Bottomless Culverts Scour Study

Mid West Hydraulics Conference
E. Lansing, Mich

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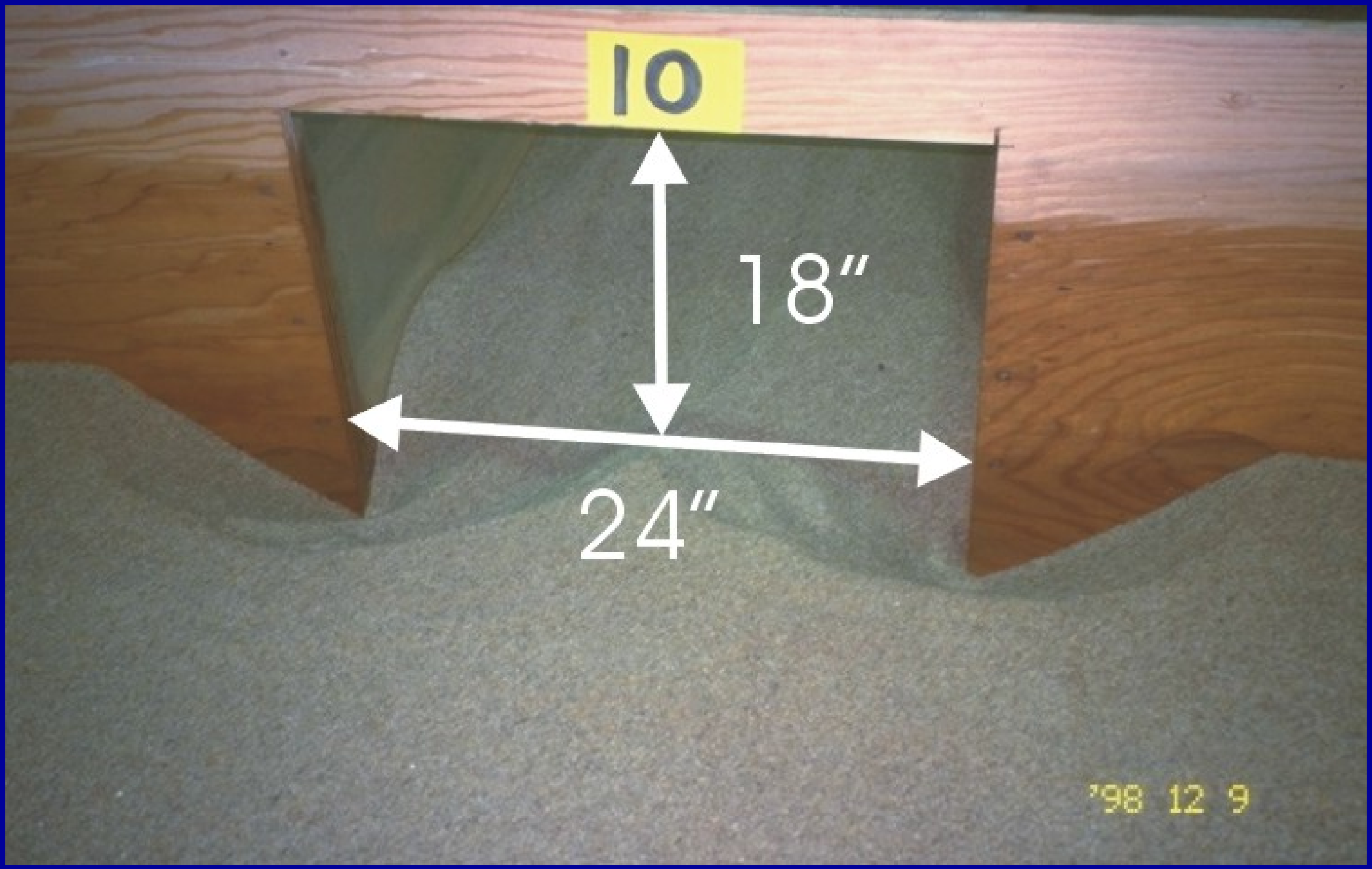
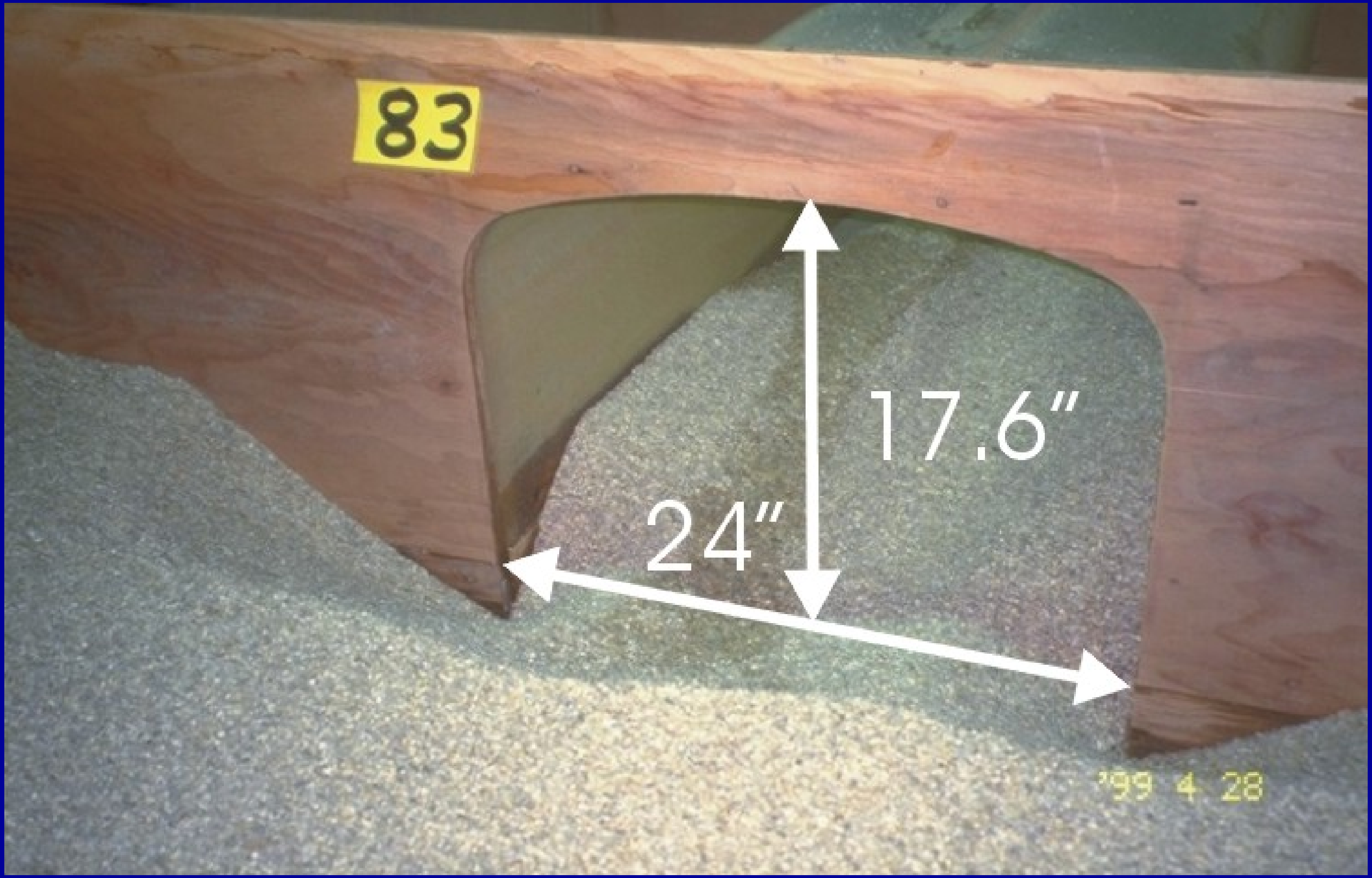
EXPERIMENTAL SET-UP
FOR THE BOTTOMLESS CULVERT STUDY



rectangular model



conspan model

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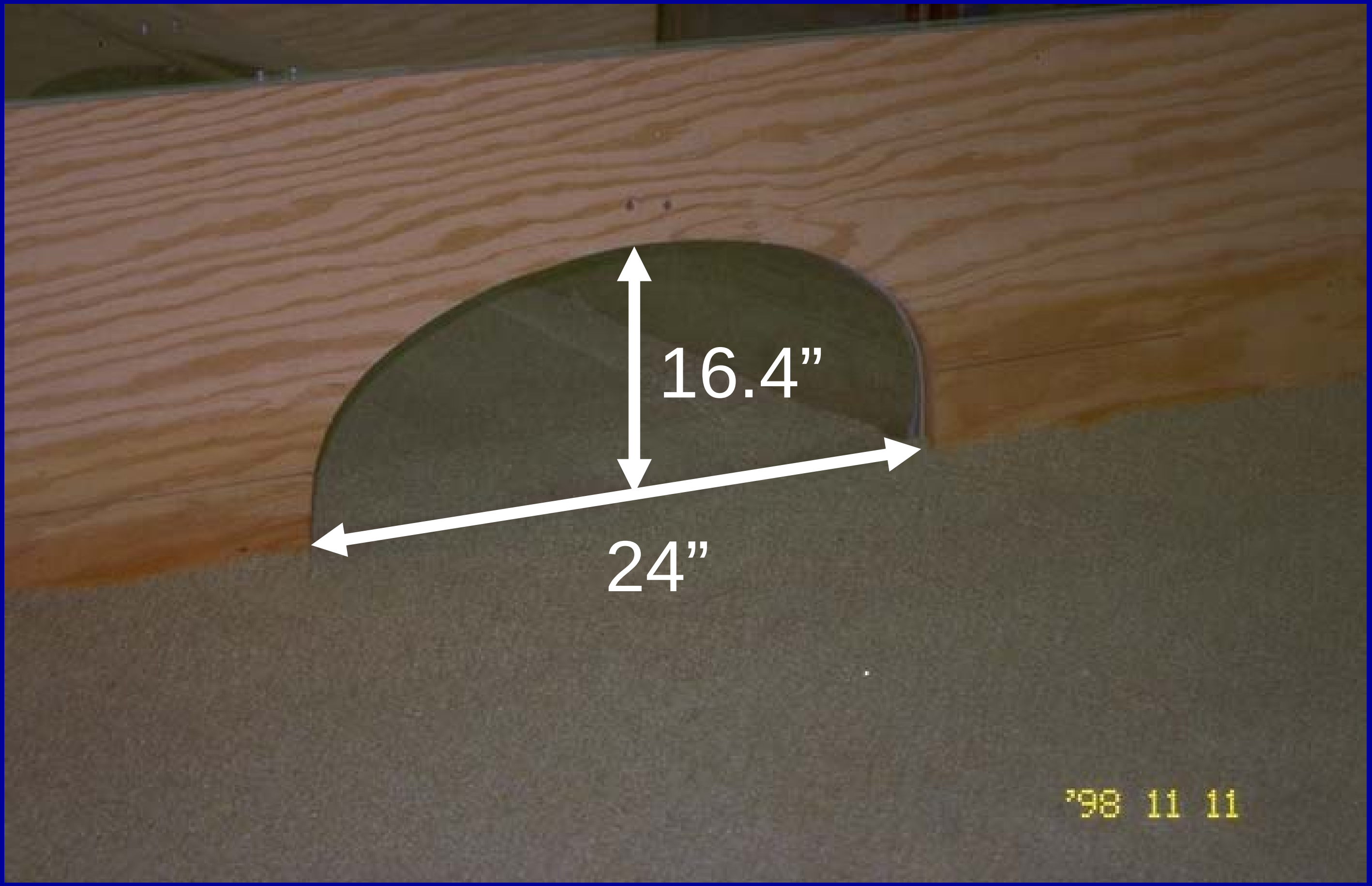

contech model

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rectangular model with wingwalls

