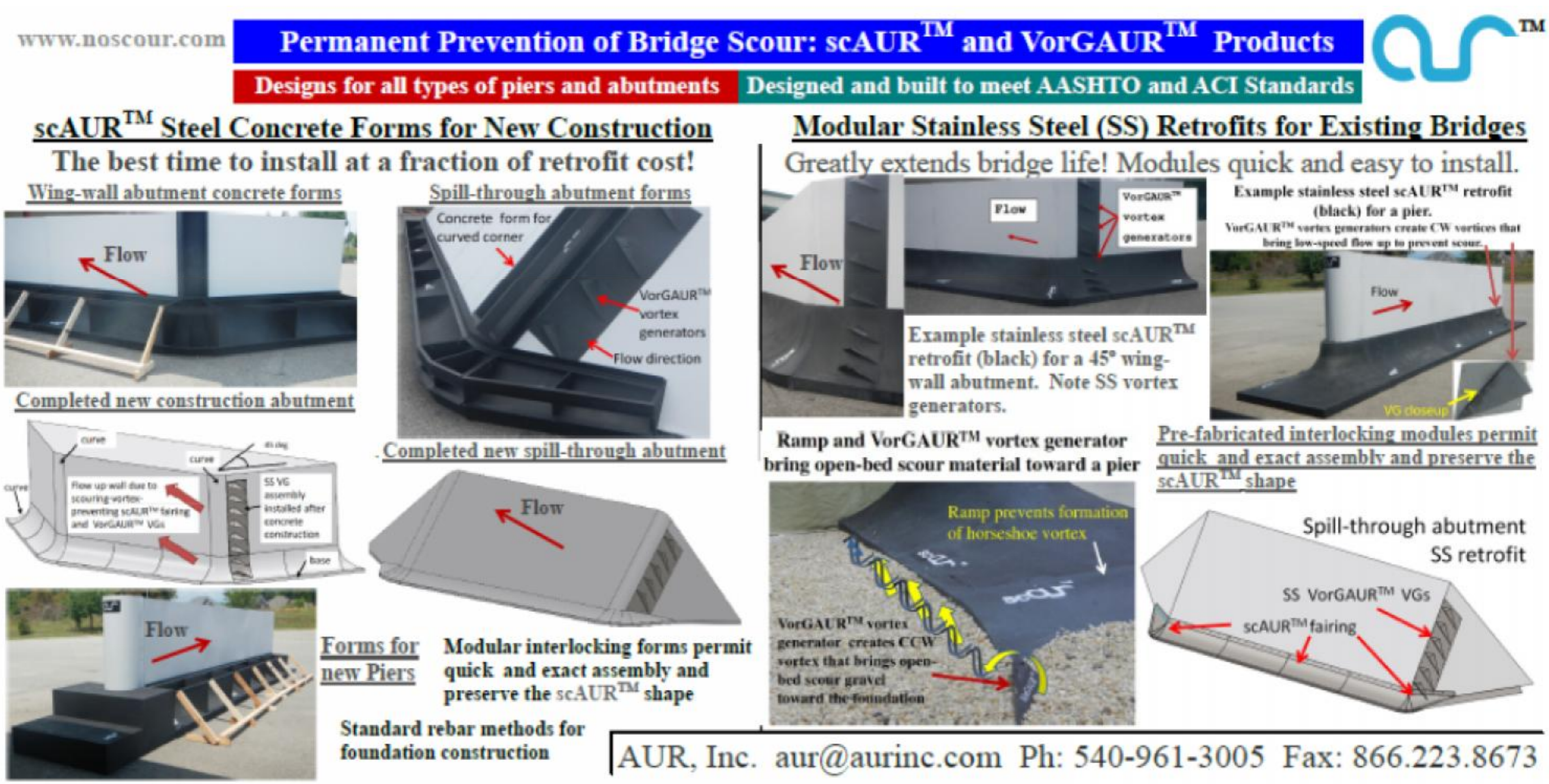
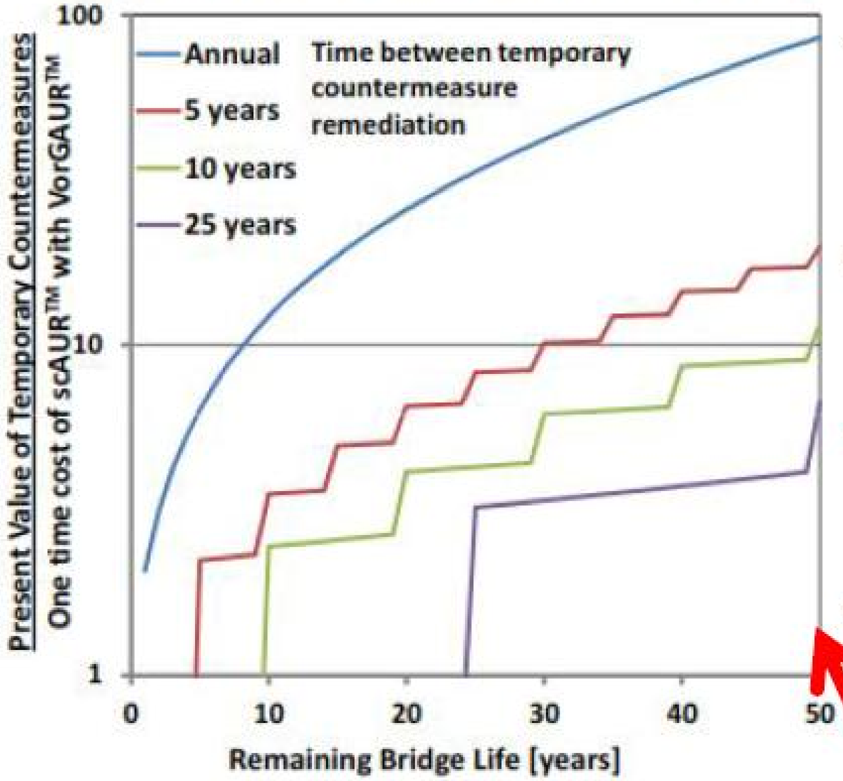
P16-0712

NCHRP-IDEA
Project 162

Low-Cost Scour-Preventing Streamlined Fairings for Bridges



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.**
aur@aurinc.com
Ph: 540-961-3005 Fax: 866.223.8673.

- 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.***

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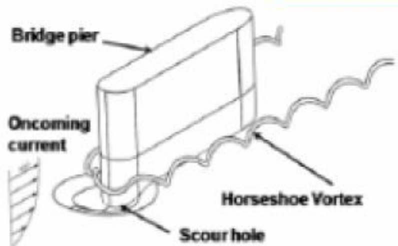
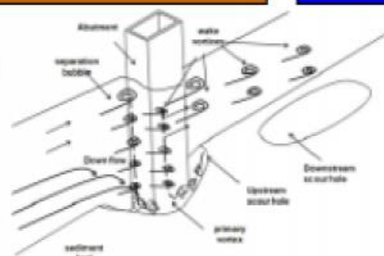
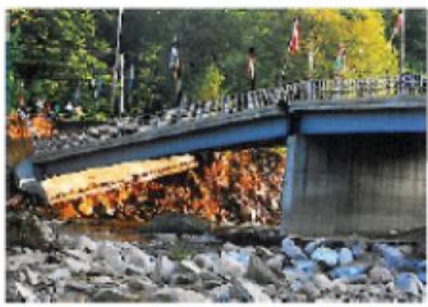
Causes of Bridge Scour





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.

