TerraSurv

Dam Deformation Surveying

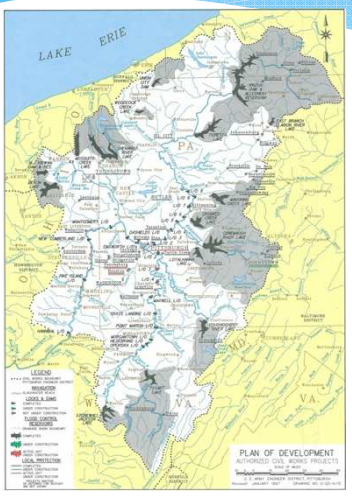
As Currently Practiced by Terrasurv, Under Contract to
the Pittsburgh District of the US Army Corps of Engineers

US Army Corps of Engineers

Civil Works in the United States

- Owns and Operates 609 dams
- 19,000 km of inland waterways
- 212 Navigation Locks
- World's Largest Public Works Agency
- 8 Divisions in the US
- 41 Districts in US, Asia, Europe
- Civil Works District in US are by Drainage Basin

US Army Corps of Engineers Pittsburgh District

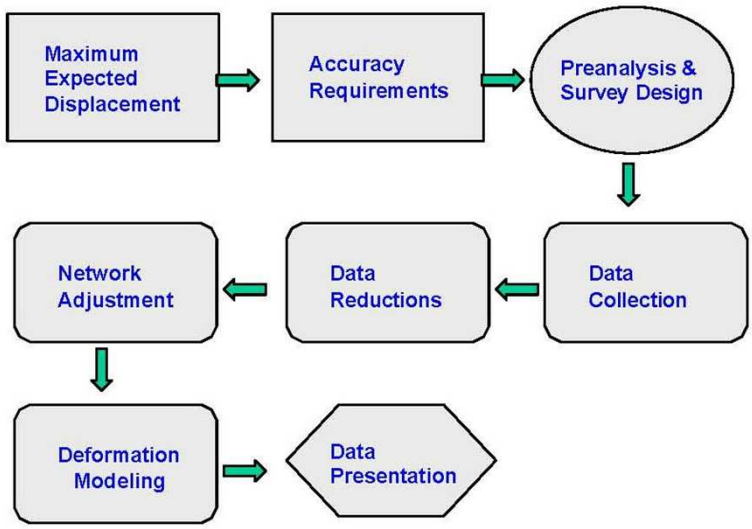


- Allegheny, Monongahela & Ohio Rivers – 328 miles of navigable waterways
- 16 flood control reservoirs
  - 8 concrete gravity dams
  - 8 earth-rockfill dams
- 23 navigation locks
- 26,000 mi^2 (67,200 km^2) of drainage area
- Known as the "Headwaters District"

Monitoring Requirements

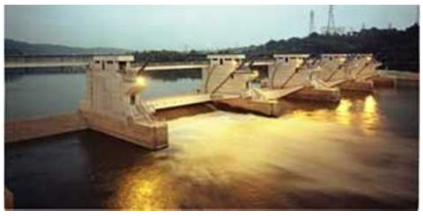
- Annually for reservoirs
- Semi-Annually or less for navigation locks
  - More frequent observations for "problem" structures
- Survey Specifications and Accuracy requirements can be found in USACE Engineer Manual EM 1110-2-1009 "Structural Deformation Surveying"
  - http://140.194.76.129/publications/eng-manuals/em1110-2-1009/toc.htm

Deformation Survey Data Flow



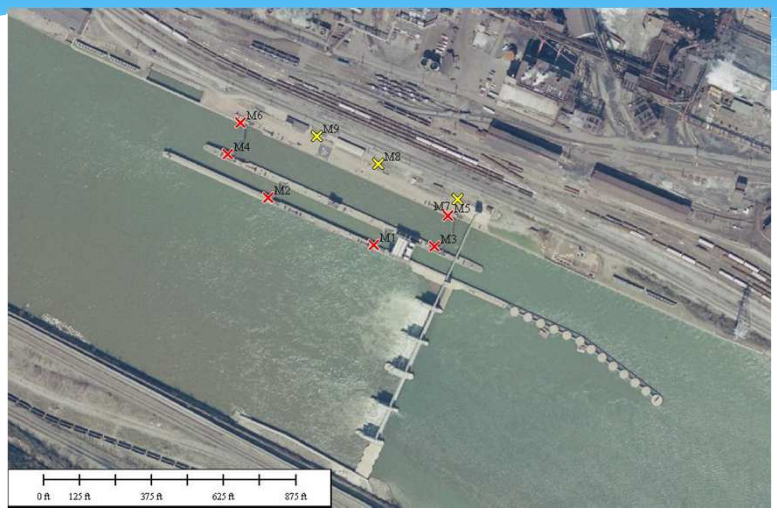
Navigation Structure Pre-Analysis

- Monongahela River L/D #2 at Braddock, PA, built in 1905
- New gated dam and new abutment added in 2004
- Two lock chambers-110' X 720' (33.5 m X 219.5 m) and 56' X 360' (17.1 m X 109.8 m)
- Land wall 2500' (762 m) long
- River wall 1900' (579 m) long
- Middle wall 1050' (320 m) long

