# Bridge Scour & the Structural Engineer

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## What Is Bridge Scour and How Important Is It?

You are at the beach, standing at the edge of the water and the waves come and go around your feet, digging a hole around them. You are experiencing scour. Bridge scour is the erosion of soil due to the flow of water around bridge supports. Scour is the number one cause of bridge failures in the USA. The following statistics were calculated using the National Bridge Failure Database compiled by the Structures Division of the New York State Department of Transportation, and provided to the author by Mike Sullivan of the NYSDOT. From 1966 to 2005, there have been at least 1,502 documented bridge failures. Of those bridge failures, 58% were due to scour. Second on the list, but far behind, were collisions by ships, trucks, or train impacts, and overload. Earthquakes were a distant number 8 on the list.

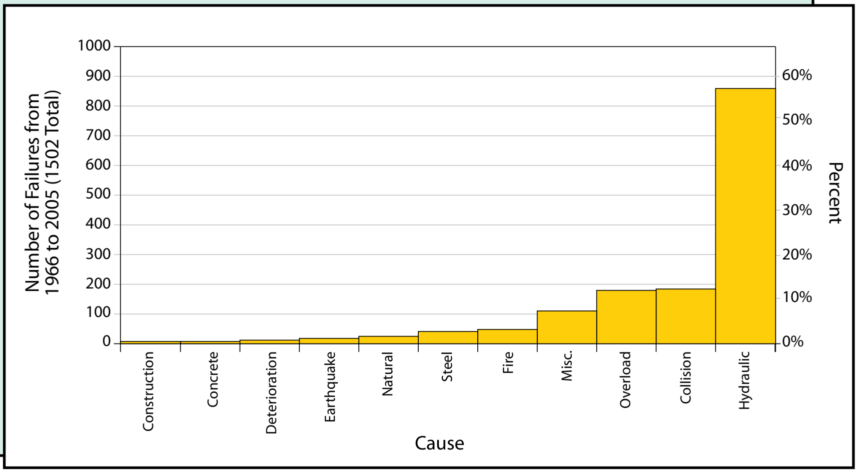


*Figure 1: Causes of bridge failures in the USA*

### *Many Bridges Need Scour Attention*

According to the Federal Highway Administration (FHWA), there are over 600,000 highway bridges in the USA, about 500,000 of which are over water. Under the Bridge Scour Evaluation Program, since 1988, the State Departments of Transportation have evaluated nearly all their bridges for scour. They report that over 26,000 of these bridges are scour critical. This means that, if one of those scour critical bridges is subjected to the design flood, the calculated scour depth is such that the foundation is not able to support the bridge design load. In addition to these scour critical bridges, over 85,000 bridges have unknown foundations. This creates a scour problem since once the scour depth has been calculated for the design flood, that depth cannot be compared with the foundation depth in order to decide whether or not the bridge is scour critical.

*Figure 2: Scour at Bridge Pier*
*Courtesy of University of Louisville, Kentucky*

## Soil Erosion

Water applies a fluctuating force on each soil particle. The faster the water flows, the higher that force is. If the force is sufficiently high or fluctuates enough, the soil particle or a particle cluster is dislodged and erosion starts. This is the erosion threshold for a given soil represented by the critical velocity, $V_c$. The stresses associated with $V_c$ are always quite small, and of the order of magnitude of the stress you feel when you blow gently on your hand. On the other hand, the soil resistance can vary greatly. For coarse grain soils with no cementation, the resistance is simply linked to the weight of the particle; this is why fine sands are some of the most erodible materials on earth, resisting much less than one meter per second of water velocity. Large riprap stones, however, can resist water with a velocity of over 10 meters/second. For fine grained soils, the gravity forces become small compared to the electrostatic and electromagnetic forces between particles, which resist erosion to various degrees. Some fine grained soils are very erodible, others are very resistant to erosion. The best way to determine their resistance to erosion is through testing, such as EFA testing (*Figure 3*). Even if erosion is very slow, it may not be negligible.

