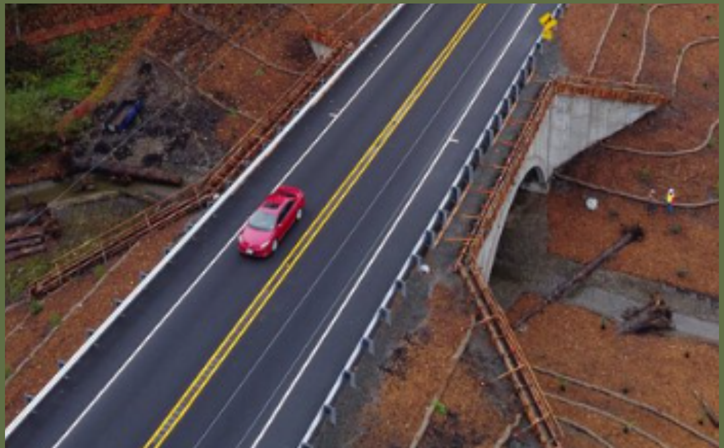
Fiber-reinforced polymer wildlife crossing infrastructure

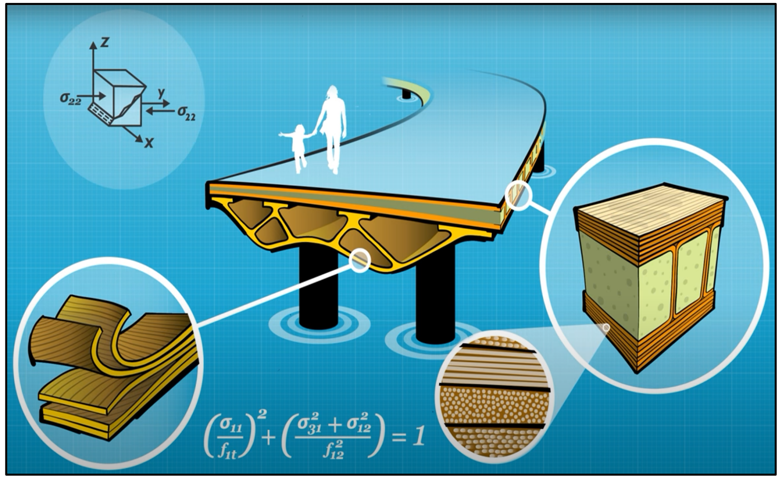
Presenter

Matthew Bell

Western Transportation Institute



FRP Wildlife Crossing Workflow



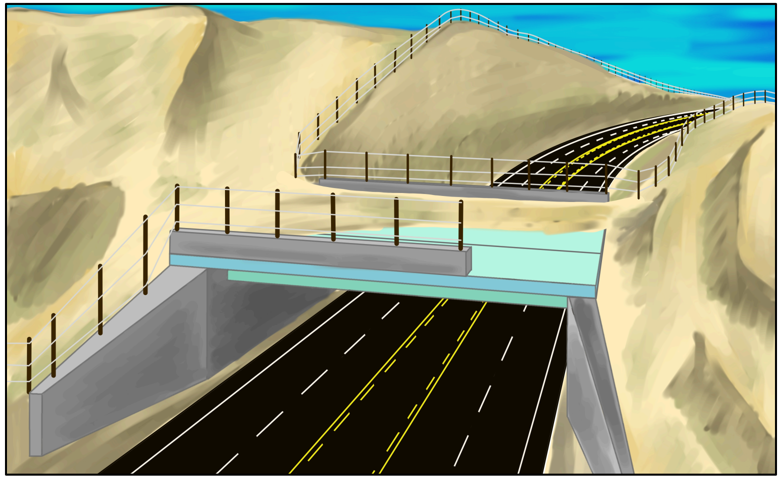
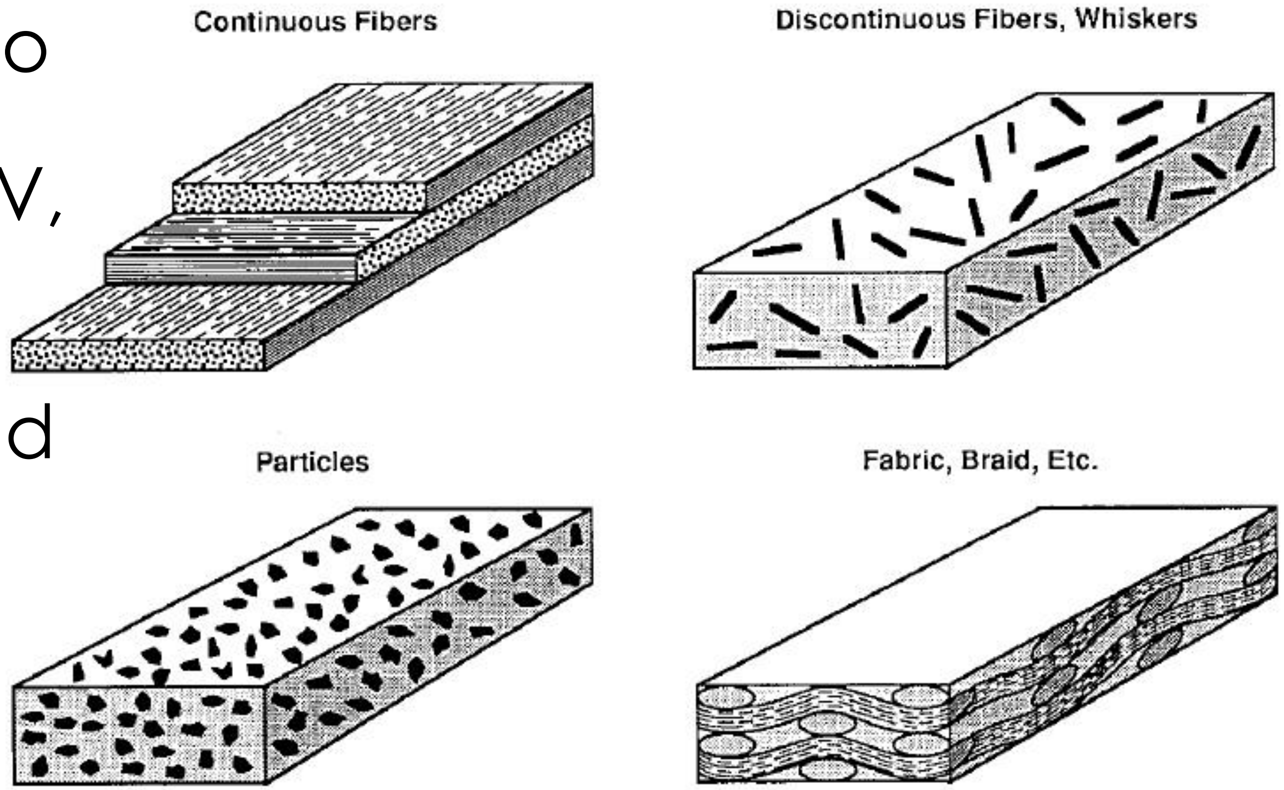


Photo credit: Terry McGuire

Understand FRP composites, material properties, and manufacturers → Design an FRP wildlife overpass with DOT input → Compare FRP life-cycle costs to traditional materials

