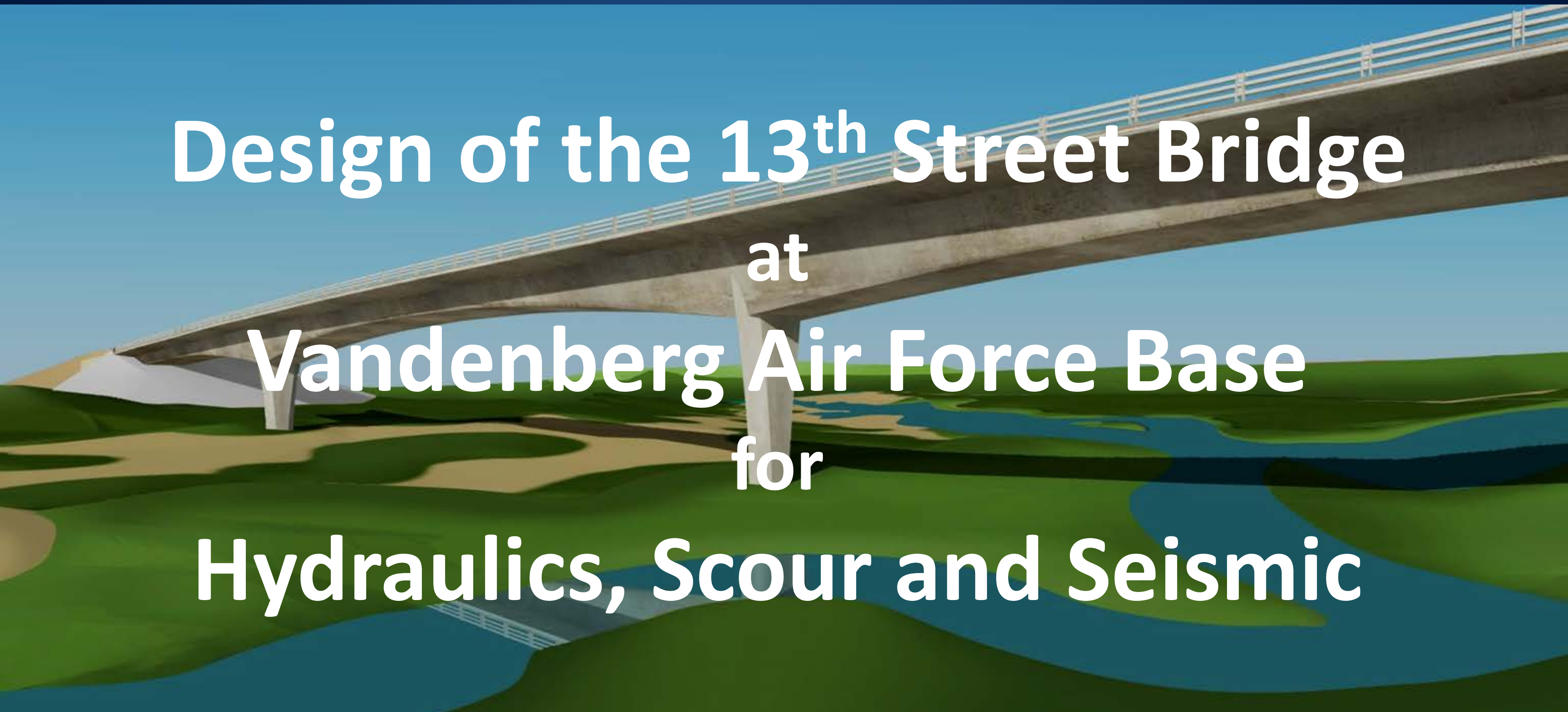
US Army Corps of Engineers

Design of the 13th Street Bridge at Vandenberg Air Force Base for Hydraulics, Scour and Seismic

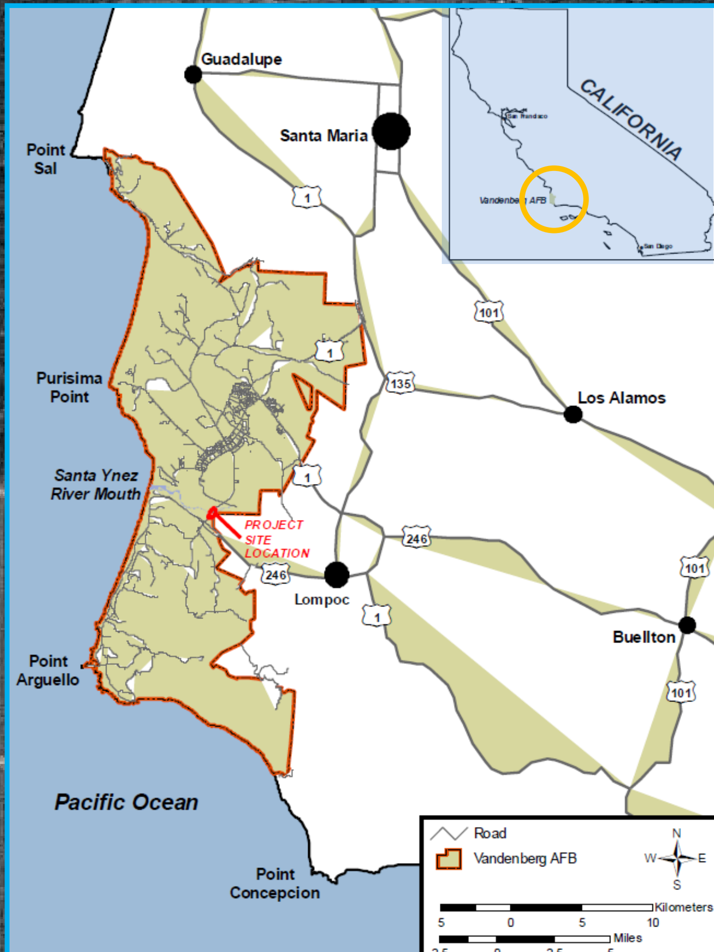


Western Bridge Engineers' Seminar

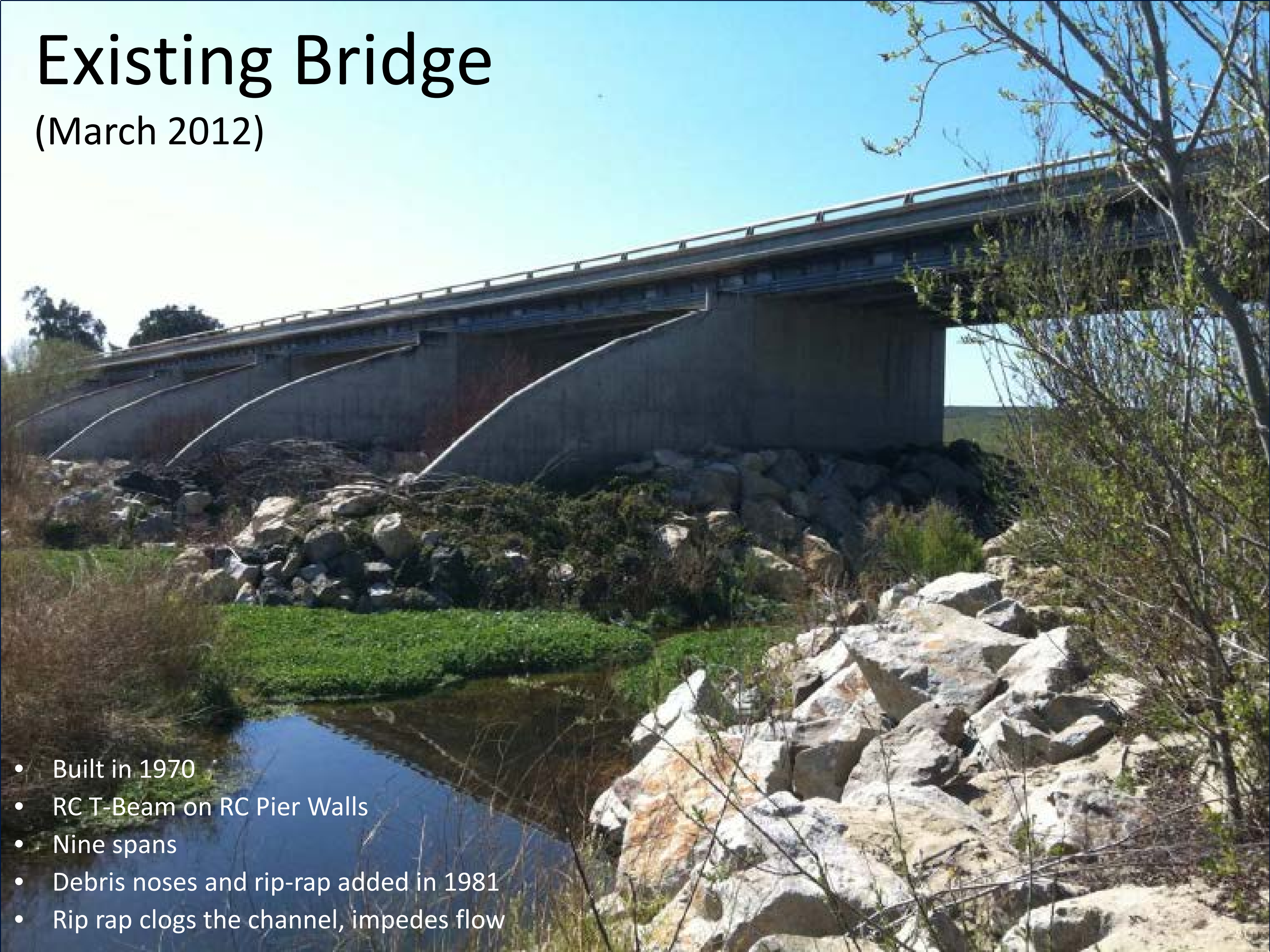
Reno, Nevada, September 10, 2015

Project Location

- Vandenberg AFB
- Coastal Santa Barbara County
- 150 miles NW of LA
- 230 miles south SF

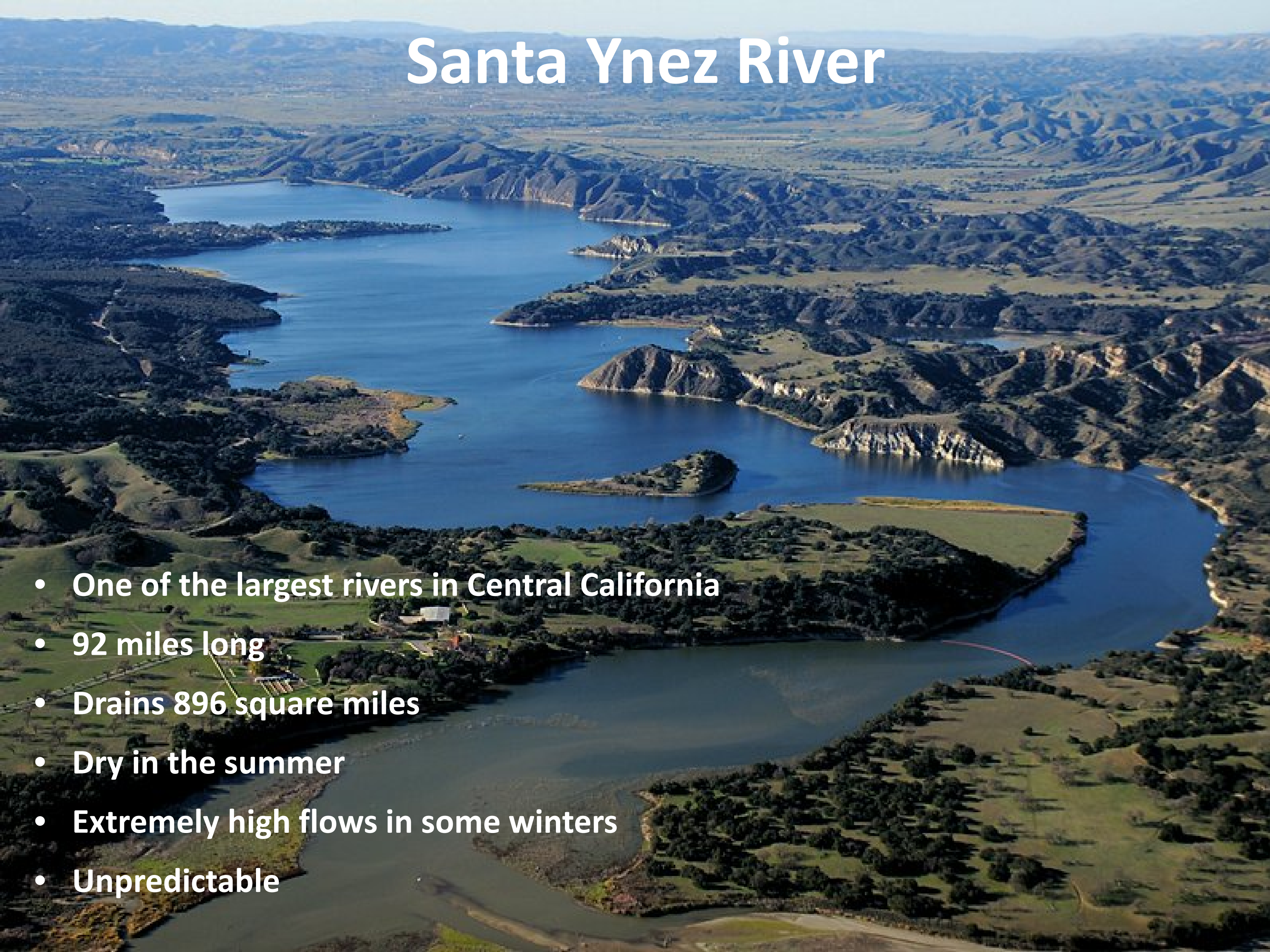


Existing Bridge
(March 2012)



- Built in 1970
- RC T-Beam on RC Pier Walls
- Nine spans
- Debris noses and rip-rap added in 1981
- Rip rap clogs the channel, impedes flow

Santa Ynez River



- One of the largest rivers in Central California
- 92 miles long
- Drains 896 square miles
- Dry in the summer
- Extremely high flows in some winters
- Unpredictable

Santa Ynez River Watershed

Watershed Areas:

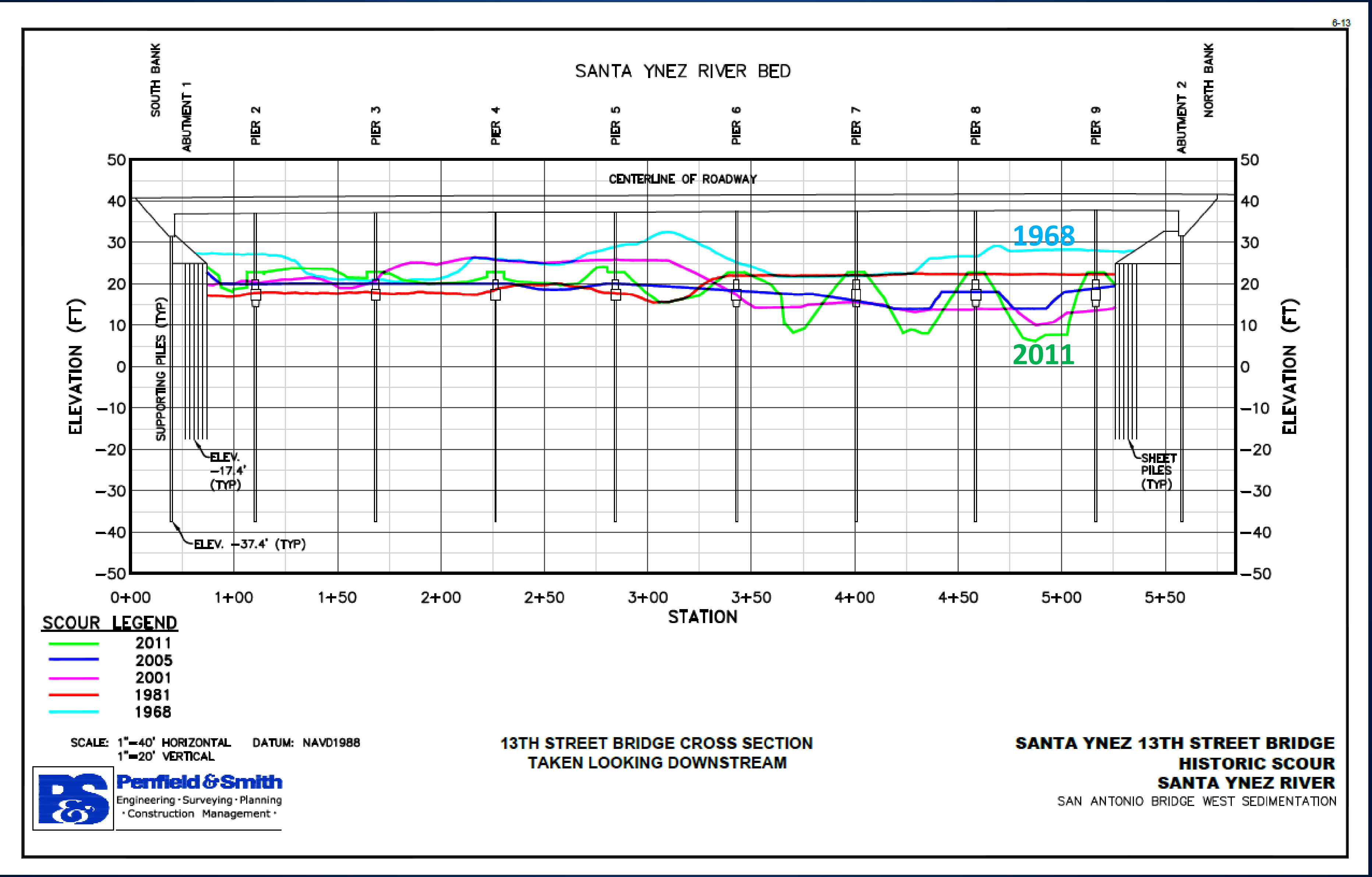
- Bradbury Dam: 417 sq mi
- 13th Street Bridge: 881 sq mi

Total: 896 sq mi (70 mi long x 13 mi wide)

History of Hydraulic and Scour Issues

- 1968 – Older bridge washed out in winter storm
- 1970 – New bridge under construction. Piles damaged by flood waters.
- 1978 - Storm washed out southern approach roadway
- 1981 – Scour issues. Debris noses and rip-rap added.
- Winter 2003 - Existing steel piles exposed by scour
- Summer 2003 - Micropiles and additional rip-rap added as part of an emergency contract

Historical Scour



Importance of 13th Street Bridge

- Only direct route between north and south parts of base
- Critical to several programs, including movement of essential space-launch equipment
- Carries essential communication lines

Geotechnical Issues:

- High groundwater
- Deep alluvium (upper 80 ft)

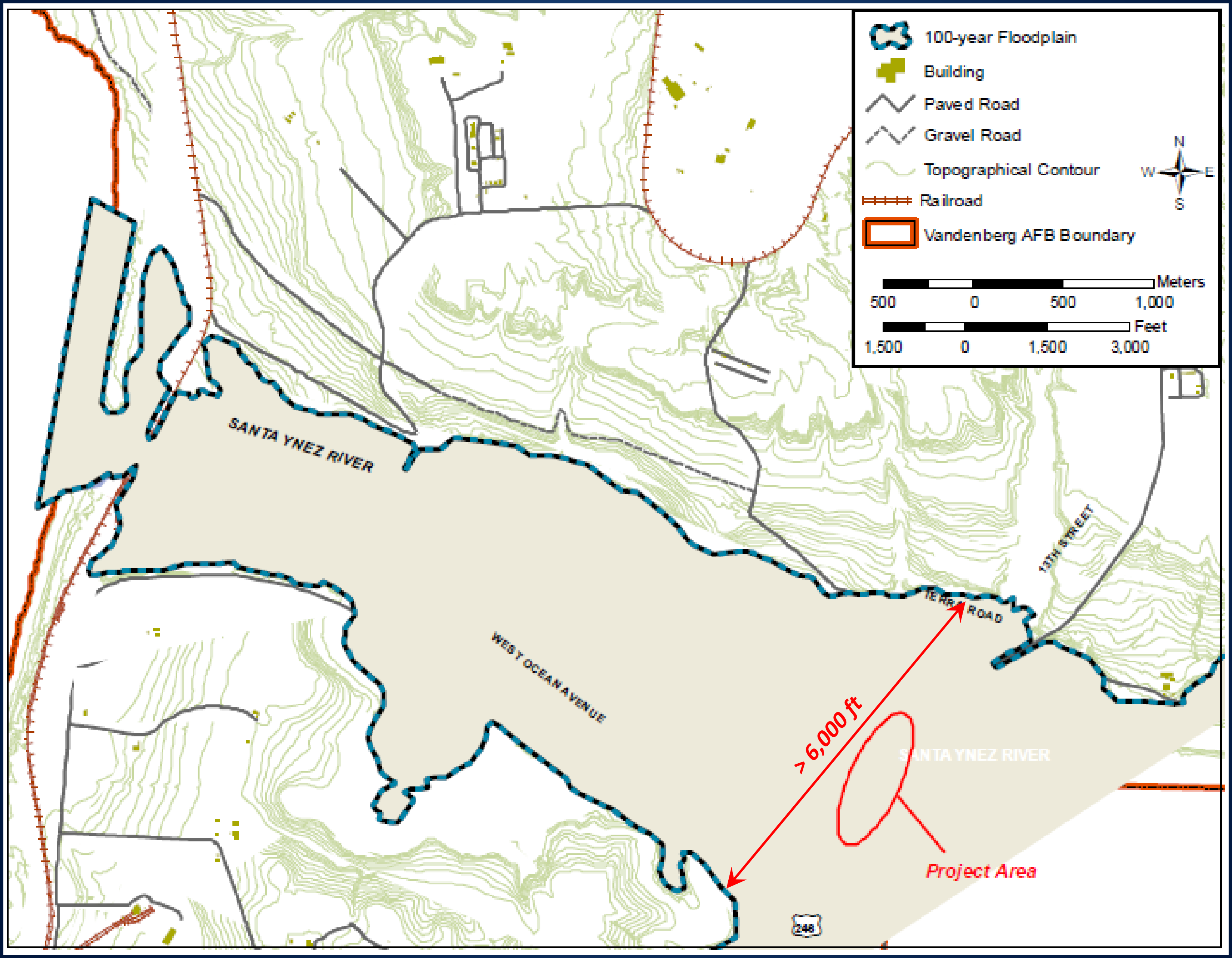
Seismic Issues:

