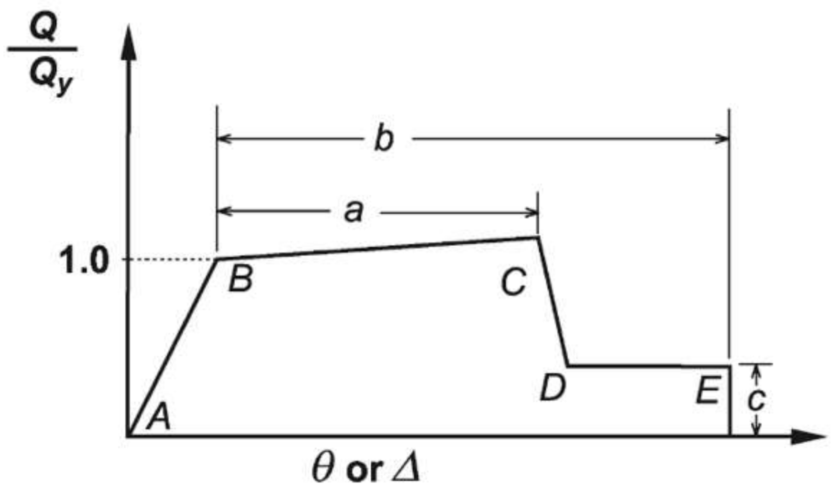
- Linear Static Procedure (LSP):
  - Linear Elastic Analysis of the Structure
  - Gravity Loads and Static Lateral Loads
- Linear Dynamic Procedure (LDP):
  - Linear Elastic Time History Analysis of the Structure
  - Acceleration Records that are Representative of the Anticipated Seismicity
- Nonlinear Static Procedure (NSP):
  - Static Analysis of the Structure
  - Nonlinear Load-Deformation Responses
  - Gravity Loads and Monotonically Increasing Lateral Load Pattern
- Nonlinear Dynamic Procedure (NDP):
  - Time History Analysis Similar to that Used in the NSP Analysis
  - Nonlinear Load-Deformation Responses

Pushover Analysis

ASCE 41-13

Nonlinear Static Procedure (NSP):

- Nonlinear Member Behavior



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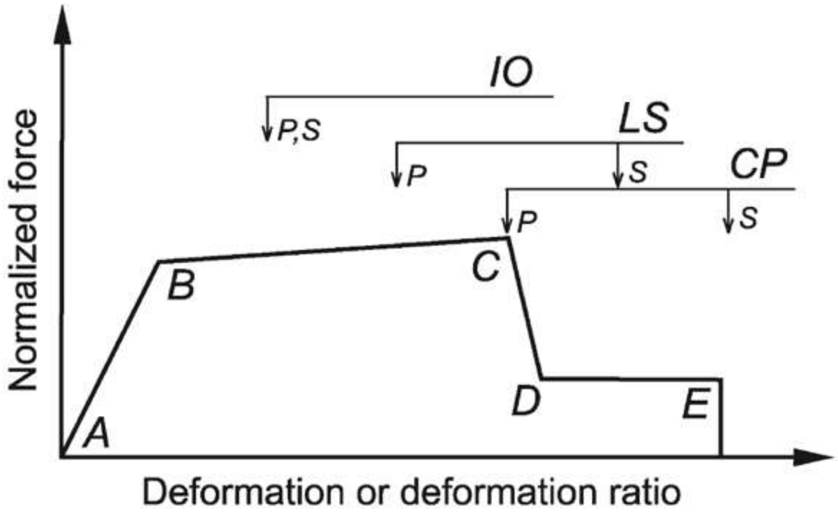

(b)

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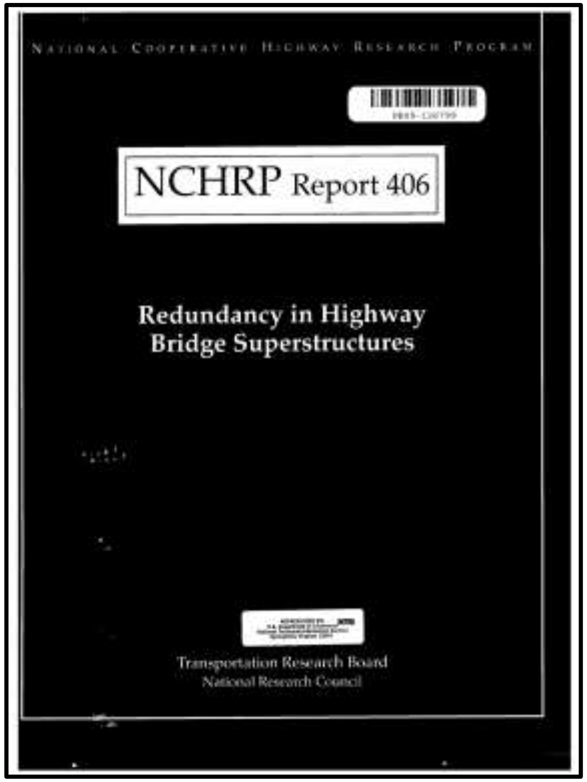
Our Approach

Combine the Reliability Basis and Acceptance Criteria of NCHRP Report 406... **...with the Analysis Methods of ASCE 41.**



