Spillway Conduit Rehabilitation – Key Factors to Know

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MADCS 15th Annual Workshop / October 30, 2024

Montana Association of Dam and Canal Systems
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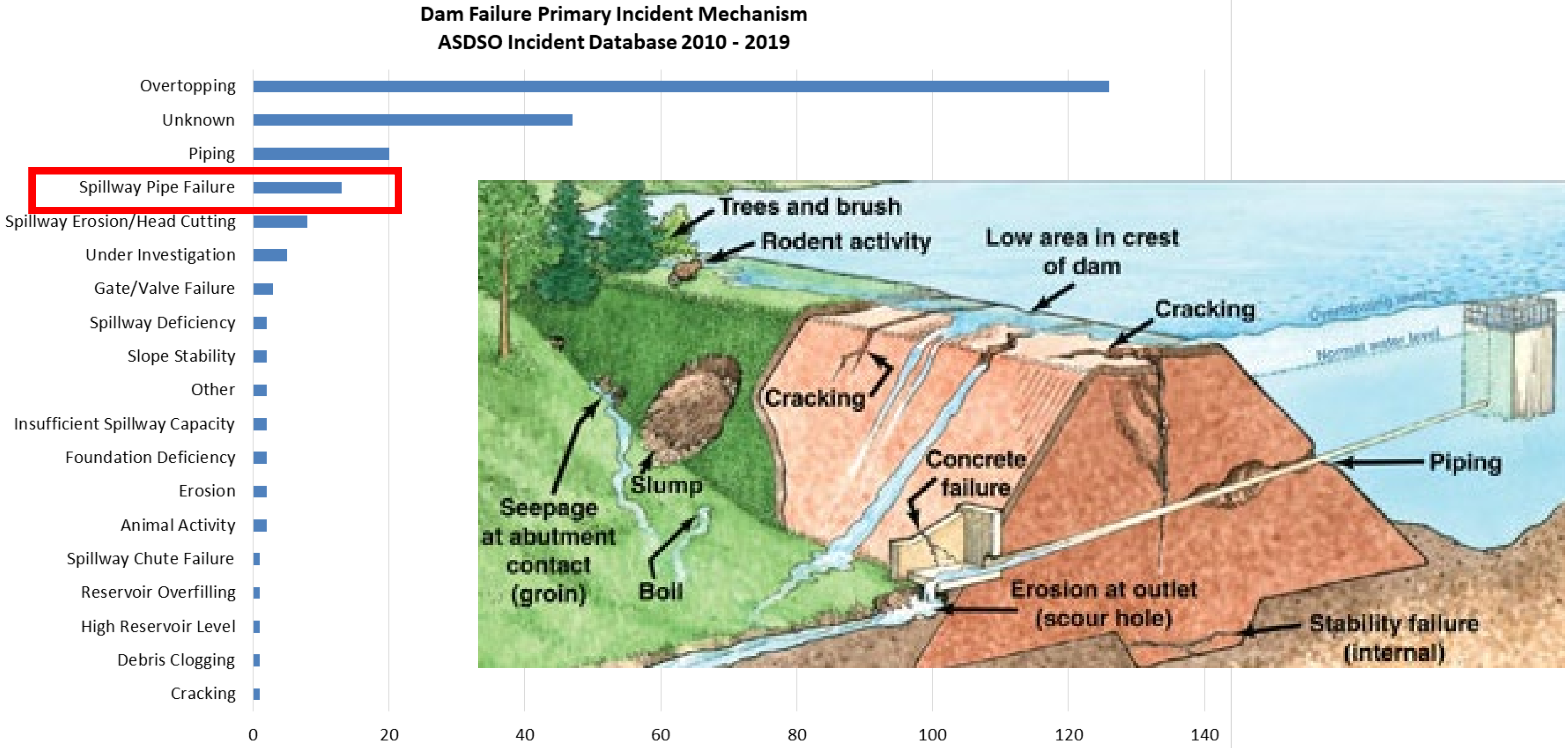
Presentation Outline

- How Do Dams Fail and Why are Spillway Conduits Important?
- Conventional Spillway Conduit Rehabilitation Methods
- Conduit Materials Typically Used in Embankment Dams
- General Approaches to Designing Conduits in Embankments
- Design and Construction Considerations for:
  - Replacement Spillway Conduits
  - Sliplining
  - CIPP Liner

How Do Dams Fail?



REMINDER

A conduit is a discontinuity that creates opportunities for seepage, settlement, and cracking that can lead to uncontrolled leakage and failure.

