SCOUR COUNTERMEASURE DESIGN FOR SEQUENTIAL VIADUCTS ON ANKARA – POZANTI HIGHWAY

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ABSTRACT

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Foundations of river bridges need to be protected with respect to excessive scouring. Degree of protection depends on the severity of scouring action around bridge piers and abutments. A case study is carried out to design appropriate protective measures for sequential viaducts located on Ankara-Pozantı highway in Turkey. A number of analyses are conducted to obtain water surface profiles throughout the study reach. Local scour depths at piers and abutments of the viaducts are then obtained. The design process for countermeasures is performed concerning hydraulic, hydrologic, constructional, and economical requirements. To this end, riprap, partially grouted riprap, and articulated concrete blocks are studied in these view points. A criterion based on a selection index, which is defined by the National Cooperative Highway Research Program in the USA, is applied in this study. Implementation of partially grouted ripraps at infrastructural elements is found to be an appropriate solution.

Keywords: Bridge, pier, abutment, scour, armoring countermeasure

ÖZ

ANKARA – POZANTI OTOYOLU ÜZERİNDEKİ ARDIŞIK VİYADÜKLERİN AYAKLARININ ETRAFINA KORUMA PROJESİ GELİŞTİRİLMESİ

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Nehir yataklarından geçen köprülerin ayakları aşırı oyulmaya karşı uygun koruma projeleriyle korunmalıdır. Korumanın derecesi köprü orta ve kenar ayaklarının etrafında oluşabilecek oyulmaya bağlıdır. Bu tez çalışması, Ankara – Pozantı otoyolu üzerinde bulunan bir takım viyadükler üzerinde uygun koruma projesinin tasarımı üzerine gerçekleştirilmiştir. Bir takım su yüzeyi analizleri yapılarak, köprü orta ve kenar ayaklarındaki yerel oyulma derinlikleri hesaplanmıştır. Oyulma miktarlarına bağlı olmak üzere, hidrolik, hidrolojik, yapısal ve ekonomik gereklilikleri de göz önünde bulundururak riprap kaplama, kısmi harçlı riprap kaplama, bağlanmış beton bloklar gibi ayakları koruma projeleri tasarlanmıştır. Bu koruma projelerinin seçimi, ABD'de faaliyet gösteren Ulusal Otoyol Araştırma İşbirliği Programı'nca bahsedilmiş olan seçme endeksine bağlanmıştır. Çalışmalar sonucunda altyapı elemanlarının korunması için kısmi harç kaplama tekniğinin daha uygun olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Köprü, köprü ayağı, kenar ayak, yerel oyulma, oyulma önleyici düzenlemeler

To my mother and my grandfather

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LIST OF SYMBOLS AND ABBREVIATIONS

ACB	: Articulated concrete block
A_L	: Average cross-sectional excavation area
A_{pi}	: Percentage of increase at the area
A_0	: Original cross-sectional area
$A_{\Delta 1}$	: Excavation area of Δ_1
$A_{\Delta 2}$	: Excavation area of Δ_2
$A_{\Delta 3}$	: Excavation area of Δ_3
b	: Width of pier perpendicular to the approach flow direction
C_a	: Cost of ACB units
C_{at}	: Transportation and placement cost of ACB units
C_{ex}	: Cost of excavation
C_{ext}	: Transportation cost of excavation
C_{gr}	: Cost of cement slurry and grouting
C_f	: Cost of geotextile filter
C_{fl}	: Cost of filling with granular material
C_{flt}	: Transportation cost of filling material
C_r	: Cost of riprap
C_{rt}	: Cost of riprap transportation
CSU	: Colorado State University
CW	: Clear-water condition
D	: Hydraulic depth
D_B	: Riprap diameter in terms of side B
D_{r15}	: Diameter of riprap of which 15% is finer
D_{r50}	: Median riprap size
D_{r85}	: Diameter of riprap of which 85% is finer
D_{r100}	: Diameter of riprap of which 100% is finer
D_{10}	: Size of grain for which 10% is finer
D_{50}	: Median sediment size
D_{60}	: Size of grain for which 60% is finer

D_{95}	: Size of grain for which 95% is finer
d_s	: Scour depth
d_{se}	: Equilibrium scour depth
F_r	: Froude number
F_{r1}	: Froude number just upstream of pier
g	: Gravitational acceleration
n_b	: Roughness coefficient due to bed material
n_1	: Roughness coefficient due to cross sectional variance
n_2	: Roughness coefficient due to channel geometry
n_3	: Roughness coefficient according to undulations at river bed
n_4	: Roughness coefficient due to vegetation
m	: Coefficient due to sinuosity
KG	: Kırkgeçit Creek
K_1	: Correction factor for pier nose shape
K_{1a}	: Correction factor for abutment nose shape
K_{2a}	: Correction factor for flow angle of attack
K_2	: Correction factor for flow angle of attack
K_3	: Bed condition correction factor
K_4	: Correction factor for armoring by D_{95} grain size
L	: Length
L_s	: Sub-reach length
LB	: Live bed condition
LCC	: Life cycle cost
Q	: Discharge
Q_2	: Peak discharge corresponding to 2-year return period
Q_{100}	: Peak discharge corresponding to 100-year return period
Q_{si}	: Rates of sediment transport into the control volume
Q_{so}	: Rates of sediment transport out of the control volume
SI	: Selection Index
S_S	: Specific gravity of riprap
S1	: Factor of bed material size and transport
S2	: Factor of severity of debris or ice loading

