2018 National Hydraulic Engineering Conference

Low-Cost Scour-Preventing Fairings for Bridges – Permanent Solution for Foundation Rock Scour

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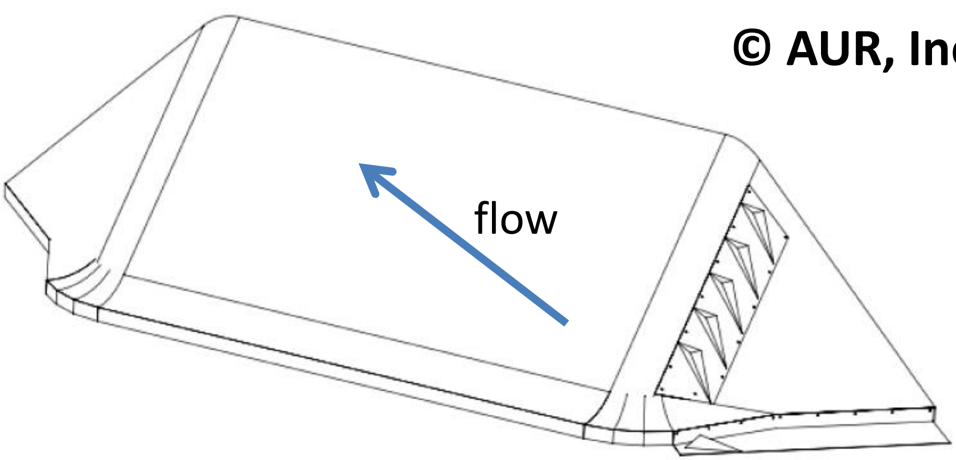

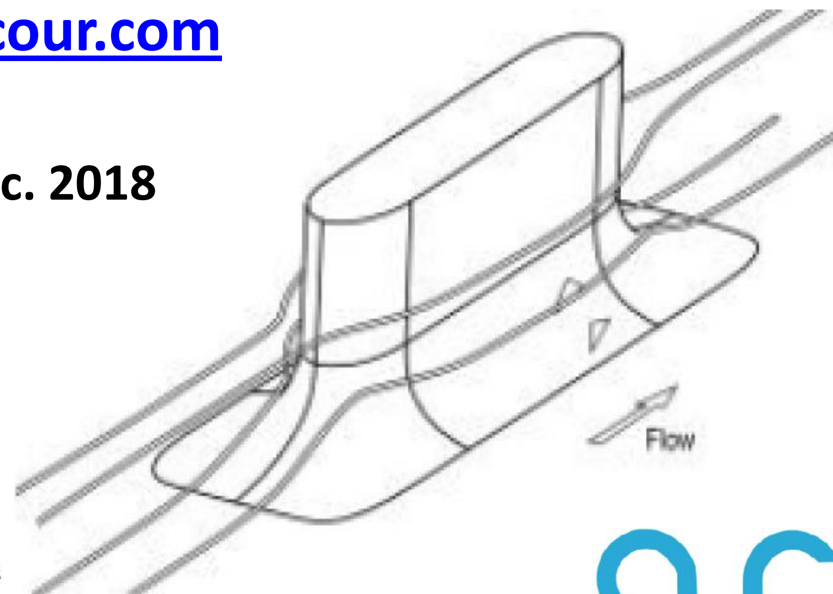

MOTIVATION - Avoid Future Bridge Failures due to Scour

OUTLINE – THE PROBLEM – FOUNDATION ROCK SCOUR

- **A heavily used large long bridge is downstream of a bend in a river and has the most severe scour under the pier seals of any relatively new bridge in this state.**

- **Swirling flow brings the highest velocity surface water down to the river bottom.**

- **The limestone under the base seals of the piers, which do not have pilings, has been partially scoured away, not the concrete seals.**

- **One pier has lost 35% of its load-bearing strength and 65% of its moment-bearing strength. The loss of this bridge would devastate the local rural economy.**

- **One year without this bridge would cost the economy more than the cost of the proposed project.**

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2010, 2013, and 2016 State Bridge Inspection Reports Show Progression of Scour of Limestone under the Seal (Side views)

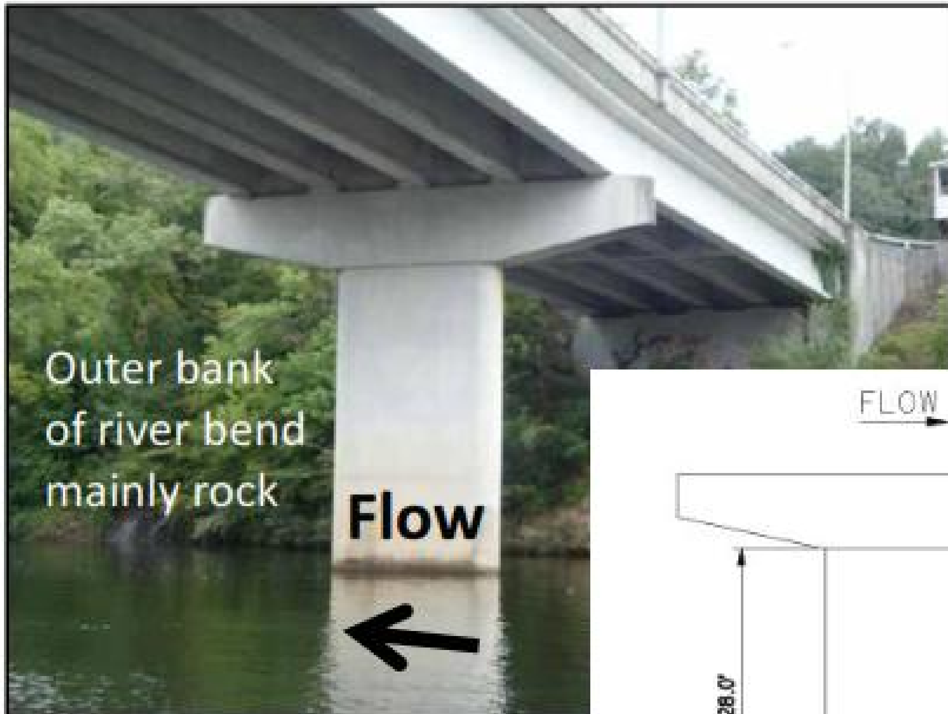
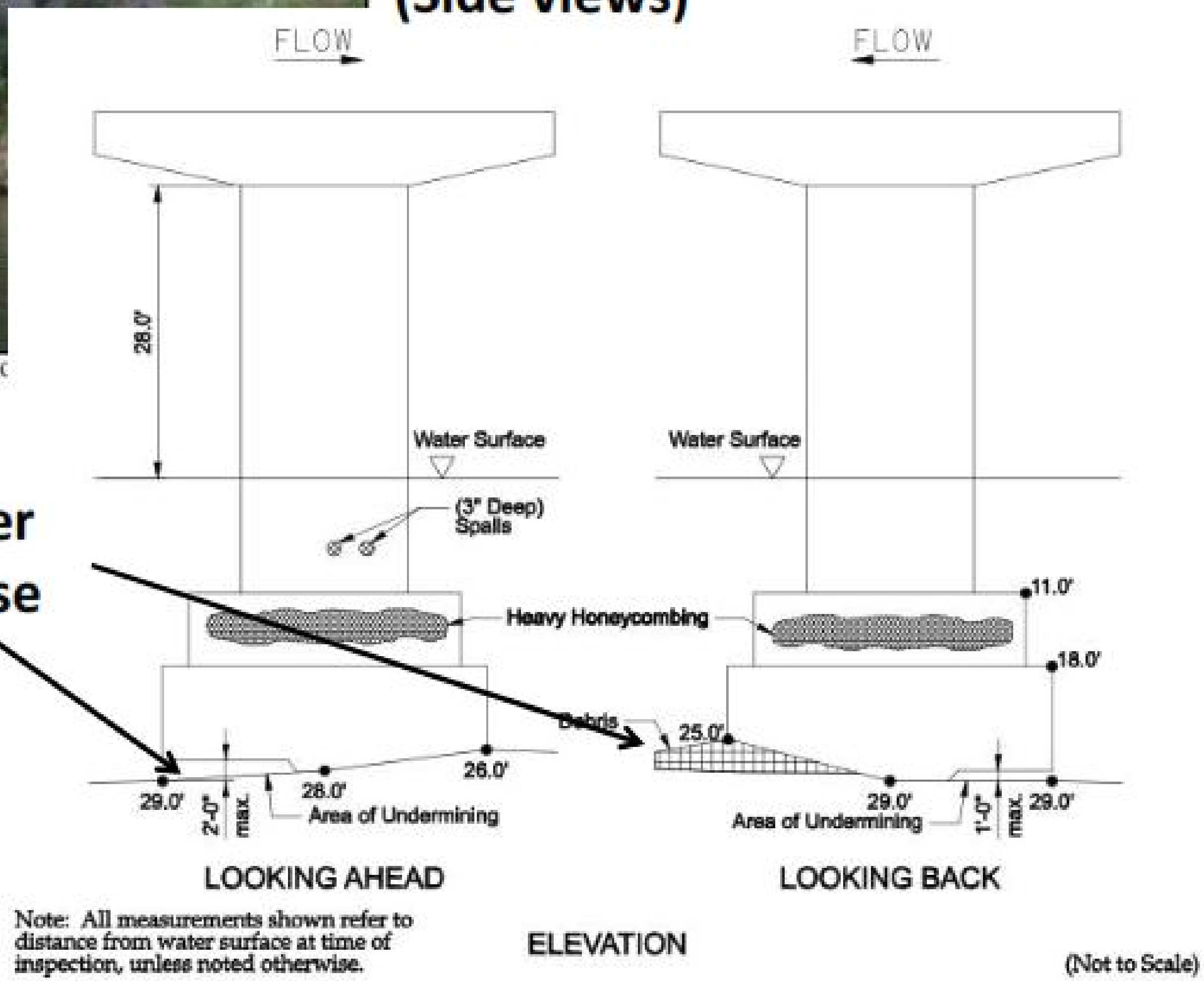