Deteriorated CMP Spillway Conduits

Conventional Spillway Conduit Rehabilitation Methods

Conduit Materials Typically Used in Embankment Dams
Concrete Pipes

- Reinforced Cast-in Place Concrete
  - Long history of use by major federal agencies
- Precast Concrete – RCP, RCCP, and PCCP
  - USBR prohibits use of precast concrete conduits through embankment dams
  - NRCS uses RCCP/PCCP for embankments dams
- Aggressive water or soil chemistry can limit service life

Conduit Materials Typically Used in Embankment Dams
Plastic Pipes

- Primarily used for sliplining existing conduits or drainpipes
- Shorter service life (~50-yr) compared to concrete conduits (~100-yr)
- Less robust joint integrity
- Do not bond well with soil and require full encasement

- Thermoplastic
  - Solid materials that change shape when heated
  - PVC or HDPE (preferred for sliplining)
- Thermoset
  - Rigid after curing and cannot be reformed
  - CIPP

Conduit Materials Typically Used in Embankment Dams
Metal Pipes

- Steel
  - Used in some sliplining applications
  - More often used as liner in reinforced cast-in place concrete conduits
  - Protected with a variety of linings and coatings
  - Require concrete encasement to assure compaction
- Ductile-iron
  - Introduced in 1955 and commonly used in water/wastewater systems
  - Greater range of deformation and less brittle than CIP
  - Also has greater tensile and compressive strength than CIP
  - Require concrete encasement to assure compaction
- Cast-iron
  - Typically limited up to 15-inch diameter
  - Many CIP have been in service for over 100-yrs
  - Not considered acceptable for dam construction by any federal agency
- CMP
  - Service life of ~25 to 50-yrs
  - Aggressive conditions can significantly reduce service life
  - Major federal agencies prohibit their use on high hazard dams

Technical Manual: Plastic Pipe Used in Embankment Dams

Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair

November 2007

FEMA

Technical Manual: Conduits through Embankment Dams

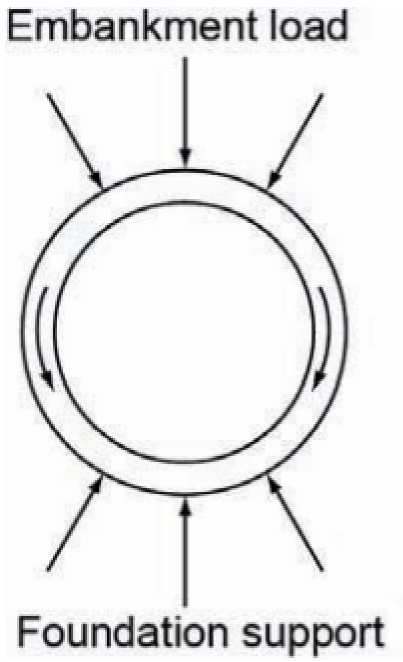
Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair

September 2005

FEMA

Common Approaches to Designing Embankment Conduits
Rigid Pipe Design

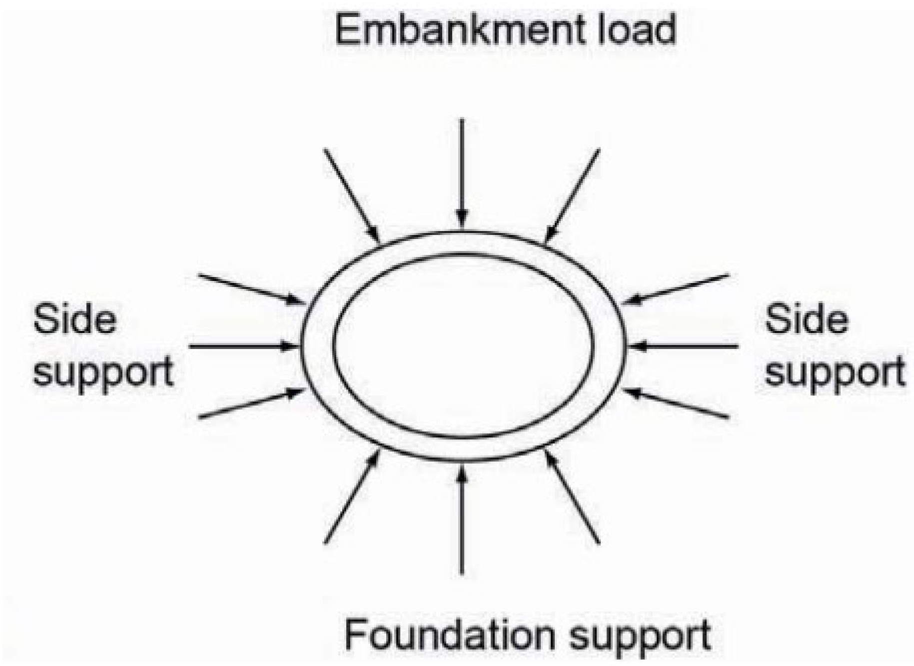
- Rigid Pipe Design
  - Applies to
    - Reinforced Concrete Pipe
    - Cast Iron
    - Clay Pipe
  - Assumes pipe maintains shape under loading by transferring load to the foundation through the pipe wall
  - Rigid pipe is considered stiffer than surrounding fill
  - Does not require support from surrounding fill
  - Only allow minimal deflection without structural distress



