HEC 18, HEC 20, & HEC 23 Applications

Mid-Western Hydraulics Engineers Conference

East Lansing, Michigan

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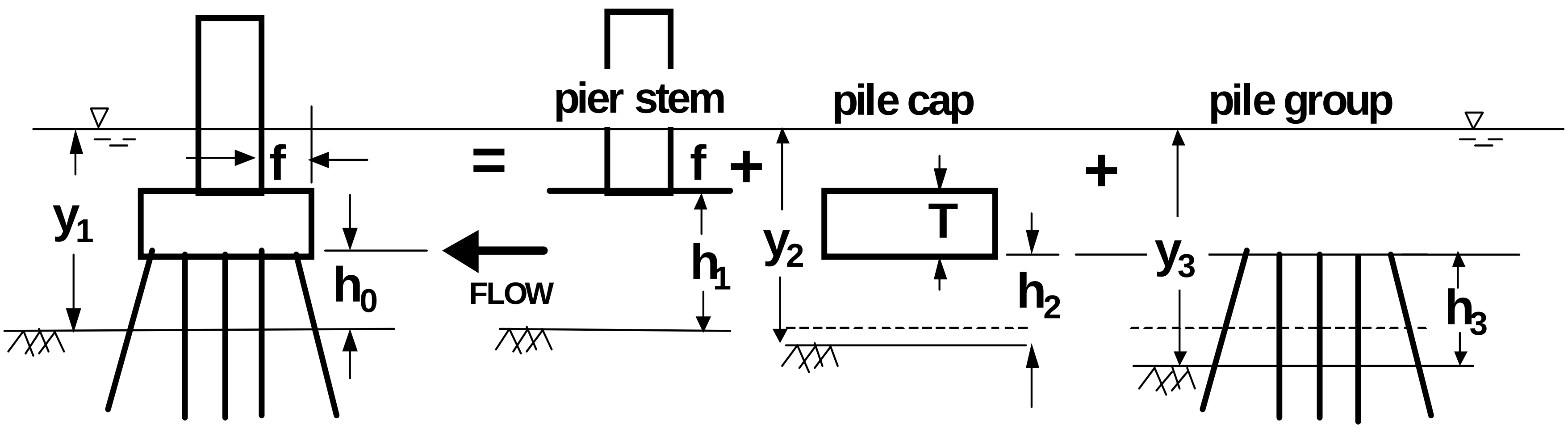
HEC 18, HEC 20, & HEC 23 Applications

- HEC 18 – Complex Pier Scour Estimation
- HEC 20 – Meander Migration Prediction
- HEC 23 – Risk Based Countermeasure Selection

COMPLEX PIER FOUNDATIONS

- Pier stem
- Pile cap
- Pile groups
- Any/all may produce scour

SCOUR COMPONENTS



$$y_s = y_{s\,pier} + y_{s\,pc} + y_{s\,pg}$$

“SUPERPOSITION OF THE SCOUR COMPONENTS” METHOD

- Determine components exposed to flow
- Determine scour for each component
- Add scour components for total scour

DEPTH and VELOCITY ADJUSTMENTS

$h_1 = h_0 + T$

$y_2 = y_1 + y_{s\ pier}/2$

$h_2 = h_0 + y_{s\ pier}/2$

$y_3 = y_2 + y_{s\ pc}/2$

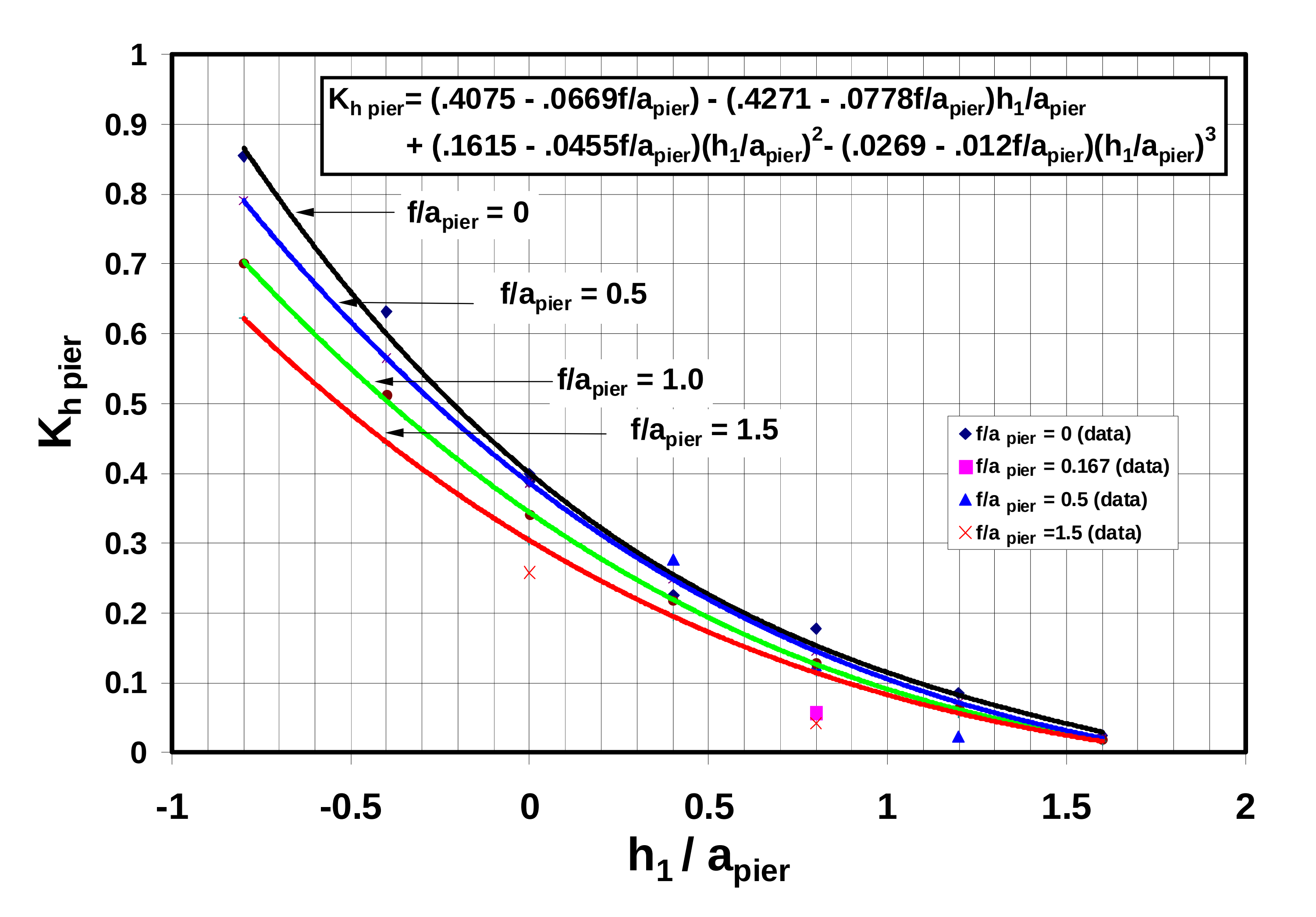
$h_3 = h_2 + y_{s\ pc}/2$

$V_1 y_1 = V_2 y_2 = V_3 y_3$

PIER STEM SCOUR COMPONENT

$$\frac{y_{spier}}{y_1} = K_{hpier}\left[2.0K_1K_2K_3K_4\left(\frac{a_{pier}}{y_1}\right)^{0.65}\left(\frac{V_1}{\sqrt{gy_1}}\right)^{0.43}\right]$$

SUSPENDED PIER SCOUR RATIO



PILE CAP (FOOTING) SCOUR DEPTH COMPONENT

Case 1 – Bottom of the pile cap is above the bed (by design or as a result of scour)

Case 2 – Bottom of pile cap is on or below the bed

Pile Cap Component

- Reduce the pile cap width, a_{pc}, to an equivalent full depth solid pier, a^*_{pc}
- The equivalent pier width, an adjusted flow depth, y_2, and an adjusted flow velocity, V_2, used to estimate the scour component

