Aurora Avenue Bridge Retrofit

Strengthening a Historic Bridge

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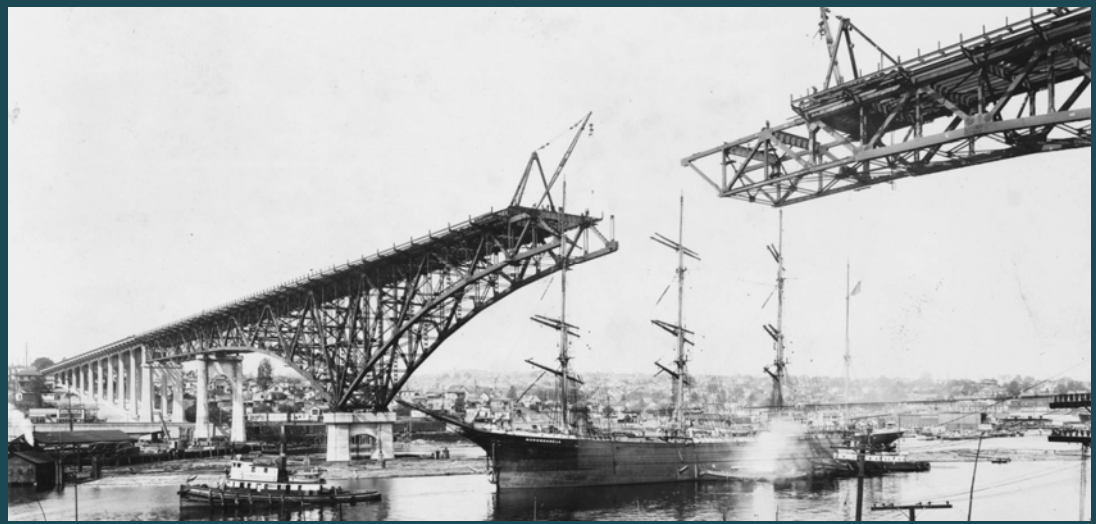
Aurora Avenue Bridge

- *Also known as the George Washington Memorial Bridge*
- *Spans Lake Washington ship canal at the entrance to Lake Union*
- *Designed and built between 1929 and 1931*

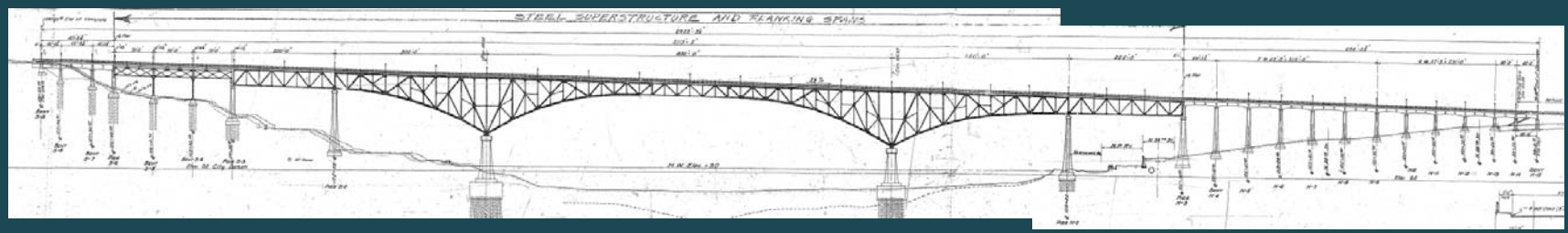


Aurora Avenue Bridge

- *Located on a critical emergency route*
- *Currently listed in the National Register of Historic Places*
- *Distinctive Architectural Features*
  - **Cruciform columns, Haunched Girders**

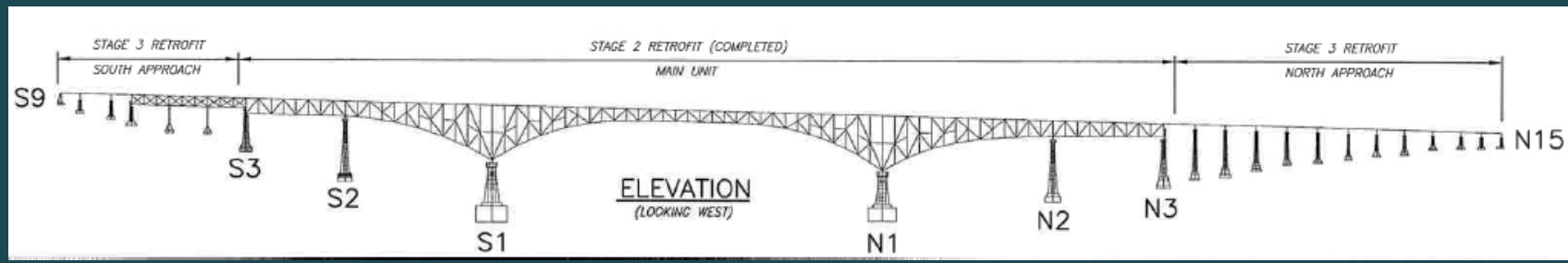
Aurora Avenue Bridge

- *Total bridge length = 2,955 ft*
- *3 Units:*
  - **South Approach (6 concrete girder and steel truss spans) = 380 ft**
  - **Main Unit (5 steel deck truss spans) = 1881 ft**
  - **North Approach (12 concrete girder spans) = 694 ft**



