NCHRP-IDEA Project 162 Final Report

Full-Scale Prototype Testing and Manufacturing and Installation Plans for New Scour-Prevention scAUR™ and VorGAUR™ Products for a Representative Scour-critical Bridge in Virginia

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The Virginia Center for Transportation Innovation and Research
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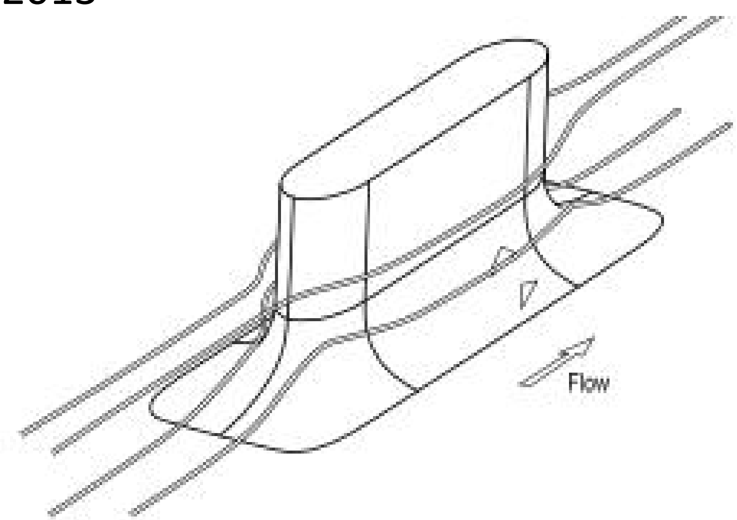
Applied University Research, Inc.



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Conclusions from NCHRP-162

scAUR™ with VorGAUR™ prevent bridge scour

● Computational fluid dynamics (CFD) results for model and full-scale piers show that the **scAUR™ fairing is effective in preventing scour producing vortices at both model and full scale.**

● **At higher Reynolds numbers and larger pier sizes**, pressure gradients and turbulent fluctuation stresses are lower than at model scale, so **the possibility of scour at the same flow speed is lower**, as supported by other NCHRP studies of model and full-scale results.

● Other CFD by AUR shows that **scAUR™ and VorGAUR™ products also prevent scouring vortices around bridge piers downstream of bending rivers.**

● **No scour was observed** around the scAUR™ with VorGAUR™ pier model **for any smaller gravel in the susceptible scour range, 38.1 < *t/d50* < *64.6*,** recommended by previous researchers. Here *t/d50* is the ratio of pier width to median sediment grain diameter. (Final Report Reviewer #5: "The selection of t/d50 near 50 was an astute decision.")

Conclusions from NCHRP-162 (cont.)

● **scAUR^{TM} and VorGAUR^{TM} products prevent scour on vertical wall, spill-through, and wing-wall abutments** in model scale AUR flume tests. Will work as well or better at full scale.