## Types of Scour and Other Definitions

Scour around bridge supports includes contraction, pier, and abutment scour (*Figure 4*). *Contraction scour* is due to the acceleration of the water in a contracted part of the waterway which is often created by the presence of approach embankments, or the geometry of the bridge and/or the channel itself. This increase in water velocity leads to a scour depth $Z_c$ along the entire width of the contracted section. *Pier scour* is due to the acceleration of the water around the pier. This increase in water velocity leads to a scour depth $Z_p$ at the pier. *Abutment scour* is due to the acceleration of the water around the abutment at the end of the approach embankment. This increase in the velocity of the water leads to a scour depth $Z_a$ near the abutment. In current practice, scour depths are added as shown on *Figure 4*.

*Degradation* refers to the case where the general elevation of the river bed is lowered by erosion. This occurs in the longitudinal direction of flow and may be added to the other scour components. This case may occur when a river is artificially straightened, or when there is downstream gravel mining. *Aggradation* refers to the case where deposition takes place at a bridge location. This may be due to slope failures upstream, with the river carrying the soil of the failed slope mass downstream.

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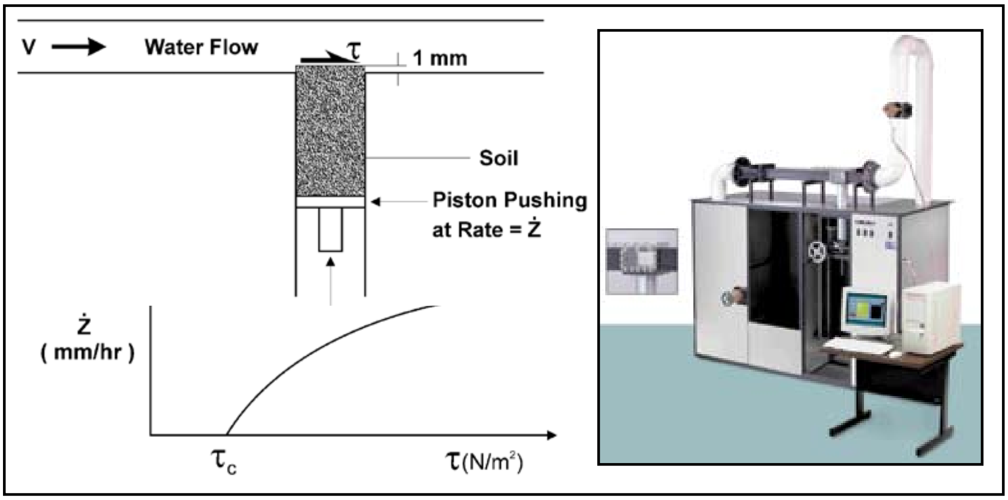


*Figure 3: Erosion Function Apparatus (EFA)*

*Clear water scour* occurs when the river does not carry any appreciable quantity of soil particles, or the soil particles remain in suspension during the flow. *Live bed scour* occurs when the river carries soil particles and some of them are deposited on the river bed during the scour process; the balance between this deposition and the erosion of the river bottom leads to a net scour, but the deposition decreases the scour effect compared to clear water scour. Therefore, clear water scour is a more conservative assumption. Clear water scour is usually assumed in cohesive soils, while live bed scour may occur in cohesionless soils if the water velocity is higher than the critical velocity in the river.

*Debris scour* occurs when tree trunks for example float down the river and get caught at a bridge. They increase the obstruction to the flow, thereby increasing the depth of the scour hole.

## Scour Depth Prediction

### Input Parameters

Any calculation to predict the depth of scour at a bridge requires three distinct types of parameters related to the water, the soil, and the geometry of the channel and the obstacle(s) to the flow of water.

With regard to the soil, the main parameter is the resistance to erosion. This resistance may be characterized by the *erosion function* which defines the relationship between the water velocity, or hydraulic shear stress, and the erosion rate of the soil (*Figure 3*).