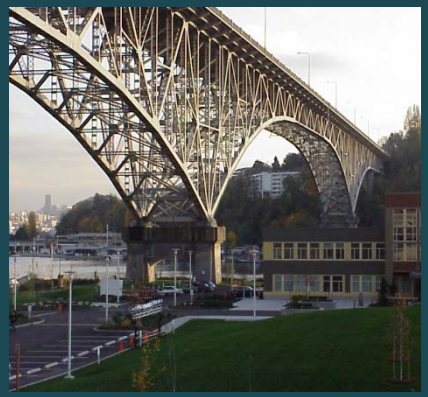
Aurora Avenue Bridge – Retrofit Phases

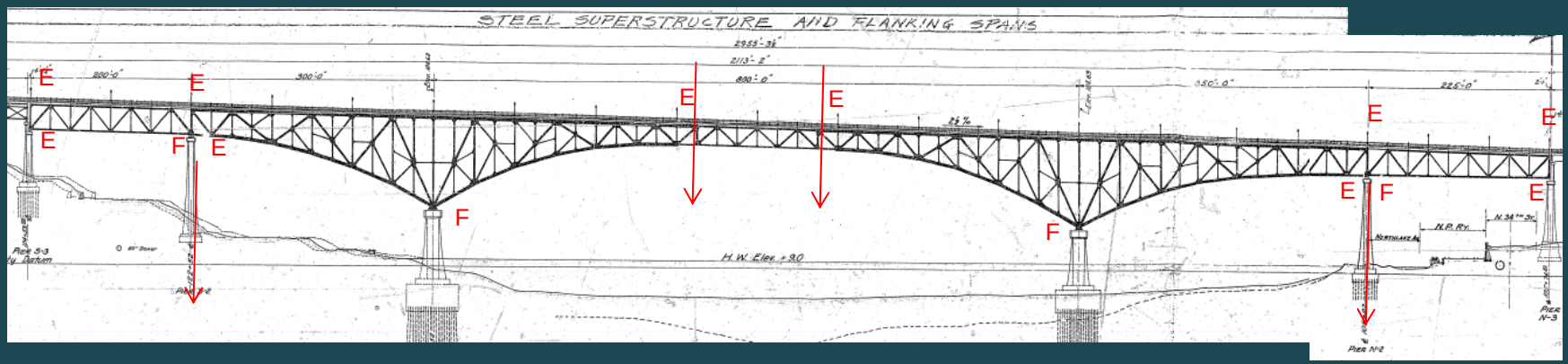
- *Retrofit broken up into stages:*
  - Stage 1 & 2: Main Unit
  - Stage 3: North and South Approaches



Aurora Avenue Bridge

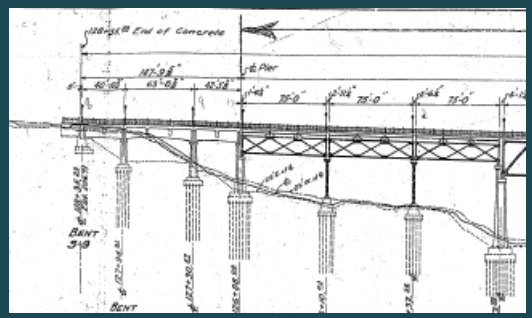
- *Main Unit*
  - Statical System – anchor piers, cantilever trusses, and suspended span
  - Tapered cruciform concrete columns, lightly reinforced (#4 @18”)
  - Expansion joints at Piers N3, N2, S2, S3, and ends of suspended span



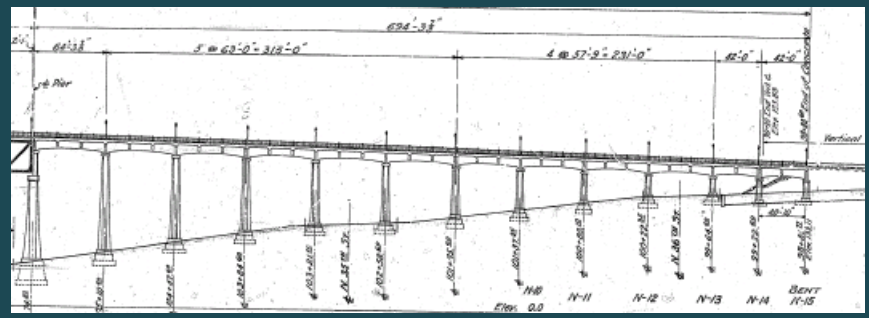


Aurora Avenue Bridge

- *South Approach*
  - Reinforced concrete spans with split cruciform columns
  - 75’ truss spans, steel bents pinned top & bottom

