Innovative FRP Solutions for Repair of Tunnels and Manholes

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Outline of Presentation

- Introduction to FRP
- Wet Layup
  - Tunnel Repair
  - Pipe Repair
  - Asset Management
- FRP Laminate for Internal Repair of Pipes
- Sandwich Construction for Manholes & Walls
- InfinitPipe®

Civil Engineering Materials

- **Compression (Concrete, Masonry, etc.)**
- **Tension (Steel)**

Problem:

Capacity of members is often governed by insufficient area or poor detail of steel reinforcement.

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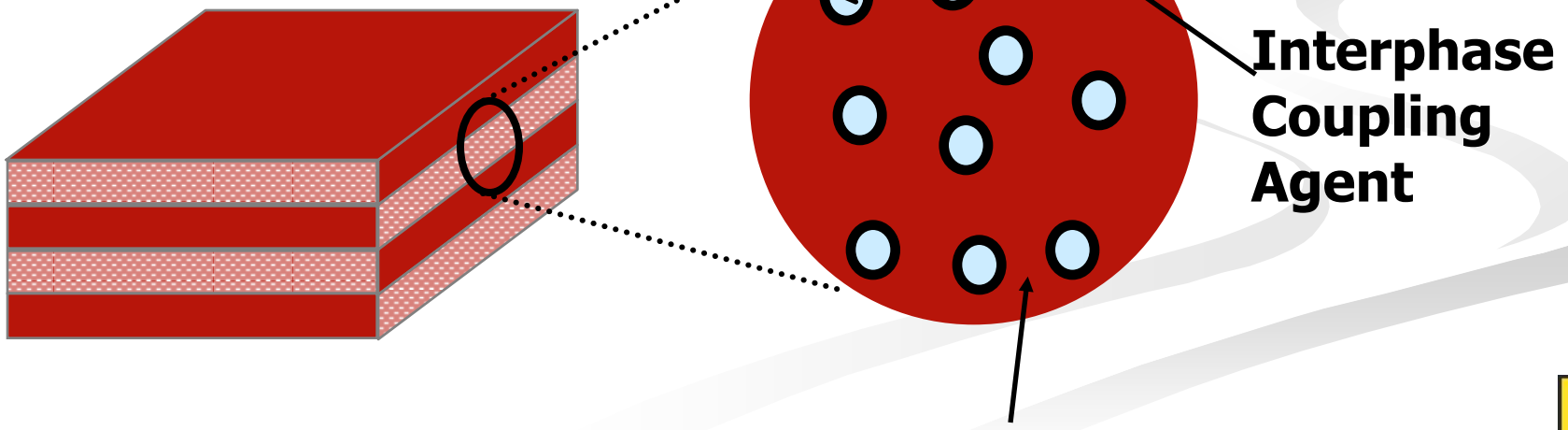
Fiber Reinforced Polymer (FRP)

Why is it called FRP?

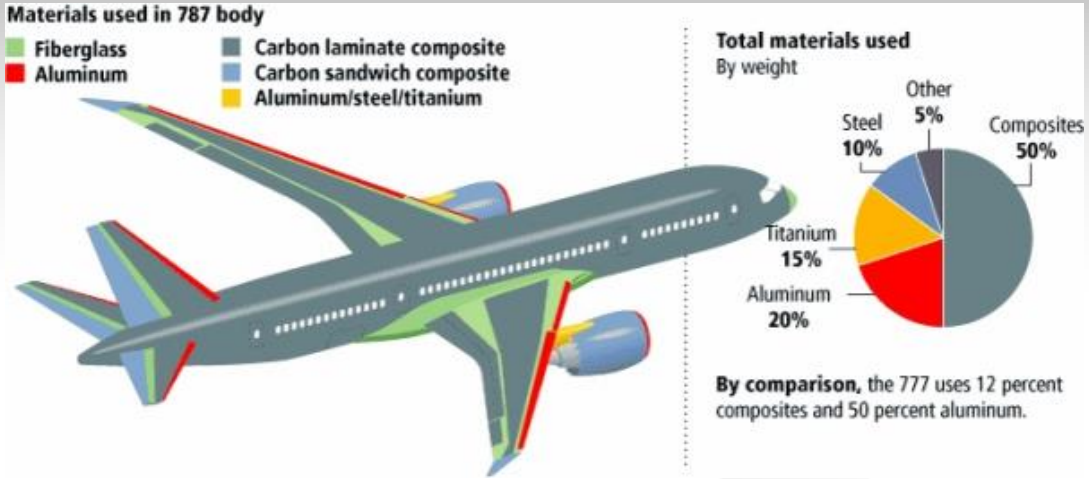
- It is a Polymer (i.e. epoxy, vinyl ester, etc.) that has been reinforced with a Fiber (e.g. carbon, glass, etc.)
- FRP does not have the same strength in all directions; these types of materials are called *anisotropic*



FRP Products

History of FRP in Various Industries

Corvette C1 - 1953



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FRP Version 1.0 Introduced March 1990

Epoxy-bonded glass fiber-reinforced plastic plates may provide a corrosion-free solution to increasing the load-carrying capacities of concrete bridges.

Fiber Composite Plates Can Strengthen Beams

by H. Saadatmanesh and M. R. Ehsani

About one-half of the approximately 600,000 highway bridges in the United States are in need of replacement or rehabilitation. Many of these bridges were originally designed for smaller vehicles, lighter loads, and lower traffic volumes than are common today.[1] Consequently, a large number of bridges in this country have inadequate load carrying capacities for today's traffic. Compounding this problem is the loss of strength due to corrosion of reinforcement and spalling of concrete.

These bridges must be either replaced or rehabilitated if present and future traffic needs are to be adequately served. In many cases, maintenance alone will not bring a structurally deficient bridge up to current standards — strengthening (which costs far less than replacement) must also be considered.

