Case Studies of Bridge Failure due to Scour and Prevention of Future Failures

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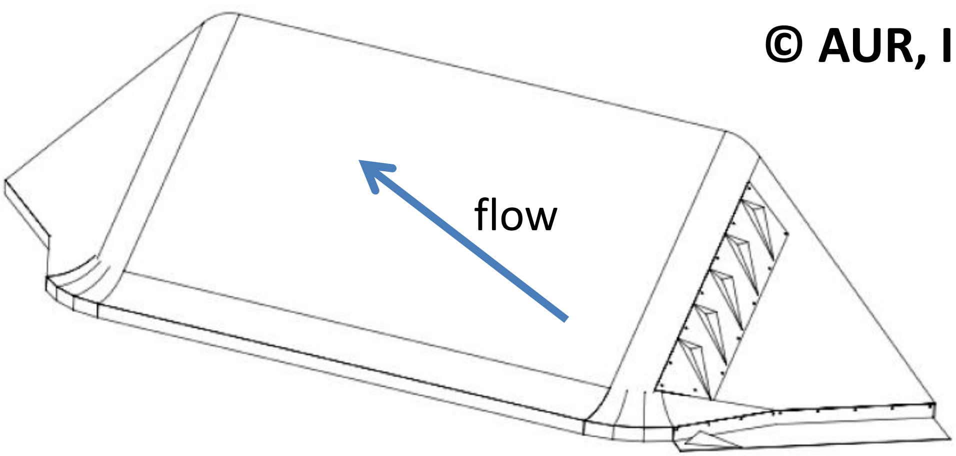

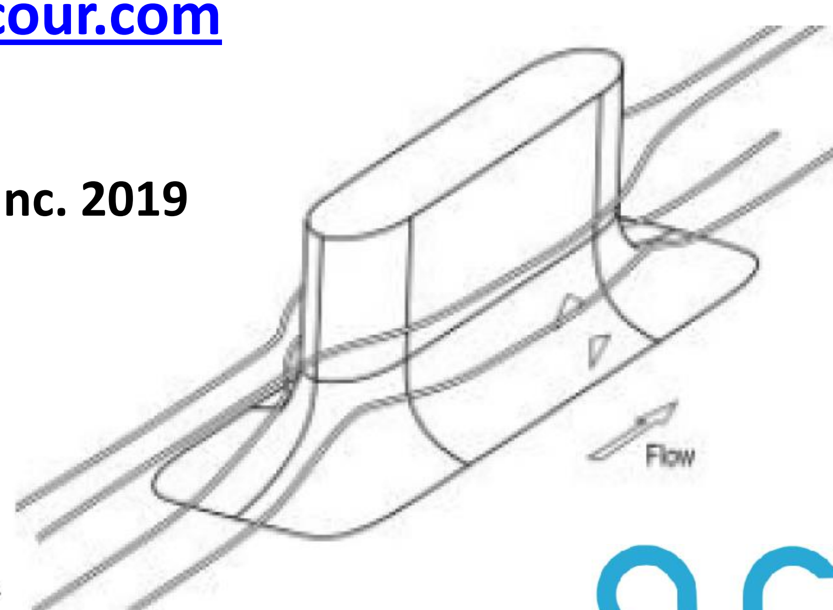

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Introduction and Background of Dr. Simpson

- 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. 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.

US Bridges Over Water – Big Scour Problem

- ➢80% of failures are due to scour often during floods and peak flow events (Lin et al. 2013; Flint et al.)
- ➢Over 70% NOT designed for scour (Flint et al. 2017)
- ➢20,904 out of 484,500 are "scour critical"(Hunt 2009)
- ➢Existing bridges more likely to fail due to climate and land use changes (Flint et al. 2017)

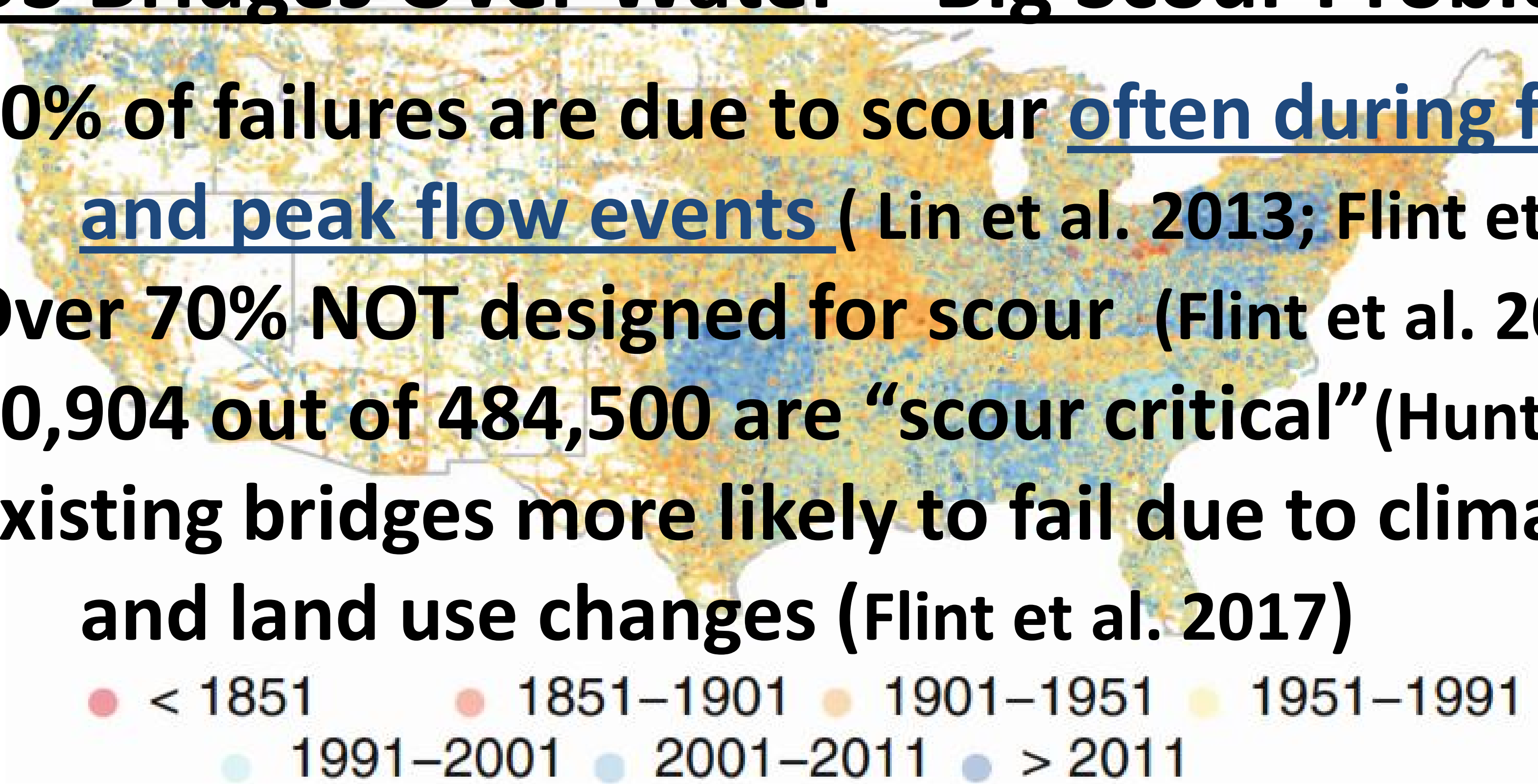


Fig. 1. (Color) Continental U.S. bridges over water by construction year; approximately 370,000 of 504,000 were built before 1991, when new scour design provisions were adopted (range: 1697–2011; median: 1973) (data from FHWA 2012)

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.

Outline of Topics

Here two case studies of bridge failures due to scour show that <u>scouring-vortex-preventing designs</u> would have prevented the scour failures and will prevent future failures at all flow speeds.

- **Failure of the Schoharie Creek Bridge**
- **The Loon Mountain Bridge Abutment Failure**
- **The Nature of Scour**
- **Proven Features of ScAUR™ that Prevent Scouring Vortices**
- **Application of ScAUR™ And VorGAUR™ Products to the Schoharie Creek Bridge**
- **Application of ScAUR™ and VorGAUR™ Products to the Loon Mountain Abutment**
- **Cost of the Bridge Failures and Cost-effective ScAUR™ and VorGAUR™ Products**
- **Conclusions**

MOTIVATION - Avoid Future Bridge Failures due to Scour

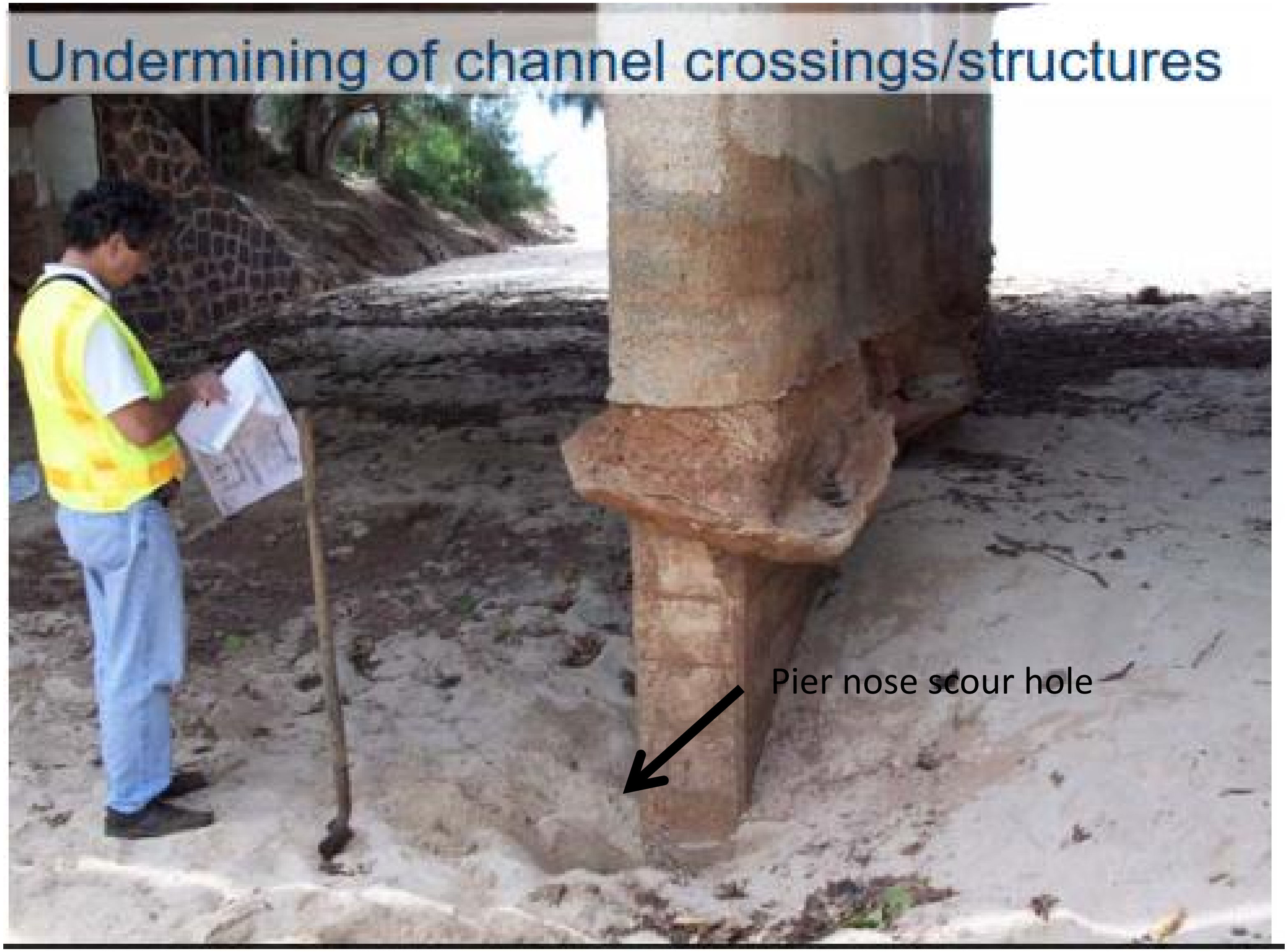


Photo from **Introduction to Sediment Transport Modeling Using HEC-RAS**
by Marty Teal, ASCE Continuing Education Course, AWI031414

Failure of the Schoharie Creek Bridge, NY State Thruway, April 5, 1987

Photo by Sid Brown, https://dailygazette.com/article/2017/04/04/thruway-bridge-collapse-of-1987-it-sounded-like-a-bomb-going-off

Wikipedia https://en.wikipedia.org/wiki/Schoharie_Creek _Bridge_collapse）

- **Stream flooded from high April 1987 rainfall and snow melt.**
- **Normal 6 foot water depths rose to 25 feet - third highest in recorded history.**
- **The high flood speed (15 fps) created an approximately 10 foot deep by 30 foot wide scour hole around Pier 3.**
- **Two 60-foot sections of the 540-foot-long bridge fell 110 feet into the creek.**
- ***<u>Five vehicles fell into the creek and ten occupants died.</u>***

Causes of the Schoharie Creek Bridge Failure

A number of design and maintenance deficiencies

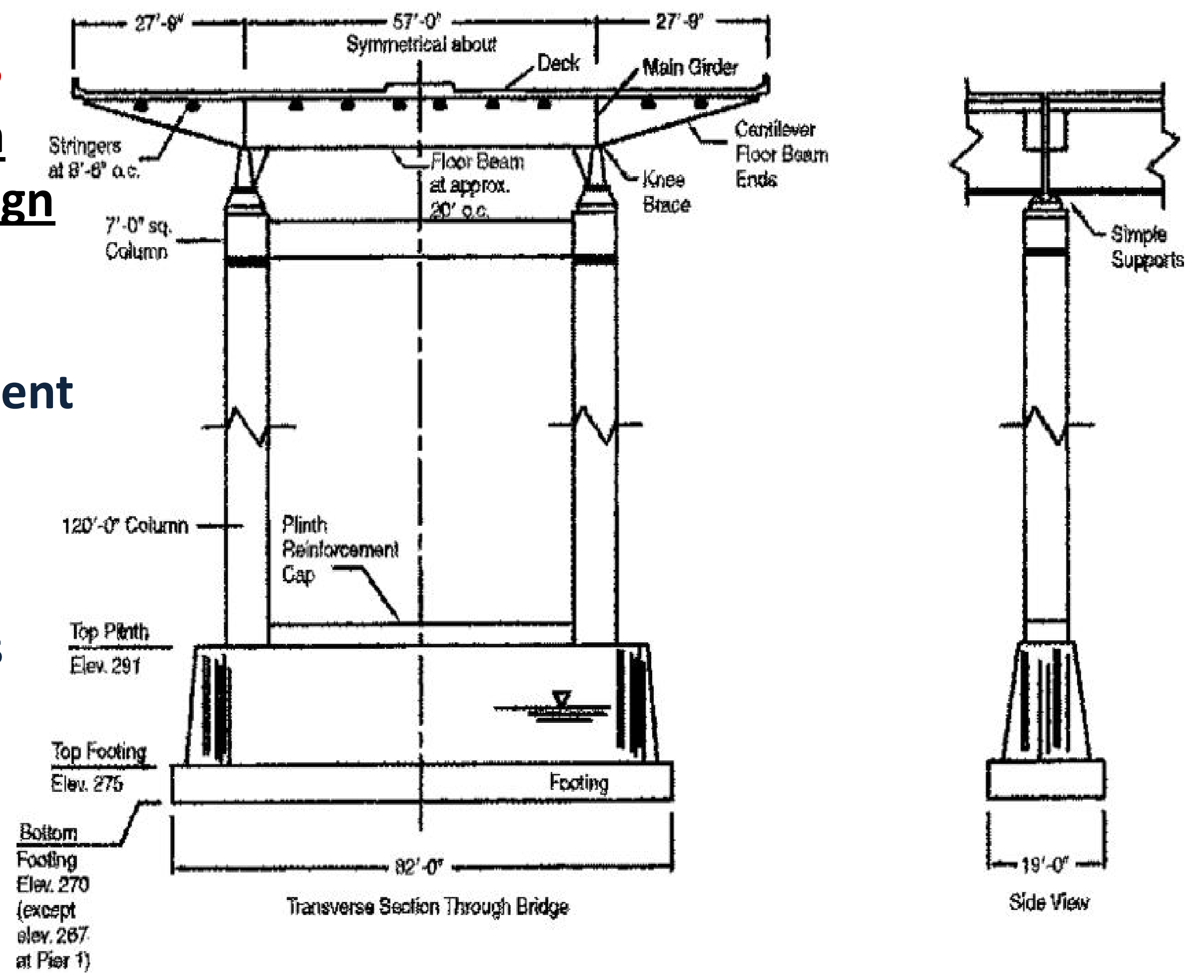
<u>Flood velocity was higher than anticipated in the original design</u>

Piers supported by spread footings with limited embedment into the riverbed.

