

Methods to detect and measure scour around bridge foundations

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Submitted: 19/05/2021; Accepted: 11/09/2021; Published online: 18/10/2021

Abstract: Bridges are indispensable structures vital to the operation of road and rail transportation networks. Crossing rivers and artificial waterways, however, presents a risk to their foundations due to scour actions. Scour is the number one cause for bridge failures and may occur beneath any bridge, large or small, with supports located within the waterway. This paper provides a summary of present scour detection and measurement equipment and associated assessment methodologies. In this regard, particular emphasis is placed on structural health monitoring better to evaluate the presence and influence of potential scour. A Sensitivity Analysis on a newly introduced monitoring system is also assumed. Furthermore, much research has been undertaken to create a technology that can instantly identify and detect bridge scour, improving survey reliability through prior inspection and prompt intervention. This research will explore and evaluate bridge scour detection methods employed and suggest a possible path for developing the detection system to identify scour depth effectively and efficiently. Finally, our key aim is to minimize human effort in identifying and bridge scour by using a quick, easy-to-use, cost-effective process, resulting in fewer injuries and economic savings.

Keywords: *water action; Bridge scour; detection methods*

1. Introduction and motivation

Bridges are critical engineering components within transportation networks (road, rail, pipeline, and waterway) that provide a means of crossing waterways, valleys (viaducts), and other networks (road/rail overpass). As a result, they may be exposed

to a variety of hazards, both natural and man-made. They are at the confluence of natural barriers and human networks by the very nature of their location and function. Any damage or loss of function could result in lives lost, as well as an economic and social disaster. Engineers who study bridge damage and collapse cite scour as the number one cause for loss of operational capacity. Bridge failures due to scour have been reported by ([1], [2], and [3]), with 6000 bridge failures in the USA and 140 UK rail bridge failures during 1846-2013. A database of over 600,000 US bridges was studied and compared to 1,700 collapses due to hydraulic action by [4]. They found a wide divergence of causes and evaluated many rating systems to predict performance. Scour is also identified as the bridge management risk most likely to be impacted by climate change; approximately 1 in 20 in the UK are expected to be at high risk by 2080 [5]. Given the potential impact, mitigation measures are equally daunting with costs averaging 25 to 76 million euros annually for 2040–2100 [6].

Within risk and resilience, scour is one of many natural hazards that bridges are designed to resist. Others would include wind (hurricane, tornado), flooding (high water level, high velocity, and debris), earthquake (shaking, liquefaction), and temperature extremes (thermal stresses, expansion, and contraction). Man-made hazards would include extreme traffic and vehicle loads, collisions, and accidents from vehicles as well as ships and barges. Depending on what is permitted on the bridge, there is also the possibility of fire and explosions. The recent focus on force protection for critical infrastructure highlights the potential of terrorist attacks [7].

Further assessment of risk involves quantifying the severity and recurrence of these hazards and estimating the structural resilience of the bridge system to them. Finally, exposure levels and response to an event must be evaluated. So, the types and depth of bridge scour are an integral part of risk assessment for every bridge crossing a waterway [8].

2. Scour along waterways

Scour is the removal and transport of sediment from around hydraulic structures. As a natural process, sediments are constantly eroded, transported, and deposited along waterways. However, certain hydraulic conditions will erode large volumes of material from around bridge foundations that weaken their support capacity and compromise the safety of the superstructure.

Three primary terms are used to categorize scour, specifically general scour, contraction scours, and local scour. General scour includes the natural processes of aggradation and degradation of streambeds due to changing hydraulic parameters such as variations in flow discharge or sediment amount [9]. It drives the natural

evolution of a waterway and results in the constant re-routing of the river channel when there are no natural or artificial obstacles [10].

Contraction scour occurs due to sudden channel geometry changes that constrict flow, causing an increase in water velocity. For example, bridge piers, shoreline facilities, hydraulic control structures, even ship traffic, can alter the channel cross-section and induce higher flow velocities. The increased speeds lead to higher sediment bed shear stresses, and if the stresses exceed the threshold level of the bed material, sediments mobilize and scour initiated [11].