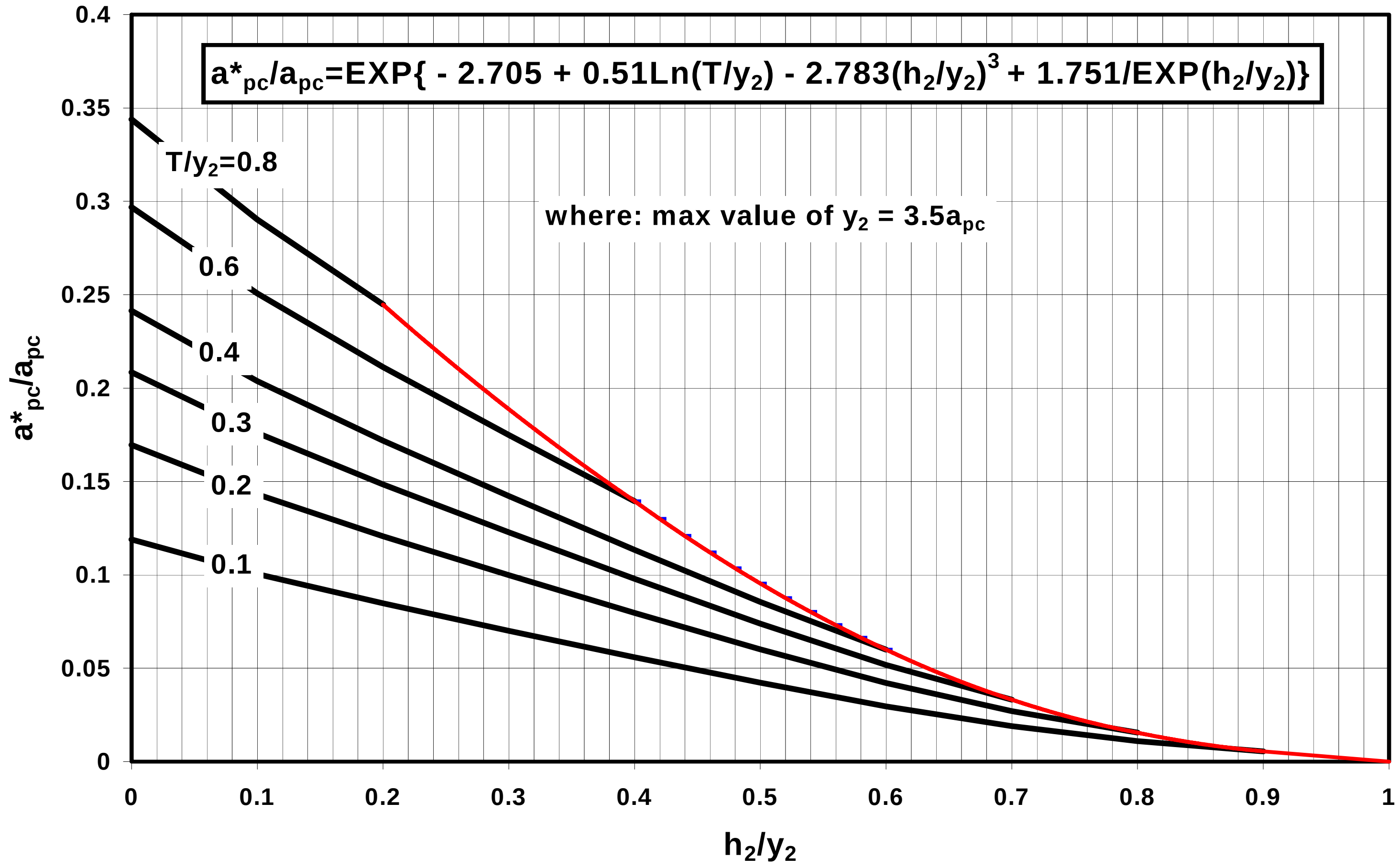
RECALL

T = Thickness of Pile Cap

$y_2 = y_1 + \frac{1}{2} y_{s\ pier}$

$V_2 = V_1 * y_1/y_2$

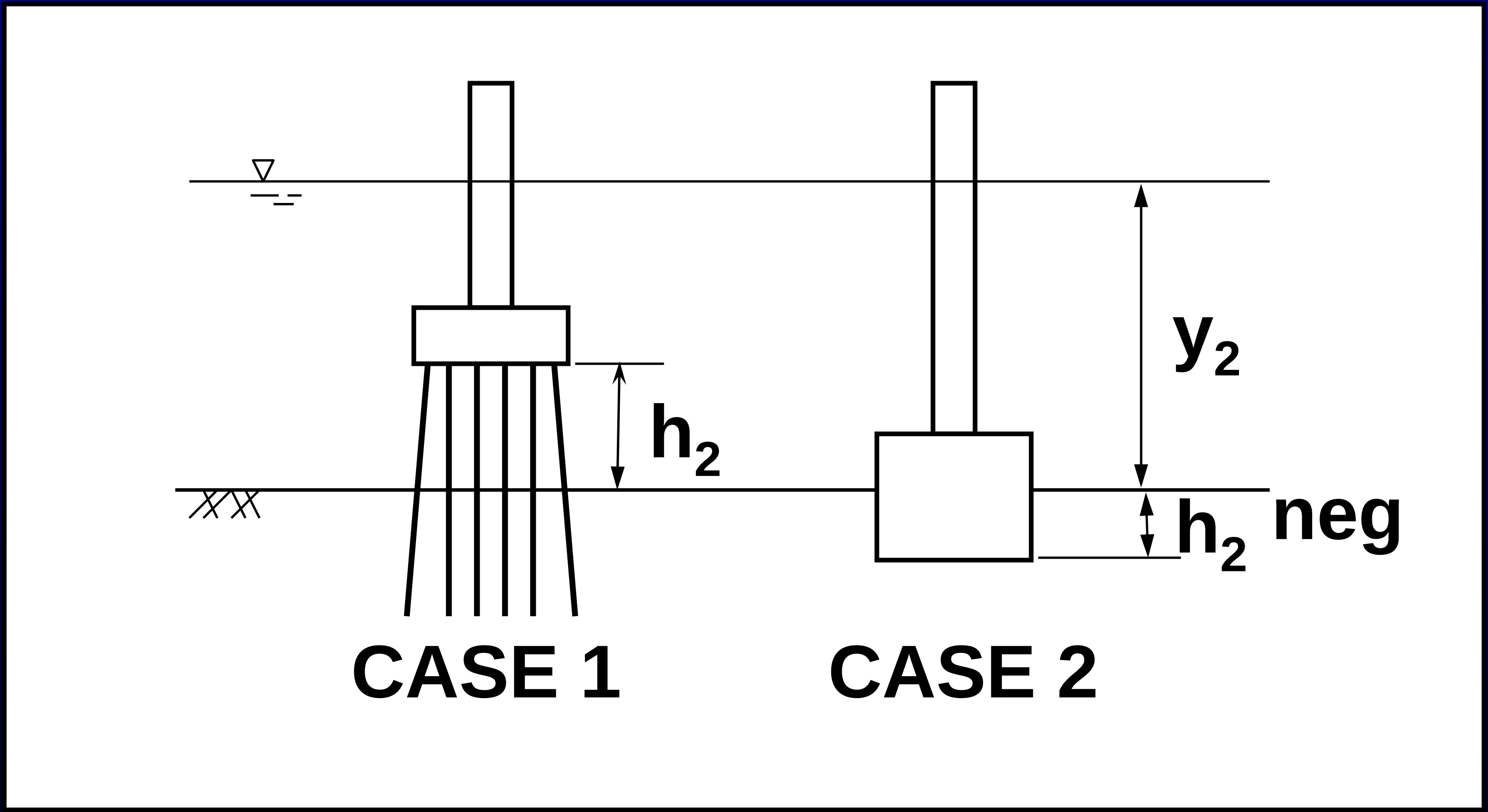
CASE 1 – PILE CAP (FOOTING) EQUIVALENT WIDTH



PILE CAP (FOOTING) SCOUR COMPONENT

$$\frac{y_{spc}}{y_2} = 2.0K_1K_2K_3K_4K_w\left(\frac{a^*_{pc}}{y_2}\right)^{0.65}\left(\frac{V_2}{\sqrt{gy_2}}\right)^{0.43}$$

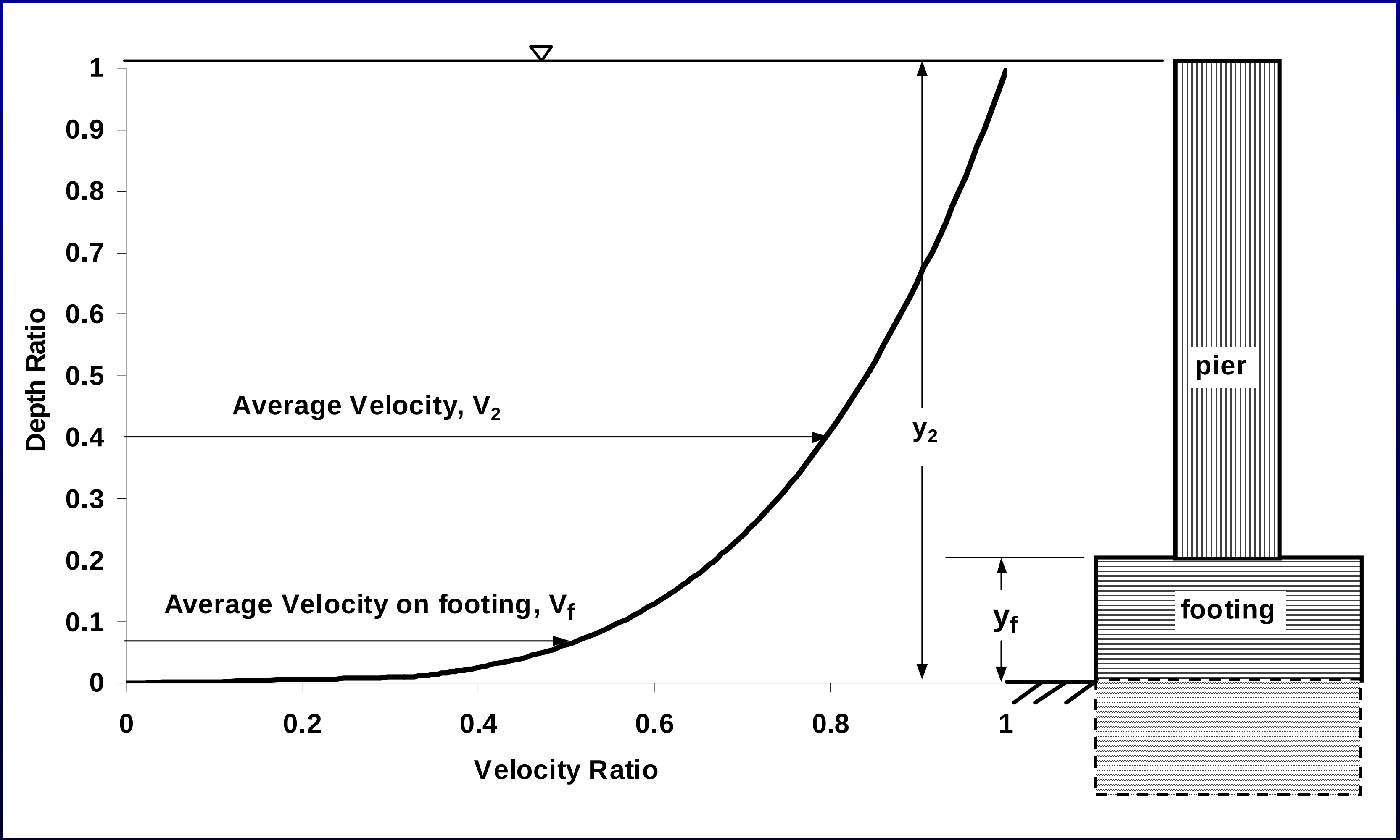
PILE CAP CASE 2



CASE 2 – BOTTOM ON OR BELOW THE BED

- Use full pile cap width, a_{pc}
- Use exposed footing height, y_f
- Use velocity at exposed footing, v_f

VELOCITY AND DEPTH ON EXPOSED FOOTING



AVERAGE VELOCITY, V_f

$$\frac{V_f}{V_2} = \frac{\ln\left(10.93\,\frac{y_f}{K_s} + 1\right)}{\ln\left(10.93\,\frac{y_2}{K_s} + 1\right)}$$

CASE 2 – PILE CAP (FOOTING) SCOUR COMPONENT

$$\frac{y_{spc}}{y_f} = 2.0 K_1 K_2 K_3 K_4 K_w \left(\frac{a_{pc}}{y_f} \right)^{0.65} \left(\frac{V_f}{\sqrt{g y_f}} \right)^{0.43}$$

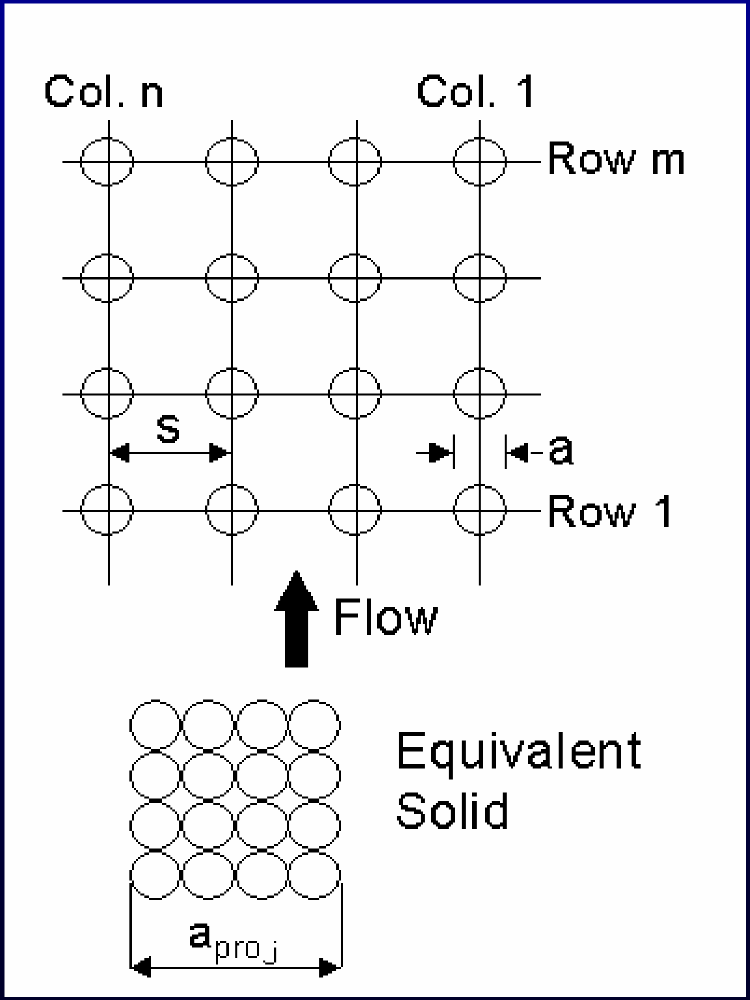
CASE 2 – TOTAL SCOUR

$$y_s = y_{s\ pier} + y_{s\ pc}$$

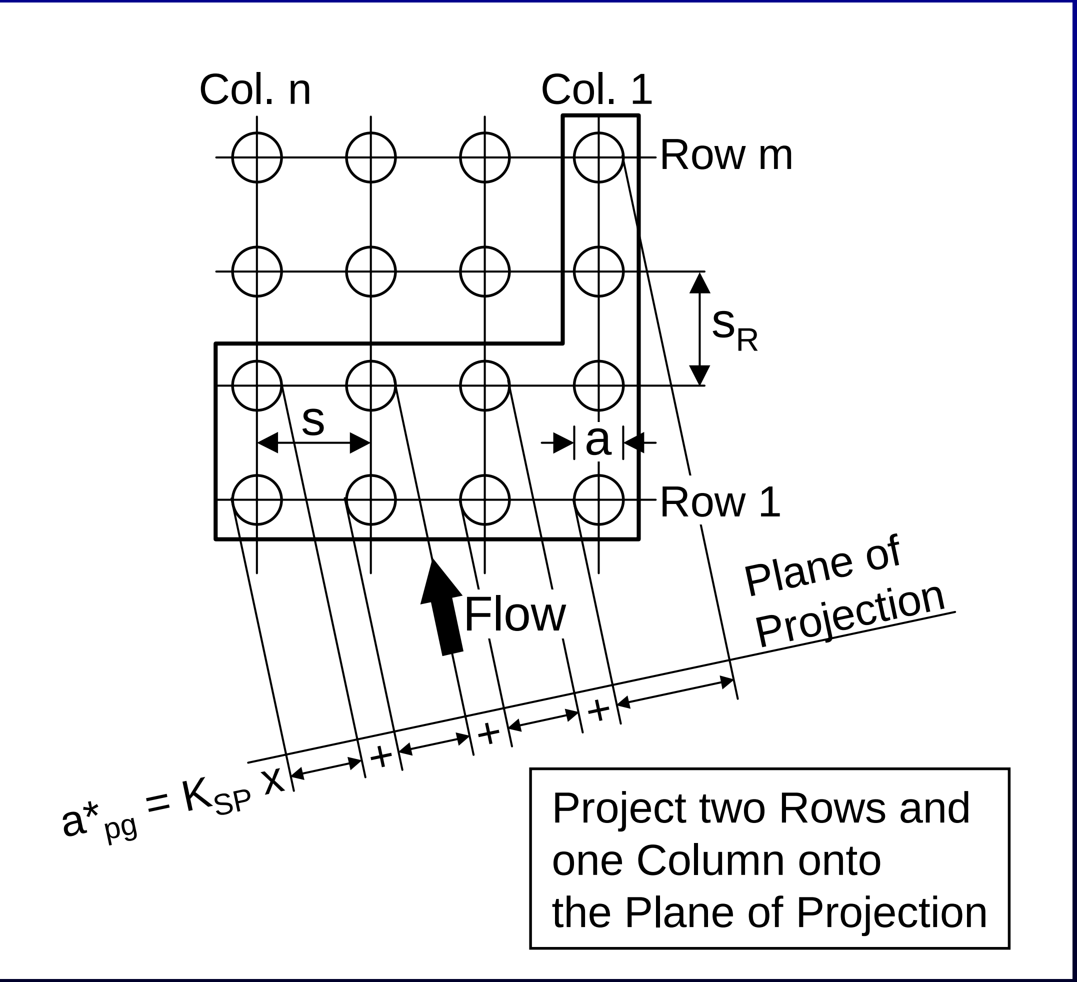
PILE GROUP SCOUR COMPONENT

- Determine projected width of piles
- Determine the effective width
- Adjust the flow depth, velocity and exposed height of the pile group
- Determine pile group height factor
- Compute scour component

