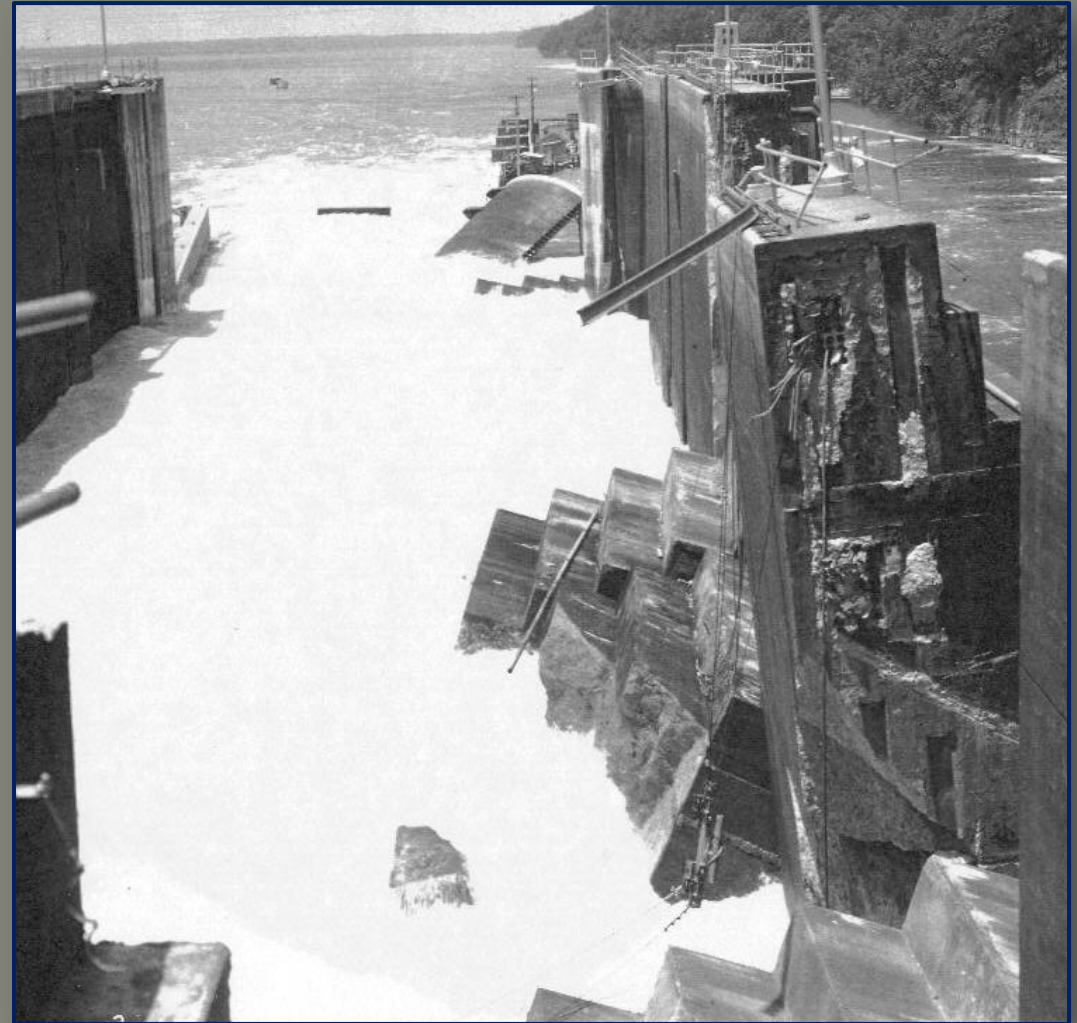


# SLIDING FAILURES AT FIVE LOCK AND DAM PROJECTS

## Dam and Cofferdam Failures within the Ohio River Basin

AEG 62<sup>nd</sup> Annual Meeting  
September, 2019

Mike Nield, Senior Engineering Geologist  
U.S. Army Corps of Engineers, Huntington WV  
LRD Dam Safety Production Center  
Dam Safety Modification Mandatory Center of Expertise



*"The views, opinions and findings contained in this report are those of the authors(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation."*

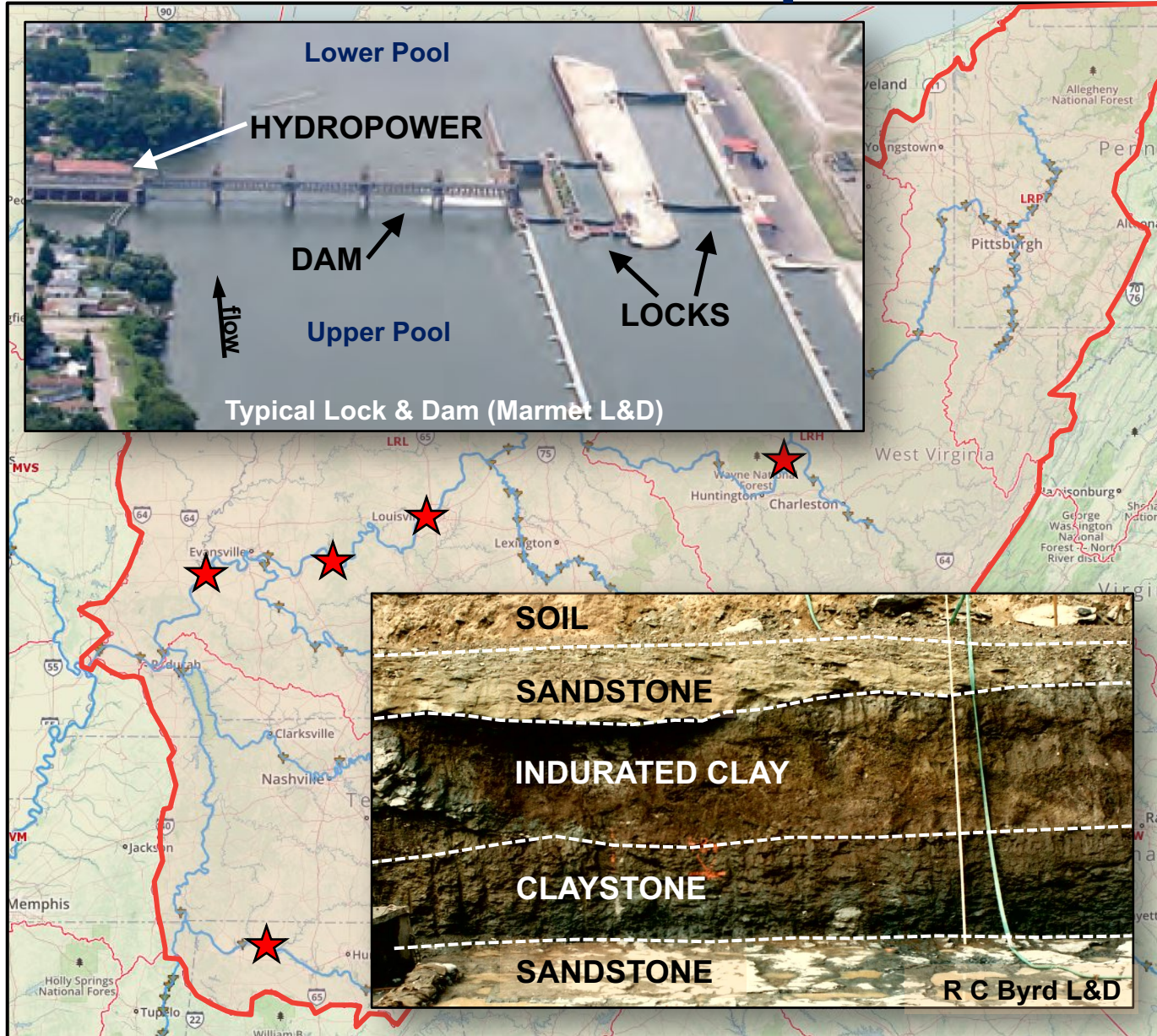
**BUILDING STRONG<sup>®</sup>**  
*and Taking Care of People!*



US Army Corps of Engineers<sup>®</sup>  
Huntington District



# Common Aspects of the Five Projects



- Located within the Ohio River Basin
- Lock and dam projects
- 1 dam and 4 cofferdams
- Founded on near-horizontal, interbedded, sedimentary rock
- 100's of feet of structure slid
- Failures from 1912 – 1971, listed in chronological order

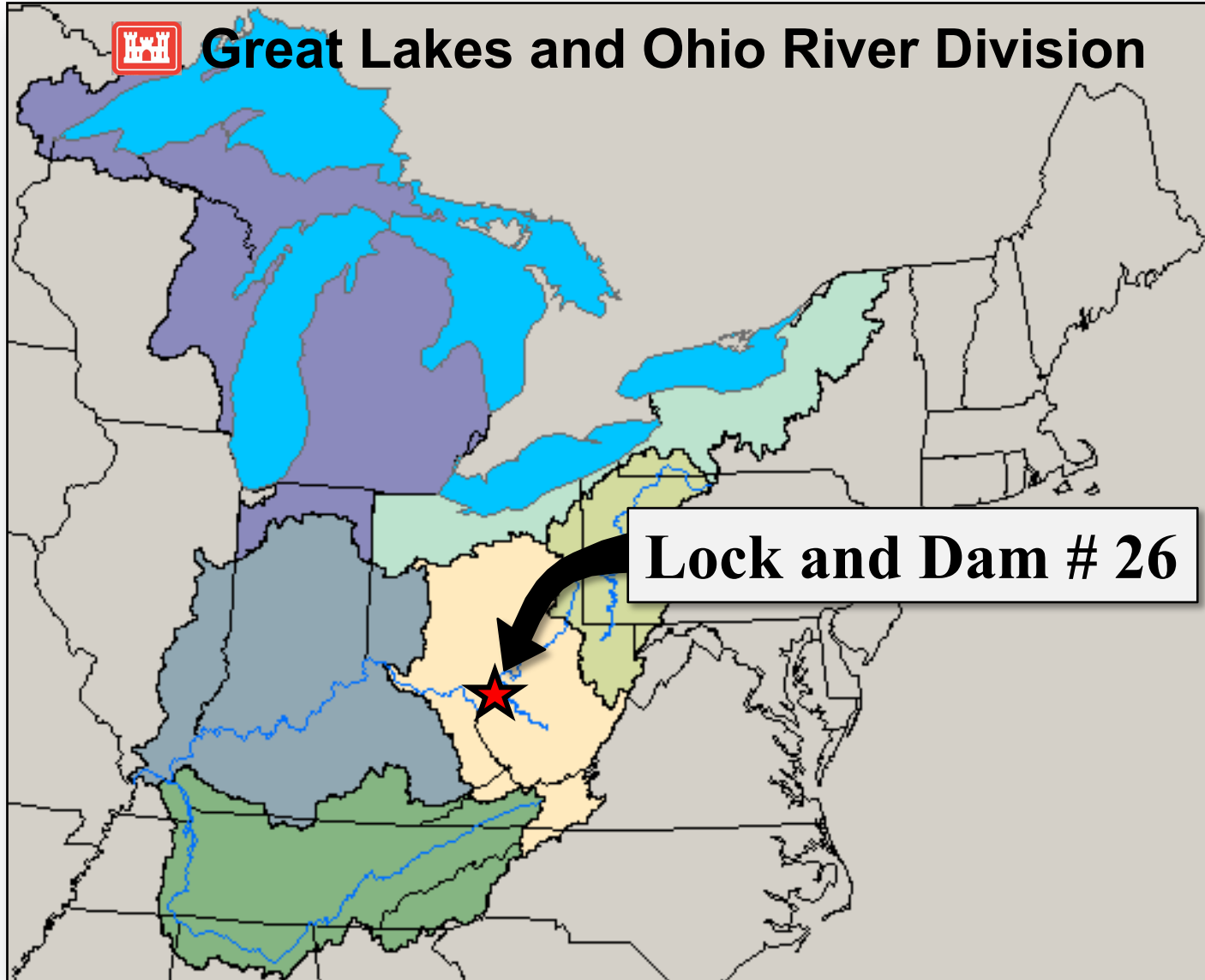


# *Sliding Failures at Five Lock and Dam Projects*

## OUTLINE

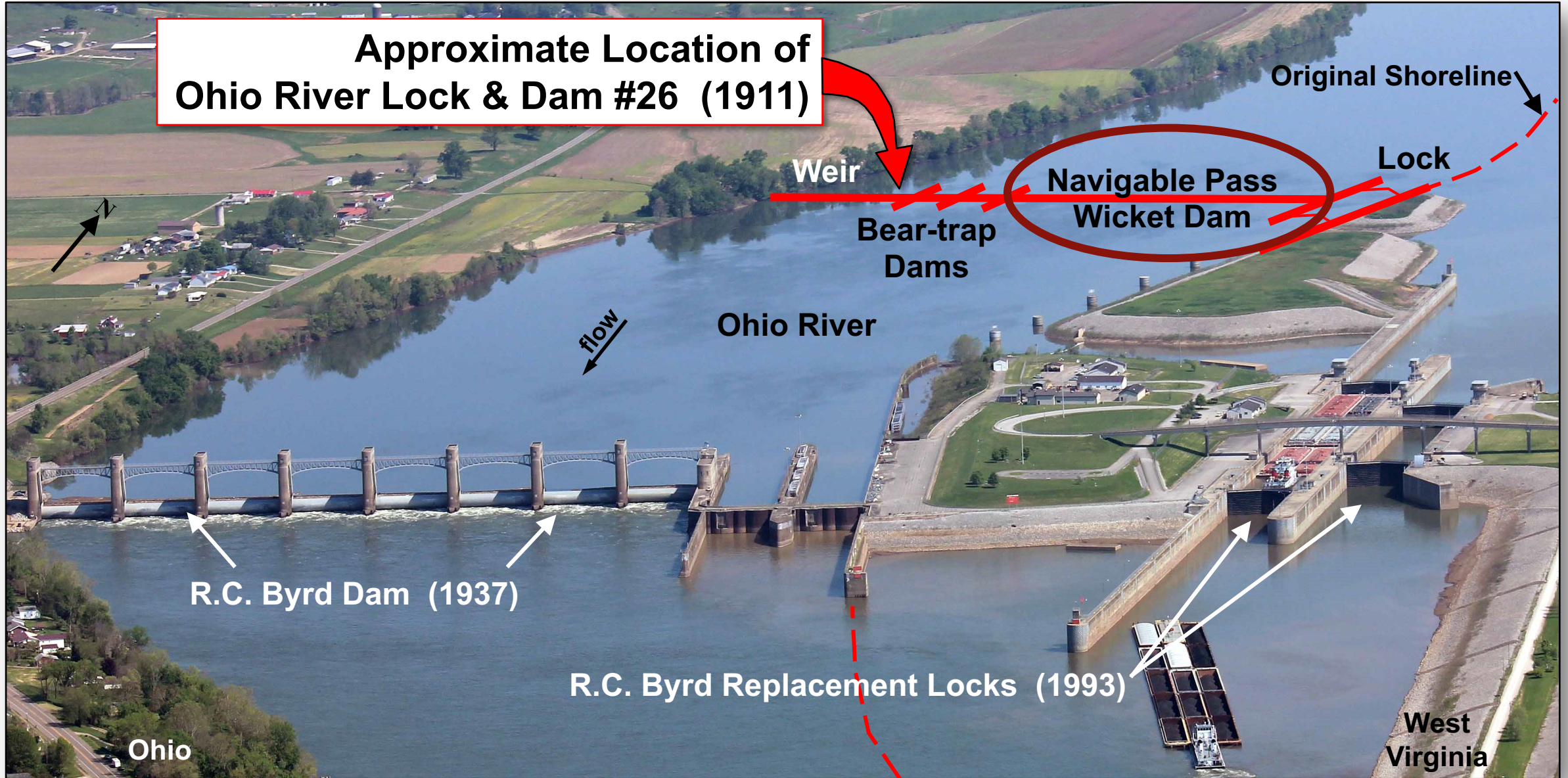
- 1. Ohio River Lock and Dam #26**
- 2. Louisville and Portland Canal**
- 3. Wheeler Lock and Dam**
- 4. Cannelton Lock and Dam**
- 5. J T Myers Lock and Dam**

# Ohio River Lock and Dam # 26 – General Information



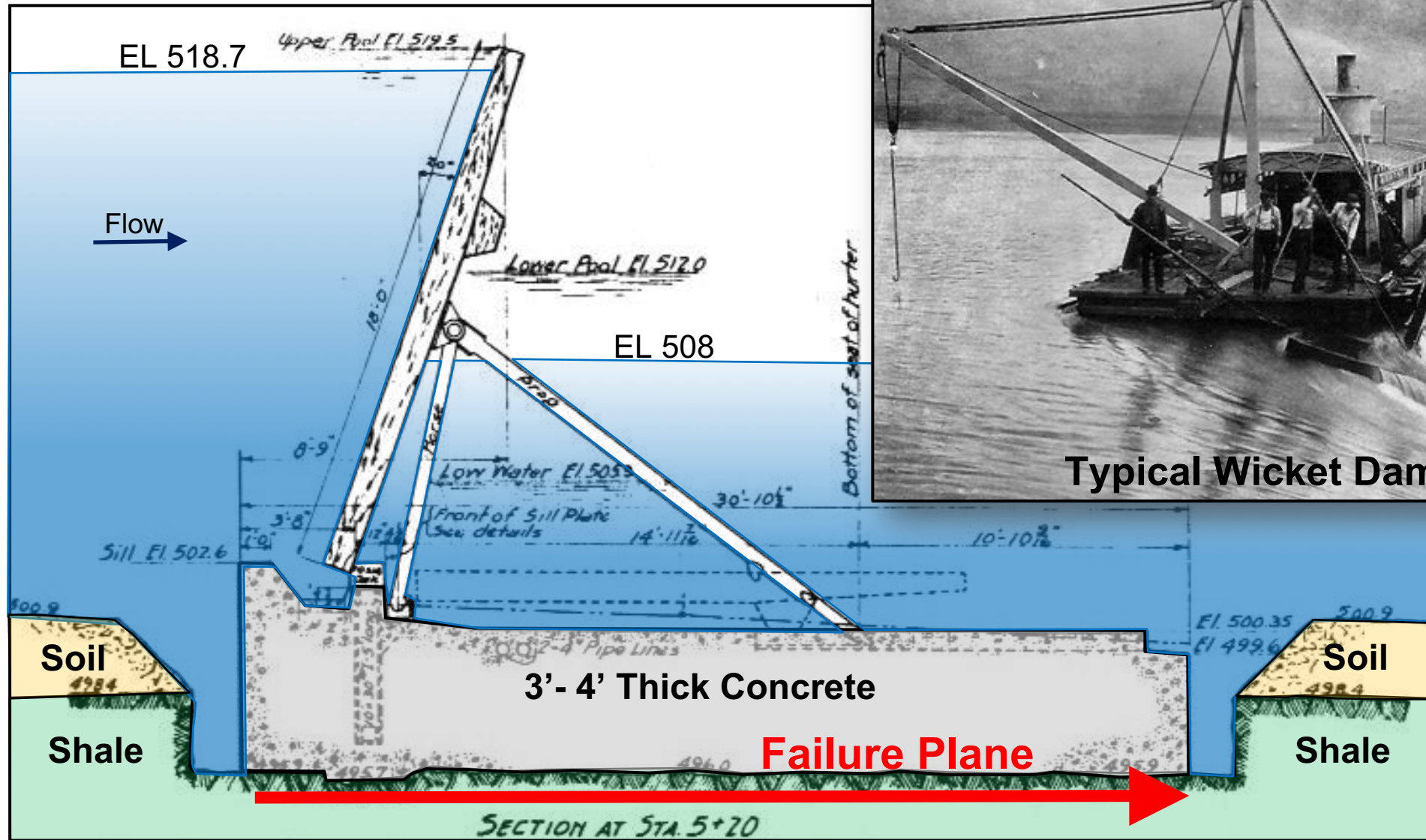
- Located on the Ohio River, at WV/OH boarder.
- Canalization of the Ohio River
  - 49 locks & dams (now 19)
  - 9' deep channel
  - 600' x 110' lock chambers
  - Completed 1929
- Lock and Dam #26  
Constructed in 1911
- Wicket Dam failed Aug 8, 1912

