Two Steel Box Girder Bridges
Evaluating Redundancy

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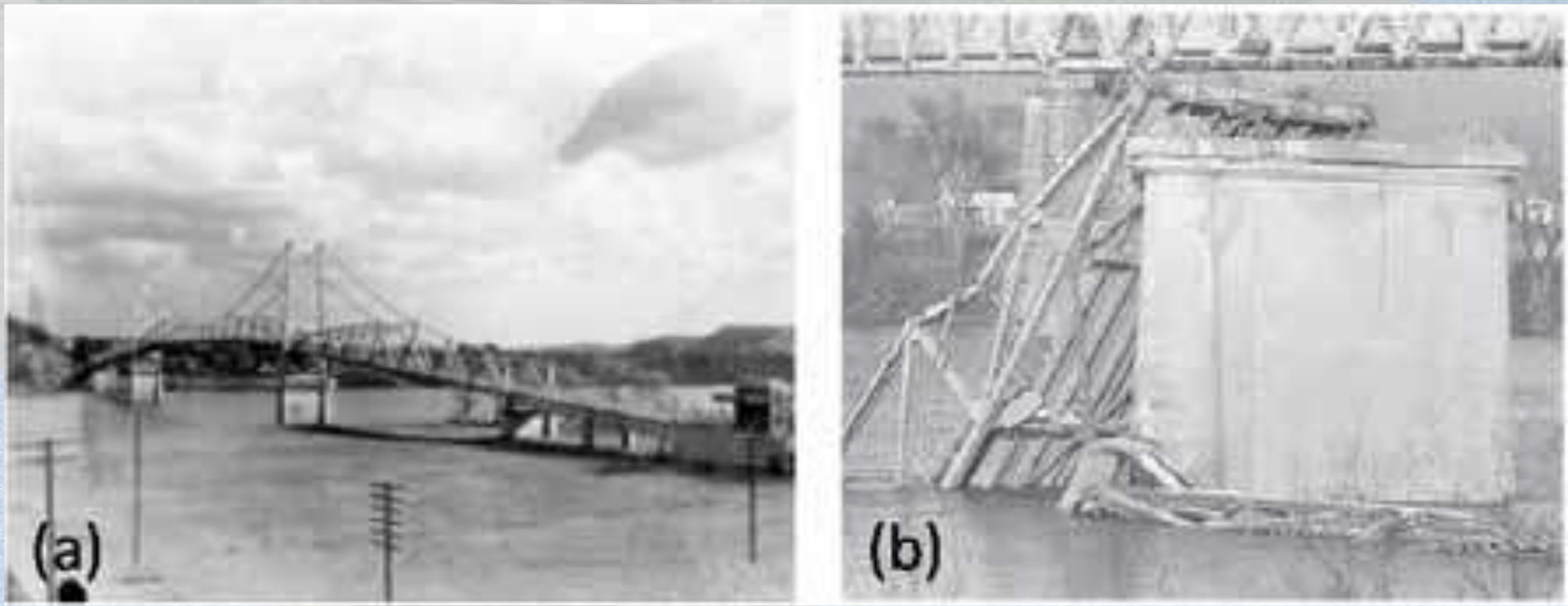
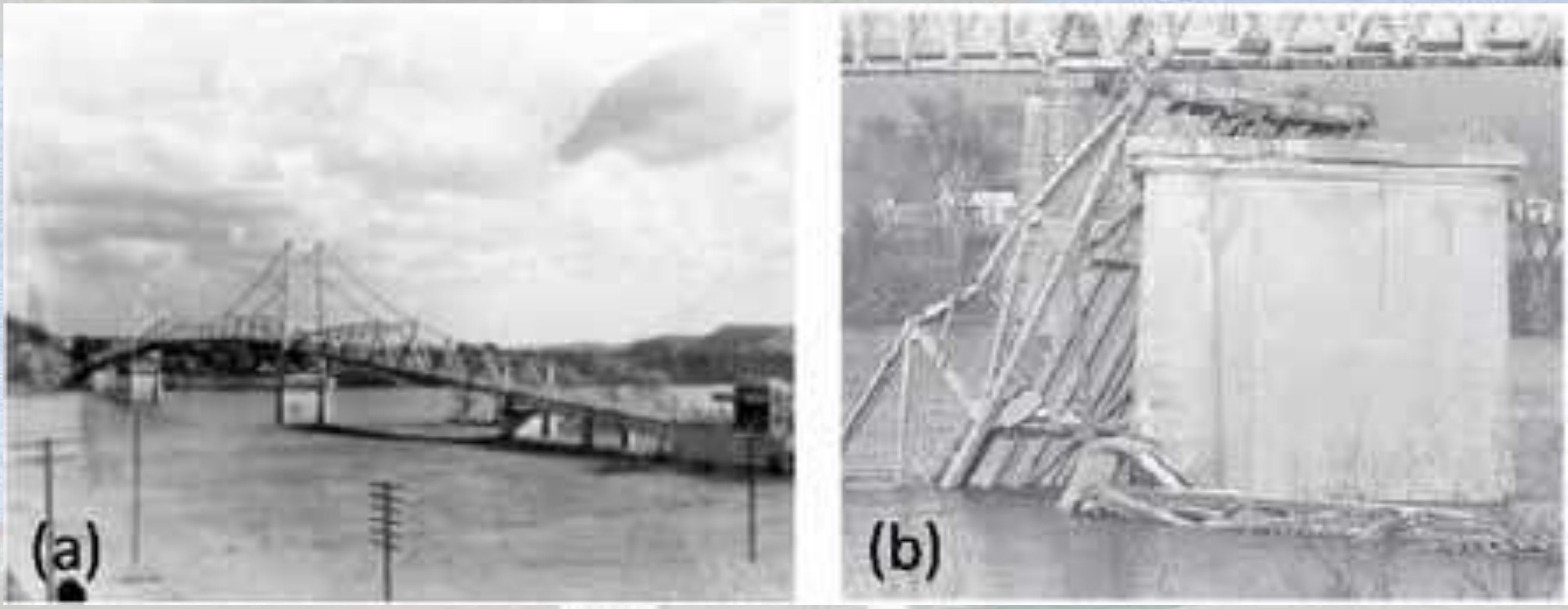
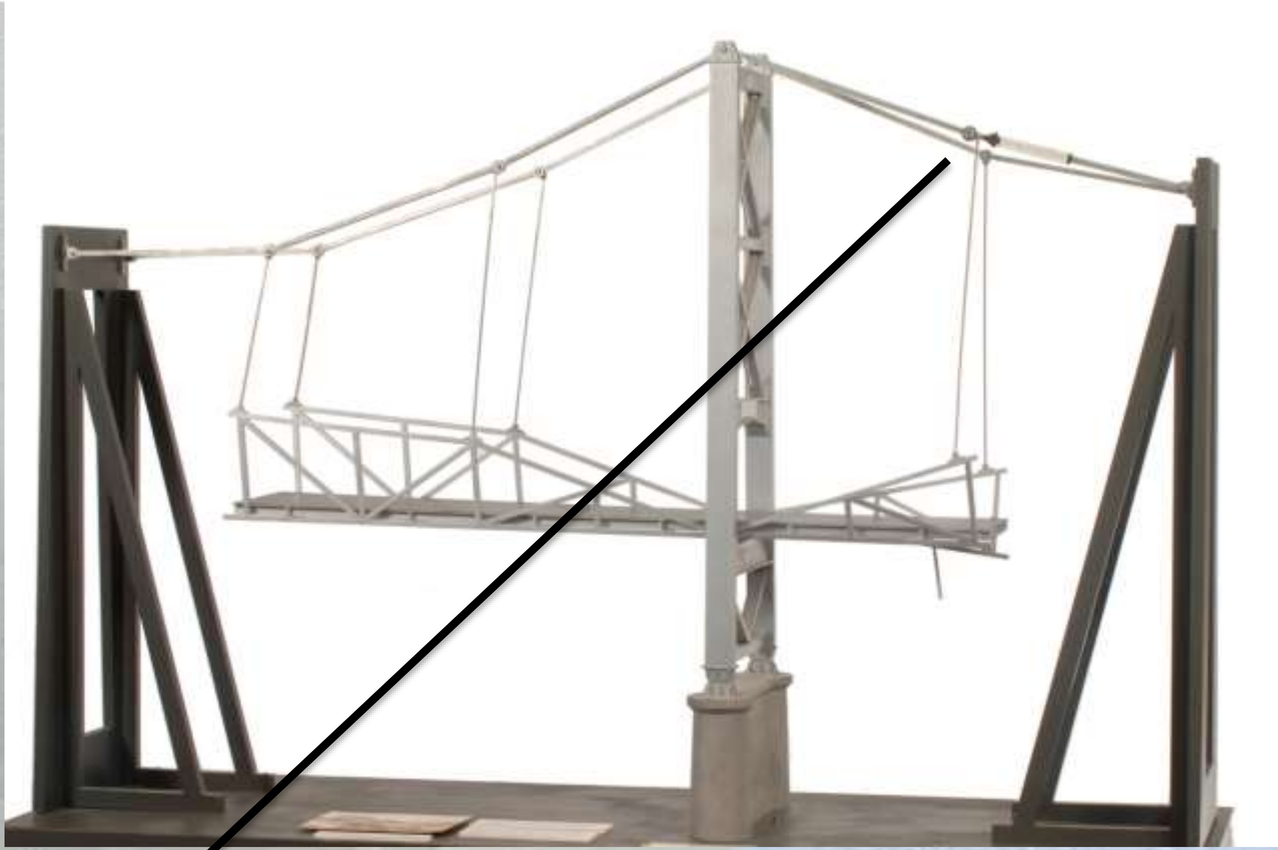
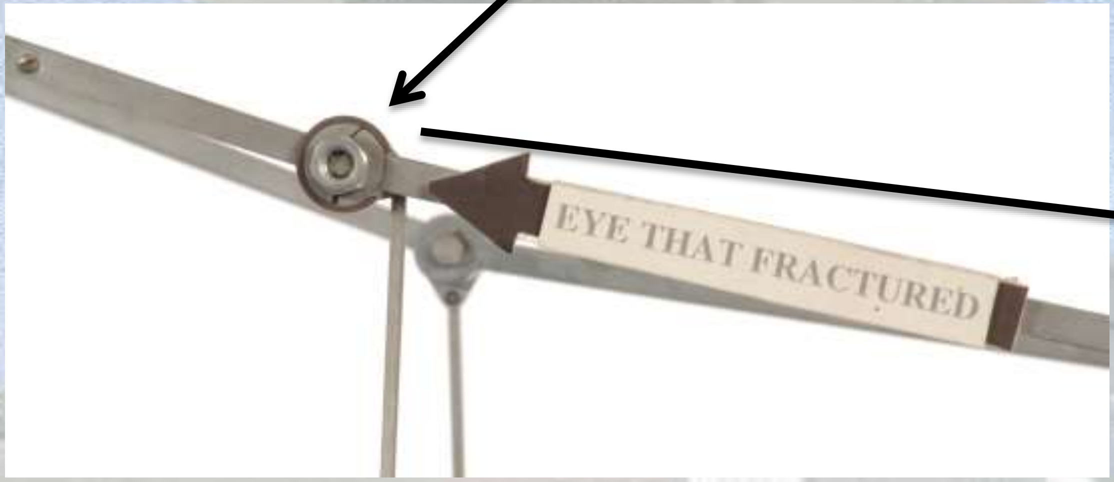
Brief Introduction