- High risk of liquefaction in upper 80 ft
- High risk of lateral spreading at abutments
- Important bridge needs to be operational after earthquake

Drew Road, Imperial County, CA, April 2010

Close-up of failed area of Drew Road, April 2010

100 Year Floodplain



Structural Design Criteria

1. AASHTO LRFD Bridge Design Specifications, 4th Edition, 2007 with 2009 Interims

2. California Amendments to LRFD, 2011

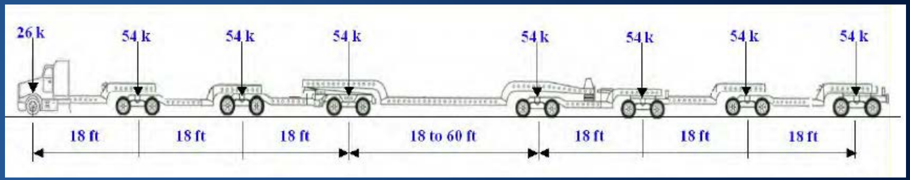
3. Caltrans Seismic Design Criteria v1.7, 2013

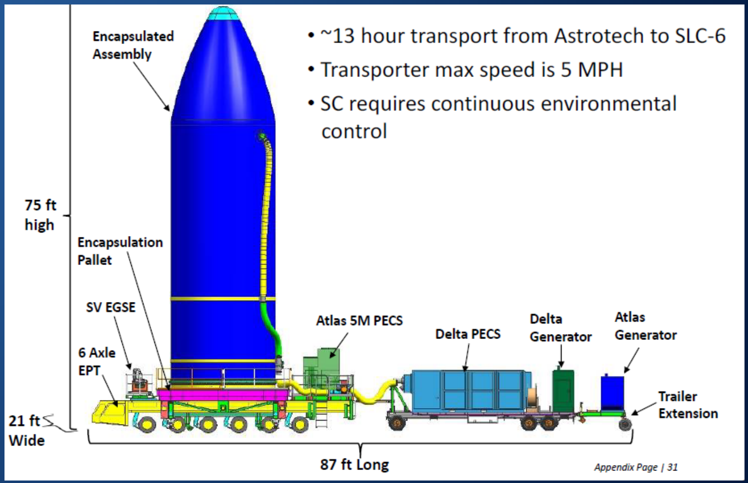
4. Project Specific Structural Design Criteria (Section 6 of Basis of Design Document)

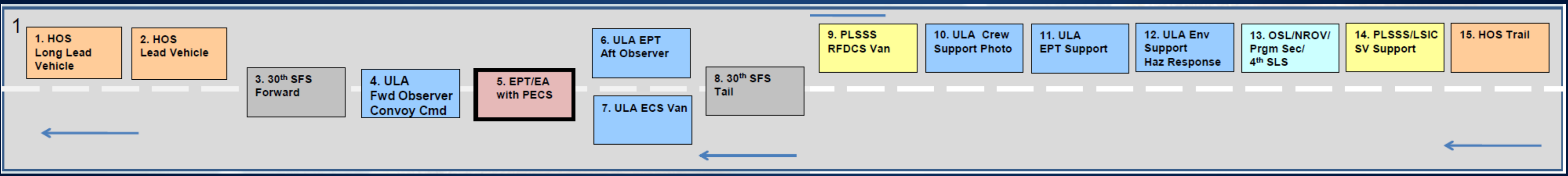
Superstructure Design – Live Loads

Vehicle		GVW
AASHTO Vehicles	**HL-93 Design Truck**	**72 kips**
	HL-93 Design Tandem	50 kips
	HL-93 Contraflexure	130 kips
	HL-93 Low Boy	100 kips
	Lane Load	**0.64 kip/ft**
California Permit Vehicle	**P-15 Permit Truck**	**404 kips**
Vandenberg AVB Special Vehicles (22 Vehicles)	Hendrickson Tractor and 2 Rear Axle	181 kips
	Hendrickson Tractor and 3 Rear Axle	197 kips
	HME Tractor and 2 Rear Axle	188 kips
	HME Tractor and 3 Rear Axle	204 kips
	EPT-PECS Transport Vehicle	149 kips
	w/ 3 to 9 Axle (8 various configurations)	**245 kips**
	ATLAS V 500 Series Payload Transporter	**280 kips**
	Adiitional Transport Configuration (T.E.)	147 kips
	PeaceKeeper Missile Transporter	213 kips
	1 ASTS Type-2 LTV	**291 kips**
	Type II Transporter with SR118 Payload	214 kips
	Strongback Missile Transporter	148 kips
	Liebherr LTM 6 Axle Truck and 3 Axle Dolly	171 kips
	Crane	134 kips
	Crane	163 kips
	Convoy	**385 kips**

- Standard AASHTO (HL93 Design Truck)
- Caltrans Permit Truck (CA P-15)
- Special Vandenberg AFB Vehicles







Design Methodology for Special Vehicles

- Special vehicles evaluated in Strength II combo, like permit truck
- Load Factor = 1.35
- Only one special vehicle at a time
- They close the bridge to regular traffic
- The special vehicle is the only heavy vehicle on the bridge (not combined with HL-93)

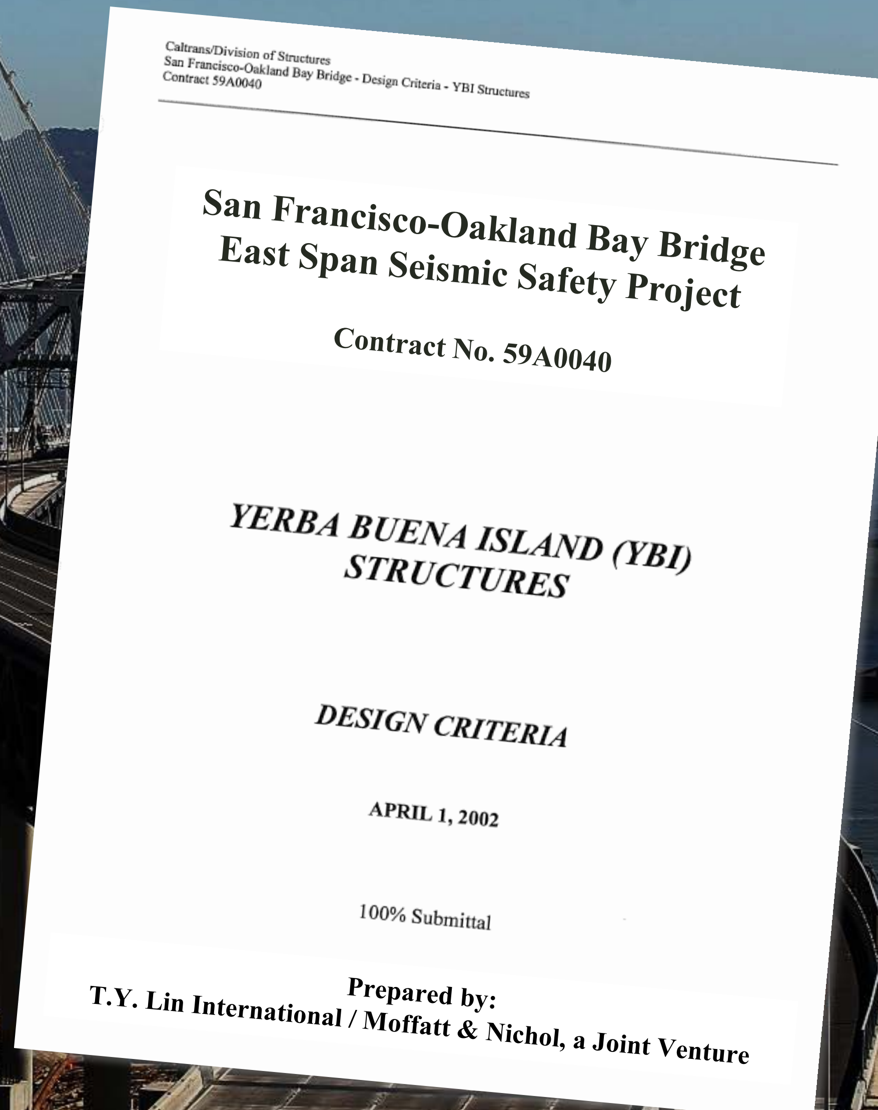
Space Shuttle Enterprise being transported to launch site in 1980's

Seismic Design Criteria

- Standard Bridge
  - Caltrans SDC v1.7
- Important Bridge
  - Project specific seismic design criteria

Seismic Design Criteria

- Keep bridge operational after design level earthquake (MCE)
- Limit ductility to 2 in piles and 3 in above ground hinges (easily inspected)
- Limit permanent deformations to 12” in substructure
- Limit settlement to 2” in foundations


Caltrans/Division of Structures
San Francisco-Oakland Bay Bridge - Design Criteria - YBI Structures
Contract 59A0040

San Francisco-Oakland Bay Bridge
East Span Seismic Safety Project

Contract No. 59A0040

YERBA BUENA ISLAND (YBI)
STRUCTURES

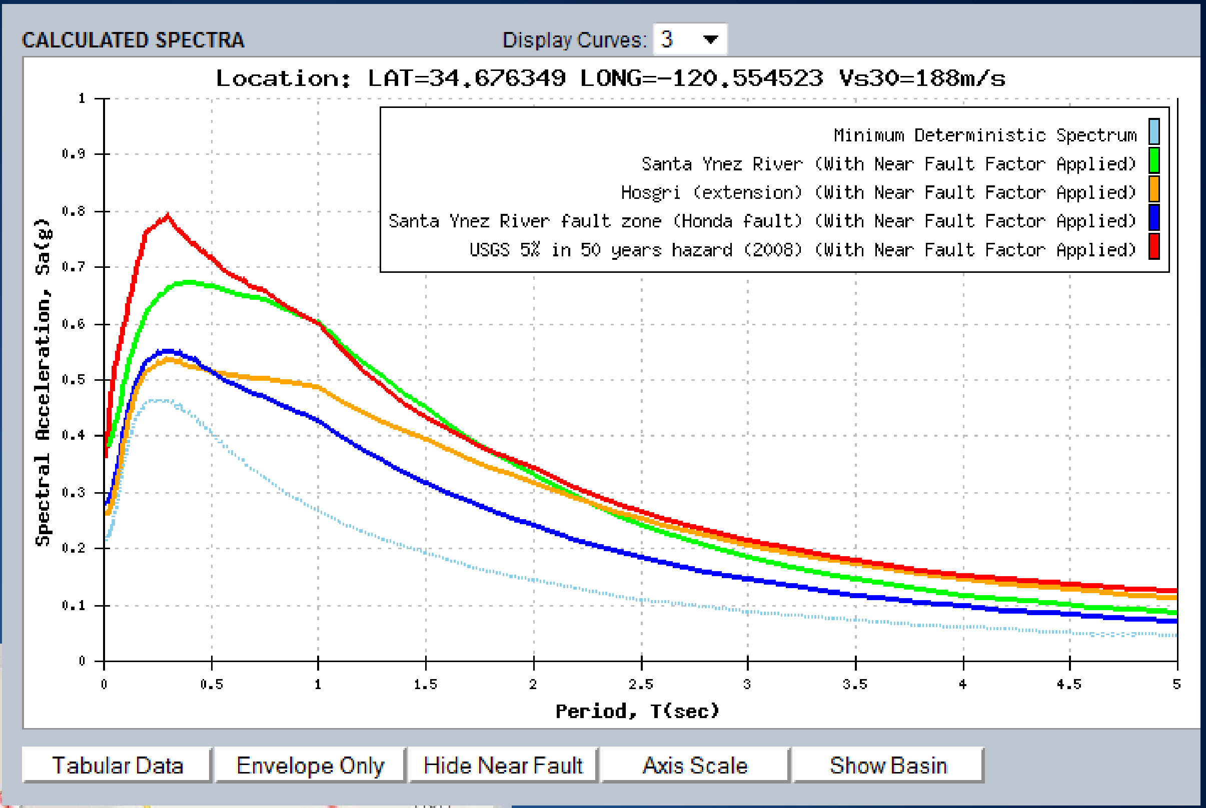
DESIGN CRITERIA

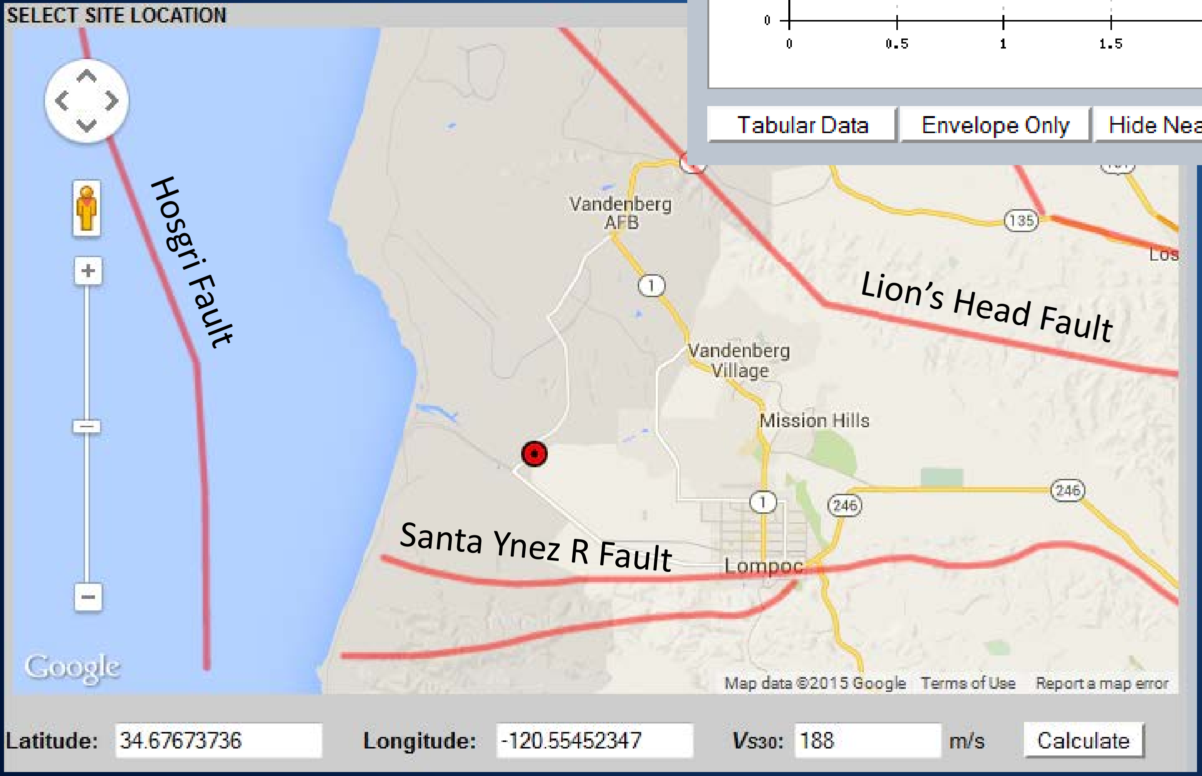
APRIL 1, 2002

100% Submittal

Prepared by:
T.Y. Lin International / Moffatt & Nichol, a Joint Venture

Seismic Loading





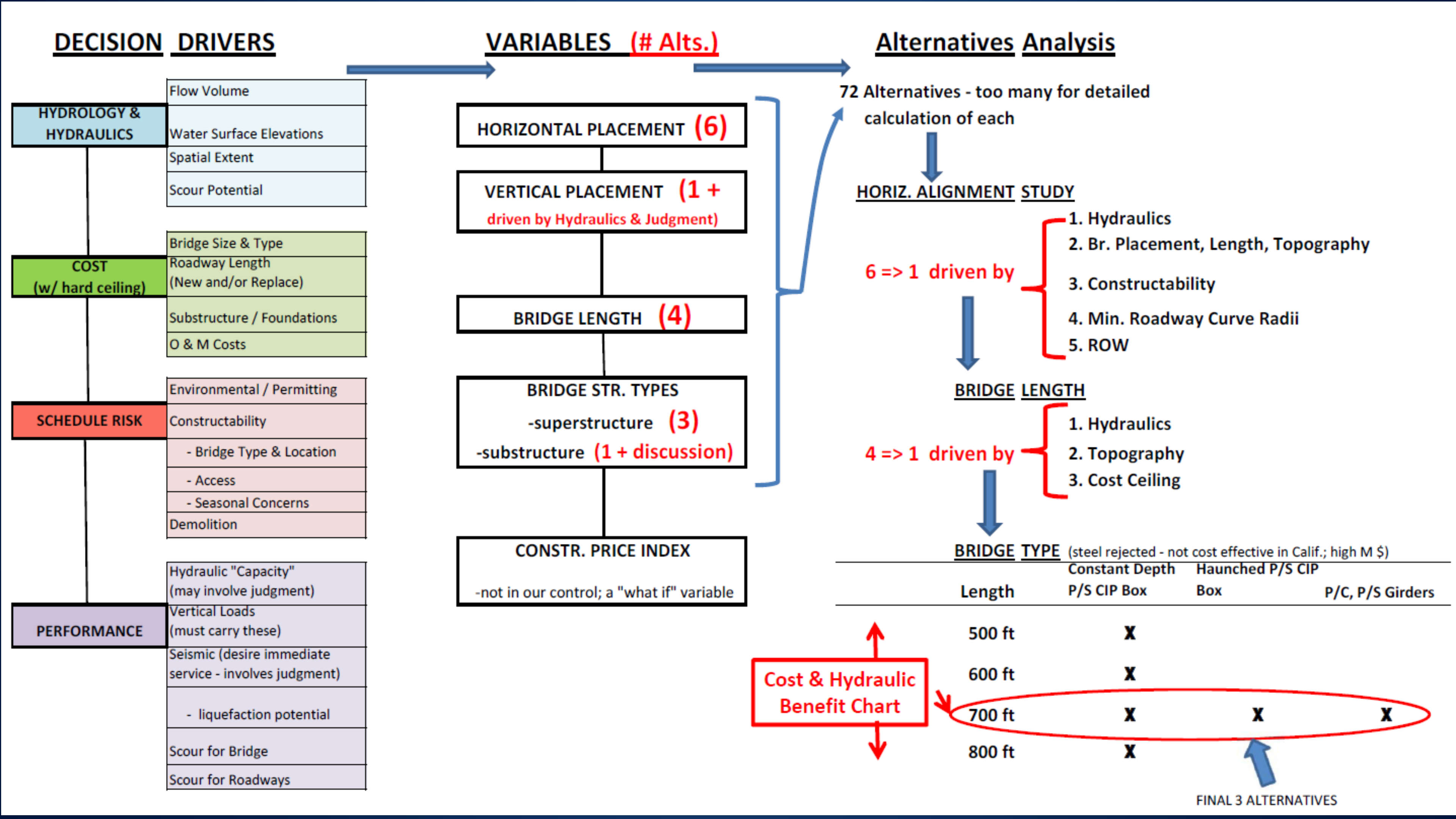
- Site-specific curve per Caltrans ARS Online
- Liquefaction accounted for with reduced shear wave velocity
- Vs30 = 188 m/s

Type, Size and Location Study

6 Alignments, 4 Bridge Lengths, 3 Bridge Types
72 Alternatives – Too Many For Detailed Analysis

LOCATION: **Horizontal Alignment**	6 => 1, Driven by: 1. Hydraulics 2. Bridge Placement & Length/ Topography 3. Constructability 4. Curve Radii Minimum 5. Right of Way
SIZE: **Bridge Length Study**	4 => 1, Driven by: 1. Hydraulics 2. Topography 3. Cost Benefit Analysis
TYPE: **Bridge Type**	3 => 1, Concrete Bridge Steel Rejected - Not cost competitive in CA - High maintenance cost

Size, Type and Location Analysis Process



Horizontal Alignments – Study Results

Alignment 1

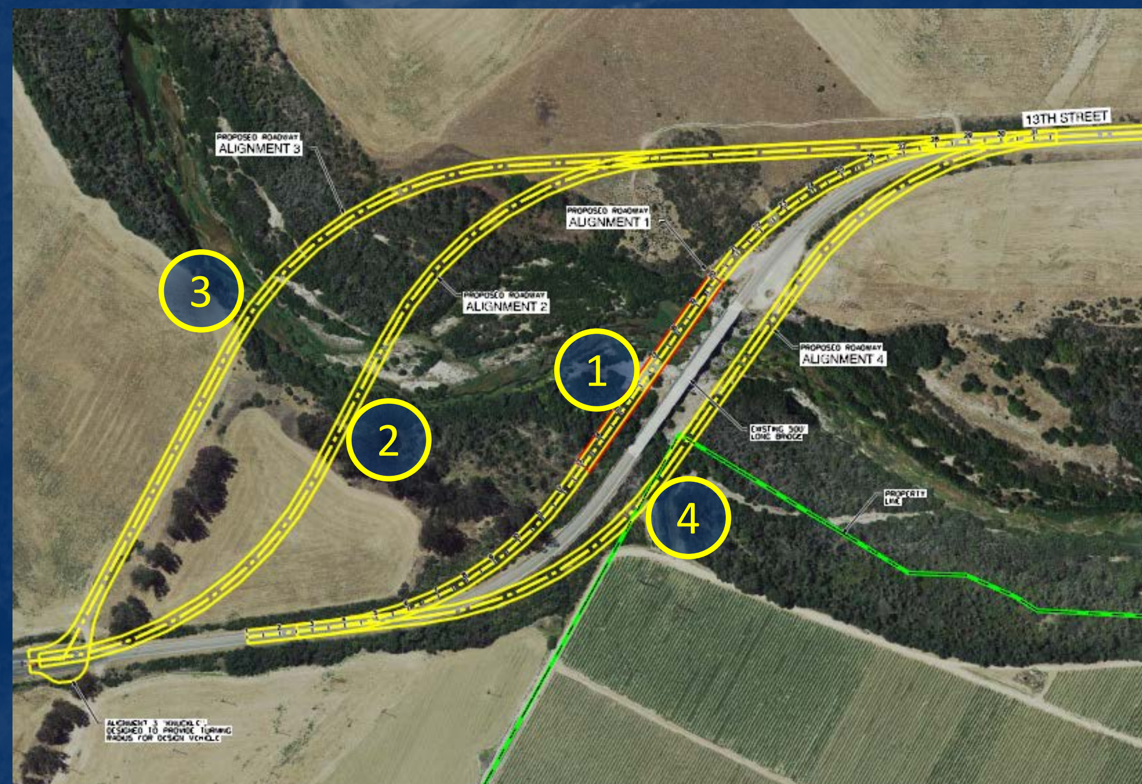
- Minimizes new approaches
- Can build new bridge and remove old bridge from same access road