The term “local scour” is given to describe erosion that occurs around hydraulic structures such as bridge piers and abutments (Fig. 1). An interacting set of unsteady flow features lifts and transports sediment from the pier foundation. They comprise flow impact with the pier face, creating a downward flow and an upward flow with a roller vortex; flow converging, constricting, then diverging; the creation, movement, and collapse of large scale turbulence in the foundation of the pier junction (horseshoe vortex, Fig. 1); a detaching shear layer where the pier cross-section curves back past its widest point; and, wake vortices generated through the pier's wake. The features evolve as scour develops. For example, when the water flow faces an obstruction such as a bridge pier, downward flow is convinced at the upstream end, causing localized corrosion around this construction [12]. The combined actions of the three forms of scour described may lead to significant losses in soil from around foundation elements.

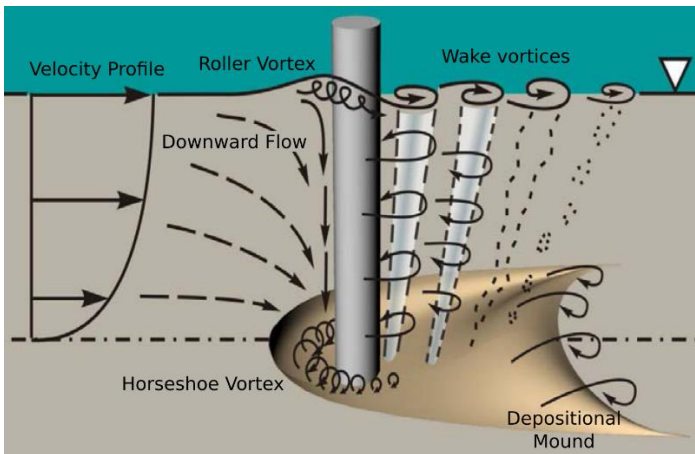


Figure 1. Local scour around the cylindrical pier in deep water, adapted from [13].

3. Damage from scour

Examples of scour causing serious bridge failures as the 1987 Schoharie Creek Bridge (Fig. 2a), part of Interstate-90 New York USA, where ten lives were lost. At the collapse, peak flow was 1,840 m³/s with a (70- 100) year return period. The foundations of the four bridge piers were large spread footings 25 m long, 5.5 m wide, and 1.5 m deep without piles. The footings were set 1.5 meters into the streambed on highly dense ice contact layered glacial that the designers deemed non-erodible. Flume investigations of the stratified drift, on the other hand, revealed that some material would be eroded at 1.5 m/s, with substantial rates at 2.4 m/s. A 1:50 scale 3-D physical model study indicated a prototype flow velocity of 3.3 m/s along the pier that failed. Additional modeling estimated 4.6 m of maximum scour depth. The prototype pier (pier 3) had a scour depth of 4.3 meters at the breakdown time. In 1995, the Arroyo Pasajero Bridge (Fig. 2b) on Interstate-5, California (USA), collapsed, killing seven people. The stream system is temporary (usually dry), with a sand bed having planar topography. While discharges were hard to quantify, the USGS using slope-area methods, determined that the 1995 discharge ranged 462–1,141 m³/s with the best estimate of 773 m³/s and recurrence 75 years [14].

Factors contributing to the I-5 bridge failure were:

- Regional subsidence causing an increase in channel slope (higher velocities)
- The original design changed by placing a solid web wall between columns to repair damage from an earlier flood. The wall had an angle of attack from 15 to 26 degrees, blocking thru-flow and potentially increasing local pier scour depth by a factor of 3.6 – 4.4
- There was a 33 percent increase in drainage area upstream from land-use change and a channel to link two streams.
- Long-term degradation of 3 m since the bridge was built
- Channel width reduction of 90 to 120m to a bridge width of 37 m.



