Seismic Behavior & Retrofit Design of Admiral Way: A Conjoined Steel & Concrete Bridge

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TranTech Engineering and Jacobs
Client: SDOT

Western Bridge Engineers Seminar
September 7, 2023

AGENDA

Investigations that we completed to assess vulnerabilities and design retrofit measures:

1. Identifying lateral load paths
2. Response simulation models
   - Inelastic link slab modeling
   - V&V
3. Foundation issues:
   - Stepping analysis
   - Stacked spread footings
   - Pedestal retrofit options
4. Novelties:
   - Zipper-frames,
   - No shoring during gusset-plate strengthening with countersunk bolts,
   - New pry-out design procedure for anchor bolts in polymer jacketed sections,

What we will talk about:

A. Project history and background

B. Identifying lateral load paths

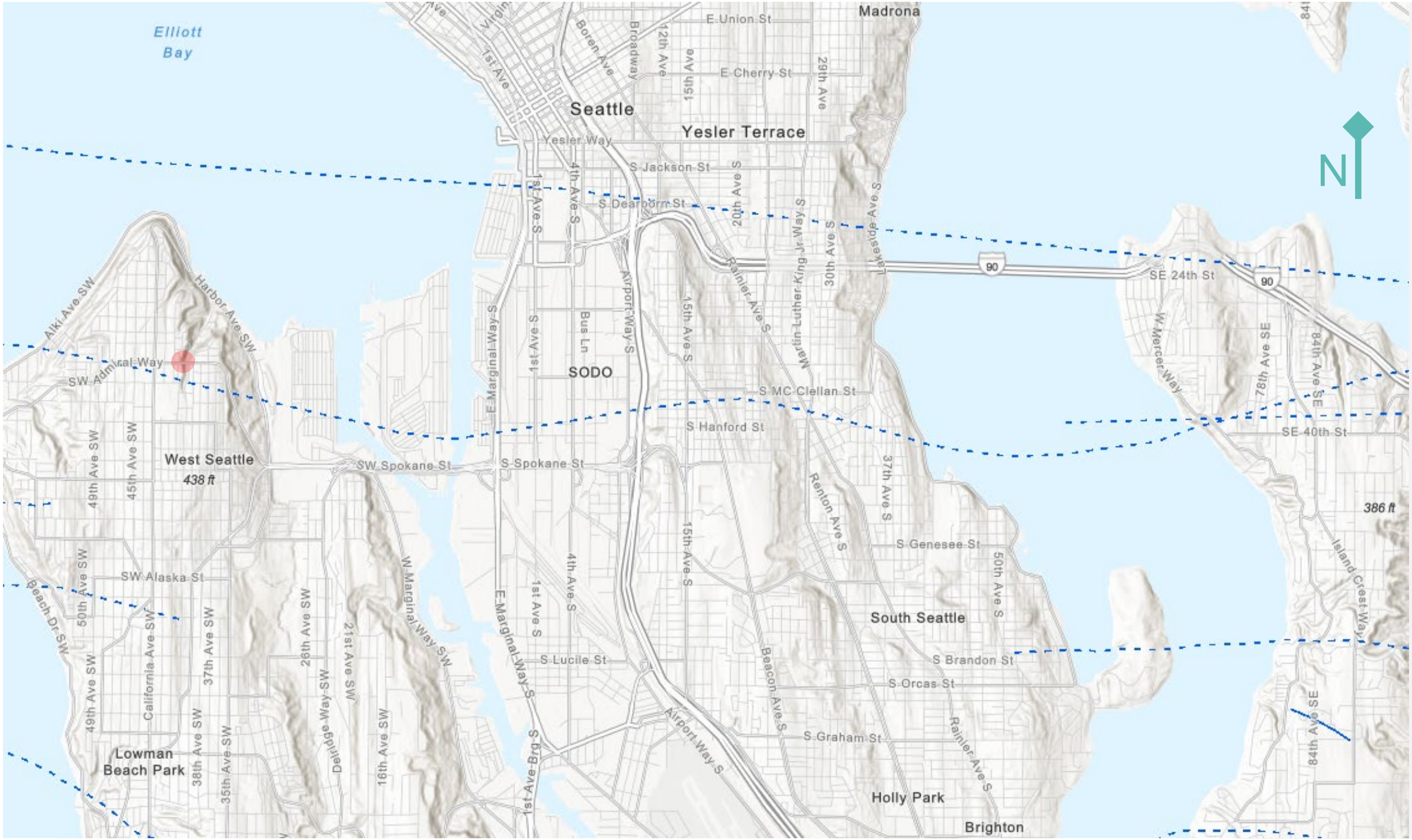
C. Response simulation models
   - Inelastic link slab modeling
   - V&V

D. North Bridge

ABOUT THE PROJECT

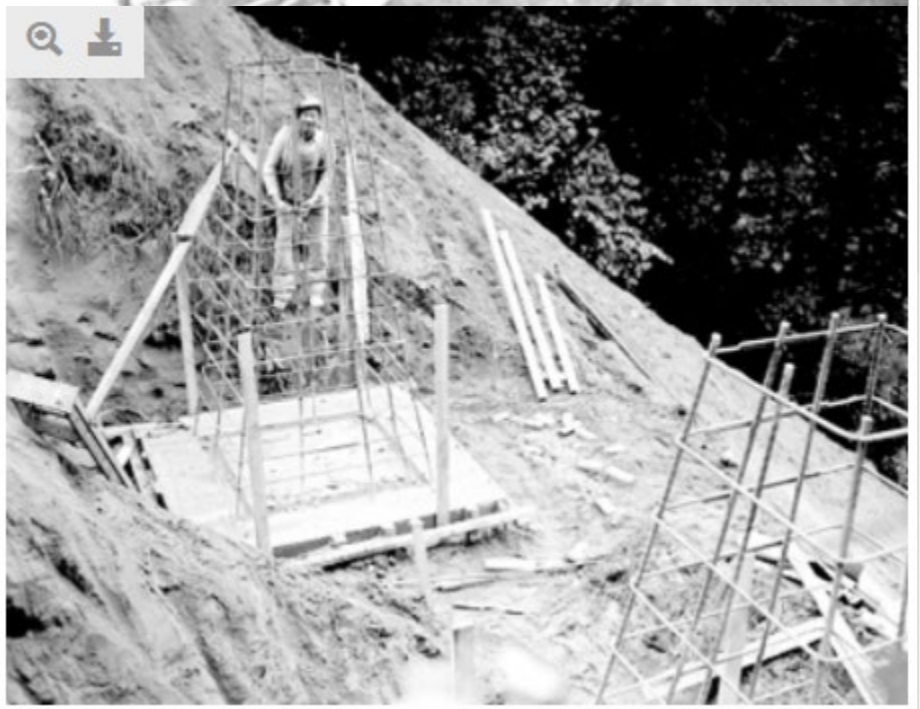
A major arterial in West Seattle.