Alignments 2 & 3

- Need longer bridge
- Longer approach roads
- Need two access roads

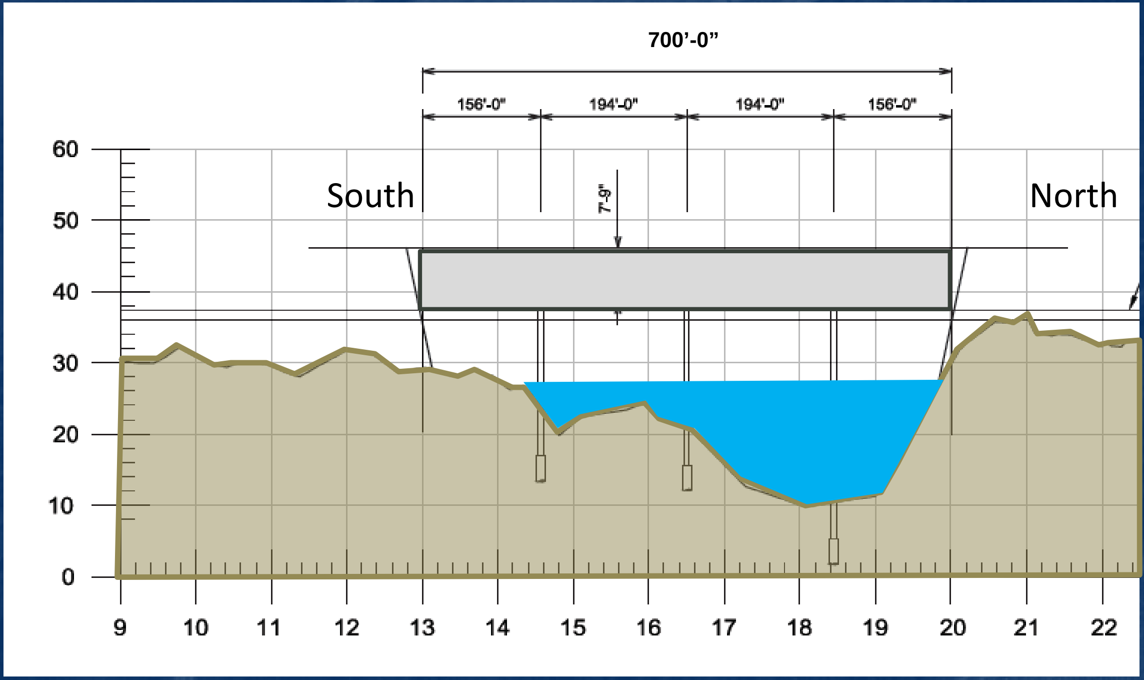
Alignment 4

- Similar to Alignment 1 but encroaches into private parcel



Bridge Length Study

- Topography to south is flat
  - No obvious place to land bridge
- Flood plain is 6,000 ft wide
- Existing bridge 500 ft long
  - Has scour issues
- Previous study estimated 700 ft long bridge
  – Budget at $19M
- Longer bridge is better hydraulically

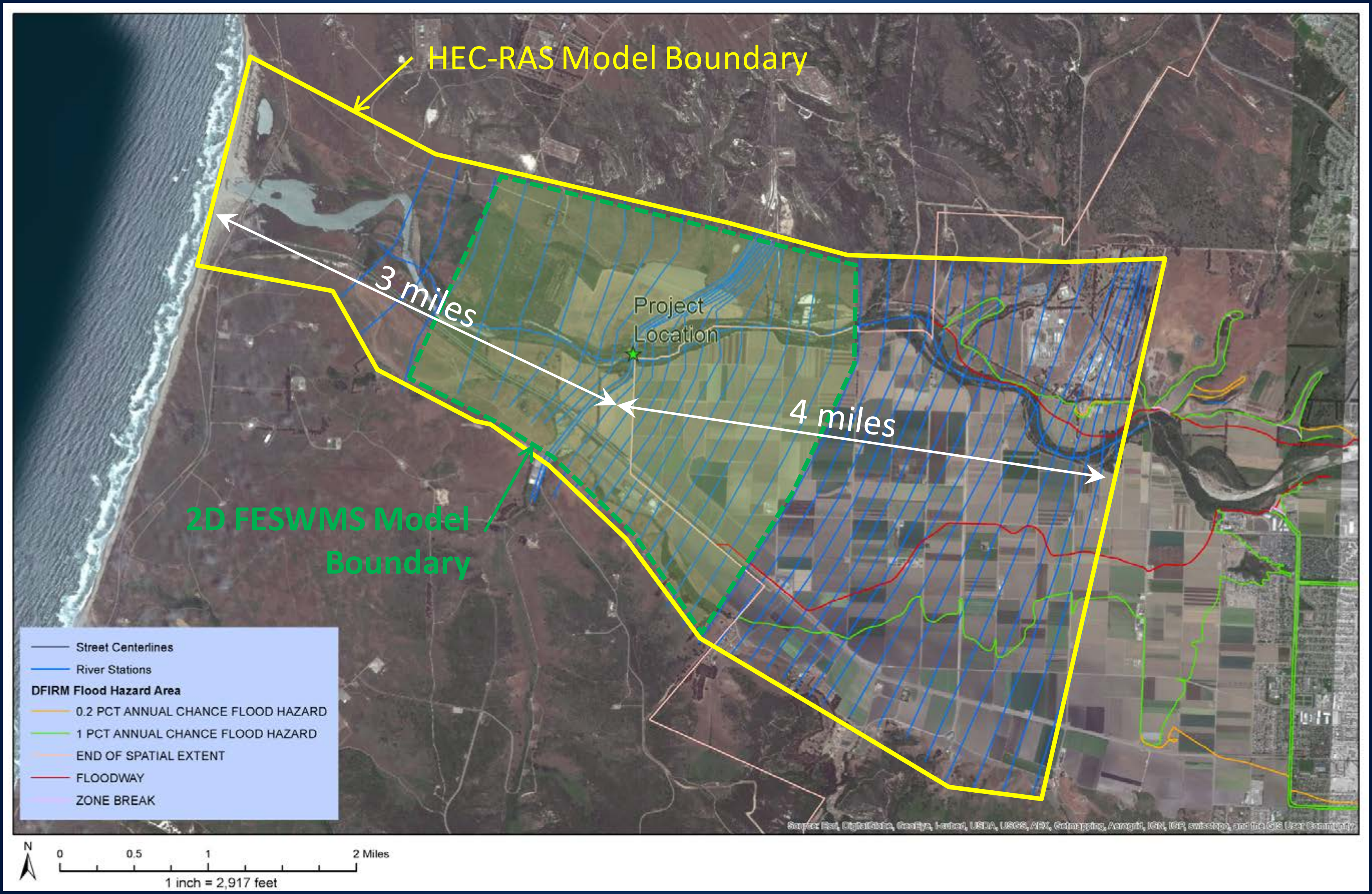


Bridge Elevation – Alignment 1

- Evaluate 500 ft, 600 ft, 700 ft and 800 ft bridges
- Length Study based on Alignment 1 and CIP/PS Box Girder (Baseline)

Hydraulic Analysis

Preliminary 1D (HEC-RAS) and 2D (FESWMS) Modeling Areas



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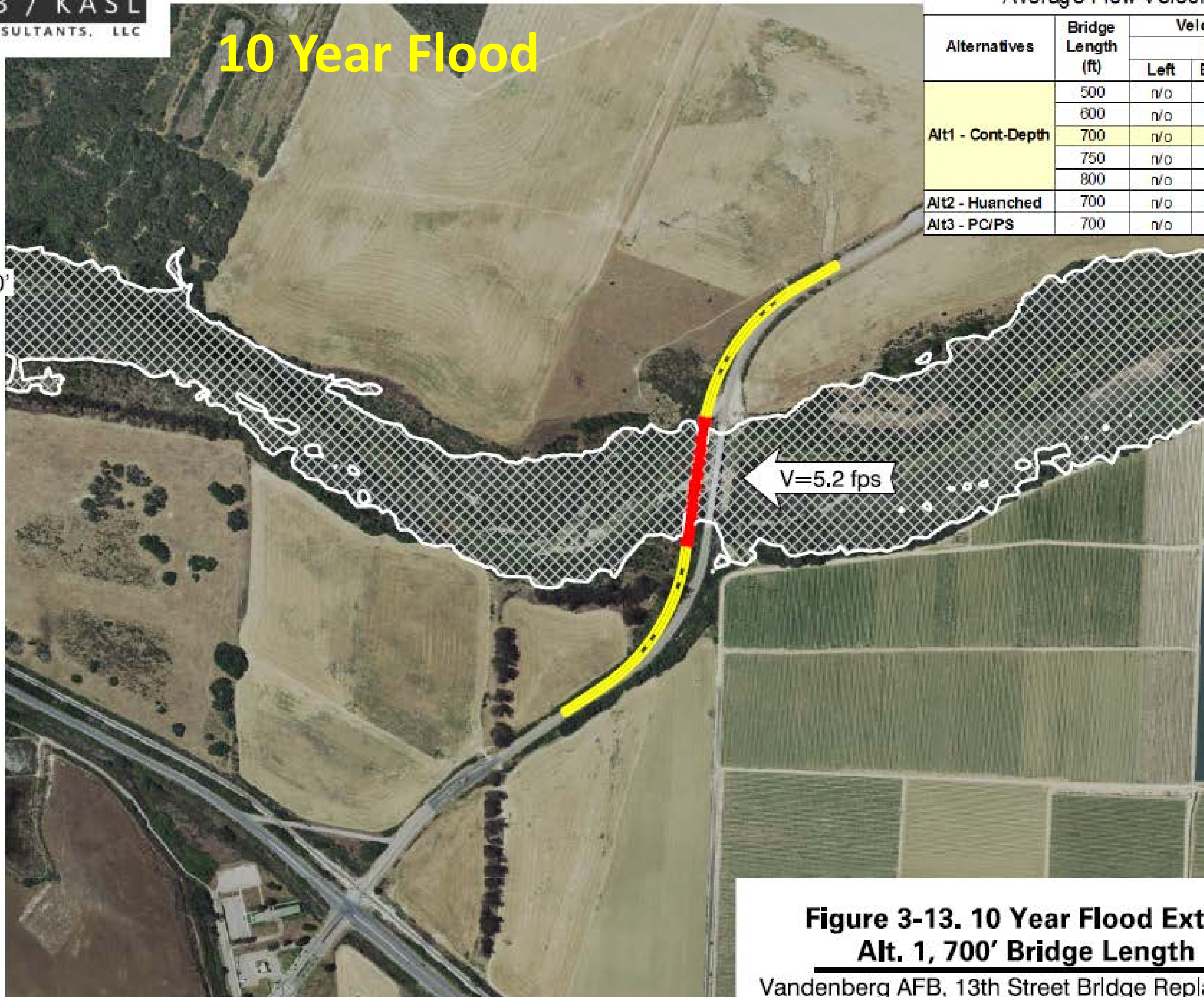
A+E CONSULTANTS, LLC



Average Flow Velocities

Alternatives	Bridge Length (ft)	Velocity (fps) 10-yr		
		Left	Bridge	Right
Alt1 - Cont-Depth	500	n/o	7.2	n/o
	600	n/o	5.8	n/o
	700	n/o	5.2	n/o
	750	n/o	5.0	n/o
	800	n/o	4.7	n/o
Alt2 - Huanched	700	n/o	5.1	n/o
Alt3 - PC/PS	700	n/o	5.4	n/o

Figure 3-13. 10 Year Flood Extent
Alt. 1, 700' Bridge Length
Vandenberg AFB, 13th Street Bridge Replacement

FILE: S:\5665-03 Vandenberg AFB Bridge\Exhibits_FIG 3-13_10 YEAR FLOOD_ALT 1.dgn
DATE: 2/20/2014

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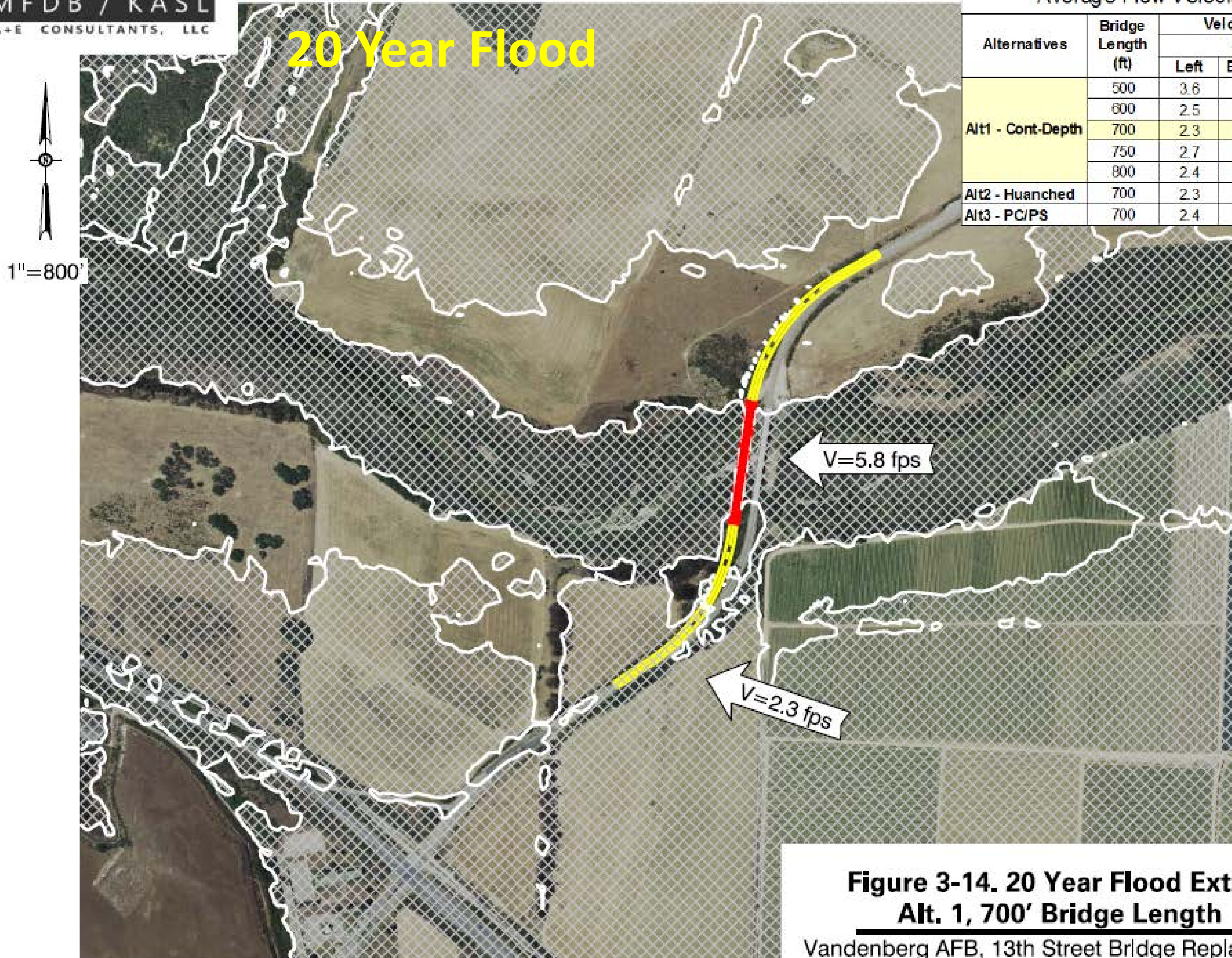

Average Flow Velocities

Alternatives	Bridge Length (ft)	Velocity (fps) 20-yr Left	Bridge	Right
Alt1 - Cont-Depth	500	3.6	7.1	n/o
	600	2.5	6.3	n/o
	700	2.3	5.8	n/o
	750	2.7	5.7	n/o
	800	2.4	5.4	n/o
Alt2 - Huanched	700	2.3	5.7	n/o
Alt3 - PC/PS	700	2.4	6.0	n/o

Figure 3-14. 20 Year Flood Extent
Alt. 1, 700' Bridge Length
Vandenberg AFB, 13th Street Bridge Replacement

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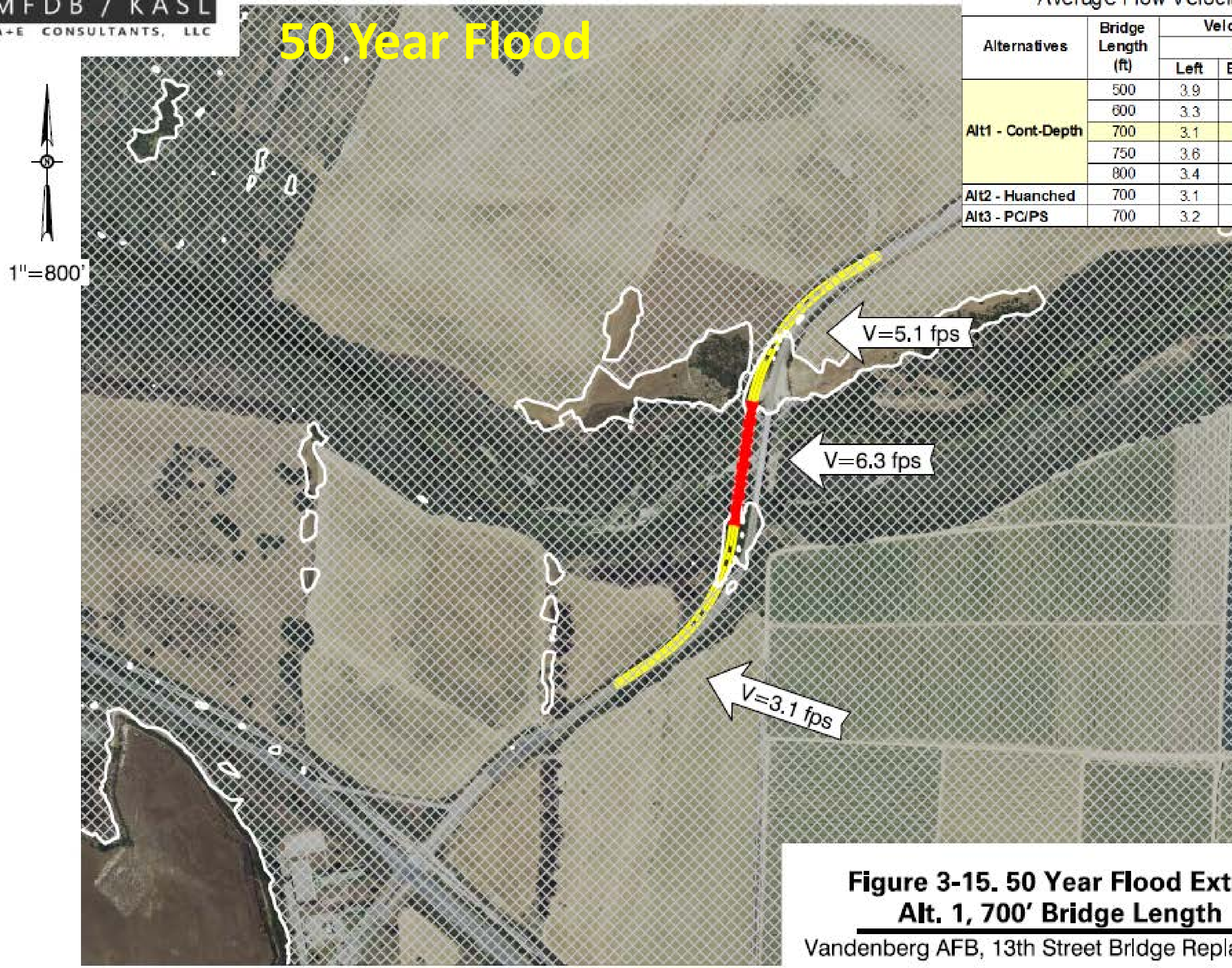

Average Flow Velocities

Alternatives	Bridge Length (ft)	Velocity (fps) 50-yr		
		Left	Bridge	Right
Alt1 - Cont-Depth	500	3.9	7.2	4.1
	600	3.3	6.6	4.0
	700	3.1	6.3	5.1
	750	3.6	5.9	4.4
	800	3.4	5.8	3.9
Alt2 - Huanched	700	3.1	6.3	4.9
Alt3 - PC/PS	700	3.2	6.3	4.1

Figure 3-15. 50 Year Flood Extent
Alt. 1, 700' Bridge Length
Vandenberg AFB, 13th Street Bridge Replacement

FILE: S:\5665-03 Vandenberg AFB Bridge\Exhibits_FIG 3-15_50 YEAR FLOOD_ALT 1.dgn
DATE: 2/20/2014

