Automated Scour Detection Arrays using Bio-Inspired Magnetostrictive Flow Sensors

Identifying and Establishing Project Goals and Needs (Deliverable 2A: Summary of DOT Survey Results)

May 2013

Michigan Technological University
USDOT Cooperative Agreement No. RITARS-12-H-MTU

Principal Investigator: **Dr. R. Andrew Swartz, Assistant Professor**
Department of Civil and Environmental Engineering
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931
(906) 487-2439
raswartz@mtu.edu

Program Manager: **Caesar Singh, P.E.**
Lead Engineer/Program Manager
Research Development & Technology RITA, U.S. Dept. of Transportation
1200 New Jersey Avenue, SE, E33-123
Washington, DC 20590
(202) 366-3252

Caesar.Singh@dot.gov

MichiganTech

Table of Contents

Executive Summary

A 14 question survey was distributed to 79 state DOT hydraulics and bridge management personnel soliciting their opinions regarding the aspects of the proposed bioinspired scour monitoring system including questions about application, usefulness, installation concerns, desired system resolution, and commercialization issues. Responses are not individually identifiable by individual of DOT agency by the investigators or in this report.

Based on the responses from the DOT Bridge and Hydraulic Engineers listed above it can be concluded that:

1. Scour is a problem in fewer than 10% of bridges, primarily due to successful monitoring and/or countermeasures.
2. Most bridges do not use permanently-embedded scour detection sensors.
3. Of those that use permanent sensors, all states only used them on 'scour critical' bridges.
4. When used, permanent sensors are mounted on piers or abutments and at the scour depth considered critical to collapse, with a few applications on the deck beams.
5. Sensors are mainly buried in the riverbed with some bolted onto the bridge.
6. The most common method of scour detection was a survey rod from the bridge deck for shallow flows and divers for deeper flows, with some using sonar.
7. At least one sensor is needed near the scour-critical elevation but more are also necessary at other elevations and near the bridge beams.
8. At least one sensor is needed at the front of the structure but more are also helpful at the sides and rear of the structure.
9. Scour levels need not be reported more often than hourly.
10. Scour information should be sent when a threshold level is crossed but continuous data should also be available via the internet.
11. Annual monitoring costs should be kept to under $1,000, if possible, but no more than $10,000.
12. Installation by burying in the riverbed is preferred with other acceptable methods being bolted onto the bridge and in a post. Installation in flowing water is acceptable.
13. Sensors are needed on piers and abutments, but not necessarily on riverbanks, or culverts.
14. There was not a significant preference for ownership arrangements with both DOT owned and private service provider being acceptable.

The full set of questions and responses is presented in this report.

Introduction

Real-time scour monitoring on bridges for scour can lead to the saving of property and lives. In this regard, Michigan Technological University is conducting research into the feasibility of using magnetostrictive sensors for this purpose.

Task 2 of the research project is as follows:

> The team will canvass the state DOT agencies to solicit additional information regarding the needs of bridge owners for scour monitoring as state DOT agencies represent a large and influential group of bridge owners. We hope to achieve three goals: 1) understand the costs associated with their current scour inspection paradigm for the final project cost/benefit analysis; 2) understand the information they would require from a remote monitoring system in terms of sensor density and location, sampling frequency, information, visualization, service life, and cost; and 3) establish acceptable installation methods for sensors, particularly at piers. State DOT's response rate will be a critical evaluation criterion; the team will follow up with respondents for additional information when appropriate.

Outputs include:

Improved understanding of bridge owner costs associated with scour.

Improved understanding of system requirements.

The Task 2 deliverable is this report.

Procedure

The survey questions were as follows:

Question 1. On what percent of bridges is bridge scour a problem for your agency?
Percentage (1-100%)_____
_____None, due to successful monitoring and/or countermeasures
_____None, due to favorable site conditions

Question 2. Do you use permanently-embedded scour detection sensors?
_____Yes
_____No

Question 3. How is it decided if scour sensors are needed on a particular bridge?
_____Bridge is considered ‘scour critical’
_____River is subject to high flow velocity.