Figure 2. (a) Schoharie Creek Bridge [15] and (b) Arroyo Pasajero [14]

4. Methods to monitor bridge scour

Bridge designers can reduce scour through both hydraulic and structural countermeasures [15]. Hydraulic approaches may reduce abrupt flow expansion or contraction caused by poor streamlining, such as blunt pier faces. Such changes often lead to the generation of the vortices responsible for scour. Maintaining larger bridge openings at the design stage and streamlining pier geometries reduce vortex generation. Another critical factor is to keep openings clear by removing debris that often obstructs flow. However, deposits of the natural canal and upstream erosion may frequently modify the flow angle, and rationalized abutments pose similar difficulties. Structural features can be included during the design stage to locate spread footing below maximum scour depth and add rip-rap to the base of piers. This assumes the maximum depths are specific and hydraulic conditions will remain relatively constant over the bridge's lifetime. Another approach is based on the observational method where scour is monitored over time, and remediation works are implemented as needed [16]. When implemented correctly, this can be an efficient and economical method.

As part of a general bridge asset management scheme, visual inspection is the most common monitoring technique [17]. They often incorporate the employment of divers to check foundation elements and estimate their depth of scour by use of basic instruments with a structural examination [18]. Two important disadvantages of this method are that inspections during flooding are impossible, and scour holes tend to be filled in as floodwaters subside. Since scour holes may refill after flooding, misinterpretation of the inspection may hide the true extent of the scour problem.

Scour depth may be measured or monitored in a variety of ways. They include:

- In-place devices that sense the presence (or absence) of soil. They may be penetration rods, floats with embedded switches, conductivity or dissolved oxygen sensors, or a variety of other approaches. They are often used when frequent or regular monitoring is required [15].
- Remote/portable sensors, which scan a greater area than sensors in (1) using sonar, geophysics, or similar concepts.
- Response analysis of the bridge, single pier, or abutment. Instead of measuring scour depth directly, they measure the effect of scour on the vibration response of the bridge or its components.

All the measuring and monitoring methods may be adopted into an overall program of operational health monitoring for the bridge. Each of these approaches has its advantages, and they are discussed further in the following sections

4.3. Scour monitoring using in-place (fixed) instrumentation

Most instrumentation fixed to the structure consists of sounding rods, driven rods with sensors, fathometers (sonar), buried transmitters, or tilt and vibration sensors. Table 1, presented at the end, lists a summary of all methods discussed here. Sonar devices can be mounted on the upstream face of the bridge pier and measure the distance to the stream bed. Measurements can be recorded continuously over any period to determine the depth of scour and refill during a high-flow event (Fig. 3a). Additional data logging and transmission equipment, as well as a solar panel or standard line power supply, would complete the package. Magnetic sliding collars (Fig. 3b) are rods attached to the face of a pier or abutment and driven into the streambed. A magnetic sensor collar is lowered to the streambed. If the streambed corrodes, the collar recesses the rod into the scour hole, and the depth indicates the amount of scour. Magnets in the collar come into proximity with switches within the rod that close as the magnet slides into the scour hole. The data logger senses the switch condition and determines the level of the collar and scour activity. Magnetic sliding collars can only be used to monitor the maximum scour depth. Buried float-out devices can be active or inert buried sensors (Fig 3c) with a radio transmitter that may be active or awaiting activation. The signal, when engaged, is detected by a nearby receiver. The float-out is buried in a horizontal orientation and either transmits this state or does not transmit at all. When scour occurs to the depth of the device, it floats, changing its direction to vertical, and either activates (if previously dormant) or transmits a different signal. The receiver listens to the new signal and knows which device is sending it. Scour depth is based on the burial depth of the newly activated signal. The float-out sensor is easy to install in dry or nearly dry conditions, under armor stone and rip-rap, or at various pre-determined depths. Due

to low power requirements, the float-out sensor can remain buried for many years and activate when released by scour activity [20].