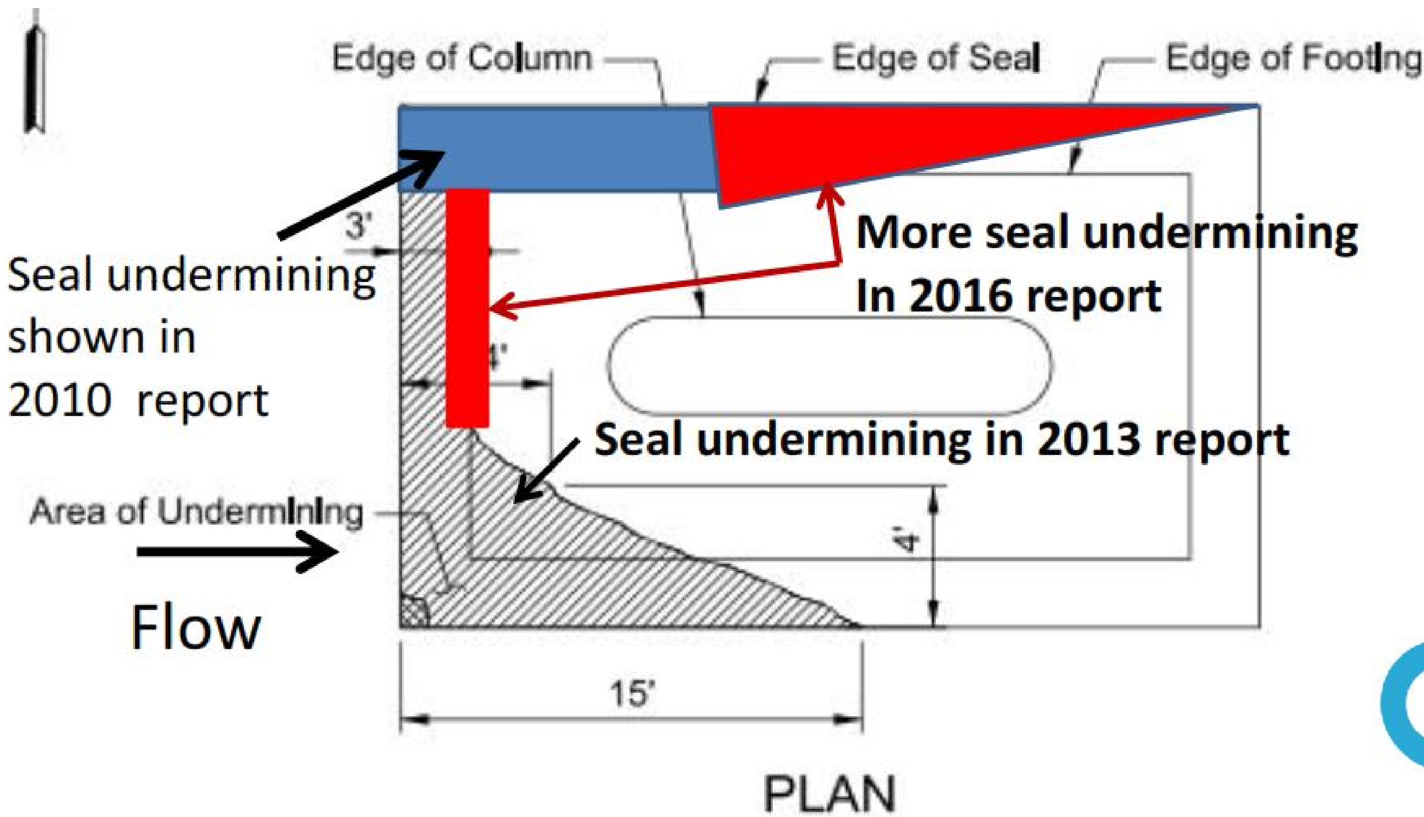
Photo 3: Looking Back Static

Undermined gaps under the seal filled with loose debris



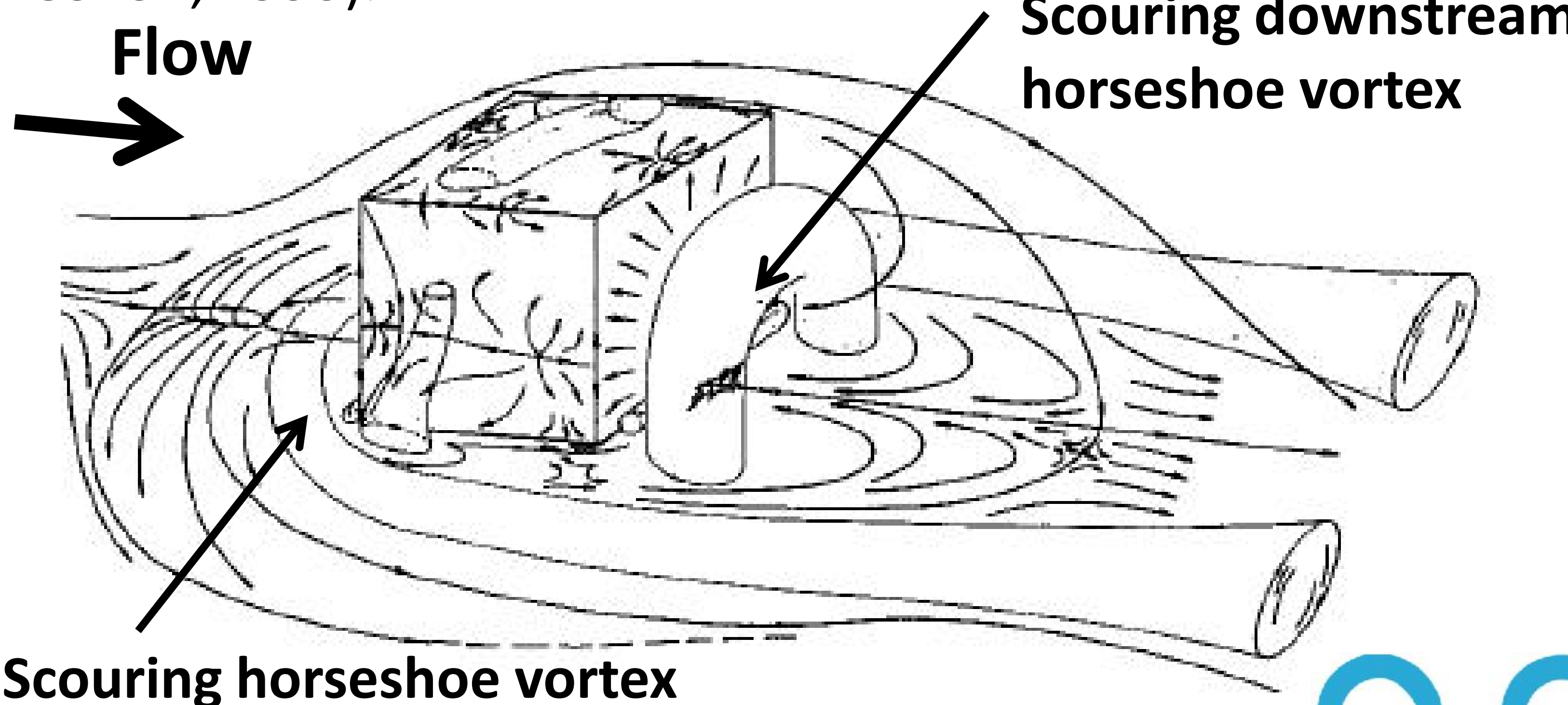
2010, 2013, and 2016 State Bridge Inspection Reports Show Progression of Limestone Scour under the Seal

