Research Report
KTC-99-57/SPR 157-94

KENTUCKY TRANSPORTATION CENTER

CORRELATION OF ROCK QUALITY DESIGNATION AND ROCK SCOUR AROUND BRIDGE PIERS AND ABUTMENTS FOUNDED ON ROCK

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Research Report KTC-99-57
KYSPR-94-157

Correlation of Rock Quality Designation and Rock Scour Around Bridge Piers and Abutments Founded on Rock

by

Tommy C. Hopkins and **Tony L. Beckham**

Tommy C. Hopkins
Chief Research Engineer
Head of Geotechnology

Tony L. Beckham
Research Geologist

Kentucky Transportation Center
College of Engineering
University of Kentucky

in cooperation with the
Kentucky Transportation Cabinet
The Commonwealth of Kentucky
and
Federal Highway Administration

September 1999

December 3, 1999

Mr. Jesse A. Story
Division Administrator
Federal Highway Administration
330 West Broadway
PO Box 536
Frankfort, Kentucky 40602-0536

SUBJECT: Implementation Statement: Final Report of Research Study KYSPR 94-157, Rock Scour of Highway Bridge Foundations, Report 99-57

Dear Mr. Story:

The potential for local scour at a bridge pier or abutment needs to be determined so that foundations can be designed to resist failure during large floods. While procedures have been formulated and suggested for evaluating, or assessing, the scour potential of local scour depths at bridge piers and abutments located on unconsolidated alluvial material, only interim guidelines in the form of a memorandum [FHWA, written communication (1991)] are available for evaluating the scour potential at footings placed on rock. The empirical guides relate quantifiable geotechnical indices to a qualitative measure of the ability of the foundation rock to resist erosion. However, the empirical guidelines lack documented proof or verification by means of either experiment or observation.

To test the validity of some the FHWA guidelines for assessing the scour of rock supporting bridge piers and abutments, and to provide a direction for future research, we felt that this potential problem -- rock scour-- should be researched and examined. Initially, one of the questions that arose was whether scour occurs at bridge piers and abutments founded on rock. In effort to answer this key question, the Geotechnology Section of the Kentucky Transportation Center performed on-site inspections of some 400 bridges where bridge footings were located on rock. Although there are many bridge sites where stream bed alluvial deposits cover the foundations of piers and abutments--and they are not visible-- a large portion of piers and abutments in this state are located on rock.

Generally, overburden soils --except in major flood plains and the far western portions of the Jackson Purchase Region-- are very thin in Kentucky. As a result of this condition, a large number of bridge abutments and piers in Kentucky were found to have been placed on rock foundations that are visible during low flow. These initial inspections show that scour at bridge piers and abutments placed on rock does occur. Scour, in these cases, was defined as the loss of foundation rock around the pier and abutment. The scour observed at those sites generally did not appear to be threatening, or causing bridge instability. However, if left unchecked, the scour could eventually lead to failure. Appropriate Cabinet personnel were notified of the sites where scour had been observed and appropriate actions were taken.

As a means of evaluating rock scour at existing sites, a rock scour hazard rating system is proposed in this report. Since we have discovered that some rock scour occurs, we have intensified our inspection efforts. A consulting engineering firm was hired to make in-depth inspections of bridges under the jurisdiction of the Cabinet. In performing these inspections, the firm used the hazardous rating system devised by personnel of the University of Kentucky Transportation Center. This firm examined several hundred bridges and found a few sites that had small amounts of scour. Based on those observations by the University Transportation Center and the consulting firm, rock scour is not a significant problem in Kentucky. In the few cases observed, those sites did not appear threatening and could readily be repaired by placing concrete in the scour holes.

SINCERELY,

J. M. (Mac) YOWELL
State Highway Engineer

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16. Abstract

Local scour around the base of a bridge pier or abutment occurs as the result of flow acceleration around the obstruction, formation of a vertical pressure gradient along the upstream end, and generation of vortices at the base of the structure. The flow patterns around piers and abutments are complex in detail, and the complexity increases as a scour hole forms in the bed around the structures. The potential for local scour at a bridge pier or abutment needs to be estimated so that foundations can be designed to resist failure during large floods. While procedures have been suggested for estimating local scour depths at bridge piers and abutments located on, or in unconsolidated alluvial material, only interim FHWA guidelines (July 1991) in the form of a memorandum are available for evaluating the scour potential at footings placed on rock. The empirical guides relate quantifiable geotechnical indices to a qualitative measure of the ability of the foundation rock to resist erosion. However, the procedure lacks documented proof or verification by means of either experiment or observation. To test the validity of some of the more significant FHWA guidelines for assessing the rock scour, on-site inspections of some 400 bridges with footings located on exposed rock were performed. A large number of bridge abutments and piers in Kentucky were found to have been placed on rock foundations that are visible during low flow. These inspections show that scour at bridge piers and abutments placed on rock does occur. As a means of evaluating rock scour at existing sites, a rock scour hazard rating system was proposed. Based on the inspections, rock scour is not a significant problem in Kentucky. Statistically, only about 0.5 percent of the observed bridges had significant vertical scour. Generally, when scour was observed the depth of vertical scour was less than about 10 inches. In the few cases observed, the scour holes could be easily repaired by filling with concrete. An approximate relationship between vertical rock scour depth next to the abutment, or pier, and Rock Quality Designation (RQD) was developed. Also, an approximate relationship between horizontal rock scour penetration beneath a pier, or abutment, footer and Rock Quality Designation (RQD) is presented. Generally, the geology at sites where scour was observed consisted of interbedded layers of limestone and shale layers, or very thin shale partings. Freezing and thawing apparently caused the blocks to breakup and flooding velocities of the streams tended to wash out the blocks around footers.

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EXECUTIVE SUMMARY

Local scour around the base of a bridge pier or abutment occurs as the result of flow acceleration around the obstruction, formation of a vertical pressure gradient along the upstream end, and generation of vortices at the base of the structure. The flow patterns around piers and abutments are complex in detail, and the complexity increases as a scour hole forms in the bed around the structures. The potential for local scour at a bridge pier or abutment needs to be estimated so that foundations can be designed to resist failure during large floods. While procedures have been suggested for estimating local scour depths at bridge piers and abutments located on unconsolidated alluvial material, only interim guidelines from FHWA (July 1991) are available for evaluating the scour potential of rock. The empirical guides relate quantifiable geotechnical indices to a qualitative measure of the ability of the foundation rock to resist erosion. However, the procedure lacks a proven correlation between rock properties and resistance to scour.

To examine FHWA guidelines for assessing the scour of rock supporting bridge piers and abutments, on site inspections of bridges with footings located on rock and assessments of erosional effects were performed. Some 400 bridges, where footings and abutments were located on rock and where the rock foundations were visible, were examined for rock scour. During the first phase of this study, a large number of bridge abutments and piers in Kentucky were found to have been placed on rock foundations that are visible during low flow. These initial inspections show that scour at bridge piers and abutments placed on rock does occur. During the preliminary survey, it appeared that some eight percent of the bridges that were surveyed had rock scour. However, a closer examination of the bridges showed that actually rock scour occurred at only two percent of the nearly 400 bridges surveyed. Scour depths greater than 10 inches occurred at only three of the four hundred bridges. However, these bridges were not in urgent danger because of rock scour. At other sites where scour occurred, the vertical scour was less than about 10 inches.

During the latter stages of this research study, the Kentucky Transportation Cabinet intensified its effort to examine scour conditions at some 8,277 bridges in Kentucky. A consulting engineering firm was hired to make in-depth inspections of bridges under the jurisdiction of the Cabinet. As a means of evaluating rock scour at existing sites, a rock scour hazard rating system was developed and proposed. Although this firm started its inspection initially in the far western portion of Kentucky, where deep foundations are prevalent, they inspected several bridges where shallow rock foundations exist. In their first pass through in Kentucky, Highway Districts 1 through 12, the consulting firm inspected some 2,877 bridges by the end of 1997. Bridges inspected were those with known foundations or documented scour problems. Excluding Districts 10 through 12, the University of Kentucky Transportation Center received from the consultant a list of sixteen bridge sites documenting their rock scour ratings. This firm noted that other data would be available after February 1998. In April of 1998, the consulting firm supplied UKTC with four additional sites which were located in Districts 10 through 12 (according to their information, some 777 bridge sites were reviewed). Eight of the 21 sites surveyed by the consultant were rated as having “High” rock scour. The Geotechnology Section of UKTC inspected and rated the 20 sites supplied by the consultant. Some 5,400 sites were later inspected by the consultant; however no additional rock scour ratings were received.

In the second phase of this study, a relationship between vertical rock scour and Rock Quality Designation (RQD) was developed. Also a relationship between horizontal rock scour beneath a footer and Rock Quality Designation (RQD) was developed. These relationships can serve as a guide in designing bridge footers founded on rock in Kentucky.

Geologically, Kentucky soils and rock formations were not affected by past glacial events, except for glacial materials deposited in the Jackson Purchase area of Western Kentucky and in the mouths of streams that flow northward toward the Ohio River. A vast majority of the many streams and tributaries were not affected by past glacial events. There are numerous streams and tributaries which have thin sediment beds or exposed bedrock in the streambeds. Consequently, most bridge piers and abutments are located in bedrock, or point bearing piles resting on bedrock. These streams have had millions of years to cut down through softer and weaker materials, and have apparently cut down to highly resistant layers.

Based on observations of bridge foundations founded on exposed rockbeds of some 400 bridges, and the observations of the Cabinet's consultant, scour around bridge footings founded in rock is not a significant problem in Kentucky. In the few cases where rock scour was observed, the scour could be repaired easily by placing concrete in the scour hole. None of the bridges, where rock scour was observed, were immediately threatened.

INTRODUCTION

Local scour around the base of a bridge pier or abutment (that is, the difference in elevation between the ambient bed level and the bottom of the scour hole) occurs as the result of flow acceleration around the obstruction, formation of a vertical pressure gradient along the upstream end, and generation of vortices at the base of the structure. The flow patterns around piers and abutments are complex in detail, and the complexity increases as a scour hole forms in the bed around the structures. The potential for local scour at a bridge pier or abutment needs to be estimated so that foundations can be designed to resist failure during large floods. Because the total cost of a bridge failure is typically large, design of pier and abutment foundations that will withstand extremely rare floods is almost always economical.

While the Federal Highway Administration (FHWA) [Richardson, Davis. (1993)] suggests a procedure for estimating local scour depths at bridge piers and abutments located on unconsolidated alluvial material, only interim guidelines in the form of a memorandum (Gordon, FHWA, 1991) are available for evaluating the scour potential at footings placed on rock, as shown in Figure 1. The empirical guides relate quantifiable geotechnical indices to a qualitative measure of the ability of the foundation rock to resist erosion. However, the procedure lacks documented proof or verification by means of either experiment or observation.

Figure 1. A scour hole at a bridge abutment founded on rock, KY Route 1659 bridge over Glenn's Creek in Woodford County, Kentucky.

Objectives

Major objectives of this study were to observe and assess the erodible nature of different geological formations at selected bridges in Kentucky, determine the amounts of erosion at highway bridge foundations containing rock scour, examine rock core data when available, and determine if values of Rock Quality Designation (RQD) could be related, or correlated, to rock scour at bridge abutments and piers.

Scope of the Study

More than 8,000 bridges and culverts are located in Kentucky. To define the general scope of the rock scour problem in Kentucky and to provide a general evaluation of the FHWA guidelines for assessing the scour of rock supporting bridge piers and abutments, on-site inspection of several hundred bridges with footings located on exposed bedrock were performed to observe rock scour. The conditions, including any erosional effects, of the exposed bedrock and footings were observed and assessed. As a means of evaluating rock scour at existing sites, a rock scour hazard rating system was developed and used in the assessments of the sites. Although it was beyond the scope of this study to observe the conditions at more than 8,000 bridges and culverts, the original strategy was to define the extent of the problem in Kentucky statistically by observing the conditions at about 400 bridges (located throughout Kentucky--where the bridge foundations were exposed bedrock). This represented approximately five percent of the bridges in Kentucky. Considerable time and effort were required to locate sites with exposed rock foundations and to evaluate conditions at each site. Initially, the Cabinet provided a list of some fifty potential rock scour sites. Conditions at these sites were observed and two of the sites were scored as sites with some rock scour. However, the search was eventually expanded to include some 360 additional bridges.

One of the major difficulties encountered during the study was identifying a sufficient number of sites where rock scour had occurred. Since a major aim of the study was to correlate values of Rock Quality Designation (RQD) and rock scour, sites where rock scour had occurred were needed to perform detailed studies. During the later stages of the study, the Kentucky Transportation Cabinet engaged a consultant to observe the scour conditions at the majority of bridges in Kentucky under their jurisdiction. A rock scour rating system devised by the University of Kentucky Transportation Center during this research study was used by the consultant in observing the conditions at those bridge sites. Where rock scour was indicated by the consultant, the data was transmitted to the Kentucky Transportation Center for further observations. This effort increased the number of rock scour sites for additional detailed study. Location of a sufficient number of rock scour sites for core drilling required observing some 400 bridges by the Kentucky Transportation Center and several thousands of bridges by the Cabinet's consultant. At selected sites, especially at a few sites where rock scour was observed, the rock foundations were drilled to obtain core specimens. A few sites were drilled where no rock scour was present. Rock Quality Designation (RQD) values were determined for the core runs. Efforts were made to correlate, or relate, rock scour and values of RQD.

NATURAL FACTORS AFFECTING ROCK SCOUR

Natural factors affecting scour at bridge piers and abutments founded on rock include the rock type and frequency of discontinuities within the rock unit , resistance of the rock to abrasion, and exposure of the rock to weathering. More rapid rates of scour are expected around piers and abutments founded on highly fractured and easily weathered rock, such as clayey shales and other soil-like, overconsolidated materials, and on rock exposed to mechanical and chemical weathering forces.

Rock Type, Physiographical Units, and General Geology of Bridge Foundations in Kentucky

General Classes of Rock

The three classes of rock, based on geologic origin, include igneous, metamorphic, and sedimentary. Igneous rocks are formed by solidification of molten or partially molten material. Generally, uniform in structure, igneous rocks exhibit little or no stratification and cleavage planes. Metamorphic rocks are formed from other types of rock as the result of changes in temperature and pressure, and from the chemistry of pore fluids, and generally have a layered or planar structure. Igneous and metamorphic rocks are not present in Kentucky (except for one igneous intrusion in Ellioit County). The basic rock type found in Kentucky is sedimentary.

Physiographic Units

Physiographic units of Kentucky (McFarlan 1943), Figure 2, include the Inner and Outer Bluegrass regions, the Knobs area, the Eastern and Western Coal Fields, the Mississippi Plateau, and the Jackson Purchase Area. Except in the southeastern part of Kentucky, the topography consists of several plateau levels that are in various stages of dissection. Maximum relief occurs in the eastern portion of the state. In this region, elevations may vary from about 900 feet to slightly more than 300 feet. According to McFarlan, “the plateaus are uplifted peneplains, but more frequently cuestas formed on gently dipping formations notably resistant to erosion.” The Pleistocene glaciation has not affected the topography of the state as it did in states to the north. Regional features are the result of erosion and several cycles of erosion are involved.

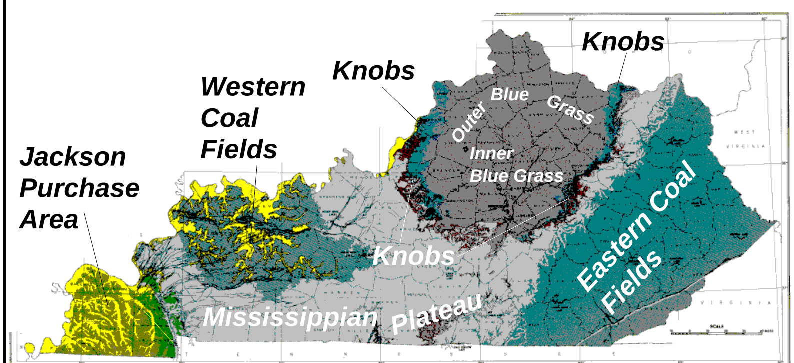

Figure 2. Physiographic Diagram of Kentucky

General Geology of Bridge Foundations in Kentucky

Based on geologic origin, exposed bed rocks in Kentucky are classified as sedimentary. Sedimentary rocks were formed by consolidation, or cementation, of sediment, or fragments, of other rocks deposited in water. Sedimentary rocks are products of disintegration and decomposition by weathering of preexisting rock. These rocks are formed by mechanical cementation, chemical precipitant, and pressure (Gordon, FHWA 1991). Occasional partings filled by metamorphic rock or unconsolidated material are sometimes present. Examples of sedimentary rock are limestone, sandstone, dolostone, and shale. Sedimentary rock units in Kentucky were formed during the Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian geological periods. Areal extent of these geological periods in Kentucky is illustrated in Figure 3.

With the exception of Quaternary Deposits, shales are associated with all periods. Shales of the Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian have been involved in many road-building problems. Certain formations have been particularly troublesome. The Kope and Fairview Formations (interbedded shales and limestone) of the Ordovician Period in northern Kentucky have caused numerous embankment, cut slope, and pavement problems on Interstates 75 and 71 in northern Kentucky and have caused extensive roadway failures of KY 8 (along the Ohio River, east of Covington). In the Knobs region, east of the Cincinnati Arch, the Crab Orchard Formation (Silurian) has been involved in many embankment failures. Many Mississippian shales behave poorly. For instance, the lower Borden Formation (Nancy and New Providence Members) tends to cause many pavement problems. The Henley shale bed caused construction problems on Interstate 64 east of Morehead. Also, shales of the Eastern (Pennsylvanian) and Western (Mississippian) Kentucky Coal Fields, such as the Breathitt Formation (near Jackson, KY) and Tradewater (Western Kentucky) have been troublesome.