MFDB / KASL
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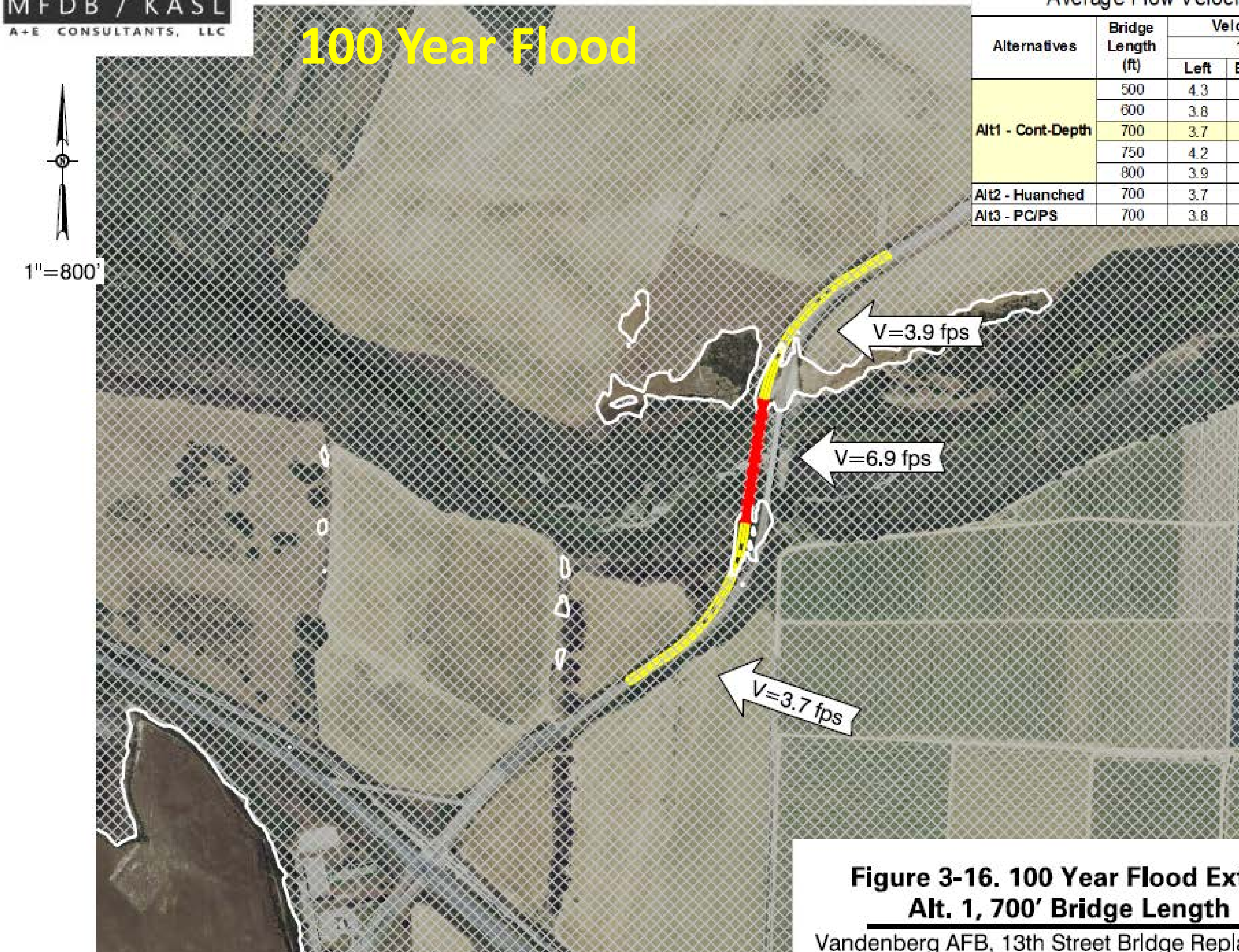


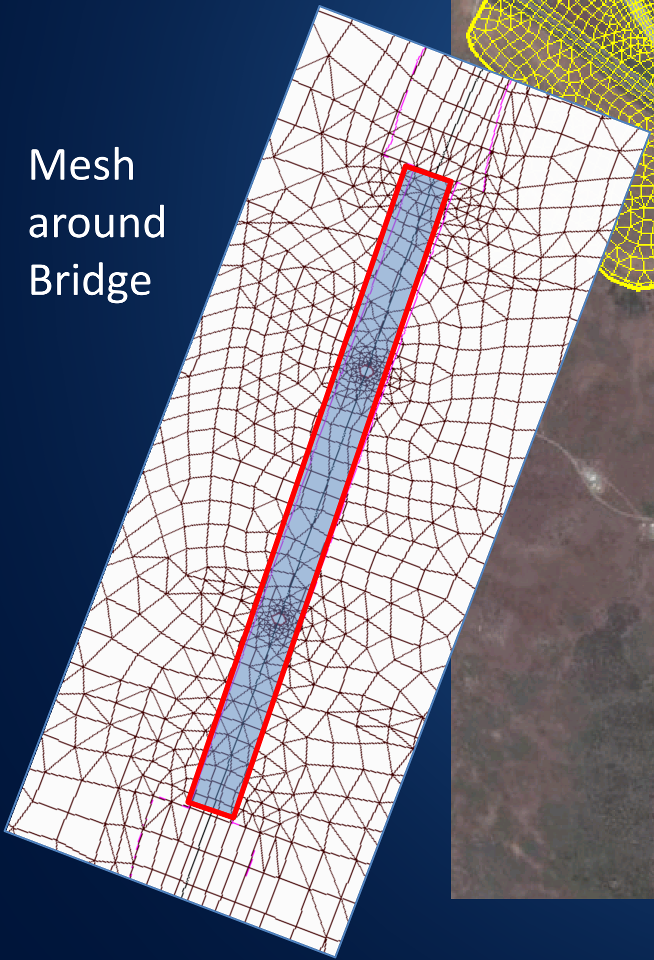
Average Flow Velocities

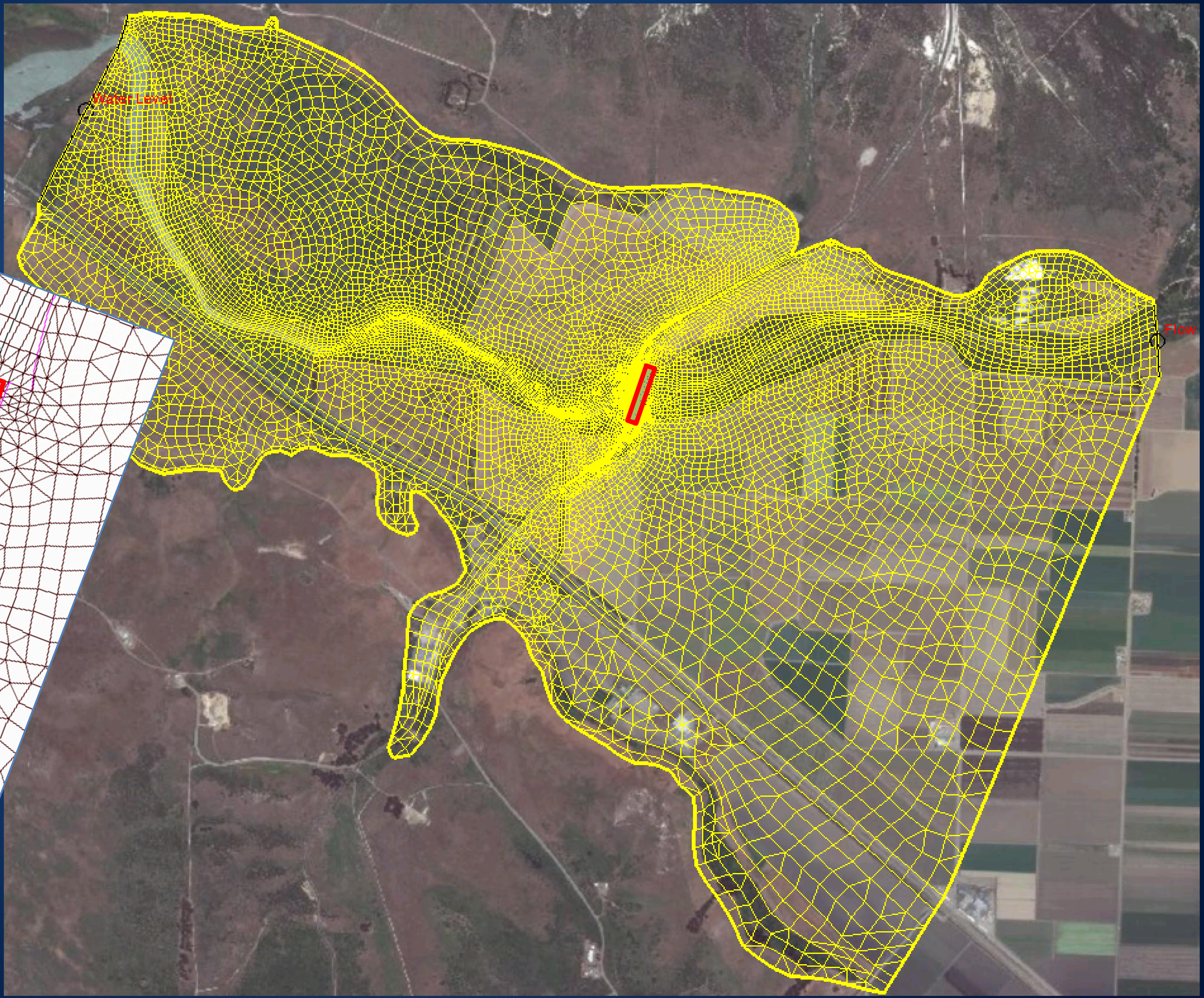
Alternatives	Bridge Length (ft)	Velocity (fps) 100-yr Left	Velocity (fps) 100-yr Bridge	Velocity (fps) 100-yr Right
Alt1 - Cont-Depth	500	4.3	7.4	4.4
	600	3.8	7.1	4.0
	700	3.7	6.9	3.9
	750	4.2	6.6	3.7
	800	3.9	6.5	3.6
Alt2 - Huanched	700	3.7	6.9	3.8
Alt3 - PC/PS	700	3.8	6.8	4.0

Figure 3-16. 100 Year Flood Extent
Alt. 1, 700' Bridge Length
Vandenberg AFB, 13th Street Bridge Replacement