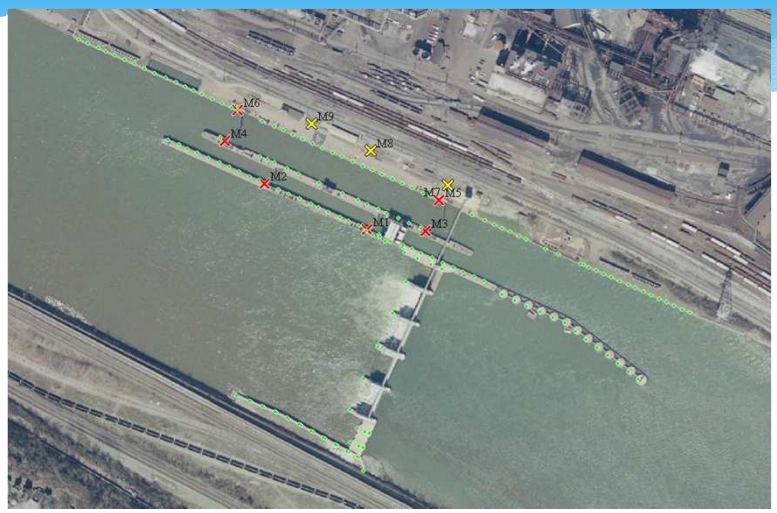


L/D #2 Monongahela River

Monuments (X) and Pedestals (X)