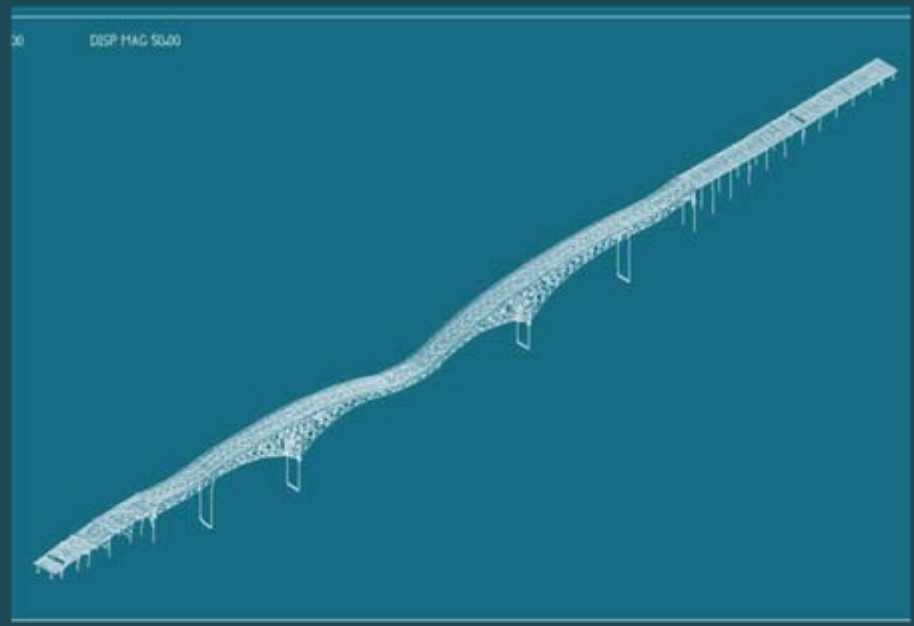


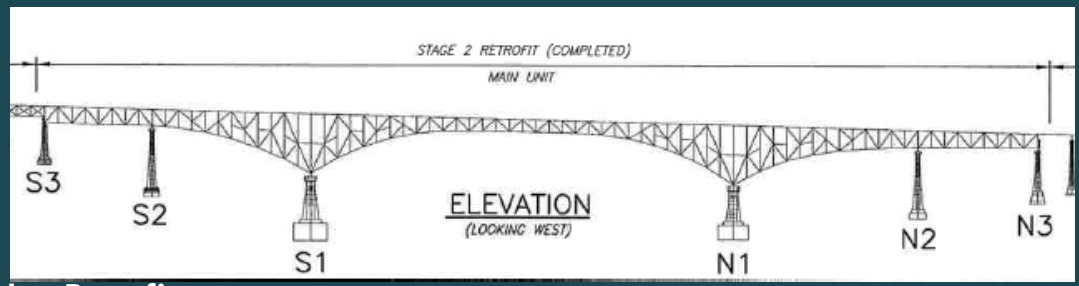
- *North Approach*
  - Varying height piers, cruciform columns (#3@12”)
  - Continuous frames separated by split columns



Aurora Avenue Bridge – Main Unit

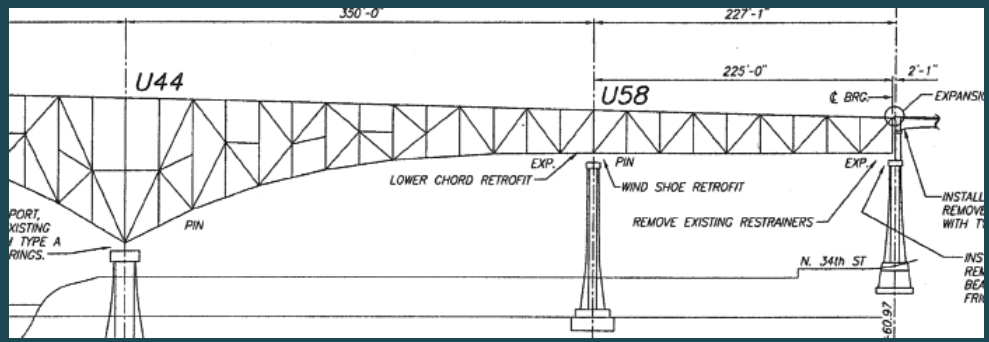
- *ADINA Time History Analysis*
- *475-yr Return Period EQ, a = 0.32 g*
- *Vulnerabilities Identified – Main Unit:*
  - Lateral Capacity of Bearings
  - Shear and Flexural Capacity of Columns
  - Deficient Truss Members





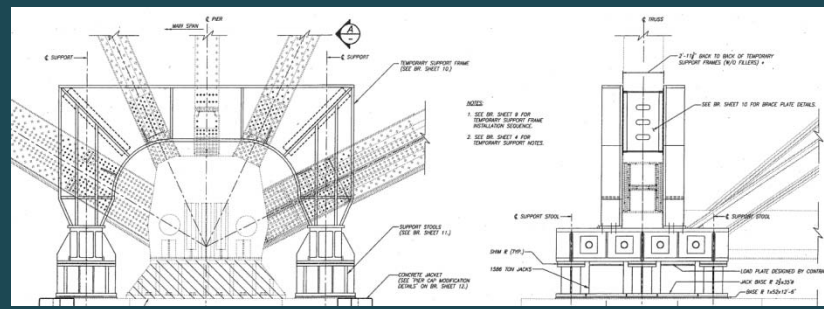
Aurora Avenue Bridge – Main Unit Retrofit

- *Friction Pendulum Bearings at N1/S1 & N3/S3*
  - Reduced shear demand on columns
  - Reduced truss demands
- *Shock Transmission Units at N2/S2*
  - FP Bearings not feasible at uplift piers
  - Restraint of Expansion at anchor Piers
  - Redistribution of Forces between Piers



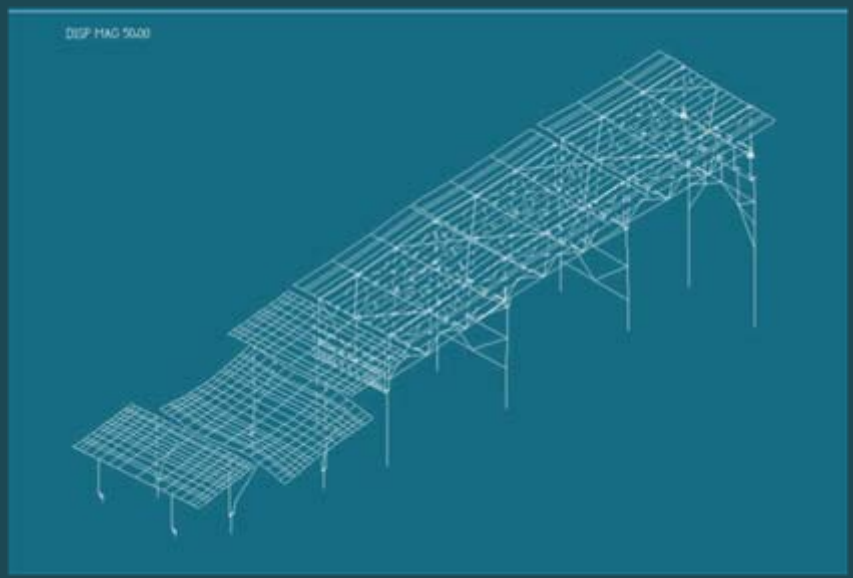
Aurora Avenue Bridge – Main Unit Retrofit