<u>PLAN VIEW</u> of undermined areas of a concrete seal under the pier over scoured limestone. Pier has lost over 35% of its original weight strength and 65% of the clockwise moment strength against the counter-clockwise moment imposed by the bridge structure and the traffic load. <u>Tests in AUR Flume duplicated the scour. Tests with scAUR™ products prevented the scour.</u>



Flow Behavior Around a Seal

The scour that occurs around the seal foundation is due to the near-surface high velocities produced by horseshoe vortices formed around the model. This flow behavior around a surface-mounted cube has been represented well by Martinuzzi and Tropea (J. Fluids Eng., ASME, Vol. 115, pp 85 -92, 1993).



Some Facts about Scouring Vortices

The more blunt the nose of a pier, abutment, or seal, the greater the downflow and the stronger the vortex and the scouring.

Vortex strength scales on the approach velocity U and the width w of the pier. Vortex strength varies like Uw.

Stretching of vortices due to contraction of the flow intensifies the velocities in the vortex, thus causing more scour.

Simpson, R. L., 2001, "Junction Flows," Annual. Rev. Fluid Mech., Vol. 33, pp. 415–43.

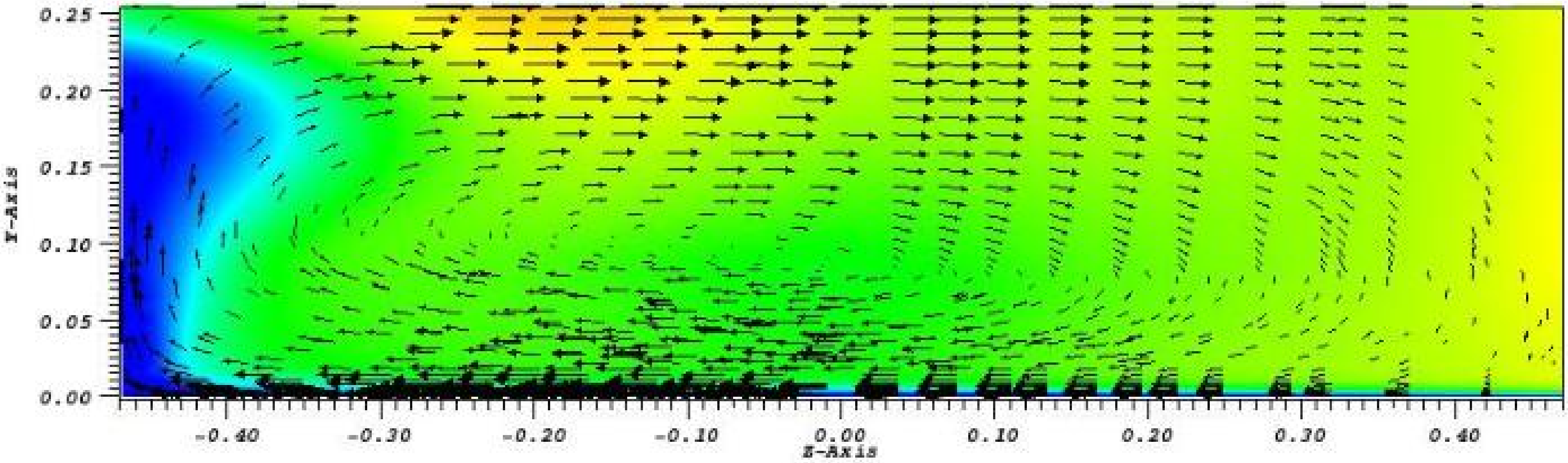
Some Observations and Practical Tips for Assessing the Potential for Scour and Catastrophic Bridge Failure

- Examine existing scour under lower flowrates.
- Blunt piers, abutments, and seals are bad designs and cause more scour than streamlined designs.

> Piers and Abutment downstream of river turns and bends are particularly susceptible to scour. →

High velocity surface water hits outer bank, moves to the bottom of the river and scours hydraulic structures – can modify scAUR™ shape to account for swirl.

Mean flow stream-wise vortices are produced after the curved section. CFD by AUR, Inc.



Introduction and Background of Dr. Simpson

- An internationally recognized fluid dynamics researcher, inventor, and author on vortex producing "juncture flows", such as those that occur in bodies of water around hydraulic structures such as bridge piers and abutments, and surface roughness effects on flow. (Over 300 publications). Past President & Fellow AIAA; Fellow ASME, M. ASCE.
- Currently a consultant and advisor to NASA on reducing adverse aspects of "juncture flows" between airplane wings and a fuselage.
- For over 30 years his US Navy sponsored research at Virginia Tech, where he was the Jack E. Cowling Professor of Aerospace and Ocean Engineering, provided much data for the prevention of acoustic noise producing vortices on submarines.
- Over the last years, he has applied this fluid dynamics background to designing and testing the scouring-vortex preventing streamlined fairings **scAUR™** for bridge piers and abutments.
- Novel tetrahedral vortex generators **VorGAUR™** create counter-rotating vortices that oppose the effects of scouring vortices & prevent debris collection.
- Three US patents have been awarded.
- Model and full-scale tests under the sponsorship of the National Co-operative Highway Research Program **(NCHRP-IDEA Report 162)** have proven these designs.
- Cost-effective stainless steel retrofits for existing bridges and concrete forms for new bridges are available for various bridge and river-bed situations.

OUTLINE – THE SOLUTION TO FOUNDATION ROCK SCOUR

> The permanent solution - prevent the swirling flow from reaching the limestone under the seal. Traditional scour countermeasures do not do this.

> Based on many years of R&D, streamlined fairing designs for piers and underwater structures with vortex generators that counteract the swirling vortex have been developed, tested, and proven by AUR, Inc. under National Co-operative Highway Research Program (NCHRP) sponsorship to permanently prevent pier scour and debris buildup.

> AUR flume model tests showed similar scour results for this bridge base seal to those from underwater inspections. When an appropriate streamlined fairing design was added to the seals, there was no scour.

AUR Flume Tests Case 39: Base seal model in the flume

Setup before tests

No scour protection

The water velocity is 0.6–0.02 m/s at which the open bed pea gravel begin to be carried downstream. The model is located on the bed level. The black gravel A of specific gravity of 3.7 and the size of 1.18mm - 1.4 mm are distributed around the seal model. Note that the pea gravel has its specific gravity of 3 and the size of 3.2mm – 6.4mm.

