NTSB National Transportation Safety Board

Office of Research and Engineering

Gusset Plate Inadequacy

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Presentations

1. Bridge description and collapse
2. Construction activities on bridge at time of collapse
3. Gusset plate inadequacy
4. Finite element analysis
5. Design and review process
6. Bridge load rating and bridge load analysis
7. Bridge inspections
8. Gusset plate inspections

Introduction

- January 15, 2008, interim safety recommendation to the Federal Highway Administration
  - Require bridge owners to evaluate gusset plates when modifications were being considered
- Based on
  - Initial on-scene findings
  - Federal Highway Administration analysis

Overview

- Bridge design basics
  - Allowable Stress Design methodology
  - Design forces
- I-35W design
  - Review of design documents
  - Evaluation of gusset plates
  - Clearly inadequate capacity of gusset plates at U10 and other nodes

Bridge Design Basics

- Design began in 1962
- Governed by AASHO specifications
- 1961 AASHO *Standard Specifications for Highway Bridges*
- 1961/1962 AASHO *Interim Specifications*
- 1964 Minnesota Highway Department *Standard Specifications for Highway Construction*

Bridge Design Basics

- Allowable Stress Design methodology
- Stress = Force/Area
- Truss member forces counteract the weight of structure and traffic

Bridge Design – Allowable Stress

- AASHO allowable stress no more than 55 percent of the yield stress
- Yield stress defines limit of usable load-carrying capacity of a material
- The allowable stress level ensures a substantial margin of safety

Bridge Design - Forces

- Design force: calculated in accordance with AASHO specifications
- Design force calculated from dead load plus live load plus impact
- Live load = AASHO-specified lane loads
- AASHO-specified lane load
  - Represents unusual, heavy traffic load
  - Provides additional margin of safety

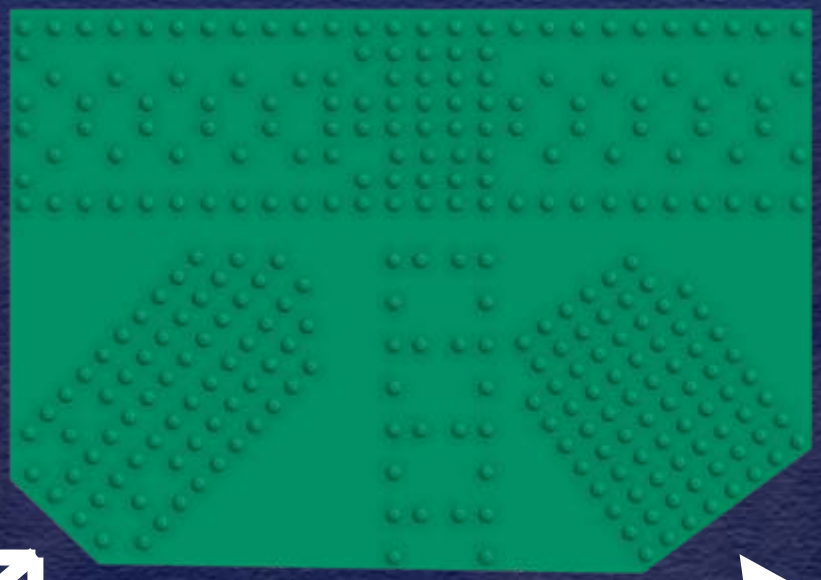
Bridge Design – General Review

- Design documents obtained from Mn/DOT and Jacobs Engineering
- Included drawings and computation sheets
- Complete and detailed documentation, except for main truss gusset plates
- Design was also evaluated using finite element models
- Appropriate design methodology
- No significant deficiencies, other than in main truss gusset plates

Bridge Design – Gusset Plates

- AASHO specifications stated that gusset plates shall be of ample thickness to resist shear, direct stress, and flexure
- No documents showing main truss gusset plate design
- Documents did show design methodology for welded floor truss gusset plates
- Analysis guided by gusset plate design for welded floor trusses