S3	: Factor of constructability constraints
S4	: Factor of inspection and maintenance requirements
T_r	: Return period
t	: Time
t_c	: Thickness of riprap layer
u	: Velocity
u_c	: Mean threshold velocity
u_0	: Velocity of approach flow
V	: Volume of the control element
V_e	: Total excavation volume
V_{pd}	: Percentage of decrease at the velocity
V_0	: Local maximum velocity at original cross section
V_1	: Average flow velocity just upstream of each pier
$V_{\Delta 1}$	: Local maximum velocity at Δ_1 amount of excavated cross section
$V_{\Delta 2}$	: Local maximum velocity at Δ_1 amount of excavated cross section
$V_{\Delta 3}$	: Local maximum velocity at Δ_1 amount of excavated cross section
W	: Weight of riprap
WS	: Width of scour protection mat of ACB
X1	: Upstream extent of ACB
X2	: Downstream extent of ACB
y	: Approach flow depth
Y_a	: Flow depth just upstream of pier.
Y1	: Flow depth just upstream of pier
α	: Approaching flow angle.
ρ	: Water density
σ_g	: Geometric standard deviation of particle size distribution
γ_r	: Specific weight of riprap
Δ	: Depth of excavation
Δ_r	: Relative density

CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

While the people give a shape to the world; hydrological, geological and meteorological conditions always show reflections against them. Various types of structures should be designed to withstand adverse effects of these conditions. Hydraulic structures are designed to tackle water-related problems and utilize benefits obtained from water storage and diversion. Special emphasis should be given to yield environmentally-friendly design solutions with minimal damage to the local people and all types of facilities.

Bridges and viaducts are very important elements of transportation systems. The degree of importance pronounces with the increase in the traffic intensity and diversity of the types of vehicles. Therefore, site-specific conditions should be assessed in detail to make a realistic decision-making in the design. Bridge design, therefore, needs collaborated actions of a group of engineers from different fields of civil engineering. Although the main aspect is focused on structural and constructional requirements, specialists in the fields of transportation, construction, and geotechnical engineering would also undertake partial responsibilities in the analysis and design of various components of a bridge. In case of a bridge crossing a wide alluvial river, a hydraulic engineer takes an important role in order to check the system conformity in view of hydraulics (Turan and Yanmaz, 2011).

River bridges can fail or be damaged because of flow-induced problems. Of these problems, scouring action at infrastructural elements of bridges dominates. With the presence of piers and abutments in the flow section, the net flow carrying area of the cross-section decreases, leading to an increase in local sediment transport capacity. The loose stream bed would then undergo a severe scouring, especially during high flows. A schematic description of the scour development at a bridge opening is presented in Figure 1.1. Statistical studies indicate that leading cause of bridge failures all over the world is hydraulic factors, such as excessive scouring, pronounced backwatering, clogging of the bridge opening due to debris accumulation, and occurrence of pressure and weir types of flows (Yanmaz, 2002)

In order to assure bridge safety with respect to the aforementioned aspects, design conditions of the project must be applied at the construction site in a strict manner. In new designs, realistic solutions should be developed such that the above stated problems are minimized. For the existing bridges, necessary remedial actions should be taken with reference to the local conditions. Periodic application of various monitoring views can further help in early detection of scour-critical conditions. Critical scour is specified as the depth of scour in reference to the footing elevation of that bridge. If the final eroded bed level around the bridge foundation reaches the upper elevation of its footing, this bridge is stated as scour critical (Pearson et al., 2002).

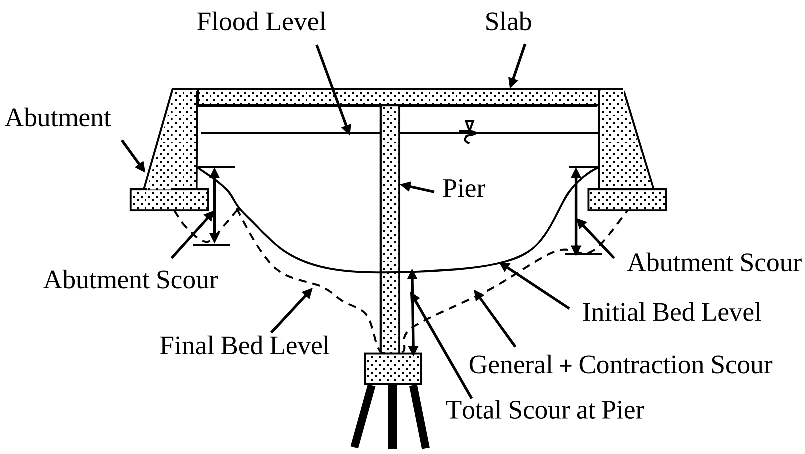


Figure 1.1 A definition sketch for local scour around bridge piers and abutments (Yanmaz, 2002)

Scour countermeasures are vital in avoiding scour criticality on bridges. Such countermeasures can prove helpful by minimizing the stream instability as well as providing continuous monitoring. However, selection of applicable and feasible countermeasure type requires intensive analysis regarding hydraulic and sedimentologic regime of the river concerned and level of flow-structure interaction.

1.2 Objective of the Study

This thesis aims to find out a suitable and feasible countermeasure type for sequential viaducts located on Ankara – Pozantı highway. The study area is located on this highway between 338+355.00 km and 349+660.94 km. These viaducts cross Kırkgeçit River at some sections. That is why hydrologic evaluations of the basin of Kırkgeçit River form the basis of this study. Within this context, various relevant hydrologic and geomorphologic parameters are determined to compute the flow rates for various return periods. Water surface profile computations are performed for these flows to compute the possible depths of scour at infrastructural elements of these viaducts under the most scour susceptible conditions. Armoring type of scour countermeasures is assumed to be applicable to the current engineering practice in Turkey. That is why placement details of riprap, partially-grouted riprap, and articulated concrete units are studied in view of practical applicability and economic feasibility.