# Ohio River Lock and Dam # 26 - Location



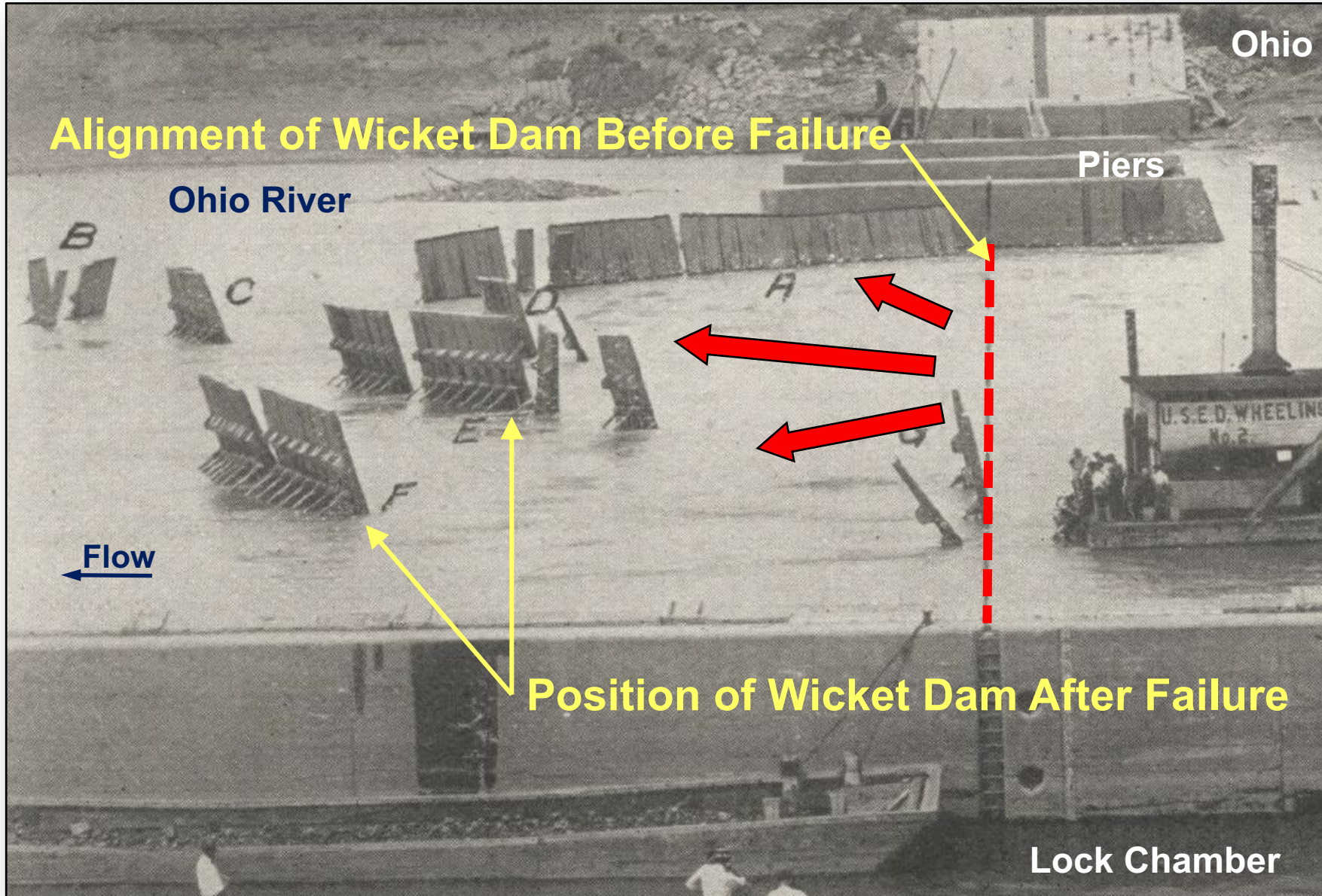
Aerial Photo – R.C. Byrd Locks and Dam

# Ohio River Lock and Dam # 26 – Wicket Dam



Cross Section – Chanoine Wicket Dam – Ohio River Lock and Dam #26

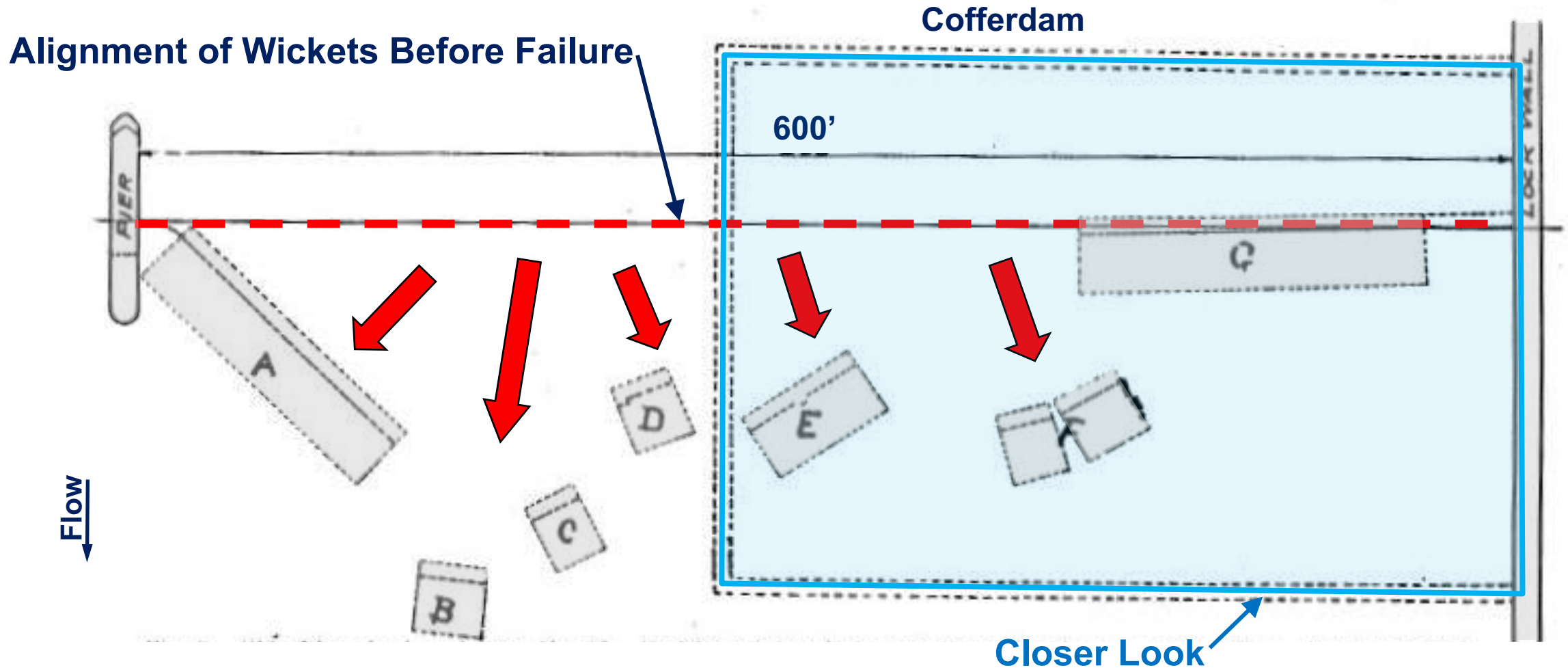
# Ohio River Lock and Dam # 26 – Dam Failure



- Second time wickets were raised
- 10.7' head of water
- Failed on Aug 8, 1912 at 6:30 am
- Initiated in middle of 600' long dam
- Slid up to 157 feet downstream

Photo taken from West Virginia Side – After Failure

# Ohio River Lock and Dam # 26 – Monolith Locations



Plan View – Position of Navigable Pass Foundations After Failure



# Ohio River Lock and Dam # 26 – Dewatered Monoliths

“The rock upon which the concrete rested had a very small frictional coefficient and was composed of layers through which water could penetrate and produce an upward pressure on the base of the dam” from “*Failure of Navigable Pass, Dam No. 26, Ohio River*”

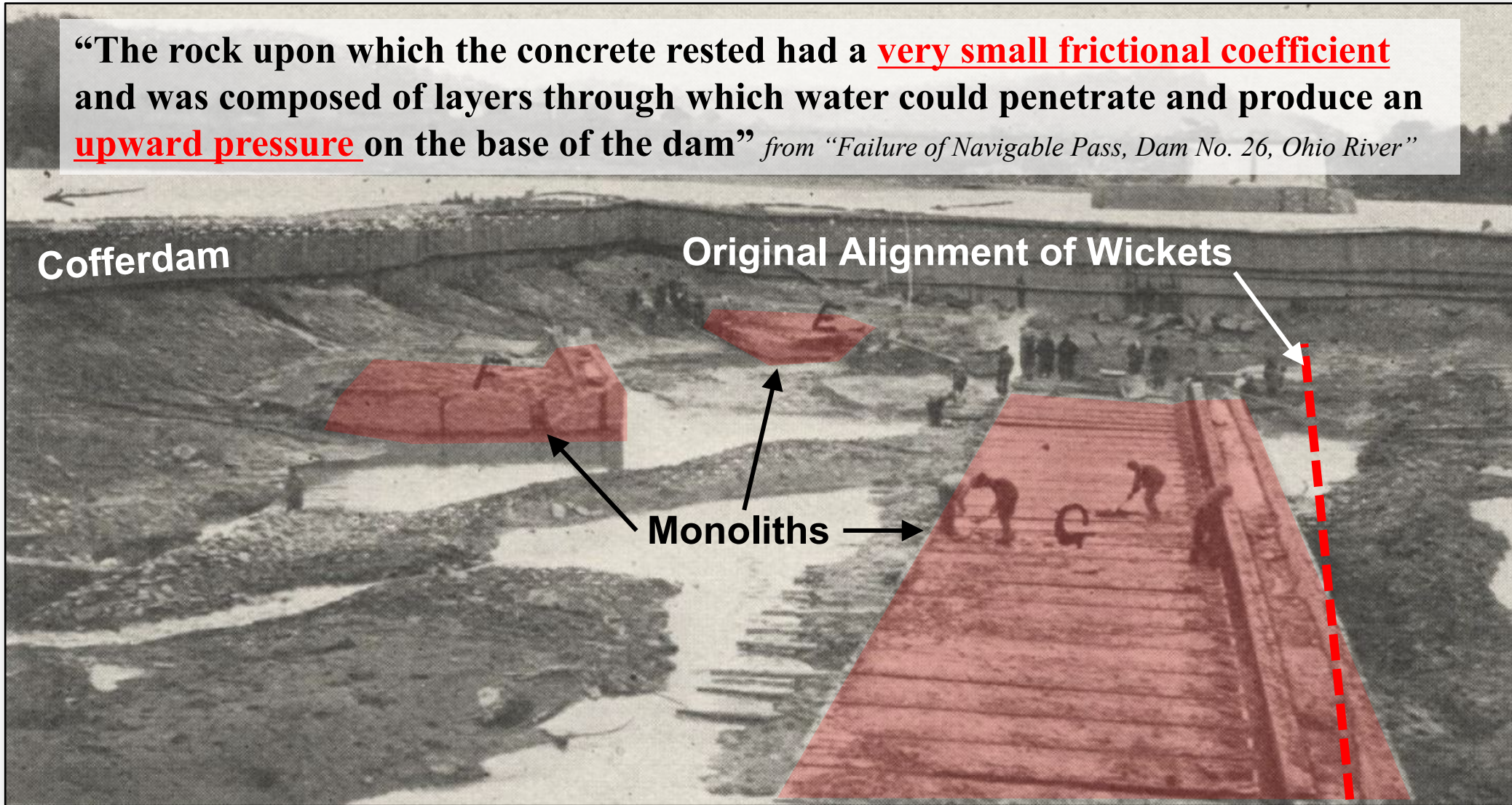
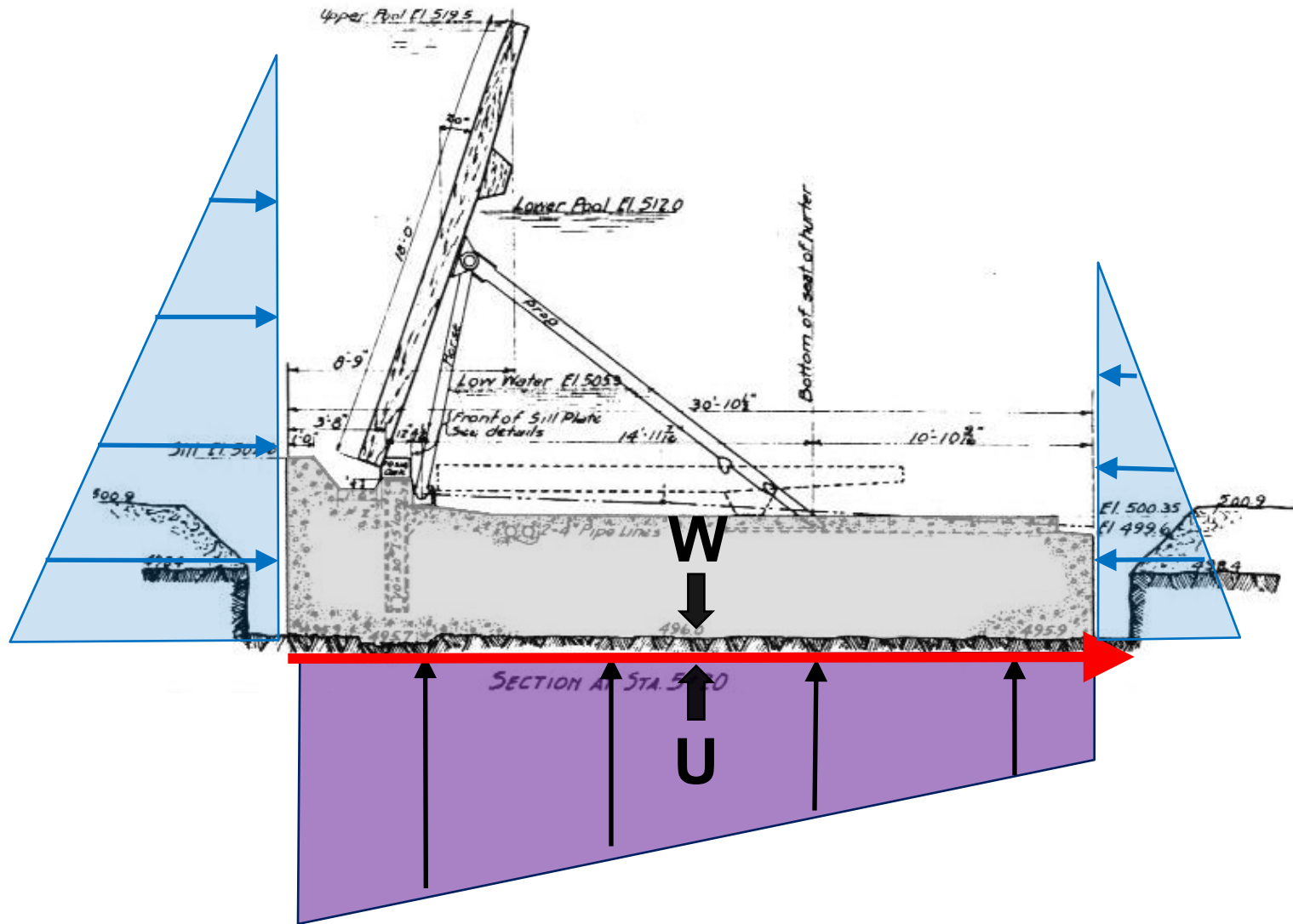


Photo Taken Within Cofferdam Showing Location of Failed Monoliths



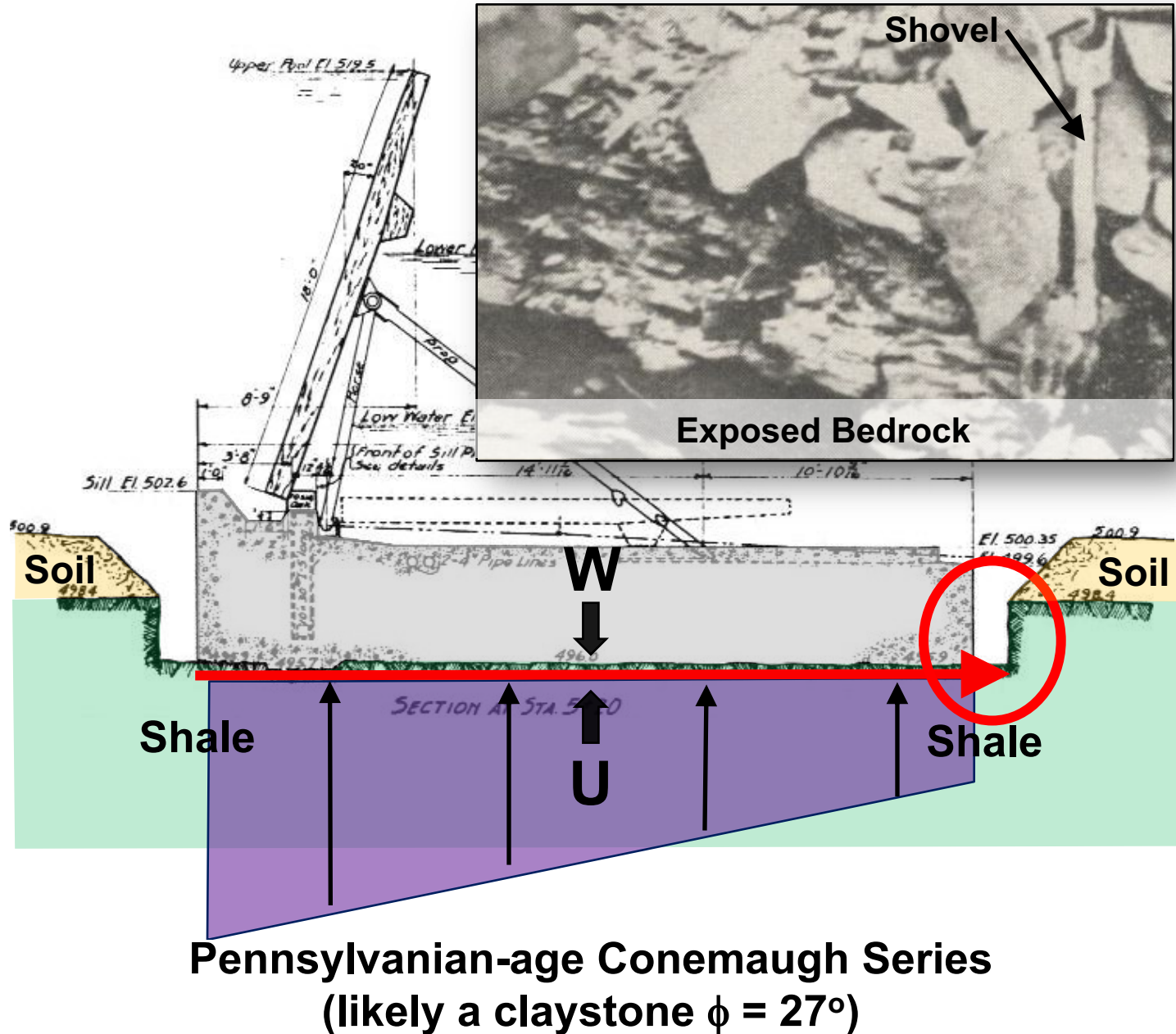
# Ohio River Lock and Dam # 26 – Factors Leading to Failure



- Sliding plane was slightly below base.
- Original design: full uplift acting on 50% of foundation (typical for that era).
- Today, without drains, full uplift would be applied to 100% of foundation.