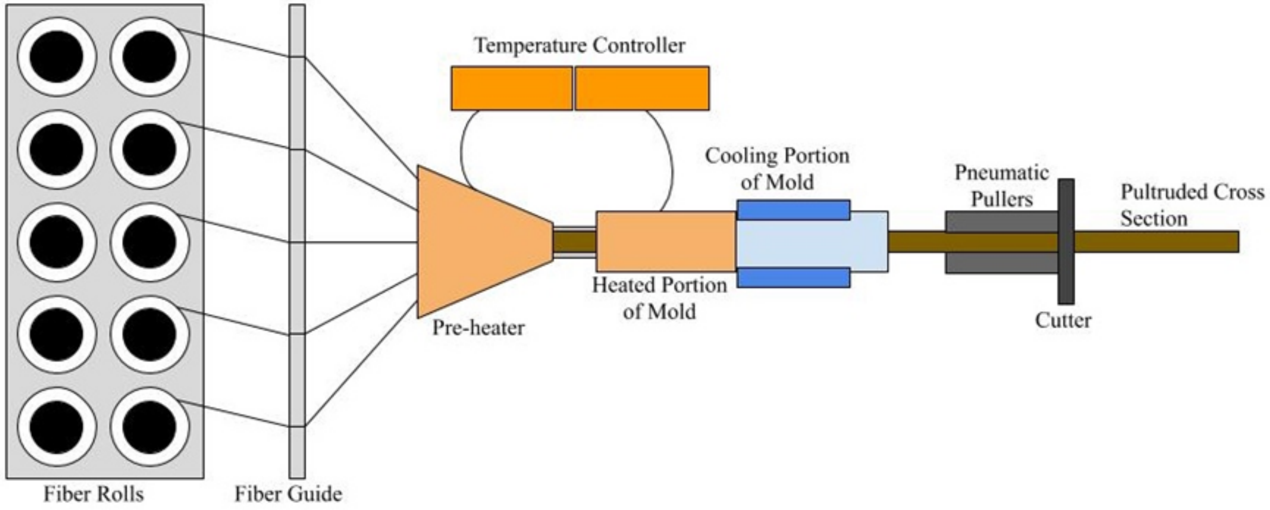
FRP Composites

- High strength-to-weight ratio
- Corrosion, rot, water, fire, UV, and impact resistant
- Reduced transportation and construction costs
- Little/no maintenance
- Service life ≥ 100 years