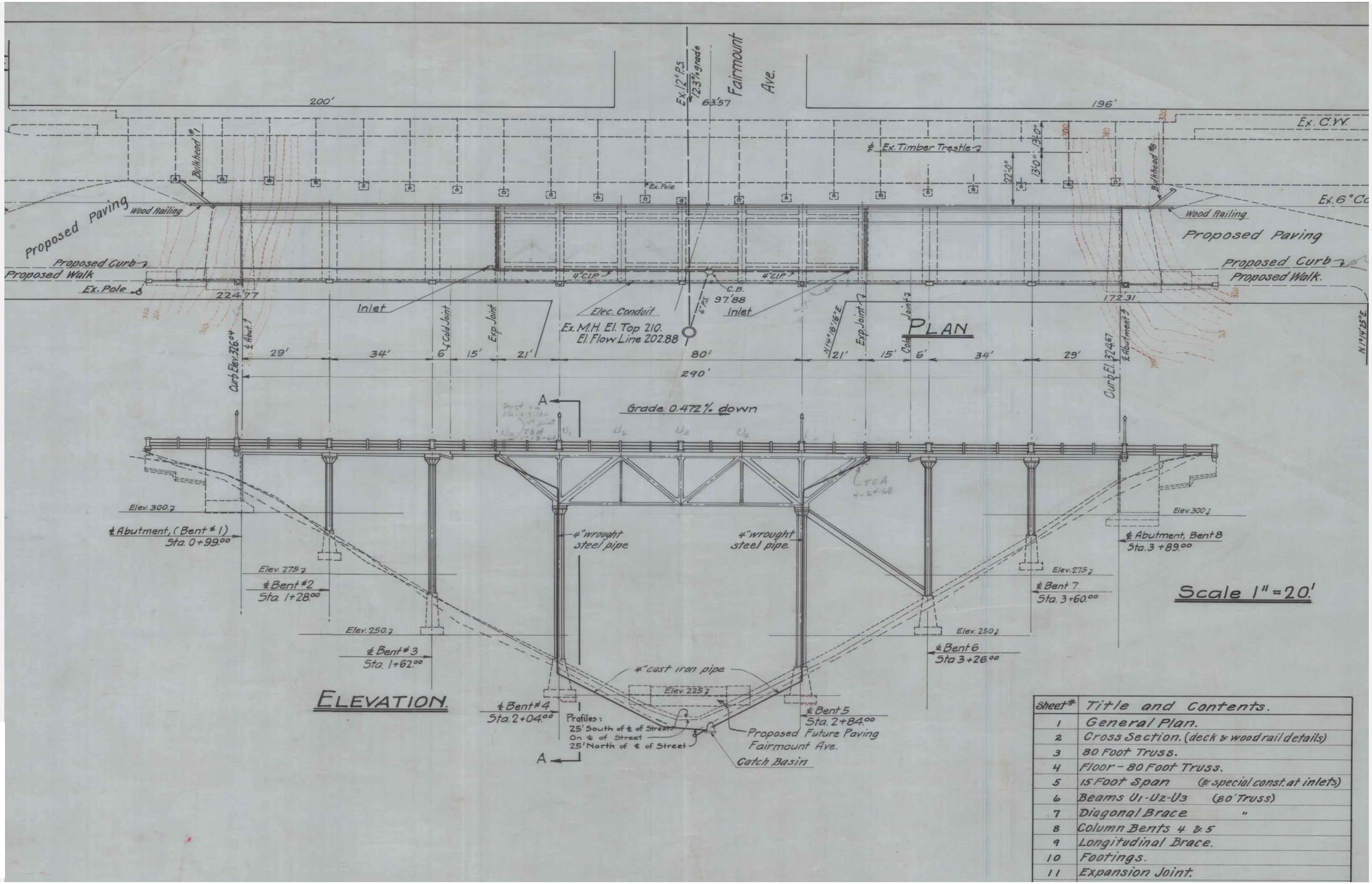
- 300-foot length 90-foot tall over a steep ravine
- 7-span concrete bridge (North). 1927. Main span 80’.
- 5-span steel bridge (South). 1949. Main span 84’.
- Partial seismic retrofit longitudinally merged in 1995.


Elliott Bay
Madrona
E Union St
E Cherry St
Seattle
Yesler Terrace
Yesler Way
S Jackson St
S Dearborn St
Broadway
12th Ave
15th Ave
29th Ave
Boren Ave
1st Ave
4th Ave S
1st Ave S
20th Ave S
30th Ave S
Lakeside Ave S
Martin Luther King Jr Way S
Rainier Ave S
90
SE 24th St
W Mercer Way
78th Ave SE
84th Ave SE
SE 40th St
386 ft
Island Crest Way
SODO
Bus Ln
Airport Way S
E Marginal Way S
15th Ave S
S MC Clellan St
S Hanford St
Alki Ave SW
Harbor Ave SW
SW Admiral Way
West Seattle
438 ft
SW Spokane St
S Spokane St
49th Ave SW
45th Ave SW
50th Ave SW
SW Alaska St
Beach Dr SW
California Ave SW
37th Ave SW
26th Ave SW
21st Ave SW
W Marginal Way SW
Delridge Way SW
16th Ave SW
38th Ave SW
35th Ave SW
Lowman Beach Park
Renton Ave S
37th Ave S
S Genesee St
50th Ave S
South Seattle
S Lucile St
S Brandon St
S Orcas St
Beacon Ave S
S Graham St
Rainier Ave S
Holly Park
Brighton
84th Ave SE
N

EXITING CONDITIONS

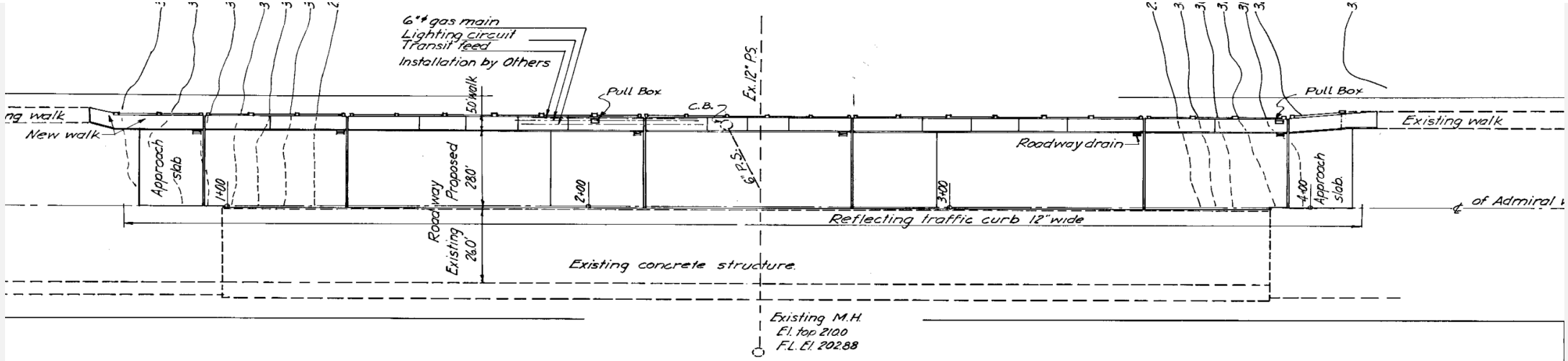
Steel or concrete?