In Dec 15 of 1967, the Silver Point Bridge in Point Pleasant, West Virginia suddenly collapsed into the Ohio River





EYE THAT FRACTURED

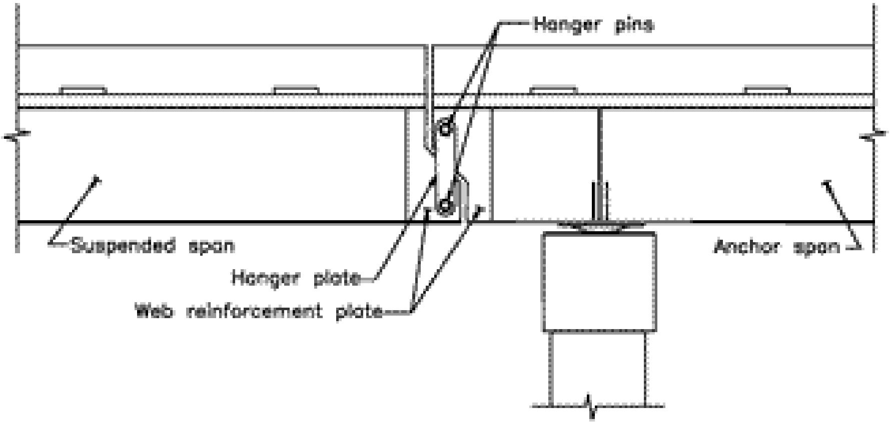

Some of the Important Dates

1968- U.S. Congress required Secretary of Transportation to establish a national bridge inspection standard. The Secretary was also required to develop a program to train bridge inspectors.

1971- National Bridge Inspection Standards (NBIS) came into being

1978- Bridges with Fracture Critical Elements were introduced into AASHTO

1983- Collapse of **Mianus River Bridge in Connecticut**



Definition of Fracture Critical Member

"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"

Currently, two box girder bridges are classified as bridges with fracture critical elements

Where we are going from here on

States with most Twin Steel box Girder bridges

- Florida 127
- Texas 105
- Colorado 81
- Connecticut 71
- Oklahoma 49
- Massachusetts 48
- Mississippi 39
- Oregon 34
- Alaska 33
- Illinois 28
- Louisiana 28

Examples of evidences pointing to two line girder bridge systems being redundant

A number of incidents involving the full-depth fracture of in-service, two-girder bridges provide evidence that, in certain cases, a redundant load path does exist in these structures even though they have not been given credit for such.

Full-depth fracture of one of the two girders on the Neville Island Bridge on I 79 in Pittsburg, Pennsylvania-1977

Texas Experiment

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Test 1

Test 2

Test 3

Many State DOTs are of the opinion that two steel box girders should be removed from the fracture critical list

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U.S. Department of Transportation
Federal Highway Administration

Memorandum

Date: June 20, 2012

For in-service inspection protocol, Structural Redundancy demonstrated by refined analysis is now formally recognized and may also be considered.

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Two Available Methods to Check Redundancy of Two Steel Box Girder Bridges

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Two Methods for Evaluating Redundancy of Damaged Structure

- Texas Method
  - Simplified Mechanisms with Fallback to More Advanced Analysis if Insufficient
  - All Load Carried by Intact Girder

- NCHRP 406
  - Consider Three Limit States (Reserve Ratios)
    - Ultimate, Functional, Damaged
  - Load Factor for Each Intended to Provide Target Relative Reliability Similar to 4-Girder Bridge
  - Non-Linear FE Analysis

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Simple approaches used by Texas to check redundancy

- Result in many "conservative" assumptions that may defeat the purpose

- lean itself to check each bridge one at the time

Proposed FDOT Approach

- Divide the state inventory of two steel box girder bridges into several categories

- For each category develop an "Equivalent" simple span bridge that could represent all bridges in that category

- Assess the redundancy of the "Equivalent" simple span bridge using detail numerical analysis.

Proposed FDOT Approach

There are several questions that needs to be answered in order to achieve this objective

Proposed FDOT Approach

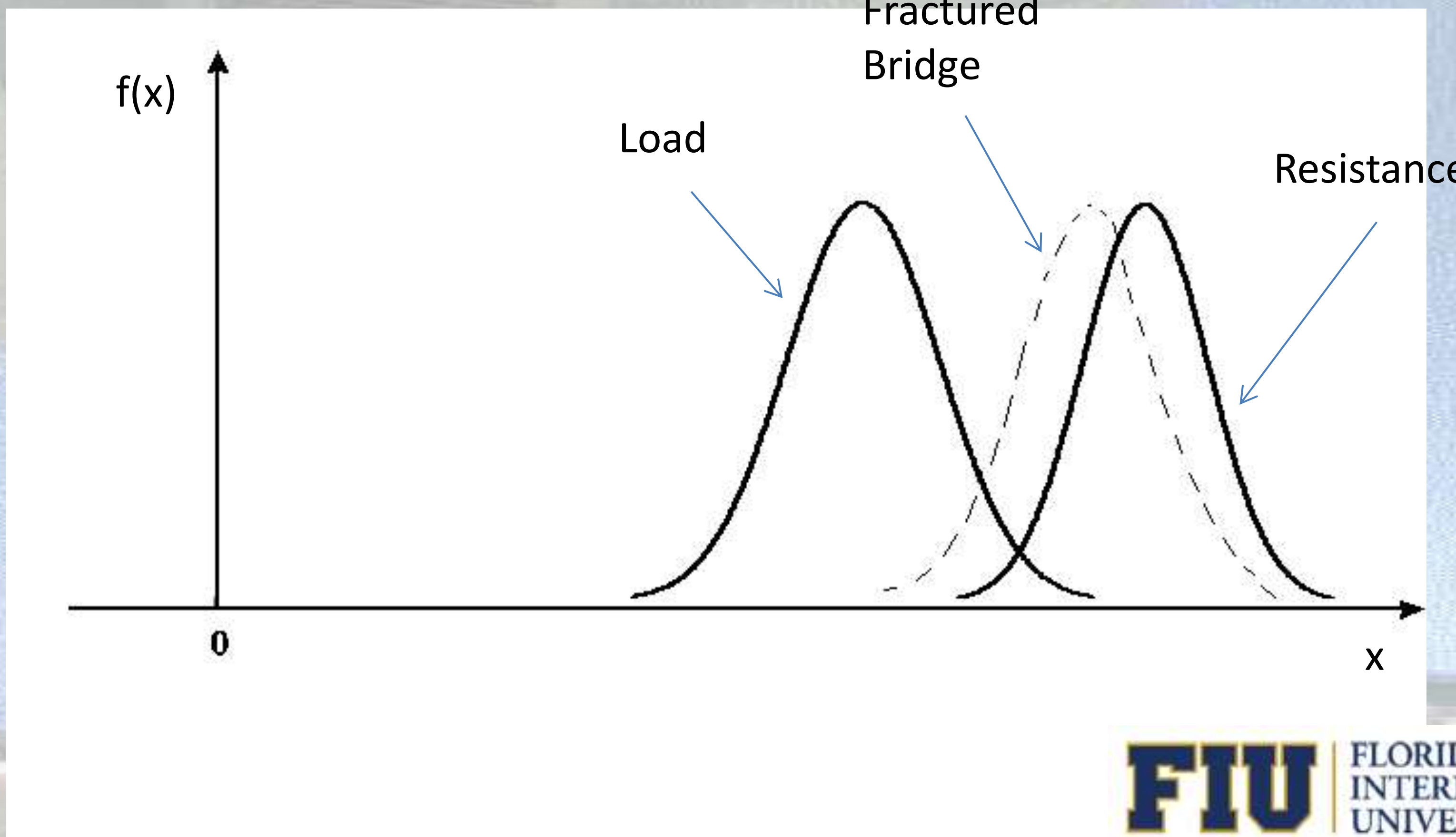
What should be the geometry and dimensions of the “Equivalent” simple span bridge?

How much load the damaged bridge should be able to carry?

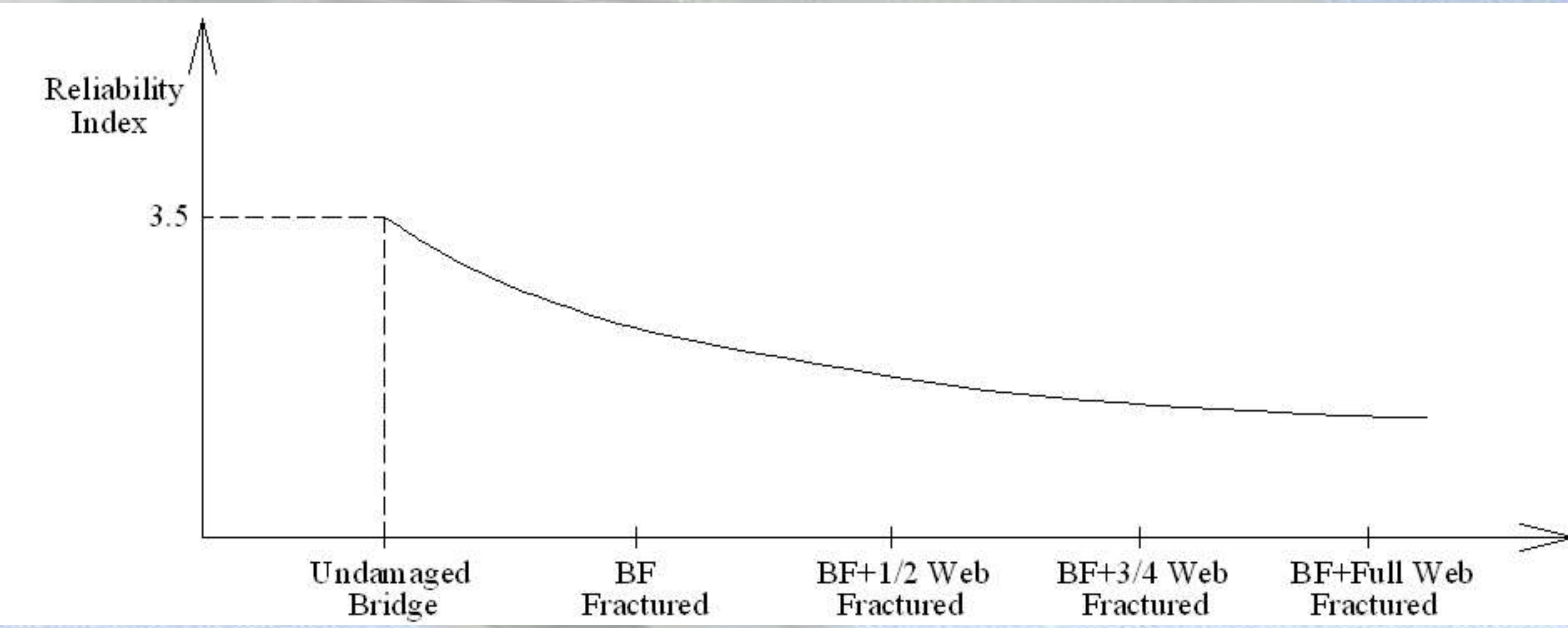
Should there be a deflection criteria, in addition to the load carrying capacity requirement?