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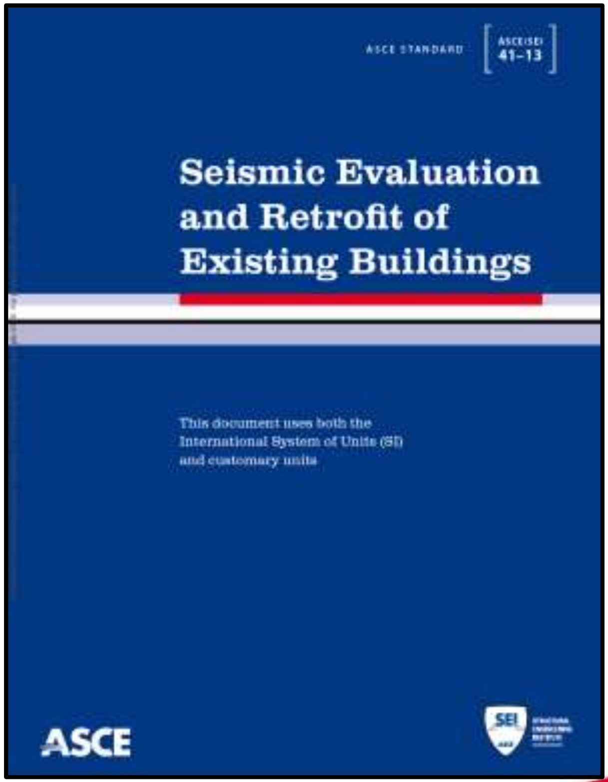
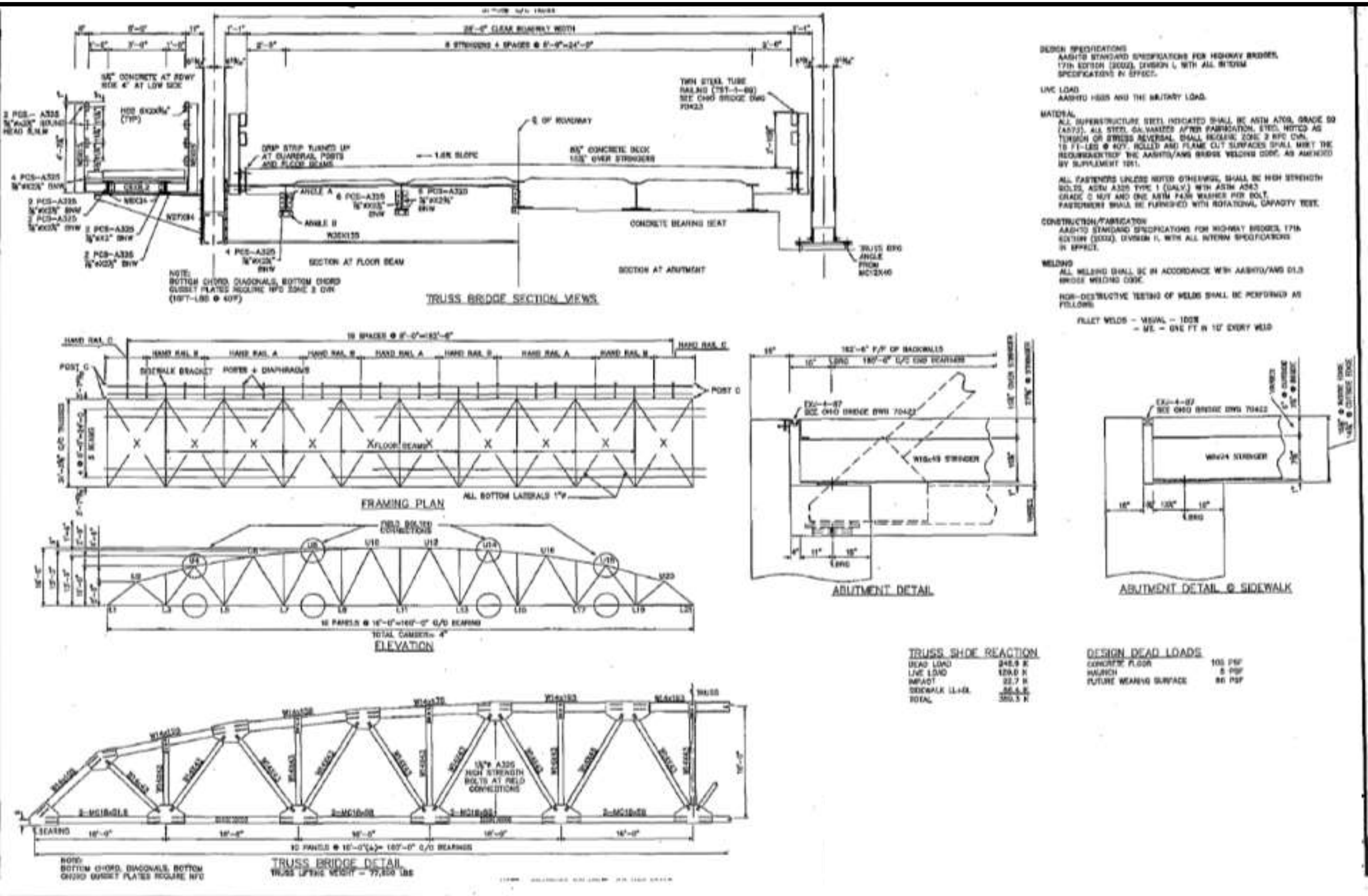
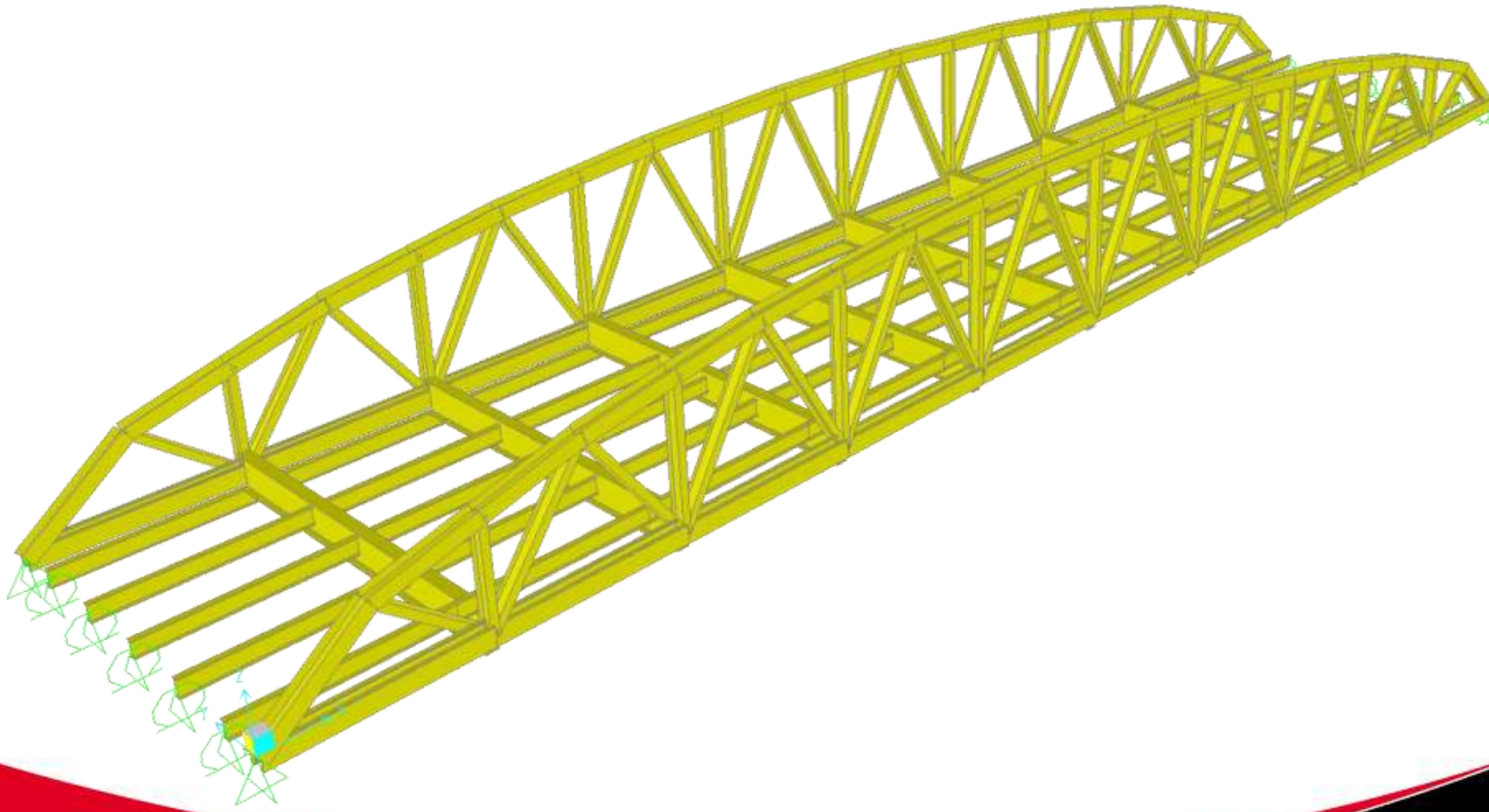