With regard to the geometry, the parameters are the cross sections of the waterway and the dimensions of the obstacle(s) obstructing the flow including the bridge structure.

With regard to the water, the main parameters include the *peak water velocity* for a certain frequency event (100-year flood and 500-year flood), or a complete *velocity hydrograph* over a design period of time. The 100-year flood is the flood which has 1 chance in 100 to occur in any one year. The probability that a 100-year flood will take place during the 75-year design life of a bridge is 53%. The probability that a 500-year flood will take place during the 75 year design life of the bridge is 14%. The *maximum scour depth* is the scour depth which would occur if a given velocity were to be applied for an infinitely long period of time. The *final depth of scour* is the depth of scour reached when the bridge is subjected to a velocity hydrograph of finite time duration. In coarse grained soils, the maximum depth of scour is the scour depth which is calculated because one flood event usually lasts long enough to generate the maximum depth of scour. In fine grained soils, that is not the case and the final depth of scour may be calculated.

## Scour Depth Calculations

The guidelines for scour depth calculations are presented in FHWA document Hydraulic Engineering Circular No.18 (HEC-18), *Evaluating Scour at Bridges* (Richardson and Davis, 2001). These should be used in conjunction with FHWA HEC-20, *Stream Stability at Highway Structures* (Lagasse, Schall and Richardson, 2001). These are a set of recommended guidelines. HEC-18 covers the case of predictions of the maximum scour depth in coarse grained soils (HEC-18-Sand), and predictions of the maximum and the final scour depth in fine grained soils (HEC-18-Clay).

The comparison between the measured scour depths and the predicted scour depths according to HEC-18-Sand (*Figure 5*) indicates that, in nearly all cases, the predictions are larger than the measurements. Therefore, HEC-18-Sand is a safe prediction method in that the probability of exceeding the predicted value in the field is very low. One of the reasons for this is that often sands have a significant amount of clay in them. This clay content slows down the scour process and does not allow the maximum scour depth corresponding to the design flood to be reached during the life of the bridge. The HEC-18-Clay method was developed to better replicate the actual behavior and predict the final scour depth in addition to the maximum scour depth.

The prediction of the final scour depth and of the maximum depth of scour with HEC-18-Clay requires the use of Windows-based program which can be downloaded free of charge from the Texas A&M University website.

### Foundation Depth

The depth of the foundation should be such that the risk for the traveling public is acceptable. This requires that the probability of exceedance of the foundation capacity be acceptably low, and that the cost to the owner be reasonable. The current practice recommends that the predicted scour depth be subtracted from the soil resistance when calculating the foundation capacity (pile length) (*Figure 7*). Then current practice proceeds by