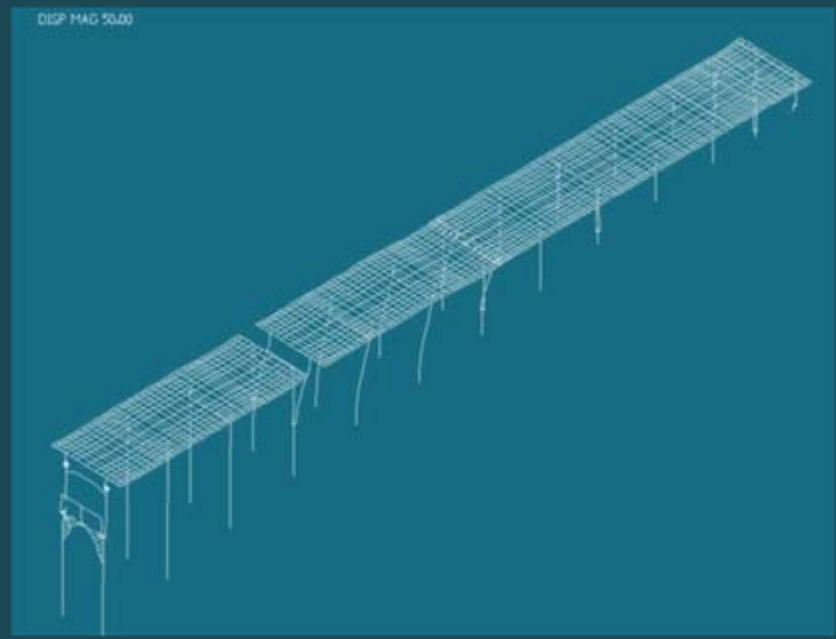
- *Installation of N1/S1 Friction Pendulum Bearings*
- *STU's installed*
- *Expansion Joint Modification for free displacement*
- *Completed 2005*



Aurora Avenue Bridge – Approach Retrofit – Vulnerability Study

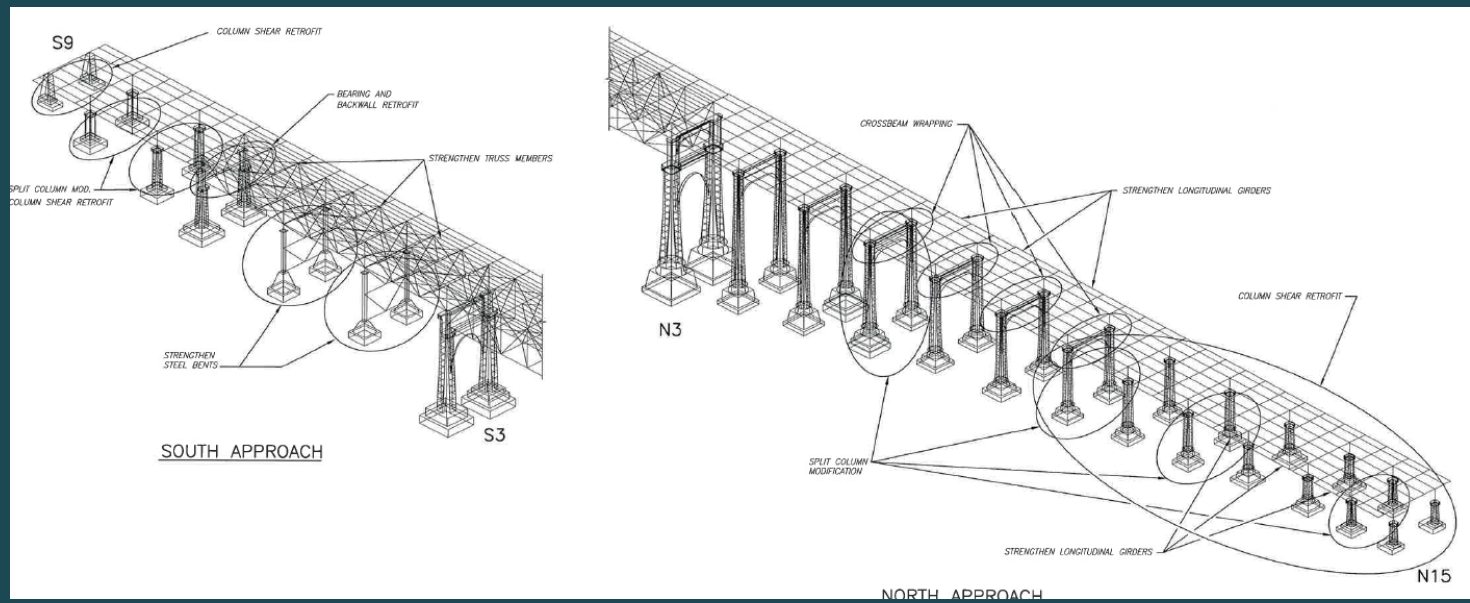
- *ADINA Time History Analysis*
- *ADINA Pushover for Verification*
- *475-yr Return Period EQ, a = 0.32 g*





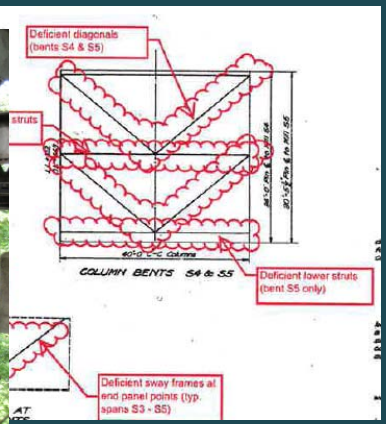
Aurora Avenue Bridge – Approach Retrofit – Vulnerability Study

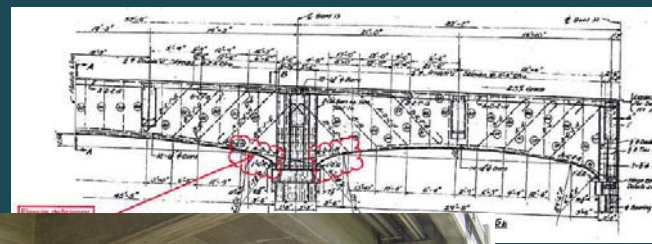
- *Cruciform columns deficient in shear*
- *Split columns deficient in bending /shear*
- *Intergral end bents / abutments strengthening req'd*



Aurora Avenue Bridge – Approach Retrofit – Vulnerability Study (cont.)