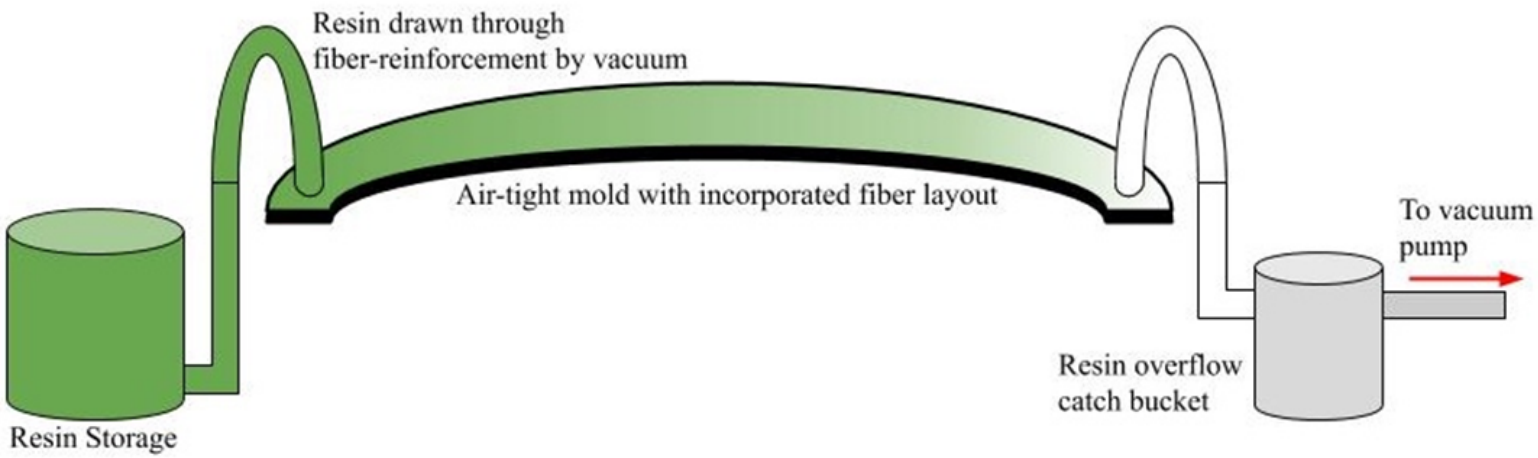


FRP Manufacturing

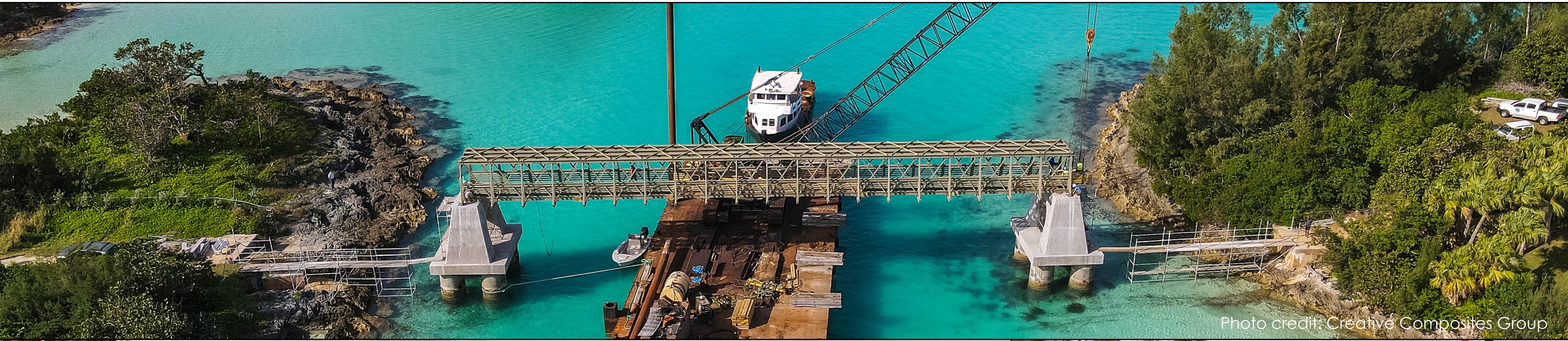
- Pultrusion molding



- Vacuum infusion



Pultrusion Bridges



Hybrid Bridges


Photo Credit: Fiberline Composites


Photo Credit: AIT Bridges


Photo Credit: FiberCore Europe


Photo Credit: AIT Bridges

Uni-mold Bridges


Photo credit: FiberCore Europe


Photo credit: FiberCore Europe


Photo credit: Lightweight Structures BV

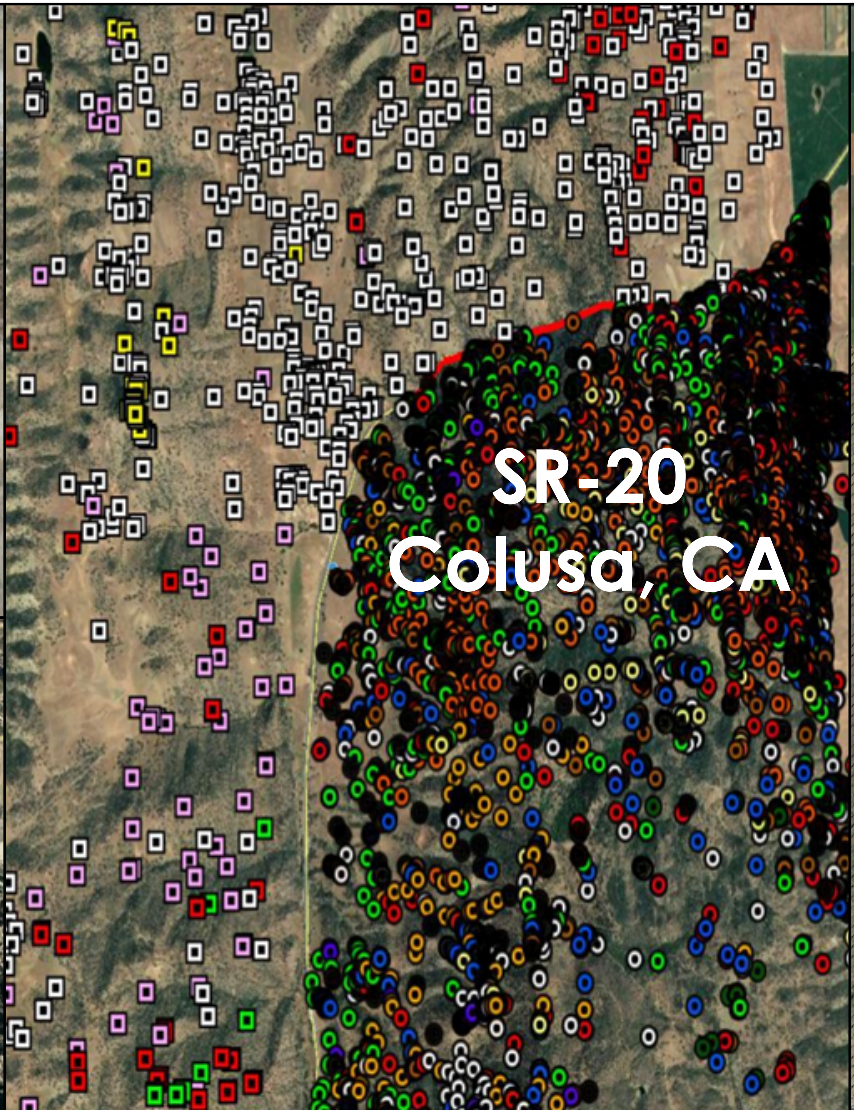

Photo credit: FiberCore Europe

FRP Design Goals

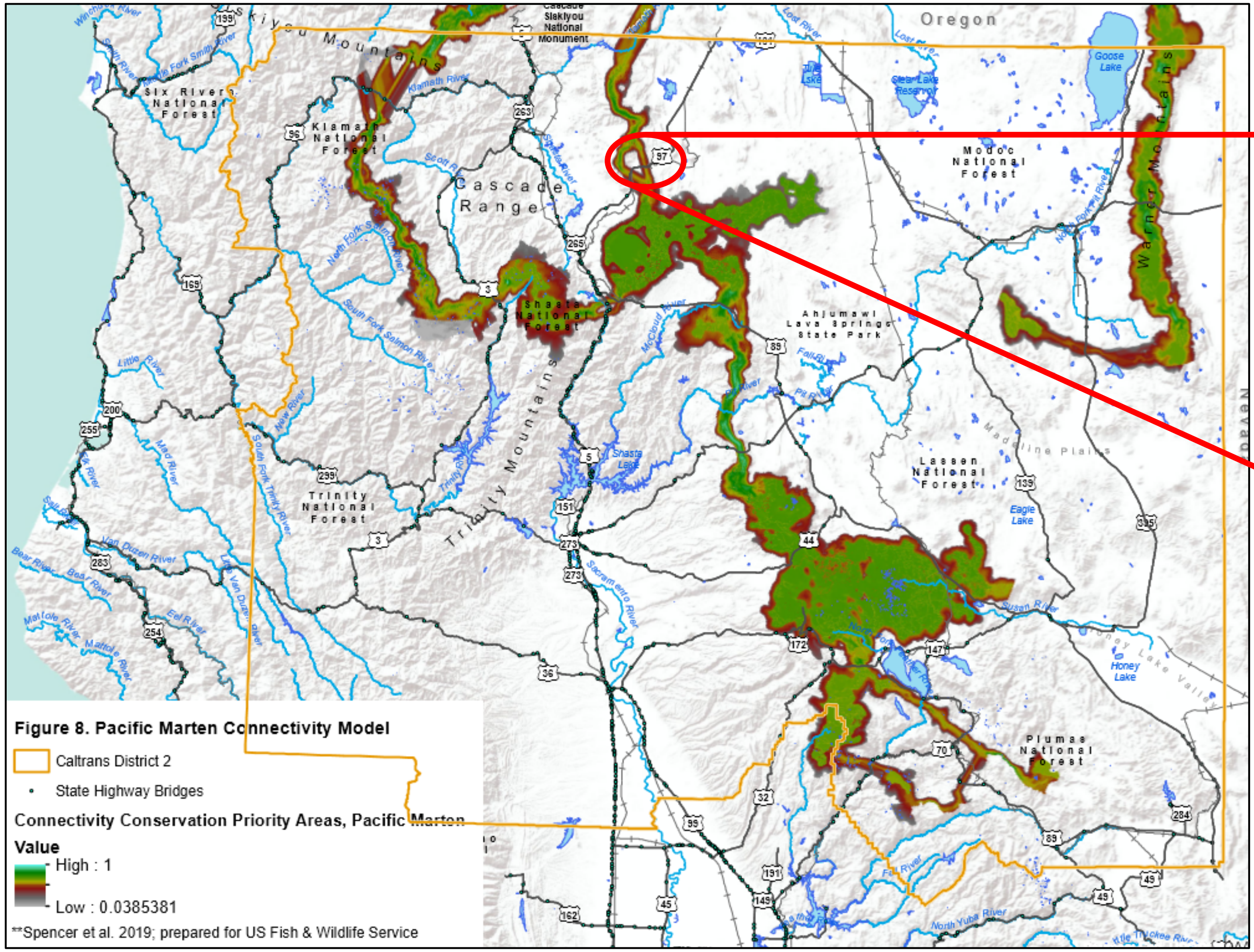
- Use real-world mitigation site
- Work with state DOT to establish construction plan and identify road blocks
- Design an FRP wildlife overpass that can be built along US roadways