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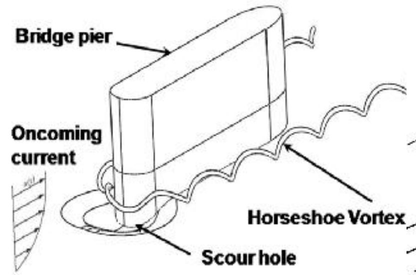
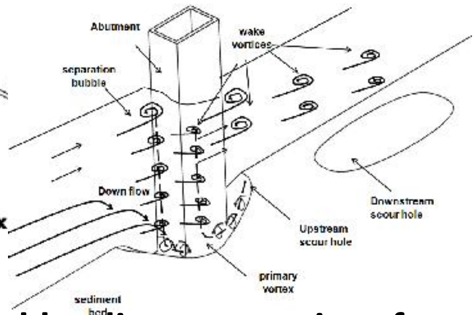
Bridge Scour is Prevented by the Use of scAUR™ and VorGAUR™ that Prevent Scouring Vortices





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

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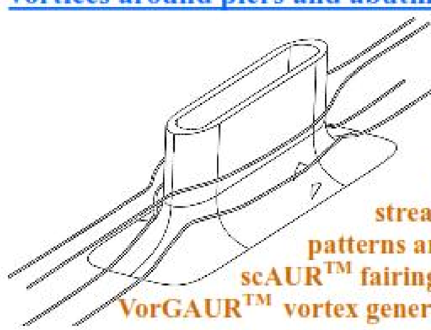
P14- 4077
P14- 5140

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

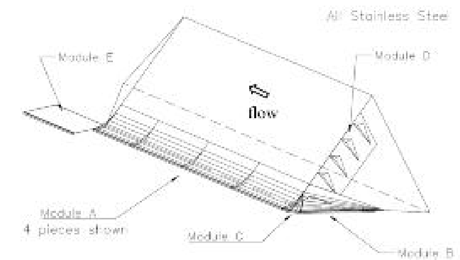
- **About 60% of bridge failures in the U.S. are due to scour (1)**
- **Over 20,000 scour-critical U.S. bridges are in danger of failure, because of scour around the piers and abutments (1).**
- **HEC 23: Rip-rap countermeasures for scour are unacceptable for new bridges; Use streamlined piers and abutments.**

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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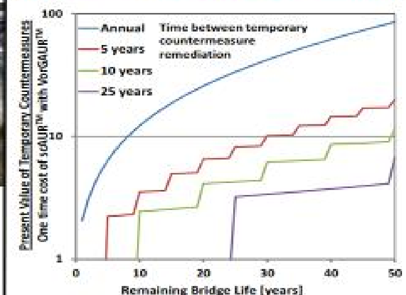
The economics of stainless steel scAUR™ with VorGAUR™ units



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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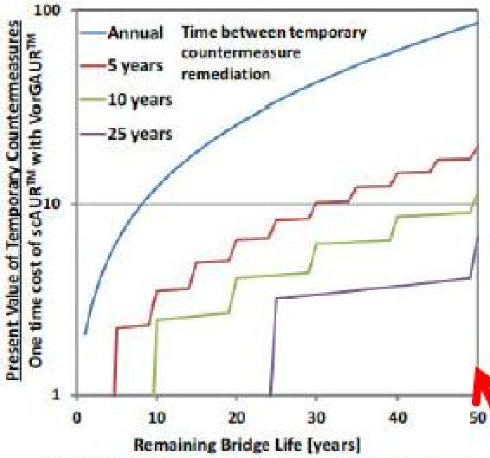
Economics of Stainless Steel *scAUR™* Retrofits



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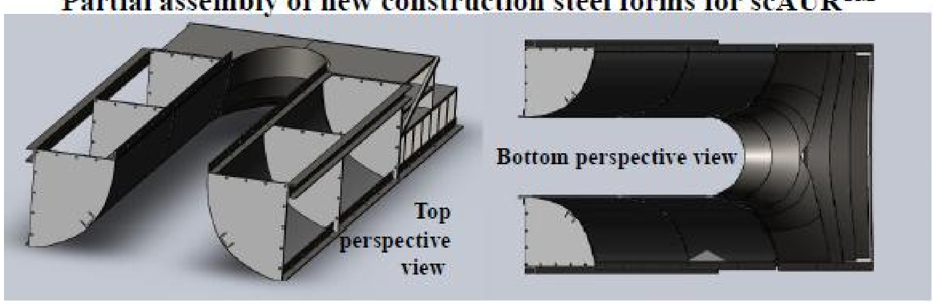
3

Manufacturing and Installation Processes

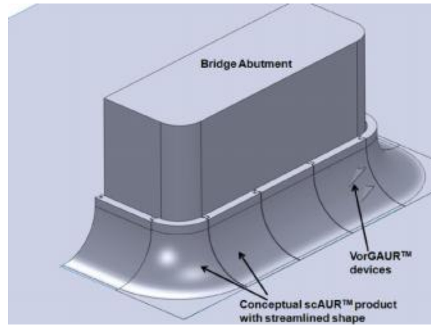
New construction – Cast-in-place Concrete – 1/3 Cost of Retrofit

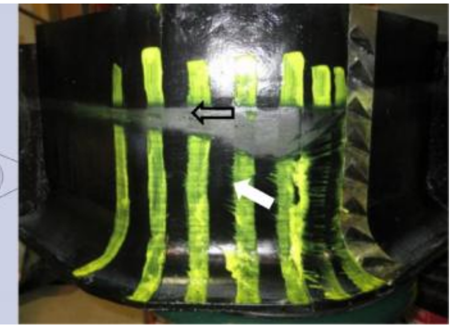
- **Only difference with current practice**: use scAUR™ steel forms for concrete
- All standard current concrete construction methods and tools used.
- Bridge pier or abutment foundation or footer top surface width and length large enough for scAUR™ concrete fairing on top.
- Rebar for the scAUR™ concrete 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™



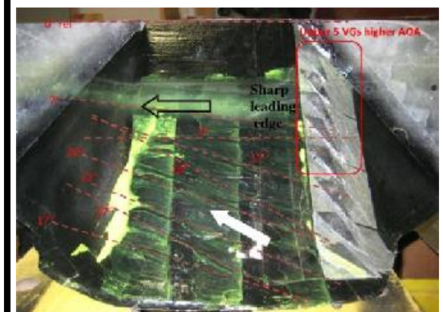
ALL Designs of Piers and Abutments are Permanently Protected from Scour by Vortex-preventing scAUR™ and VorGAUR™ :





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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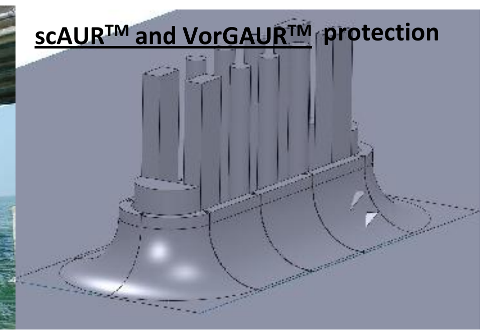
TM

Multiple pier arrangements



Protects coastal structures for 100 years

Some Recent Bridge Failures due to Scour

Abutments

The Loon Mountain Bridge in Lincoln, N.H., collapsed due to heavy scouring of the East Branch of the Pemigewasset River following Tropical Storm Irene.