(a) Load transfer in rigid pipe

Approaches to Designing Embankment Conduits
Flexible Pipe Design

- Flexible Pipe Design
  - Applies to:
    - HDPE
    - PVC
    - CMP
    - Ductile Iron
    - Steel
  - Derives it load carrying capacity from its ability to transfer load to the surrounding soil
  - Defined as a pipe that deflects at least 2 percent out of round without structural distress



(b) Load transfer in flexible pipe

Replacement Spillway Conduit Materials

- Preferred Pipe Material – PCCP used on many high hazard earth dams
- Alternative Pipe Material – DIP, which may be more cost effective and more readily available for smaller conduits
- Other Steel and Plastic Pipe are not typically considered due to less robust joints and requiring a full encasement

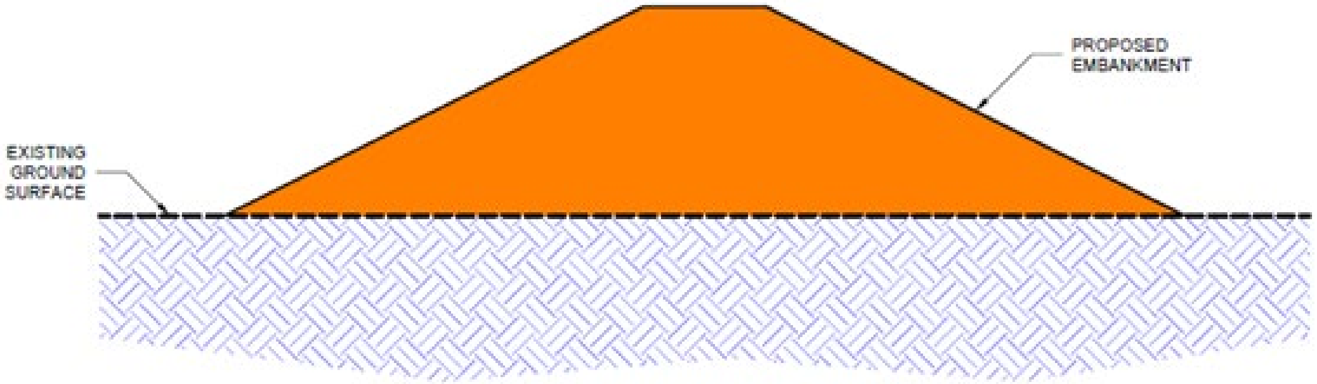
PCCP Design Considerations
Rigid Pipe Design

- Reinforced concrete design of precast concrete pipes has been standardized by manufacturers
- Design procedures specified in AWWA MP (RCP and RCCP) and AWWA C304 (PCCP)
- As an alternate to theoretical reinforced concrete design, there is an indirect design procedure based on product testing
- NRCS requires that precast concrete pipes be tested for three-edge bearing and meet certain performance criteria
- NRCS has worked with AWWA to develop design curves as a basis for proof of strength
- NRCS TR-5 *Structural Design of Underground Conduits* includes procedures to determine three-edge bearing strength, which needs to be included on the construction drawings and verified through testing or documentation