Among the methods used to strengthen girders in existing bridges are external post-tensioning and the addition of epoxy-bonded steel plates to the tension flange. External post-tensioning by means of high-strength strands or bars has been successfully used to increase the strength of girders in existing bridges and buildings.[2-7] This method does, however, present some practical difficulties in providing anchorage for the post-tensioning strands, maintaining the lateral stability of the girders during post-tensioning, and protecting the strands against corrosion.

The addition of epoxy-bonded steel plates to the tension face of concrete girders has been used effectively in Europe, South Africa, and Japan.[1] This method is primarily used to repair and strengthen reinforced concrete elements with insufficient load carrying capacity due to mechanical damages, functional changes, or corrosion. The principles of this strengthening technique are fairly simple: steel plates are epoxy-bonded to the tension flange of the beam, increasing both the strength and stiffness of the girder; the shear capacity of the girders can also be increased by attaching steel yokes to the web.

The advantages of this structural system include ease of application and elimination of the special anchorages needed in the post-tensioning method. A shortcoming of the method is the danger of corrosion at the epoxy-steel interface, which adversely affects the bond strength. An effective way of eliminating the corrosion problem is to replace steel plates with corrosion-resistant synthetic materials such as fiber composites. In addition to corrosion resistance, many fiber composites have tensile and fatigue strengths that exceed those of steel.

Previous studies

Much of the work in the United States has been related to the bonding of steel to steel,[8,9] while in other countries research has primarily been related to the bonding of steel to concrete.[1] Several researchers have investigated the strengthening of existing concrete girders with epoxy-bonded steel plates.[10-15]

MacDonald and Calder studied the behavior of concrete beams externally reinforced with steel plates bonded to their tension flanges.[10] They tested a series of 11.5-ft (3.5-m) and 16-ft (4.9-m) long beams in four-point bending. Each beam had a rectangular cross secton of 6 x 10 in. (150 x 250 mm). It was concluded that substantial improvements in performance could be achieved in terms of ultimate load,

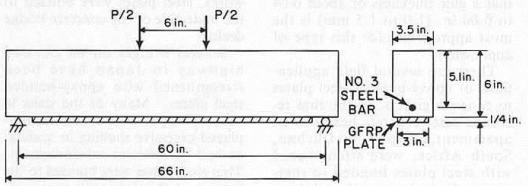

Fig. 1. — Beam test setup.

Original Concept Demonstration

Carbon FRP instead of reinforcing steel

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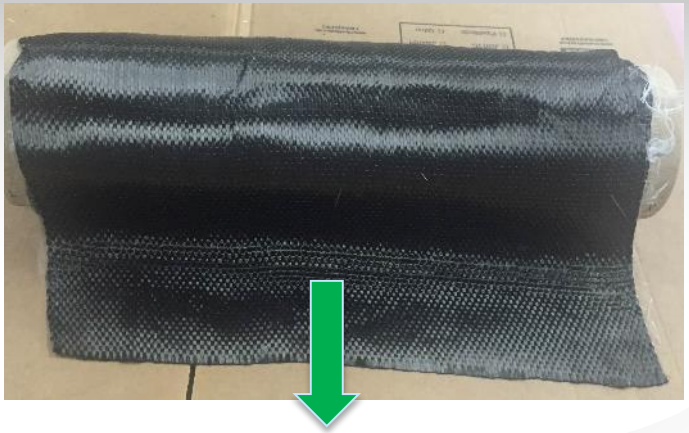
Blast Protection

Advantages of FRP

- **High Tensile Strength *(3-5 times stronger than Steel)***
- **Low Weight *(no foundation adjustments required)***
- **Corrosion Resistance & Protection**
- **Chemical Protection**
- **Waterproof**
- **Speed of Construction**
- **Versatility**
- **Odorless & Non-Toxic (QuakeWrap Products)**
- **NSF-61 Certified for pipes ≥ 8 inches**
- **Minimal Investment**

Design with FRP

- **ACI Committee 440**
- **Steel:**
  No. 7 Gr. 60
  T = (0.60)(60) = 36 kips
- **Carbon FRP:**
  6 inch-wide strip
  T = (6”)(6 k/”) = 36 kips



Carbon Fabric

Thickness: 0.05 in. (1.3 mm)
Weight: 0.38 lb/ft^2 (1.83 kg/m^2)
T = 6000 lb/in. (1050 N/mm)

One layer of this fabric ≈ No. 7 Gr. 60 placed at 6 in. o.c.

Note: Little change in weight or thickness

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Sample Projects

Testing + R&D

Condo, FL

Piles, Australia

Bridge, NM

Settling Tank, MX

UN Lebanon

High Rise, AK

Pipe, Costa Rica

Kazakhstan

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AZ State Hospital Utility Tunnel

Utility Vault (Pull Box)

Tucson Electric Power

Utility Vault (Pull Box)

Tucson Electric Power

Univ. of Arizona North Tunnel

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Univ. of Arizona North Tunnel

Univ. of Arizona North Tunnel

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El Encanto Hydropower, Costa Rica

1750m x 2.1m diameter (July 2009)

Sloped Terrain

Water seeping into pipe

Leaks continued after cracks were filled

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El Encanto Hydropower, Costa Rica

1.1 miles x 84-inch diameter (July 2009)

Four 600x600mm Access Ports

Poor surface conditions req'd much prep

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El Encanto Hydropower, Costa Rica

Challenge: Not only strengthen but to leak proof

Successful pressurization tests on July 15, 2009

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Steel Pipes for 300° F Air, Carlsbad, CA

42" curved pipe (August 2011)

Tests of Steel Pipes (5-inch Dia.)