Spread footing under Pier 3 rested on highly erodible soils (i.e. layers of gravel, sand, and silt) and backfill

Inadequate "riprap" rock protection

Inadequate inspection and maintenance.



Sections showing the Schoharie Creek Bridge pier supported on a spread footing . From NTSB, 1988.

Other Aggravating Factors in the Schoharie Creek Bridge Failure

- **Debris accelerated the downward scouring flow.**
- **Berms increased the floodwater speed under the bridge.**
- **A high hydraulic gradient formed between upstream and downstream in the spring.**
- **Insufficient design of the bridge structure for scour conditions:**

>> The superstructure bearings allowed for the uplift and slide of the superstructure from the piers;
>>Simple spans without any redundancy were utilized;
>> The lightly reinforced concrete piers had limited ductility;

photo credit: U.S. Department of the Interior, U.S. Geological Survey

>> Deficient plinth reinforcement resulted in sudden cracking of the plinth instead of a hinging failure.

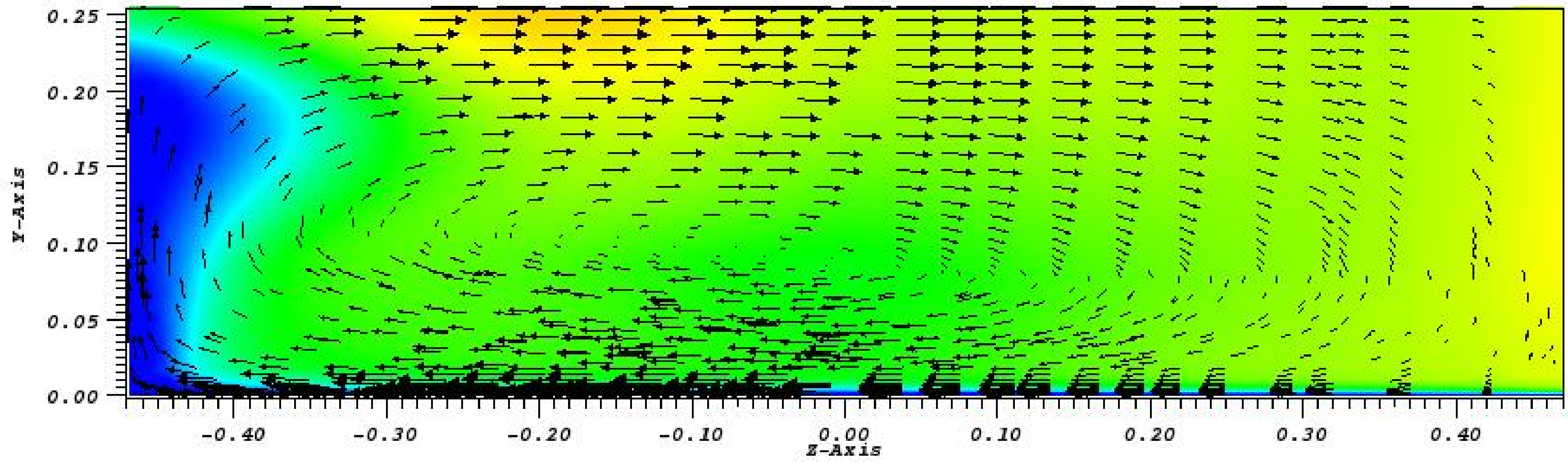
Some Observations and Practical Tips for Assessing the Potential for Scour and Catastrophic Bridge Failure

- **No earlier bridge pier and abutment footing or foundation design prevents scouring vortices.**
- **Designs should be based on extreme events.**
- **Use the physical understanding of flood processes and situations, not just statistical probabilities from past experiments, codes, and events.**

Piers and Abutments 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 – **modify scAUR™ shape to account for swirl.**

Mean flow stream-wise vortices are produced after a river bend. **CFD by AUR, Inc.**

Inner radius **Outer radius**



The Loon Mountain Bridge Abutment Failure

In August 2011 high water due to Tropical Storm Irene washed out an abutment of the Loon Mountain, New Hampshire Bridge.

This bridge abutment was on the outer bank in a bend in the river, so swirling flow brought high velocity water into the outer river bank, causing quick erosion and loss of soil and rock under the concrete part of the abutment.

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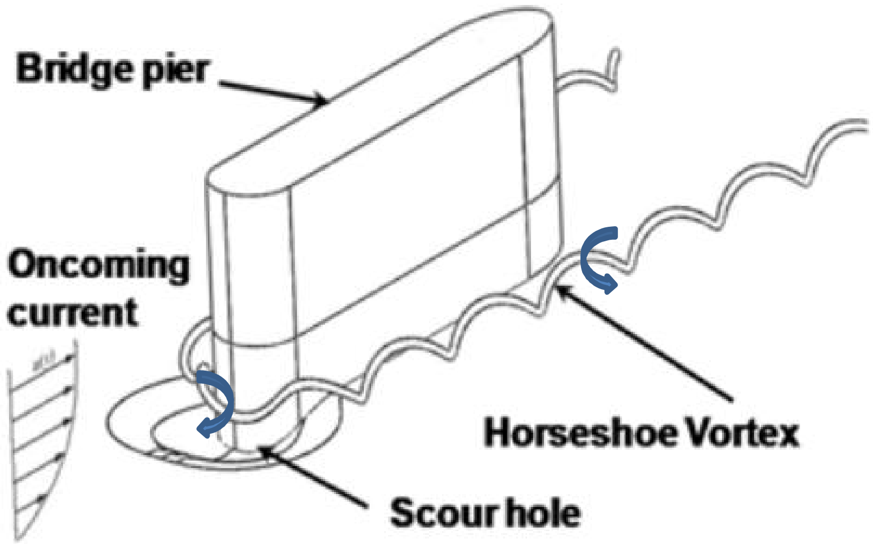
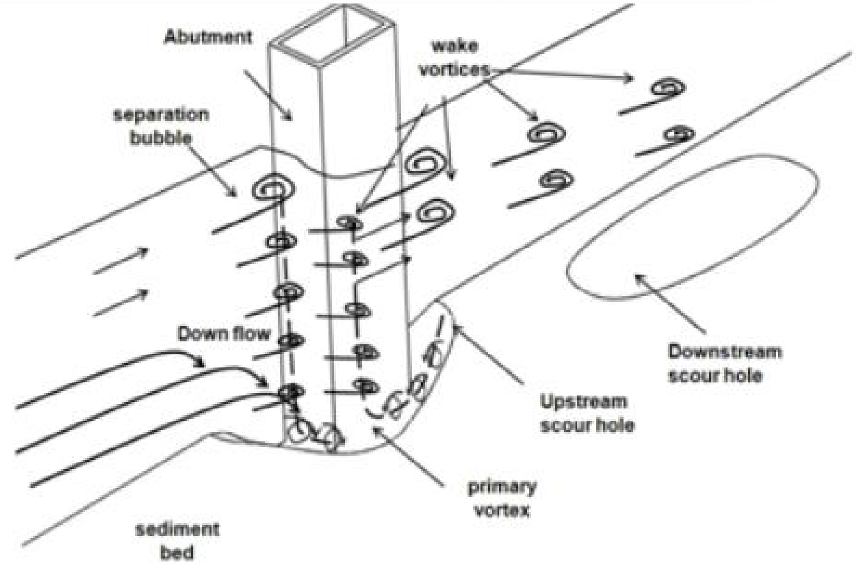
Causes of Bridge Scour





Bridge scour is produced by discrete vortices formed around unprotected piers (left above) and abutments (right). Many near catastrophes and loss of life have occurred, as shown in examples

LIKE TORNADOS - VORTEX STRETCHING INCREASES VELOCITY

$V_2 = V_1(A_1/A_2)^{1/2} = \Gamma/(\pi d_2)$ = Strength of Vortex/(Perimeter of Vortex)

V_1 , V_2 rotational velocity components of vortex

A_1 , A_2 cross-sectional area of vortex

diameter d of vortex.

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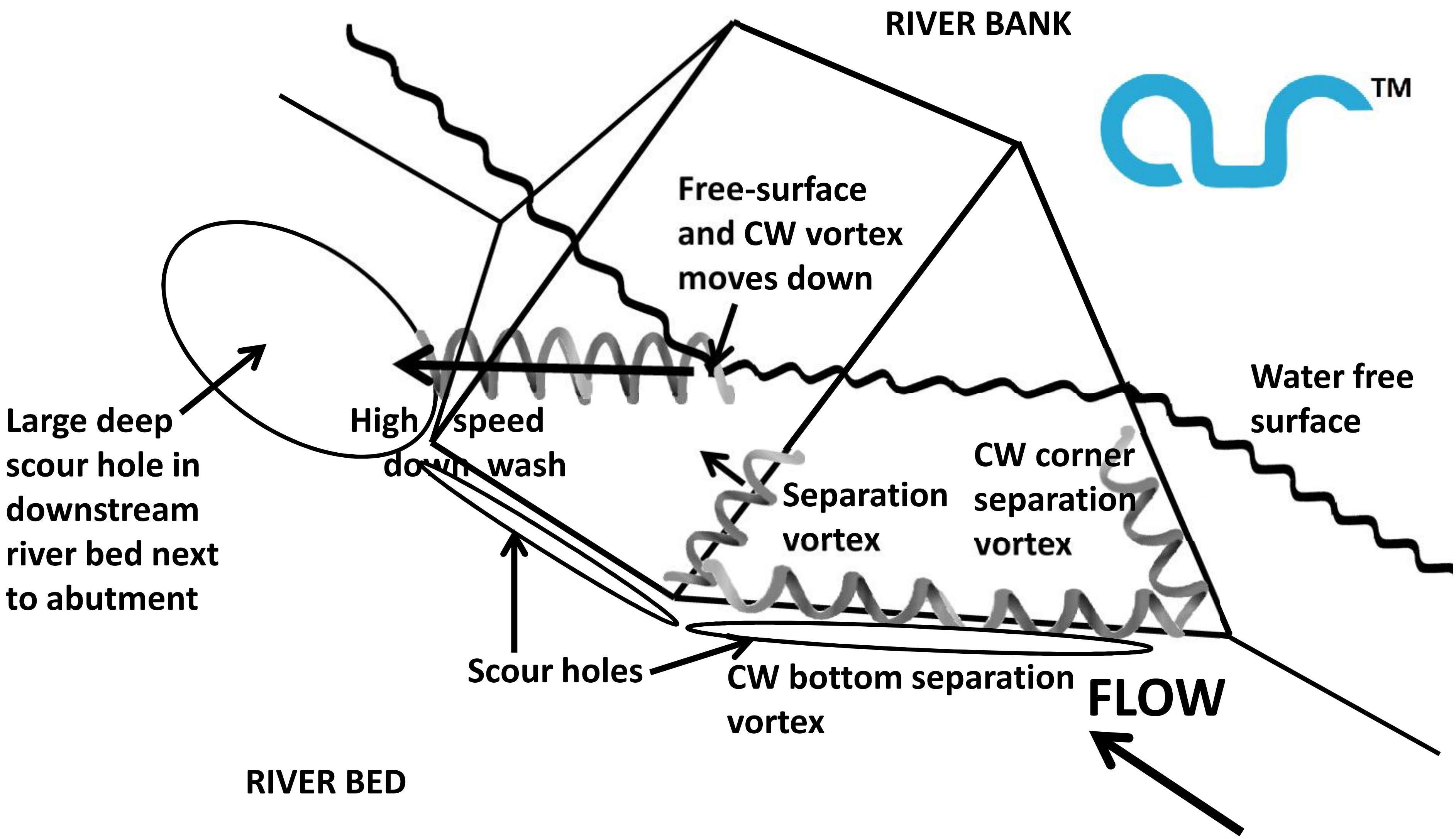
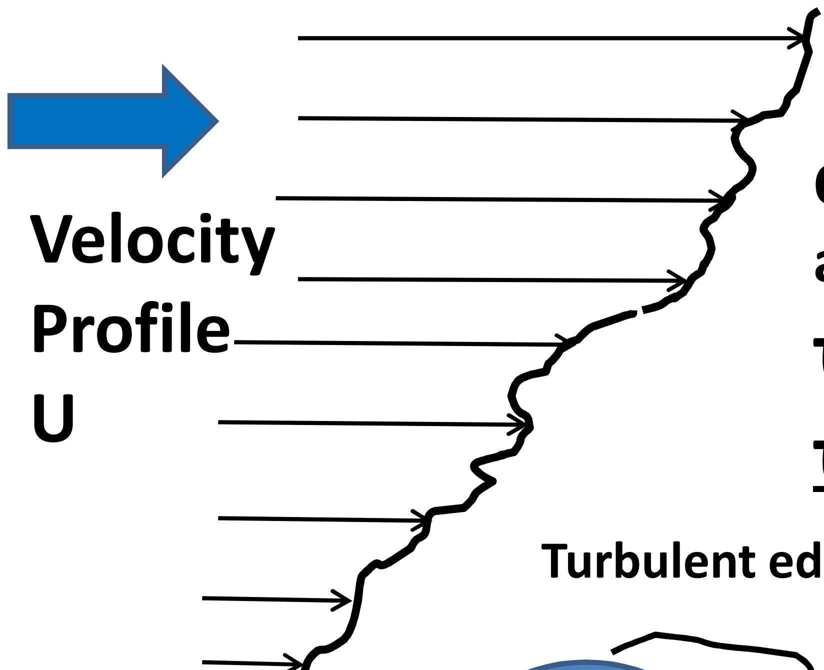
Spill-through abutment without scour countermeasures



Fundamental Mechanism of Scour on River Bed

Turbulent flow over river bed



Shields Number Θ describes incipient motion of bed material

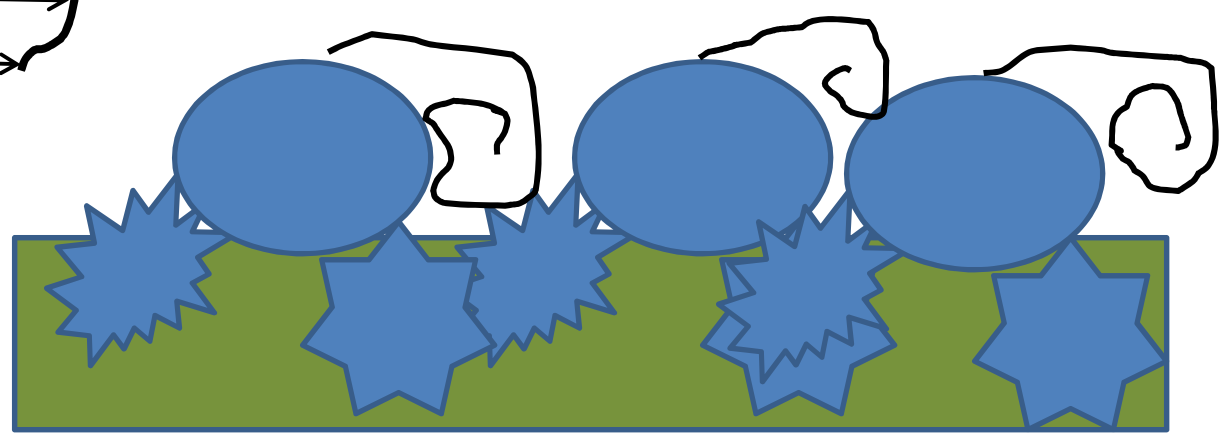
$$\theta = \frac{\tau}{(\rho_{\mathrm{p}} - \rho) g d}.$$

Θ = ratio of effective shear force to apparent weight; motion is F($Re_{particle}$)

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

KEEP U LOW!