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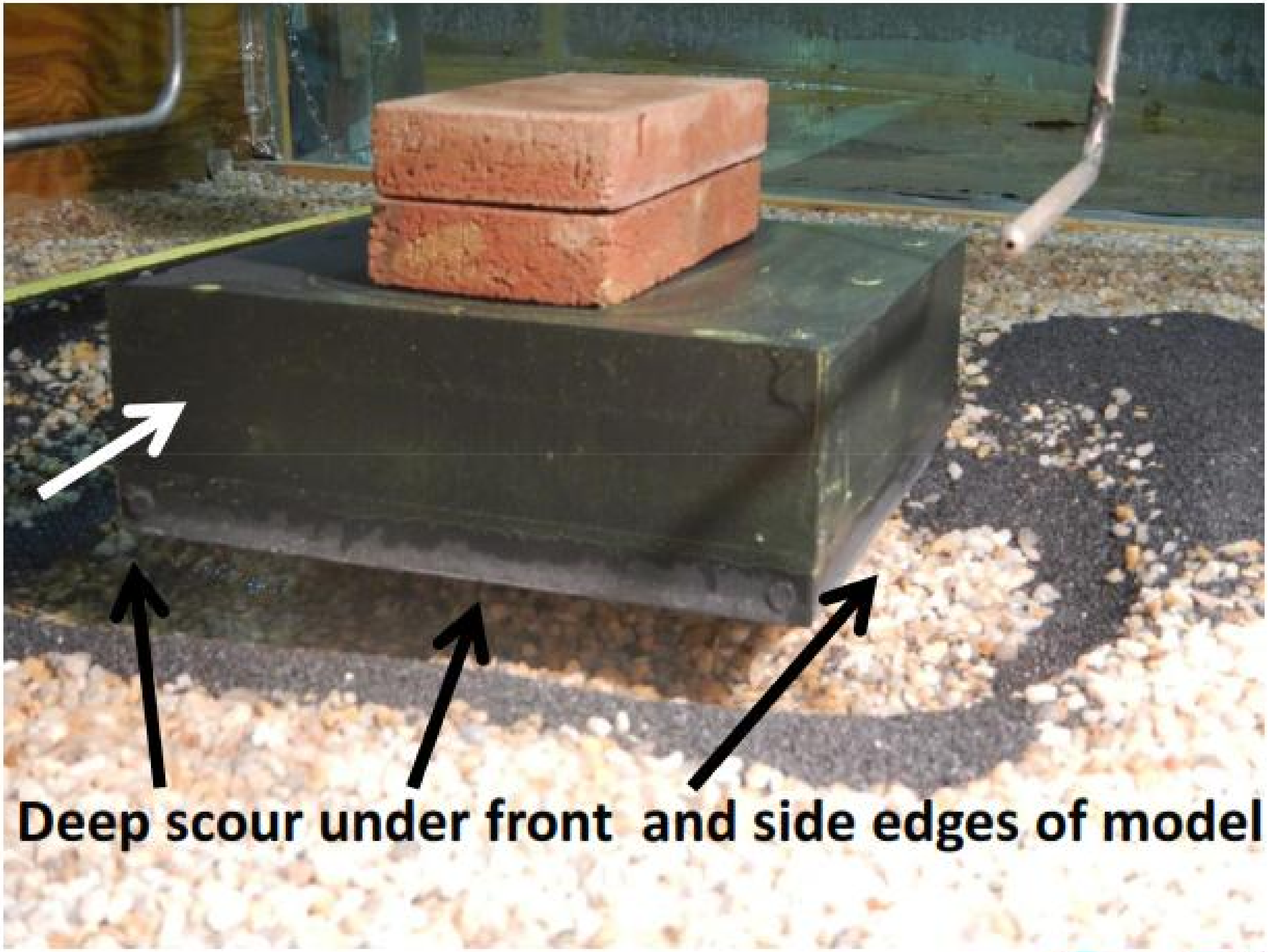
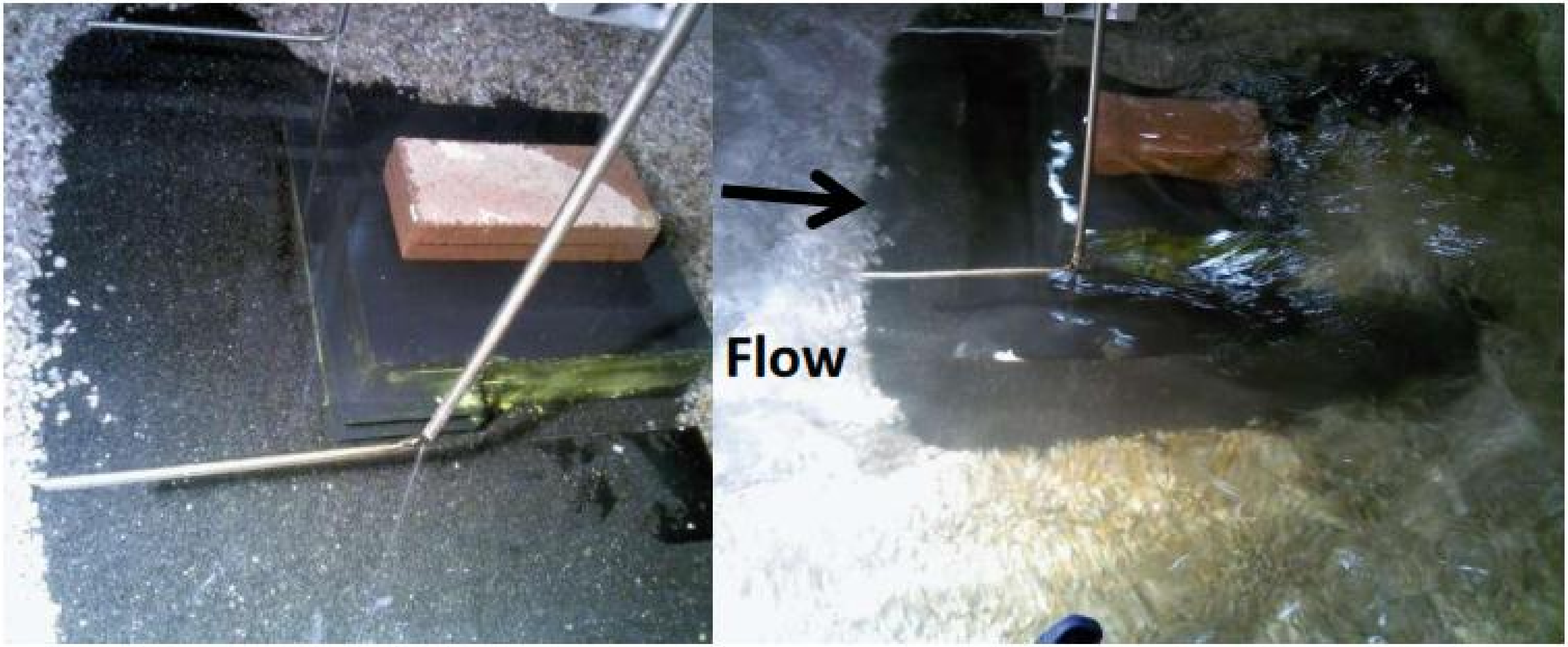
AUR Flume Tests Case 39: Base seal model in the flume

RESULTS AFTER ONE HOUR TEST RUN



AUR Flume Tests Case 43: Seal model with C-shaped extended ramp on the front and both sides



Top view of the scale model of the Bridge Pier Seal <u>with streamlined fairings</u> <u>BEFORE</u> test (left) and DURING test (right).