PROJECTED WIDTH FOR ALIGNED FLOW



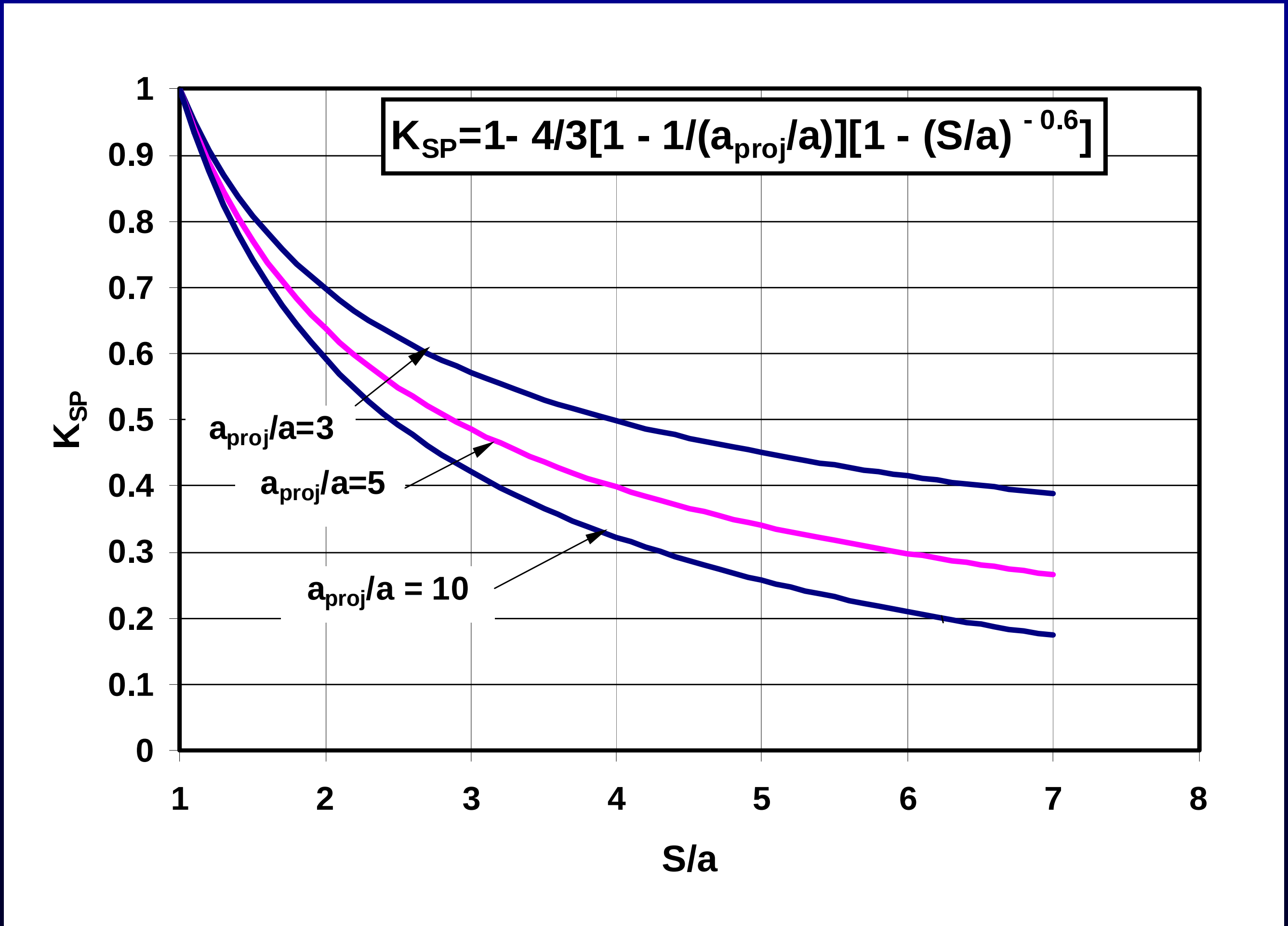
PROJECTED WIDTH FOR SKEWED FLOW



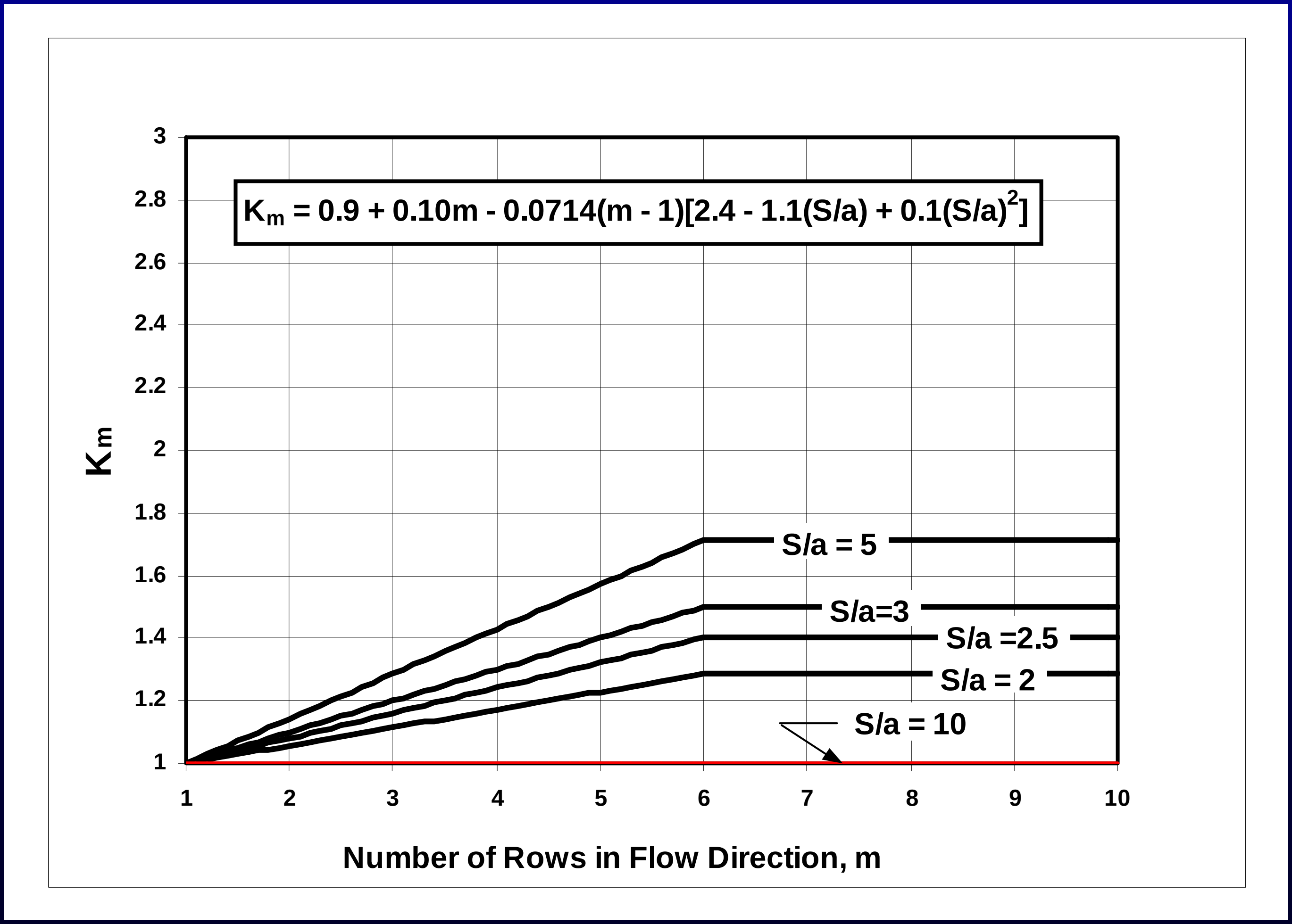
EFFECTIVE WIDTH OF AN EQUIVALENT FULL DEPTH PIER

$$a^*_{pg} = a_{proj} K_{sp} K_m$$

PILE SPACING FACTOR



ADJUSTMENT FACTOR FOR NUMBER OF ALIGNED ROWS



RECALL

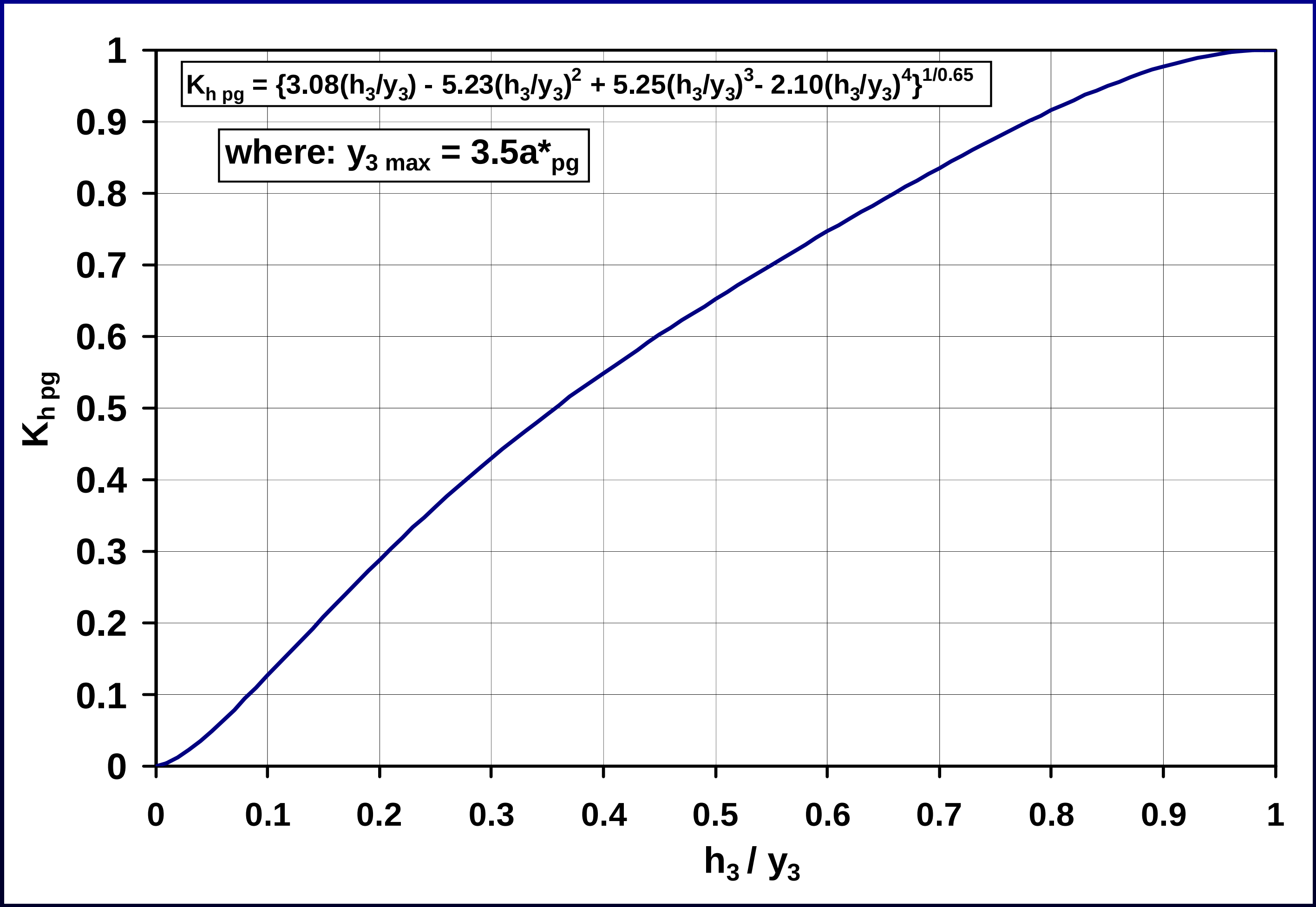
$$y_3 = y_2 + \tfrac{1}{2} y_{spc}$$

$$V_3 = V_2 * y_2 / y_3$$

SCOUR EQUATION FOR PILE GROUP

$$\frac{y_{spg}}{y_3} = K_{hpg}\left[2.0K_1K_3K_4\left(\frac{a^*_{pg}}{y_3}\right)^{0.65}\left(\frac{V_3}{\sqrt{gy_3}}\right)^{0.43}\right]$$