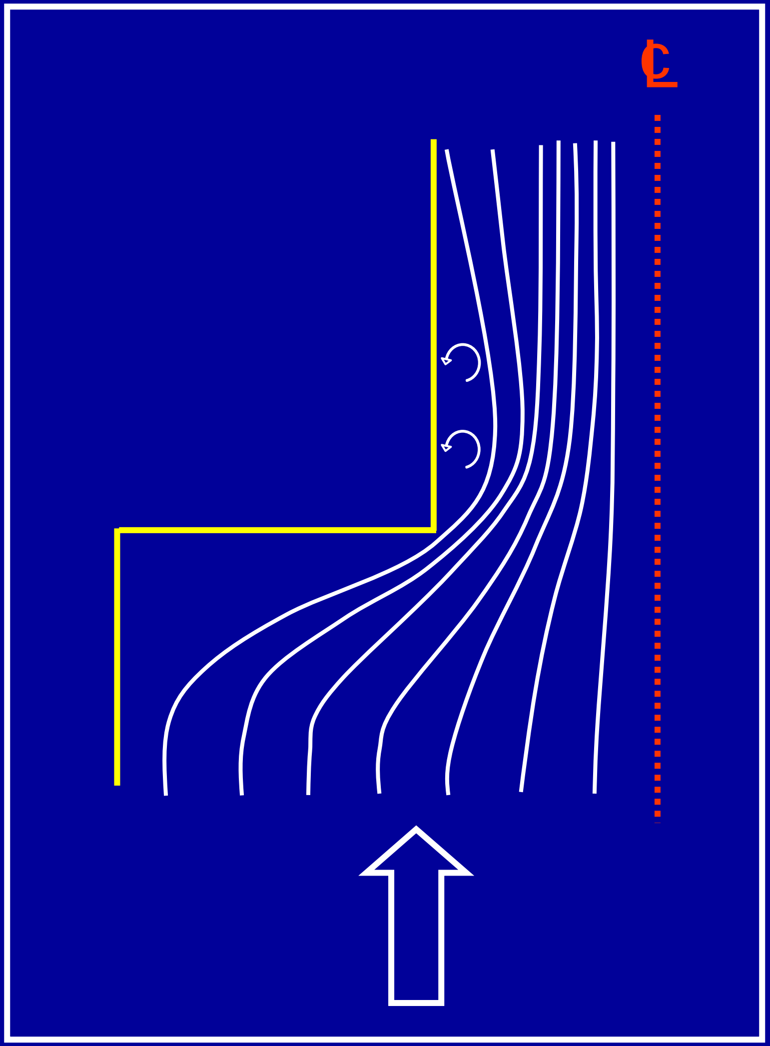
Bottomless Culvert Analysis

• Max scour occurs at u.s. corners of bottomless culverts; analogous to bridge Abutment scour.

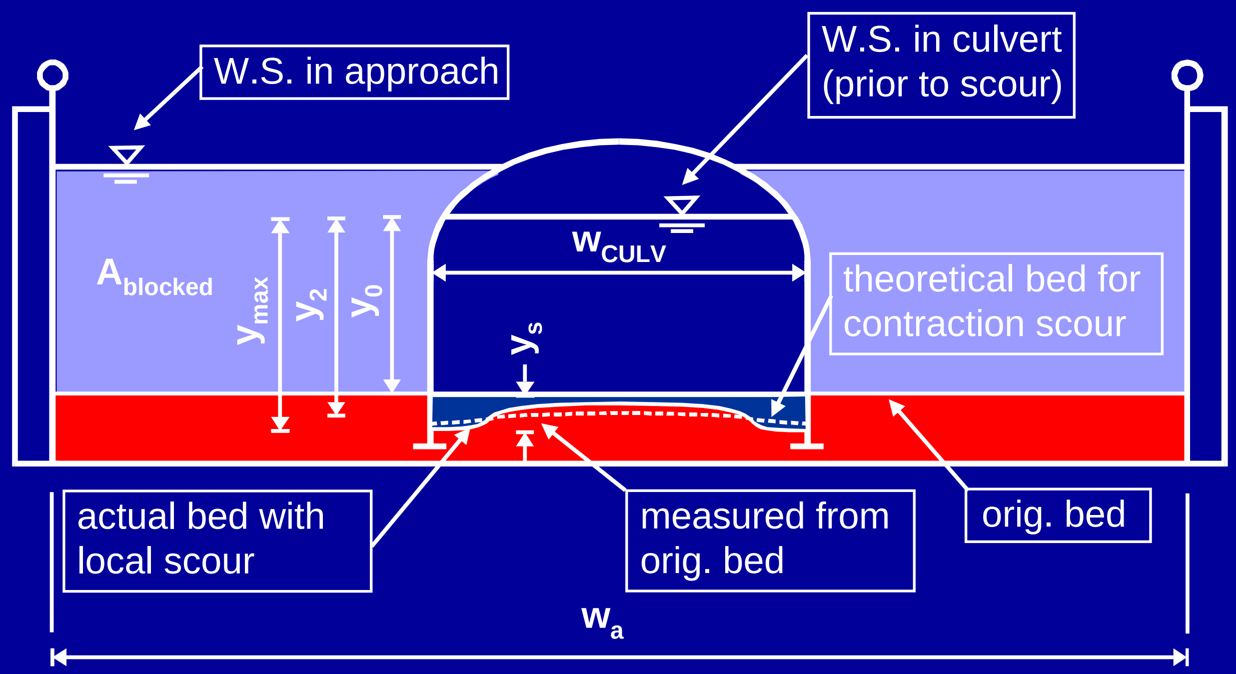
• max scour at culverts (like abutment scour) can be conceptualized as a form of contraction scour where the bed elev adjusts to flow distribution with an amplification factor attributed to high turbulence and vorticity in a mixing zone.

THEORETICAL BACKGROUND

FLOW CONCENTRATION



DEFINITION SKETCH



y_2 is a flow distribution component that is computed as contraction scour

CONCEPTUAL ANALYSIS

- Determine a local representative velocity, V_R, near abutment prior to scour.
- Compute the representative unit discharge, q_R, near the abutment

$$q_R = v_R \cdot y_0$$

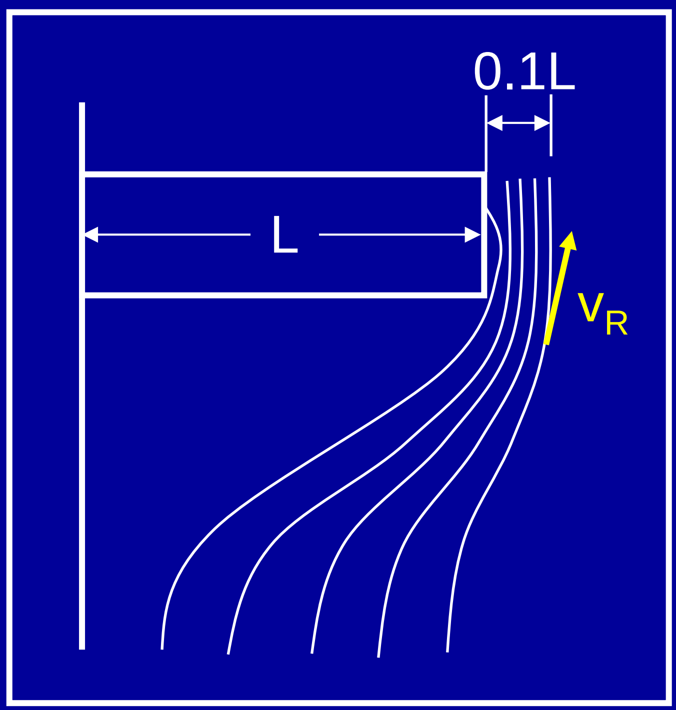
- Determine the critical incipient motion velocity, V_c, for the bed material in the culvert.

CONCEPTUAL ANALYSIS (CONT'D)

- **ASSUME THE UNIT DISCHARGE REMAINS CONSTANT IN THE CONTROL VOLUME.**
- Calculate the equilibrium contraction scour flow depth, y_2.
- Calculate the amplification factor, K_{ADJ}, to account for vortices and secondary currents.
- Calculate the max scour flow depth

$$y_{max}=K_{ADJ}\, y_2$$

MD DOT (CHANG) Method for q_R



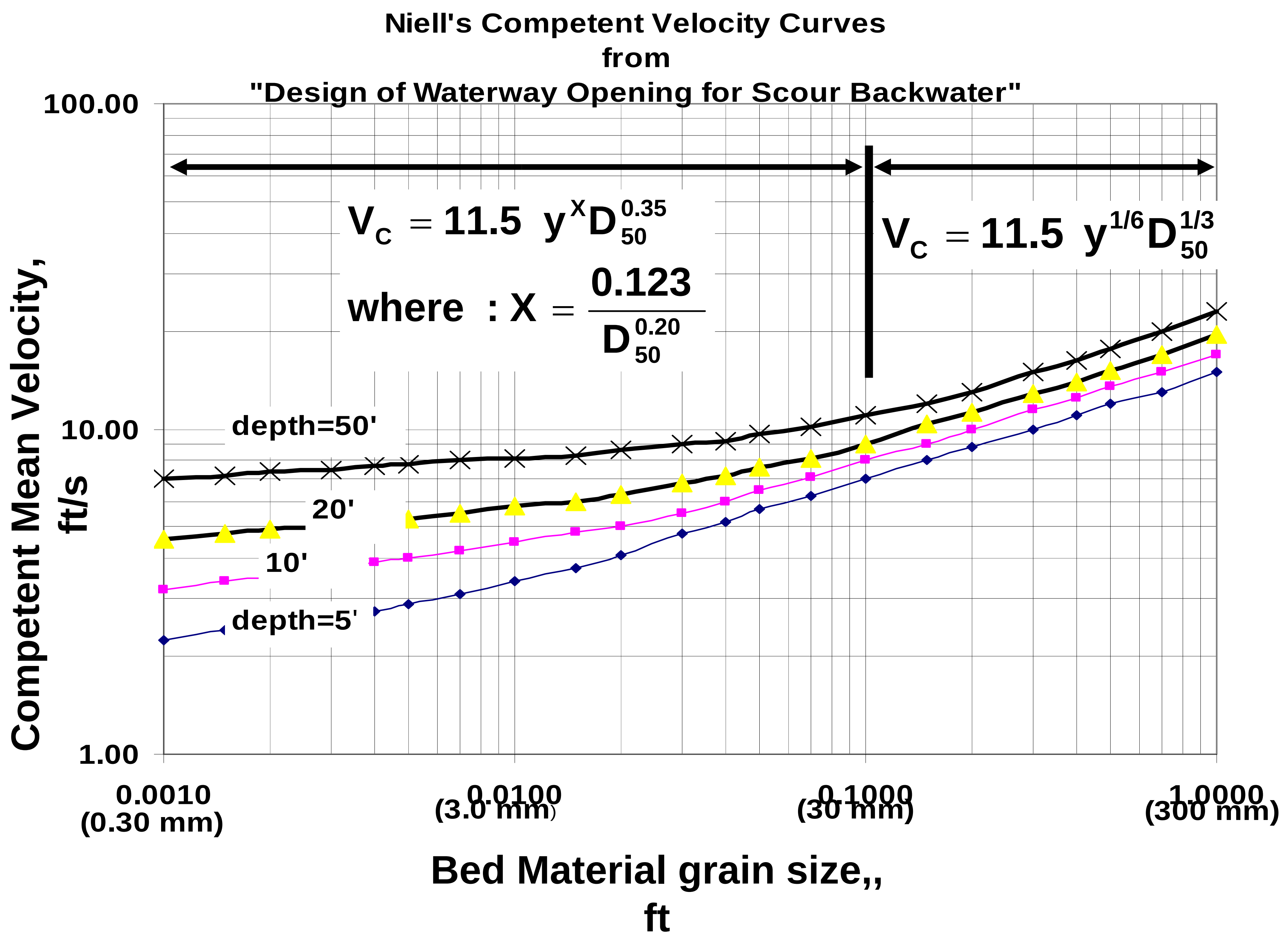
used potential flow transformation

$$v_R = K_v \left[\frac{Q}{A_{opening}} \right]$$

at point 0.1 L distance from Abutment face

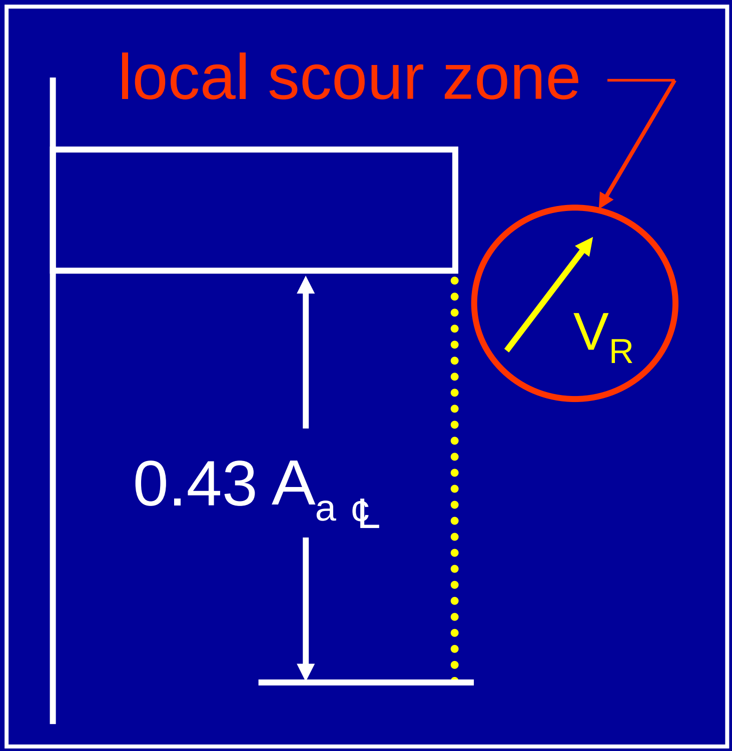
$$K_v = 1 + 0.8 \left(\frac{w_{opening}}{w_a} \right)^{15}$$