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.

> The more blunt the nose of a pier or abutment, 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.

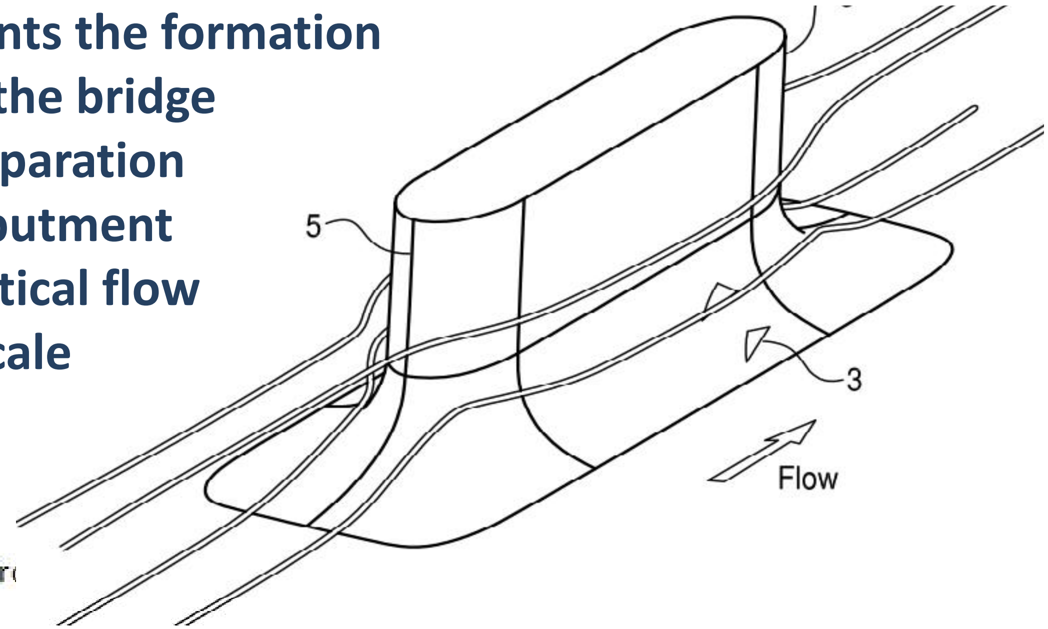
Simpson, R. L., 2001, "Junction Flows," Annual. Rev. Fluid Mech., Vol. 33, pp. 415–43.

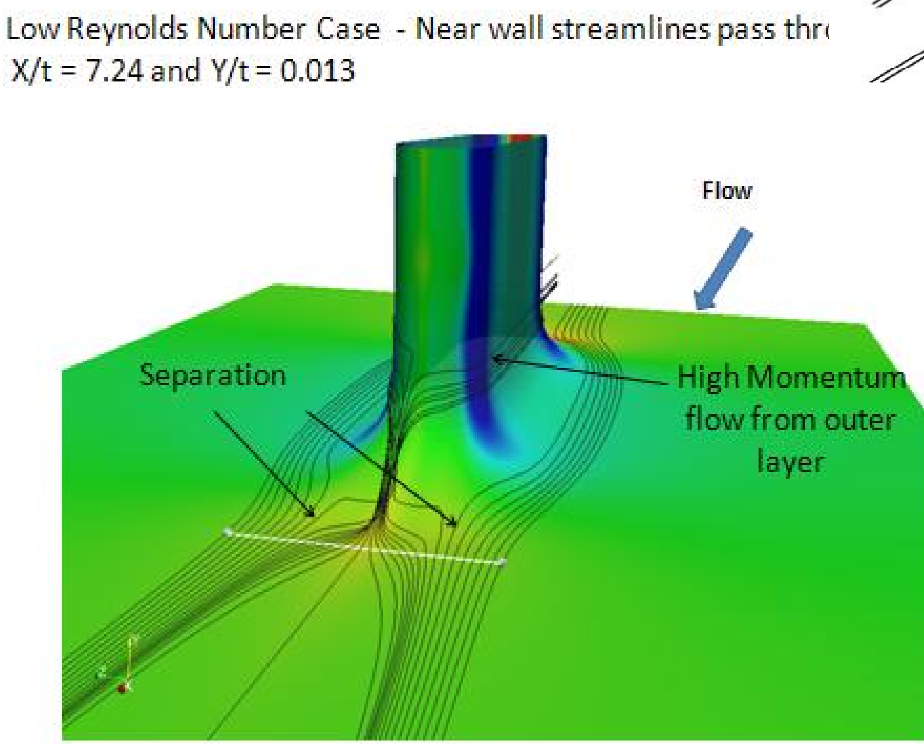
What can be done to prevent vortices that cause scour? *Use (1) surface shapes that prevent the formation of discrete scouring vortices* and (2) tetrahedral vortex generators that cause the higher velocity flow to stay on top of the river and counteract the scouring vortices.

TM

Proven Features of scAUR™ that Prevent Scouring Vortices

The patented scAUR™ design prevents the formation of highly coherent vortices around the bridge pier or abutment and reduces 3D separation downstream of the bridge pier or abutment with the help of the VorGAUR™ vortical flow separation control. Proven at full-scale by the NCHRP-IDEA-162 tests.



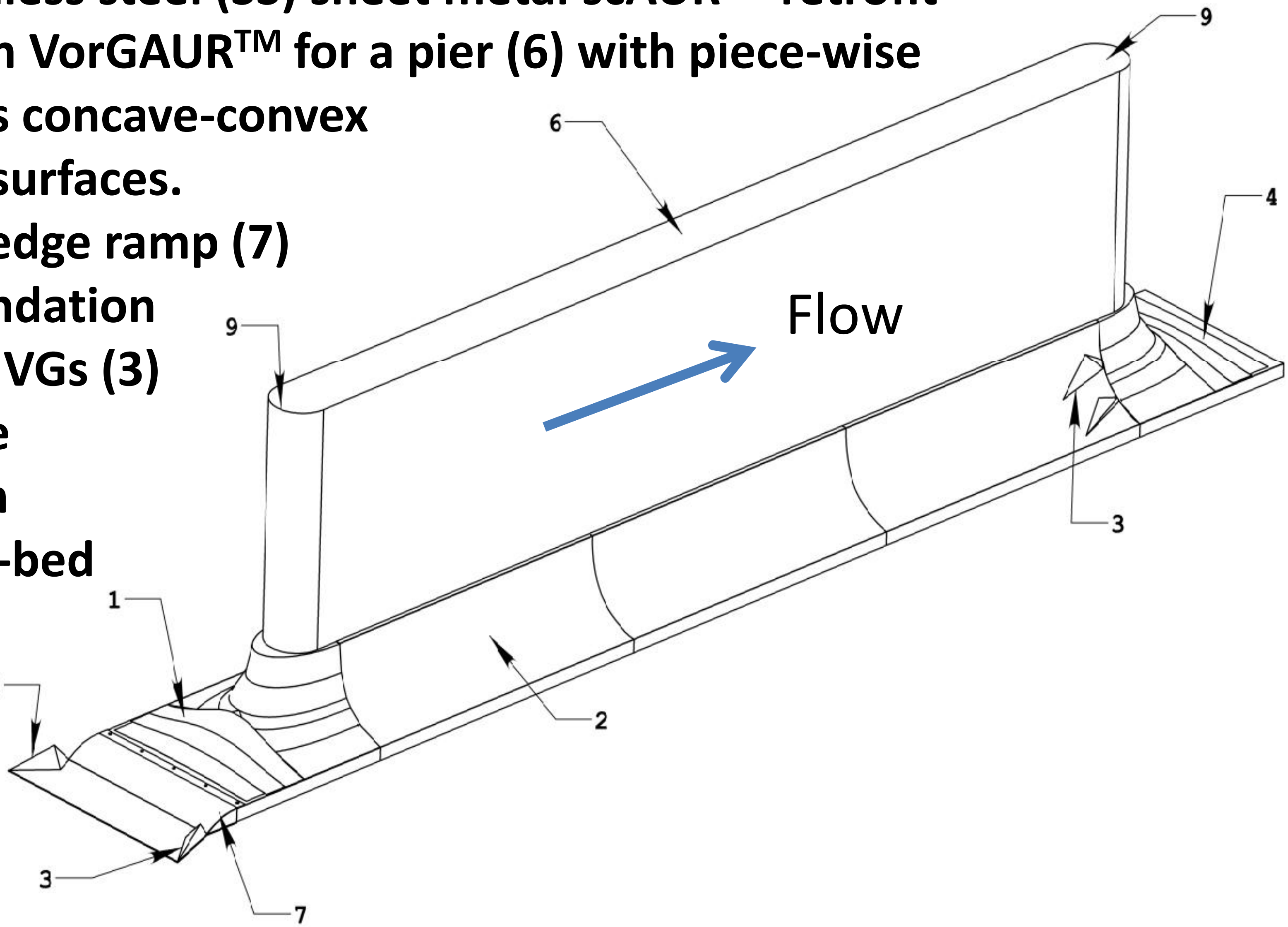


Streamlines around a scAUR™ fairing around a pier (5) with VorGAUR™ vortex generators (3) that produce no scouring vortices.

Application of ScAUR™ and VorGAUR™ Products to the Schoharie Creek Bridge

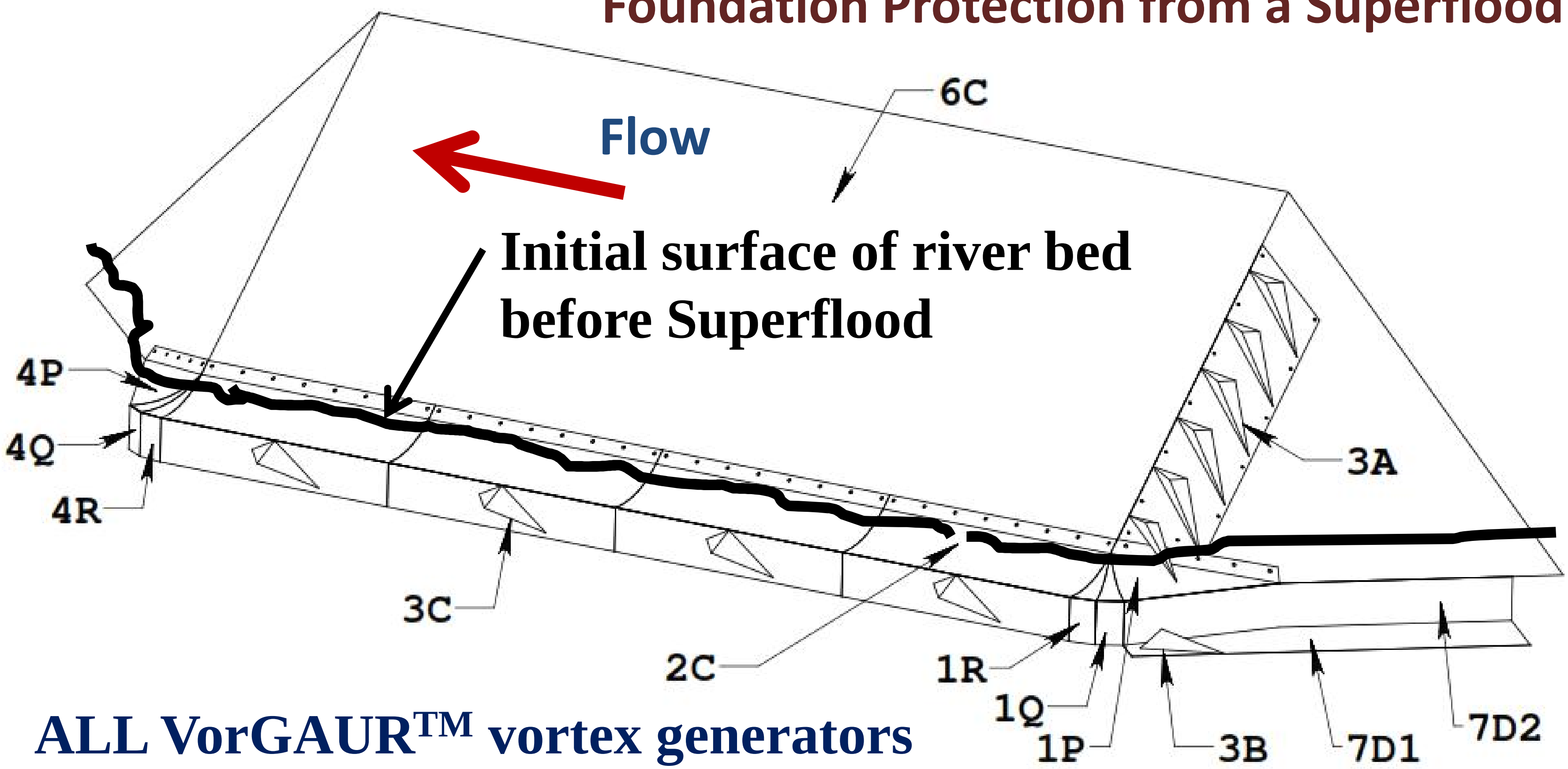
> Use stainless steel (SS) sheet metal scAUR™ retrofit fairing with VorGAUR™ for a pier (6) with piece-wise continuous concave-convex curvature surfaces.