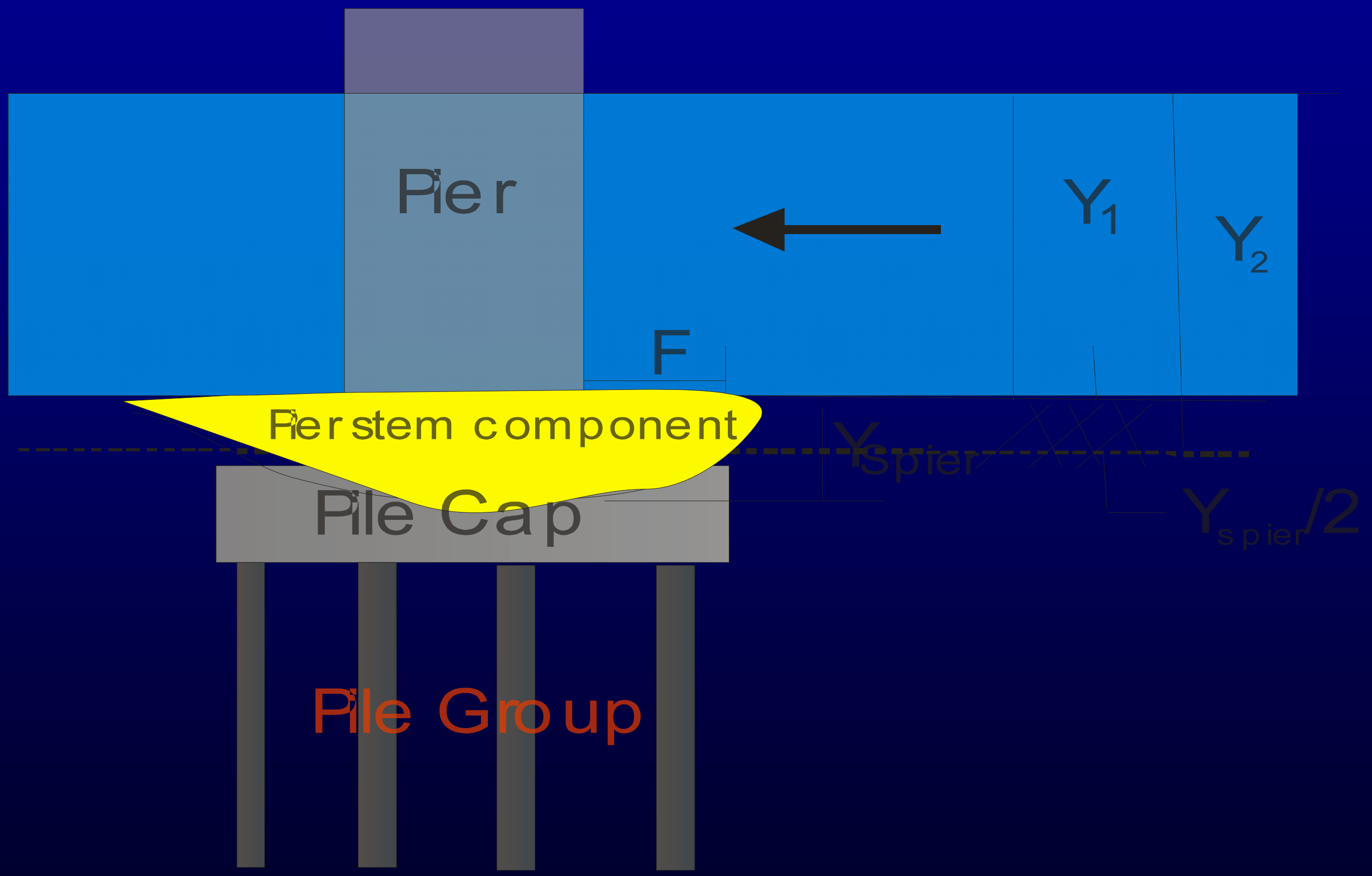
PILE GROUP HEIGHT ADJUSTMENT FACTOR



COMPLEX PIER TOTAL SCOUR

$$y_s = y_{s\ pier} + y_{s\ pc} + y_{s\ pg}$$

Frequent question---
How to handle this situation



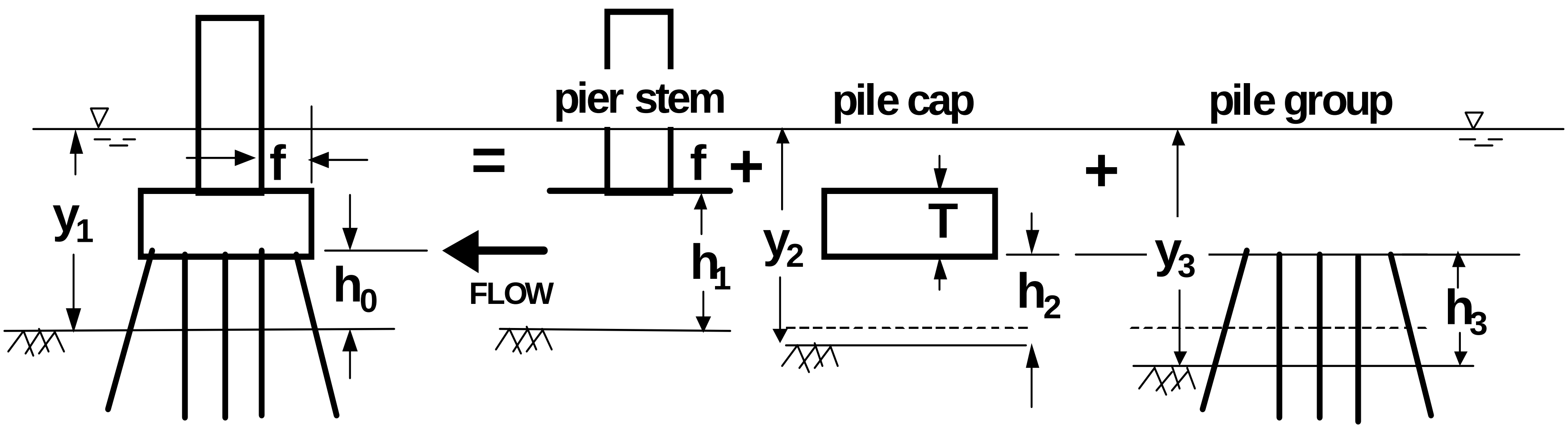
COMPLEX PIER VELOCITY AND DEPTH

$y_{s\ pier}$ from V_1, y_1, h_1

$y_{s\ pc}$ from V_2, y_2, h_2 (or V_f, y_f)

$y_{s\ pg}$ from V_3, y_3, h_3

SCOUR COMPONENTS

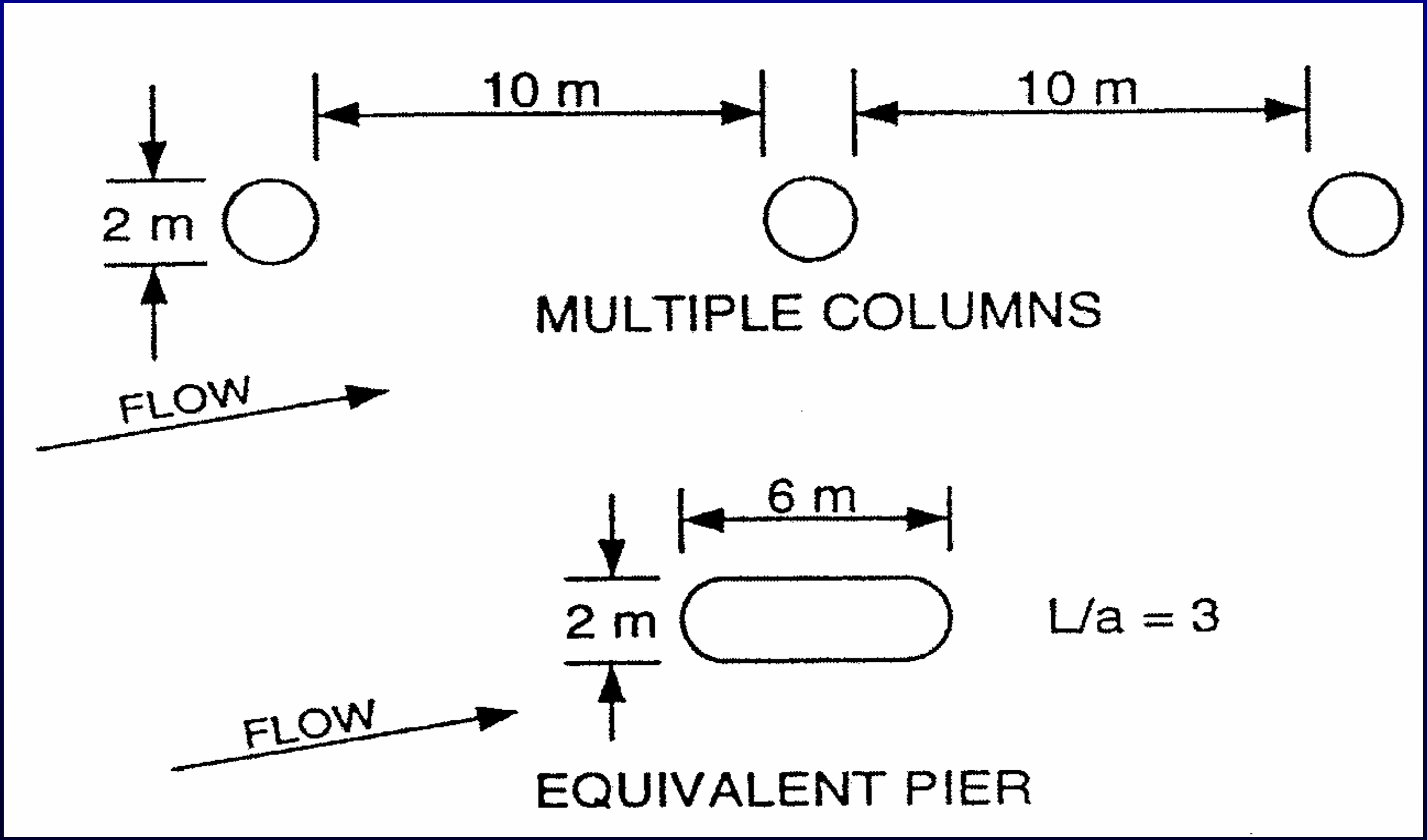


$$y_s = y_{s\,pier} + y_{s\,pc} + y_{s\,pg}$$

MULTIPLE COLUMNS SKEWED TO THE FLOW

- Use the CSU equation with $K_1 = 1.0$
- Spacing < 5a, use equivalent pier
- Spacing > than 5a, use single column and $K_2 = 1.2$
- Consider debris

MULTIPLE COLUMNS SKEWED TO THE FLOW



LEARNING OBJECTIVES

- Identify the components of complex pier scour
- Apply the HEC-18 equation for complex pier foundations

HEC 20, Stream Stability at Highway Structures – Third Edition

- Quantitative techniques for stream stability analysis
- Predict meander migration
- Calculate long-term degradation

Meander Migration

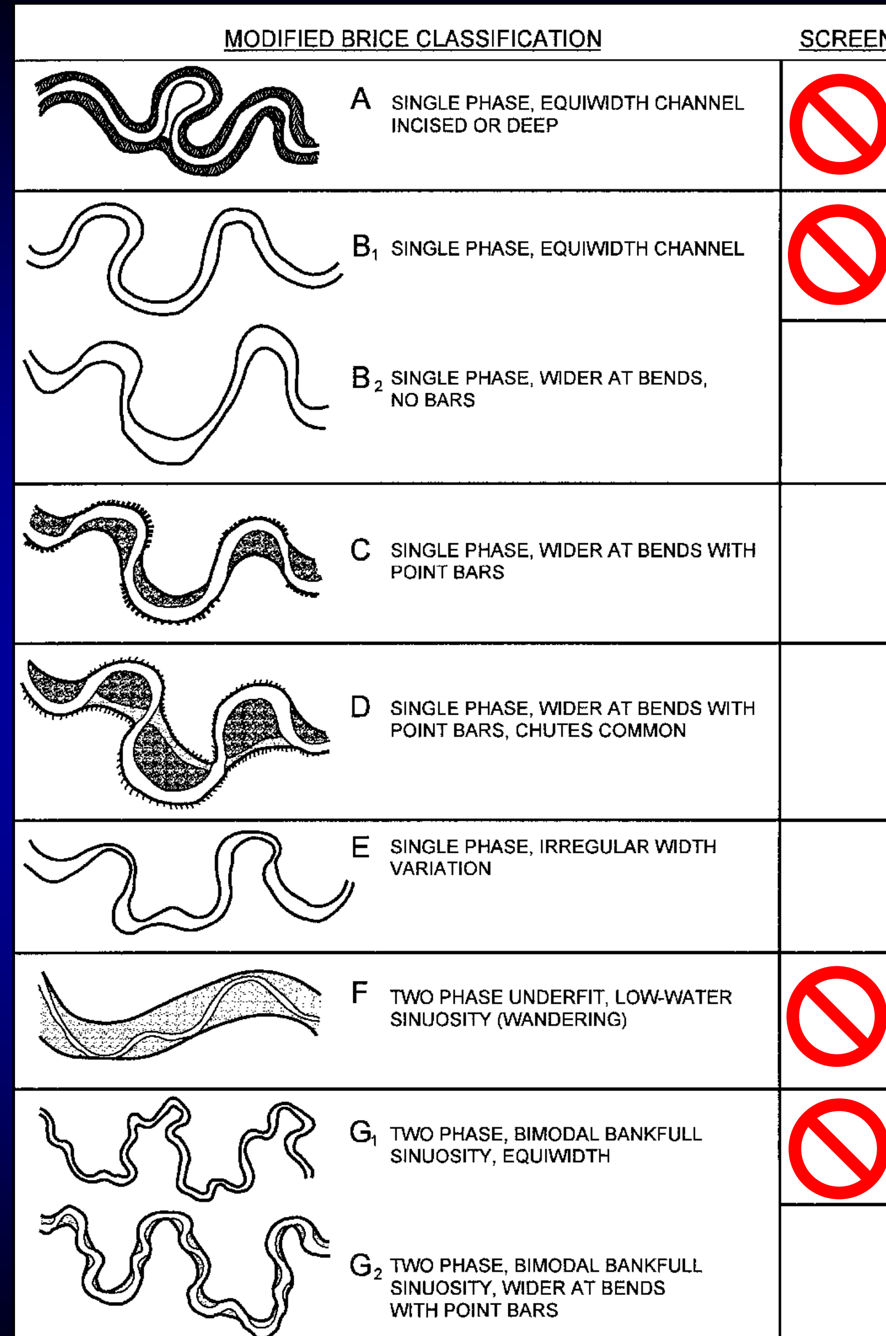
- HEC-20 introduces aerial photography comparison techniques
- NCHRP 24-16 provides methodologies
  - Manual overlay techniques
  - GIS-based approach