Consider an Example

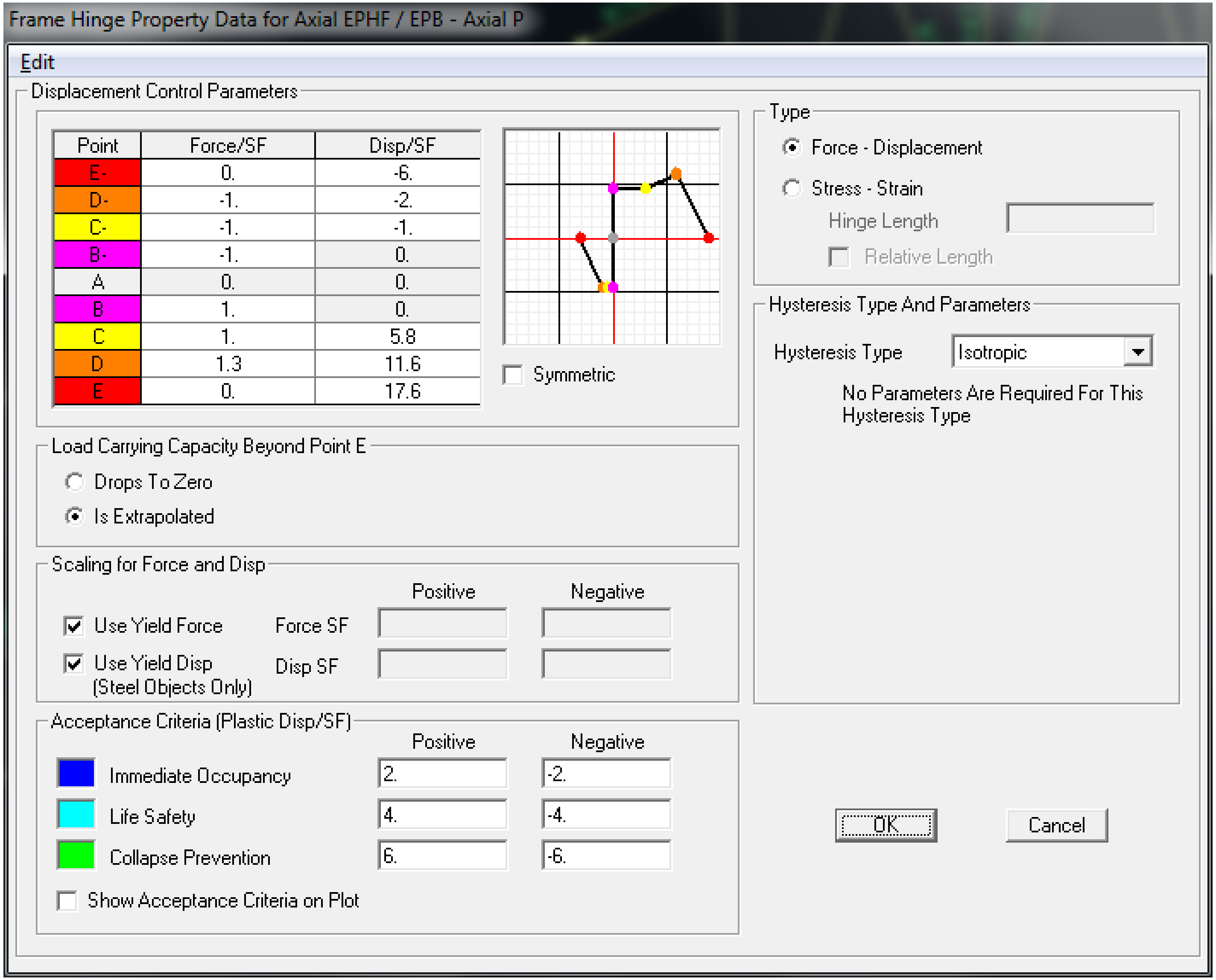


Step 1 – Create an FE Model



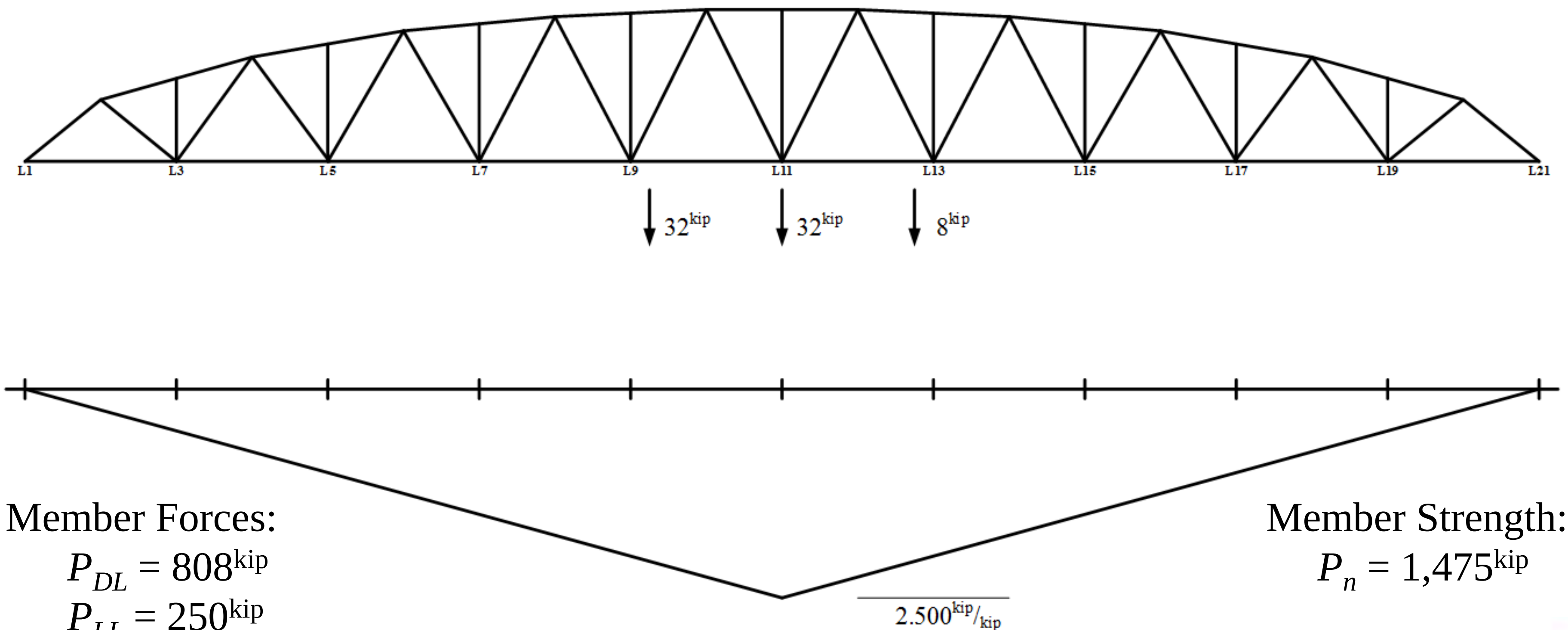
Step 1 – Create an FE Model

Nonlinear Hinge Models



Step 2 – Define Loads and Find LF_1

Find Truck Position for Maximum Force in Member Being Evaluated.