Pertamina Oil Company, Indonesia

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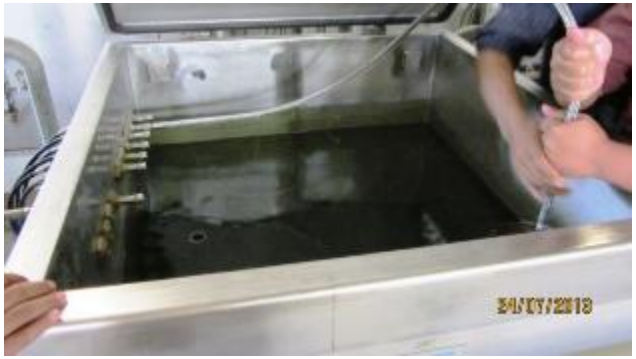
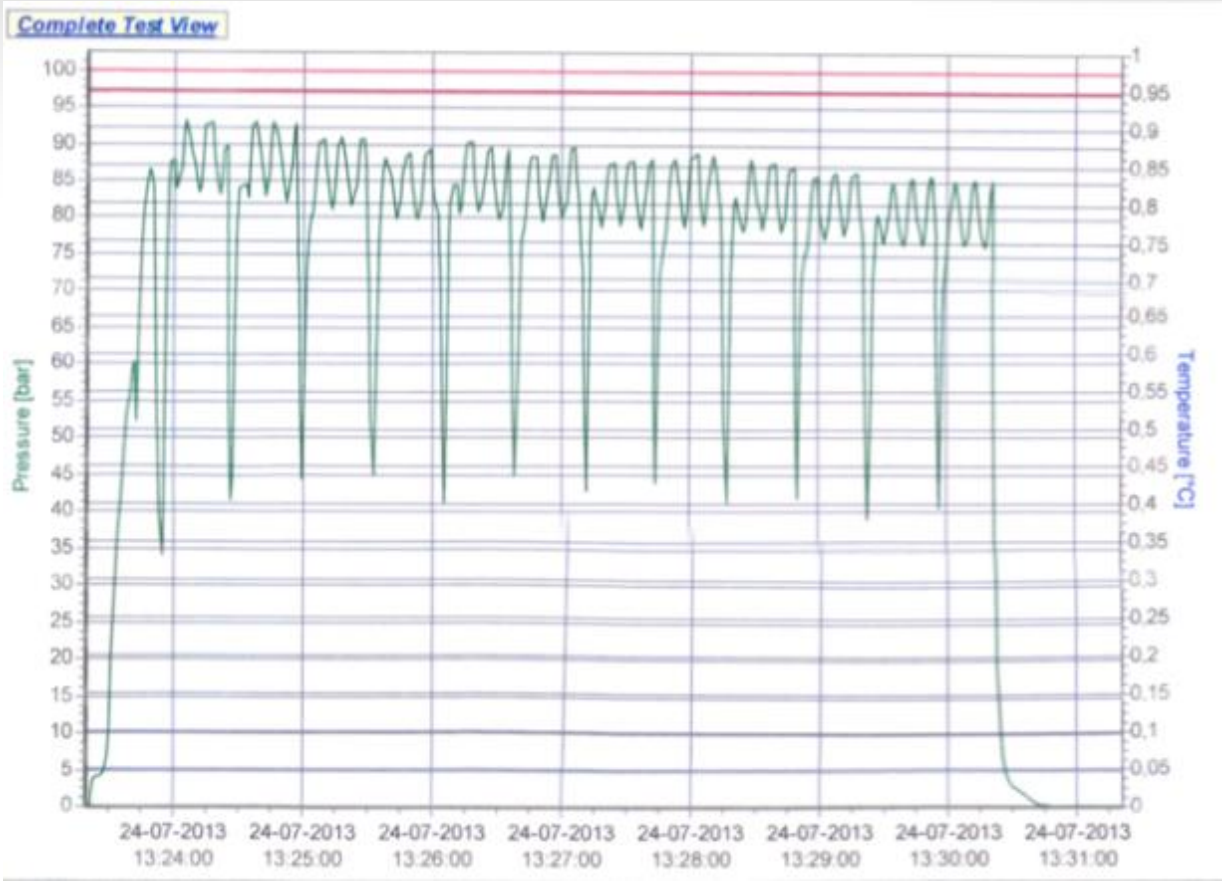
Test of Steel Pipe to 1300 psi (90 bar)





Wet Layup Repair of Pressure Pipe in water

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Corroded Steel Pipe in Mine

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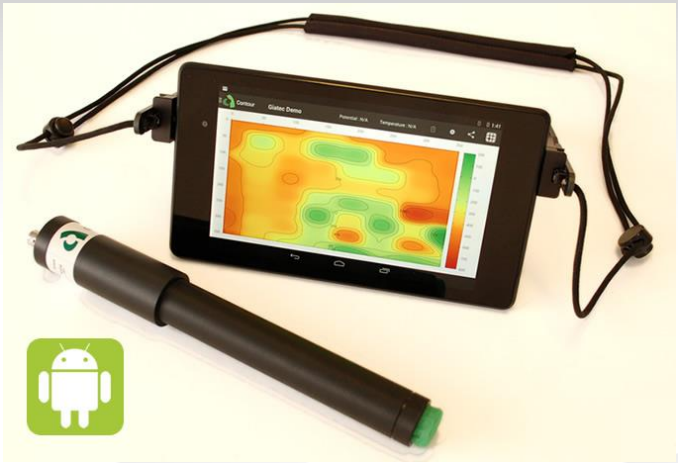
Asset Management

- **ASTM C876 Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete**
- **Requires hard wire connection to reinforcing steel**
- **Tablet-based NDT Probe**
- **Bluetooth wireless sensor**
- **Generates half-cell contour plots (i.e. corrosion maps) in real time**
- **Easy grid generation**