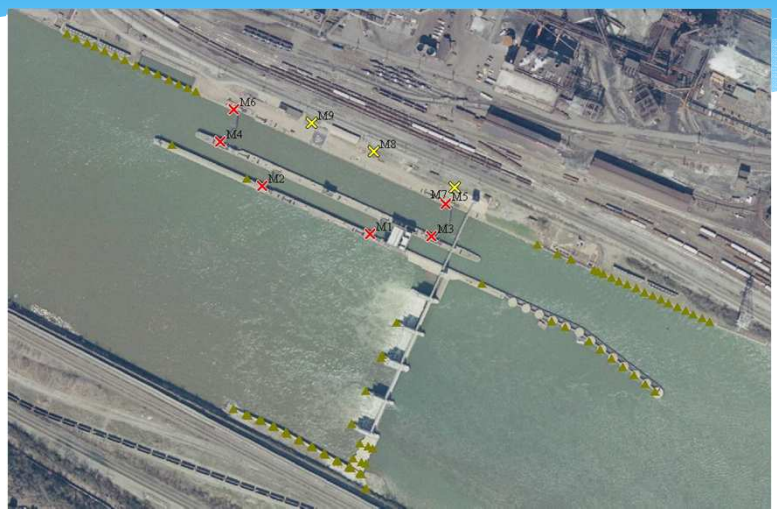


Monitoring pins



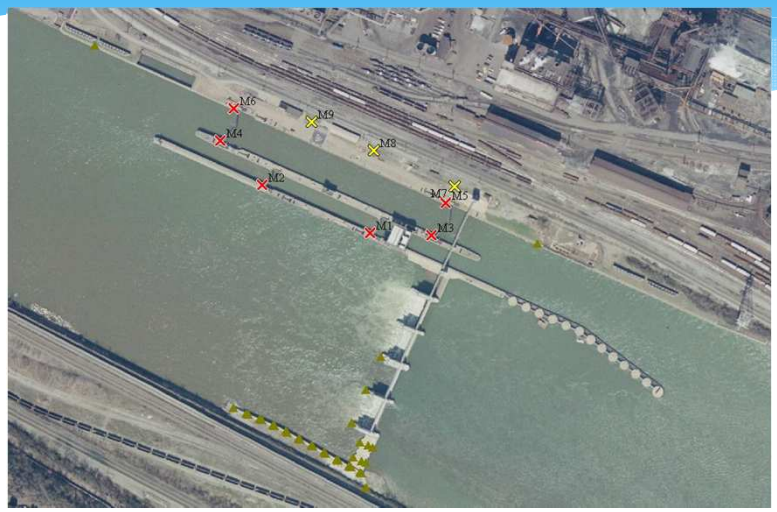
Conventional Network

Results–pins with error ellipses >3 mm



HOLDING 3 PEDESTALS M7, M8, M9

Results–pins with error ellipses >3 mm



HOLDING 3 PEDESTALS & 6 MONS ON BEDROCK MONOLITHS

Results–pins with error ellipses >3 mm

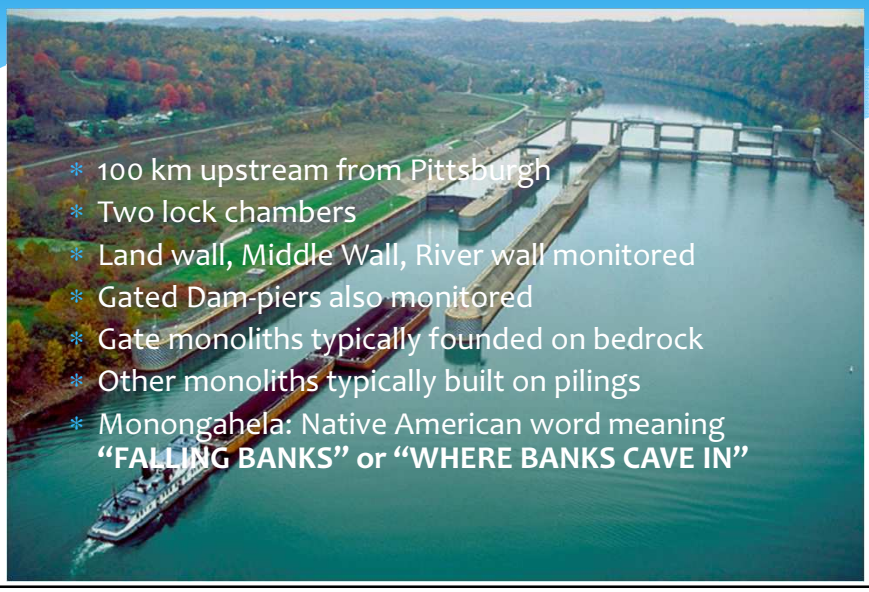
Add constraint on left bank abutment-remaining points are 4 mm

Summary

* It was necessary to add constraints beyond the reference pedestals located off structure
* A "primary" network is created to validate the on structure points which are subsequently constrained
* GPS can be used for distant parts of the network, as the GPS is more accurate over longer lines, while the total station is more accurate over short lines

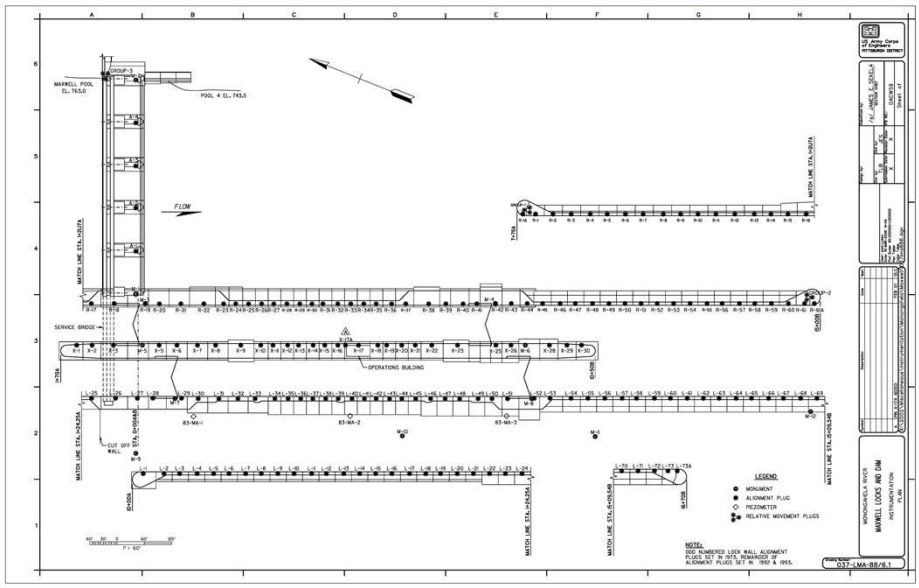
Redundant Measurements

Maxwell Locks and Dam



- 100 km upstream from Pittsburgh
- Two lock chambers
- Land wall, Middle Wall, River wall monitored
- Gated Dam-piers also monitored
- Gate monoliths typically founded on bedrock
- Other monoliths typically built on pilings
- Monongahela: Native American word meaning **"FALLING BANKS" or "WHERE BANKS CAVE IN"**