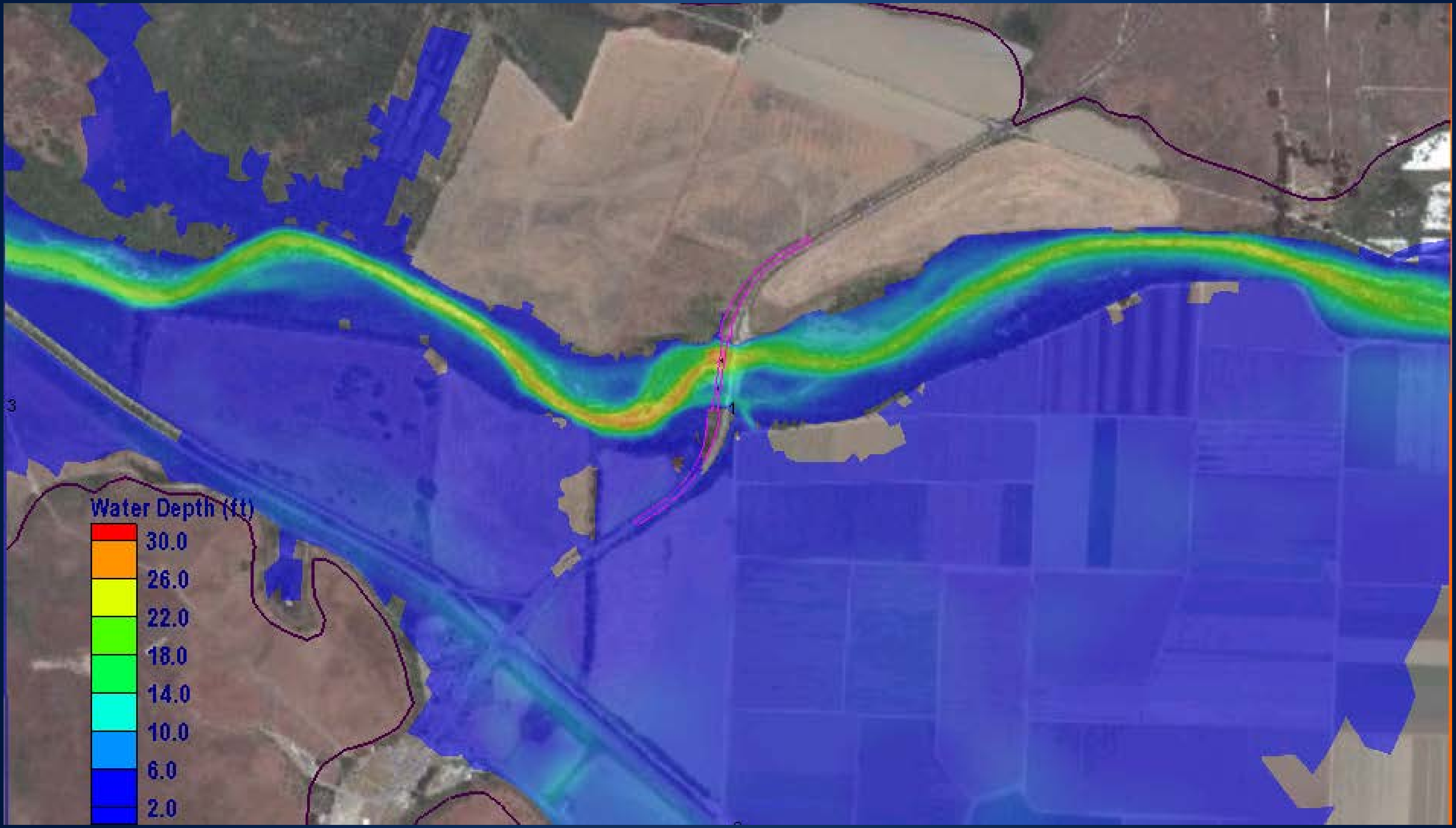
2D Hydraulic Modeling Mesh

Mesh around Bridge

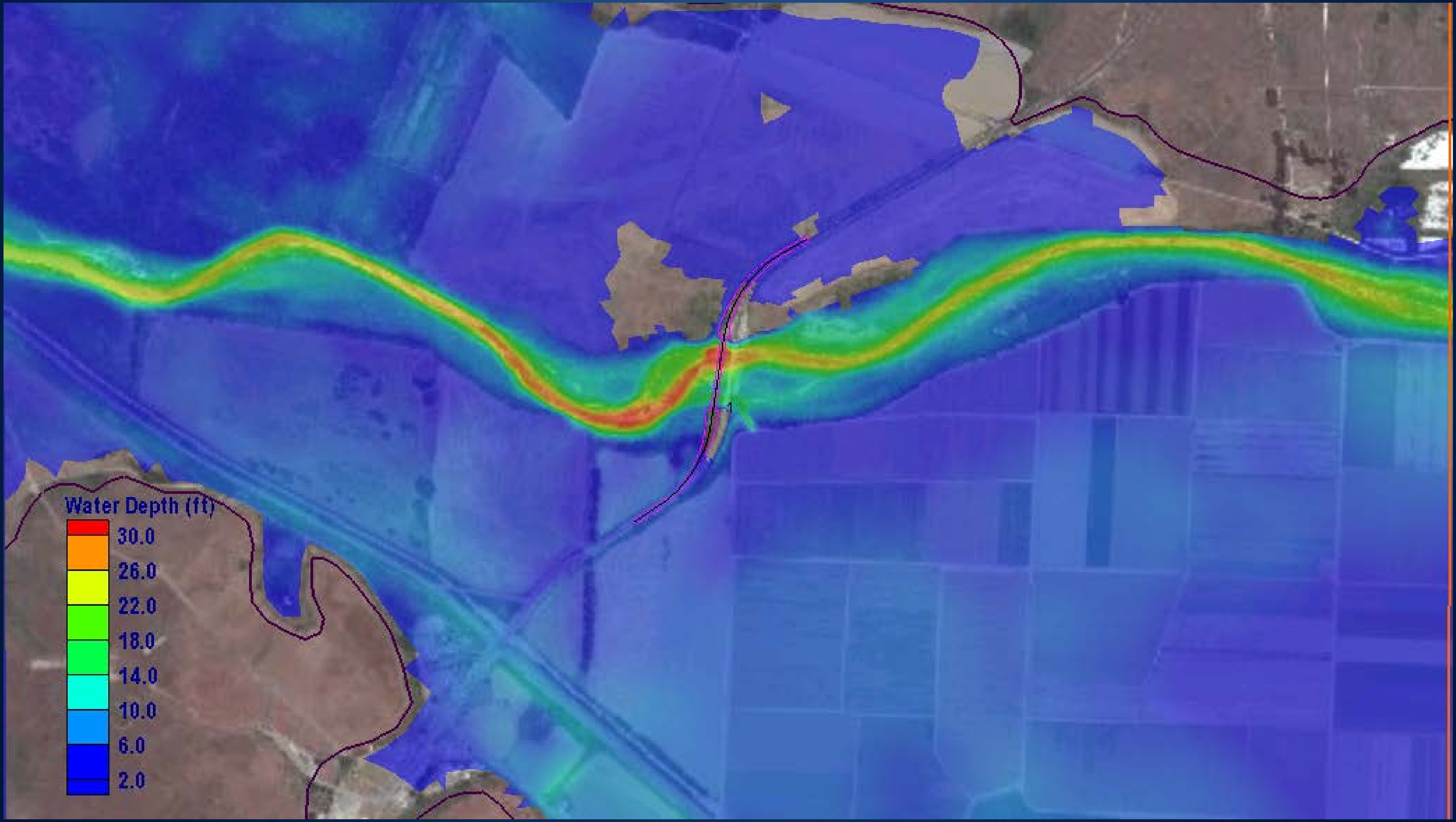




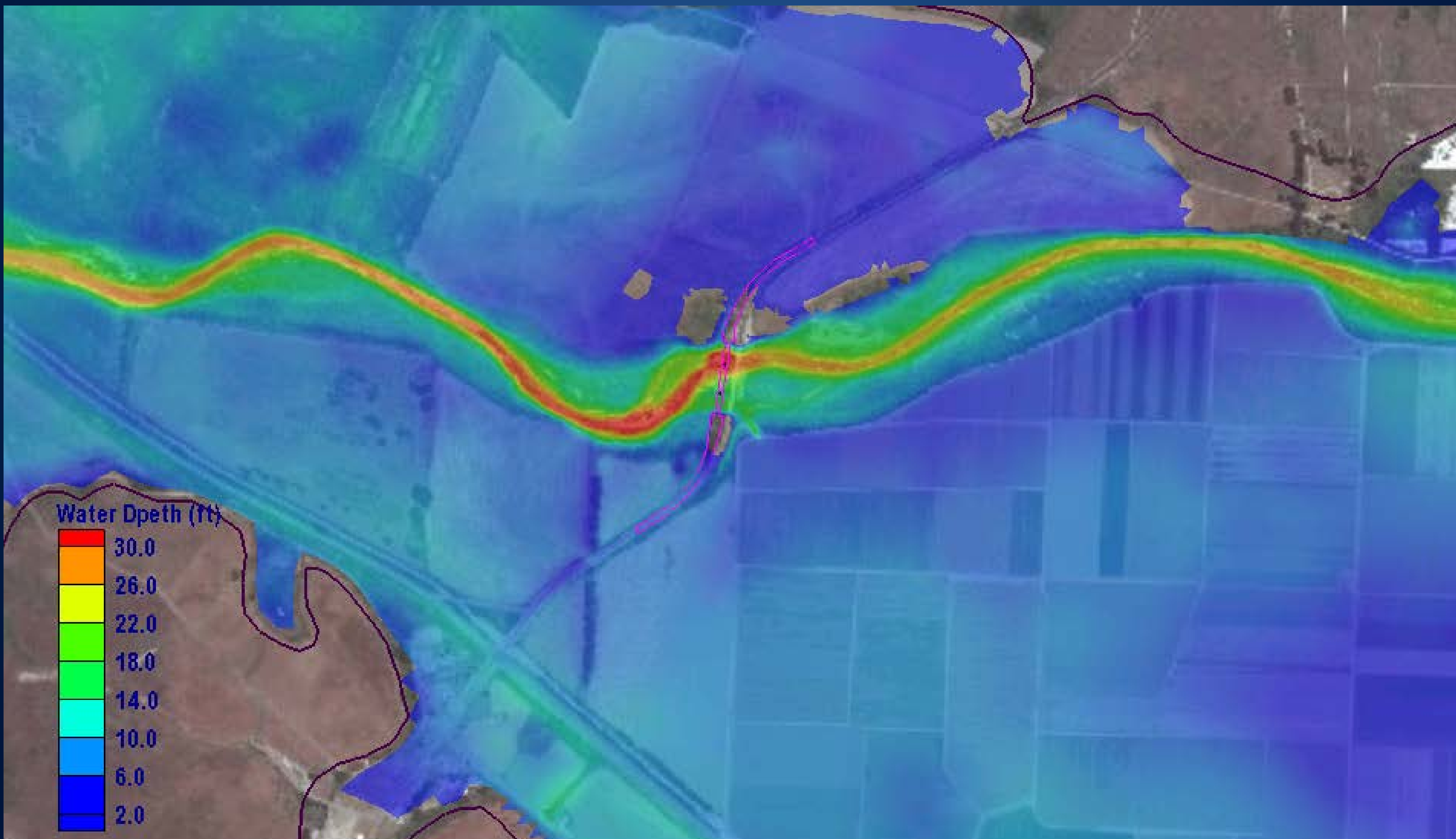
20-Year Flood Inundation Water Depth



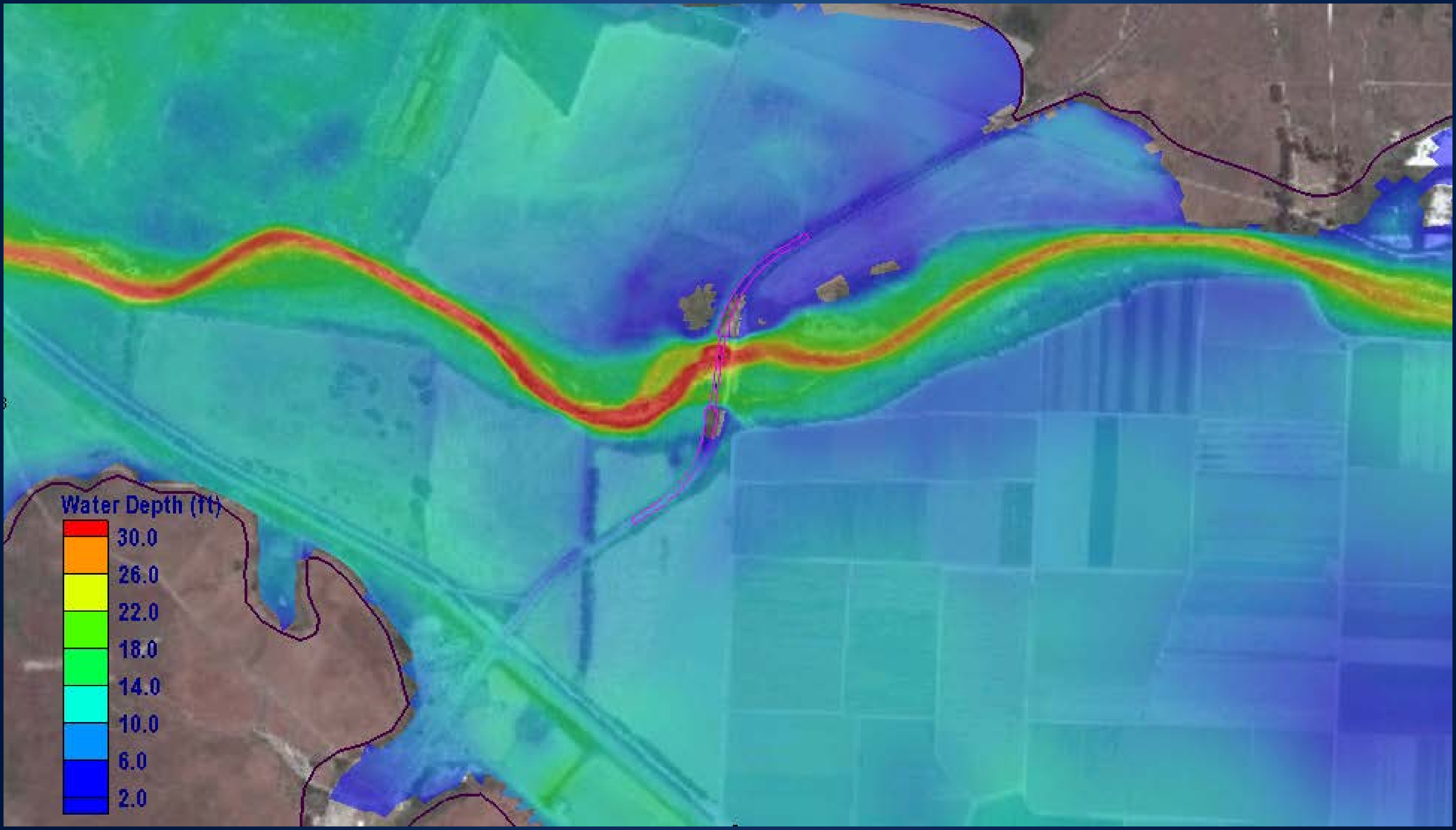
50-Year Flood Inundation
Water Depth



100-Year Flood Inundation
Water Depth



200-Year Flood Inundation
Water Depth



Hydraulic Performance

River Flow Distribution

Bridge Length	10-year Flood 27,700 cfs			15-year Flood 39,400 cfs			20-year Flood 50,000 cfs		
	South Bank	Under Bridge	North Bank	South Bank	Under Bridge	North Bank	South Bank	Under Bridge	North Bank
500’	0%	100%	0%	5%	95%	0%	24%	76%	0%
600’	0%	100%	0%	0%	100%	0%	17%	83%	0%
700’	0%	100%	0%	0%	100%	0%	14%	86%	0%
800’	0%	100%	0%	0%	100%	0%	11%	89%	0%

Bridge Length	50-year Flood 95,600 cfs			100-year Flood 146,000 cfs			200-year Flood 213,600 cfs		
	South Bank	Under Bridge	North Bank	South Bank	Under Bridge	North Bank	South Bank	Under Bridge	North Bank
500’	47%	49%	4%	50%	37%	13%	52%	28%	20%
600’	40%	57%	3%	45%	43%	12%	49%	32%	19%
700’	37%	61%	2%	42%	48%	10%	45%	37%	18%
800’	35%	63%	2%	41%	51%	10%	45%	39%	16%

Hydraulic Performance

WSE and Flow Velocity

Bridge Length	Water Surface Elevation, Feet, NAVD88					
	10-yr	15-yr	20-yr	50-yr	100-yr	200-yr
500’	30.1	32.4	33.5	36.3	37.7	39.4
600’	29.8	32.0	33.3	36.1	37.6	39.4
700’	29.6	31.8	33.0	36.0	37.4	39.3
800’	29.4	31.5	32.7	35.8	37.2	39.0
Difference: 500’ to 800’ Bridge	**0.7**	**0.9**	**0.7**	**0.5**	**0.5**	**0.4**

Bridge Length	Average Flow Velocity (fps)					
	10-yr	15-yr	20-yr	50-yr	100-yr	200-yr
500’	7.2	**7.9**	7.1	7.2	7.4	7.3
600’	5.8	6.7	6.3	6.6	**7.1**	6.9
700’	5.2	6.0	5.8	6.3	**6.5**	6.5
800’	4.7	5.4	5.4	5.8	**6.5**	6.9
Difference: 500’ to 800’ Bridge	**35%**	**32%**	**24%**	**19%**	**12%**	**5%**

Hydraulic Performance

Scour Depth

Bridge Length	Scour Depth per HEC-18		
	South Abutment	Piers	North Abutment
500’	29’	28’	29’
600’	25’	25’	25’
700’	23’	24’	22’
800’	20’	21’	19’
Difference between 500’ and 800’ Bridge Lengths	**9’**	**7’**	**10’**

Construction Cost vs. Bridge Length

(Baseline CIP/PS Box Girder Bridge)

Bridge Length	Bridge Cost	Roadway and Fill	Rock Slope Protection	Contractor Markups	Total Construction Cost
500’	$8,200,000	$3,500,000	$2,400,000	$2,000,000	**$16,100,000**
600’ (+20%)	$9,600,000	$3,300,000	$2,100,000	$2,100,000	**$17,100,000** (+7%)
700’ (+40%)	$11,000,000	$3,100,000	$1,900,000	$2,200,000	**$18,200,000** (+13%)
800’ (+60%)	$12,400,000	$3,000,000	$1,800,000	$2,200,000	**$19,400,000** (+20%)

Bridge Type Study

Bridge Length	Constant Depth CIP/PS Box Girder (Baseline Bridge)	Haunched CIP/PS Box Girder	PC/PS Girders
500’	✓	—	—
600’	✓	—	—
700’	✓	✓	✓
800’	✓	—	—

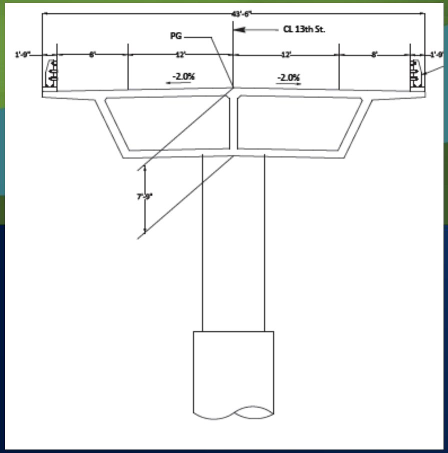
15% Design

Shaft Foundations

CIDH Piles

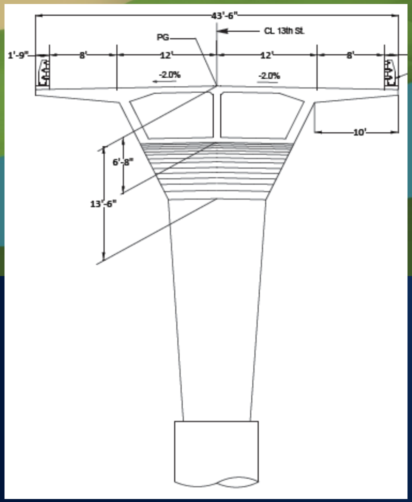
- 8 to 10 ft diameter
- 165 to 185 ft long
- Easily penetrate top 80 ft of poor soil
- Stable even when exposed
- Robust for scour and liquefactions

Alt 1 – Constant Depth CIP/PS Box Four Span



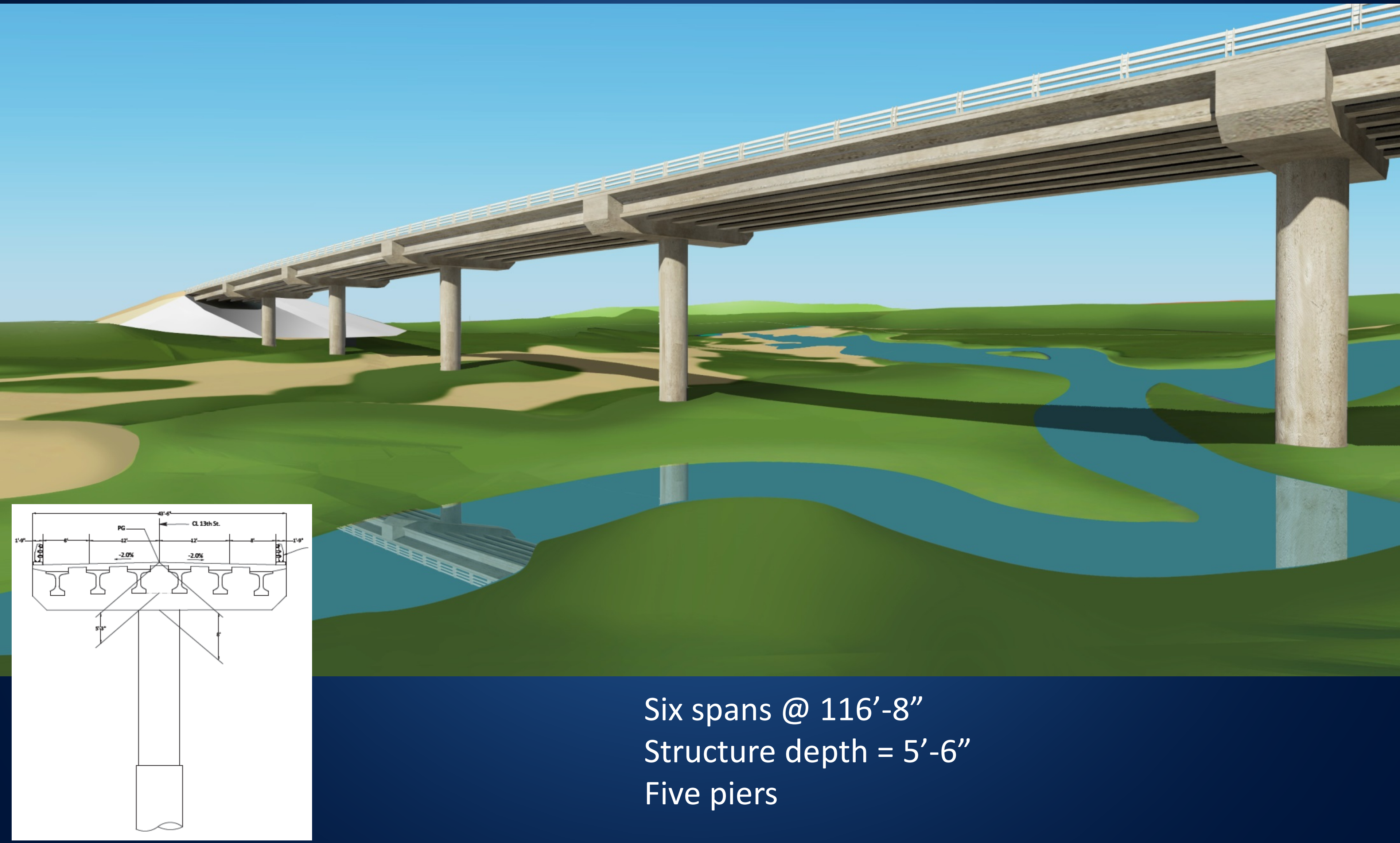
Four spans = 156’, 194’, 194’, 156’
Structure depth = 7’-9”
Three piers

Alt 2 – Haunched CIP/PS Box
Three Span



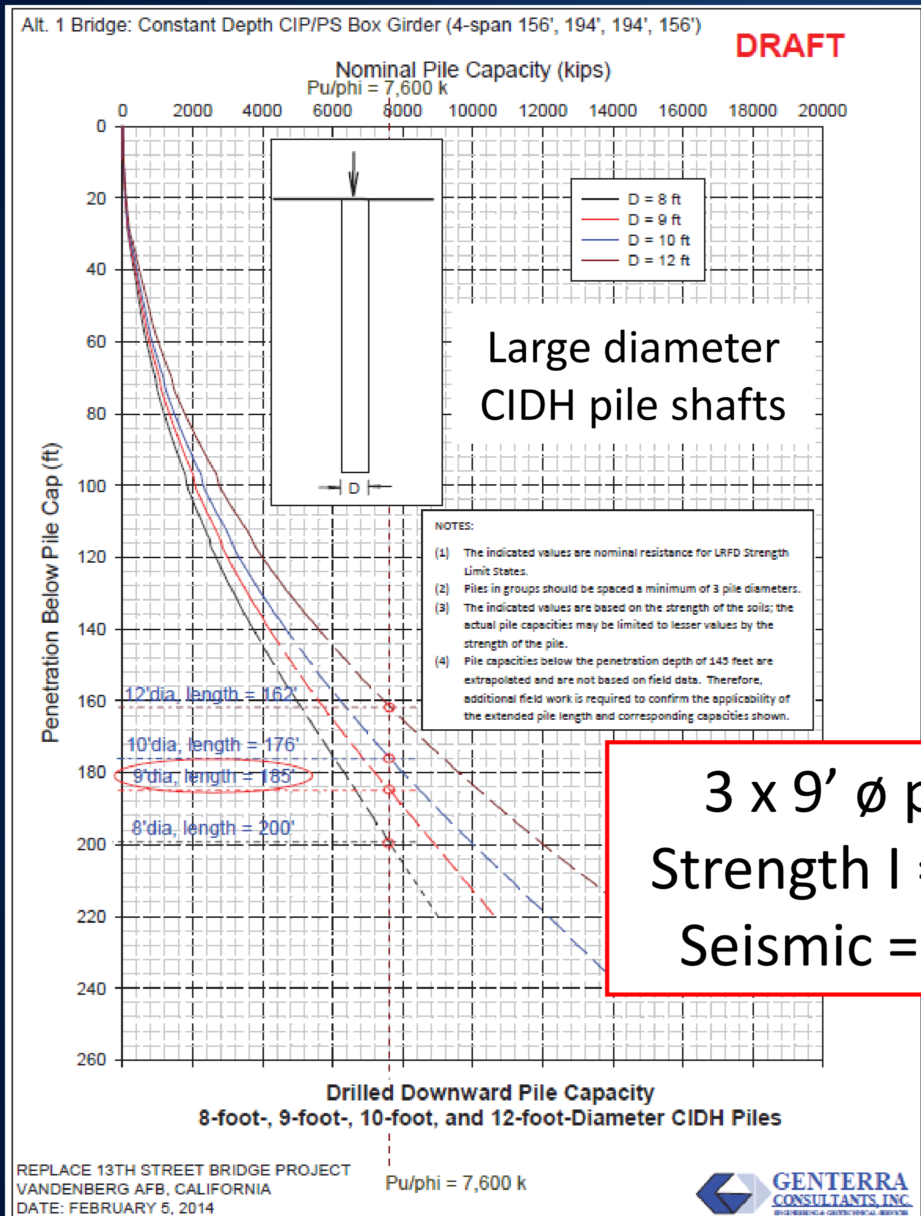
Three spans = 215’, 270’, 215’
Structure depth = 6’-9” min, 13’-6” max
Only two piers

