PEN 1 & PEN 2
Levee Engineering Assessment

• Following 44 CFR 65.10 (FEMA)
• Standard: US Army Corps Manuals
• Roles:
  – Cornforth: Seepage, Stability, Settlement
  – WEST: Freeboard, Scour Protection
  – MCDD: Interior Drainage
  – Group Mackenzie: As-Builts
44 CFR 65.10 CERTIFICATION REQUIREMENTS
44 CFR 65.10 CERTIFICATION REQUIREMENTS

HYDRAULIC ANALYSES
(FLOOD LEVELS)

3 FT. MIN.
HYDRAULIC ANALYSES (FLOOD LEVELS)

3 FT. MIN.

SLOPE STABILITY
44 CFR 65.10 CERTIFICATION REQUIREMENTS

HYDRAULIC ANALYSES (FLOOD LEVELS)

3 FT. MIN.

SETTLEMENT (LOSS OF FREEBOARD)

SCOUR PROTECTION

SLOPE STABILITY
44 CFR 65.10 CERTIFICATION REQUIREMENTS

HYDRAULIC ANALYSES (FLOOD LEVELS)

3 FT. MIN.

SETTLEMENT (LOSS OF FREEBOARD)

SCOUR PROTECTION

THROUGH SEEPAGE

SLOPE STABILITY

INTERIOR FLOODING (PUMP CAPACITY)
44 CFR 65.10 CERTIFICATION REQUIREMENTS

HYDRAULIC ANALYSES (FLOOD LEVELS)

SETTLEMENT (LOSS OF FREEBOARD)

SCOUR PROTECTION

3 FT. MIN.

THROUGH SEEPAGE

SLOPE STABILITY

UNDER SEEPAGE

INTERIOR FLOODING (PUMP CAPACITY)
PEN 1
Site Investigation

- 57 Borings Total
- Crest, riverward and landward side toes
- Set of borings every ~1,000 feet
- 44 borings on land, 13 over water
- Depths ranged from 20 to 100 feet
- Falling head permeability tests
- SPT’s and undisturbed samples every 5 ft
- Not able to access railroad embankment
PEN 2
Site Investigation

- 74 Borings Total
- Crest, riverward and landward side toes
- Set of borings every ~1,000 feet
- 51 borings on land, 23 over water
- Falling head permeability tests
- Depths ranged from 20 to 90 feet
- SPT’s and undisturbed samples every 5 ft
Site Geology

• Embankment fill underlain by Columbia River Alluvium
• Fill: Loose sandy silt/silty sand, to soft clayey silt
• Fill Sources: Dredged, railroad cuts, district interior
• Alluvium: Loose, interlayered, sandy silt/silty sand, and soft, clayey silt
• Dense gravels under soft alluvium
Lab Testing Program

- Natural water content
- Grain size and plasticity (Atterberg limits)
- Unit weights
- Consolidation
- Strength tests – TxCU & Direct Shear (levee fill)
- Strength tests – TxCU (foundation soils)
PEN 1 Soil Parameters

- **Embankment Fill**
  - Unit Weight: 102 to 119 pcf
  - Coef. of Consolidation: 2,600 ft²/yr
  - Strength: $\phi'$ = 32 degrees to 36 degrees

- **Alluvium**
  - Unit Weight: 94 to 121 pcf
  - Coef. of Consolidation: 2,400 ft²/yr
  - Strength: $\phi'$ = 32 degrees, $c'$ = 50 psf
PEN 2 Soil Parameters

- **Embankment Fill**
  - Unit Weight: 107 to 116 pcf
  - Coef. of Consolidation: 2,700 ft$^2$/yr
  - Strength: $\phi^\prime = 33$ degrees to 37 degrees

- **Alluvium**
  - Unit Weight: 93 to 118 pcf
  - Coef. of Consolidation: 2,400 ft$^2$/yr
  - Strength: $\phi^\prime = 30$ to 32 degrees, $c^\prime = 50$ psf