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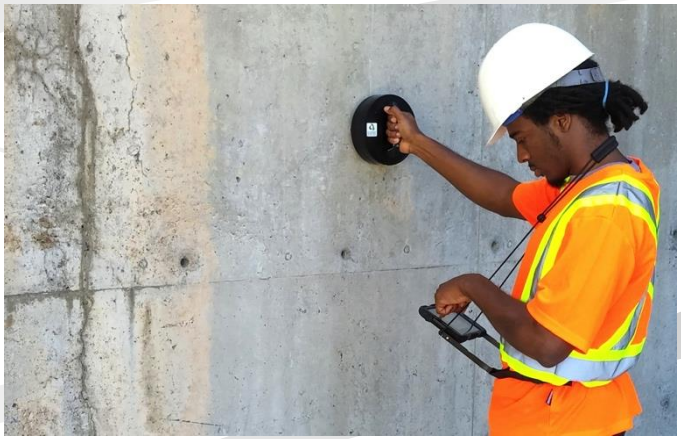
Asset Management

- Non-invasive
- No hard wiring required
- Very fast rate to measure:
  1. Corrosion rate of rebar
  2. In-situ electrical resistivity of concrete
  3. Corrosion potential of rebar
  4. Ambient temperature & relative humidity



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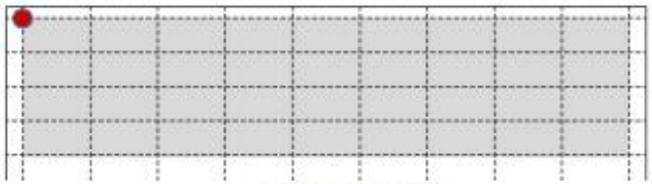
Case Study: Bridge Abutment



Abutment Wall

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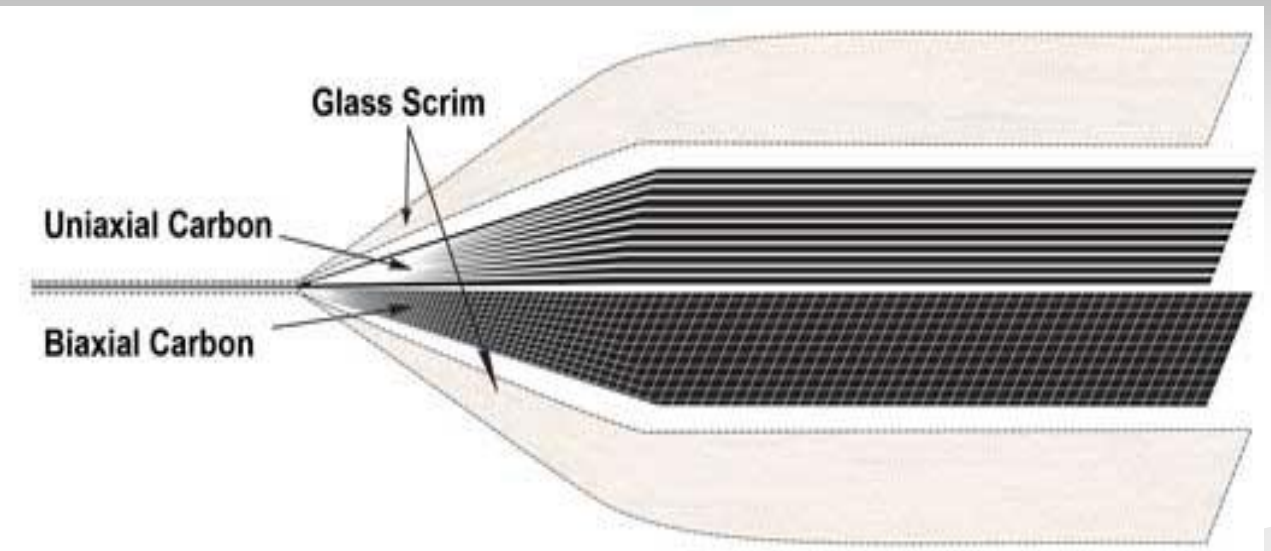
Multi-Layered SuperLaminate™
(Patent Pending)



- **Multi-Axial Reinforcement**
- **Thickness ≈ 0.01 -0.025 inch (0.25-0.67mm)**
- **Tensile Strength ≈ up to 155,000 psi (1030 MPa)**
- **Infinite combinations of strength & stiffness can be produced**
- **ISO 9000 Certified**