Question 4. If used, where are the sensor(s) located on the bridges, and why?
_____Bridge deck
_____Deck beams
_____Pier or abutment
_____Near critical scour depth of pier or abutment

Question 5. If used, how are the scour sensors installed?
_____Bolted onto bridge
_____Buried in riverbed
_____Flow diverted first
_____Installed in flowing water
_____Other (please specify)

Question 6. What are the scour inspection methods commonly used for typical bridges in your inventory and their approximate costs per bridge?
_____Survey rod from bridge deck (cost)
_____Divers (cost)
_____Other (please specify)

Question 7. What are the desired number and location of sensor systems?
_____Only one sensor is needed near the scour-critical elevation
_____Sensors are needed at many elevations

_____Sensors near the bridge beams to monitor water surface

Question 8. Sensors are needed at the structure:
_____Front
_____Sides
_____Rear

Question 9. How often is the scour condition needed?
_____Once a minute
_____Once a hour
_____Once a day
_____Once a month

Question 10. How should the info be displayed to DOT engineers to make the best use of it?
_____Message when sensor is triggered
_____Continuous sensor status
_____Cell phone message
_____Log onto a sensor website with sensor status
_____Other (please specify)

Question 11: What annual cost per bridge is reasonable for monitoring?
_____Under $100
_____Under $500
_____Under $1,000
_____Over $10,000
_____Other (please specify)

Question 12: What installation methods are acceptable for permanently-embedded sensors?
_____Bolted onto bridge
_____Buried in riverbed
_____Sensors in a post that is installed near the structure (perhaps using a hollow stem auger)
_____Flow diverted first
_____Installed in flowing water

Question 13. Are scour sensors needed on the following structures?
_____Piers
_____Abutments

_____River banks
_____Culverts
_____Other

Question 14. Ownership of sensor system preference:
_____Owned and maintained by your DOT
_____Owned and maintained by a private service provider
_____No preference

Methods

The survey questions as listed above were sent out using SurveyMonkey in such a way that the respondent was anonymous. The survey email was sent to all DOT Bridge and Hydraulic Engineers in all 50 states at the following email addresses (obtained from Dan Ghere at FHWA and at: http://design.transportation.org/Documents/AASHTO%20State%20Hydraulics%20Contact%20Info%20Summer%202011.xlsx

flournoyg@dot.state.al.us <mailto:flournoyg@dot.state.al.us>
ramseyd@dot.state.al.us <mailto:ramseyd@dot.state.al.us>
michael.knapp@alaska.gov <mailto:michael.knapp@alaska.gov>
IItty@azdot.gov <mailto:IItty@azdot.gov>
Mark.Earl@arkansashighways.com <mailto:Mark.Earl@arkansashighways.com>
glenn_s_decou@dot.ca.gov <mailto:glenn_s_decou@dot.ca.gov>
kevin_flora@dot.ca.gov <mailto:kevin_flora@dot.ca.gov>
steve_ng@dot.ca.gov <mailto:steve_ng@dot.ca.gov>
amanullah.mommandi@dot.state.co.us
<mailto:amanullah.mommandi@dot.state.co.us>
michael.masayda@ct.gov <mailto:michael.masayda@ct.gov>
barry.benton@state.de.us <mailto:barry.benton@state.de.us>
reginald.arno@dc.gov <mailto:reginald.arno@dc.gov>
rick.renna@dot.state.fl.us <mailto:rick.renna@dot.state.fl.us>
bmcmanus@dot.ga.gov <mailto:bmcmanus@dot.ga.gov>
sbeck@dot.ga.gov <mailto:sbeck@dot.ga.gov>
curtis.matsuda@hawaii.gov <mailto:curtis.matsuda@hawaii.gov>
lotwick.reese@itd.idaho.gov <mailto:lotwick.reese@itd.idaho.gov>
matthew.oconnor@illinois.gov <mailto:matthew.oconnor@illinois.gov>
cmweaver@indot.in.gov <mailto:cmweaver@indot.in.gov>
david.claman@dot.iowa.gov <mailto:david.claman@dot.iowa.gov>
orth@ksdot.org <mailto:orth@ksdot.org>
ronald.matar@ky.gov <mailto:ronald.matar@ky.gov>
mitra.hashemieh@la.gov <mailto:mitra.hashemieh@la.gov>
michael.wight@maine.gov <mailto:michael.wight@maine.gov>
akosicki@sha.state.md.us <mailto:akosicki@sha.state.md.us>
kpujara@sha.state.md.us <mailto:kpujara@sha.state.md.us>
richard.g.murphy@state.ma.us <mailto:richard.g.murphy@state.ma.us>
potvinc@michigan.gov <mailto:potvinc@michigan.gov>
andrea.hendrickson@state.mn.us <mailto:andrea.hendrickson@state.mn.us>
rwesterfield@mdot.state.ms.us <mailto:rwesterfield@mdot.state.ms.us>