How much load the damaged bridge should be able to carry?

Probability Density Function



Reliability index of new and damaged bridge

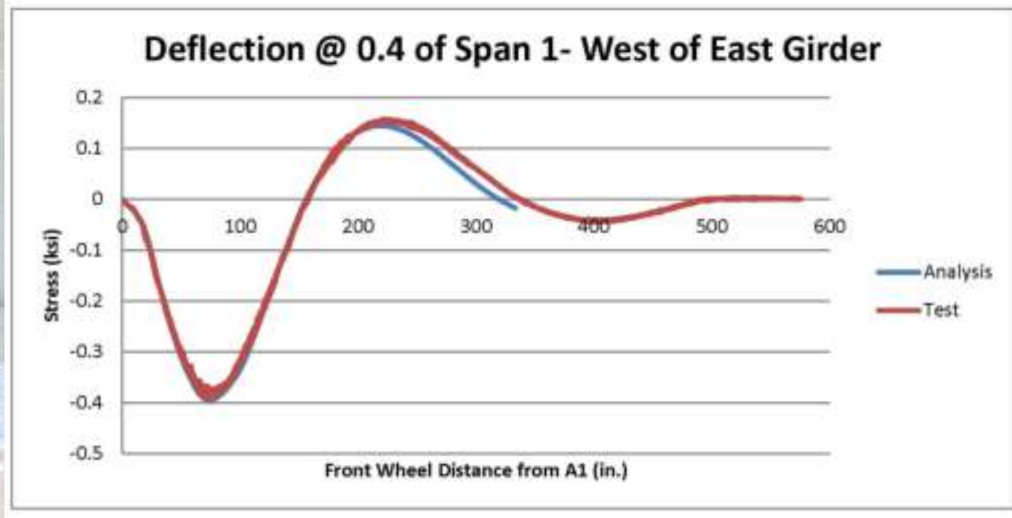


Proposed FDOT Approach

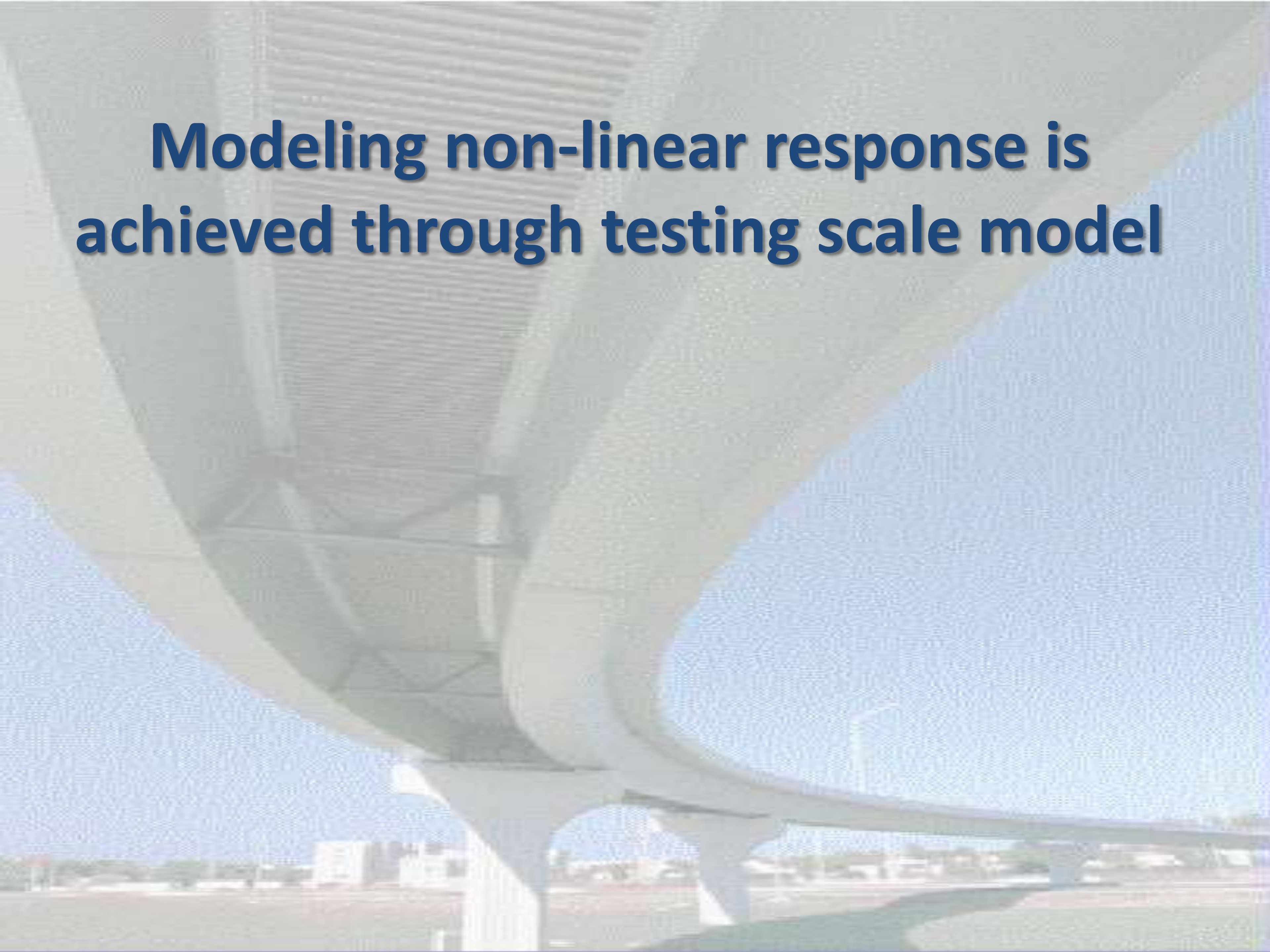
Development of PDF for capacity of damaged bridge and detail analysis of the “Equivalent” bridge demands understanding the behavior of damaged bridge

Modeling elastic response was simple and verified using field test

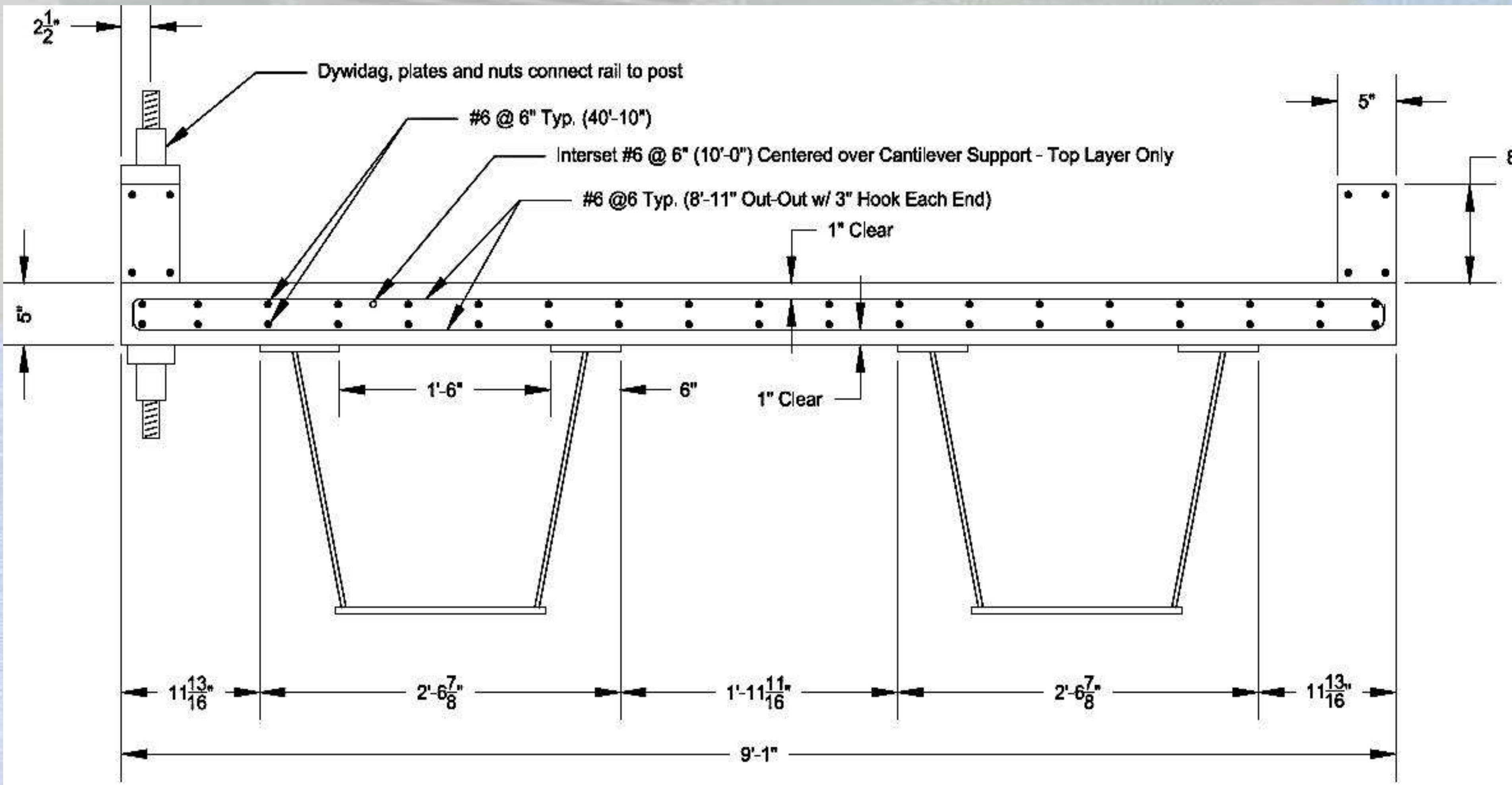
Have field tested two steel box girder bridge under elastic load



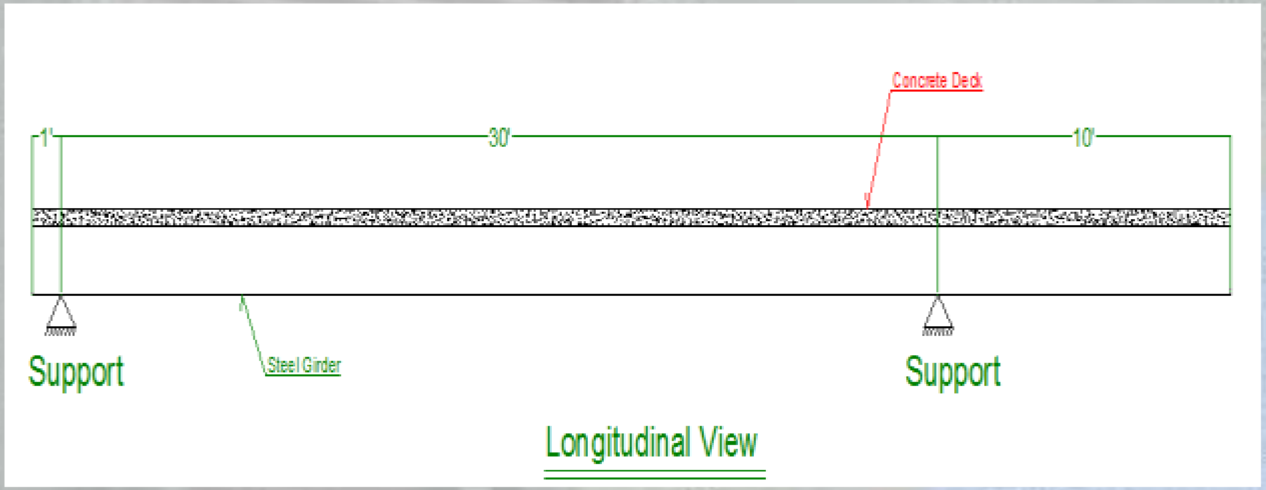
Modeling non-linear response is achieved through testing scale model