1.3 Scope of the Thesis

The scope of the thesis covers the study of the subjects highlighted in the previous section. The related information is conveyed in five chapters with the contexts stated below:

- Chapter 1 includes introductory remarks and description of the scope and aim of the study.

- Chapter 2 explains basic concepts of bridge scour including types of scour.

- Chapter 3 discusses characteristics and design aspects of armoring type countermeasures and their selection criterion.

- The case study is presented in Chapter 4. Characteristics of the project area, related hydrologic calculations, river flow modeling approach, scour computations, countermeasure design applications and possible recommendations specific to the project area are introduced.

- Chapter 5 gives the conclusions derived from this study. Moreover, recommendations for the future studies are also presented.

- Details of computations, program outputs, and related information are given in Appendices A through D.

CHAPTER II

THE MECHANISM OF BRIDGE SCOUR

2.1 General

One of the most uncertain parts of the design of river bridges is the footing details, especially the required safe depth of burial of footings against scouring action. As a result of removal of considerable amount of foundation material from the surrounding of piers and abutments, large scour holes may develop, which affect the bridge stability in adverse manner. Since this study is mainly concentrated on the design applications of armoring type scour countermeasures, only basic information is given on the mechanism and type of bridge scouring.

2.2 The Mechanism of Scouring

Alluvial streambeds are subject to erosion due to the increased rate of sediment transport, which may arise due to the contraction of the flow area. A vortex field is then developed around bridge piers and abutments. Possible changes at alluvial beds can be examined with reference to the sediment continuity equation (Yanmaz, 2002):

$$\frac{dV}{dt} = Q_{si} - Q_{so} \tag{2.1}$$

where V is the volume of the control element taken at the alluvial bed, t is the time, Q_{si} and Q_{so} are the rates of sediment transport into and out of the control volume. The local sediment transport capacity increases at a bridge opening due to flow acceleration. Under steady uniform flow conditions, when the upstream sediment transport rate is smaller than that of the contracted section, Q_{so} will be greater than Q_{si}, meaning that the bed lowers with respect to time. This phenomenon is named as scouring. Streambed scouring may be categorized into three classes i.e. local scour, localized scour, and general scour. If scouring occurs around an object like a pier or abutment, it is termed as local scour around that obstacle. Localized or contraction scour refers to bed lowering because of the constriction of the flow area at certain sections along the river reach concerned. The general or degradation scour occurs irrespective of the presence of any human interference, such as implementation of various types of hydraulic structures and utilization of rivers for various project requirements.

The mechanism of scouring at piers and abutments is mainly the same. That is why only bridge scouring mechanism is discussed in a concise manner in this text. Water surface elevation at the upstream face of a bridge pier increases due to an abrupt decrease of velocity and formation of a stagnation pressure plane. The degree of rising of water level depends on the velocity of the approach flow, u_0, and geometric characteristics of the bridge pier. Due to a strong pressure increase at the upstream face of a pier, the three-dimensional turbulent boundary layer separates. Since the velocity u_0 decreases from the free surface downwards, the stagnation pressures, $\rho u_0^2/2$, where ρ is water density, also decrease from the surface downwards. This produces a downward pressure gradient, and hence a downward velocity component. When this downward velocity component interferes with the approach velocity, the so-called horseshoe vortices generate at the bed level as shown in Figure 2.1. Eroded materials are carried around the pier by the combined action of accelerating flow and horseshoe vortices. The strength of horseshoe vortices depend on the flow Reynolds number and the geometry of the bridge pier. Wake vortices develop as a result of shear stress gradients in the separated wake region. Rate of particle erosion by means of wake vortices depends on the flow intensity and the geometric characteristics of the pier. The horseshoe vortices are stronger than wake vortices. Therefore, the maximum scour depths are normally observed at the upstream side of the pier (Yanmaz, 2002).

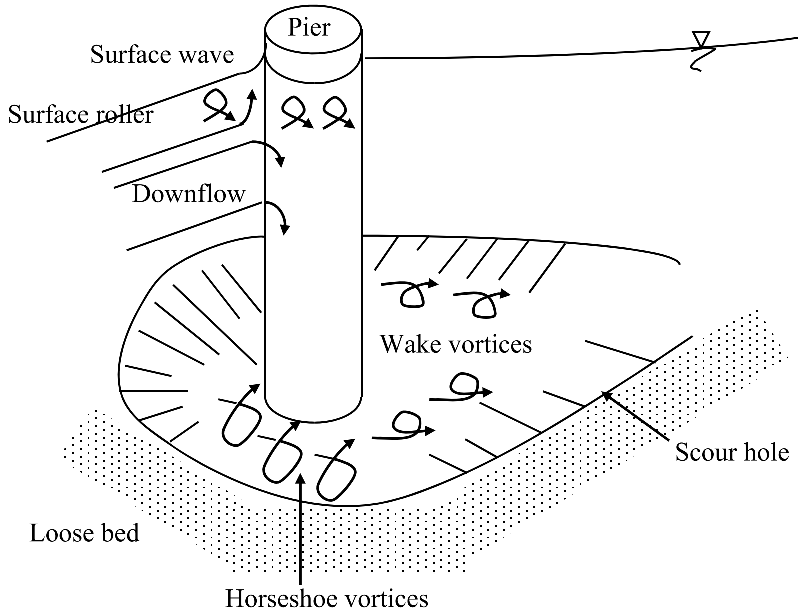


Figure 2.1 Vortex systems around a bridge pier (Yanmaz, 2002)