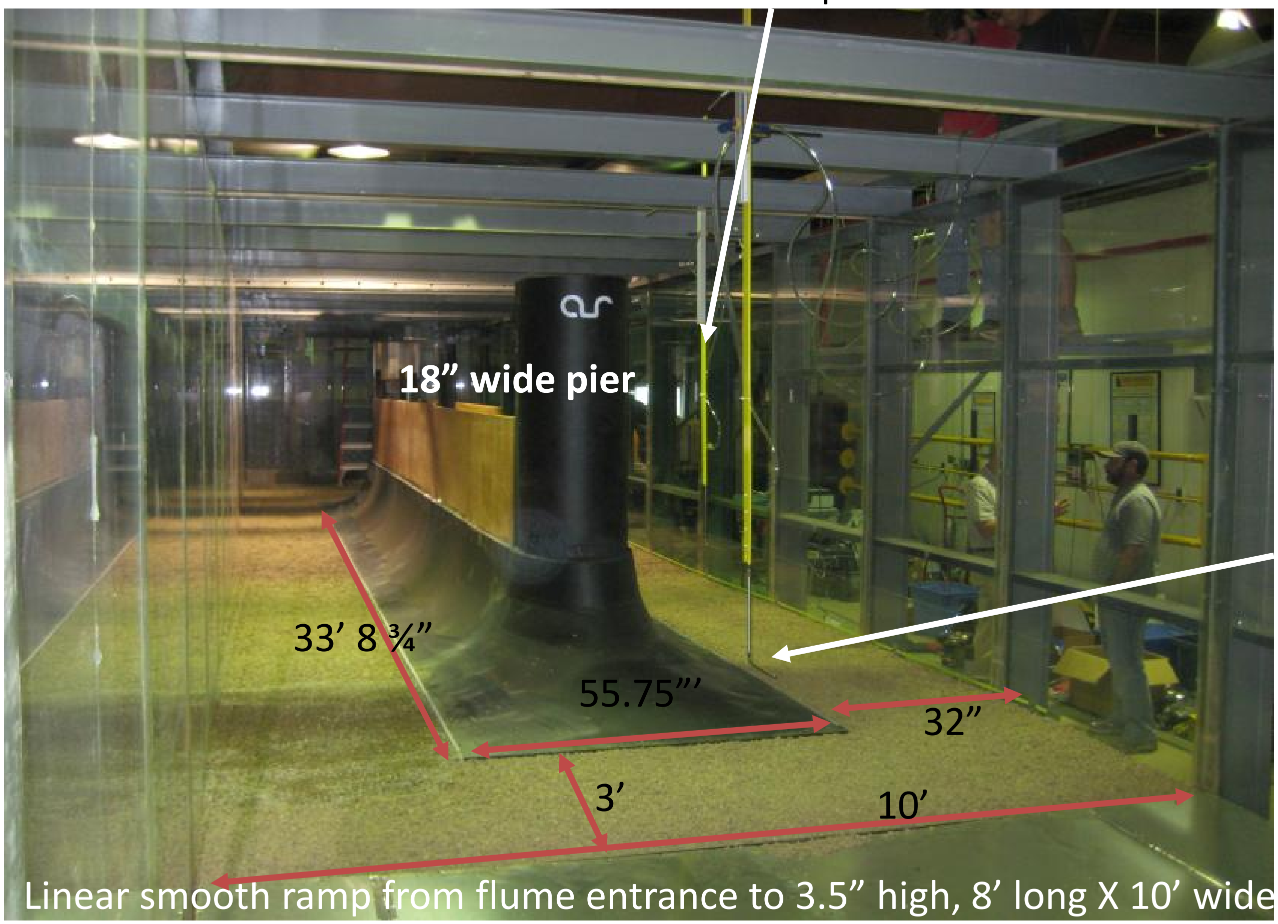
● **A curved ramp fairing surface (Patent Pending) in the front of the scAUR^{TM} fairing foundation prevents undermining of the foundation by open bed scour for piers and abutments and was tested successfully in the AUR flume and at full-scale.**

● **Full-scale tests of** scAUR^{TM} and VorGAUR^{TM} products under 5 different configurations **were conducted in a large flume**, **with no scour around the model**, after full-scale model flow blockage effects were considered, which were comparable to results for the 1/7 size models in the AUR flume.

<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

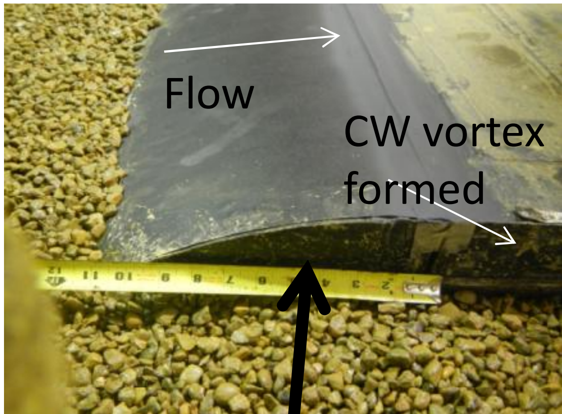
2nd pitot static probe for flow velocity between the pier model and the flume side wall
6” below water surface
3’ upstream from the front fairing