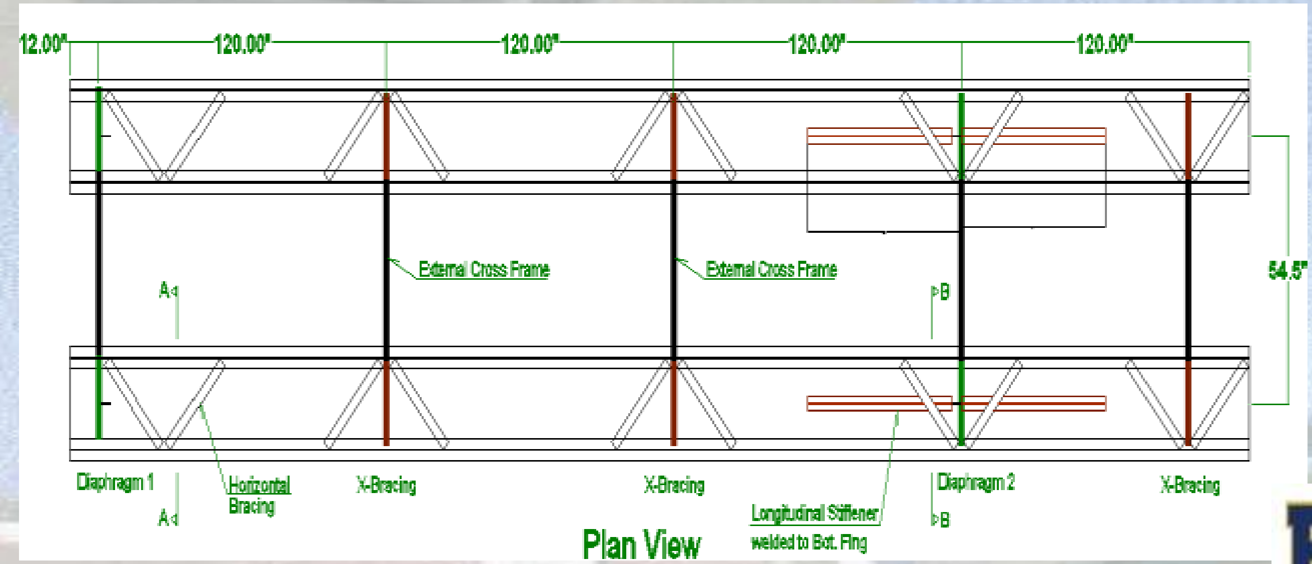


Laboratory Specimen Design



Laboratory Specimen Design





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Formwork and Reinforcement

Finished Bridge Specimen

Saw-cutting on the Bottom Flange

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Experimental Testing - Phase I

Damage State	Test	Name	Hydraulic Ram	Rail	Continuity	Loading type	Max load (kips)
Undamaged	1	Static	2	N	N	S	50 each
	2		1	N	N	U	50
	3		1	N	Y	U	50
	4		2	Y	N	S	50 each
	5		1	Y	Y	U	50
	6		1	Y	N	U	50
Bottom Flange Fractured	7	Static	2	Y	N	S	50 each
	8		1	Y	Y	U	50
	9		1	Y	N	U	50
	10		2	N	N	S	50 each
	11		1	N	N	U	50
	12		1	N	Y	U	50
	13	Cyclic	1	Y	N	U	60 kips
Full-Web Fractured	14	Static	2	Y	N	S	50 each
	15		1	Y	Y	U	50
	16		1	Y	N	U	50
	17		2	N	N	S	50 each
	18		1	N	N	U	50
	19		1	N	Y	U	50
	20	Ultimate	1	N	N	U	Until collapse

Static Elastic Test Results

Test	Characteristics (Rail/Continuity/Load)	Max Displacement (in)	Elastic Stiffness (kip/in)	Max Strain in West Girder (in/in*10^6)	Max Strain in East Girder (in/in*10^6)	Max Strain in Cross Frames (in/in*10^6)
Undamaged						
1	NNS	0.333	307	460	464	21
2	NNU	0.203	243	168	286	56
3	NYU	0.179	276	140	257	57
4	YNS	0.303	327	418	410	19
5	YYU	0.174	287	137	238	57
6	YNU	0.194	257	162	263	54
Fractured bottom flange (from Test 7 to Test 13)						
7	YNS	0.337	300	459	851	22
8	YYU	0.180	281	146	506	59
9	YNU	0.206	248	176	578	59
10	NNS	0.337	300	449	1260	16
11	NNU	0.218	228	180	610	58
12	NYU	0.188	265	148	539	59
13	Cyclic Loading (YNU)	Sec 3.2	Sec 3.2	Sec 3.2	Sec 3.2	Sec 3.2
Fractured web in addition to the bottom flange (from Test 14 to Test 19)						
14	YNS	0.563	177	722	1701	154
15	YYU	0.371	159	383	1243	184
16	YNU	0.452	131	471	1451	191
17	NNS	0.634	162	762	1872	155
18	NNU	0.494	119	494	1531	195
19	NYU	0.393	150	390	1279	186

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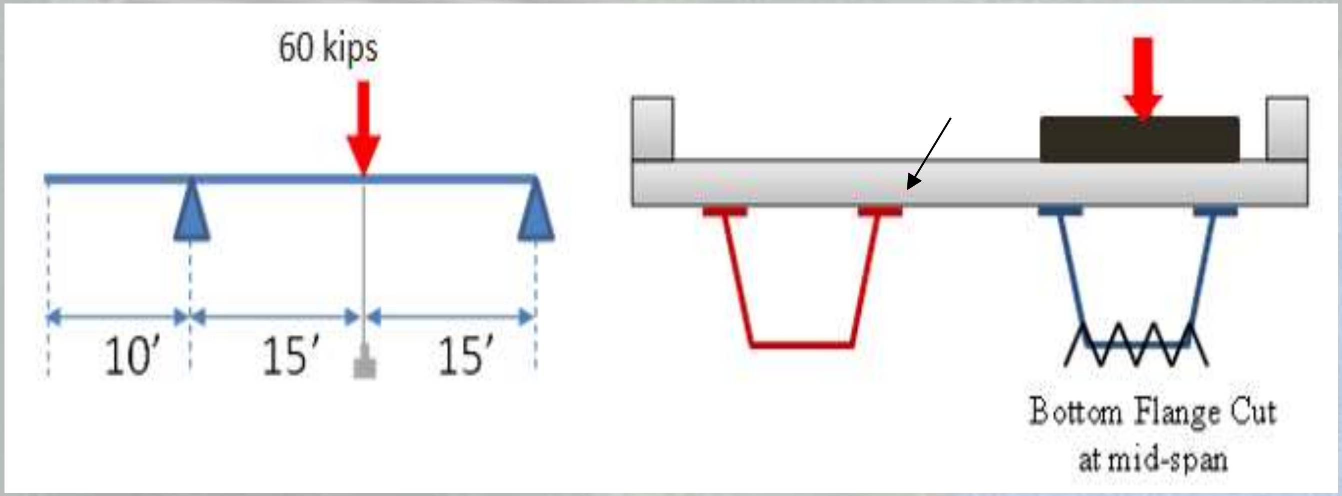
Cyclic Loading



Type "C" Fatigue Category
Threshold Stress: 10 ksi
Estimated trucks for two years of traffic: 940,000 cycles

Crack propagated to top flange after about 210,000 cycles- Equivalent to about 5.5 months of traffic

Cyclic Test Results and Damage Observations

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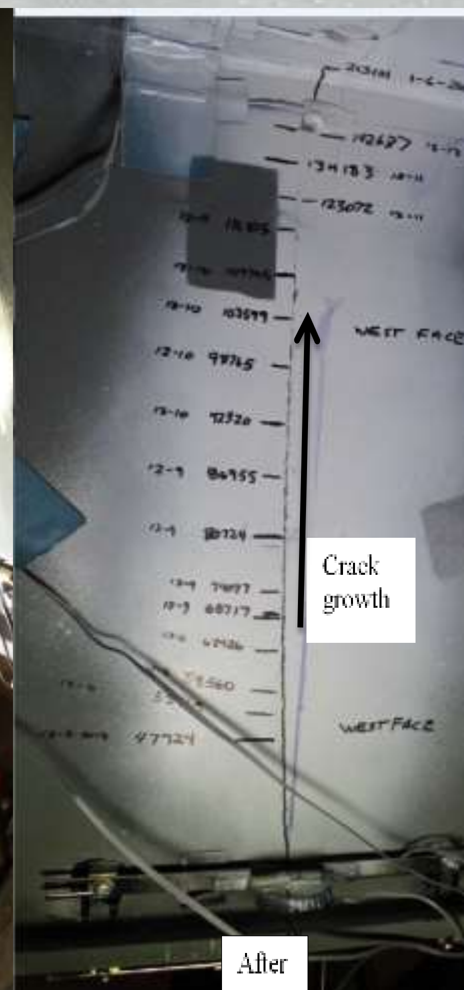