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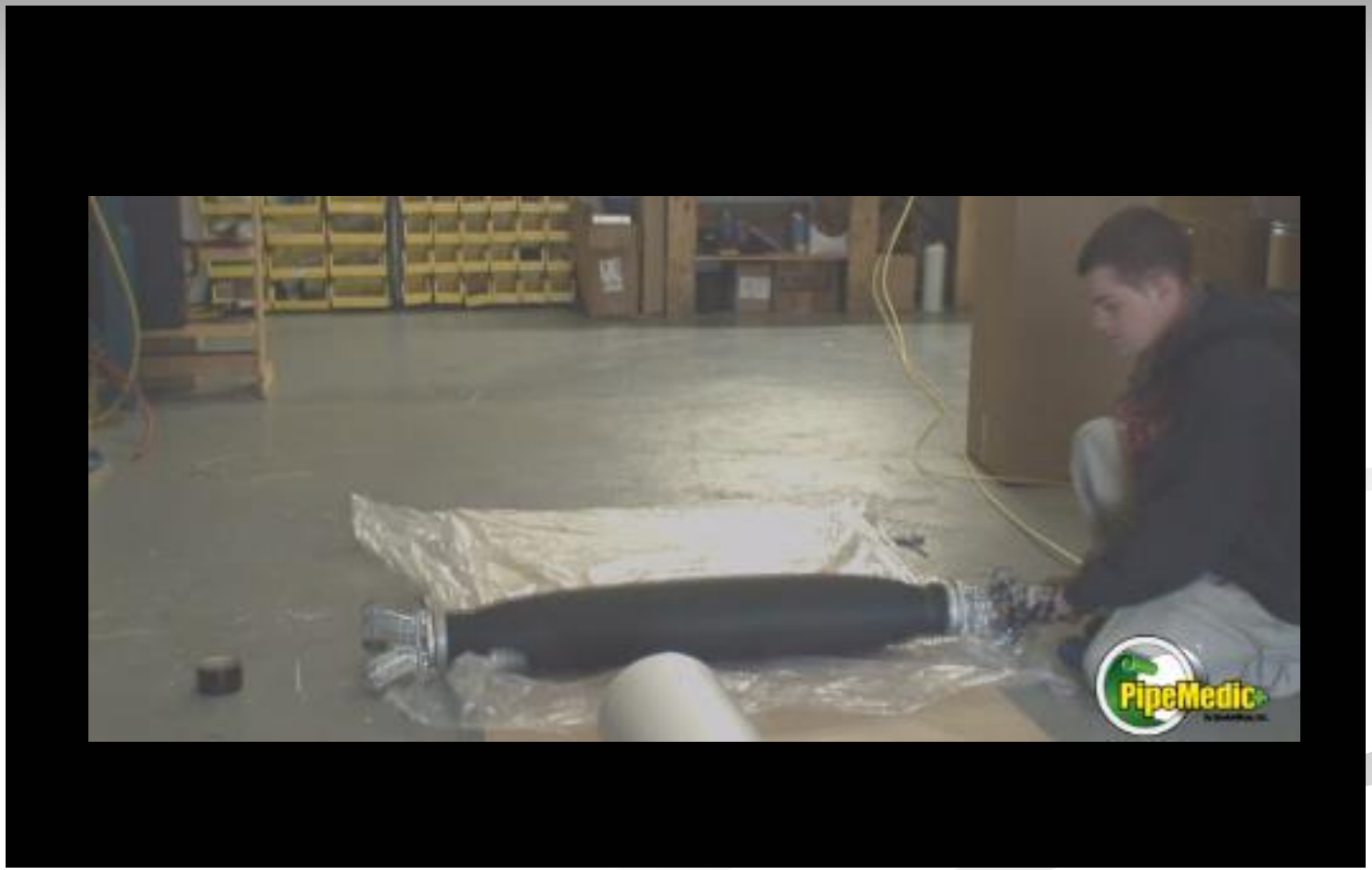
Small (200mm) Diameter Pipe Repair



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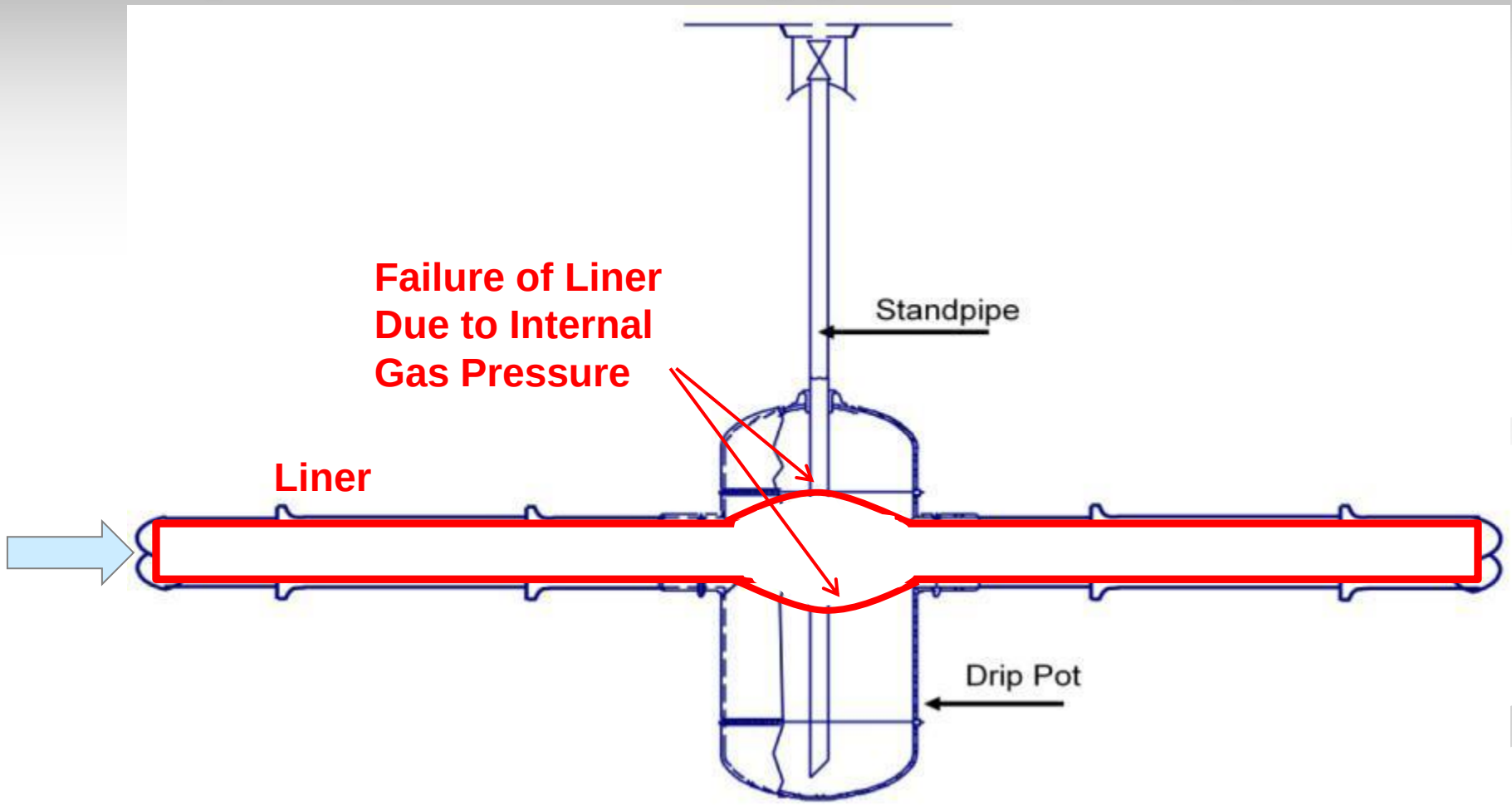
Bridging a Gap in a Pipeline
(Gas Technology Institute)



How do we create a pressurized pipe?

