Load Rating of Pile-Supported Bridges

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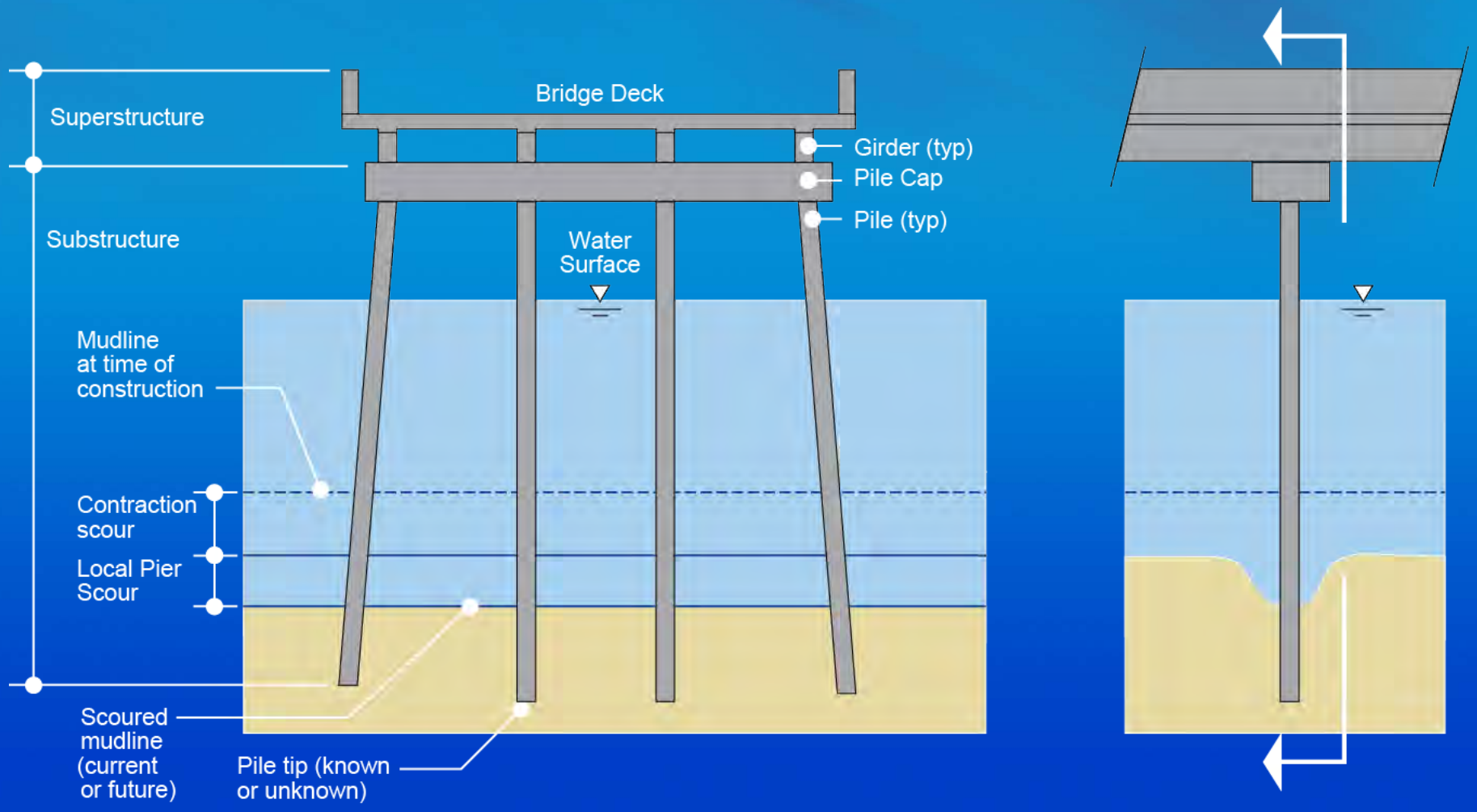