2.3 Types of Scour

Two types of scour develop at loose boundaries, i.e. clear water scour and live-bed scour, depending on whether or not there is bed load transportation at the upstream. In case of clear water scour, the flow inertia is relatively low that the bed shear stress is smaller than the threshold value defined for the given bed material. Scour occurs at the contracted section due to the local acceleration of the flow and continues until the scour hole becomes stable. When the bed shear stress exceeds the threshold value, there is bed load transportation at the upstream which interferes with the local sediment transport rate at the scour hole. For live bed scour, sediment is transported through the scour hole by means of an excess shear stress. However, in case of clear water conditions, particles on the surface of the scour hole may be occasionally moved but are not carried away (Yanmaz, 2002). Under live bed condition, scour depth increases rapidly with time and then fluctuates about a mean value known as equilibrium scour depth, d_{se}. Figure 2.2 shows the scour development around a bridge pier with respect to time, t, and velocity, u. In Figure 2.2, u_c is the mean threshold velocity. Because of the continuous changes of the bed resistance under turbulent flow conditions and random supply of sediment into the scour hole, the depth of live-bed scour exhibits fluctuations with respect to time.

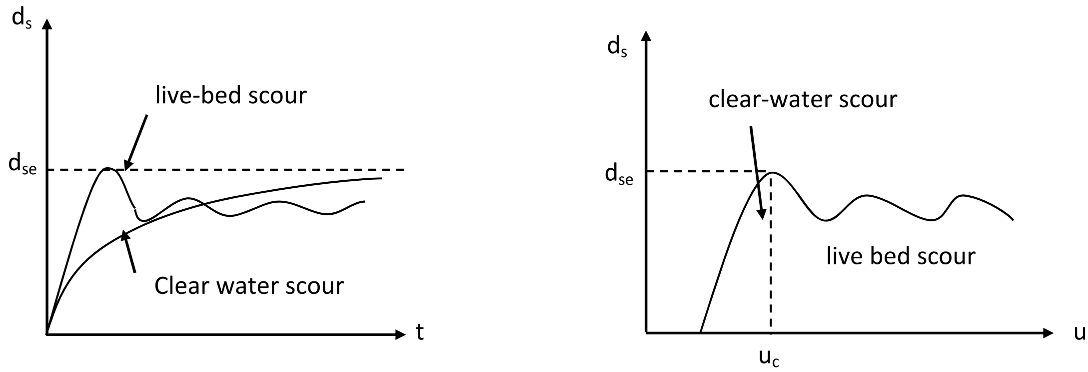


Figure 2. 2 Variation of scour depth with time and velocity (Yanmaz, 2002)

2.4 Governing Scouring Parameters

Estimation of the scour depth at piers and abutments of a river bridge is of importance for a safe footing design. Several investigators have studied the problem of local scour around bridge piers and abutments extensively. However, no single analytically derived equation is available because of the difficulties of the problem, such as combined effects of complex turbulent boundary layer, time-dependent flow pattern, and sediment transport mechanism in the scour hole (Yanmaz and Altınbilek, 1991). That is why the scouring phenomenon remains one of the challenging fields of hydraulic engineering.

Using a dimensional analysis, the following relationship can be obtained for a single pier in an alluvial bed having non-cohesive bed material in a straight river, which is subject to relatively long severe flow conditions with high turbulence intensity.

$$\frac{d_s}{b} = f_3\left(\frac{y}{b}, F_r, \sigma_g, \frac{b}{D_{50}}\right) \tag{2.2}$$

in which d_s is the depth of scour, y is the depth of approach flow, b is the pier size perpendicular to the approach flow direction, F_r is Froude number, σ_g is geometric standard deviation of particle size distribution, and D is median sediment size. Since the mechanism of scouring is similar, in case of abutment, pier size can be replaced by abutment length L. The reader is advised to refer to Melville and Coleman (2000), and Yanmaz (2002) for further information on the effects of these variables on bridge scouring. Most of the scour-prediction equations reported in the literature are of the form of Equation (2.2). In this chapter, only some well-known equations are presented.

HEC – 18 procedure recommends the use of Colorado State University (CSU) equation as a standard scour-prediction equation in the United States. This equation is (Richardson et al., 2001):

$$\frac{d_s}{b} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{Y1}{b}\right)^{0.35} F_r^{0.43} \qquad (2.3)$$

where

Y1: Flow depth just upstream of pier.

K_1: Correction factor for pier nose shape

K_2: Correction factor for flow angle of attack

K_3: Bed condition correction factor.

K_4: Correction factor for armoring by D_{95} grain size.

D_{95}: Size of grain for which 95% is finer

In addition to CSU equation, Froehlich (1991) suggested an equation for local pier scour calculations in 1991 and it is involved in HEC-RAS program as an alternative equation. This equation is (Froehlich, 1991):

$$d_s = 0.32 K_1 (b)^{0.62} Y_1^{0.47} F_{r1}^{0.22} D_{50}^{-0.99} + b \qquad (2.4)$$

The HEC – 18 developed an equation which is called as HIRE Equation (Richardson, 1990) for scour depth calculations around abutments. This equation is:

$$d_s = 4Y_a\left(\frac{K_{1a}}{0.55}\right)K_{2a}F_r^{0.33} \tag{2.5}$$

where

Y_a: Flow depth just upstream of abutment.

K_{1a}: Correction factor for abutment nose shape

K_{2a}: Correction factor for flow angle of attack

CHAPTER III

BRIDGE SCOUR COUNTERMEASURES

3.1 General

River bridges could get severally damaged or collapse due to excessive scouring around piers and abutments. Such scouring could be caused not only by live bed conditions under high flow, but also by clear water condition under low flow. In recent years, design and construction of hydraulically safer new bridges has become possible thanks to advances in modeling capabilities and cumulative experience.