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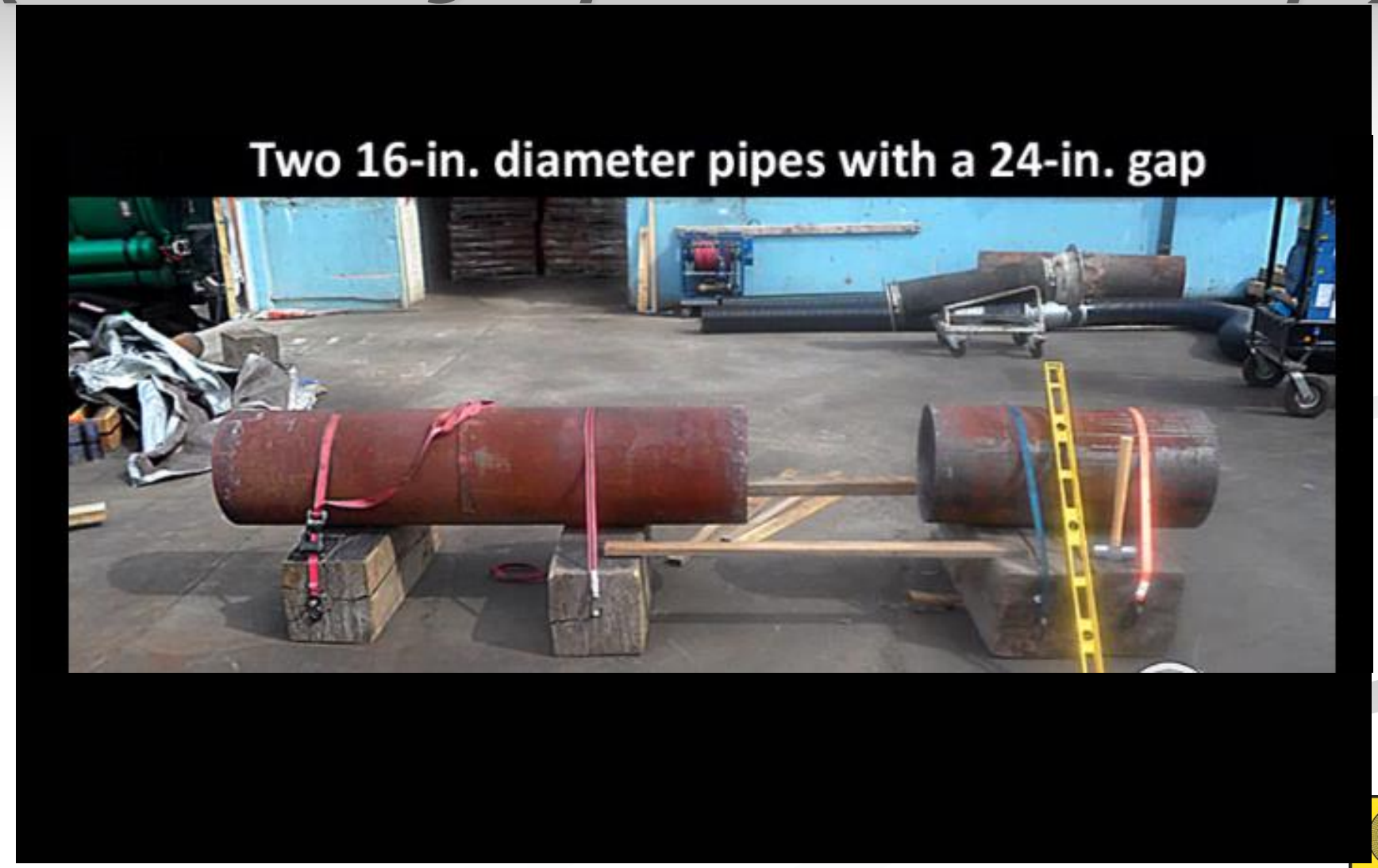
Bridging a Gap in a Pipeline

(600mm Long Gap in 400mm Diam. Pipe)



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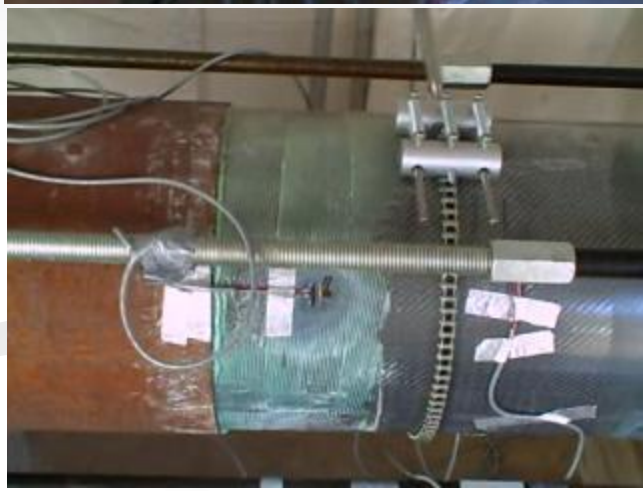
Pressure Testing

on October 16, 2010

- **Gas Technology Institute**
- **Max Operating Pressure = 60 psi (4.1bar)**
- **Tested to 250 psi (17.2 bar)**
- **Ultimate Capacity = 900 psi (62 bar)**



Field Application

- First Project was completed in Feb 2011
- Client: PSE&G (NJ Gas Utility)
- Contractor: Progressive Pipeline Management
- 2-ft gap in 16” cast-iron pipe
- Winner of ……..