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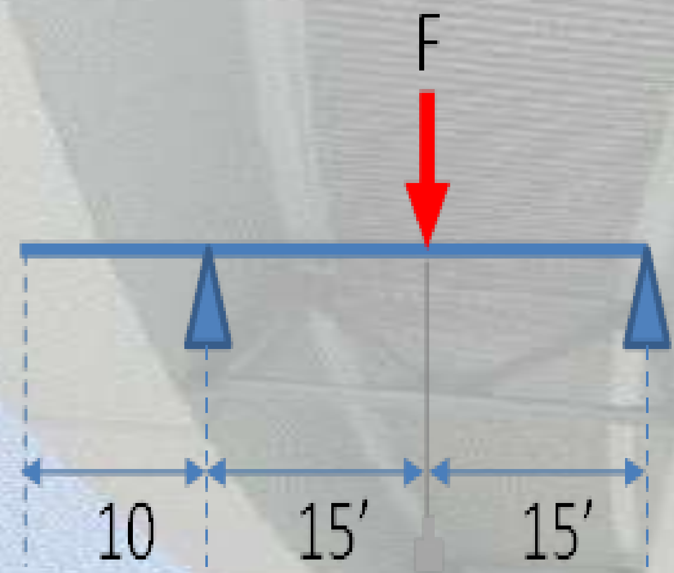
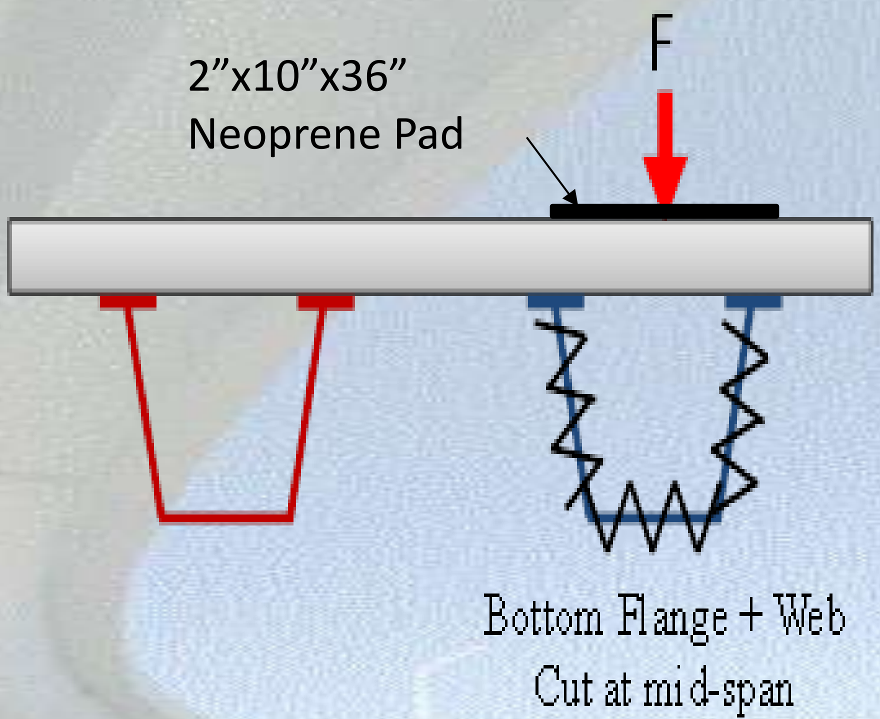
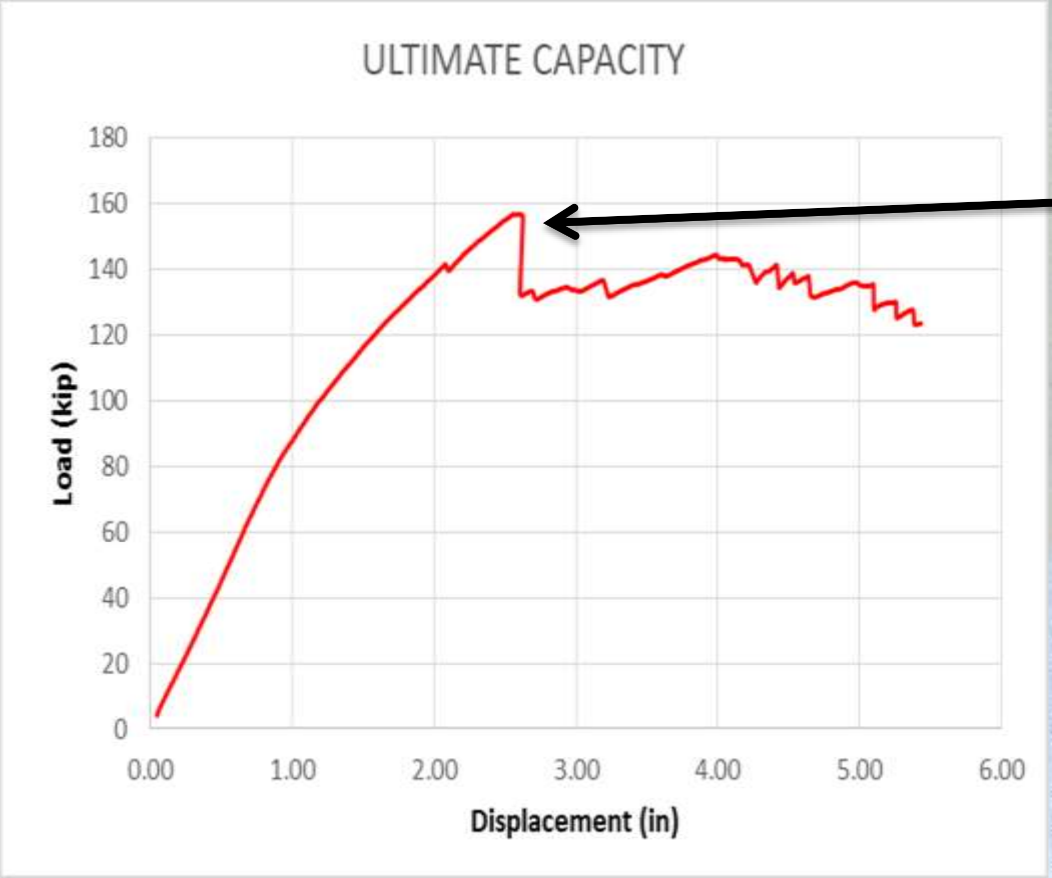
Ultimate Test – Phase I





Ultimate Test Results



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Damage Observations

Damage Observations

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Damage Observations

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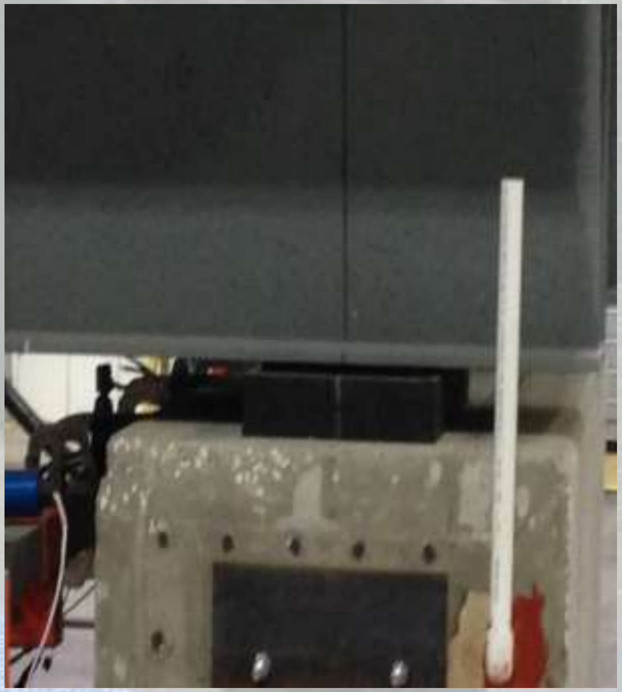
Uplift in Undamaged Girder



North Support

South Support

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Damage at ends

This splitting was attributed to the internal transverse shear forces that was produced to balance the unequal displacements of two girders.

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Reconstruction Process

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Reconstruction Process

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Reconstruction Process

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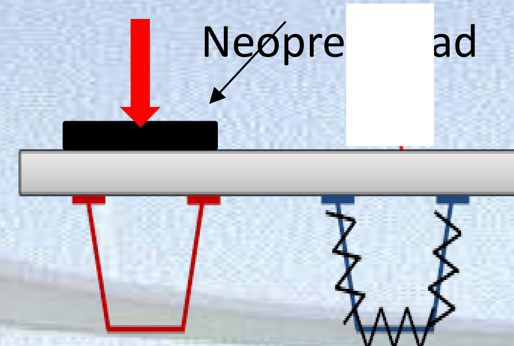
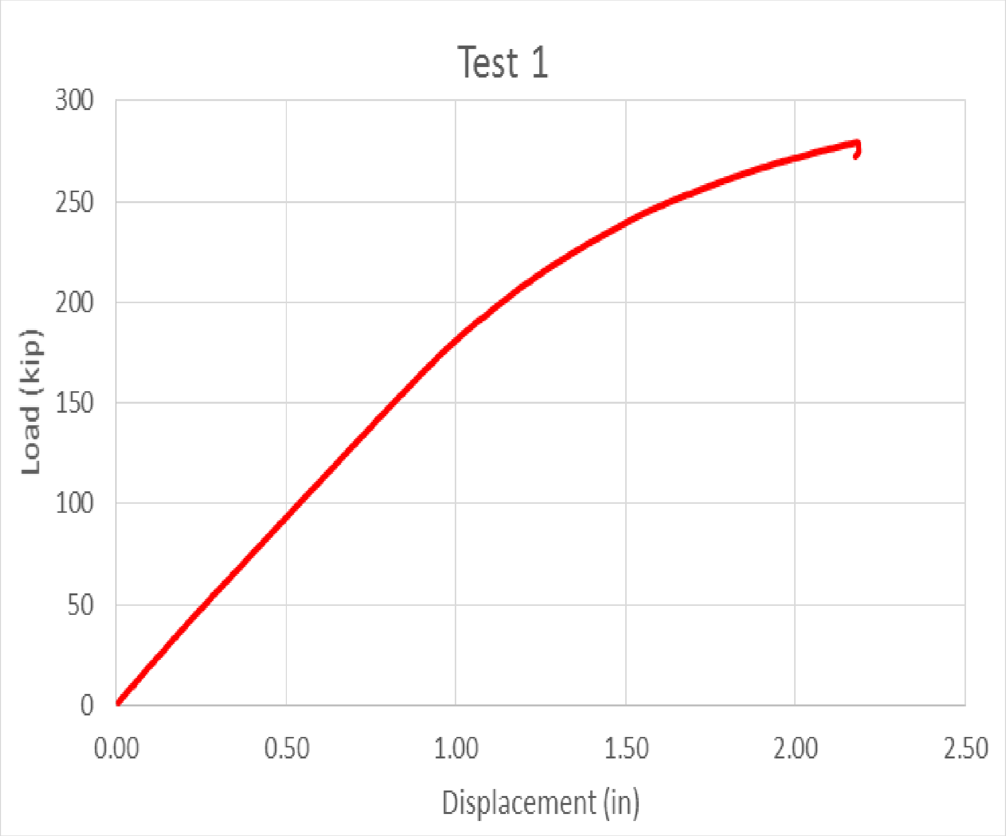
Phase II - Test 1



Phase II- Test I

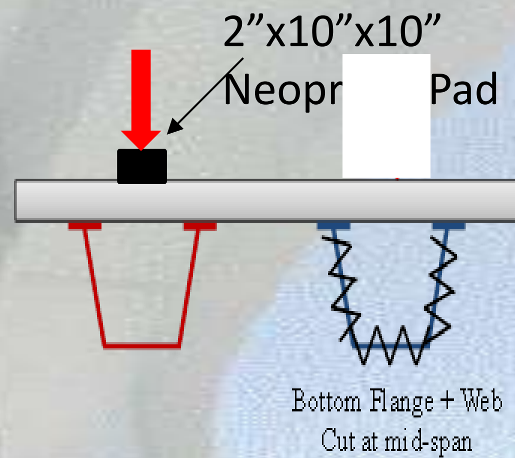


- No major damage in the deck were observed
- The good girder experienced a significant yielding in bottom flange.