Member Forces:

$P_{DL} = 808^{kip}$

$P_{LL} = 250^{kip}$

Member Strength:

$P_n = 1{,}475^{kip}$

Step 2 – Define Loads and Find LF_1

Member Failure (LF_1): The member failure limit state is defined as the capacity of the structure to resist first member failure. A member failure is defined as the exceedance of strength as computed using AASHTO equations for strength:

$$LF_1 = \frac{P_n - P_{DL}}{P_{LL}}$$

$$LF_1 = \frac{1,475^{\text{kip}} - 808^{\text{kip}}}{250^{\text{kip}}} = 2.668$$

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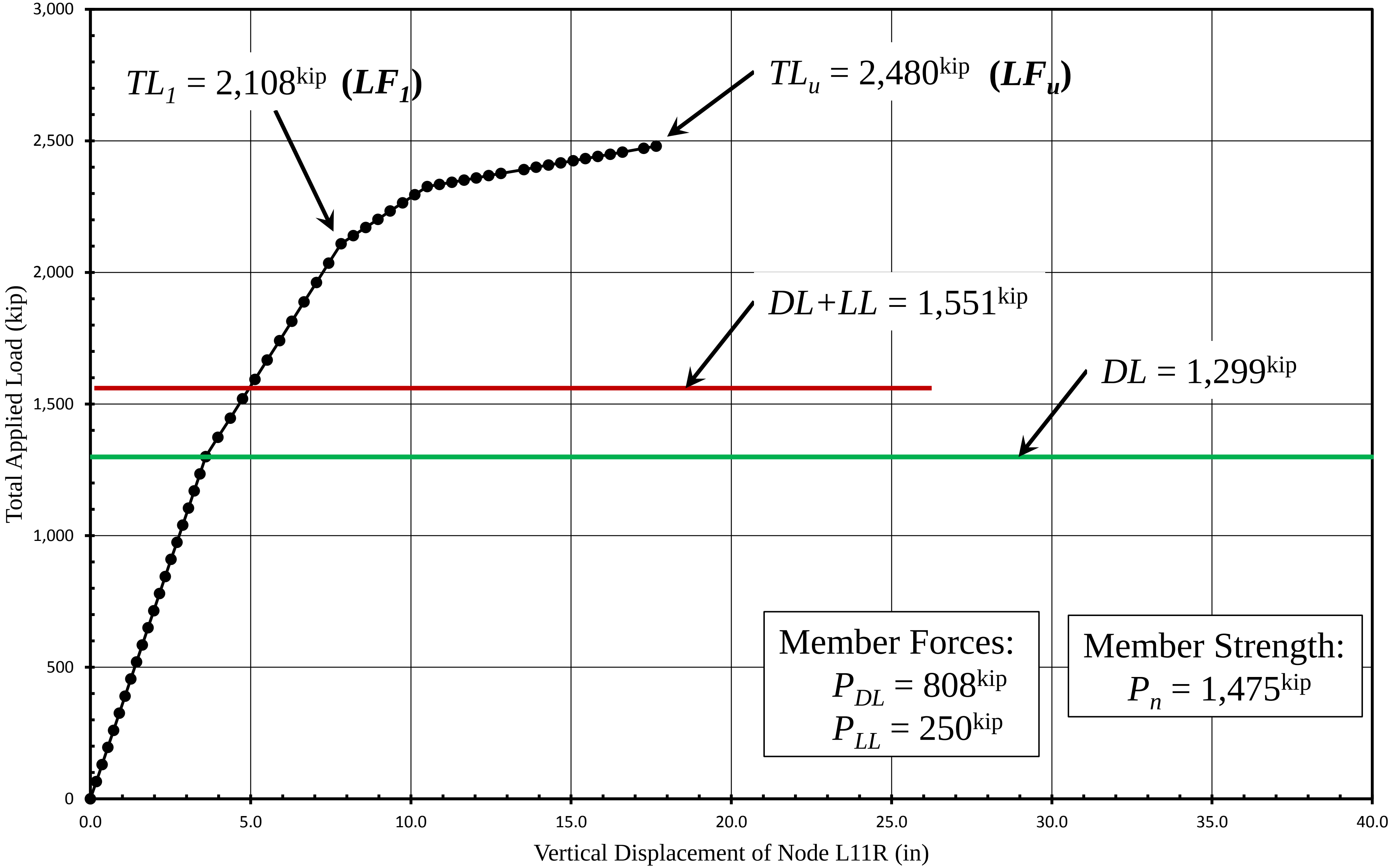
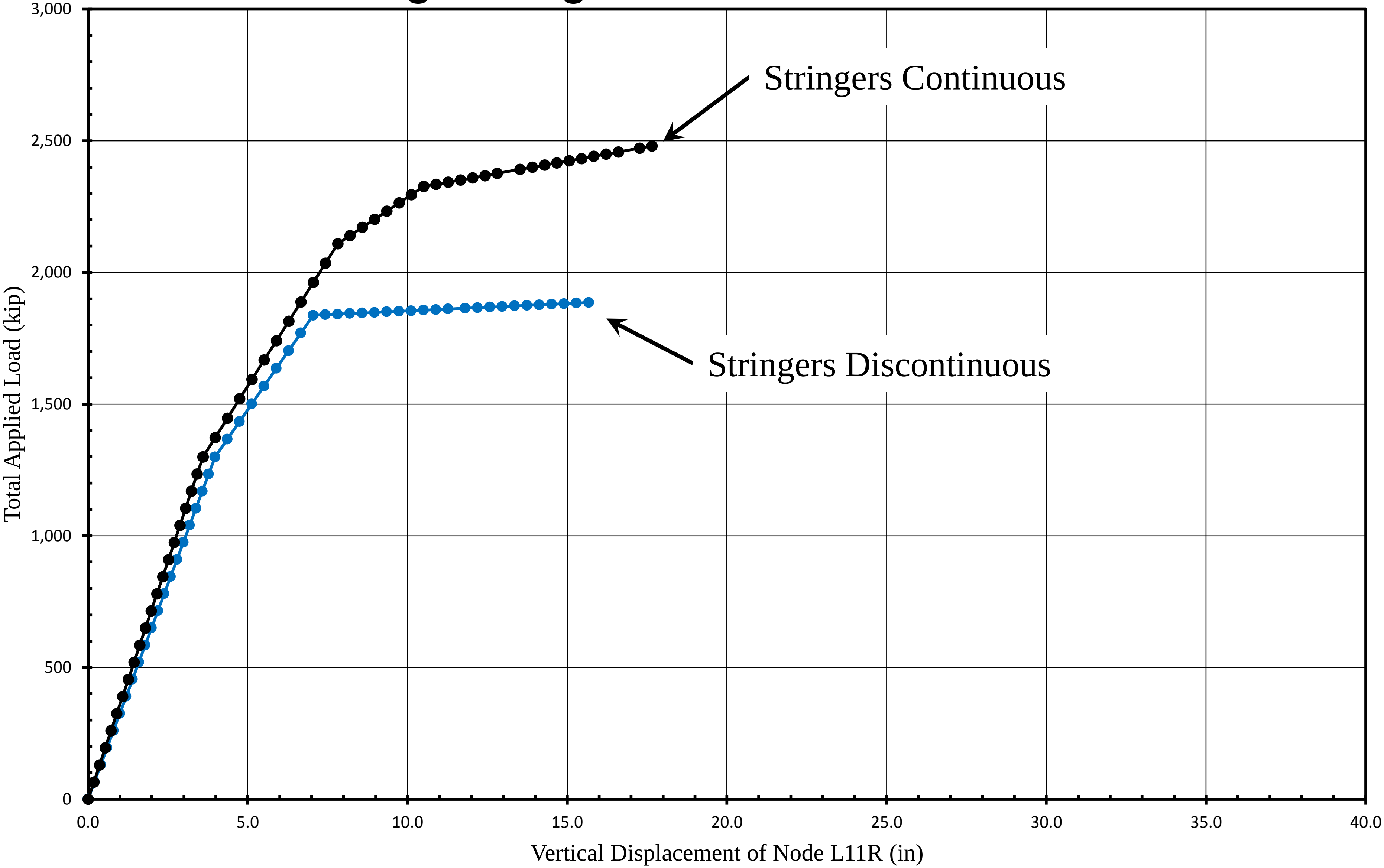
Step 2 – Define Loads and Find LF_1