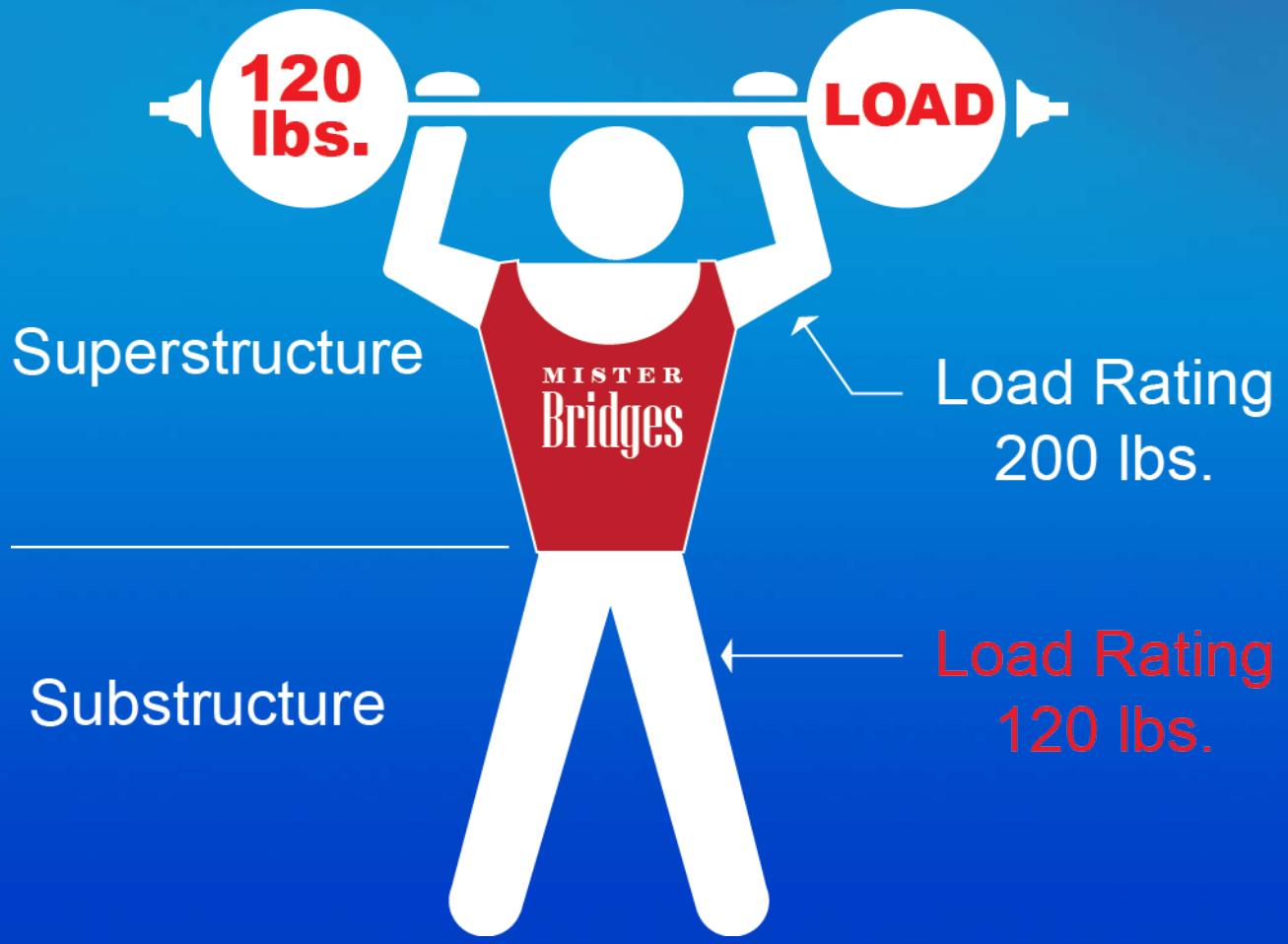
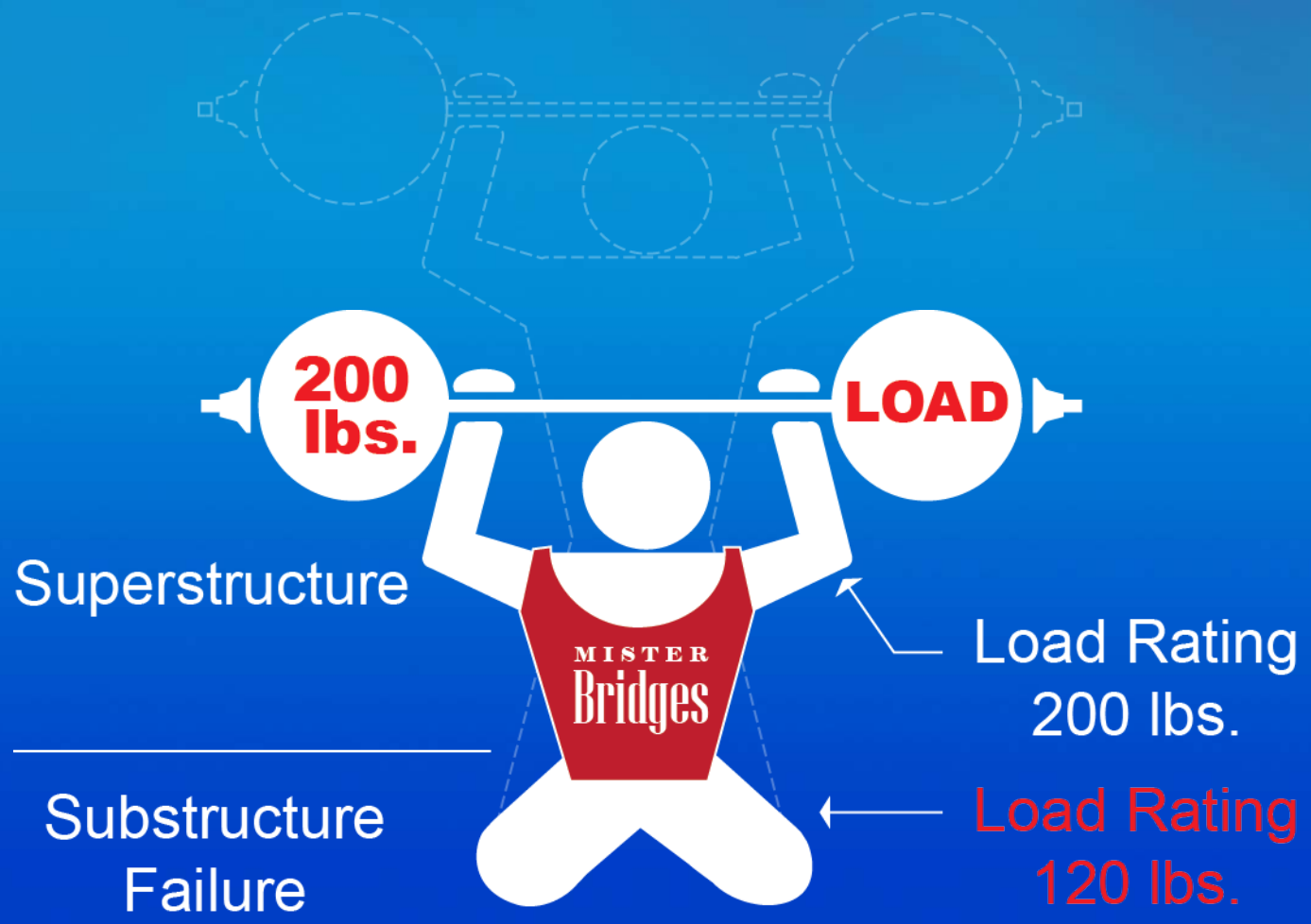
Schematic of Bridge Structure Over Waterway