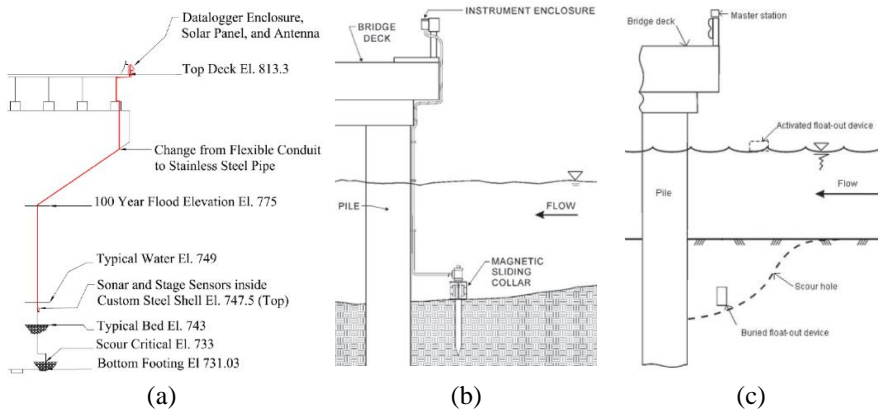


Figure 3. Fixed devices (a) sonar, (b) magnetic collars, (c) float-out device, modified from [21]

Other fixed systems may use sounding rods, time-domain reflectometry, or other sensors such as dissolved oxygen to report the scour depth. Sounding rods are placed on the surface of the river sediment (Fig. 4a). They have an enlarged base that will not penetrate the surface but move downward as the sediments erode beneath. An encoder box measures the downward movement and relays the information to the data collection/transmission system. Time-domain reflectometry (TDR, Fig. 4b) uses two wires to sense the dielectric environment outside the sensor. Sediments and water have different dielectrics, and the TDR device will detect the interface. Only the sensing length is used to measure depth. A tilt meter is sensitive enough to measure variations in abutment tilt (Fig. 4c) that may be a result of daily temperature changes, expected changes in water levels, or regular operations. Once those behaviours are catalogued, deviations from that behaviour would trigger an alarm that warns engineers to check the bridge for dangerous conditions. With some further calibration and analysis, the cause of the unusual behaviour may be determined. Vibration monitors are worked similarly; however, this approach uses the principle of calculating the critical occurrence of the rod fixed in the streambed. The opposite relationship between fundamental frequency and the sensor of the rod length is applied to monitor scour depth. It uses structural vibration sensors, such as accelerometers or fiber-optic (FBG) devices, to be used as the scour sensor's dynamic sensing feature. However, this approach is yet to be thoroughly tested. It is continuing research, and studies are being carried out on it [22].

All of the in-place instruments are limited to a small area of interest immediately surrounding the probe. They give little information about the areal extent of scour or specific hydraulic conditions (aside from depth of scour).

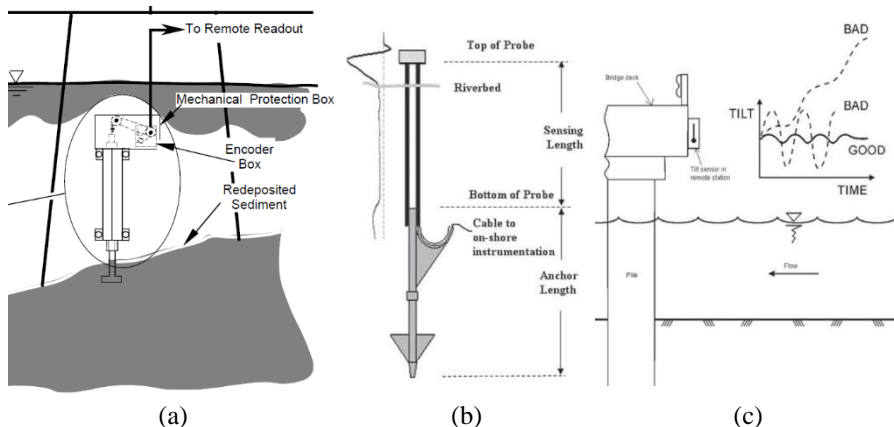


Figure 4. In-place measurements (a) recording sounding rod, (b) TDR probe, (c) tilt meter [9, 21]