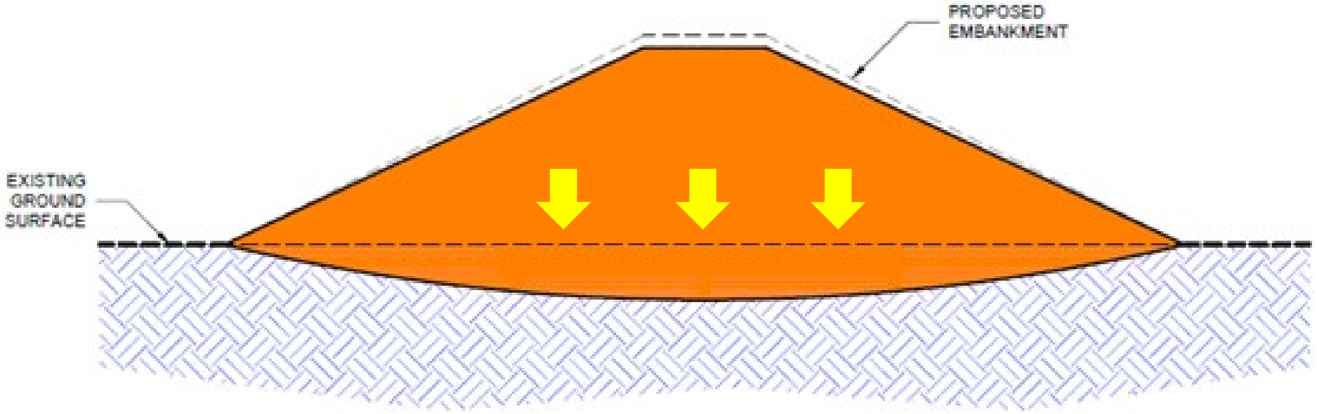
DIP Spillway Conduit - Flexible or Rigid Pipe Design?

- DIPs are typically designed as flexible conduits in non-dam applications
- However, NRCS allows the use of DIP in embankment dams if they are designed as a rigid conduit
- Follow NRCS TR-5 procedures to determine three edge bearing strength similar to PCCP, with additional requirements specific to DIP provided in a 1968 SCS Memorandum

Geotechnical Considerations for Replacement Conduits
Foundation Settlement – Joint Integrity