$$\mathbf{q_R = V_R \times y_0}$$



Niell's Competent Velocity Curves
from
"Design of Waterway Opening for Scour Backwater"
$V_C = 11.5\ y^X D_{50}^{0.35}$
where : $X = \frac{0.123}{D_{50}^{0.20}}$
$V_C = 11.5\ y^{1/6} D_{50}^{1/3}$
depth=50'
20'
10'
depth=5'
100.00
10.00
1.00
0.0010
(0.30 mm)
0.0100
(3.0 mm)
0.1000
(30 mm)
1.0000
(300 mm)
Competent Mean Velocity, ft/s
Bed Material grain size,, ft

GKY Method for q_R



$$V_R = \sqrt{V_X^2 + V_Y^2}$$

$$v_x = Q / A_{opening}$$

$$v_y = \frac{Q_{blocked\ \text{CL}}}{0.43\ A_{a\ \text{CL}}}$$

where: $Q_{blocked\ \text{CL}}$ = Approach flow blocked by embankment on one side of channel cL

$A_{a\ \text{CL}}$ = Tot approach flow area on one side of channel cL

$$q_R = V_R \times y_0$$

Shields/Manning/Blodgett Method for v_c

$$SP = \frac{\tau_c}{(\gamma_s - \gamma) D_{50}}$$

Shields

$$n = K_{u2}\, 0.0185\, y^{1/6}$$

Blodgett (for sand size)

$$\tau = \gamma\, y\, S_F$$

$$S_F = \frac{v^2 n^2}{K_{u1}^2\, y^{4/3}}$$

Manning

$$V_C = \frac{K_U\, 0.28\, D_{50}^{1/2}\, y_0^{1/6}}{n}$$

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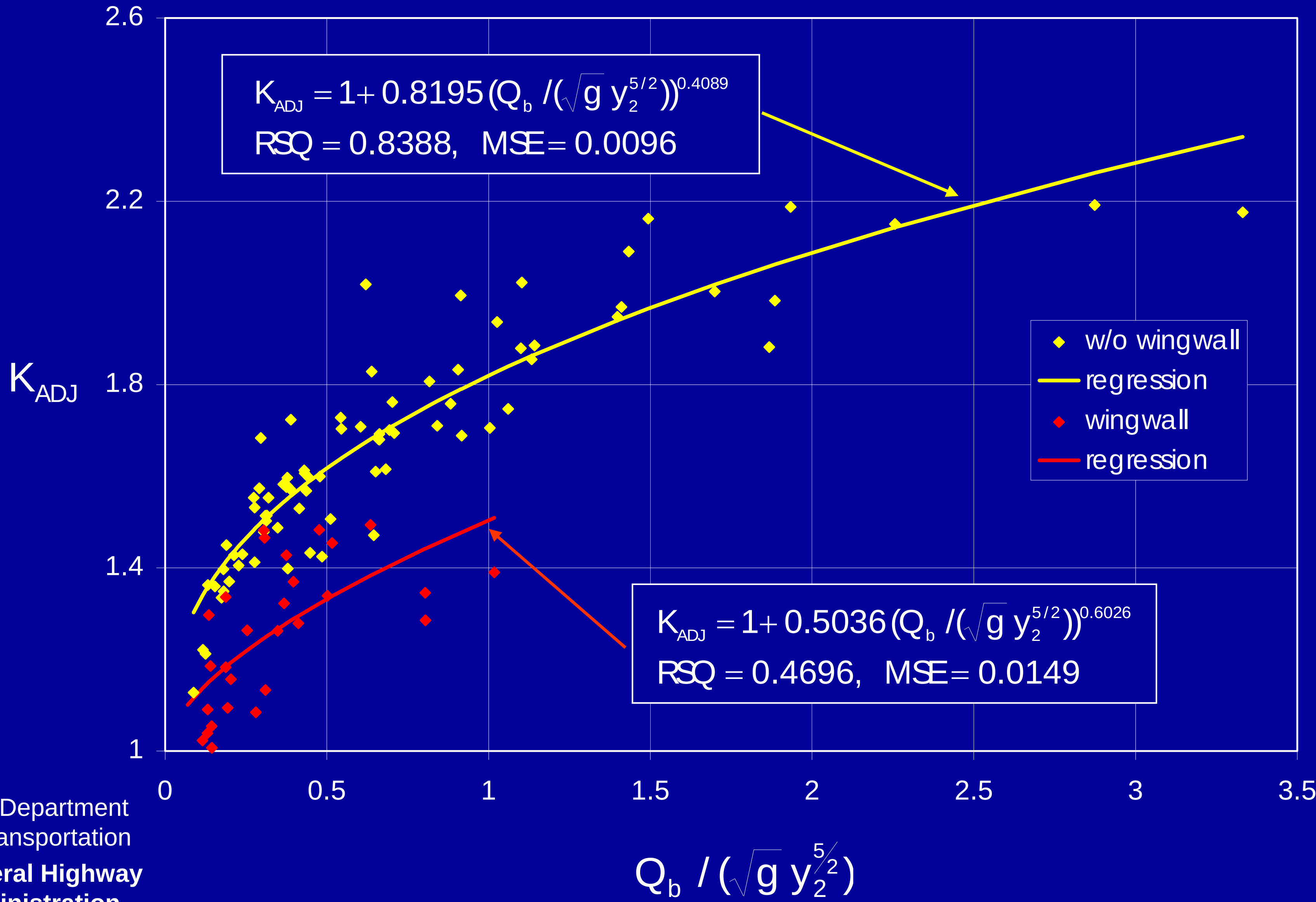
GKY V_R, SMB V_c, $K_{ADJ} = f(Q_b / (\sqrt{g}\, y_2^{5/2}))$



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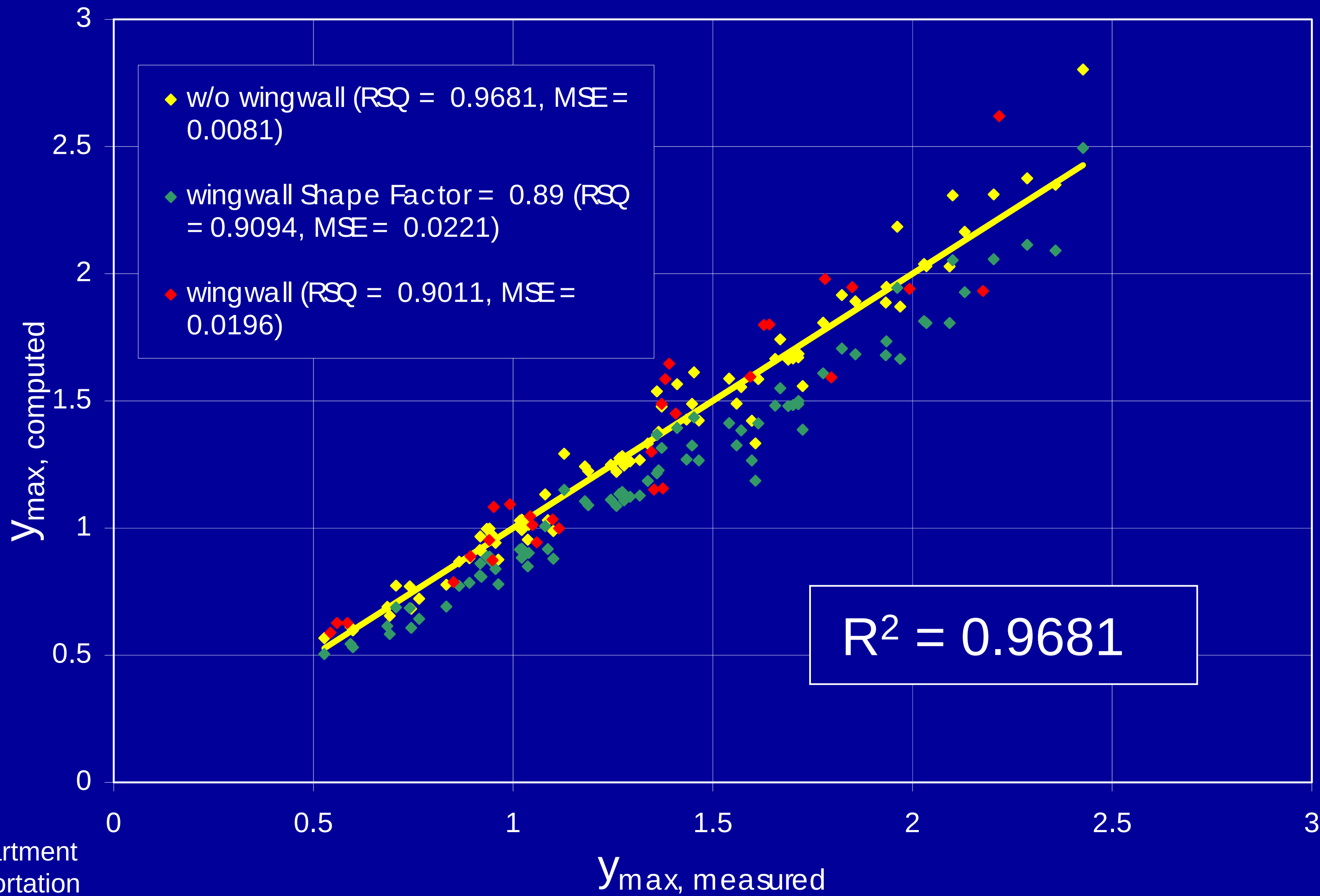
$y_{max,\ measured} - y_{max,\ calculated}$