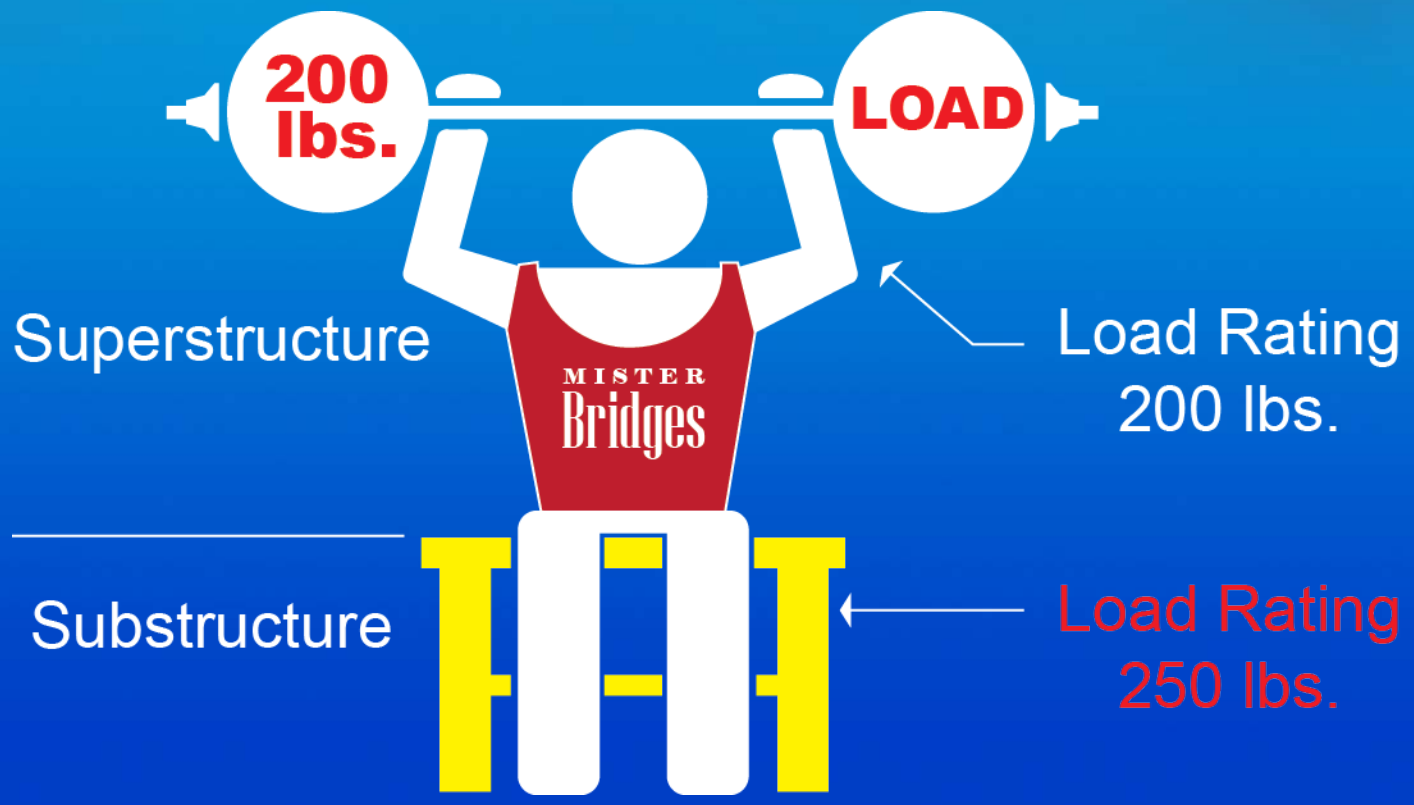
Mr. Bridges
Safe Weight Lifting Load



Mr. Bridges
Leg Collapse



Mr. Bridges
Safe Lifting via Weight Bench



Background

- Bridge load rating is traditionally based on the superstructure components
- Rarely does the bridge load rater consider the load carrying capacity of the substructure

Background continued

- Manual for Condition Evaluation of Bridges (MCEB) (AASHTO 2010) states:

"…members of substructures need not be routinely checked for load capacity".