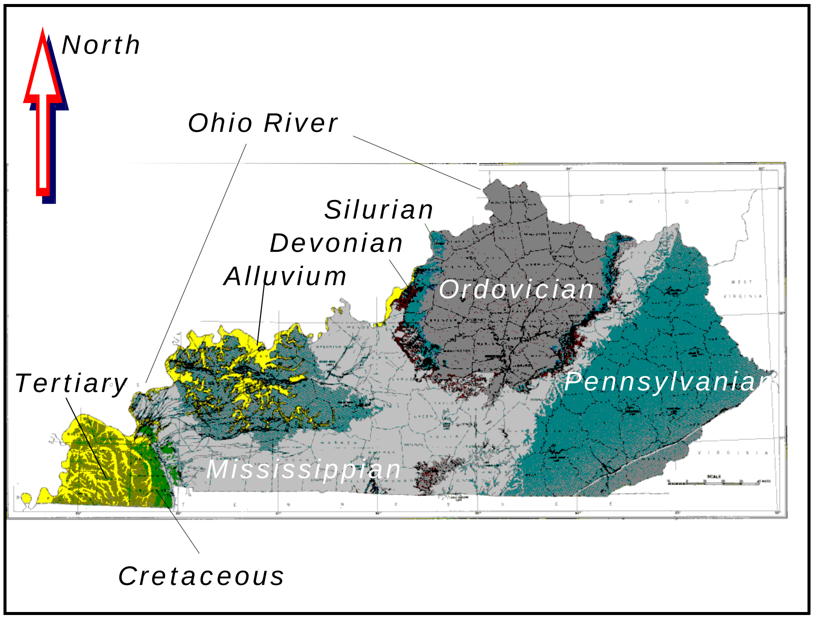

Figure 3. General Geology of Kentucky(US and Kentucky Geologic Survey).

In addition to the Ordovician, Silurian, Devonian, Mississippi, Pennsylvanian geologic periods, other geologic periods occurring in Kentucky, include the Quaternary, Tertiary, and Cretaceous System deposits. Ages of those periods range from 135 million years to 12,000 years. Except in valleys of rivers in Kentucky that flow northward and areas in western Kentucky, the geology and soils of Kentucky were not significantly affected by the ancient ice sheets of the Illinoian and Wisconsin (McFarlan, 1943) glaciers. The Illinoian Ice Sheet reached Kentucky and left scattered drift in the Ohio River Counties reaching from Oldham to Bracken. However, thickness of the drift is not sufficient to materially influence the topography or soils. According to McFarlan, the Ohio River at the mouth of the northward flowing, Kentucky River came into existence when ponding of the northward flowing rivers, which also includes the Licking and Big Sandy, occurred because of an ice dam that was formed by the glaciers. Formerly, those rivers, and other tributaries of Kentucky, flowed northward toward the Great Lakes region. As the backwaters increased in elevation due to the ice blockage, they eventually broke across low divides near the ice margin and flowed in an east-west direction creating the Ohio River. McFarlan describes this creation as the "amalgamation of a number of more or less east-west tributaries of these ponded rivers as the backwater broke across low divides (cols) near the ice margin."

McFarlan also notes that the Wisconsin Ice Sheet did not cross into Kentucky. However, large out washes from meltwater of this glacier combined with sediment from flooding of the northward flooding rivers of Kentucky created backwaters in western Kentucky and caused the filling of valleys up to depths of 150 feet. Broad-bottomed, alluvium-filled (deposits of sand, silts, and clays) valleys are very characteristic of the Western Coal Fields and Jackson Purchase area of western Kentucky (Figure 2).

The Ohio and other major streams are trenching through these deposits even today. According to McFarlan, the alluvial fill probably includes Illinoian and Wisconsin materials. Heights of the Illinoian (600 to 620 feet at Cincinnati) and the Wisconsin (540 feet at Cincinnati) fills were sufficient to cause ponding of the Kentucky and Licking rivers a considerable distance upstream. Borings performed at Carrollton, Kentucky (Hopkins, 1969) show that the bench deposits in the Kentucky flood plains are some 100 feet thick. They consisted of layers of brown silty clay, white sand, gray-bluish clay with sand lenses, and sand.

Except for unconsolidated deposits of the Tertiary and Cretaceous geological periods located in the far-western portion of Kentucky and deep alluvium deposits found in large streams, the vast majority of Kentucky soils typically consist of shallow overburden materials--residual soils--that range approximately from zero to 30 feet in thickness. The state has some 1,100 miles of navigable streams and rivers--second only to Alaska.

Although some of the major stream valleys along the Ohio River were filled with alluviium, many smaller tributaries located throughout Kentucky were not affected by the alluvial filling because they were located at higher elevations. There are numerous small streams and tributaries of these larger streams which have thin sediment beds or exposed bedrock in the stream beds. Consequently, most bridge piers and abutments in Kentucky are founded on bedrock or point-bearing piles resting on bedrock. Many soils located north of the Ohio River were subjected to extremely high preconsolidation pressures due to the thick glacial ice sheets. Some of the clay-like materials are extremely overconsolidated and hard. Highly, overconsolidated soils, can be deceptively hard in appearance but may be susceptible to erosion under flowing water. Typically, this is not the case in Kentucky.

Residual soils in Kentucky, as well as alluvial deposits in streams, were not exposed to the very high stresses imposed by the weight of the glacial ice sheets. As shown in Figure 3, vast areas of Kentucky contain ancient geological formations that have been in place some 310 million to 500 million years. Apparently, many of the smaller tributaries have trenched through the soft, residual clays and clayey shales over the past several millions of years until harder, more resistant materials have been reached. Although the many streams are continually cutting down through the sedimentary rock, the process has apparently advanced to a stage that, on a geological scale, stable conditions are generally indicated in many regions of the state. Approximately 92 percent of the roadways under the jurisdiction of the Kentucky Transportation Cabinet consist of two lanes. Many of the bridge piers and abutments of the two-lane roadways have built been constructed on exposed rock foundations of usually very resistant materials at very shallow depths. Part of the efforts of this study was to actually observe conditions at bridge piers and abutments located on exposed bedrock and at shallow depths.

Weathering Factors

Weathering is the process by which rock is broken down into smaller and smaller fragments from the effects of mechanical, chemical, and biological actions. The principal variables controlling the rate of weathering are the composition and structure of the rock, the climate, and the length of time during which weathering has taken place.

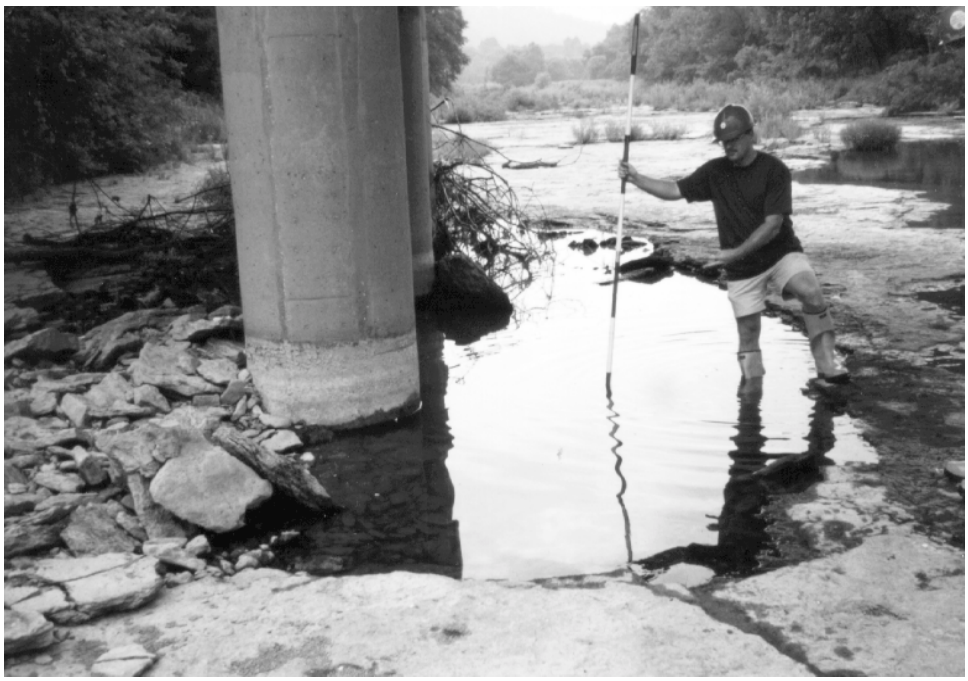

Figure 4. Weathered bedrock around a scour hole at a bridge pier, State Route 607 bridge over Cedar Creek in Owen County, Kentucky.

Rocks can be mechanically broken down by forces resulting from thermal expansion and contraction. Bare rock exposed to the atmosphere is subject to large variations in temperature from day to night. However, frost action or ice wedging is much more effective than heat in producing mechanical weathering. Water that has entered cracks, crevices, and pores of a rock mass usually starts to freeze at the upper surface, where it is in contact with the cooling air. As it passes from the liquid to solid state, water expands. In time, the water below is confined by an ice plug at the surface. Then, as the freezing continues, trapped water expands, and large pressures are exerted outward that can be great enough to dislodge fragments at the rock's surface. The frequency of frost action depends on the climate and the amount of rock surface exposed to the atmosphere. Dislodged fragments of mechanically weathered rock are angular in shape-- the size depends on the type of rock. An example of a weathered bedrock around a scour hole is shown in Figure 4.

Chemical weathering or chemical decomposition of rock transforms the original rock into something different, usually causing a significant change in the chemical composition and physical appearance of the rocks. Some rock, such as limestone, is soluble in water, especially if the water contains carbon dioxide.

Almost all rocks are broken by systems of fractures or joints. Joints can greatly influence the weathering of rocks by effectively cutting large blocks of rock into smaller ones, thereby increasing the surface area where chemical reactions take place, and by acting as channels through which water can penetrate to break down the rock by frost action. A highly jointed rock body will weather more rapidly than a solid one. The frequency of joints depends largely on the rock type and rock formation.

PREVIOUSLY SUGGESTED GUIDELINES

Previously, the Federal Highway Administration (1991) suggested some interim guidelines for assessing the scour potential of rock supporting bridge piers and abutments, and to provide a direction for future research. Because of a few bridge failures caused by scouring and a lack of knowledge concerning the scouring of rock, that agency apparently felt somewhat compelled to issue general guidelines pertaining to the scour of rock foundations supporting bridge piers and abutments. These general guidelines are summarized in Table 1.

Discontinuities in foundation rock supporting bridge footings can play a significant role in fostering rock scour when many fractures are prevalent. If the units are sufficiently small in the fractured rock, then the increased velocities of the flowing water around bridge piers, or abutments, may carry the smaller rock fragments downstream and erode the support of the bridge pier or abutment. Although the rock unit(s) may not have rock fractures, the rock unit may still have the potential to erode. For example, if the rock formation consists of very soft, erodible shale, then scour potential may be high. Hence, other means may have to be used to assess the scour potential of the foundation rock. The general guidelines suggest that scour potential may be evaluated using the unconfined compression test. If the unconfined strength is less than about 250 psi, then samples in general are not considered to behave as rock. This guideline is, perhaps, more applicable to homogenous rock units.

Where the rock unit consists of inter bedded layers, such as soft shale and limestone, or sandstone, the guideline may not be applicable, especially where the inter bedded layers are thin and exposed to the weather. In northern climates subjected to freezing and thawing, the rock inter bedded layers may fracture into small units that can be swept downstream. Obtaining samples of sufficient length for testing is especially difficult because the specimens may split along the inter bedded shale layers. A comment similar to the comment on the use of the unconfined compressive test can be made regarding the slake-durability index, sulfate soundness, and Los Angeles abrasion test. The applicability of those tests depends on the homogeneity of the rock unit. For example, the slake durability of rock units containing limestone layers with thin shale partings may have values of slake durability greater than 90 percent. However, the unit may still scour because of the low strength along the thin shale partings. In this case, obtaining enough material for slake-durability testing is not feasible. Using the sulfate soundness test may not be practical because this test generally requires a large amount of material which in many cases may not be available. Use of this test may be restricted to large bridge projects. The most useful test for assessing scour potential appears to be the Rock Quality Designation (RQD). An attractive feature of this test is that it is typically performed at bridge sites. It is a good measure of the competency of a rock unit.

Table 1. General guidelines pertaining to the scour potential of rock foundations of bridges. (After the Federal Highway Administration, Gordon, 1991)

Scour Potential Parameter	General Guideline	Comment
Rock Discontinuities/Defects (Influences Behavior)	Drill cores with one fracture or less per foot Drill cores with five or six fractures per foot	Good quality rock Poor quality rock and more scourable
Slake-Durability Index	Less than 90%	Poor quality rock
Unconfined Compressive Strength (Q_u)	Les than 250 psi (1724 kPa)	Samples in general are not considered to behave as rock As Q_u strength increases, scourability deceases
Abrasion (Los Angeles)	Loss less than 40%	Scourable
Sulfate Soundness (*Note: this test requires a large amount of material*)	Threshold loss rates of 12 (sodium) and 18 (magnesium)	Indirect measure of scour potential
Rock Quality Designation (RQD)	Rock Quality Designation (RQD) Less than 50%	Assume rock is soil-like with regard to scour potential

PRELIMINARY SURVEY

To develop an understanding of the scope and severity of rock scour around bridge abutments and

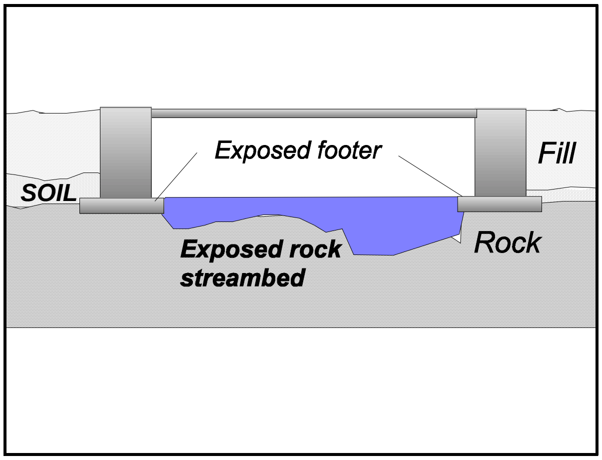

Figure 5. Single-span bridge with abutments located on rock.

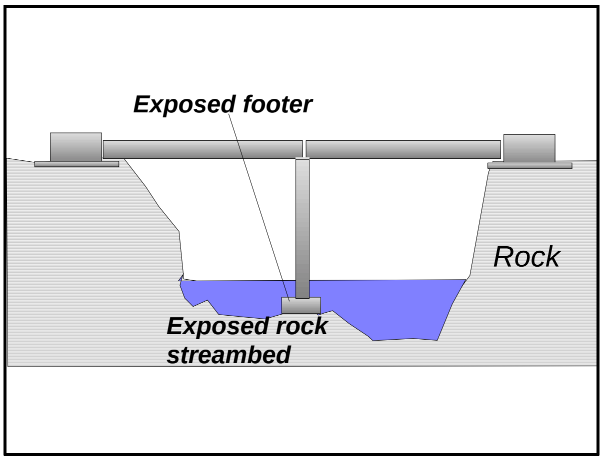

Figure 6. Two-span bridge with pier and abutments founded of rock.

pier foundations, conditions at a sampling of bridge sites in Kentucky where the streambed consisted of exposed bedrock were observed. Generally, the exposed rock in the streambeds was subject to many freezing and thawing cycles and, oftentimes, to wetting and drying cycles -- conditions which are considered severe. Sites selected for examination were initially chosen from a data base compiled by the Kentucky Transportation Cabinet. Later, a random search of sites was performed to increase the number of observations. In performing the survey of those sites, conditions observed at each site were classified according to one of the following three general preliminary categories:

- # Low—no rock scour is present,
- # Moderate—rock scour is noticeable or appears to be a potential problem, and,
- # High—noticeable rock scour is present and may pose a structural hazard.

The basic rock scour strategy consisted of examining numerous exposed rock streambeds of several different geologies at low flow and observing the scour conditions around the pier or abutment. If the scour condition of a given type of geology did not show scour at several sites under different flow conditions, then it was assumed that for the same geological formation under several feet of sediments the geological formation would probably not scour under a few flooding events during the life of the abutment or pier.

Typical bridge configurations observed during the rock scour survey are shown in figures 5, 6, 7, and 8. The single-span bridge situation depicted in Figure 5 occurred very frequently. Some 50 percent of the bridges that were surveyed were of this type.

Sites particularly vulnerable to soil scour are depicted by the situations in Figures 7 and 8. Although rock scour is not initially associated with these situations, the banks of these streams are prone to

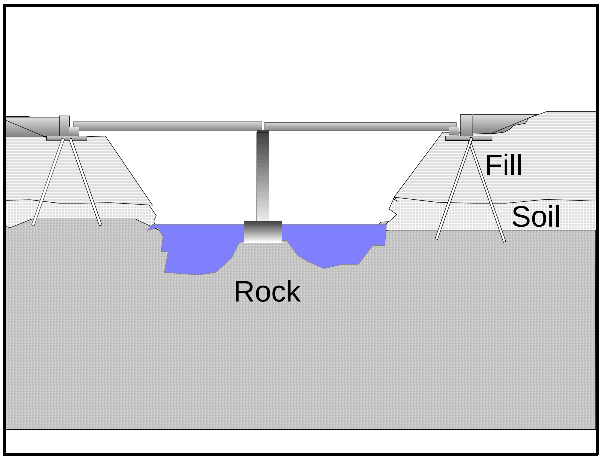

Figure 7. Two-span bridge with the pier located on rock and the abutments located on point-bearing piles resting on rock.