# Ohio River Lock and Dam # 26 – Factors Leading to Failure



- Sliding plane was slightly below base.
- Original design: full uplift acting on 50% of foundation (typical for that era).
- Today, without drains, full uplift would be applied to 100% of foundation.
- Sliding resistance of bedrock (shale) was overestimated
- No passive wedge

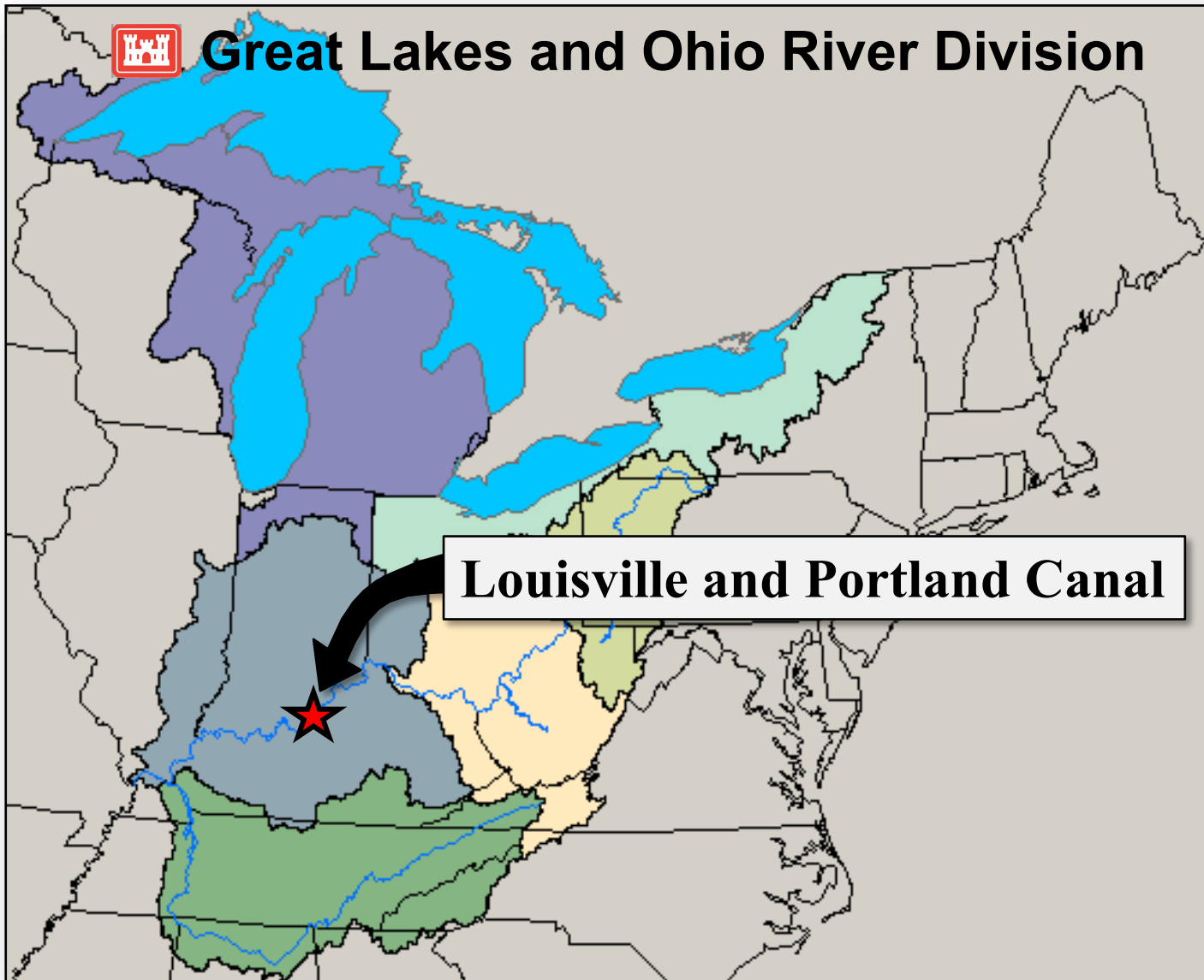


# *Sliding Failures at Five Lock and Dam Projects*

## OUTLINE

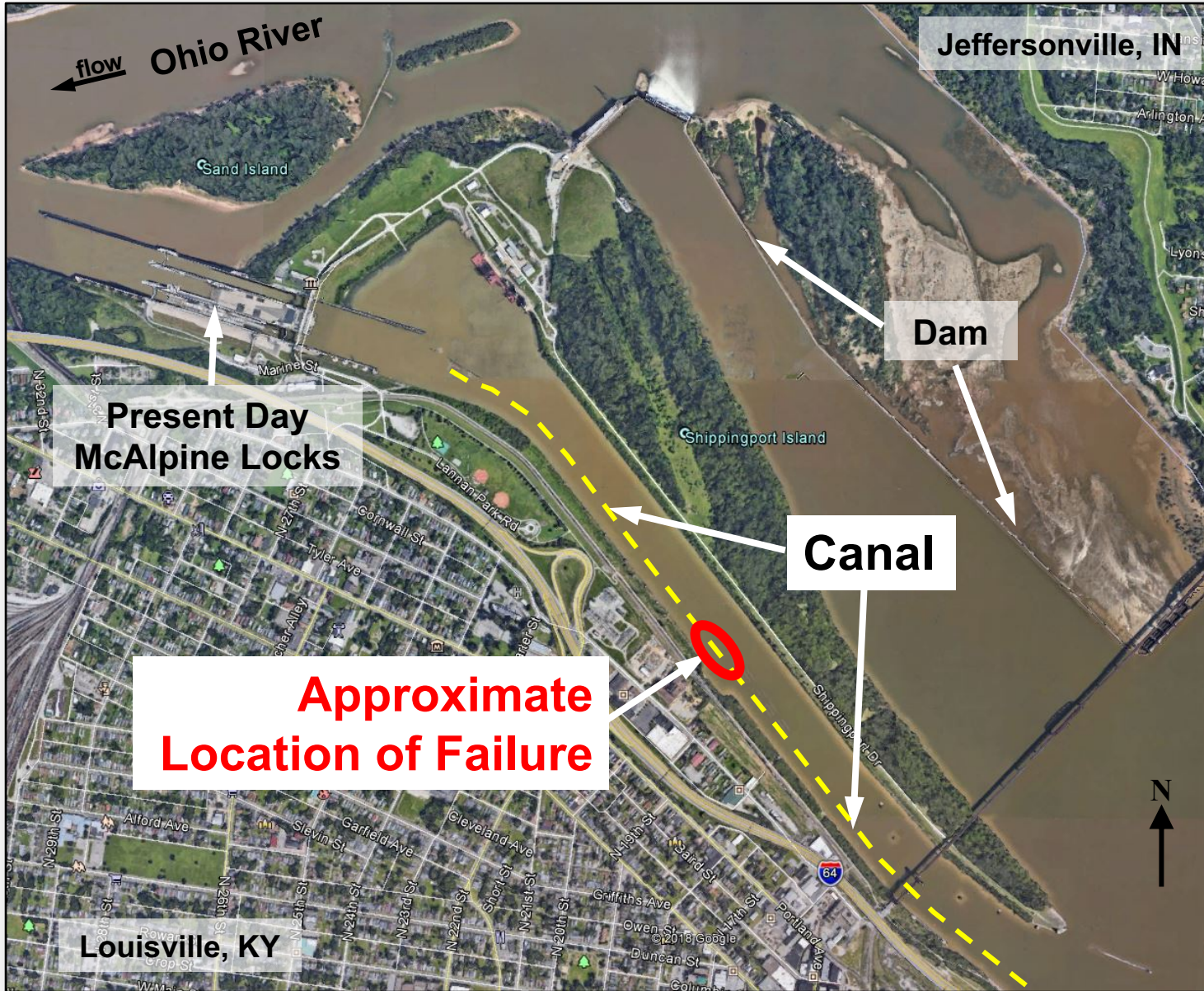
1. **Ohio River Lock and Dam #26**
2. **Louisville and Portland Canal**
3. **Wheeler Lock and Dam**
4. **Cannelton Lock and Dam**
5. **J T Myers Lock and Dam**

# Louisville and Portland Canal – General Information



- Located on the Ohio River at Louisville, KY
- Canal widened in 1915
- Construction contractor-designed cofferdam failed Oct. 5, 1915

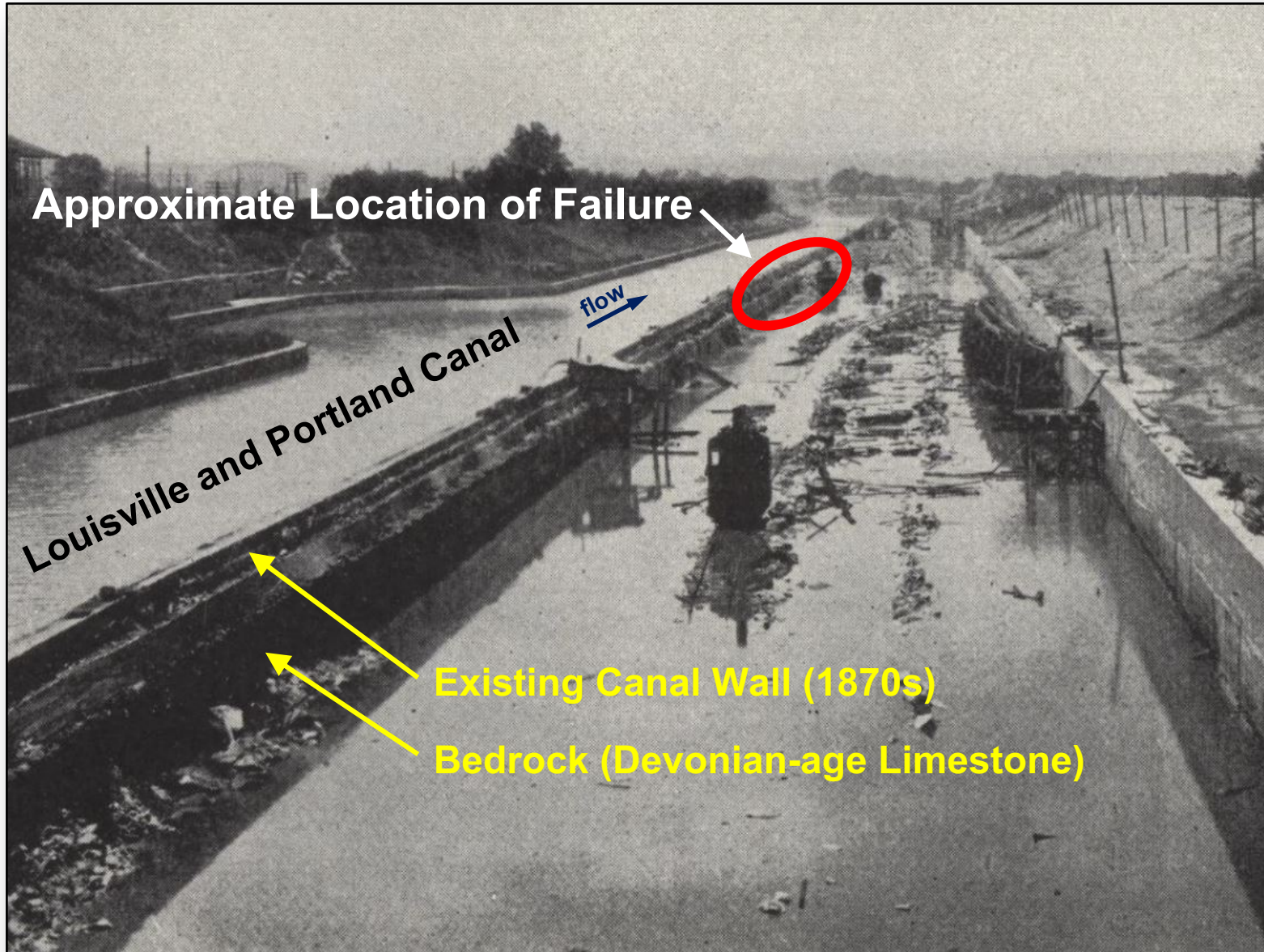
# Louisville and Portland Canal – Location & History



- Falls of the Ohio, obstruction to navigation, 26' drop in 2 mi
- 1830's: original canal (50' wide) with series of three locks
- Widened canal and larger locks:
  - 1870's
  - 1910's – 1920's
  - 1960's
  - 1990's



# Louisville and Portland Canal – Dewatered Cofferddam



Construction Photo – Widening Canal

- Widening canal from 87' to 200'
- Construction contractor used the pre-existing canal wall (built 1870s) and underlying limestone as a cofferdam
- Cofferdam failed at 7:50am on Oct. 5, 1915
- One death



# Louisville and Portland Canal – Cofferddam Failure

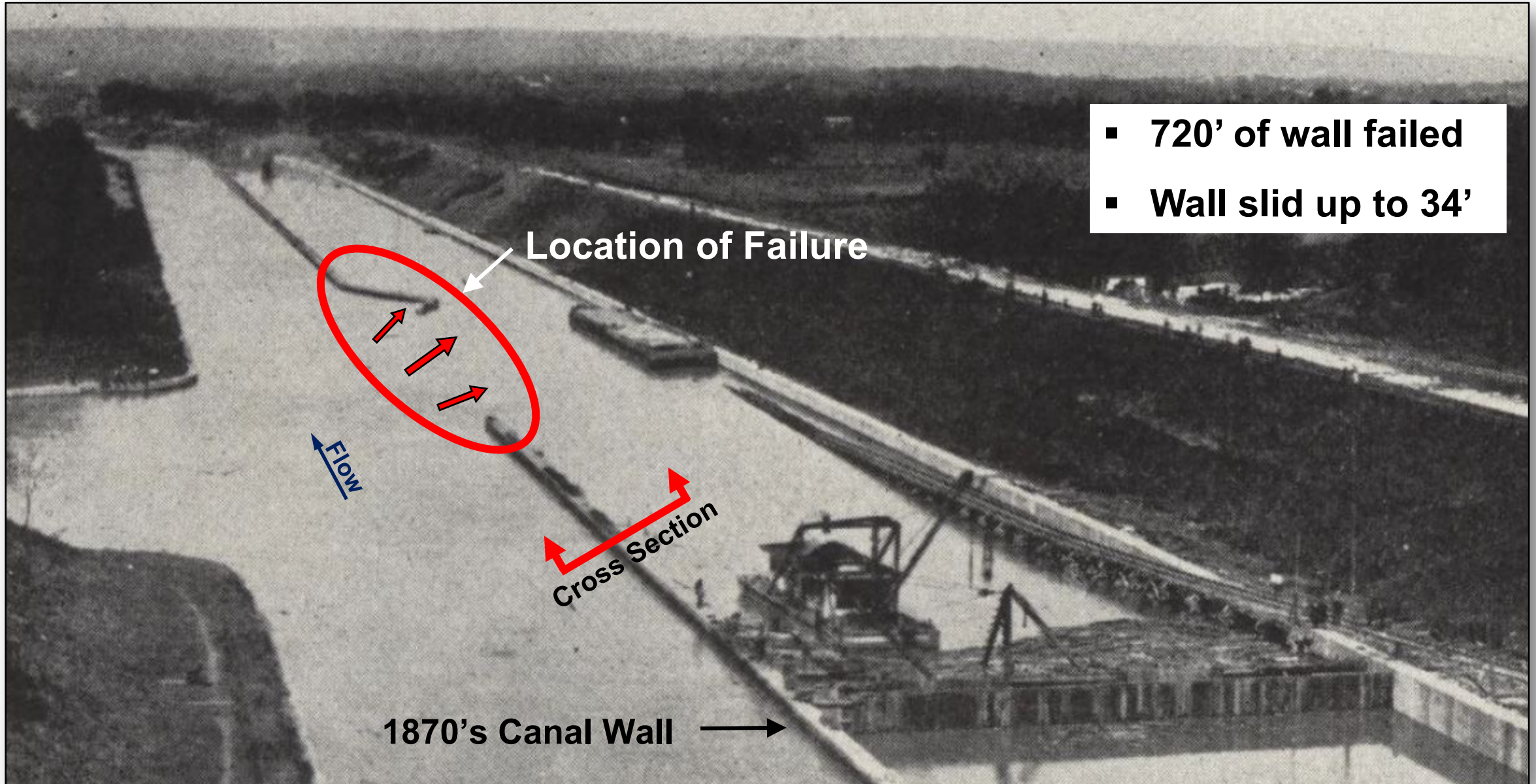
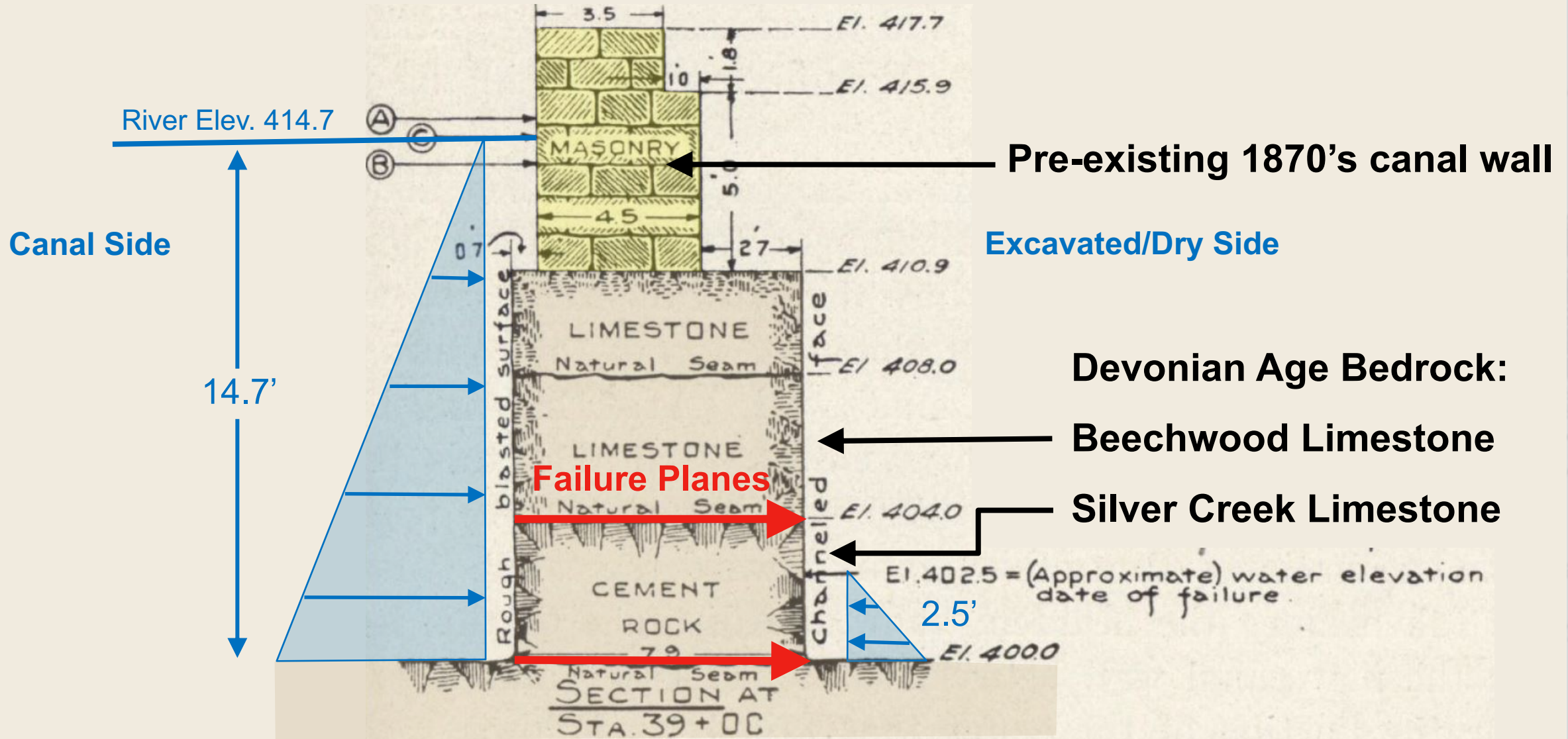