- *Concrete girders deficient in bending*
- *Steel truss spans – lateral wind bracing insufficient for seismic demands*
- *Steel truss bents – lateral bracing (struts and diagonals) insufficient for seismic demands*



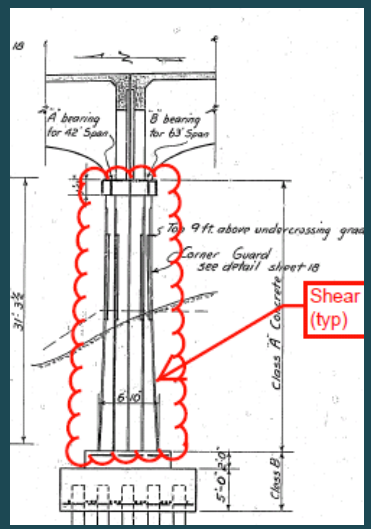


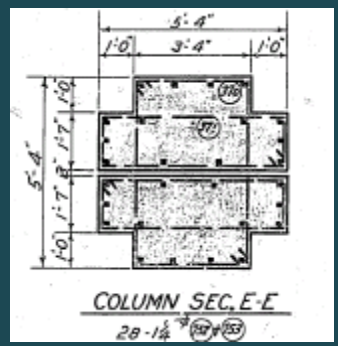
Aurora Avenue Bridge – Approach Retrofit Considerations

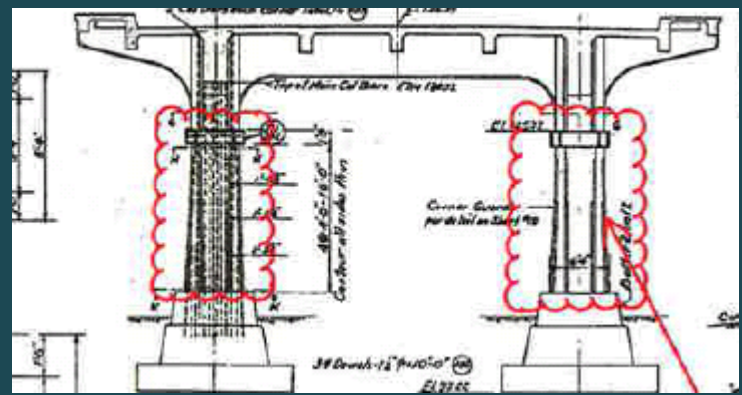
- *Historical Structure – look of the columns can't change*
- *Statical System – split columns provide for thermal movements*
- *What to do?*

Aurora Avenue Bridge – Vulnerability Study Recommendations

- *Retrofit cruciform columns using FRP (for shear).*
- *Modify cruciform split columns to eliminate split joints.*
- *Strengthen longitudinal concrete girders for moment using FRP or concrete jackets.*
- *Strengthen 75’ truss span elements and S-4 and S-5 secondary elements.*

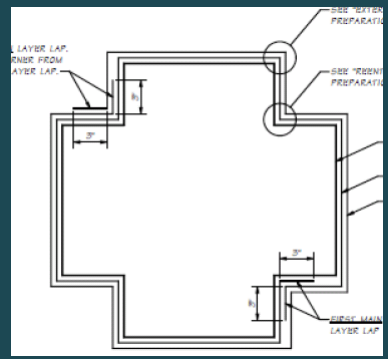




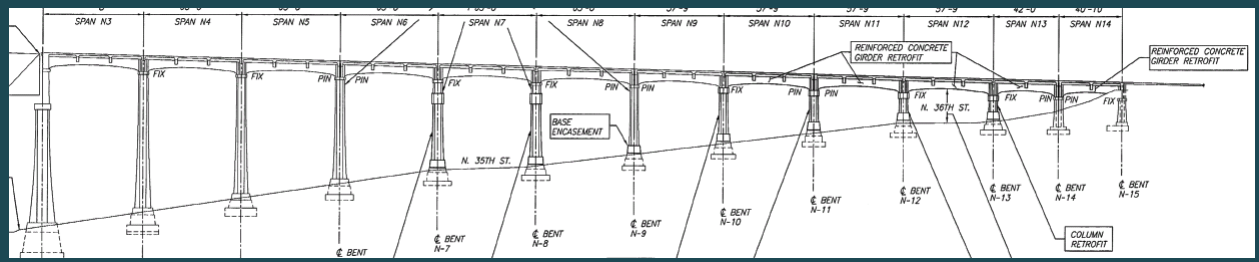


Aurora Avenue Bridge – Approach Retrofit Next Steps

- *Testing program to verify effectiveness of FRP shear retrofit on cruciform columns*

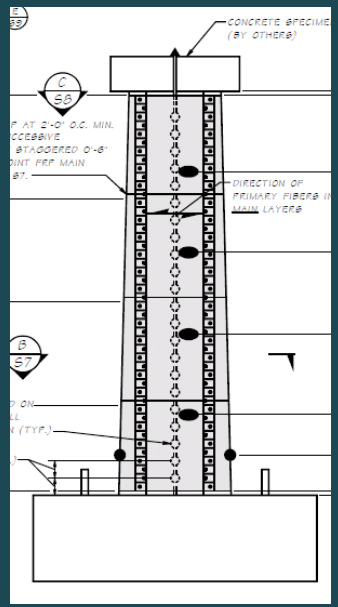


- *Verify service and seismic performance of concrete frames with modified statical system (eliminated splits)*



Aurora Avenue Bridge – Column Testing Overview

- *Washington State University*
- *Dr. David I. McLean, Brian J. Walkenhauer*
- *Goal: Verify the effectiveness of FRP wrapping for improving shear performance in cruciform columns*
  - **Solid columns**
    - **re-entrant corner anchorage**
    - **hinge confinement**
  - **Split columns**
    - **Shear transfer @ split column interface**