For the Undamaged Bridge

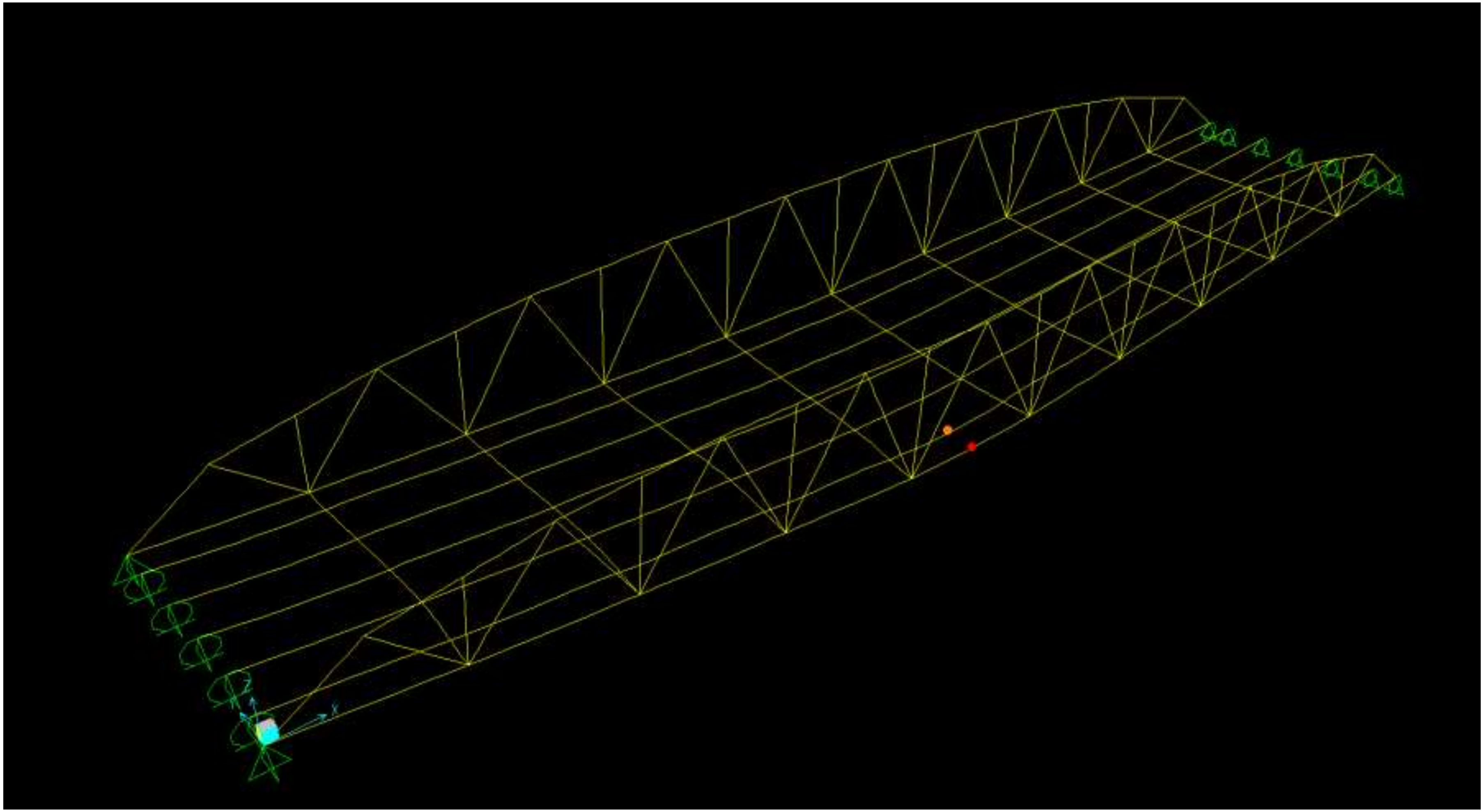


System Redundancy

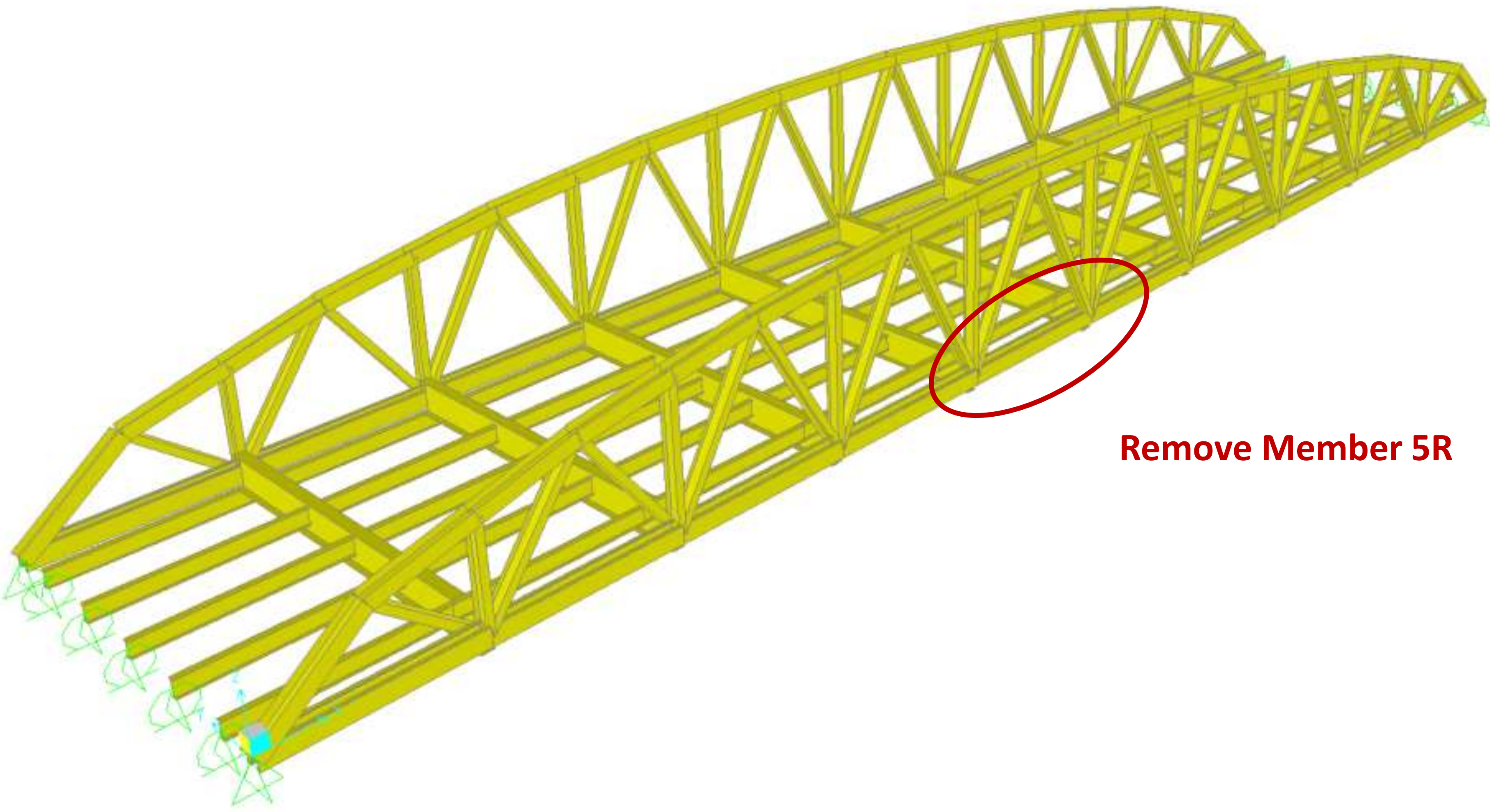
For the Undamaged Bridge



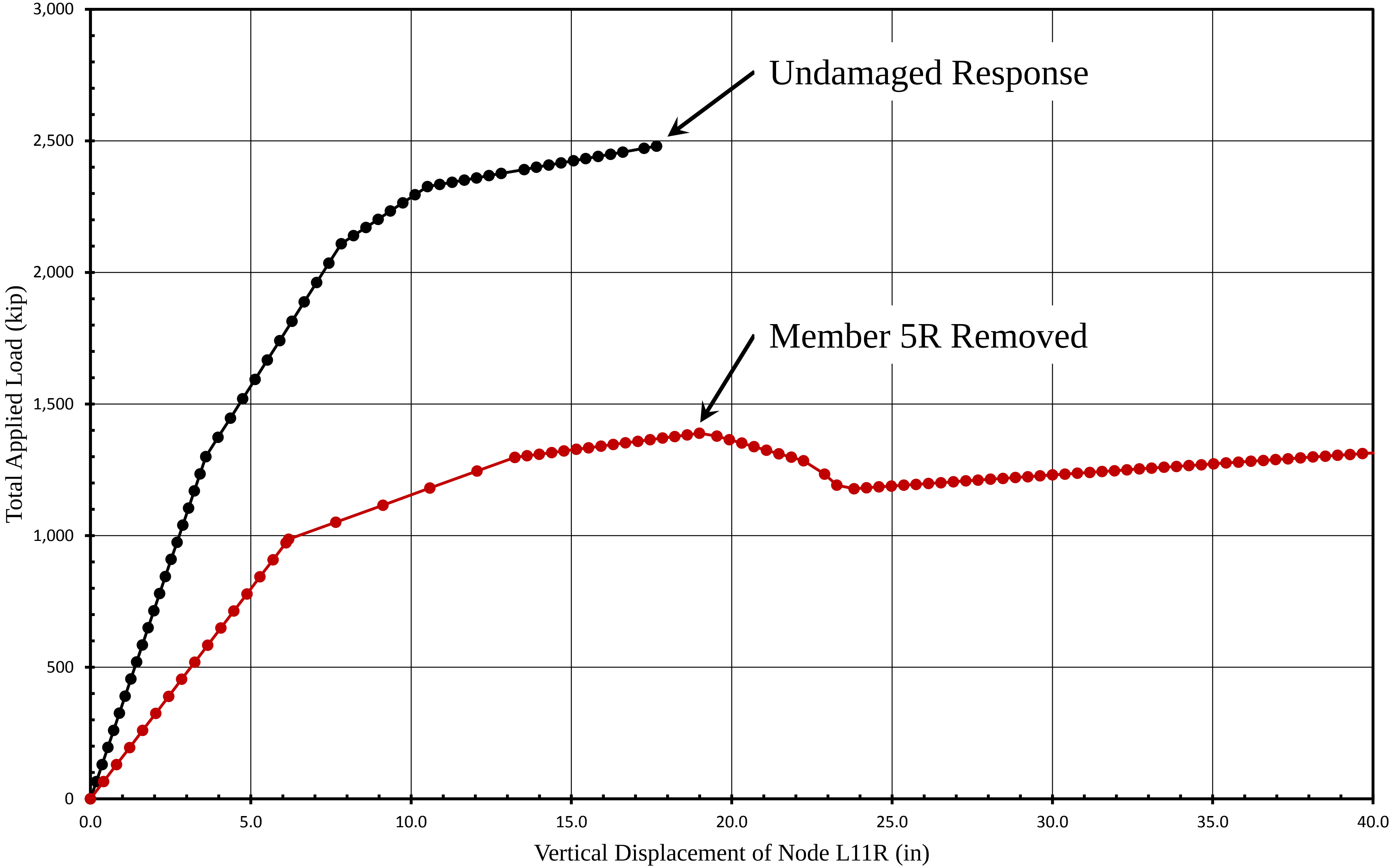
System Redundancy



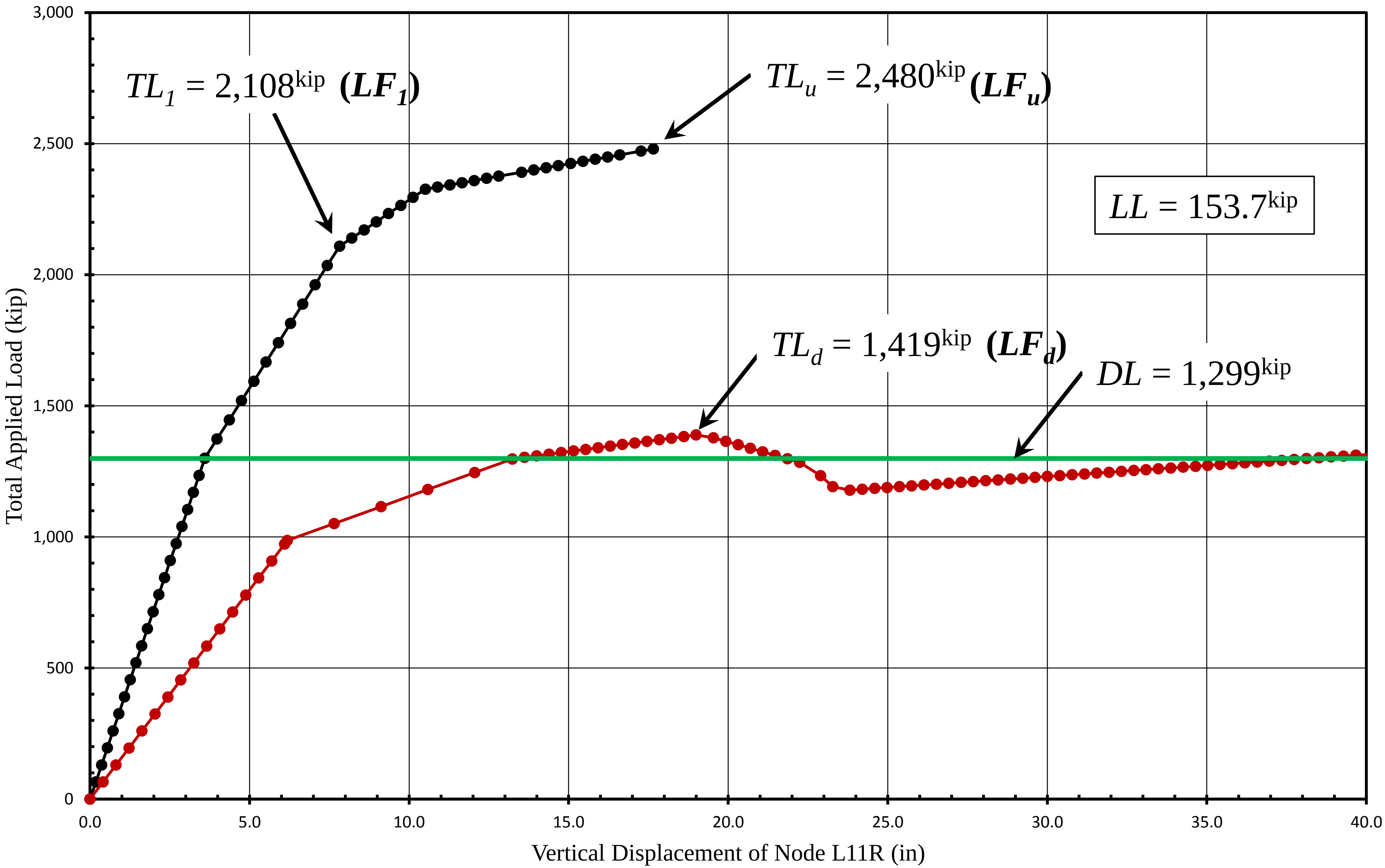
Step 3 – Remove the FCM and Find LF_d



Step 3 – Remove the FCM and Find LF_d



Step 3 – Remove the FCM and Find LF_d



Step 3 – Remove the FCM and Find LF_d

Damaged Condition Limit State (LF_d): The load factor associated with the damaged condition is taken as

$$LF_d = \frac{TL_d - DL}{LL}$$

$$LF_d = \frac{1,419^{\text{kip}} - 1,299^{\text{kip}}}{153.7^{\text{kip}}} = 0.7807$$

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Step 4 – Evaluate Bridge Robustness

Reserve Ratio for Damaged Bridge

$$R_d = \frac{LF_d}{LF_1} \square \frac{\text{Collapse Strength of the Damaged Bridge}}{\text{Design Strength of the Undamaged Bridge}}$$