Photo – Location of Failed Section of Cofferdam

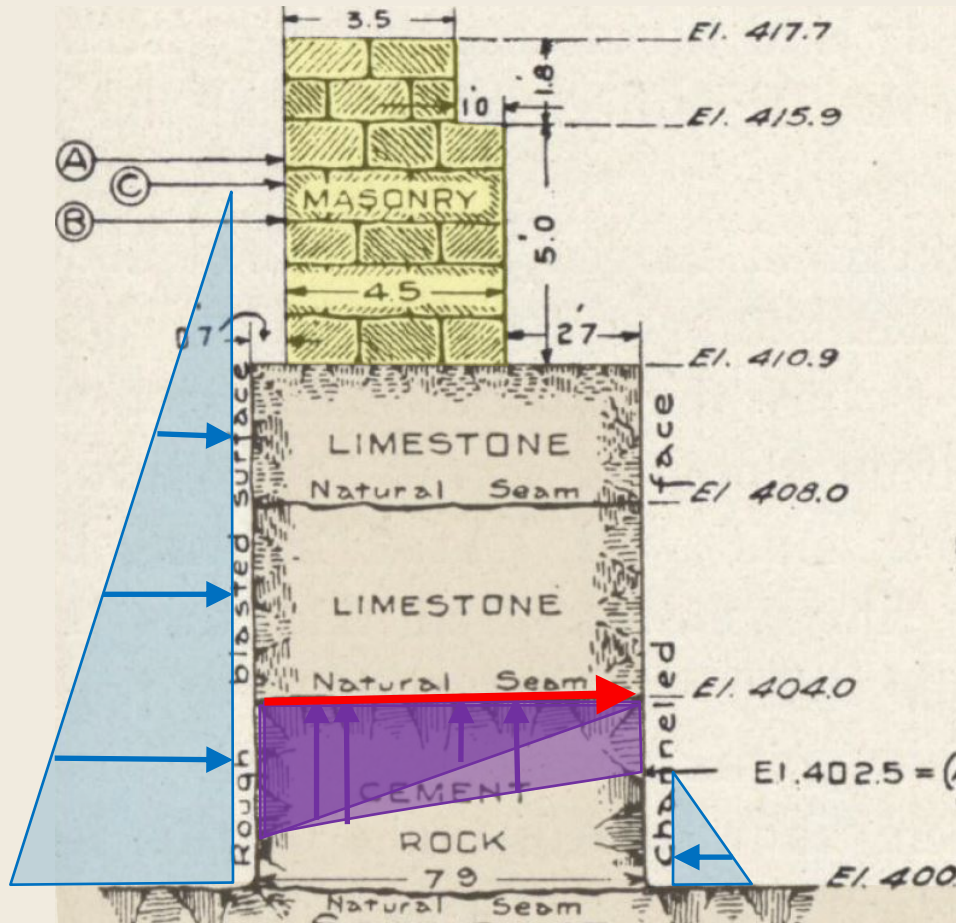


# Louisville and Portland Canal – Failure Planes



Cross Section - Cofferdam

# Louisville and Portland Canal – Factors leading to Failure



CONDITIONS	Base at El. 404
	Ratio of Hor. to Vert. Forces
ASSUMED	
No upward pressure on base.	0.28
Full upward pressure at outside edge varying uniformly to zero pressure at inside edge of base.	0.35
Full upward pressure over $\frac{1}{2}$ base	0.35
Full upward pressure over entire base	0.49

Could fail if phi angle is 16° or less

Could fail if phi angle is 19° or less

Could fail if phi angle is 26° or less

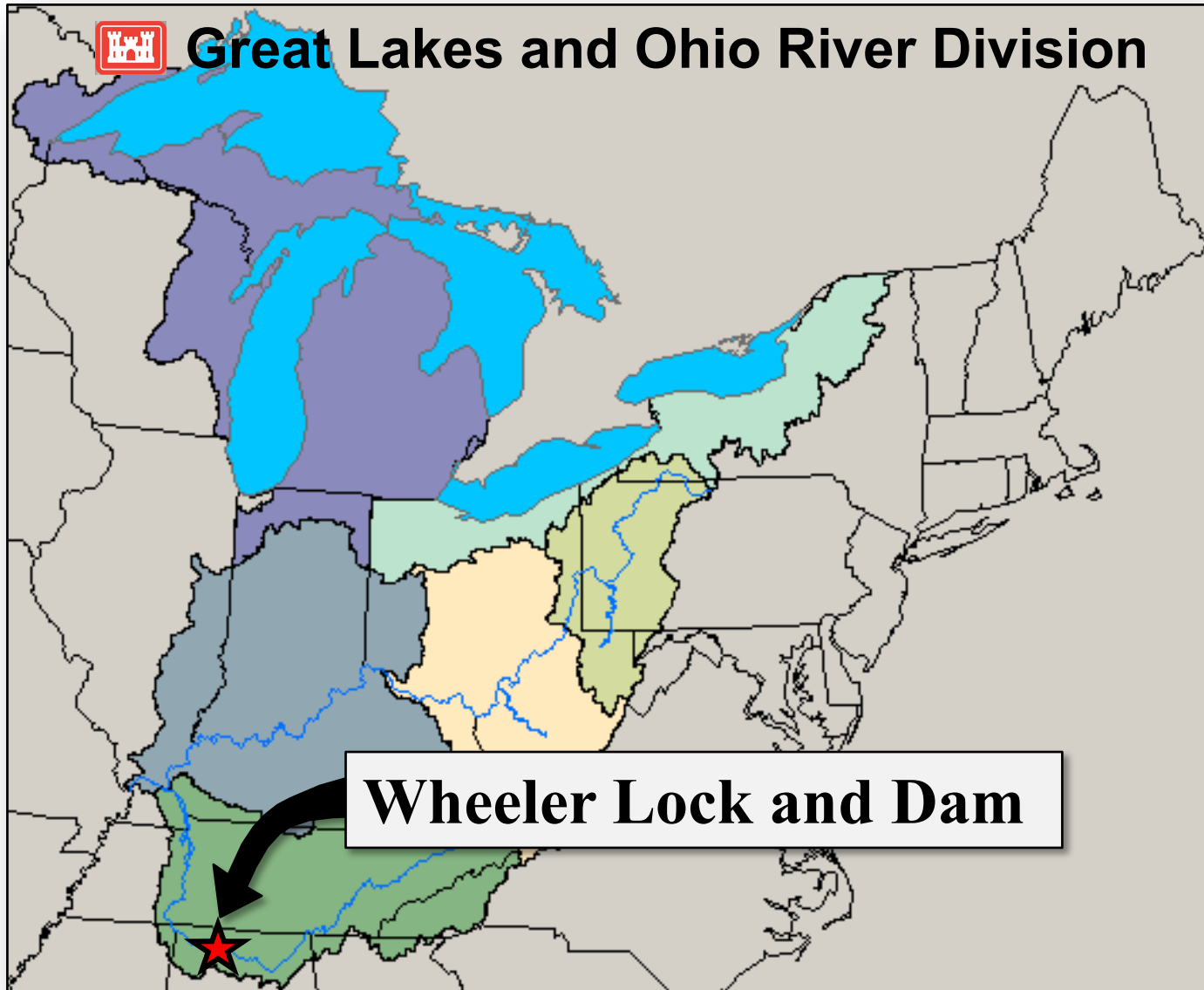
- Wedges were used to stop seepage from dry side (increased uplift pressure)
- Some borings had “silt or clay seam” at elev. 404 (lower phi angle)
- Blasting may have moved/shifted bedrock (post-peak rock strength)

# *Sliding Failures at Five Lock and Dam Projects*

## OUTLINE

1. **Ohio River Lock and Dam #26**
2. **Louisville and Portland Canal**
3. **Wheeler Lock and Dam**
4. **Cannelton Lock and Dam**
5. **J T Myers Lock and Dam**

# Wheeler Lock and Dam – General Information



- Located on the Tennessee River in Northern Alabama.
- Muscle Shoals obstruction
- Original lock constructed in 1934
- Additional 110' x 600' lock proposed 1960s, located adjacent to the original lock.
- Original lock wall was used as part of the cofferdam, failed in 1961.

# Wheeler Lock and Dam – Location of New Lock

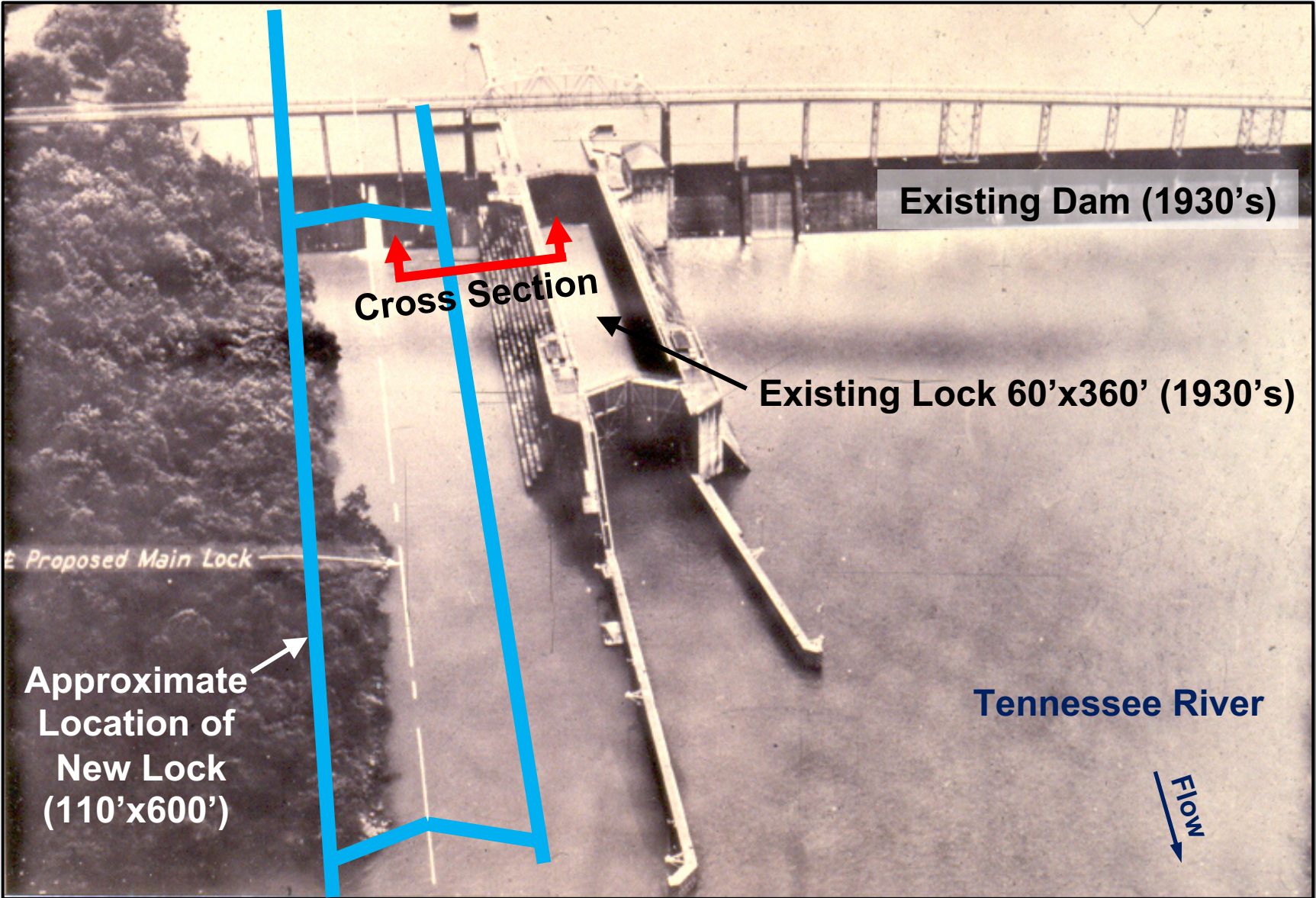
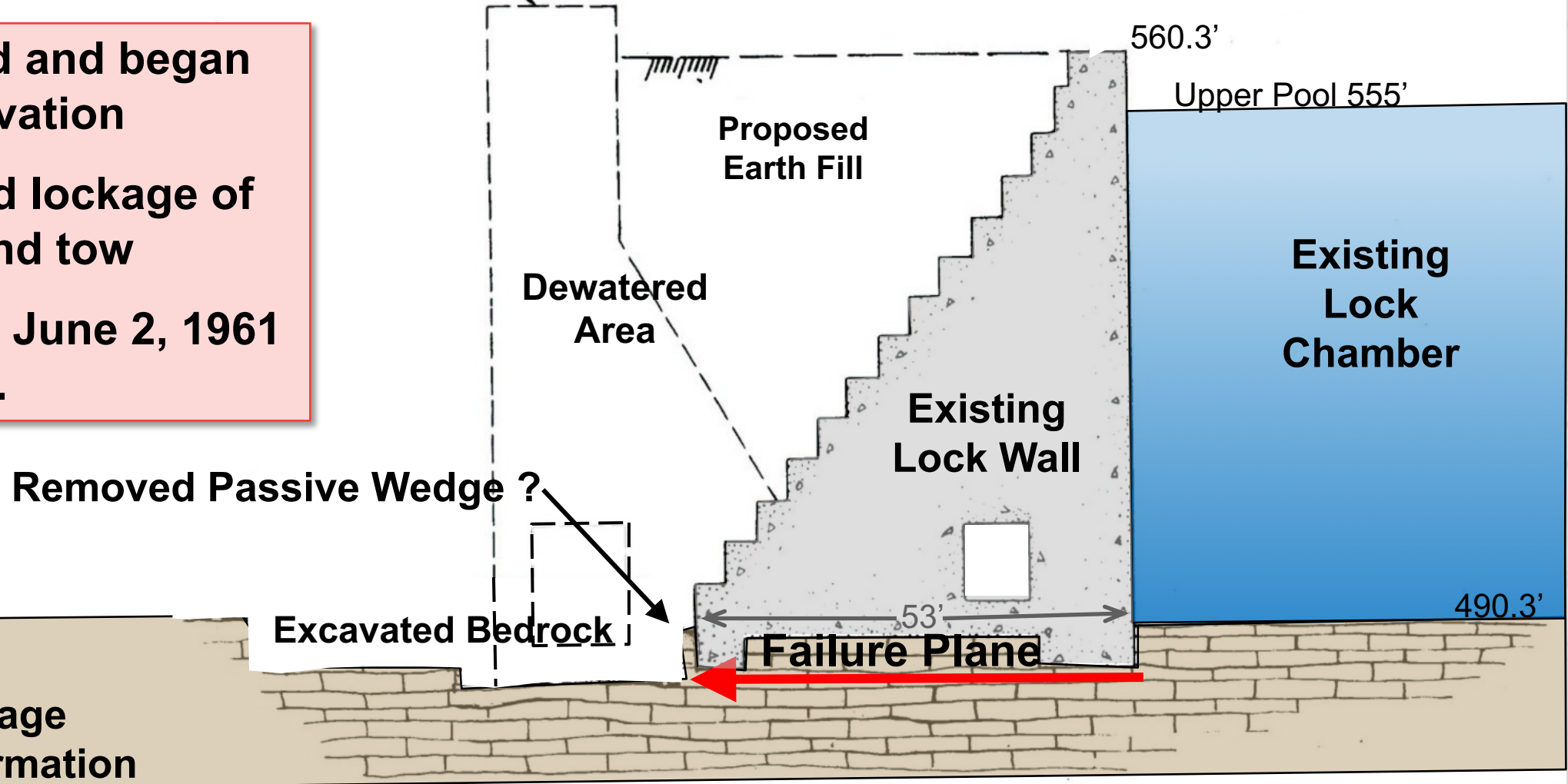


Photo Prior to Construction of Proposed New Lock

# Wheeler Lock and Dam – Excavation for New Lock

Proposed New River Wall

- Dewatered and began rock excavation
- Completed lockage of an upbound tow
- Failure on June 2, 1961 at 9:30pm.



