Observed Structural Bridge Damage from M_w 7.8 Earthquake in Southern Turkiye (Turkey) and Model for Nonlinear Time-History Analysis

by

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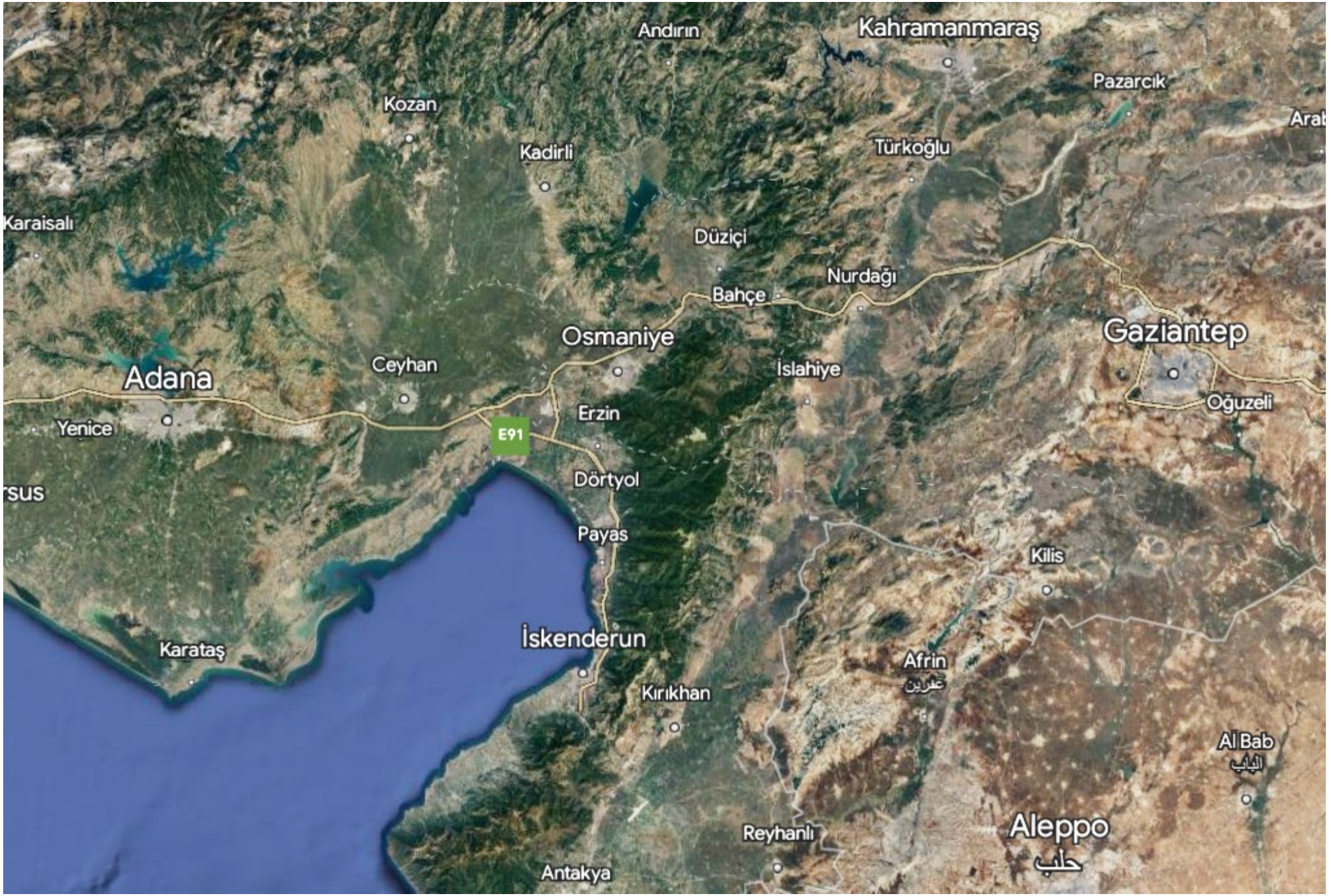
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Oğuzeli
Yenice
Erzin
E91
Dörtyol
Payas
Kilis
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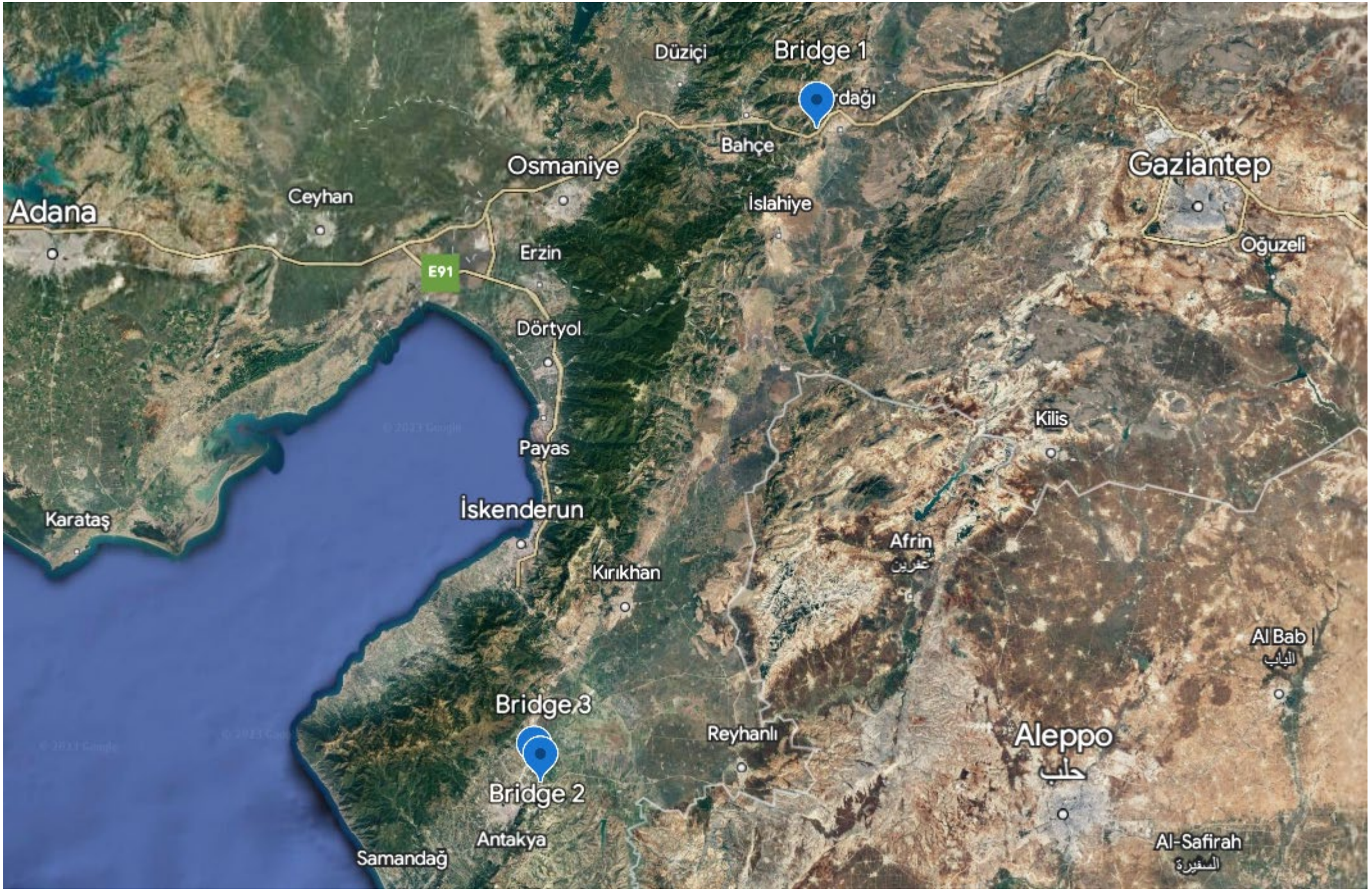
Antakya


Düziçi
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Adana
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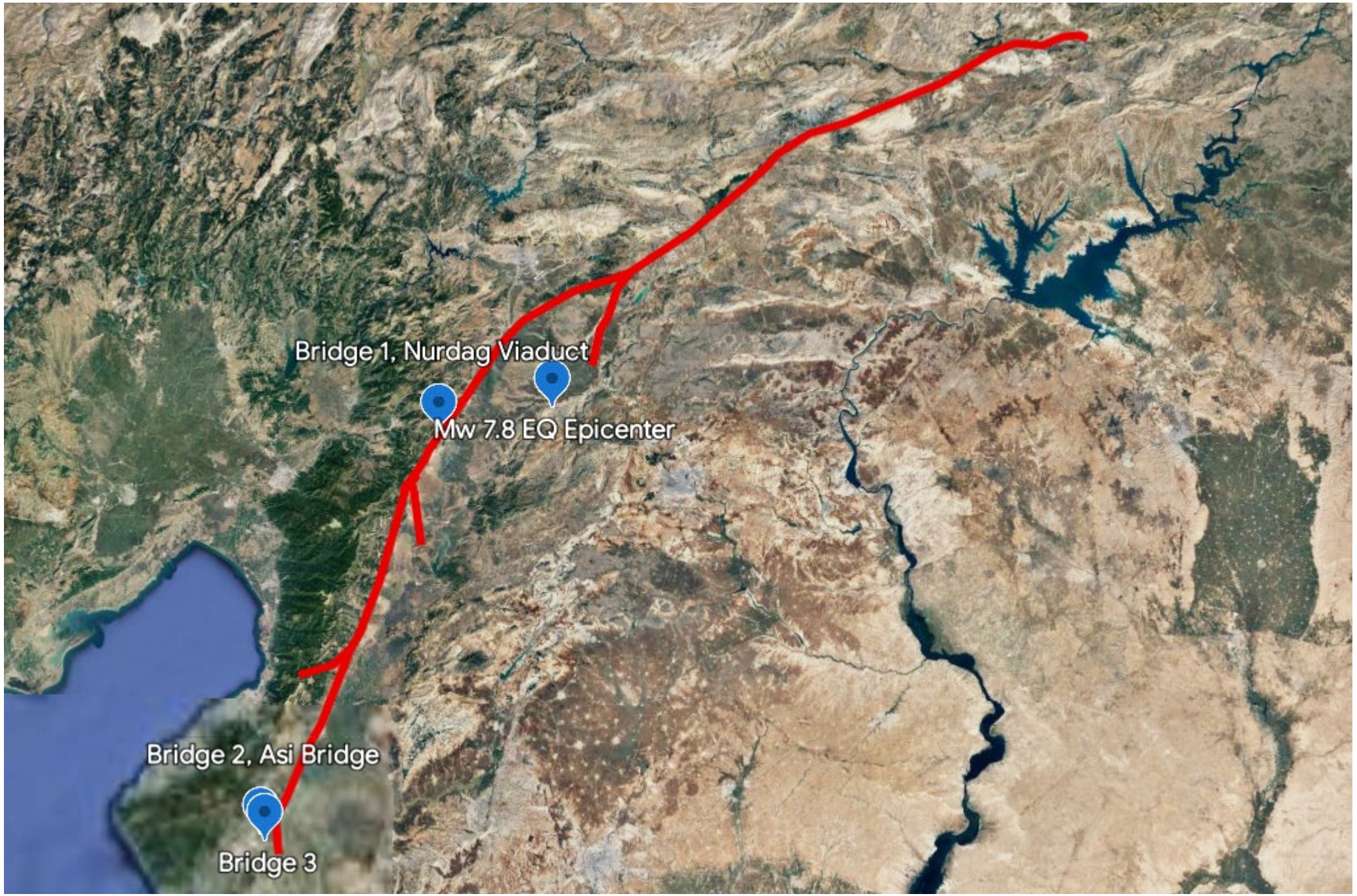
Oğuzeli
E91
Erzin
Dörtyol
Kilis
Payas
İskenderun
Karataş
Afrin
عفرين
Kırıkhan
Al Bab
الباب
Bridge 3
Reyhanlı
Aleppo
حلب
Bridge 2
Antakya
Al-Safirah
السفيرة
Samandağ

180 mile (290 km) Rupture Length for M_w 7.8 earthquake (*M* 8.1/ Richter Scale)

Equivalent Distance of **San Diego to Santa Barbara** in California or most of the length of **Taiwan**



180 mile (290 km) Rupture Length for M_w 7.8 earthquake

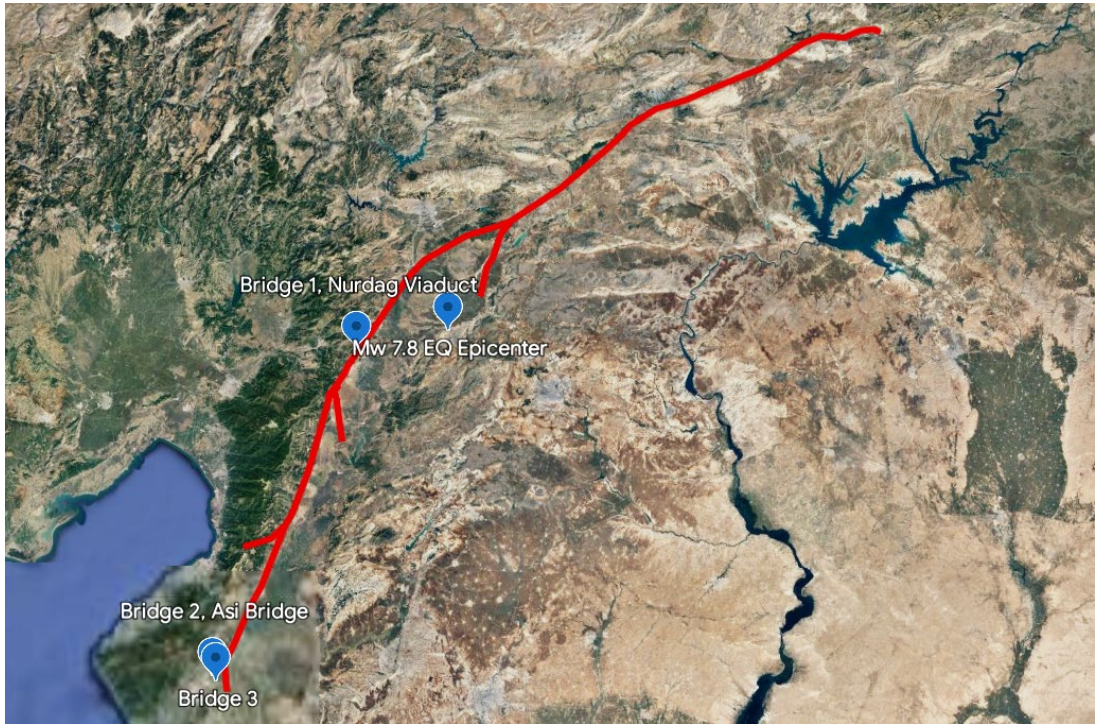
Bridge 1 – 0.05 miles (80 m) from the fault rupture