SUMMARY

$$v_r = \sqrt{v_x^2 + v_y^2} \qquad v_x = \frac{Q}{(w_{CULV}\, y_0)} \qquad v_y = \frac{Q_{b\ \mathrm{℄}}}{0.43\ A_{a\ \mathrm{℄}}}$$

v_c from Shields, Manning, Blogdett

$$y_2 = \frac{v_R\, y_0}{v_c}$$

$$K_{ADJ} = K_{SHAPE}\left[1 + 0.8195\left(\frac{Q_{blocked}}{\sqrt{g\, y_2^{5/2}}}\right)^{0.4089}\right]$$

where K_{SHAPE} = 0.89 for wingwalls

$$y_{max} = K_{ADJ}\, y_2$$

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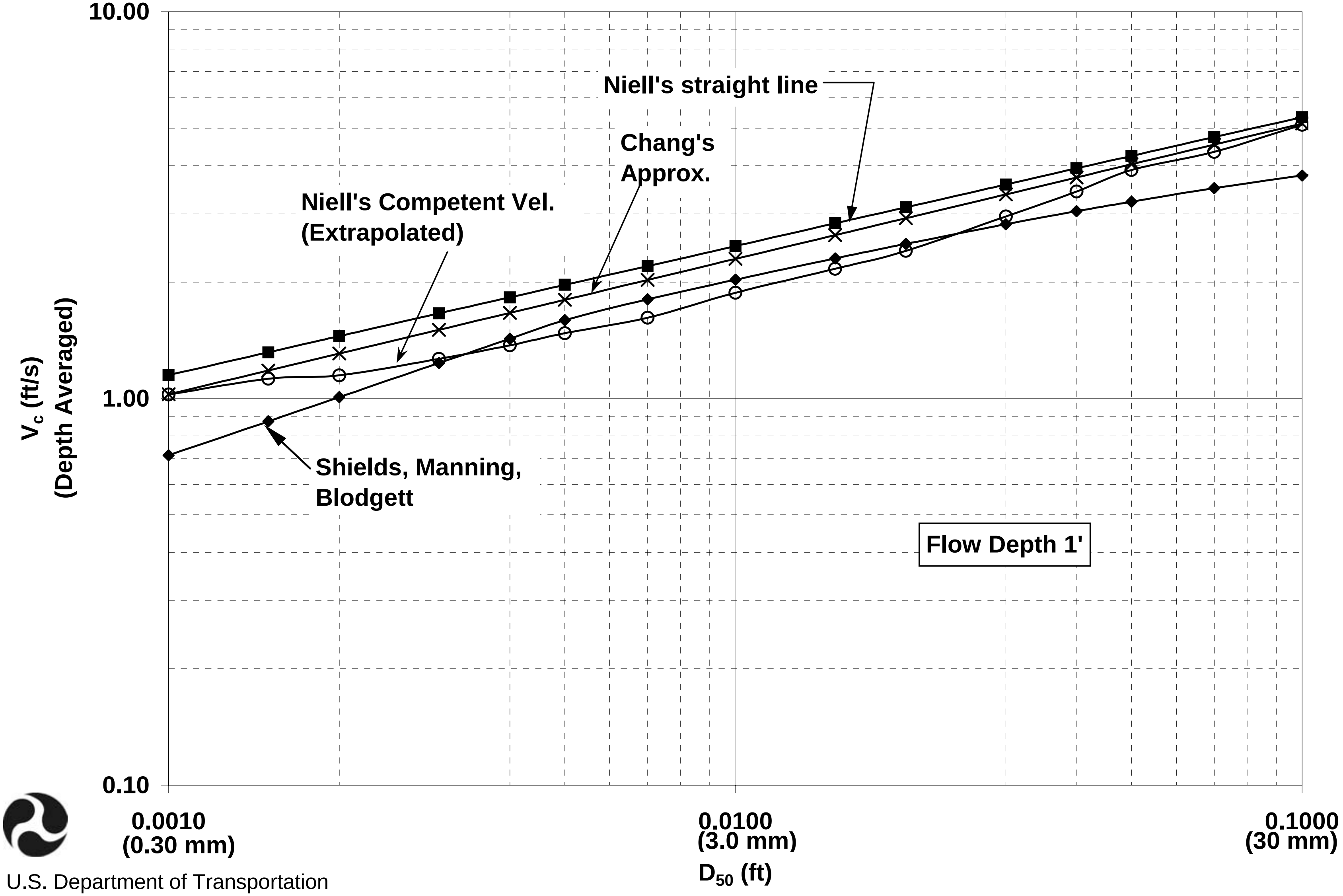
COMBINED COMPETENT VELOCITY CURVES FOR FLOW DEPTH 1.0’



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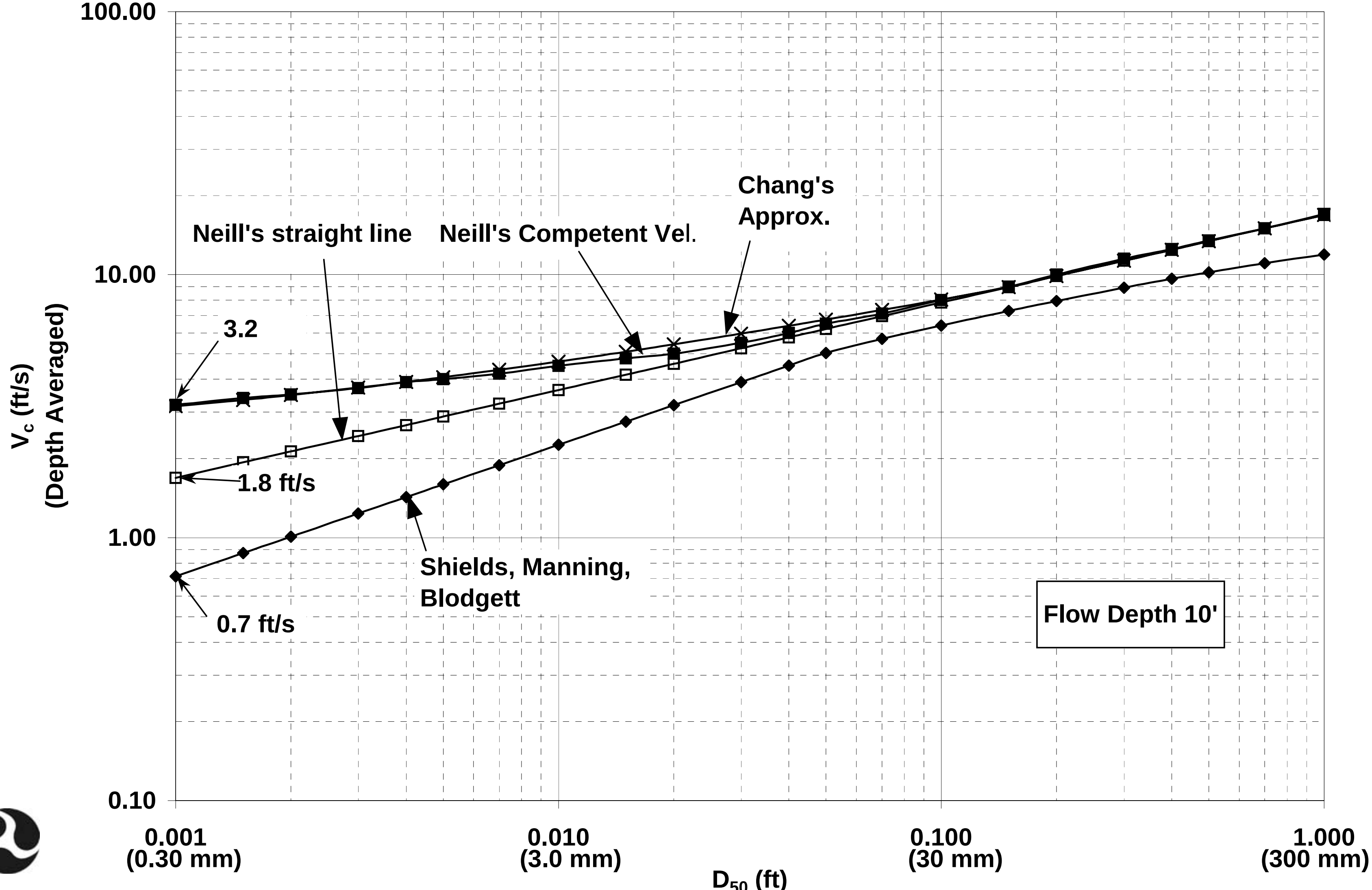
COMBINED COMPETENT VELOCITY CURVES FOR FLOW DEPTH 10’



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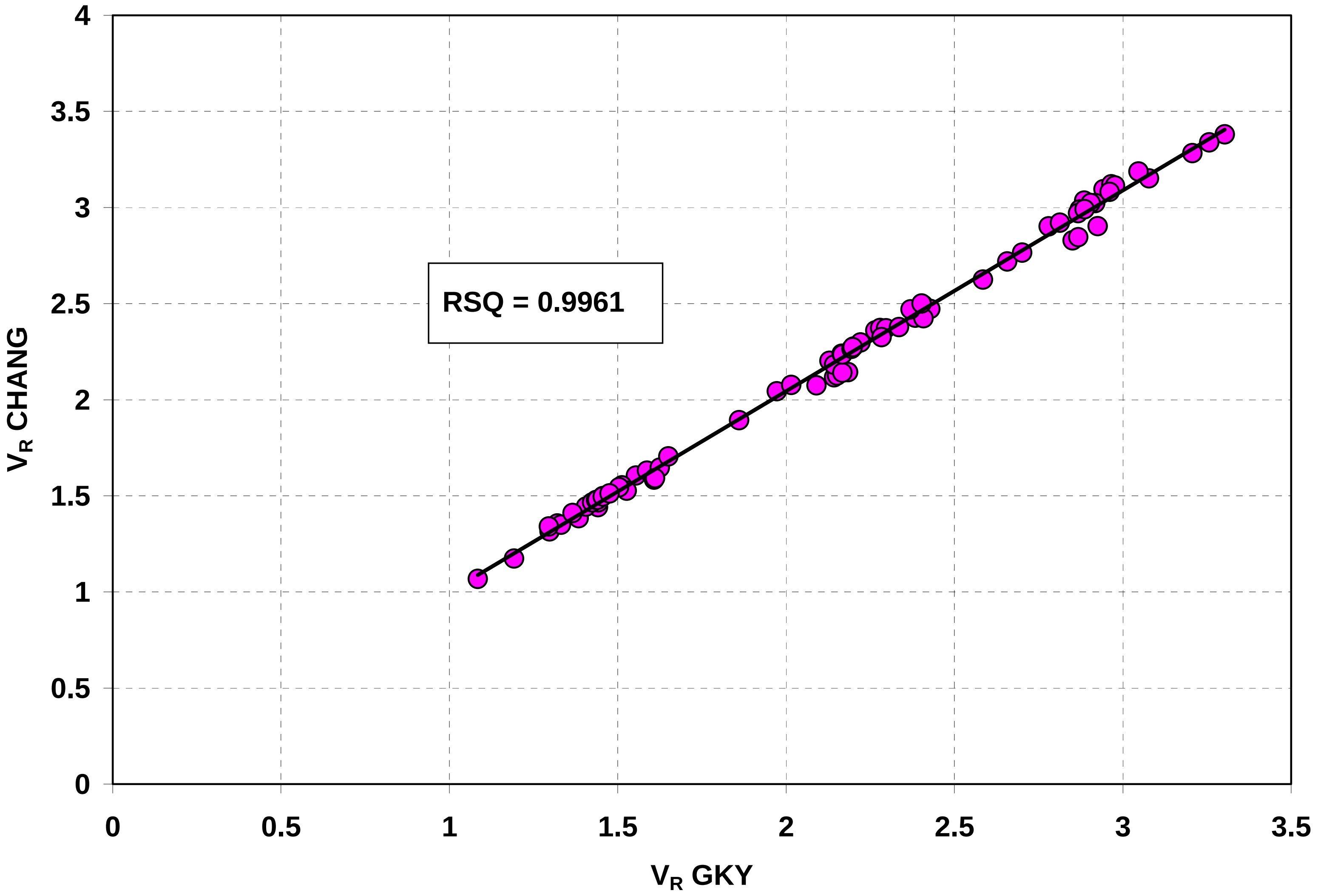
COMPARISON BETWEEN CHANG'S AND GKY'S RESULTANT VELOCITIES