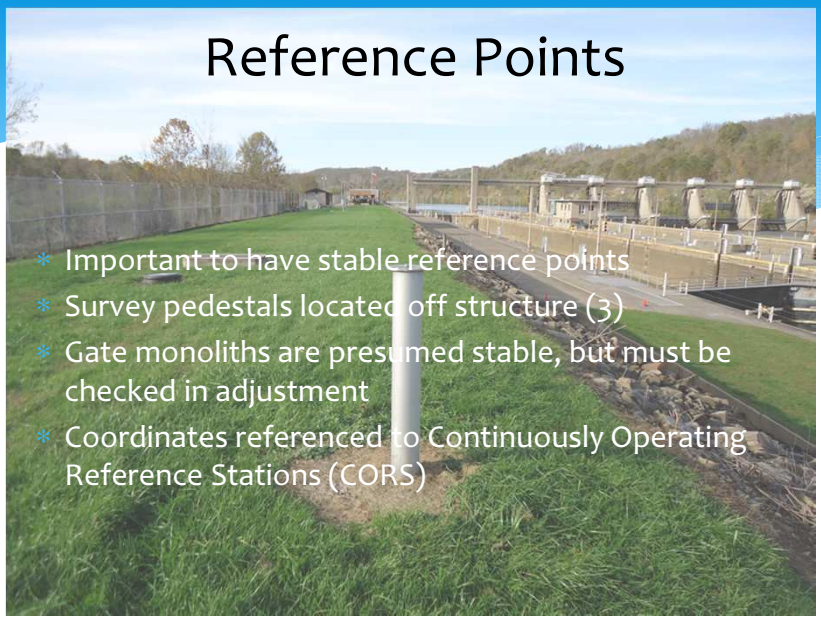
Maxwell Locks and Dam



Alignment and Settlement

- Typically done every two years
- Settlement done by precise differential levels
- Alignment done by micrometer prior to 2005
  - Measured displacement for each point from reference line
  - Only determined movement perpendicular to force
    - Landward/riverward for monoliths located parallel to flow
    - Upstream/downstream for dam piers
  - affected by heat waves, centering errors, personal bias, etc
- High accuracy robotic total station used since 2005
  - Redundant data adjusted by least squares
  - Coordinates used to compute offsets

Reference Points



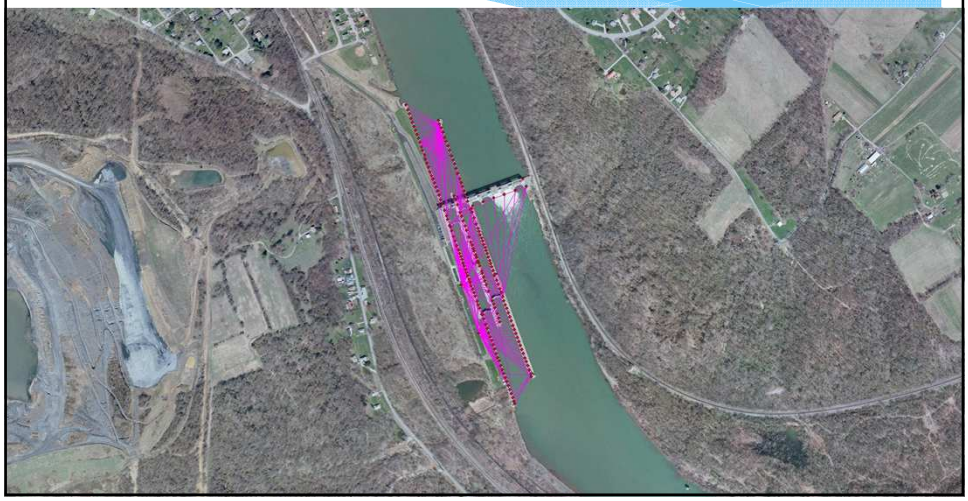
- Important to have stable reference points
- Survey pedestals located off structure (3)
- Gate monoliths are presumed stable, but must be checked in adjustment
- Coordinates referenced to Continuously Operating Reference Stations (CORS)