Bridge 2 – 2.5 miles (4.0 km) from the fault rupture

Bridge 3 – 2.0 miles (3.14 km) from the fault rupture

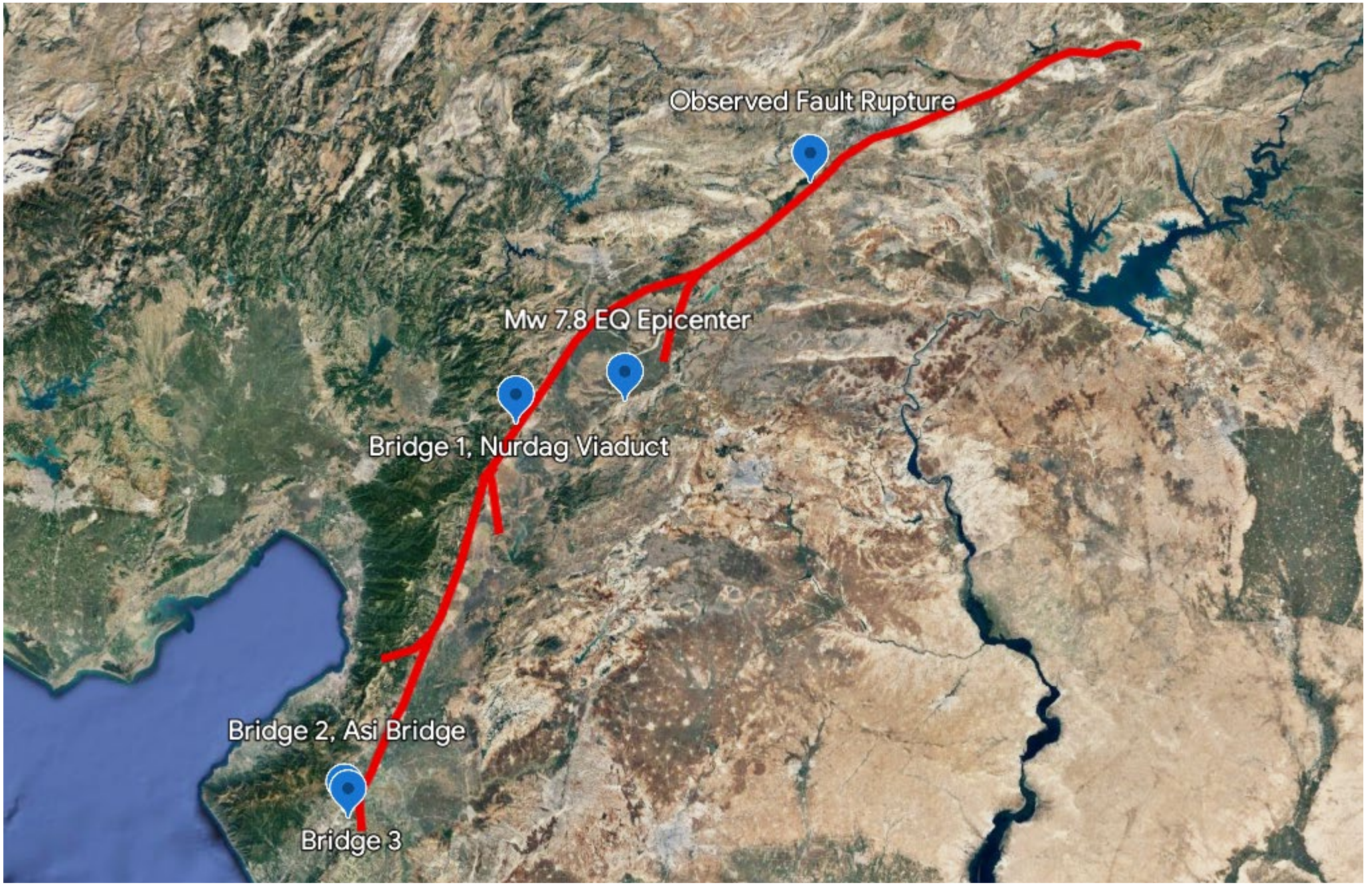
Intensity of Ground Shaking Follows the Fault Rupture Line for a Large Earthquake

- Not concentric circles about the earthquake epicenter -



Fault Rupture (USGS)

Ground Shaking Intensity (USGS)



Observed versus Defined (USGS) Fault Rupture

1906 San Francisco Earthquake

2023 Turkiye Earthquake

Observed Fault Rupture

Six Days in the Field in Southern Turkiye, Team Mountain Goats

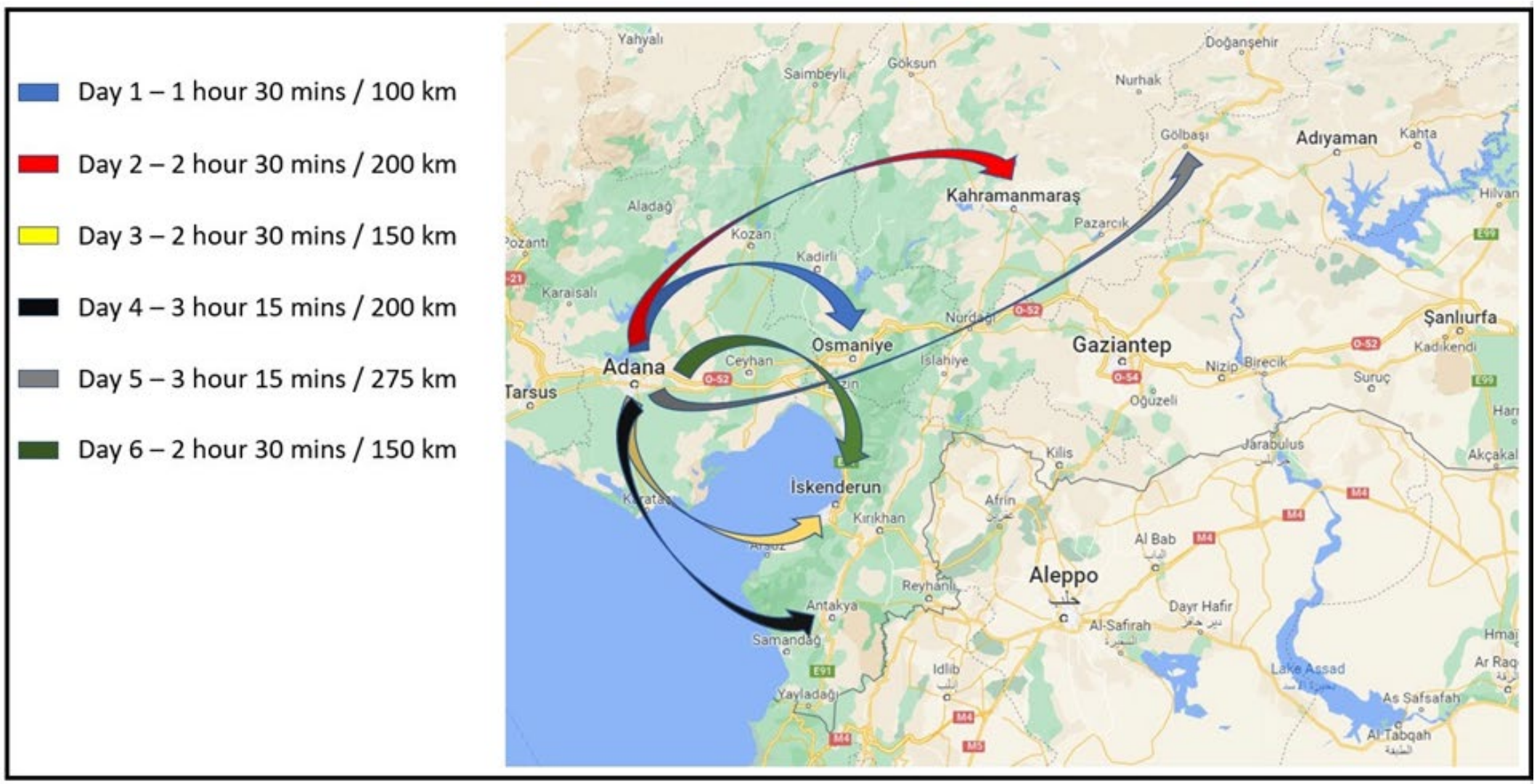
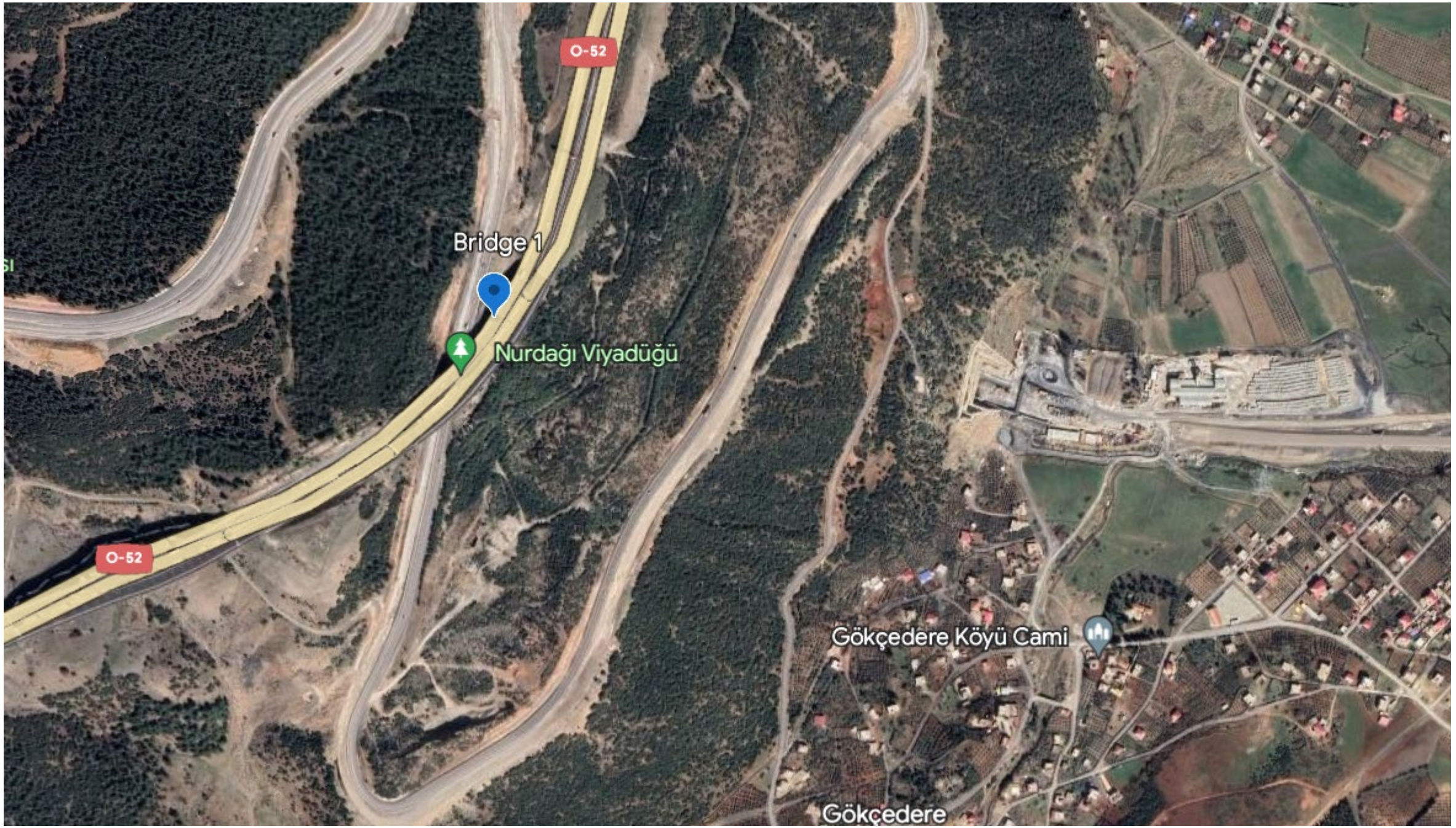
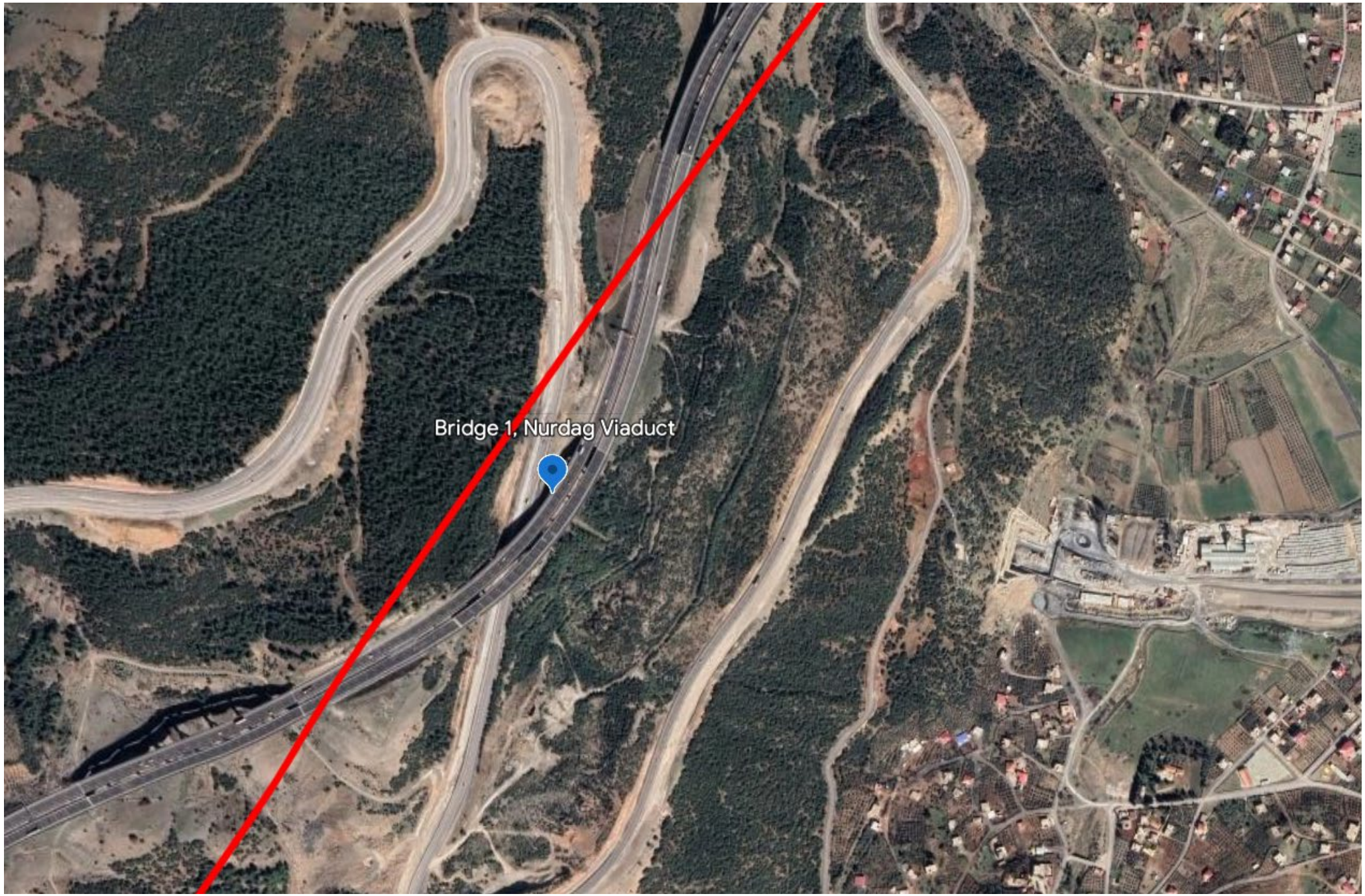