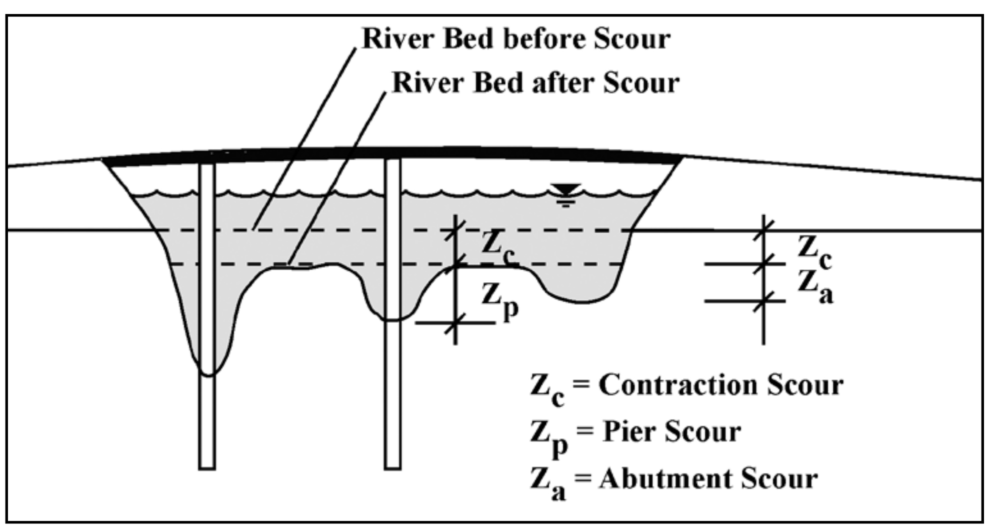


*Figure 4: Types of Bridge Scour*

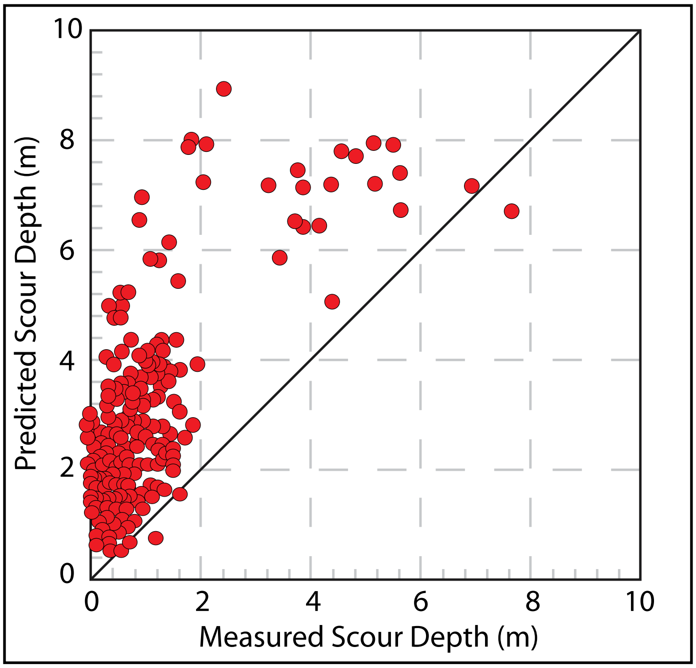


*Figure 5: HEC-18 Sand predictions against USGS-Mueller (1996) Database*

using a usual geotechnical/structural factor of safety of 2 to 3 when the 100-year flood is considered in scour depth calculations, and a geotechnical/structural factor of safety of 1 for the 500-year flood. The risk levels used by the various disciplines (hydraulic, geotechnical, structures) for foundation design are not the same. Efforts should be made to select a common risk level, and have each discipline develop design rules accordingly.

## Bridge Scour Countermeasures

The main source for scour countermeasures in the United States is the FHWA Hydraulic Engineering Circular No. 23 (HEC-23), *Bridge Scour and Stream Instability Countermeasures – Experience, Selection, and Design Guidance* (Lagasse, Zevenbergen, et. al., 2001). Scour countermeasures are defined as measures to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems. A Plan of Action (POA) should be developed for each scour critical bridge. The POA includes inspection strategies and counter measure alternatives. Monitoring structures during and/or after flood events can also be considered an appropriate countermeasure.

Scour countermeasures may be divided into three general types: hydraulic, structural or monitoring. A selection matrix in HEC-23 provides guidance in six different categories.

### *Hydraulic Countermeasures*

Hydraulic countermeasures may be classified as river training structures that modify flow, or armoring countermeasures that resist erosive flow.

River training structures alter the hydraulics, and mitigate erosion and depositional conditions. Examples of river training structures include spurs, weirs and bulkheads. Armoring countermeasures act as a resistant layer to hydraulic forces. They may be revetments and bed armors, or local armoring. The revetments and bed armoring are used to protect the streambed and/or banks. Local scour armoring refers to the protection of individual piers and abutments from local scour. Riprap is the most commonly used armoring countermeasure. Other types include gabions, articulated blocks, and grout filled or sand cement bags.

### *Structural Countermeasures*

Structural countermeasures consist of modifications of the bridge foundations or superstructure. Foundation strengthening may consist of reinforcement and/or extension of the foundations of the bridge. Pier geometry modifications are used primarily to minimize local pier scour. They may reduce the local scour at a pier, or help to transfer the scour to a location away from the pier.