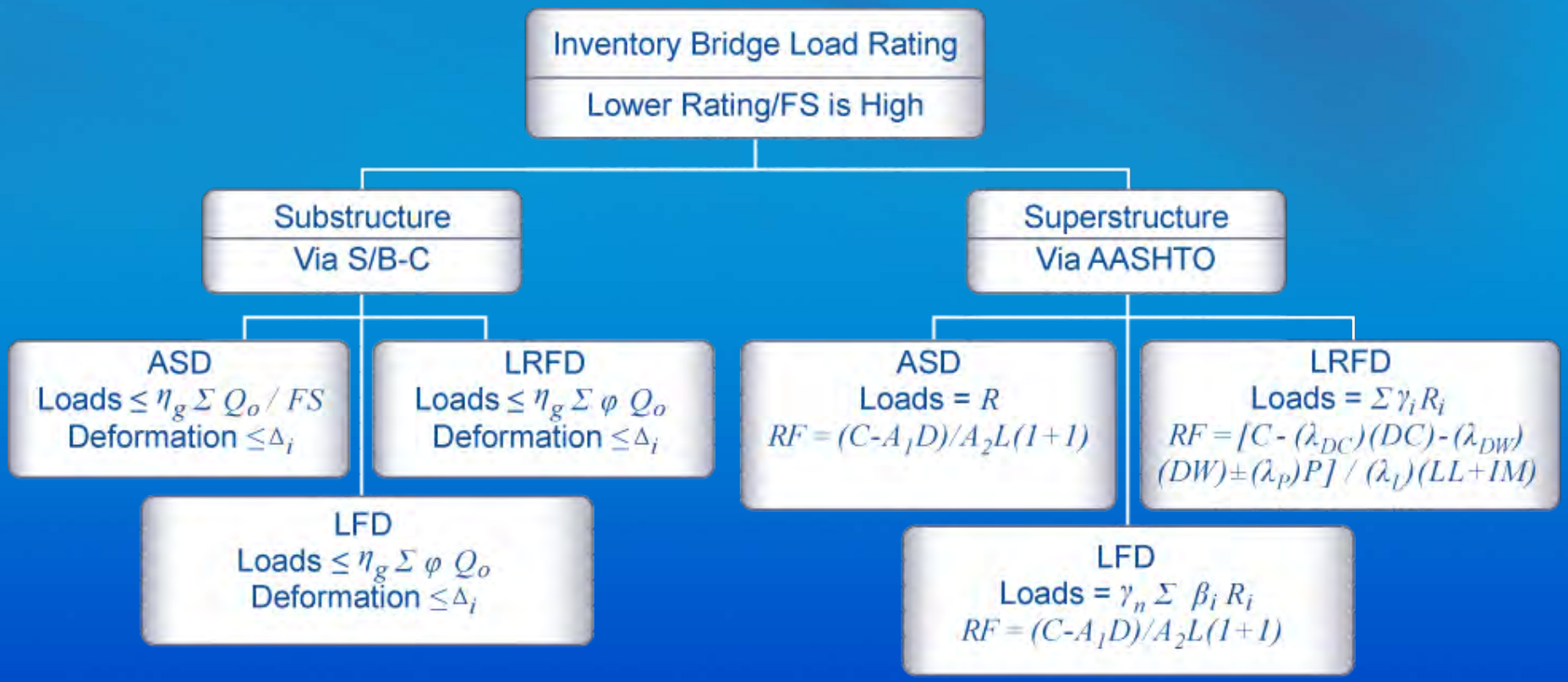
and

"Substructure elements should be checked in situations where the Engineer has reason to believe that their capacity may govern the load capacity of the entire bridge".

Structural Perspective

- MCEB requirement related to considering the substructure in a bridge load rating is applicable to bridges over waterways
- State of Practice about Substructure:
  a) No mention at all
  b) Left to bridge engineers' judgment
  c) Using a qualitative rather than a quantitative approach
  d) Considering structure integrity but not soil failure, if done
- **Substructure**: Weakest Link in Bridge Load Rating
- Bridges Over Waterways Need to be Re-Evaluated
  - Prevent Catastrophic Failure
  - Reduce Maintenance/Repair Costs

Inventory Bridge Loading Flowchart

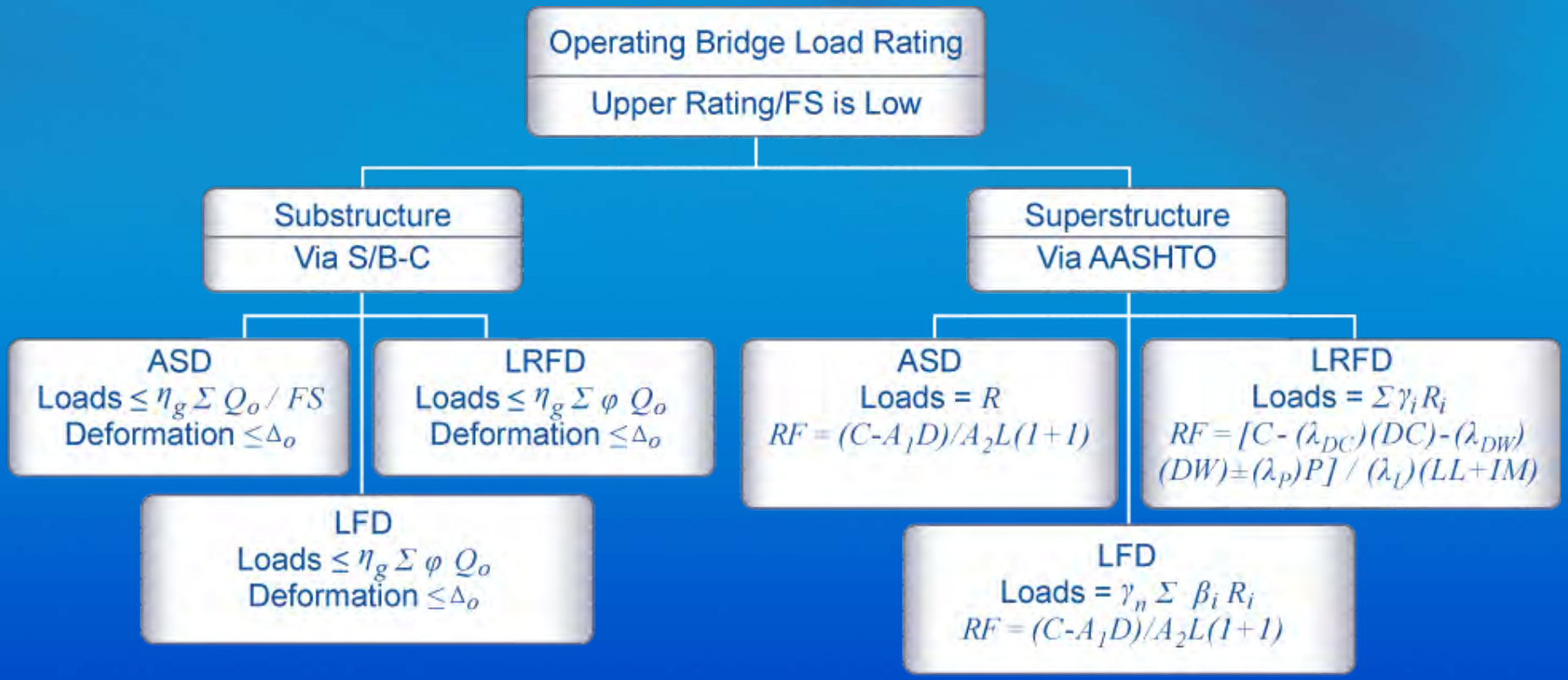


Load Factors

Rating Methodology	LRFR	LFR	ASR
Dead Load Factors	λ_{DC} - 1.25 λ_{DW} - 1.25	A_1 - 1.3	A_1 = 1.0
Live Load Factors	λ_L Inventory - 1.75 Operating - 1.35 Legal - 1.4 to 1.8 Permit - 1.15 to 1.8	A_2 Inventory - 2.17 Operating - 1.3	A_2 = 1.0
Dynamic Load Allowance/Impact Factor	Constant	Span Length Dependent	Article 6.7.4 (AASHTO 2000)

Source : AASHTO (2008; 2010)

Operating Bridge Loading Flowchart



Substructure Rating
Proposed Method

- Static/Back-Calculation (S/B-C) is used to perform the analysis - an iterative process using finite element modeling (FB-MultiPier)
  - ⇨ Axial Loads & tip elevations - FB-Deep, Driven, etc.
  - ⇨ Graph FEM results - live load vs. corresponding settlement
- Loading level corresponding to a pre-defined deformation (settlement criteria) is determined as the load rating.