  2011 Trenchless Technology

  Project of the Year Award

- Over 40 Such Repairs

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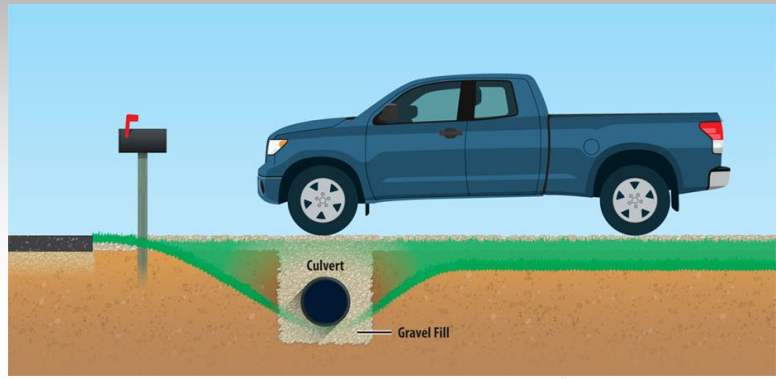
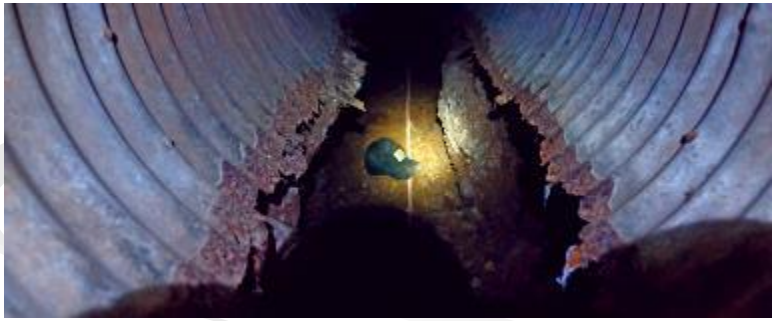
Repair of CMP Culvert

- **Invert of culverts corrode easily**
- **Similar to a weak bridge, corroded culverts limit the load-carrying capacity of roadways**
- **Replacement causes traffic delays, takes time and $$**
- **In-situ repair is faster/economical; no traffic disruption**





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Composite Sandwich Concept

Steel I-beam

RELATIVE STIFFNESS	1
WEIGHT (Pounds/ft^2)	0.910

Gillies Road Culvert

Cairns, QLD

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Gillies Road Culvert

Cairns, QLD

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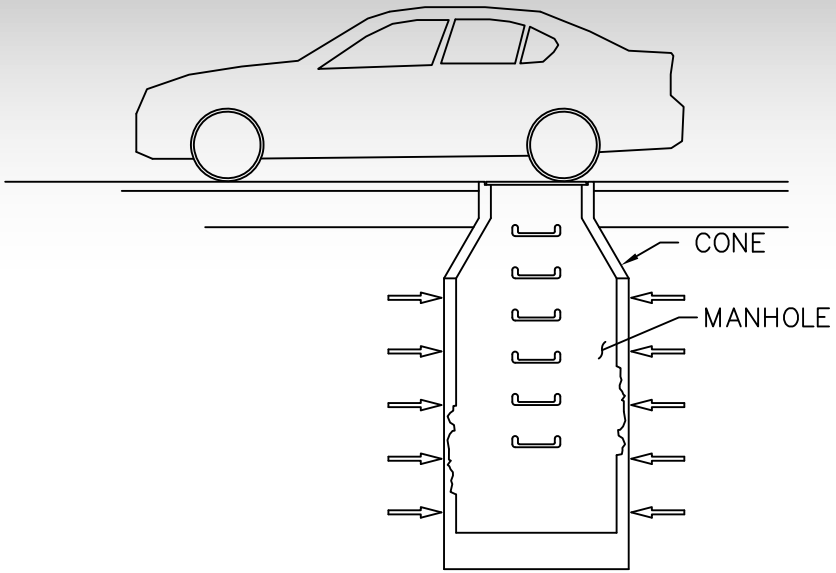
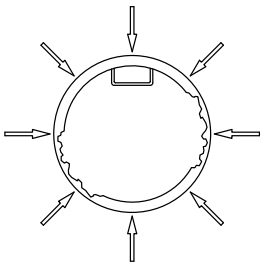
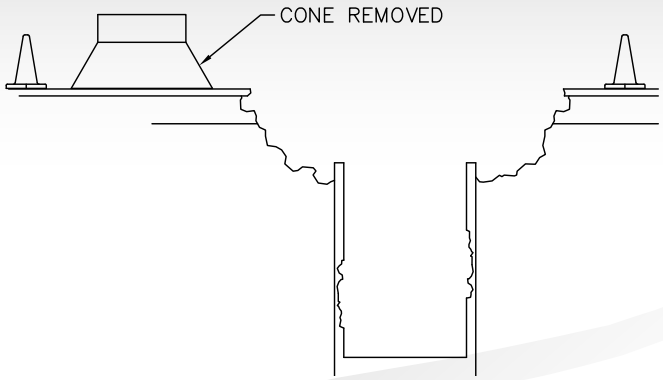
Gillies Road Culvert