Aurora Avenue Bridge – Column Testing

- *7 specimens – 5 solid columns, 2 split columns – 1/3 scale*

Col. 1/5

As-built column (no FRP) – 2 specimens

Col. 2

FRP jacket, no corner anchorage, no hinge confinement

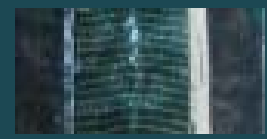
Col. 3

FRP jacket, steel angle with bolts, no hinge confinement

Col. 4

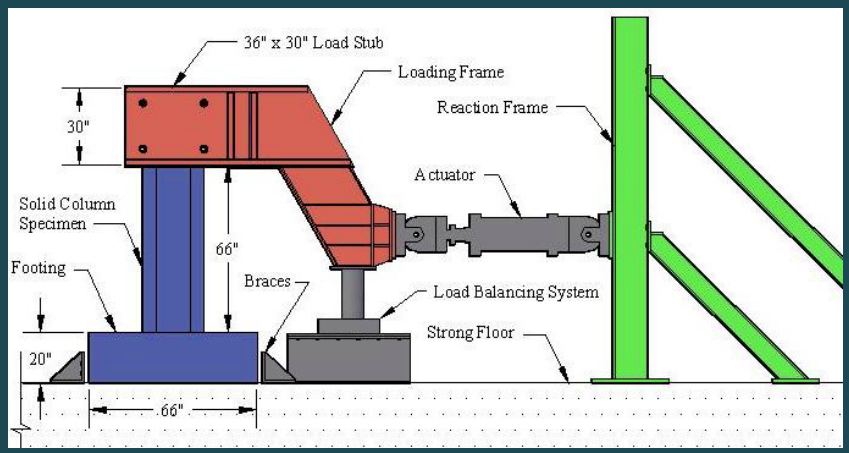
FRP jacket, FRP anchors, hinge confinement collars

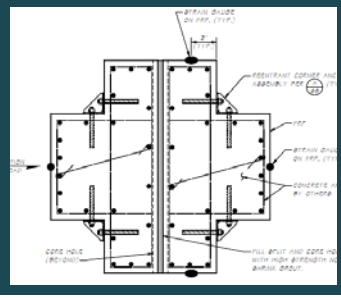
- *Split Columns (6 & 7):*
  - **FRP jacket, FRP anchors, cored/grouted split, confinement collar – 2 specimens**

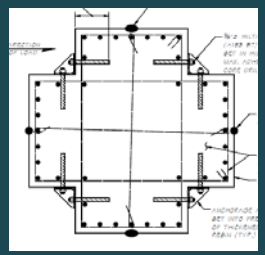


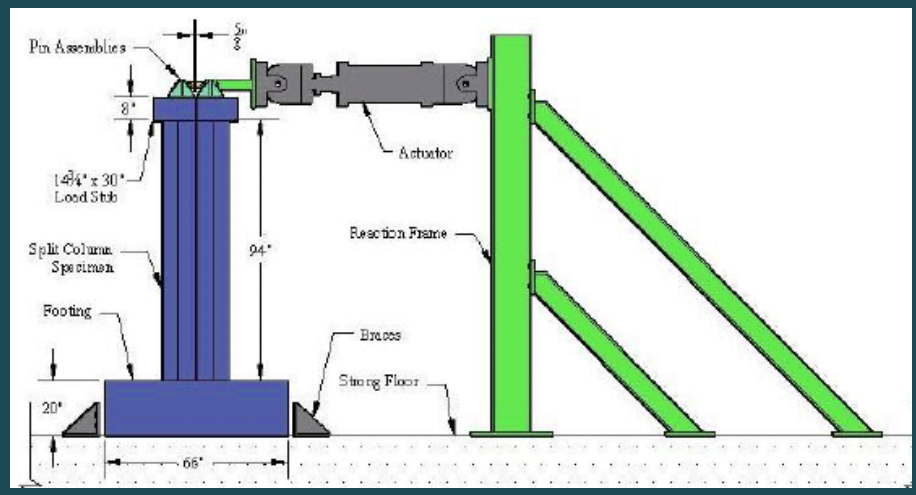
Aurora Avenue Bridge – Column Testing Setup

- *Solid columns loaded in double bending (fix-fix)*
- *Split columns loaded in single bending (fix-pin)*



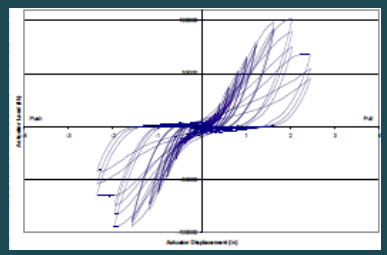


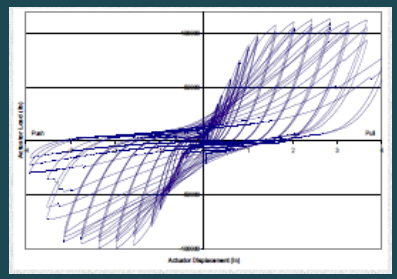




Aurora Avenue Bridge – Column Testing Results

- *As-built solid columns – shear failure w/ modest ductility (μ = 4.8)*
- *Column 2 – shear failure w/ slightly improved ductility*
- *Column 3 – flexural failure & hinge degradation w/ improved displacement capacity*
- *Column 4 – flexural failure w/ ductile response (μ = 6.8)*
- *Split columns – able to transfer shear across split with shear keys only (no reinforcement required)*





Column	V_y (kips)	Δ_y (in.)	K_y (k/in.)	V_{max} (kips)	Δ_{max} (in.)	μ_Δ	Drift (%)	E_{total} (k-in.)
1	27	0.54	60	98	2.8	4.8	3.8	290
2	49	0.53	91	101	2.8	5.3	4.3	400
3	50	0.62	81	105	3.2	5.2	4.9	490
4	56	0.59	94	113	4.0	6.8	6.1	650
5	49	0.54	90	103	2.4	3.0	3.3	300
6	36	1.42	25	47	6.0	4.2	5.6	110
7	28	1.32	21	50	6.0	4.6	5.6	120