The Loon Mountain Bridge in Lincoln, N.H.
collapsed due to heavy scouring around the abutment after
11 inches of rain. (From Structural Engineer, p. 32, August 2013)

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<u>ALL of these failures would have been prevented and the piers and abutments permanently protected from scour by vortex-preventing scAUR™ with VorGAUR™</u>

USGS photo
file:///F:/Abutments/File%20Abutment_scour2.jpg.htm

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Piers

Scour revealed as cause of Irish bridge collapse

3 September 2009 | By Diarmaid Fleming

Scour undermining a Victorian masonry bridge pier has been identified as the likely cause of a near-disastrous collapse of a section of railway viaduct on the Dublin-to-Belfast main line.

http://www.nce.co.uk/news/structures/scour-revealed-as-cause-of-irish-bridge-collapse/5207460.article

Schoharie Creek, NY State Thruway, April 5th , 1987; 5 vehicles fell into the river, and 10 occupants died. **The direct cause of the collapse was excessive scour under bridge pier** (Storey and Delatte, 2003). The indirect human cause of the collapse was the failure to maintain the bridge riprap (Storey and Delatte, 2003). The lawsuits against the New York State Thruway Authority were settled for a total cost of about $4.5 million with 50% inflation (Wattson, 2007)

Bridge scour: Potentially catastrophic

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- Five vehicles fell into the river, and ten occupants died;
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photo credit: U.S. Department of the Interior, U.S. Geological Survey

Reference

1. Chris Storey and Norbert Delatte, 2003, Lessons from the Collapse of the Schoharie Creek Bridge, ASCE, Forensic Engineering, pp. 158-167

2. Peter S. Wattson, 2007, "Compensating Victims of Bridge Collapses Outside Minnesota"

Paper 16-0712, Transportation Research Board 95th Annual Meeting

Walter E. Washington Convention Center, Washington, DC

January 10-14, 2016.

Title: Implementation of NCHRP IDEA 162: Low-Cost Scour-Preventing Streamlined Fairings for Bridges

4621 words, 11 figures

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Abstract

Cost-effective optimized robust scour preventing three-dimensional convex-concave hydrodynamic fairings with attached vortex generators have been designed, developed, extensively tested, and are now available for practical use. These were tested for bridge piers and abutments during a National Co-operative Highway Research Program (NCHRP-IDEA) project. Their particular shape prevents creation of scouring vortices that cause the local scour problem for any river level, speed, and angles of attack up to 20 degrees, unlike a fairing shape used by FHWA that does not prevent scour. This device exceeds requirements for HEC-23. Cost-effective versions are of stainless-steel or conventionally cast concrete that are attached to an existing or cast as part of the base of a new hydraulic structure above the footing, respectively. The vortex generators energize the decelerating near-wall flow with higher-momentum flow, resulting in a more steady, compact downstream separation and wake and substantially mitigated scour inducing vortical flow. Experimental test results confirm that scAUR™ scouring-vortex-preventing fairings prevent foundation local scour for smaller sediments, wing-wall and spill-through abutments, and full-scale piers, as well as preventing the effects of open-bed scour on foundations.

Other advantages of this robust device over other current approaches are: (1) much lower costs for scour prevention and bridge maintenance; (2) much lower probability of bridge failure;(3) lower river levels due to lower drag and lower flow blockage around the pier or abutment; (4) much lower possibility for debris and ice buildup; and (5) greater protection of piers and abutments against impact loads.

Introduction- Background of Bridge Pier and Abutment Scour

Removal of river bed substrate around bridge pier and abutment footings, also known as scour, presents a significant cost and risk in the maintenance of many bridges throughout the world and is one of the most common causes of highway bridge failures (1). It has been estimated that 60% of all bridge failures result from scour and other hydraulic-related causes (2). This has motivated research on the causes of scour at bridge piers and abutments (3) and led bridge engineers to develop numerous countermeasures that attempt to reduce the risk of catastrophe. Unfortunately, all currently used countermeasures are temporary responses that require many recurring costs and do not prevent the formation of scouring vortices, which is the root cause of the local scour (4,5). Consequently, sediment such as sand and rocks around the foundations of bridge abutments and piers is loosened and carried away by the flow during floods, which may compromise the integrity of the structure. Even designing bridge piers or abutments with the expectation of some scour is highly uncertain, since a recently released study (4) showed huge uncertainties in scour data from hundreds of experiments. None of the conservative current bridge pier and abutment footing or foundation designs prevent scouring vortices, which are created when the flow interacts with underwater structures, so the probability of scour during high water or floods is present in all current designs.

The bridge foundations in a water current, such as piers and abutments, change the local hydraulics drastically because of the appearance of large-scale unsteadiness and shedding of coherent vortices, such as horseshoe vortices. Figure 1 is a sketch of the horseshoe vortex formed around the base of a pier by a separating boundary layer. The horseshoe vortex produces high bed shear stress, triggers the onset of sediment scour, and forms a scour hole.

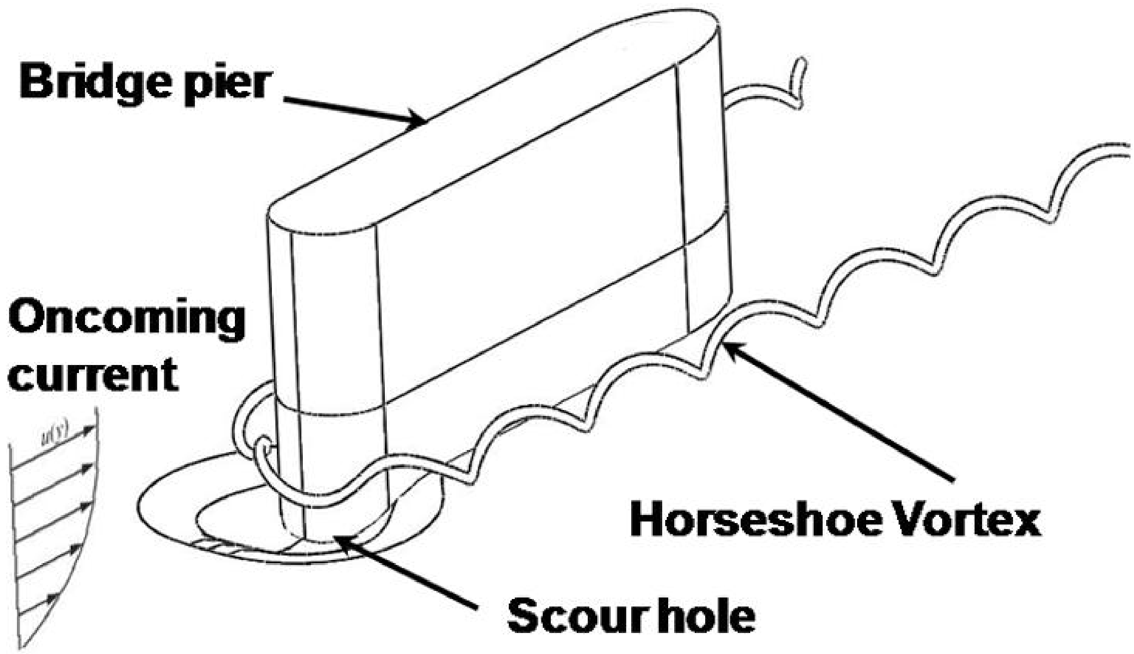

Figure 1. The formation of a horseshoe vortex around the bottom of a bridge pier with no scouring-vortex prevention.

The flowfield around an abutment is also highly three-dimensional and involves strong separated vortex flow (6). A separation bubble is formed at the upstream corner of the abutment. Unsteady shed wake vortices are created due to the separation of the flow at the abutment corners. These wake vortices are very unsteady, are oriented approximately parallel to the abutment edge and have low pressure at the vortex cores. These vortices act like small tornadoes, lifting up sediment and creating a large scour hole behind the abutment. The downflow at the front of the abutment is produced by the large stagnation pressure gradient of the approaching flow. The down flow rolls up and forms the primary vortex, which is similar to the formation of the horseshoe vortex around a single bridge pier.