Image developed by team member Tunc Deniz Uludag


O-52
Bridge 1
Nurdağı Viyadüğü
O-52
Gökçedere Köyü Cami
Gökçedere

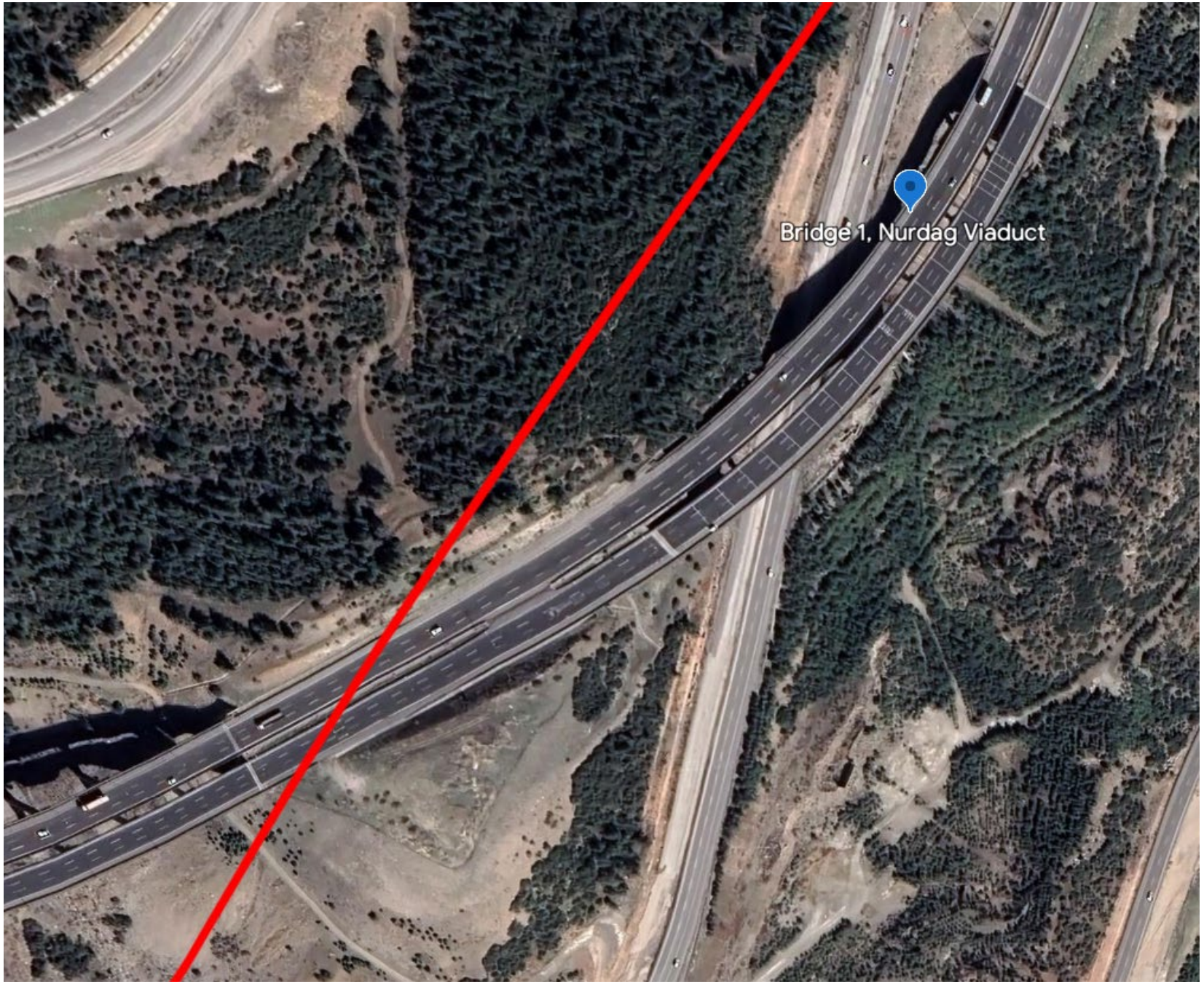


Fault Rupture

Google Earth

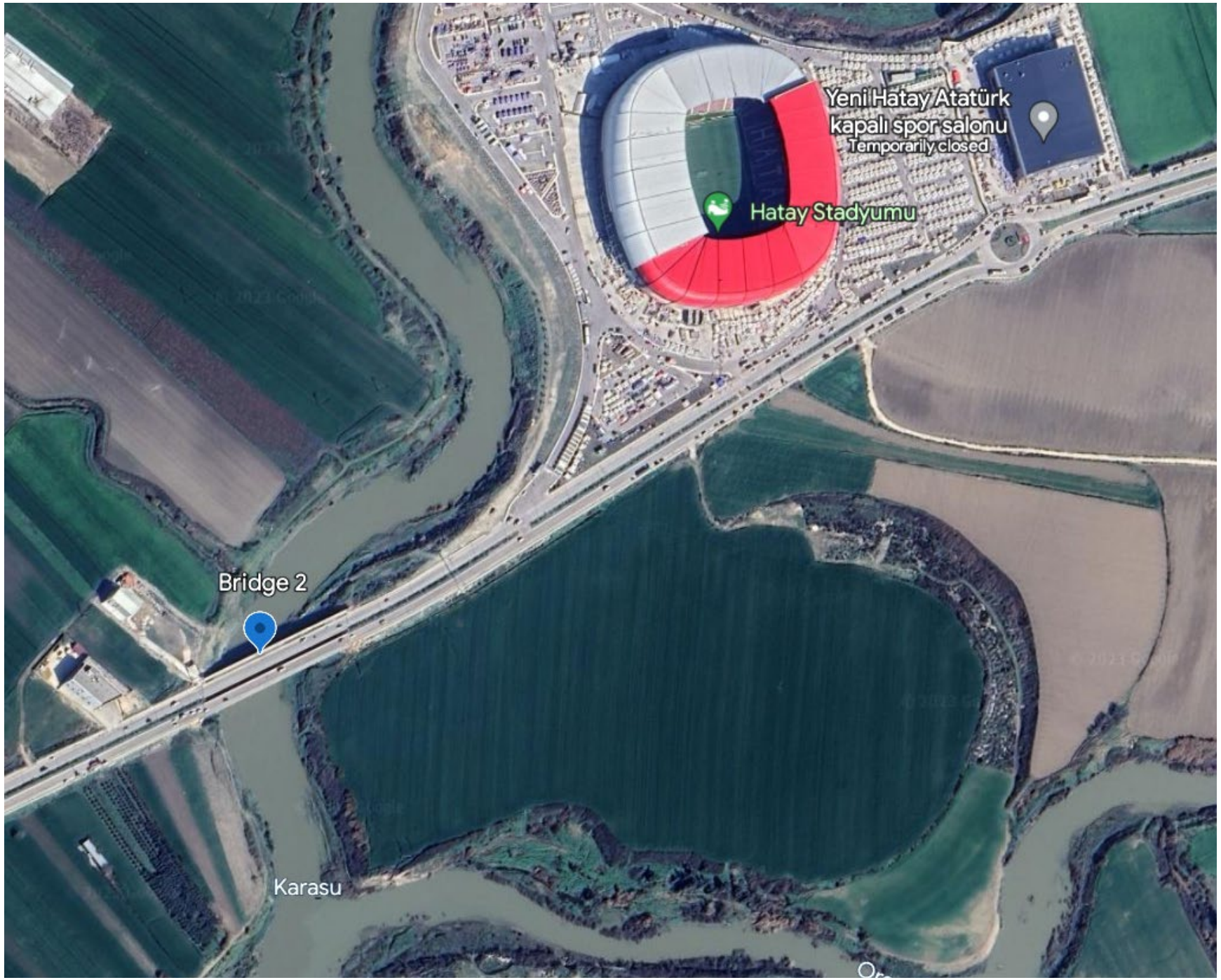
Fault Rupture

Google Earth



Fault Rupture

Google Earth



Asi Bridge

Google Earth

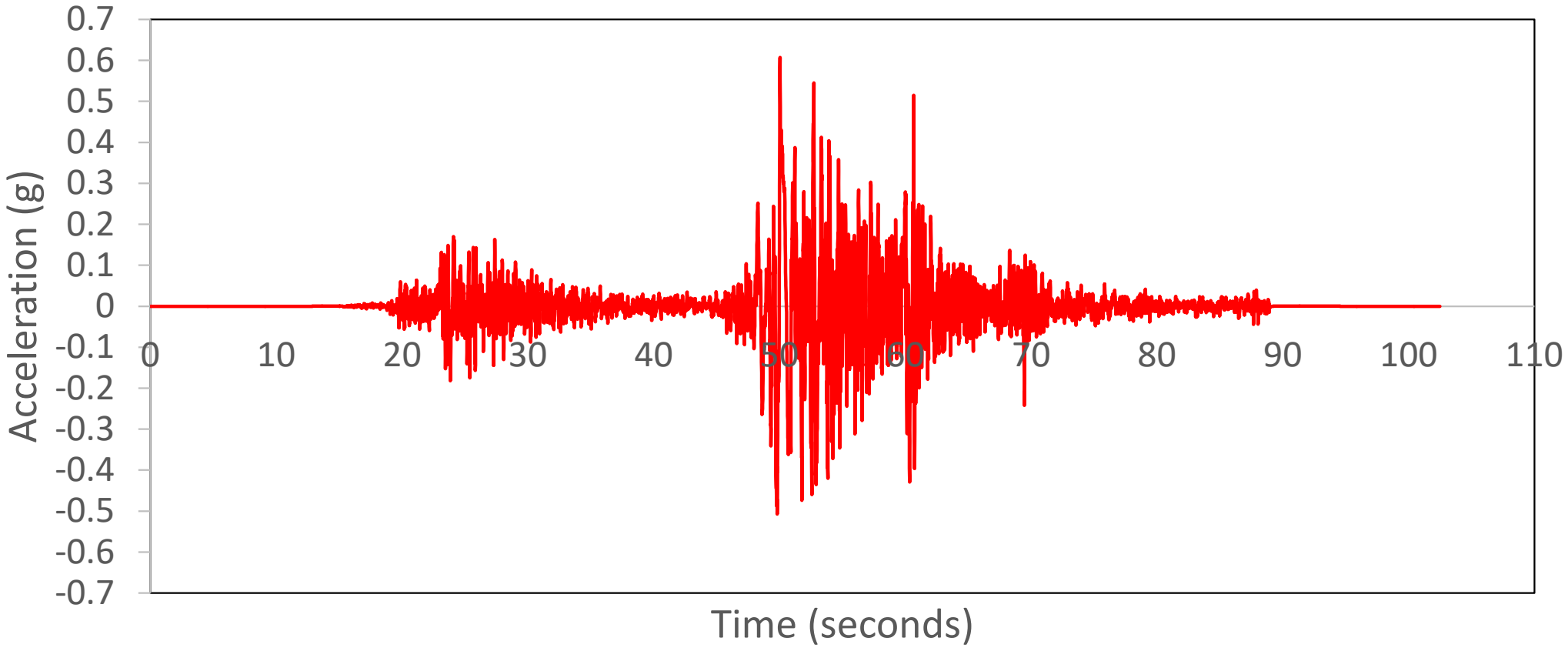
Google Earth

Google Earth

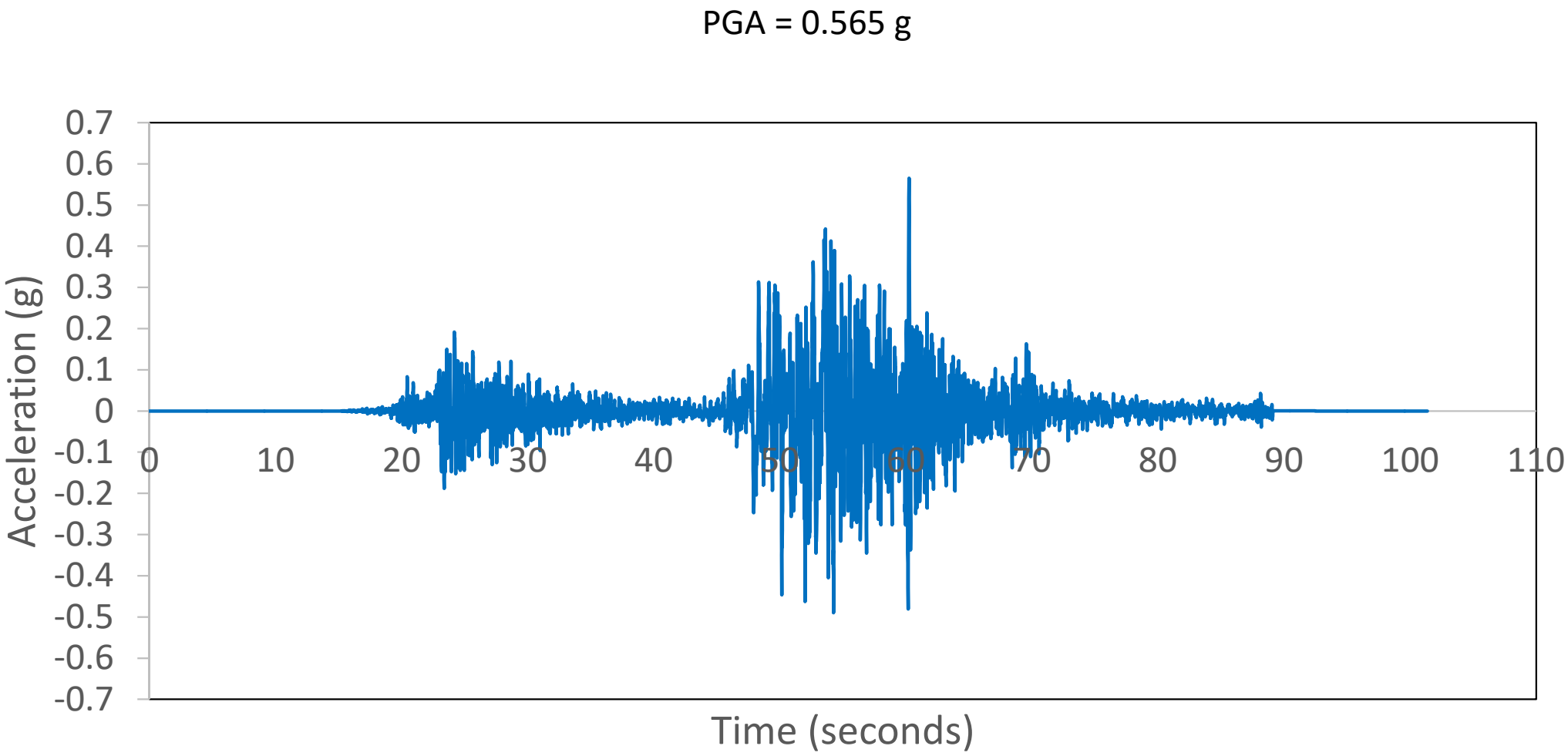
EW Motion for Station 2712, Closest to Bridge 1