### *Monitoring Countermeasures*

Monitoring countermeasures are useful in the early identification of potential scour problems. The three basic types of scour monitors include fixed and portable instrumentation, and visual monitoring. Scour monitoring may be a permanent or temporary countermeasure.

Fixed monitors are placed on the bridge structure. The recommended fixed monitors include magnetic sliding collars, sonar monitors, float out devices, and tilt and vibration sensors. Sonar monitors can be used to provide a timeline of scour, whereas magnetic sliding collars can only be used to monitor the maximum scour depth. Float out devices measure the particular depth where they were buried, and tilt and vibration sensors measure movements of the bridge.

Portable instrumentation describes monitoring devices that can be manually carried and used along a bridge, and transported from one bridge to another. Portable instruments are more cost effective in monitoring an entire bridge than fixed instruments; however, they do not offer a continuous watch over the structure. Portable instrumentation used at bridges include sounding rods, sonars on floating boards, scour boats and scour trucks.

Visual inspection monitoring may be at standard regular intervals, may include increased monitoring during high flow events (flood watch), and land monitoring and/or underwater inspections.

## Design Considerations for New and Rehabilitated Bridges

The FHWA recommends that a hydraulic study be conducted for each bridge site to determine appropriate bridge waterway openings and foundations. The foundation should be designed by an interdisciplinary team of geotechnical, structural and hydraulic engineers. It is almost always cost-effective to provide a foundation that will not fail, even from a very large flood event or super flood.

The hydraulic design considerations are best applied early in the preliminary design of new or rehabilitated bridges. Although other issues will often dictate the design parameters of the bridge, consideration of the hydraulics may help reduce the scour and stream stability problems at a crossing. Consideration given to items such as the location of the bridge, span lengths, and the shape and orientation of the substructure units can contribute to more favorable hydraulic openings.

The following three sections include design considerations from HEC-18 (Richardson and Davis, 2001). It is recommended that those working in hydraulic design of bridges consult this manual for additional considerations and details. All of the FHWA HEC manuals may be viewed on the FHWA Hydraulics Engineering website ***(http://www.fhwa.dot.gov/engineering/hydraulics)***.

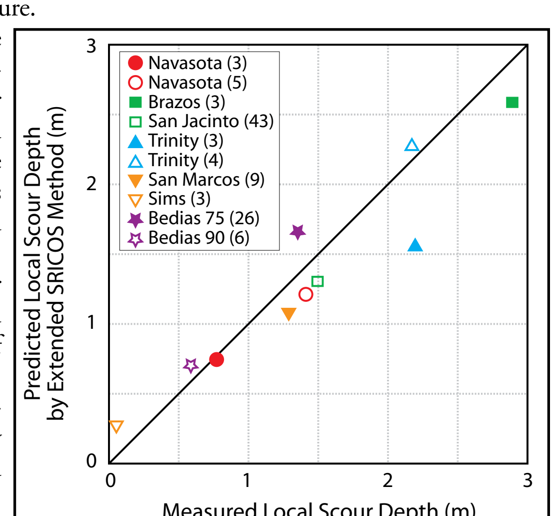


*Figure 6: HEC-18 Clay predictions against 8 bridge case histories in Texas*

*General Design Considerations*

For bridges where overtopping flows and debris and ice forces are of concern, the following are recommended:

- Hydraulics and traffic conditions may necessitate consideration of a bridge that will be partially or even totally inundated during high flows at some bridge sites. These pressure flow forces through the bridge waterway should be analyzed during the bridge design.
- The bridge superstructure elevation should be above the general elevation of the approach roadways so that the approaches are overtopped first.
- The elevation of the lower cord of the bridge should be increased above the normal freeboard for streams that carry a large amount of debris and ice.
- When overtopping is likely, the superstructure should be shallow and open to minimize resistance to the flow.
- Superstructures should be securely anchored to the substructure if buoyant; debris or ice forces are probable.

