

Use of Fiber-Reinforced Polymer Composites for Bridge Repairs in Montana

Intermediate TP Meeting, 08/22/2023

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Outline

- **Introduction**
- **FRP application techniques**
- **Timber bridge repair with FRP**
- **RC bridge repair with FRP**
- **Montana bridge repair with FRP**
- **Summary of Meeting with CDOT**
- **Expected Scope for Tasks 2 and 3**

Introduction

FRP Application
Techniques

Timber Bridge
Repair with FRP

RC Bridge
Repair with FRP

Montana Bridge
Repair with FRP

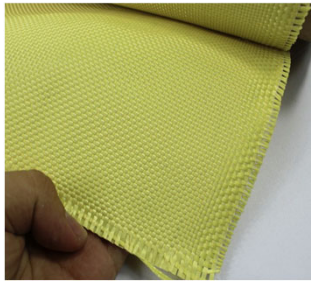
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CDOT Meeting

Scope
for tasks 2 and 3

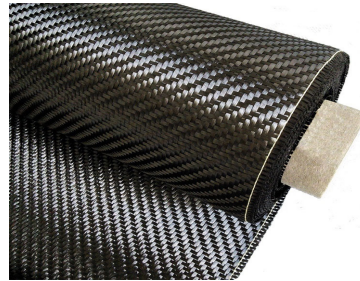
What is Fiber Reinforced Polymer (FRP)?

FRPs consist of a thermosetting or thermoplastic polymer matrix and embedded reinforcing fibers.

- **Fibers:** Aramid, Basalt, Boron, Carbon, Glass.
- **Fiber Architecture:** Nonwoven, woven, unidirectional, bi-directional.
- **Polymer matrix:** Epoxy, Vinyl ester, Polyurethanes.



Aramid fiber



Carbon fiber



Glass fiber



GFRP rebar



FRP sheet piling

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Advantages

- High strength-to-weight ratio
- Resistant to corrosion
- Less installation time (less traffic closure)
- Appearance



Disadvantages

- Failure at high temperature (glass transition temperature)
- Expensive
- Toxic to workers
- Difficult to apply (debonding)

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External wrapping

- Most common methods of using FRP for strengthening and repairing.
- Three main processes:
 - Wet layup systems,
 - Prepreg systems,
 - Precured systems.
- FRP wet layup method involves:
 - Surface preparation,
 - Fiber fabric placement,
 - Epoxy resin application.



External wrapping, Bridge A5657, Missouri
(Parretti et al. 2003)

Near Surface Mounted (NSM) bars

- Used to strengthen beams, columns, and beam-column connections.
- NSM application method includes:
 - Cutting a series of shallow channels on concrete or masonry surfaces in the desired direction,
 - Partially filling with epoxy mortar,
 - Placing reinforcements into the channels,
 - Smoothing the surface.



Strengthening with NSM bar,
(Aiswarya and Prabhakaran, 2017)

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Laminates

- The application process involves:
 - Preparing the structure surface,
 - Attaching FRP laminates using an epoxy resin system,
 - Mechanical fasteners are often used to prevent debonding.



FRP laminates,
(Morsy and Mahmoud, 2013).

FRP strips

- FRP strips are commercially available in varied sizes.
- FRP strips require less installation time.
- Do not require skilled labor.
- Application process of FRP strips:
 - Predrill or mark the fastener location on the FRP strip,
 - Clean the surface of the structure,
 - Place and clamp the FRP strip on the structure surface,
 - Fasten the FRP strip to the structure with bolts.
- Selecting bolts is critical while strengthening with FRP strips.



FRP strips,
(Schorer et al., 2008).