2.00 miles (3.21 km) from Bridge 1

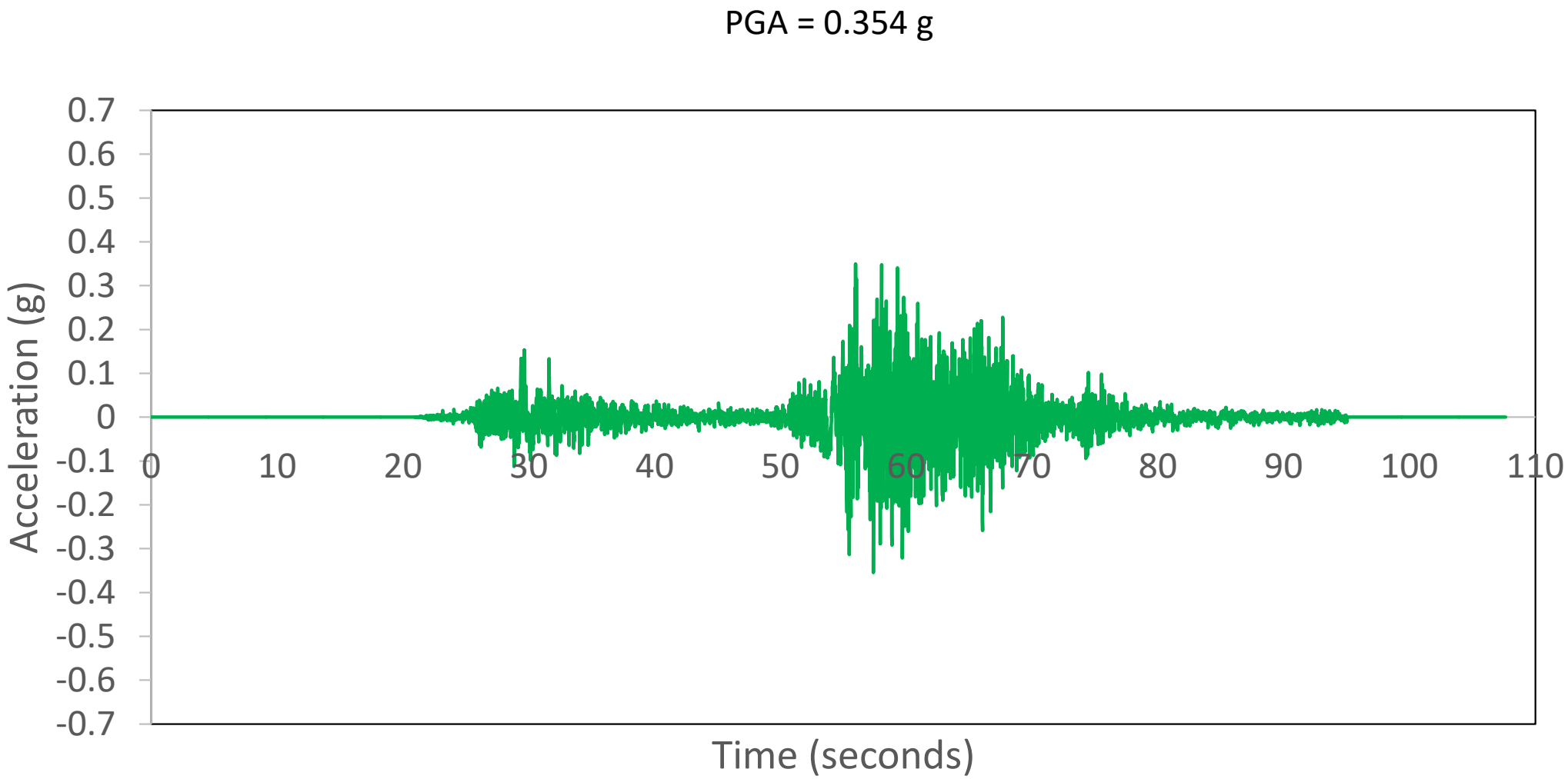
PGA = 0.607 g



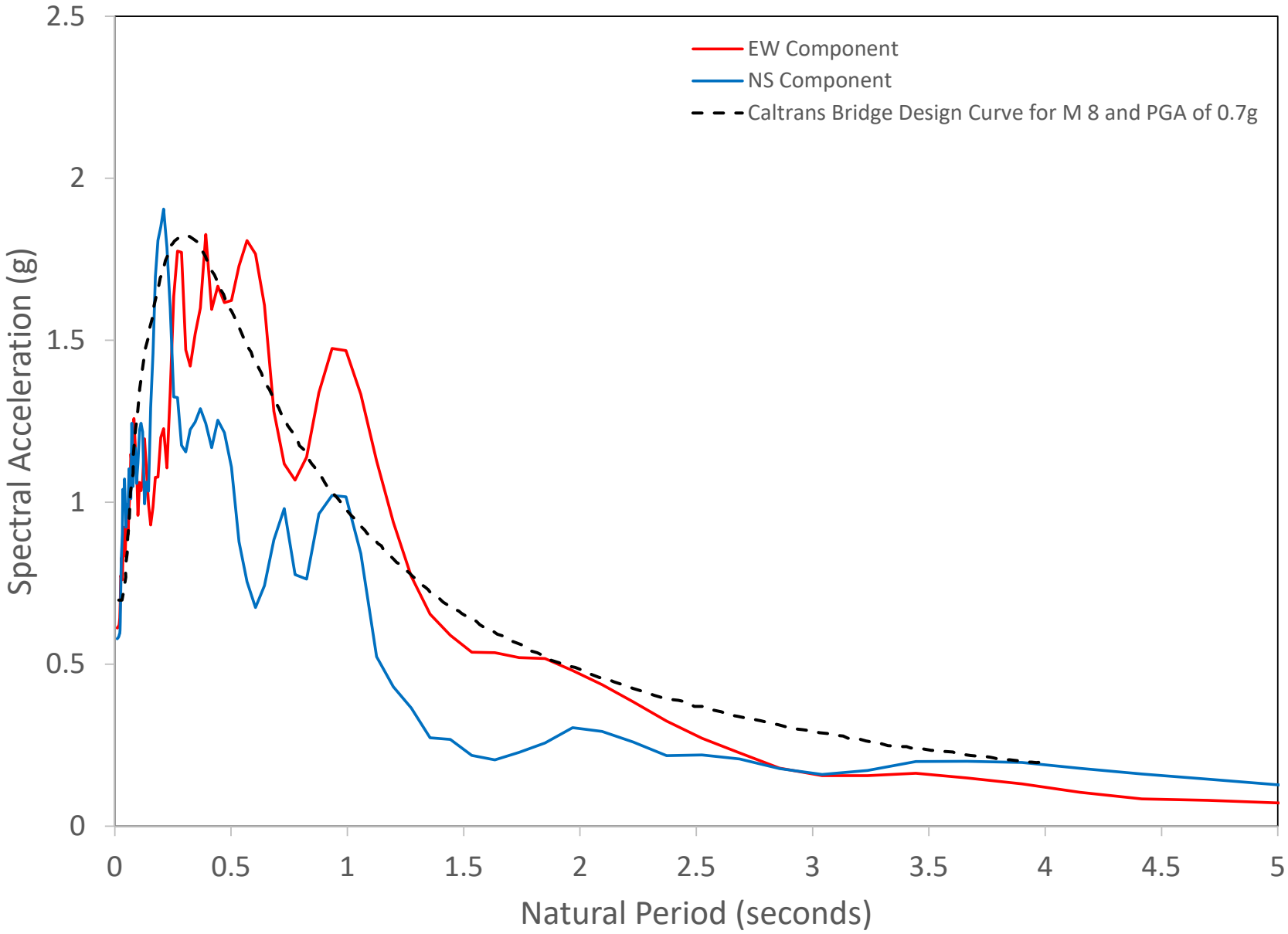
NS Motion for Station Closest to Bridge 1



Vertical Motion for Station Closest to Bridge 1

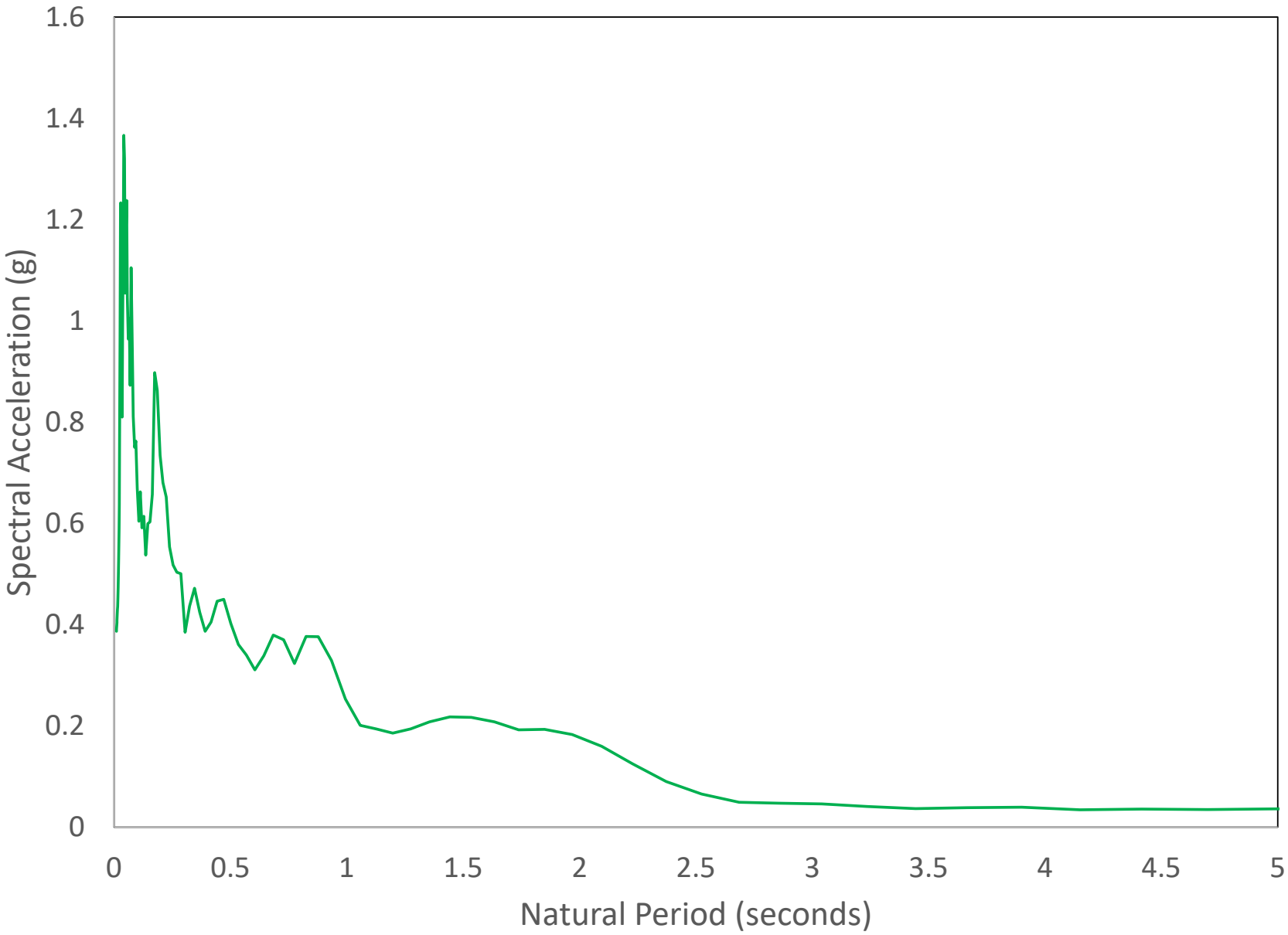


EW and NS Spectra for Station Closest to Bridge 1



PSA (EW) = 1.83 g
PSA (NS) = 1.90 g
PSA (Caltrans) = 1.82 g

Vertical Spectra for Station Closest to Bridge 1

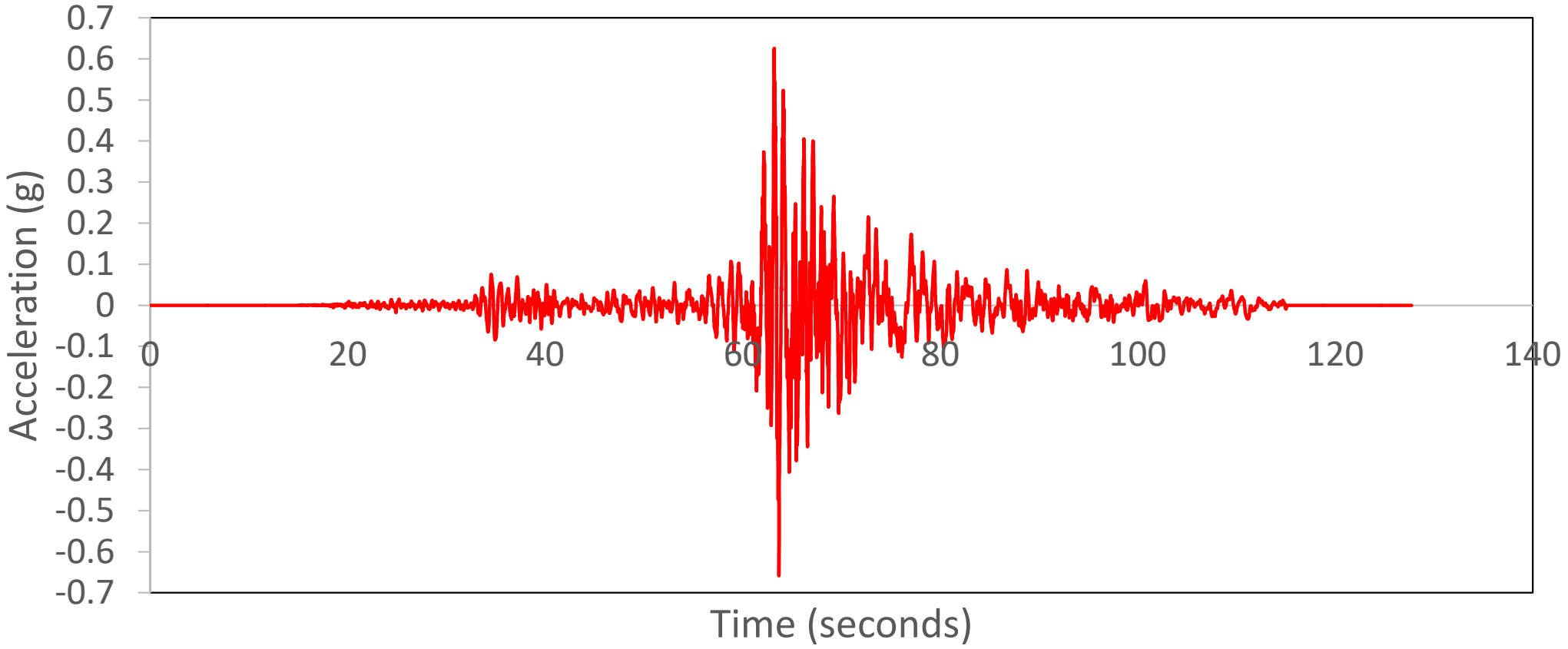


PSA (Vertical) = 1.37 g

EW Motion for Station 3124, Closest to Bridges 2 and 3

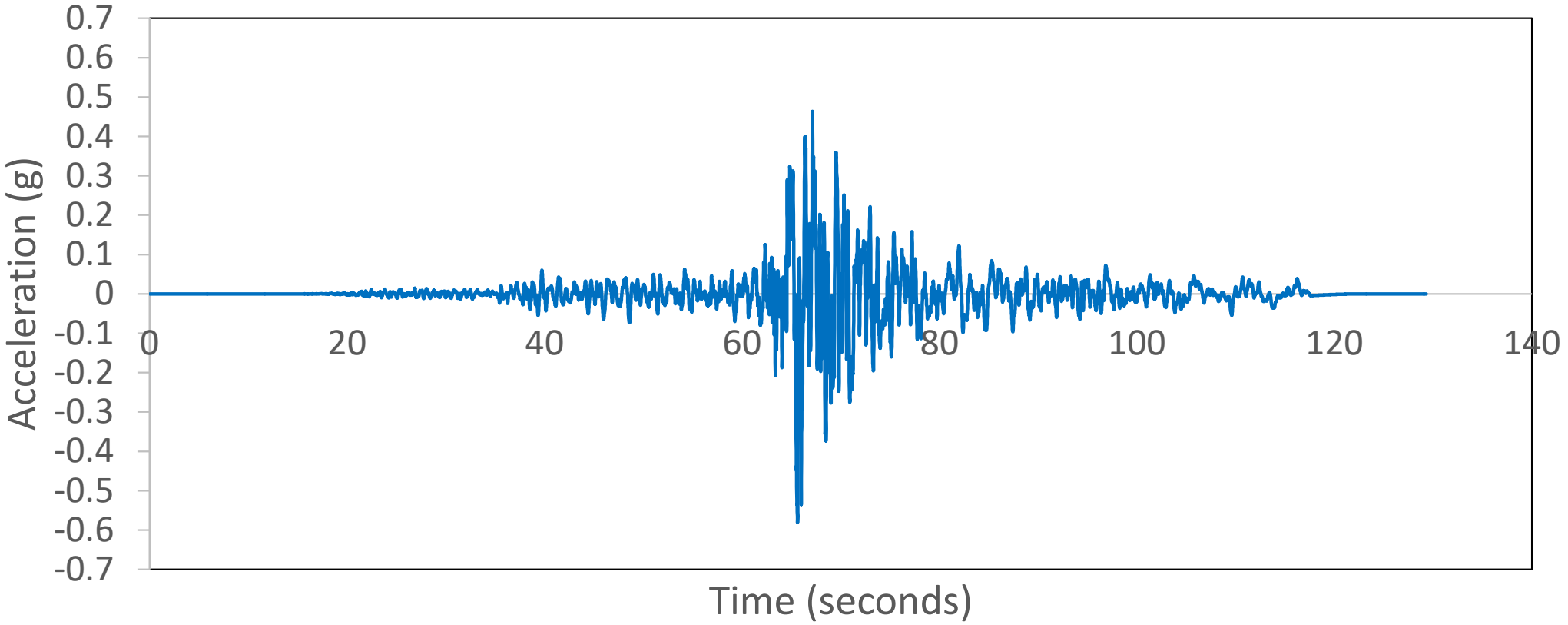
2.14 miles (3.44 km) from Bridge 2 and 2.33 miles (3.75 km) from Bridge 3