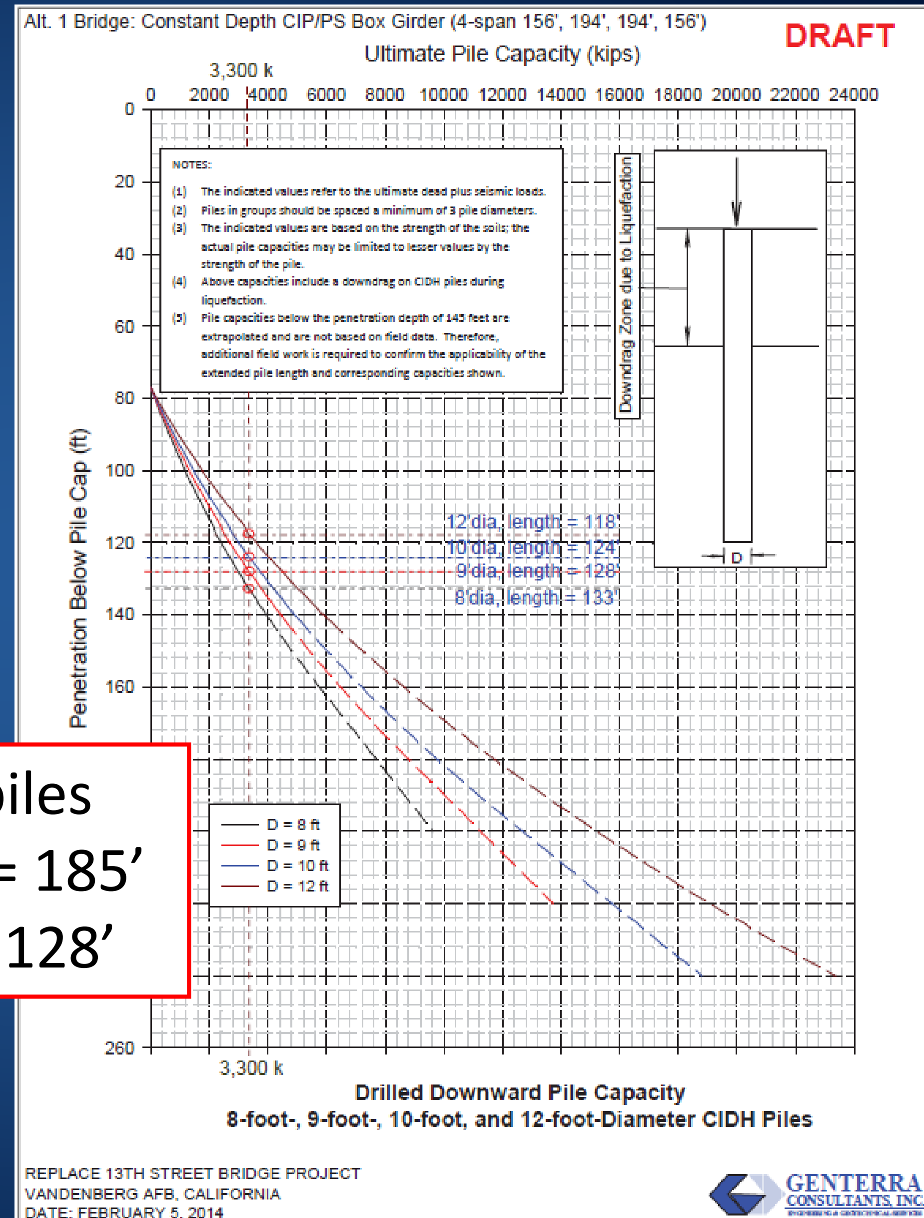
Alt 3 – PC/PS Bulb-Tee Girder
Six Span



Six spans @ 116'-8"
Structure depth = 5'-6"
Five piers

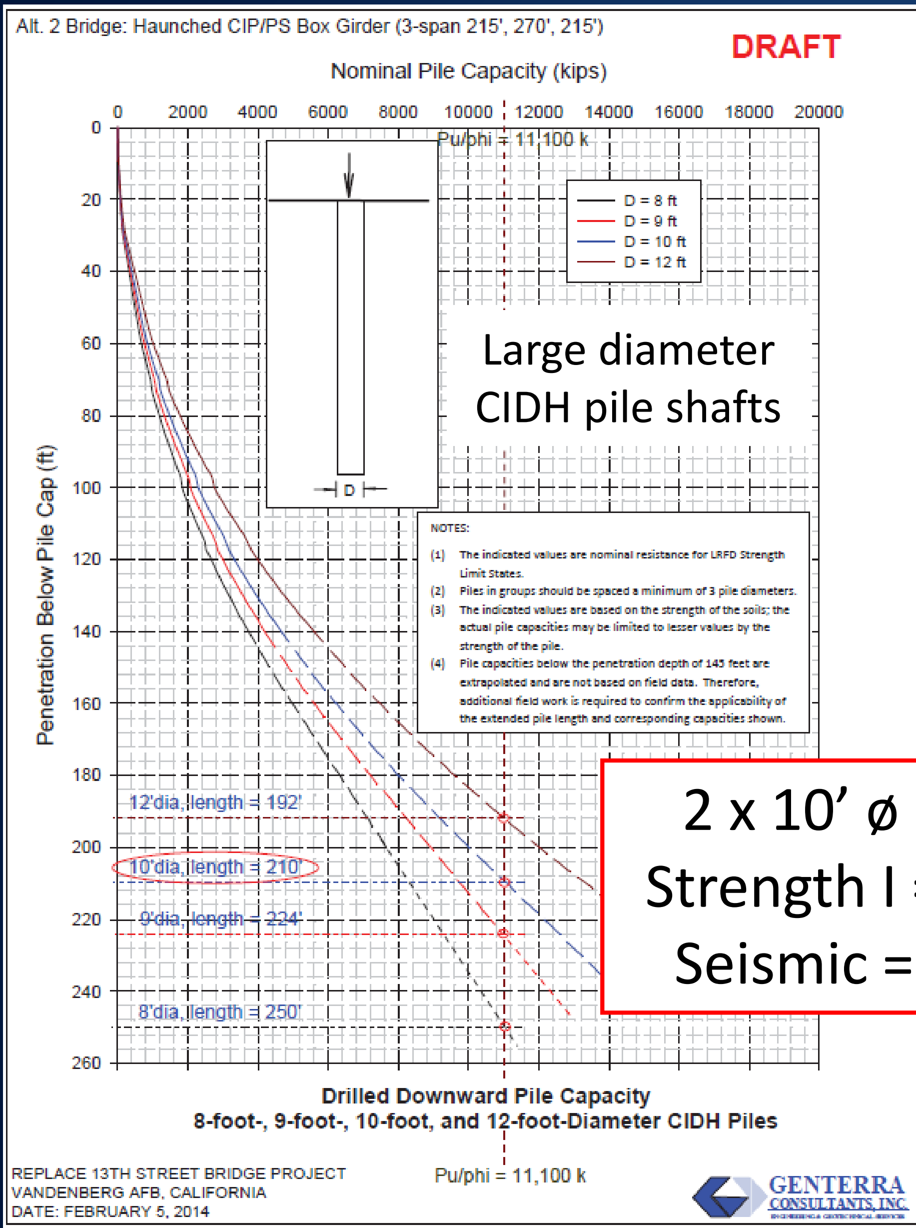
Alt 1 – 750’, 4 Span, CIP/PS Box Girder

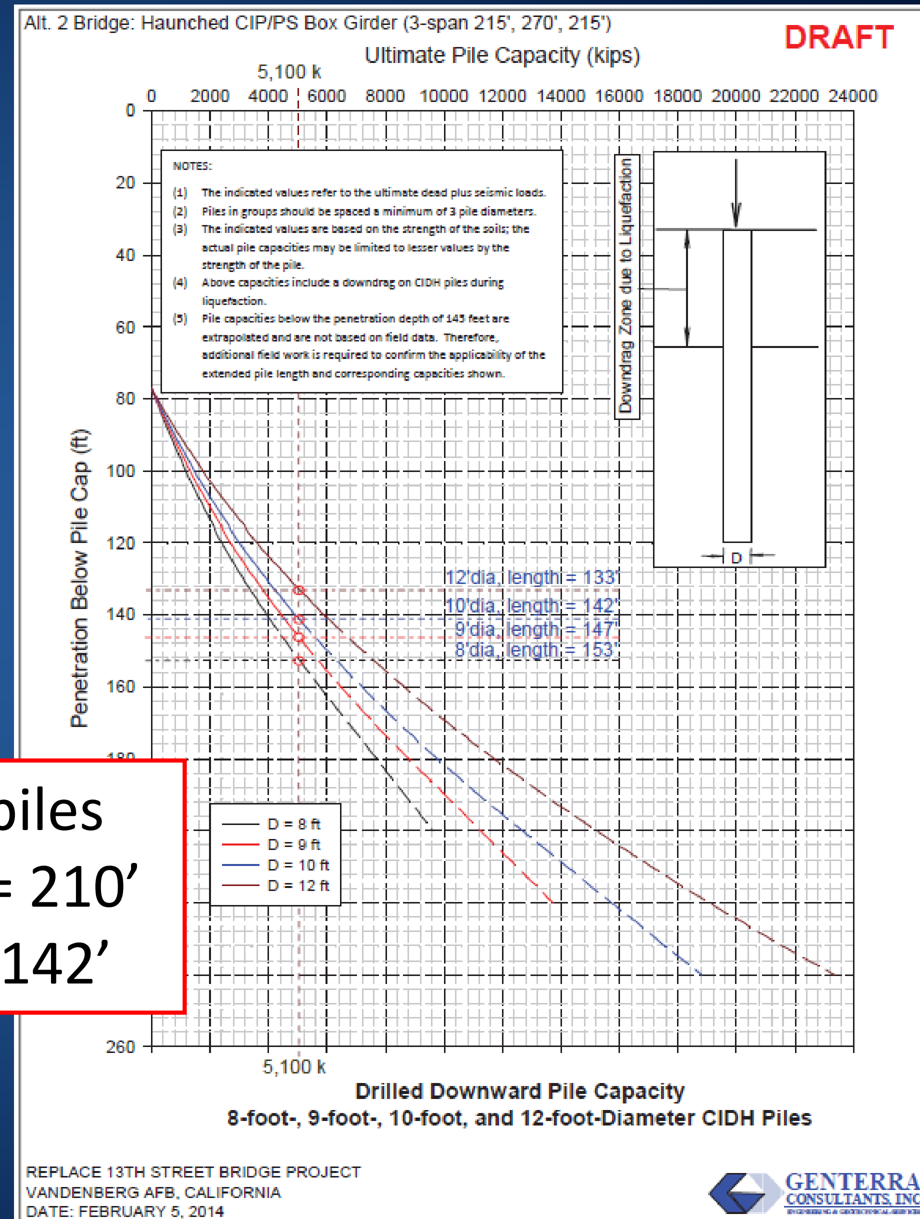




3 x 9’ ø piles
Strength I = 185’
Seismic = 128’

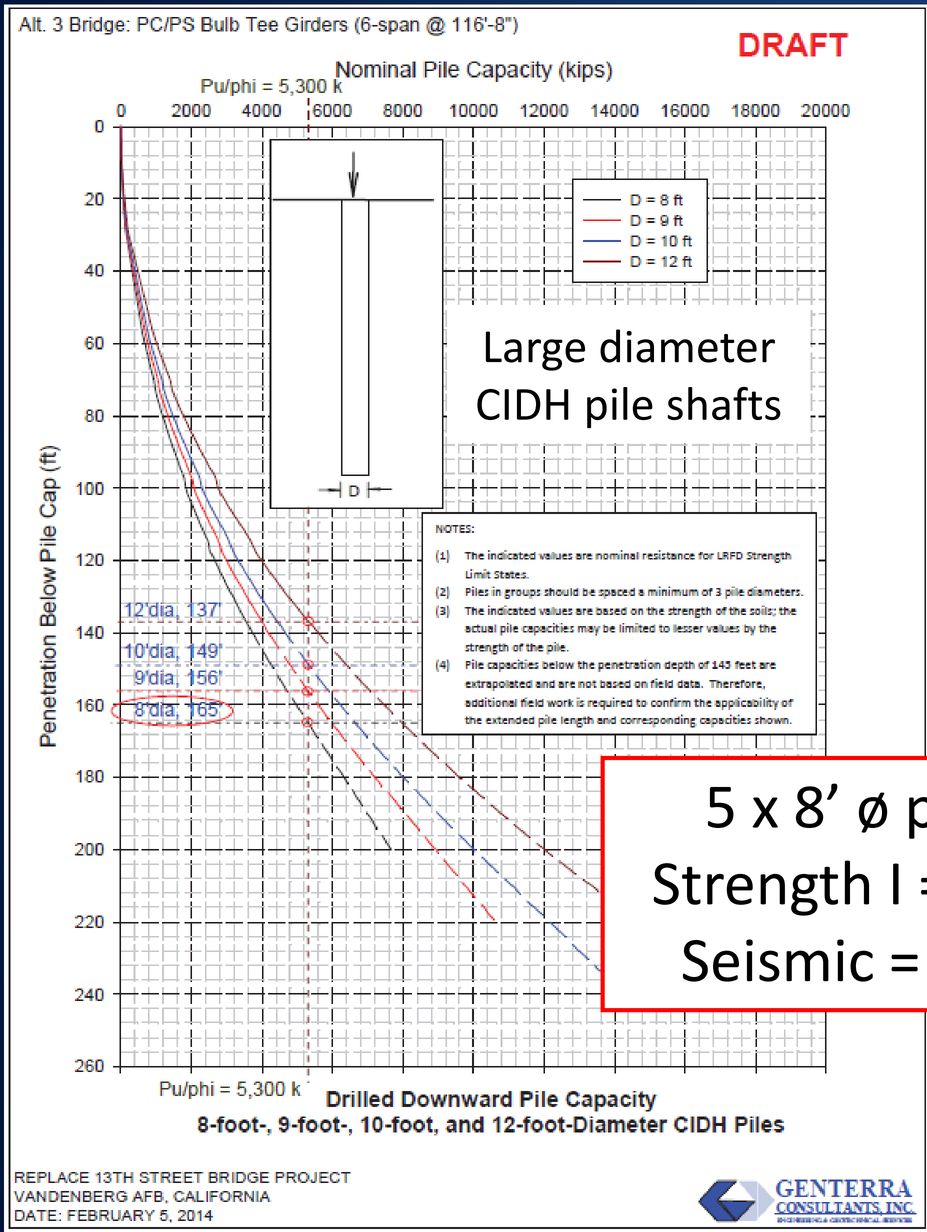
Alt 2 – 750', 3 Span, CIP/PS Haunched Box

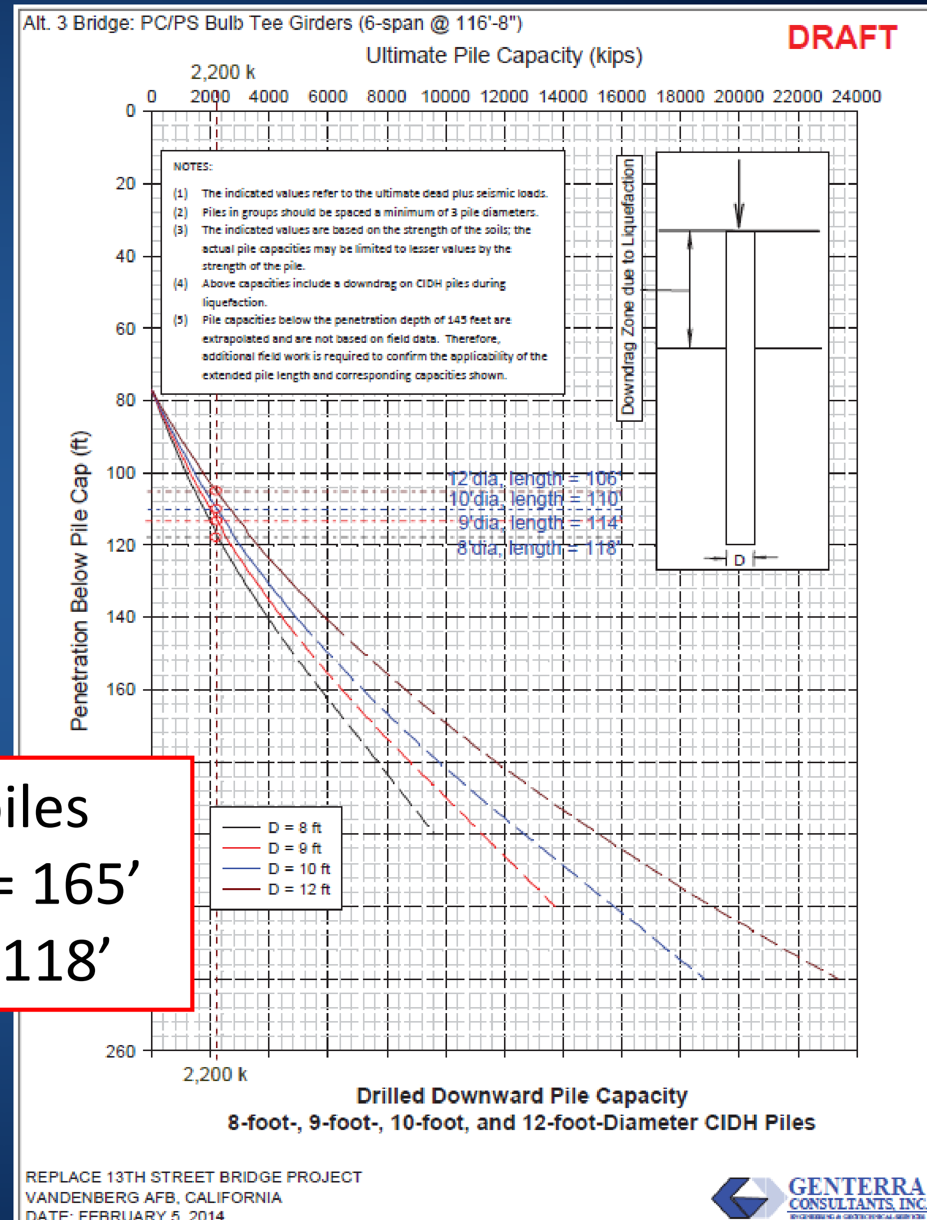




2 x 10' ø piles
Strength I = 210'
Seismic = 142'

Alt 3 – 750', 6 Span, PC/PS Bulb-Tees

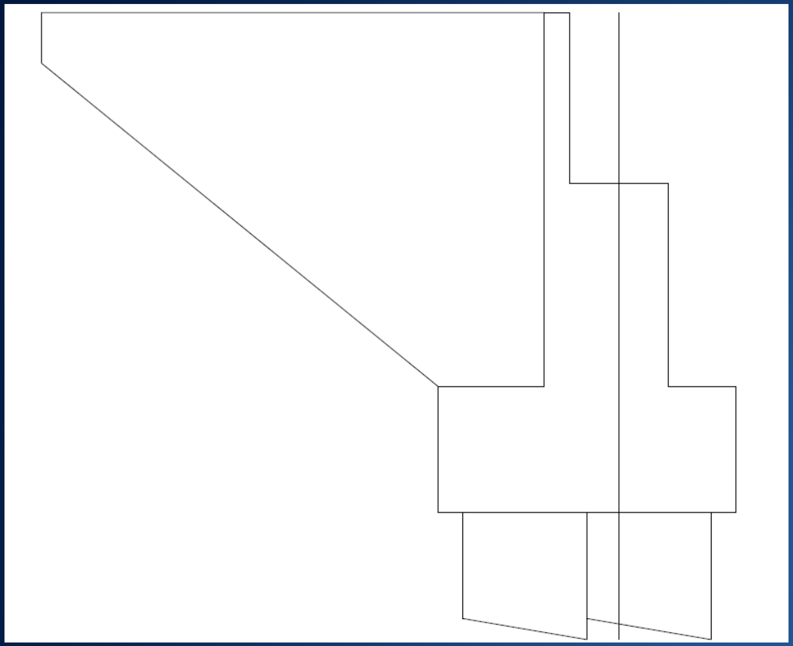


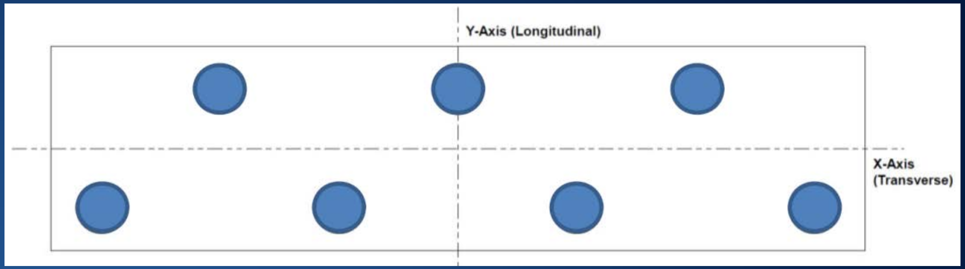


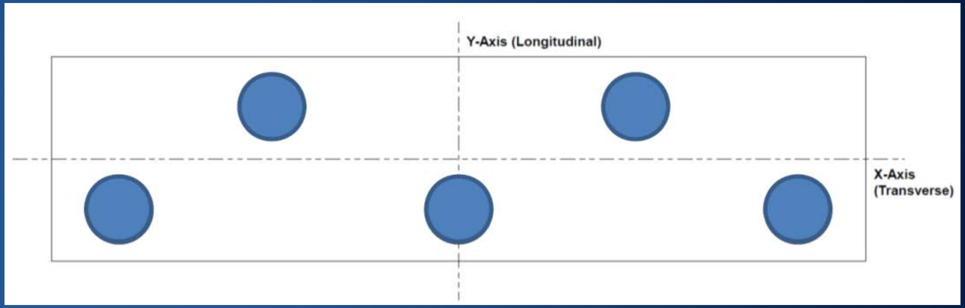
Large diameter CIDH pile shafts

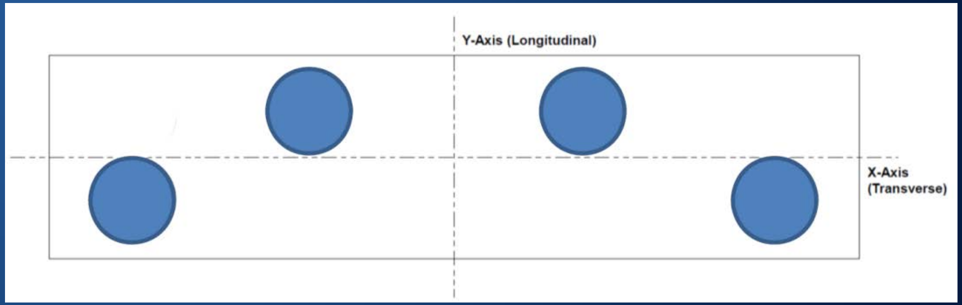
5 x 8' ø piles
Strength I = 165'
Seismic = 118'

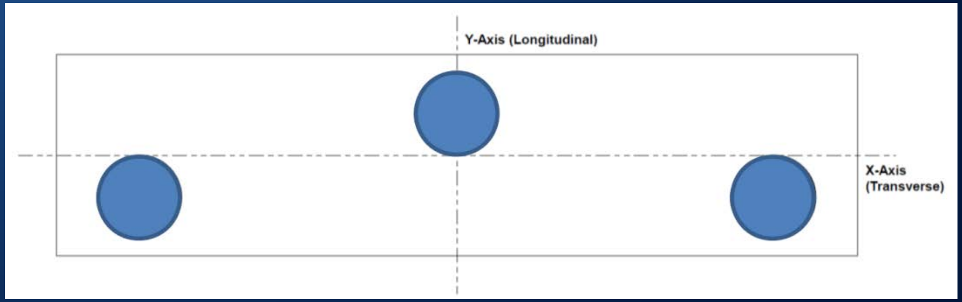
Abutments – CIDH Pile Study











700’ long Bridge

7 x 3’ ø piles, 80’ long
5 x 4’ ø piles, 90’ long
4 x 5’ ø piles, 100’ long
3 x 5.5’ ø piles, 110’ long

Construction Cost vs. Bridge Type

(700 ft Long Bridge)

Bridge Type	Spans	Bridge Cost	Roadway and Fill	Rock Slope Protection	Contractor Markups	Total Construction Cost
Alt 1 CIP/PS Box	**4**	$11,000,000	$3,100,000	$1,900,000	$2,200,000	**$18,200,000**
Alt 2 Haunched Box	**3**	$10,600,000	$3,100,000	$1,900,000	$2,200,000	**$17,800,000** (-$400k)
Alt 3 PC/PS Girders	**6**	$12,600,000	$3,100,000	$1,900,000	$2,300,000	**$19,900,000** (+$1.7M)

Maintenance Costs

Alt 1 CIP/PS Box Girder, Four-Span

Item	Frequency (years)	No. Times in 75 years	Quantity	Units	Unit Cost	Cost Ea. Time	Cost over 75 years
Repair spalls in bridge deck	30	2	70	CF	$ 150	$ 10,500	$ 21,000
Overlay bridge deck with methacrylate	30	2	28,000	SF	$ 1.25	$ 35,000	$ 70,000
Repair cracks and spalls on girder flanges	30	2	-	CF	$ 300	$ -	$ -
Remove debris accumulation from piers	5	15	3,000	CF	$ 5.00	$ 15,000	$ 225,000
						Total =	$ 316,000

Alt 2 CIP/PS Haunched Box Girder, Three-Span

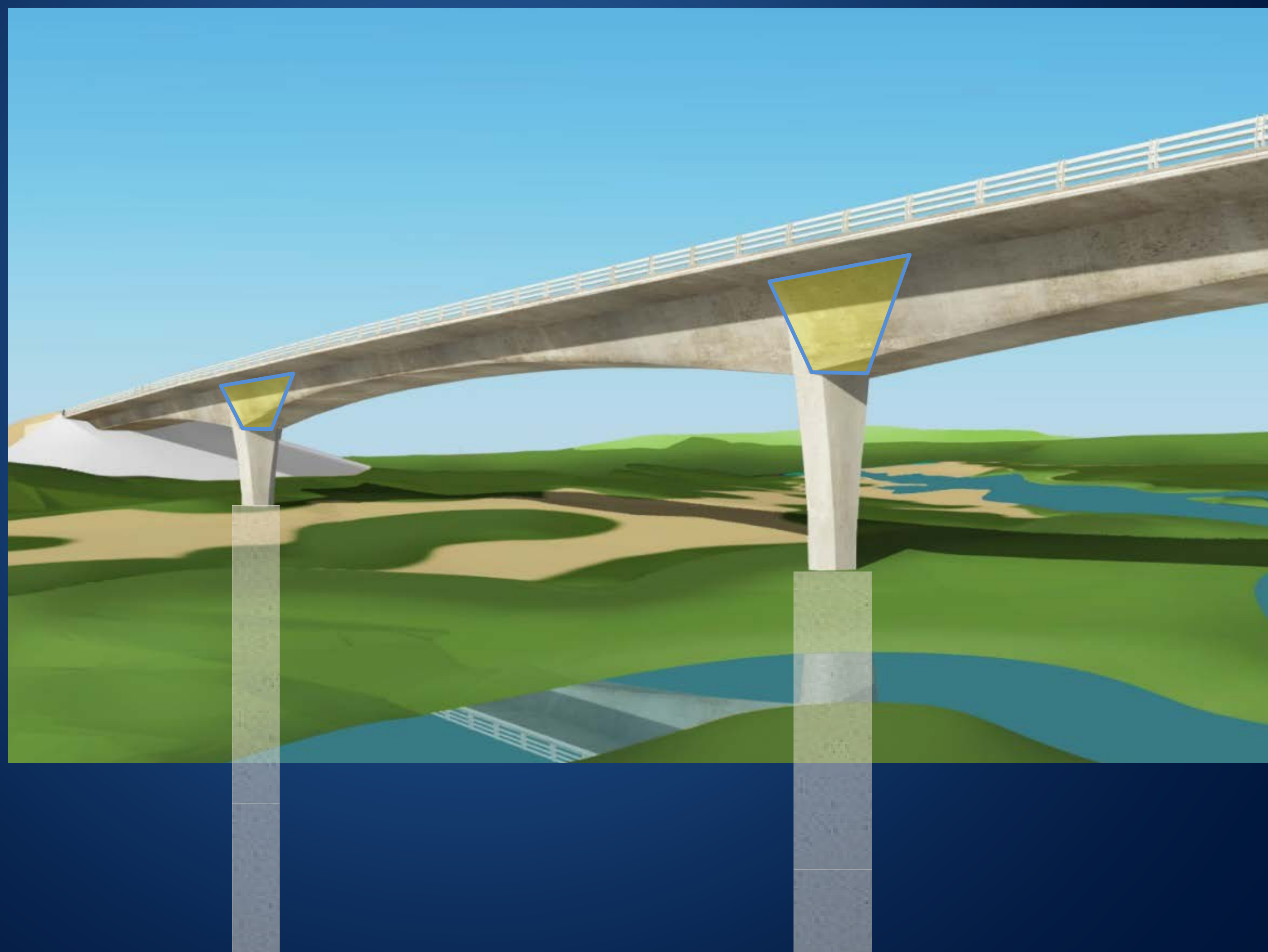
Item	Frequency (years)	No. Times in 75 years	Quantity	Units	Unit Cost	Cost Ea. Time	Cost over 75 years
Repair spalls in bridge deck	30	2	70	CF	$ 150	$ 10,500	$ 21,000
Overlay bridge deck with methacrylate	30	2	28,000	SF	$ 1.25	$ 35,000	$ 70,000
Repair cracks and spalls on girder flanges	30	2	-	CF	$ 300	$ -	$ -
Remove debris accumulation from piers	5	15	2,000	CF	$ 5.00	$ 10,000	$ 150,000
						Total =	$ 241,000