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

View from upstream

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



Straight-sided leading edge curved ramp

Straight-sided curved ramp prevented scour around the upstream and sides of the exposed foundation, <u>protecting the foundation from open bed scour.</u>

Looking upstream

Manufacturing and Installation Processes (1)

<u>Retrofit to an Existing Bridge – 3 alternatives</u>

- **Pre-cast or cast-in-place concrete scAUR™ components** (AUR experience with molds, forms , prototype scAUR™ pre-cast components, so the process and costs are known.)
- **"Shotcrete" examined for a concrete scAUR™ fairing as a retrofit to a bridge.** Many sources of failure and the <u>shotcrete process is not a cheaper alternative to pre-cast concrete</u> when its uncertain quality and the likelihood of correcting mistakes are considered.
- **Stainless steel (SS) is most attractive for a scAUR™ retrofit bridge fairing .** Its <u>corrosion resistance gives it a lifetime of 100 years</u> even in seawater environments, using a proper thickness, construction methods, and type of SS. It is an <u>effective way to reduce weight and the cost associated with casting custom reinforced concrete structures</u>. Another benefit is that the SS VorGAUR™ vortex generators could be welded directly onto the side sections instead of having to be integrated into the rebar cage of the reinforced concrete structure.

Manufacturing and Installation Processes (2)

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>

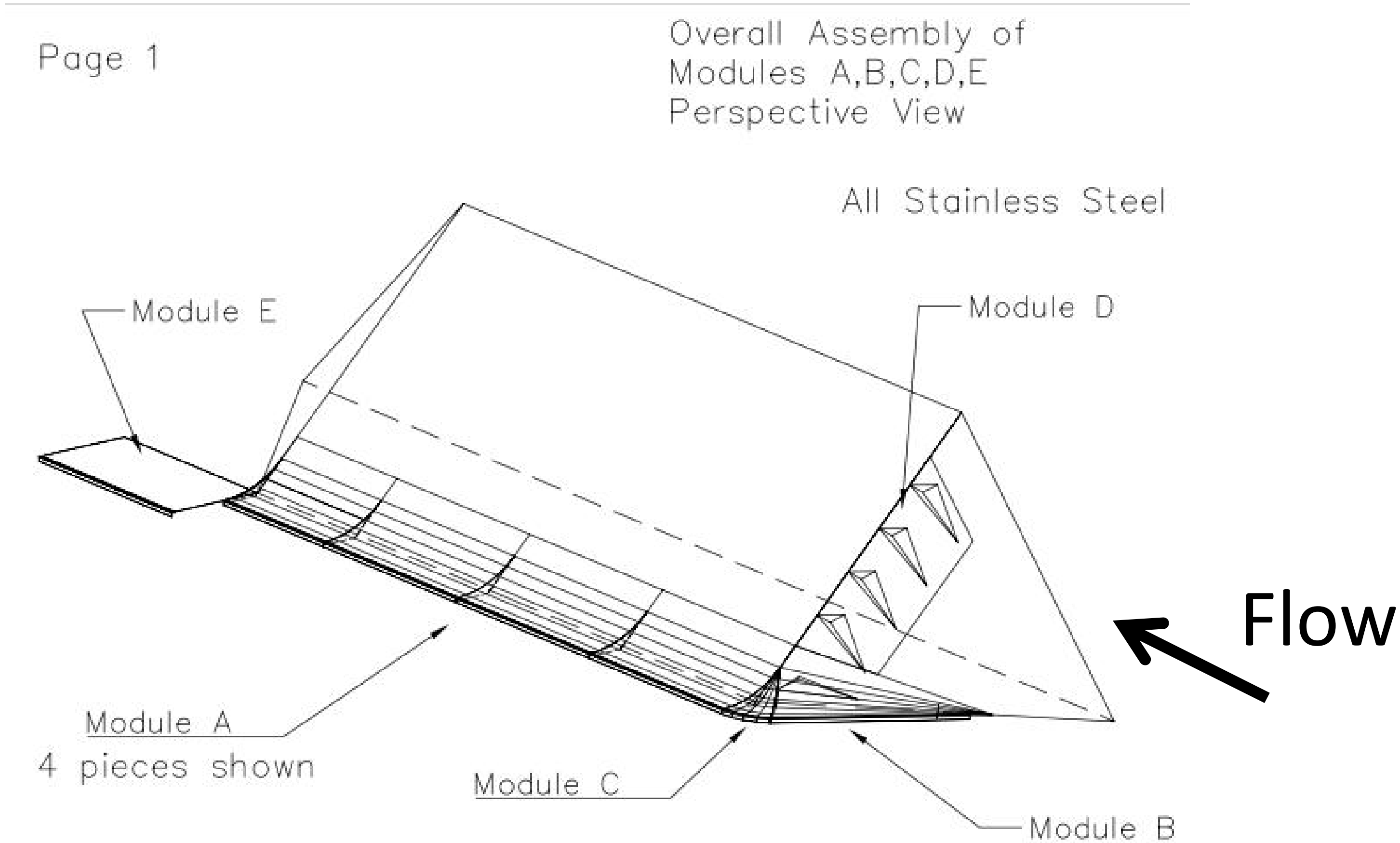
●Costs developed from current cost information and quotations from concrete and steel fabricators and construction costs websites.