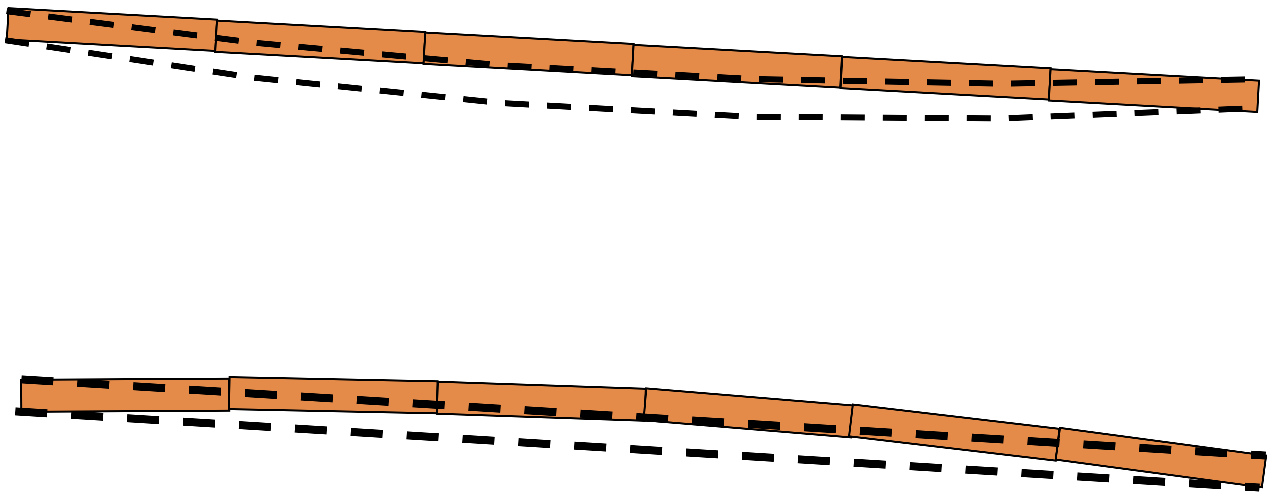


EMBANKMENT DESIGN

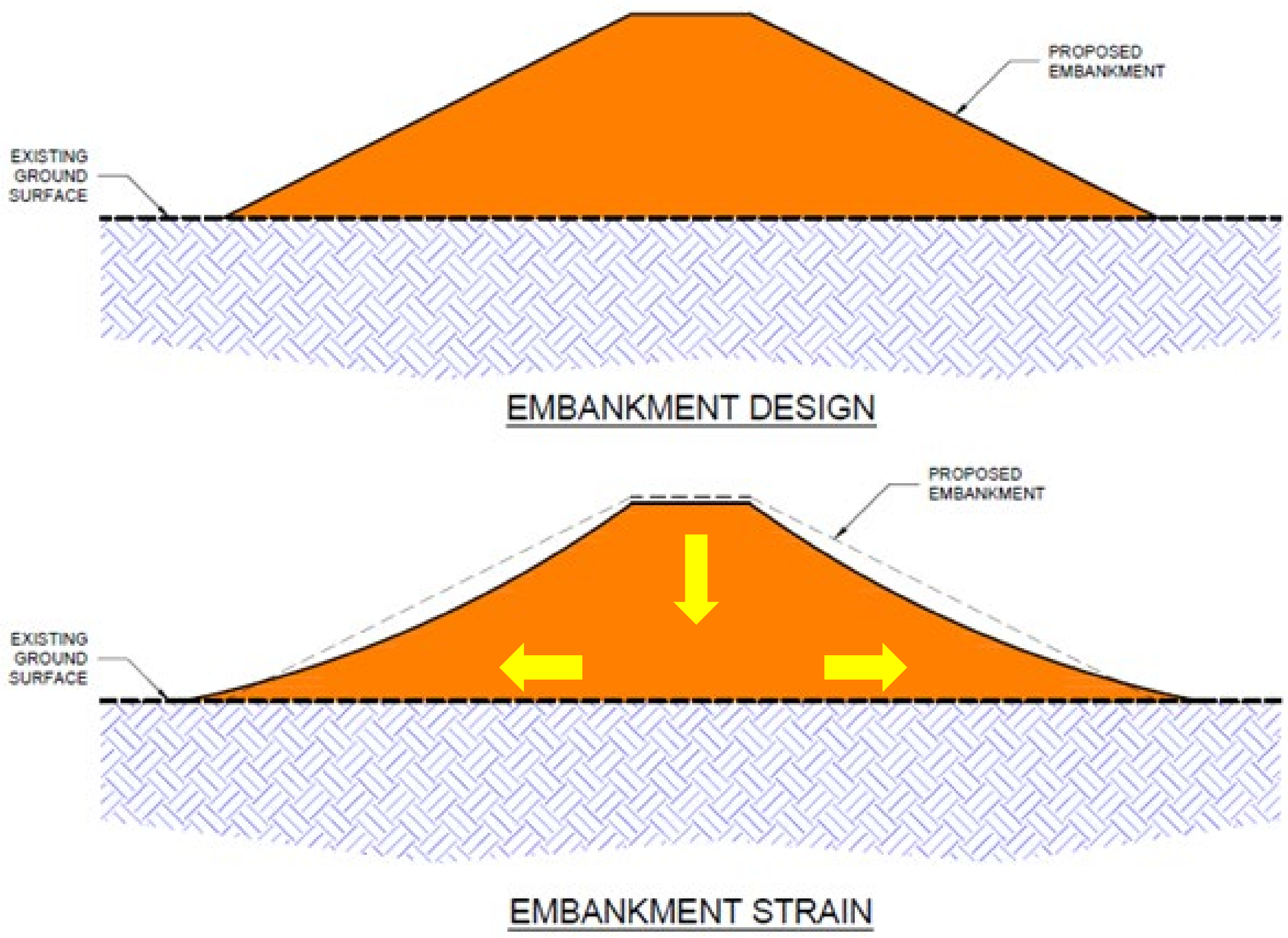


EMBANKMENT SETTLEMENT

Conduits Designed w/ Camber to Account for Settlement

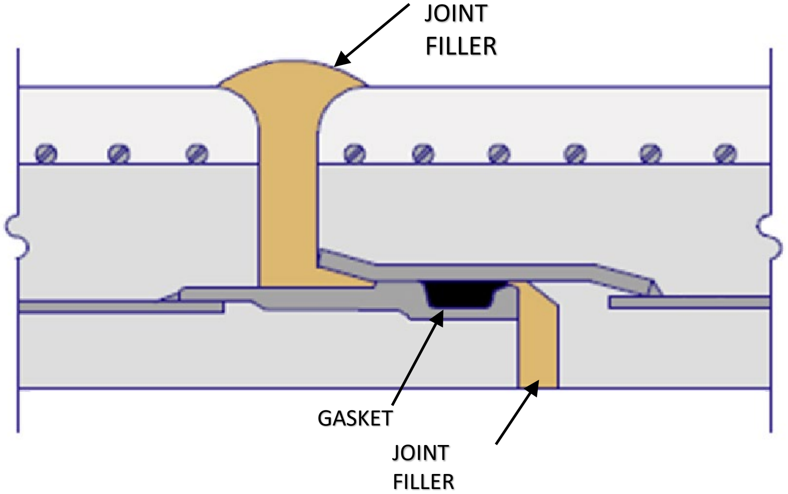


Geotechnical Considerations for Replacement Conduits
Embankment Strain – Joint Integrity