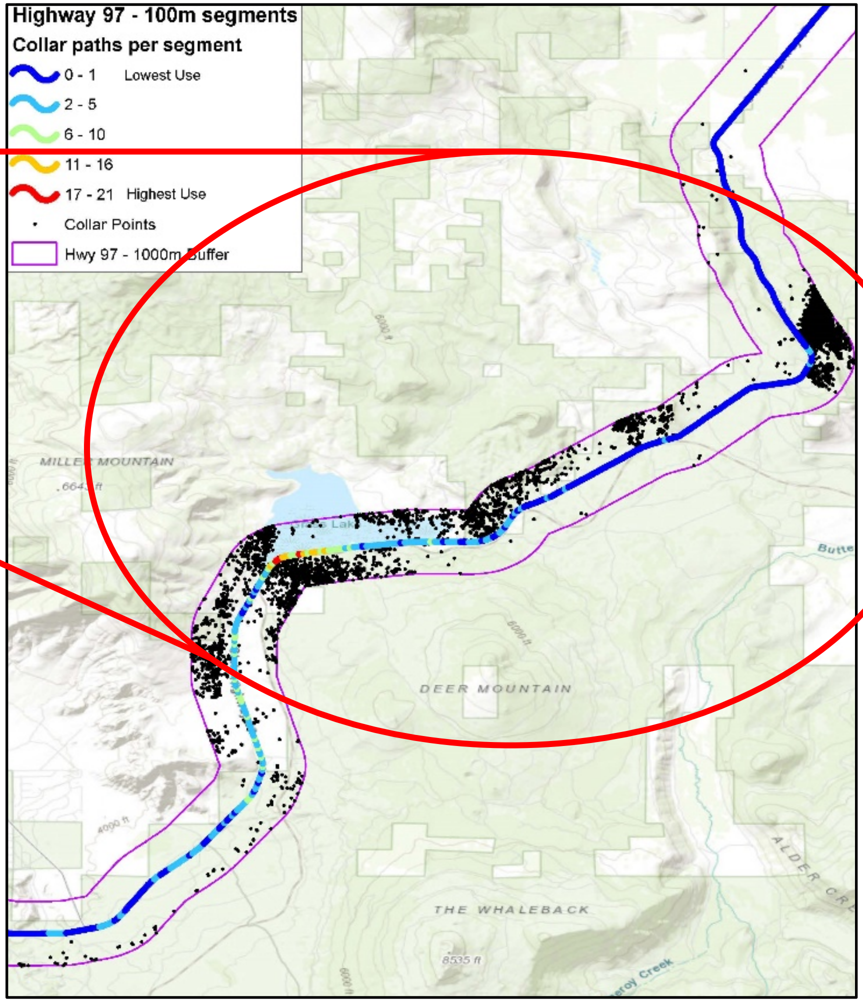

Photo credit: ARC Solutions

Proposed Mitigation Sites



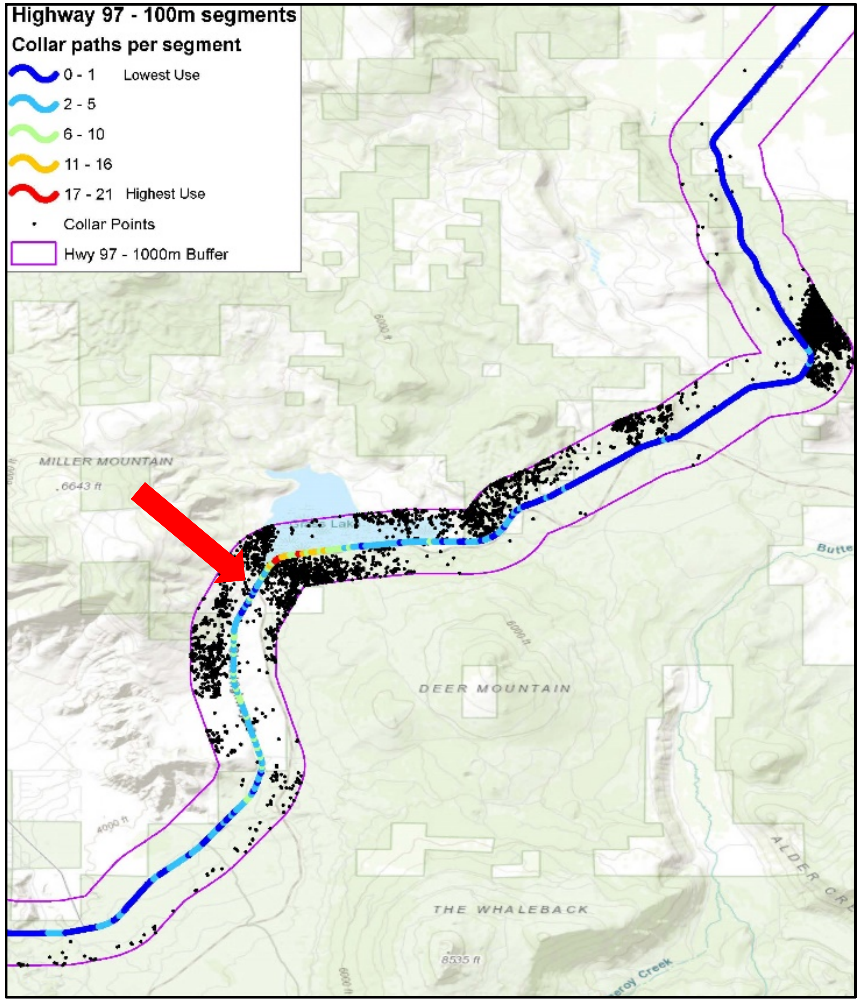
US-97 in Siskiyou County, CA



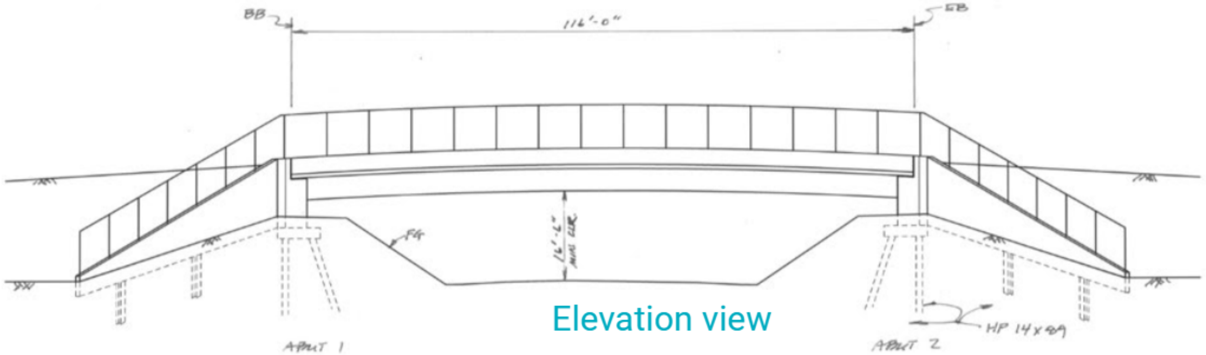


US-97 Site Visit

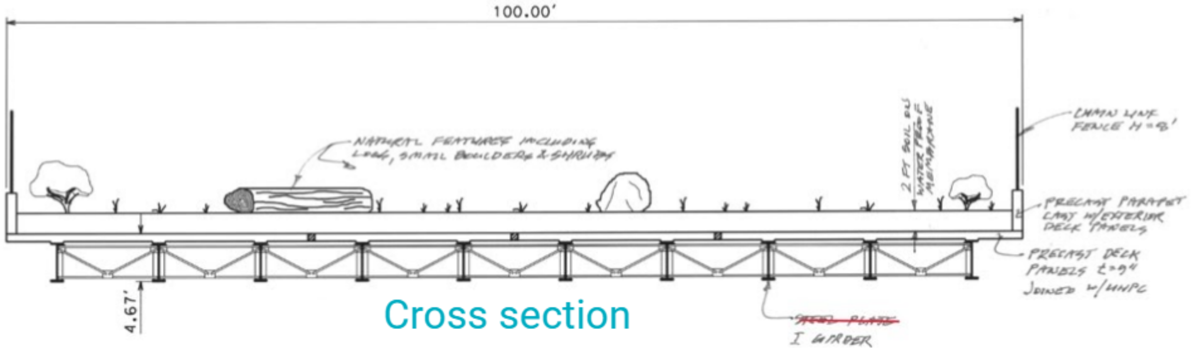
Grass Lake Summit



Grass Lake Summit



Elevation view



Cross section

Advanced Infrastructure Technologies

- FRP composite tub girders
- Bridge spans up to 120 ft

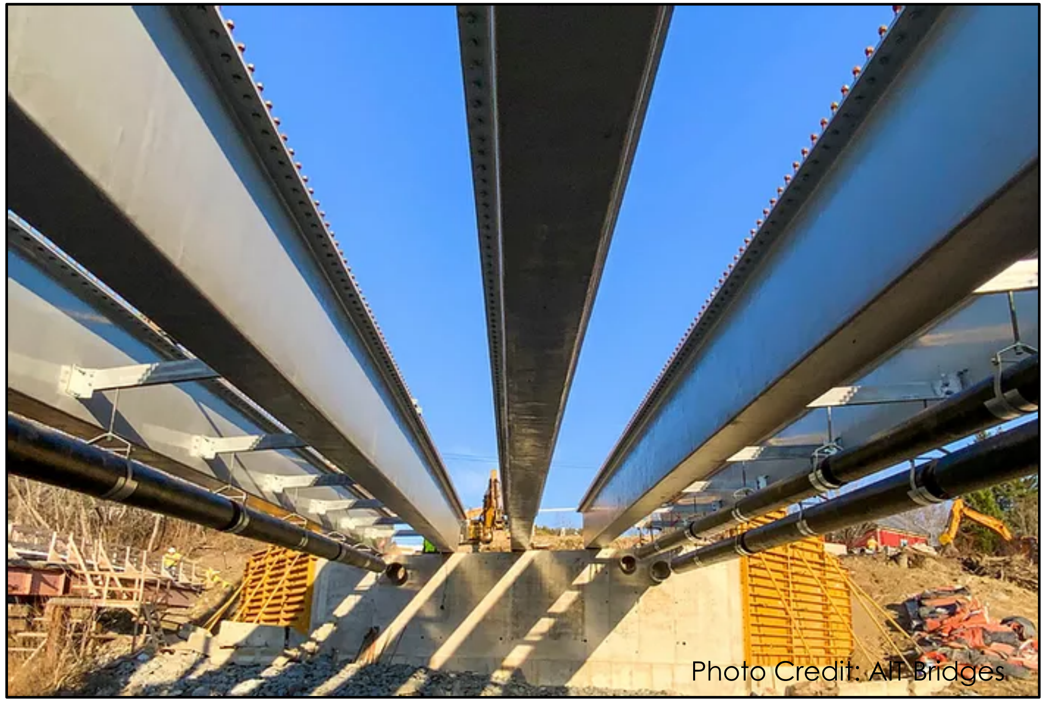


Photo Credit: AIT Bridges


Photo Credit: AIT Bridges

AIT BRIDGES


Photo Credit: AIT Bridges

Virtual Design Lab

- Robert Ament, Road Ecology Program Manager, Western Transportation Institute - Montana State University
- Matthew Bell, Research Engineer, Western Transportation Institute - Montana State University
- Marta Brocki, Associate Director, ARC Solutions
- Renee Callahan, Executive Director, ARC Solutions
- Damon Fick, Senior Research Engineer, Western Transportation Institute - Montana State University
- Manode Kodsuntie, Senior Bridge Structures Engineer, Caltrans
- Heidi Kuntz, Senior Structure Maintenance Investigations, Caltrans
- Terry McGuire, Professional Engineer, Consultant
- Robert Rock, Landscape Architect, Living Habitats
- Ryan Stiltz, Technical Liaison Engineer, Caltrans
- Marcel Huijser, Research Scientist, Western Transportation Institute - Montana State University