It should be noted that rip rap countermeasures are not acceptable design elements for new bridges (1). To avoid liability risk to engineers and bridge owners, new bridges must be over-designed to withstand 500-year superfloods, assuming that all sediment is removed from the ‘scour prism’ at that flow rate (1). Unlike temporary scour countermeasures, the streamlined control Against Underwater Rampage fairing scAUR™ (pronounced like ‘scour’) designs avoid liability risk by preventing or drastically diminishing the scour prism and reducing the cost of new bridge engineering and construction. This greatly reduces the probability of failure, by the tenets of catastrophic risk theory (7).

Features of scAUR™ that Prevent Scouring Vortices

Using the knowledge of how to prevent the formation of discrete vortices and separation for junction flows (8,9,10), prior to the NCHRP-IDEA-162 project, AUR developed, proved using model-scale tests, and patented new local-scouring-vortex-prevention scAUR™ products. The scAUR™ design fundamentally alters the way the river flows around a pier or abutment. The scAUR™ scouring-vortex preventing fairing, US Patent No. 8,348,553, and VorGAUR™

tetrahedral vortex generators, US Patent No. 8,434,723, are practical long-term permanent solutions. A hydraulically optimum pier or abutment fairing 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 (Figure 2). This is in contrast to a fairing shape used in an unpublished FHWA study which did not prevent scour for flows at angles of attack.

Recent NCHRP research using hundreds of sets of scour data (4) shows that model-scale bridge scour experiments produce much more severe scour depth to pier size ratios than the scour depth to pier size ratios observed for full-scale cases due to scale or size effects. Thus, the scAUR™ fairing will work just as well in preventing the scouring vortices and any scour at full scale as at the proven model scale.

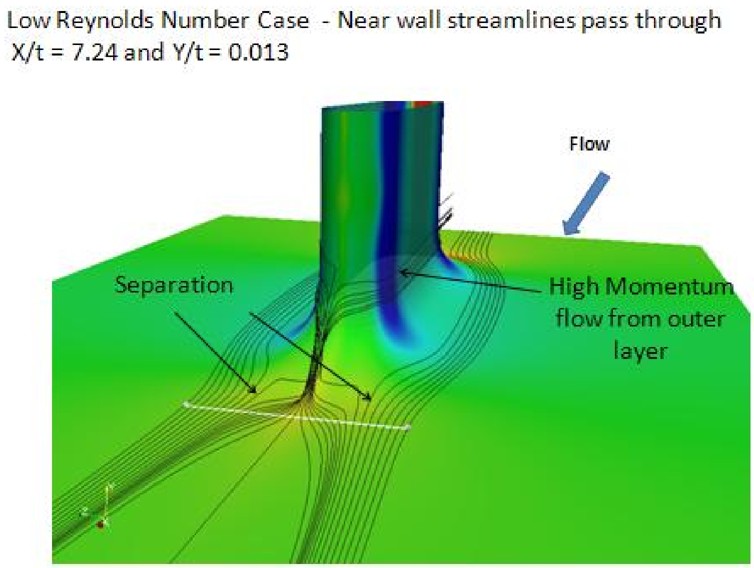

Figure 2 Low Reynolds number case CFD calculated flow streamline patterns around a scAUR™ streamlined bridge pier fairing. Flow indicates no discrete vortex formation on nose and sides.

Recent NCHRP-IDEA-162 Project

This project focused on providing more evidence that the scAUR™ and VorGAUR™ concepts and products work at full scale in preventing scour-producing vortices and for a wider range of geometries and conditions. Task I, which is not discussed further here, dealt with selecting a scour-critical bridge in Virginia for prototype installation (7). Further computational work on the effect of pier size or scale (Task II) and model flume tests for other sediments (Task III), other abutment designs (Task IV.A), and for open bed scour conditions (Task IV.B) were done to expand confidence in these concepts and designs. Constructed full-scale prototypes (Task V, not discussed here) were tested (Task VI). Cost-effective manufacturing and installation of scAUR™ and VorGAUR™ products were further developed (Task VII).

<u>TASK II – Computational Fluid Dynamic (CFD) Calculations for a Full-scale Pier compared to low Reynolds Number Model-scale CFD</u>

While much previous AUR computational and experimental work at model size ($Re_t = 1.34x10^5$, pier width t = 0.076m) was done to prove these designs, Reynolds number and bridge pier size effects were examined using computations to confirm the applicability of these products at full scale ($Re_t = 2.19x10^6$, t = 0.624m). Since the V2F Reynolds-averaged Navier-Stokes (RANS) model in the Open Foam code is proven to accurately compute 3D flows and the presence of any separation or discrete vortices (7,8,9,10,11,12), then the behavior of mean streamlines, the local non-dimensional surface pressure coefficient C_p, and the local surface skin friction coefficient C_f are sufficient to determine if any separation or discrete vortices are present(7).

Figure 2 shows a perspective view from downstream of near-wall streamlines that pass through X/t = 7.24 at Y/t = 0.013, where t is the pier width. No vortices or separation are observed upstream of the stern or tail of the pier and there are similar streamline features for both Reynolds numbers. An important feature in the C_p and the C_f results is the lack of any abrupt changes in the slope of C_p or C_f over a short distance, which means that there is no discrete vortex formation and separation. The non-dimensional drag on the pier is clearly lower for the higher Reynolds number case because C_f is always lower and the overall drag is an integral of the surface shearing stress over the pier surface area. In addition, these results show lower flow blockage than without the scAUR™ and VorGAUR™ products because low velocity swirling high flow blockage vortices are absent. As a result, water moves around a pier or abutment faster near the river surface, producing a lower water level at the bridge and lower over-topping frequencies on bridges during flood conditions for any water level when no discrete vortices are present.

Based on the past published work on scour and experience of AUR *(8, 9, 10)*, more physical evidence and insights support the idea that these scour vortex preventing devices will work better at full scale than model scale. Scouring forces on river bed materials are produced by pressure gradients and turbulent shearing stresses, which are instantaneously unsteady. At higher Reynolds numbers and sizes, pressure gradients and turbulent fluctuation stresses are lower than at model scale, so scour at the same flow speed is lower. **Work by others *(3,4,13)* supports the conclusion that scour predictive equations, developed largely from laboratory data, overpredict scour on full-scale underwater structures. Thus, the scAUR™ and VorGAUR™ work as well or better in preventing the scouring vortices and any scour at full scale as at the proven model scale.** Other CFD by AUR, not reported here, shows that scAUR™ and VorGAUR™ products also prevent scouring vortices around bridge piers downstream of bending rivers.

TASK III Flume Tests with Several Smaller Size Sediments at Model Scale

Data on the performance of the scAUR™ fairing and VorGAUR™ VGs were obtained using several smaller size sediments at model scale in the AUR flume to prove the applicability of the designs for fine sediments (*7).* All tests were at a flow speed of 0.66mps when incipient open bed scour of the pea gravel (3.2mm to 6.3mm) was first observed. Melville (14) states that the greatest equilibrium scour depth occurs around a circular pier (width = t) when it is surrounded by uniform sediment at times when the flow velocity equals the critical value, i.e., incipient conditions for open bed scour. Also, live bed scour depth is never larger than incipient scour depth. Melville states: "Recent data by *Sheppard et al.* (13)

demonstrate **significant scour depth reductions for increasing t/*d50* when t/*d50* > 50**. ***Thus, local scour depths at field scale may be significantly reduced from those observed in the laboratory."*** The "t/*d50*" term is the ratio of pier width to median grain diameter. **A value of t/*d50*=50 was used, with a range of sediments from 38.1 to 64.6**.