Reference Network-Assumed Stable checked by adjustment

Monitored Points

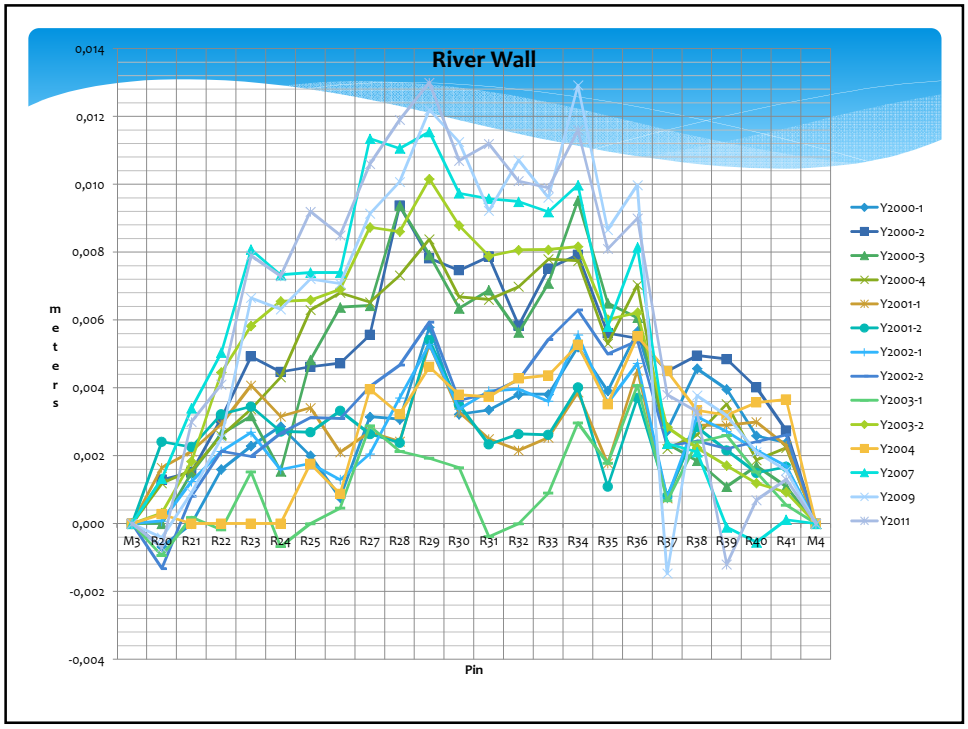
- Pins with punch marks in each monolith
- Use stakeout prism to minimize setup errors and setup time
- Each point shot from at least 2 different setups
- Design accuracy=3 mm