● 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 (3)

A similar cost study for <u>abutments</u>, also shows similar relative costs for the 3 approaches. The total cost for a 32' long <u>spill-through or wing-wall stainless steel abutment is $25K</u>.



Example stainless steel scAUR™ retrofit for a spill-through abutment.

Manufacturing and Installation Processes (4)

New construction – Cast-in-place Concrete

● **Only difference with current practice**: **use scAUR™ steel forms for concrete (ACI 318-11)**

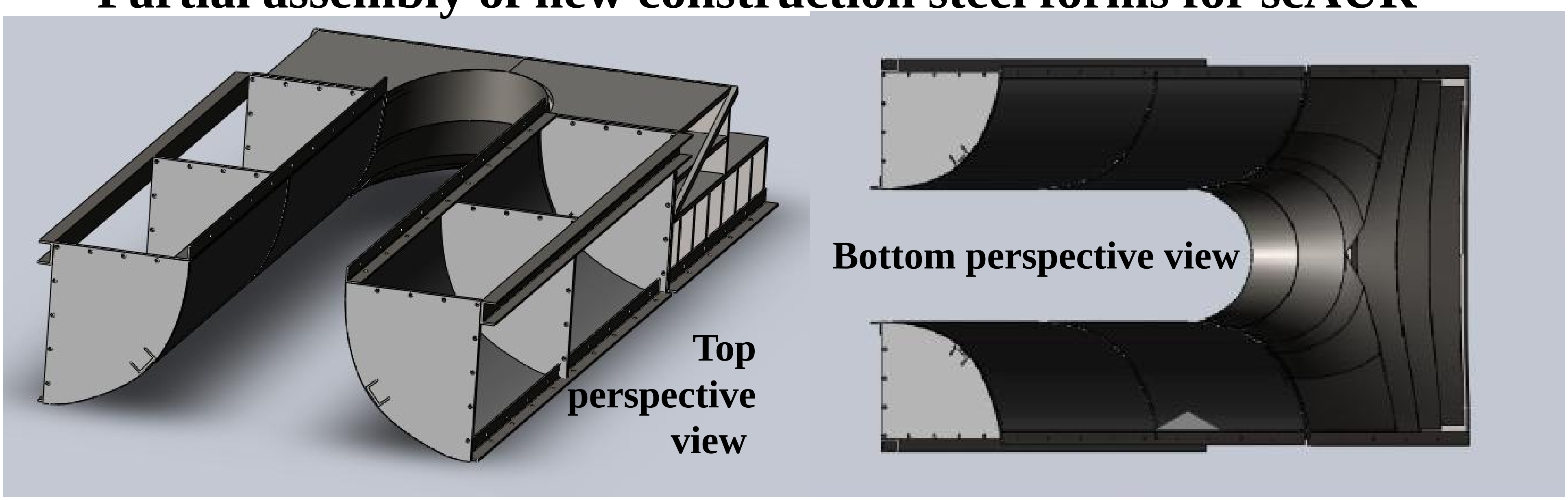
● All standard current concrete construction methods and tools used.