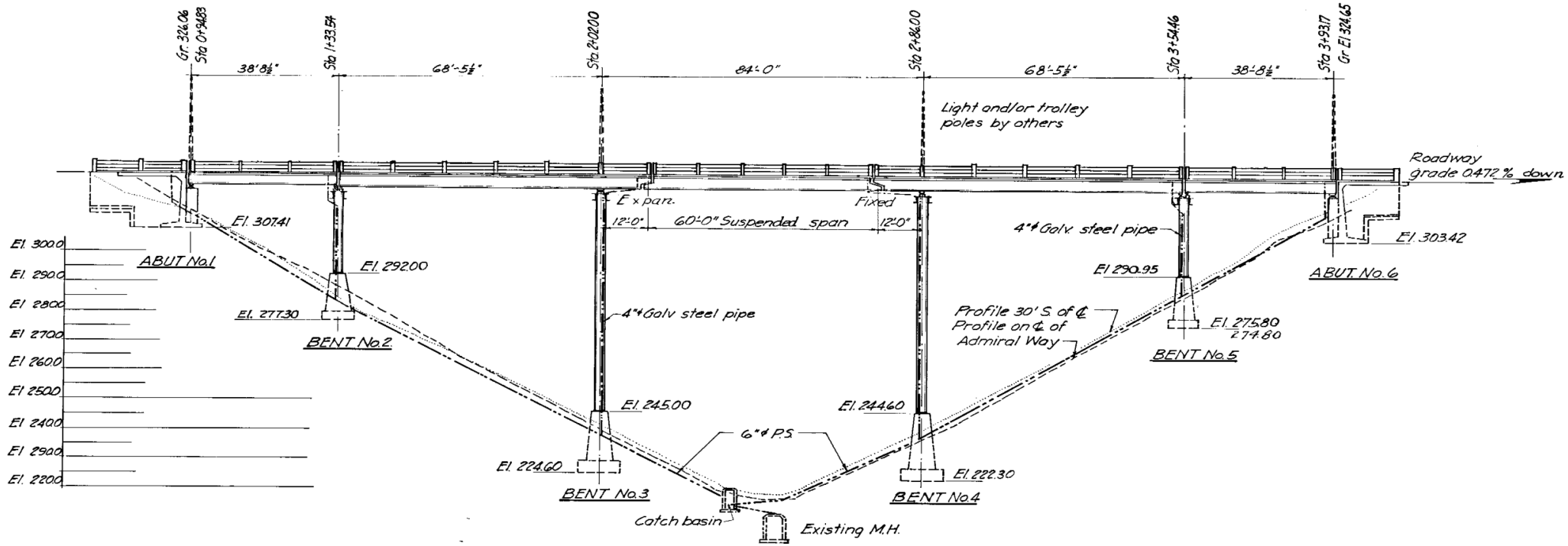


Sheet #	Title and Contents.
1	General Plan.
2	Cross Section. (deck & wood rail details)
3	80 Foot Truss.
4	Floor - 80 Foot Truss.
5	15 Foot Span (& special const. at inlets)
6	Beams U1-U2-U3 (80' Truss)
7	Diagonal Brace "
8	Column Bents 4 & 5
9	Longitudinal Brace.
10	Footings.
11	Expansion Joint.

1927



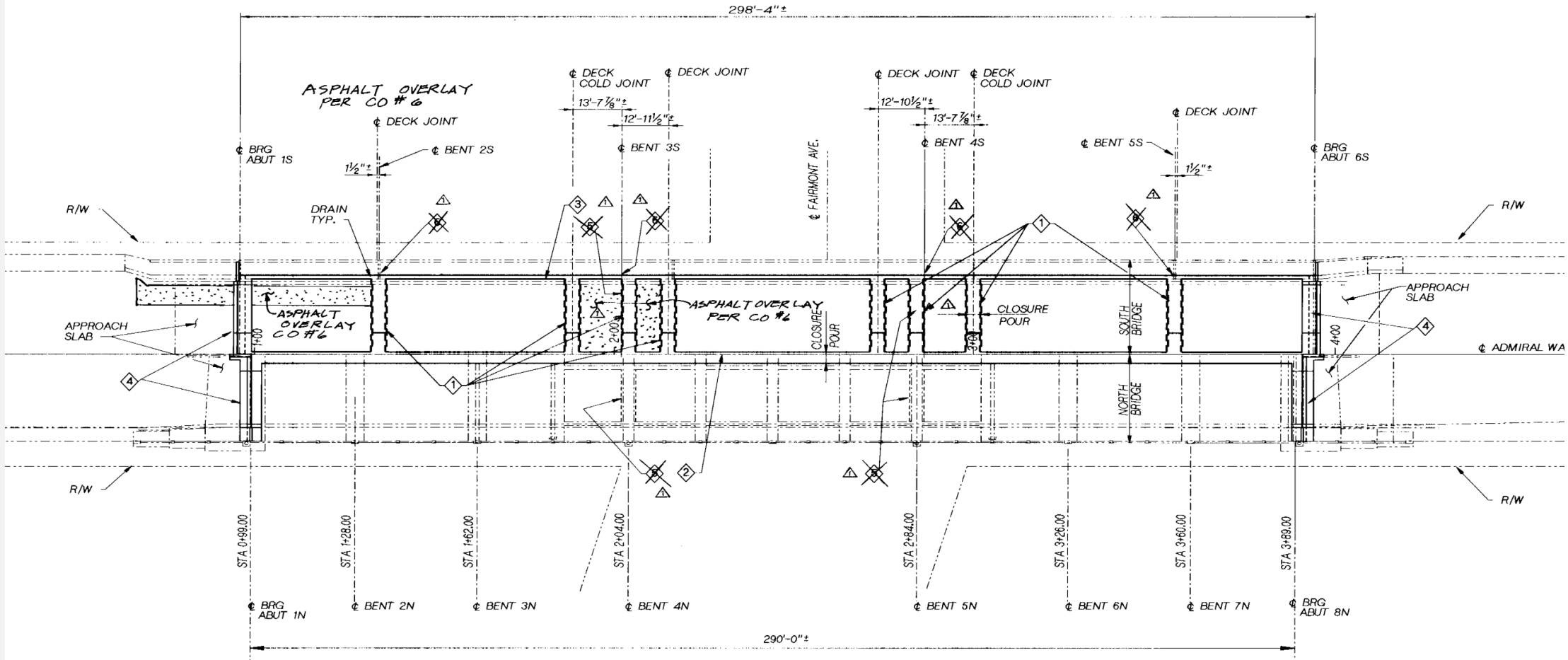
PLAN



ELEVATION

Scale 1"=20'

1949



PLAN
1"=20'-0"

1995

UNIQUE CHALLENGES

Where are the bents?

UNIQUE CHALLENGES

A plethora of adverse conditions!

Longitudinal Direction

- Two different structures with different materials (ductile and brittle), load-resisting systems, weights, etc. are fused together.
- Depending on several factors, the structures may or may not respond to seismic excitations in phase, each requiring a set of provisions.
- Is there a concrete truss in there?
- Odd structural shapes (e.g., concrete struts).
- Sub-Superstructure interaction due to abutment shoring.
- Longitudinal closure pour breathing and incipient seismic pounding.

Transverse Direction

- Bridge bents are offset. Where is a bent for pushover analyses?
- Tall bents undergo rocking response and uplift on an unstable slope.
- Stabilizing the foundation creates soil bearing failure and unacceptable settlements.
- Asymmetric response (push towards concrete structure or steel structure? What happens the next cycle?)
- Deck is partially semi-composite (inducing torsion) with very peculiar pushover behavior in the longitudinal direction.

BOUNDING UNCERTAINTY IN 61 MODEL-SETS

Independent Investigations in Support of Design

- Rocking analyses (no rocking, tall bents rock, all bents rock),
- Nonlinear buckling analyses, justification of buckling mode of tall bents in the long. direction,
- Lock-in forces in gussets, columns, capbeams,
- Longitudinal deck joint failure assessment,
- Failure analysis with zipper struts, protection of bent struts, enhanced ductility,
- Consideration for pushover reversal,
- Open-sections torsional strengthening,
- Soil-structure Interaction on unstable site,
- Various boundary-conditions based on original details (*e.g.*, column bases),
- Steel column-concrete pedestal joint anchorage deficiency – how effective is composite wrapping?
- Pedestals post-tensioned anchor rods – consideration of service conditions on foundation bearing.