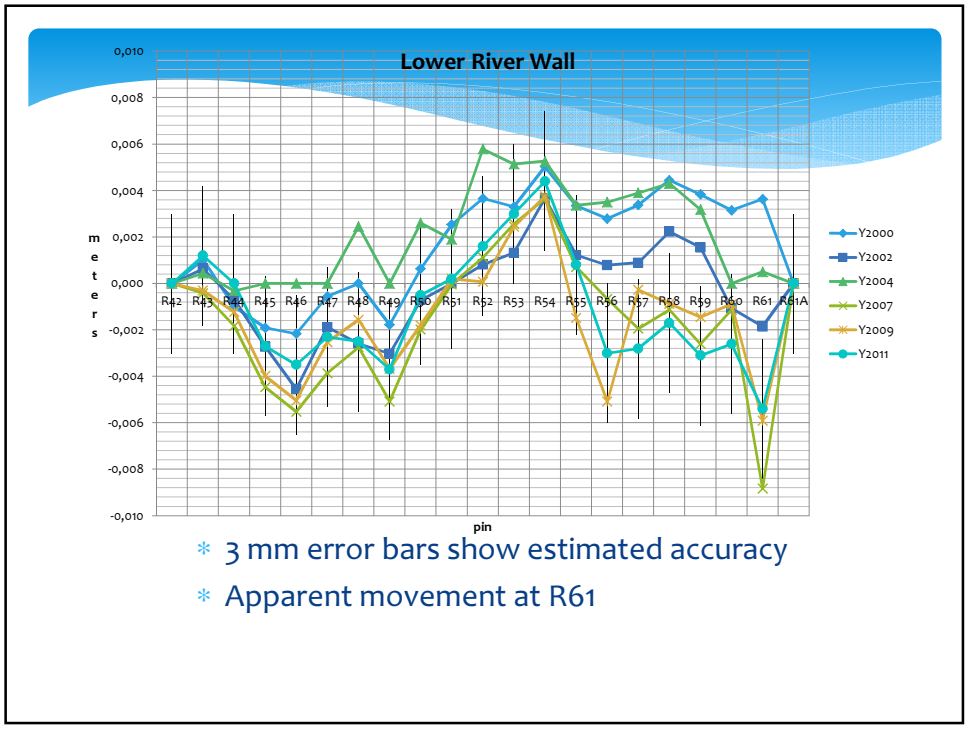
Maxwell Locks and Dam



Data Reductions

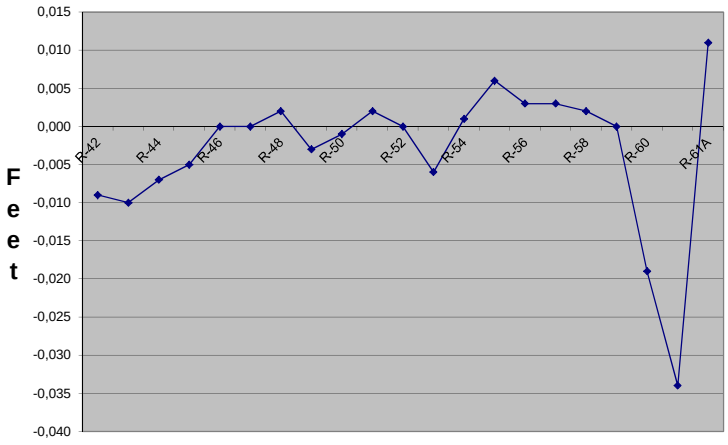
- Distances corrected for atmospheric delay
- Distances and vertical angles reduced to mark-to-mark values
- Observation weighting is important to obtain homogenous results and realistic error estimates
- Networks adjusted using Geolab-least squares adjustment program
- Offsets from reference lines computed using adjusted coordinates after LSA using custom software





- 3 mm error bars show estimated accuracy
- Apparent movement at R61

Settlement Results-Year 2000 base



Settlement Surveys

- Use same points as alignment surveys
- Closed loops
- Trimble Dini 12
- 2 and 3 m Invar rods
- Kukkimaki collimation test at start of each day
- Verification of reference point(s)
- Now tied to North American Vertical Datum of 1988
- Each project has 1 or more points in National Spatial Reference System (NSRS)
  - Required after Katrina disaster in New Orleans
  - achieved on all 16 reservoirs, Ohio River (6 locks), and Monongahela Rivers (9 locks)
  - Allegheny River in progress (8 locks)

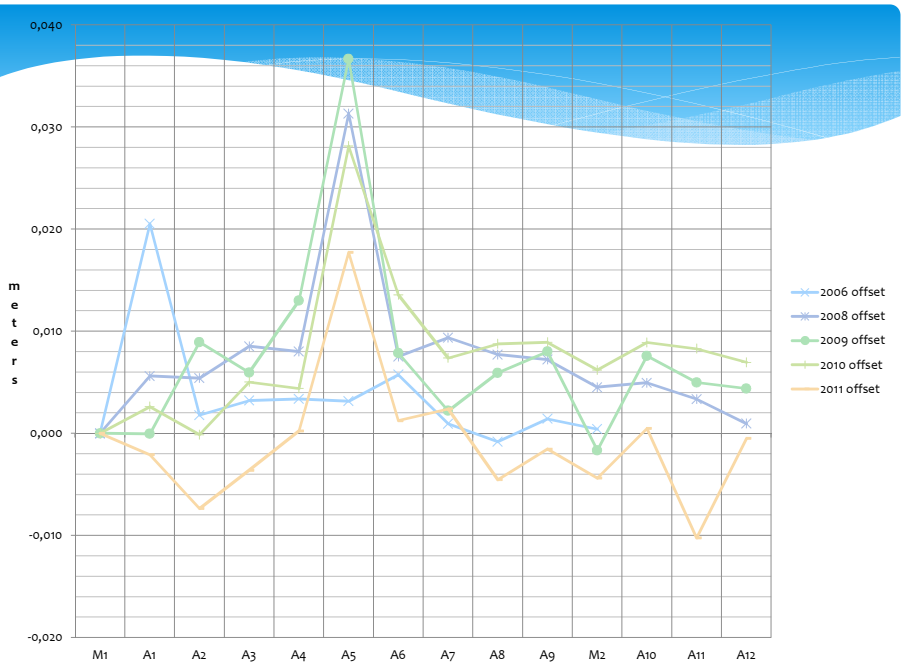
M J Kirwan Dam

- Earth and Rock fill dam
- 25 m height
- 3.0 km length
- Width at base: 244 m
- Volume of earth: 2.5 million m^3