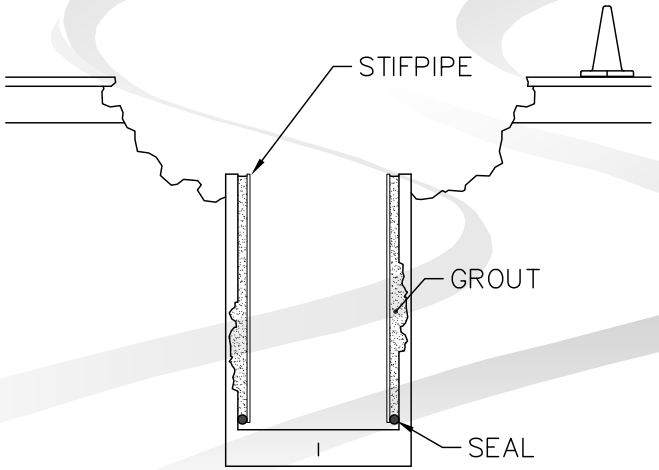
Cairns, QLD

Repair of Manholes with StifPipe®







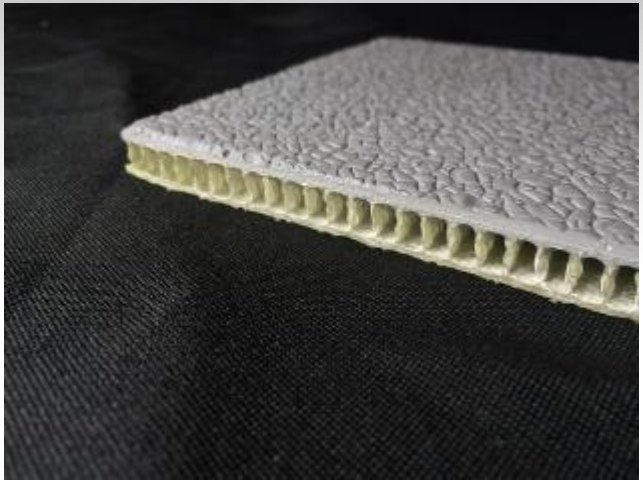


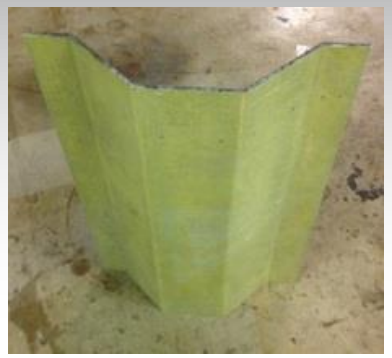
Repair of 29 Manholes in Pressure Pipe

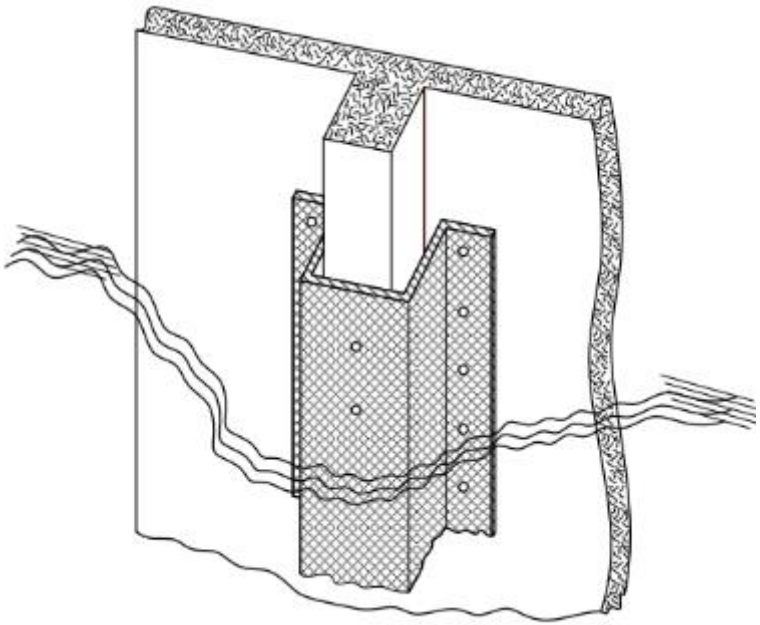
(Aguirre, Puerto Rico)

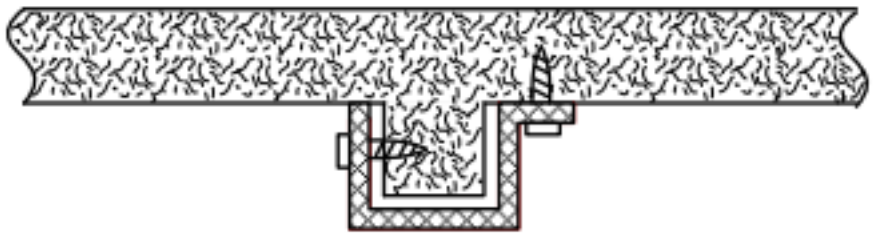
Stay-In-Place Forms

(Patent Pending)









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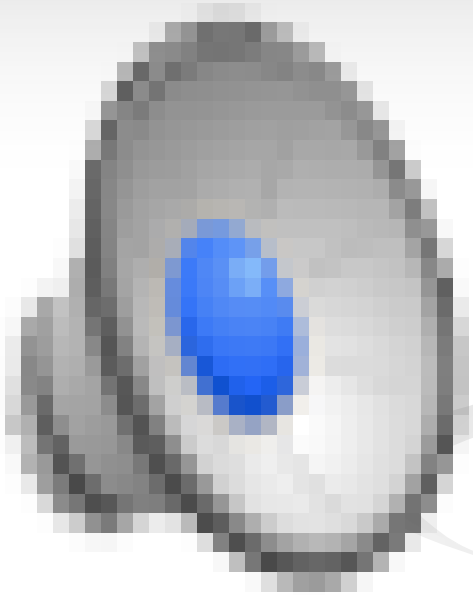
Onsite-Manufactured InfinitPipe®



Services Offered

- **Turnkey Design-Build**
  - **NDT Evaluation / Asset Management**
  - **Sealed Engineering Drawings in 50 States**
  - **All Materials**
  - **Installation**
- **Accepting Full Responsibility for Repair**

Thank you for your Attention!

Questions?

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