Phase II- Test 2

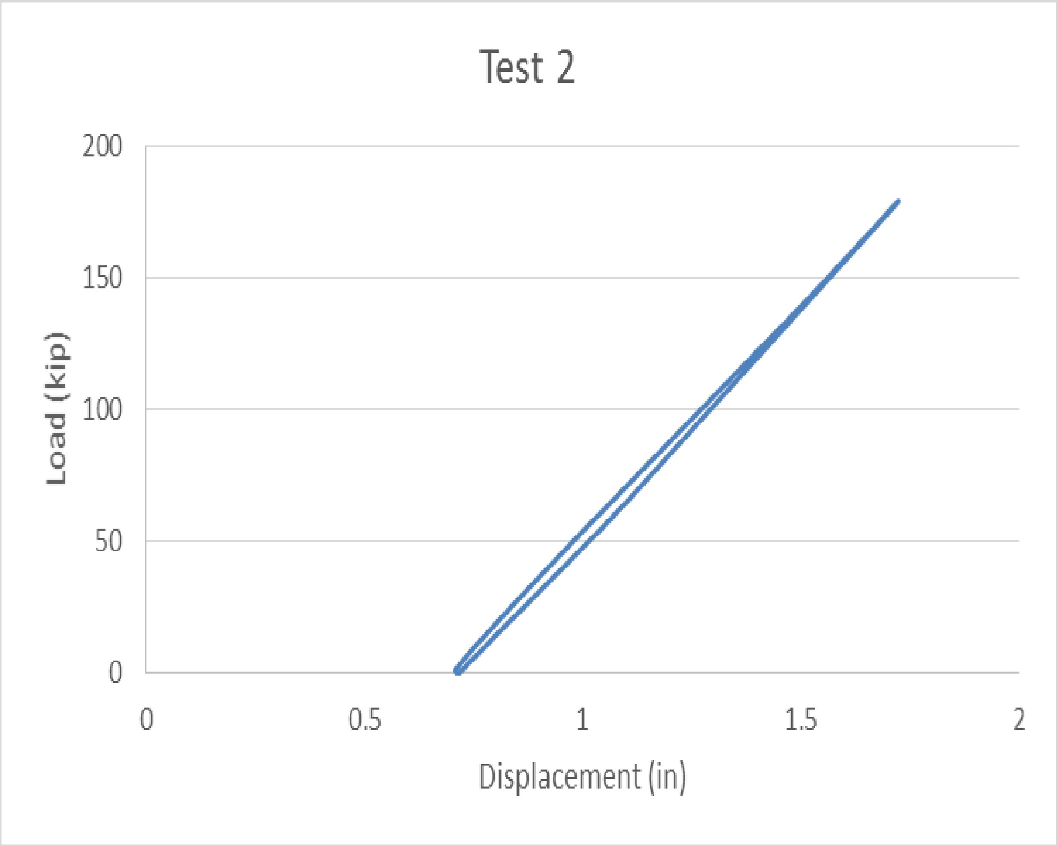
- This test is similar to test 1; however, with a smaller loading pad (2”x10”x10”)

Longitudinal View



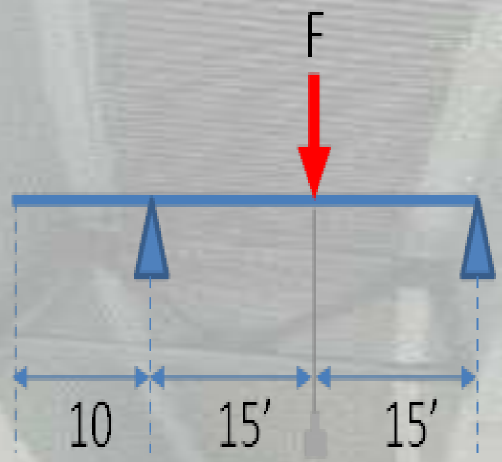
Cross-Section View

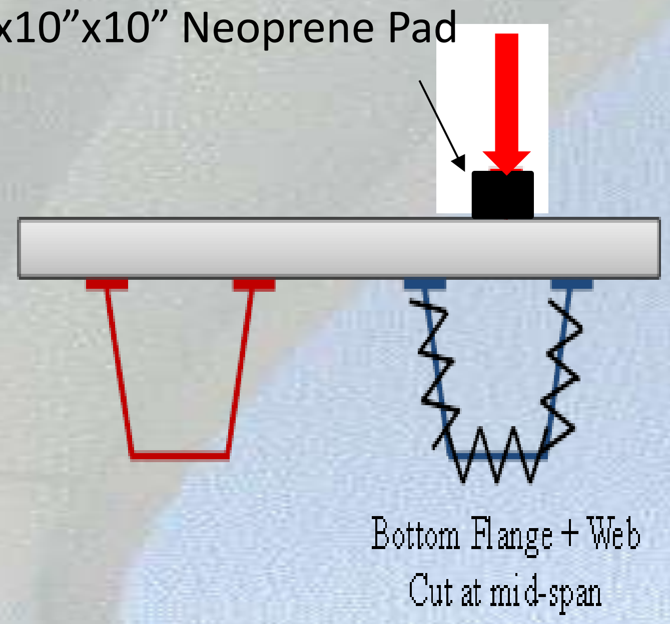
Phase II – Test 2



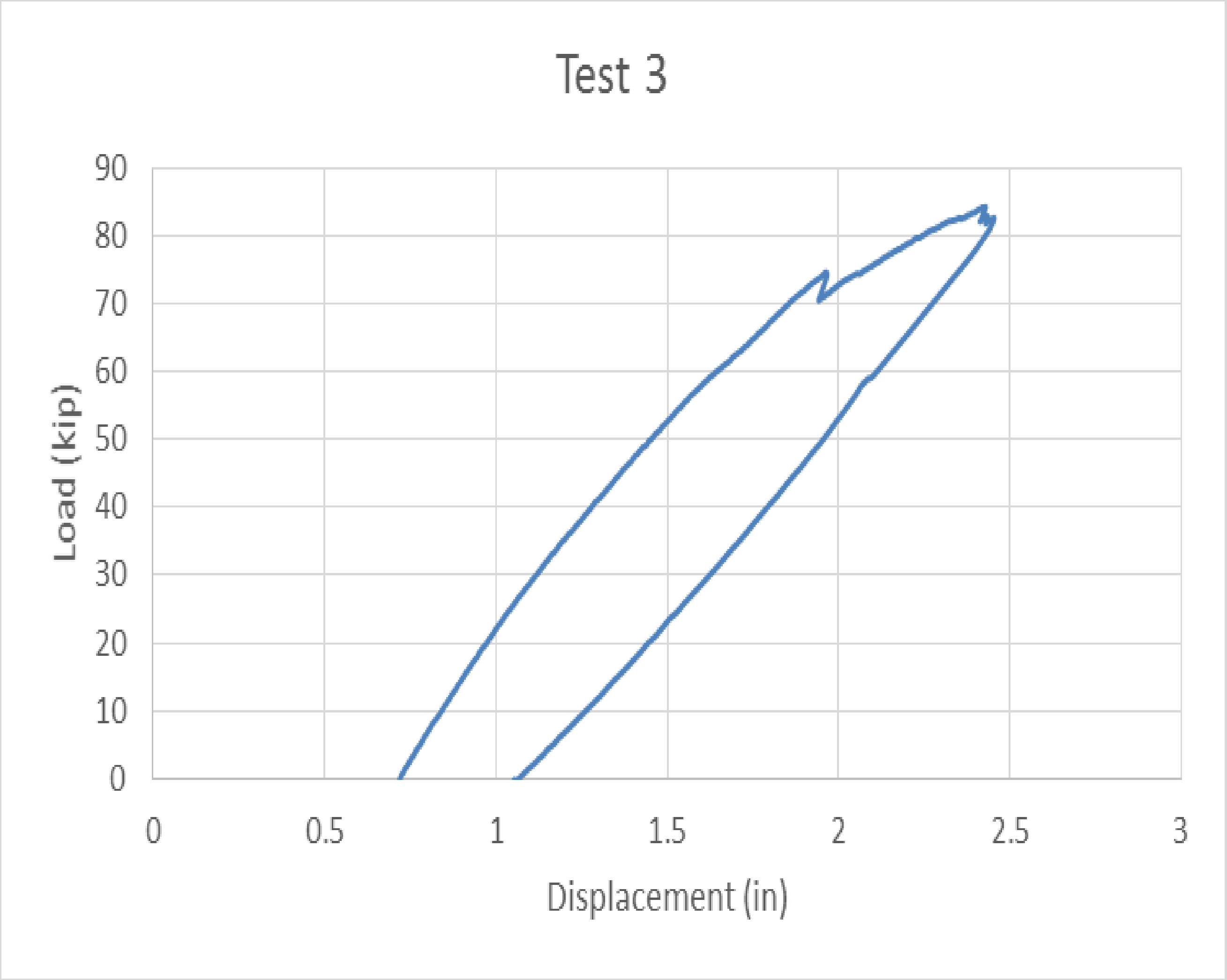
A permanent displacement was observed as a result of Test 1

Phase II – Test 3





Phase II – Test 3



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Phase II – Test 3

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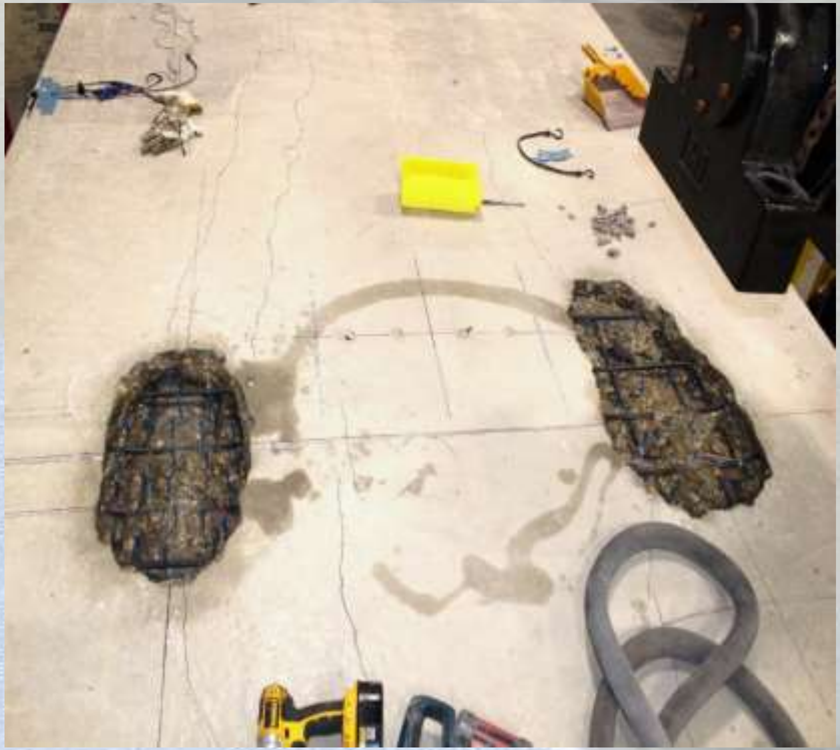
After Completion of Test 3
Deck was Repaired