> Leading edge ramp (7) & pier foundation protecting VGs (3) protect the foundation from open-bed scour.



Application of scAUR™ and VorGAUR™ SS Products to the Loon Mountain Abutment

Spill-through Abutment with VorGAUR™ Vortex Generators (3C) for Added Foundation Protection from a Superflood

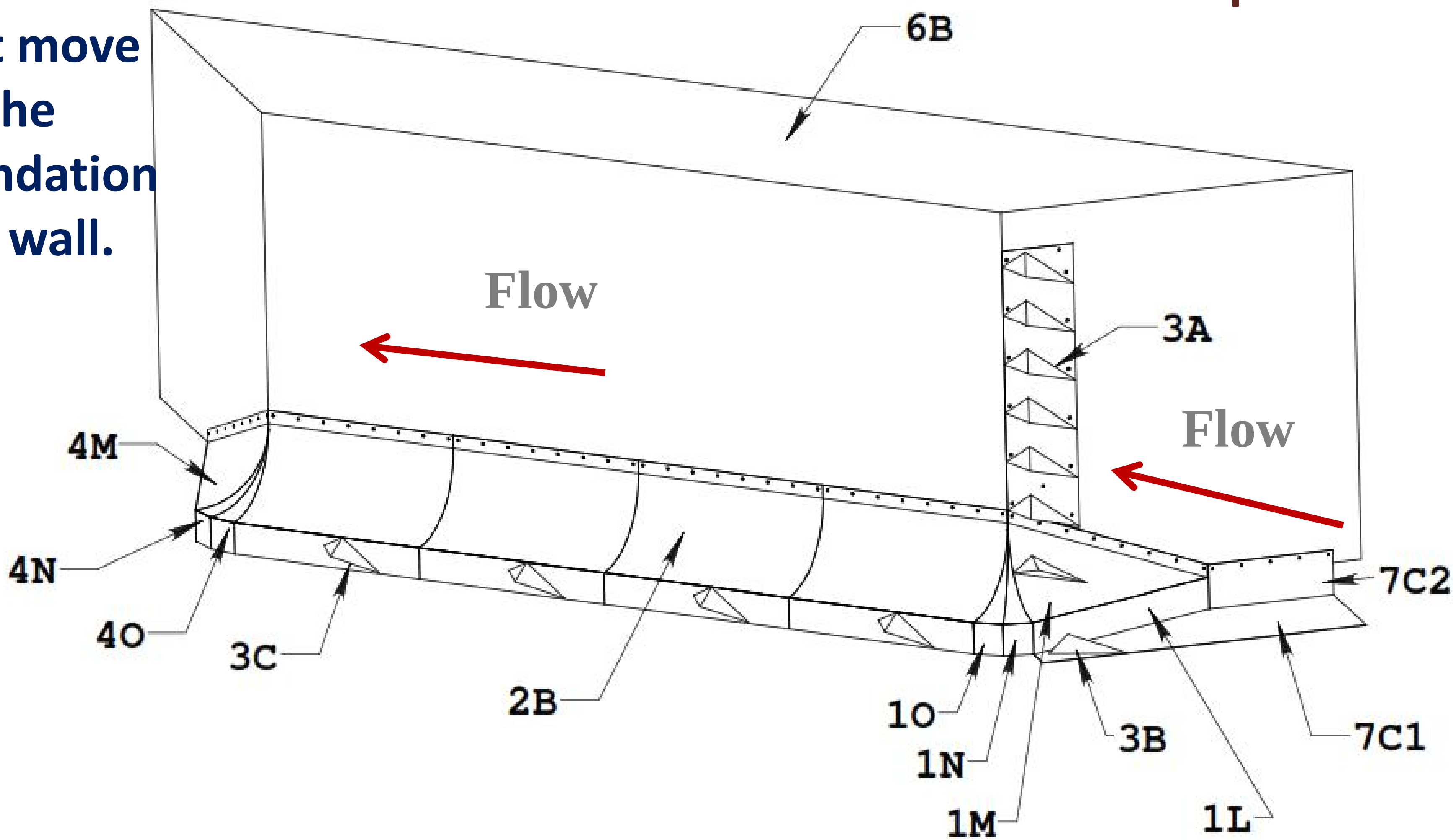


ALL VorGAUR™ vortex generators produce stream-wise vortices that move up the foundation and wall, bringing river-bed material toward the abutment

Application of scAUR™ and VorGAUR™ SS Products to the Loon Mountain Abutment

ALL vortex generators produce stream-wise vortices that move up the foundation and wall.

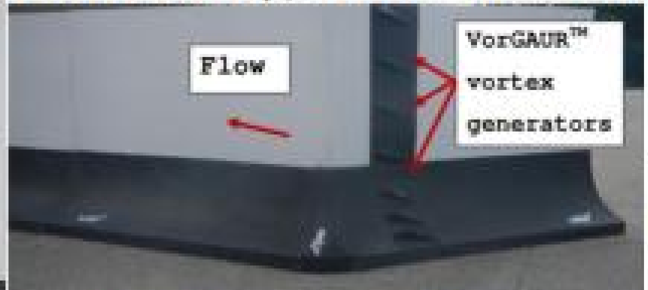
Wing-wall Abutment with VorGAUR™ Vortex Generators (3C) for Added Foundation Protection from a Superflood



Permanent Solution: scAUR™ and VorGAUR™ Products

Modular Stainless Steel (SS) Retrofits for Existing Bridges

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

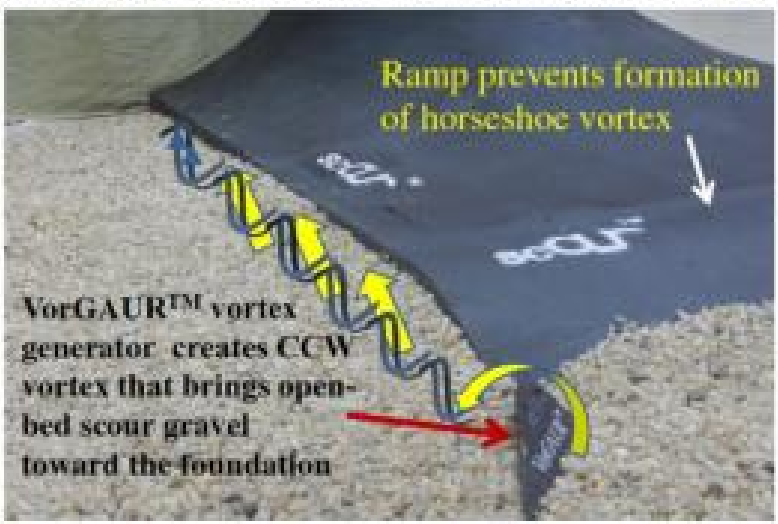


Example stainless steel scAUR™ retrofit (black) for a 45° wing-wall abutment. Note SS vortex generators.

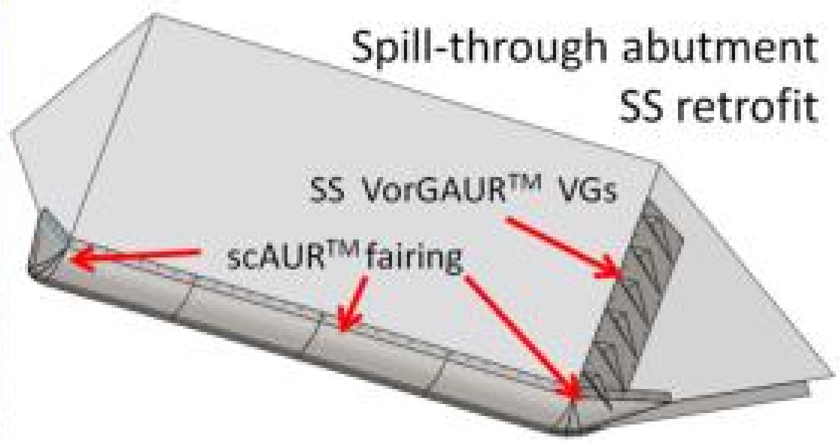
Example stainless steel scAUR™ retrofit (black) for a pier.

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



Cost of the Bridge Failures and Cost-effective Manufacturing and Installation of scAUR^{TM} and VorGAUR^{TM} Products

For the Schoharie Creek Bridge collapse, the estimated cost of the disaster and recovery was at least $45M. Of the $42M in civil lawsuits, at least $10M was awarded. For about $250K in 1987 or 0.45% of what was eventually spent, both piers could have been protected permanently from scouring vortices for all water flow speeds. (Details on low manufacturing costs by Simpson and Byun*)

For the Loon Mountain Bridge abutment collapse, about $8M was spent on temporary repairs and a new replacement bridge. It would have cost about $71K in 2011 to install stainless steel retrofit scAUR^{TM} with VorGAUR^{TM} components PRIOR to the collapse. Thus, for less than 0.9% of what was spent after the abutment collapse, the abutment could have been permanently protected from scouring vortices for all water speeds.

* Simpson, R.L. and Byun, G. IBC 17-89 “Low Cost Scour Preventing Fairings for Bridges”

Conclusions

> Many bridges over water are susceptible to scour of supporting rocks and soil by vortices created at the structure during peak flow events such as floods.

> scAUR™ with VorGAUR™ designs and components prevent the formation of scouring vortices for all flow speeds.

> In every case of failure, expenditure of a small amount prior to the failure would have saved 100 times or more funds for a recovery. This, of course, does not include the loss of life that may occur by the failure.

Conclusions (Cont.)

> Designs for various types of piers, footings, abutments, angles of attack, river swirl, and bed conditions have been tested at model scale and some at full scale and show no scouring vortices .

> Computational fluid dynamic (CFD) studies show that no scouring vortices are produced.

> Other advantages of these designs are: much lower present value of all costs, lower river levels and flow blockage, lower possibility for debris and ice buildup, and greater protection of piers and abutments against impact loads.

Contact Us for More Information About Other Cases or If You Have Questions

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Backup and Other Slides

Current Scour Prediction Methodologies

> **Traditional hydraulics methods**: one-dimensional continuity, momentum and energy equations. Use mean flow values. In some cases, 2D calculations are used.

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

> The approach in HEC 18 and HEC 29 is to correlate laboratory data for scour depth to obtain correction factors, which are up to 50% off.

Computational Fluid Dynamics (CFD) - AUR Approach - More Reliable Answers for a Specific Bridge

- 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.

  More expensive to gather all of the needed information and run code.

One still needs to implement a lasting remedy!!

Temporary Countermeasures and Liability

- **Rip rap countermeasures are not acceptable design elements for new bridges** (HEC 23, subsection 2.1.1, also, e.g. VA DOT Drainage Manual, subsection 12.3.2)
- **To avoid liability risk to engineers and bridge owners**, new bridges must be drastically over-designed to withstand up to 500-year superfloods, assuming that all sediment is removed from the ‘scour prism’ at that flow rate. (HEC 23: 2.1.1)
- **scAUR™ products avoid liability risk** by eliminating or drastically diminishing the scour prism, **reducing the cost** of new bridge engineering and construction
- Eliminating or drastically diminishing the scour prism **GREATLY reduces the probability of failure,** by the **tenets of catastrophic risk theory.**

PERMANENT COST-EFFECTIVE SOLUTION

1. Through many years of design and testing, streamlined scAUR™ fairings with vorGAUR™ counter-rotating vortex generators that <u>PREVENT THE VORTICES THAT CAUSE SCOUR ARE AVAILABLE FOR INSTALLATION .</u>
2. Save up to 90% of current scour-countermeasures-related expenses over the life of a bridge.
3. Proven <u>prevention of scour</u> 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.

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.**

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Contacts: aur@aurinc.com; 540-961-3005; FAX 866-223-8673

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™

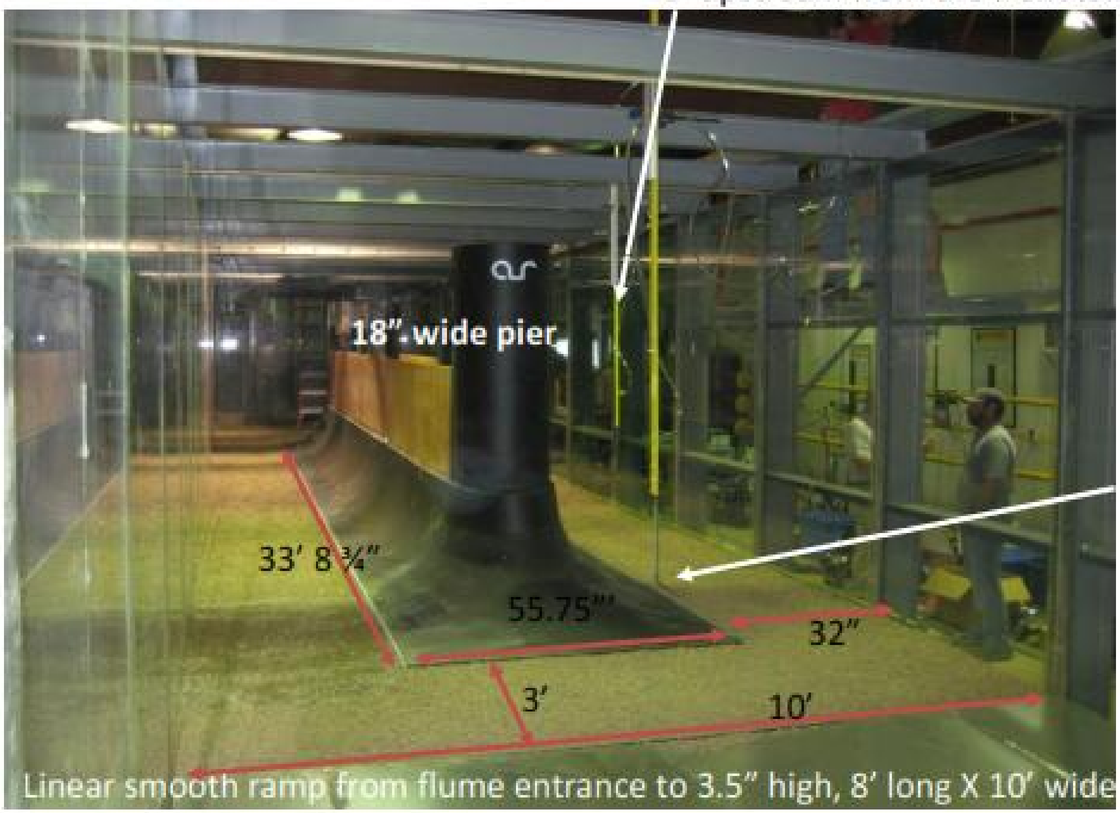
1. Much lower present value of present and future scour mitigation costs as compared to other approaches.
2. Lower drag force, flow blockage, water level, and over-topping frequencies on bridges during flood conditions, any water level or inflow turbulence level.
3. Debris accumulation prevention and 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.

No Scour During Full-scale Tests

<u>Full-scale Tests</u>: Photo of the AUR full-scale scAUR™ with VorGAUR™ pier model in the University of Iowa Institute of Hydraulic Research (IIHR) Environmental Flume Facility (EFF).