PGA = 0.659 g

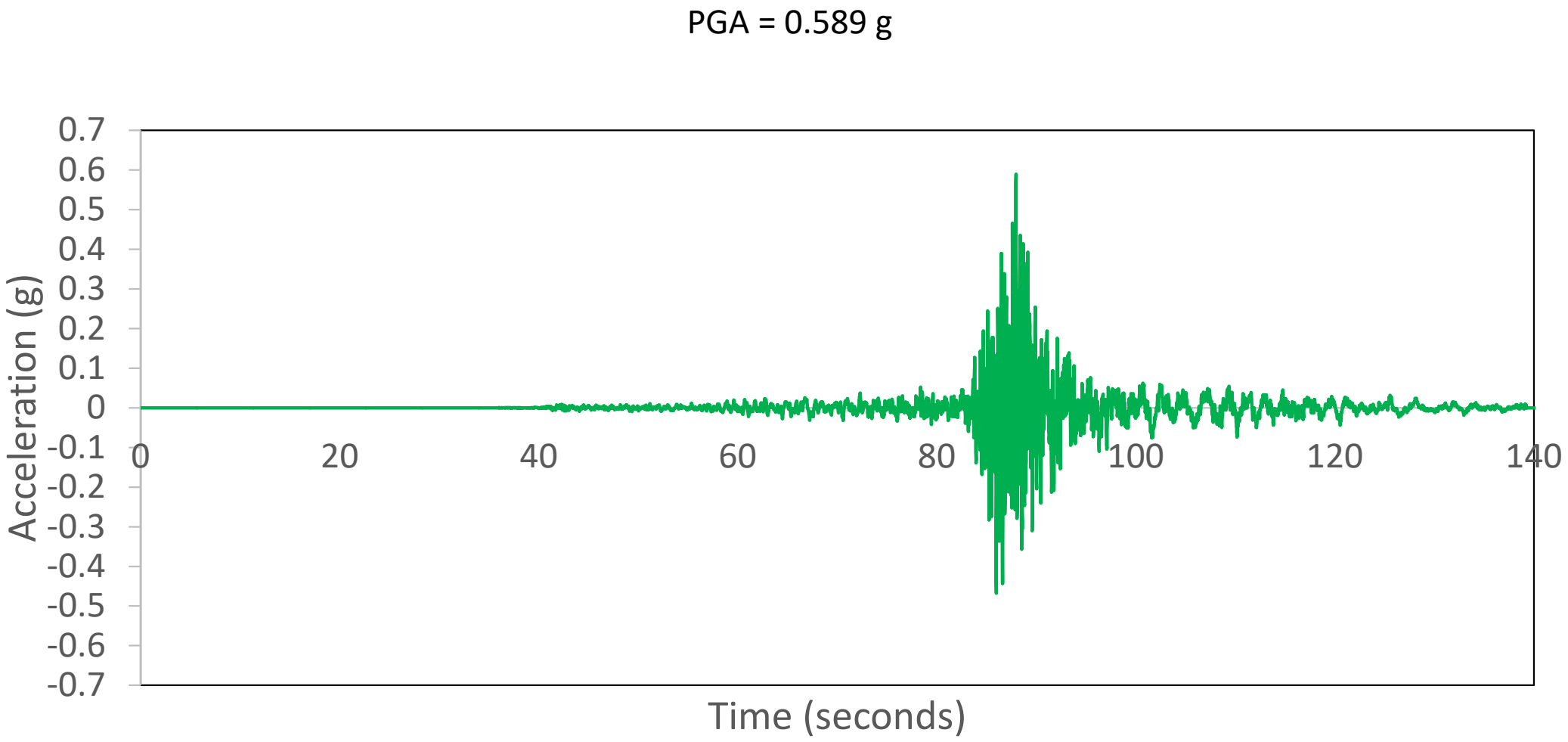


NS Motion for Station Closest to Bridges 2 and 3

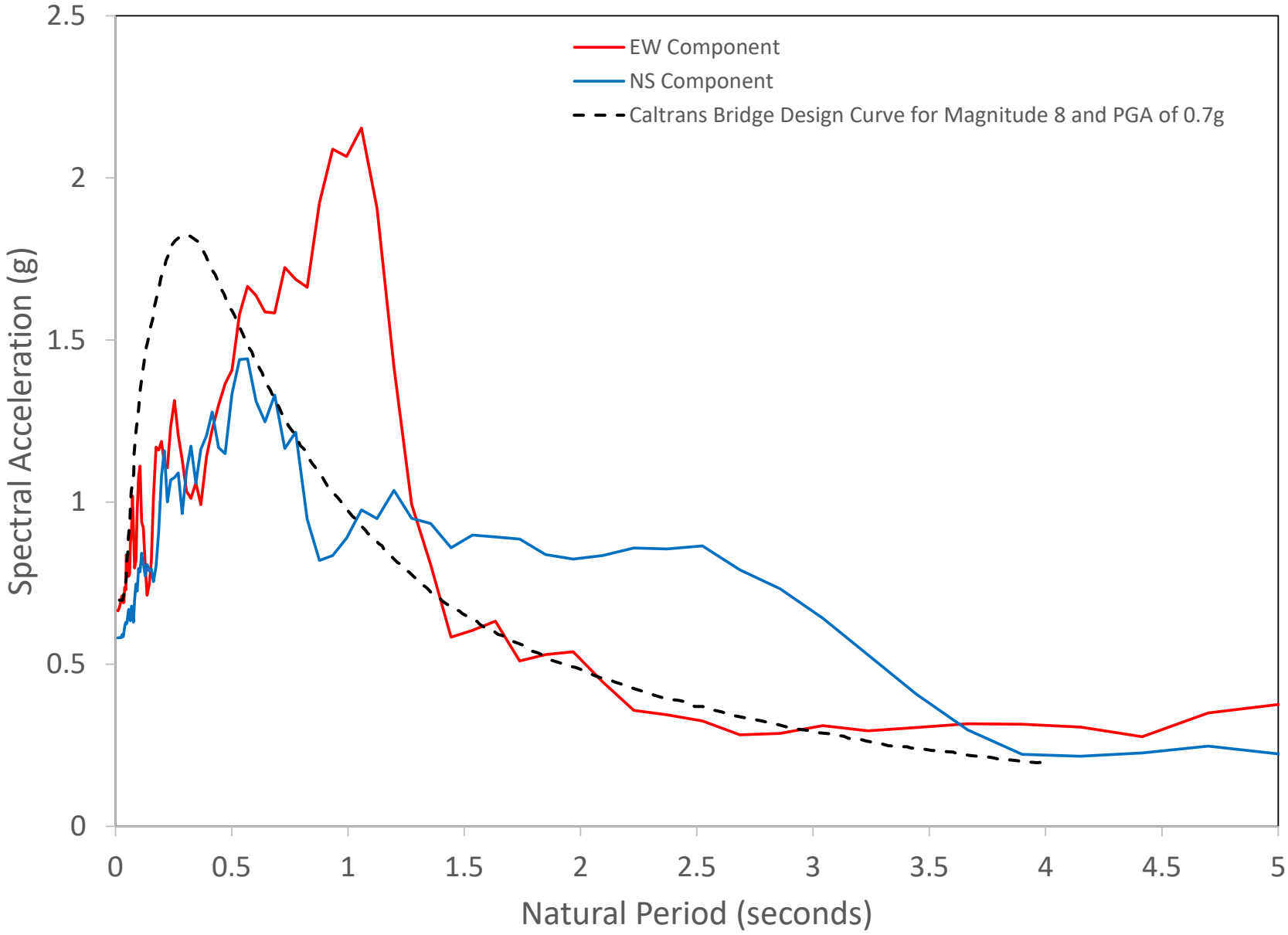
PGA = 0.581 g



Vertical Motion for Station Closest to Bridges 2 and 3

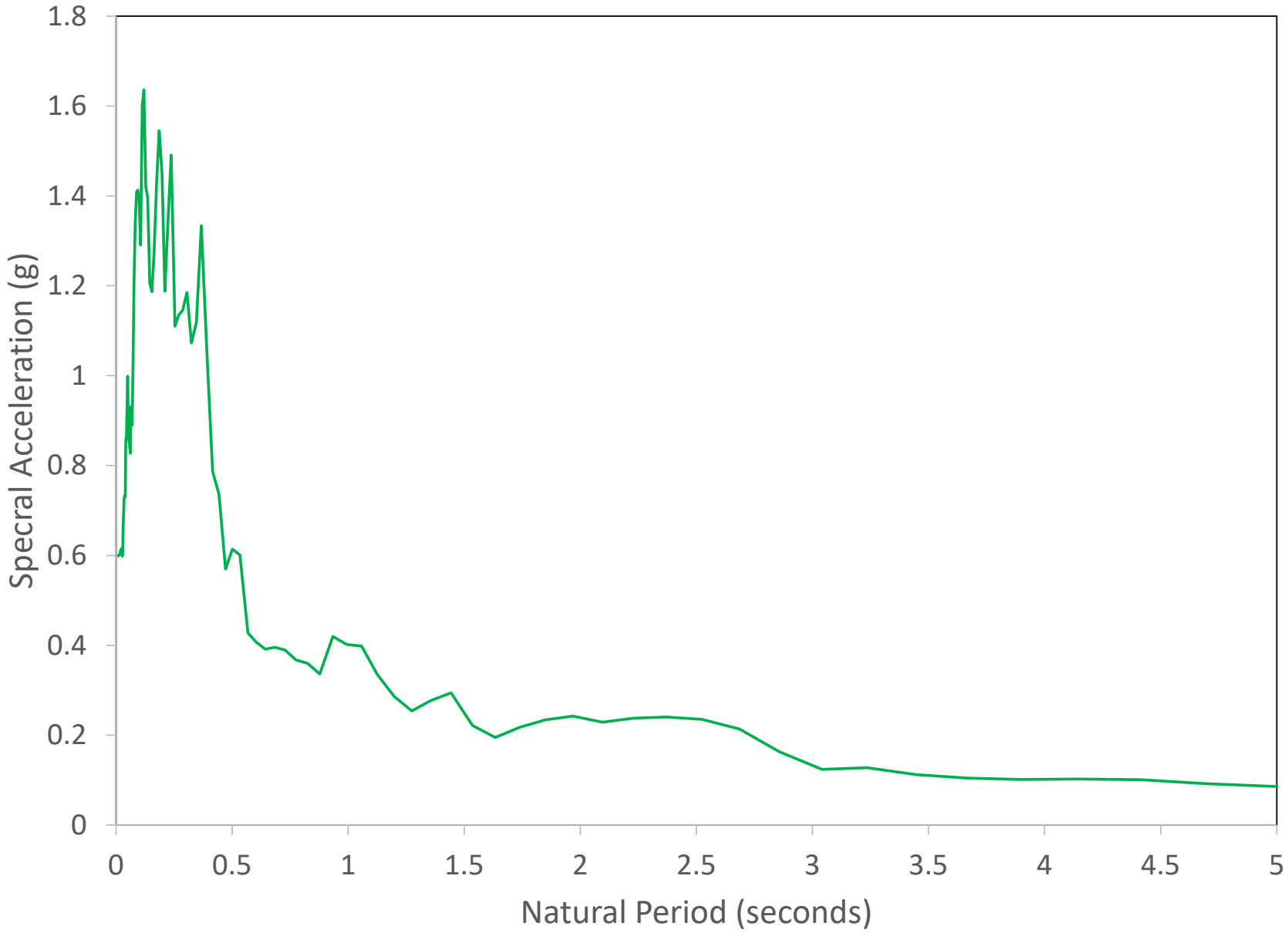


EW and NS Spectra for Station Closest to Bridges 2 and 3



PSA (EW) = 2.15 g
PSA (NS) = 1.44 g
PSA (Caltrans) = 1.82 g

Vertical Spectra for Station Closest to Bridges 2 and 3



PSA (Vertical) = 1.64 g

Bridge 1, 10’ Diameter Cantilever RC Columns, about 80’ Tall

(Nurdagi Viaduct)

18.1 miles (29.2 km)
from the epicenter of
the *Mw* 7.8 earthquake

260 feet (80 meters)
from the fault rupture

Plastic hinge formed about 25% up the column height

Bridge 1, Looking Toward Abutments

Bridge 1, Looking Toward Opposite Abutments

Bridge 1, Side View of Plastic Hinge

Bridge 1, Close-Up of one side of Plastic Hinge

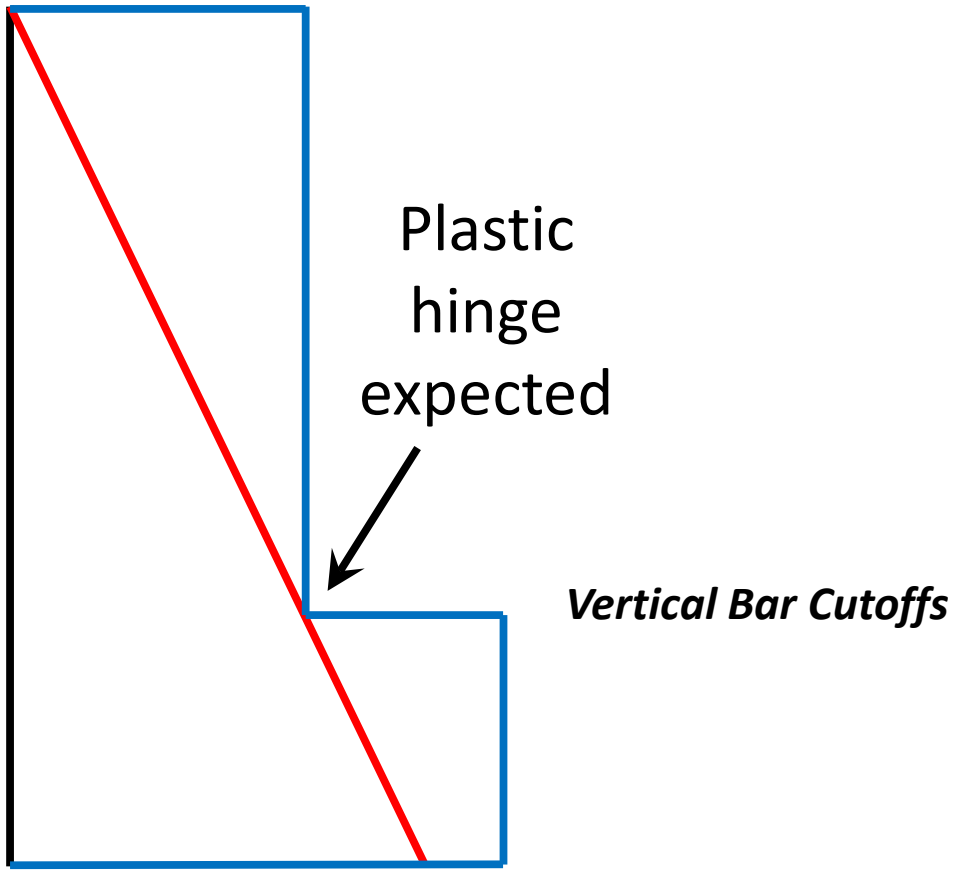
Vertical Rebar Buckled, Transverse Rebar Yielded and Deformed

Bridge 1, Opposite side of Plastic Hinge, Spalled Concrete only

No Rebar Buckled, and Transverse Rebar not Deformed

Bridge 1, Plastic Hinge not at Base of Column

Moment Capacity
Moment Demand



Bridge 1, Abutment Damage

Bridge 2, Overall View

(Asi Bridge)