AUR Flume Tests

Case 43: Seal model with C-shaped extended ramp on the front and both sides

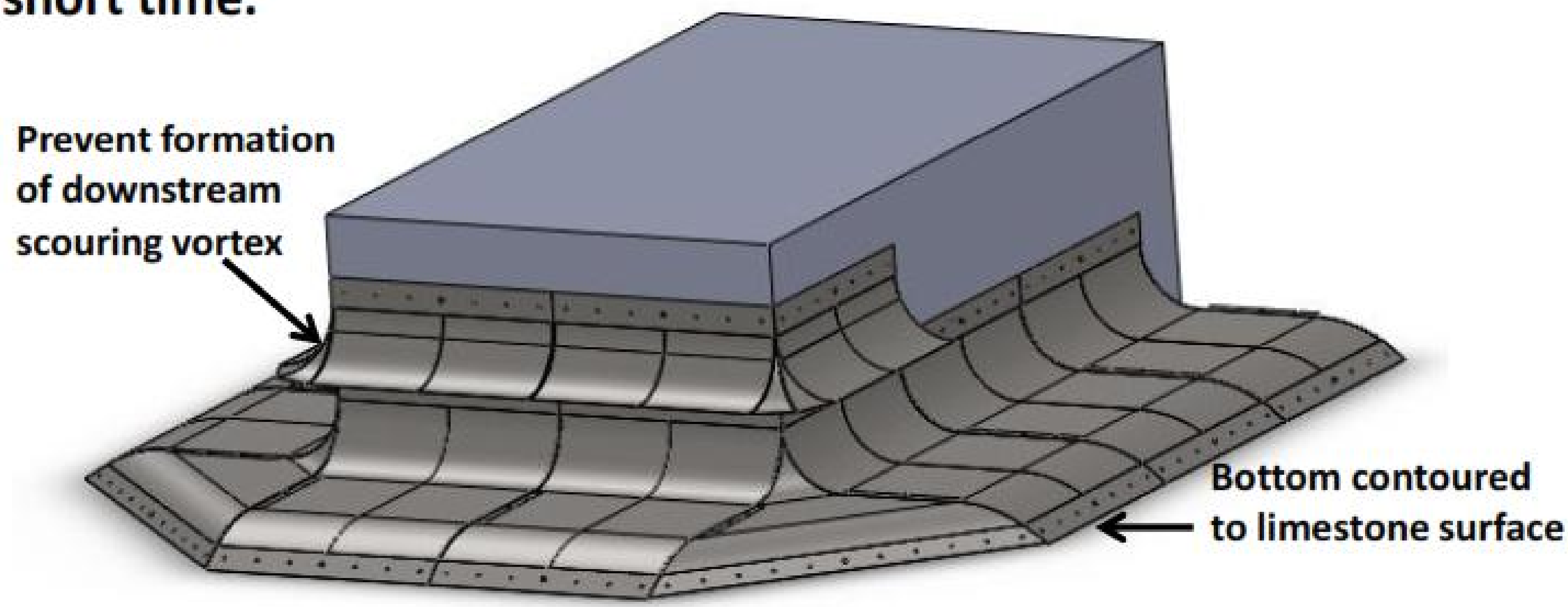
RESULTS AFTER ONE HOUR TEST RUN

Note that the streamlined ramps and fairings have prevented scour near and under the seal and downstream.

SELECTED PROVEN DESIGN: Case 43: Seal model with C-shaped extended ramp on the front and both sides

< Is the ONLY scouring-vortex-preventing design for foundation rock scour prevention.

< Uses cost-effective modular stainless steel units that can be attached to the concrete seal using standard methods over a short time.



This design is protected by United States Patents 8,348,553 and 9,453,319

Conclusions About Preventing Foundation Rock Scour

- **<u>The permanent solution</u> - prevent the swirling flow from reaching the limestone under the seal. <u>Traditional scour countermeasures do not do this.</u>**

- **AUR flume model tests showed similar scour results for the bridge base seal to those obtained from underwater inspections.**

- **<u>An appropriate streamlined fairing design was added to the seal model and tested in the AUR flume with no scour .</u>**

- **This Is the ONLY scour countermeasure design for foundation rock scour prevention.**

- **This project will restore the strength of these piers using accepted methods, and fabricate and install a scouring-flow-altering stainless steel streamlined fairing design that permanently prevent future scour under the seal.**

™

GENERAL CONCLUSIONS

Local scour of bridge piers and abutments is a common cause of highway bridge failures.

All commonly used scour countermeasures are temporary and do not prevent the root cause of local scour – discrete large-scaled vortices formed by separations on underwater structures.

Knowing how to prevent the formation of discrete vortices, AUR developed, proved using model-scale and full-scale tests, and patented new local-scouring-vortex-prevention products that are practical cost-effective long-term permanent solutions to the bridge pier and abutment local scour problem.

Cost-effective manufacturing and installation plans were developed.

The present value cost of these products over the life of a bridge are an order of magnitude cheaper than current scour countermeasures.

Concrete forms for new bridges and stainless steel retrofit versions for existing bridges are now available. Plans for installation of these products on scour-critical bridges are underway.

Numerous Applications of scAUR™ with VorGAUR™

Use (1) surface shapes that prevent the formation of discrete scouring vortices **and (2) tetrahedral vortex generators that cause the higher velocity flow to stay on top of the river and counteract the scouring vortices. (3) Save up to 90% of current scour-countermeasures-related expenses over the life of a bridge. (4) Retrofits for existing cases and forms for new construction.**

1. **Piers of all designs - +/- 45 degrees angle of attack.**
2. **Piers with "dogleg" for greater angles of attack.**
3. **Piers downstream of river bends with swirl.**
4. **Isolated and groups of Pilings.**
5. **Spill-through and Wing-wall abutments with surface vortex control and foundation protection vortex generators – at angles of attack and with swirl.**
6. **All cases above with narrow passages and/or open bed scour.**
7. **NEW - Prevent damage of underwater utility components.**
8. **NEW - Prevention of bedrock scour under piers, seals, and abutments.**

See www.noscour.com

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New 2017 Publication Predicts Even Higher US Bridge Failure Rates due to Scour

Madeleine M. Flint et al. 2017 **Historical Analysis of Hydraulic Bridge Collapses in the Continental United States,** ***ASCE Journal of Infrastructure Systems***, 2017, 23(3): -1--1 © ASCE, ISSN 1076-0342.

Floods, scour, and other hydraulic events are the most common causes of total or partial bridge collapse in the United States.

Predictions of the risk to built infrastructure posed by climate and land-use change have suggested that bridge collapses may increase due to more frequent or intense flooding.

Of the approximately 504,000 bridges over water in the United States, more than 70% were constructed before 1991 and were not required to be explicitly designed for scour.

Bridge collapses frequently coincided with the maximum flow recorded at the gauge site (daily mean flow: 19 of 35; peaks: 21 of 31) and also frequently coincided with tropical cyclones (14 of 35), suggesting that, in many cases, collapses occur during unprecedented or rare events.

BACKUP SLIDES

INTRODUCTION AND SUMMARY

1. Through many years of design and testing, streamlined scAUR™ fairings with vorGAUR™ counter-rotating vortex generators that PREVENT THE VORTICES THAT CAUSE SCOUR ARE AVAILABLE FOR INSTALLATION .
2. Save up to 90% of current scour-countermeasures-related expenses over the life of a bridge.
3. Proven prevention of scour in laboratory and full-scale testing for many configurations for piers and abutments, including flows up to 45 degrees angle of attack, bridges downstream of river bends and swirling flows, narrow passages, flows with open bed scour.
4. US Patents 8348553, 8434723, and 9453319.

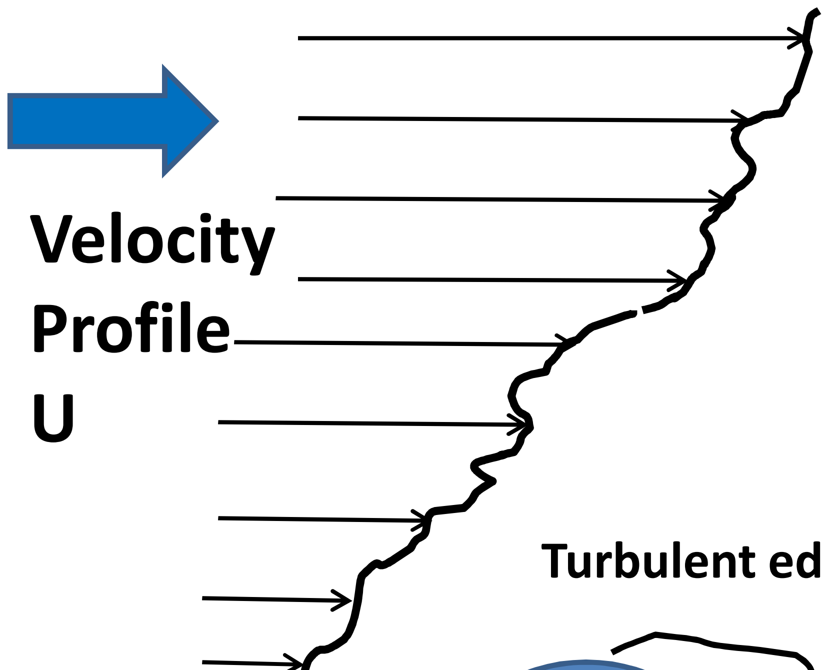
Outline of Topics

This presentation is oriented to provide practical information about how to recognize a potentially catastrophic bridge scour situation. Appropriate use of streamlined scAUR™ fairings with vorGAUR™ counter-rotating vortex generators will prevent scour.

1. Scour is the cause of bridge washouts and the major cause of bridge failures over water. Several examples are given.
2. Fundamental mechanism of scour on a river bed. Need to keep low velocity water on the bottom of the river.
3. What causes scour? Vortices that bring higher velocity water to the river bed and erode rocks, gravel, dirt, and sand.
4. Which bridge pier and abutment features cause vortices that cause scour? Surfaces that cause vortices and higher velocity water to move down to the bottom of the river.
5. What can be done to prevent vortices that cause scour? Use surfaces that prevent the formation of scouring vortices and vortex generators that cause the higher velocity flow to stay on top of the river.
6. Examples: piers, abutments, dogleg piers, piers in narrow passages, piers and abutments downstream of river turns, foundation protection for super floods.
7. Cost considerations.