Settlement Considerations

Superstructure

Settlement Criteria for Bridges (*After Xanthakos 1995*)

Settlement Magnitude (inch)	Basis for Recommendation	Recommended By
2	Not Harmful	Bozozuk (1978)
2.5	Ride Quality	Walkinshaw (1978)
>2.5	Structural Distress	Walkinshaw (1978)
4	Ride Quality and Structural Distress	Grover (1978)
4	Harmful but Tolerable	Bozozuk (1978)
>4	Usually Intolerable	Wahls (1990)

Angular Distortion for Bridges (*After Xanthakos 1995*)

Angular Distortion	Basis for Recommendation	Recommended By
< 0.004	Tolerable for Continuous Bridges	Moulton, et al. (1985) Duncan and Tan (1991)
< 0.008	Tolerable for Simple-Span Bridges	Duncan and Tan (1991)

Settlement Considerations

Substructure

Substructure

- Ultimate Pile Load (Q_o)

  $$Q_o = Q_p + Q_s$$

  Where

  Q_p = Ultimate Tip (Point) Load

  Q_s = Ultimate Shaft (Skin) Load

– Full Mobilization of Q_s

  0.25 to 0.40 Inch *(Vesic 1977)*

– Full Mobilization of Q_p

  10% B Driven Piles

  Up To 30% B Bored Piles

  Where B = Pile Width (Diameter) *(Vesic 1977)*

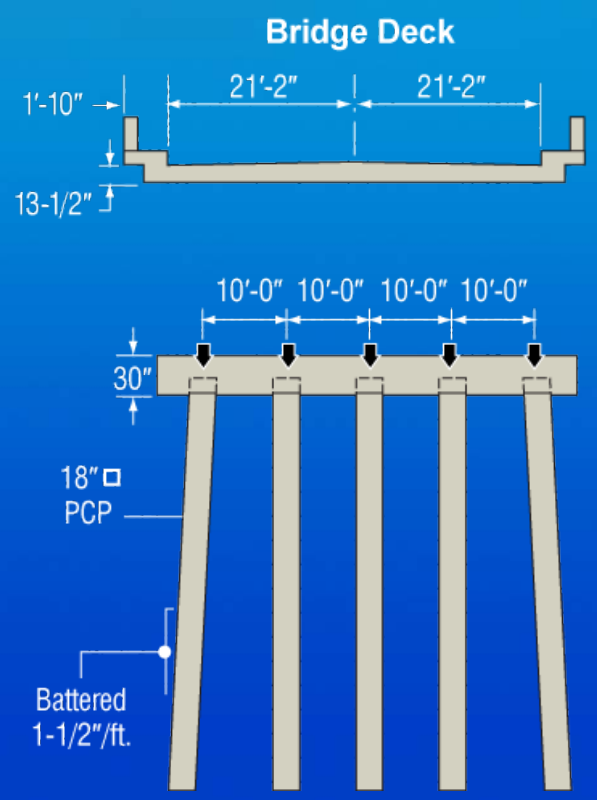
Proposed Settlement Criteria

- Settlements of 1 to 1.25 inches and 2 to 2.25 inches have been proposed to establish inventory and operating substructure load rating, respectively

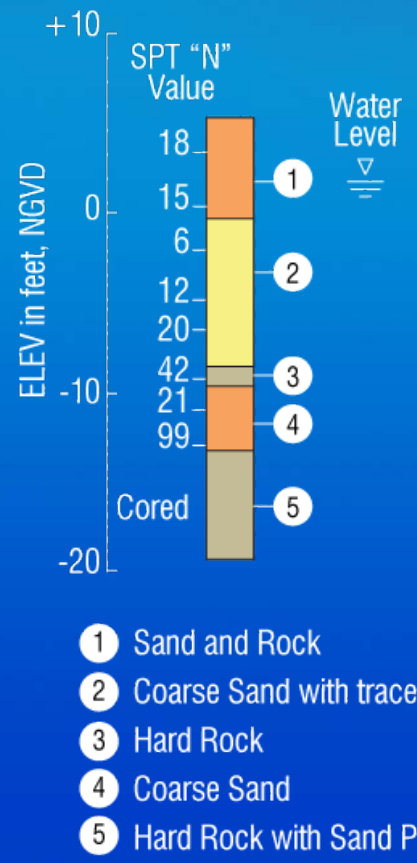
Case Histories

Bridge No. 030064
Collier County, Florida

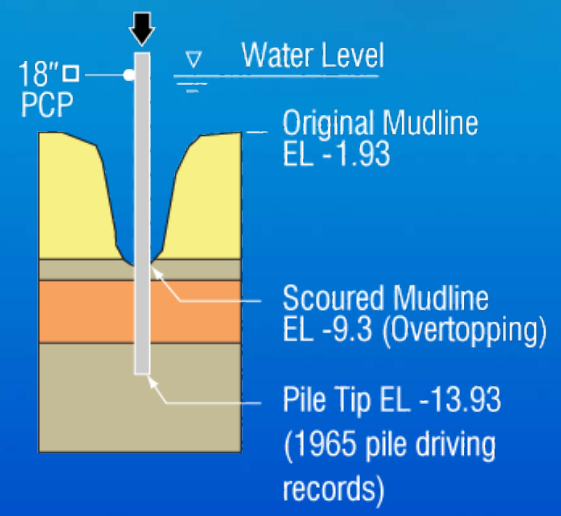
Typical Bridge Components
Bridge No. 030064