● 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™



Manufacturing and Installation Processes (5)

Incremental Cost for New construction

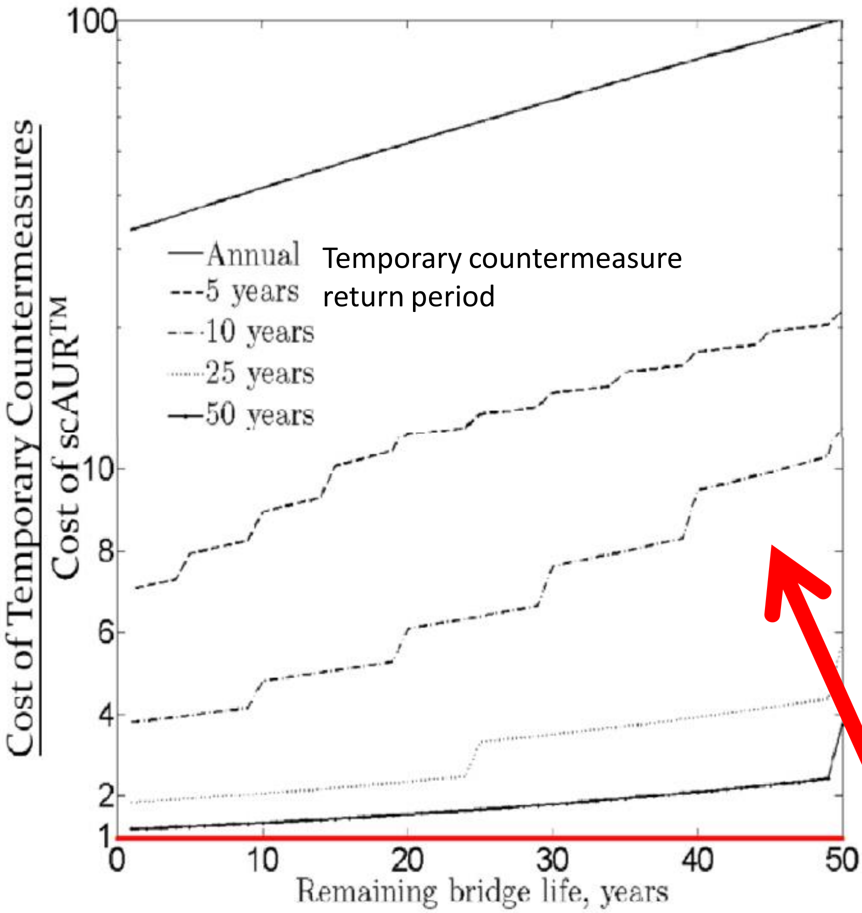
	Pier Width (ft)					
	1.5	2	3	4	5	6
Cost of added materials & labor	$3,340	$ 5,690	$13,200	$25,100	$41,800	$64,100
Cost of steel scAUR form fabrication	$1,400	$2,490	$ 5,600	$ 9,960	$15,600	$22,400
Cost of form transportation (in VA)	$2,000	$2,000	$ 4,000	$ 4,000	$ 6,000	$ 6,000
Total cost for new construction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

Estimated <u>incremental costs</u> of adding the scAUR^{TM} fairing to new construction for additional rebar, concrete, labor, scAUR^{TM} 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^{TM} fairing on piers is during new construction.

The Economics of ***scAUR***^{TM}

(Pre-cast Concrete Example; <u>Stainless steel even better!</u>)



Computed with 7% inflation and 5% tax exempt interest.
Example of a bridge with six piers and two abutments requiring protection.