5/21/2013
Final setup in IIHR EFF

2nd pitot static probe for flow velocity between the pier model and the flume side wall
6" below water surface
3' upstream from the front fairing

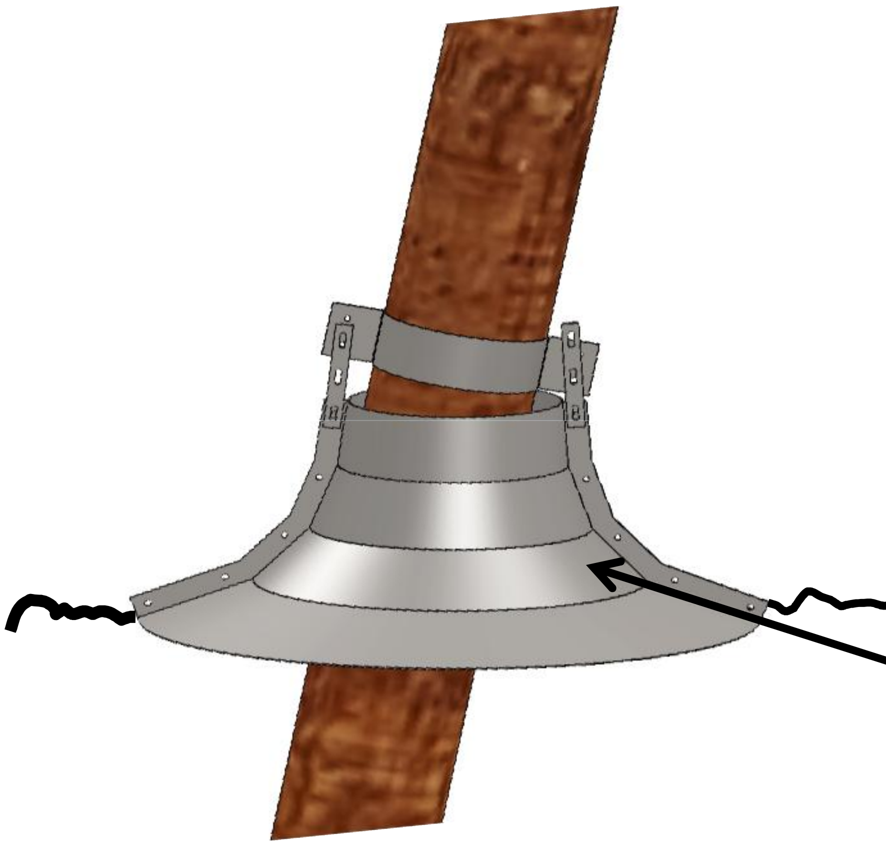


View from upstream

NCHRP-IDEA Supported Tests

Pitot static probe for free-stream velocity
6" below water surface
3' upstream from the front fairing
flume centerline

Circular Pile Scouring Vortex Protection

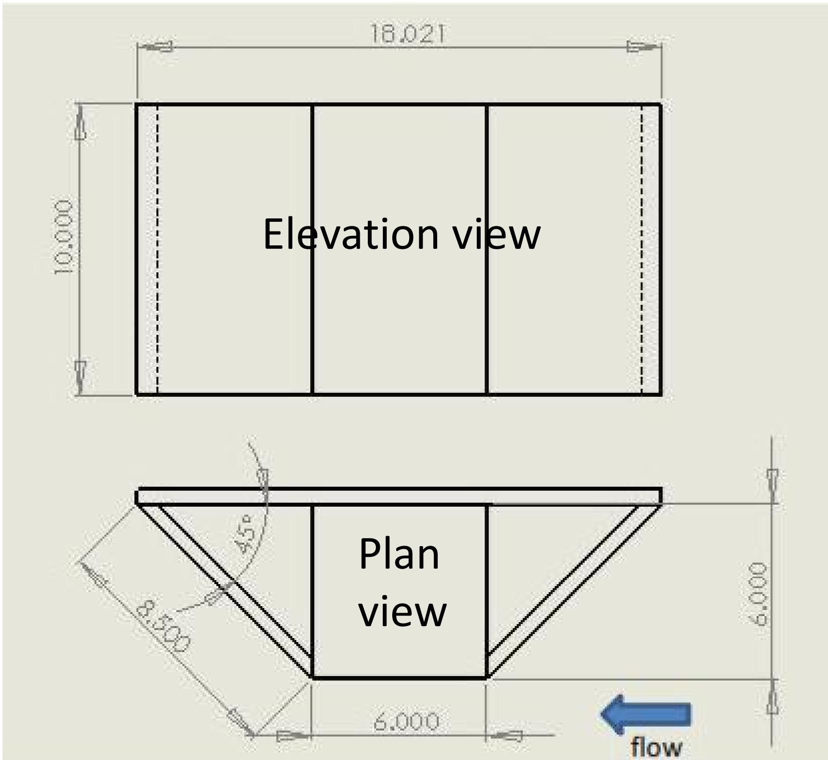


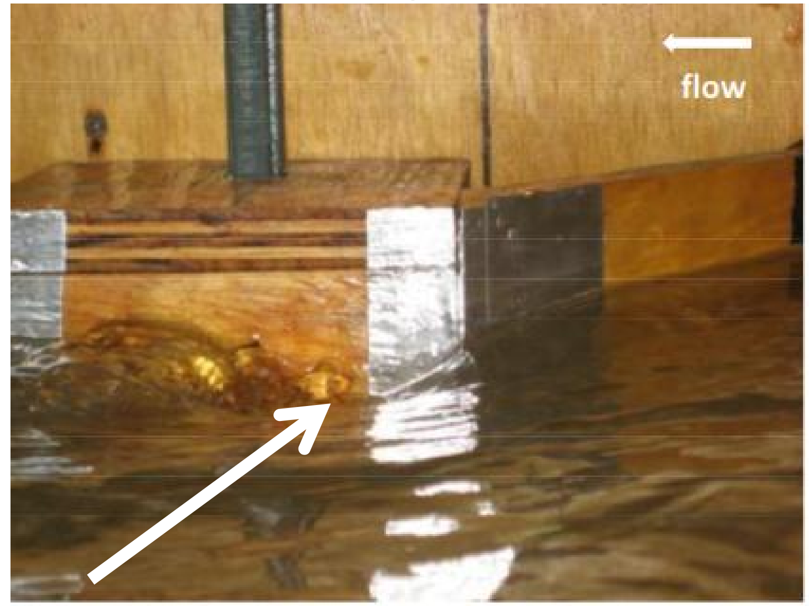
Case 48

Streamlined scAUR™ fairings with vorGAUR™ counter-rotating vortex generators

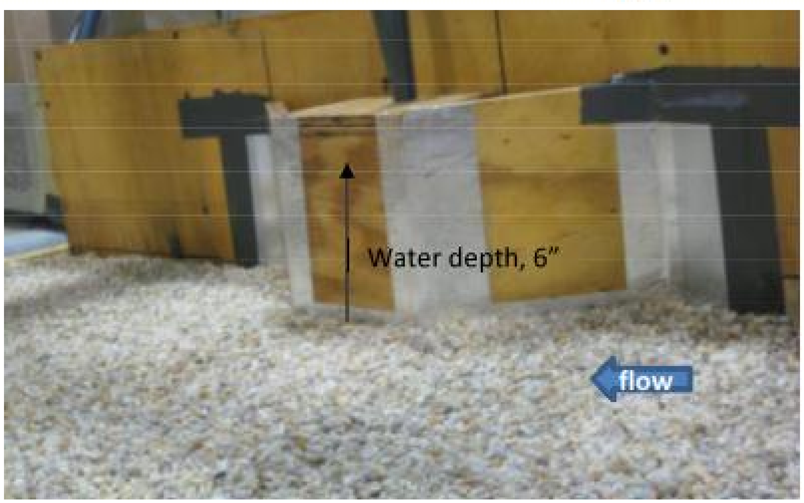
Proven principle of scour research – if it does not scour at model scale, it does not scour at full scale for the same sediment size

Wing-Wall Abutment - Case 17 – no scour protection





Free-surface vortex ; scour hole shown below



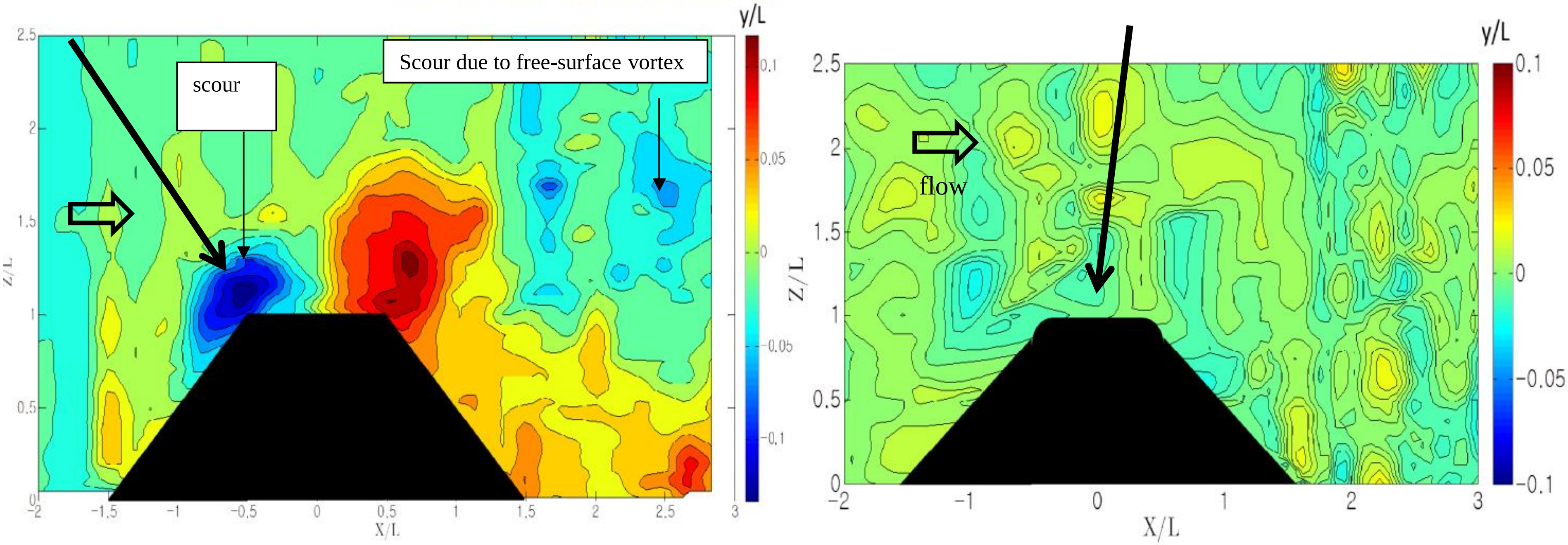
Flume test results of a scAUR™ model as a <u>wing-wall bridge abutment</u> scour countermeasure

•The results demonstrate that with the scAUR™ fairing and VorGAUR™ devices around the abutment, the upstream scour hole is <u>prevented</u> and the downstream scour hole is negligible.

No scAUR™ used – deep scour occurs

scAUR™ used – no scour occurs !

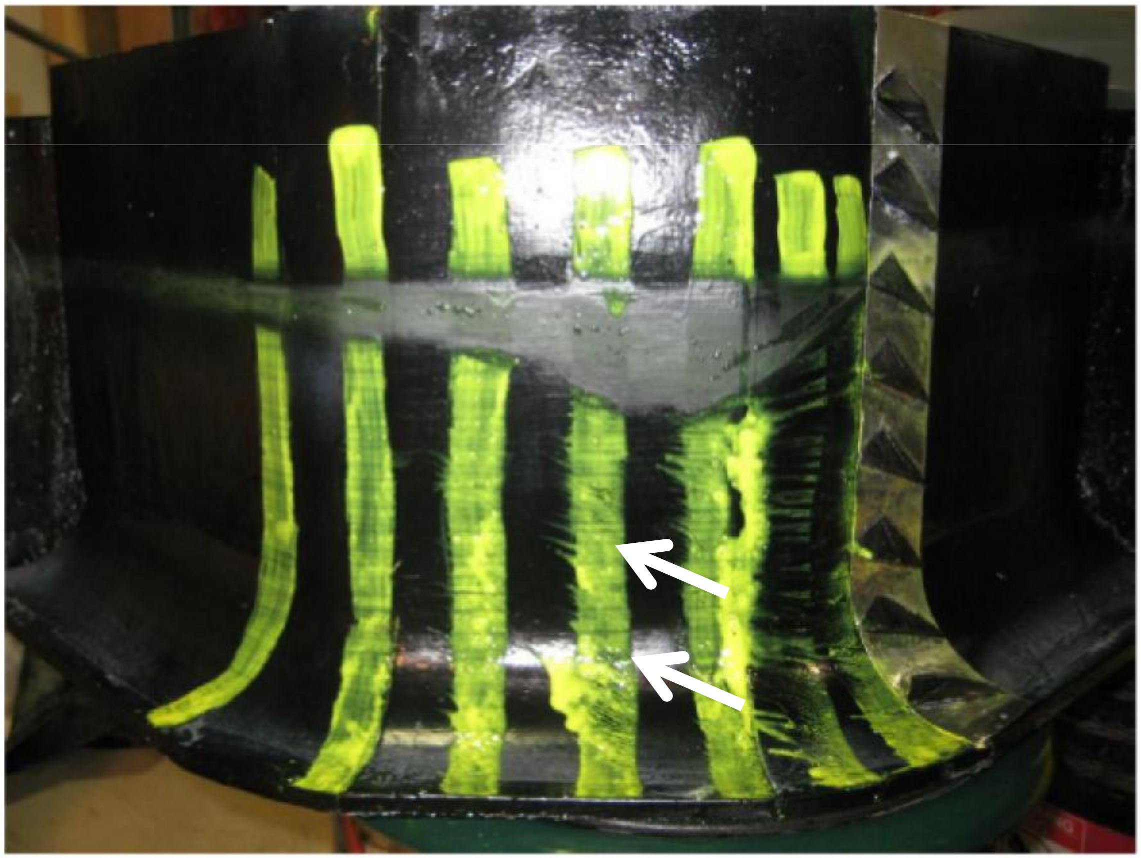
Bed Elevation Contour of Flume Test Results



Surface oilflow results for Case #20 (scAUR™ modified wing-wall abutment with VGs).

> Oilflow technique used at the US Navy's David Taylor Model Basin determines local surface skin friction mean direction; some yellow oil flows downstream in a local flow direction, which is observed against the black surface.

> scAUR™ and VorGAUR™ bring lower velocity flow up from the flume bottom and prevent the scour around the bottom of the abutment.