Alignment & Settlement Network

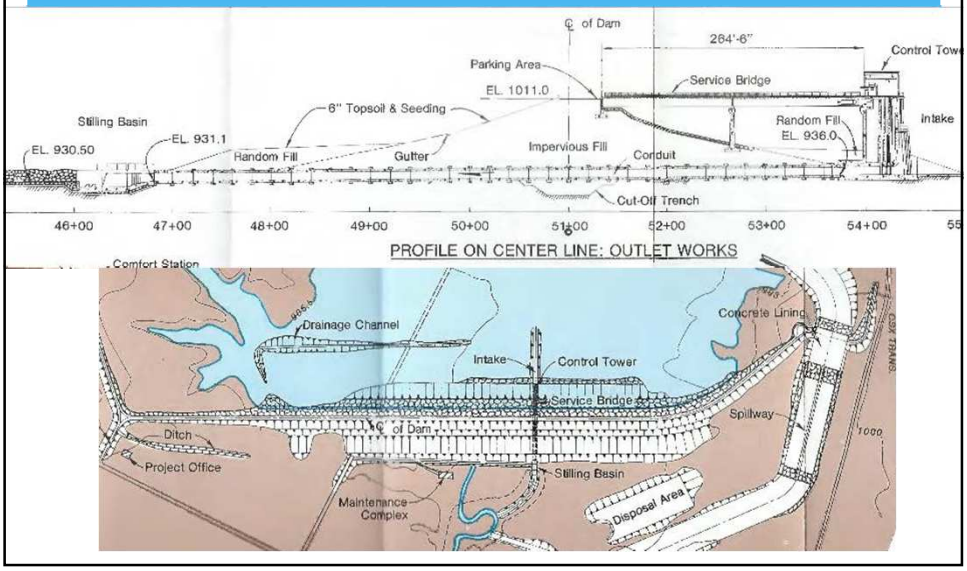
Alignment Survey

- Prior to 2005, done optically
  - Very difficult due to distance
  - EDM used from picnic area on right bank upstream of dam
- 2005-2007: combination of GPS and EDM as mentioned above
- 2007-present: GPS only
  - 2 base units, 3 roving units
  - Static methods, 20 minutes minimum, usually 30+