80.8 miles (130 km) from the epicenter of the Mw 7.8 earthquake

2.5 miles (4.0 km) from the fault rupture

Bridge 2, Exterior Shear Key Failures

Bridge 2, Close-Up of Exterior Shear Key Failure

Bridge 2, Exterior Shear Key Damage, Looking Along Bridge

Bridge 2, Rubber Bearing Pads on Ground

Bridge 2, End-of-Girder Damage, Exterior Girder

Bridge 2, no Concrete left at End-of-Girder, Exterior Girder

Bridge 2, Overall Exterior Girder Damage

Bridge 2, Prestress Stand from Precast Girder

Bridge 2, Close-Up of Prestress Strand

Bridge 2, Interior Girder Damage

Bridge 2, Close-Up of Interior Girder Damage

Bridge 2, Interior Girder Damage – no concrete left

Bridge 2, Damage and Twisting of Girder End

Bridge 2, Close-Up of Damage and Twisting of Girder End

Bridge 2, Bent Vertically/Horizontally Precast Girder

Bridge 2, Plastic Hinge at Base of Column in Weak Direction

Bridge 2, Approach Settlement

Bridge 2, Approach Settlement

Bridge 3, Side View

81.4 miles (131 km)
from the epicenter of
the Mw 7.8 earthquake

2.0 miles (3.14 km)
from the fault
rupture

Bridge 3, from Underneath

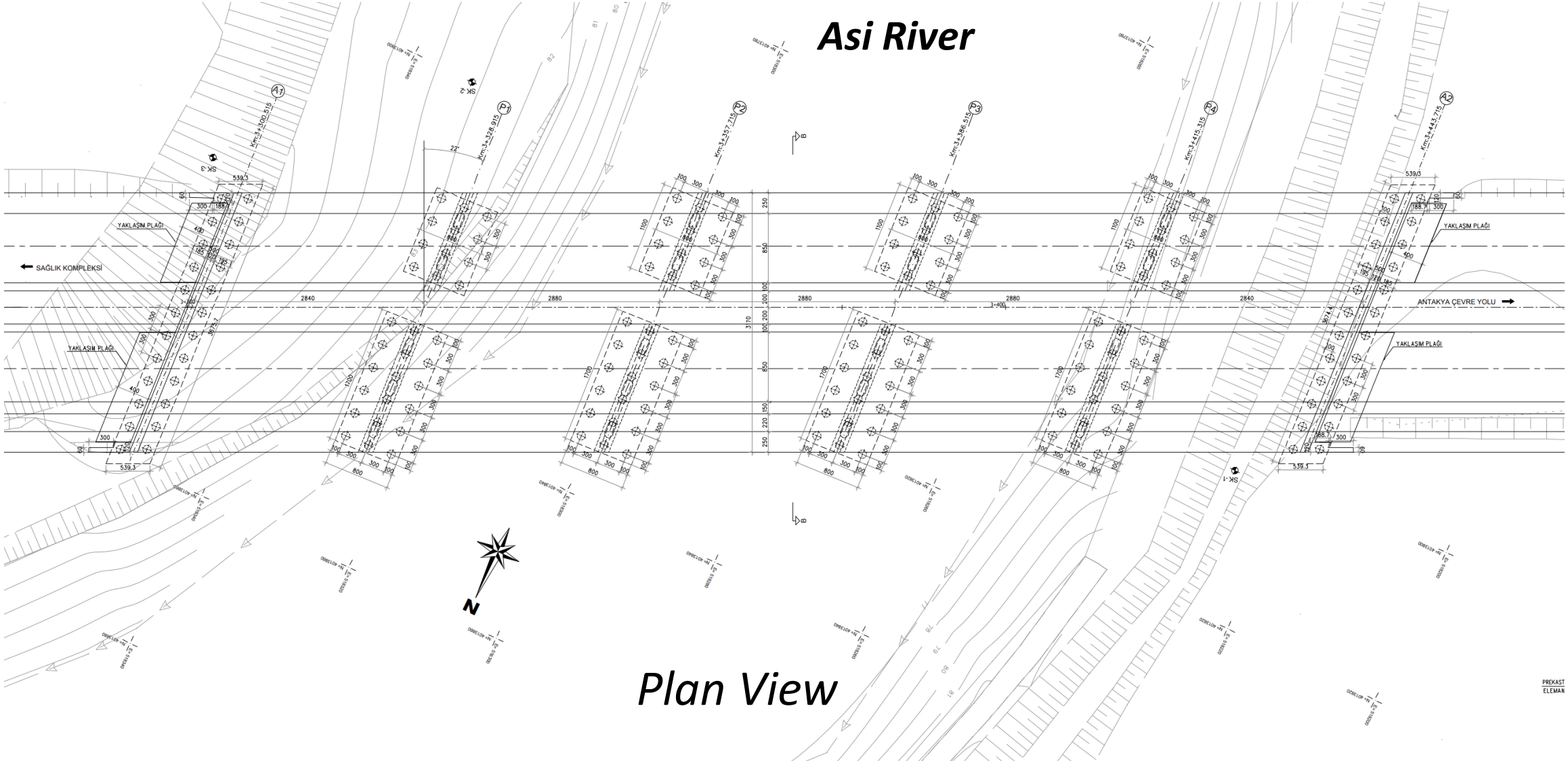
Bridge 3, End-of-Girder Damage

Bridge 3, Close-Up of End-of-Girder Damage

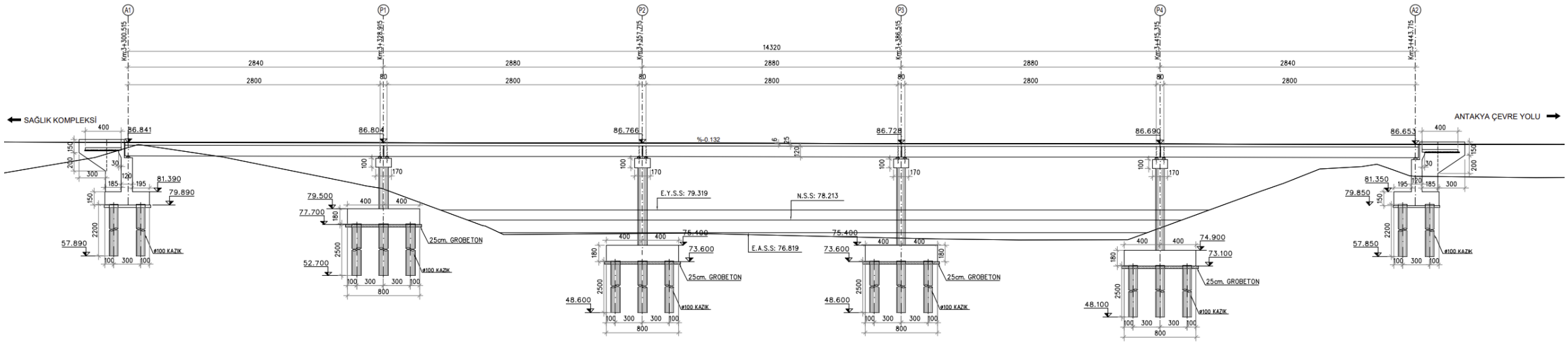
Bridge 3, Exterior Shear Key Damage

Bridge 3, Interior Shear Key Failure

Bridge 2 (Asi Bridge), Bridge Plans and Analysis Model

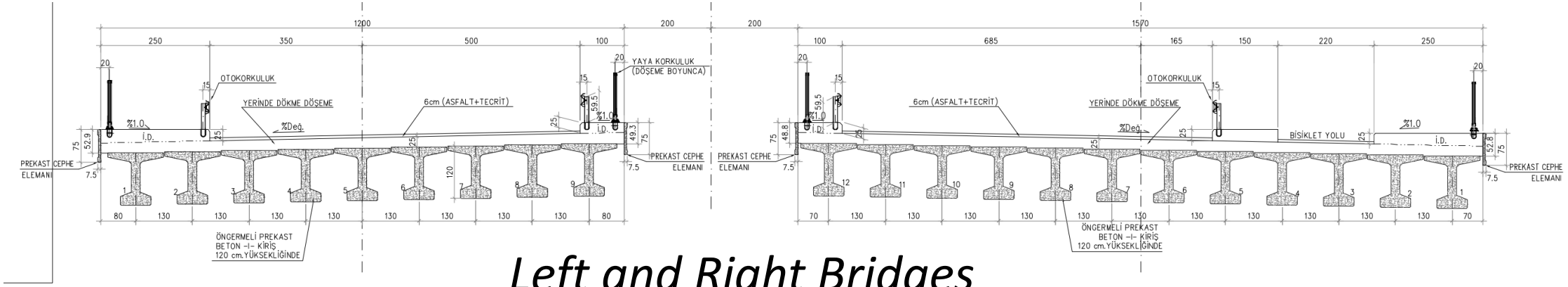


Plan View

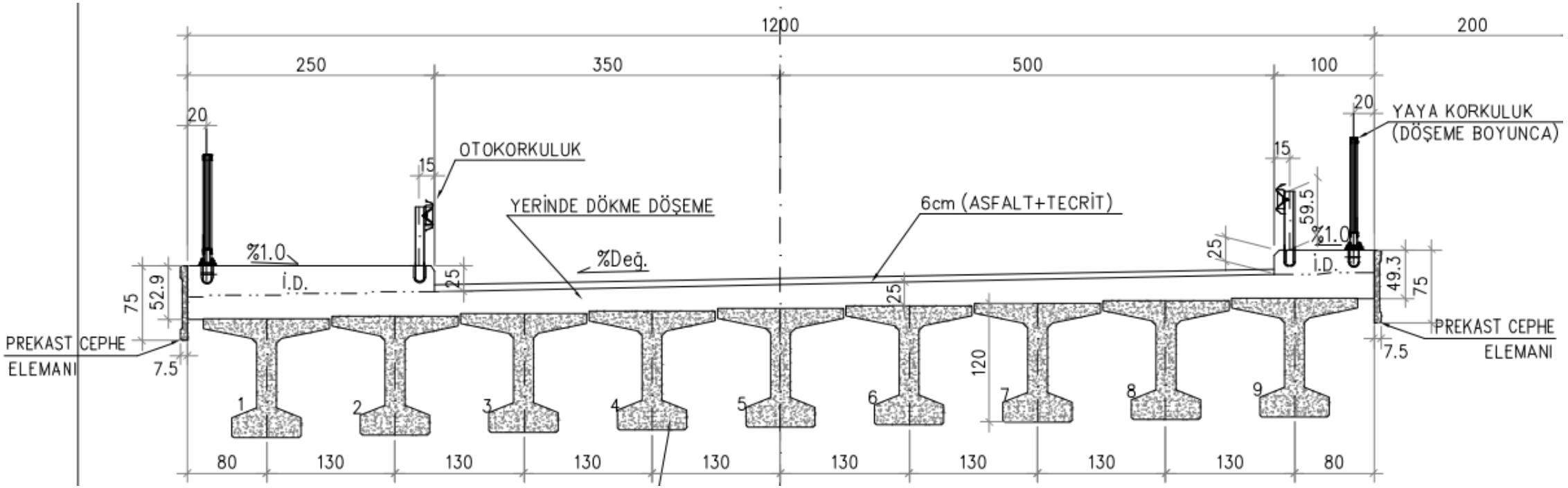


Elevation View

Bridge 2, Cross-Section

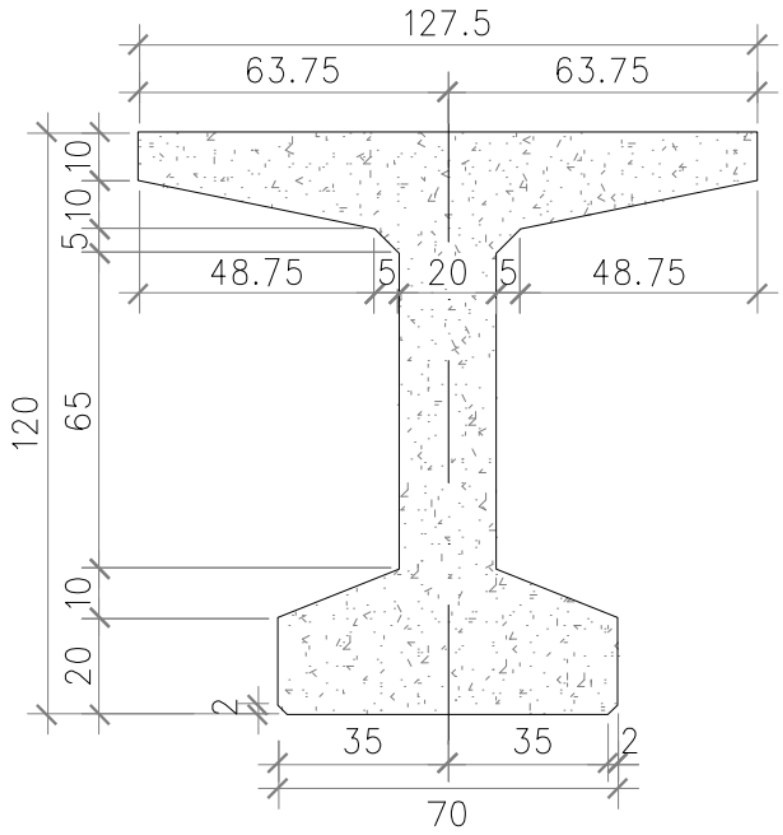


Left and Right Bridges



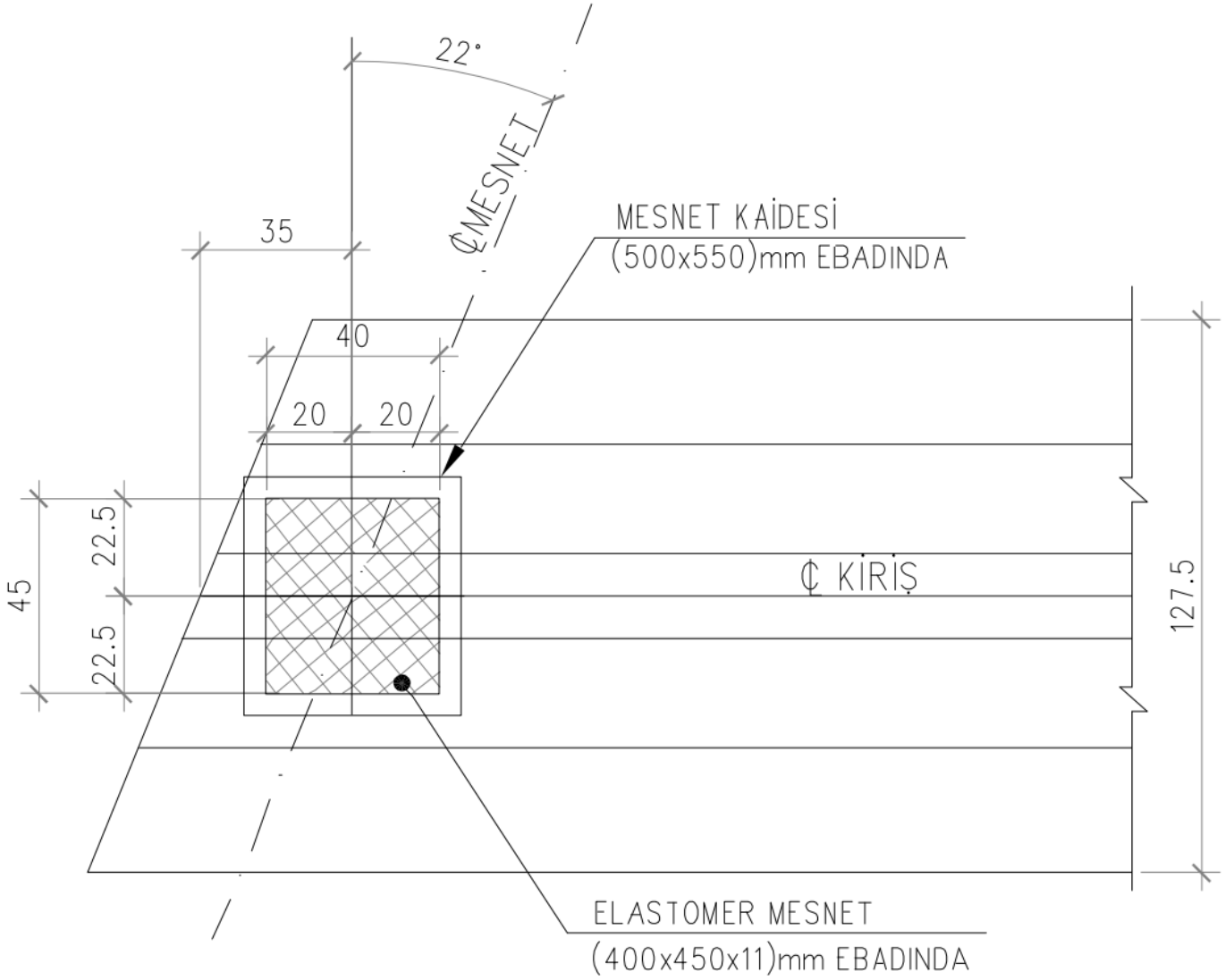
Left Bridge (Analysis Model is for Left Bridge only)