Three sieved sand or gravel sizes were used to encompass this range for previously reported flow conditions where scour will be the greatest for the AUR t = 76.2mm wide model pier: **Gravel A**: 1.18 to 1.4 mm; **Gravel B:** 1.4 to 1.7mm; **Gravel C**: 1.7 to 2mm. Usually smaller sediment scours before larger pea gravel. **No scour around the scAUR™ model occurred for any of these black slag gravel at speeds when the open bed pea gravel began to scour *(7)* within the y/t = +/- 0.004 measurement uncertainty.**

Task IV.A – Flume Tests of SCAUR™ and VorGAUR™ Concepts for a Larger Class of Abutments

The performance of scAUR™ and VorGAUR™ concepts for wing-wall and spill-through abutments was examined by model scale flume tests at incipient open bed scour flow speeds of 0.66mps (7) and show that scAUR™ and VorGAUR™ prevent the formation of scouring vortices and scour.

Figure 3 shows surface oilflow results for a scAUR™ modified wing-wall abutment with VorGAUR™ vortex generators (VGs)*(7)*. The mixture of yellow artist oil paint and mineral oil flows with the skin friction lines. Yellow streaks are first painted about perpendicular to the flow direction on a black painted surface. The flow causes some oil to be carried downstream in a local flow direction, which can be observed against the black painted surface. **Figure 3 clearly shows that the effects of the scAUR™ with VorGAUR™ are to bring lower velocity flow up from the flume bottom and prevent the scour around the bottom of the abutment.**

With a scAUR™ modified wing-wall abutment with VGs, there is not only no scour around the model base (Figure 4), but there is no open bed scour hole farther downstream of the model around x/L = 2. This is because the VGs generate counter-rotating vortices which diffuse and reduce the strength of the free-surface generated vortex, which caused the scour hole farther downstream of the model for the untreated case.

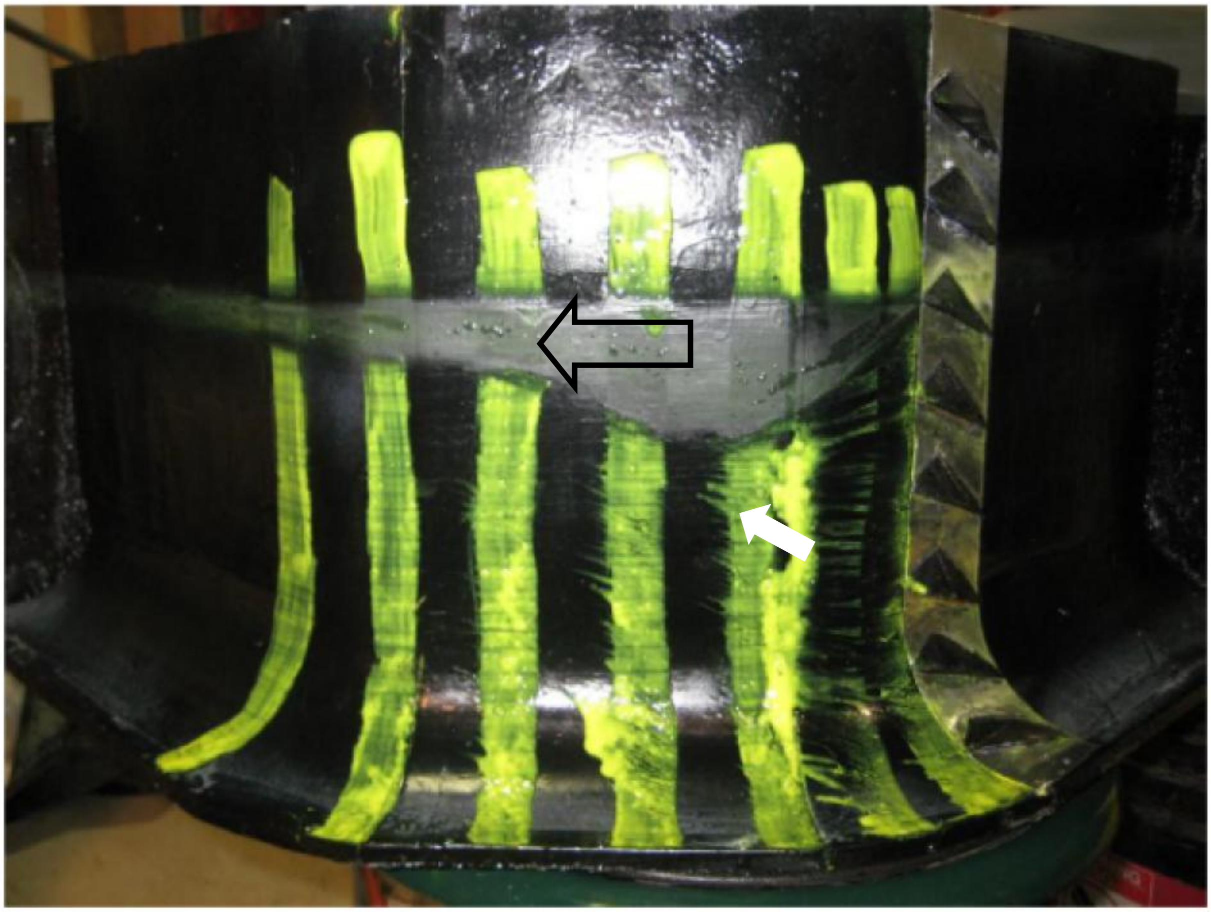

Figure 3. Surface oilflow results for the modified wing-wall abutment model with VGs. Flow from right to left. The upward streaks show that scAUR™ and VorGAUR™ products cause the flow to move up the abutment. The gray region is produced by a mixture of the oilflow material and waterborne substances at the free surface.

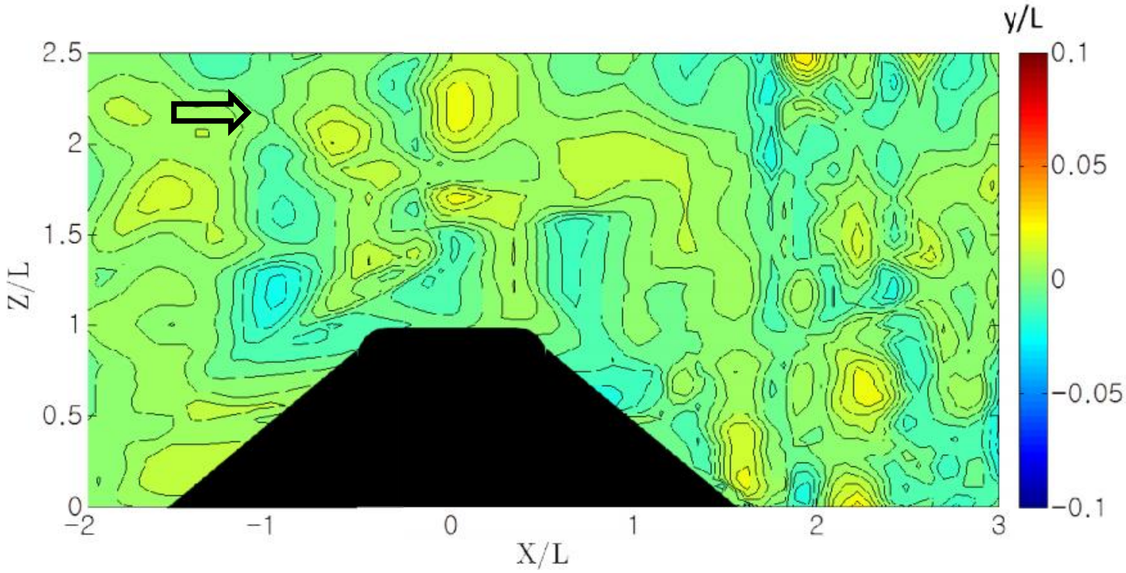

Figure 4. Bed level change contours after and before flow around the scAUR™ modified wing-wall model with VorGAUR™ VGs. L is the abutment length into the flow. No scour observed at any location (7).