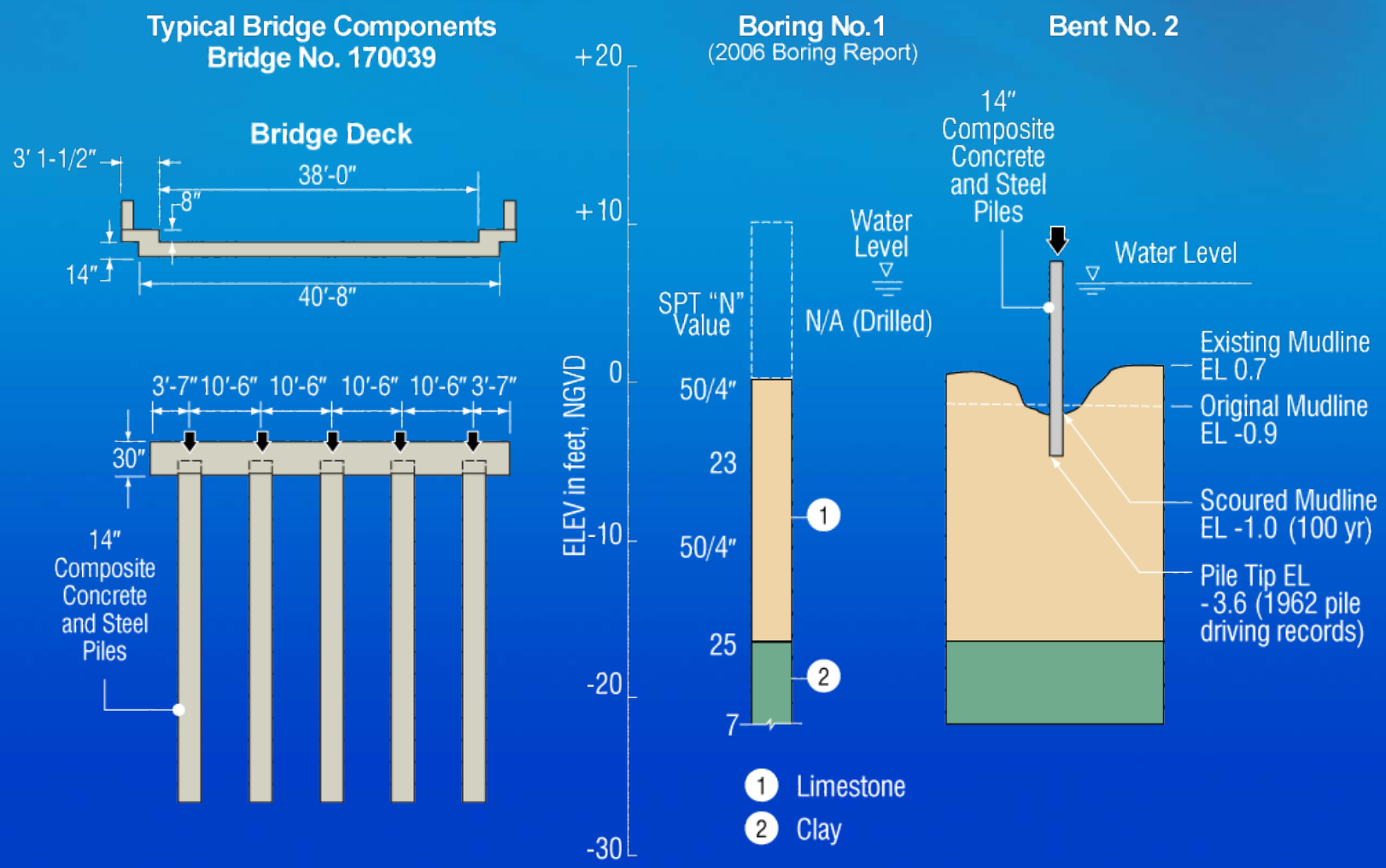
Boring No.5
(1965 Boring Report)