Limestone:  
Mississippian-age  
Fort Payne Formation

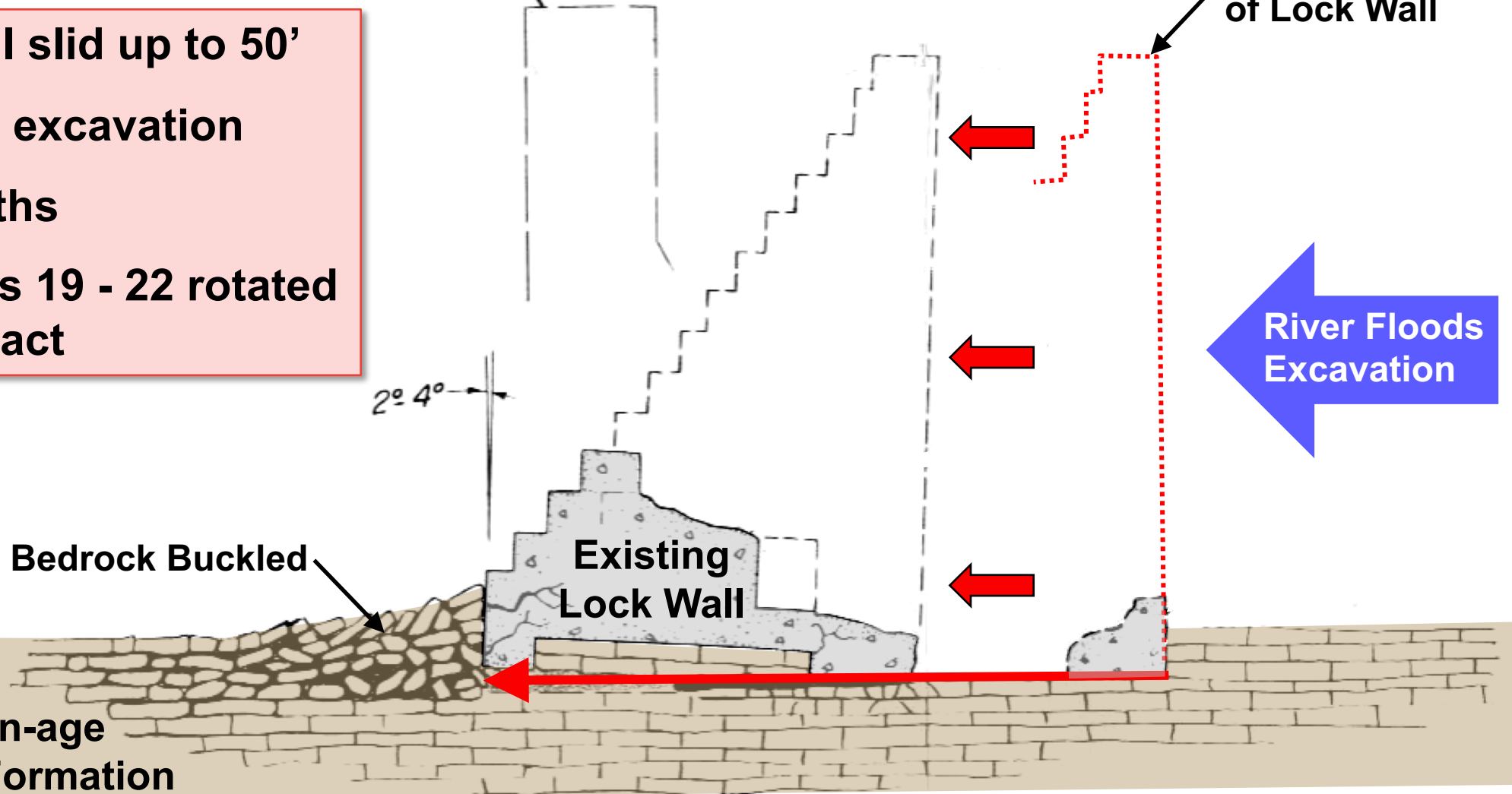
Cross Section – Lock Wall – Before Failure

# Wheeler Lock and Dam – Sliding Failure

Proposed New River Wall

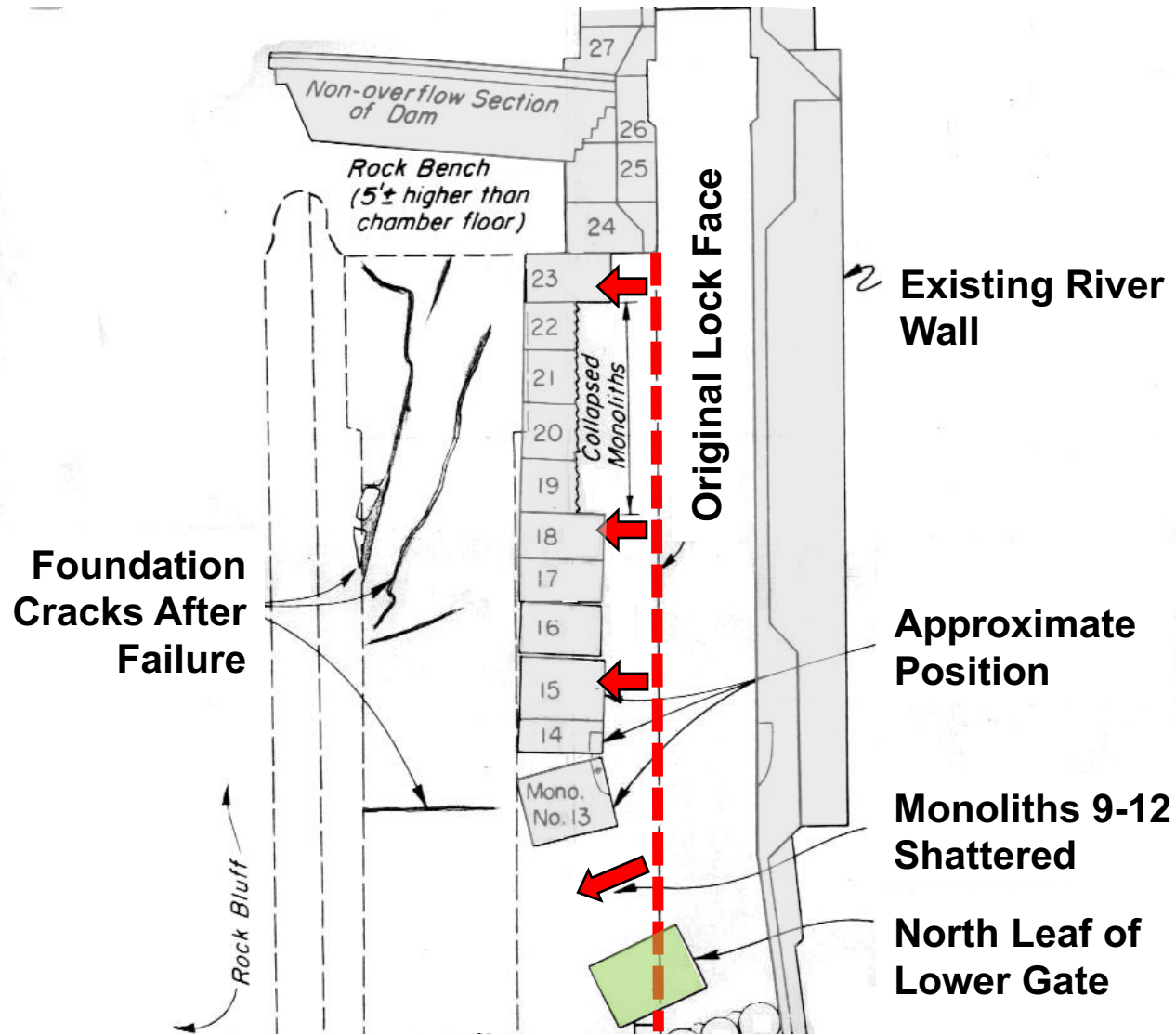
Original Location of Lock Wall

- Land wall slid up to 50'
- Flooding excavation
- Two Deaths
- Monoliths 19 - 22 rotated after impact

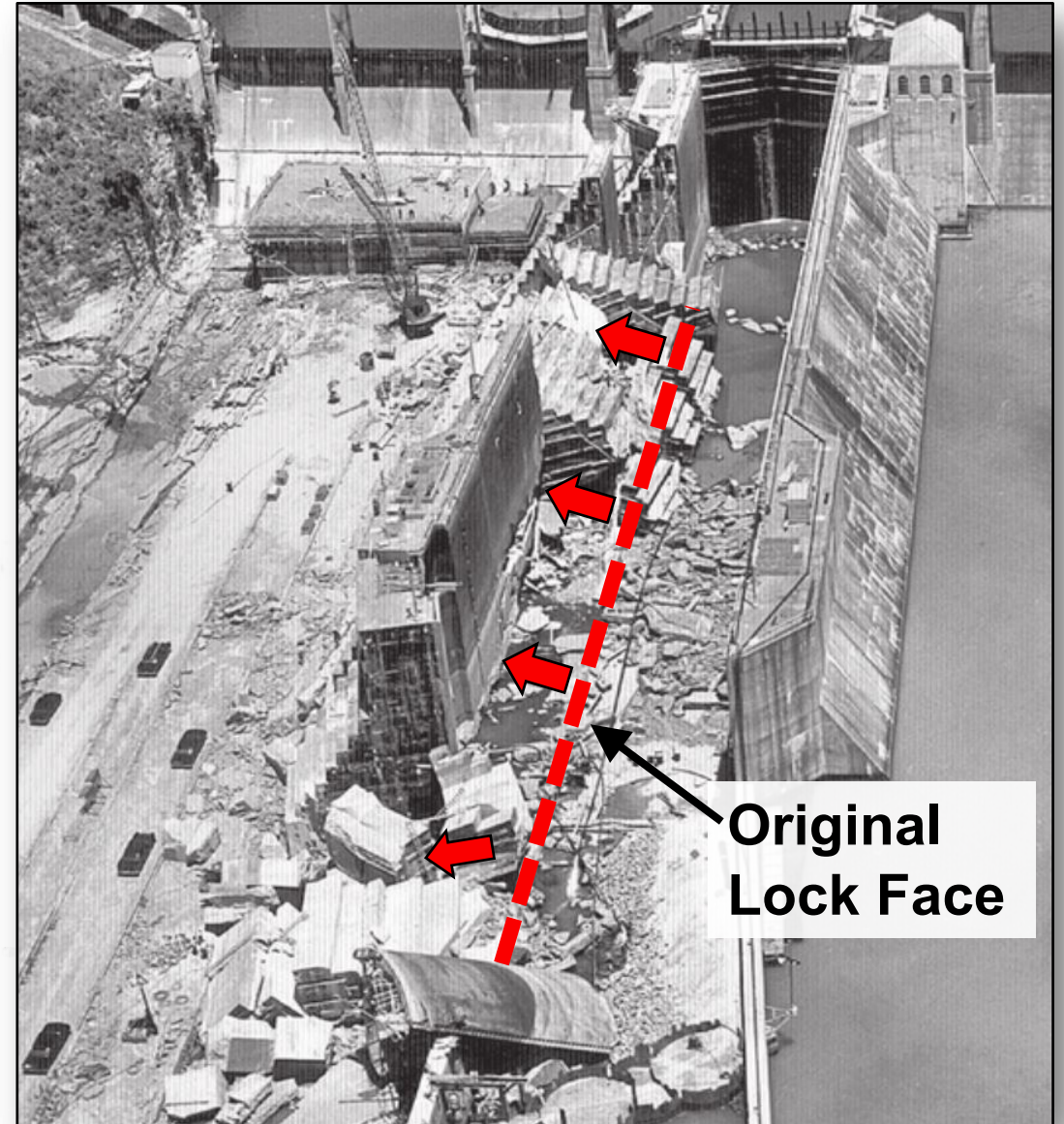


Cross Section – Lock Wall – After Failure

# Wheeler Lock and Dam – Plan View and Photo After Failure



Plan View – After Failure



Aerial Photo – After Failure - Dewatered



# Wheeler Lock and Dam – Photo After Failure

- Seepage noted during lockage
- Blast may have been concurrent with failure



**Photo Viewed from Proposed New Lock After Failure of Original Lock**

# Wheeler Lock and Dam – Factors Leading to Failure



Photo Looking Downstream – After Failure

- Thick limestone foundation having a shale seam (0.5' thick), with an undetected **thin clay seam** (1/16 to 3/8" thick) at the base of the shale.
- Overestimated sliding resistance of bedrock
- Excavation “daylighted” clay seam, removing the passive wedge (blasting impact?)

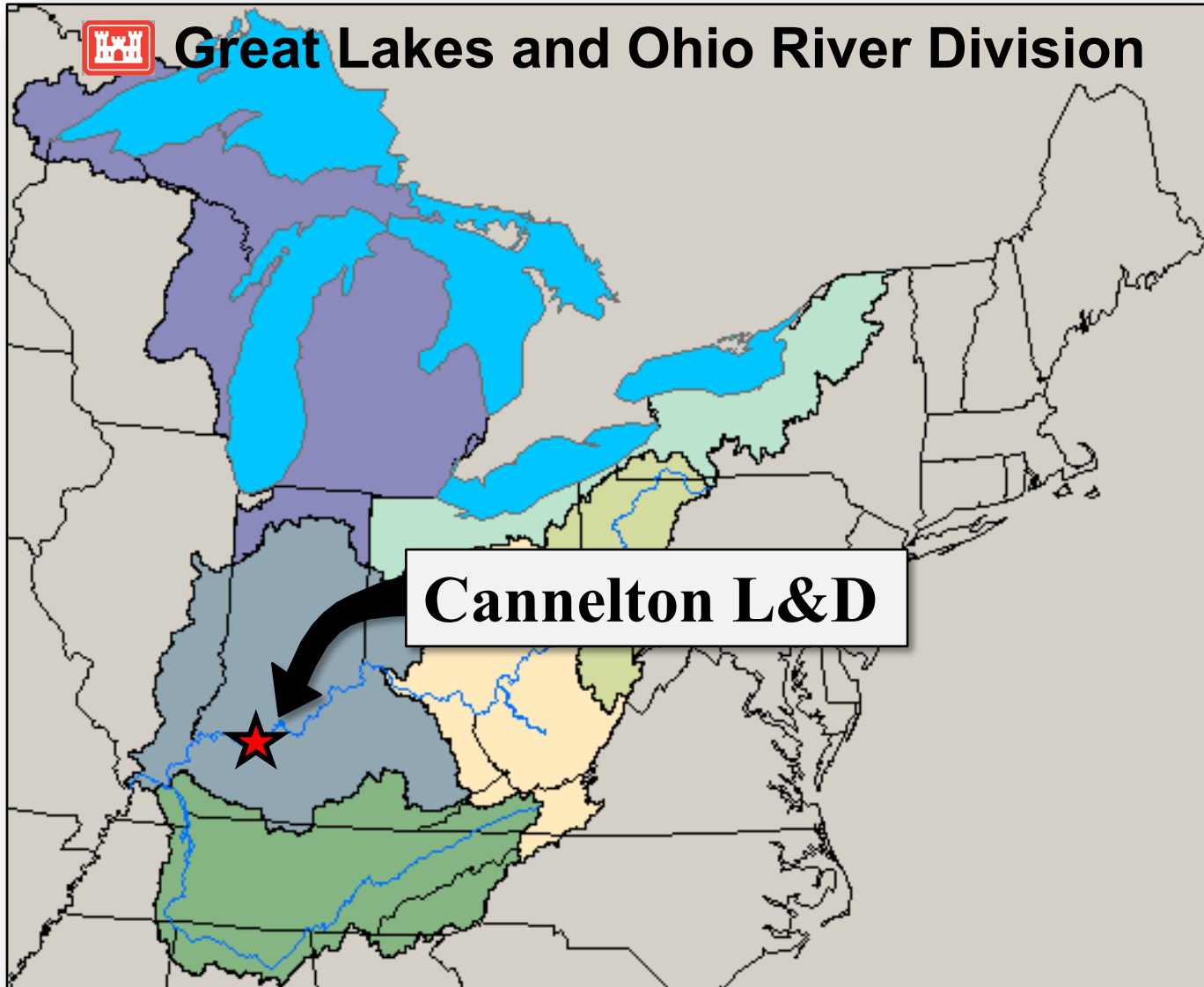


# *Sliding Failures at Five Lock and Dam Projects*

## OUTLINE

- 1. Ohio River Lock and Dam #26**
- 2. Louisville and Portland Canal**
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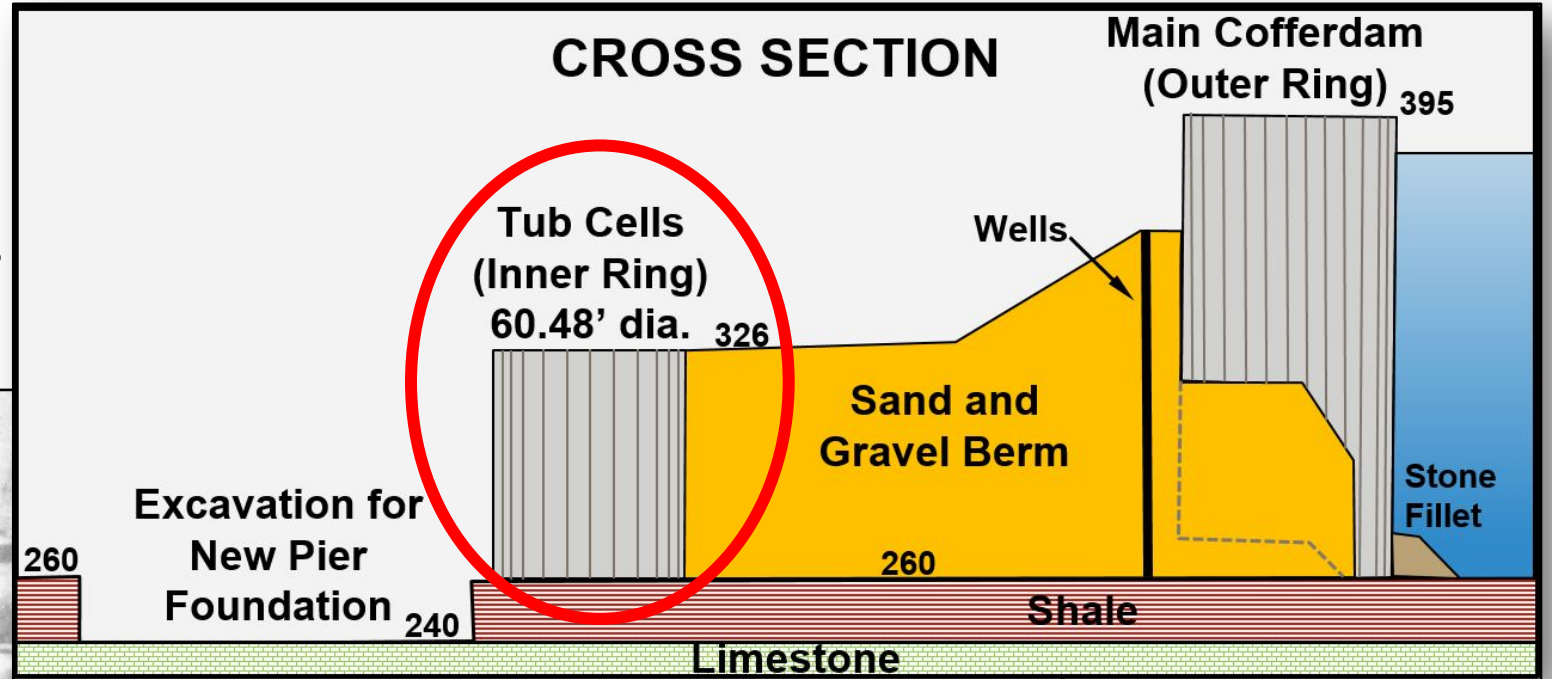
# Cannelton Lock and Dam – General Information



- Located on the Ohio River at IN/KY boarder.
- Construction contractor-designed double-ringed sheet-pile cell cofferdam
- Excavation for the new dam pier foundations
- Progressive sliding failure, with distress indicators from Oct 19 to Nov 1, 1967 (14 days)

# Cannelton Lock and Dam – Photo & Section of Cofferddam

- Double-ringed sheet-pile cell cofferdam
- Inner ring of cofferdam cells founded on top of rock



Mississippian-age  
Waltersburg Shale

Tub Cells  
(Inner Ring of Sheet-Pile Cells)