Flow and scour depth results are given for flume tests without and with scAUR™ modified spill-through abutment with VorGAUR™ VGs under the same 0.66mps flow (7). The surface oilflow (Figure 5) clearly shows that the scAUR™ and VorGAUR™ products bring lower velocity flow up from the flume bottom and prevent scour around the bottom of the abutment. Deep scour holes occur around the foundation for the untreated spill-through abutment (7). Figure 6 shows no scour around the upstream contraction and near the base of the modified spill-through abutment due to the fairing. Although there is still a very minor scour at the downstream of the model, its max depth (-0.02L) is much lower than that for an untreated abutment. **The open bed scour due to the free surface vortex has been prevented.**

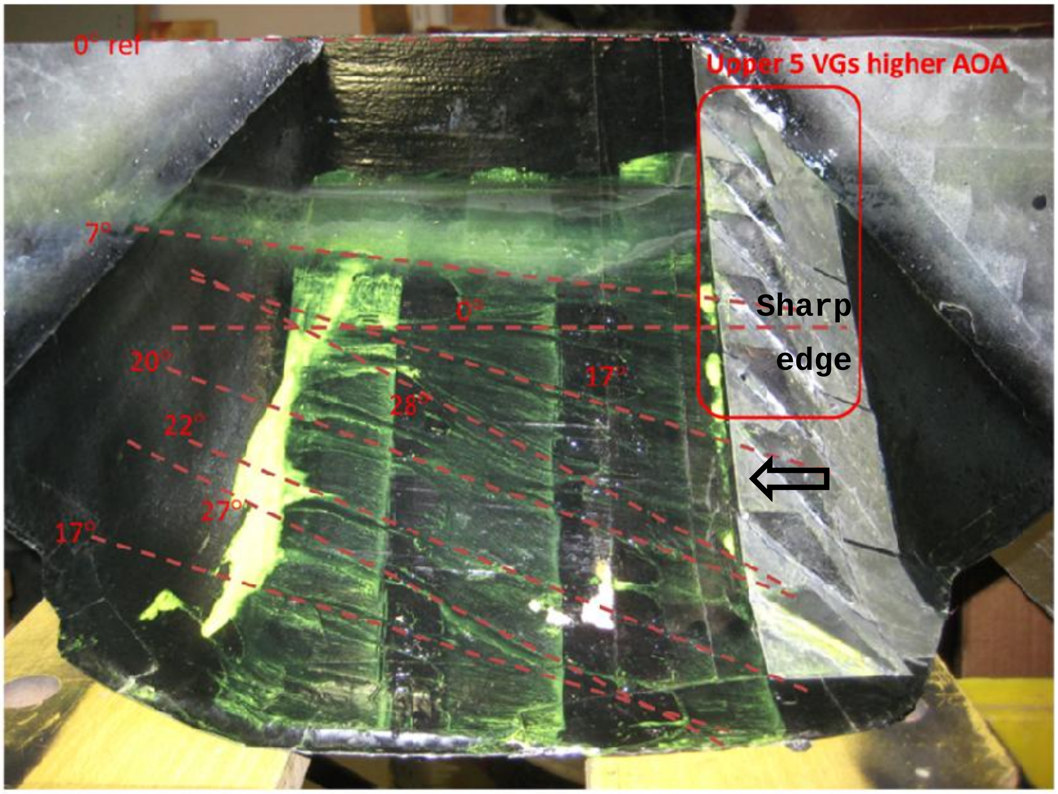

Figure 5. Surface oilflow results for modified sharp-edge spill-through abutment model with 8 VGs. Note that scAUR™ and VorGAUR™ cause the flow to move up the abutment as it moves downstream, bringing low speed fluid from the bottom of the river and preventing scour. The gray region is produced by a mixture of the oilflow material and waterborne substances at the free surface *(7)*.

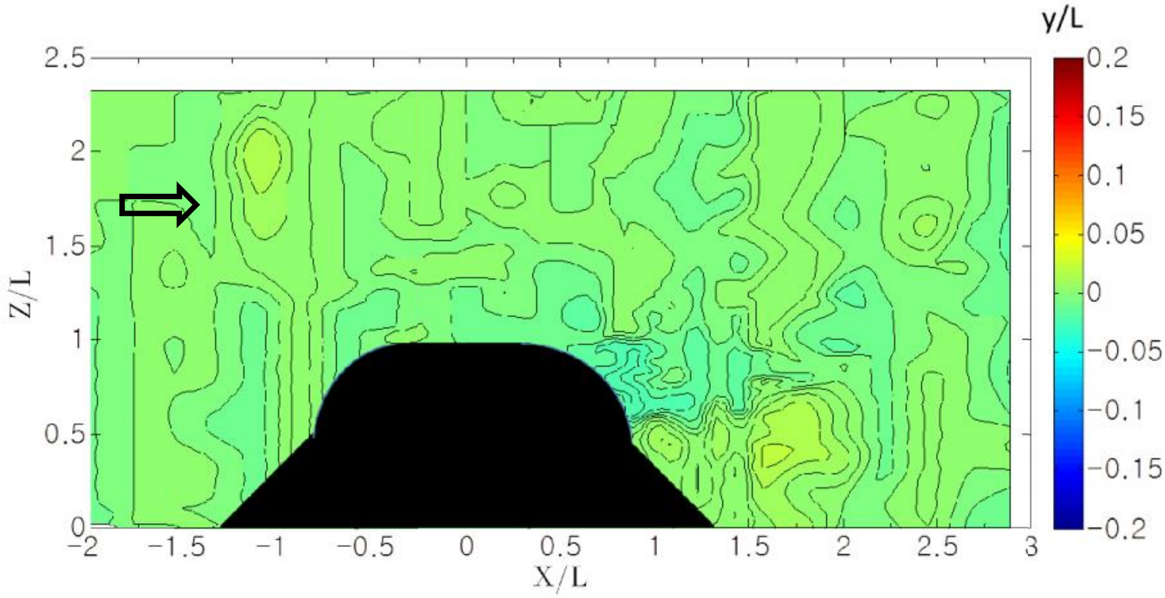

Figure 6. Bed level change contours after and before flow around the scAUR™ modified sharp-edge spill-through model with VorGAUR™ VGs (L = 229mm). No scour at any location (7).

<u>TASK IV.B – Flume Tests of Foundations Exposed by Open Bed Scour</u>

Aspects of the scAUR™ and VorGAUR™ design features have been expanded for use around the foundation (AUR Provisional Patent) to protect the foundation from the effects of contraction scour, long term degradation scour, settlement and differential settlement of footers, undermining of the concrete scAUR™ segments, and effects of variable surrounding bed levels.

As all AUR flume studies have shown (7), under these conditions scour of the open bed material occurs at a lower river speed before scour of the material around the base of the scAUR™

fairing occurs.

This means that scour of the river bed away from the scAUR™ protected pier or abutment occurs first and that the river bed level will be lower away from the pier or abutment. If a pier or abutment foundation is exposed, it will still have a higher immediate surrounding river bed level than farther away. Even so, one would like to further arrest scour around the foundation to prevent high speed open bed scour from encroaching on the river bed material next to the foundation.

Second, if the front of the foundation of a pier or abutment is exposed to approach flows, then a foundation horseshoe or scouring vortex is formed at the front which will cause local scour around the pier or abutment. This suggests that a curved-top ramp be mounted in front of the foundation that prevents the formation of this foundation horseshoe vortex.

Based on these facts, flume tests were conducted with 3 foundation leading edge ramp configurations: (1) an exposed rectangular foundation with no front ramp protection, (2) an upstream curved-top foundation ramp with trapezoidal span-wise edges to produce a stream-wise vortex to bring open bed materials toward the foundation, and (3) a curved-top upstream foundation ramp with straight span-wise edges. Gravel A was used around the foundation since it was the smallest gravel tested in this project in Task III. **In summary, all of these foundation tests show that a leading edge straight-sided curved top ramp prevents scour around a foundation when there is open bed scour, as shown in Figure 7.**

Figure 7. Gravel level after flume test for 12.7mm high elevation with a 12.7mm high straight-sided curved leading edge ramp. No scour is observed (7).