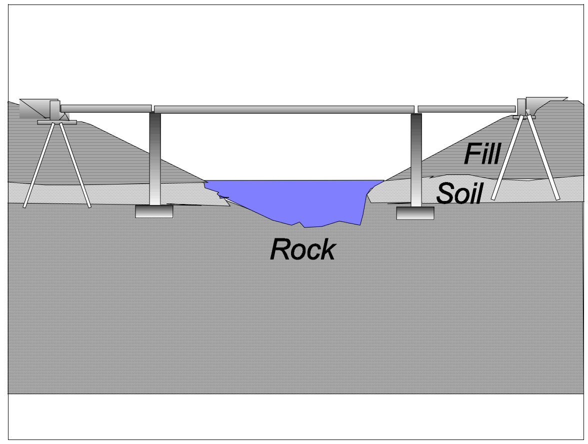

Figure 8. Three -span bridge with piers founded on bedrock and located in the approach embankments and abutments located on point-bearing piles.

soil scour. If these embankments are left unchecked, then rock scour could potentially be part of the problem. Both soil scour and rock scour could occur. Two case histories of scour at the banks of streambeds have been described by Hopkins (1973, 1985; and McNulty 1979). In both of these situations, the toe of approach embankments scoured, or eroded, and caused major movements, as illustrated in Figure 9, of the approach embankments toward the river. At one site, a slide occurred in the front portion of the embankment and exposed the point-bearing piles. Fortunately, these two sites had been monitored

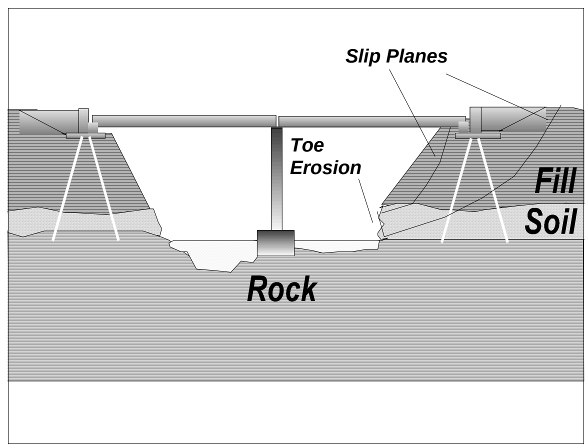

Figure 9. Unstable bridge approach embankment created by toe erosion, or scour.

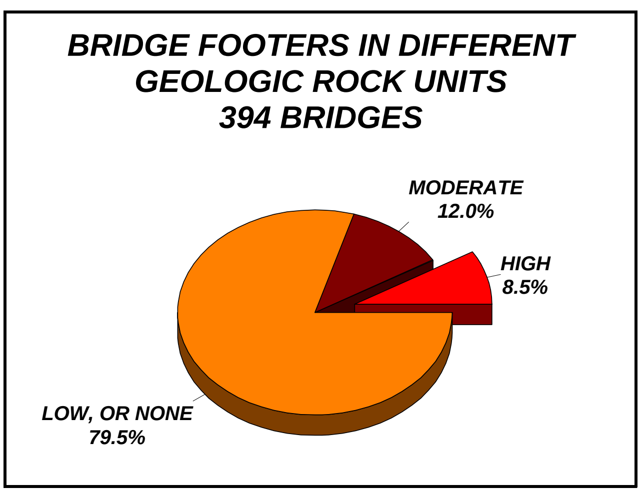

Figure 10. Preliminary ratings of rock scour at 394 randomly selected bridges.

over a period of several years, and remedial measures were designed to halt movements of the approach embankments and prevent complete collapse of the bridges. Total cost of the remedial measures at the two bridge sites was 2.3 million dollars. In both cases, the rock streambed was exposed to potential erosion.

Some 400 bridge sites were examined for rock scour. General location and distribution of the sites were scattered throughout the different geological regions of Kentucky, with the exception of the Jackson Purchase area, which consists of tens of feet of soil deposits and lies in flood plains of major rivers. The depth to bedrock in vast regions of Kentucky is usually small. Hence, in many cases, (at least in Kentucky), the streambeds consist of exposed bedrock, or only a few feet of stream sediments.

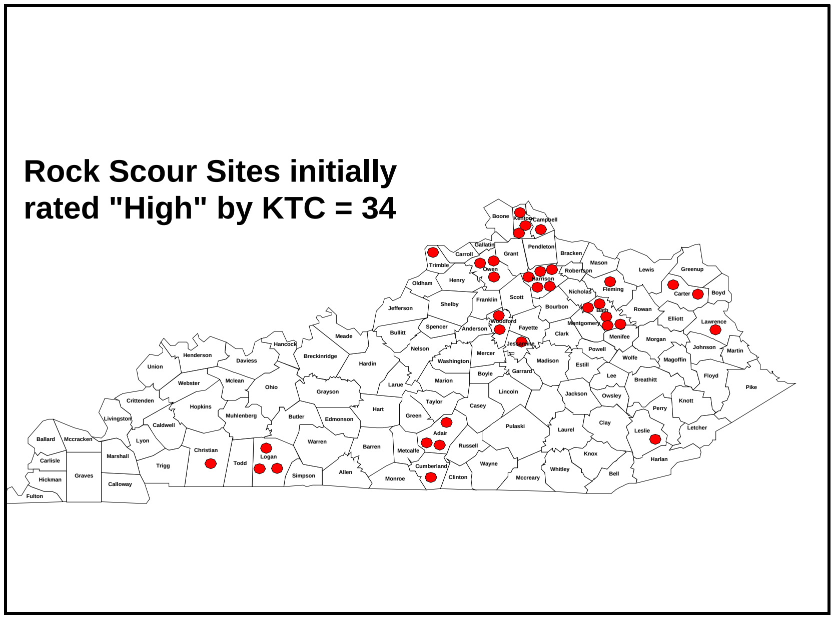

Figure 11. Location by county of preliminarily rated "High" scour sites.

The intent of the preliminary rating was to classify the rock scour condition at each site and to determine bridge locations where a more detailed rating and examination should be obtained at a later date. Rock scour conditions in the preliminary rating were divided into three broad categories: low (none or nominal scour); moderate (some scour close to or adjacent to footer); and high (deep scour located adjacent to, or undercutting the footer). As indicated from the preliminary ratings, Figure 10, about 8.5 percent of the 394 bridges (some 30 locations) were rated "high." The rock scour condition at some 12 percent of the locations was rated "moderate," while the condition of about 80 percent of the locations was rated "low," or none. County locations of the "high" classified bridges are shown in Figure 11. Geology of the streambed rock units at the different locations consisted of clayey shales, siltstones, sandstones, hard shales, sandstones, interbedded limestone and shale, and limestone with shale partings. Two factors which would appear to be significant to the development of rock scour are the geology of the exposed rock of the streambed and age of the bridge. To examine the influence of geology (sedimentary rocks only) on the development of rock scour, an analysis of bridge sites located in the Kope and Fairview Shale Formations was made. Both formations contain interbedded layers of clayey shale and limestone. However, the major portion of the Fairview

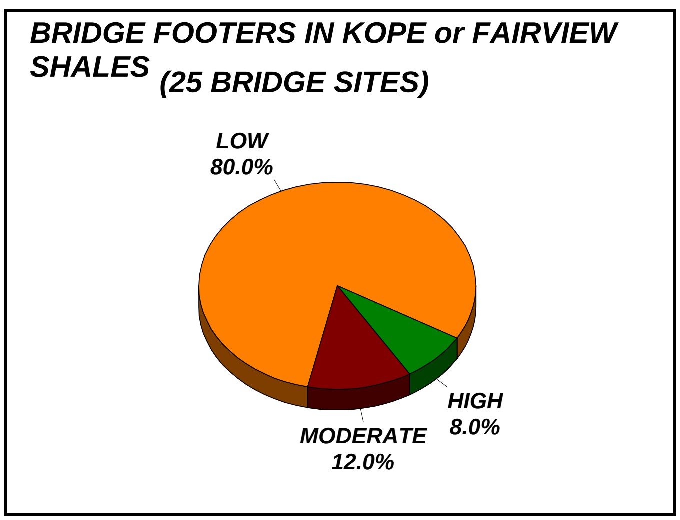

Figure 12. Rock scour ratings of bridge abutments or pier footers constructed in Kope or Fairview Shale.

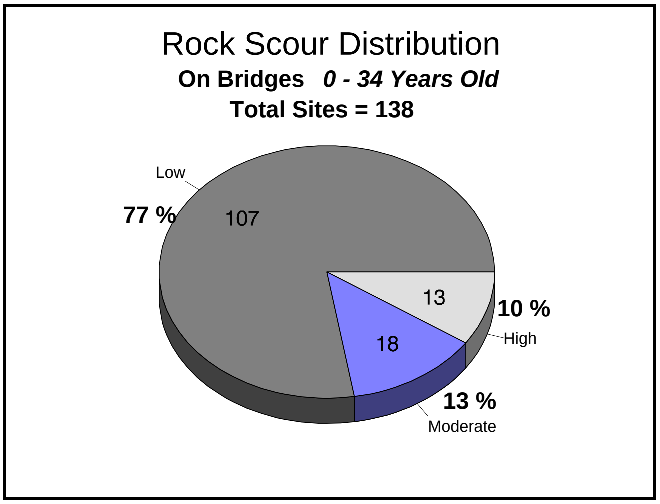

Figure 13. Scour quality distribution for bridges 0 to 34 years old.

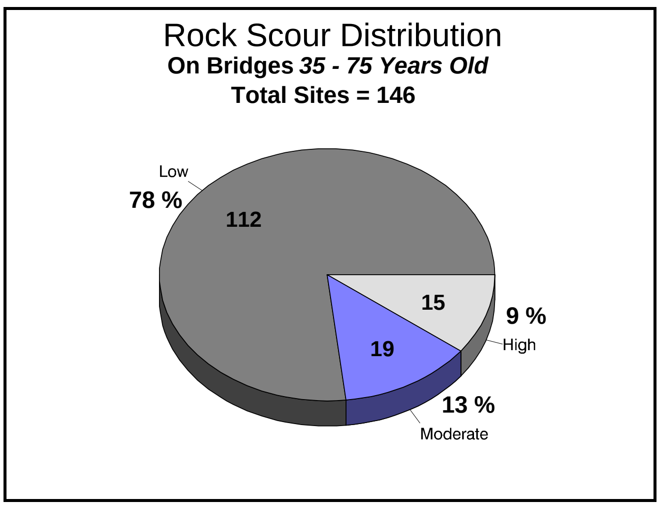

Figure 14. Scour quality distribution for bridges 35 to 75 years old.

Formation consists of limestone layers while the major portion of the Kope Formation consists of clay shale. Numerous highway engineering problems (landslides, pavement failures, etc.) are associated with these shales (Hopkins, 1983; 1988). The slake-durability index of these shales ranges from about zero to 20 percent. Jar slake index of this material is zero -- the material, after drying, degrades into flakes when exposed to water. Hence, it was anticipated that rock scour would be prevalent in areas containing this exposed clayey shale. However, the scour condition of 25 bridges in the Kope and Fairview Shales, Figure 12, was rated "high" at only 8 percent, or two bridges -- essentially the same percentage observed for the larger group of bridges, as shown in Figure 8.

"Moderate" and "low" ratings of bridge footers in the Kope and Fairview Shale were essentially the same as those observed for the larger group of bridge locations. Hence, based on this simple analysis, the type of geology of the rock unit (sedimentary only) does not appear to significantly influence the development of rock scour in Kentucky.

To determine the influence of the age of the bridge footer on the development of rock scour, bridges with known ages were divided into two age groups: 0 - 34 years and 35 - 75 years. Analyses of the two age groups are shown in Figures 13 and 14. The percentages of rock scour condition for bridges ranging from zero to 34 years were about 10, 13, and 77, which correspond to scour ratings of high, moderate, and low, respectively. For bridges in the 35 - 75 year age group, corresponding percentages were about 19, 13, and 78, respectively. Hence, the distribution of scour condition of the older bridge footings was essentially the same as the younger bridges. This indicates, although certainly not conclusively, that the age of the bridge footing is not a major factor (in Kentucky)leading to the development of rock scour. That is, it is not necessarily true that as the age of footer increases, the likelihood for the development of rock scour increases.

ROCK SCOUR HAZARD RATING SYSTEM

As a refinement of the rating system, a detailed rating system was devised so that the risk at different sites could be differentiated numerically. Using the numerical system, the sites can be sorted and priorities of risks at identified sites can be established. The detailed rating is shown from left to right in Table 2; the set points (3, 9, 27, 81) increase exponentially. The exponential scouring system allows a rapid increase in score and provides a means of distinguishing the more hazardous locations. Moreover, for optimal use, the reviewer has some latitude to score a condition between set points. A suggested form for rating the conditions at a given location is shown in Appendix A.

Three factors were considered of major importance in evaluating rock scour. These are: proximity, depth, and penetration of rock scour adjacent to, or undercutting the abutment or pier footer. Proximity is defined as the general location of rock scour in the streambed and its relative position to the footer, as shown in Figure 15. For example, rock scour may be occurring at a site, but it may be located some distance from the footer of the bridge abutment or pier. In this case, the rock scour

Table 2. Proposed Rock Scour Hazard Rating System

Category	Rating Criteria and Score			
	3 Points	*9 Points*	*27 Points*	*81 Points*
Scour Proximity	None	Far from footer	Near footer	Adjacent
Construction Depth d_c	None	Hole next to footer	Near bottom of footer	Fully exposed footer
Scour Depth d_s	None	Up to 2"	6"	> 6"
Penetration, d_p	None	Up to 2"	6"	> 6"
Average Annual Daily Traffic (AADT)	400	800	1200	1600

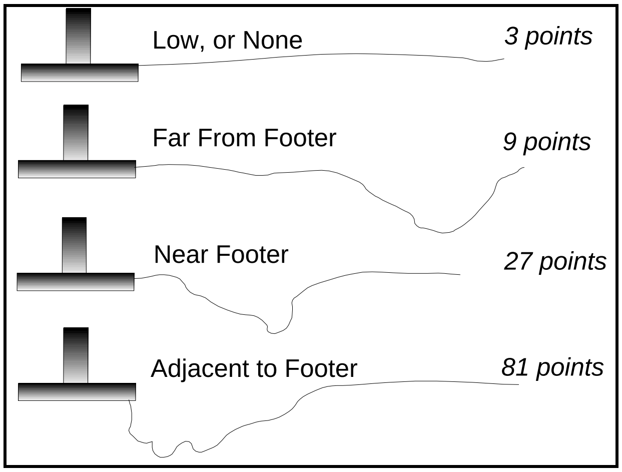

Figure 15. Schematic illustrating the four rock scour conditions of proximity.

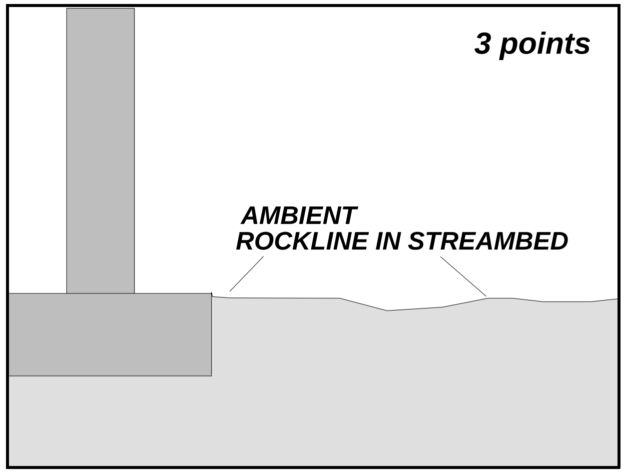

Figure 16. None or slight rock scour.

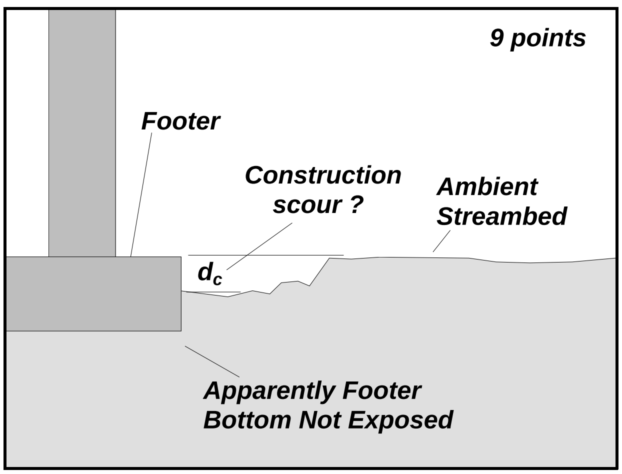

Figure 17. Small hole next to the footer.

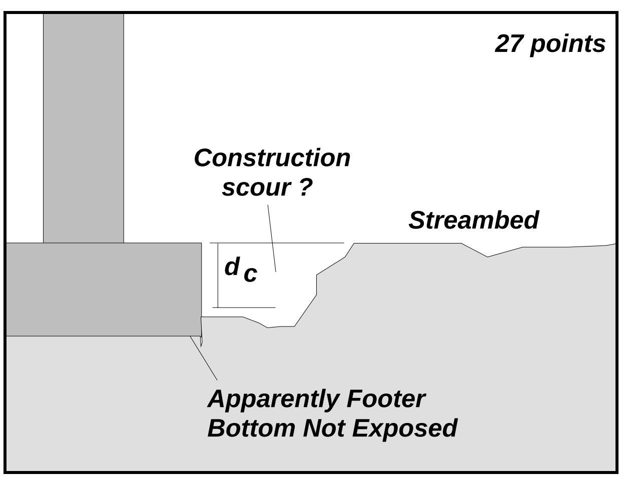

Figure 18. Scour depth near the bottom of the footer.

is rated moderate. If no rock scour is observed, then the condition is rated low. If the scour is located adjacent to the footer, then the scour condition is rated high.