U10 - Member Forces Transferred by the Gusset Plate



Upper chord
924,000 lbs
compression

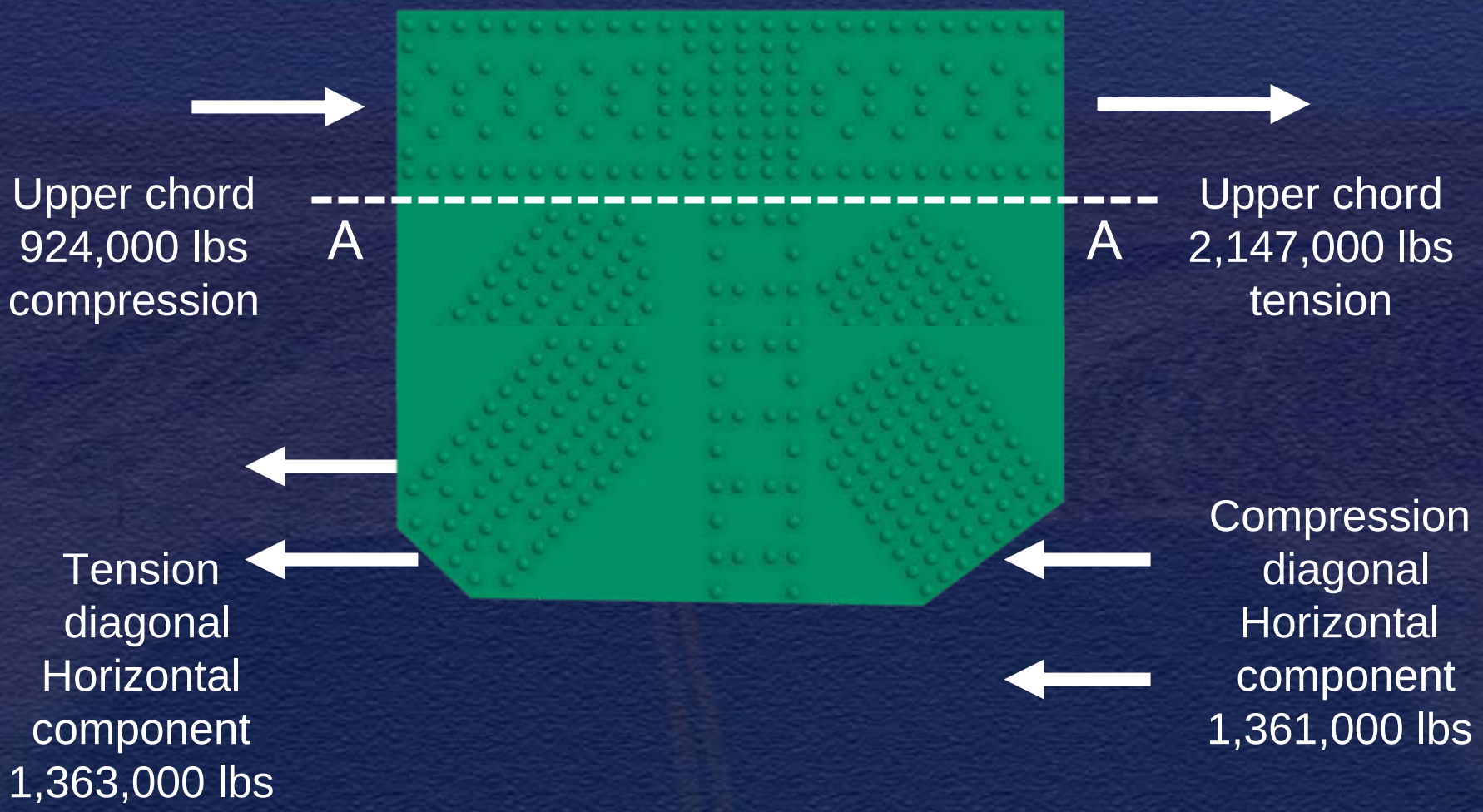
Upper chord
2,147,000 lbs
tension