TASK VI. Tests of Full-Scale scAUR™ and VorGAUR™ Prototype in the University Of Iowa Institute of Hydraulic Research (IIHR) Flume.

Full-scale pier model scour tests were conducted during 2013 in the high flow quality University of Iowa Institute of Hydraulic Research (IIHR) 3.05m wide Environmental Flow Facility, which is described at the website:

http://www.iihr.uiowa.edu/research/instrumentation-and-technology/environmental-flow-facility/. Two test gravel sediment sizes (specific gravity = 3) were used during each test. With only a trace amount below 3.2mm, by weight about 63% of the smaller sediment gravel was between 3.2mm and 6.3mm and 37% was between 6.3mm and 9.5mm. The larger test gravel, which filled most of the flume bed, was between 9.5mm and 16mm. A 88.9mm outside diameter vertical circular cylinder model was located downstream of the scAUR™ model about 0.46m from a flume side wall and 0.46m from the end of the gravel bed and tested with the larger gravel at the same time as each of the several configurations of the scAUR™ full-scale model to show that the flow conditions cause scour with the cylinder. Test runs continued until after the cylinder scour reached equilibrium conditions with no further observed scour. With the larger gravel, the equilibrium scour hole was 76mm deep in front of the cylinder and extended 89mm upstream with a span-wise width of 0.28m.

Measurements were obtained for the scour depth around the base of the model after the flume was drained using photos of laser sheet surface locations (5), surface oilflows over the model to determine the local surface flow direction, and some pitot tube flow velocity data in front of and around the model. Five full-scale model configurations were tested with the larger and smaller gravel on opposite sides of the model (7). Configuration A, a full-scale 10.16m long 1.42m wide scAUR™ model with 6 VorGAUR™ vortex generators with three 2.44m side sections on each side, as shown in Figure 8, flush with the gravel bed top; Configuration B, same as Configuration A, but with 8 VorGAUR™ vortex generators; Configuration C, same as B, but with the straight-sided leading edge curved-top ramp like in Figure 7 above and the model 76mm above the surrounding gravel bed; Configuration D, full-scale scAUR™ with 8 VorGAUR™ vortex generators with only one side section on each side and flush with the gravel bed; Configuration E, full-scale scAUR™ nose and tail sections with 4 nose section VorGAUR™ vortex generators with no side sections.

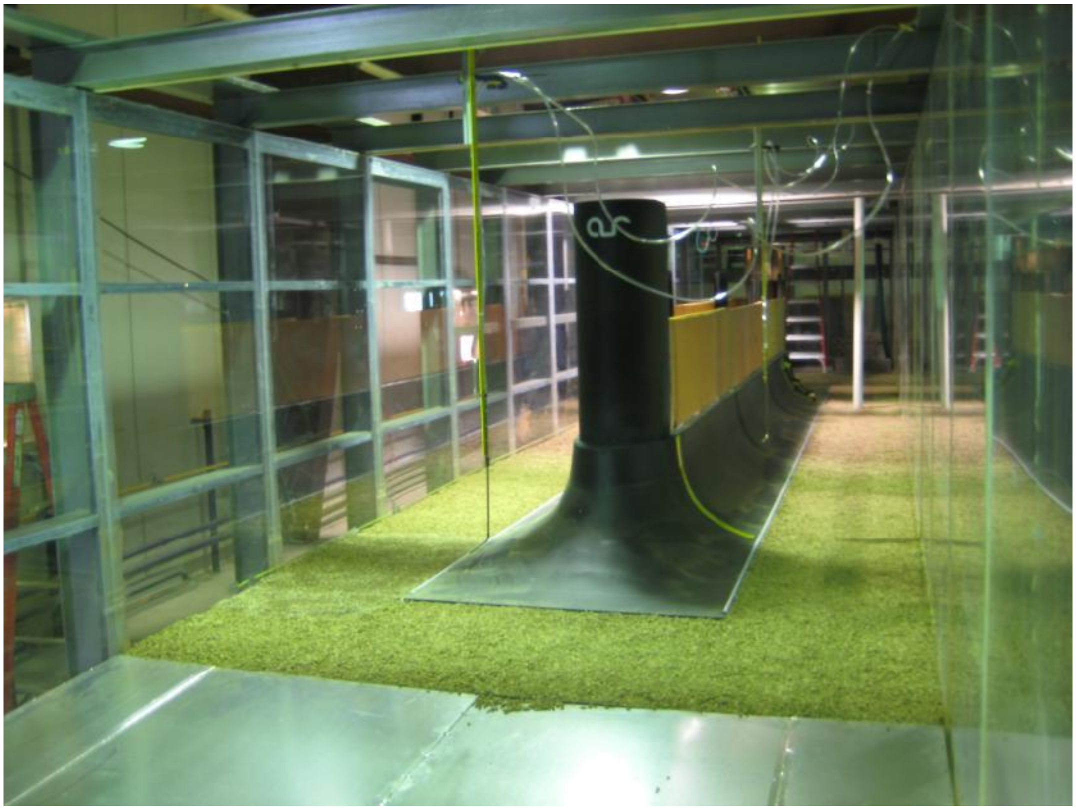

Figure 8. Photo from upstream of the AUR full-scale 10.16m long 1.42m wide scAUR™ with VorGAUR™ vortex generators model in the IIHR Environmental Flume Facility with three 2.44m side sections on each side for Configurations A and B. Small and large gravel on opposite sides are flush with the edge of the model.

In summary, the full-scale model tests confirmed that there was no scour around the front and sides for each Configuration with either the smaller or larger gravel, as was also observed at model scale. Only a small amount of scour of the smaller gravel was observed downstream, which was due to full-scale model width to flume width (0.15 to 1/3) flow blockage effects, which were comparable to flow blockage results for the 1/7 size models in the AUR flume (7).

TASK VII. Cost-effective Manufacturing and Installation of scAUR™ and VorGAUR™ Products

Before this project, AUR performed a cost benefit analysis of scAUR™ with VorGAUR™ as compared to current scour countermeasures *(7).* Published information shows that current expenses are required for scour monitoring, evaluation, and anti-scour mitigation design and construction, usually with rip-rap. For a bridge closed due to scour, the cost to motorists due to traffic detours is estimated to be as great as all other costs combined, but were not included in the analysis *(7).*

There is no situation where scAUR™ and VorGAUR™ products cost more than current countermeasures. There is no situation where any type of scour is worse with the use of the scAUR™ and VorGAUR™ products than without them. The more frequent that scouring floods occur, the more cost effective are scAUR™ and VorGAUR™. Clearly, scAUR™ and VorGAUR™ products are practical and cost-effective for US highway bridges (7).

In order to further reduce costs and increase the versatility of the scAUR™ and VorGAUR™ products, multiple manufacturing alternatives were considered. The required labor, materials, time, logistics, and practical issues were examined and used to evaluate manufacturing alternatives (7). Since the NCHRP-IDEA-162 project, detailed full-scale cost-effective versions have been developed for installation.