4.2 Scour monitoring using portable instrumentation

Schall and Price [23] presented an extensive discussion on the theory and practice of using portable monitoring equipment. Being written in 2004, much of the technology is less expensive, but many of the concepts, design processes, and practical problems with deployment and handling are still the same. Portable instruments include four components:

- The measuring instrument (sonar, geophysical, etc.)
- The system to deploy the instrument (crane, paddleboard, remote-controlled boat, drone).
- Method to record horizontal (x, y) position of the instrument. It may also include some vertical (z) references as well.
- Data storage and transmission.

With newer technologies, components 3 and 4 have become much more economical and efficient. RTK GNSS modules, weighing 35gm, can record location information with centimetre accuracy for less than 500 euro [21]. Data storage options can be on-device with SD cards holding 128GB+ of data or transmitted to a receiver station or smartphone. With higher accuracy come different challenges: one must know the

various locations of the RTK module and the sensor. If the sensor is moving, then any time lag between sensor trigger and position report will impact the sensor's reported vs. actual location.

Sonar systems use a variety of transponders and methods. Generally, the signal is a narrow beam to reduce the possibility of signal averaging over a wider area. Monitoring concepts for structural structures have been through a steady growth phase over the last decade. As a result, they play a role in the design of new and emerging architectures. This chapter briefly reviews a selection of the more often used scour detection and measuring techniques. In terms of the instruments used, they are divided into portable instrumentation methods and integrated instrumentation methods. Mobile instrumentation methods include Physical probing, fathometers (Sonar), and Geophysical information, while fixed or integrated instrumentation methods include buried RF sensors, sonar, and other similar devices [24] as shown in Fig. 5.

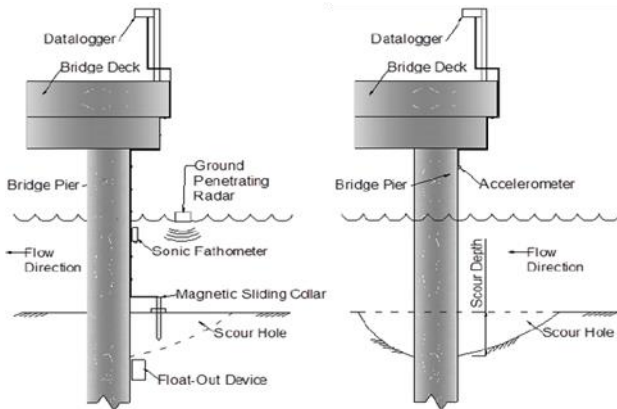


Figure 5. Portable (mobile) system measurement [26].

4.2.1. Fathometers and Manned ships

Fathometers or acoustic depth sounders are commonly used for portable scour measurements. In addition, precision survey-grade hydrographical survey fathometers and fish finders are used. Transducers are fixed to a pole, hand-line, tethered buoy, or boom while measurements are taken from the bridge. Kneeboards and pontoon-style floats are examples of tethered float platforms. In fast-moving, swirling water, the size of the float is critical for stabilization. In addition, a bridge inspection truck can deploy floating or non-floating structures. When the bridge is well over the river, this is especially helpful. For instance, bridges more than 15

meters above the sea are usually inaccessible from the bridge surface unless this method is used.

[25] Created an articulated arm to position a sonar transducer. The machine was trailer-mounted and could be used on bridge decks ranging from 5 to 15 meters above the water's level. An onboard computer measured the transducer's orientation about a known location on the bridge deck based on the boom's angle and the space between the boom pivot and the transducer.

Manned ships are used as a scour measurement platform. They usually need enough distance below the bridge and near the launch facilities. During floods, it may be a challenge as the river level can exceed or submerge the bridge's low chord, and boat ramps may be submerged. A fathometer is typically used for depth measurements, and GPS devices are usually used for location. The construction of an unscrewed prototype boat was prompted by concerns about safety, launching, and approval. A compact flat-bottomed jon yacht, an 8-hp outboard engine, a fathometer, and GPS with remote controls are applied. It was put to the test through six floods with great results [25].