Alt 3 PC/PS Bulb-Tee Girder, Six-Span

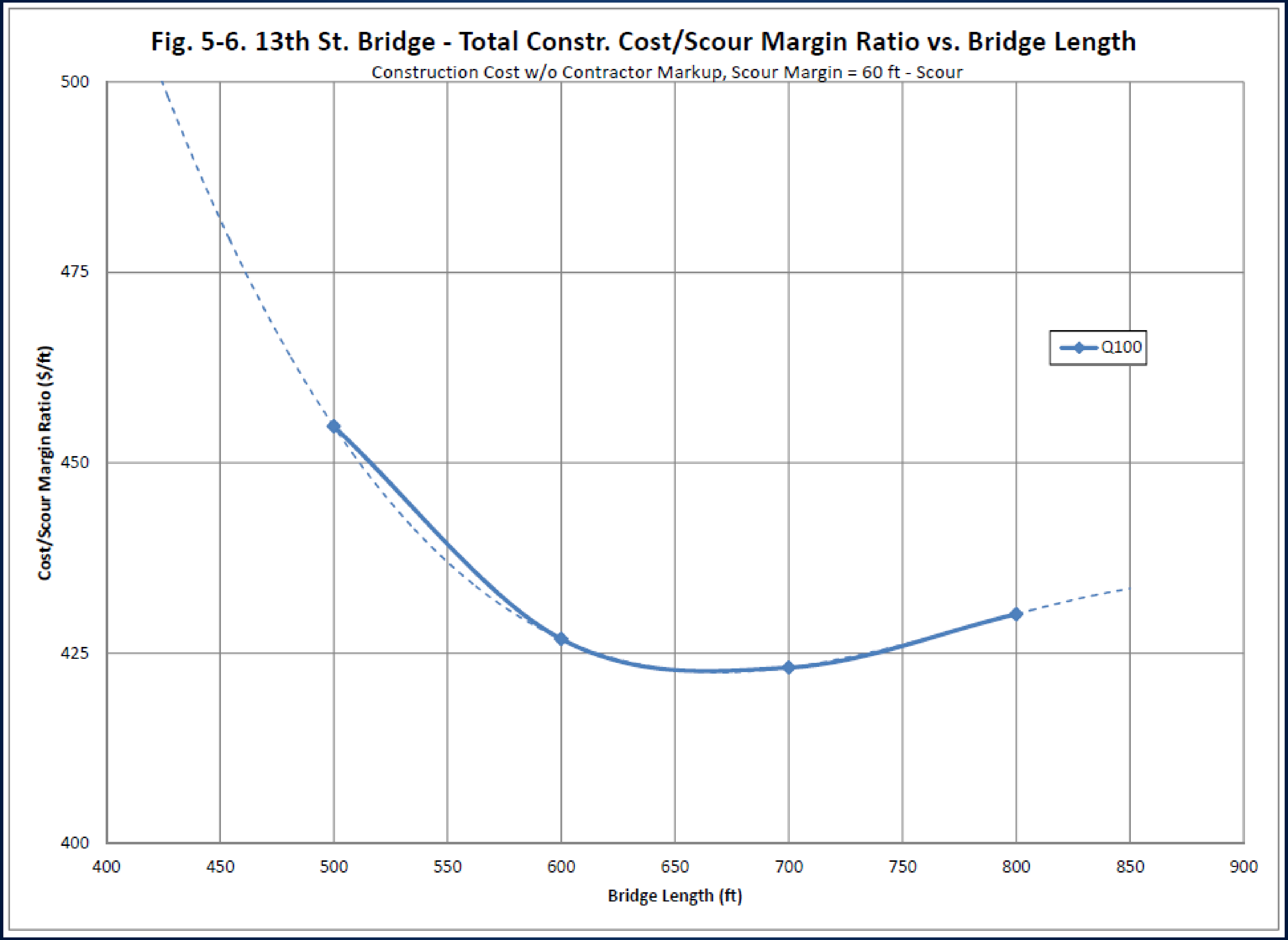
Item	Frequency (years)	No. Times in 75 years	Quantity	Units	Unit Cost	Cost Ea. Time	Cost over 75 years
Repair spalls in bridge deck	30	2	70	CF	$ 150	$ 10,500	$ 21,000
Overlay bridge deck with methacrylate	30	2	28,000	SF	$ 1.25	$ 35,000	$ 70,000
Repair cracks and spalls on girder flanges	30	2	50	CF	$ 300	$ 15,000	$ 30,000
Remove debris accumulation from piers	5	15	5,000	CF	$ 5.00	$ 25,000	$ 375,000
						Total =	$ 496,000

Seismic Performance
Advantages of Alt 2 – Haunched Box

- Largest and deepest piles → most margin against scour and liquefaction
- Deepest bent caps → most reserve capacity to resist column hinging

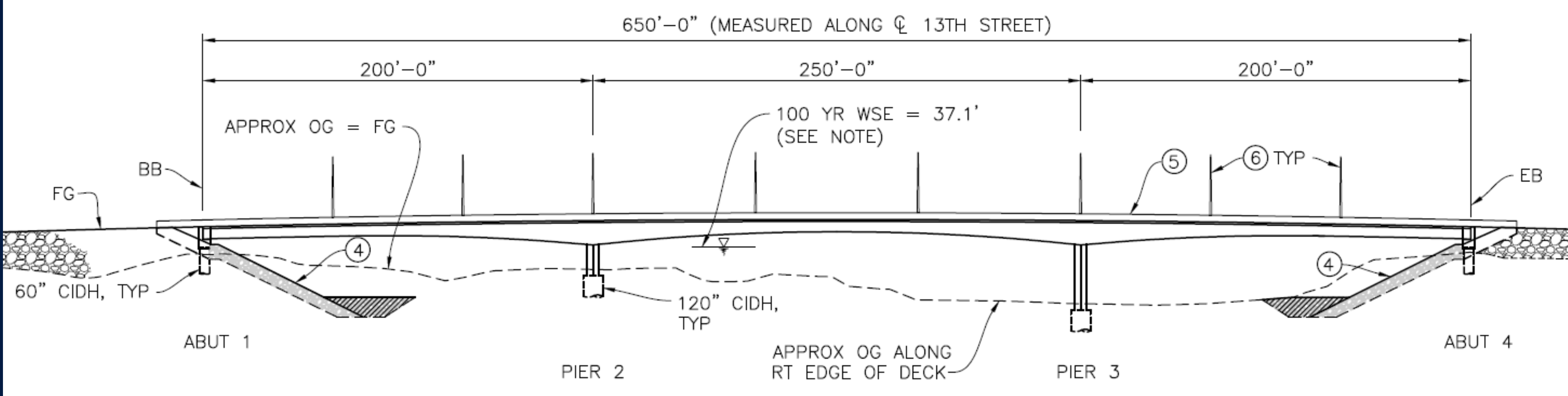


Refinement of Bridge Length



Final Bridge Design

Three-Span, CIP/PS Box Girder, L = 650 ft



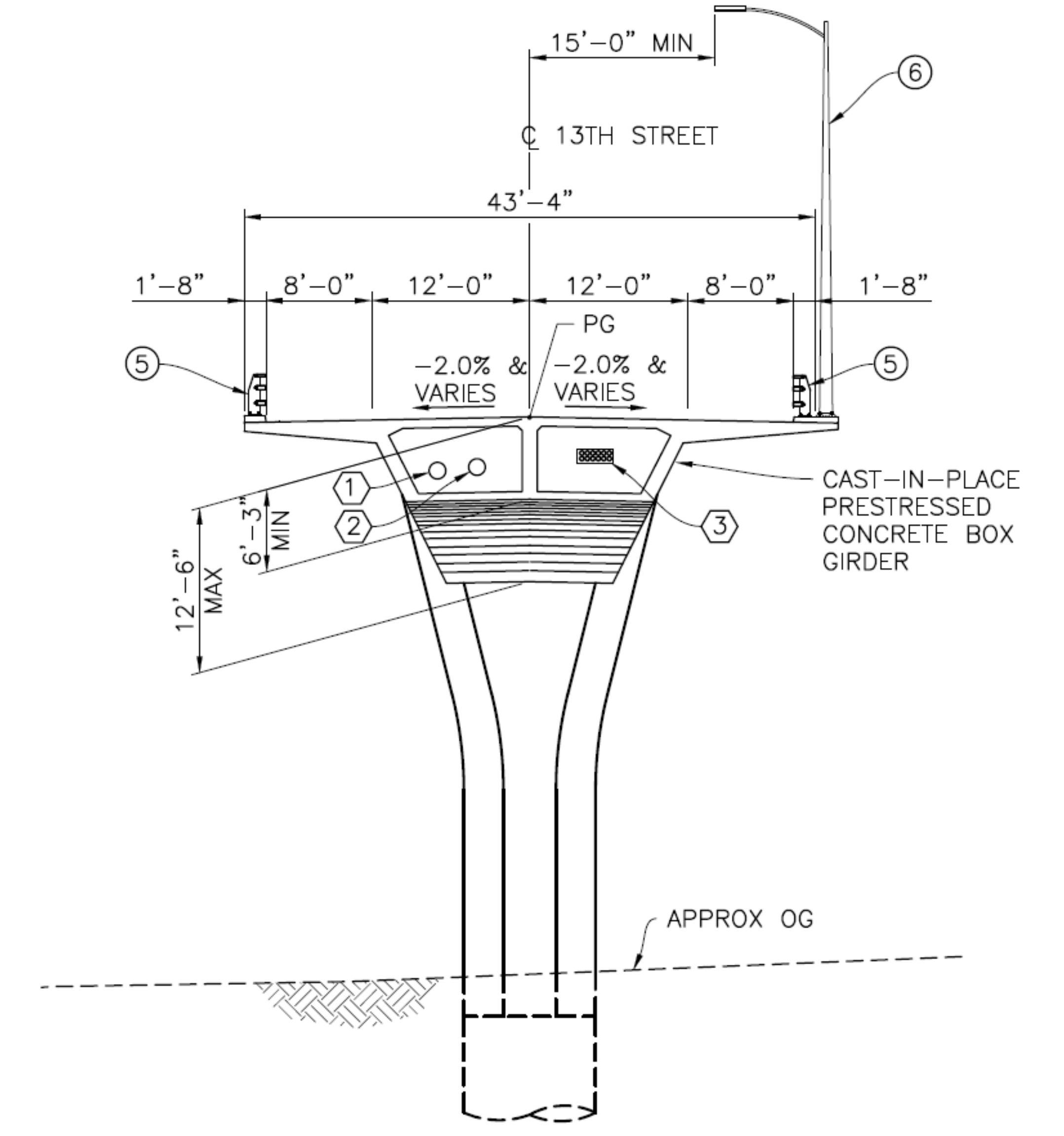
ELEVATION

650 ft long, Three Span CIP/PS Haunched Box Girder

Final Bridge Design

Three-Span CIP/PS Box Girder L = 650 ft

- Variable depth box girder
  - 6’-3” at mid-span and abutments
  - 12’-6” at piers
- Single columns
- Large mono-pile foundations



TYPICAL SECTION

Final Bridge Design

Three-Span, CIP/PS Box Girder, L = 650 ft

Seismic Design Strategy

Design Issues:

- 80 ft of liquefaction
- High lateral spreading loads at abutments

Performance Requirements:

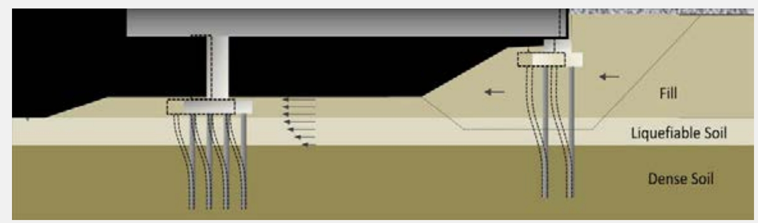
- Below ground plastic hinges Ductility demand < 2
- Above ground plastic hinges Ductility demand < 3
- Plastic deformations at deck level < 12”
- Foundation settlement < 2”

Lateral Spreading at Abutments

- Follows Caltrans Guidance
- Lateral spreading loads are very large
- Cannot keep abutment piles elastic
- Need to limit ductility demand in pile hinges to < 2 per design criteria
- Was a struggle to get pile design to work (meet criteria)

Caltrans

Guidelines on Foundation Loading and Deformation due to Liquefaction Induced Lateral Spreading

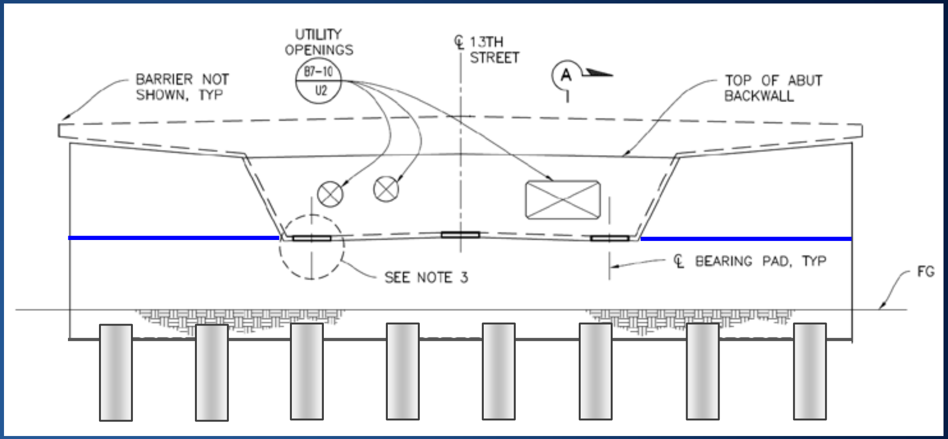


January 2012

Seismic Design Strategy

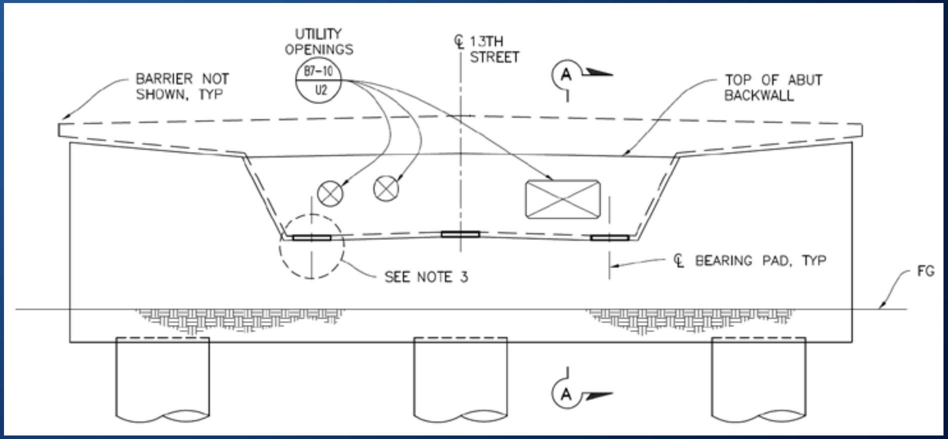
Standard Design Practice:

- Sacrificial shear keys and back walls at abutments prevent damage to small piles
- Piers take 100% of seismic load

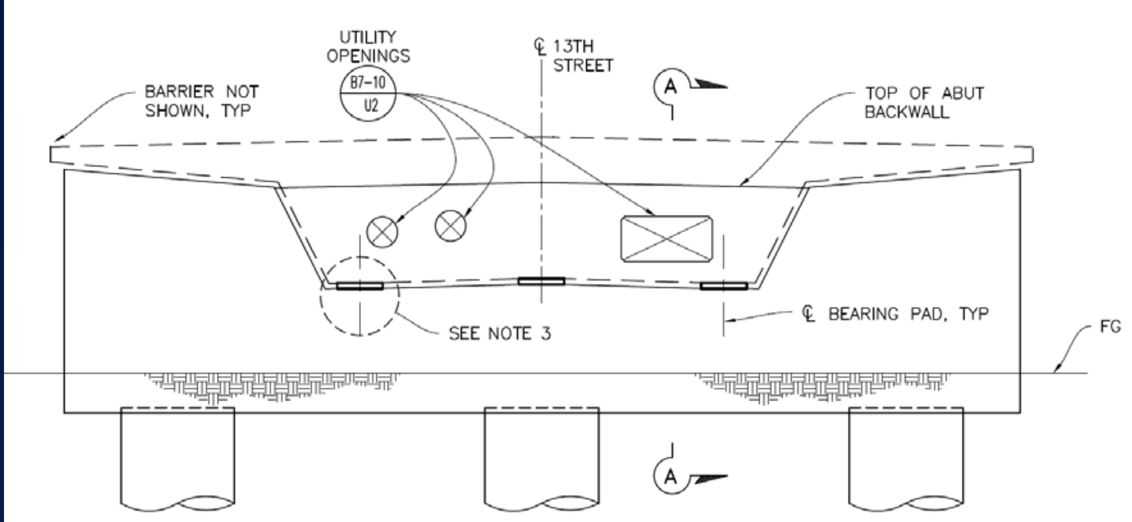


Our Design:

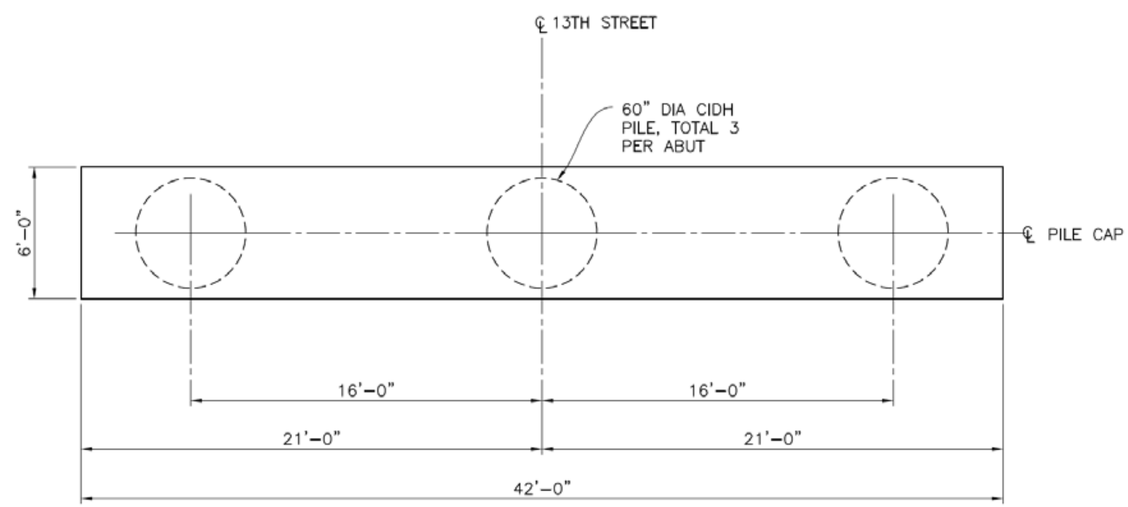
- Need large abutment piles to resist lateral spreading loads
- Use strong back wall to engage superstructure and reduce bending demands on piles
- Under seismic shaking, abutment piles and piers share load
- Displacement and ductility demands on piers are reduced