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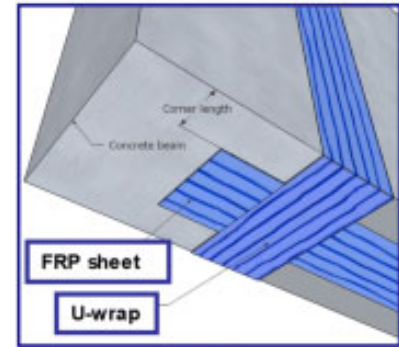
Scope for tasks 2 and 3

	External Wrapping	Laminates	NSM bars	FRP strips
Advantages	<ul style="list-style-type: none">• Simple application process, especially with the wet layup method, leading to faster installation.• Suitable for various structural shapes and configurations.• Enhances corrosion resistance of the strengthened elements.• Relatively lower cost compared to other FRP strengthening methods.	<ul style="list-style-type: none">• Offers a high-strength reinforcement system with excellent mechanical properties.• Lightweight and can be easily applied on various surfaces.• Long-term durability and resistance to environmental degradation.	<ul style="list-style-type: none">• Provides excellent confinement and flexural strengthening to reinforced concrete elements.• Can be concealed within the structure, preserving aesthetics.• Offers enhanced durability and resistance to environmental factors compared to external wrapping.	<ul style="list-style-type: none">• Offers localized strengthening to targeted areas.• Easy to handle and apply.• Can be a cost-effective option for specific strengthening requirements.
Disadvantages	<ul style="list-style-type: none">• May affect aesthetics.• Vulnerable to damage during installation.• Can be sensitive to environmental conditions during installation (e.g., temperature, humidity).	<ul style="list-style-type: none">• Requires precise surface preparation and bonding to ensure effective adhesion.• Thicker laminates may add thickness to the structure, affecting aesthetics.• Susceptible to damage from impact.	<ul style="list-style-type: none">• More complex installation process than external wrapping or strips.• Requires precise cutting and grouting, which can be time-consuming and labor-intensive.• Difficult to apply on thin or lightweight structures.	<ul style="list-style-type: none">• Limited load-carrying capacity compared to full external wrapping or laminates.• May require careful surface preparation for adequate bonding.• May not be suitable for heavily loaded structural members.

Anchorage systems

➤ U-wrap:

- Providing layering in the transverse direction reduces debonding.
- Two key parameters for transverse wrapping are the angle and number of wraps.
- Multiple 90° U-wraps enhance ductility, while 45° U-wraps maximize overall capacity.

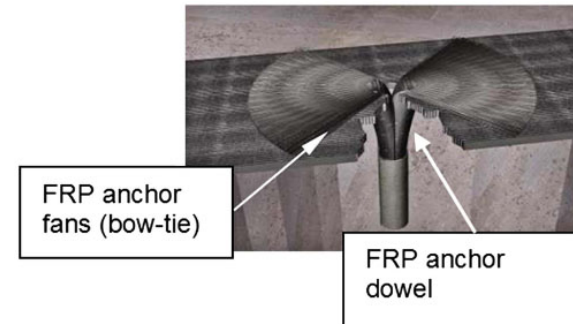


U-wrap,

(Lee and Lopez, 2020)

➤ Spike anchorage:

- This anchorage system has two parts:
 - Anchor dowel; inserted into a predrilled hole,
 - Fan; fanned out and epoxied over the external wrapping.
- This technique is more suitable for wide elements like walls and slabs.



Spike anchorage,

(Kalfat et al., 2013).

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Anchorage systems

➤ Mechanical Anchorage:

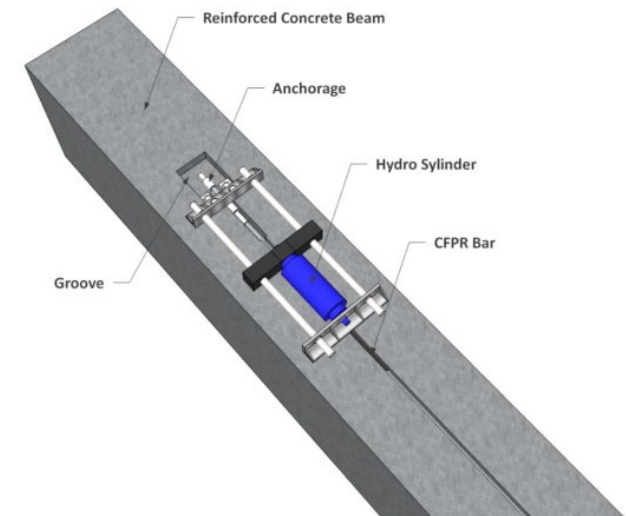
- Bolts are commonly used at different locations, especially at the ends, to securely hold the FRP laminates.
- To prevent the brittle failure of structures strengthened with FRP strips, mechanical anchorage at the ends is provided.



Mechanical anchorage,
(Kalfat et al., 2013).

➤ Anchorage for NSM bars:

- Anchorage is required at the ends of FRP NSM bar applications to prevent slippage of the FRP bar.
- Anchorage is also necessary for prestress NSM systems to reduce the prestress loss.



Anchorage for NSM,
(Lee et al., 2017).

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Timber Bridge Repair with FRP

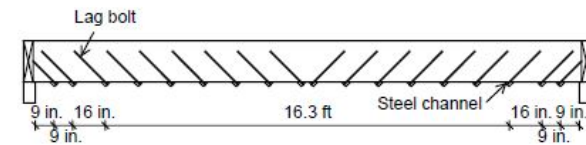
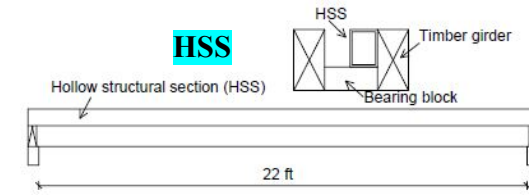
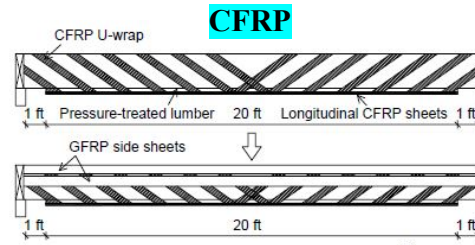
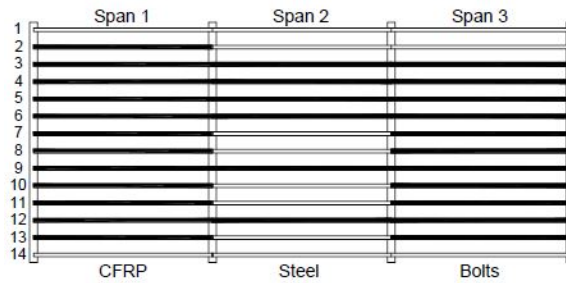
RC Bridge Repair with FRP

Montana Bridge Repair with FRP

Summary of CDOT Meeting

Scope for tasks 2 and 3

Timber girder



Timber bridge in Washington County, Colorado [Kim 2023]



Covered wooden bridge in Sins, Switzerland [Meier 2000]



Timber railroad bridge in Moorefield, West Virginia [Smith 2004]



Introduction

Timber pile

FRP Application Techniques

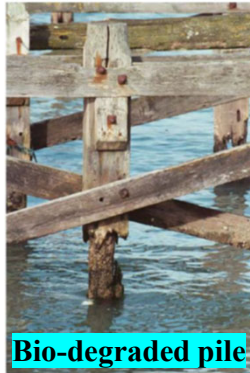
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Bio-degraded pile