On the other hand, for existing bridges, it is of vital importance to take countermeasures to control the scouring so that the bridge can continue to function properly for the rest of its life time. It should be noted that depending on the location and functional purpose, several additional socio-economic losses could occur during the time required for reconstruction or repair of the damaged bridge.

At existing river bridges, various types of countermeasures can be installed to decrease the rate of scouring by protecting the river bed, diverting the flow, or reducing the vortices around the piers.

Selected countermeasures should be economical, reliable, and easily be constructed in accordance with the country practices. Efficiency must be verified in both laboratory and real natural conditions. Furthermore, chosen countermeasure should enable continuous observation, analysis and easy maintenance under various flow conditions during its life time. Armoring type countermeasures are widely used because of ease of construction, repair, and maintenance. In this thesis, only the characteristics of these countermeasures will be discussed and design and construction guidelines are provided.

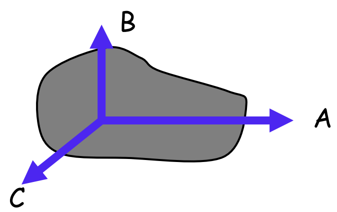
3.1.1 Rock Riprap at Piers

Rock riprap is the most commonly used countermeasure type throughout the world, thanks to its high availability, economic feasibility, and ease of implementation. It is more flexible than the rigid protections. Rock riprap is applied in order to reduce the erosive effects of rivers around the bridge piers and abutments and hence to stabilize foundation conditions of infrastructural elements. The adequacy of the riprap placement is dictated by the selection of the appropriate weight and proper placement technique. The weight of a riprap is approximately the 85% weight of a cube having sides D_B, where D_B is the riprap diameter in terms of side B according to a coordinate system shown in Figure 3.1.

$$W = 0.85\gamma_r D_B^3 \tag{3.1}$$

where γ_r is the specific weight of riprap which is desired to be greater than or equal to 25 kN/m^3 (Lagasse et al., 2007). Elongated shapes should be avoided for ripraps. That is why the ratio of the side lengths is limited by A/C<3.0 (Lagasse et al., 2007).

Turbulence and high velocity may cause removal of riprap around bridge piers which may result in fatal damages. Therefore, after application of rock riprap, the bridge should periodically be inspected, especially during and after flood times to ensure the stability of riprap (Lagasse et al., 2001).



The design of rock riprap is based on the determination of median stone diameter (D_{r50}) in which shape of the pier and maximum local velocity play an important role. Theoretically, the size of a riprap can be determined from the equilibrium of forces acting on it at the bed level. Since the disturbing forces like dynamic lift and drag forces are functions of the velocity square, most of the available equations giving the required riprap size are expressed as a function of the velocity square. A list of such equations can be found in Melville and Coleman (2000). In this thesis, only one of these equations i.e. Isbach equation, which is commonly used in the American practice, is presented (Lagasse et al., 2001):

$$D_{r50} = 0.692 \frac{(K_1 u)^2}{(S_s - 1)2g} \tag{3.2}$$

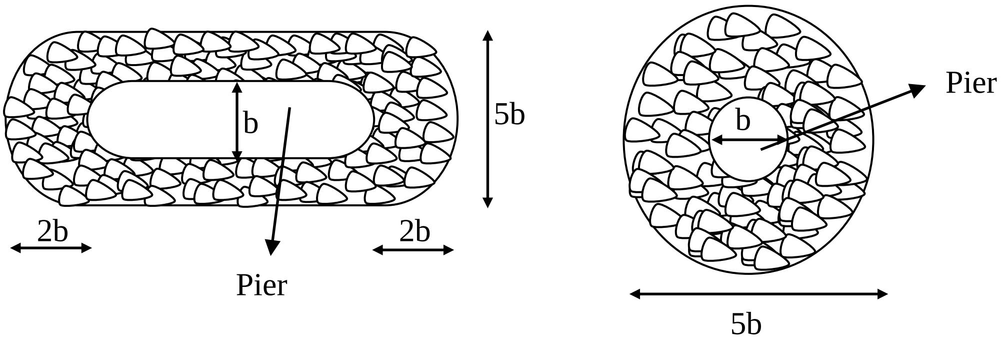
where u corresponds to the design velocity in m/s; S_s is the specific gravity of riprap and it is taken as 2.65, the constant K_1 stands for shape effect of the pier and is taken as 1.5 for round-nosed shaped pier and 1.7 for rectangular shaped pier. For conservative design, the value of K_1 is accepted as 1.7 in HEC-23 criteria (USACE, 2010). According to the Equation (3.2), the design velocity is accepted as the maximum of all local velocities at the upstream face of the piers. In HEC-23 criterion, the maximum size of the riprap is recommended not to exceed $2D_{r50}$.

Lagasse et al. (2007) defines 10 riprap classes according to the size gradations. Recommended gradations for each class are presented in Table 3.1. The purpose of gradation criteria is to provide the target value of 2.0 for uniformity coefficient, which may range between 1.5 to 2.5.