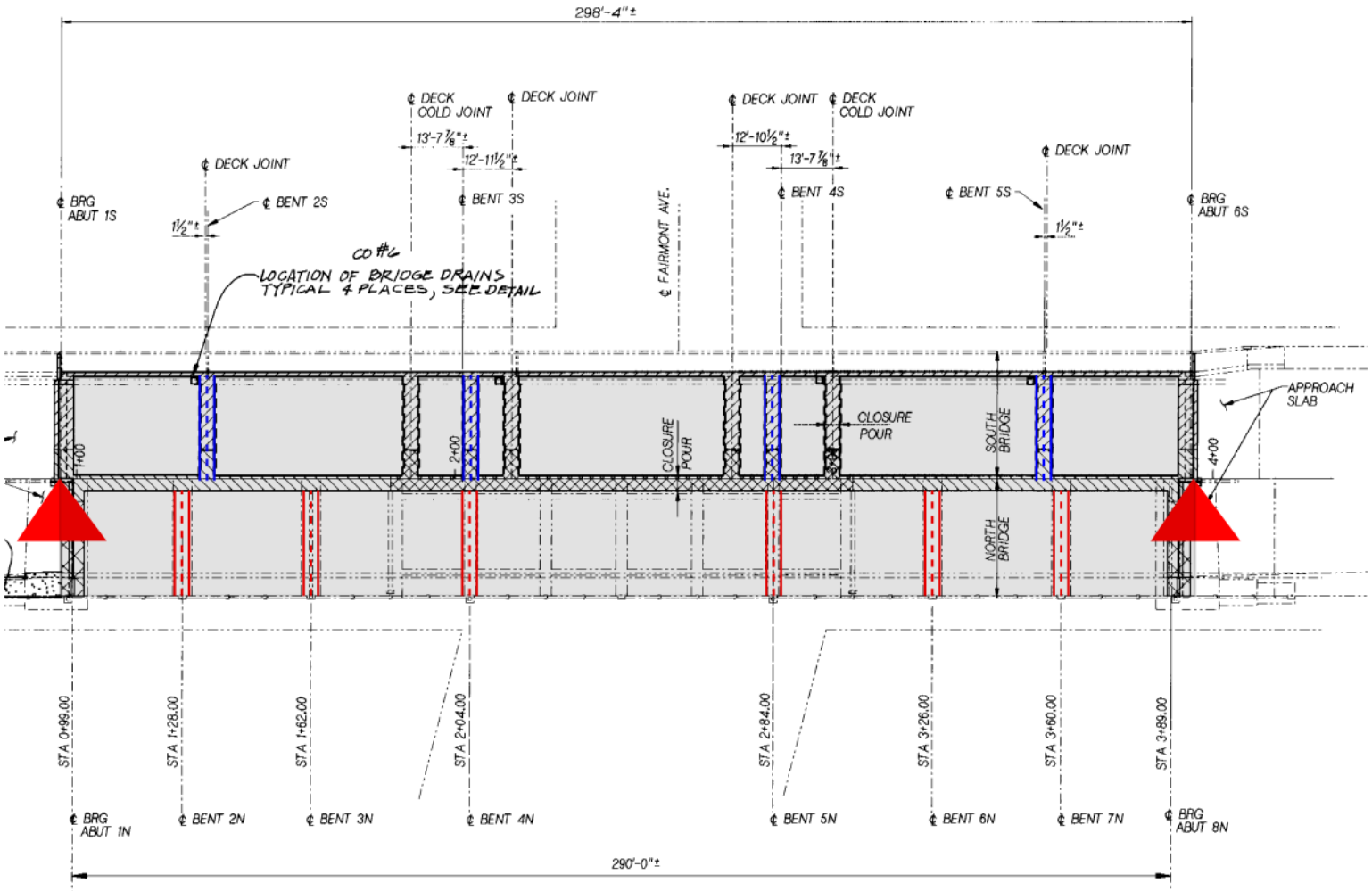
New Yorker, March 23, 2022

"So, according to your chart, you've been experiencing brief surges of hope followed by prolonged waves of dread."

TRANSVERSE ANALYSIS

Where are the bents?

HOW IS TRANSVERSE PUSHOVER PERFORMED?

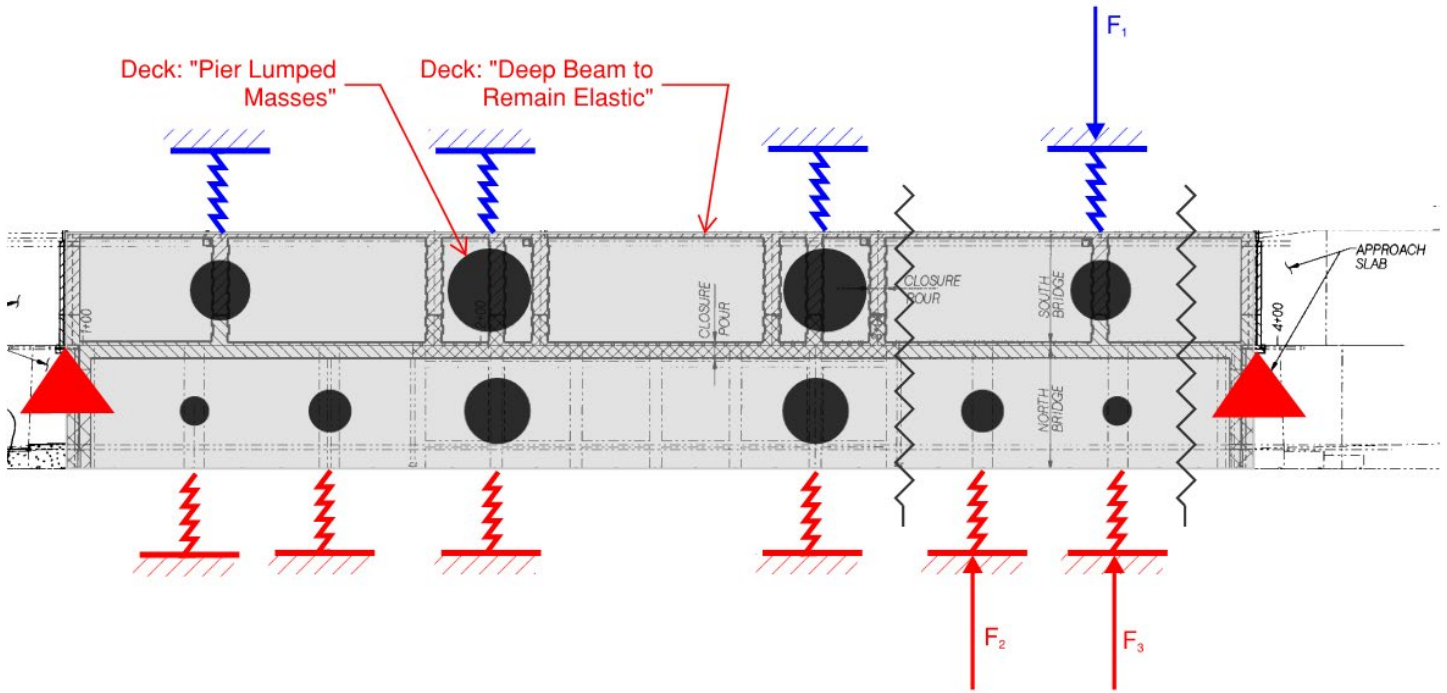


Q: How to identify isolated bents?

PLAN
1"=20'-0"

THE ANATOMY OF TRANSVERSE SEISMIC RESPONSE

Nigel Priestley's dual load paths analogy (elastic superstructure, inelastic substructure)



THE IMPORTANT ROLE OF ASSUMPTIONS

Are the bridges really merged?