Tension
diagonal
1,975,000 lbs

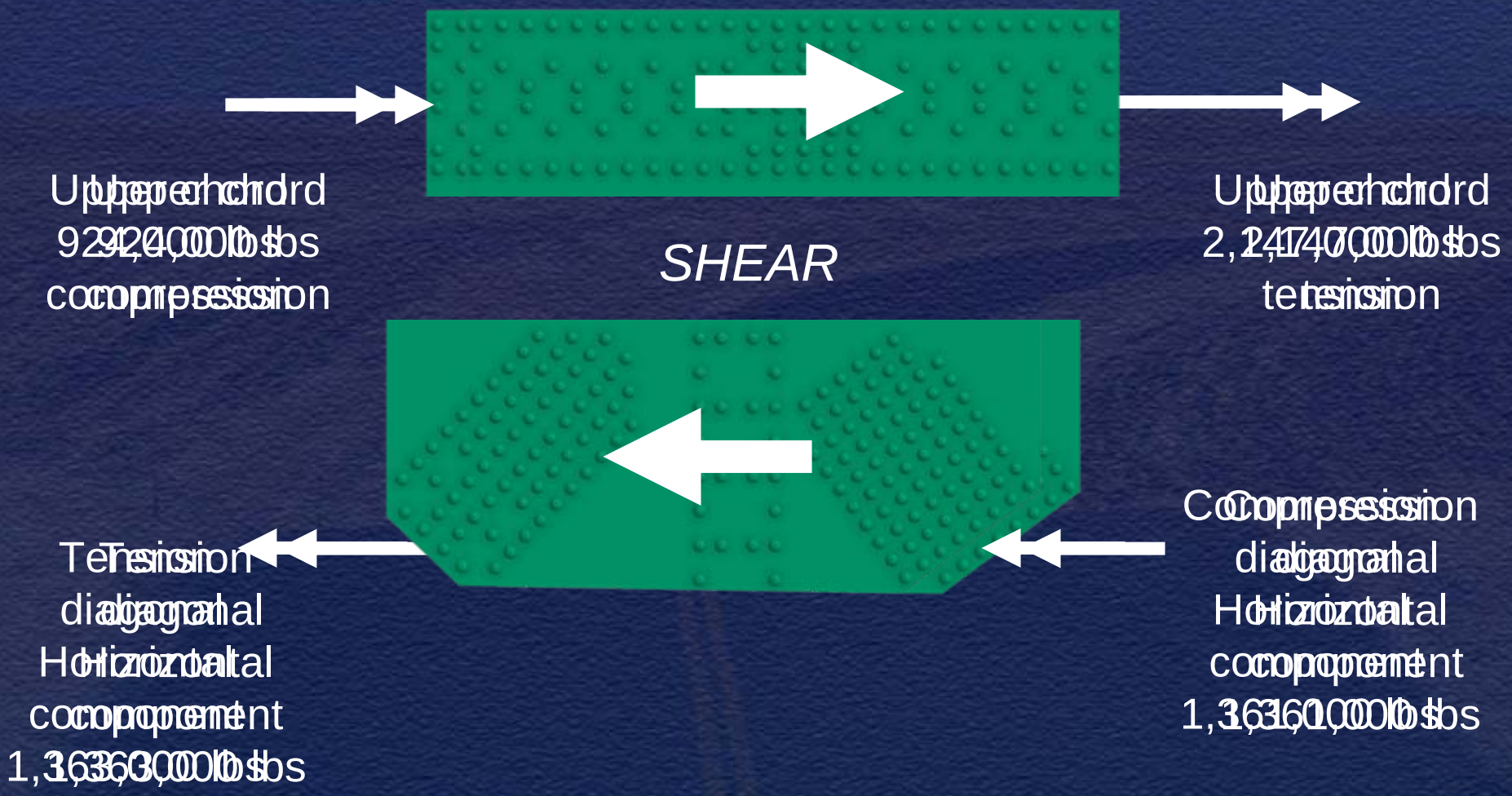
Vertical
540,000 lbs
tension

Compression
diagonal
2,288,000 lbs

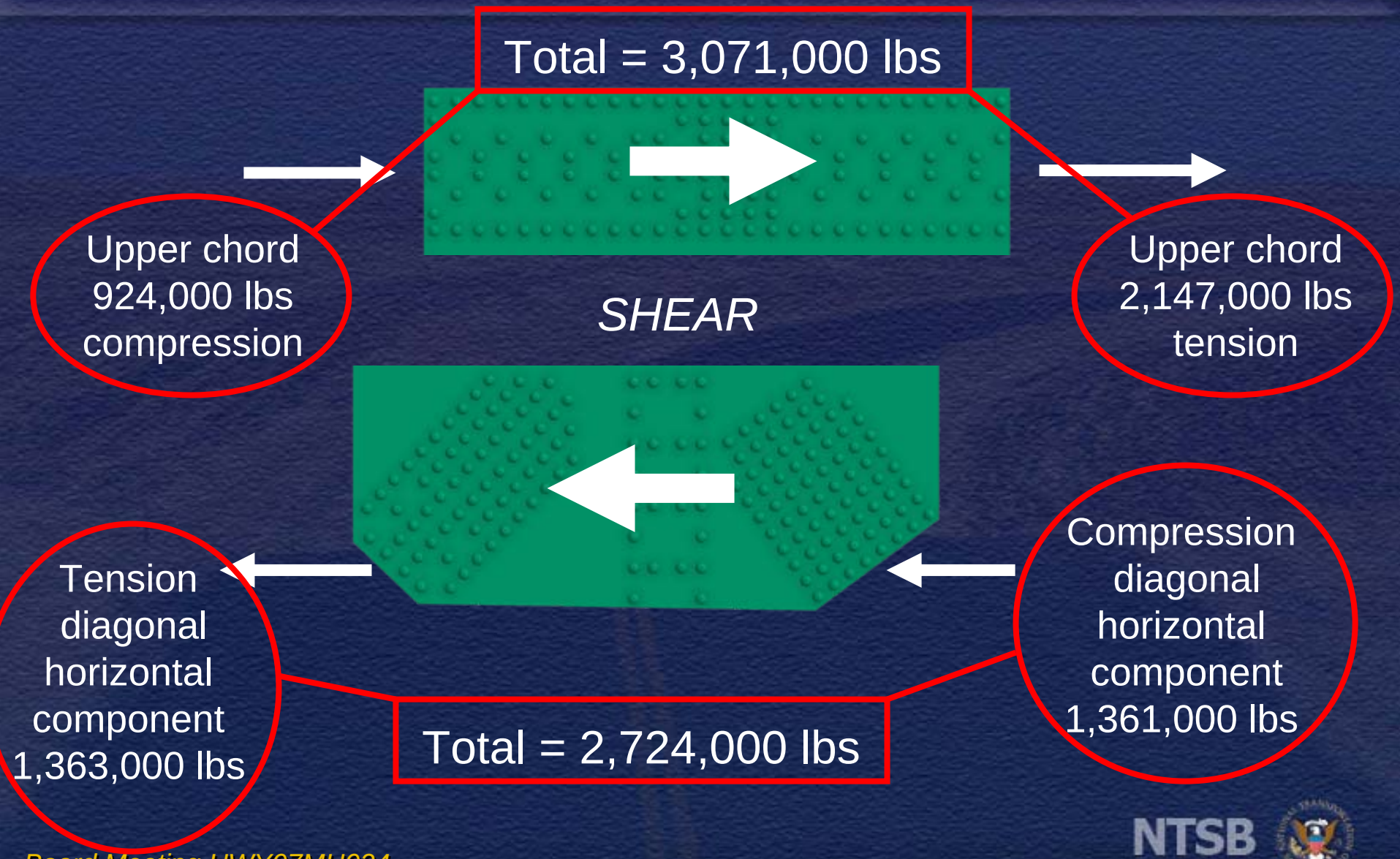
U10 - Design for Shear



U10 - Design for Shear



U10 - Design for Shear



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Bridge Design – U10 Calculations