- Temporary countermeasures carry compounding future costs with ***real present value.***
- ***scAUR***^{TM} is a permanent countermeasure with a ***one-time cost***.
- **<u>scAUR™ prevents the risk of catastrophic failure due to local scour.</u>**
- At left, the methods of **HYRISK** were adapted to compare scAUR^{TM} to temporary countermeasures.
  - Risks due to temporary countermeasures incur substantial costs.
  - 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.***

Payoffs

.The payoffs for practice that were identified by the earlier AUR work and confirmed by the NCHRP- 162 Project are:

1. **Permanently prevent the formation of local scouring vortical flows due to flow separation** around bridge piers and abutments of any width to length ratio that cause local scour for any size or scale bridge pier or abutment.
2. **Permanently prevent local scour**, even at large angles of stream crossflow or swirling flow due to river bends.
3. **Much lower present value of present and future scour mitigation costs** as compared to current approaches.
4. **Lower drag force, flow blockage, water level, and over-topping frequencies on bridges during flood conditions, for any water level or turbulence level.**
5. **Debris accumulation prevention and piers and abutments protection from impact loads.**
6. **High quality proven-technology prefabricated stainless steel or cast concrete components** for quality control and rapid installation.
7. **More stability for the soil and rocks surrounding the piers and abutments.**
8. **100 year or more lifetimes and longer bridge life.**

Reviewers' Recommendations – Future Steps

NONE of the 7 reviewers disputed the results or were critical of the work.

Reviewer 1. "The research appears thorough and the results encouraging. The research has reached a point where **more focus is needed on field installations since that is the proof of true effectiveness.** However, the IDEA program has done its part and, hopefully, the PI will be able to carry on with further implementation."

Reviewer 2. "I am not an expert on the topic. For a general reader the report has a lot of very good Technical Information. **I suggest that they contact more state DOTs and present the results in events where there is a major gathering of bridge engineers from state DOTs."**

Reviewer 5. **This product seems very promising** and should be sent to the AASHTO Technical Committee On Hydrology and Hydraulics for review, comment, and possible further testing recommendations."

Reviewer 6. "**I am pleased to see Virginia DOT interest in a pilot application** and hope to hear about the results."

Reviewer 7. "It is a good report. It shows potential for a break through but the final proof depends on how it works in an actual field implementation which is planned with one or two scour critical bridges in Virginia they have selected. It will be interesting to see in the future how the implementation on Virginia bridge works, provided funding is secured from FHWA to do so."

Primary Candidate Virginia Bridge

Route 360 Westbound Bridge over the Appomattox River

- **Selected since it is a relatively new bridge and has at least two piers, a high average daily traffic, and a scour-critical rating of three or lower and available streamflow data for a substantial waterway. Year built: 1982; ADT: 8,995 vehicles per day; Spans: 3; Piers: 2; Scour rating: 3.**

- The July 2008 Inspection Report (taken from uglybridges.com) indicates that for <u>channel protection,</u> "Bank is beginning to slump. River control devices and embankment protection have widespread minor damage. There is minor stream bed movement evident. Debris is restricting the channel slightly.[level 6]". **For <u>scour protection</u>, the "Bridge is scour critical; bridge foundations determined to be unstable. [level 3]."**

- It appears that the two piers have very similar flow exposure and sediment erosion. Even though the footing is only exposed on pier 2, both have had scour problems and sediment erosion. It has consistent flow conditions.

- The inspection report also has a recommendation to place "rip rap in eroded areas under structure and along exposed Pier 2 footing". **The scAUR™ retrofit could be placed instead of rip rap and provide a good full-scale test**