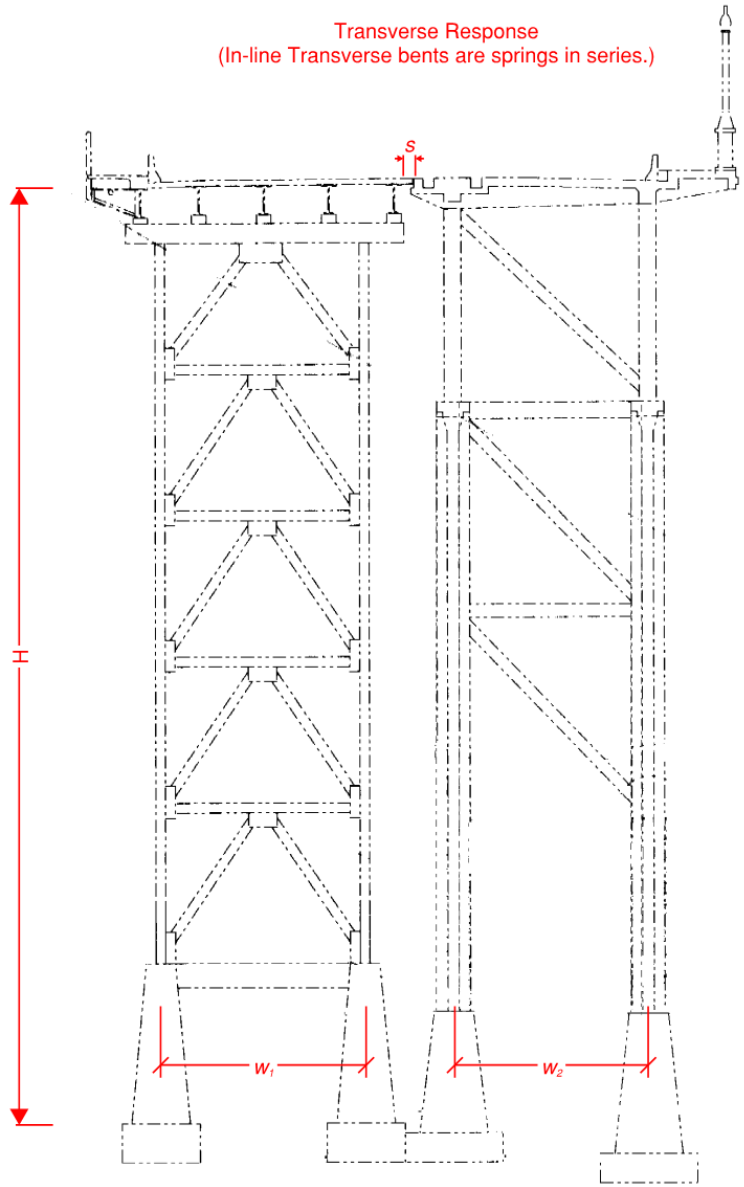
JOINING DIFFERENT STRUCTURES INTRODUCES COMPLEXITY.

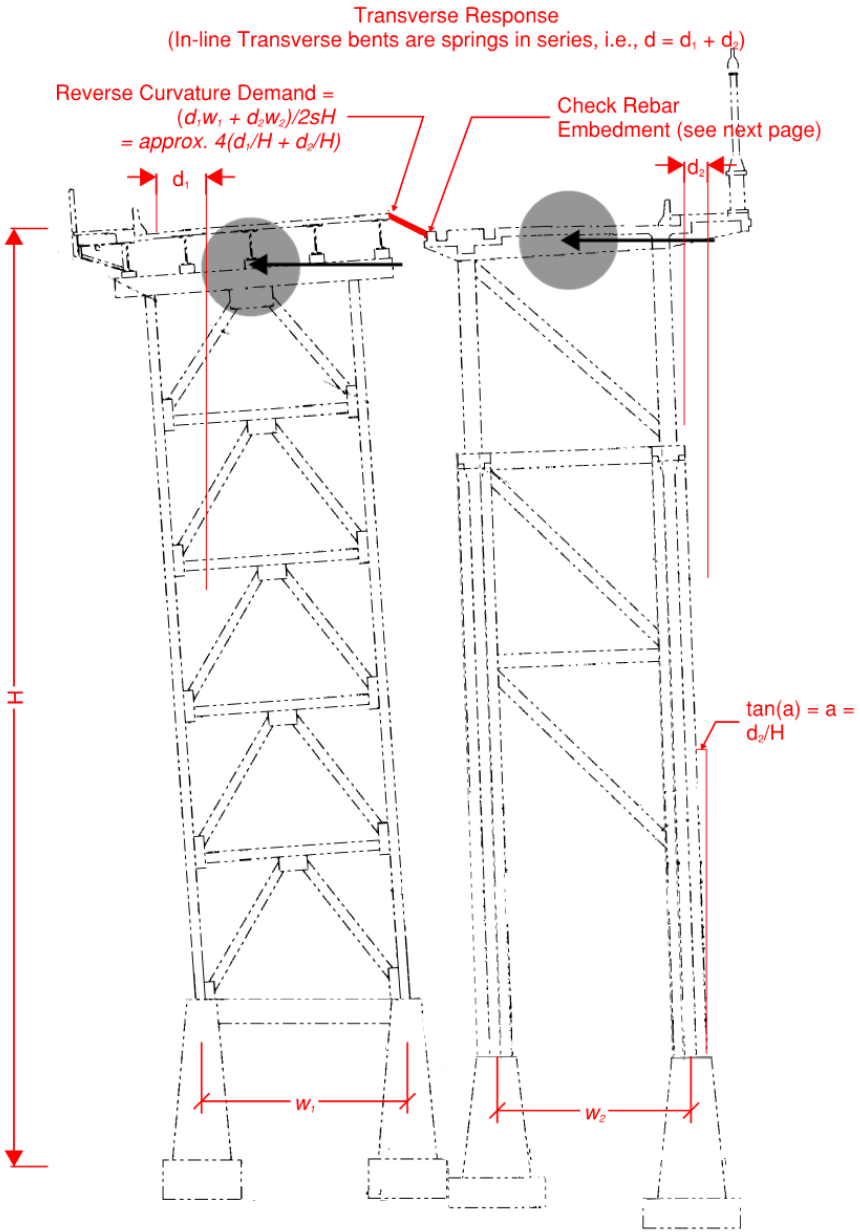
The Academy Museum of Motion Pictures

- Different demand displacements, enforcing compatibility of displacements,
- Non-classical damping is in play,
- Irregularities in mass and stiffness introducing odd modes of vibration,
- Irregularities in mass and stiffness induce stress concentration.

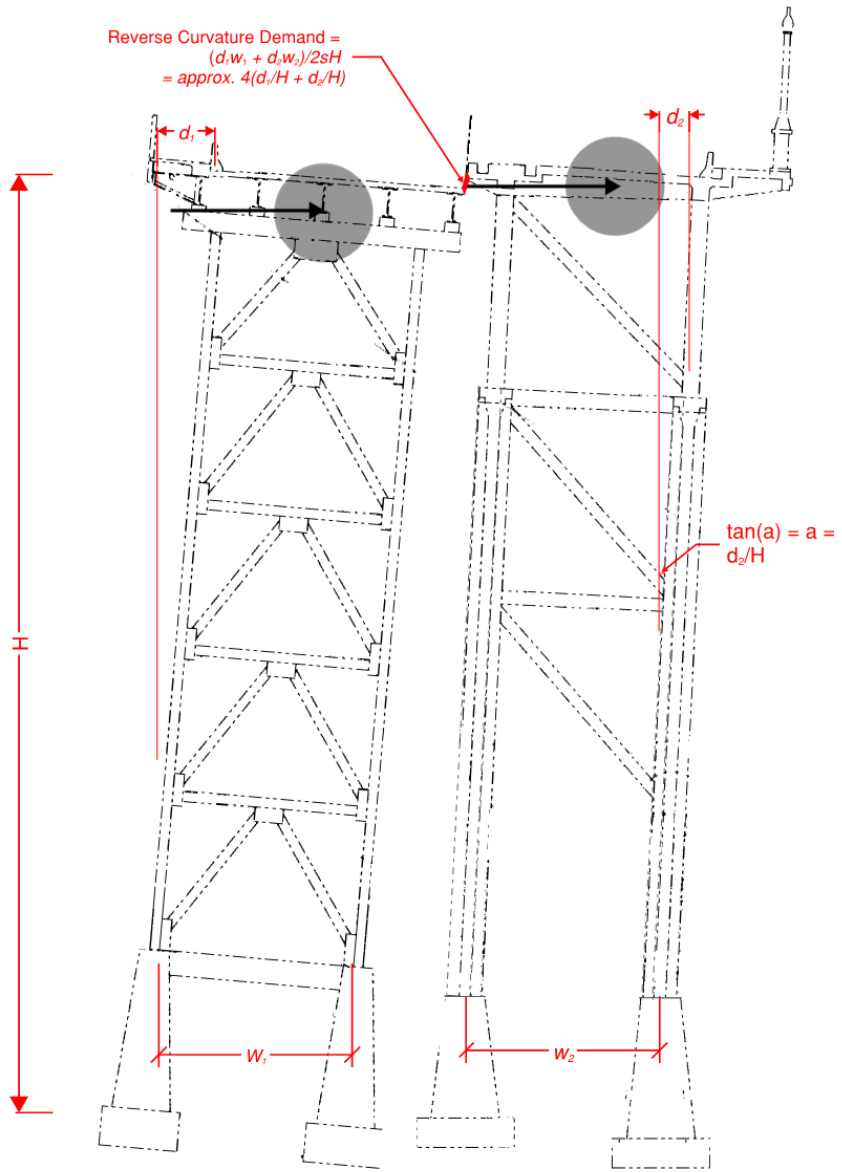
Structures, July 2022

Transverse Response
(In-line Transverse bents are springs in series.)