Table 3.1 Size gradations for standard classes of riprap in mm (Lagasse et al., 2007)

Class	**D_r (mm)**	**D_{r100} (max)**	**D_{r15} (min)**	**D_{r15} (max)**	**D_{r50} (min)**	**D_{r50} (max)**	**D_{r85} (min)**	**D_{r85} (max)**
I	152.4	304.8	94	132.1	144.8	175.3	198.1	233.7
II	228.6	457.2	139.7	198.1	215.9	266.7	292.1	355.6
III	304.8	609.6	185.42	266.7	292.1	355.6	393.7	469.9
IV	381	762	233.7	330.2	368.3	444.5	495.3	584.2
V	457.2	914.4	279.4	393.7	431.8	520.7	596.9	698.5
VI	533.4	1066.8	330.2	469.9	508	609.6	698.5	825.5
VII	609.6	1219.2	368.3	533.4	584.2	698.5	787.4	939.8
VIII	762	1524	469.9	660.4	723.9	876.3	990.6	1168.4
IX	914.4	1828.8	558.8	800.1	863.6	1054.1	1193.8	1409.7
X	1066.8	2133.6	647.7	927.1	1016	1231.9	1384.3	1638.3

The placement detail of riprap around bridge piers is normally dictated with reference to the extension possibility of the scour hole around the pier. Care should be taken in placement such that good interlocking is achieved among ripraps and the desired gradation is achieved according to the criterion given in Table 3.1. One of the typical placement details is shown in Figure 3.2.



Determination of thickness (number of layers) and filter placement details are of importance for safe riprap design. The thickness of riprap varies from $3D_{r50}$ to $5D_{r50}$ according to the severity of hydraulic conditions (Lagasse et al., 2007).

In rock riprap installation two types of filters can be used: granular and geotextile filters according to the characteristics of the bed material. Application of granular filters can be alone or as a transition between fine-grained base soil and geotextile filter. According to Brown and Clyde (1989), the thickness of the single layer granular filter needs to be at least 15 cm. If it is applied in multiple layers, the thickness of each layer can varies from 10 to 20 cm. The material used in granular filter (D_{50} size of the filter) is selected based on the coefficient of uniformity (D_{60}/D_{10}) of the base soil and the filter material (Heibaum, 2004). However, for dune-type bed forms or under water installations, granular filter is not recommended. In this case only a geotextile filter can be applied (Lagasse et al., 2007).

Geotextile filter may also be placed beneath the riprap installation. The filter should be laid and pulled carefully, as it is liable to tearing. When it is laid in parts around bridge piers, upstream part should be placed on the downstream part. Dimensions and placement of riprap and geotextile filter around bridge piers are depicted in Figure 3.2. Geotextile filter should be laid all around the pier with the extension width equals to 3/4 of the pier width as shown in Figure 3.3 such that the ends of geotextile are not subject to the external flow conditions. In Figure 3.3, t_c stands for the thickness of riprap layer. The total area of geotextile filter equals to 9/16 of net surface area of rock riprap protection. A typical riprap application around a bridge pier is presented in Figure 3.3.

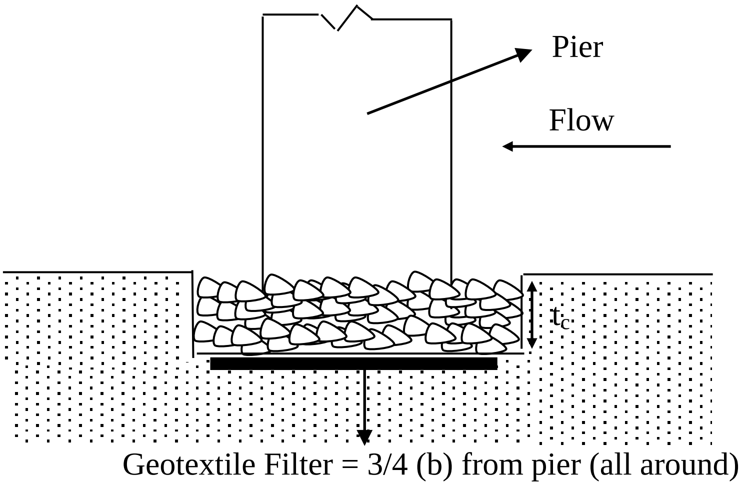


Figure 3.3 Dimensions and Placement of Riprap and Filter in Cross-Sectional View (Yanmaz, 2002)

Figure 3.4 An application of riprap around bridge piers (Newsline, 2007)

3.1.2 Partially Grouted Riprap at Piers

Main purpose of partially grouted riprap is to increase the stability of stones by using cement slurry. Moreover, partially grouted riprap is used for places that riprap size is too big or not available at the project site. Table 3.1 shows the classification of ripraps based on size gradations. According to the size gradations, only classes II, III and IV are applicable for partially grouted riprap installations (Lagasse et al., 2007). The 50% of the porosity between those ripraps should be grouted with the cement slurry.

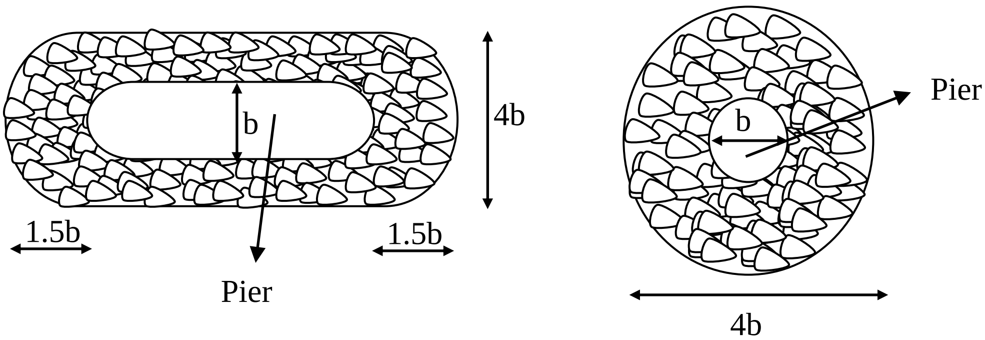
The design procedure of partially grouted riprap is very similar to that of rock riprap. The median stone diameter (Dr_{50}) is also important parameter and given by Equation (3.2). Cement slurry is injected into riprap matrix by taking several criteria into account, such as technique of filling and the amount of filling. Recommended mix proportions for partially grouted riprap are presented in Table 3.2. Grout filling is applied into spaces between stones. The application of grouting is conducted by sequential layering of ripraps.