- Sandra Jacobson, Wildlife Biologist, United States Forest Service (retired)
- Nina-Marie Lister, Ecologist and Planner, Toronto Metropolitan University
- Richard Lis, Senior Environmental Specialist, California Department of Fish and Wildlife
- Eric Ruilison, Biologist, Caltrans
- Robin Solari, Landscape Architect, Caltrans
- Jim Gutierrez, Senior Bridge Engineer, FRP Specialist, Division of Engineers Services, Caltrans
- Liz Fairbank, Center for Large Landscape Conservation
- Darin Martens, U.S. Forest Service / Wyoming Department of Transportation / FHWA
- Kerry Molz, Project Management, Caltrans

observed on site

not present

not confirmed

SAFETY CONCERN

Rocky mountain elk
Black-tailed deer

CONSERVATION CONCERN

Gray wolf
Black bear
Mountain lion

OTHER LOCAL SPECIES

Porcupine
Pronghorn antelope
American beaver
Common muskrat
Ringtail
American badger
Western spotted skunk
Stripped skunk
Yellow-bellied marmot
American marten
Fisher
Northern river otter
Raccoon
Gray fox
Red fox
Coyote
Bobcat

Snowshoe hare
Black-tailed jackrabbit

Botta's pocket gopher
Northern pocket gopher*
Mazama's pocket gopher
Long-tailed weasel

Belding's ground squirrel
California ground squirrel
Golden-mantled ground squirrel
Western gray squirrel
Douglas' squirrel
Northern flying squirrel

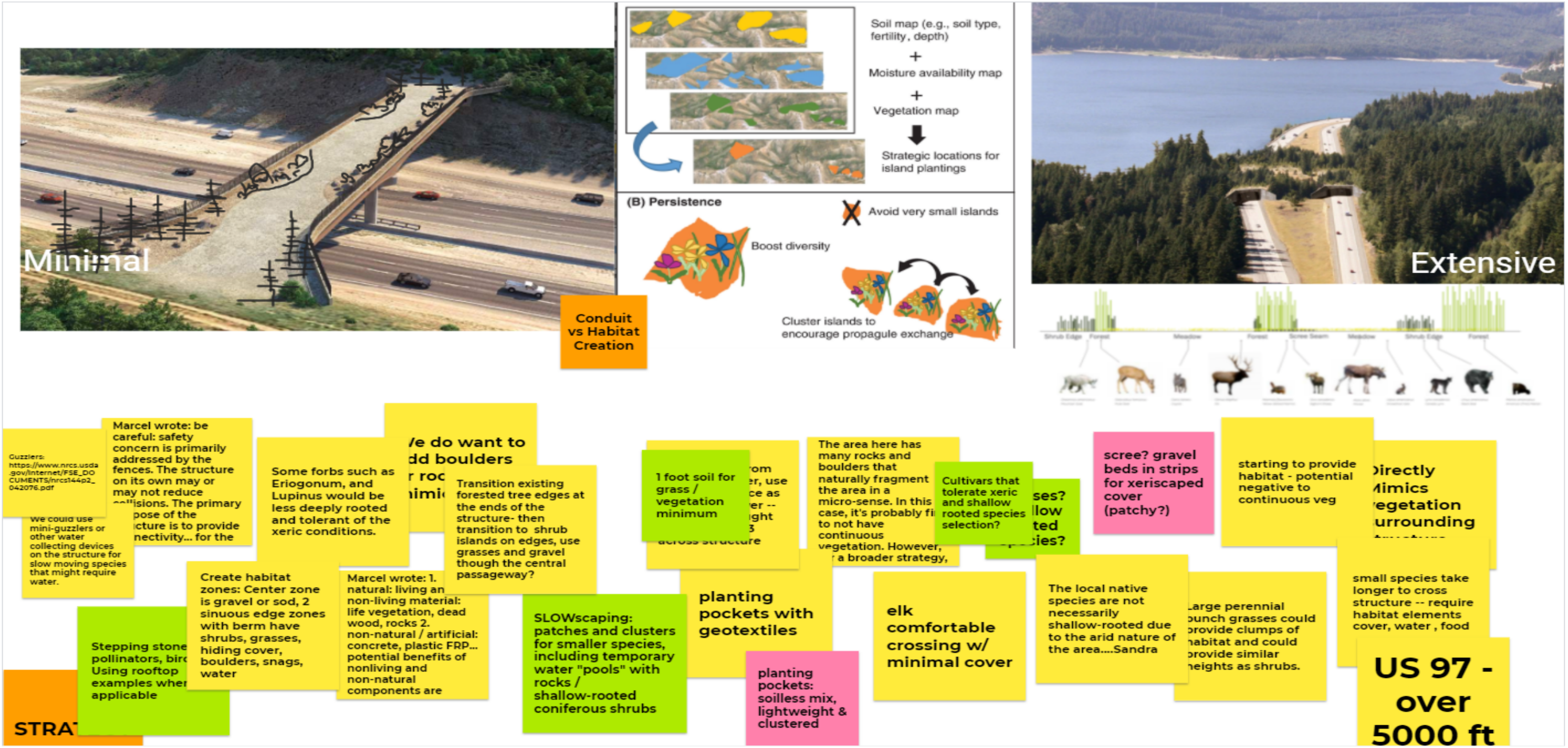
Great basin pocket mouse
Western harvest mouse
Deer mouse
Brush mouse
Pinyon mouse
House mouse
Western jumping mouse