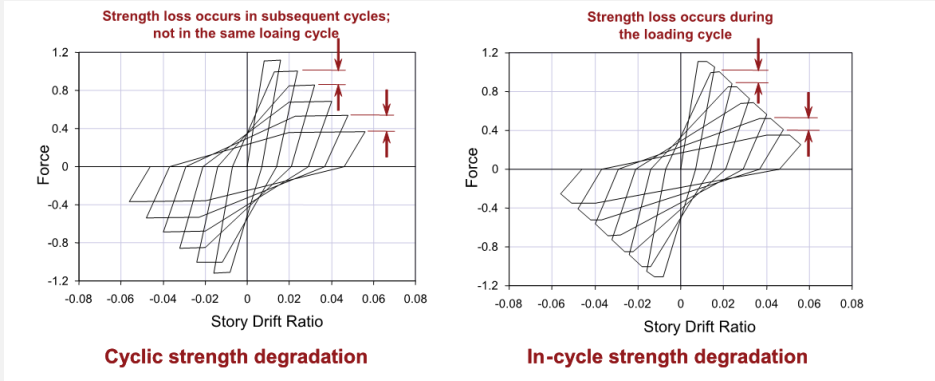

Transverse Response
(In-line Transverse bents are springs in series, i.e., d = d1 + d2)
Reverse Curvature Demand =
(d1w1 + d2w2)/2sH
= approx. 4(d1/H + d2/H)
Check Rebar
Embedment (see next page)
d1
d2
H
tan(a) = a =
d2/H
w1
w2

Transverse Response

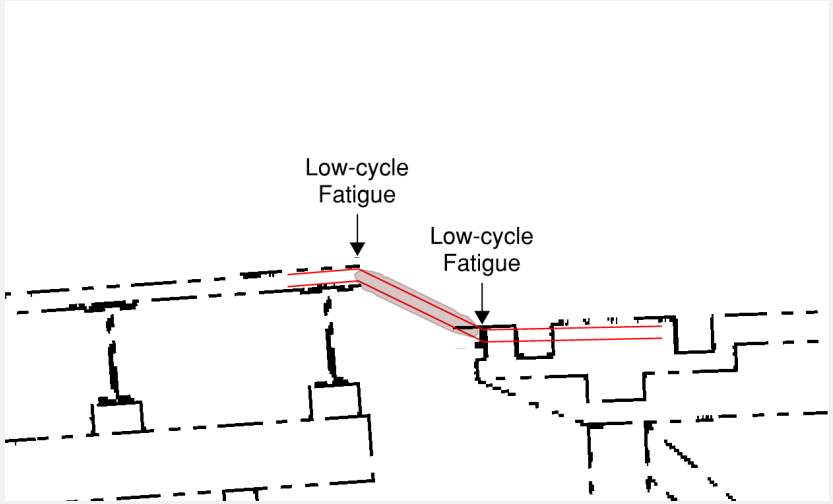


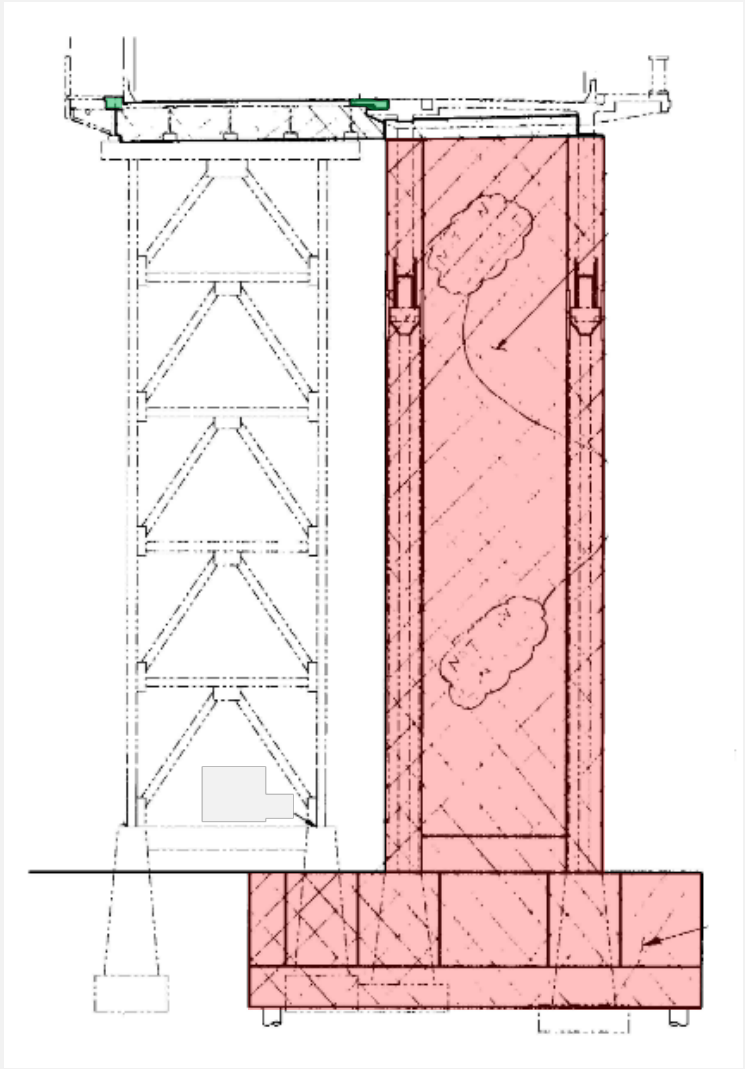
ASSUMPTION VERIFICATION IS PRUDENT.

- Pushover is a monotonic static analysis,
- The effects of ground motion duration (number of loading cycles), and rate effects are not considered explicitly in pushover,
- What happens to the longitudinal link joint with cyclic degradation? Low-cycle fatigue of reinforcement?
- Link slab yield line in flexure vs. membrane action,
- Dynamic pounding if separation occurs.