The second factor considered critical to the condition of the footer is the depth of scour. This condition is complicated by the fact that oftentimes during construction of the footers, the space to be occupied by the footer is over excavated, which creates a hole, or space, that is larger than the space in the bedrock unit occupied by the footer. When first observing such a hole, the immediate impression is that deep scour has occurred in the rock. However, in many instances, a portion of the apparent scour is due to over excavation. In some instances, the over excavated holes may have originally been backfilled with aggregate which has washed out at some subsequent time after construction. In other cases, some sediment has been deposited in the over-excavated space adjacent to the footer.

In defining the depth of scour, the relation of the top of the footer and the general elevation of the existing ambient rockline is noted. Four general conditions are noted in the rating system, as represented by Figures 16 through 19. In Figure

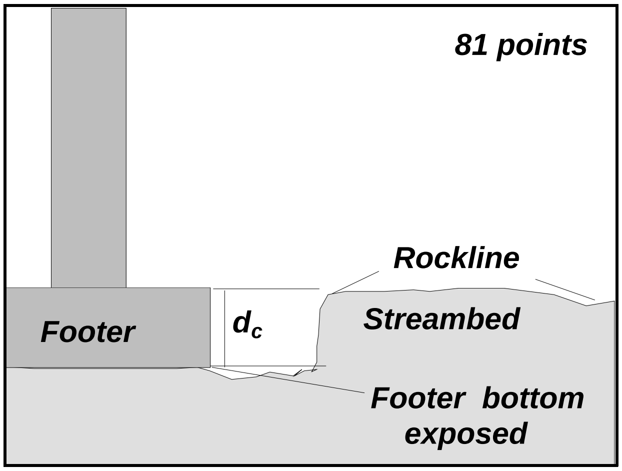

Figure 19. Scour depth at the bottom of the footer.

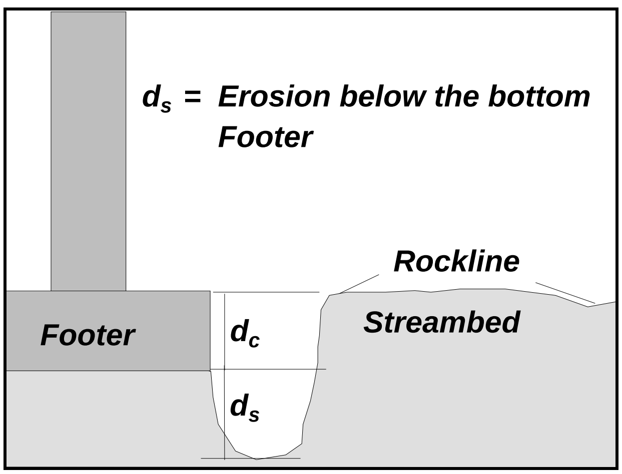

Figure 20. Scour depth below bottom of footer.

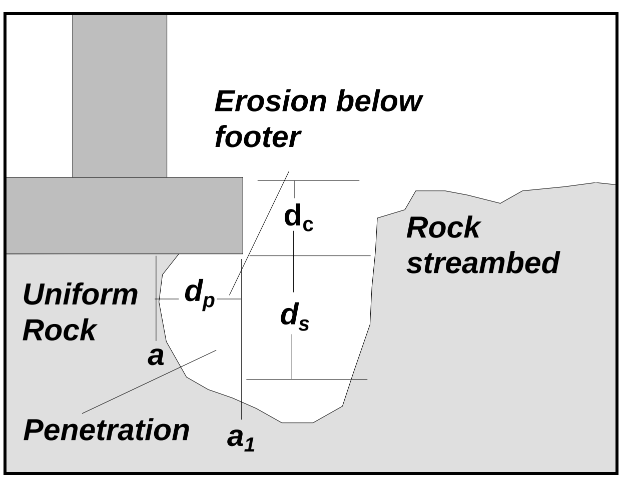

Figure 21. Erosion penetration under footer foundation.

16, no scour is apparent and the scour condition is rated low, or given a numerical value of zero to three points. In Figure 17, a local scour hole is visible around the footer. However, the bottom of the footer is not readily visible. In this situation, erosion of the rock unit adjacent to the footer may be actual erosion or the hole may be due to over excavation. This condition is given a moderate rating and assigned a value of about nine points.

In Figure 18, the bottom of the apparent scour hole appears to be at the same level as the bottom of the footer -- a condition that is rated as high, or a value of 27 points is assigned to this situation. Finally, as shown in Figure 19, whenever the bottom of the scour is at the bottom of the footer or below, the condition is rated very high and a value of about 81 points to 100 points would be assigned to this situation. In addition to a maximum d_c score, a quantitative measurement, d_s, as shown in Figure 20, from the bottom of the apparent scour to the exposed footer line is taken and scored in this case, as illustrated in Table 2.

Construction scour, d_c, could include rock that was fractured during construction, but not excavated. The fracture rock may have been washed away at a later date.

The third factor considered critical to the performance and service of the abutment or pier footer is erosion penetration beneath the footer. Penetration of rock scour is the horizontal distance (line ***a-a₁*** in Figure 21) measured from the face of the footer to the eroded face of the rock unit beneath the footer. Two different conditions have commonly been observed in Kentucky (sedimentary rocks). In the first case, Figure 21, the rock unit is uniform in structure and erosion occurs directly below the footer. The second case, Figure 22, involves a footer resting on interbedded layers of hard, or durable,

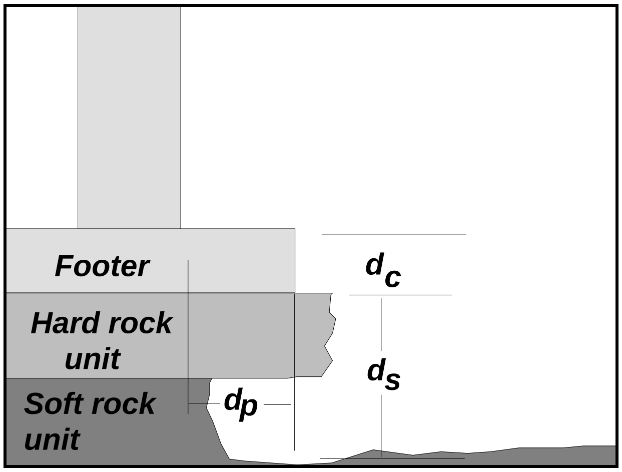

Figure 22. Erosion penetration occurring within interbedded layers.

and soft, nondurable, rock units. Erosion penetration occurs indirectly as a result of differential erosion between the durable and nondurable units. Generally, the footer is oftentimes located on the durable rock unit. However, if the hard member is thin, the footer may be undercut as the softer member erodes. If the penetration is merely adjacent or zero, then the condition is rated low. When penetration is about two inches, the condition is rated moderate. For a penetration of two to six inches, the condition is serious. When the penetration is greater than 6 inches, the condition is rated very serious. Although these penetration values were arbitrarily selected, they are based on several hundred observations. A fourth factor, Annual average Daily Traffic (AADT) is included as an aid in prioritizing funds for rock scour repairs or countermeasures. Although AADT has no direct impact on the amount or severity of rock Scour, it can be used as a tool in allocation of funds for repairs.

RELATIONSHIP OF THE PROPOSED NUMERICAL RATING SYSTEM AND THE RECORDING AND CODING GUIDE FOR THE STRUCTURE INVENTORY AND APPRAISAL OF THE NATION'S BRIDGES

In the "*Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*" (FHWA, 1988), item 113 of the guide deals with the current status of the bridge's vulnerability to scour. In the inventory, this item is coded as a single digit, as shown in Table 3. The Guide notes that whenever a rating factor of 3, or below 3, is determined for a bridge foundation, the site is considered "scour critical." A scour critical bridge is defined in the Guide as "one with abutment or pier foundations which are rated as unstable due to (1) observed scour at the bridge site or (2) a scour potential as determined from a scour evaluation study." In cases where the foundations may be rock, and scour analyses and calculations cannot be made, the guide suggests using the coding that is most descriptive of site conditions (a condition that could be obtained, in many instances, by visual inspections of the footers during low flows.) A proposed relationship between the scour vulnerability rating in the FHWA guide, as outlined in Table 3, and the rock scour rating of exposed footers founded on rock foundations is shown in Table 4. Basically, a score of 301 to 500 in the proposed system would correspond to codes 0, 1, 2, and 3 of the guide-- a rating of scour critical. This rating identifies structurally endangered bridges. A score ranging from 126 to 300 from the proposed system identifies bridges that are scour prone and corresponds approximately to items 4, 5, and 6 of the FHWA Guide. A score below 125 identifies bridge foundations as stable, or low scour.

Table 3. Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (after FHWA, 1988)–Item 113.

Code	Description
9	Bridge foundations (includingpiles) well above flood water elevations.
8	Bridge foundations (including piles) determined to be stable for calculated scour conditions; calculated scour is above top of footing.
7	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical.
6	Scour calculation/evaluation has not been made. Use only to describe case where bridge has not been evaluated for scour potential.
5	Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles.
4	Bridge foundations determined to stable for calculated scour conditions; field review indicates action is required to protect exposed foundations from effects of additional erosion and corrosion.
3	Bridge is scour critical; bridge foundations determined to be stable for calculated scour conditions: ▬ Scour within limits of footing or piles. ▬ Scour below spread-footing base or pile tips
2	Bridge is scour critical; field review indicates that extensive scour has occurred at bridge foundation. Immediate action is required to provide scour countermeasures.
1	Bridge is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic.
0	Bridge is scour critical. Bridge has failed and is closed to traffic.

Table 4. Proposed Relationship Between Rock Scour Hazard Rating system and Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges.

Rock Scour Hazard Rating System Score	Description	Comments
0 – 125	Identifies bridge foundation scour conditions as "low"	Corresponds to scour vulnerability codes, 7, 8, and 9, item 113, of the *"Recording and Coding Guide for the Structure and Appraisal of the Nation's Bridges"*
126 – 300	Identifies and warns of scour-prone bridges as "moderate," or stable	Corresponds to scour vulnerability codes, 4, 5, and 6, item 113, of the *"Recording and Coding Guide for the Structure and Appraisal of the Nation's Bridges"*
301 – 500	Identifies structurally endangered as "high"	Corresponds to scour critical codes, 0, 1, 2, and 3, and 9, item 113, of the *"Recording and Coding Guide for the Structure and Appraisal of the Nation's Bridges"*

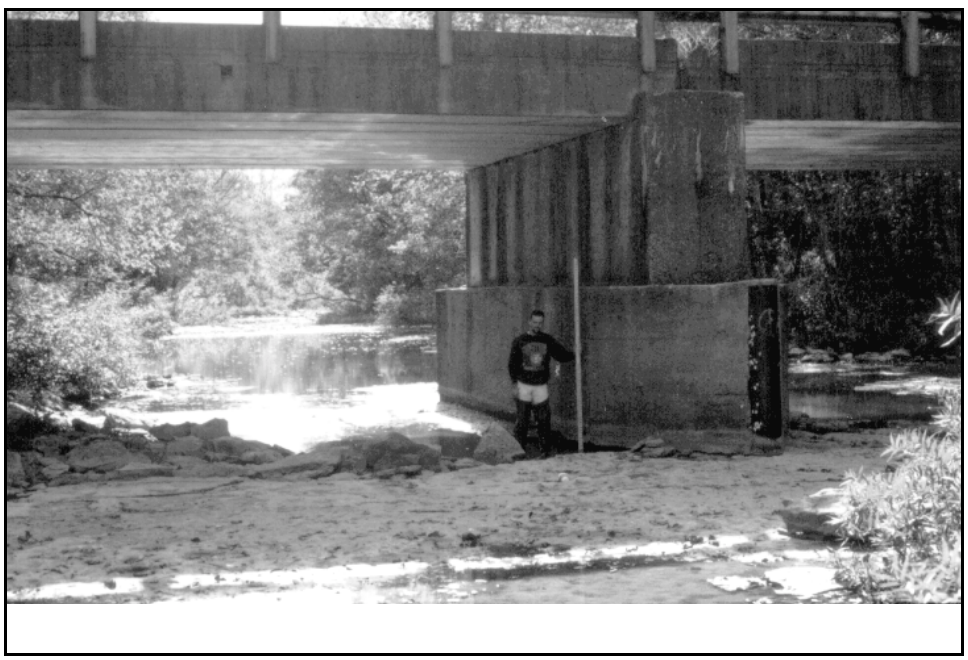

Figure 23. General view of local scour hole adjacent to concrete bridge footer.

Example Case

To illustrate the use of the numerical rating system, a bridge site was selected and rated using the proposed rock scour hazard rating system. A general view of the rock streambed at this site is shown in Figure 23. A close-up view of the apparent rock scour is shown in Figure 24. As shown in

Figure 24. Close-up view of local scour showing

these Figures, the proximity of the apparent rock scour is adjacent to the footer. Consequently, the proximity condition is assigned a value of 100 points. Close examination of the scour hole depth, d_c, Figure 24, reveals that the bottom of the footer is exposed. This condition is given 100 points. The scour hole depth, d_s, extends several centimeters below the bottom of the footer. A value of 100 points is assigned to this condition. As shown in Figures 25 and 26, the erosion has penetrated beneath the footer more than 6 inches at several points along the length of the footer. This condition is given a value of 100 points. Finally, the average annual daily traffic is 210 vehicles per day. Because this value is below 400, Table 1, this condition is given a value of above 2 points. The total score for this site is 402 points. As shown in Table 4, a score of 402 corresponds to a code of 2 or 3 of the FHWA Guide -- that is the scour is below the spread footing and countermeasures should be considered.

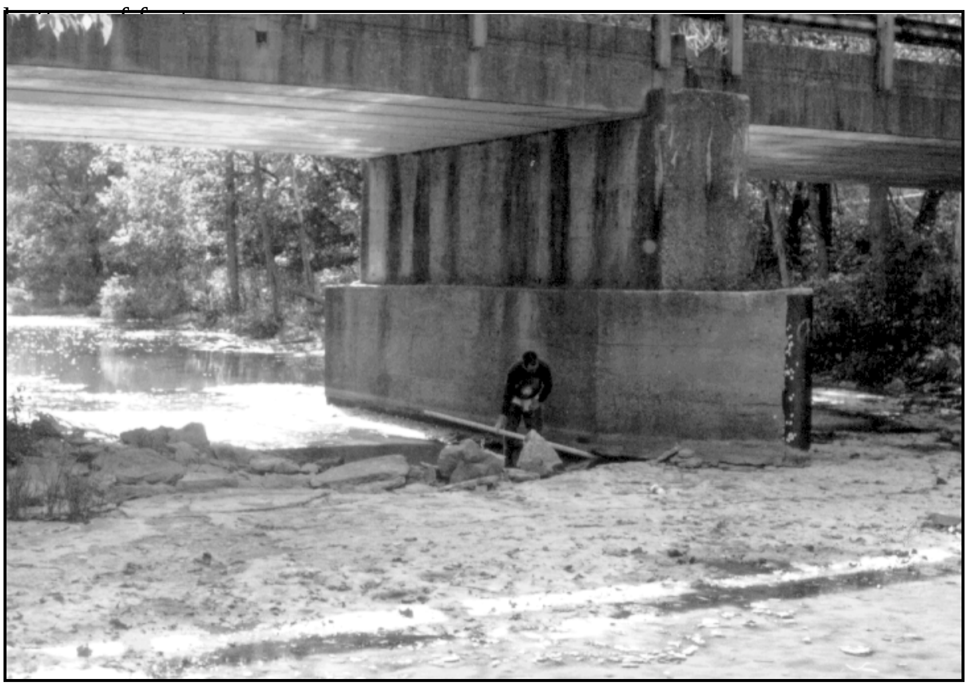

Figure 25. Overview of range pole penetrating below the bottom of the footer.

Numerical Rating of Sites Previously Rated "High Scour"

In the preliminary observations of some 394 bridge sites where the footers were located on rock and visible, 34 sites had received an initial scour rating of a "high." To test the proposed rock scour hazardous rating system, 34 sites were reevaluated numerically using

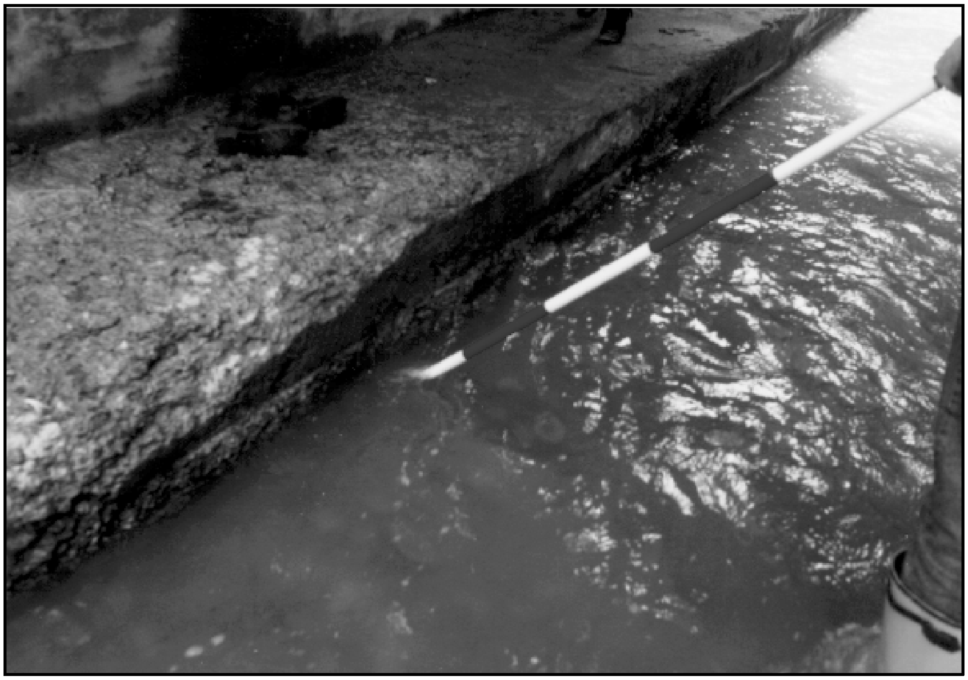

Figure 26. Close-up view of range pole penetrating below bottom of footer.

the scour rating system listed in Table 2. In performing the detailed observations, as outlined in Table 2, the scour criticality of several of the sites was lowered, as shown in Figure 27. Distribution and general locations of the 394 bridge sites and the eight sites rated as "High Scour" are shown in Figure 28.