Primary Candidate Virginia Bridge

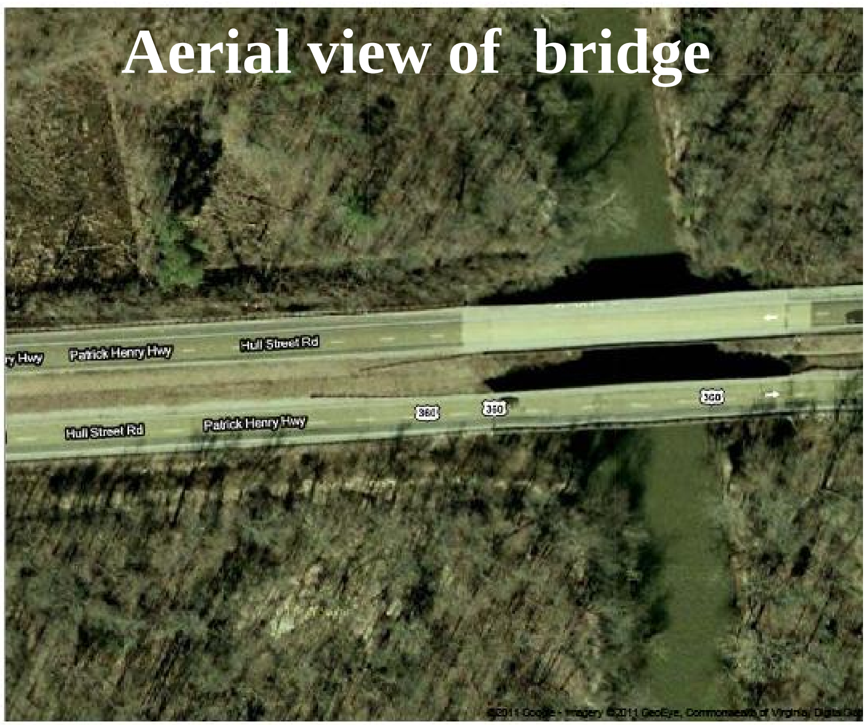
Route 360 Westbound Bridge over the Appomattox River

<u>Some Features</u>

● **Two 2 foot wide piers 36 feet long semi-circular nose and stern piers on the westbound bridge**

● **Concrete footer or foundation of each pier of about 6 feet wide with a flat top.**

● **While currently covered with 1’ – 2’ diameter rip-rap rocks, the east abutment of the westbound lanes appears to be a spill-though type.**



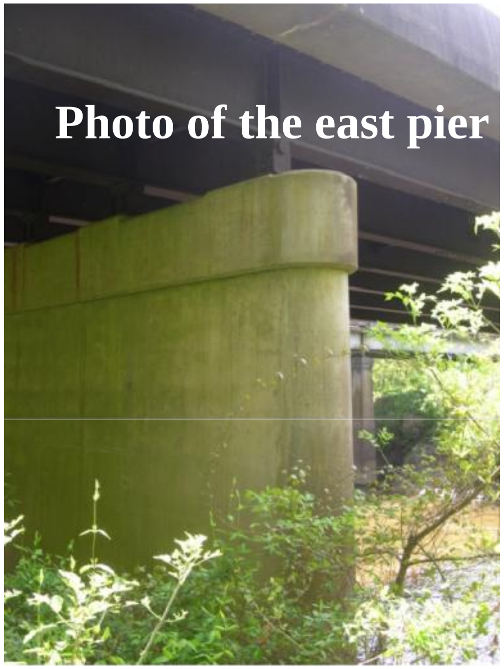
Aerial view of bridge

Photo of the east pier

Primary Candidate Virginia Bridge

Route 360 Westbound Bridge over the Appomattox River

<u>Estimated Retrofit Costs Using scAUR™ with VorGAUR™</u>



Right - East abutment covered with 1' to 2' rip-rap. (AUR photos, April 24, 2013)

- **<u>scAUR™ with VorGAUR™ cost for one pier - all components and installation about $32K.</u>**

- **Installation for an abutment would cost $25K.**

- **Additional engineering, overhead, G&A, and profit are not included in these estimates.**

<u>Specific plans</u> for the manufacture and installation of full-scale scAUR™ and VorGAUR™ products for the Rt 613 bridge over the Dry River

Aerial photo of the Route 613 Bridge over the Dry River in Rockingham County, Virginia HTRIS No. 15949. (Google maps, 2012)