dale.henderson@modot.mo.gov <mailto:dale.henderson@modot.mo.gov>
mgoodman@mt.gov <mailto:mgoodman@mt.gov>
kevin.donahoo@nebraska.gov <mailto:kevin.donahoo@nebraska.gov>
kirk.harvey@nebraska.gov <mailto:kirk.harvey@nebraska.gov>
cwolf@dot.state.nv.us <mailto:cwolf@dot.state.nv.us>
sswana@dot.state.nh.us <mailto:sswana@dot.state.nh.us>
mrichardson@dot.state.nh.us <mailto:mrichardson@dot.state.nh.us>
tmallette@dot.state.nh.us <mailto:tmallette@dot.state.nh.us>
david.ahdout@dot.state.nj.us <mailto:david.ahdout@dot.state.nj.us>
wgannett@dot.state.ny.us <mailto:wgannett@dot.state.ny.us>
dmorse@dot.state.ny.us <mailto:dmorse@dot.state.ny.us>
dchang@ncdot.gov <mailto:dchang@ncdot.gov>
bpfeifer@nd.gov <mailto:bpfeifer@nd.gov>
jeffrey.syar@dot.state.oh.us <mailto:jeffrey.syar@dot.state.oh.us>
tngo@odot.org <mailto:tngo@odot.org>
llewis@odot.org <mailto:llewis@odot.org>
alvin.shoblom@odot.state.or.us <mailto:alvin.shoblom@odot.state.or.us>
ed.foltyn@odot.state.or.us <mailto:ed.foltyn@odot.state.or.us>
cnewcomer@state.pa.us <mailto:cnewcomer@state.pa.us>
c-dnewell@state.pa.us <mailto:c-dnewell@state.pa.us>
lusantos@dtop.gov.pr <mailto:lusantos@dtop.gov.pr>
vpalumbo@dot.ri.gov <mailto:vpalumbo@dot.ri.gov>
rfura@dot.ri.gov <mailto:rfura@dot.ri.gov>
helmspw@scdot.org <mailto:helmspw@scdot.org>
smoakck@scdot.org <mailto:smoakck@scdot.org>
kevin.marton@state.sd.us <mailto:kevin.marton@state.sd.us>
ali.hangul@tn.gov <mailto:ali.hangul@tn.gov>
jon.zirkle@tn.gov <mailto:jon.zirkle@tn.gov>
aronnfel@txdot.gov <mailto:aronnfel@txdot.gov>
jamesbaird@utah.gov <mailto:jamesbaird@utah.gov>
nick.wark@state.vt.us <mailto:nick.wark@state.vt.us>
ba.thrasher@vdot.virginia.gov <mailto:ba.thrasher@vdot.virginia.gov>
kramerc@wsdot.wa.gov <mailto:kramerc@wsdot.wa.gov>
darrin.a.holmes@wv.gov <mailto:darrin.a.holmes@wv.gov>
douglas.w.kirk@wv.gov <mailto:douglas.w.kirk@wv.gov>
najoua.ksontini@dot.state.wi.us
<mailto:najoua.ksontini@dot.state.wi.us>
AnnMarieE.Kirsch@dot.wi.gov <mailto:AnnMarieE.Kirsch@dot.wi.gov>
william.bailey@dot.state.wy.us <mailto:william.bailey@dot.state.wy.us>
william.ray@la.gov <mailto:william.ray@la.gov>

Parviz.eftekhari@state.nm.us <mailto:Parviz.eftekhari@state.nm.us>
john.r.woodroof@odot.state.or.us
<mailto:john.r.woodroof@odot.state.or.us>
jon.zirkle@tn.gov <mailto:jon.zirkle@tn.gov>
dstuhff@utah.gov <mailto:dstuhff@utah.gov>
rodney.taylor@dot.state.wi.us <mailto:rodney.taylor@dot.state.wi.us>
najoua.ksontini@dot.state.wi.us
<mailto:najoua.ksontini@dot.state.wi.us>

The initial survey was sent out for respondents to fill out by SurveyMonkey on March 26, 2013, after which reminder emails were sent out on April 10, 2013 and April 30, 2013.