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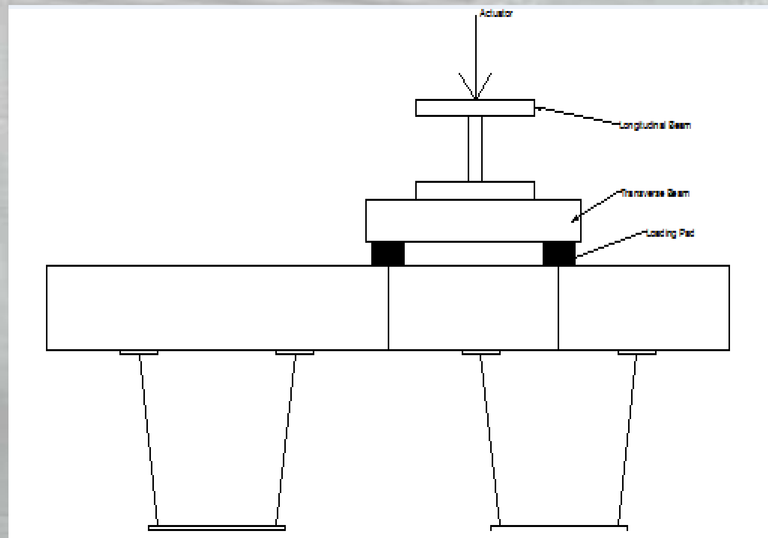
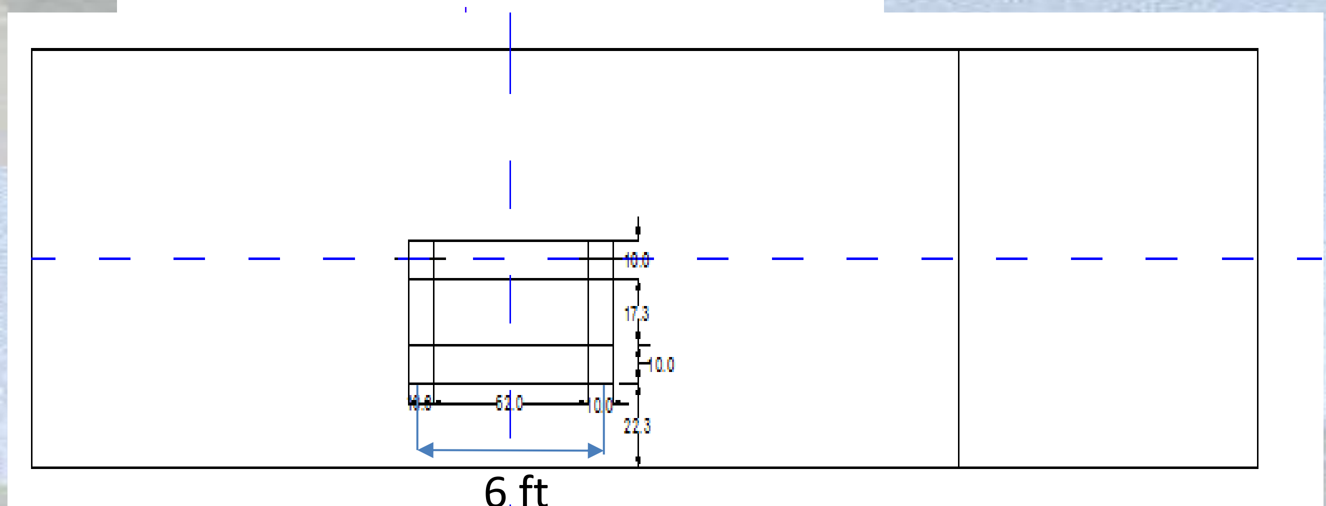
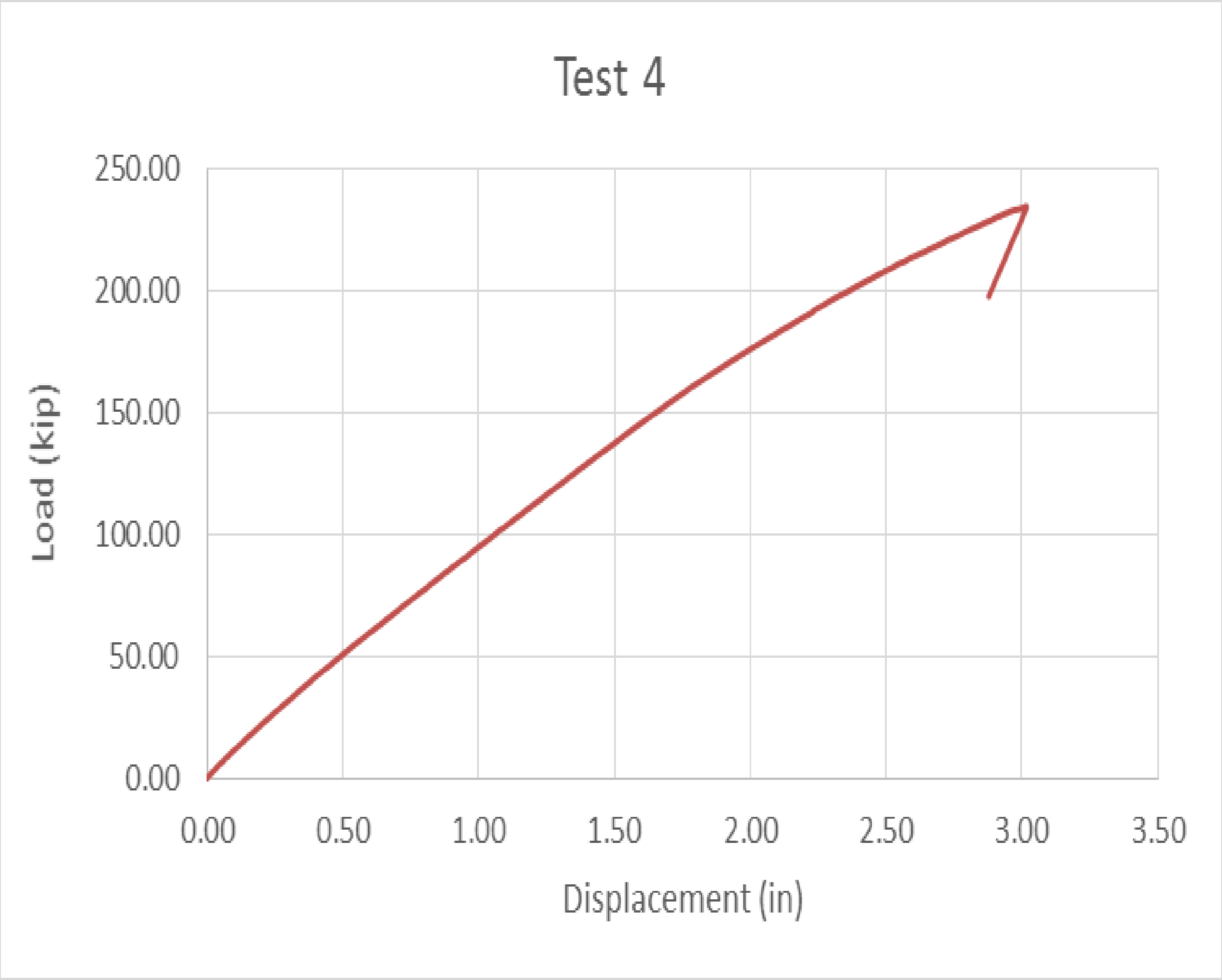
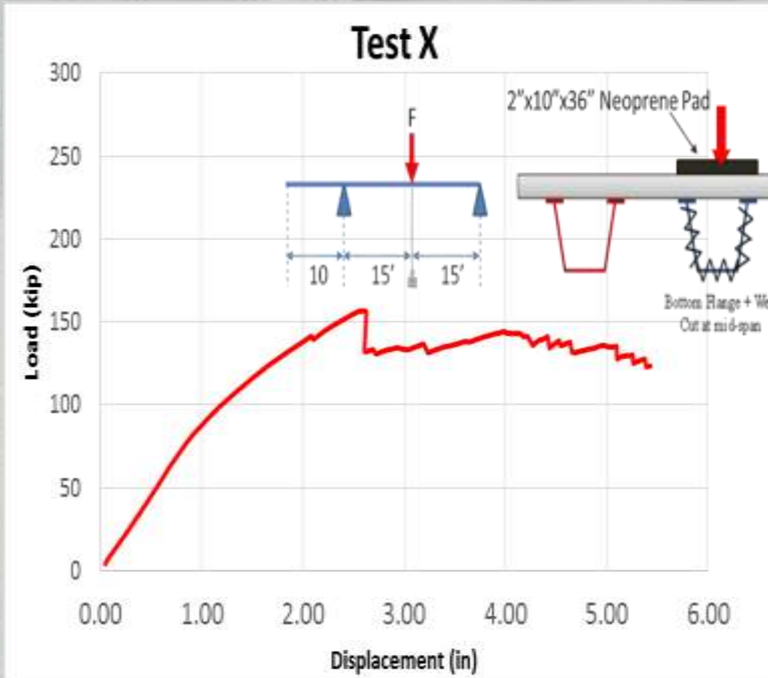
Phase II – Test 4