The benefit of GPS over conventional land-based intrusion detection eliminates the need for line-of-sight between control points. GPS can be used at night and in inclement weather, particularly useful for scour tracking during floods. The downside of GPS is that it cannot be used in parts where the overhead obstructions, such as tree canopy or bridge decks. Though, GPS measurements up to the bridge face have been accurate without going under the bridge.

4.2.2. Sonar and Geophysical Techniques

The interfaces between different resources with different physical characteristics are determined by geophysical instruments based on wave spread and reproduction measurements. Sonar and geophysical techniques vary in that geophysical approaches have sub-bottom detail, while sonar can only detect the water-soil interface and not reach the sediment layer. The key differences between various geophysical techniques are the kinds of signals emitted and the physical property modifications that produce reflections. Like sonar, a seismic instrument uses acoustic waves but at a lower range (2-16 kHz). Seismic sounds, like sonar, are susceptible to being dispersed by air bubbles and high sediment concentrations [27]. The best use of geophysical technology is to assess scour depth in infilling areas during a flood under lower flow conditions. The equipment's expense and complexity and the data's interpretation restrict widespread usage and use as a portable scour monitoring system. More developed, minor price GPR devices with electronic data dispensation capability have been recognized, these issues have

lessened. However, expense and difficulty and the need for borehole details and reliable bridge plan details to calibrate and interpret the results can also restrict GPR.

4.2.3. Diving Probing and sound rods

Diving is a basic scour screening system in which a trained bridge inspector conducts a manual inspection of the bridge underwater. This system will capture scour data from various sites, and the water clarity does not affect the data collection process. However, the downside of this approach is that it can be costly, making it more ideal for worst-case cases. It also has a strong potential for risk. Furthermore, owing to the subjectivity of the regulators, the data produced from such visual inspections may have a high degree of uncertainty [28]. A sound rod is used for the bridge inspector to manually test a bridge by placing a rod or weight on the streambed to determine the sediment depth. The bottom of the rod must be wide to keep the rod from entering the streambed due to the rod's weight and friction induced by running water. When the riverbed is sand, sounding rods appear to go into the streambed, affecting their accuracy. Diving probing has many advantages, including the fact that it is not compromised by air entrainment or heavy sediment levels, and it can be used in fast, shallow water. The critical problem with this approach is the inaccuracy of the data samples gathered and the possible risks inherent with this method. Besides, this approach can be costly and does not have the capability of automatic warnings.

4.3. Applying other new methods for scour detection

The soil-structure interface mechanism is complicated during scour. However, the material displacement under (or around) the base during scour induces increased tension and decreased residual soil stiffness. Although the vibration of the structure depends on the device's rigidity, the observation of variations in vibration rates is a possible tool for detecting damage and monitoring health. The framework's average frequency related to the bridge piers could be found by applying spectral analysis approaches, for example, the FFTs accelerometers equestrian and frequency domain fragmentation on the bridges. The underwater instruments have often been used to calculate the progression of the scour depths over time. However, few investigations have been accompanied to understand the impact of the scour on the bridge system's reaction. Some of the instruments designed to test the bridge structure's reaction to the scour including tilt-meters which measure the comparative variation of the structural feature and, as such, also for distinguishing differential settlements that may happen as a consequence of the scour process. The only significant drawback of the system is that it does not straight designate the scour's extent. Devices capable of specifically assessing structural distress are expected to help engineers undertake the necessary repair arrangements for critical structures before the collapse.

Furthermore, Accelerometers are used to compute the structural reaction, especially in a change in boundary conditions [19].

There has been a spectral analysis reaction, and an elastic reaction spectrum of the seismic guidelines was created for this method of analysis that characterizes the activities of the earthquake [29]. In addition, a nonlinear study of the complex past of time was conducted to detect the potential behind non-elastic conditions. The principal findings are that the continuum analysis of reactions is an estimated method for assessing the optimum importance of inner forces and the nonlinearity of the pier segment reduces the inner forces and movement compared to linear analysis. This method could be considered a possible tool for detecting bridge damage and monitoring health, and distinguishing differential settlements that may happen due to the scouring process.