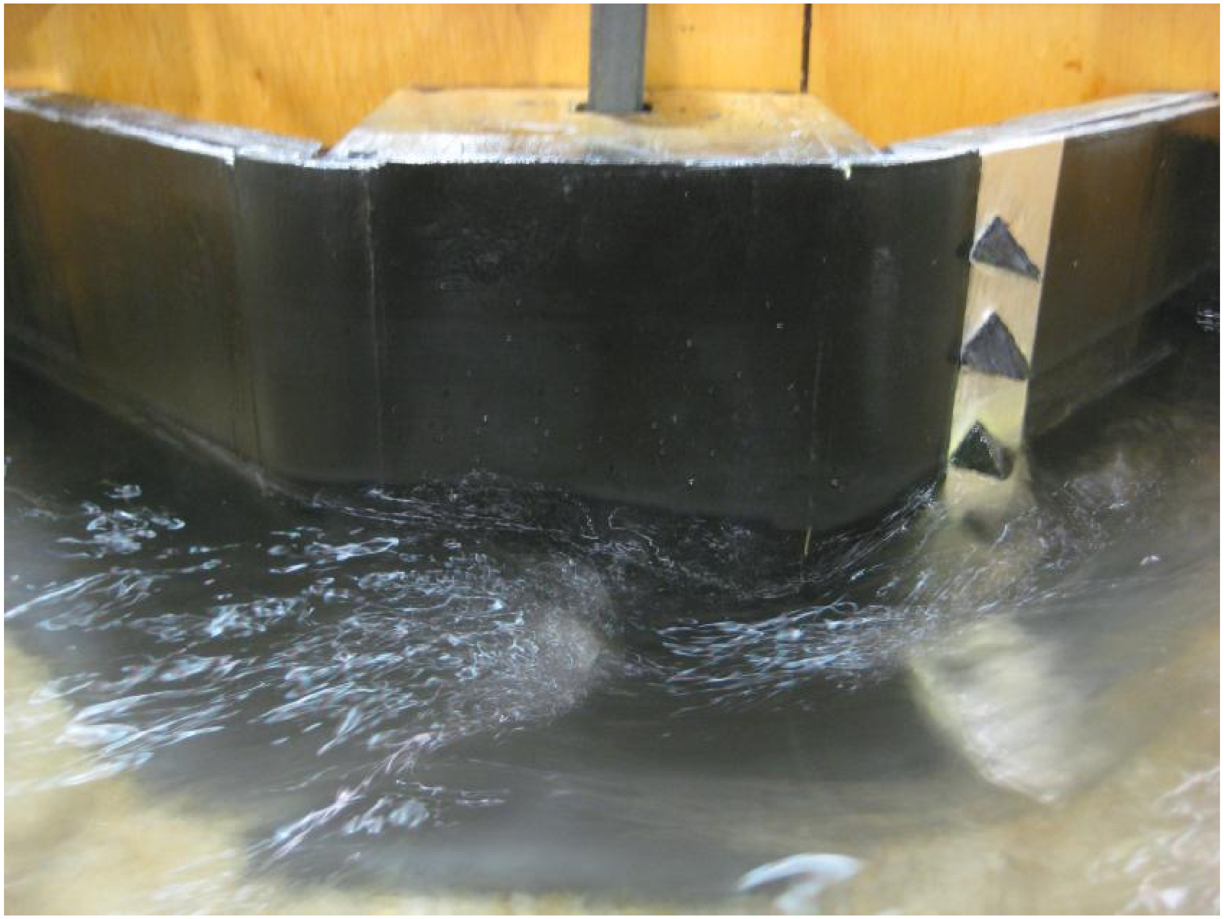


Surface oilflow results for the case #20 modified wing-wall abutment model with VGs. The gray region is produced by a mixture of the oilflow material and waterborne substances at the free surface.

Free-surface water flow around the abutment model in the flume for case #20 (scAUR™ modified wing-wall abutment with VGs).

> No scour around the model base AND no open bed scour hole farther downstream of the model.

> VGs diffuse and reduce the strength of the surface vortex.



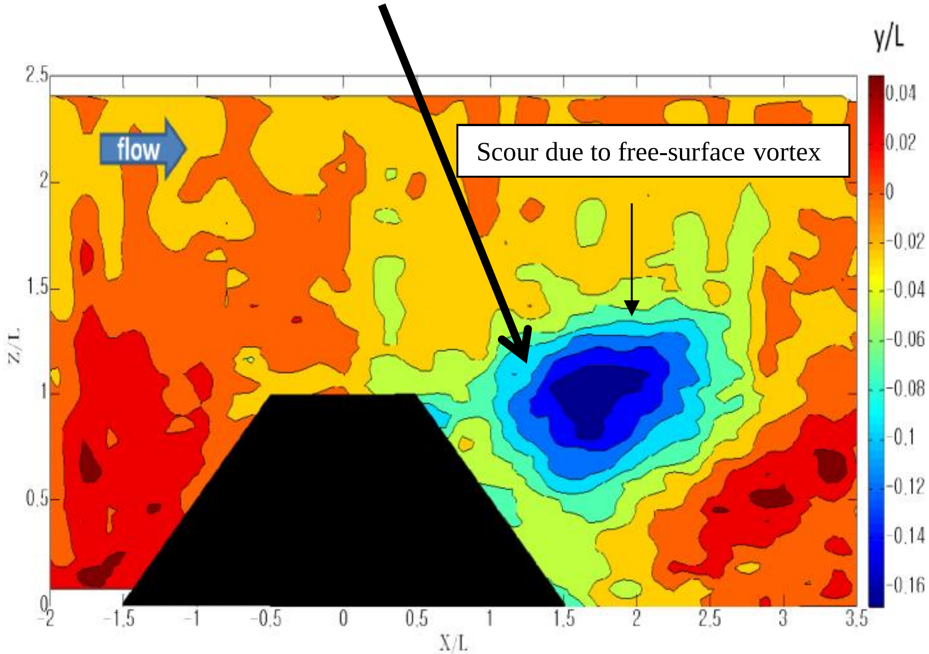
View of case #20 modified wing-wall abutment model with VGs. Note the free surface height change after the contraction due to the surface vortex.

Flume test results of a scAUR^{TM} model as a **spill-through bridge abutment** scour countermeasure

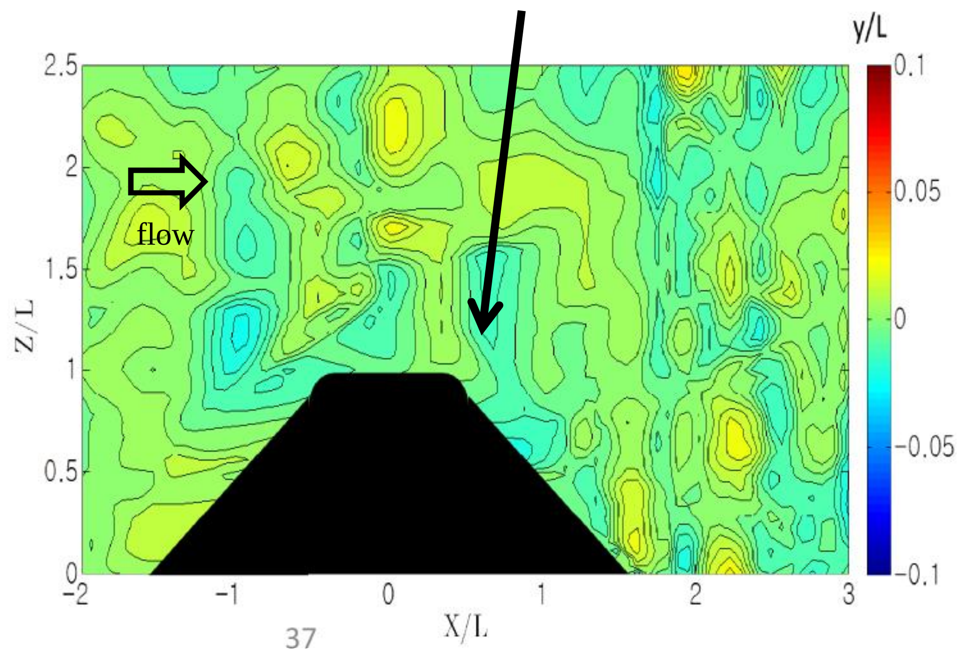
- The results demonstrate that with the scAUR^{TM} fairing and VorGAUR^{TM} devices around the abutment, the downstream scour hole is negligible.

Bed Elevation Contour of Flume Test Results

No scAUR^{TM} used - deep scour occurs



scAUR^{TM} used – no scour occurs !

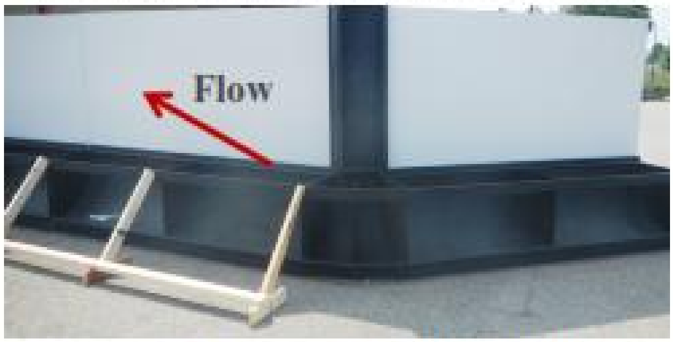


Permanent Solution: scAUR™ and VorGAUR™ Products

scAUR™ Steel Concrete Forms for New Construction

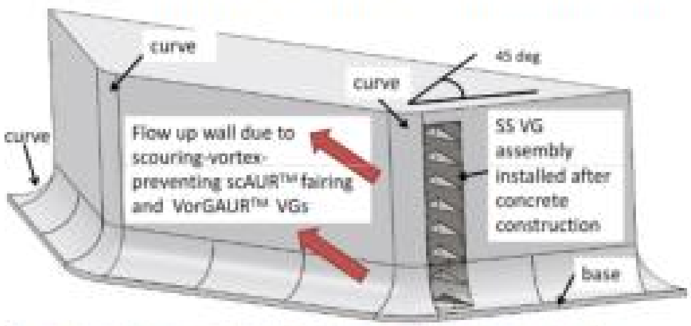
The best time to install at a fraction of retrofit cost!

Wing-wall abutment concrete forms

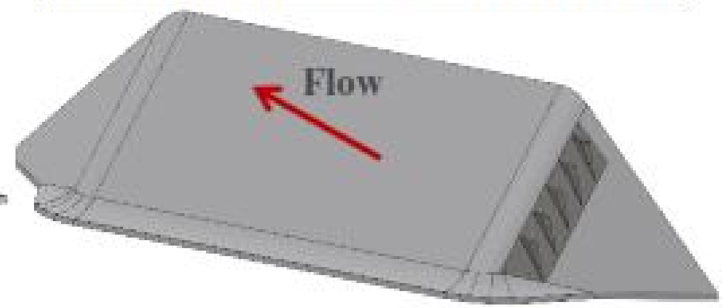


Spill-through abutment forms

Completed new construction abutment



Completed new spill-through abutment



Forms for new Piers

Modular interlocking forms permit quick and exact assembly and preserve the scAUR™ shape

Standard rebar methods for foundation construction

AUR, Inc.

Another Candidate Bridge

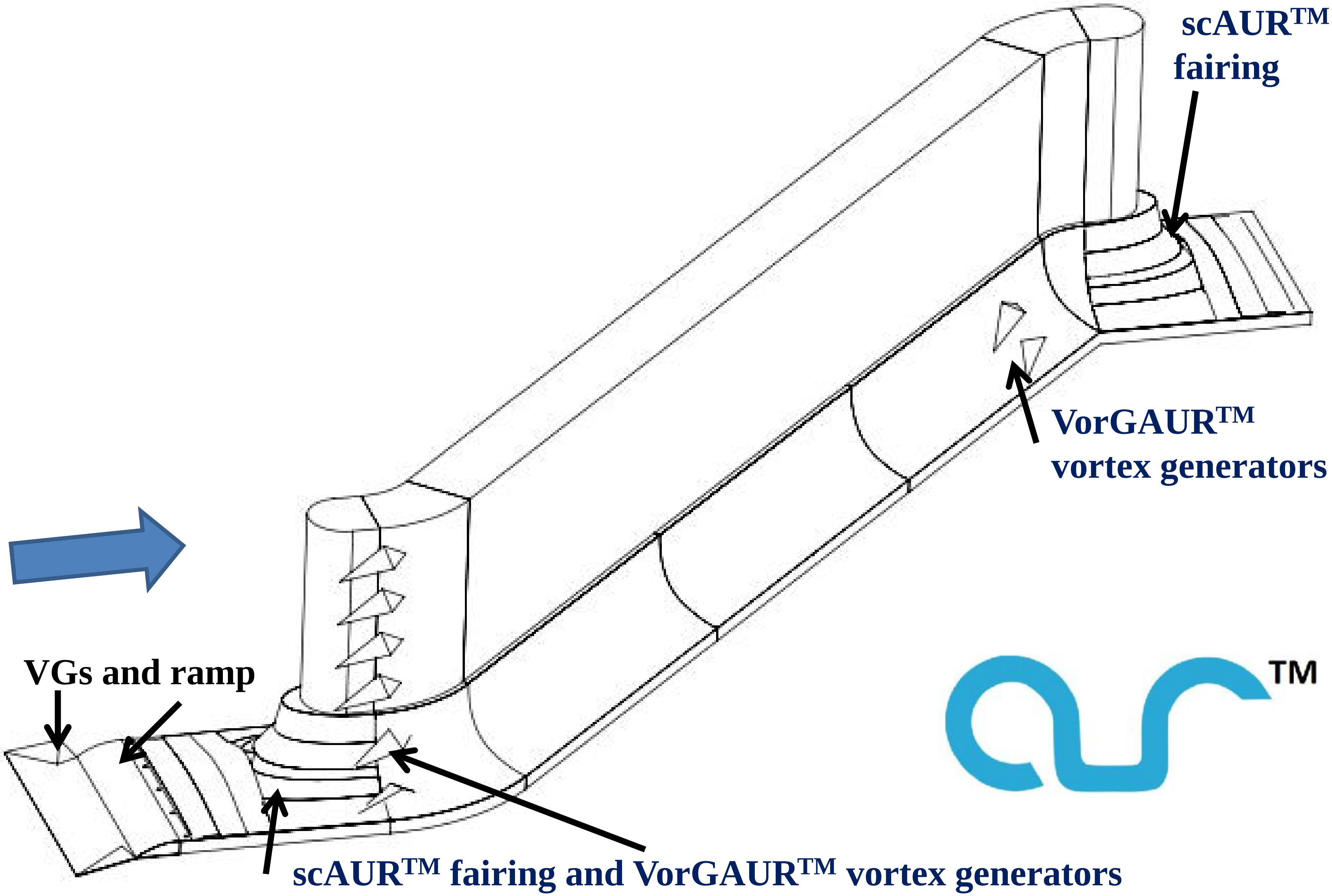
<u>Retrofit to a Bridge that suffered scour during a flood</u>

• Piers are at 45 degrees to the flow and require additional features and costs for scAUR™ and VorGAUR™ products to prevent scour.
• To prevent separation around the pier nose and tail during a flood, stainless steel nose and tail extensions to the pier are proposed, forming a "dogleg" shape. Centerline of pier nose and tail extensions and the nose and tail of the scAUR™ are aligned with the on-coming flow direction. VorGAUR™ vortex generators are used to energize the near-wall flow upstream of the adverse pressure gradient regions around the pier and prevent separation and scour.