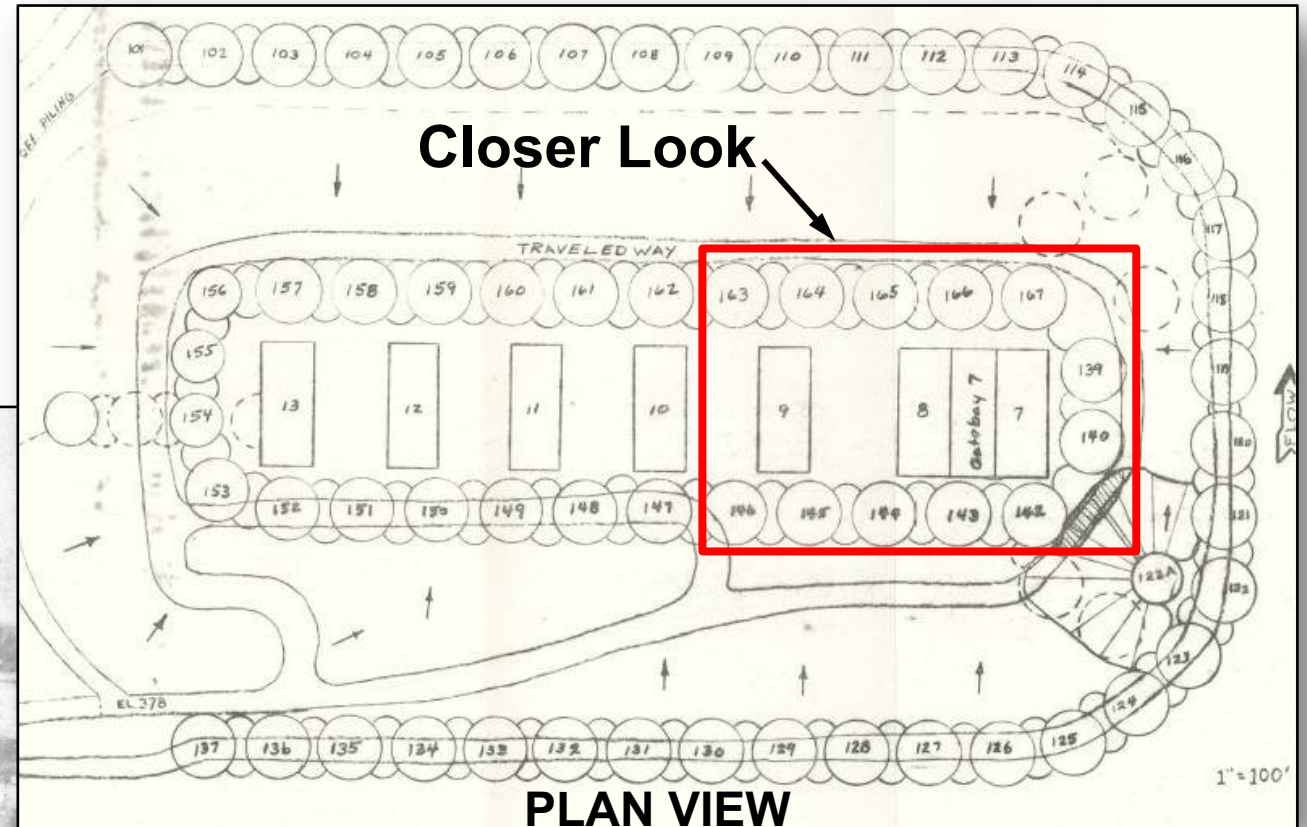
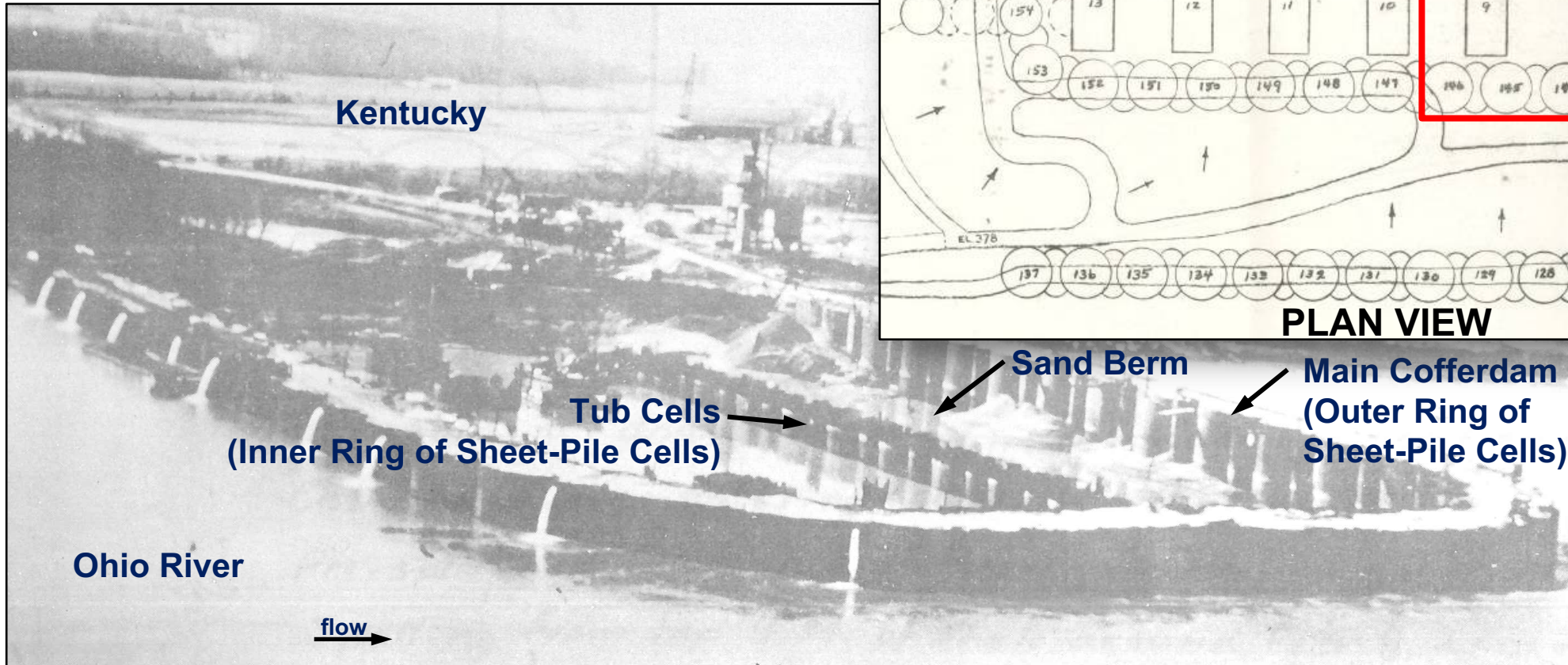
Sand Berm

Main Cofferdam  
(Outer Ring of Sheet-Pile Cells)

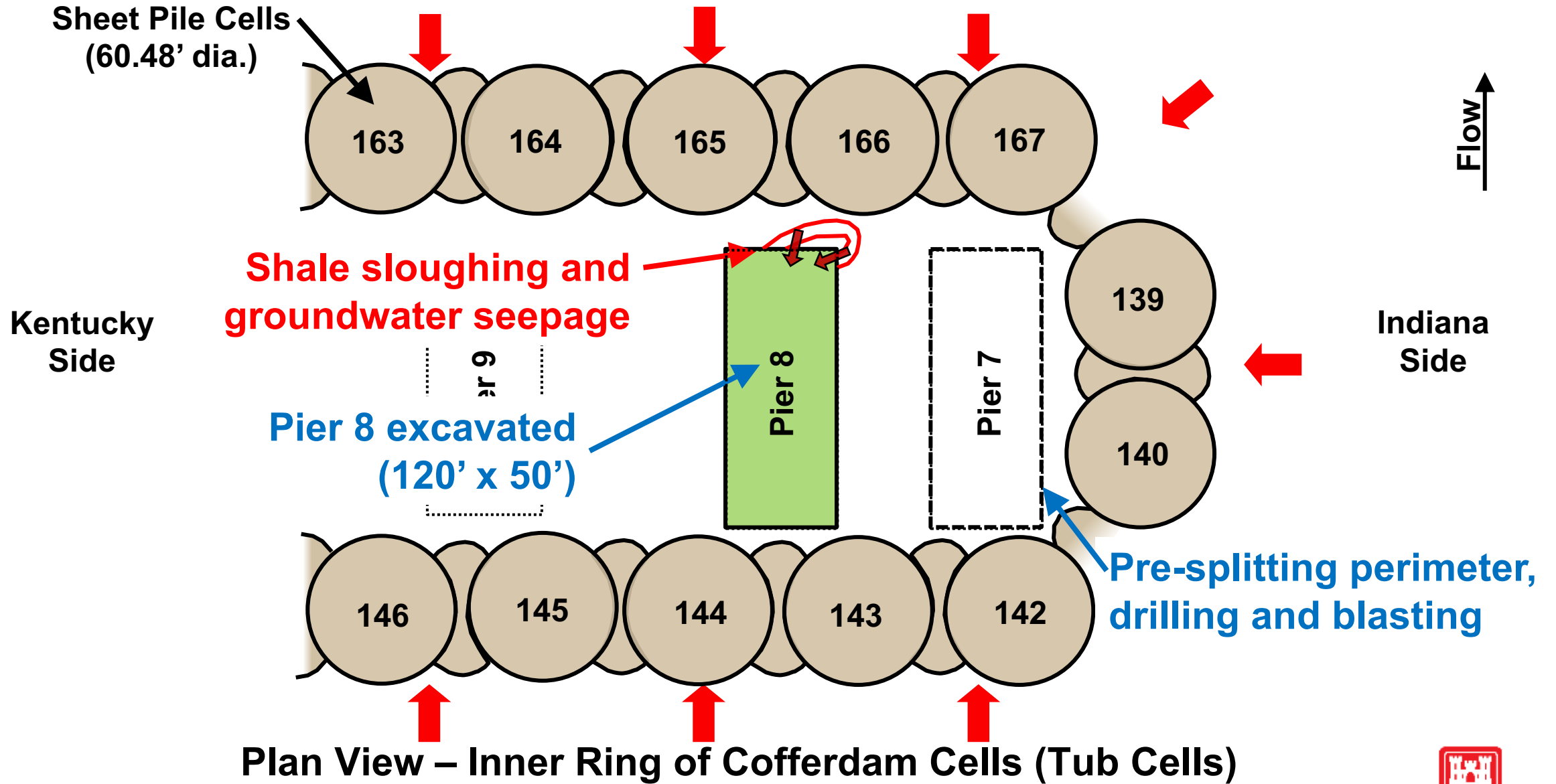


# Cannelton Lock and Dam – Photo & Plan View of Cofferdam

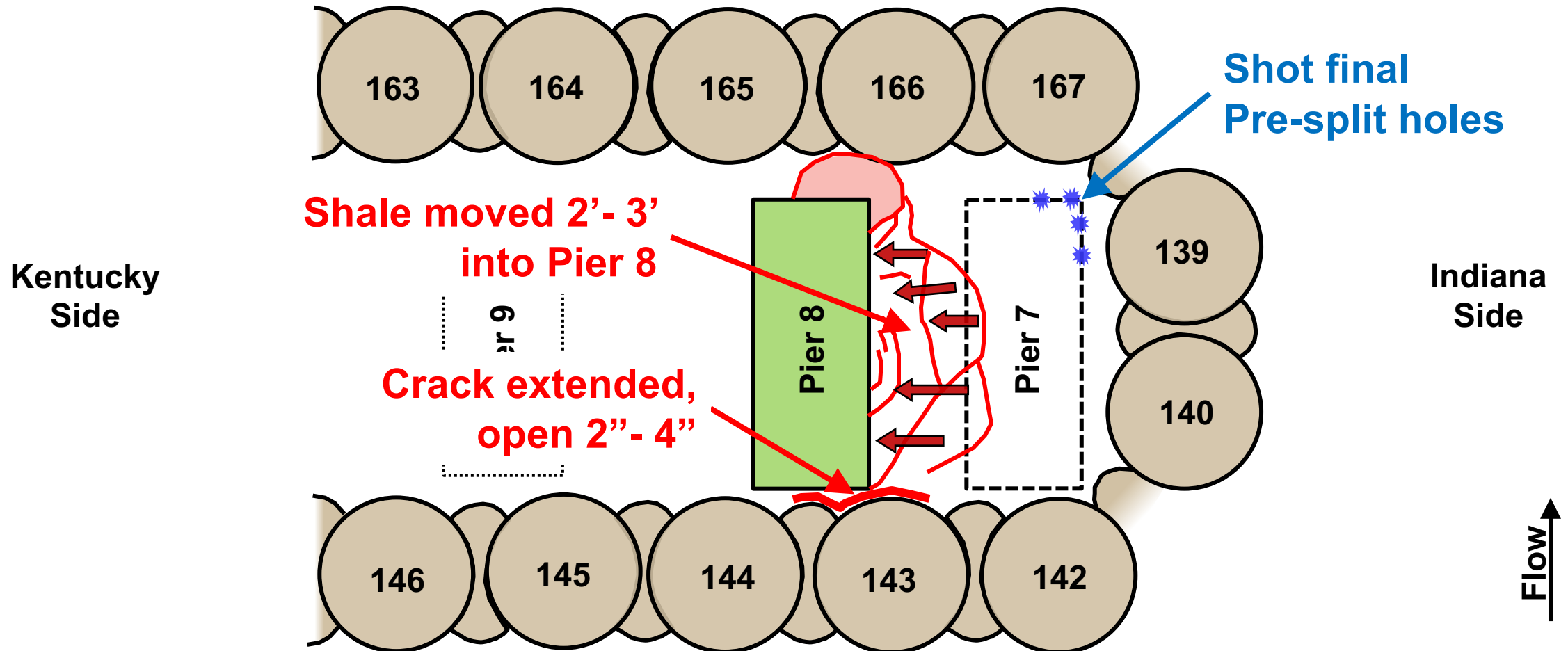
- Double-ringed sheet-pile cell cofferdam
- Inner ring of cofferdam cells founded on top of rock



# Cannelton Lock and Dam – Oct 19, 1967 (day 1)



# Cannelton Lock and Dam – Oct 21, 1967 (day 3)

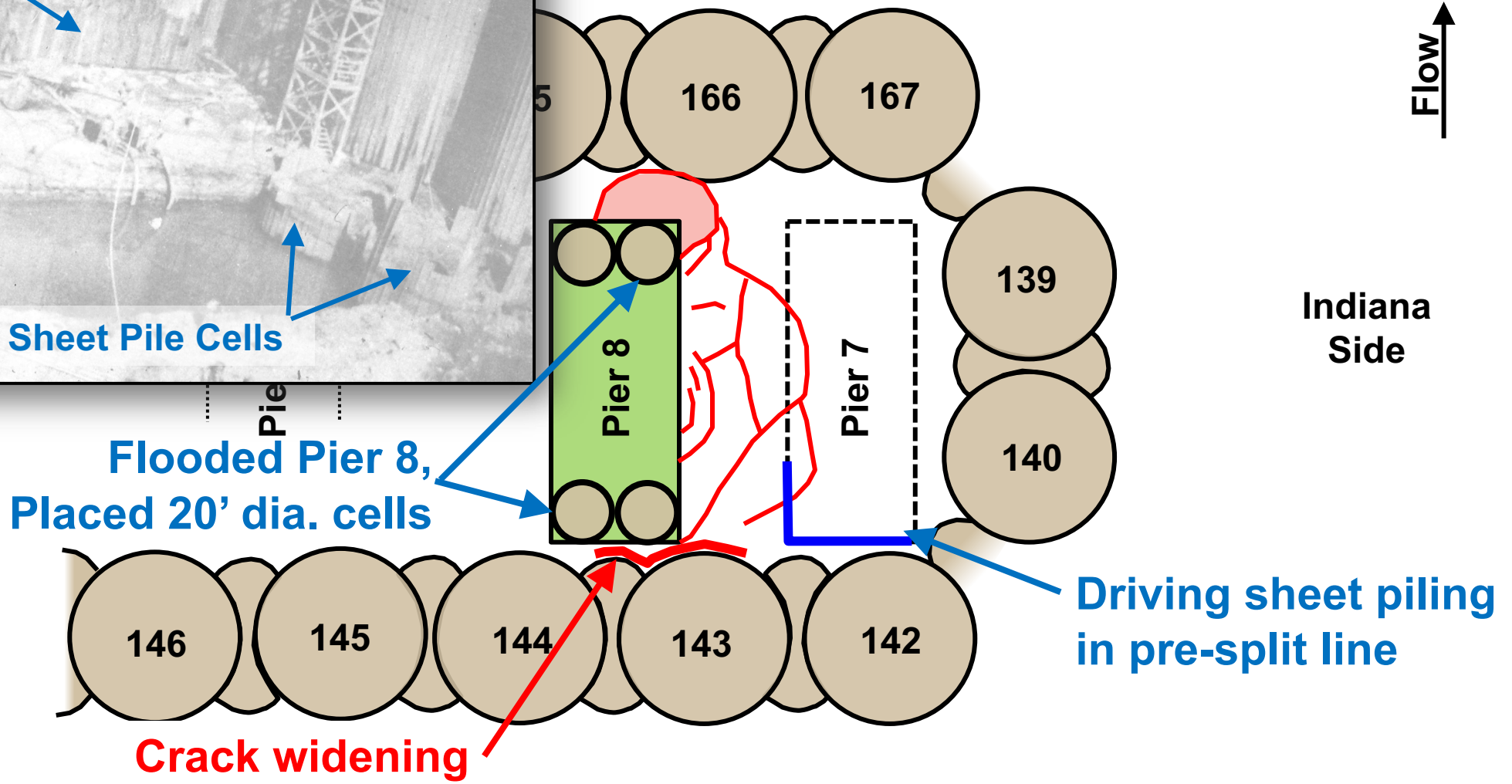
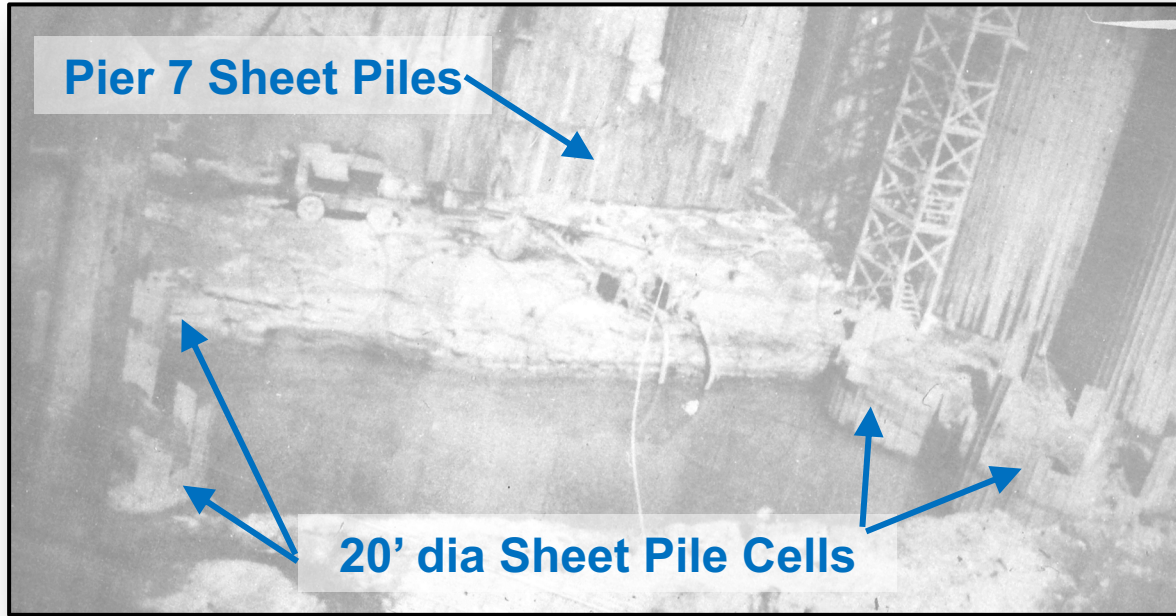


Plan View – Inner Ring of Cofferdam Cells (Tub Cells)