California red-backed vole
Montane vole
Long-tailed vole
California vole*

Dusty-footed woodrat
California kangaroo rat
Bushy-tailed woodrat

Marcel wrote: I would use 2 angles simultaneously when designing the dimensions and habitat: 1. target species 2. mimic surrounding habitat

Virtual Design Lab: Landscaping



Virtual Design Lab: Engineering

Basic

- AIT Composite tub girder
- Reinforced-concrete
- Steel/wood fence posts and jump-outs
- Large rocks for wing walls
- Concrete barriers

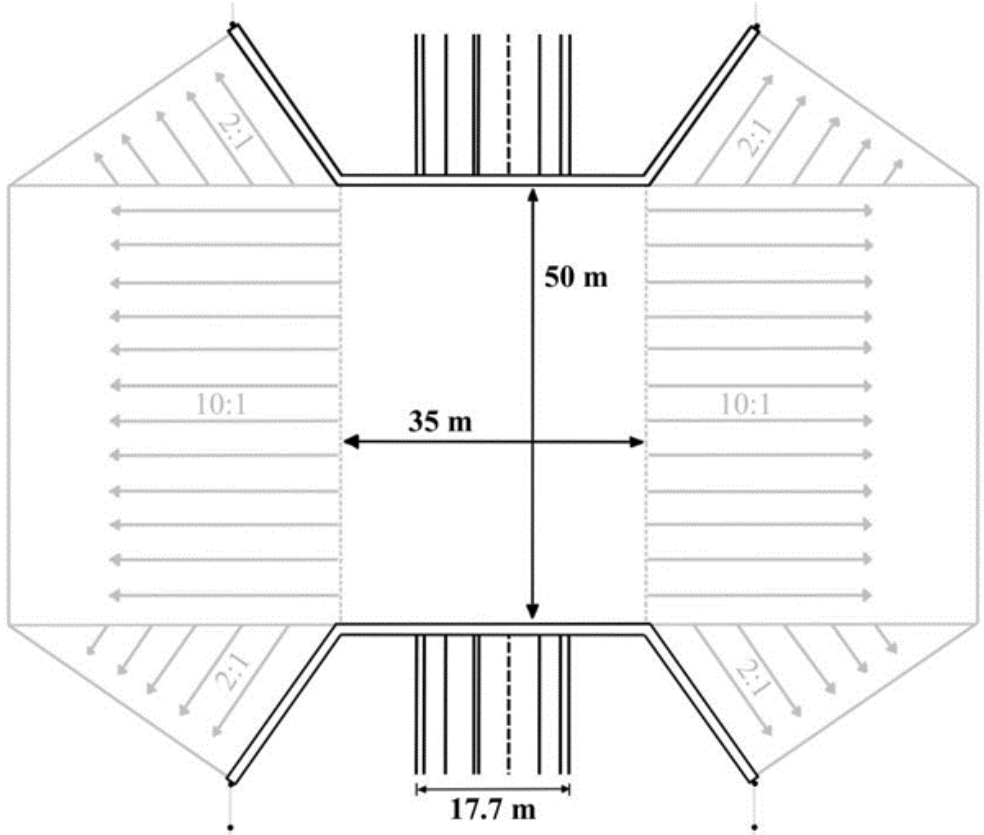
Enhanced

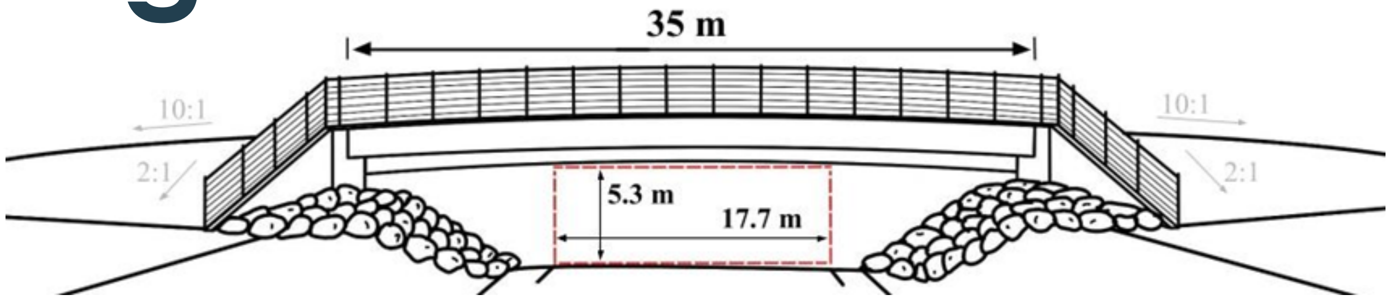
- FRP fence posts
- FRP barriers
- FRP or Epoxy-coated rebar
- Lightweight concrete
- Recycled FRP for non-structural elements