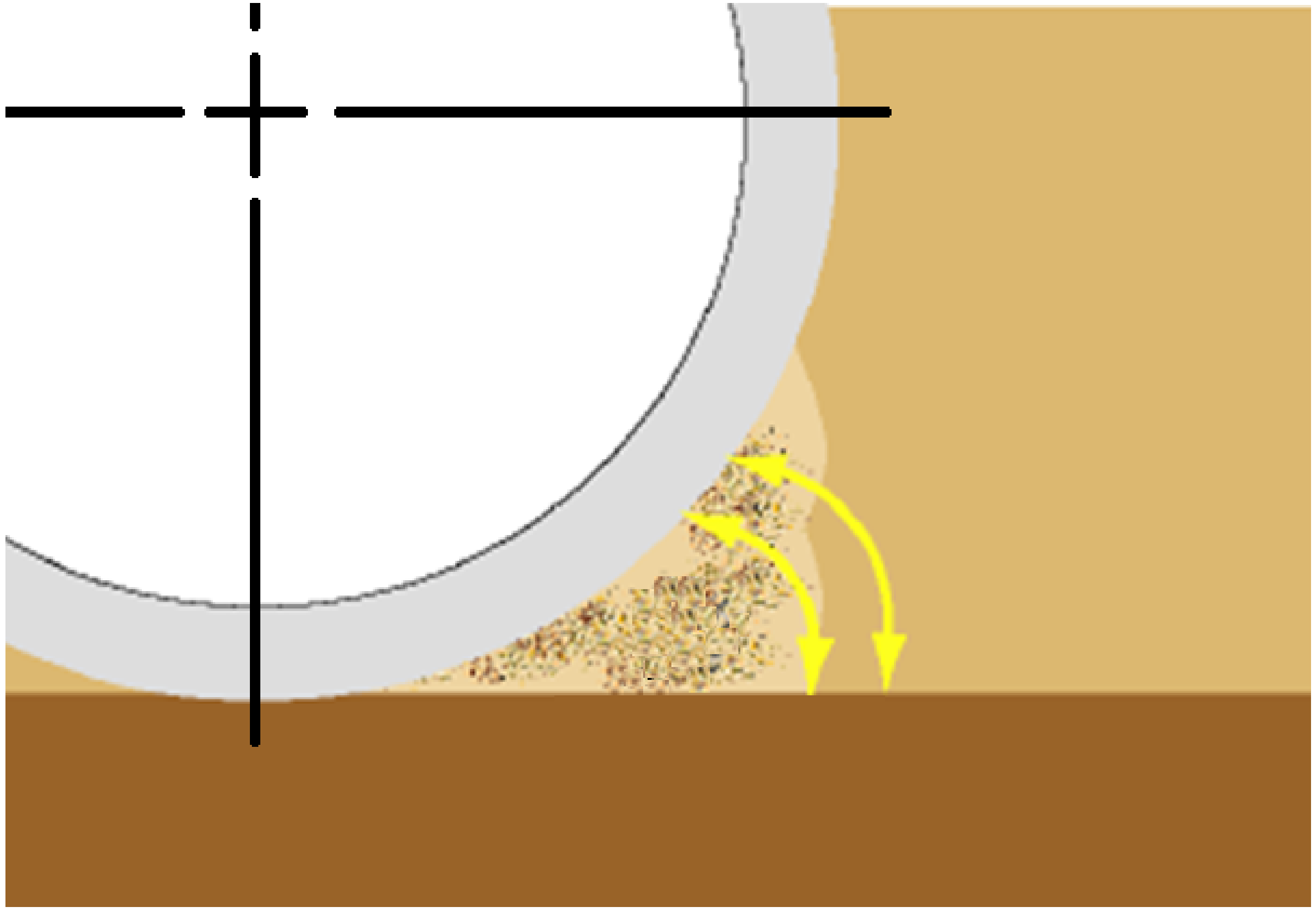
Replacement Conduits - Joint Selection

- Water tight
- Soil tight
- Flexibility
- Deep
- Allows for movement without compromising the seal