An Internet of Things (IoT) and Artificial Intelligence (AI) combination scoring system is created and deployed to get real-time measurements in scour depth. These vibration-based MEMS devices are packaged in a water-resistant steel ball in a barrel cage to survive extreme flooding. First, the fluvial water-level fluctuations surrounding the jetty are made using the Mask R-CNN profound learning model with real-time CCTV pictures (Fig. 6). Then, the scour-depth development is simulated with the hydrodynamic model and the sediment transport formula using the specified local scour formulas [30]. The overall performance of the hydrodynamic modelling is reasonable, based on the technique stated above, for whole scour-depth development. Moreover, it can anticipate scour-depth changes in bridge failure for early warning.



Figure 6. Fixing of the scour observing scheme, sensors, and the wireless station [30].

5. Summary

The author summarises the main results in Table 1 and Table 2 that contain the relevant methods, their tools, and experiments, as well as the properties of the methods based on international literature.

6. Conclusion

All methods presented in scour detection are costly in monetary costs, and more human resources are required. Therefore, instead of investing so much money on new gadgets, sensors can be used that are already integrated into our smartphones. A primary mobile phone, which anybody can use, can identify scour beneath bridges foundation (piers and abutments). The key aim is to minimize human effort in identifying scour by using a quick, easy-to-use, cost-effective process, resulting in minor injury due to bridge collapse.

Conversely, traditional procedures mostly use underwater tools to detect bridge scour depths and shape, which are also difficult to distinguish in instrument deployments and facilities. Recently, the method of Vibration-based destruction monitoring has been discovered to overcome specific difficulties by investigating the natural frequency range of a bridge or bridge part. Additionally, the advancement of these fixed and portable scour measurement devices, along with GPS, remotely operated ships, instrumented vehicles, and knowledge of the need to calculate and monitor bridge spacing, have greatly enhanced the scour database, methods for forecasting spacing depths, bridge scour and bridge protection.

Table 1. The portable bridge scour instrumentation detection methods

	Tools and experiments	Properties
Diving probing and sound rods	<ul style="list-style-type: none"> • A basic scour screening system in which a trained bridge inspector conducts a manual inspection of the bridge underwater. • A sound rod is used for the bridge inspector to manually test a bridge by placing a rod or weight on the streambed to determine the sediment depth. 	<ul style="list-style-type: none"> • Capture scour data from a variety of sites, and the water clarity does not affect the data collection process. • It can be costly, making it more ideal for worst-case cases. • It is a strong potential for risk. • Owing to the subjectivity of the regulators, the data produced from such visual inspections may have a high degree of uncertainty. • It is not compromised by air entrainment or heavy sediment levels, and it can be used in fast, shallow water. • The critical problem with this approach is the inaccuracy of the data samples gathered and the possible risks inherent with this method.
Fathometers	<ul style="list-style-type: none"> • Acoustic depth sounders are commonly used for portable scour measurements. • Precision survey-grade hydrographical survey fathometers and fish finders are used. • Transducers are fixed to a pole, hand-line, tethered buoy, or boom. • Kneeboards and pontoon-style floats are examples of tethered float platforms • Articulated arm to position a sonar transducer.. • Manned ships are also used as a scour measurement platform. 	<ul style="list-style-type: none"> • A bridge inspection truck can deploy floating or non-floating structures. • The advantage of GPS over traditional land-based vulnerability scanning is that it reduces the need for line-of-sight among control points. • The GPS may be used at night and in inclement weather, which can be especially useful for flood monitoring. • The downside of GPS is that it cannot be used in parts where overhead obstructions, such as tree canopy or bridge decks. • GPS measurements up to the bridge face have been accurate without going under the bridge.
Geophysical data	<ul style="list-style-type: none"> • The interfaces between different resources with different physical characteristics are determined by geophysical instruments based on wave spread and reproduction measurements. • Sonar and geophysical techniques vary in that geophysical approaches have sub-bottom detail, while sonar can only detect the water-soil interface and not reach the sediment layer • More developed, minor price GPR devices with electronic data dispensation capability have been renowned. 	<ul style="list-style-type: none"> • Differences between various geophysical techniques. Like sonar, a seismic instrument uses acoustic waves at a lower range (2-16 kHz). • The best use of geophysical technology is to assess scour depth in infilling areas during a flood under lower flow conditions • The equipment's expense and complexity and the data's interpretation restrict widespread usage and use as a portable scour monitoring system. • Expense, difficulty, and the need for borehole details and reliable bridge plan details to calibrate and interpret the results can also restrict GPR.