The following results were collated on May 30, 2013.

Results

There were 33 respondents to the survey, probably reflecting the views of 33 out of the 50 states, although it is possible that more than one DOT engineer from a state responded to the survey.

Table 1: Question 1- On what percent of bridges is bridge scour a problem for your agency?*

	(1-5)%	(6-10)%	(11-15)%	(16-20)%	(21-25)%	Response Count
Percentage	46.15% (12)	30.77% (8)	7.70% (2)	7.70% (2)	7.70% (2)	26
None, due to successful monitoring and/or countermeasures	8					8
None, due to favorable site conditions	3					3
answered question						30
skipped question						3
comments						15

**Some respondents chose one of the "None" options but also chose a numerical percentage. These were considered in the respective "None" groups.*

Comments:

1. The scour critical bridges.
2. The percentage is low because of efforts to install mitigation at problem sites and for liberal use of riprap on new bridges
3. Estimated.
4. All remaining SC bridges are scheduled for replacement in next 8 yrs
5. Sort of depends on what you consider a "problem". This is an educated guess, and also depends on if we include all of the bridges in the state, or just those that we (the state) own.
6. didn't we fill this same survey out a few weeks ago?
7. WAG. Monitoring is not considered a long term solution.
8. Only about 5 percent of the bridges over water in the state are listed as scour critical and all are monitored using the Bridgewatch monitoring program.
9. Countermeasures protect others
10. PennDOT does use monitoring and scour countermeasures on scour critical bridges. However, this does not eliminate scour failures.
11. Just under 5 percent of our bridges over water are rated scour critical. All of our scour critical bridges have POAs according to FHWA requirements and are monitored using the Bridgewatch Program from US Engineering Solutions.
12. As defined by have a scour rating of 4 or less.
13. Unclear how to respond to 2 other input boxes. 3-5% of our bridges have scour concerns
14. 50% of waterway bridges

15. All scour critical bridges (unknown foundations, shallow foundations, etc) have had countermeasures placed. All new bridges have scour calcs done as part of the design, to make sure foundation is below Q500 scour. All other bridges are checked for scour when a rehab is planned. Eventually we'll check every bridge in the state.

Table 2: Question 2- Do you use permanently-embedded scour detection sensors?

	Response Percent	Response Count
Yes	15.60%	5
No	84.40%	27
answered question		32
skipped question		1
comments		9

Comments:

1. We have a research project in progress with Clemson University installing real time scour devices. One device is in with 3 more being installed this year.
2. Float out were used in the past without much success.
3. We have one location where float out devices were installed.
4. sliding collar or sonar
5. Overhead, climatic Conditions and vandalism are the impediments
6. The Bridgewatch system can monitor in place scour devices and send alerts to our inspectors when a threshold is exceeded however we have not a bridge where in place monitoring was justified for the associated cost to date.
7. On 1 structure.
8. Not currently, but we would like to.
9. We use a lot of tilt sensors which technically isn't measuring any scour; just the result of scour

Table 3: Question 3- How is it decided if scour sensors are needed on a particular bridge?

	Response Percent	Response Count
Bridge is considered ‘scour critical’.	100.00%	14
River is subject to high flow velocity.	0.00%	0
answered question		14
skipped question		19
Other replies		15

Other replies:

1. N/A
2. May be other factors, including scour history at the site and route importance (ADT, etc.).
3. The bridges also have real time USGS discharge gages and as-built plans.
4. depending on scour risk rating, sufficiency rating and ADT of the bridge.
5. The bridge is scour prone

6. Float out device was installed on a bridge with a failed countermeasure as an interim measure until funding could be found and a mitigation contract completed. The float out devices are now under the riprap.
7. N/A
8. we don't use sensors
9. Dependent on risk assessment, so far we have used this on major river bridges with high ADT or bridges with chronic scour issues that can't be monitored easily by other methods.
10. Would be case by case.
11. NA
12. Long term monitoring would be required in lieu of very expensive or otherwise difficult scour mitigation techniques.
13. This structure has sandy soil which made it a concern.
14. Don't use scour sensors
15. N/A

Table 4: Question 4- If used, where are the sensor(s) located on the bridges, and why?