Screening And Classification

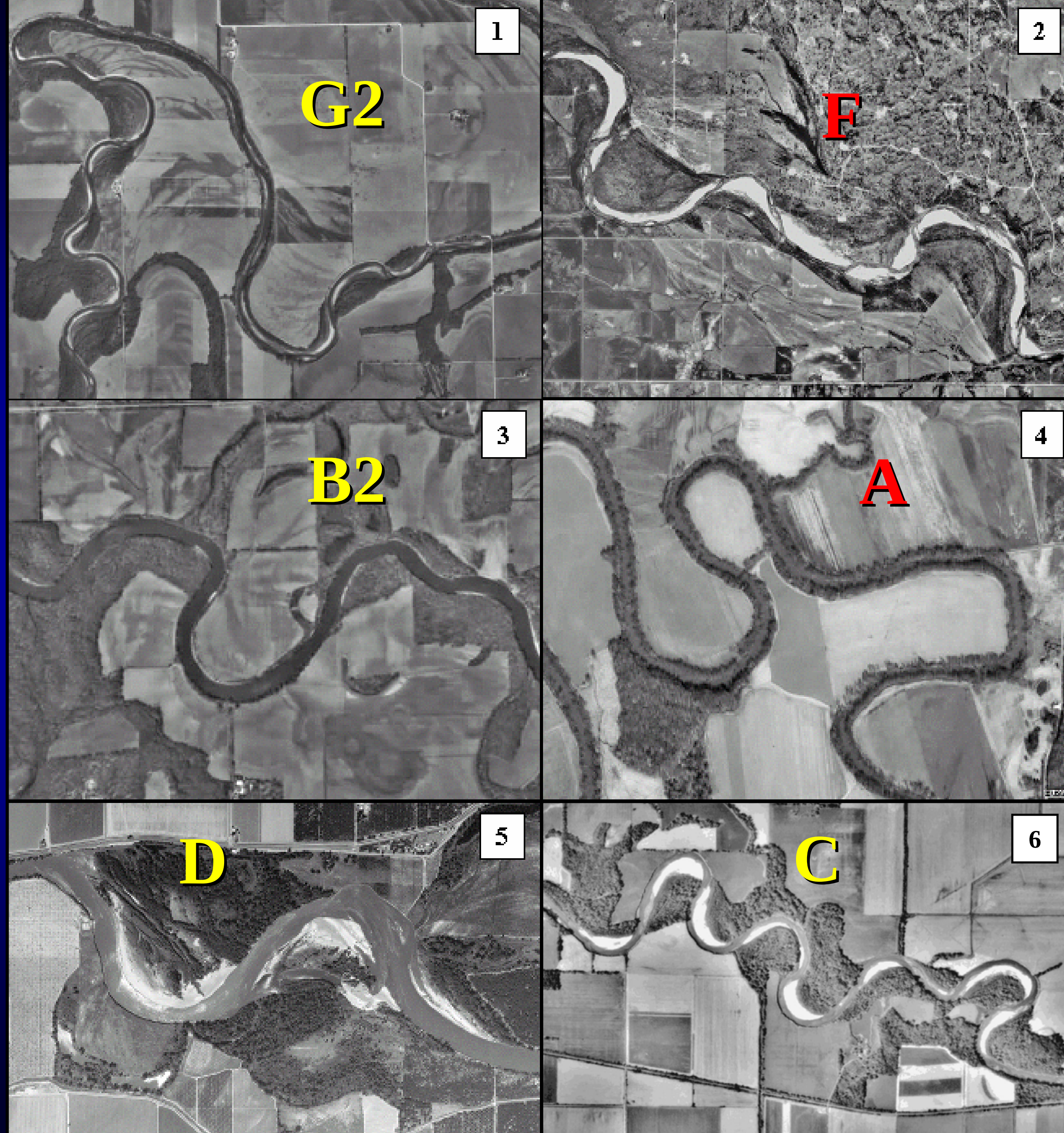
- Initial Screening:
  - Braided channels (highly unstable)
  - Anastamosing and anabranching channels (multiple channels)
- Classification:
  - Based on a modified classification scheme of channel pattern originally developed by Brice (1975)
  - Used to classify meandering river types and screen out very stable or extremely unstable meandering channels

Modified Meander Pattern Classification Scheme

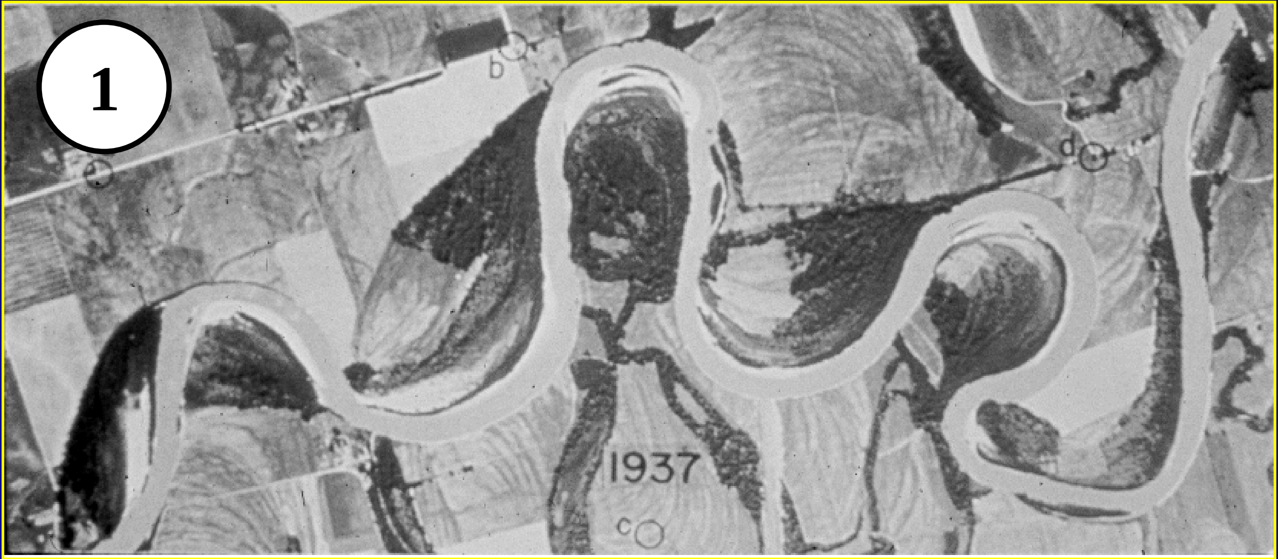
(🛇 = Screened out)