Bridge 2, Precast Girder Details and Rubber Bearing



PREFABRİK KİRİŞ EN KESİTİ

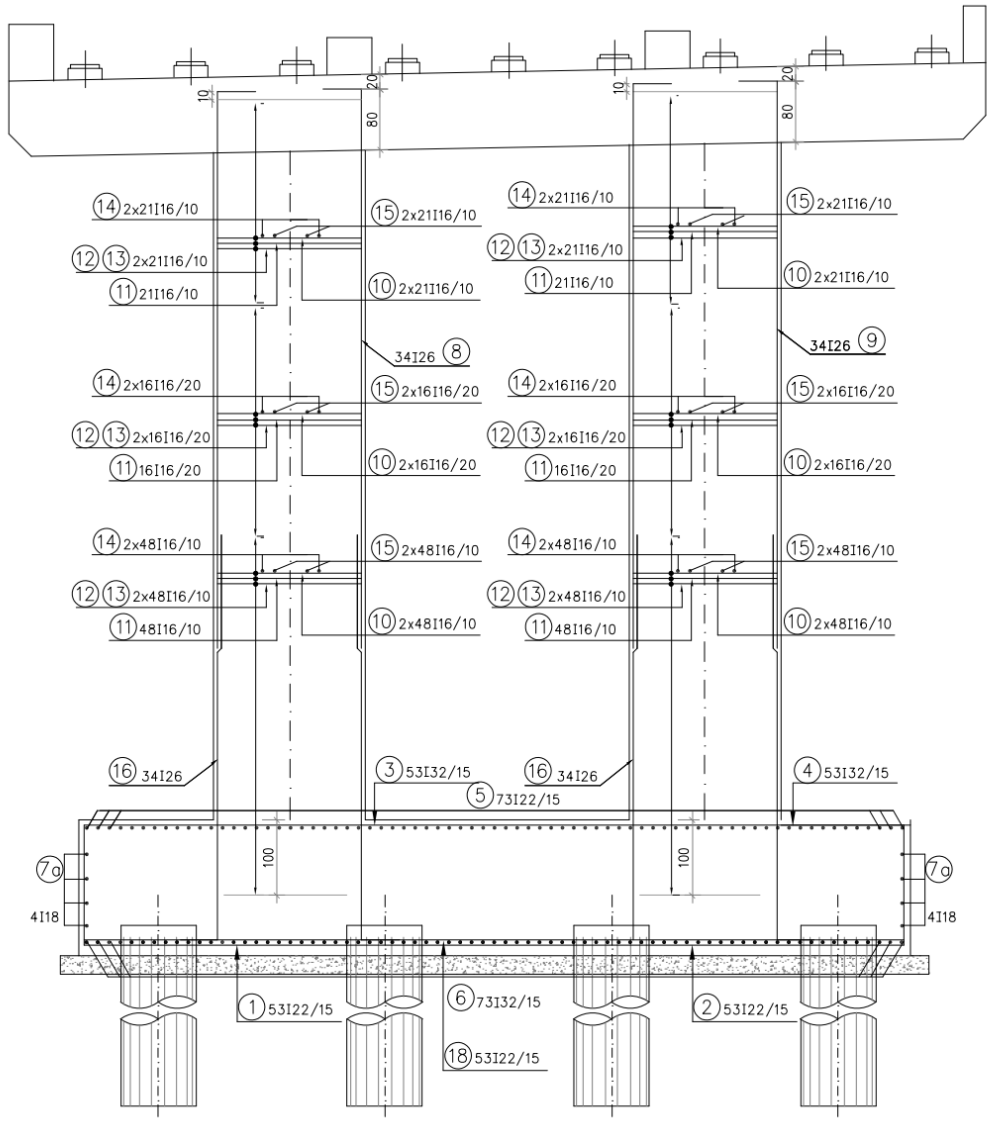
ÖLÇEK:1/20



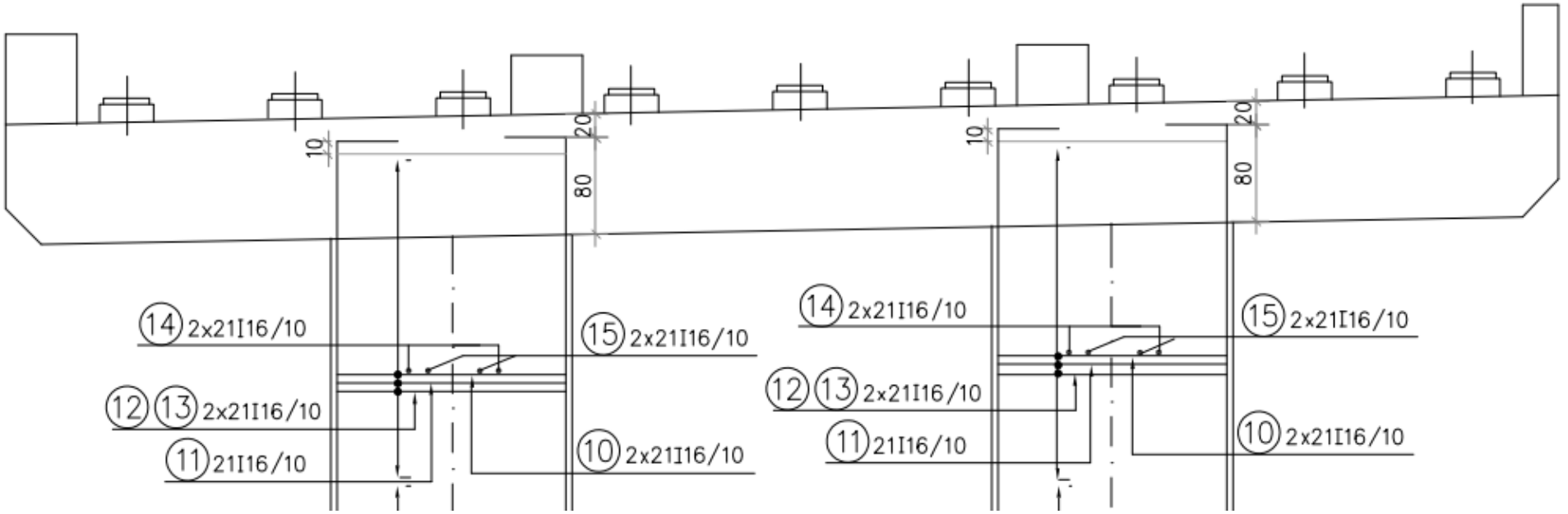
TİPİK MESNET YERLEŞİMİ

ÖLÇEK : 1 / 20

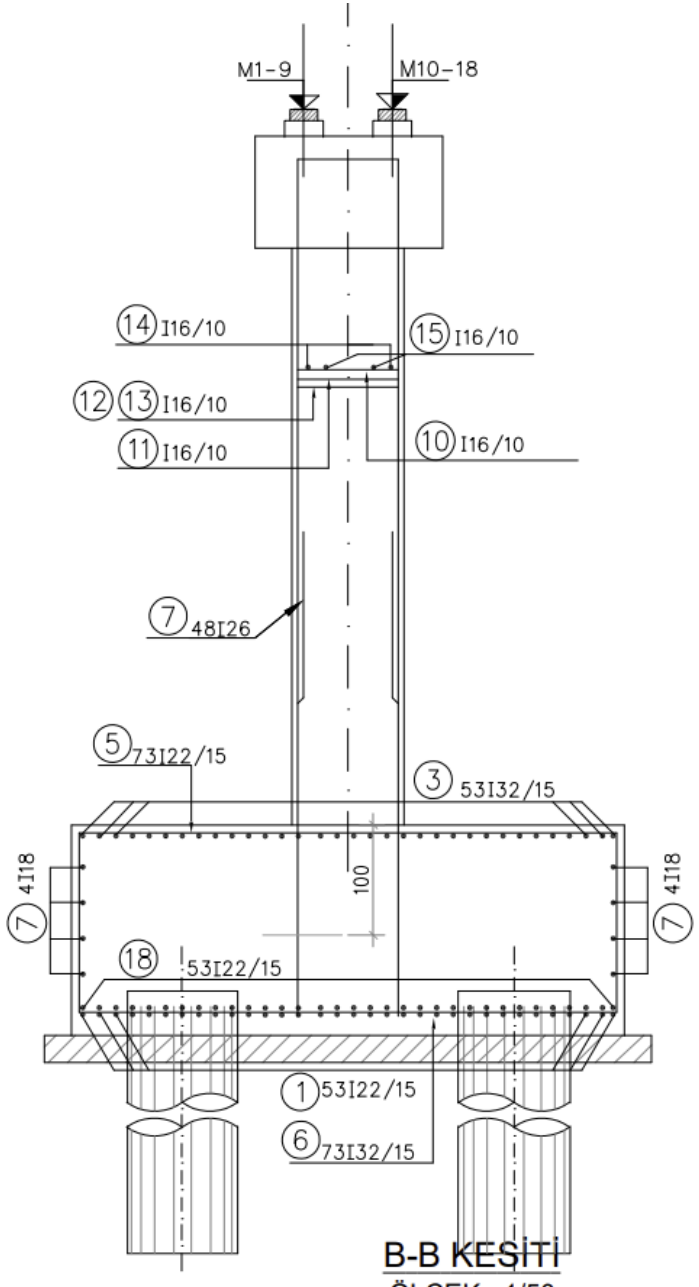
Bridge 2, Overall Bent Details



Bridge 2, Close-Up of Upper Bent Details



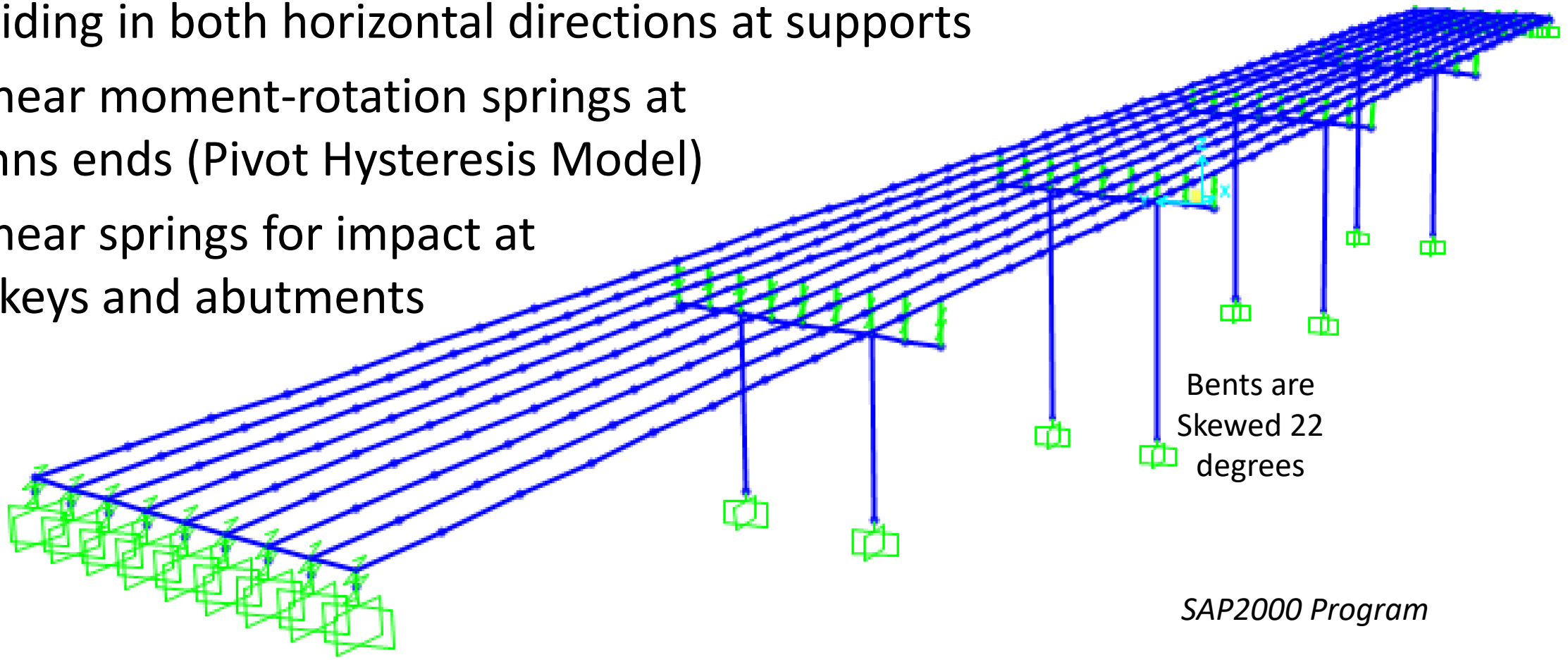
Bridge 2, Side view of Bent and Girder Supports



Bridge Model (in progress) – Beam Elements for Precast Girders and Columns

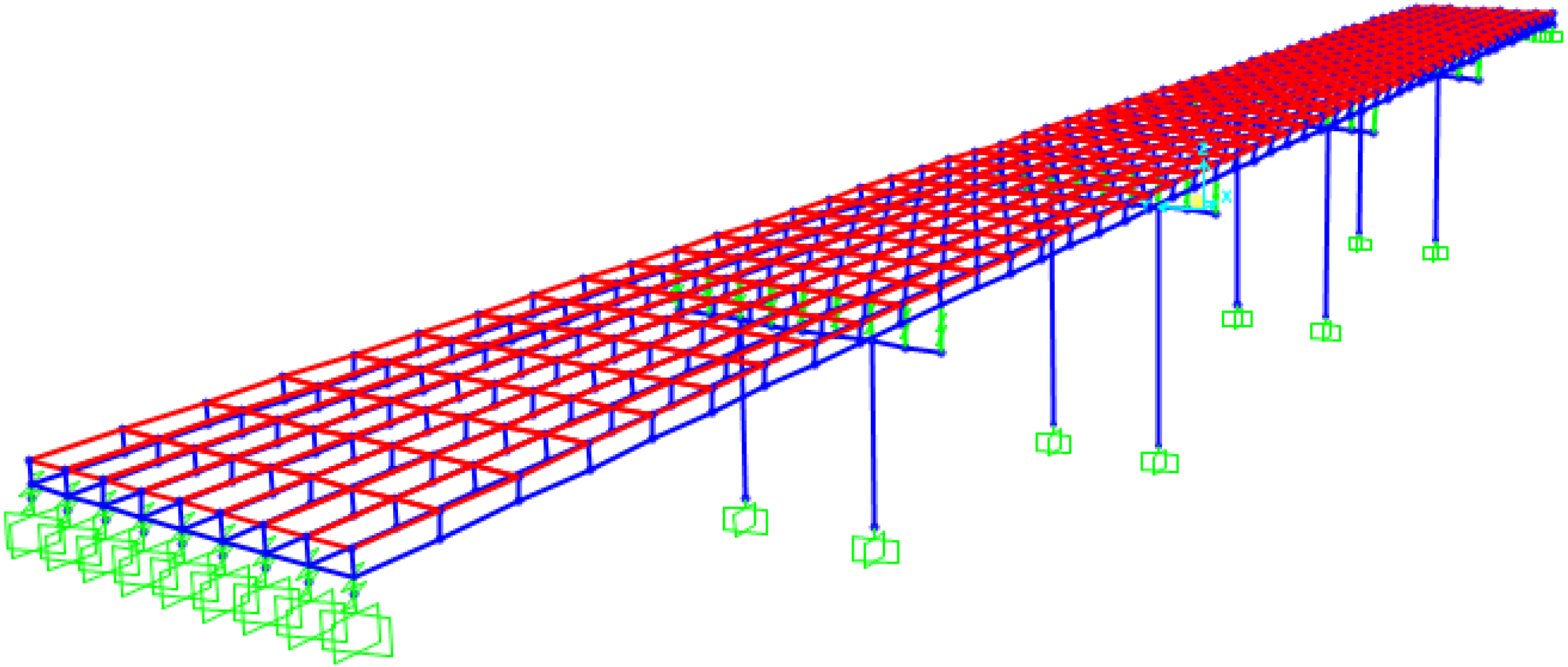
(Left Bridge)

- Nonlinear springs at all girder ends
- Allow girder uplift (compression but no tension force), and sliding in both horizontal directions at supports
- Nonlinear moment-rotation springs at columns ends (Pivot Hysteresis Model)
- Nonlinear springs for impact at shear keys and abutments