	Yes	No	Rating Count
Bridge deck	11.1% (1)	88.9% (8)	9
Deck beams	22.2% (2)	77.8% (7)	9
Pier or abutment	76.9% (10)	23.1% (3)	13
Near critical scour depth of pier or abutment	68.8% (11)	31.3% (5)	16
answered question			18
skipped question			15
Other (please specify)			7

Other replies:
1. not used
2. Buried under the riprap protection (float-outs)
3. Not on simply supported members. Trying to monitor for settlement, so pier members better. Some float-outs (limited battery life) installed at scour depth.
4. Can be site specific, safety of the inspector is a key compenent
5. NA
6. The sensors are located on the upstream end of the pier and abutment that historically have had scour issues at two levels. The first level is to warn us of an issue the second level requires the bridge be closed.
7. N/A

Table 5: Question 5- If used, how are the scour sensors installed?

	Response Percent	Response Count
Bolted onto bridge	29.40%	5
Buried in riverbed	41.20%	7
Flow diverted first	5.90%	1
Installed in flowing water	5.90%	1
Other (please specify)	17.60%	3
answered question		17
skipped question		16

Other replies:

1. not used
2. We have done it multiple ways, I wanted to select: Bolted onto bridge, buried in riverbed, and installed in flowing water.
3. Bolted and buried. Dry conditions allow buried devices.

Table 6: Question 6- What are the scour inspection methods commonly used for typical bridges in your inventory and their approximate costs per bridge?

	Response Percent	Response Count
Survey rod from bridge deck (cost)	31.00%	9
Divers (cost)	10.30%	3
Other (please specify)	58.60%	17
answered question		29
skipped question		4

Other replies:

1. Survey rod is used, divers are used, bathymetric survey.
2. routine bridge inspection and maintance reports also divers perform underwater inspection every 5 year and post floods as well.
3. We Use both methods listed depending on site conditions.
4. Survey rod, and divers for deep rivers
5. Probing of streambed during inspection. Also have used sidescan sonar
6. We use bridge inspection including underwater inspection.
7. In water probing or divers. approx cost 2,000
8. Tape down from bridge deck, sonar imaging
9. Sonar
10. we inspect dropping weighted measuring tape from bridge deck and underwater scour using divers
11. We monitor using both methods. The regular inspections are typically done with divers, flood monitoring is generally done from the bridge deck. We have also used some side scan sonar (very limited). Cost - on deck monitoring is done with our own forces, no cost data available. Underwater inspections with divers typically cost about $2000.

12. In house bridge inspectors wade all creeks with water depths of 3 ft or less and probe with survey rod. Divers are used on bridges with depths greater than 3 ft.
13. For wadable channels, scour inspection is performed by bridge safety inspection teams using probe rods. For deeper channels, scour inspection is performed by divers.
14. TDOT's bridge inspections are done with in house inspection teams. Underwater inspections are done for piers in excess of 3 feet of water depth and all those are done by contract divers.
15. Structures that require a underwater inspection sonar and sidescan sonar are used; which the equipment is owned by the State. (equipment cost less than $10,000) Structures with water less than 4 feet visual and probing methods are used.
16. Laser from below or weighted tape from the deck when dry is most common. Cost is trivial. Sonar from boat and divers are secondary means with a wide range of cost associated.
17. Divers are used for deeper waters. Others can be inspected by wading or are dry or in shallow water during low flows.

Table 7: Question 7- What are the desired number and location of sensor systems?

	Yes	No	Rating Count
Only one sensor is needed near the scour-critical elevation	90.9% (10)	9.1% (1)	11
Sensors are needed at many elevations	78.6% (11)	21.4% (3)	14
Sensors near the bridge beams to monitor water surface	63.6% (7)	36.4% (4)	11
answered question			19
skipped question			14
Comments:			8

Comments:

1. Depends on instrument type.
2. We currently use electronic tranducers for scour monitoring at the bridges where we have determine that they are the best suited.
3. float out devices were installed at two levels. The first level is a "warning". The second is placed lower.
4. NA
5. Depends on what you are monitoring: riprap protection, water surface elevation, or the riverbed. I'd say typically we would use one sensor located a few feet below the water surface to avoid ice and debris (with a sonar system).
6. Used Ultrasonic to measure water surface elevations. Not sure of your question.
7. NA
8. You need a warning level so you can get to the bridge and close it before it becomes unsafe.