Abutment Details



ELEVATION

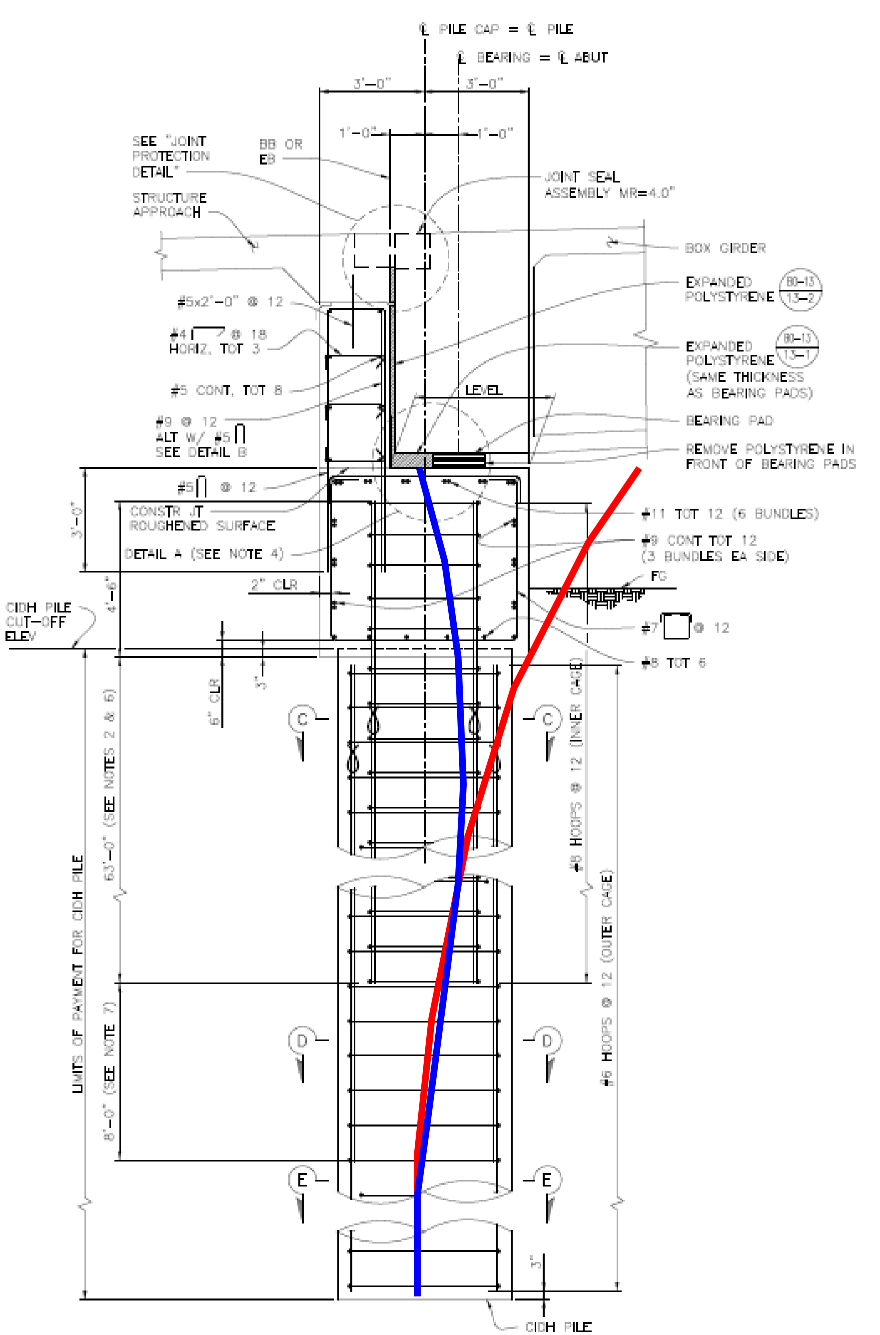


FOUNDATION PLAN

- Single row of 5 ft dia piles
- More flexible – can accommodate displacement demands better
- Simpler connection to pile cap

Special Abutment Details for Lateral Spreading

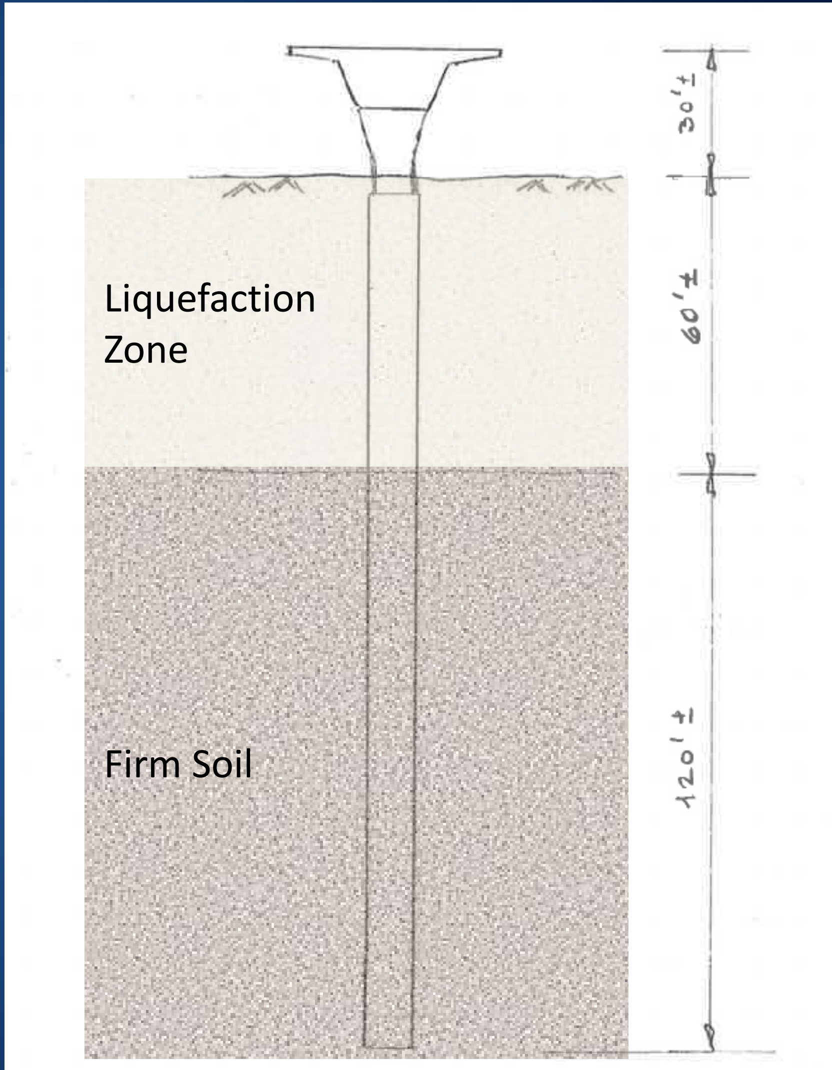
- Strong backwalls
  - 2 ft thick, #9 flexural reinf.
- Lateral spreading force is transferred through superstructure (strutted abutment)
- Reduces lateral demands on piles
- Under seismic shaking, abutment piles share load - reduces displacement demands on piers
- Cost to implement is minimal



ABUTMENT SECTION

Pier Details

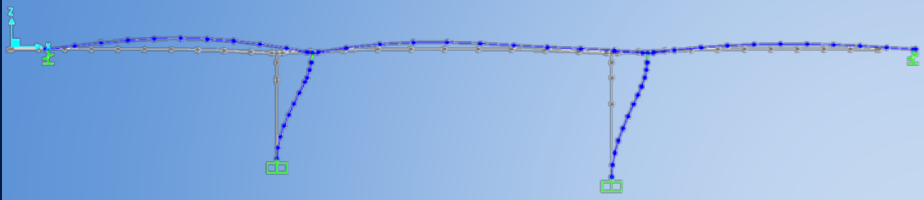
- Single column piers
- Deep mono-pile foundations
- 10 ft dia CIDH
- L = 176 ft, Pier 2
- L = 170 ft, Pier 3
- Length controlled by Strength I (3 lanes of HL93)
- Long enough for liquefaction (60’) and scour (25’)
- Pile reinf controlled by seismic (keep ductility < 2)



PIER SECTION

Longitudinal Seismic Response

Sacrificial Back Walls



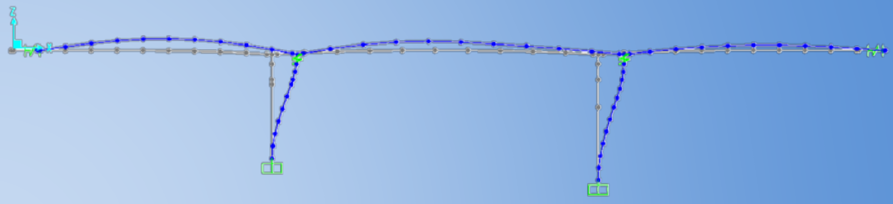
Period = 4.0 sec

Δ_{EQ} = 16”

Column Hinge

- μ_{Δ} = 2.8
- $\Delta_{plastic}$ = 10”

Strong Back Walls



Period = 1.7 sec

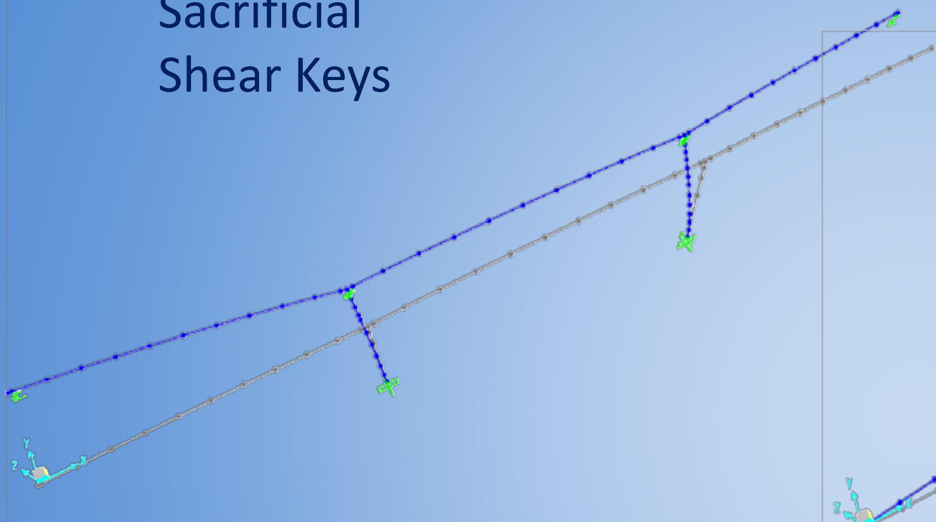
Δ_{EQ} = 12”

Column Hinge

- μ_{Δ} = 2.1
- $\Delta_{plastic}$ = 6.1"

Transverse Seismic Response

Sacrificial
Shear Keys

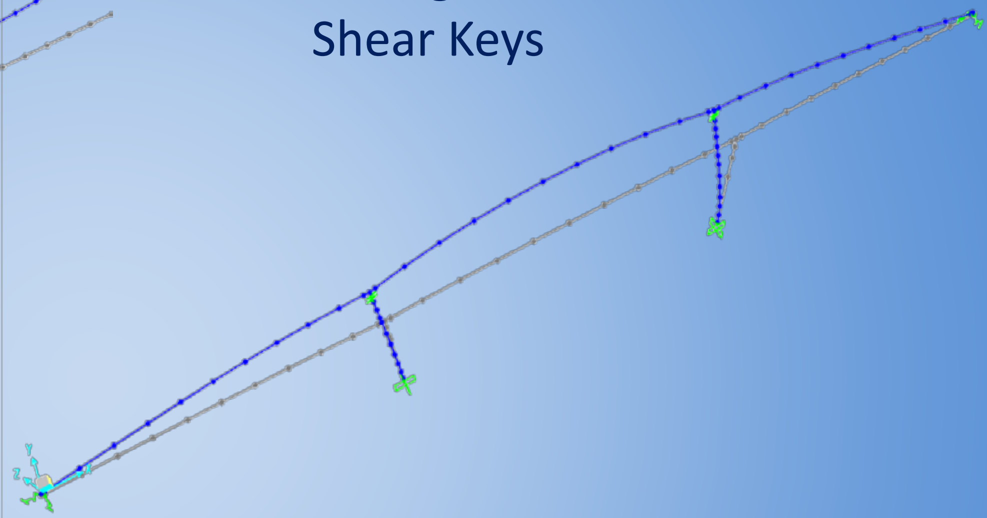


Period = 3.0 sec

Piers

- Δ_{EQ} = 18.3”
- μ_{Δ} = 1.2
- $\Delta_{plastic}$ = 2.7”

Strong
Shear Keys



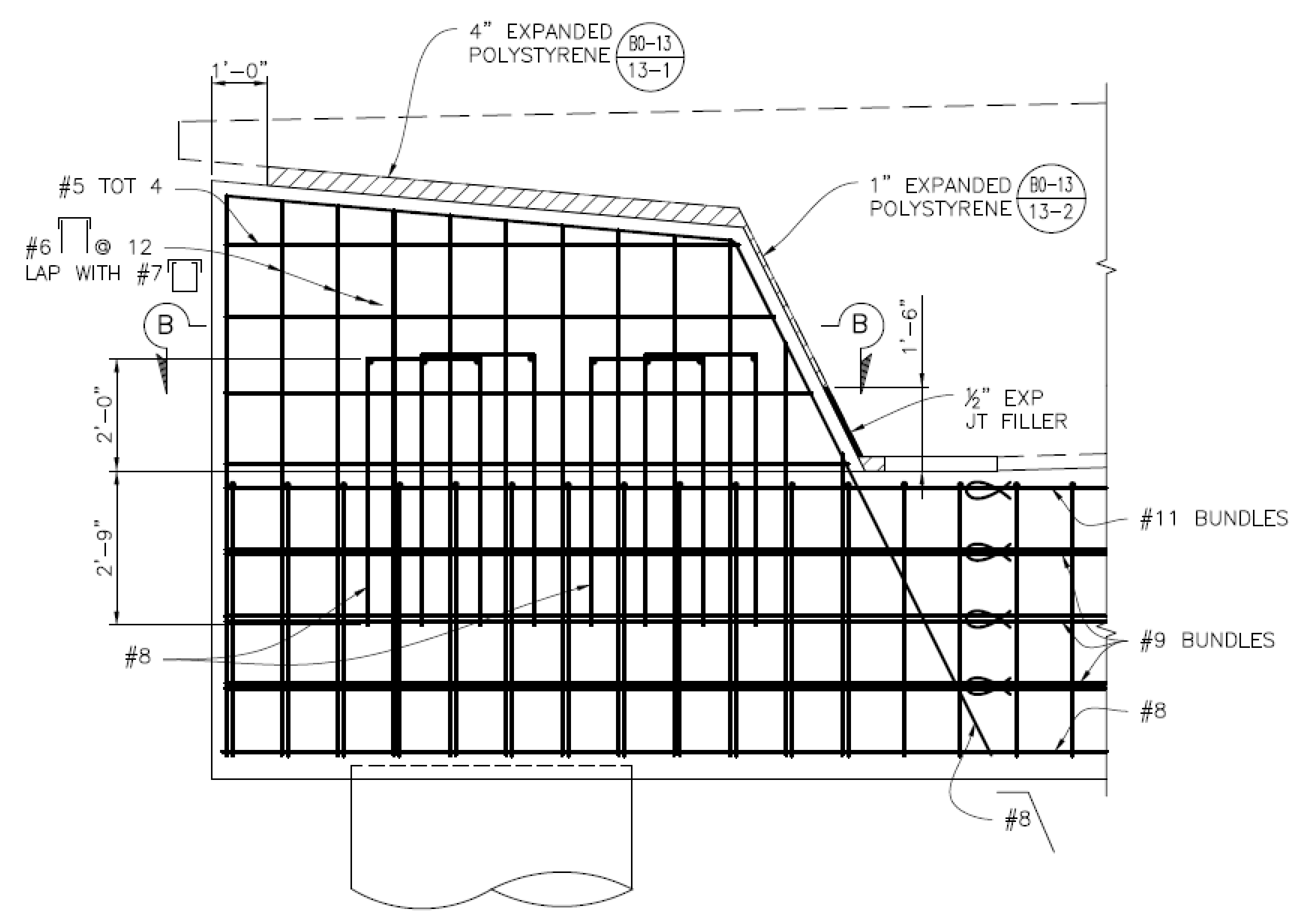
Period = 1.9 sec

Piers

- Δ_{EQ} = 12.6”
- μ_{Δ} = 0.8
- $\Delta_{plastic}$ = 0”

Abutment Shear Key Details

- 11.5 ft wide
- #8 L-shape flexural bars
- #8 U-shaped shear bars
- #11 & #9 drag bars (bundles)



ABUTMENT SHEAR KEY DETAIL

10' dia CIDH at Piers Reinforcement

Top

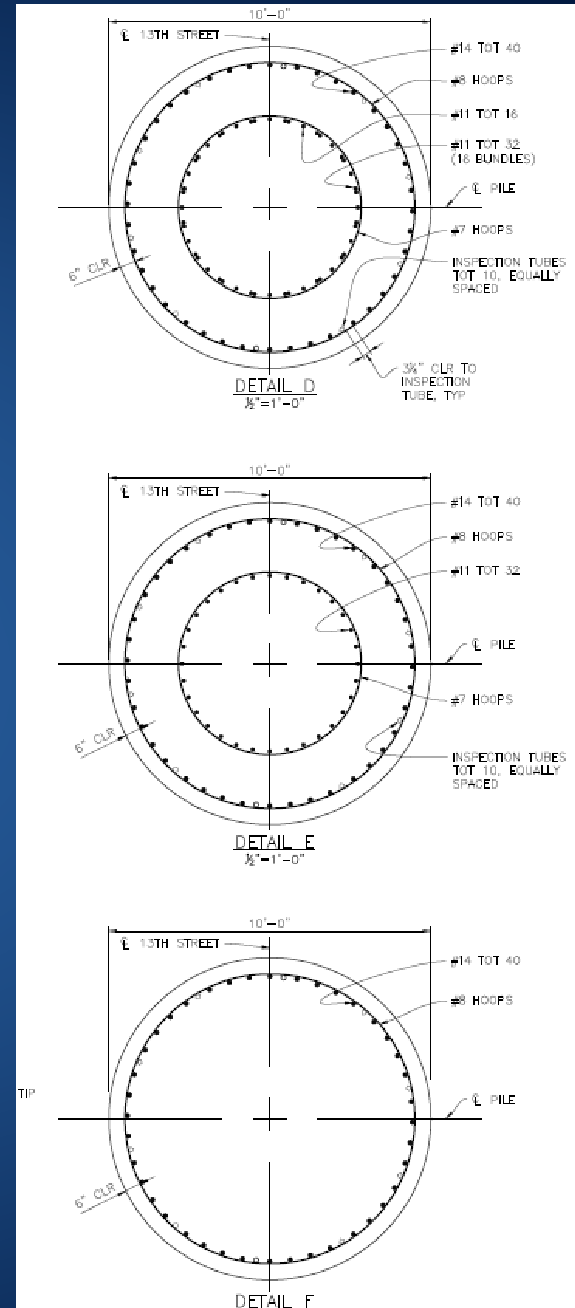
- #14 tot 40 outer
- #11 tot 48 inner
- ρ = 1.46%

Middle

- #14 tot 40 outer
- #11 tot 32 inner
- ρ = 1.24%

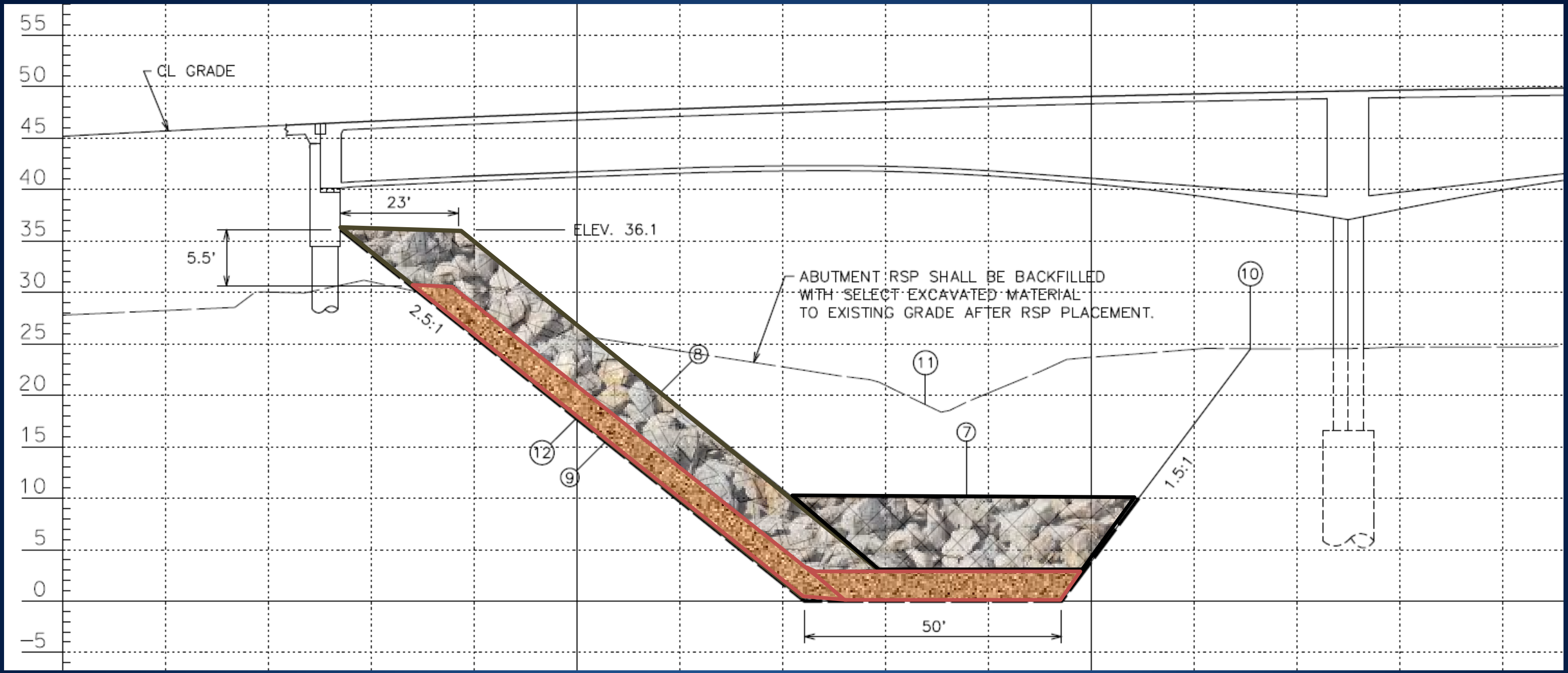
Bottom

- #14 tot 40 outer
- ρ = 0.80%



PILE SECTIONS

Rock Slope Protection



- Scour evaluated per HEC-18
- RSP Design per HEC-11 and HEC-23
- Modifications recommended by USACE to increase factor of safety
- 200 lb rock 3 ft thick,
  1-ton rock 5.5 ft thick
- South Abut, to EL 0, 50 ft toe
- North Abut, to EL -10, 30 ft toe

Acknowledgements

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Priscilla Perry, Greg Bridgestock, Steve Graff, Mike Lin

A/E Design Team:

MFDB Architects (Prime Consultant, PM for A/E Team)
Dan Dameron

KASL Consulting Engineers (Survey, Mapping, Civil, Roadway Engineering)
Jack Scroggs, Bill Ostroff

Moffatt & Nichol (Hydrology, Hydraulics, Bridge Engineering)
Tony Sánchez, Gernot Komar, Bob Dameron, Patrick Chang, Weixia Jin

GENTERRA (Geotechnical Engineering)
Soma Balachandran

US Army Corps
of Engineers

MFDB/KASL
A+E Consultants, LLC

moffatt & nichol

GENTERRA