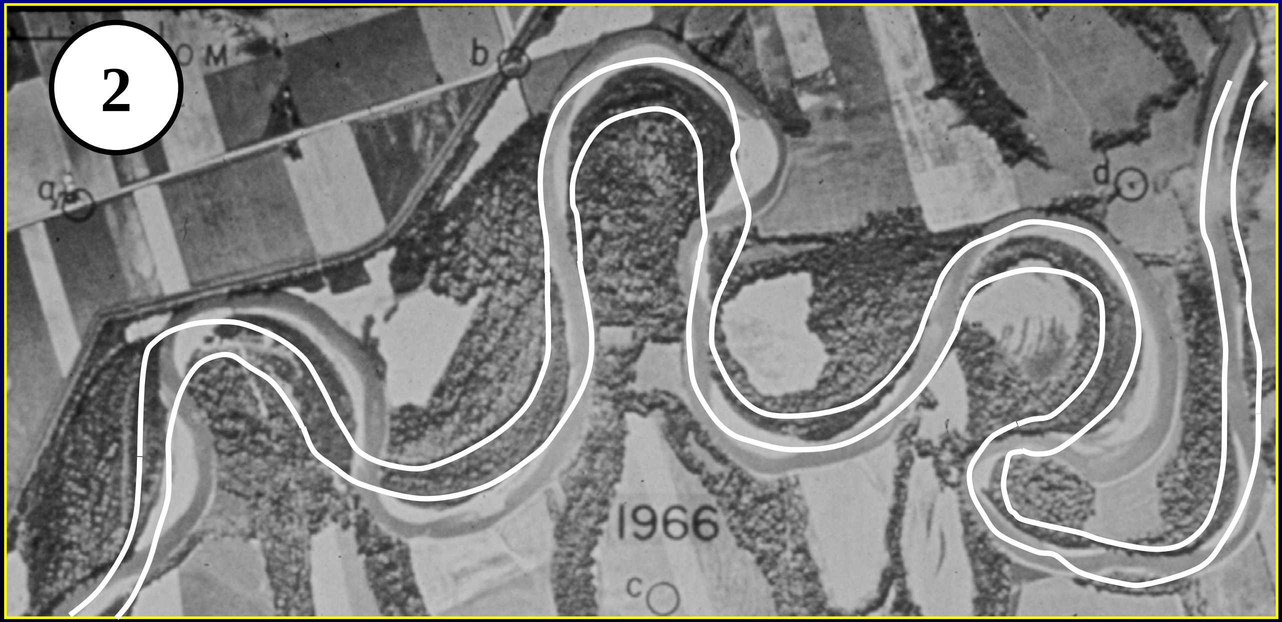


Example of Meander Pattern Classification

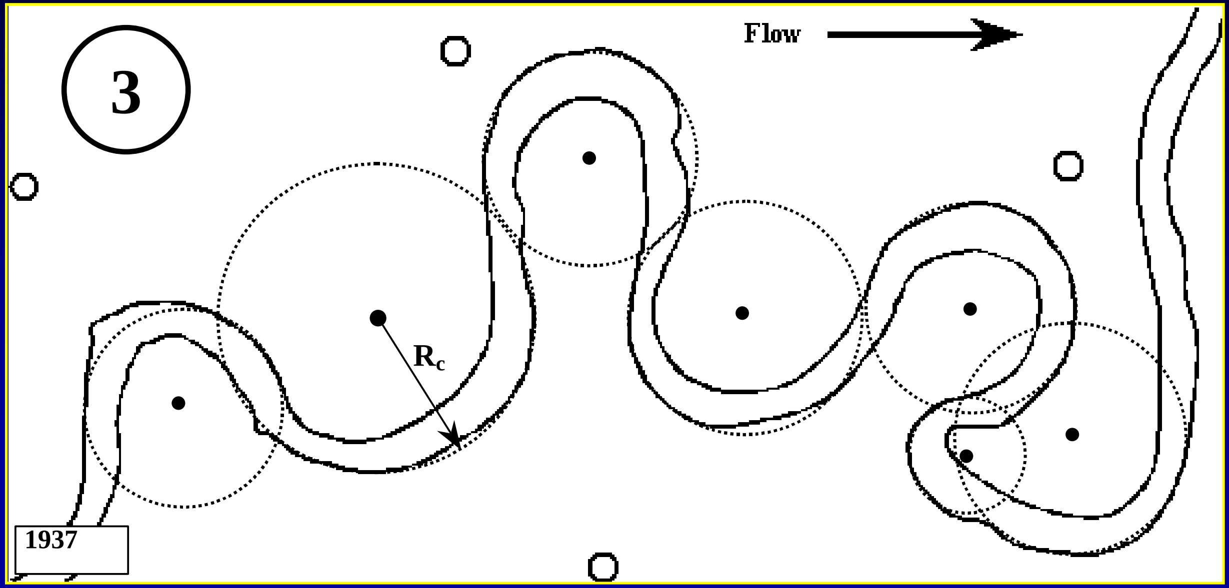


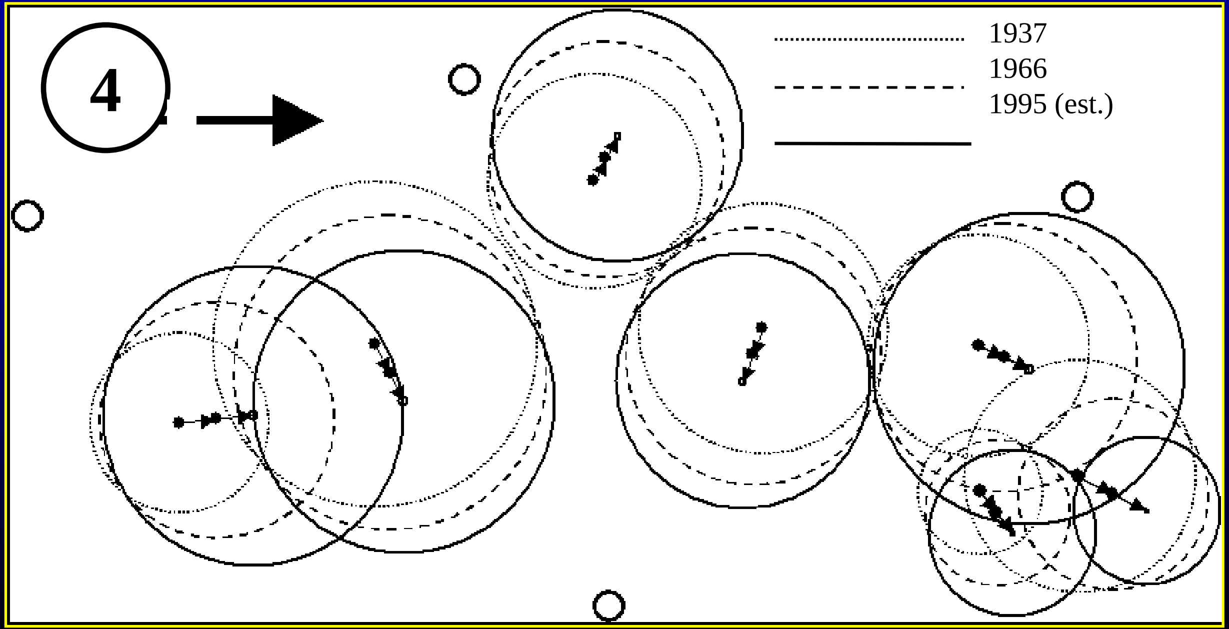
Prediction Techniques



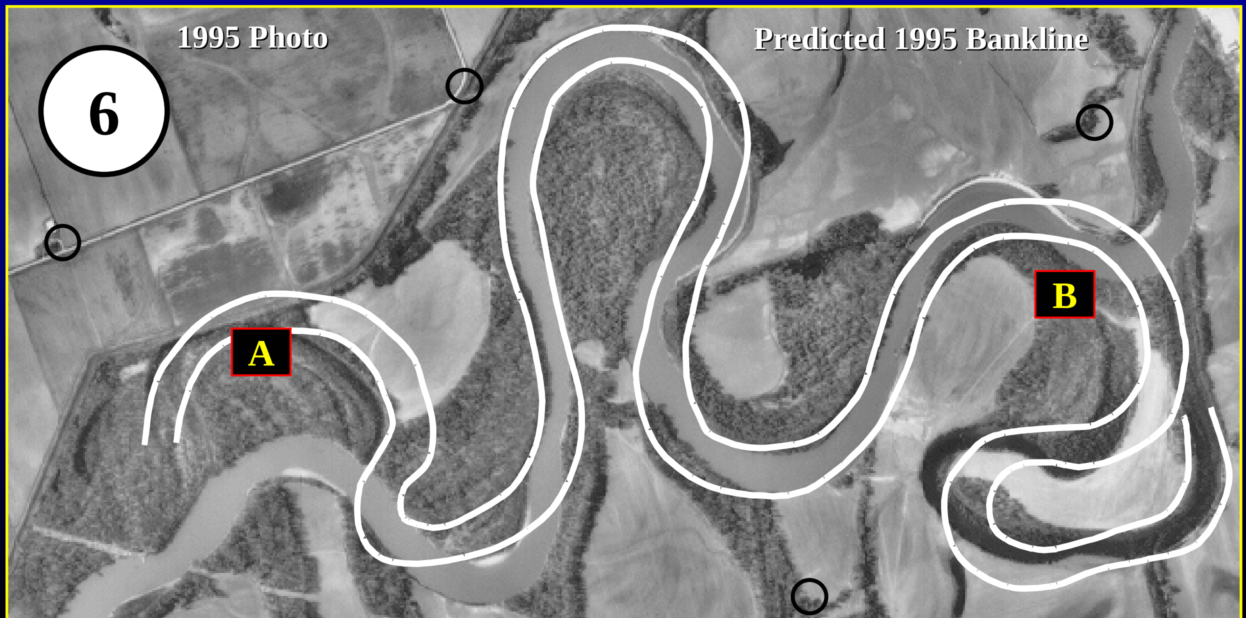


Prediction Techniques

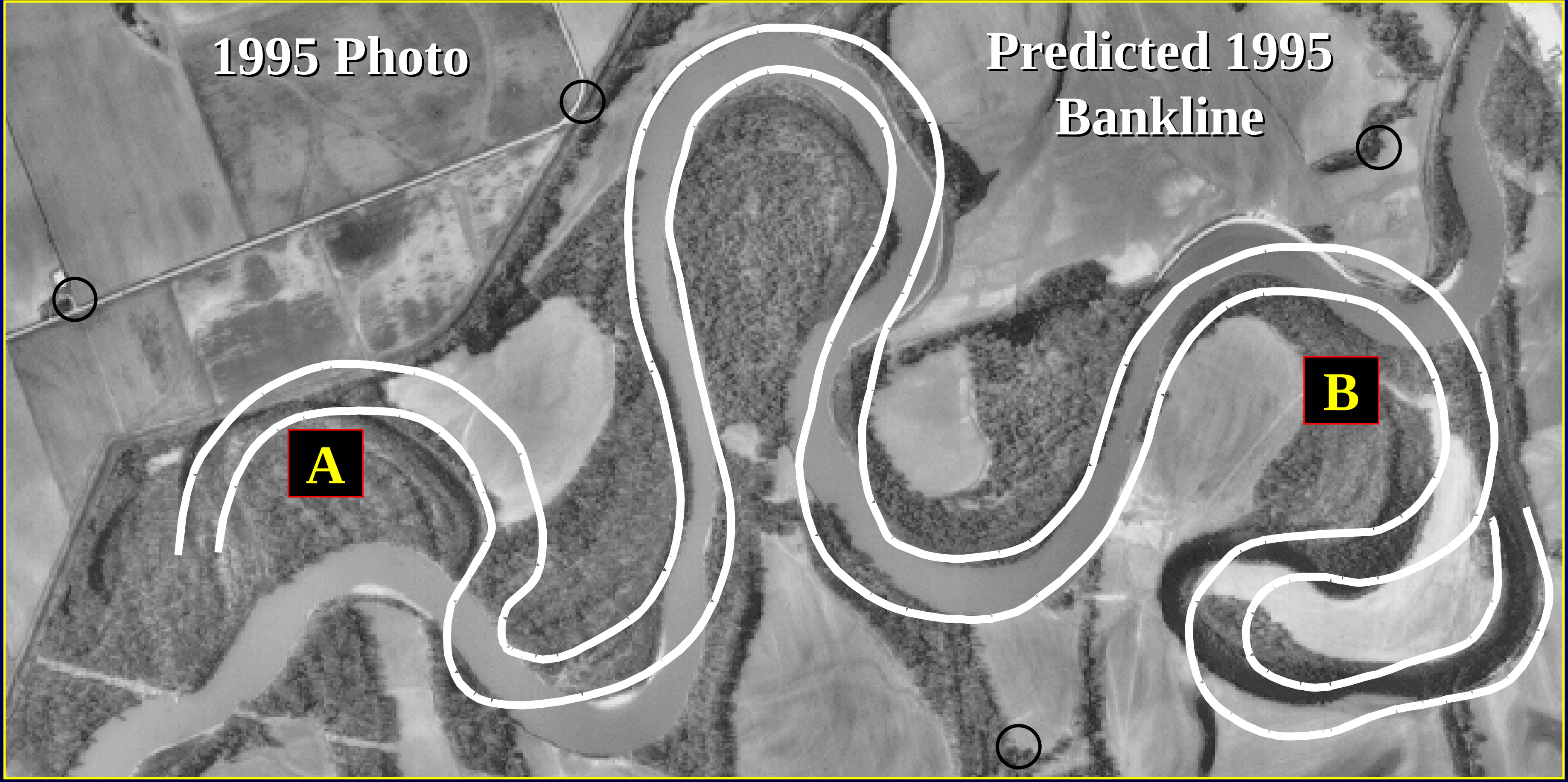




Prediction Techniques



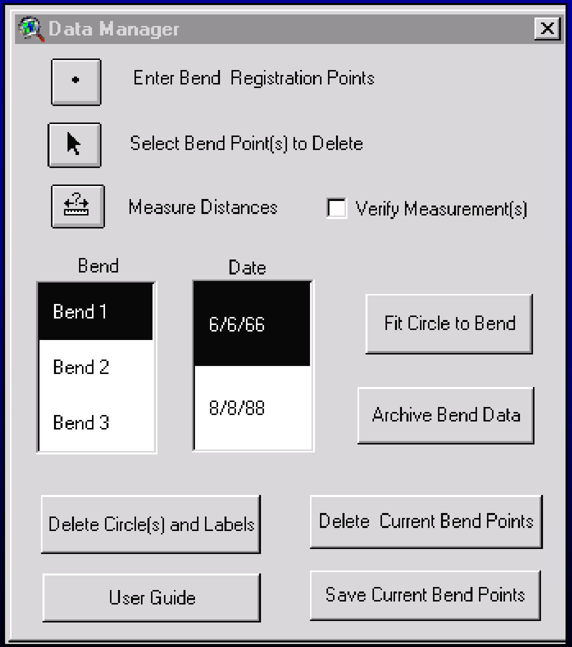
Prediction Results

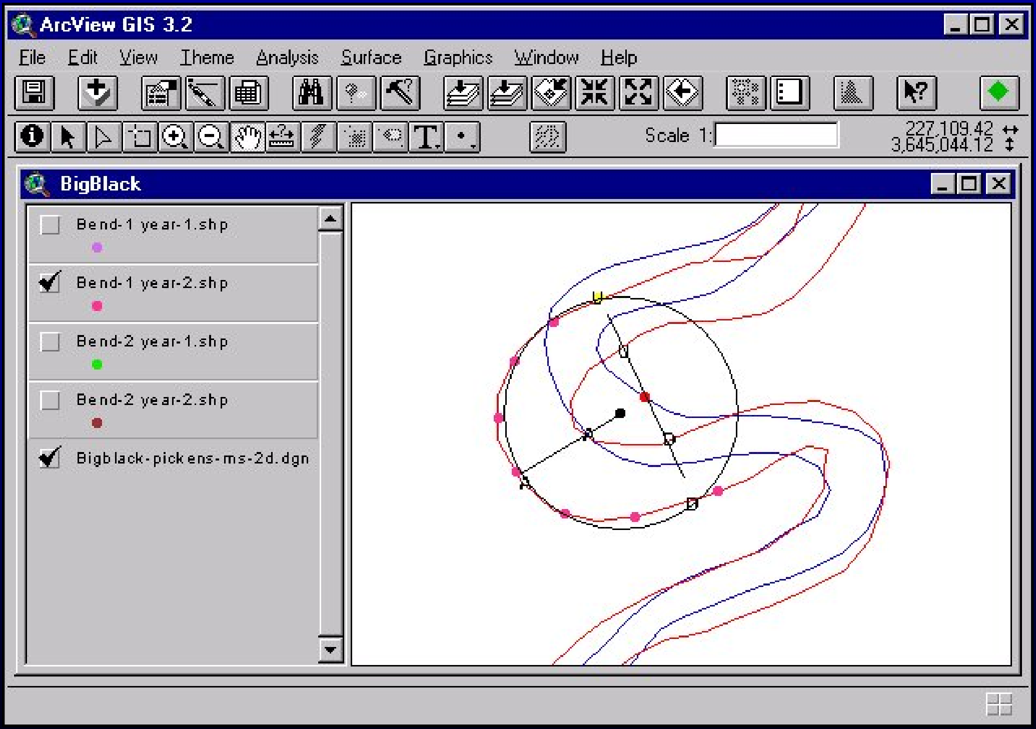


Data Logger

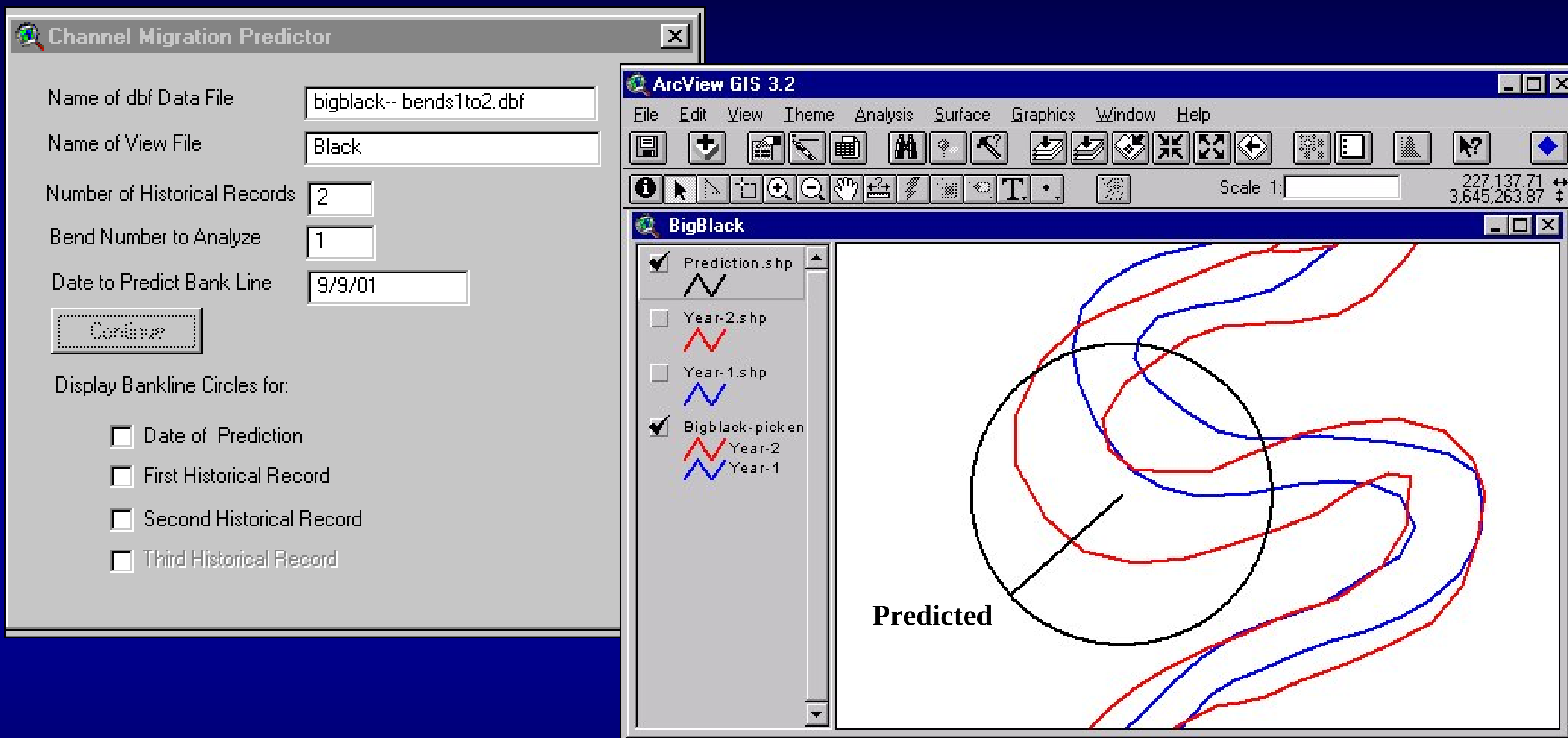
An ArcView-3.2 extension developed to:

- Measure meander planform variables
- Provide a database of measured variables for future use





CHANNEL MIGRATION PREDICTOR



An ArcView extension that uses the database and documented historic channel positions compiled using *Data Logger* to predict the approximate bankline position for a year in the future.

Testing

- Beta test with 7 state DOTs
- Apply GIS prediction to 43 bends
  - Migration direction – 80% of predictions within 30° arc
  - Migration distance - within 1% of the channel width per year over period of prediction

Results

- A stand-alone Handbook with guidelines on the use of map and aerial photo comparison techniques