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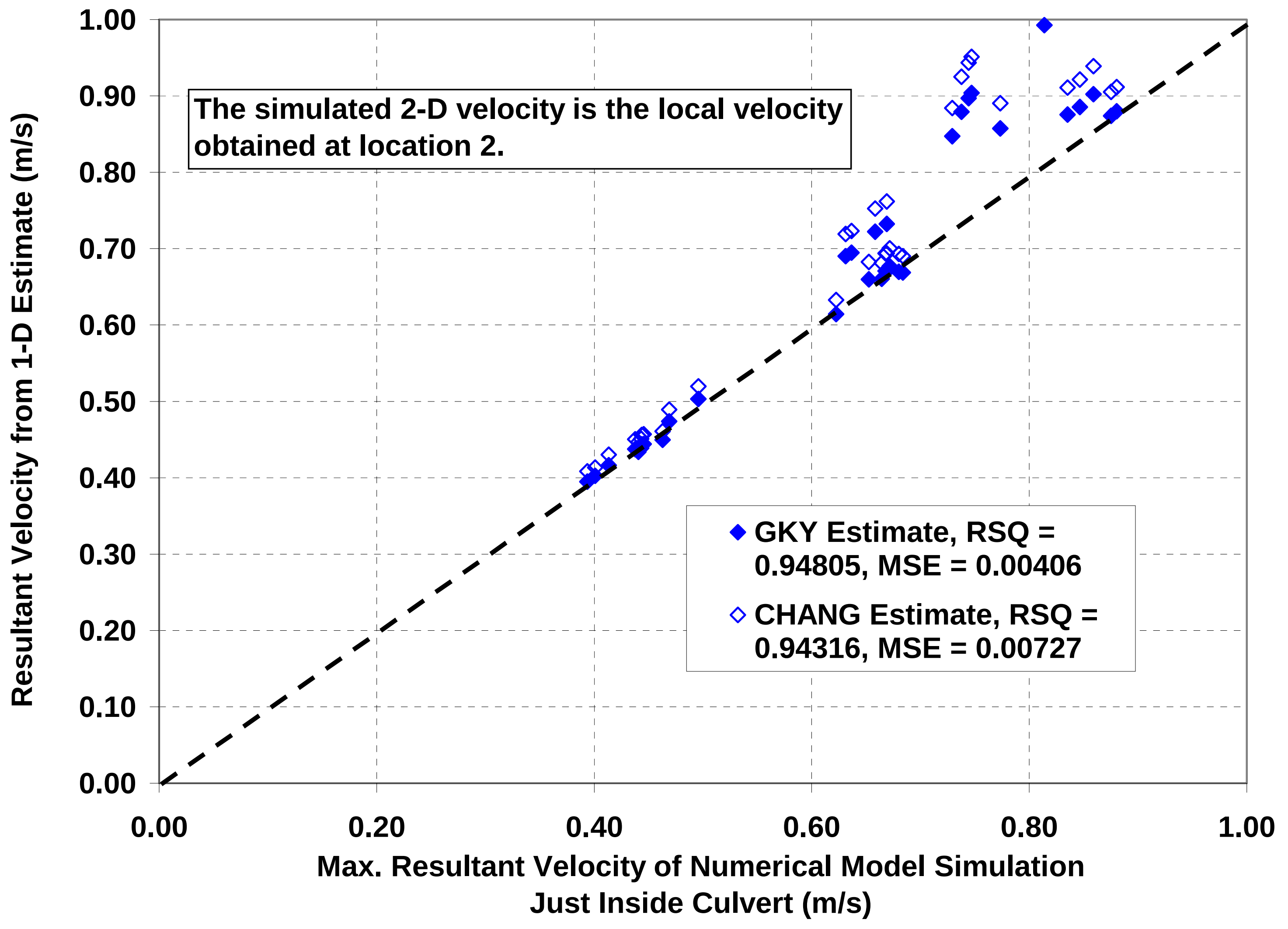
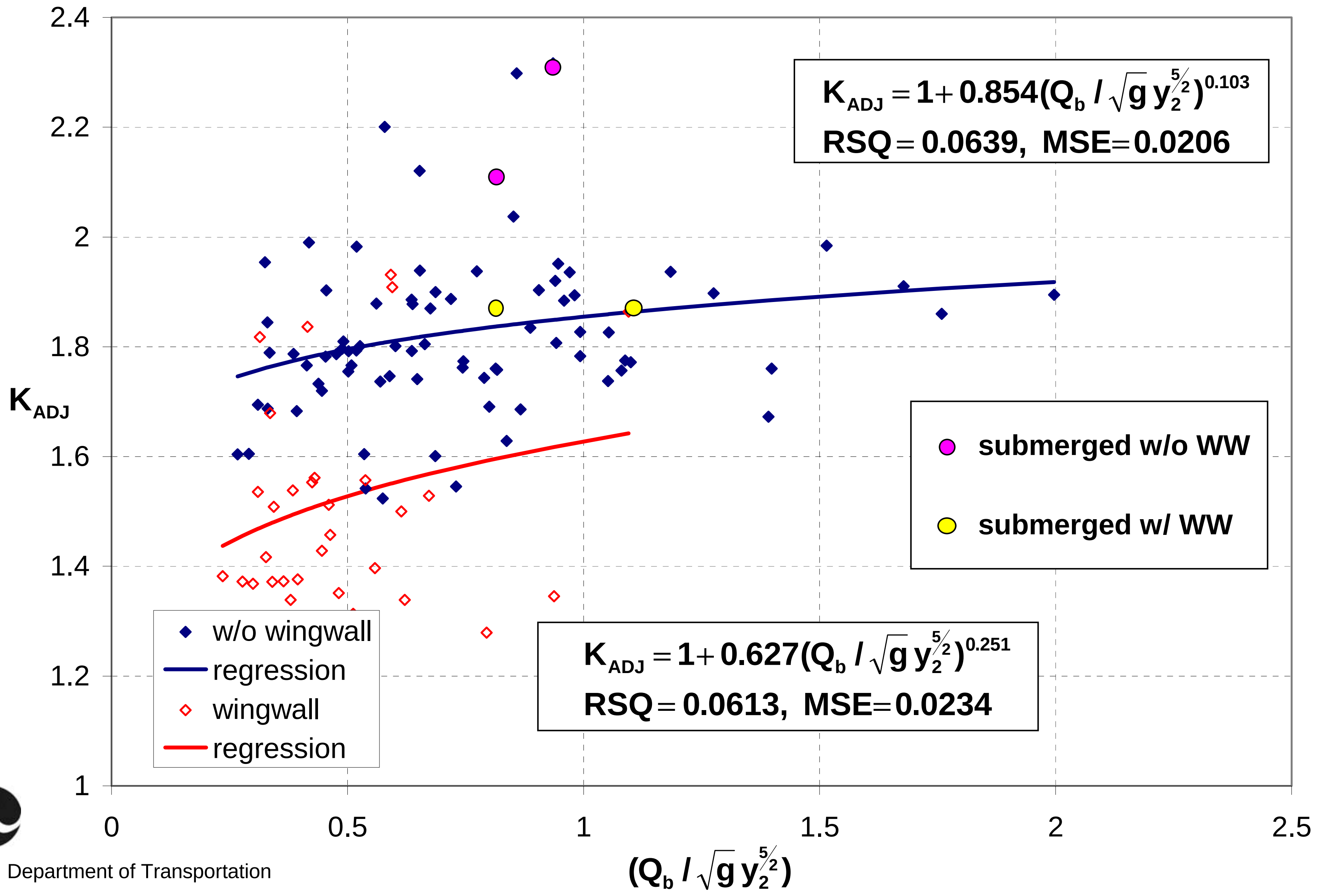
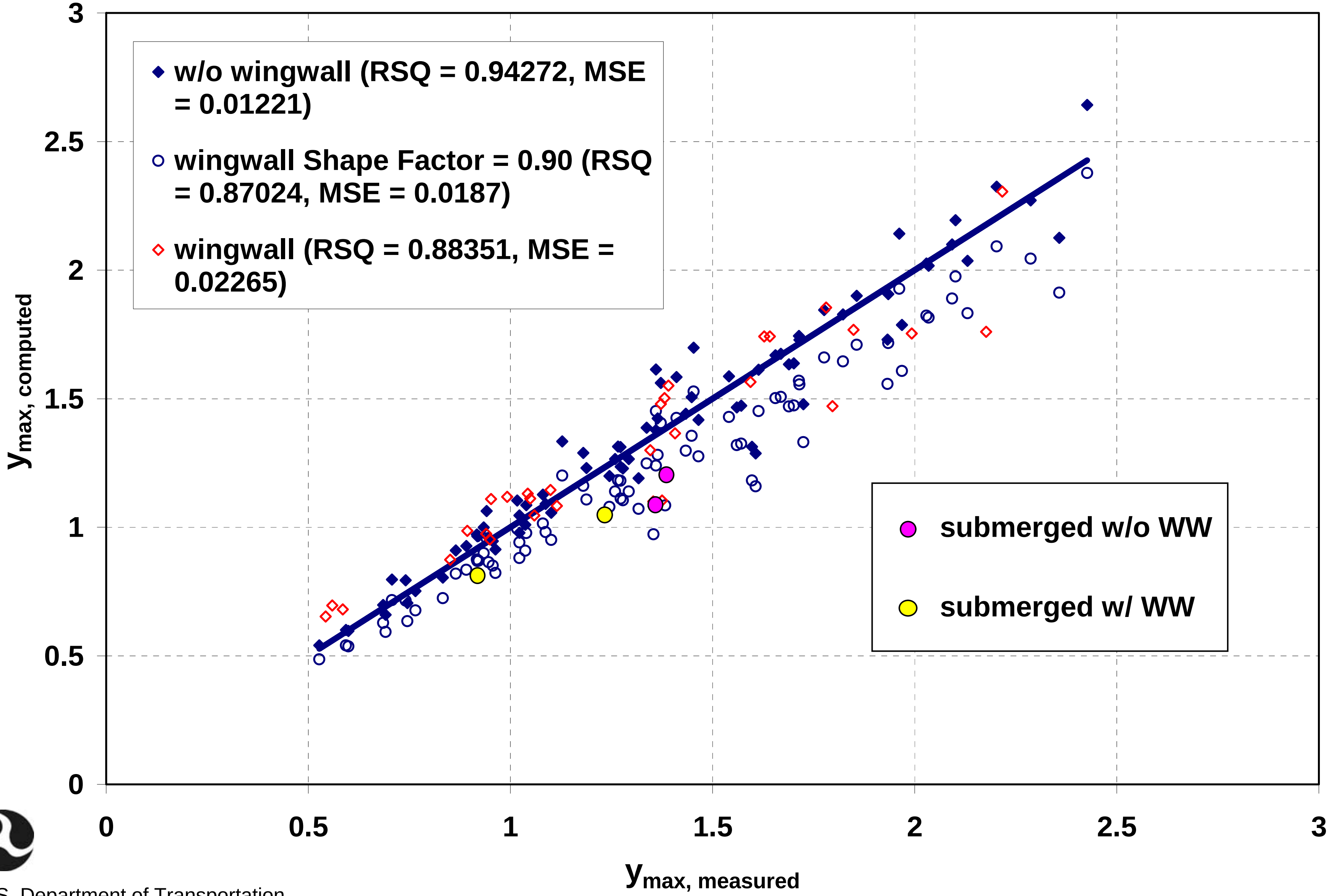
RESULTANT VELOCITY COMPARISON WITH NUMERICAL MODEL



MD DOT (CHANG'S) RESULTANT VELOCITY WITH CHANG'S APPROXIMATION EQUATION FOR V_C



MEASURED VS COMPUTED DATA



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Publication No. FHWA-RD-02-XXX
September 2002

Bottomless Culvert Scour Study:

Phase I Laboratory Report

DRAFT

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Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean Virginia, 22101-2296

SUGGESTED PROCEDURE:

STEP 1: Calculate V_R

$$V_R = K_V \frac{Q}{A_{opening}}$$

$$K_V = 1 + 0.8(W_{opening} / W_{approach})\hat{}\ 1.5$$

Step 2: Determine V_C from Neill's competent velocity curves using Chang's approximations

$$K_V = 1 + 0.8(W_{opening} / W_{approach})\hat{}\ 1.5$$

Step 3: Calculate y_2

$$y_2 = \frac{V_R\ y_0}{V_C}$$

Step 4: compute K_{ADJ}

$$K_{ADJ} = 1.0 + 0.84\left(\frac{Q_{blockedCL}}{\sqrt{g}\, y_2^{5/2}}\right)^{0.09}$$