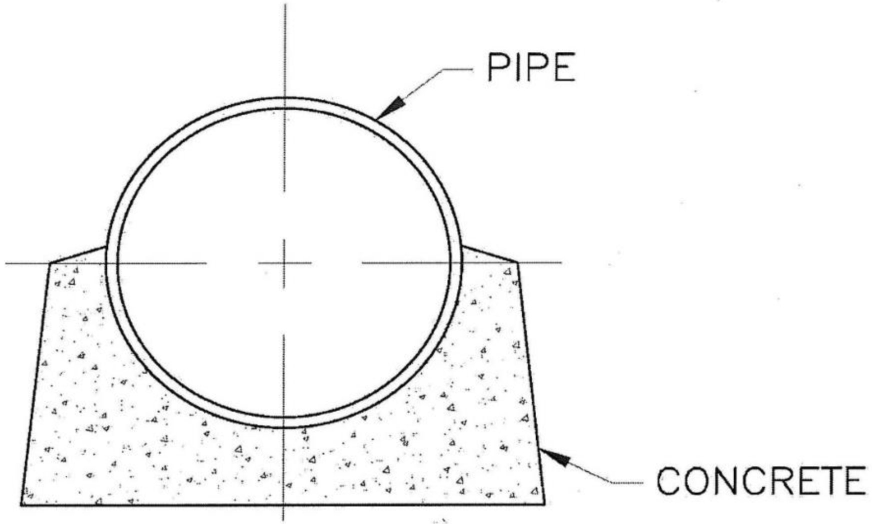


Construction Considerations for Replacement Conduits
Earthfill Compaction

- Compaction is extremely difficult below the spring line of the conduit
- Some Materials Do Not Bond Well With Soil
  - Polyvinyl Chloride (PVC)
  - High Density Polyethylene (HDPE)
- Conditions that Facilitate Compaction
  - Battered walls
  - Limit or reduce uncompacted lift thickness
  - Limit maximum particle size



Construction Considerations – Concrete Cradle or Encasement



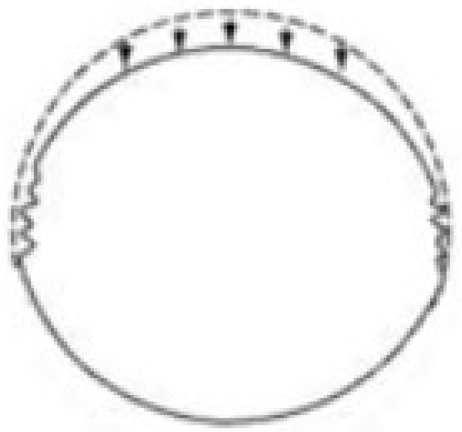
Facilitates Concrete Placement
Facilitates Earthfill Placement
Allows for Conduit Articulation

Design Considerations for Sliplining

- Installing conduit of smaller diameter and grouting of annular space
- Typically HDPE
- Plastic pipe surrounded by grout, concrete or flowable fill does not become a rigid pipe - it needs to be evaluated differently
- FEMA describes the approach as Encased Plastic Pipe Design
- Encasement provides uniform circumferential support to the plastic pipe, so cross sectional deflection is considered negligible
- Potential exists for hydrostatic pressure to develop through cracks, joints, imperfections in the encasement
- Therefore, structural design of sliplining should consider:
  - Wall Crushing
  - Wall Buckling
  - Internal Hydrostatic Pressure

Wall Crushing – Encased Plastic Pipe Design

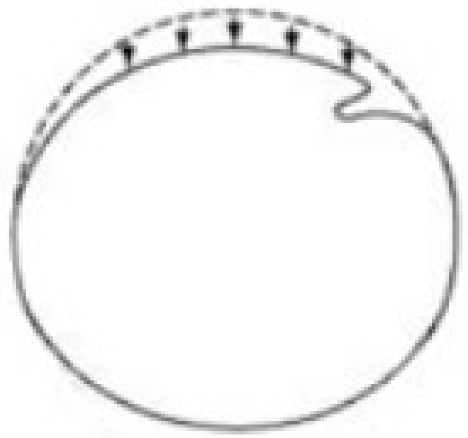
- Any support from the encasement or existing pipe is ignored
- Wall crushing typically occurs at the 3 and 9 o'clock positions
- This localized yielding typically occurs with stiff flexible pipes installed in deep compacted fill
- Less stiff flexible pipe more frequently fails from wall buckling
- Soil loads should be calculated considering a positive project condition – refer to FEMA
- Refer to FEMA for Equations for evaluating wall crushing, which will provide a min required pipe thickness



(a) Wall crushing

Wall Buckling – Encased Plastic Pipe Design

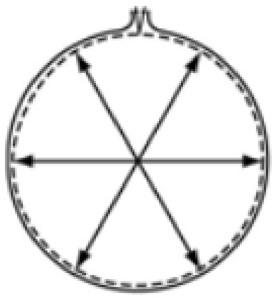
- Potential exists for an opening to develop within the grouted annulus
- So the slipliner should be designed to withstand external hydrostatic pressure from the reservoir
- Refer to FEMA for Equations for evaluating wall buckling for both short term and long term conditions.
- Short Term - checking that applied grout pressure does not exceed computed short term unconstrained collapse pressure considering some factor of safety
- Long Term – checking max hydrostatic pressure does not exceed computed long term unconstrained collapse pressure considering some factor safety