Rock Scour Sites

Details, including numerical ratings of the 34 sites, previously identified by UKTC, and initially rated as "high" scour, are summarized Tables 5, 6, and 7 (according to the rock scour rating system). Based on the relationship shown in Table 4, those bridges would be rated "Scour Critical." Numerical ratings of high scour sites, as shown in Table 5, ranged from 307 to 458. Numerical ratings of sites classified as "moderate" ranged from 129 to 273, as shown in Table 6. Numerical ratings of sites that classified as "low" ranged from 26 to 120.

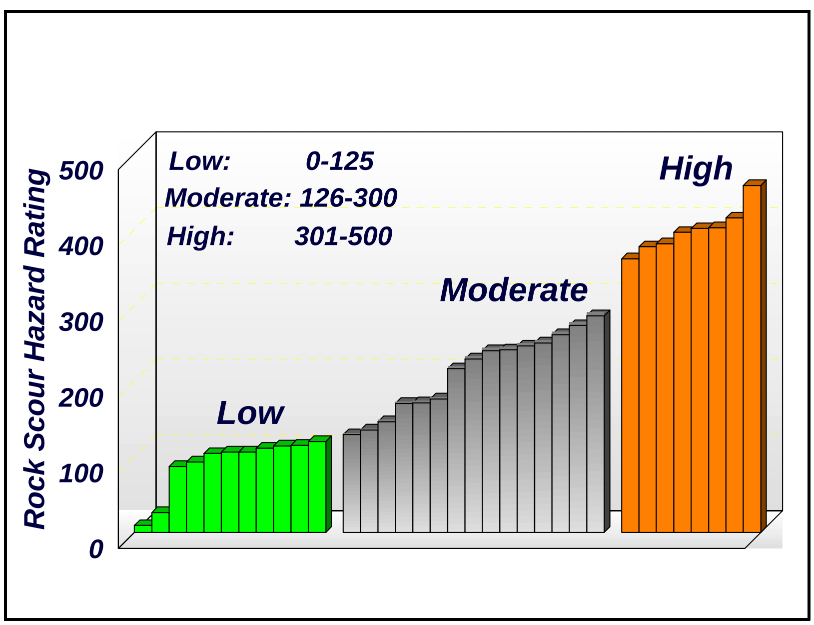

Figure 27. ***Numerical ratings of sites previously rated as having a "High" scour condition.***

During the latter stages of this research study, the Kentucky Transportation Cabinet intensified its effort to examine scour

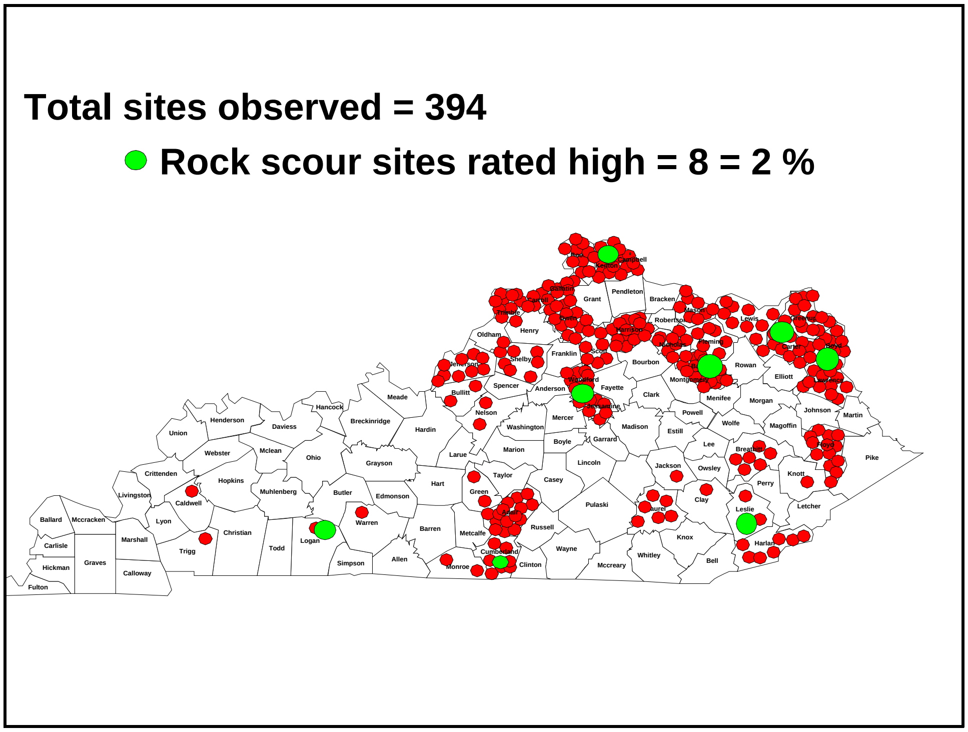

Figure 28. General locations by county of bridge sites inspected by UKTC.

conditions at some 8,277 bridges. A consulting engineering firm was hired to make in-depth inspections of bridges under the jurisdiction of the Cabinet. In performing these inspections, and after instruction, the consulting firm used the hazardous rating system, as shown in Table 2 and in APPENDIX A, which was devised and developed by personnel of the Geotechnology Section of the University of Kentucky Transportation Center. The research study was extended for a period so that any scour sites found by the consultant could be studied and drilled by UKTC.

Although this firm started its inspection initially in the far western portion of Kentucky, where deep foundations are prevalent, they inspected several bridges where shallow rock foundations exist. In their first pass through Kentucky Highway Districts 1 through 12, the consulting firm inspected some 2,877 bridges by the end of 1997. Bridges inspected were those with known foundations or documented scour problems. Excluding Highway Districts 10 through 12, UKTC received from the consulting firm a list of sixteen bridge sites with rock scour. This firm noted that other data would be available after February 1998. In April of 1998, the firm supplied UKTC with four additional sites which were located in Districts 10 through 12 (according to their information, some 777 bridge sites were reviewed). Data pertaining to the set of 20 sites are given in Tables 8 and 9. Data pertaining to sites identified as having a high scour rating are summarized in Table 8. Sites classified as having moderate and low scour are shown in Table 9. The Geotechnology Section of UKTC also inspected and rated the twenty sites supplied by the consultant. Both the consultant and UKTC ratings are shpown in Tables 8 and 9. Some 5,400 sites were later inspected by the consultant; however, no additional rock scour ratings were received. Locations of the sites submitted by the consulting firm are shown in Figure 29.

Table 5. Bridge Scour Ratings of Sites Identified by the University of Kentucky Transportation Center as "High."

Route	County	Stream	Bridge No.	Scour Class	Numerical Rating	Year Built and Age	Max. d_s (in.)	Max. d_p (in.)	Geology	RQD (%) Core Run (Ft)	Comments
US 60	Bath	Hurricane Creek	6-B00023	*High*	458	1925 74	24	24	Siltstone interbedded w/shale	0 0.0 - 1.5 65 1.5 - 7.5	Drilled by UKTC Replaced 1996
US 60	Carter	Tygrats Creek	22-B00037	*High*	415	1953 46	10	6	Grey Siltstone (Cowbell Member of Borden Formation)	87 0 - 5	Drilled by UKTC Identified as Moderate by consultant; Repairs made in 1997 to abutments, pier, and footers
KY 3072	Kenton	Cruises Creek	59-B00077	*High*	402	1978 21	12	26	Limestone/w shale partings		
KY 707	Lawrence	Pine Branch	64-C00035?	*High*	401	1930- 66 - 1933? 69?	36	60	Shale and Siltstone (Conemaugh Formation); shale highly weathered	0 0 - 5 0 5 - 10	Drilled by UKTC
KY 2057	Leslie	Cutshin Creek	66-B00055	*High*	396	1929 70	6	24	Sandstone	NA	Scour Critical Rating = 4 (Nov. 96); stone pier
Elm Fork Road	Jessamine	Hickman Creek	57-C00029?	*High*	377	1987? 12? Deck only?	7	24	Limestone/w shale partings	17 0 - 5 25 5 - 10	Drilled by UKTC Footer bottom fully exposed
KY 1466	Logan	Clear Fork Creek	71-B00065	*High*	361	1940 59	>6	12	Sandstone	NA	
KY 704	Cumberland	Pine Branch	29-B00055	*High*	307	1987? 12? (Deck only?)	?8	24	Limestone(Leipers) with clay seams @0.2,0.4,0.7,1.0,1.1-1.7,2.0,2.2,2.6,2.7,3.9, and 4.4 ft.	22 0 - 1.5 67 1.5 - 6.5	Drilled by UKTC

Table 6. Bridge Scour Ratings of Sites Identified by the University of Kentucky Transportation Center as "Moderate" Scour.

Route	County	Stream	Bridge No.	Scour Class	Numerical Rating	Year Built	Age	Max. d_s (in.)	Max. d_p (in.)	Geology	RQD (%)	Core Run (Ft)	Comments/Action
KY 1997	Campbell	Brush Creek	19-B00017	*Mod*	*273*	*1984*	*15*	5	26	Limestone layers w/ interbedded shale layers , or partings	NA		
KY 111	Bath	Prickly Ash Ck.	6-B00066	*Mod*	*261*	*1979*	*20*	1.5	6	Siltstone layers	NA		
CR 5246	Logan	Pleasant Grove Ck.	71-C00060	*Mod*	*250*	*1953*	*46*	6	1.5	Limestone plates	NA		
KY 1308	Logan	Red River	71-B00064	*Mod*	*246*	*1978*	*21*	1	0	Limestone plates	NA		
KY 61	Adair	Petty's Fork	1-B00025	*Mod*	*241*	*1926*	*73*	< 2	< 2	Limestone layers w/ shale partings	NA		Drill holes at bottom of scour hole
KY 1338	Christian	Tradewater River	24-B00026	*Mod*	*240*	*?1978 Deck*	*21 only*	0	18	Limestone layers w/ shale partings	NA		New beam poured on old footer
KY 1488	Trimble	Patten Creek	112-B00028	*Mod*	*229*	*1954*	*45*	0	6	Layered limestone	NA		
KY 14	Kenton	Little Cruises Ck.	59-B00031	*Mod*	*216?*	*1970*	*29*	34	< 2	Limestone layers w/ interbedded shale layers, or partings	NA		
KY 368	Owen	Cedar Creek	94-B00015	*Mod*	*176*	*1955*	*44*	2	2	Limestone w/ shale partings	NA		
KY 1323	Adair	Bull Run Ck.	1-B00032	*Mod*	*171*	*1952*	*47*	< 2	< 2	Limestone layers w/ shale partings	NA		
KY 111	Bath	Prickly Ash Ck.	6-B00028	*Mod*	*170*	*1957*	*42*	0	< 2	Limestone/siltstone layers	NA		
KY 1659	Woodford	Glenn's Creek	120-B00009	*Mod*	*146*	*1951*	*47*	0	0	Limestone/w shale partings	NA		May be Bridge 120-B000011
KY 36	Harrison	Mill Creek	49-B00032	*Mod*	*135*	*1926*	*73*	0	< 2	Limestone & shale layers	NA		
KY 1659	Woodford	Glenn's Creek	120-B00012	*Mod*	*129*	*1952*	*47*	< 2	< 2	Limestone /w shale partings	NA		Scour Critical Rating (Nov. 96)
KY 32	Harrison	Adam's Branch	49-B00057	*Mod*	*286*	*1982*	*17*	7	7	Limestones layers w/ interbedded shale layers	NA		? Correct Bridge #

Table 7. Bridge Scour Ratings of Sites Identified by the University of Kentucky Transportation Center as "Low Scour."

Route	County	Stream	Bridge No.	Scour Class	Numerical Rating	Year Built	Age	Max. d_s (in.	Max. d_p (in.)	Geology	RQD	Core Run (Ft)	Comments/Action
KY 607	Owen	Cedar Creek	94-B00030	*Low*	*120*	*1978*	*21*	0	0	Limestone/w interbedded shale	44 85	0- 3.3 3.3-8.3	
KY 1303	Kenton	Banklick Ck.	59-B00026	*Low*	*115*	*1965*	*34*	0	0	Limestone/w interbedded shale	NA		
KY 111	Bath	White Oak Creek	6-B00029	*Low*	*114*	*1969*	*30*	0	0	Siltstone/w shale layers	NA		Siltstone collapsing, but bridge piers not affected
KY 1944	Bath	Trib. White Oak Ck.	6-B00071	*Low*	*111*	*1983*	*16*	0	0	Layered siltstone and shale	NA		Drill holes present
KY 704	Adair	Burns Creek	1-B00028	*Low*	*106*	*1952*	*47*	0	0	Chattanooga shale	63 50	0-5 5-10	Drilled by UKTC
US 60	Carter	Fleming Fork	22-B00041	*Low*	*106*	*1923*	*76*	0	0	Siltstone	92	0-5	Drilled by UKTC
KY 36	Harrison	Twin Creek	49-B00033	*Low*	*104*	*1926*	*73*	0	< 2	Limestone/w shale interbedded	NA		
KY 368	Owen	Magadore Ck.	94-B00013	*Low*	*93*	*1940*	*59*	0	0	Limestone/w shale partings	NA		Too many broken rocks from upstream to evaluate scour
US 62	Harrison	Smally Branch	49-B00015	*Low*	*87*	*1930*	*69*	0	0	Limestone/w shale interbedded	NA		Possible filled contraction
KY 32	Harrison	Twin Creek	49-B00031	*Low*	*26*	*1961*	*38*	0	0	Limestone w/ interbedded shale	NA		*Newly poured concrete fixed scour at footer*

Table 8. Bridge Scour Ratings of Sites Identified by the Kentucky Transportation Cabinet's consulting engineer as "High."

Route	County	Stream	Bridge Number	Scour Class	Numerical Rating Consultant	Numerical Rating UKTC	Year Built	Age	Max. d_s (in.)	Max. d_p (in.)	Geology	RQD (%)	Core Run (Ft)	Comments
US 60	Carter	Dry Branch	22-B00036	*High*	333	400	1923	76	12	24	Grey siltstone, no bedding planes, Cowbell Member of Borden Formation	Abut No. 1 86 95 Abut No. 2 20 88	 0 - 5 5-10 0 - 5 5-10	Drilled by KyTC; Inspected by UKTC 12-22-97; High Scour; Bridge replaced 1998
CR 1006	Harrison	Elk Lick Creek	49-C00006	*High*	327	403	1981?	18?	24	12	0-5 ft.; 2-4 in. Grey, coarse grained limestone layers with 2-6 in. Of clays shale seams (Tanglewood Member of Lexington Limestone)	17	0-5	Drilled 8-97 by UKTC; Inspected by UKTC;High Scour
US 31E	Bullitt	Hough Run Creek	15-B00007	*High*	327	365	1924	75	12	2	Limestone w/ shale partings	60	0-5	Drilled 8-97 by UKTC; Inspected by UKTC 5-21-97; Vertical Scour; Bridge replaced, US 31E
CR 1243	Washington	Road Run Branch	115-C00026	*High*	327	384	1935	64	12	36	Limestone w/ shale partings Calloway Creek Limestone	7	0-5	Drilled 8-1-97 by UKTC; Inspected by UKTC 5-21-97; High Scour;
KY2004	Jackson	SF Sta. Camp Ck.	55-B00036	*High*	327	384	1938	61	14	12	Limestone w/ shale partings	68	0-5	Drilled by UKTC 10-13-98; Inspected by UKTC; High Scour
CR 9999	Morgan	Allen Day Creek	88-C00049	High	347	361	1930	69	18	48	Sandstone	NA		Inspected Mod d by KTC 9-17-98 Scour by UKTC

Table 9. Bridge Scour Ratings of Sites Identified by the Kentucky Transportation Cabinet's consulting engineer as sites with Moderate and Low Scour Conditions.