$Q_{blocked\ CL}$ is approach flow blocked on one side of centerline of channel

Step 5: Compute maximum scour

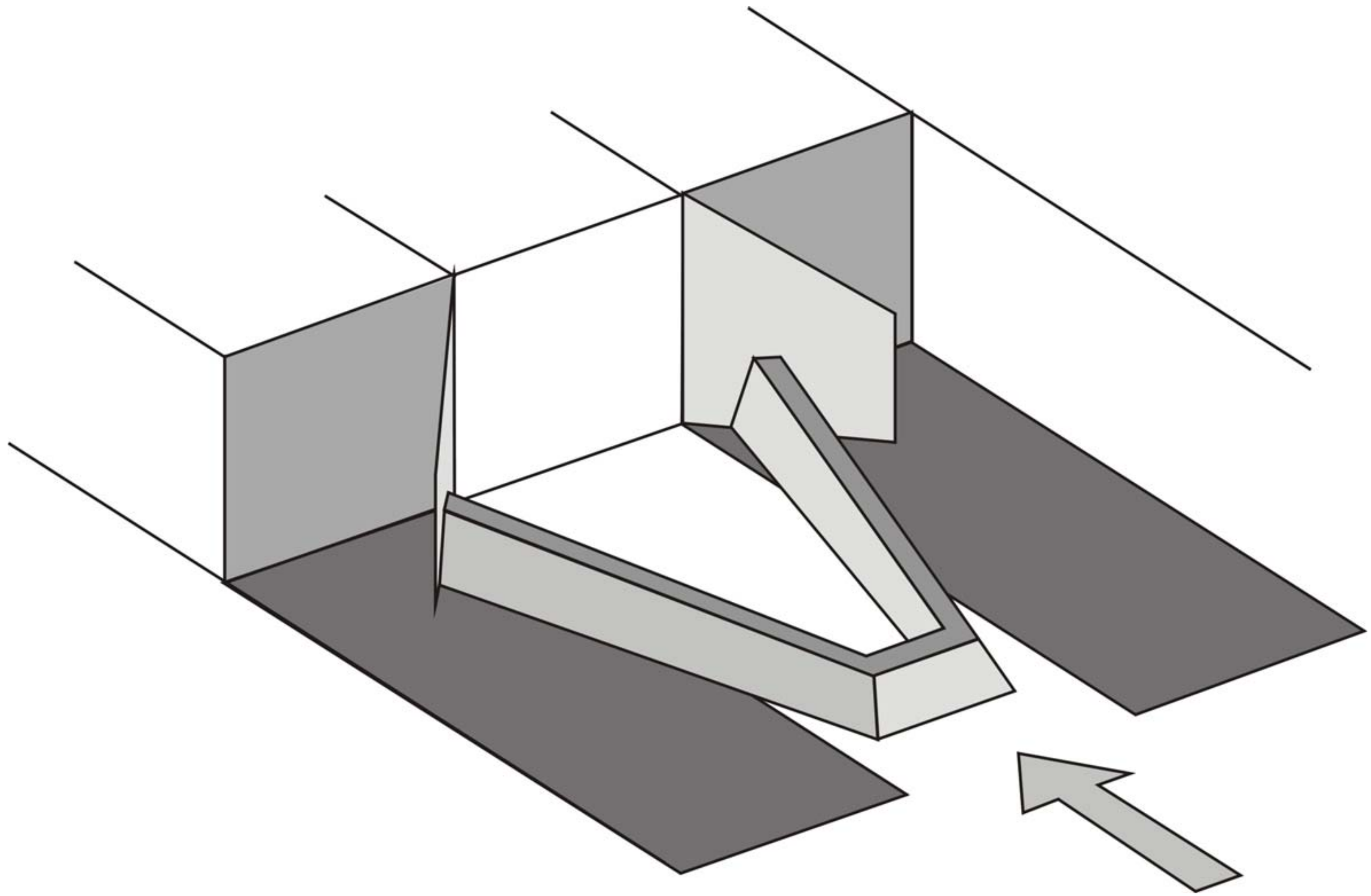
$$y_{max} = K_{ADJ} y_2$$

MD DOT Phase II

- Cross Vanes to reduce Inlet Scour
- Submerged Entrance Validation Tests
- Pre-Scour Flow Distribution
- Extent of Protection for Corners
- Countermeasures for Outlet Scour
- Evaluation of Proposed Std Design