Table 8: Question 8 – Sensors are needed at the structure:

	Yes	No	Rating Count
Front:	100.0% (21)	0.0% (0)	21
Sides:	78.6% (11)	28.6% (4)	14
Rear:	61.5% (8)	38.5% (5)	13
Other (please specify)			8
answered question			21
skipped question			12

Other replies:

1. Typically where the worst scour occurs - at the leading edge of the piers.
2. Site specific. Sensor locations are determined on a case by case basis.
3. It's really a case by case decision
4. We have seen scour at all of these locations.
5. NA
6. Normally front, maybe sides, normally not the rear.
7. NA
8. Most problems appear at the nose, but hydraulic skew can move this location depending on the site conditions.

Table 9: Question 9- How often is the scour condition needed?

	Response Percent	Response Count
Once a minute	12.50%	2
Once an hour	68.80%	11
Once a day	18.80%	3
Once a month	0.00%	0
answered question		16
skipped question		17
Comments:		11

Comments:

1. Every 1-3 hours during high flow events. Otherwise, every week or month to ensure the instrument is still working.
2. During flash floods and during spring snow melt.
3. Seasonally dependant.
4. Under high flow conditions, otherwise once a month
5. Not sure what this question is asking.
6. NA
7. During significant rain events and established inspection frequencies.
8. Every 4-8 hours should suffice
9. Measure often, but may only need reporting hourly or daily if nothing is moving.
10. NA

11. The buried devices will send an alert when activated. In addition we have implemented BridgeWatch which lets us know when enough rainfall and\or flow (from USGS gauge stations) is likely to produce scour which is approximately within a minute of live data.

Table 10: Question 10- How should the info be displayed to MDOT engineers to make the best use of it?

	Response Percent	Response Count
Message when sensor is triggered	21.70%	5
Continuous sensor status	17.40%	4
Cell phone message	8.70%	2
Long onto a sensor website with sensor status	17.40%	4
Other (please specify)	34.80%	8
answered question		23
skipped question		10

Other replies:

1. I don't know. I'm a PennDOT engineer.
2. All good options. Automated e-mail/text message when a threshold is reached. Continuous monitoring via website is good option also.
3. more than one option should be used, incase of power outage or cell phone service is down durinng the time of need.
4. NA
5. Best to have message when sensor is triggered, but also have the continuous data available on a website to view when interested/needed.
6. All of the above. Need overlapping notification to make the correct determination of the bridge status.
7. NA
8. We recieve a mesaage when the sensor or threshold is triggered though e-mail or text message. In addition we can log into a web site to monitor rainfall NWS and flow USGS through BridgeWatch.

Table 11: Question 11- What annual cost per bridge is reasonable for monitoring?

	Response Percent	Response Count

Under $100	4.30%	1
Under $500	21.70%	5
Under $1,000	39.10%	9
Under $10,000	0.00%	0
Over $10,000	0.00%	0
Other (please specify)	34.80%	8
answered question		23
skipped question		10

Other replies:

1. Varies, depending on the importance of the bridge and the scour history at the site. $1,000 is reasonable for "important" bridges.
2. For small bridges ideally under $1K while $10K for larger bridges may be okay
3. Currently using BridgeWatch to monitor rainfall intensities. It is hard to estimate cost because we have internal overhead to adminster the system
4. NA
5. Do you include the capital cost here (spread out over the life for cost)? I'm a little confused, but I would say in the $500 range seems appropriate with capital and maintenance costs (and phone plans, etc).
6. NA
7. Our current monitoring with the Bridgewatch program is under $10 per month per bridge.
8. The float out devices for one bridge were approximately $15,000 counting labor to install and maintain the sytem for seven years a total of $24,500 or $3,500 per year. BridgeWatch was implemented for $350 per bridge per year.

Table 12: Question 12- What installation methods are acceptable for permanently-embedded sensors?