Simpson Strong-Tie



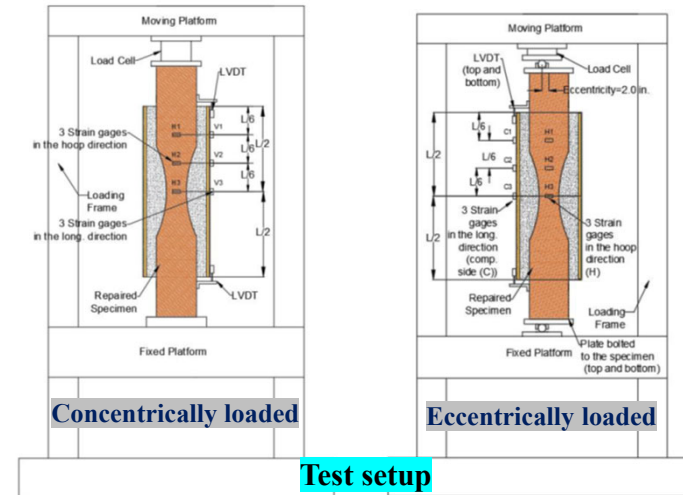
Denso



Pilemedic

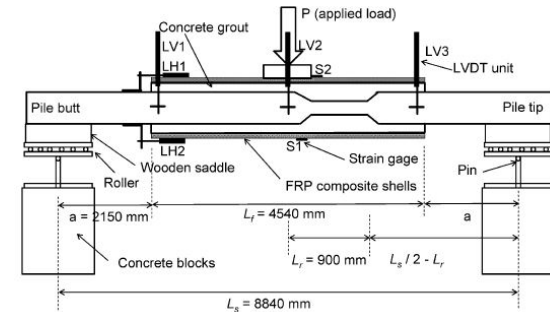
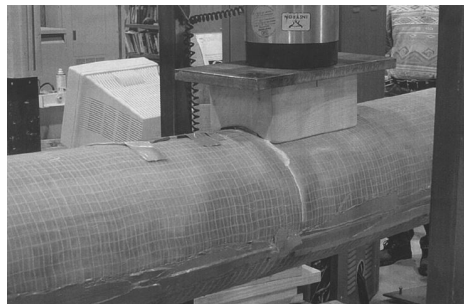
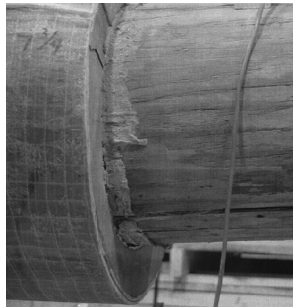


Repaired timber piles



Test setup

Deteriorated timber pile rehabilitation, Louisiana [Menkulasi et al. 2017]



Test setup

FRP repaired wood pile evaluation under bending tests, University of Maine [Anido et al. 2003]

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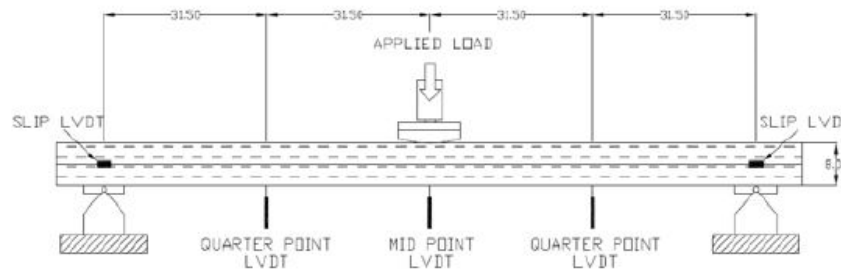
Timber pile cap



FRP strips



Composite beams



Test setup



Mechanically Fastened FRP Strengthening for Timber Pile Caps in Wisconsin Railroad Bridges [Schorer et al., 2008]

Introduction

RC girder

FRP Application Techniques

Timber Bridge Repair with FRP

Cracked girder



Repaired girder

Retrofit of the Louisa-Fort Gay bridge, Kentucky [Choo et al. 2007]