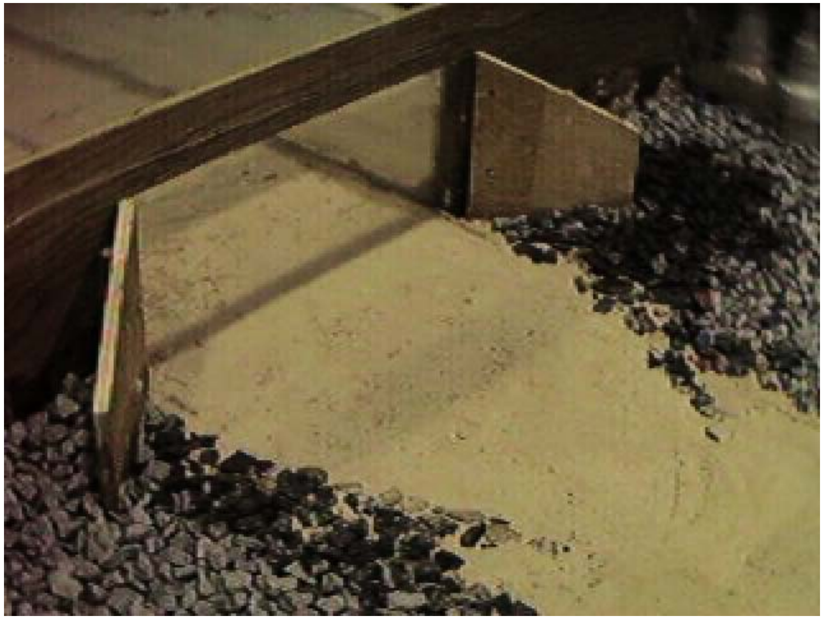
rectangular model with wingwalls

EXPERIMENTAL ARRANGEMENT OF THE CULVERT WITH CROSS VANE

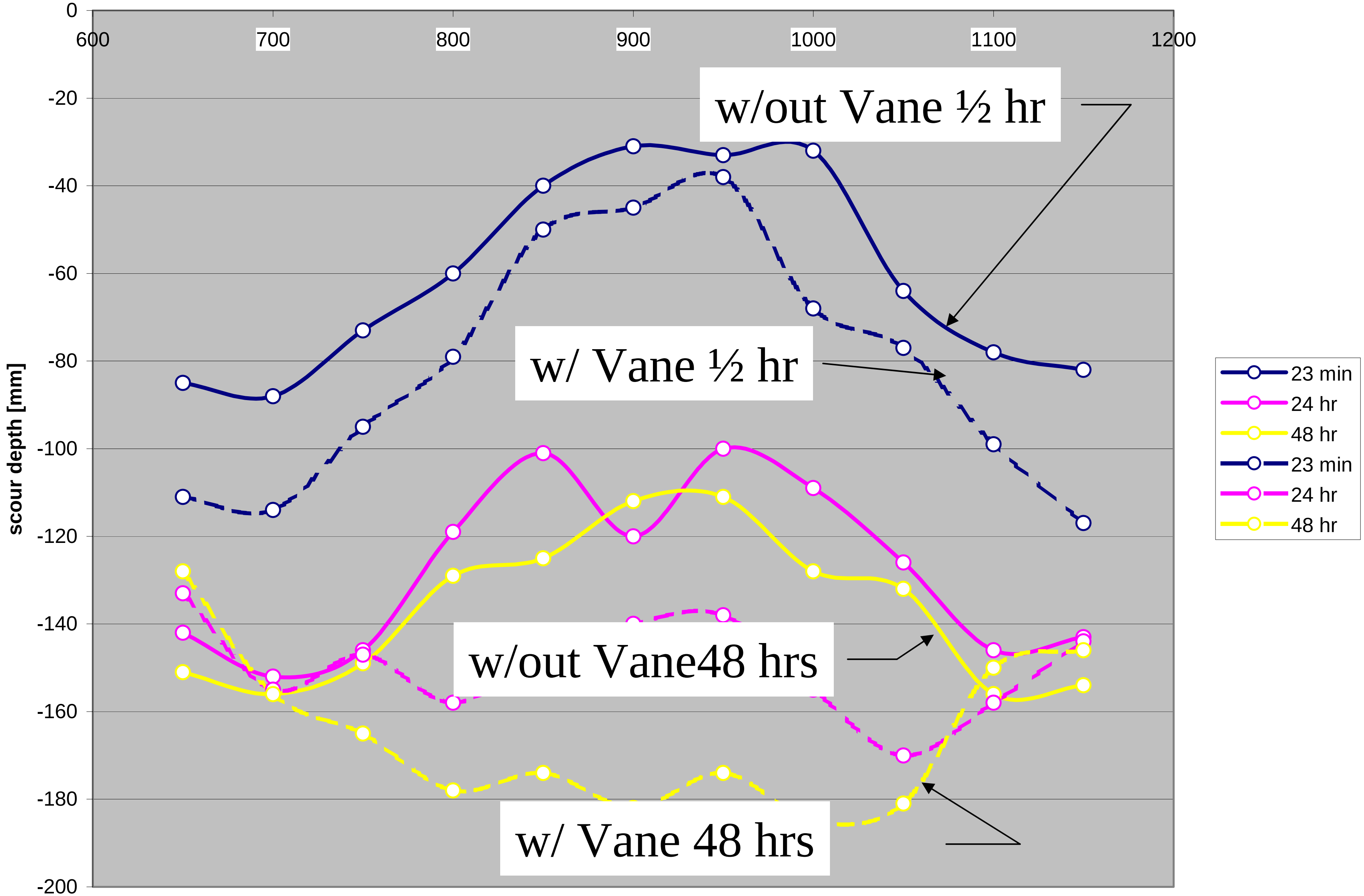


FABRICATION OF THE CROSS VANE

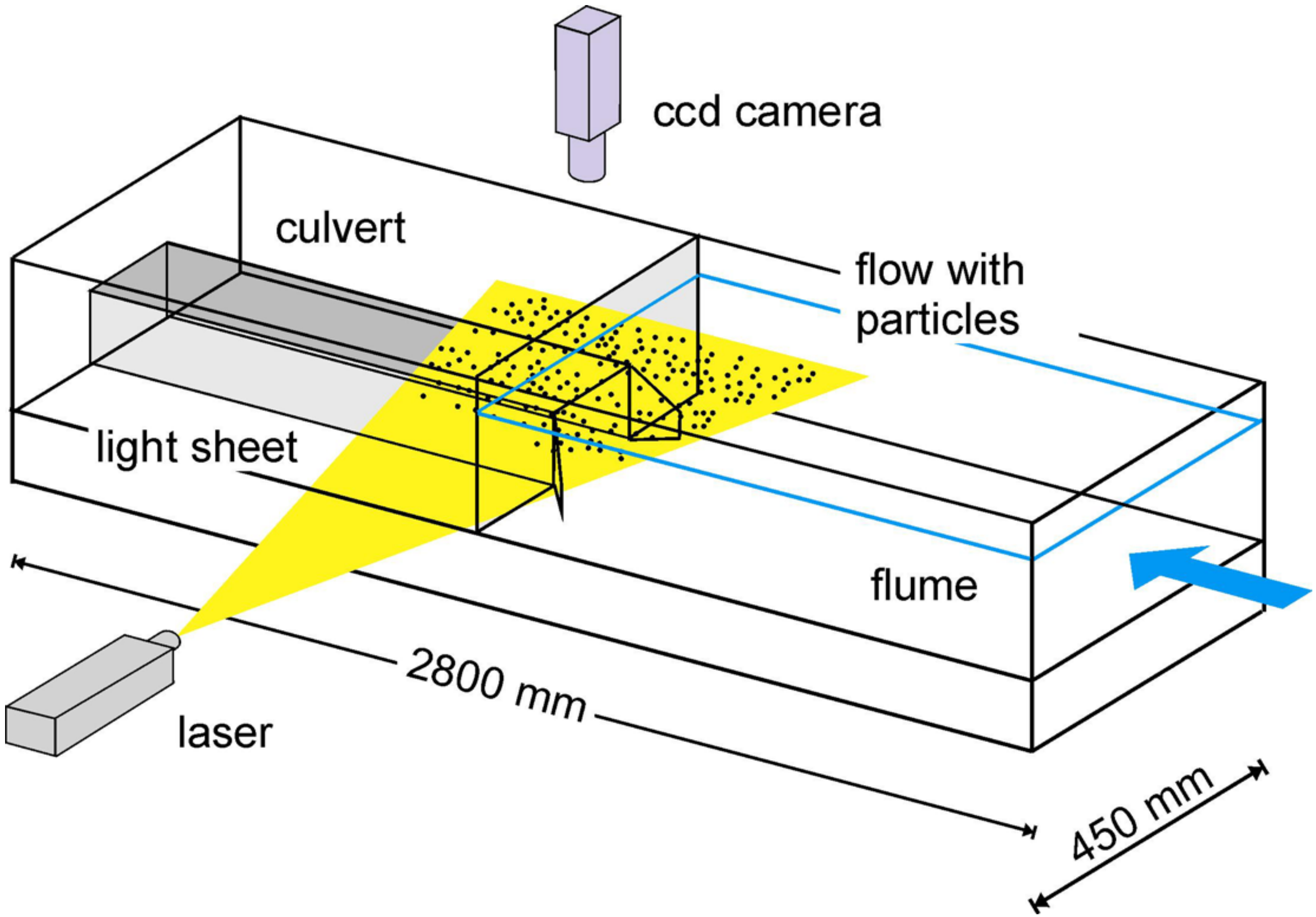
EXPERIMENTAL ARRANGEMENT
THE CULVERT WITH CROSS VANE



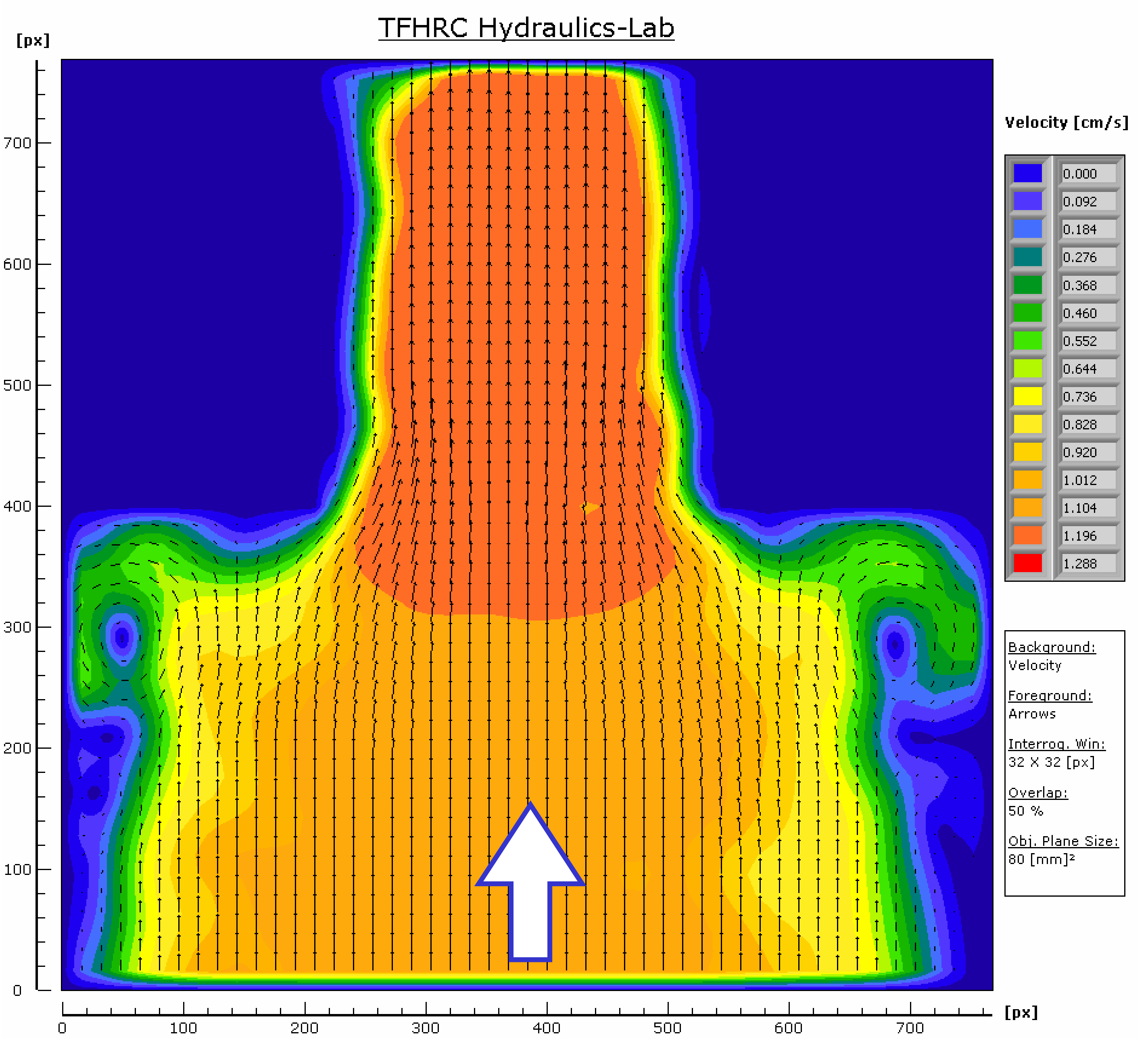
W/ AND W/O CROSS VANE



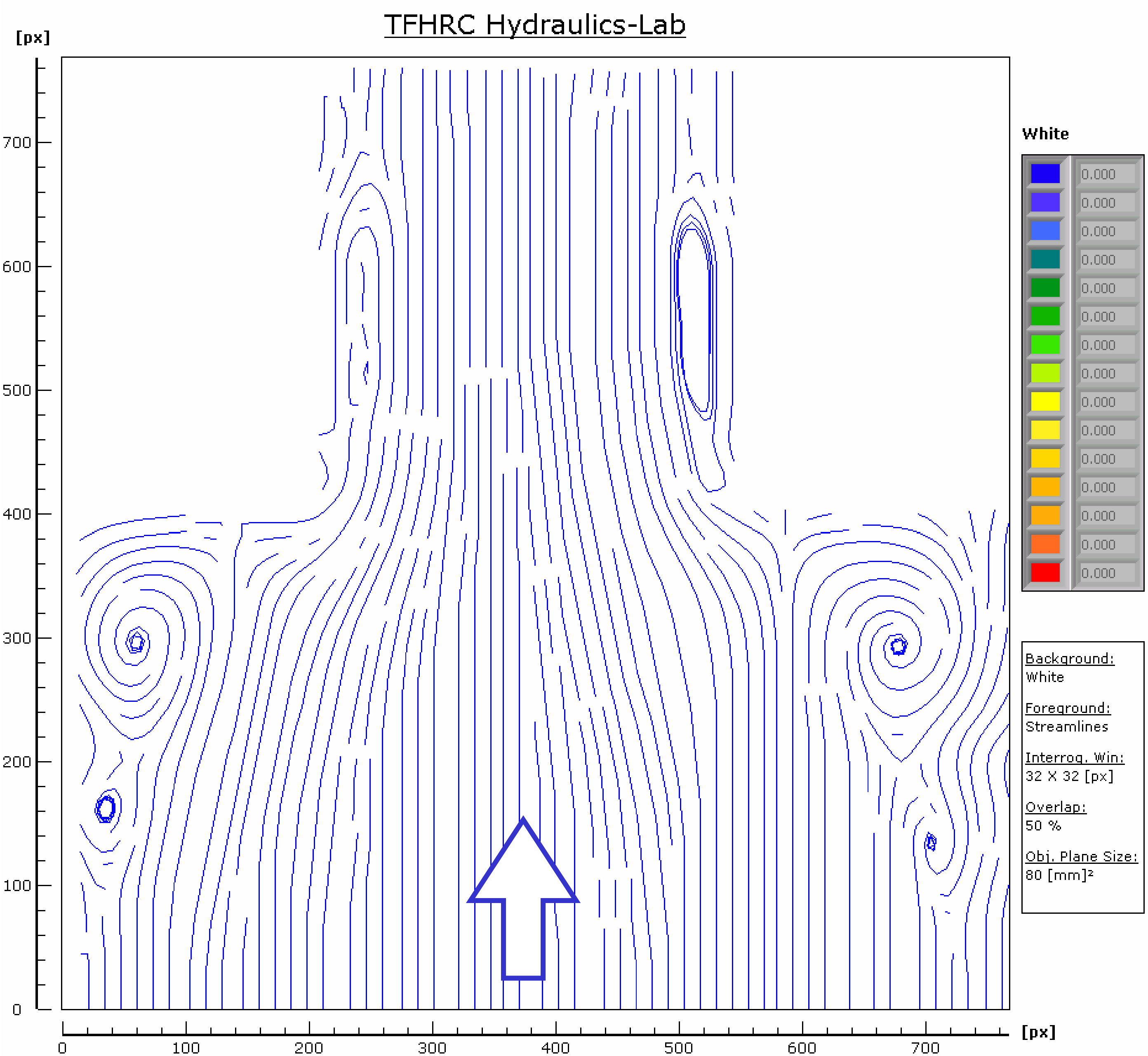
EXPERIMENTAL ARRANGEMENT FOR PIV WITH HORIZONTAL LIGHT SHEET



PIV POST PROCESSING VELOCITY FLOW FIELD



PIV POST PROCESSING STREAMLINES



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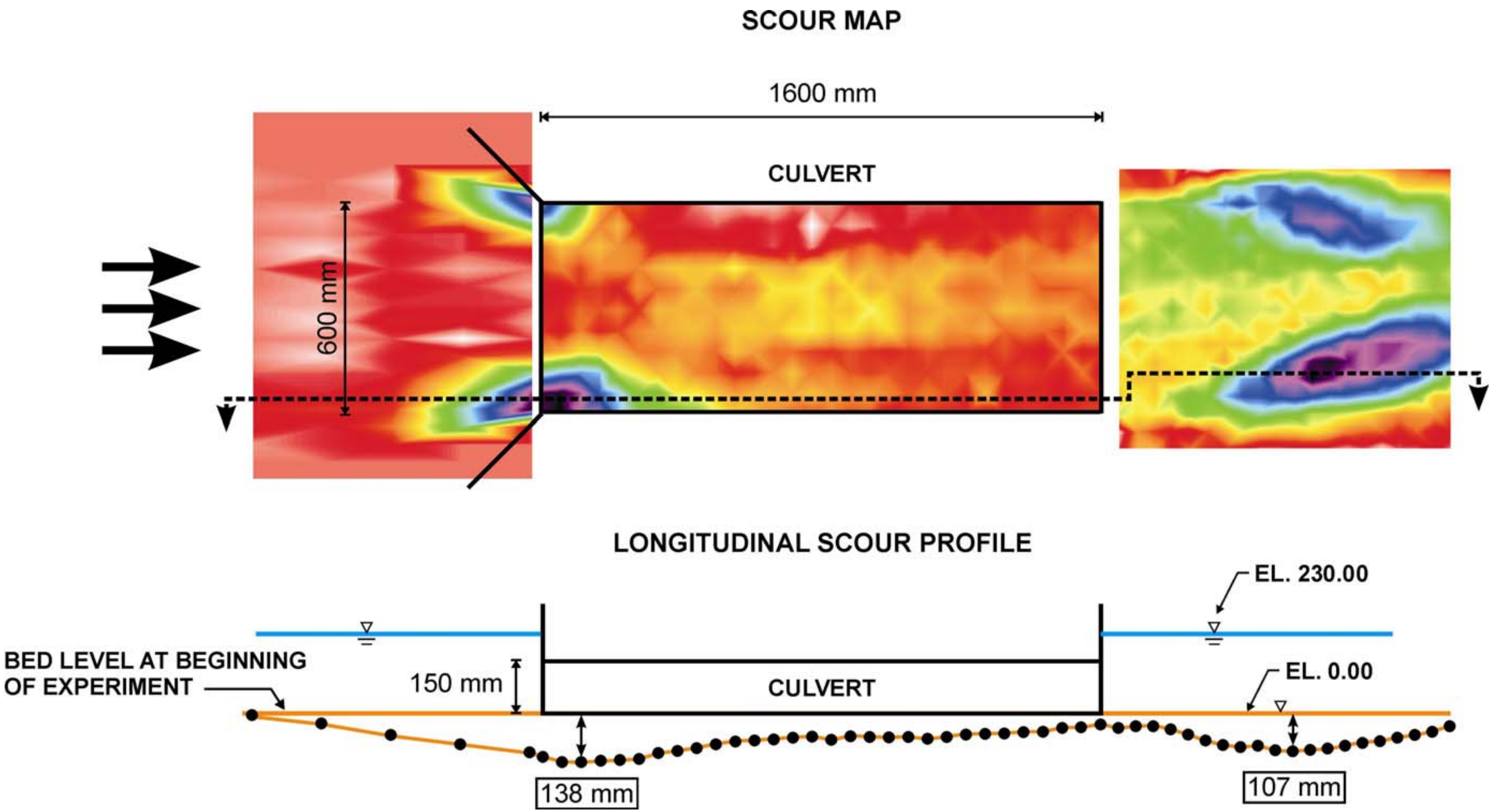
SCOUR MAP FOR SUBMERGED FLOW