Table 2. The fixed bridge scour instrumentation detection methods

Methods	Tools and experiments	Properties
Sounding rods	<ul style="list-style-type: none"> • The binding of the rod in its supporting enclosure (pipe), • The producer (Cayuga Industries) and the USGS on coarse-bed streams • long probes installed in the stream bed at the point of interest. 	<ul style="list-style-type: none"> • A substantial depth of scouring, in sand-bed streams, sand deposited between the rod and its supporting section would also tie it up • In sand-based non-cohesive bed materials, the rod would penetrate a considerable and indeterminate volume into the bed • It could be costly and timewasting. • The precision of the measurement is affected by varying temperatures in the channel, with relative errors of 5% reported in some studies
Driven Rods (Buried)	<ul style="list-style-type: none"> • Both sensors and instruments supported by a vertical support member such as a shaft, rail, or column mounted vertically in the bed • The gravity sensor is placed in the stream bed near the guided rod scheme. • A remote sensing component is typically used to detect changes in the depth of the gravity sensor. 	<ul style="list-style-type: none"> • This system offers a reasonably easy method for tracking the scour depth's advancement. • There is a range of drawbacks as Scour depths may only be noticed in the instrument's immediate vicinity, meaning that several devices could be needed to catch the scour's actual (global) effect. • The element uses a gravity device that remains at the deepest depth of the scour throughout each flood incidence. This means that it will have to be reset, which could be costly and timewasting, and would not include details on the scour hole's refilling
Electrical conductivity devices	<ul style="list-style-type: none"> • Use the variations in the different media's electrical conductivity to determine the water-sediment interface's direction using two probes 	<ul style="list-style-type: none"> • As the material between the probes varies, the capacity to draw a current would also change. • This phenomenon can be used to show the presence and extent of the scour.
Sonar-based sensors	<ul style="list-style-type: none"> • permanent devices that are typically mounted on the pier and abutment. • Sonar emits pulse waves and processes the trip portable time of a pulse from the riverbed. 	<ul style="list-style-type: none"> • Both scour, and accumulation of sediments can be measured using sonar sensors • The measurements are influenced by heavy sediment and turbulent flow in the sea. • High-end sonars with a large depth capacity and high resolution can be costly
Time Domain Reflect-meter (TDR)	<ul style="list-style-type: none"> • Time Domain Reflect-meter (TDR) based approaches use a similar sonar approach to measure scour. 	<ul style="list-style-type: none"> • Determining the portion of the conduits submerged in the stream bed. • TDRs are capable of repeatable measurements and are very durable. • involve much fuel, making them costly.
Vibration-based method	<ul style="list-style-type: none"> • Calculating by the essential occurrence of the rod fixed in the streambed. • It uses structural vibration sensors, such as accelerometers or fiber-optic (FBG) devices. 	<ul style="list-style-type: none"> • To monitor scour depth, the opposite relationship between essential frequency and the sensor of the rod length is applied. • This approach is yet to be thoroughly tested. and studies are being carried out on it.

Acknowledgment

Professor Csaba Koren helped and supported the publishing of this paper in Széchenyi István University as part of the New solutions in the design of road and railway infrastructure course submission.

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