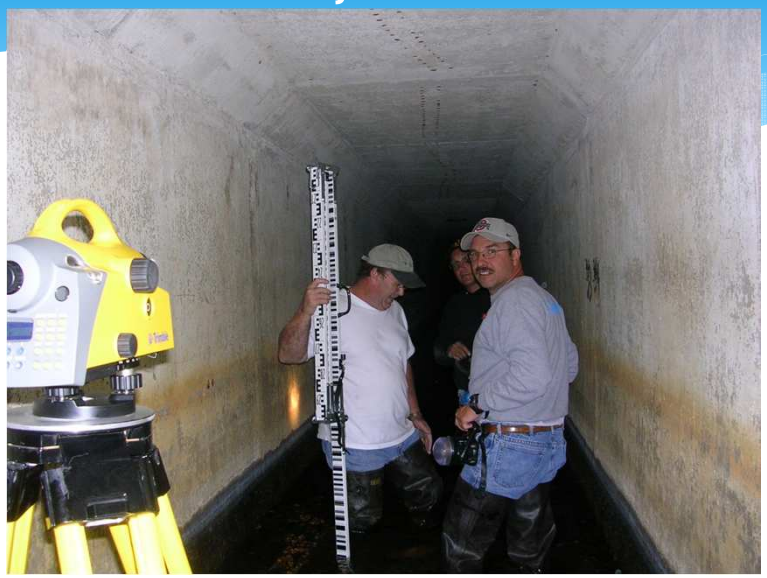


Conduit

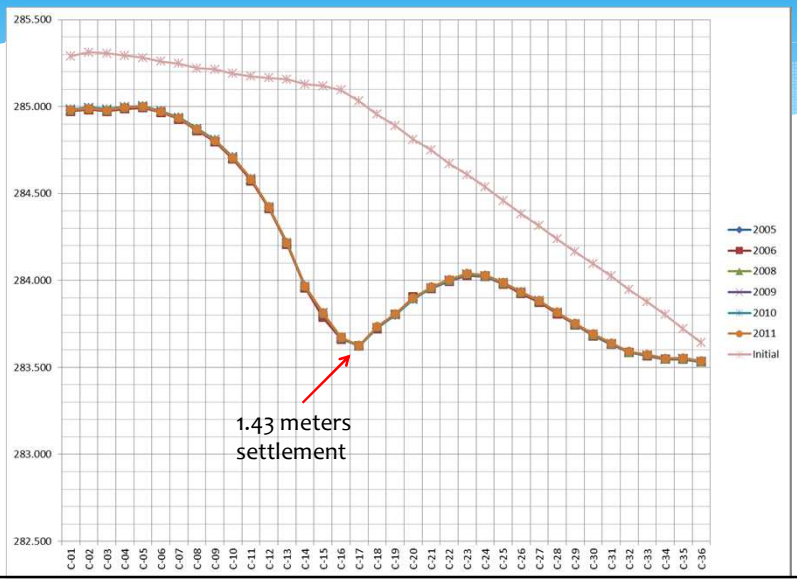
Kirwan Conduit



Settlement surveys-Outflow tunnels

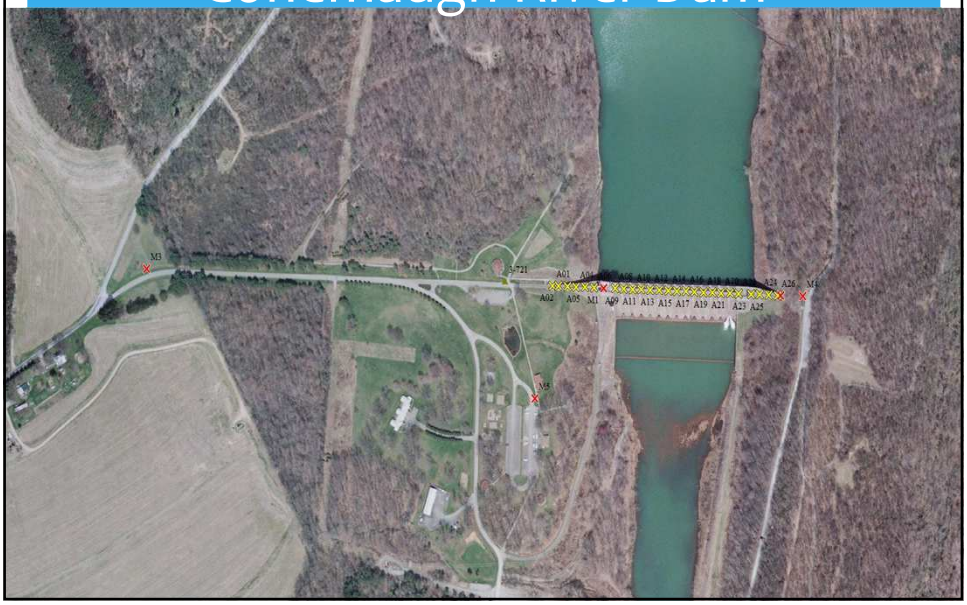


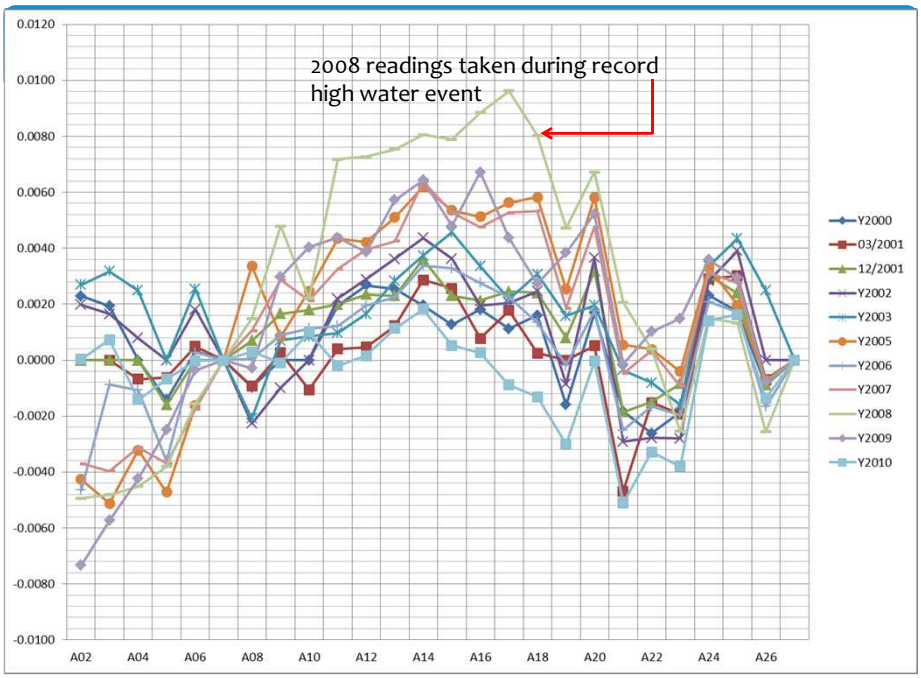
Conduit Settlement



Conemaugh River Dam

Conemaugh River Dam





Questions?

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