Aurora Avenue Bridge – Column Testing Conclusions

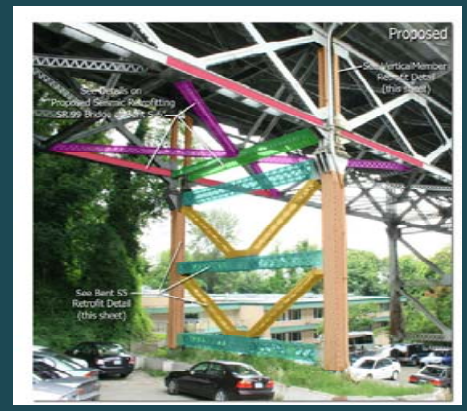
- *FRP, properly anchored, is effective at enhancing shear strength to achieve ductile response*
- *FRP alone does not provide adequate hinge confinement for cruciform shape*
- *FRP anchors or steel angle are effective at anchoring re-entrant corner*
  - **FRP easier to install and do not alter appearance of column**
- *Steel collar filled with grout is effective at confining hinge regions*
- *Cored holes with grout detail is effective at transferring split column interface shear*

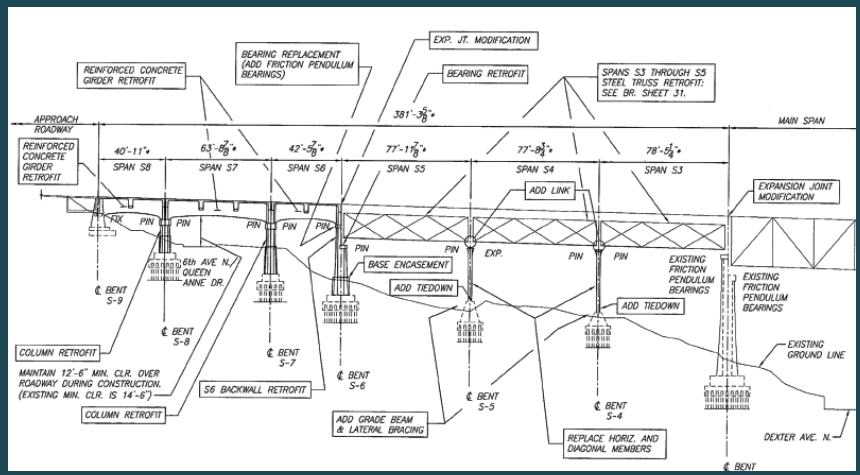
Aurora Avenue Bridge – Approaches – Retrofit Design Overview

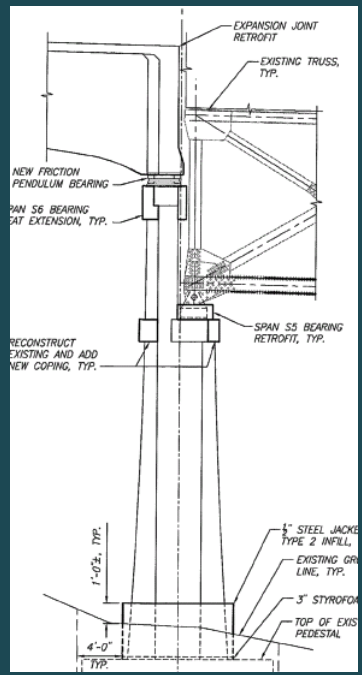
- *South Approach – concrete spans*
- *South Approach – truss spans*
- *North Approach*

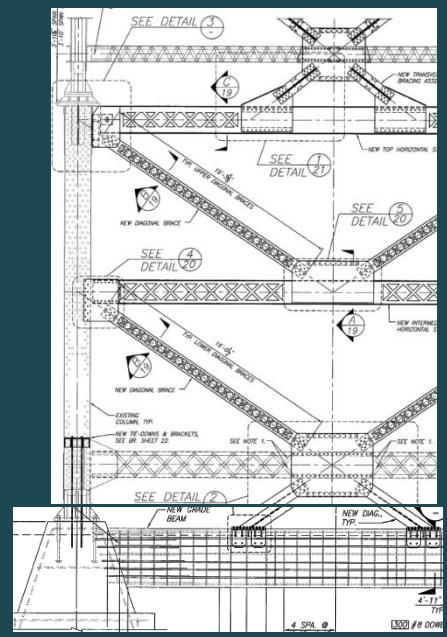
Aurora Avenue Bridge – Approaches – Design phase developments

- *South approach*
  - Added Friction Pendulum Bearing at S6
    - Eliminated costly abutment S9 retrofit, shear retrofit at S6, longit moment retrofit at S6 backwall
  - Added grade beam and tiedowns at steel bents
    - Transverse shear transferred away from pin joints, avoids complete bent replacement