$$R_d = \frac{LF_d}{LF_1} \square \frac{0.7807}{2.668} = 0.2926$$

- Criterion for Robustness: $\boldsymbol{R_d \geq 0.50}$

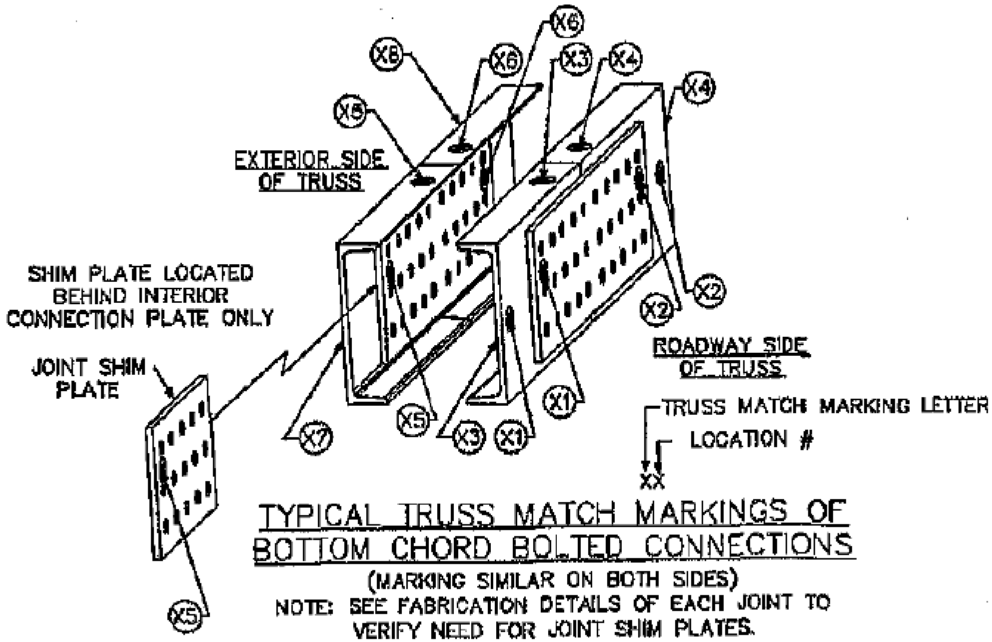
Member is Fracture Critical

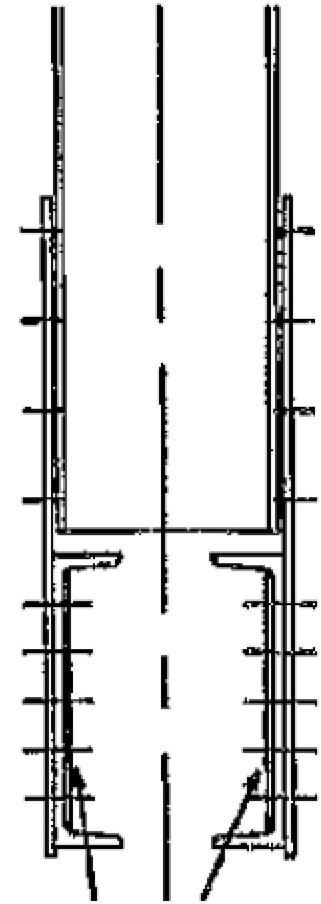
US Bridge Truss #4

Member 5R actually consists of two channels

US Bridge Truss #4

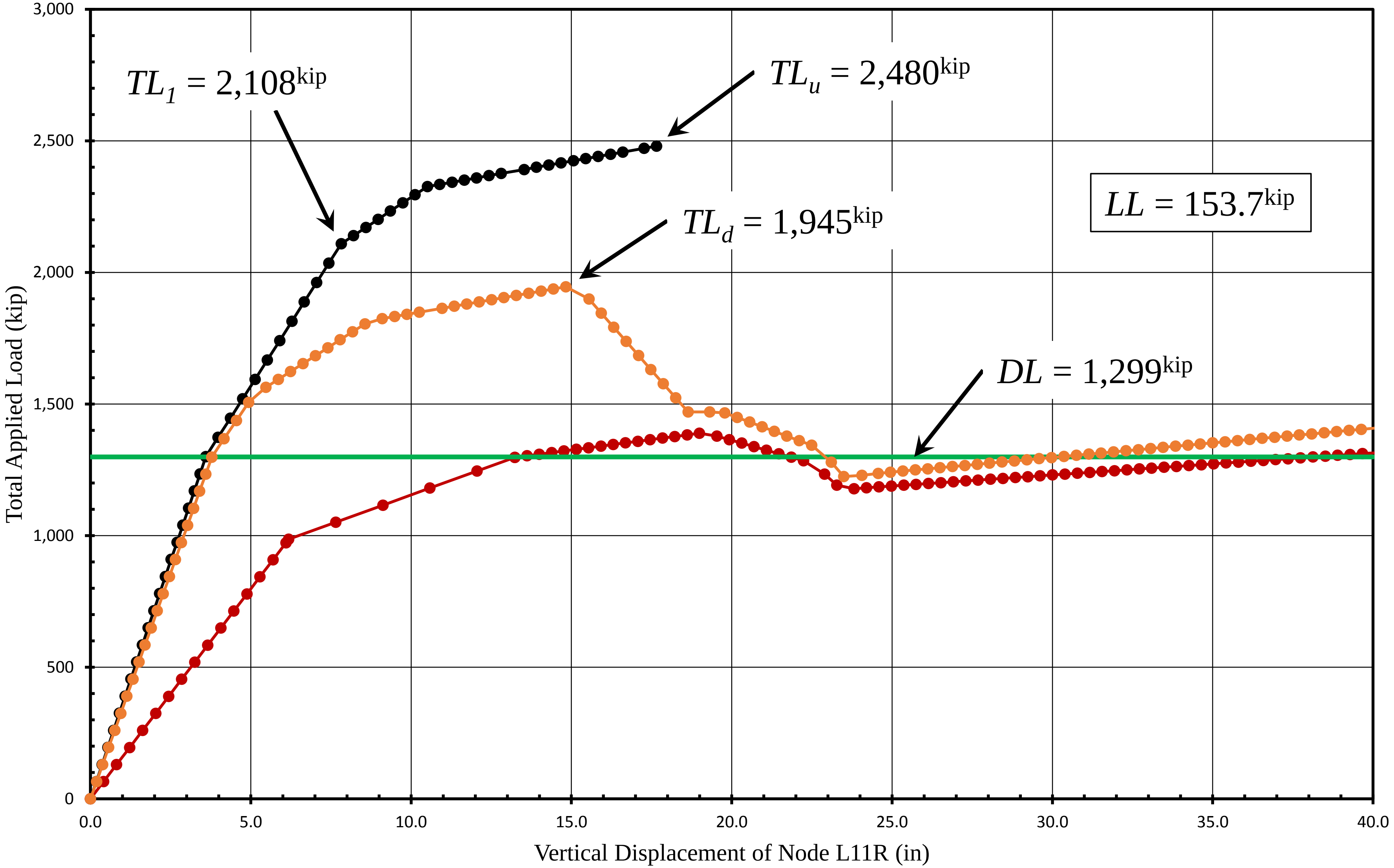
Member 5R actually consists of two channels





What if only one of the two channels is removed?

Step 3 – Remove the FCM and Find LF_d



Step 4 – Evaluate Bridge Robustness

Reserve Ratio for Damaged Bridge

$$LF_d = \frac{1,945^{\text{kip}} - 1,299^{\text{kip}}}{153.7^{\text{kip}}} = 4.203$$

$$R_d = \frac{LF_d}{LF_1} \; \frac{4.203}{2.668} = 1.575$$