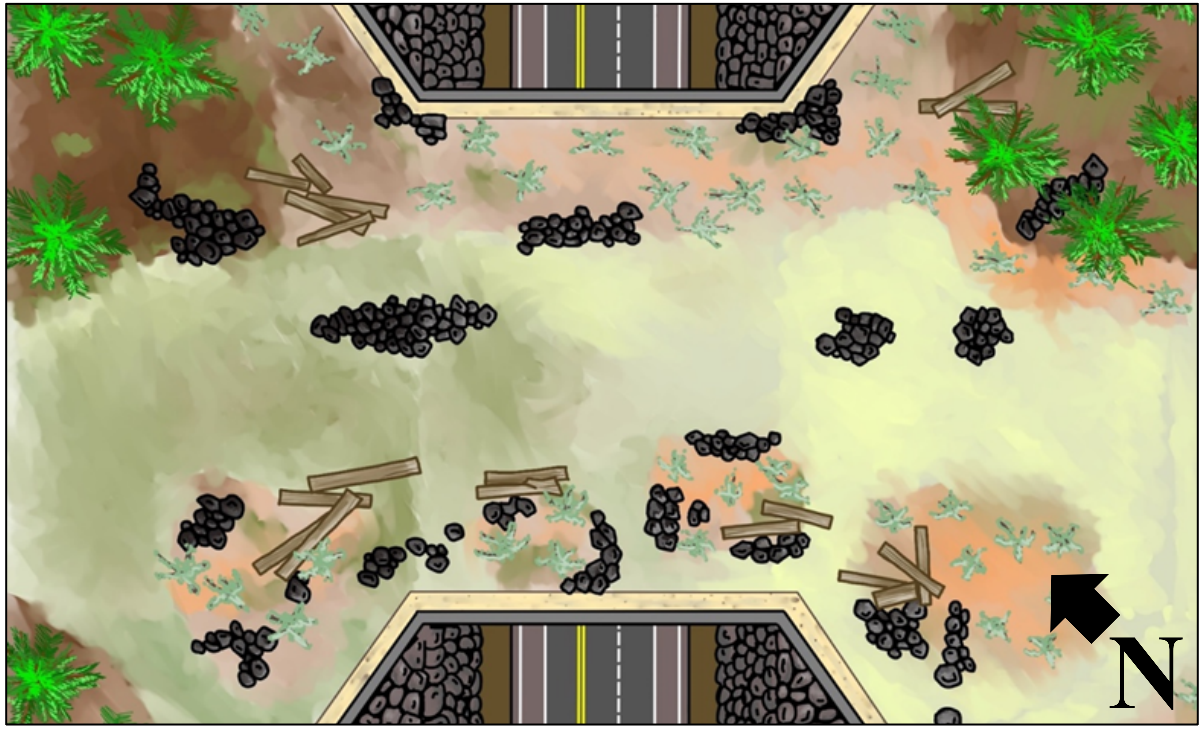
Innovative

- AIT CT girders for root development
- Bubble decks
- FRP sound barriers
- Recycled FRP in Concrete
- 3-D Printing

FRP Structural Designs

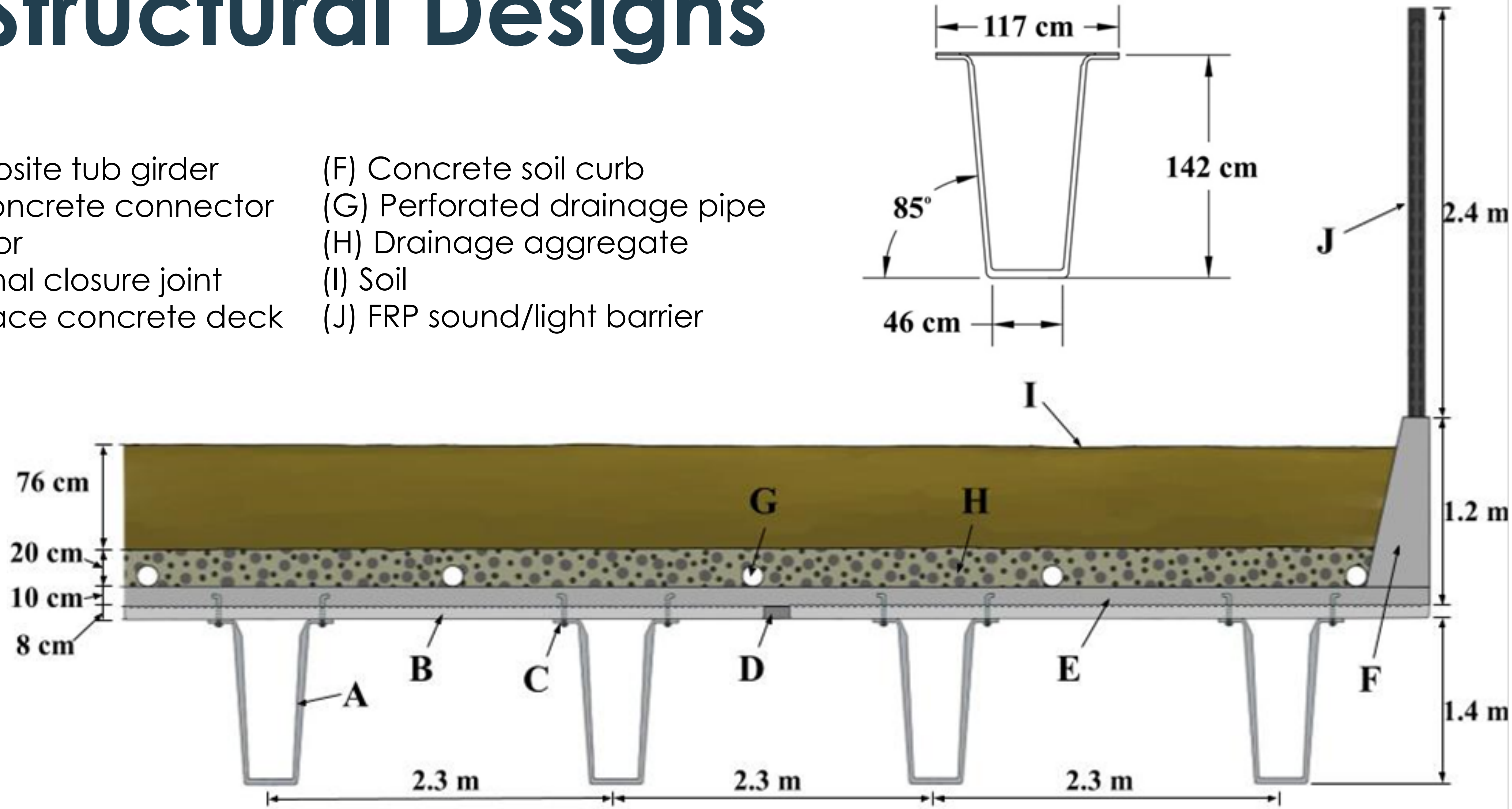




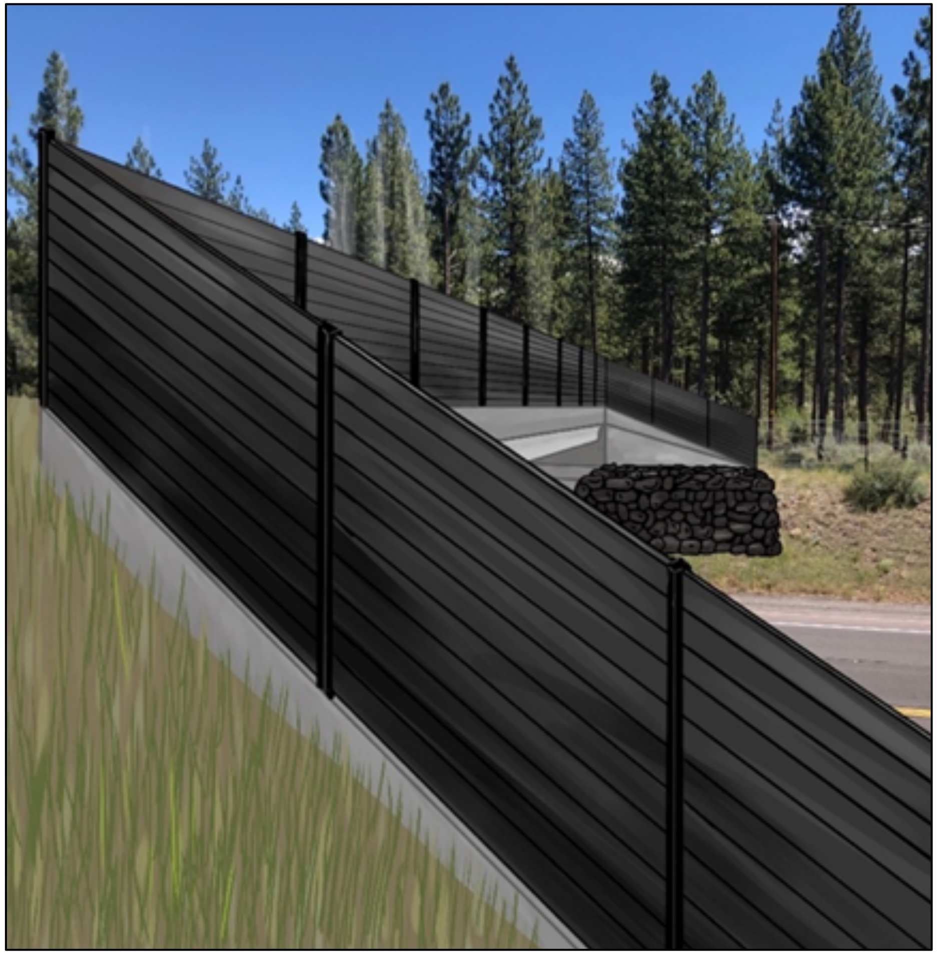


FRP Structural Designs

(A) AIT composite tub girder
(B) Precast concrete connector
(C) FRP anchor
(D) Longitudinal closure joint
(E) Cast-in-place concrete deck
(F) Concrete soil curb
(G) Perforated drainage pipe
(H) Drainage aggregate
(I) Soil
(J) FRP sound/light barrier