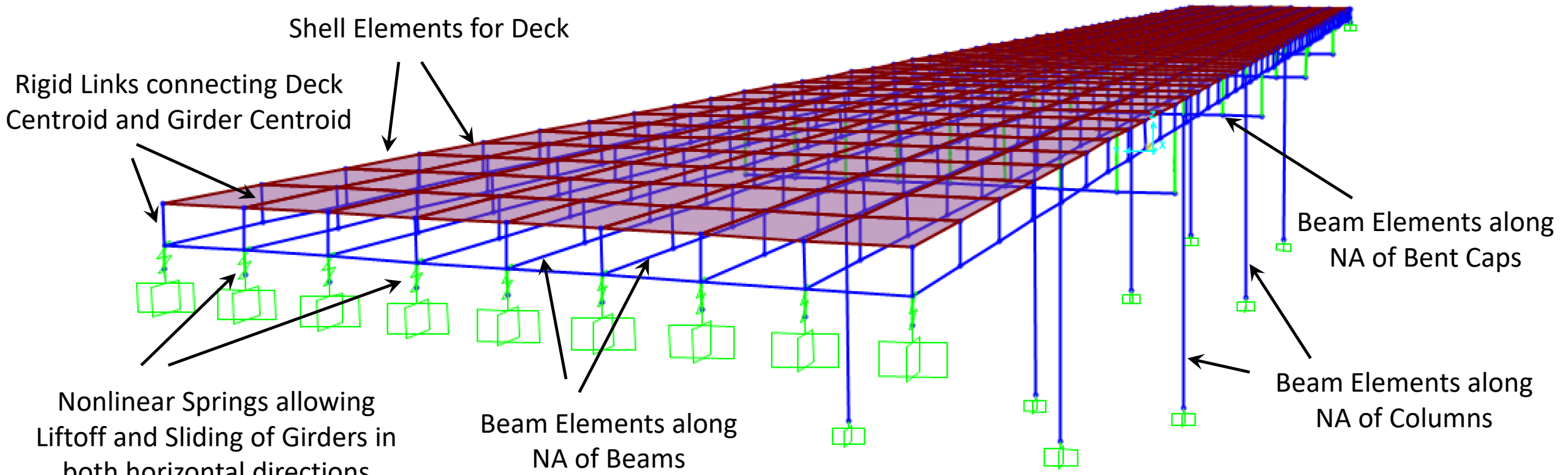


SAP2000 Program

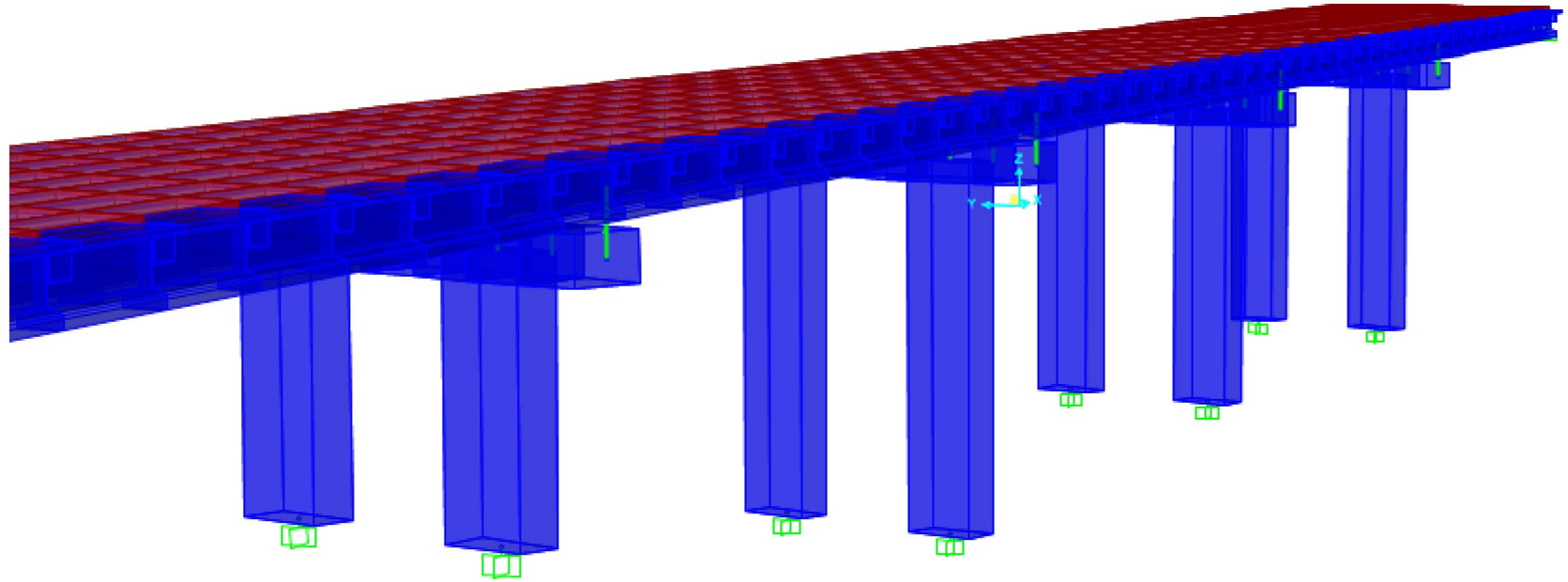
Bridge Model – Shell Elements for the Cast-in-Place Concrete Deck

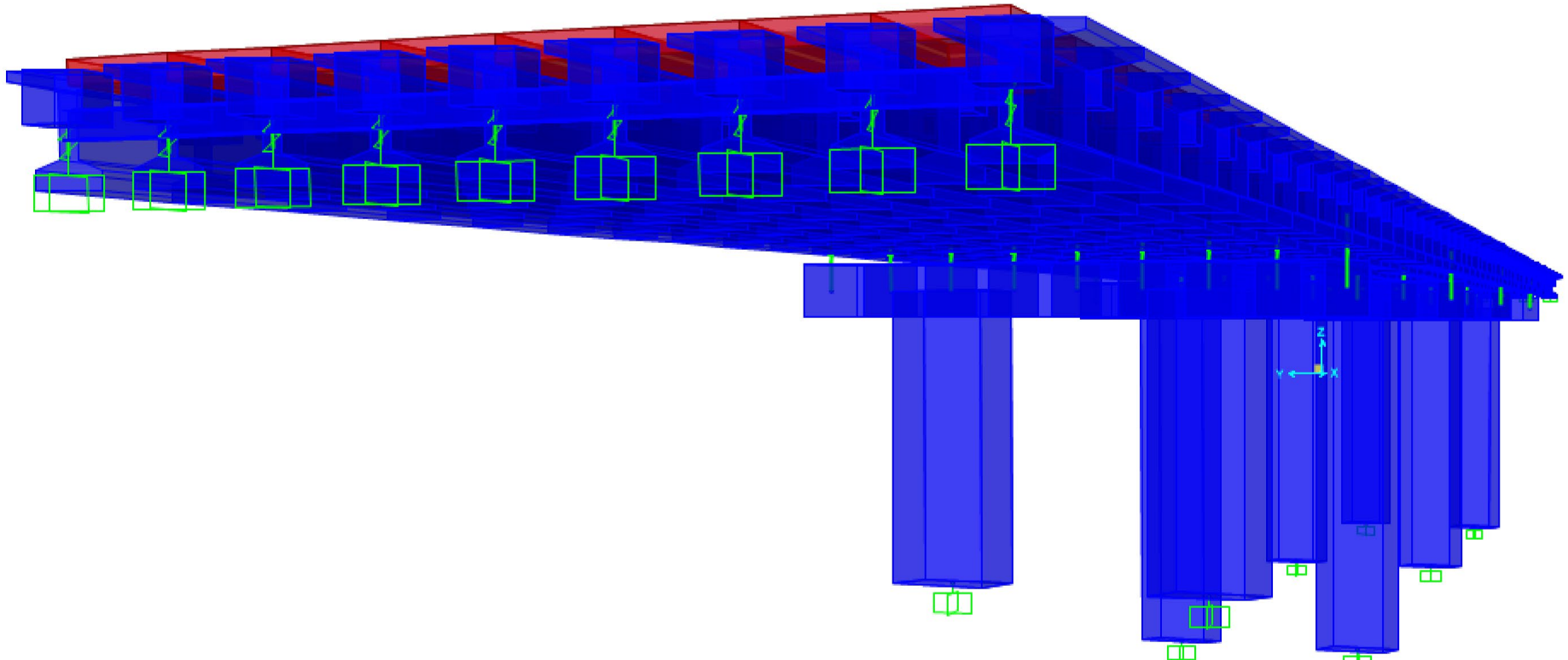


Bridge Model Details



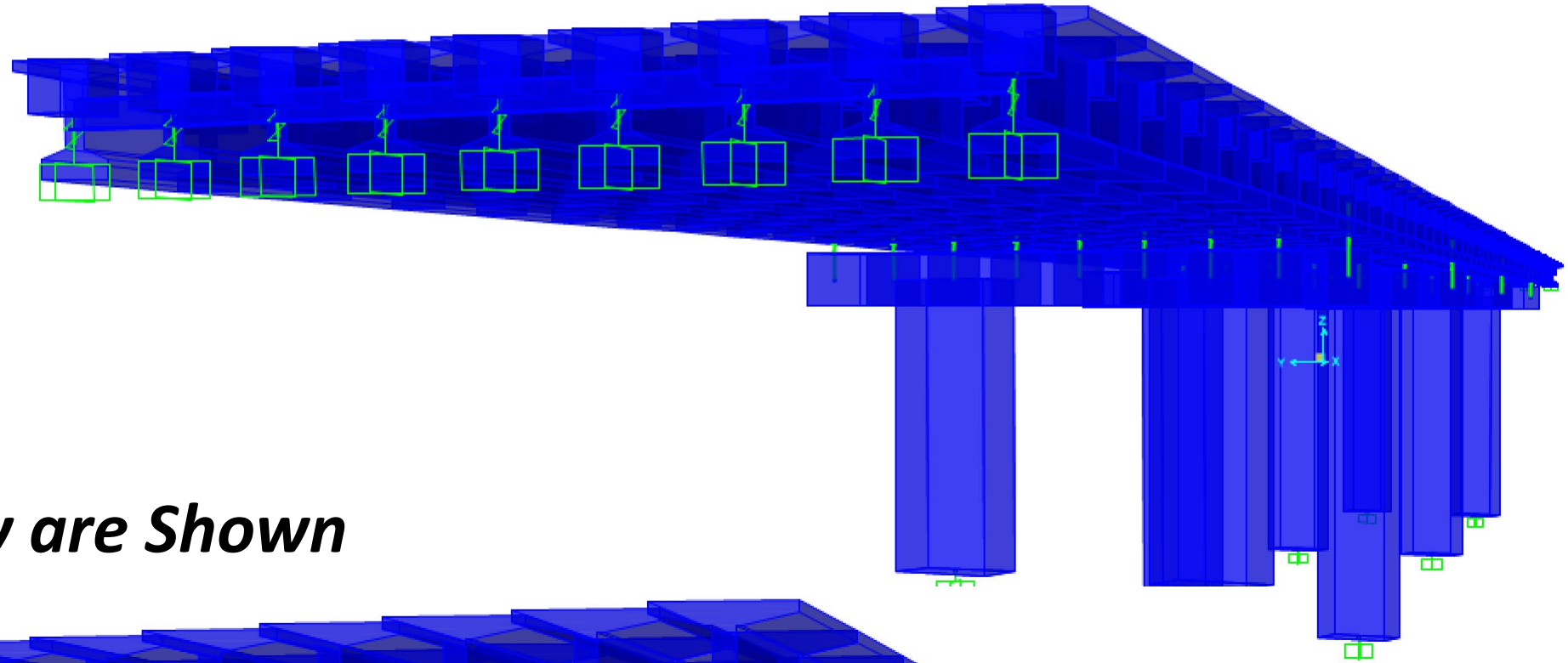
Extruded Views



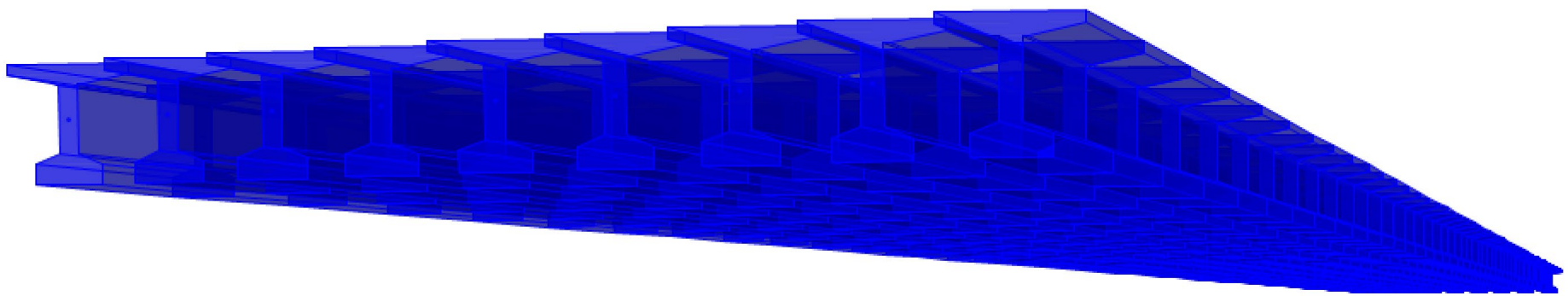


More Extruded Views

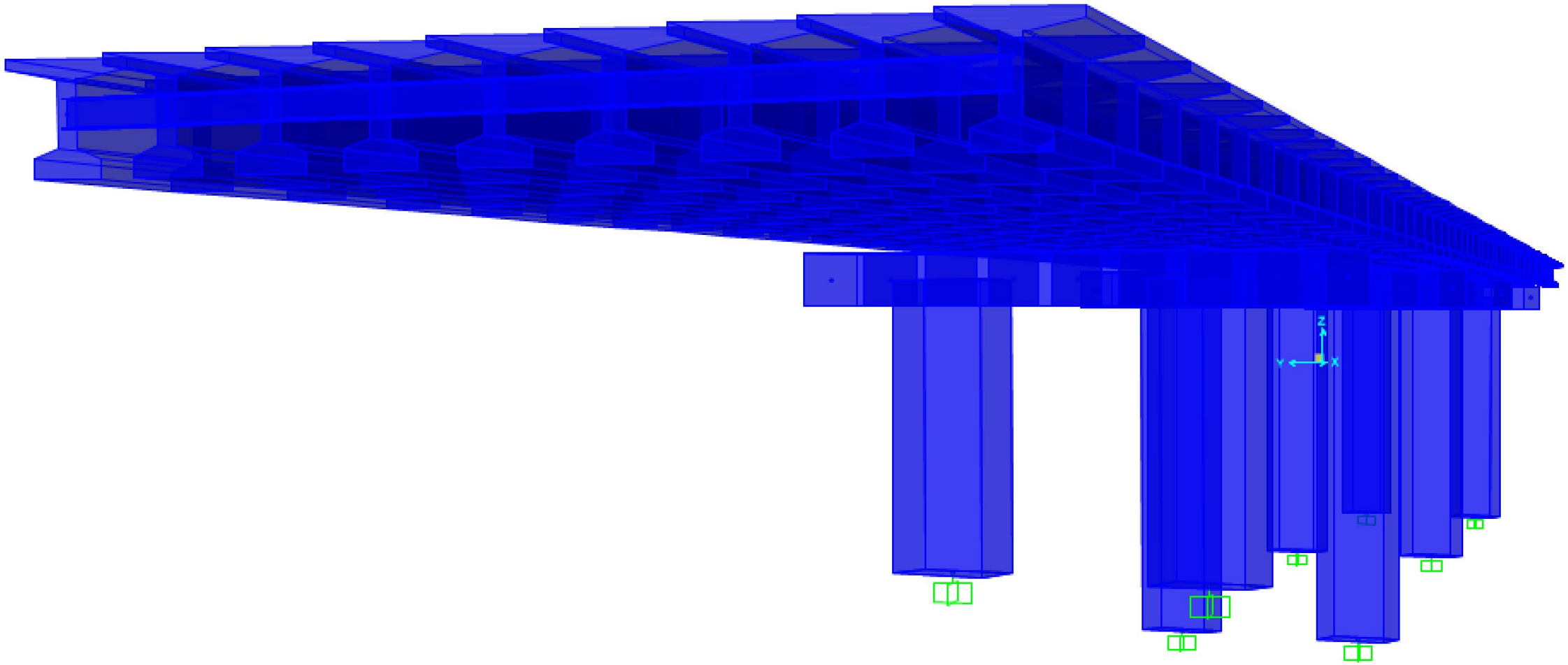
Deck not Shown



Girders Only are Shown



Extruded View, Girders, Bent Cap and Columns Shown



Conclusions (1/2)

- Bridges were heavily damaged but remained standing
- Tens of thousands of buildings collapsed
- M_w 7.8 earthquake is about *M* 8.1 on older Richter scale
- Turkiye earthquake was of similar size and type to 1906 San Francisco earthquake and the future “Big One” in California
- Fault rupture length was about the same distance as San Diego to Santa Barbara in California (with LA right between) or most of the length of Taiwan
- Shaking intensity is along the fault rupture line and not about epicenter

Conclusions (2/2)

- Unusual bridge damage of column plastic hinge part-way up cantilever column and degradation at precast girder ends
- On-going nonlinear bridge analysis – with model as shown. Based on results from this global beam and shell model, a detailed 3D Finite Element model will be developed of just the girder end region
- Recommend physical testing in the laboratory of precast girder ends, including impact forces (dynamic) in all three directions
- Recommend physical testing in the laboratory of columns with different bar cutoffs