- Criterion for Robustness: $\boldsymbol{R_d \geq 0.50}$

Member is Not Fracture Critical

With Two Channels

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Preliminary Observations

Some Members More Robust than Others

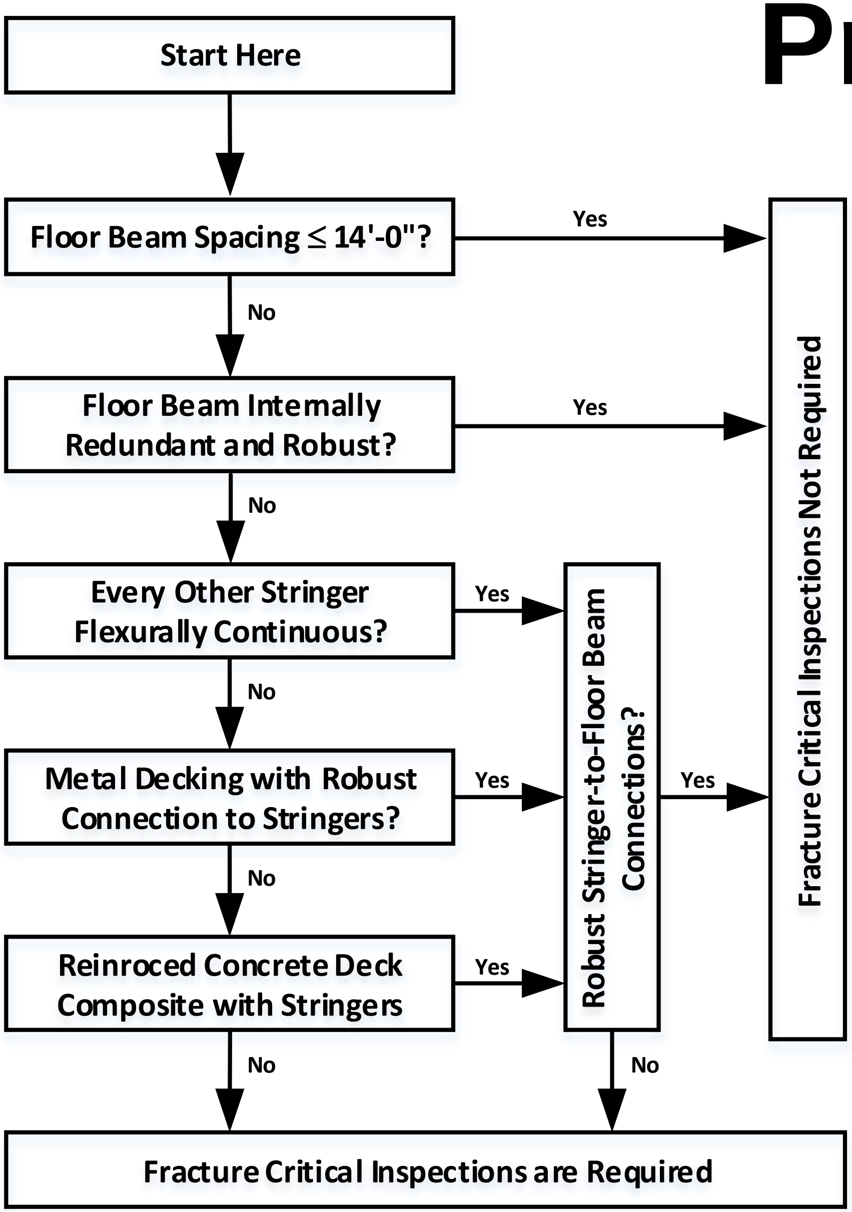
- Internally Redundant Tension Chords do Well
- Diagonal Members are Troublesome
- Floor Beams are Typically Well Behaved

...but the Devil is in the Details

- Connections between the Deck and Stringers,
- Connections Between the Stringers and Floor Beams
- Axially and Flexurally Continuous Stringers

Preliminary Conclusion

for Floor Beams



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