- ArcView-based *Data Logger* and *Meander Migration Predictor* extensions included with Handbook to assist in measuring and predicting channel migration
- Completed June 2003

Bridge Scour and Stream Instability Countermeasures, HEC-23

- Risk Based Countermeasure Selection

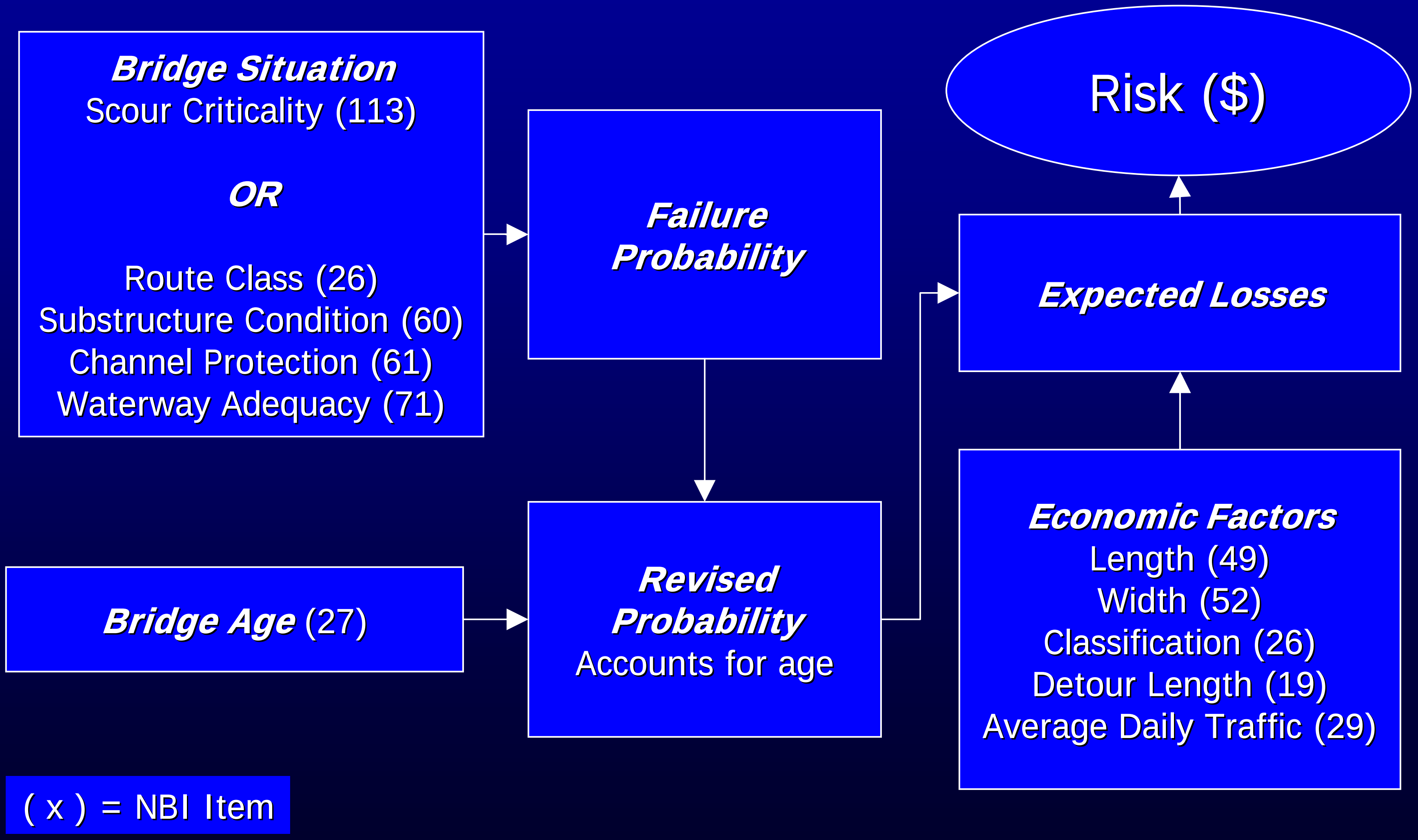
OBJECTIVE OF RISK BASED COUNTERMEASURE SELECTION

- Identify bridges at risk from scour using existing NBI data
- Prioritize bridges for countermeasures
- Examine the economic feasibility of scour countermeasure alternatives

PRIORITIZATION

- Two identical bridges except …
  - One has higher ADT
  - One has a longer detour
  - One has higher probability of failure
  - One has higher percentage of trucks
  - A combination of these factors

RISK

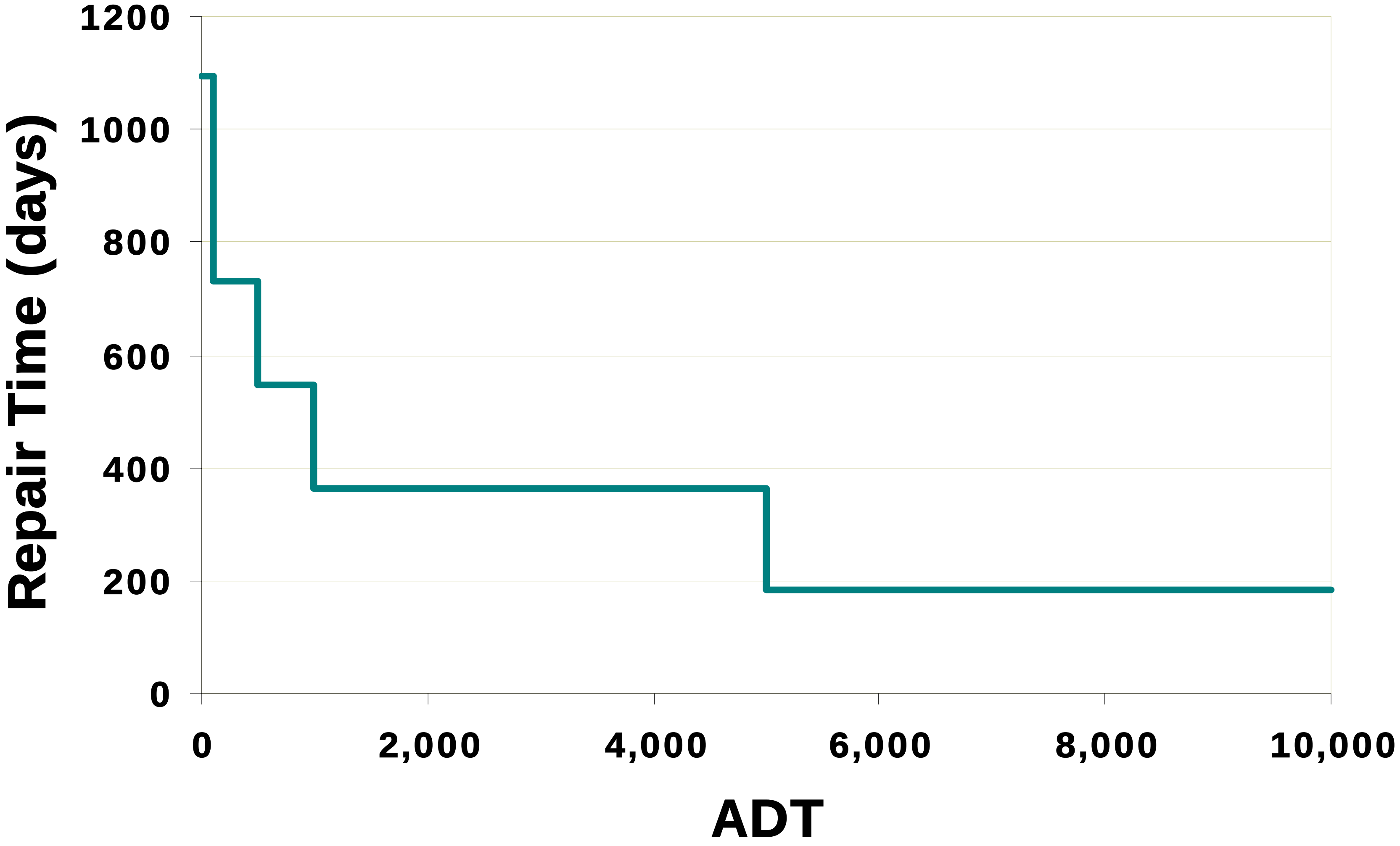

Bridge Situation
Scour Criticality (113)
OR
Route Class (26)
Substructure Condition (60)
Channel Protection (61)
Waterway Adequacy (71)
Failure Probability
Risk ($)
Expected Losses
Bridge Age (27)
Revised Probability
Accounts for age
Economic Factors
Length (49)
Width (52)
Classification (26)
Detour Length (19)
Average Daily Traffic (29)
(x) = NBI Item