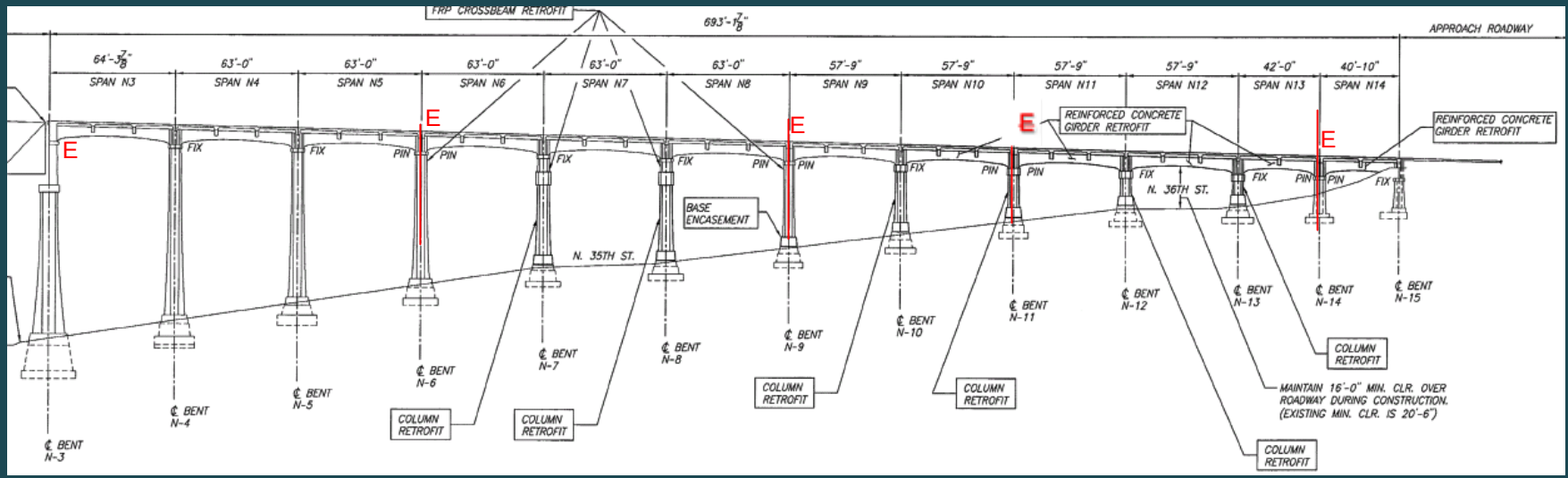






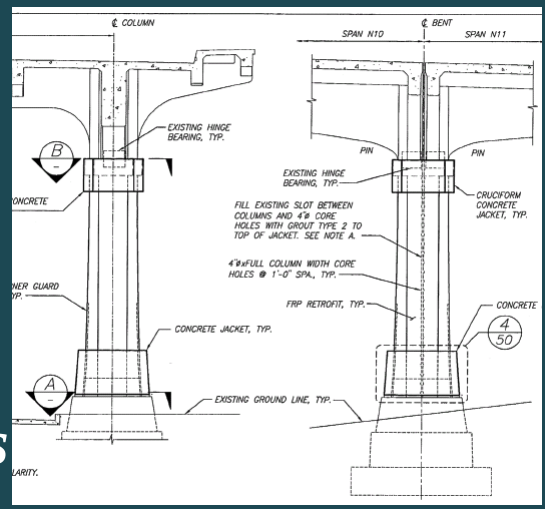
Aurora Avenue Bridge – Approaches – Design phase developments

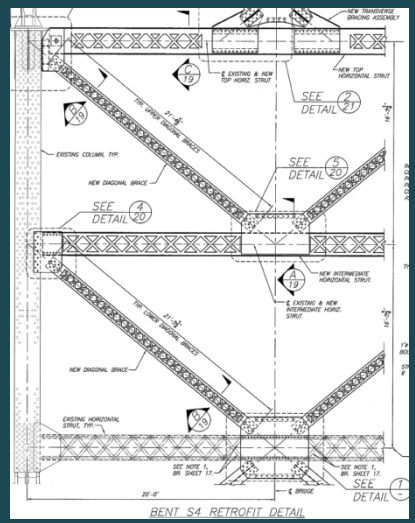
- *North approach*
  - Split columns N6, N9, and N14 left open
    - Improved longitudinal force distribution and service behavior
    - Elimination of costly abutment N15 retrofit
    - Reduced girder retrofit extent to span N10-N14 only

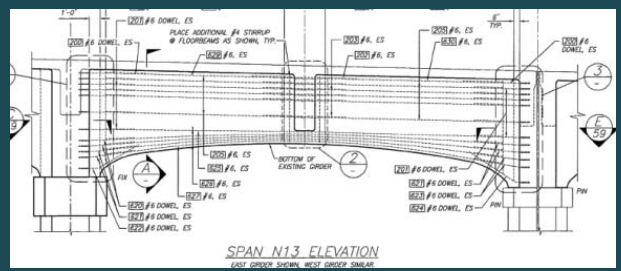


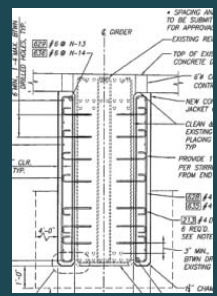
Aurora Avenue Bridge – Approaches – Design Details

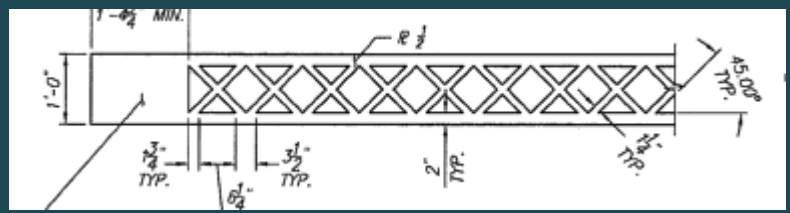
- *FRP Column Strengthening*
- *Girder Strengthening*
- *Split Column Modification*
- *Steel Bent Retrofit – aesthetic treatments*
- *Steel Truss Retrofit – aesthetic treatments*

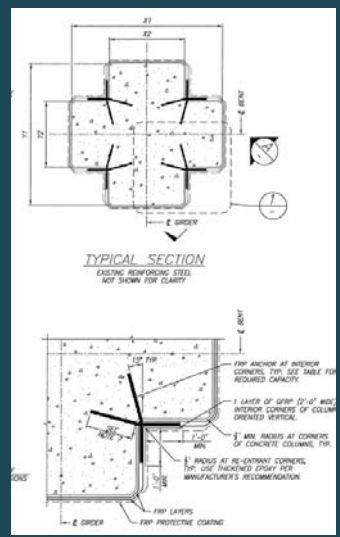












Aurora Avenue Bridge – Approaches

- *Questions?*