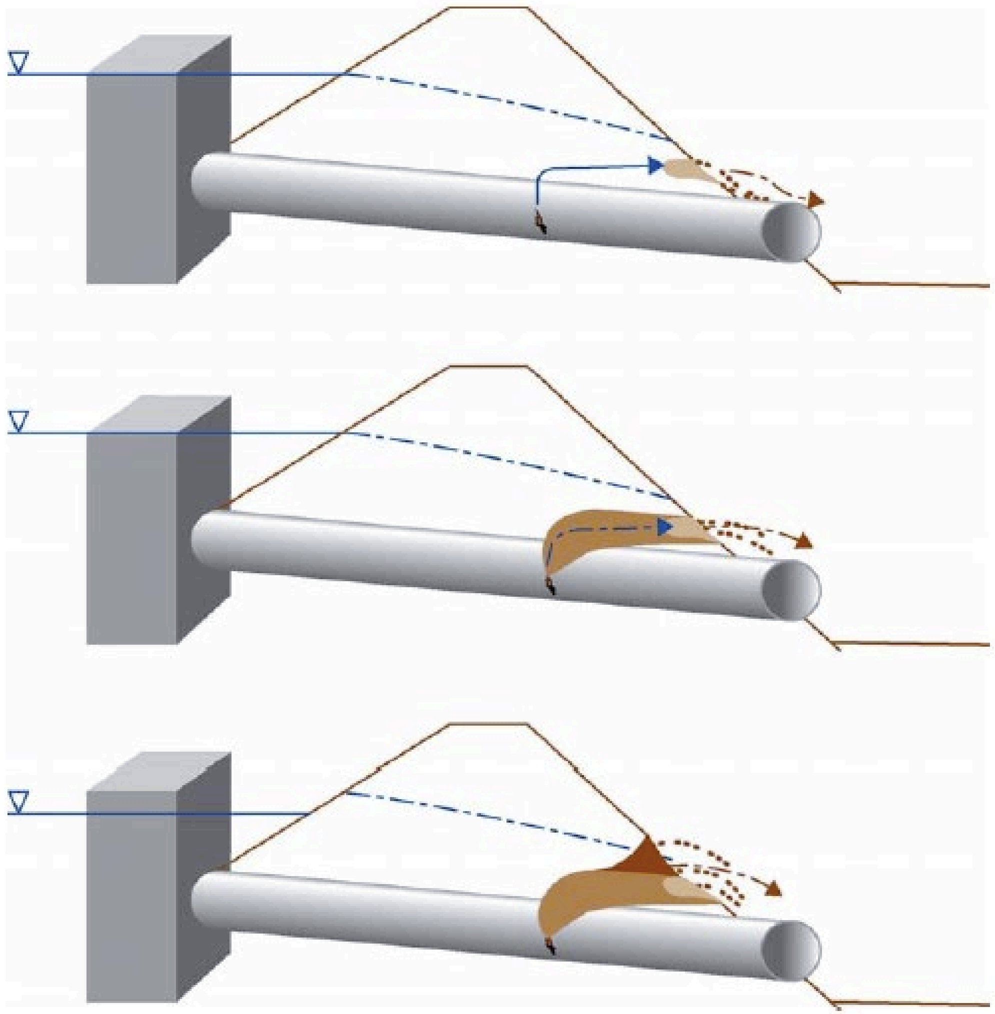
(b) Wall buckling

Internal Hydrostatic Pressure – Encased Plastic Pipe Design

- Ideally, spillway conduits through embankment dams should not be designed as pressurized conduits
- But if it is, internal hydrostatic pressure needs to be checked
- Again, refer to FEMA for the equations to check that the hydrostatic design basis does not exceed the manufactured pipe's pressure rating



(d) Excessive internal hydrostatic pressure



Design Considerations for CIPP Liner

- CIPP design does not fall into either flexible or rigid pipe design
- Structural design follows methodology in ASTM F2019 and F1216 to check liner thickness
- Soil loads computed following FEMA considering the type of conduit installation (positive/negative, projection/trench, complete/incomplete)
- Critical to evaluate the existing pipe and characterize is it as either partially or fully deteriorated
- Evaluate ovality of the existing pipe
- Refer to manufacture for proposed product data
- Select an appropriate FS based on uncertainty and confidence per USACE *Guidelines for Trenchless Technology*.

QUESTIONS??

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