Table 3.2 Mixture for 0.765 m^3 of Grout (Lagasse et al., 2007)

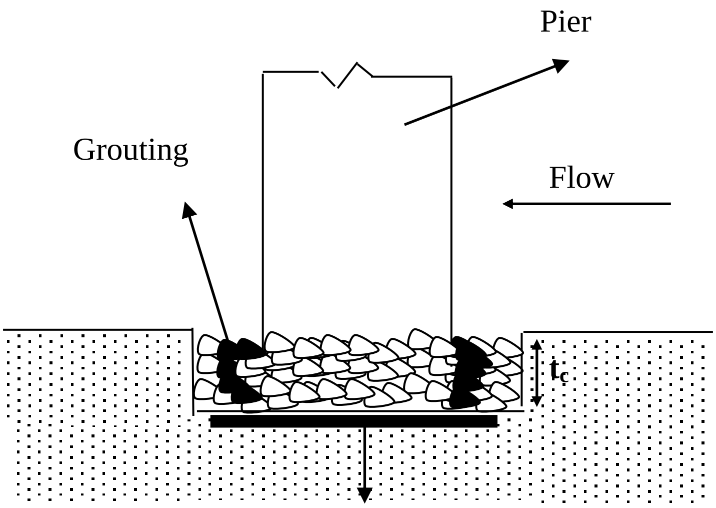
Material	Quantity by Weight
Ordinary Portland cement	336 to 345 kg
Fine concrete aggregate (sand), dry	535 to 545 kg
1/4" crusher chips (very fine gravel), dry	536 to 545 kg
Water	190 to 205 kg
Air entrained	5% to 7%
Anti-washout additive (used only for placement under water)	2.7 to 3.7 kg

A typical partially grouted riprap application is shown in Figure 3.5.

The design extents of partially grouted riprap are depicted in Figure 3.6.



The thickness in partially grouted riprap varies from $2Dr_{50}$ to $4Dr_{50}$. The installation of geotextile filter procedure is as same as the procedure used in rock riprap. Dimensions and placement of partially grouted riprap and filter around bridge piers in profile view are shown in Figure 3.7. The dimension of the geotextile filter is 3/4 of the projected width of the protection area. The total area of geotextile filter then equals to 9/16 of net surface area of partially grouted riprap protection.



3.1.3 Articulated Concrete Block (ACB) Systems

Articulated concrete block systems could be effective in prevention from scouring around the bridge piers. The design method of ACB system is based on the determination of a factor of safety using force analysis. However, hydraulic conditions include many uncertainties which require increase in the factor of safety. This may lead to over design and bring uneconomic situation. Therefore, experience and judgment are of vital importance when quantifying the factor of safety to be used for scour protection (Lagasse et al., 2001). Some examples of ACB units are shown in Figure 3.8.

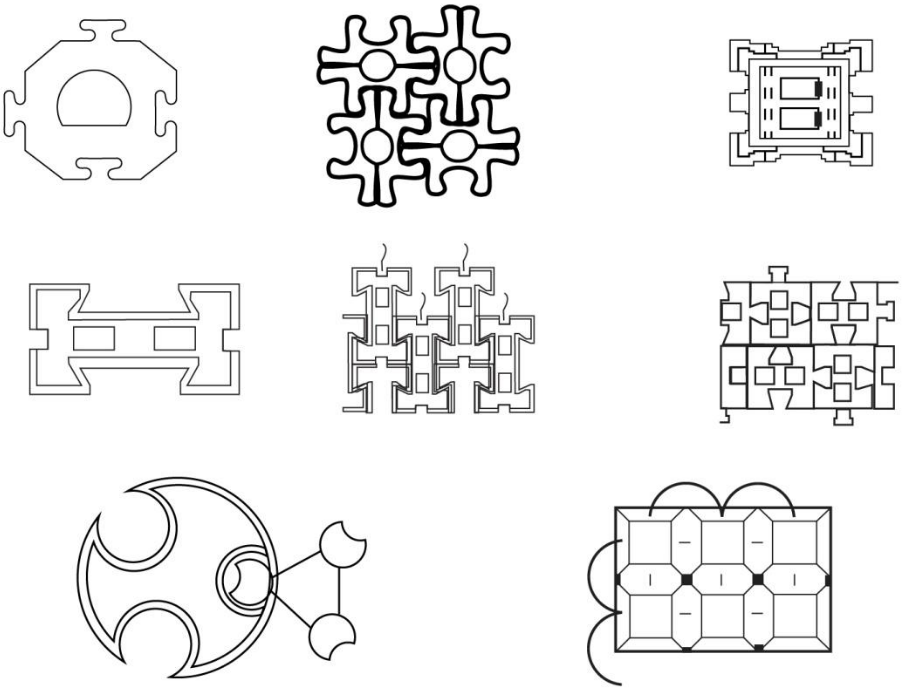


Figure 3.8 Some types of ACB units and systems (Scholl, 2010)