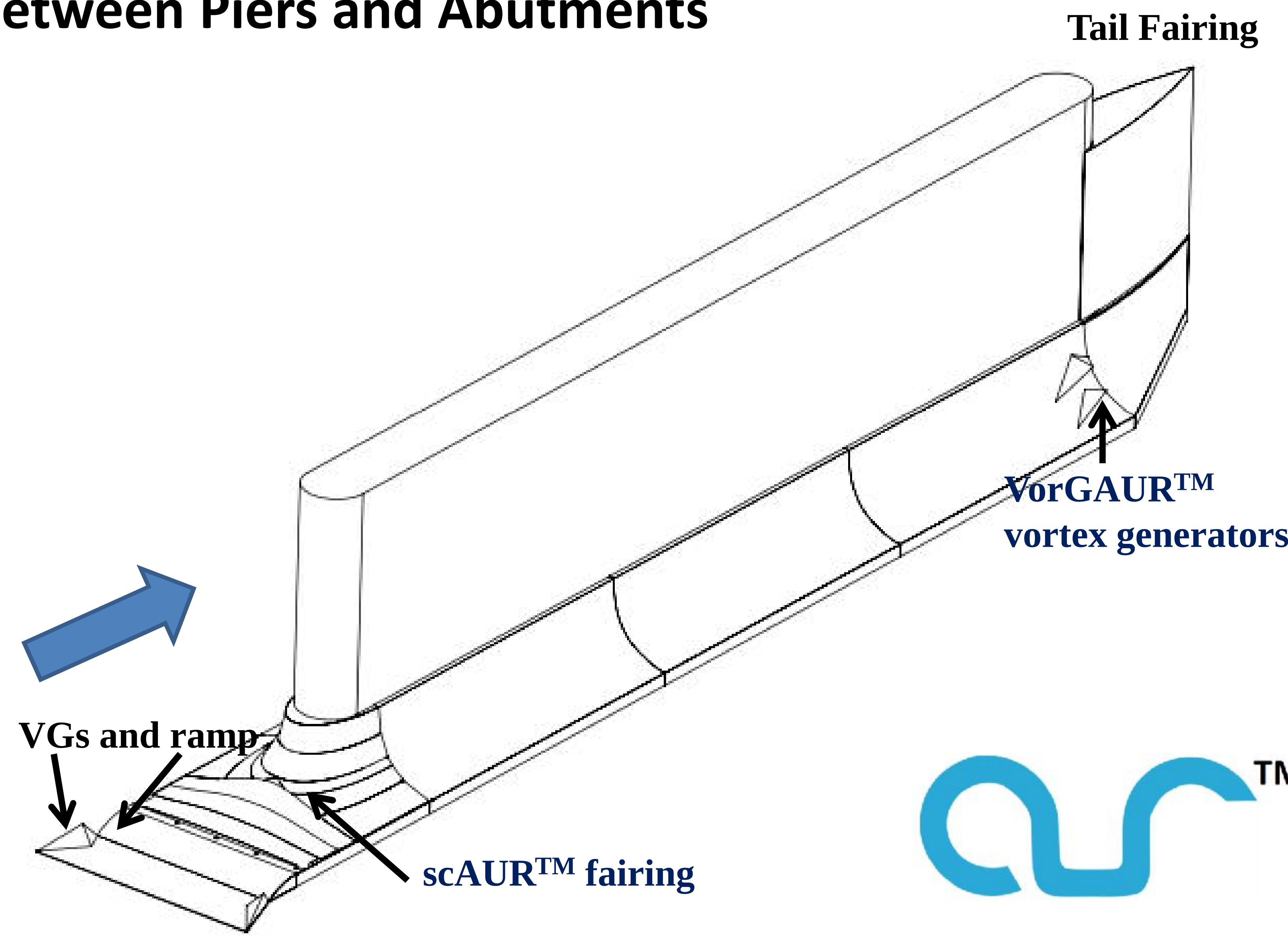
Photos of pier nose and stern additions to the AUR model used in AUR flume tests.

(left) Upstream view showing location of VGs on model front right and rear left sides. (right) Laser sheet showing no scour downstream of the model.

Dogleg For Pier at 45 degrees to Oncoming Flow



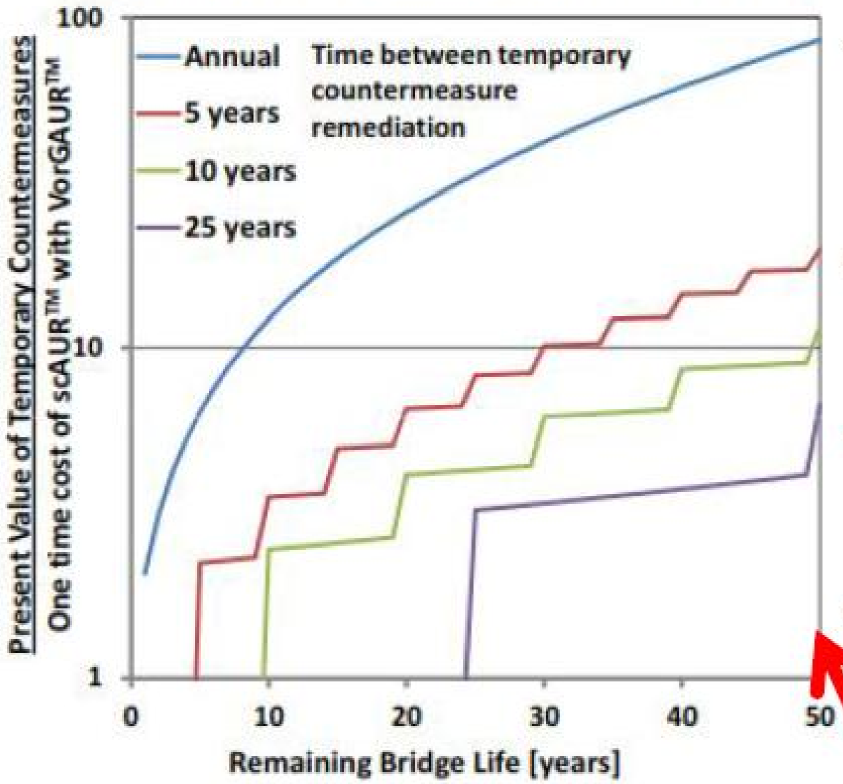
Pier Tail Assembly for Narrow Passages Between Piers and Abutments



Recurring Costs for Currently Used Temporary Pier and Abutment Scour Countermeasures

- 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.

Economics of Stainless Steel *scAUR*™ 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™ **Manufacturer AUR, Inc.**
aur@aurinc.com
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- Temporary scour countermeasures (TSC) carry compounding future costs (monitoring, inspections, engineering, remediation) with ***real present value.***
- ***scAUR***™ is a permanent sustainable scour prevention measure with a ***one-time cost***. **Stainless steel costs ½ as much as concrete.**
- ***scAUR***™ **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***™ 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™ ***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.

It is clear that stainless steel is the best choice for bridge retrofits

●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

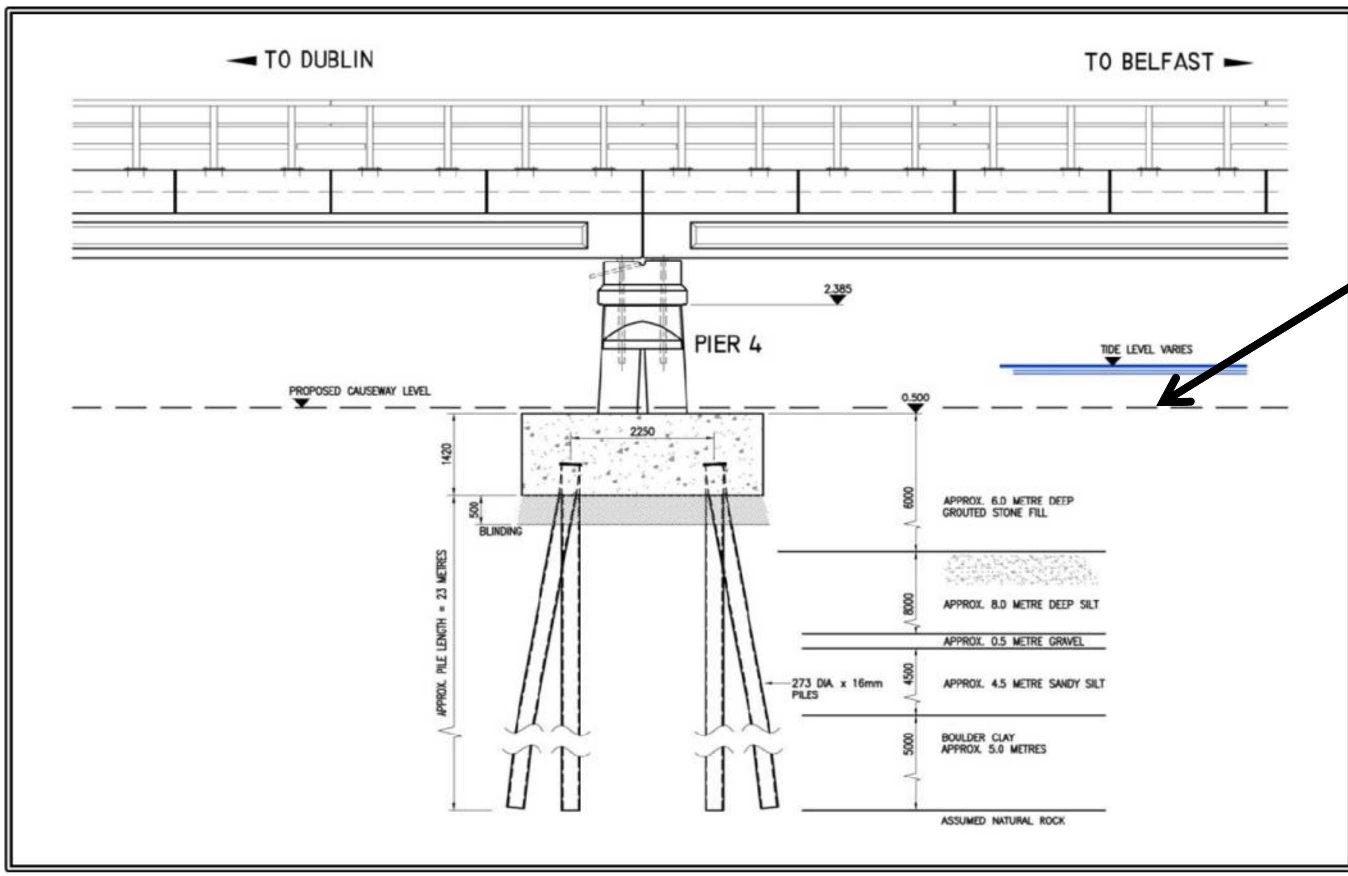
Estimated incremental costs of adding the scAUR™ fairing to new construction for additional rebar, concrete, labor, scAUR™ forms, and transportation of forms for various width pier construction for 32 foot long pier. Additional engineering, overhead, G&A, and profit are not included in these estimates.

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.

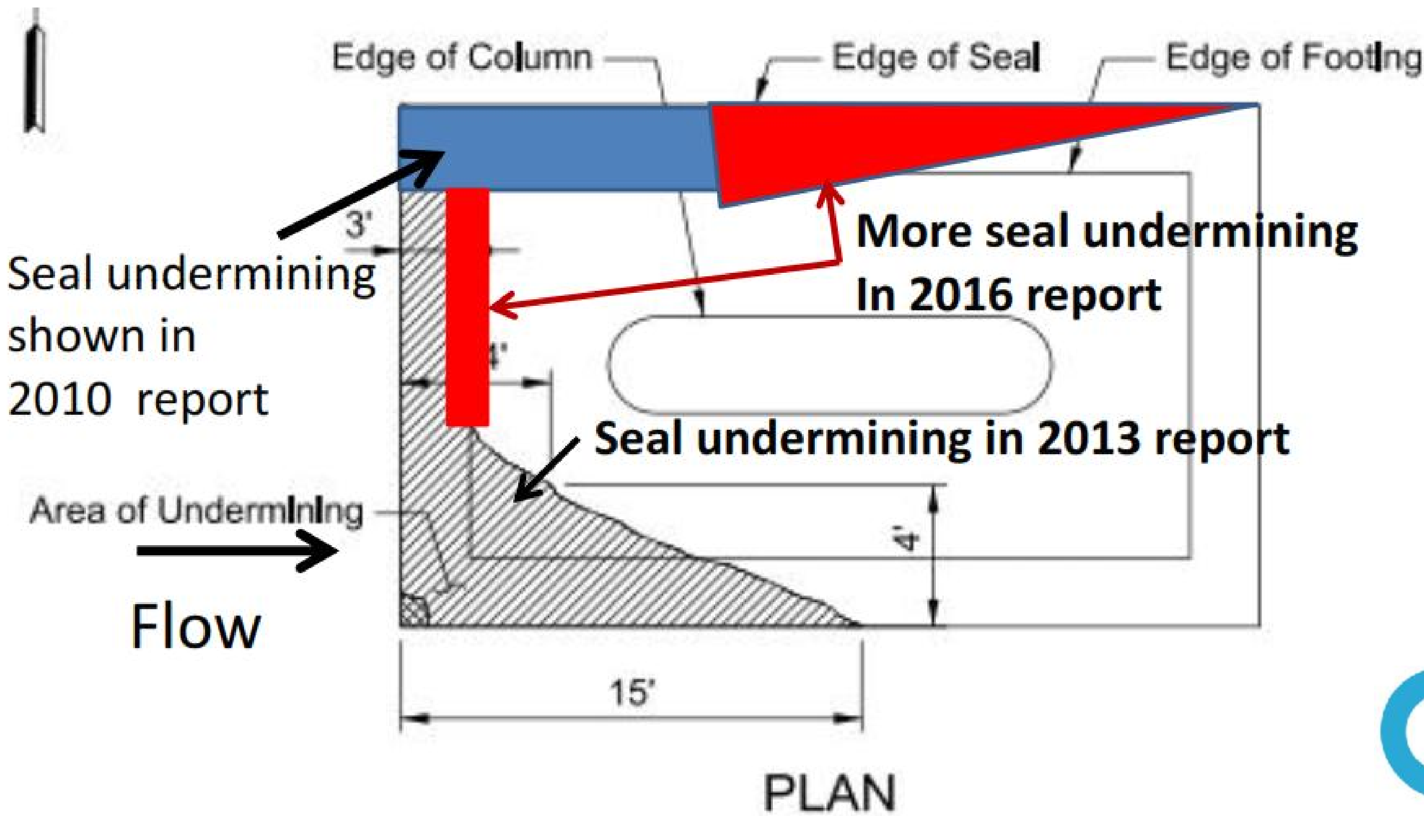
Elevation View



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

Example Case where scAUR™ with VorGAUR™ tetrahedral vortex generators will prevent scour – Bridge Owner Seeking Funding

Plan View of undermined areas of a concrete seal under a 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™ with VorGAUR™ products prevented the scour.</u>



Questions and Answers

We often encounter scour situations in streams below banks. Shotcrete faced soil with anchoring usually resist scour fairly well. Below the shotcrete wall we have clients that put in rip-rap, say, 12” to 24” size. What is the effectiveness of alternate materials to rip-rap, like mats and blocks?
We have a project where rapid drawdown after high river flows has caused significant settlement below our shotcrete wall.

All of the products and methods that you mention work to some degree. Large rip-rap has been known to be carried away by scour. The major problem is that at the bottom or edge of the treatment, soil and rocks under the treatment get washed out by high velocity water and the treatment effectiveness is lost. AUR has done scale model tests on rip-rap and other devices, but all of them do not prevent scour during super flood conditions at their edges. Undermining along edges of treatment is a problem unless you bring the lower velocity flow toward the edge. Compared to some other products, the **streamlined scAUR™ fairings with vorGAUR™** are cost competitive and they have been proven to work.