Route	County	Stream	Bridge Number	Scour Class	Numerical Rating Consultant	Numerical Rating UKTC	Year Built	Age	Max. Max. d_s (in.)	Max. d_p (in.)	Geology	RQD	Core Run	Comments
KY 713	Montgomery	Hinkston Creek	87-C00042	*Mod**	279	350	1965	34	4	8	Limestone w/ shale partings	NA		Inspected by KTC 7-24-97 High Scour by UKTC
US 60	Carter	Tygrats Creek	22-B00037	*Mod**	297	415	1953	46	10	6	Grey siltstone, no bedding planes, Cowbell Member of Borden Formation	87	0 -5	Drilled by UKTC ; Repaired in 1997; Identified as High by UKTC previously
CR 1048	Shelby	Guist Creek Trib.	106-C00020	*Mod*	273	335	1976 Deck?	73	10	> 6	Limestone and shale	NA		Inspected by KTC 8-97 Mod Scour
CR 5122	Spencer	Dutchman Creek	108-C00012	*Mod*	183	355	1975	24	8	10	Shale w/Limestone; Grant Lake, or Calloway	NA		Mod Scour Concrete poured to stop scour
St. Anthony's Church Road	Jefferson	Slate Run	56-C00185	*Mod* (UKTC)	NA	299	1950	49	1	1	New Albany Black Shale; laminated	NA		***Inspected by KTC 8-11-97*** ***Mod Scour***
KY 794	Estill	Oak Creek	33-B00038	*Mod*	273	* *	1957	42	< 6	6	Dolostone	NA		Inspected by KTC 9-18-98 ; Repaired in 1998 prior to KTC inspection
KY 1244	Washington	Siebert Creek	115-C00027	*Mod*	254	254	1933	66	2	6	Limestone with shale partings;	NA		Inspected by KTC 5-21-97 Mod Scour
US 68	Marion	Wards Branch	78-B00005	Mod	207	228	1941	58	6	6	Limestone and shale	NA		Inspected by KTC 12-23-97
KY 11	Montgomery	Lulbegrud Creek	87-B00008	*Mod*	275	214	1988	11	< 2	6	Limestone and shale	NA		Inspected by KTC 8-11-97 Mod Scour
KY 1017	Harlan	Poor Fork	48-C00004	*Mod*.	195	***	1928	71	6	0	Siltstone and	NA		Inspected by KTC 11-11-98 Debris
KY 1228	Washington	Station Run	115-C00025	*Mod*	183	201	1978	21	2	6	Limestone with shale layers	NA		Inspected by KTC 5-21-97; Mod Scour
KY 1216	Woodford	Craig Creek	120-C00016	*Mod*	147	141	1972	27	2	6	Limestone with shale partings	NA		Inspected by KTC 8-97 Low Scour
KY 1659	Woodford	Glenn's Creek	120-B00012	*Mod*	261	261	1951	48	2	6	Limestone with partings; Grant Lake	NA		Identified as Mod by KTC Previously
CR 1057	Nelson	Plum Run Creek West Fork	90-C00012	*Low*	51	105	1960?	39?	< 2	< 2	Limestone and shale	NA		Inspected by KTC 8-97 Low Scour

* Rated High by UKTC ; ** Not rated–Footers covered with soil and gravel because of remedial construction;*** Not rated–Footers covered with debri

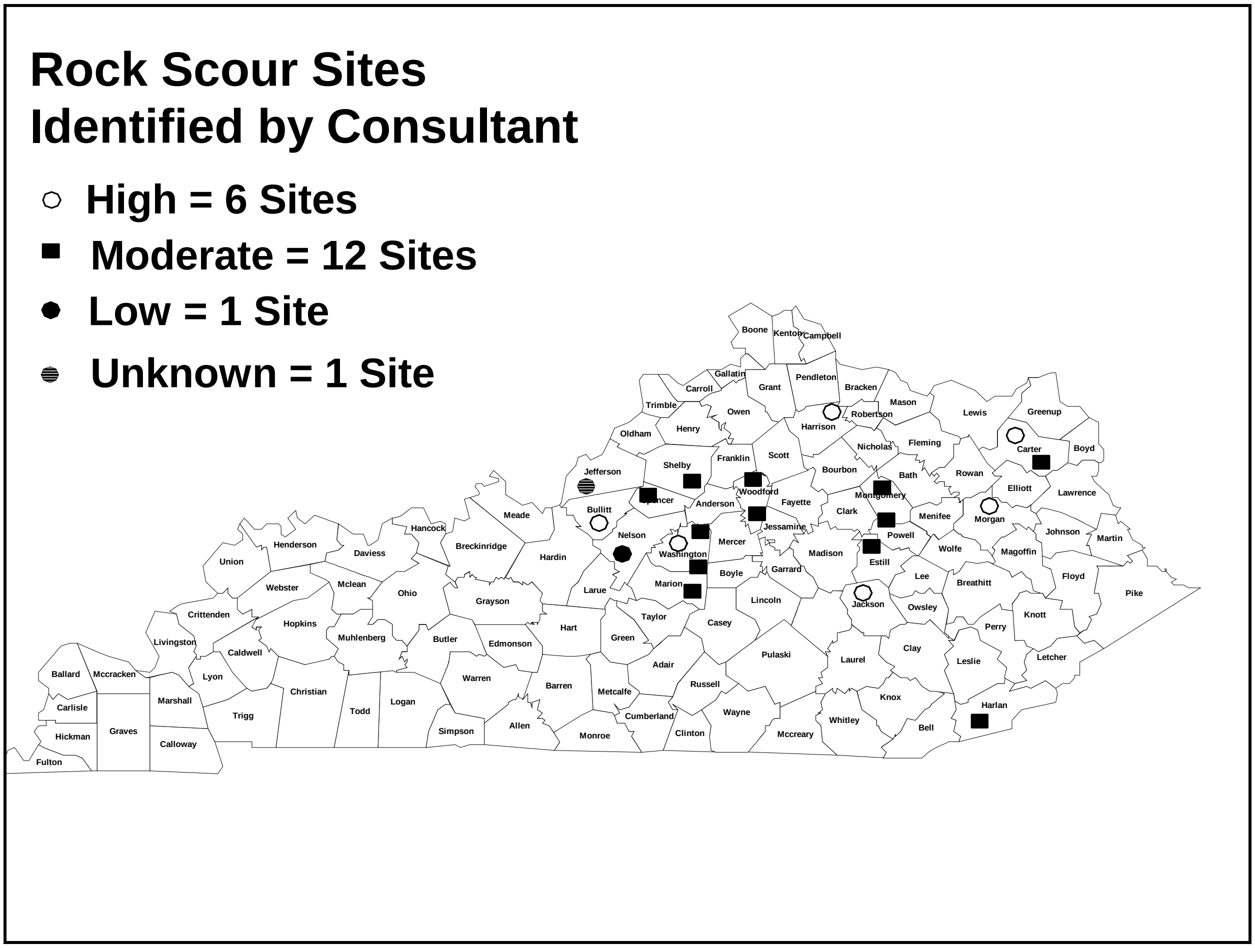

Figure 29. Location of rock scour sites by county submitted by consulting firm.

Ages of the sites listed in tables 5 through 9 ranged from 12 to 76 years. In Figures 30 and 31, the ages of the bridges (shown in Tables 5 - 9) are shown as a function of maximum vertical rock scour depth, ds, and maximum horizontal rock scour penetration, d_p. No discernable relationship between the scouring of the rock foundations and age is apparent. This indicates that, generally, age of bridge is not an apparent factor in the scouring of Kentucky rocks. This may also indicate that streams in Kentucky have cut down into fairly resistant bedrock after several million years.

Boring Program – Relationship Between RQD and Scour

Since correlation of rock scour with rock quality designation (RQD) was the major objective of this study, sites were selected for obtaining cores of the bridge riverbed. Generally, sites were selected where scour had occurred. The number of scour sites (where actual scour had occurred) selected for drilling was very limited. In some cases, the stream beds were not accessible, or involved unacceptable risks in positioning the drill in the streambed.

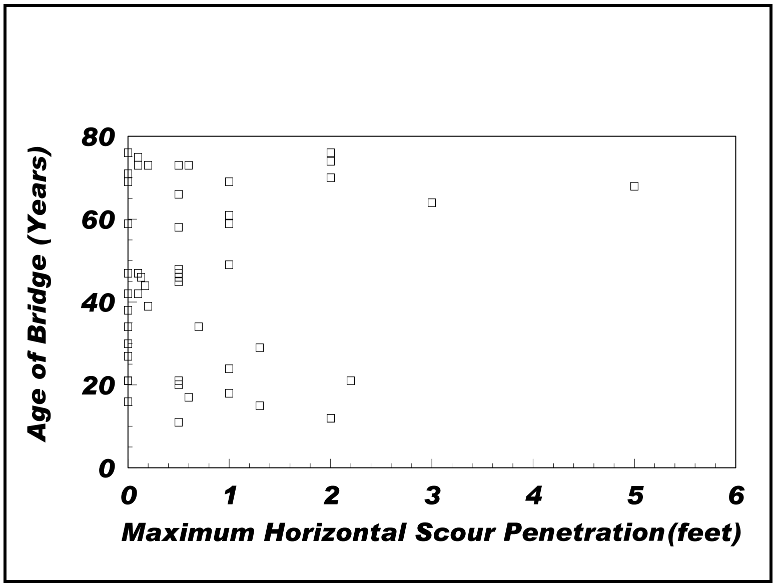

Figure 30. Age of bridge as a function of maximum horizontal scour penetration.

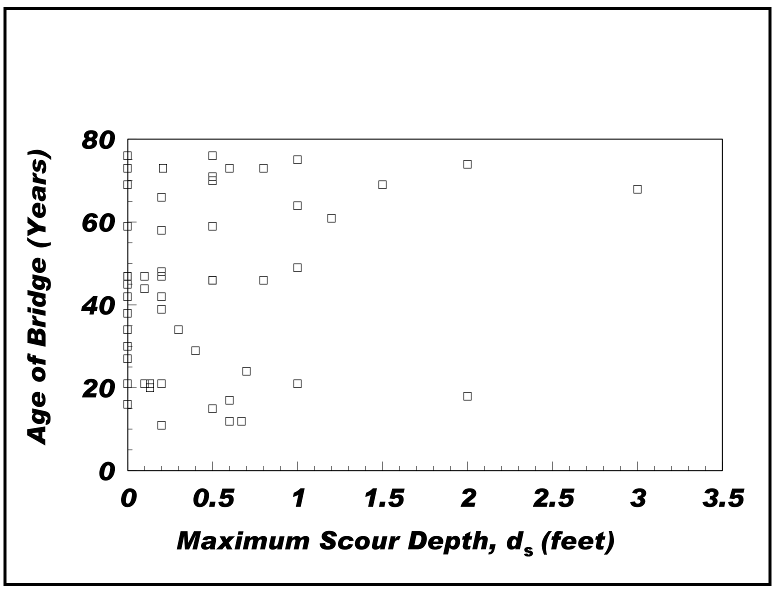

Figure 31. Age of bridge as a function of maximum vertical rock scour.

Reconnaissance and drilling of selected sites involved several steps. These were, as follows:

- Initial site visit to physically locate site.
- Determining whether the drill rig can be situated on right-of-way at the site and the logistics of maneuvering the drill rig to the desired spot to obtain core specimens of the bridge bedrock foundation.
- Contacting all utilities companies, such as water, gas, telephone, sewer, etc. to determine if (and where) these facilities are located at a given site.
- Arranging traffic control.
- Finally, once all locations of utilities are known, rock cores are obtained when the site is accessible.

Twelve sites were selected and core drilled to obtain rock specimens. Rock Quality Designation (RQD) measurements were performed on the cores. A value of Rock Quality Designation is obtained by "summing the total length of core recovered by counting the number of only those pieces of hard and sound core which are 4 inches or greater in length (Cheney, and Chassie, 1982)." The Kentucky Transportation Cabinet modified the standard procedure to sum only those pieces that are equal to or greater than 4 inches in length and cannot be broken by hand into smaller units. If the four-inch, or greater, piece can be broken by hand then the piece is not included in the determination of RQD value. Both RGD values were determined. However, in the particular cases where RQD values were determined, the two different approaches yielded the same values. Three sites were selected and drilled where rock scour had not occurred.

Logs of the rock cores and RQD values for each bridge are given in APPENDIX B. Photographs of each site also is presented in APPENDIX B. Values of RQD are shown in Tables 5, 7, and 8. Correlation of RQD values with penetration, d_p and depth of scour, d_s, are shown in Figures 32 and 33, respectively. Based on these graphs, large scour depths occur when the value of RQD is zero. If the RQD value is 10 percent, or larger, then the scour depth is ten inches, or less. If the RQD is about 50 percent, than the horizontal penetration scour is less than about 8 inches. Locations of sites where RQD was obtained are shown in Figure 34.

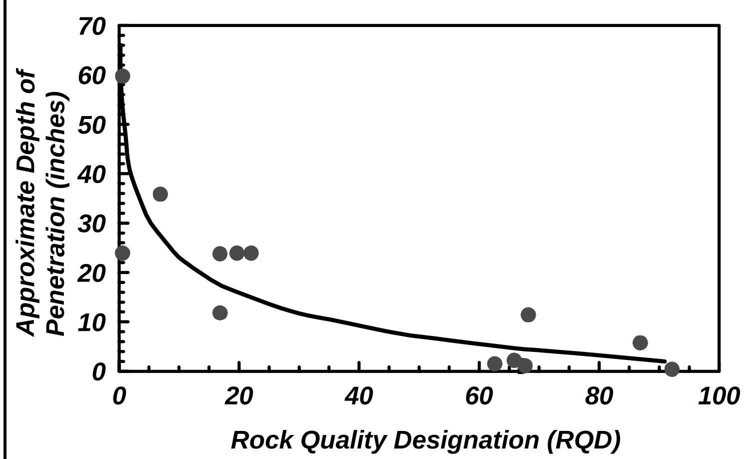

Figure 32. Approximate depth of horizontal penetration beneath bottom of footer and RQD.

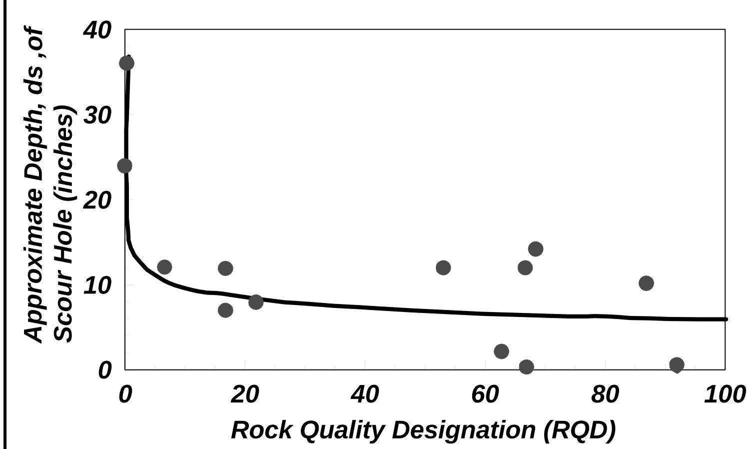

Figure 33. Approximate depth of scour and RQD.

SUMMARY AND CONCLUSIONS

Some 400 bridge sites were sampled and surveyed to determine scour conditions around pier and abutment footers. At each of these sites, the footer foundation was located on exposed rock. To observe and classify the scour conditions, a numerical scour scoring system was developed. This scoring system was related to the FHWA (1988) "*Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's's Bridges*." Based on observations of some 400 bridge sites by UKTC, and several hyndreds by a consultant:

- In Kentucky, there are hundreds of bridges where footer foundations are located on exposed bedrock.

- Initially, some 34 bridges of a sampling of 400 bridges were classified as having some type of scour. However, in a detailed examination of the 34 sites, only eight sites were considered to have some type of scour. Only two sites had scour depths greater than 10 inches and four had penetration greater than 10 inches. Depth of scour below footers usually does not exceed about 6 inches unless the value of the Rock Quality Designation (RQD) is less than about 20 percent.

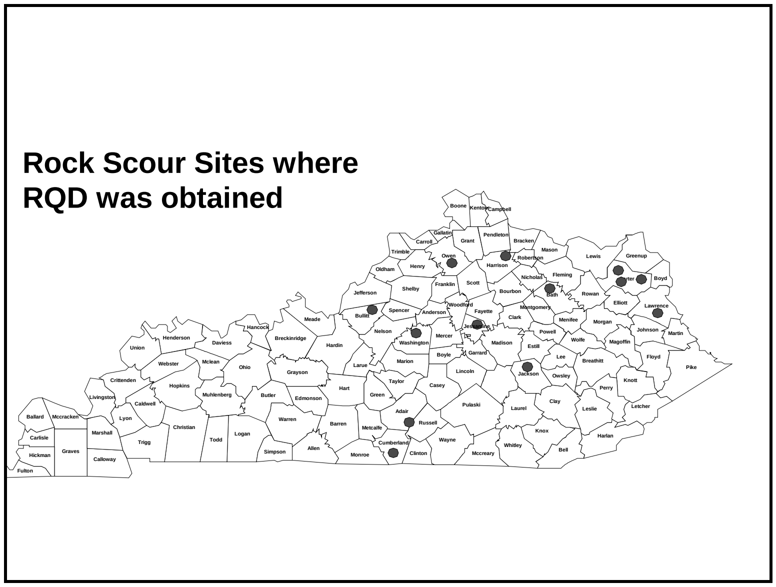

Figure 34. Locations of rock scour sites by county where Rock Quality Designation (RQD) was obtained.

- Rock scour, or the erosion of rock around abutment and pier footers, is not a significant problem in Kentucky. In the few cases where rock scour was observed, the scour holes could be readily repaired by filling the holes with concrete.

- Approximate relationships between Rock Quality Designation (RQD) values and depth of scour and horizontal penetration beneath a footer were presented.

- A review of the geology of Kentucky strongly indicates that many streams and tributaries have reached a stable state, that is, the streams have cut down over millions of years into resistant rock layers. Past glacial ice sheets did not reach most regions of Kentucky, and therefore, has not affected the soil land rock formations of Kentucky.

- Construction engineers with the Kentucky Transportation Cabinet, indicated oftentimes, in recent years, that holes over excavated in rock for bridge footers, have been filled with concrete. The entire excavated hole is filled with concrete rather than placing concrete in a formed footer. This practice should continue.