Fundamental Mechanism of Scour on River Bed

Turbulent flow over river bed



Velocity Profile U

Shields Number

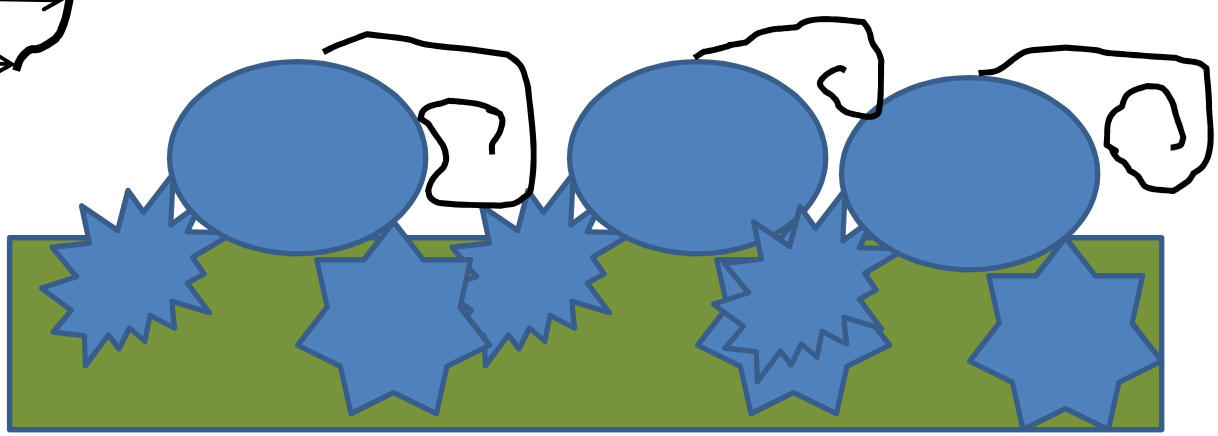
$$\theta = \frac{\tau}{(\rho_p - \rho) g d}.$$

Θ = ratio of effective shear force to apparent weight

τ = turbulent shear stress

<u>τ varies with U^2 & roughness</u>

Turbulent eddies created over bed materials



River bed of sand, dirt, gravel, and rocks

Shields Number versus Reynolds Number for incipient particle motion

Particles move when Θ > 0.03 to 0.2
Particles remain close to bed for Θ< 0.4
Particles become suspended for Θ > 0.4

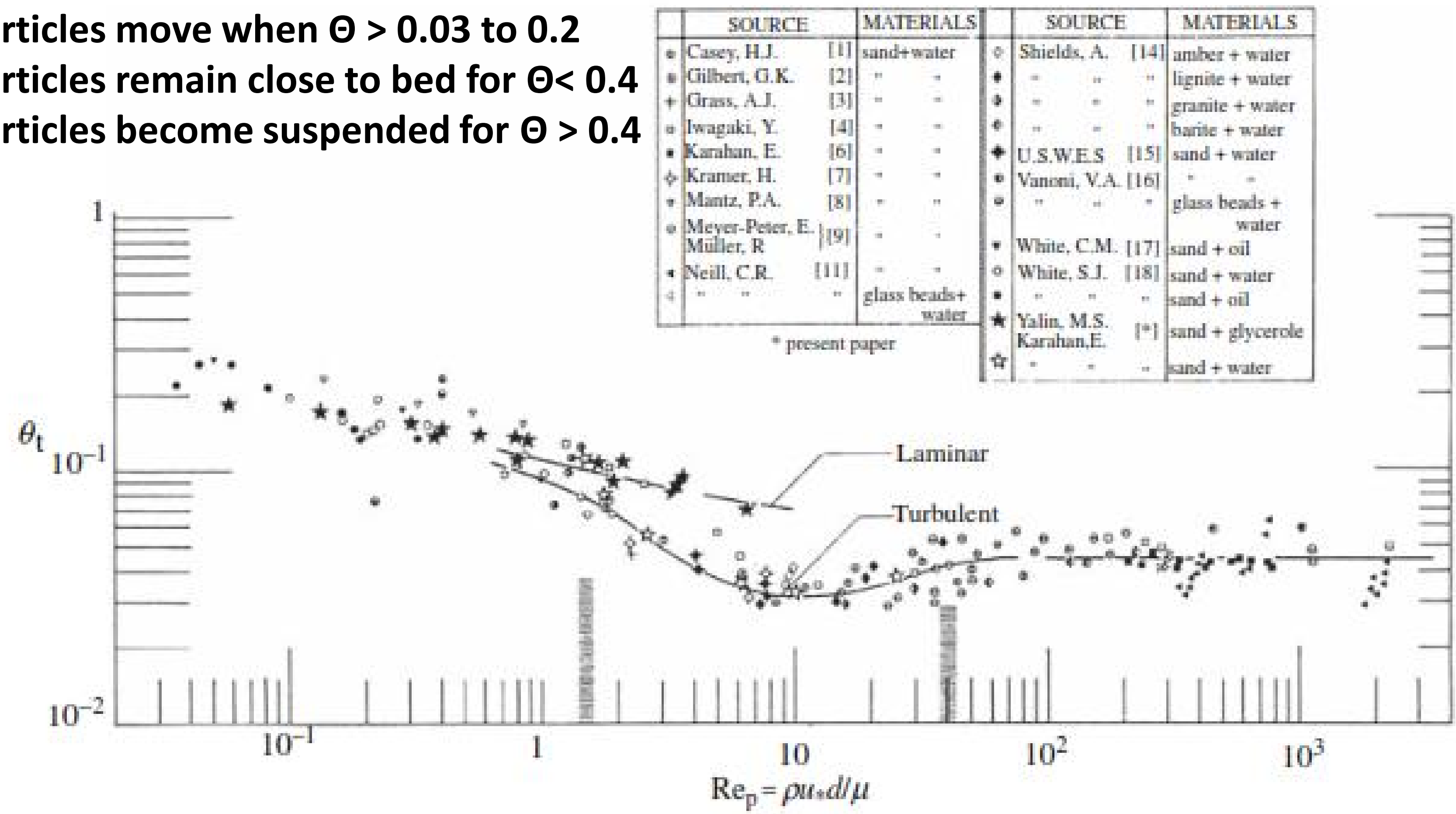


Figure 7.5 Shields diagram for incipient particle motion (Yalin, 1985).

Charru, F, 2011, Hydrodynamic Instabilities, Cambridge Univ. Press. Chapter 7. Section 3 Sediment Transport by a Flow.
Vanoni, V. A., editor, 1975, Sedimentation Engineering, ASCE Manuals and Reports on Engineering Practice – No. 54.

Current Scour Prediction Methodologies

Use one-dimensional continuity, momentum and energy equations to determine how an average river cross-sectional velocity varies over a varying cross-section river. Traditional hydraulics methods. Use mean flow values.

In some cases, two-dimensional calculations are used.

Some approximate estimates of the frictional resistance in the river is made for the type of river bottom observed.

Use the resulting local average velocity in correlations.

The approach in HEC 18 and HEC 29 is to correlate laboratory data for scour depth around circular cylinders and other shapes to obtain correction factors.

Predictions by this approach give scour depths that are larger than observed by as much as 50%.

Predicting Scour by Computational Fluid Dynamics (CFD)
More Physics based

Needed Input Information:

> Three-dimensional shape of the river bed with the surface roughness dimensions described.

> Three-dimensional inflow to the river at least 10 river widths upstream.

Use a proven three-dimensional Navier-Stokes code

- **Turbulence model (V2F, for example, used by AUR, Inc.).**
- **Surface roughness model on how roughness affects the turbulent flow.**
- **Few cases have been computed.**
- **Expensive to gather all of the needed information and run code.**
- **One still needs to implement a lasting remedy!!**

What Can Be Done to Prevent Scouring Vortices??

Which bridge pier and abutment features cause vortices that cause scour? Surfaces that cause discrete vortices that cause higher velocity water to move down to the bottom of the river.

What can be done to prevent vortices that cause scour? Use (1) surface shapes that prevent the formation of discrete scouring vortices and (2) tetrahedral vortex generators that cause the higher velocity flow to stay on top of the river and counteract the scouring vortices.

™

Some Observations and Practical Tips for Assessing the Potential for Scour and Catastrophic Bridge Failure

Scour should be estimated using the peak velocities observed for the river.

USGS data – include higher flowrate outlier points – they suggest catastrophe cases.