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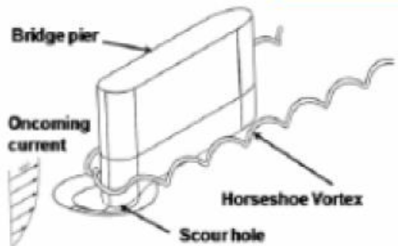
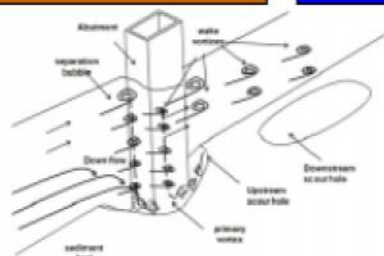
Causes of Bridge Scour





Bridge scour is produced by discrete vortices formed around unprotected piers (left above) and abutments (right). Many near catastrophes and loss of life have occurred, as shown in examples below.

Loon Mountain Bridge (Lincoln, N.H.) collapsed due to heavy scouring around the abutment after 11" of rain.

Scour caused Irish railway bridge pier collapse minutes after passage of a full Dublin-to-Belfast commuter train, 3 September 2009.

scAUR™ with VorGAUR™ products will prevent such failures.

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.

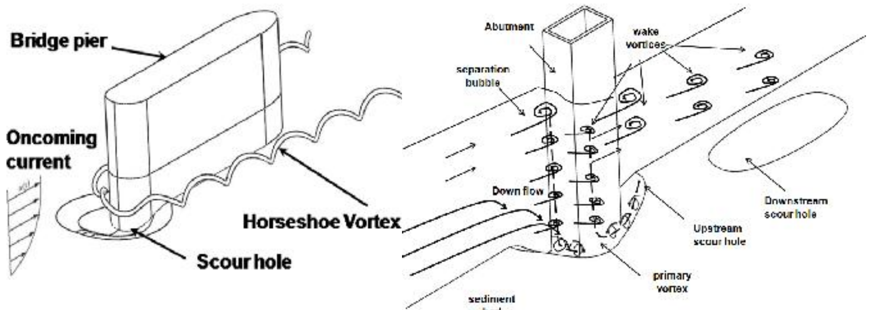
Example AUR flume test of pier with scAUR™ and VorGAUR™ - NO SCOUR! Note scour on cylinder.

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.

AUR, Inc. aur@aurinc.com Ph: 540-961-3005 Fax: 866.223.8673

Bridge Scour is Prevented by the Use of scAUR™ and VorGAUR™ that Prevent Scouring Vortices



Bridge scour is produced by discrete vortices formed around unprotected piers (left) and abutments (right)

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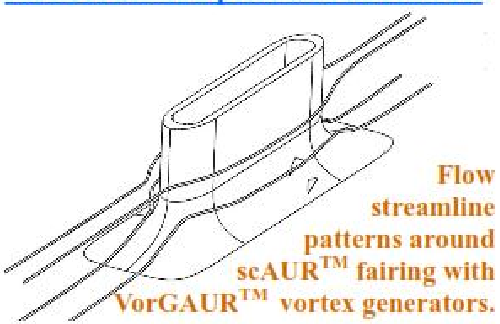
P14- 4077
P14- 5140

Full-Scale Prototype Testing and Manufacturing and Installation Plans for New Bridge-Scour-Prevention scAUR™ and VorGAUR™ Products: NCHRP IDEA Project 162

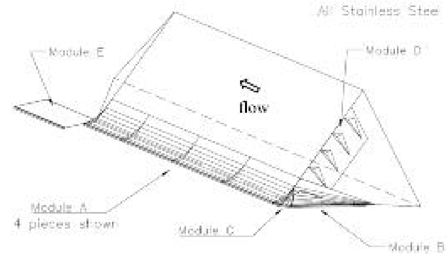
- **About 60% of bridge failures in the U.S. are due to scour (1)**
- **Over 20,000 scour-critical U.S. bridges are in danger of failure, because of scour around the piers and abutments (1).**
- **HEC 23: Rip-rap countermeasures for scour are unacceptable for new bridges; Use streamlined piers and abutments.**

Sustainable Solution : scAUR™ (2) streamlined fairings with VorGAUR™ (2) vortex generators prevent scouring vortices around piers and abutments



Flow streamline patterns around scAUR™ fairing with VorGAUR™ vortex generators.

TYPICAL APPLICATION
Scour Preventing scAUR™ and VorGAUR™ on New or Retrofit 45 degree spill-through abutment.



- **scAUR™ fairing and VorGAUR™ products prevent scouring vortices at both model and full scale.**
- **scAUR™ and VorGAUR™ products prevent scouring vortices around piers & abutments downstream of river bends.**
- **Tests show that they prevent scour at incident flow angles of attack up to 45 degrees with special design features.**
- **Tests prove that they prevent local scour for a large range of bed materials.**
- **INCREASES FLOW RATE AROUND PIERS AND ABUTMENTS**

Prevents foundation scour when there is open-bed scour.

Open Bed Scour Case: scAUR™ full-scale model with VorGAUR™ VGs raised 3" above gravel bed with leading edge curved ramp whose stream-wise vortex brings bed material toward foundation. Looking downstream (middle photo) and looking upstream (right).

Manufacturing and Installation for Piers and Abutments

Retrofits - Prefabricated scAUR™ fairing with VorGAUR™ stainless steel units are the most cost effective, easy to install, and reliable for a long life compared to concrete.

New Construction - Steel scAUR™ fairing concrete forms replace foundation concrete forms. Low costs.

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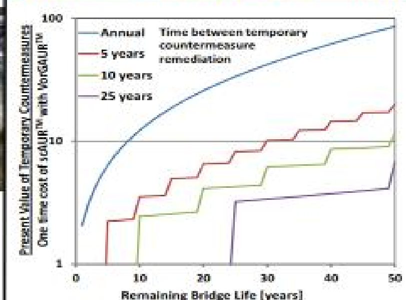
The economics of stainless steel scAUR™ with VorGAUR™ units



Cost of current temporary countermeasures ALWAYS MORE than the cost of scAUR™ after ONE scour mitigation.
Risk and liability of bridge failure is ALWAYS LESS WITH scAUR™.
Plans complete for installation on a scour-critical bridge: US 360 over the Appomattox River, VA

1.Beatrice E. Hunt (2009), Monitoring Scour Critical Bridges, NCHRP Synthesis 396.
2.scAUR™ in US Patent No. 8,348,553 and VorGAUR™ in US Patent No. 8,434,723.

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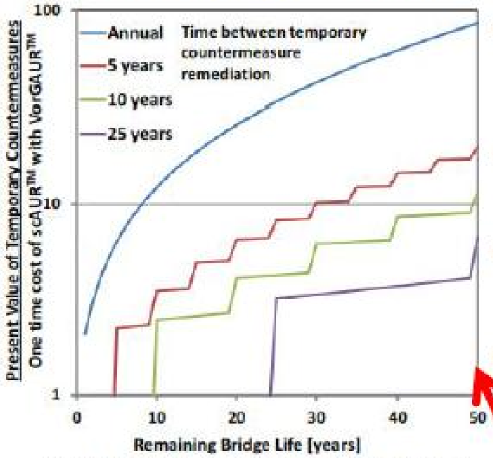
Economics of Stainless Steel *scAUR™* Retrofits



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™ Manufacturer AUR, Inc.
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- Temporary scour countermeasures (TSC) carry compounding future costs (monitoring, inspections, engineering, remediation) with ***real present value.***
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- **<u>*scAUR™* prevents catastrophic failure risk and liability due to local scour and saves >90% of present value of TSC.</u>**
- The methods of **HYRISK** used to compare *scAUR™* 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™* is the clear economic choice for bridges with or likely to have severe local scour.**

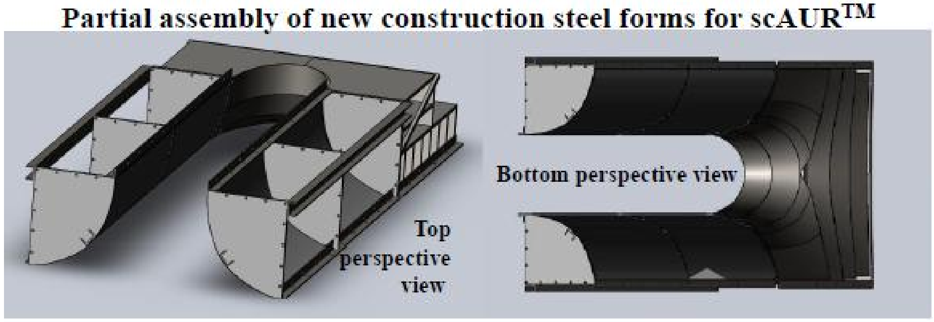
3

Manufacturing and Installation Processes

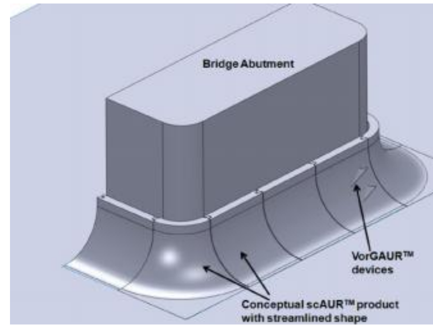
<u>New construction – Cast-in-place Concrete – 1/3 Cost of Retrofit</u>

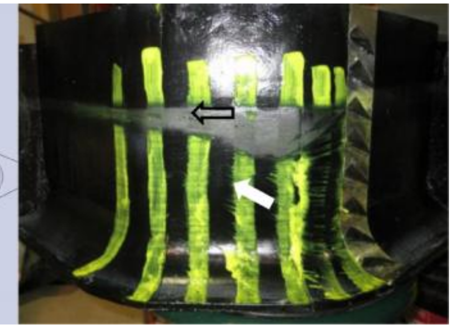
- **<u>Only difference with current practice</u>: <u>use scAUR™ steel forms for concrete</u>**
- All standard current concrete construction methods and tools used.
- Bridge pier or abutment foundation or footer top surface width and length large enough for scAUR™ concrete fairing on top.
- Rebar for the scAUR™ concrete included in the foundation during construction.
- Stainless steel rebar for welding to stainless steel vortex generators mounting plates on the surface used for specific locations.

Partial assembly of new construction steel forms for scAUR™



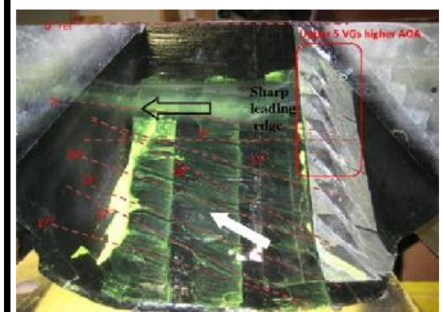
<u>ALL Designs of Piers and Abutments are Permanently Protected from Scour by Vortex-preventing scAUR™ and VorGAUR™</u>





Vertical abutment **Wing-wall abutment**

Vortex-preventing scAUR™ with VorGAUR™ cause near-river-bottom water to move up abutment and piers



Spill-through abutment

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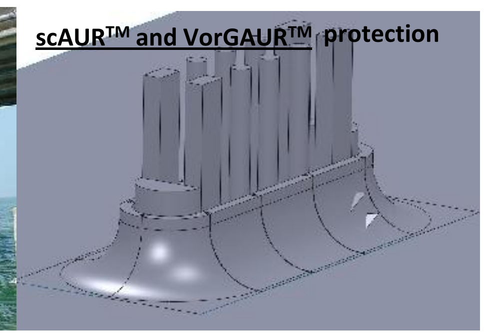
Fax: 866.223.8673

TM

Multiple pier arrangements



Protects coastal structures for 100 years

P15-5259

Low-Cost Scour-Preventing Streamlined Fairings for Bridges

www.noscour.com

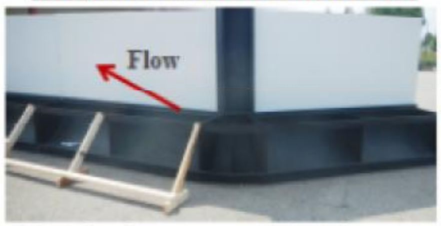
Permanent Prevention of Bridge Scour: scAUR™ and VorGAUR™ Products

Designs for all types of piers and abutments | **Designed and built to meet AASHTO and ACI Standards**

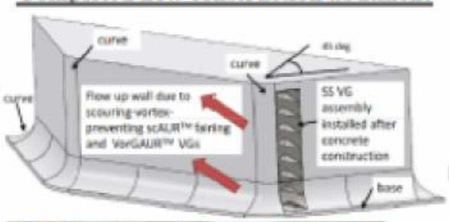
scAUR™ Steel Concrete Forms for New Construction

The best time to install at a fraction of retrofit cost!

Wing-wall abutment concrete forms

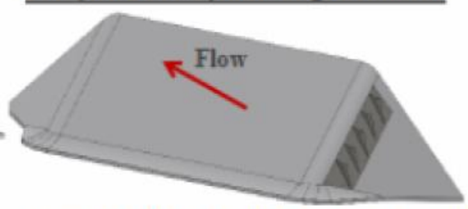


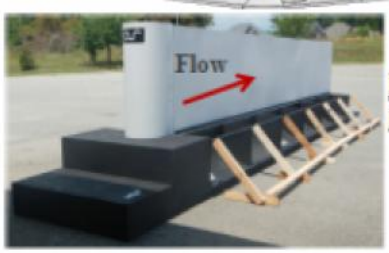
Completed new construction abutment



Spill-through abutment forms

Completed new spill-through abutment





Forms for new Piers

Modular interlocking forms permit quick and exact assembly and preserve the scAUR™ shape

Standard rebar methods for foundation construction

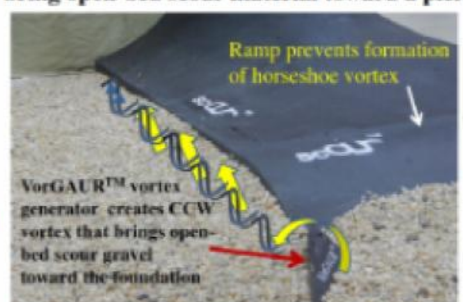
Modular Stainless Steel (SS) Retrofits for Existing Bridges

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

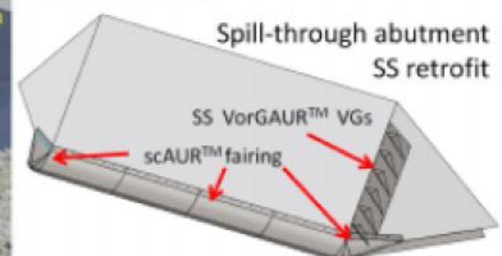
Example stainless steel scAUR™ retrofit (black) for a 45° wing-wall abutment. Note SS vortex generators.

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



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

<u>Scour should be estimated using the peak velocities observed for the river.</u>

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.

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

<u>Scour protection: Prevent high velocity water from coming into contact with erodeable river bed materials</u>. 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.

AUR Permanent Solution scAUR™ with VorGAUR™ vortex generators:
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**.