	Yes	No	Rating Count
Bolted onto bridge	92.9% (13)	7.1% (1)	14
Buried in riverbed	100.0% (15)	0.0% (0)	15
Sensors in a post that is installed near the structure (perhaps using a hollow-stem auger)	68.8% (11)	31.3% (5)	16
Flow diverted first	42.9% (3)	57.1% (4)	7
Installed in flowing water	100.0% (8)	0.0% (0)	8
Other (please specify)			6
answered question			21
skipped question			12

Other replies:

1. Sensor must have minimal protrusion. Otherwise, it might cause scour itself due to vortices/turbulence. Also, any sensor that is separate from the substructure unit is simply another obstruction that could cause scour itself or will become a debris catch point.
2. All good options. Depends greatly on the concerns the site and things you want to monitor.
3. will vary depending on site conditions and the project (new vs existing structure)
4. debris and ice are significant problems
5. NA
6. NA

Table 13: Question 13- Are scour sensors needed on the following structures:

	Yes	No	Rating Count
Piers	100.0% (22)	0.0% (0)	22
Abutments	76.2% (16)	23.8% (5)	21
River banks	35.7% (5)	64.3% (9)	14
Culverts	20.0% (2)	80.0% (8)	10
Other	20.0% (1)	80.0% (4)	5
answered question			22
skipped question			11
Comments:			5

Comments:

1. Typically concerned most with piers in live-bed conditions. The rest can usually be monitored and repaired following the event.
2. NA
3. Typically we only use these on Piers or sometimes abutments. We haven't used any on banks or culverts.
4. Culverts not part of my area. River banks normally extend outside of right of way.
5. PennDOT does not use scour sensors.

Table 14: Question 14- Ownership of sensor system preference:

	Yes	No	Rating Count
Owned and maintained by your DOT	93.3% (14)	6.7% (1)	15
Owned and maintained by a private service provider	80.0% (4)	20.0% (1)	5
No preference	75.0% (6)	25.0% (2)	8
answered question			21
skipped question			12
Comments:			7

Comments:

1. Whichever is most economical
2. Depends on costs, maintenance required. Instrument should require very little maintenance to be useful. Should also consider USGS, since this is what they do well.
3. NA
4. I think this is the second time this survey has been filled out. Can you please send survey results and information on your project to:

Wayne Gannett, P. E.
Hydraulic Engineering Unit
NYS Department of Transportation
50 Wolf Rd., Pod 4-3
Albany, NY 12232
518-457-9215

5. Hard to maintain.
6. PennDOT does not use scour sensors.
7. Both the DOT and private have their advantages and disadvantages

Conclusions

Based on the responses from the DOT Bridge and Hydraulic Engineers listed above it can be concluded that:

15. Scour is a problem in fewer than 10% of bridges, primarily due to successful monitoring and/or countermeasures.
16. Most bridges do not use permanently-embedded scour detection sensors.
17. Of those that use permanent sensors, all states only used them on 'scour critical' bridges.
18. When used, permanent sensors are mounted on piers or abutments and at the scour depth considered critical to collapse, with a few applications on the deck beams.
19. Sensors are mainly buried in the riverbed with some bolted onto the bridge.
20. The most common method of scour detection was a survey rod from the bridge deck for shallow flows and divers for deeper flows, with some using sonar.
21. At least one sensor is needed near the scour-critical elevation but more are also necessary at other elevations and near the bridge beams.
22. At least one sensor is needed at the front of the structure but more are also helpful at the sides and rear of the structure.
23. Scour levels need not be reported more often than hourly.
24. Scour information should be sent when a threshold level is crossed but continuous data should also be available via the internet.
25. Annual monitoring costs should be kept to under $1,000, if possible, but no more than $10,000.
26. Installation by burying in the riverbed is preferred with other acceptable methods being bolted onto the bridge and in a post. Installation in flowing water is acceptable.
27. Sensors are needed on piers and abutments, but not necessarily on riverbanks, or culverts.
28. There was not a significant preference for ownership arrangements with both DOT owned and private service provider being acceptable.

Acknowledgements and Disclaimer:

This work is supported by the Commercial Remote Sensing and Spatial Information Technologies program of the Research and Innovative Technology Administration (RITA), U.S. Department of Transportation (USDOT), Cooperative Agreement #RITARS-12-H-MTU, with additional support provided by the Michigan Department of Transportation (MDOT), the Maryland State Highway Administration (MDSHA), Michigan Technological University, the Michigan Tech Research Institute, and the Center for Automotive Research. The views, opinions, findings, and conclusions reflected in this paper are the responsibility of the authors only and do not represent the official policy or position of the RITA/USDOT, MDOT, MDSHA, or any other entity.