$$\text{Shear stress} = \frac{\text{Shear force}}{\text{Area}}$$

$$= \frac{3{,}071{,}000 \text{ pounds}}{100 \text{ square inches}}$$

$$= 30{,}710 \text{ pounds per square inch}$$

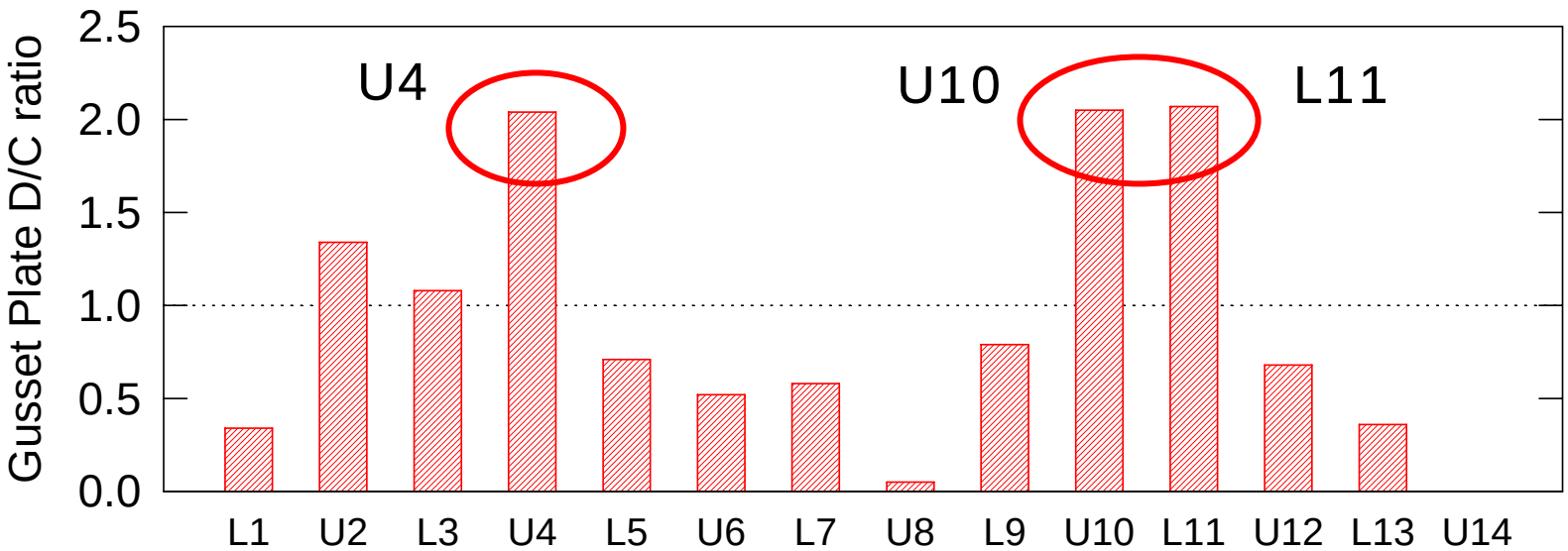
Bridge Design – U10 Calculations

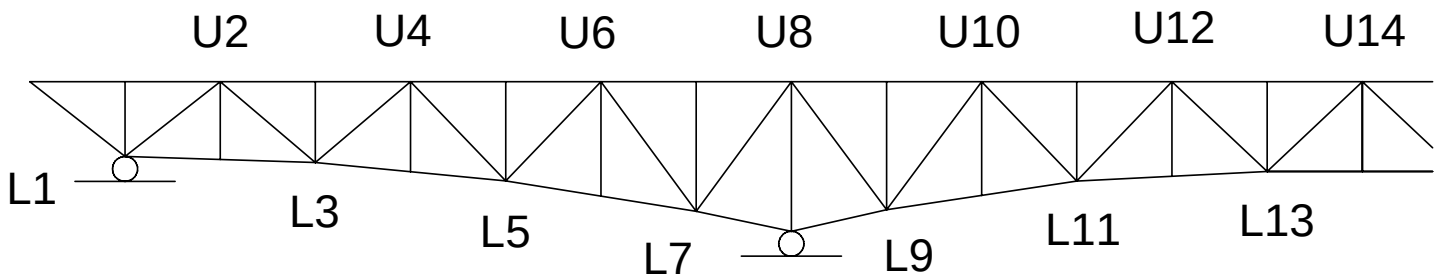
- Demand
  - = Shear stress from member design forces
  - = 30,071 pounds per square inch
- Capacity
  - = AASHO specified allowable stress
  - = 15,000 pounds per square inch
- Demand-to-Capacity ratio = 2.05

Bridge Design – U10 Calculations

- The Demand should be less than the Capacity
- The Demand-to-Capacity ratio should be less than 1
- U10 Demand-to-Capacity ratio = 2.05
- To make the Demand-to-Capacity ratio equal to 1, the U10 gusset plate thickness would have to increase from ½ inch to slightly more than 1 inch

Results - Gusset Plate Shear Analysis





Gusset Plate Analysis Summary

- Analysis showed that the U10 gusset plates had clearly inadequate capacity
- Other gusset plates had similar inadequate capacity
- No records were found for design of main truss gusset plates
- No other design deficiencies found

Result

- January 15, 2008 – Interim safety recommendation to the Federal Highway Administration

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