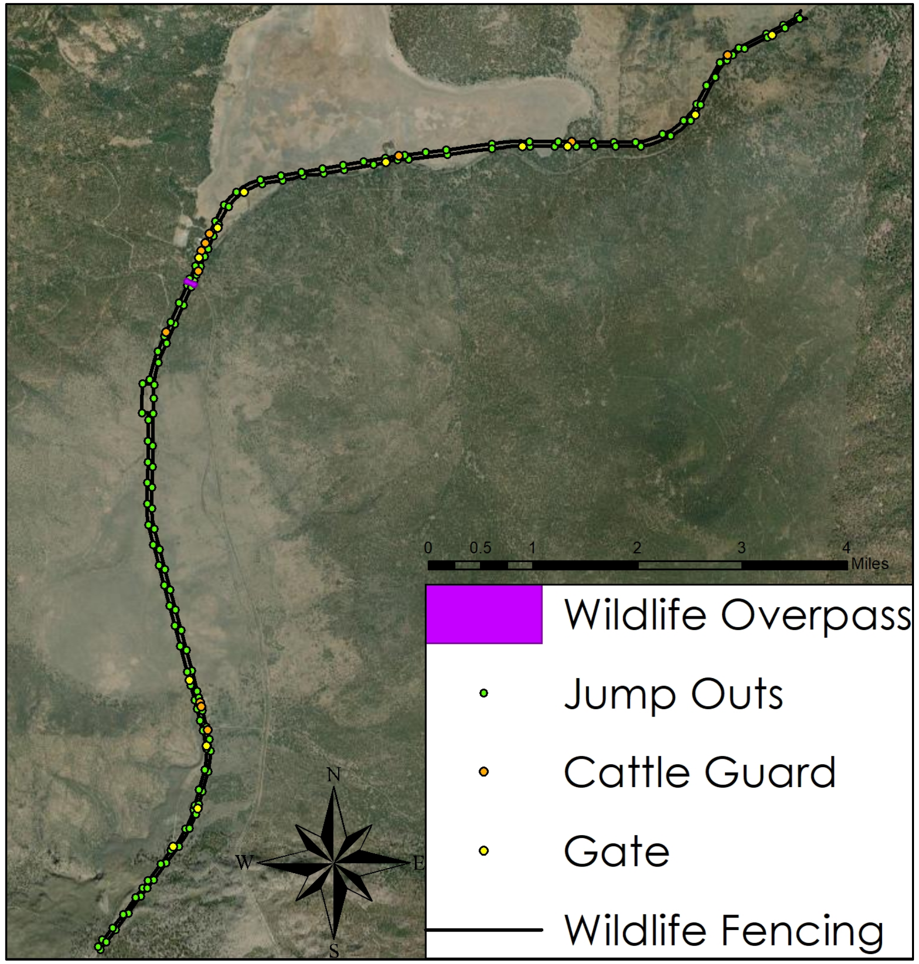


FRP Structural Designs



Life-Cycle Cost (LCC) Analysis

- Focuses on material type
- Excludes social and environmental costs
- 2.5% discount rate for future costs
- 100-year analysis
- 2019 United States Dollar



LCC Analysis: Superstructure

- Compares concrete, steel, and FRP girders
- Analysis includes girder manufacturing, transportation, construction, and maintenance
- 100 year minimum service life for FRP
- 75 year minimum service life for concrete and steel

Girder	Depth (in)	Unit Weight (lb/ft)	Total Weight (lbs)	Depth/Span Ratio
FRP Composite Tub	56	120	13,700	0.041
Prestressed Bulb Tee	54	686	78,200	0.039
Steel I-girder	54	280	32,000	0.039

LCC Analysis: Superstructure

- An FRP wildlife overpass along US-97 using the composite tub girder manufactured by AIT is estimated to cost 11% more than the prestressed concrete bridge and 30% less than the steel girder bridge over 100 years.

Wildlife Overpass Procedure	FRP	Concrete	Steel
Service life (years)	100	75	75
Manufacturing and construction costs ($)	6,151,984	5,664,678	8,890,676
Transportation costs ($)	250,000	50,269	77,376
Maintenance costs ($)	68,454	136,907	308,042
LCC Total ($)	6,470,438	5,851,854	9,276,094
LCC $/m^2 ($/ft^2)	3,724 (346)	3,369 (313)	5,339 (496)

LCC Analysis: Fencing Elements

- Compares wood, steel, and FRP elements
- Analysis includes initial earthwork, landscaping, material and construction costs
- 35-year service life for wood
- 50-year service life for steel
- 100-year service life for FRP

Mitigation Elements	Value
Total Wildlife Fence Length, mi (km)	18.2 (29.3)
Fencing Length, North of Overpass, mi (km)	8.4 (13.5)
Fencing Length, South of Overpass, mi (km)	9.9 (15.9)
Work Zone Length, mi (km)	9.0 (15.5)
Total Number of Fence Posts	8021
Total Number of Jump-outs	95
Total Number of Road Access Points	24

LCC Analysis: Fencing Elements

- Using recycled plastic FRP for wildlife fencing, jump-outs, and road access points along US-97 is estimated to cost 38% less than wood and 28% less than steel over 100 years.

Material Used	Wildlife Fencing 100-year LCC Estimates			
	Initial Construction ($)	Total ($)	$/Mile	$/ft
FRP	3,490,871	3,490,871	191,490	36
Steel	2,749,158	4,855,826	266,365	50
Wood	2,394,088	5,636,891	309,210	59

LCC Analysis Summary

- Initial costs of FRP for wildlife crossings may be higher than traditional materials but are cheaper over time with lower maintenance costs and longer service life
- An FRP wildlife overpass has maintenance costs estimated to be 50-80% less than steel and concrete equivalents
- Using FRP for the girders of a wildlife overpass and fencing elements has an estimated life-cycle cost ($9,961,309) about 5% less than using concrete and wood ($10,453,856) over 100 years

Project Conclusions

- FRP has a high strength to rate ratios and are extremely resistant to corrosion and environmental deterioration
- FRP is an advanced and adaptive material that has limitless opportunities for transportation infrastructure
- An FRP hybrid wildlife crossing and recycled plastic fencing elements can be designed and built along the US road network with minimal departure from DOT standard approval processes
- FRP is economically competitive with other traditional materials used in wildlife crossings over the service life of the structure

- Bell, M., Fick, D., Ament, R., & Lister, N. M. (2020). The Use of Fiber-Reinforced Polymers in Wildlife Crossing Infrastructure. *Sustainability*, *12*(4), 1557