Retrofit to an Existing Bridge

An installed welded stainless steel (SS) scAUR™ retrofit bridge fairing is cost-effective, being about half of all costs for precast or cast-in-place concrete manufacturing and installation (7). Its corrosion resistance gives it a lifetime of 100 years even in seawater environments, using a proper thickness, construction methods, and type of SS. It is an effective way to reduce weight and the cost associated with casting custom reinforced concrete structures. Another benefit is that the SS VorGAUR™ vortex generators can be welded directly onto the side sections instead of having to be integrated into the rebar cage of the reinforced concrete structure. Figure 9 is an example of a retrofitted wing-wall abutment. **Even for bridges with little life left, current temporary countermeasures are much more expensive when the present value of future expenses is considered (7).**

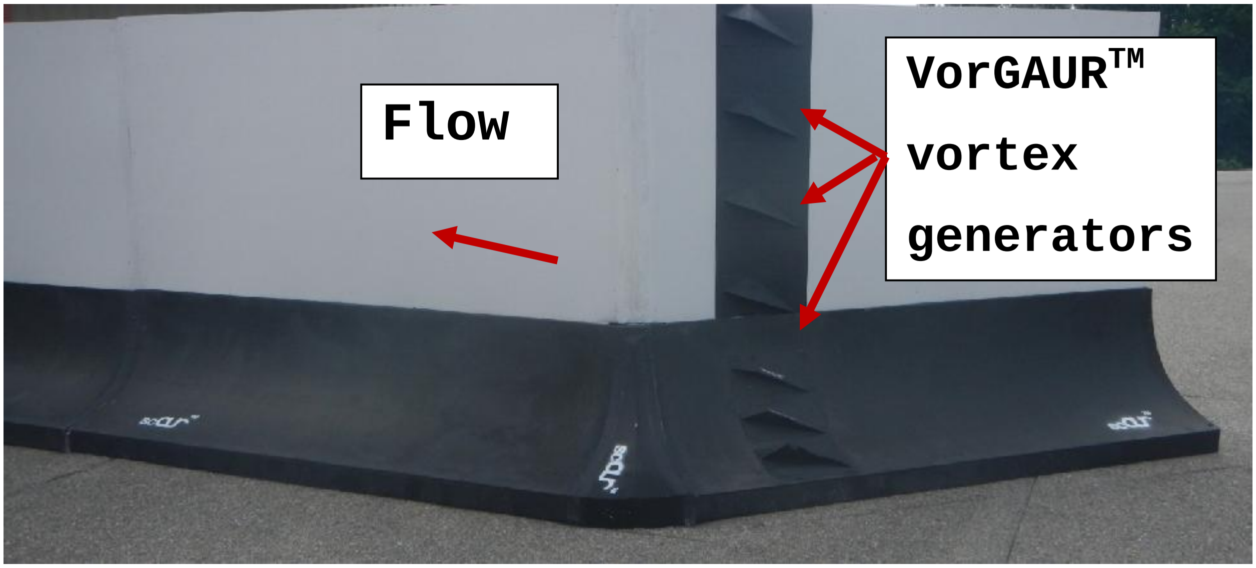

Figure 9. Photo of an example stainless steel scAUR™ retrofit (black) for a 45° wing-wall abutment. Note stainless steel VorGAUR™ vortex generators.

New construction

In the case with new construction, essentially the difference between the way cast-in-place bridge piers and abutments are constructed currently without the scAUR™ products and in the future with the scAUR™ products is that scAUR™ steel forms for the concrete are used *(7).* All standard currently used concrete construction methods and tools can be used. During the bridge design phases, the bridge pier or abutment foundation or footer top surface width and length would need to be large enough to accommodate the location of the scAUR™ concrete fairing on top. Rebar needed for the scAUR™ would be included in the foundation during its construction. Stainless steel rebar for welding to the stainless steel vortex generators mounting plates on the surface needs to be used for specific locations. Figure 10 shows example scAUR™ new construction concrete forms for a pier while Figure 11 shows example scAUR™ new construction concrete forms for a 45° spill-through abutment. **Clearly, since the new construction cost is about 1/3 of retrofit costs, the best time to include the scAUR™ fairing on piers and abutments is during new construction (7).**

Figure 10. Photo of example scAUR™ new construction concrete forms (black) for a pier.

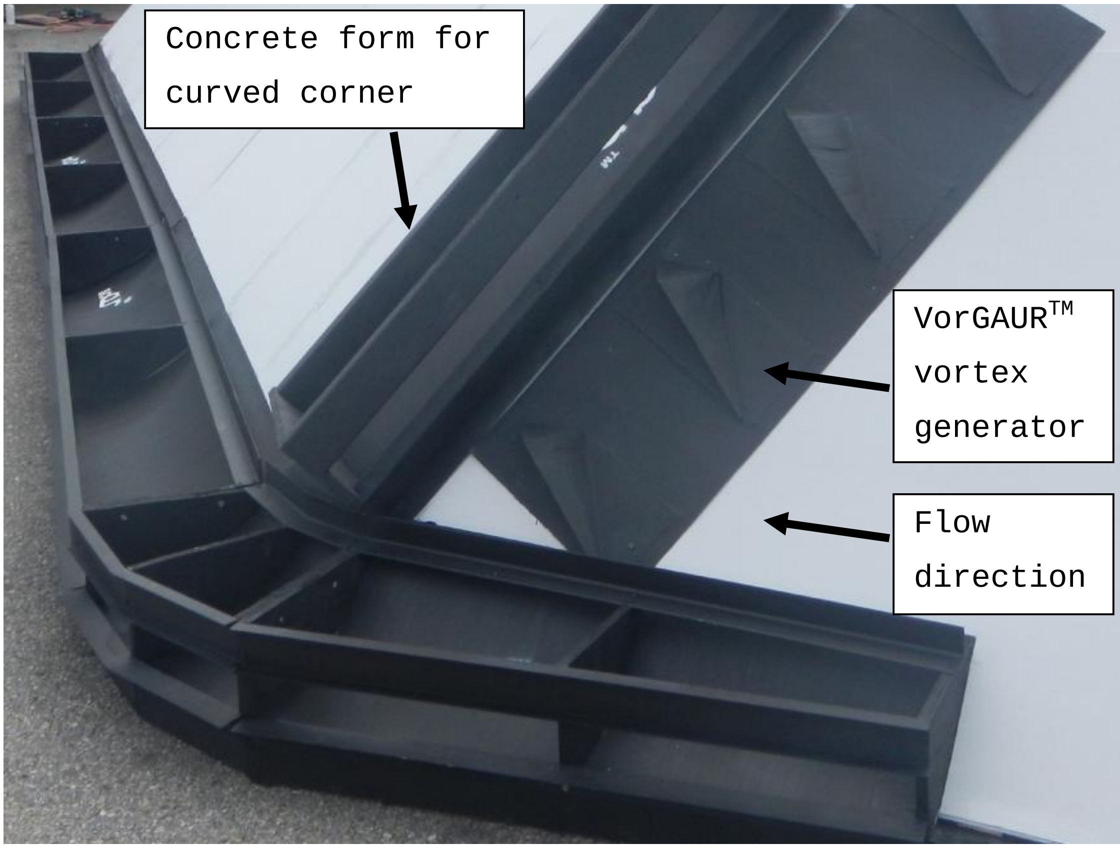

Figure 11. Photo of example scAUR™ new construction concrete forms (black) for a 45° spill-through abutment. Note stainless steel VorGAUR™ vortex generators mounted after concrete construction.

CONCLUSIONS

Local scour of bridge piers and abutments is a common cause of highway bridge failures. All currently used countermeasures are temporary and do not prevent the root cause of local scour – discrete large-scaled vortices formed by separations on underwater structures. Using the knowledge of how to prevent the formation of discrete vortices, prior to the NCHRP-IDEA-162 project, AUR developed, proved using model-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. In the NCHRP Project and later work, work on the effect of pier size or scale and model flume tests for other sediments, other abutment designs, and for open bed scour conditions showed that the products prevent scouring vortices and scour. Full-scale prototypes were successfully tested and 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 these products on scour-critical bridges are underway.

Acknowledgments

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