The following are general considerations regarding the design of the spans and foundations for all bridges:

- Continuous span bridges should be built if possible. These provide redundancy and withstand forces due to scour and resultant foundation movement better than simple span bridges.
- The scour analysis may indicate that local scour holes at piers and abutments overlap one another. If so, the scour is indeterminate and may be deeper. The span length may be increased to reduce the potential for overlapping scour holes.
- For pile and drilled shaft supported substructures subjected to scour, a reevaluation of the foundation design may require a change in the pile or shaft length, number, cross-sectional dimension and type.

*Pier Design Considerations*

- If there is a likelihood that the channel will shift, the pier foundations in the floodplains should be designed to the same elevation as pier foundations in the stream channel.
- Piers should be aligned with the direction of flood flows. The hydraulic advantages of round and pointed nose piers should be assessed. Streamline piers and use deflectors to decrease scour and minimize the potential for buildup of ice and debris.
- Multiple pile bents in stream channels may result in ice and debris buildup. Consider the use of other pier types where this is a potential problem.
- The scour analyses of piers near abutments need to consider the potential for larger velocities and skew angles from the flow coming around the abutment.

*Abutment Design Considerations*

The equations used to estimate the magnitude of abutment scour were developed in a laboratory under ideal conditions, and for the most part lack field verification. These abutment scour equations should be used to develop insight as to the scour potential. However, judgment must be used and abutment foundations should be designed for the estimated long-term degradation and contraction scour. Riprap and/or guide banks should be used to protect the abutment from local scour. Consideration should also be given to the use of spill-through sloping abutments, relief bridges and various river training structures.▪

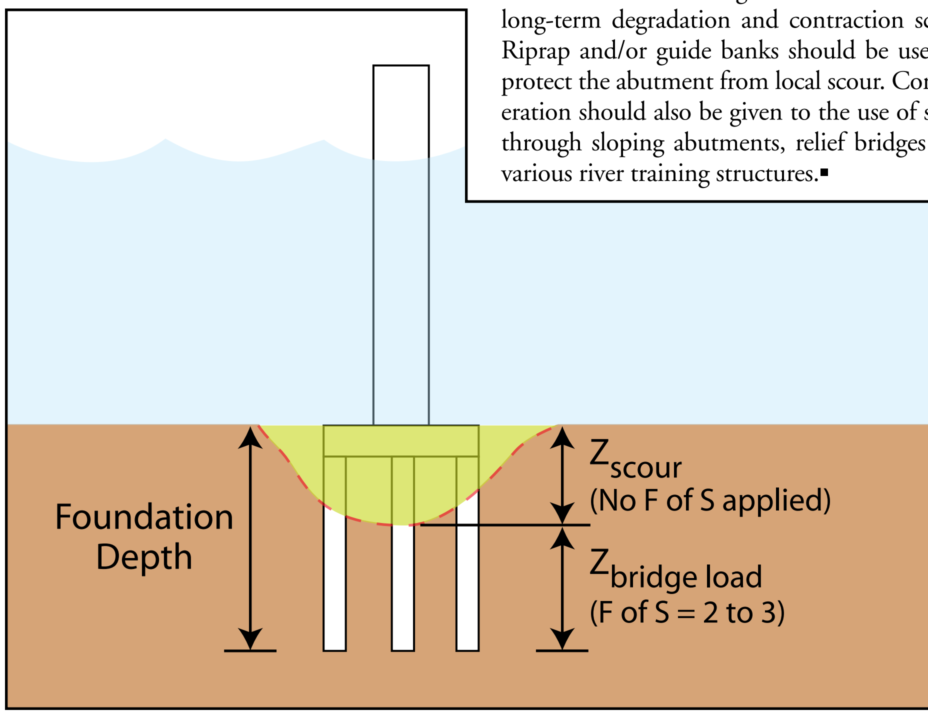


*Figure 7: Foundation depth and scour depth*

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