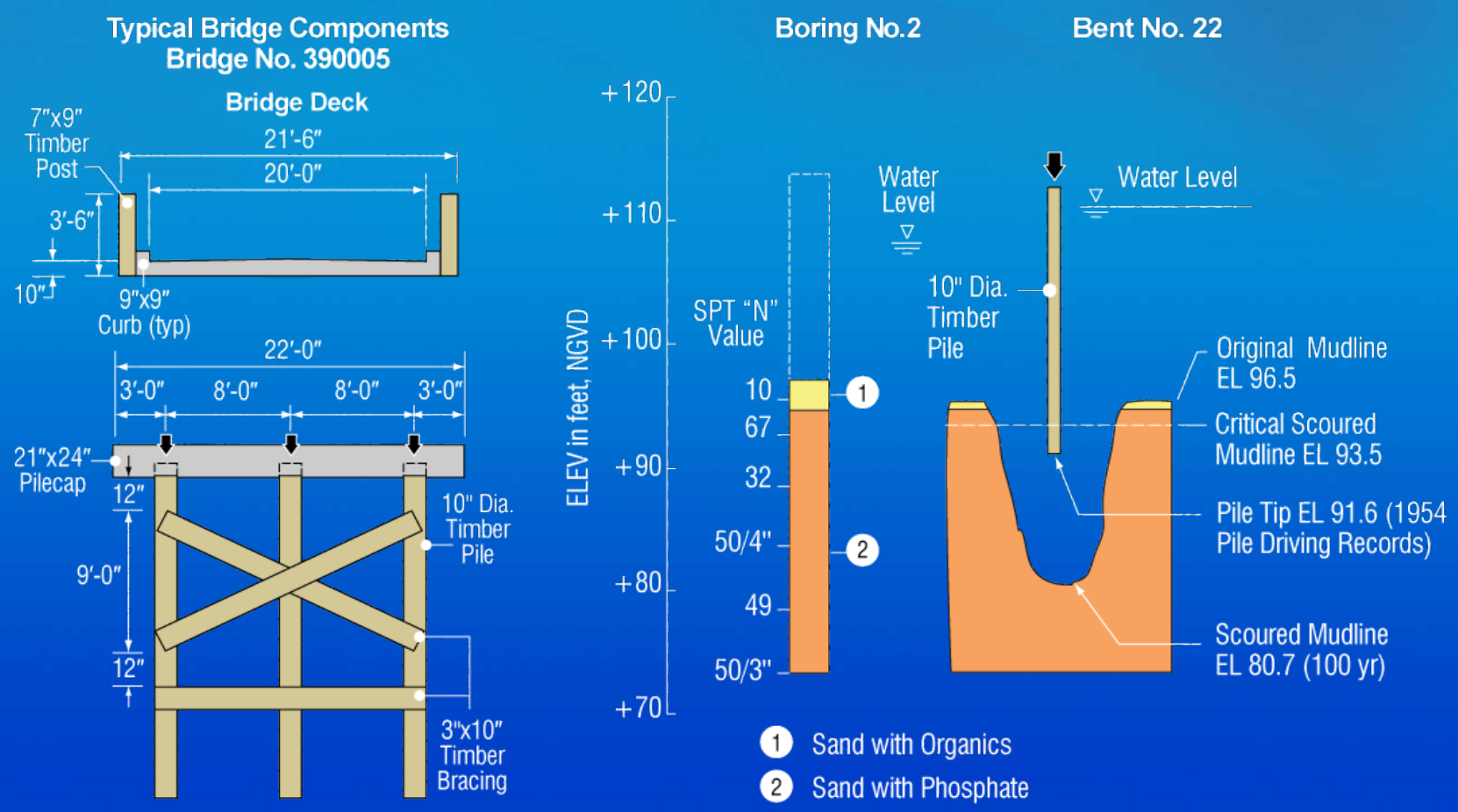
Bent No. 2



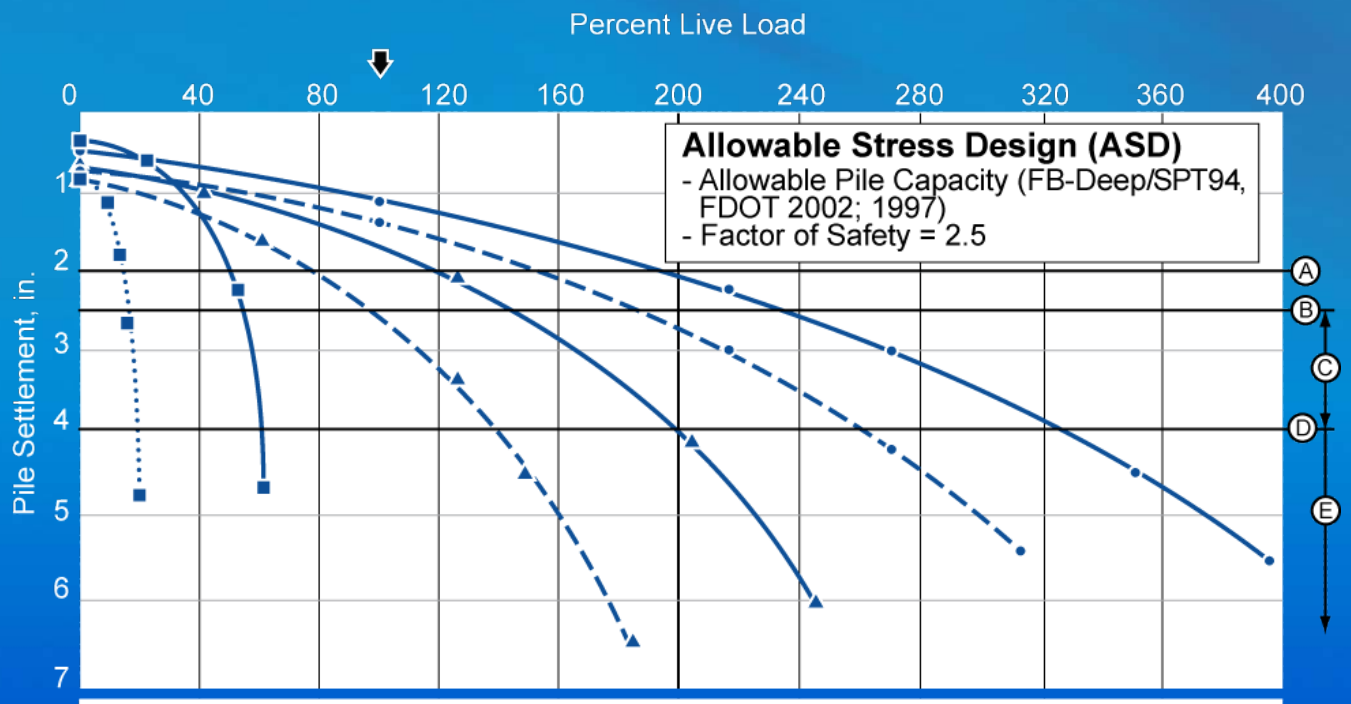
Bridge No. 170039
Sarasota County, Florida



Bridge No. 390005
Union County , Florida



Allowable Stress Rating (ASR)