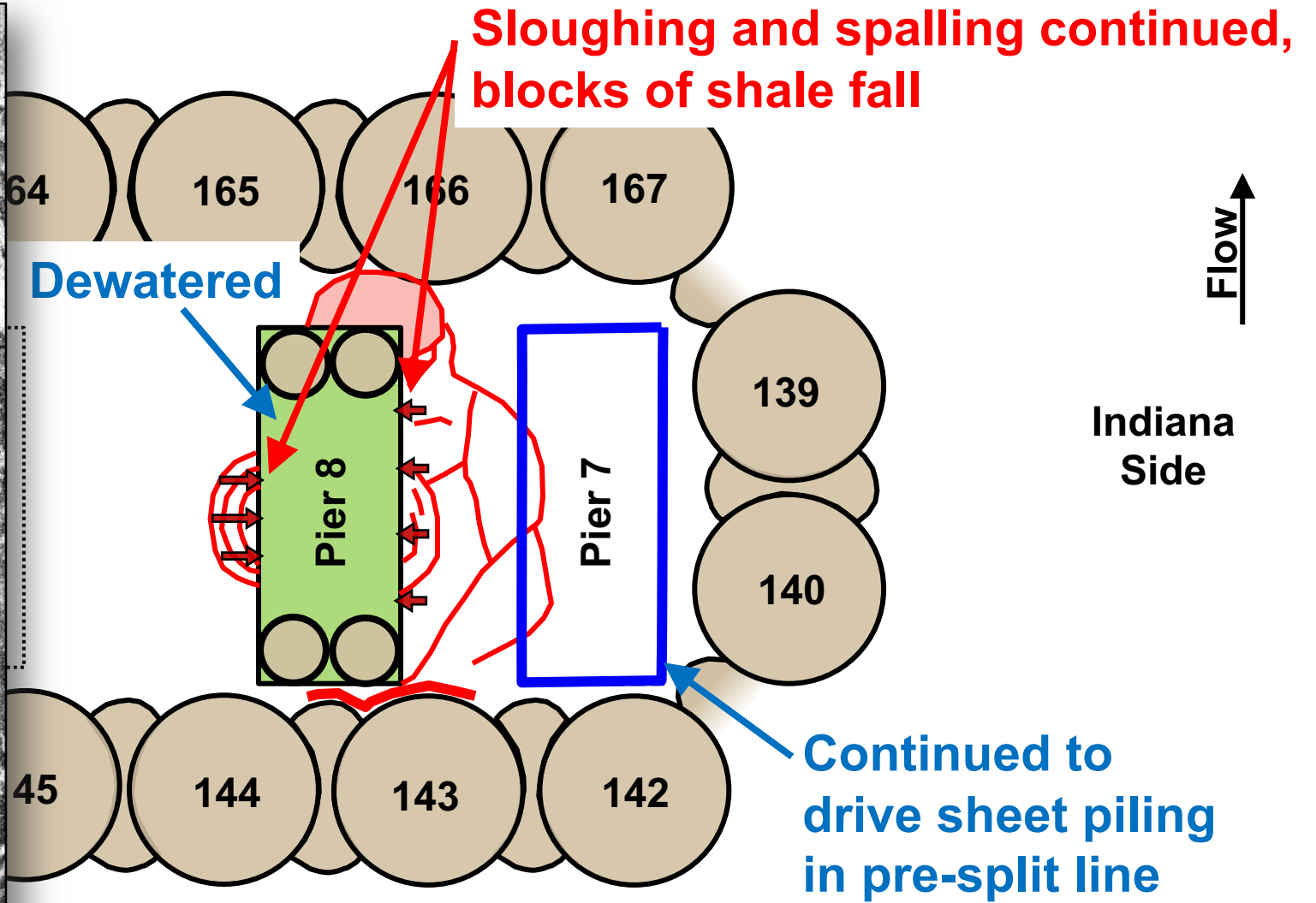
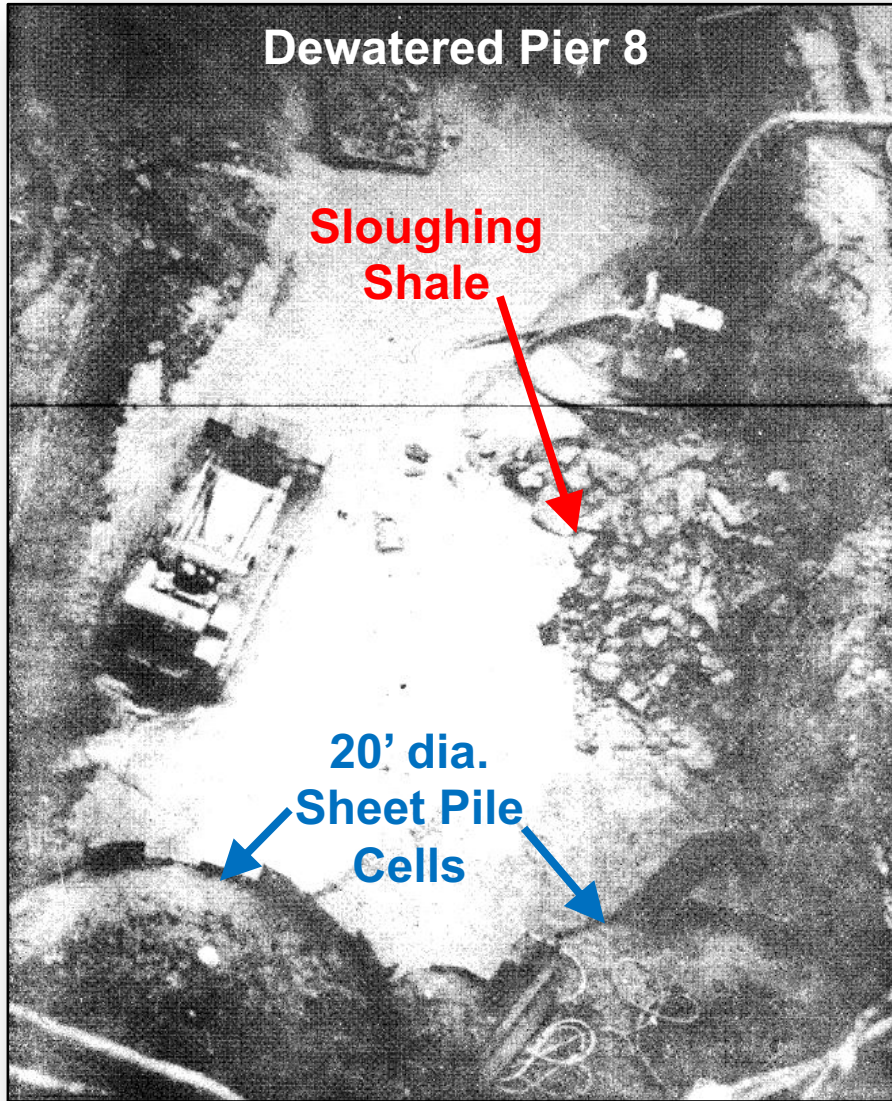
# Cannelton Lock and Dam – Oct 27, 1967 (day 9)



Plan View – Inner Ring of Cofferdam Cells (Tub Cells)



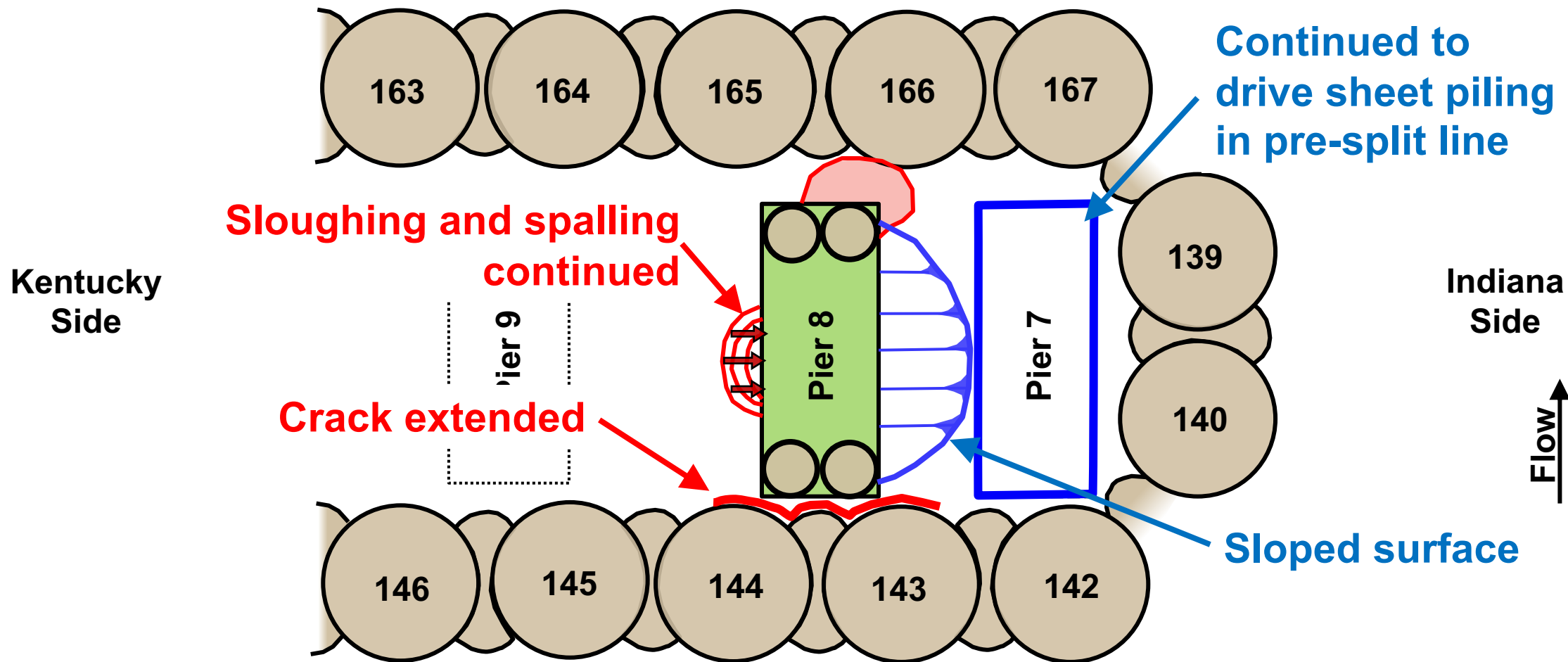
# Cannelton Lock and Dam – Oct 31, 1967 (day 13 morning)



Plan View – Inner Ring of Cofferdam Cells (Tub Cells)



# Cannelton Lock and Dam – Oct 31, 1967 (day 13 evening)

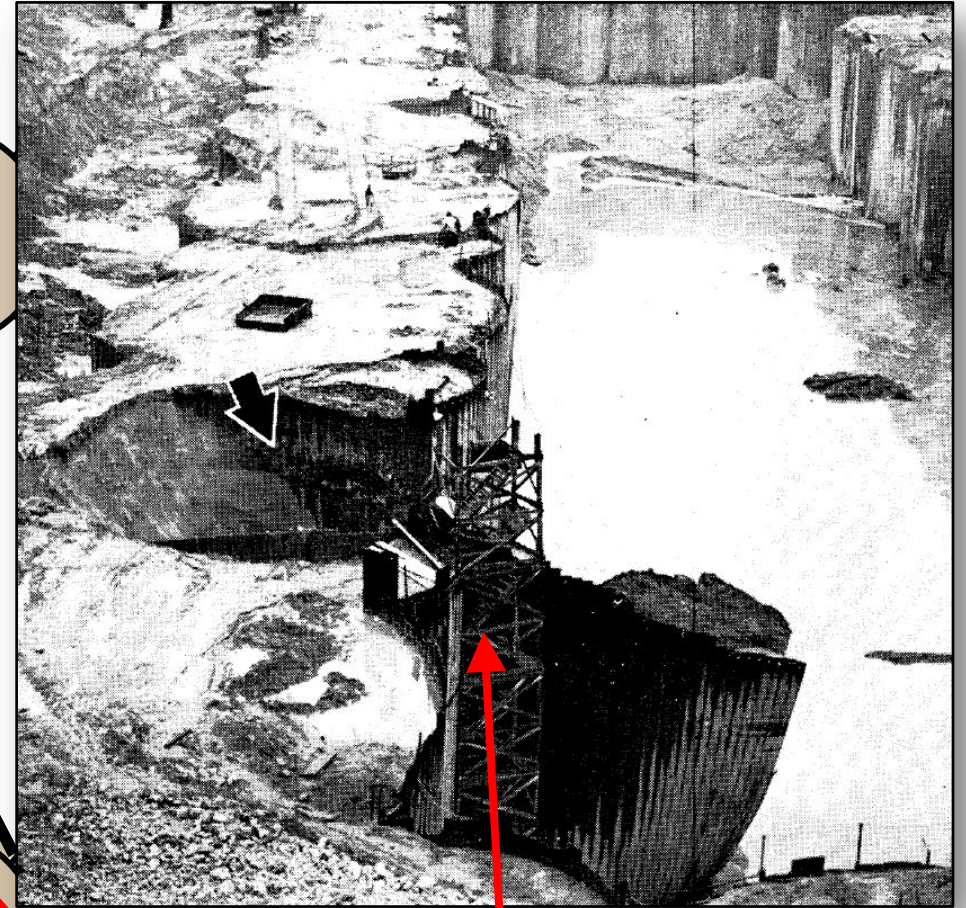
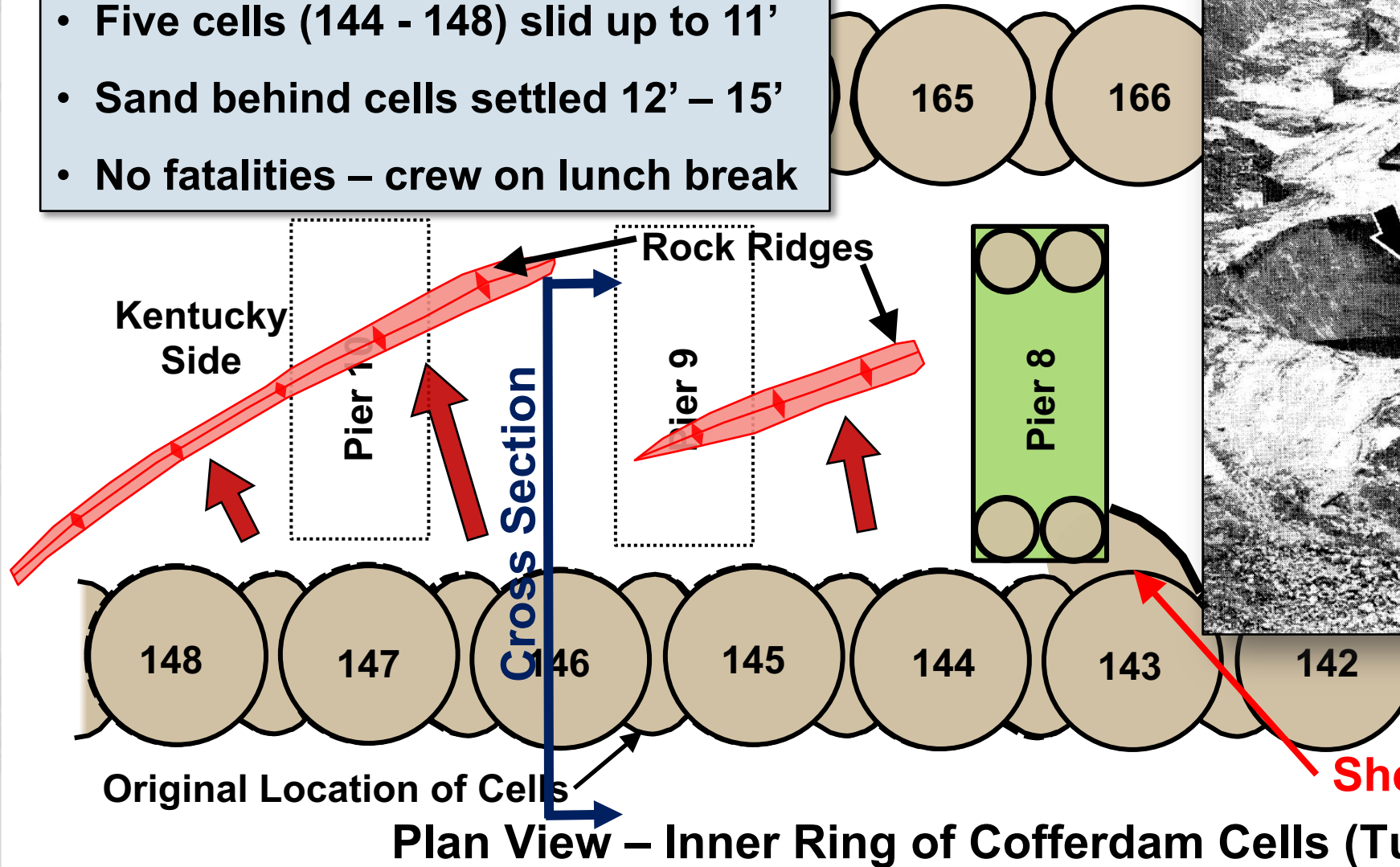


Plan View – Inner Ring of Cofferdam Cells (Tub Cells)



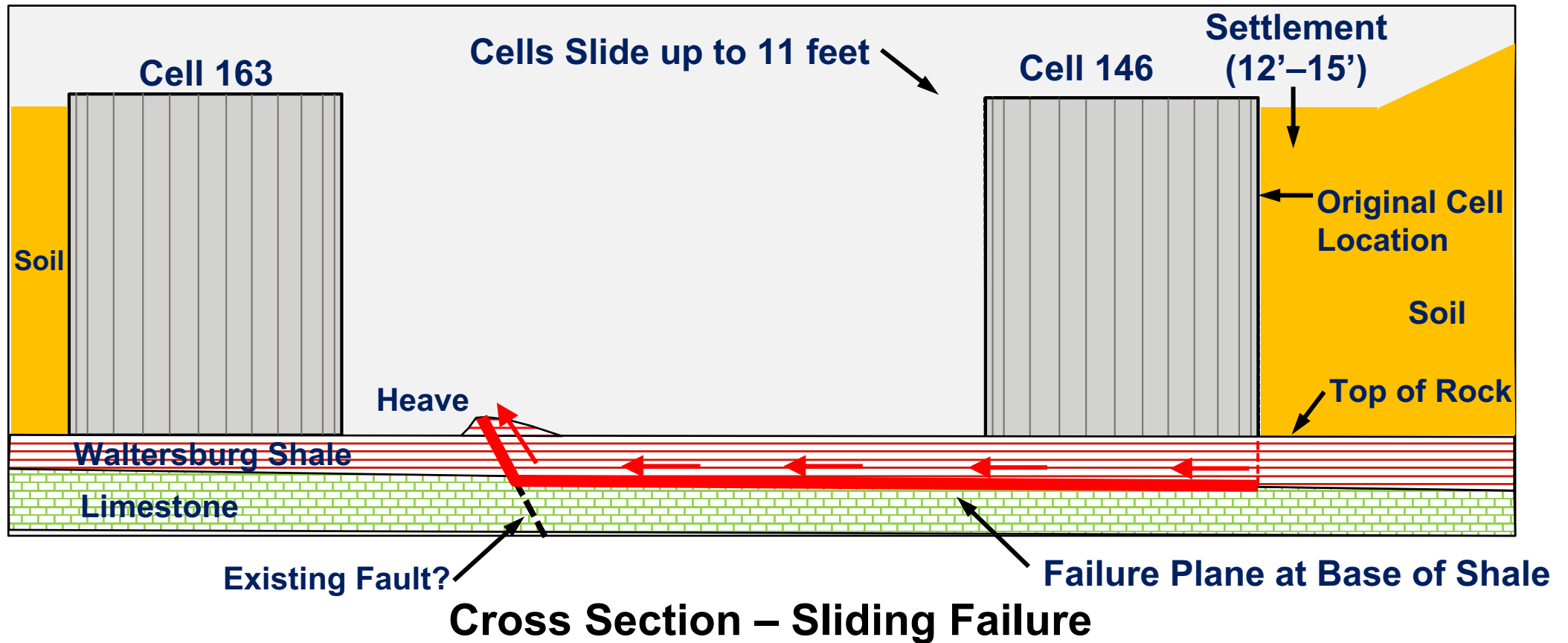
# Cannelton Lock and Dam – Nov 1, 1967 @ 0430 hr (day 14)