RC Bridge Repair with FRP

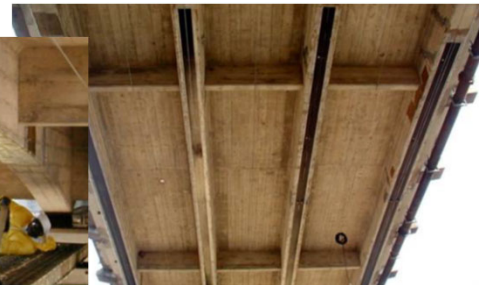
Montana Bridge Repair with FRP

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Application of FRP



FRP-strengthened girders

Repair of the Uphapee Creek bridge, Alabama

[Carmichael and Barnes 2005]



Repair of Route 378 Bridge, New York

[Elsafi et al. 2001]

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RC pile/column

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Corrosion damaged column



Repaired column

Repair of corrosion-damaged columns, Michigan [Harichandran and Baiyasi 2000]



Damaged pile 11.9.2004

Using boat



Application of FRP



Using divers

Corrosion repair of submerged concrete piles of Friendship trail bridge, Florida [Sen and Mullins 2007]

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RC pile cap

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FRP jackets for deteriorating pier cap of Silver Spring Cove Bridge, Rhode Island
[Balaguru and Lee 2005]



FRP-repair of the Morganza Spillway bridge pile cap, Louisiana [Gopu and Balaguru 2016]

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Timber bridge

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- 56 bridges underwent FRP jacket repairs on piles, with varied application heights.
- Current inspection results indicate that most of the repaired timber bridges show no significant signs of deterioration or damage and are performing as expected.

Montana Bridge Repair with FRP

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**Bridge #02568, Piles 4 and 5 of Bent 2
were FRP wrapped for full height.**



**Bridge #06131, Bottom 4ft of Bent 4
Pile 1 was FRP repaired.**

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RC bridge

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RC Bridge
Repair with FRP

- Nine RC bridges were repaired using FRP wrap, targeting different elements such as girders, caps, piles/columns.
- FRP-repaired bridges were in good condition, except bridge #02096 displayed random delamination in the FRP repair area.

Montana Bridge Repair with FRP

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Bridge #01044, girder repair



**Bridge #01490, bent cap
repair**



**Bridge #02096, random
delamination of FRP repair**

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Motivation

Consistent issues with split timber girders.

Strengthening techniques

- External wrapping with CFRP
- Lag bolts
- HSS sister beams

Key points

FRP

- Filling the split with epoxy was not possible because they weren't wide enough.
- Labor-intensive.

Lag bolts

- Didn't add enough strength to stop current loads from re-splitting the girders.
- Expensive.

HSS

- Harder to install upfront, it exhibited the expected long-term behavior.
- No maintenance required.
- Recommended HSS repair method for the future.



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Recommendations from the CDOT meeting

- Keep weather and temperature in mind during application.
- U-shaped “formwork” for FRP to hold in place.
- Purchase the FRP with the required size. Otherwise, cutting the FRP is very labor-intensive and difficult QA/QC in the field.
- HSS could be difficult for single-span bridges – less room to slide in because of the end blocking.
- Potential for future research: need to know what load distribution factors should be used on composite sister beam systems.
- Know upfront how to do the post-inspections.

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Potential applications

Single span bridge

- Sister beam placement is difficult because of the end blocking.

Exterior girder

- Difficult to attach sister beam.
- Labor-intensive (need to remove the rail and pull all the nails out).

U-shaped formwork

FRP strips/Laminates with MF (bolts, screws)

- Application of FRP with epoxy is labor-intensive and complicated.



Timber bridge in Washington County,
Colorado [Kim 2023]



FRP strips,
[Colgrove 2015]

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Lab testing

Find bridge

Mimic the damaged element (i.e., girder)
in the lab or collect similar elements

Apply FRP strengthening techniques
and existing repair technique used by MDT

Lab test in different temperature
conditions

Summarize the test results and
feasibility/applicability of FRP techniques

Field application

Applying FRP strengthening
techniques in the field

Load test using truck

Post monitoring

Open Discussion

Thank you!