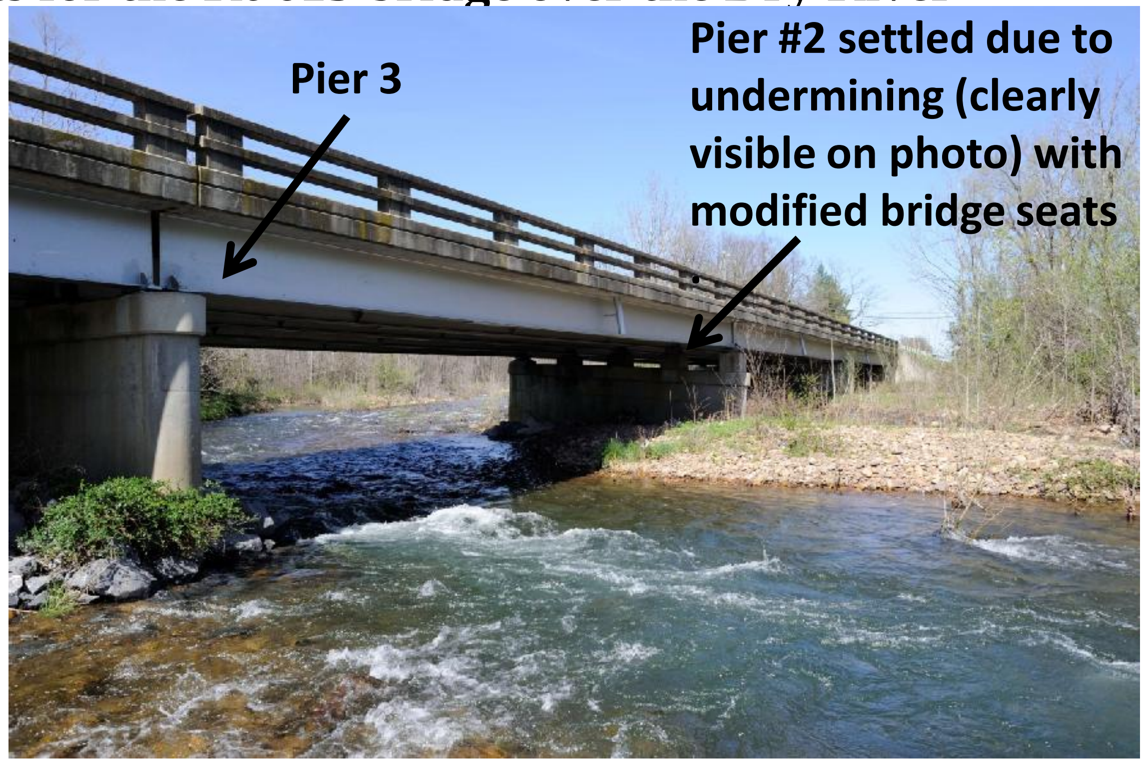


Photo of the Route 613 Bridge over the Dry River in Rockingham County, Virginia. HTRIS No. 15949. (Photo courtesy of Dr. Edward Hoppe, P.E., of VDOT)

POTENTIAL DRAWBACKS: Clearly unequal flow conditions exist on piers 2 and 3 and the abutments, so no comparisons can be made between piers and abutments without and with **scAUR™ and VorGAUR™** .

Inflow to the piers is at 45 degrees, requiring additional scAUR™ and VorGAUR™ features and raising the costs.

Another Candidate Virginia Bridge

Retrofit to Route 613 Bridge over the Dry River

- **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.

Another Candidate Virginia Bridge

Retrofit to Route 613 Bridge over the Dry River

- **Model scale experiments in the AUR flume confirm that this design prevents scour.**

- **Manufacturing and installation processes and methods would be the same as for the Route 360 bridge .**

- **Cost of $39K for one pier is higher due to the addition of the additional components required for the SS dogleg.**

- **An abutment total cost would be about $32K, also reflecting additional costs.**

- **Additional engineering, overhead, G&A, and profit are not included in these estimates.**