FEMA P440A, June 2009

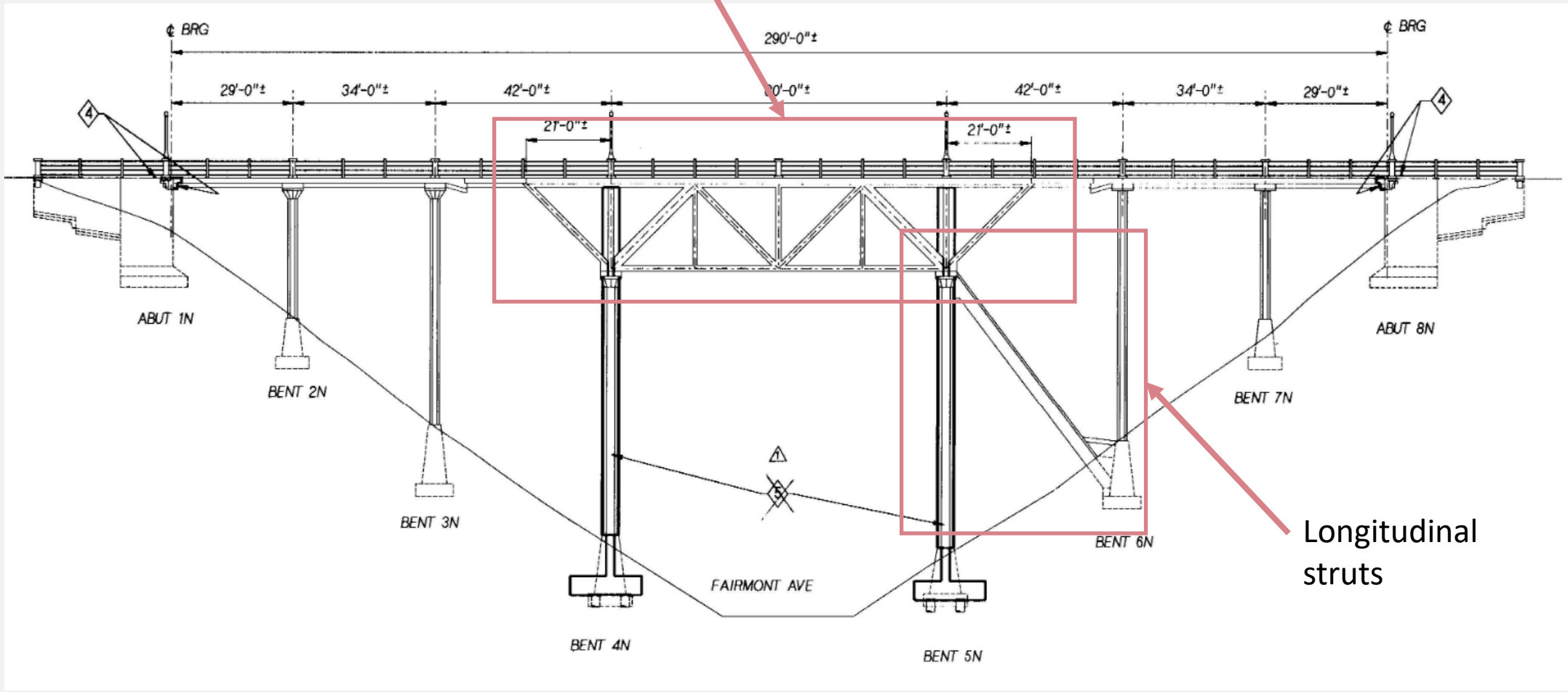




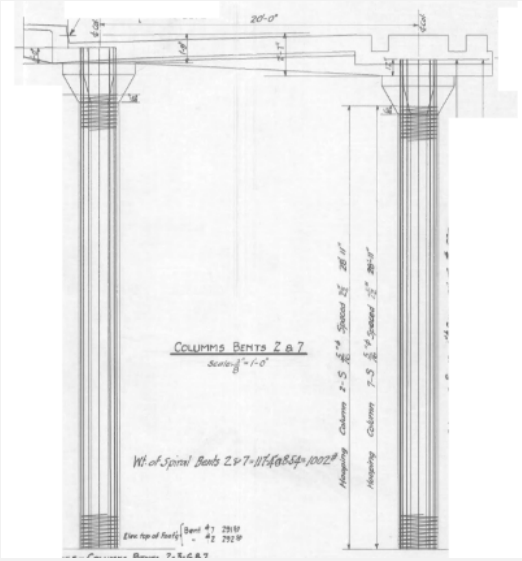
Retrofit completed in 1995

Retrofit suspended in 1995

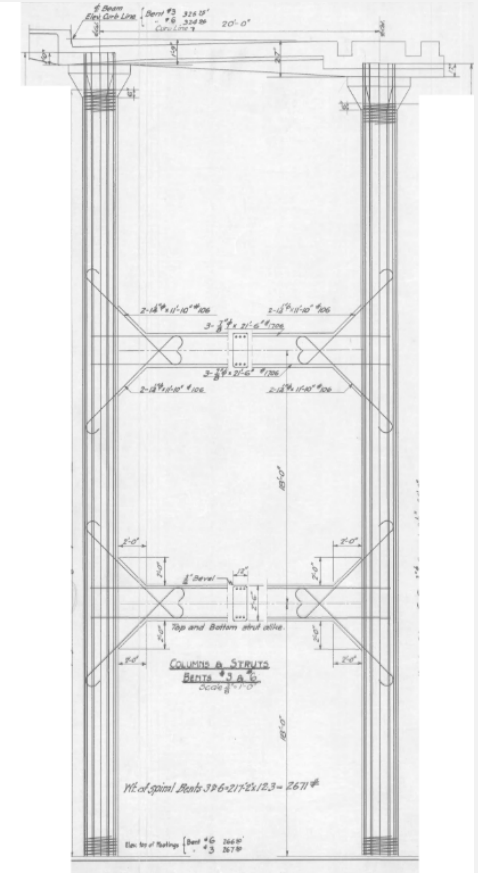
NORTH BRIDGE



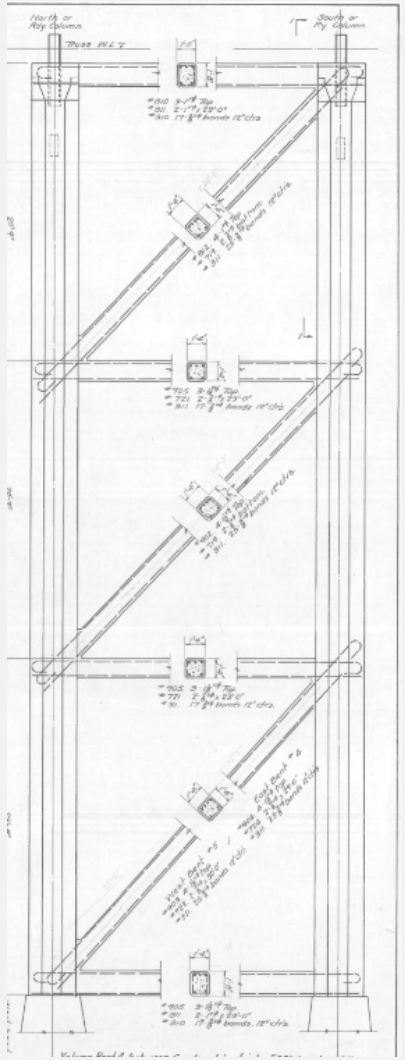
Short



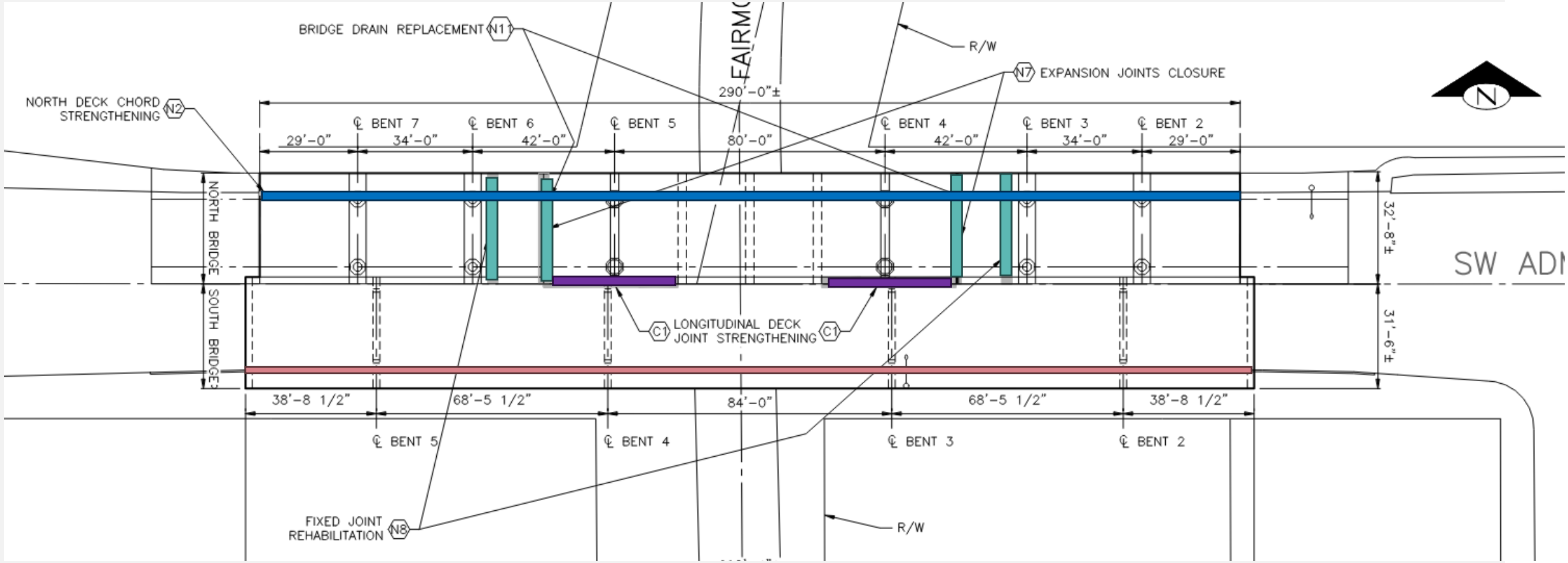
Medium



Tall



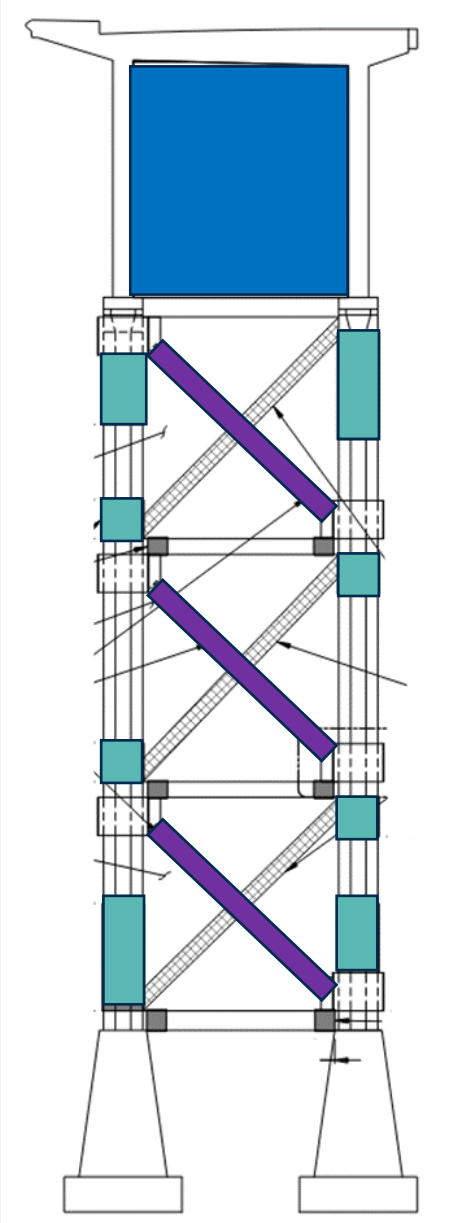
DECK STRENGTHENING



Joint strengthening Joint closing South chord North chord

BENT SOFTENING

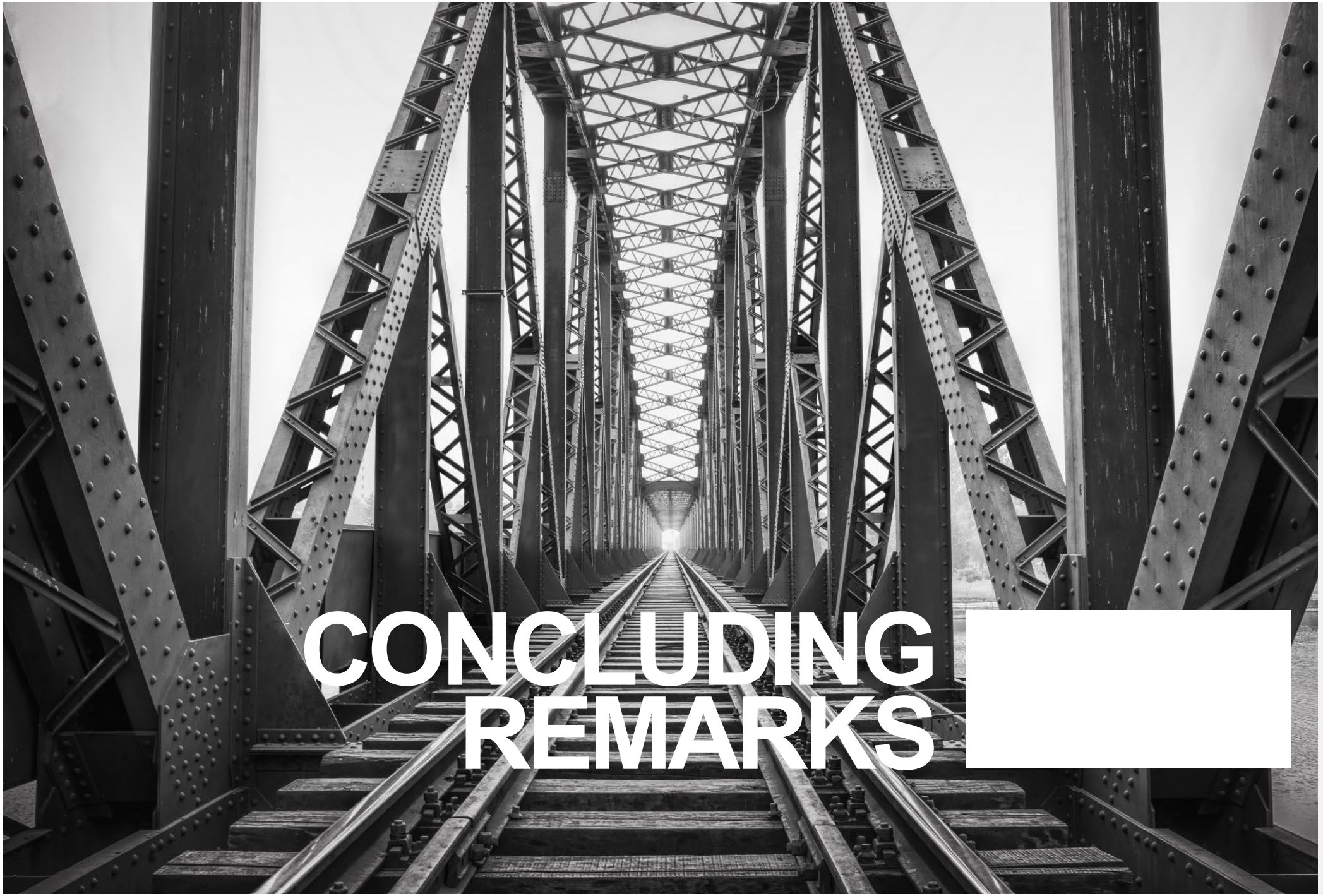
- Use of buckling restrained braces at tall bents
- Allowed increased displacement capacity
- Limited force sent to truss & footings
- Also has non-linear behavior



Buckling Restrained Braces

Carbon fiber wrapping

Shear wall



CONCLUDING REMARKS

SUMMARY

Overview of Retrofit:

- North Bridge:
  - CFRP Jacketing: Footing Pedestals
  - Gusset Plates: Covering with Countersunk Connectors:
  - Capbeams: Torsional Strengthening
- South Bridge:
  - Footing Pedestals: CFRP Jacketing
  - Columns: Flange Cover Plates
  - Gusset Plates: Covering with Countersunk Connectors:
  - Capbeams: Torsional Strengthening

Construction Challenges:

- Steep slopes,
- Environmentally-sensitive site,
- Limited work area,
- Restrictions on traffic closure,
- Budget.

THANK YOU

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