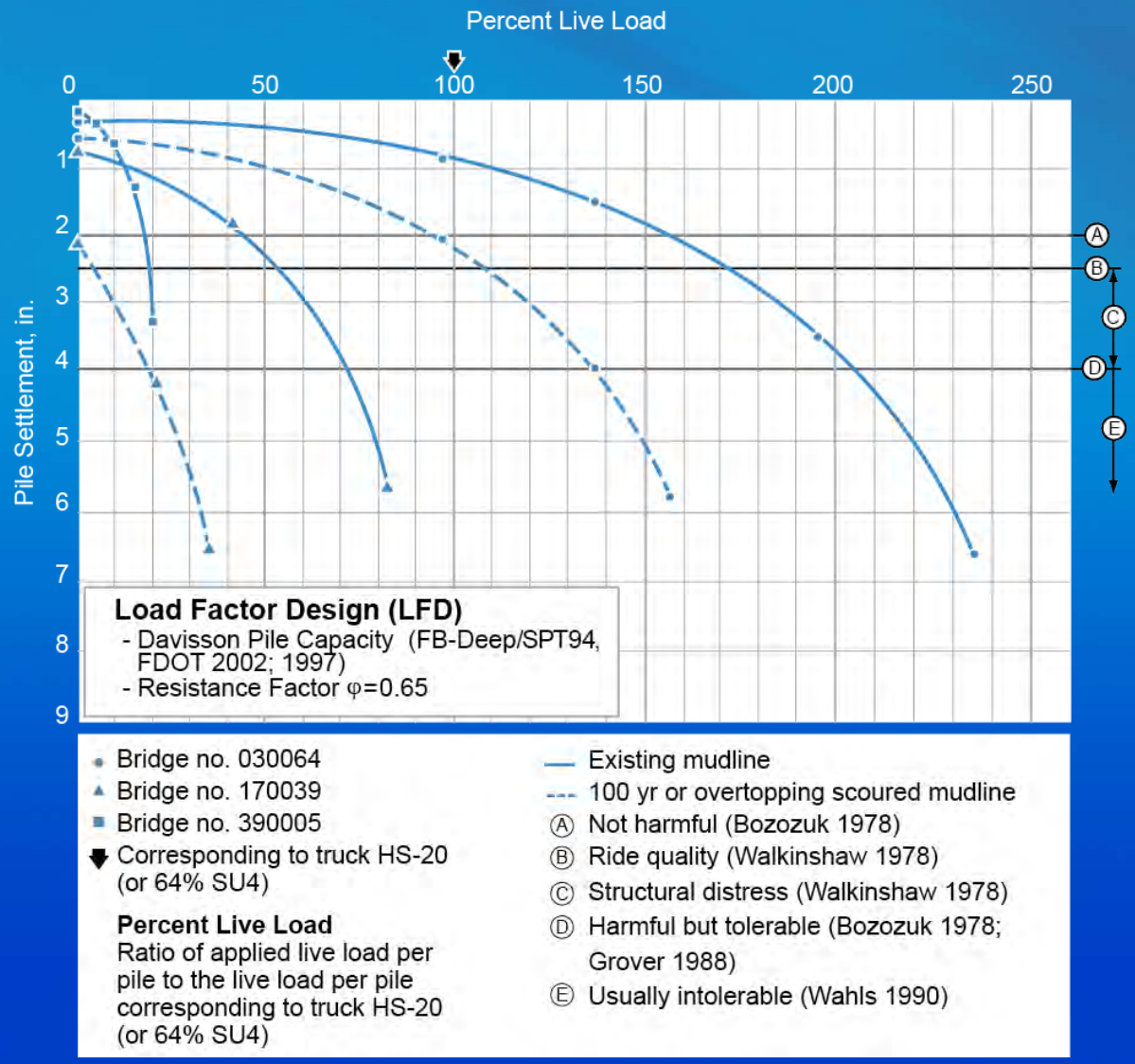


- Bridge no. 030064
- Bridge no. 170039
- Bridge no. 390005
- Corresponding to truck HS-20 (or 64% SU4)

Percent Live Load
Ratio of applied live load per pile to the live load per pile corresponding to truck HS-20 (or 64% SU4)

- Existing mudline
- 100 yr or overtopping scoured mudline
- Critical mudline
- Ⓐ Not harmful (Bozozuk 1978)
- Ⓑ Ride quality (Walkinshaw 1978)
- Ⓒ Structural distress (Walkinshaw 1978)
- Ⓓ Harmful but tolerable (Bozozuk 1978; Grover 1988)
- Ⓔ Usually intolerable (Wahls 1990)

Load Factor Rating (LFR)



Superstructure and Substructure Load Rating

Consultant	Bridge No.	Superstructure[c]		Substructure[d]							
		LFR Methodology		@ Existing Mudline Elevation				@ Critical Scour Elevation or 100-year/Overtopping Scoured Mudline Elevation			
		Inventory (tons)	Operating (tons)	Inventory (tons)		Operating (tons)		Inventory (tons)		Operating (tons)	
				ASR	LFR	ASR	LFR	ASR	LFR	ASR	LFR
Ayres & GCI (2006)	030064[a]	45	75	36	40	81	58	22	18	58	36
	170039[a]	39	65	15	6	43	18	7	N/A	29	N/A
Collins & GCI (1997)	390005[b]	13	22	10	3	12	4	1	N/A	3	N/A

a HS-20 (36 tons)
b SU-4 (35 tons)
c Based on FDOT Database (FDOT 2010)
d Based on Static/Back-Calculation (S/B-C)

ASR Allowable Stress Rating
LFR Load Factor Rating
N/A Not available due to excessive displacement or non-convergence (i.e., instability)

Conclusions

- Current practice usually assigns load ratings based on evaluation of the superstructure. Load rating a bridge based on the superstructure alone could cause either catastrophic or functional failure
- The load carrying capacity of substructure decreases as scour occurs
- Definitive methodology for assigning substructure load rating to bridges should be initiated

Conclusions continued

- All bridges over waterways should be analyzed for a substructure load rating considering the existing mudline and potential scour
- Substructure load rating should be dependent on the settlement
- Settlements of 1 to 1.25 inch and 2 to 2.25 inch have been proposed to establish inventory and operating substructure load rating respectively
- Further field monitoring and research needed to establish optimum settlement criteria.