Do not use AVERAGE velocities, one-dimensional flow analyses, correlations for channel flow that do not account for roughness, and the contraction and expansion geometry. Supported by Flint et al., 2017.

Catastrophic scour can occur rapidly over a few hours. Schoharie disaster occurred a few weeks after inspection. Supported by Flint et al. 2017

Scour protection: Prevent high velocity water from coming into contact with erodeable river bed materials. Commonly used countermeasures include large rocks (rip-rap) and other devices that are positioned in the river bed around the pier or abutment that shield the smaller scale more easily eroded gravel and sand. These approaches are subject to undermining of their own foundation, loosening of their support, and washing away themselves.

scAUR™ with VorGAUR™ vortex generators approach: Lower the velocities of the water around the piers and abutments with a continuous fully-attached fairing structure with properly placed vortex generators. This permits the bridge owner to avoid all future scour worries at a much reduced cost. **Works at all flowrates**.

Permanent Solution: scAUR™ and VorGAUR™ Products

Based on aero/hydrodynamic design concepts, scAUR™ and VorGAUR™ products prevent the discrete vortices that cause scour. Extensive computer modeling and model and full-scale testing have proven these products.

Example AUR flume test of pier with scAUR™ and VorGAUR™ - NO SCOUR! Note scour on cylinder.

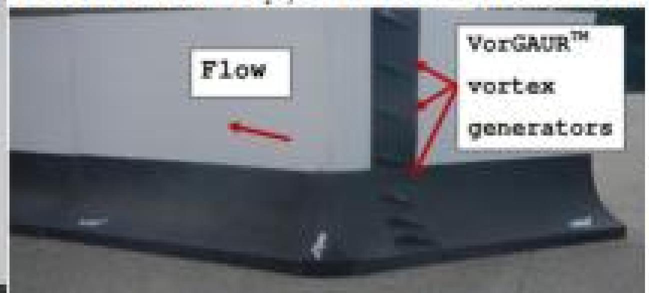
Other Features of scAUR™ and VorGAUR™

1. Much lower present value of present and future scour mitigation costs as compared to other approaches.
2. Lower drag force, flow blockage, water level, and over-topping frequencies on bridges during flood conditions, any water level or inflow turbulence level.
3. Debris accumulation prevention and pier and abutment protection from impact loads because of the streamlined flow without a horseshoe vortex, which deflects objects and debris away from the underwater structure.
4. High quality proven-technology prefabricated stainless steel or cast concrete components for quality control and rapid installation.
5. More stability for the soil and rocks surrounding the piers and abutments.
6. 100 year or more lifetimes and longer bridge life.

Permanent Solution: scAUR™ and VorGAUR™ Products

Modular Stainless Steel (SS) Retrofits for Existing Bridges

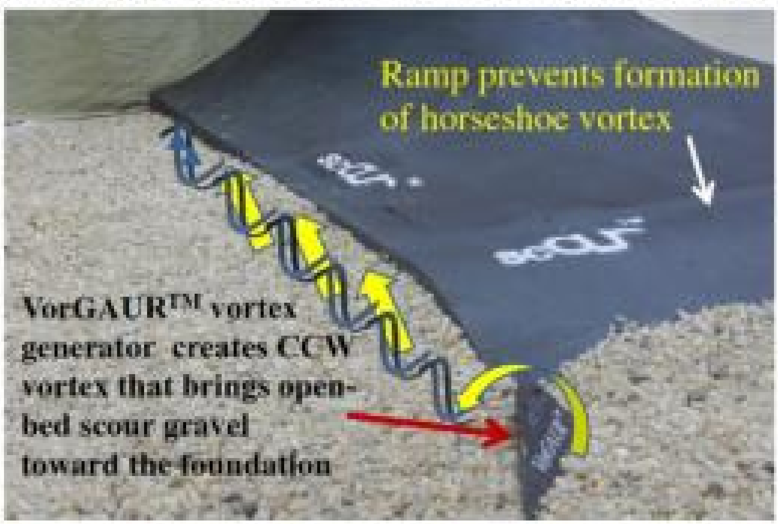
Greatly extends bridge life! Modules quick and easy to install.



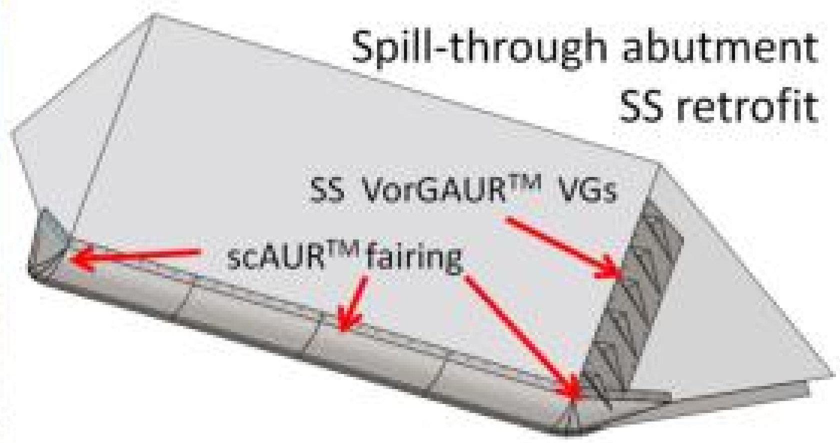
Example stainless steel scAUR™ retrofit (black) for a 45° wing-wall abutment. Note SS vortex generators.

Example stainless steel scAUR™ retrofit (black) for a pier.
VorGAUR™ vortex generators create CW vortices that bring low-speed flow up to prevent scour.

Ramp and VorGAUR™ vortex generator bring open-bed scour material toward a pier



Pre-fabricated interlocking modules permit quick and exact assembly and preserve the scAUR™ shape



Recurring Costs for Currently Used Temporary Pier and Abutment Scour Countermeasures

The following average estimated costs are based on published information:

- The average cost for real-time scour monitoring is $14400/bridge for equipment and installation and $6000/bridge for annual operation;
- The average initial scour evaluation cost is about $4050/bridge FOR EACH occurrence;
- The design service cost for scour countermeasures is about $120,000~$160,000/bridge FOR EACH occurrence;
- The average cost of mitigation construction measures is about $33,000/bridge pier or abutment FOR EACH occurrence;
- The average running cost and time cost for motorist and traffic detour is more than $750,000 per bridge FOR EACH occurrence and mitigation.

Need To Account for Future Costs for Scour Protection

Reid, R.L., 2017, **Assessing Infrastructure's True Costs**, ***Civil Engineering***, March 2017, pp.56 – 59; 83; www.asce.org/cemagazine.

SUMMARY: Many road and bridge design decisions are based on current construction costs only - ignoring long-term costs associated with maintenance, operation, and retiring a project. This ALWAYS favors temporary solutions.

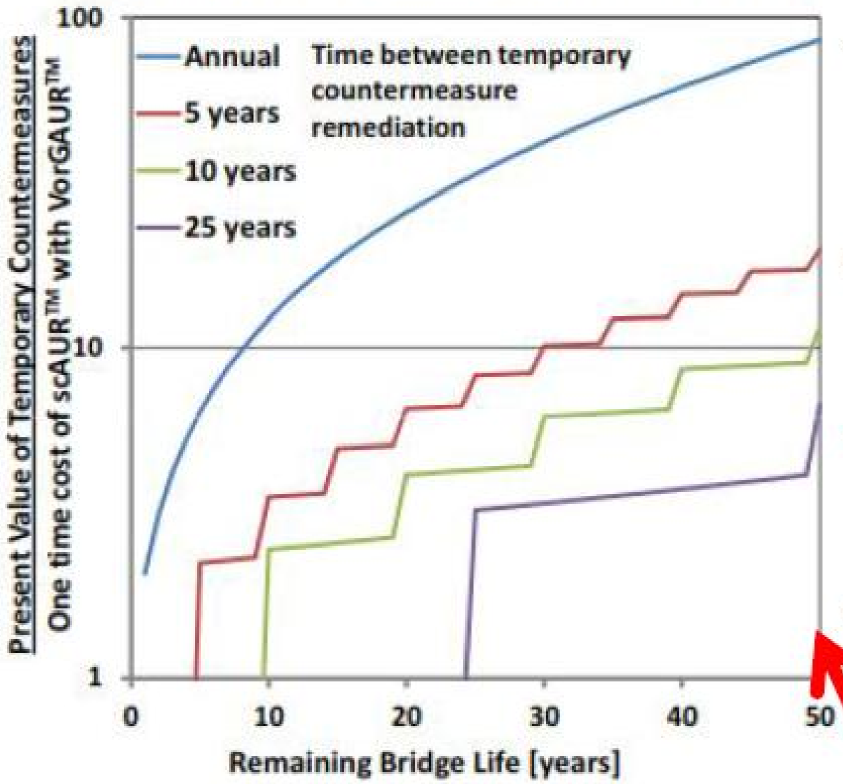
Only 59% of public-sector entities and civil engineers employ some long term life-cycle cost analysis when making decisions. Others claim "it is difficult to do".