RISK EQUATION

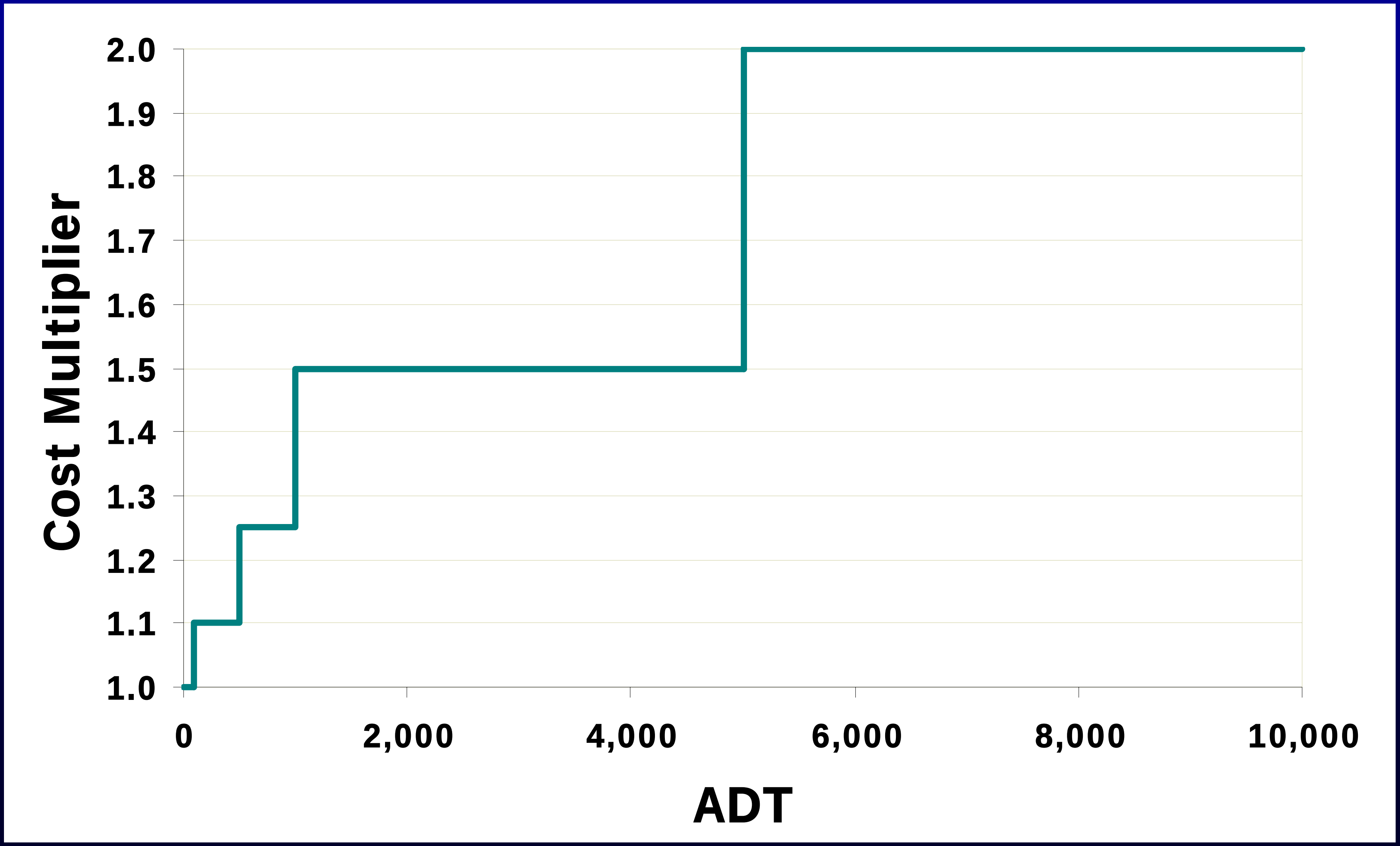
RISK($) = KP[rebuild cost + running cost + time cost]

$$RISK = KP\left[EC_1WL + C_2DAd + \left(C_3O\left(1 - \frac{T}{100}\right) + C_4\frac{T}{100}\right)\frac{DAd}{S}\right]$$

DETOUR DURATION



COST MULTIPLIER FOR EARLY REPLACEMENT



EXAMPLE RISK CALCULATION

- Bridge characteristics
  - 40’ wide by 200’ long
  - P_a=0.0333 (30-year event)
  - ADT = 2500
  - Detour length = 5 miles
  - Percent Trucks = 10 %

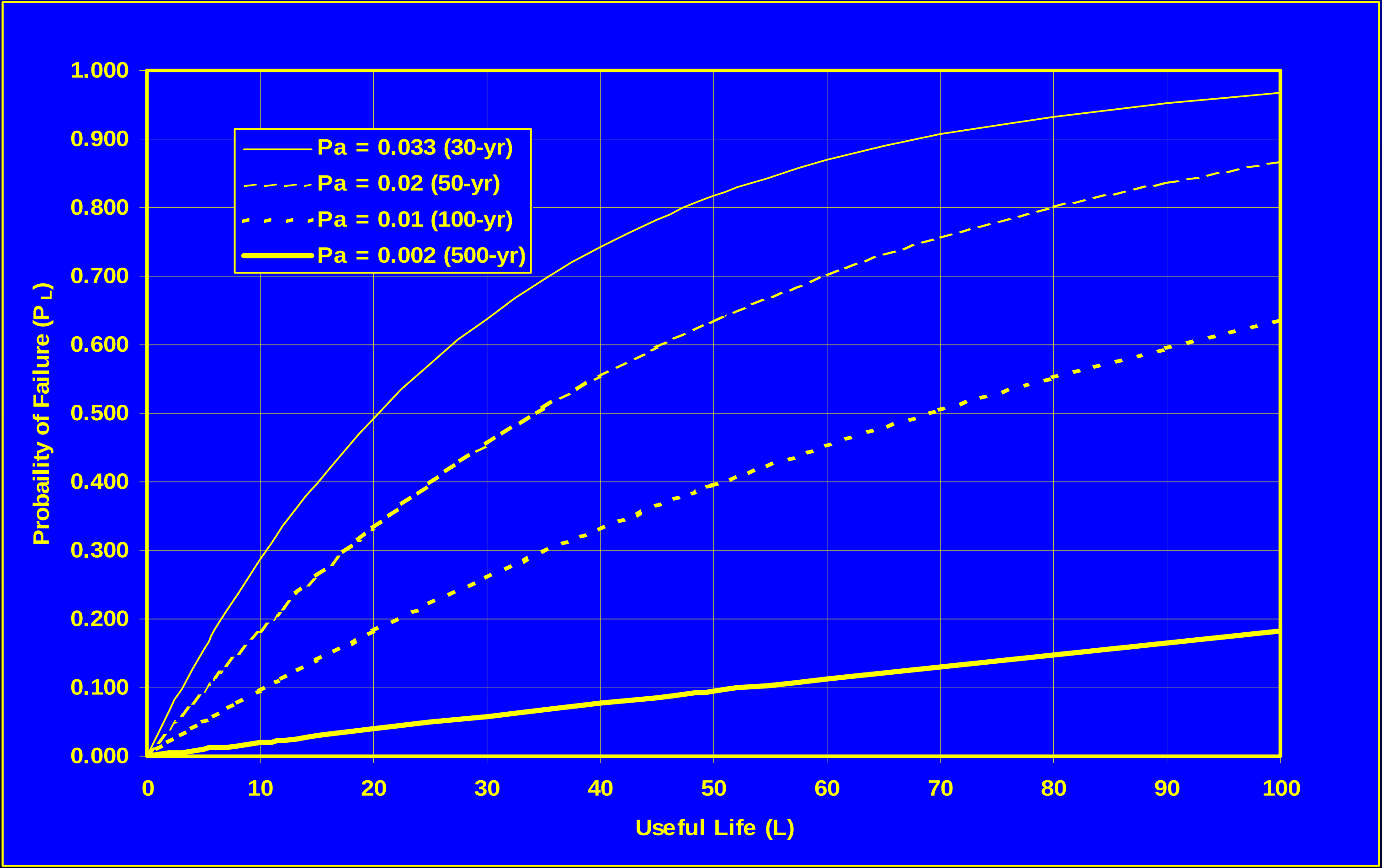
EXAMPLE RISK CALCULATION

	Bridge
Rebuild Cost	$ 720,000
Running Cost	$ 1,140,000
Time Cost	$ 1,360,000
Failure Cost (C_F)	$ 3,220,000
Risk (annual expected loss, $)	$ 107,000

PROBABILITY OF FAILURE DURING BRIDGE LIFE

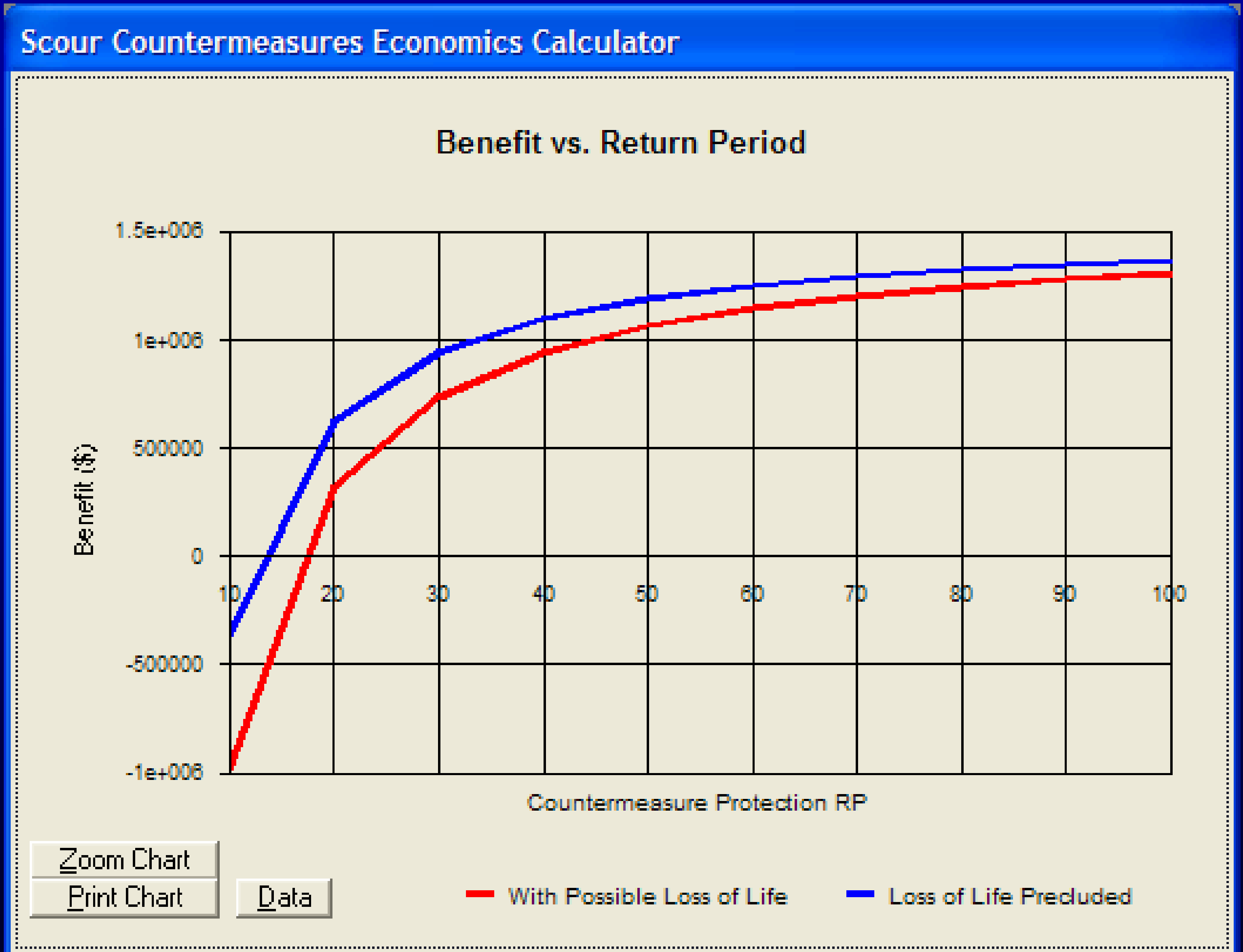
$$P_L = 1 - \left(1 - P_A\right)^L$$

PROBABILITY OF FAILURE DURING BRIDGE LIFE



BENEFIT

$$B = C_F P_L - C_F' P_L'$$


Scour Countermeasures Economics Calculator
Benefit vs. Return Period
1.5e+006
1e+006
500000
0
-500000
-1e+006
Benefit ($)
10
20
30
40
50
60
70
80
90
100
Countermeasure Protection RP
Zoom Chart
Print Chart
Data
With Possible Loss of Life
Loss of Life Precluded

COUNTERMEASURE SELECTION EXAMPLE

- Compare the benefits of several countermeasure alternatives

COUNTERMEASURE SELECTION EXAMPLE

	Existing	CM 1	CM 2
P_a	0.033 (30-yr)	0.02 (50-yr)	0.01 (100-yr)
P_L (15-yr)	0.40	0.26	0.14
Cost of Failure	$ 3,220,000	$ 3,220,000	$ 3,220,000
Benefit		$ 451,000	$ 837,000
CM cost		$ 100,000	$ 150,000
Net Benefit		$ 351,000	$ 687,000
B/C ratio		4.51	5.58

INCLUDING LOSS OF LIFE

- Can be included in Cost of Failure and Risk
- Can be eliminated with appropriate monitoring program

LOSS OF LIFE AND MONITORING

	Existing	Monitoring alone	CM 2 and Monitoring
P_a	0.033 (30-yr)	0.033 (30-yr)	0.01 (100-yr)
P_L (15-yr)	0.40	0.40	0.14
C_F + $1m, Life	$ 4,220,000	$ 3,220,000	$ 3,220,000
Benefit		$ 400,000	$ 1,240,000
CM cost		$ 25,000	$ 175,000
Net Benefit		$ 375,000	$ 1,065,000
B/C ratio		16.0	7.1

HYRISK

- Uses NBI database
- Prioritizes bridges
- Estimates probability of failure
- Estimates economic risk
- Evaluates countermeasure benefits

Scour Countermeasures Economics Calculator

Scour Countermeasures

Structure 000000000029535

Calculate

Define up to seven potential scour countermeasures for use at this bridge site. Then click "Calculate".

Name		Cost ($)	RP (y)	Lifetime P(f)	Net Benefit	Benefit/Cost
Do Nothing	☐	$0.00	16	0.6202	$0.00	-- NA --
Small RR	☐	$50,000.00	25	0.4579	$520,659.13	11.41
LargeRR	☐	$100,000.00	50	0.2614	$966,266.86	10.66
Monitor	☑	$25,000.00	16	0.6202	$360,489.08	15.42
Small RR & Monitor	☑	$75,000.00	25	0.4579	$742,372.14	10.90
Large RR & Monitor	☑	$125,000.00	50	0.2614	$1,064,623.3	9.52
	☐					

Plot | Cancel | < Back | Report > | Finish