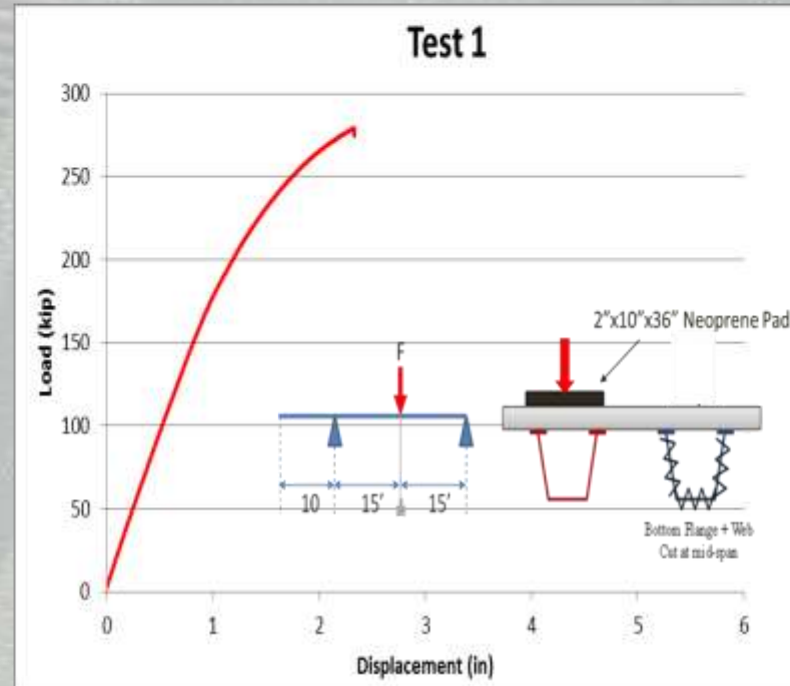


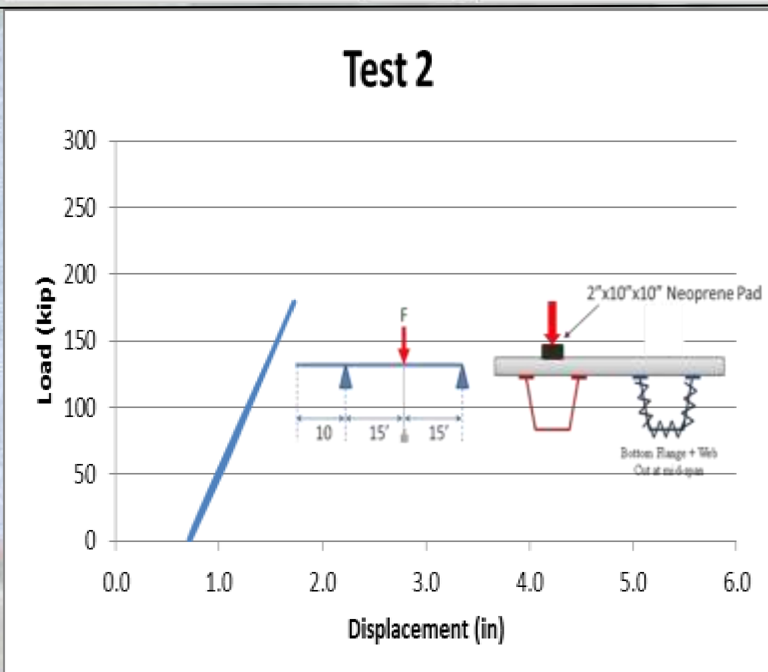


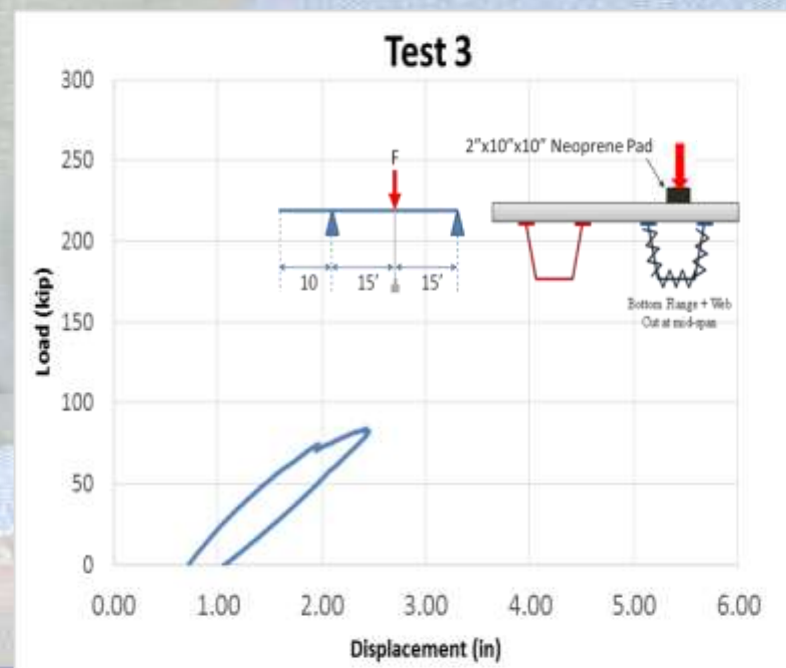
Phase II – Test 4



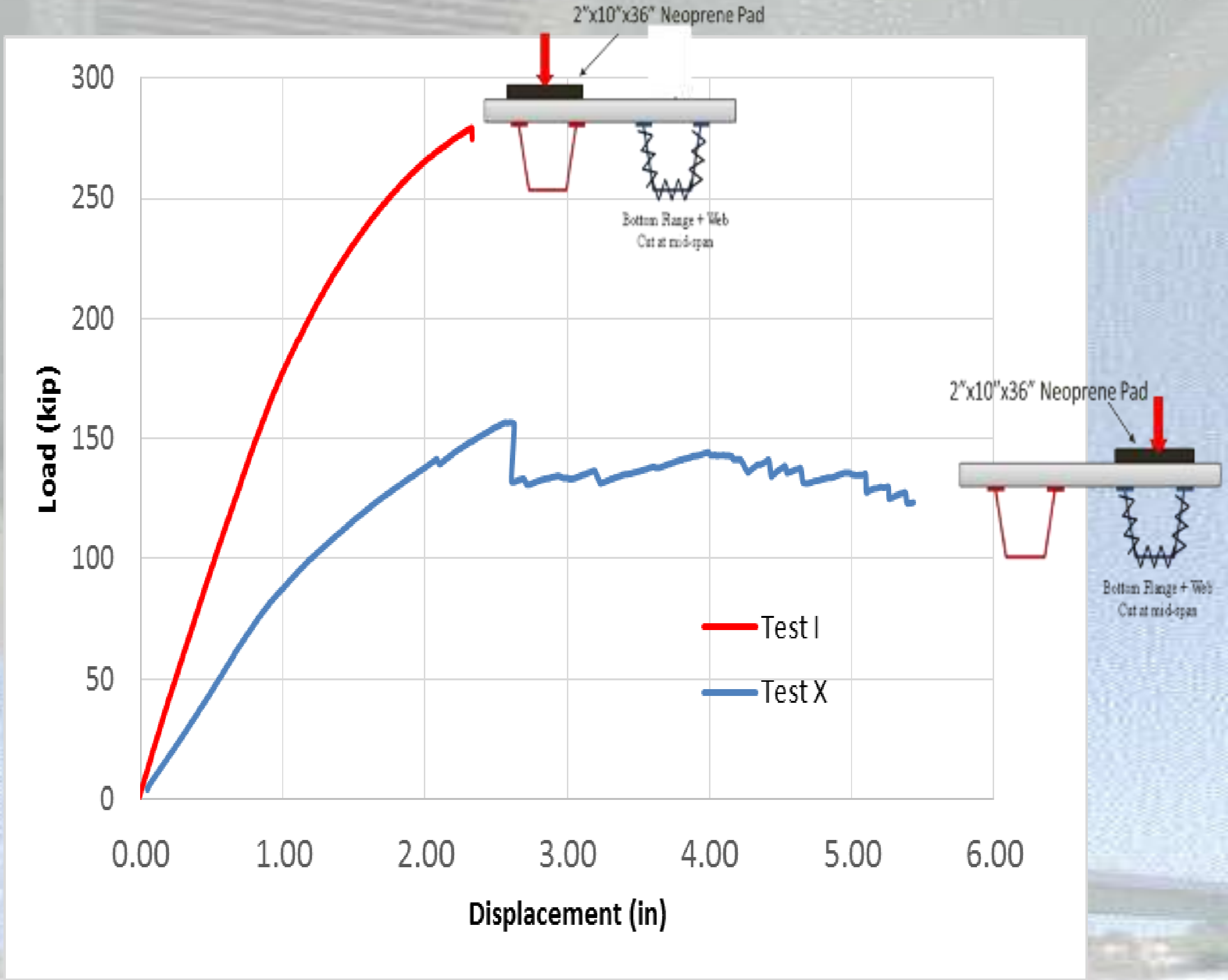

Test X
2"x10"x36" Neoprene Pad
F
10
15'
15'
Bottom Flange + Web
Cut at mid-span
Load (kip)
Displacement (in)


Test 1
2"x10"x36" Neoprene Pad
F
10
15'
15'
Bottom Flange + Web
Cut at mid-span
Load (kip)
Displacement (in)

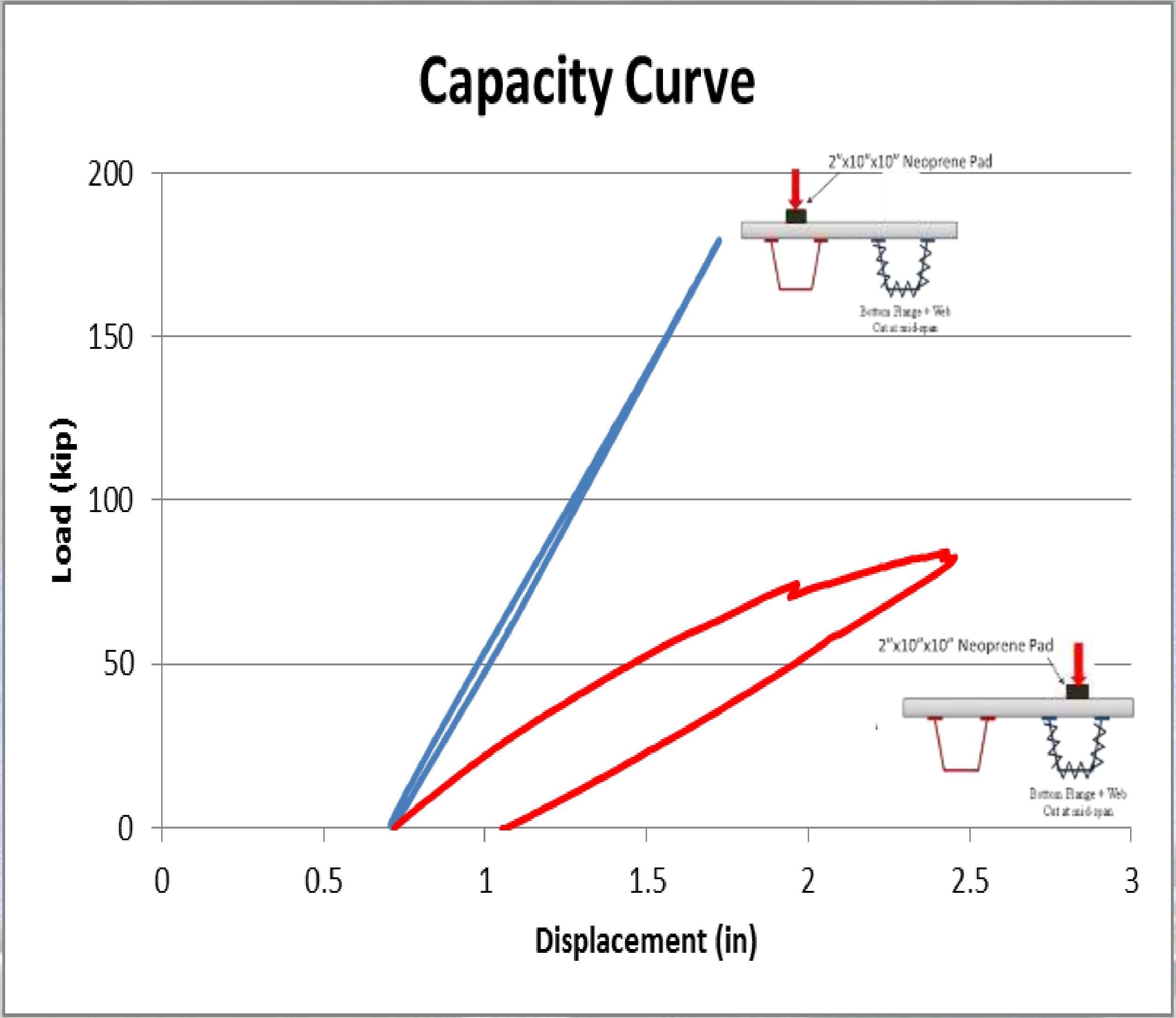

Test 2
2"x10"x10" Neoprene Pad
F
10
15'
15'
Bottom Flange + Web
Cut at mid-span
Load (kip)
Displacement (in)


Test 3
2"x10"x10" Neoprene Pad
F
10
15'
15'
Bottom Flange + Web
Cut at mid-span
Load (kip)
Displacement (in)

Test 1 vs Test X



Test 2 vs Test 3



Summary

- We have identified some of the mechanisms that contributes to load carrying capacity of damaged bridge
- We have developed preliminary criteria for establishing “Equivalent” simple span bridge
- We have developed calibrated Non Linear FEM

What We still Need to Do

- Fully comprehend the mechanisms that resists the load after damage

- Establish an approximate method for predicting load carrying capacity of damaged bridge (for simulation purposes)

- Establish the reliability index that bridge owners would feel comfortable for damaged bridge

What We still Need to Do

- Finalize the criteria for grouping the two steel box girder bridges for the purpose of establishing simple span notional bridge
- Develop steps in checking redundancy of two steel box girder bridges using FDOT proposed approach
- Time permitted, examine feasibility of modifying Texas Simple Method

What is Next

- We have developed a pooled fund study to continue the project

- The pooled fund project is scheduled to start in Jan 2016