OUTLET SCOUR COUNTERMEASURE “STREAMLINED BEVEL

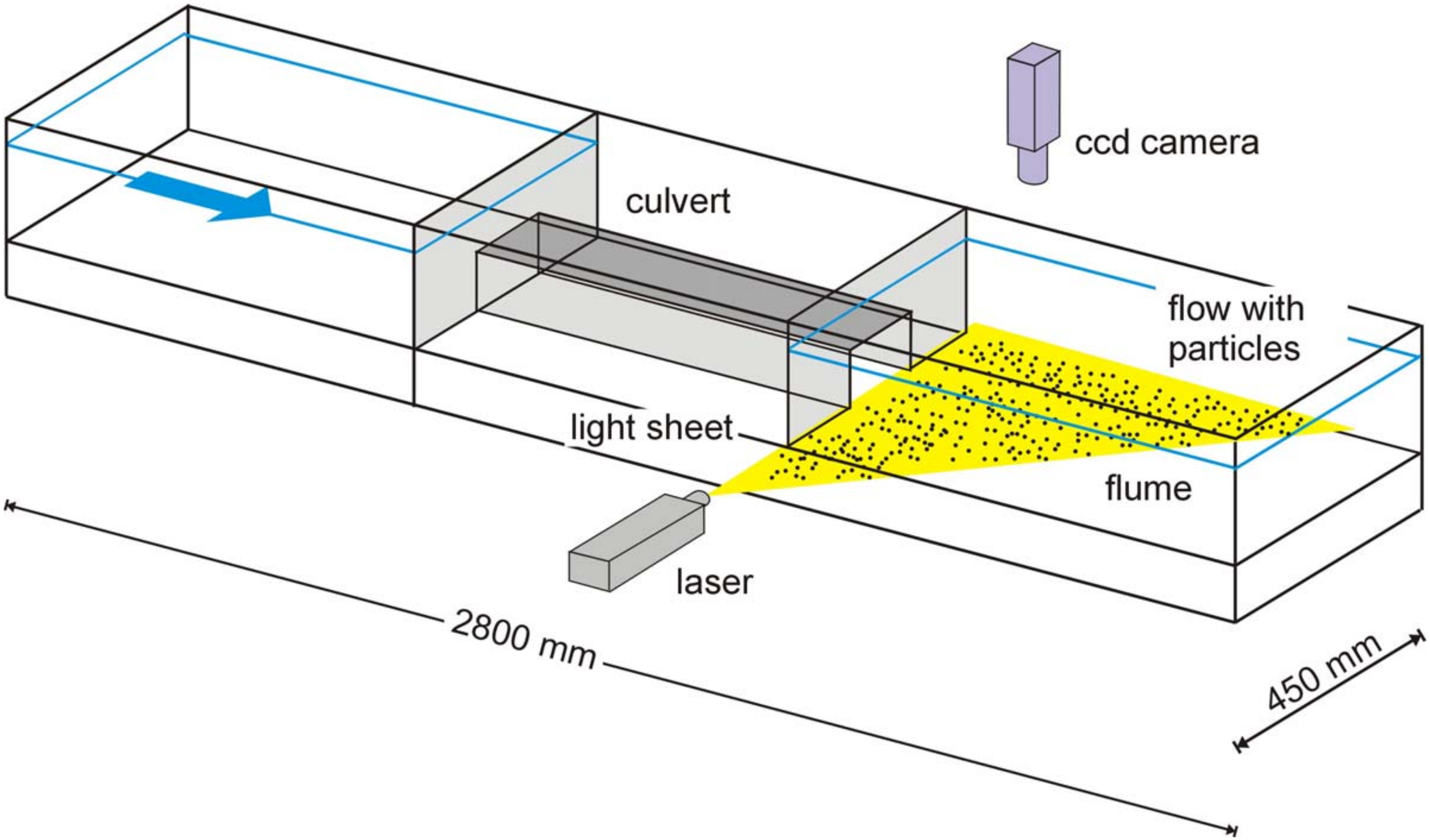
(Theoretically best shape for zero flow separation per ROUSE & HASSAN (1949) ”

OUTLET SCOUR COUNTERMEASURE “SHORT BEVEL”

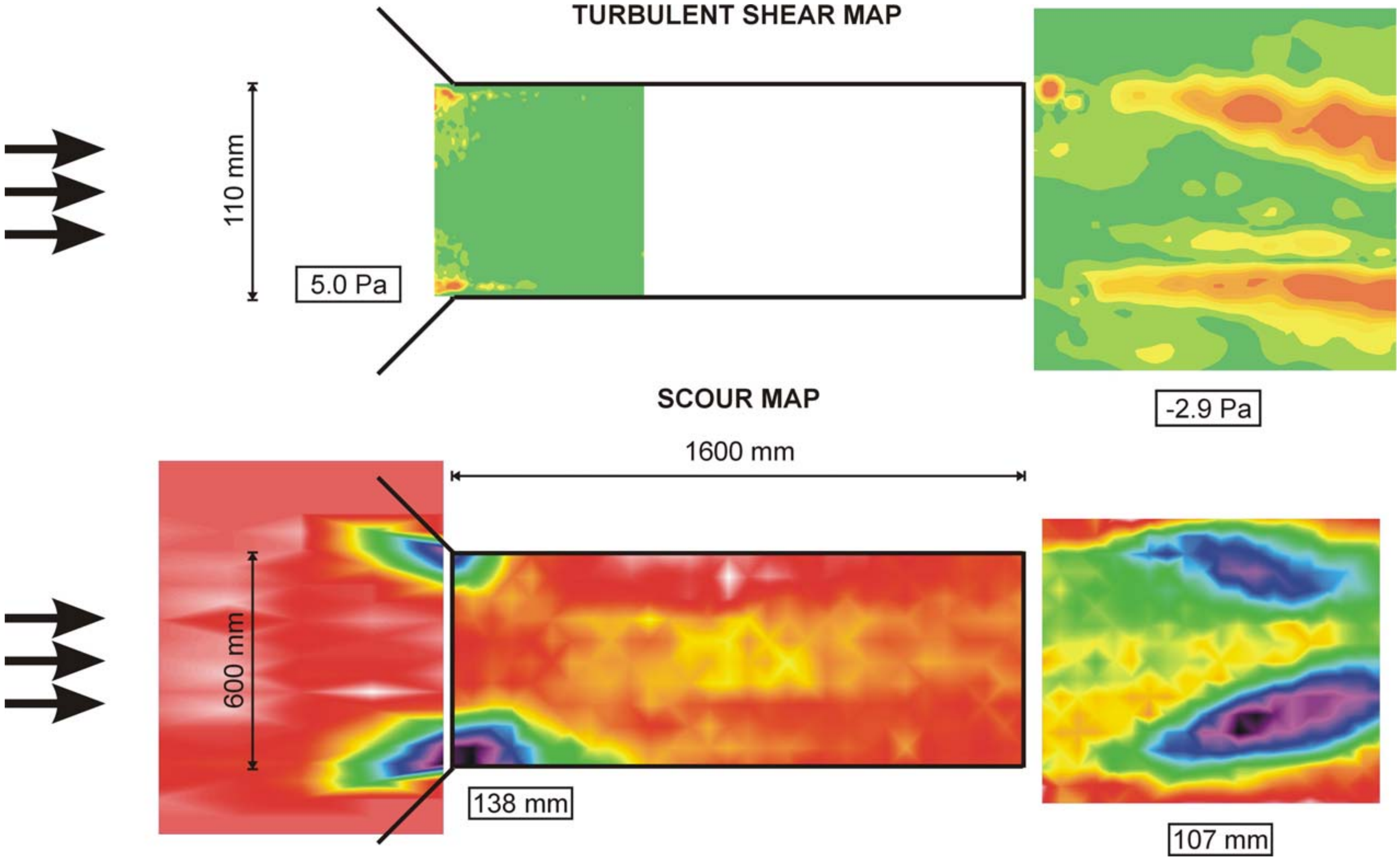
OUTLET SCOUR WITH 45 DEGREE WING WALLS

OUTLET SCOUR WITH 8 DEGREE WING WALLS

EXPERIMENTAL ARRANGEMENT FOR CULVERT TESTS USING PIV WITH HORIZONTAL LIGHT SHEET



COMPARISON TURBULENT SHEAR STRESS AND SCOUR FOR SUBMERGED FLOW



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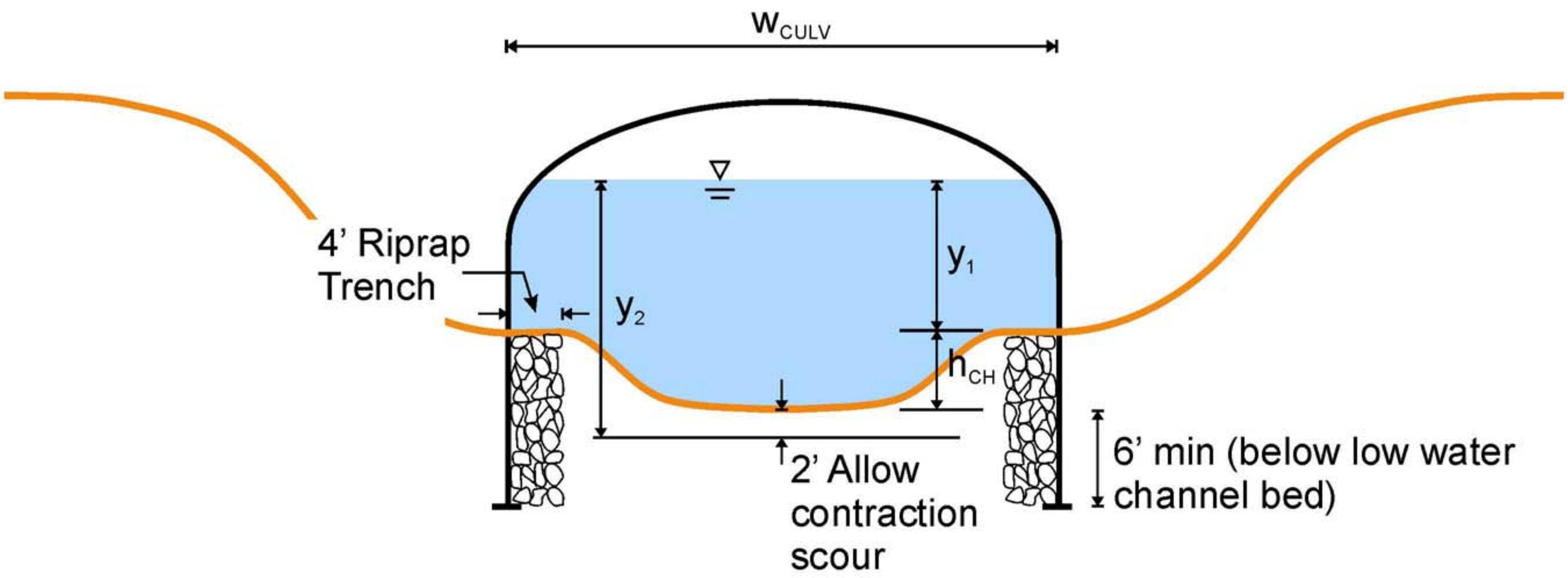
MD SHA PROPOSED STD. DESIGN



CONCLUSIONS

- Scour at the U.S. corners of bottomless culverts is analogous to bridge abutment scour.
- Simple Procedure has been provided on trial basis on request; subject to revision
- Outlet Scour is on order of magnitude of u.s. corner scour but….
- Apparent correlation between turbulent fluctuation shear stress and scour depth (may be modeled numerically)

CONCLUSIONS

- Contraction & Turbulent scour components probably should combine in addition
- Analysis limited to clear water conditions.
- Cross vanes as a countermeasure for inlet scour was not a good application
- MD DOT is working w/ County Engr and Industry to develop a safe but affordable STD DESIGN