- Cell 143 sheet pile interlock split
- Five cells (144 - 148) slid up to 11'
- Sand behind cells settled 12' – 15'
- No fatalities – crew on lunch break



# Cannelton Lock and Dam – Factors Leading to Failure

- Sliding along the base of the Mississippian-age Waltersburg Shale (clayey shale)
- Overestimated the sliding resistance at the base of the shale, with a back-calculated phi angle of  $13^\circ$  (possible clay seam)
- Reversal of stresses in shale may have reduced sliding resistance to residual strength

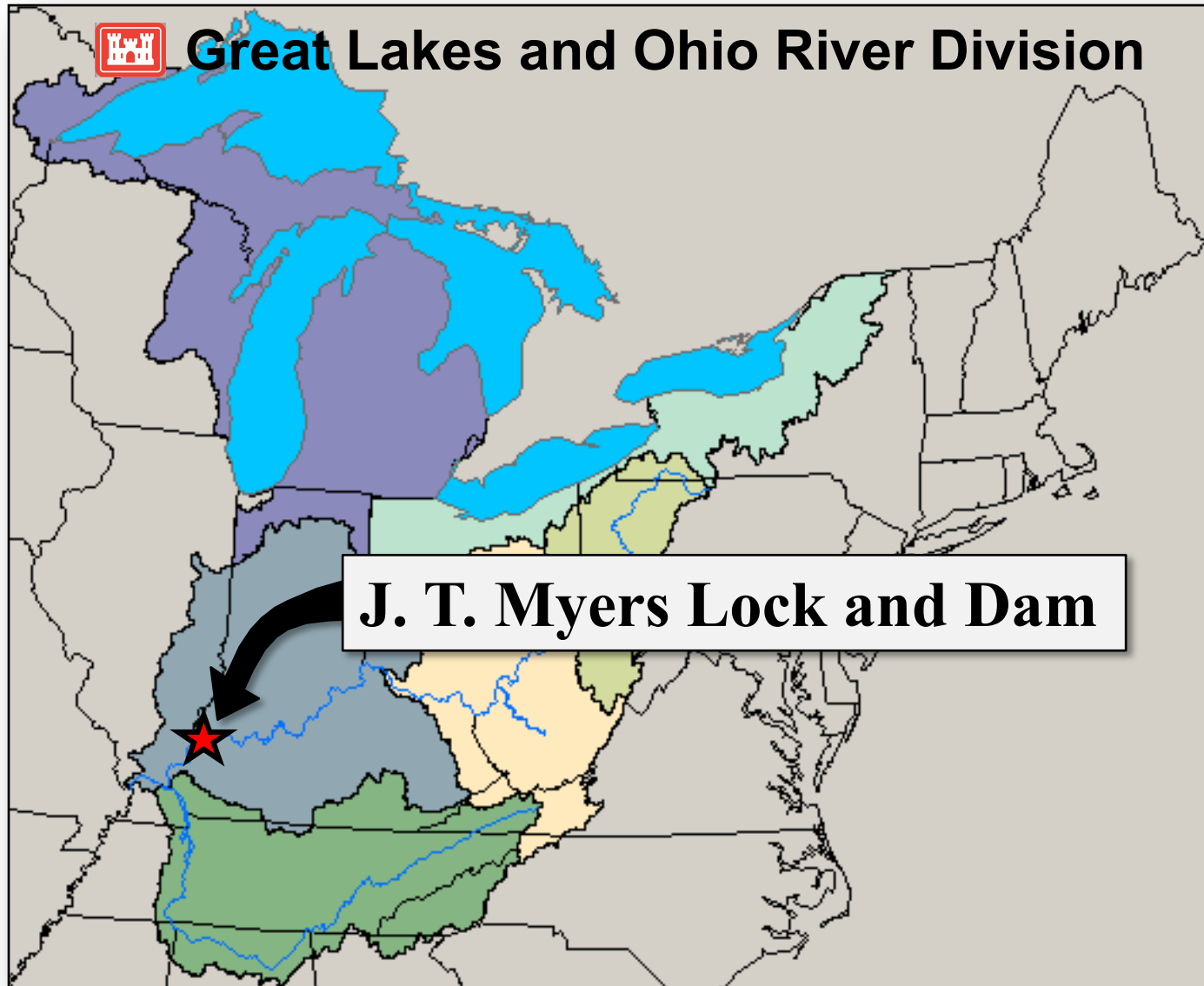


# *Sliding Failures at Five Lock and Dam Projects*

## OUTLINE

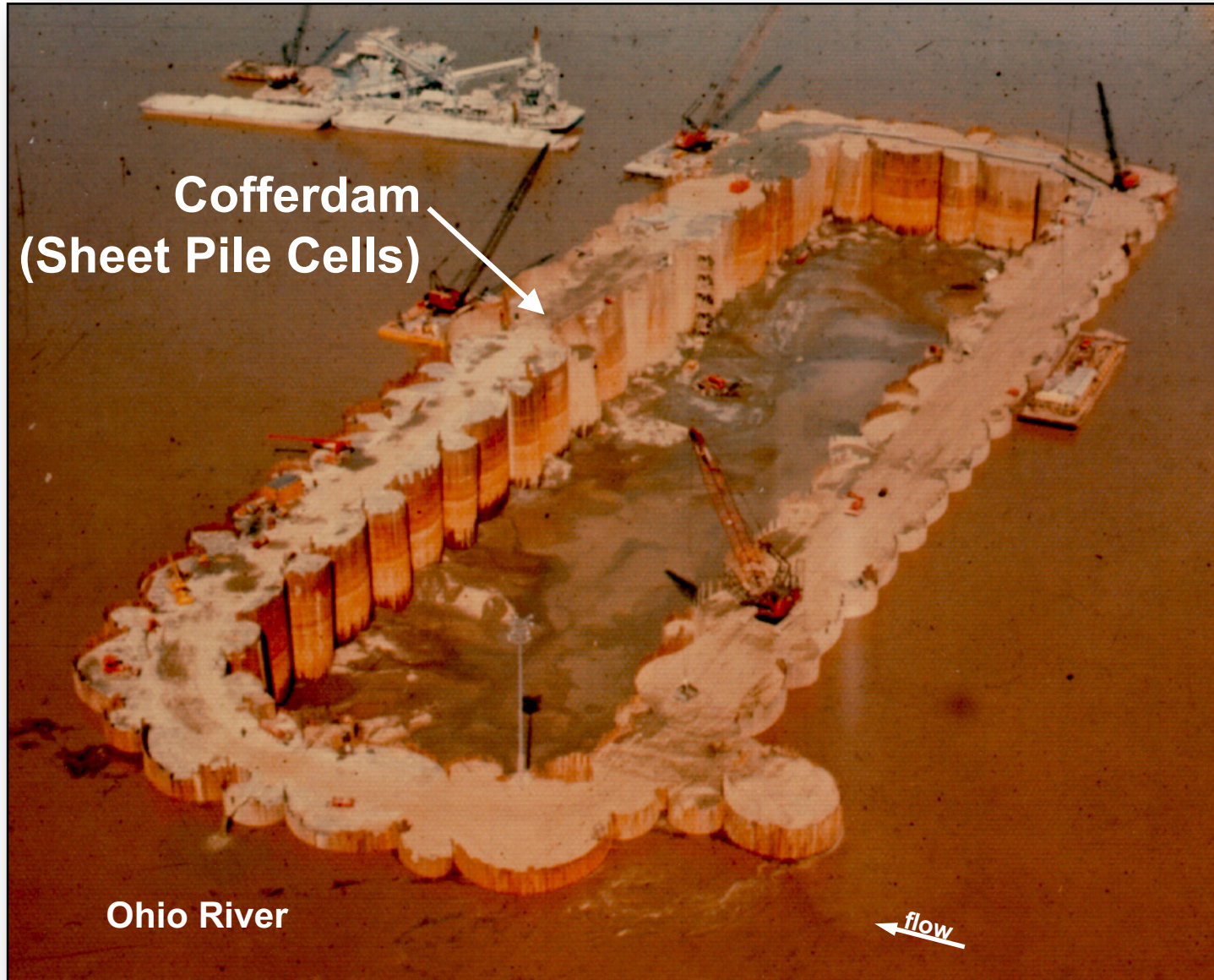
- 1. Ohio River Lock and Dam #26**
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- 5. J T Myers Lock and Dam**

# John T Myers Lock and Dam (Uniontown) – General Info



- Located on the Ohio River at IN/KY boarder. Formerly known as Uniontown L&D
- Construction contractor-designed sheet-pile cell cofferdam
- Excavation for the dam pier foundations
- Cofferdam sliding failure on Feb 26, 1971.

# John T Myers Lock and Dam – Cofferdam Prior to Failure



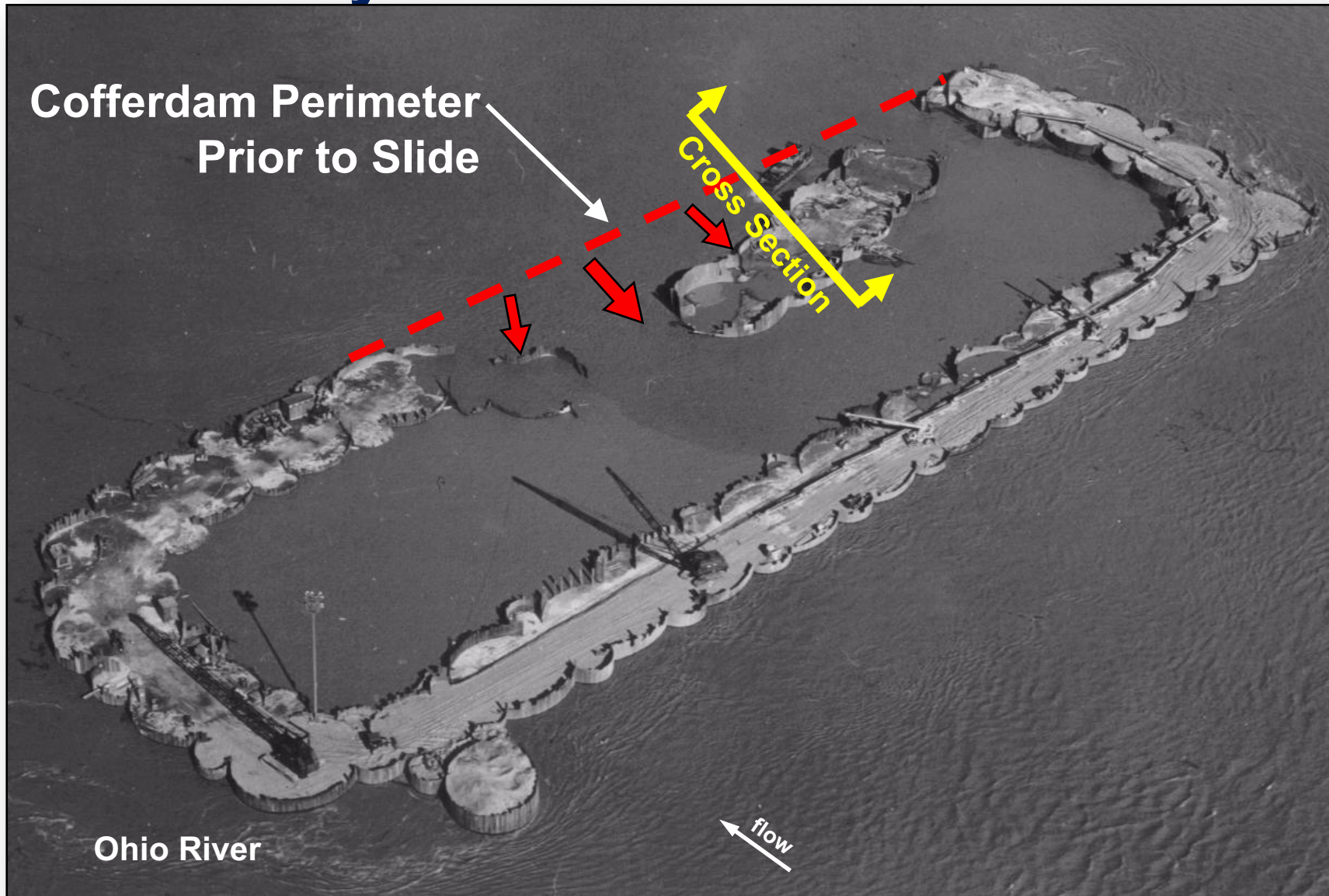
- Cofferdam sliding failure on Feb 26, 1971 during a period of high water, 10 days after dewatering.
- Started at 9:45am, movement over a period of <10 minutes
- 52 personnel were in the work area, all escaped harm.

Aerial Photo – Cofferdam - Prior to Failure





# John T Myers Lock and Dam – Cofferdam After Failure



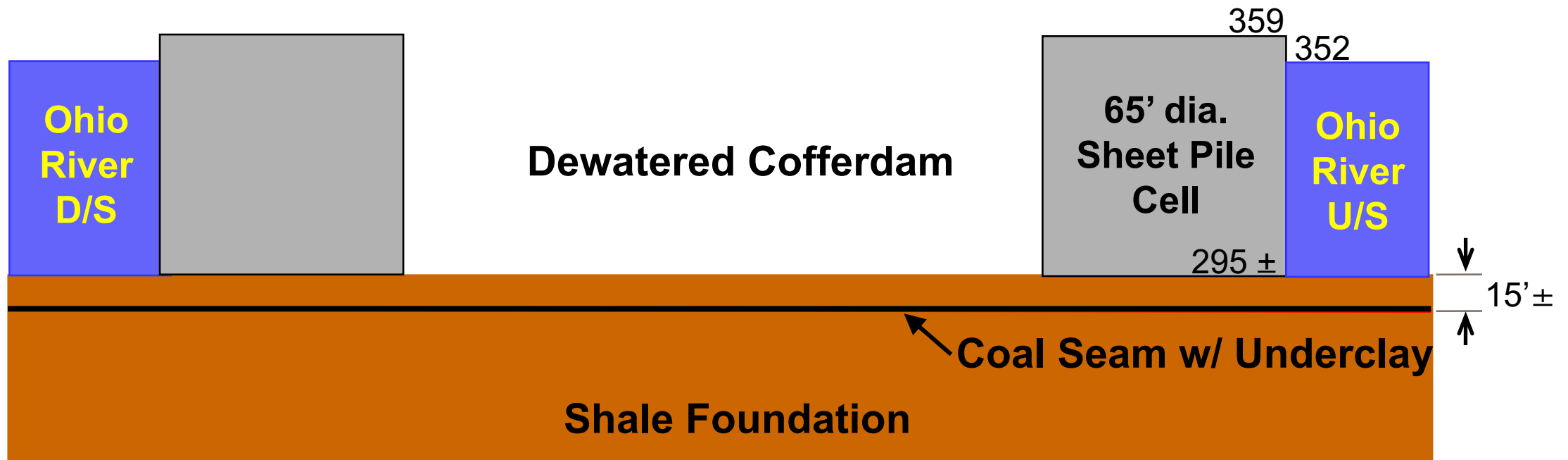
**Aerial Photo – After Failure**

- One cell ruptured
- Five cells slid 32' to 71' upstream direction
- One cell slid and collapsed



# John T Myers Lock and Dam – Planar Failure

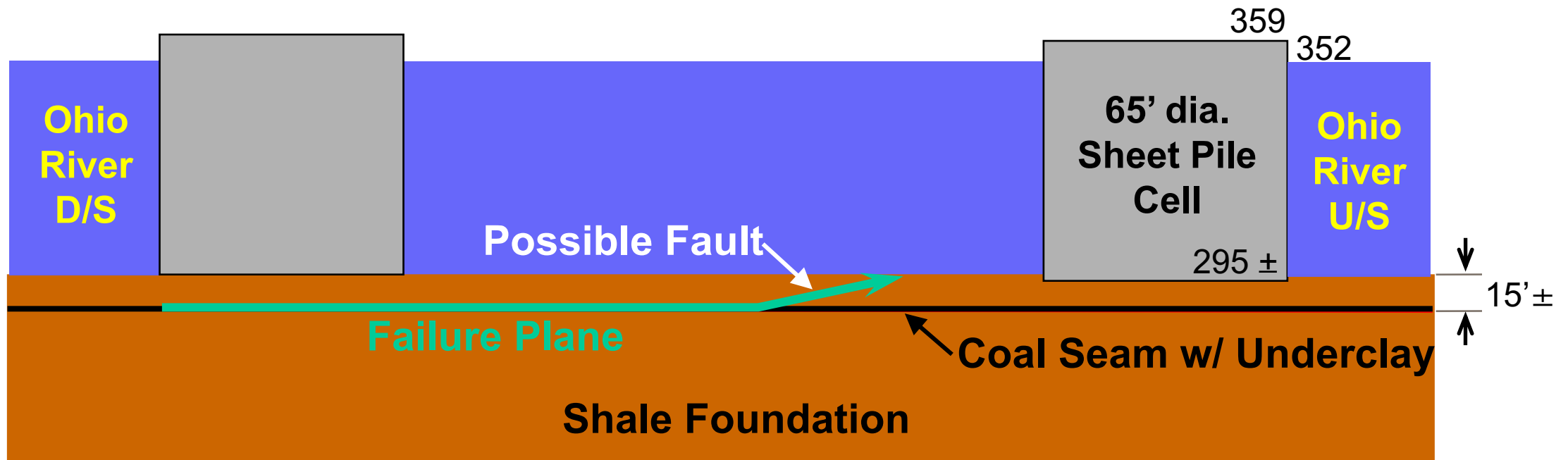
- Sliding horizontally along a coal seam underclay, 15' below top of rock
- Pennsylvanian-age Sturgis Formation (previously Lisman Formation)



Cross Section – Cofferdam Failure – Deep Seated Sliding

# John T Myers Lock and Dam – Factors Leading to Failure

- Overestimated sliding resistance of underclay
- Sliding resistance of passive wedge was reduced, due to possible fault planes



Cross Section – Cofferdam Failure – Deep Seated Sliding

# *Sliding Failures at Five Lock and Dam Projects*

## **LESSONS LEARNED**

1. Identify continuous **weak seams** in bedrock and establish **appropriate sliding parameter values** ( $\phi$  angle).
2. Consider influence of **uplift pressures** on sliding stability.
3. Anticipate how **construction activities** could affect sliding stability.
4. Install **instrumentation** and monitor structure during critical loading conditions.
5. As a result, **Corps of Engineers has designed** all major **cofferdams** at Corps projects since 1970s

# SLIDING FAILURES AT FIVE LOCK & DAM PROJECTS

## QUESTIONS ?



**US Army Corps  
of Engineers**  
Dam Safety Modification  
Mandatory Center  
of Expertise

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