Acknowledgments

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APPENDIX A

Numerical Rock Scour Hazardous Rating Form

County: ______________________ Geology Description: ______________________________

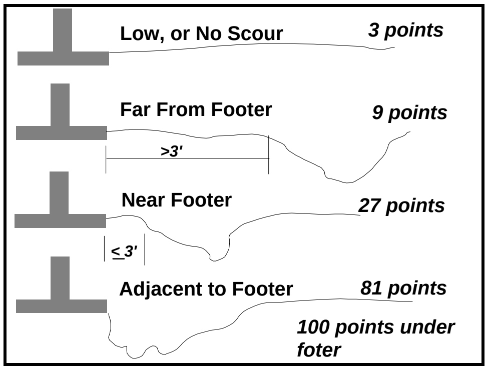
Rt. # ________________________ ____

Stream/River: _________________ ____

Bridge # _____________________

Date: ________________________

Photo #'s ____________________



Proximity:

Low/None 3 Point assesment: ________

Far 9 notes:

Near 27

Adjacent 81

Penetration, d_p:

	None	3	Point assesment: __________
	Up to 2"	9	notes:
	Up to 6"	27	
	> 6"	81	

Depth, d_c:

None	3	Point assesment: __________
Exposed Footer	9	notes:
Exposed to bottom of Footer	27	
Footer Fully Exposed	81	

d_s:	None	3	Point assesment: __________
	Up to 2"	9	notes:
	Up to 6"	27	
	> 6"	81	

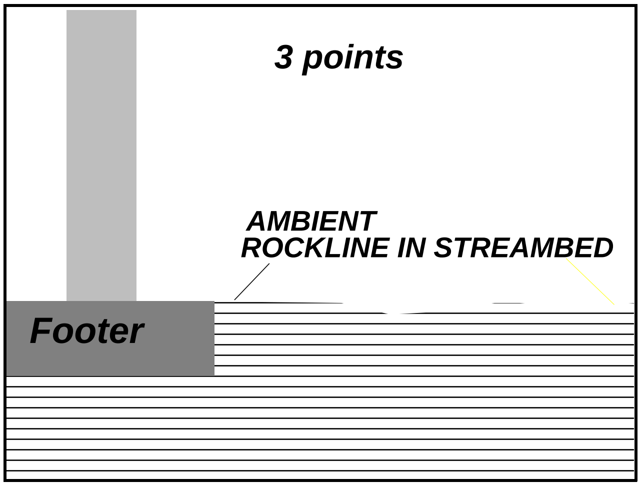
AADT:	400	3	Point assesment: __________
	800	9	notes:
	1,200	27	
	1,600	81	

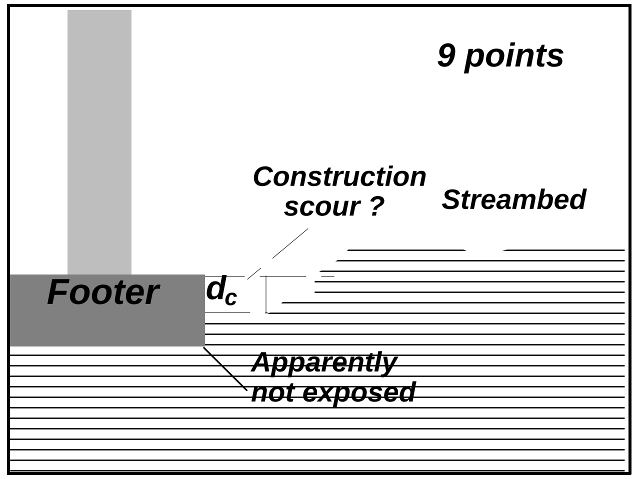
Total Score: ________________________

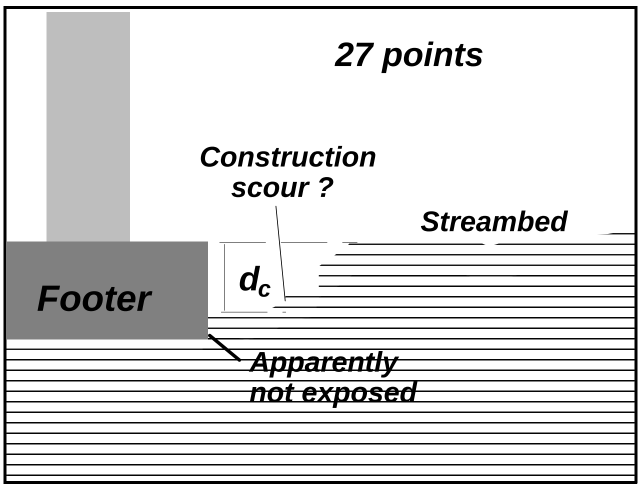
Rock Scour Category: _______________

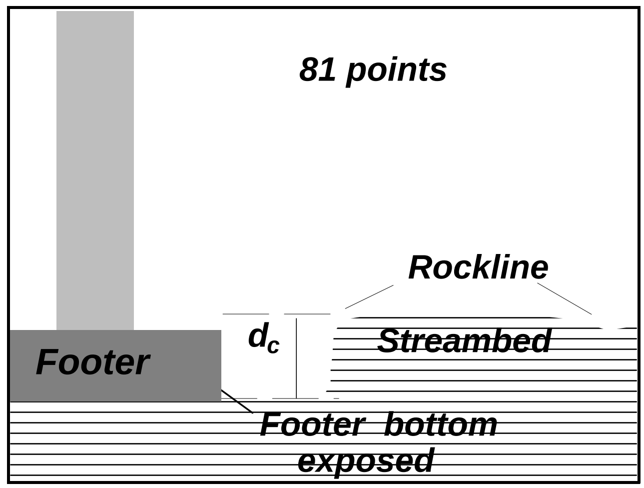
Low:	0-125
Moderate:	126 - 300
High:	301 - 500

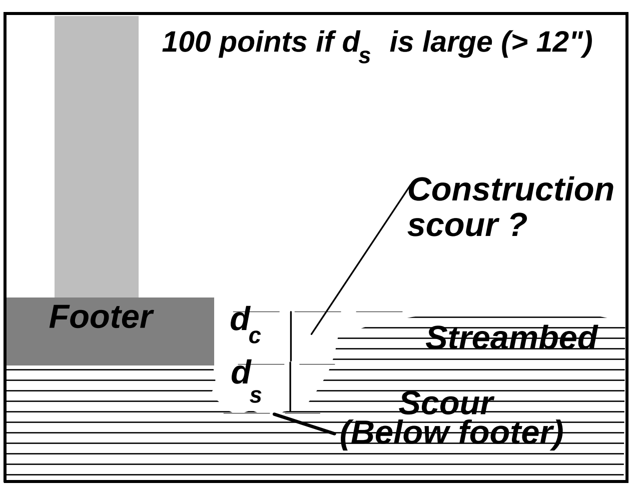
Comments:____

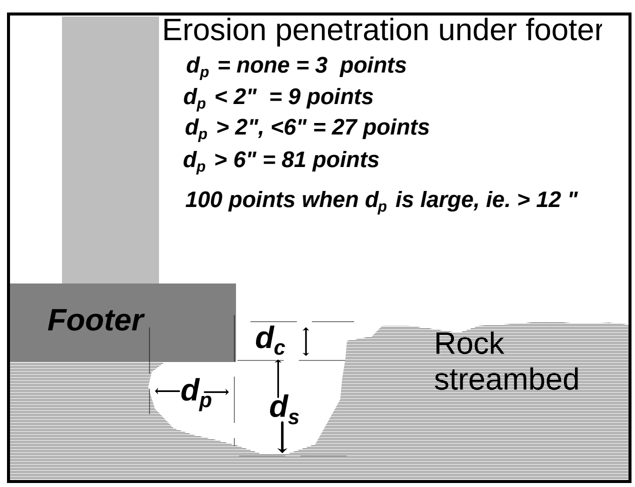

3 points
AMBIENT
ROCKLINE IN STREAMBED
Footer


9 points
Construction
scour ?
Streambed
Footer
d_c
Apparently
not exposed


27 points
Construction
scour ?
Streambed
Footer
d_c
Apparently
not exposed

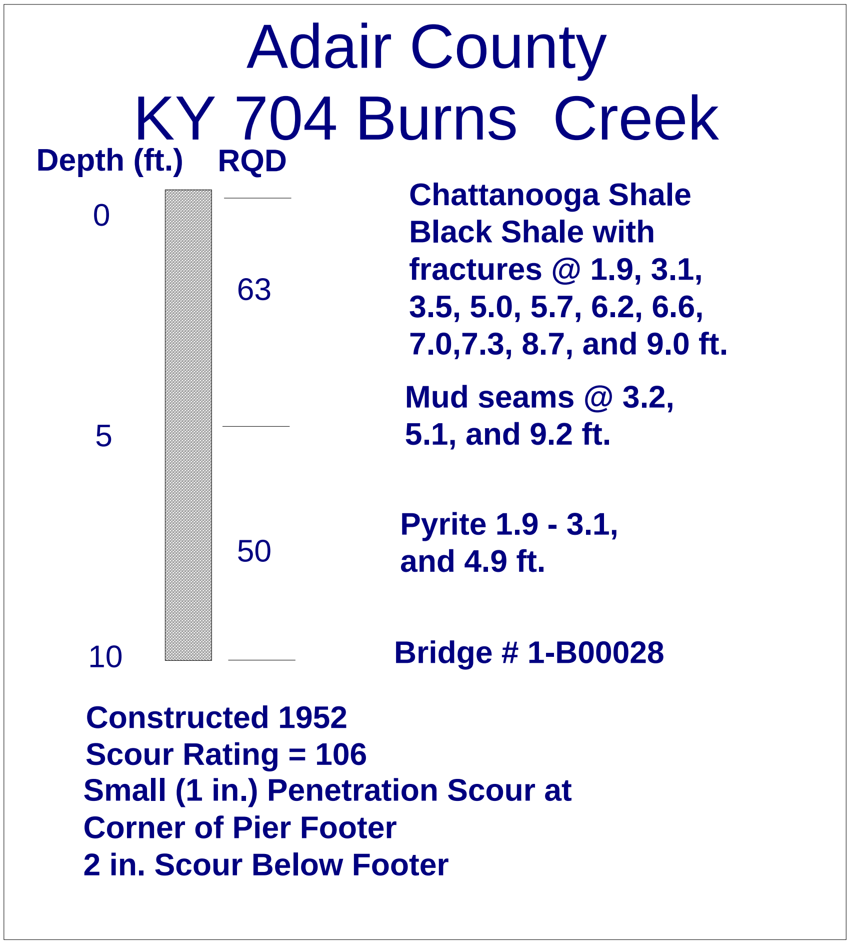

81 points
Rockline
d_c
Streambed
Footer
Footer bottom
exposed


100 points if d_s is large (> 12")
Construction
scour ?
Footer
d_c
Streambed
d_s
Scour
(Below footer)

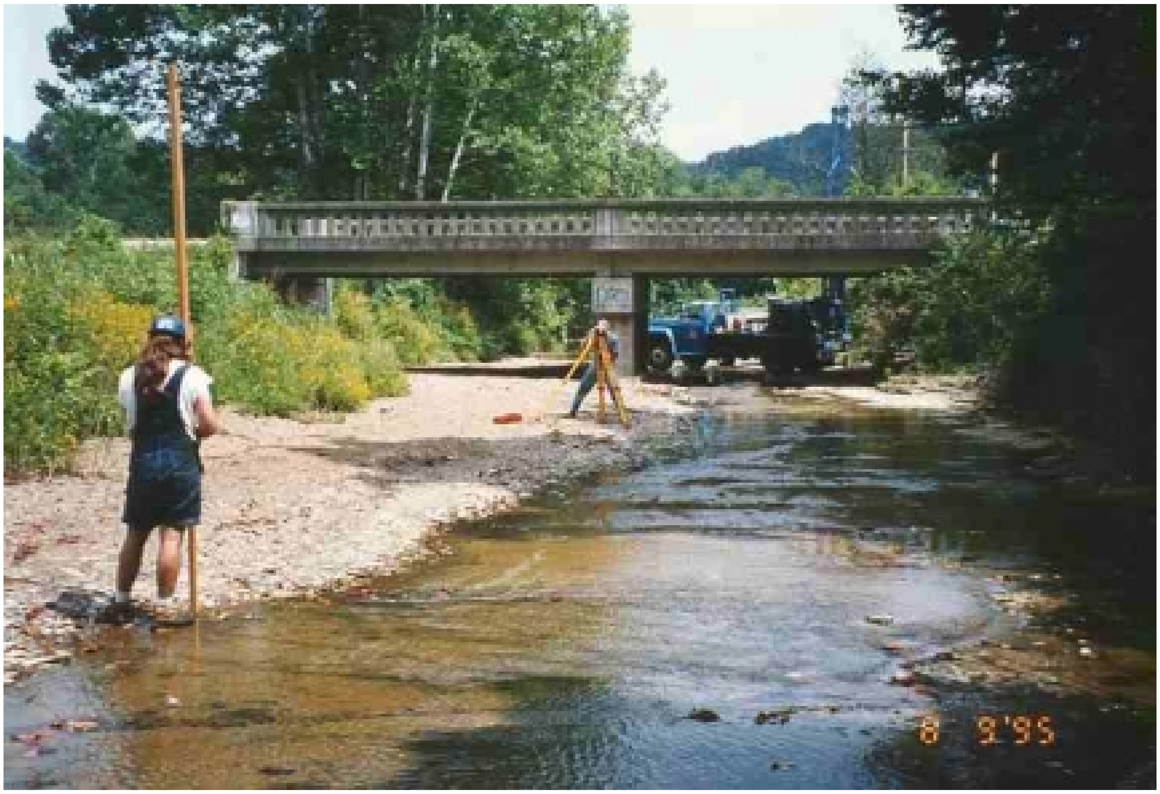

Erosion penetration under footer
d_p = none = 3 points
d_p < 2" = 9 points
d_p > 2", <6" = 27 points
d_p > 6" = 81 points
100 points when d_p is large, ie. > 12 "
Footer
d_c
d_p
d_s
Rock
streambed

APPENDIX B

Boring Logs and Photographs of Bridge Sites where Rock Quality Designation was obtained


Adair County
KY 704 Burns Creek
Depth (ft.)
RQD
0
5
10
63
50
Chattanooga Shale
Black Shale with
fractures @ 1.9, 3.1,
3.5, 5.0, 5.7, 6.2, 6.6,
7.0,7.3, 8.7, and 9.0 ft.
Mud seams @ 3.2,
5.1, and 9.2 ft.
Pyrite 1.9 - 3.1,
and 4.9 ft.
Bridge # 1-B00028
Constructed 1952
Scour Rating = 106
Small (1 in.) Penetration Scour at
Corner of Pier Footer
2 in. Scour Below Footer

Adair County KY 704 Burns Creek



Bath County
US 60 Hurricane Creek

Depth (ft.)	RQD	
0	0	Limestone, weathered with clay shale seams
1.5	65	Limestone with numerous clay shale seams
7.5		

Bridge # 6-B00023
Constructed 1925

Scour Rating = 458
2 Ft. Penetration Scour Below Footer

Bridge Replaced in 1996

Bath County US 60 Hurricane Creek

Bullitt County
US 31E Hough Run Creek

Depth (ft) **RQD**

0 — **0-1.0 Limestone, weathered with clay shale seams**

67 — **1.0 - 5.0 Limestone with clay shale seams@ 2.0,2.2,3.2,3.3,4.0**

4.7-4.8 Grey Clay shale

5.0 — **4.8-5.0Grey Limestone**

Bridge # 15-B00007

Constructed 1924

Scour Rating = 365 KTC

Scour Rating = 327 Consultant

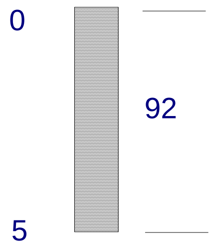
1 Ft. Vertical Scour at Pier

Route being reconstructed in 1996, 1997

Bullitt County US 31 W Hough Run Creek

Carter County
US 60 Fleming Fork Creek

Depth (ft.) **RQD**



Cowbell Member Borden Formation
0' - 0.5'Siltstone, weathered 0.5' - 5.0' grey siltstone

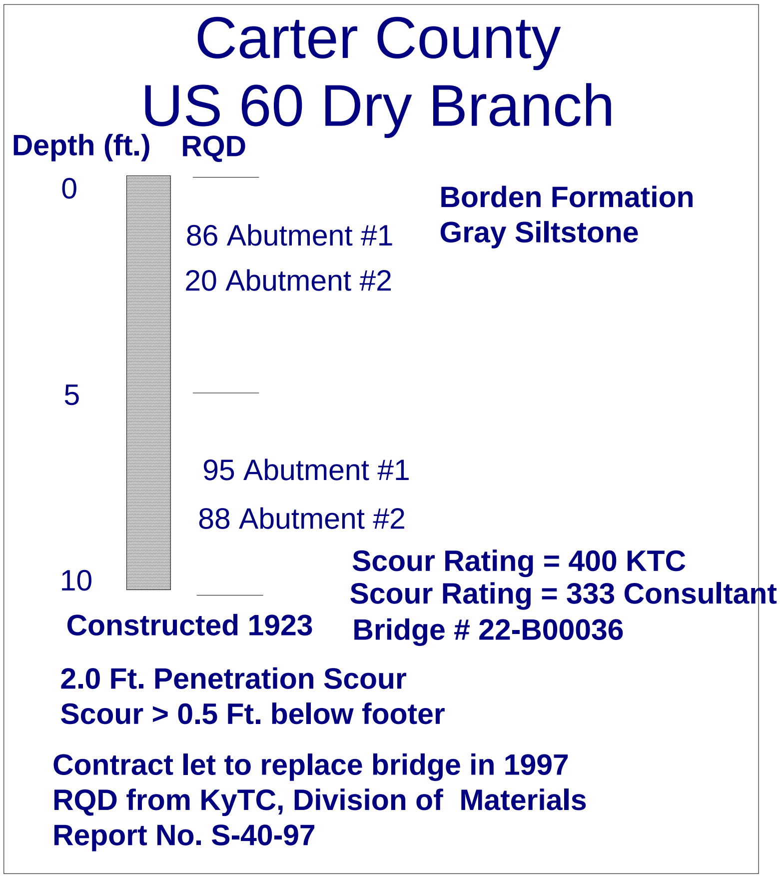
Bridge # 22-B00041

Constructed 1923

Scour Rating = 106

No Major Problems
Footer Slightly Exposed

Carter County US 60 Fleming Fork


Carter County
US 60 Dry Branch
Depth (ft.)
RQD
0
5
10
86 Abutment #1
20 Abutment #2
95 Abutment #1
88 Abutment #2
Borden Formation
Gray Siltstone
Scour Rating = 400 KTC
Scour Rating = 333 Consultant
Bridge # 22-B00036
Constructed 1923
2.0 Ft. Penetration Scour
Scour > 0.5 Ft. below footer
Contract let to replace bridge in 1997
RQD from KyTC, Division of Materials
Report No. S-40-97