Such decisions favor designs that require replacement after a short life. America can no longer afford to replace infrastructure as often as it does. Better technologies exist and need to be used.

Mattei, N.J., 2017, **ASCE President's Note -We all Have a Role to Play in Renewing America's Infrastructure, *Civil Engineering*,** April 2017, p. 12; www.asce.org/cemagazine.

"Infrastructure owners and operators must impose rates and fees that reflect the true cost of building, maintaining, and improving infrastructure, and Americans must be made to understands the rationale for this approach."

Economics of Stainless Steel ***scAUR***^{TM} Retrofits



Costs of temporary countermeasures obtained from a number of published sources.
Computed with 7% inflation and 5% tax exempt interest.
Example of a bridge with six piers and two abutments requiring protection.

scAUR^{TM} **Manufacturer AUR, Inc.**
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- Temporary scour countermeasures (TSC) carry compounding future costs (monitoring, inspections, engineering, remediation) with ***real present value.***
- ***scAUR***^{TM} is a permanent sustainable scour prevention measure with a ***one-time cost***. **Stainless steel costs ½ as much as concrete.**
- ***scAUR***^{TM} **prevents catastrophic failure risk and liability due to local scour and saves >90% of present value of TSC.**
- The methods of **HYRISK** used to compare ***scAUR***^{TM} to temporary countermeasures.
  - Risks from temporary countermeasures incur substantial costs and liabilities.
  - Failure probabilities yield the costs that are implicitly assumed by the bridge owner due to risk.

scAUR^{TM} ***is the clear economic choice for bridges with or likely to have severe local scour.***

Manufacturing and Installation Processes

Retrofit to an Existing Bridge – Costs of 3 alternatives

	Pier Width (ft)					
	1.5	2	3	4	5	6
Stainless Steel (304L)	**$ 22,000**	**$ 32,000**	**$ 62,000**	**$ 100,000**	**$ 160,000**	**$ 220,000**
Precast	$ 33,000	$ 56,000	$130,000	$230,000	$380,000	$580,000
Shotcrete	$ 30,000	$47,000	$ 96,000	$160,000	$ 250,000	$350,000

Comparison of estimated TOTAL retrofit costs for one pier of various width 32' long piers for 3 alternatives.

<u>It is clear that stainless steel is the best choice for bridge retrofits</u>

●Costs developed from current cost information and quotations from concrete and steel fabricators and construction costs websites.

● Estimates include all costs of fabrication of components and molds, materials, labor, transportation, installation, and finish work, such as painting the stainless steel with an approved concrete colored paint.

● Costs for additional required engineering, overhead, G&A, and profit are not included.

Manufacturing and Installation Processes

Incremental Cost for New construction

	Pier Width (ft)					
	1.5	2	3	4	5	6
Cost of added materials & labor	$3,340	$ 5,690	$13,200	$25,100	$41,800	$64,100
Cost of steel scAUR form fabrication	$1,400	$2,490	$ 5,600	$ 9,960	$15,600	$22,400
Cost of form transportation (in VA)	$2,000	$2,000	$ 4,000	$ 4,000	$ 6,000	$ 6,000
Total cost for new construction	$6,740	$10,200	$22,800	$39,100	$63,300	$92,500

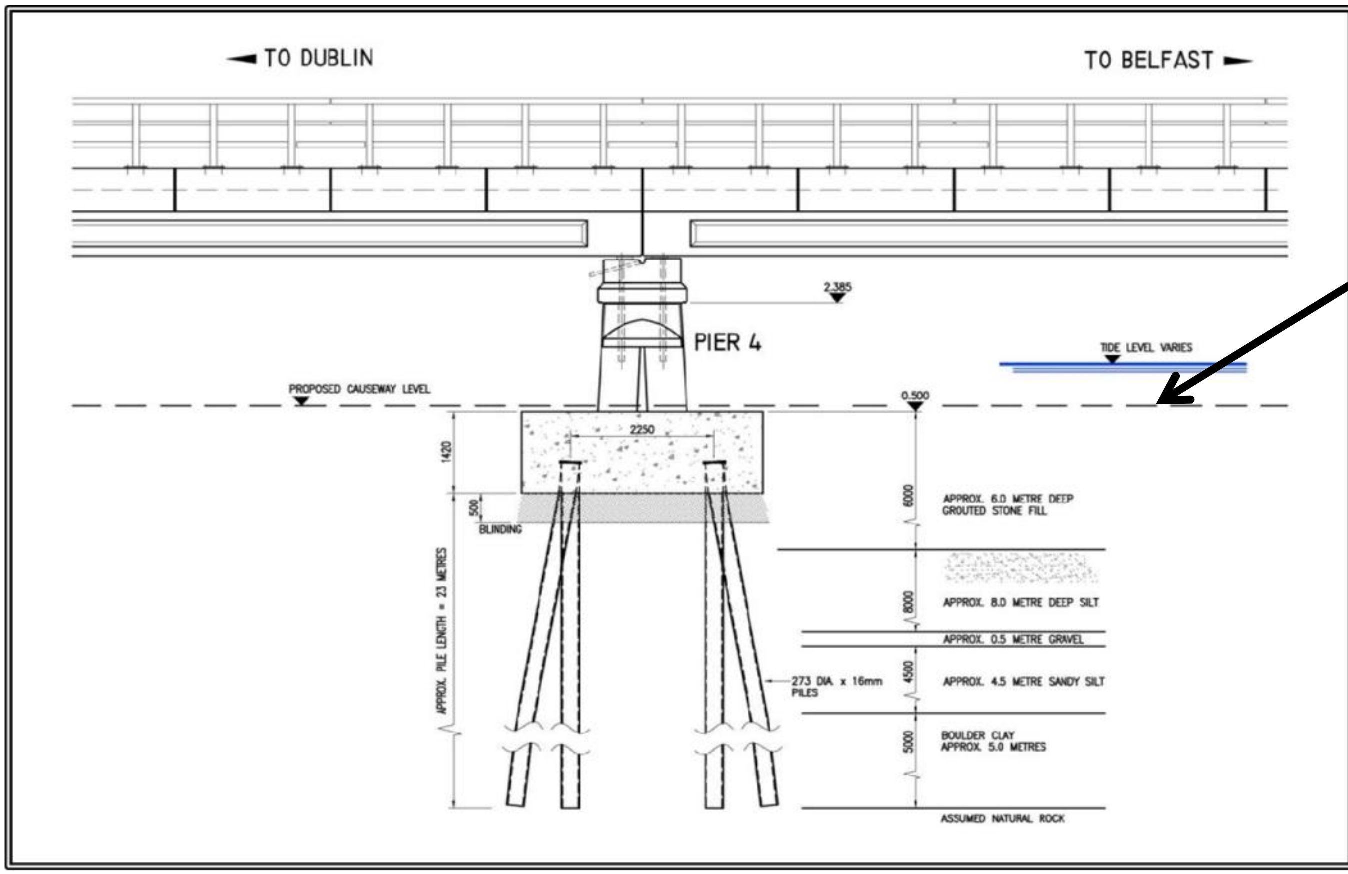
Estimated <u>incremental costs</u> of adding the scAUR™ fairing to new construction for additional rebar, concrete, labor, scAUR™ forms, and transportation of forms for various width pier construction for 32 foot long pier. Additional engineering, overhead, G&A, and profit are not included in these estimates.

Clearly, since the new construction cost is about 1/3 of retrofit costs, the best time to include the scAUR™ fairing on piers is during new construction.

Example Cases where scAUR™ with VorGAUR™ tetrahedral vortex generators will prevent scour

Flow around "pier seals", such as the new Malahide Viaduct Pier that replaced the pier that washed out in 2009.

Elevation View



In case scour occurs below this level, the wider seal will create much stronger vortices (U times width) that will scour away rock on sides of seal