Carter County US 60 Dry Branch

Carter County
US 60 Tygrats Creek

Depth (ft.) RQD

0

87

5

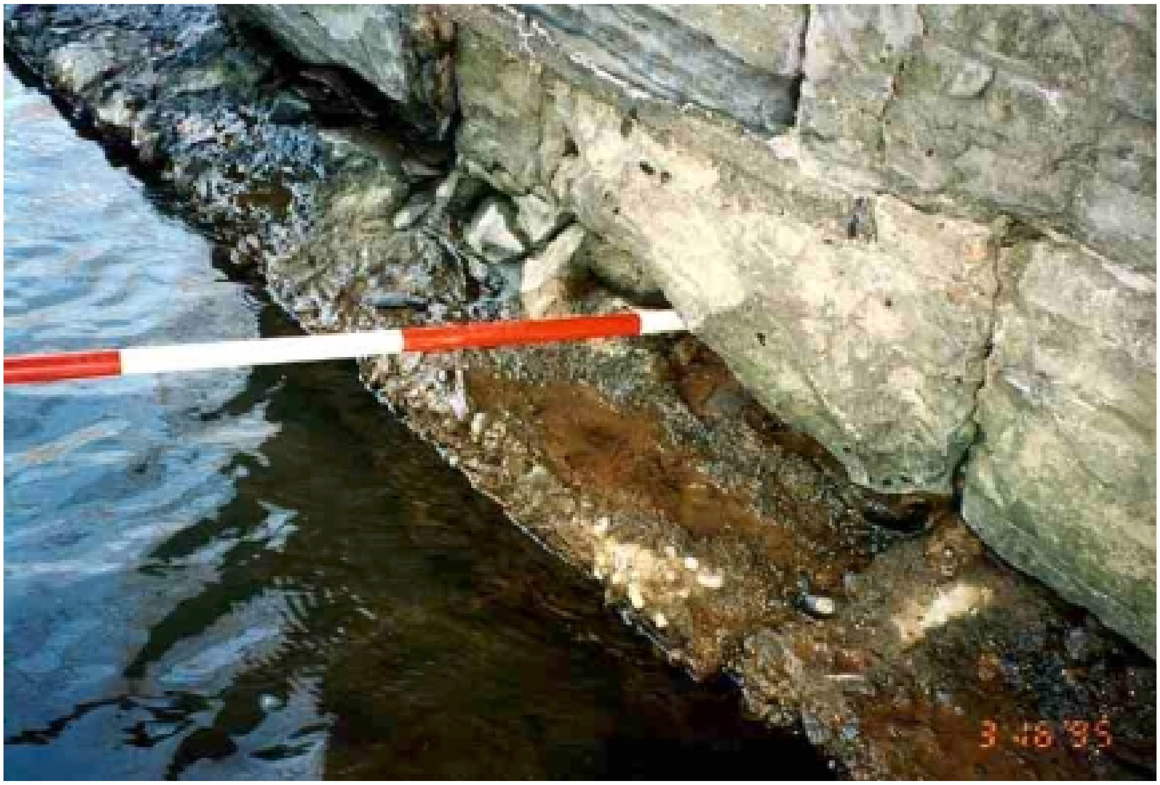
Cowbell Member Borden Formation
0' - 0.5'Siltstone, weathered
0.5' - 5.0' grey siltstone

Bridge # 22-B00037

Constructed 1953
Scour Rating = 415 KTC
Scour Rating = 297 Consultant
0.5' PenetrationScour
0.8' Vertical scour
Footers Exposed

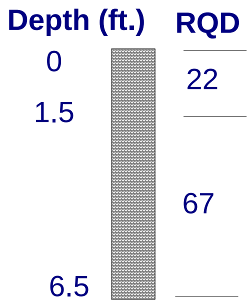
Repairs Made at Pier and Abument Footers in 1997

US 60 Carter County Tygrats Creek



Carter County, US 60 over Tygrats Creek after repairs.

Cumberland County
KY 704 Pine Branch



Leepers Limestone
Limestone with clay shale seams @ 0.2, 0.14, 0.7, 1.0, 1.1, 1.5, 1.7, 2.0, 2.2, 2.6, 2.7, 3.9, and 4.4 ft.

Bridge # 29-B00055

Constructed 1987?
Deck Only?
Scour Rating = 381 KTC

2.0' PenetrationScour
>0.5 Ft. Scour below Footer
Footers Exposed

Cumberland County KY 704 Pine Branch

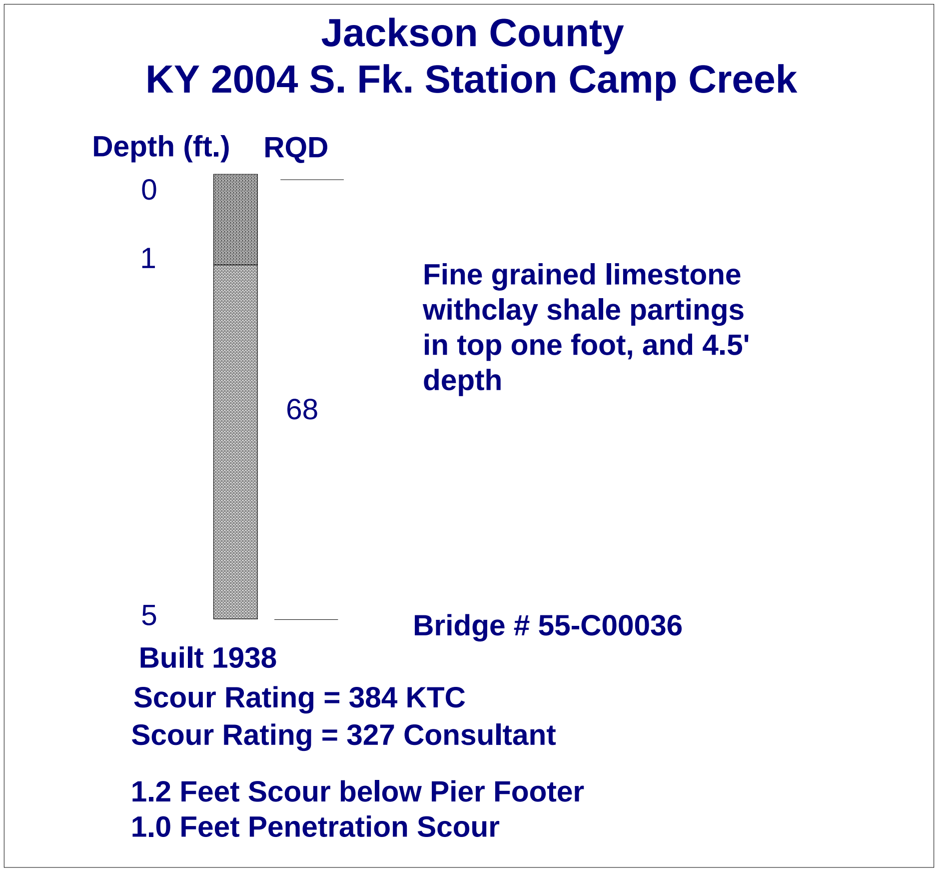
Harrison County
CR 1006 Elk Lick Creek

Depth (ft.)	RQD	
0		Tanglewood Member of Lexington Limestone
	17	0.0'- 5.0'Limestone,grey, coarse grained, 2 - 4 inches layers with clay shale layers 2 - 6 inches
5.0		

Bridge # 49-C00006
Constructed 1981

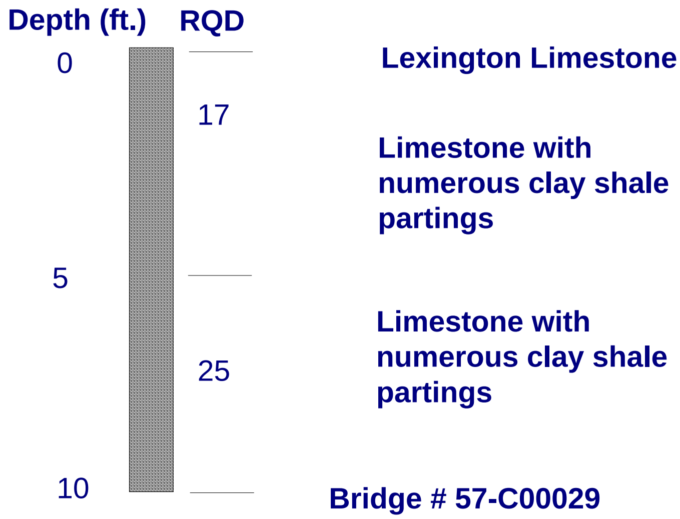
1 Ft. Penetration Scour
1 Ft. Vertical Scour
Scour Rating = 403 KTC
Scour Rating = 327 Consultant

Harrison County CR 1006 Elk Lick Creek


Jackson County
KY 2004 S. Fk. Station Camp Creek
Depth (ft.)
RQD
0
1
5
68
Fine grained limestone withclay shale partings in top one foot, and 4.5' depth
Bridge # 55-C00036
Built 1938
Scour Rating = 384 KTC
Scour Rating = 327 Consultant
1.2 Feet Scour below Pier Footer
1.0 Feet Penetration Scour

Jackson County KY 2004 South Fork Station Camp Creek

Jessamine County
Elm Fork Road Hickman Creek



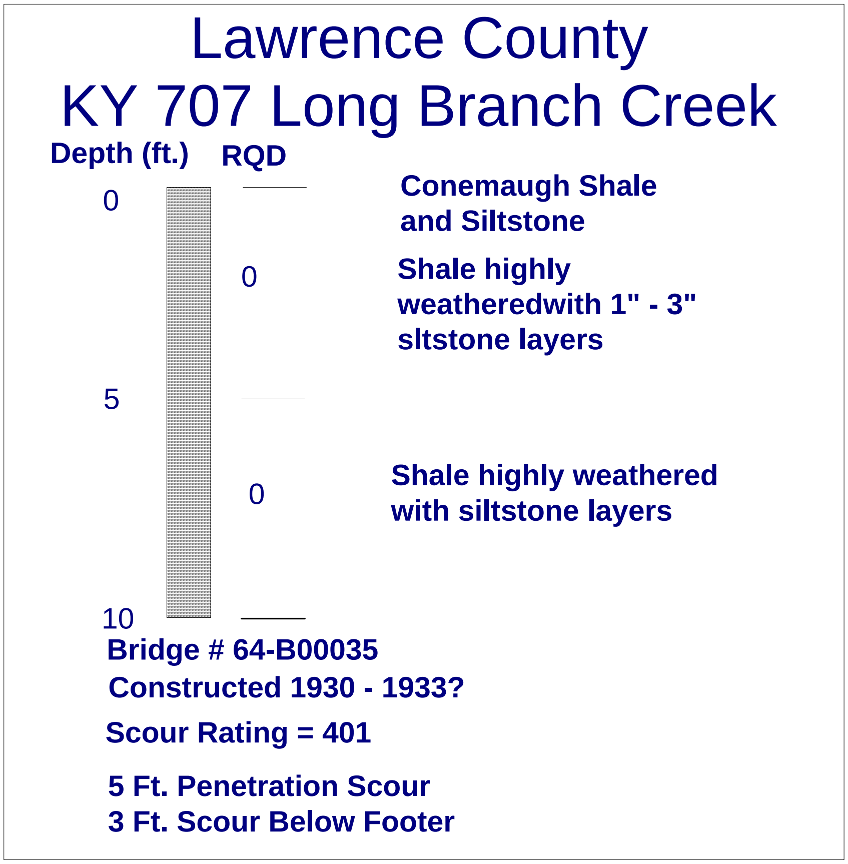
Bridge # 57-C00029

Built 1987?
Deck Only 1987?

Scour Rating = 377

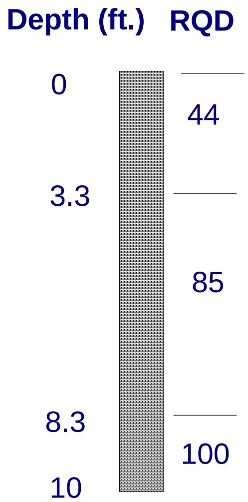
0.5 Feet Scour below Abutment Footer
2 Ft. Penetration Scour

Jessamine County Elm Fork Road Hickman Creek


Lawrence County
KY 707 Long Branch Creek
Depth (ft.)
RQD
0
5
10
0
0
Conemaugh Shale
and Siltstone
Shale highly
weatheredwith 1" - 3"
sltstone layers
Shale highly weathered
with siltstone layers
Bridge # 64-B00035
Constructed 1930 - 1933?
Scour Rating = 401
5 Ft. Penetration Scour
3 Ft. Scour Below Footer

Lawrence County KY 707 Adam's Branch

Owen County
KY 607 Cedar Creek



Grier Member of Lexington Limestone

Limestone with clay shale partings @ 0.9, 1.2, 1.7, 2.0, 2.7, 2.9, 4.1, 4.2, 4.7, 5.0, 5.7, 6.6, 7.7, 7.9, 8.0, 9.1

Bridge # 94-B00030

Constructed 1978
Scour Rating = 120

Pier Footer Partially Exposed

KY 607 Owen County Cedar Creek

Washington County
CR 1243 Road Run Branch

Depth (ft.) **RQD**

0

Lower Member
of Grant Lake Limestone

7

0.0'- 5.0'Limestone,grey,
coarse grained, 2 - 4 inches
layers with clay shale
seams 2 - 4 inches

5.0

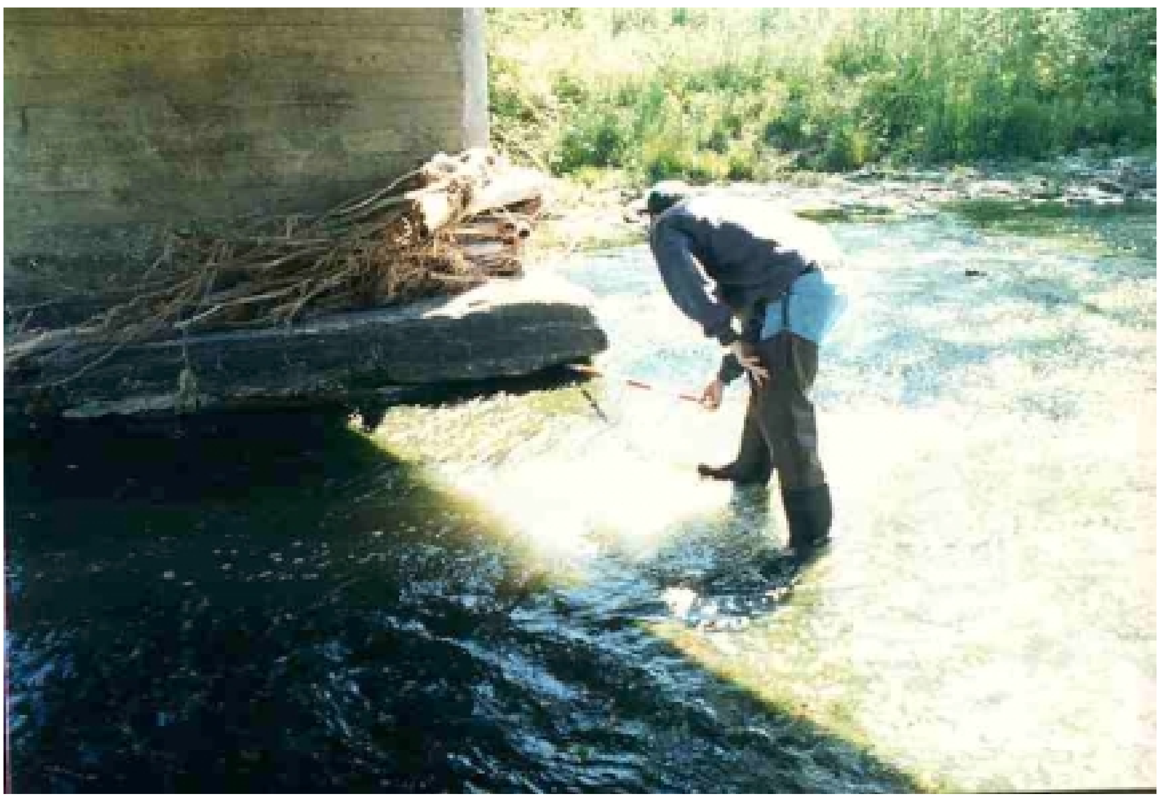
Bridge # 115-C00026

Constructed 1935

Scour Rating = 327

1 Ft. Vertical Scour and
3 Ft. Penetration Scour at Pier

Washington County CR 1243 Road Run Branch



For more information or a complete publication list, contact us at:

KENTUCKY TRANSPORTATION CENTER
176 Raymond Building
University of Kentucky
Lexington, Kentucky 40506-0281

(859) 257-4513
(859) 257-1815 (FAX)
1-800-432-0719
www.ktc.uky.edu
ktc@engr.uky.edu