The placement details of articulated concrete block systems for scour protection are shown in Figure 3.9. For maintaining the desired safety, ACB units may be joined to each other by cables. According to the figure, width of scour protection mat (WS), upstream extent (X1) and downstream extent (X2) of scour protection are calculated by using the following equations:

$$WS=2.5\ d_s+b \tag{3.3}$$

$$X1=1.25\ d_s \tag{3.4}$$

$$X2=3\ d_s \tag{3.5}$$

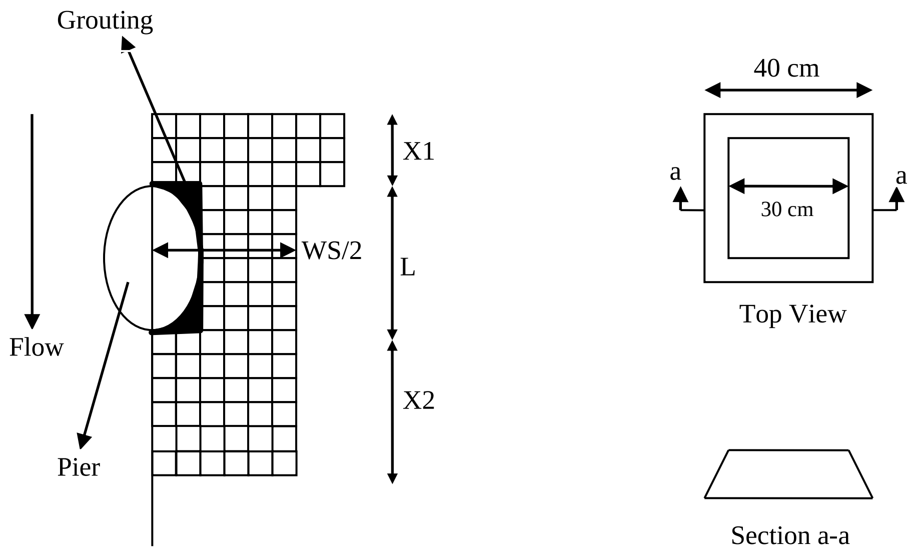


Figure 3.9 Advised Cable Tied Mat Dimensions (Lagasse et al., 2001)

Under the installation of ACB system, usage geotextile filter and granular filter are required. In Netherlands, the height of granular filter is recommended as 1m (Lagasse et al., 2001). The dimension of geotextile filter directly depends on the surface area where the ACB system located.

Area of Geotextile Filter = (X1+L+X2)*WS - Pier Area (3.6)

Volume of the granular filter is determined by multiplying the net installed ACB area and the thickness of the ACB layer. As shown in Figure 3.9, grouting needs to be applied around the pier. The results of Özdemir (2003) show that cost of grouting is negligibly small and does not affect the economic analysis of ACB system.

3.1.4 Gabion Mattresses

Although there is a limited application experience on gabion mattresses as a countermeasure for bridge piers, it has been thought that it provides economic benefit for constructors (Lagasse et al, 2007). Gabion mattresses are composed of wire mesh and inside of it is filled with rocks. The wire mesh increases the stability on the bed layer. In addition, both excavation volume on the bed and stone sizes are smaller than those of rock riprap. Therefore, this technique can be more feasible on implementation. Size ranges for rock to fill gabion mattresses are given in Table 3.3. However, it has some limitations. For example, under water placements, if the velocity of the flow is greater than 1.3 m/s, gabion mattresses could not be installed (Lagasse et al., 2007). Typical gabion mattress and use of it around bridge piers are shown in Figures 3.10 and 3.11.

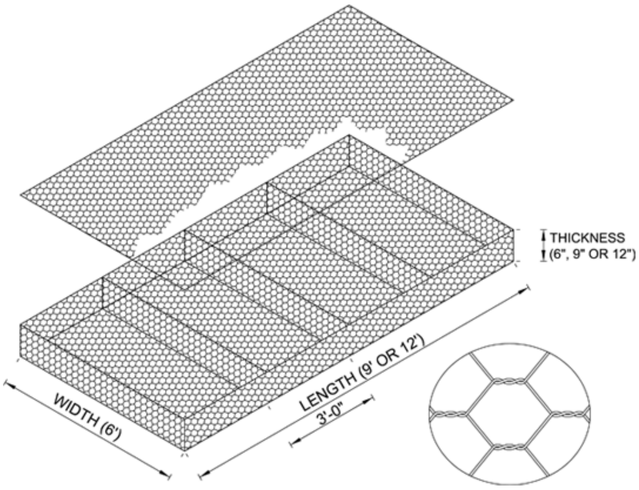


Figure 3.10 Typical Gabion Mattress

(http://www.sun-gabion.com/Reno-Mattresses/products-83-Reno-Mattress.htm, 2010)

Table 3.3 Size Ranges for Rock to Fill Gabion Mattresses (Lagasse et al., 2007)

Mattress Thickness (cm)	Range of stone sizes (cm)
15	7.6 to 12.7
23	7.6 to 12.7
30	10 to 20

Figure 3.11 Use of Gabion Boxes around Bridge Piers
(http://gabions.cc/index.html, 2006)

The design process for bridge piers is developed by the U.S. Federal Highway Administration (FHWA). The life span of the gabion mattresses depends on the integrity of the wire as coarse bed load creates an abrasion on it. Therefore, while usage of gabion mattresses in sand or fine sand bed layers might be convenient; gravel beds are strictly not appropriate for it. For optimum design, gabion mattresses should be placed along two times pier width in all directions around pier. For slopes that are steeper than 1V:2H where V and H stand for vertical and horizontal values of inclination, respectively, the mattresses should not be applied. However, there can be some exceptions where dimensions can be greater (Lagasse, et al., 2007).

The placement details of a geotextile filter is almost the same as the previous countermeasures. The filter should not be laid down completely under the mattresses; instead, two – third of the extension distance in all directions around pier is appropriate for filter area. Figure 3.12 depicts the design criterion of the gabion mattresses.

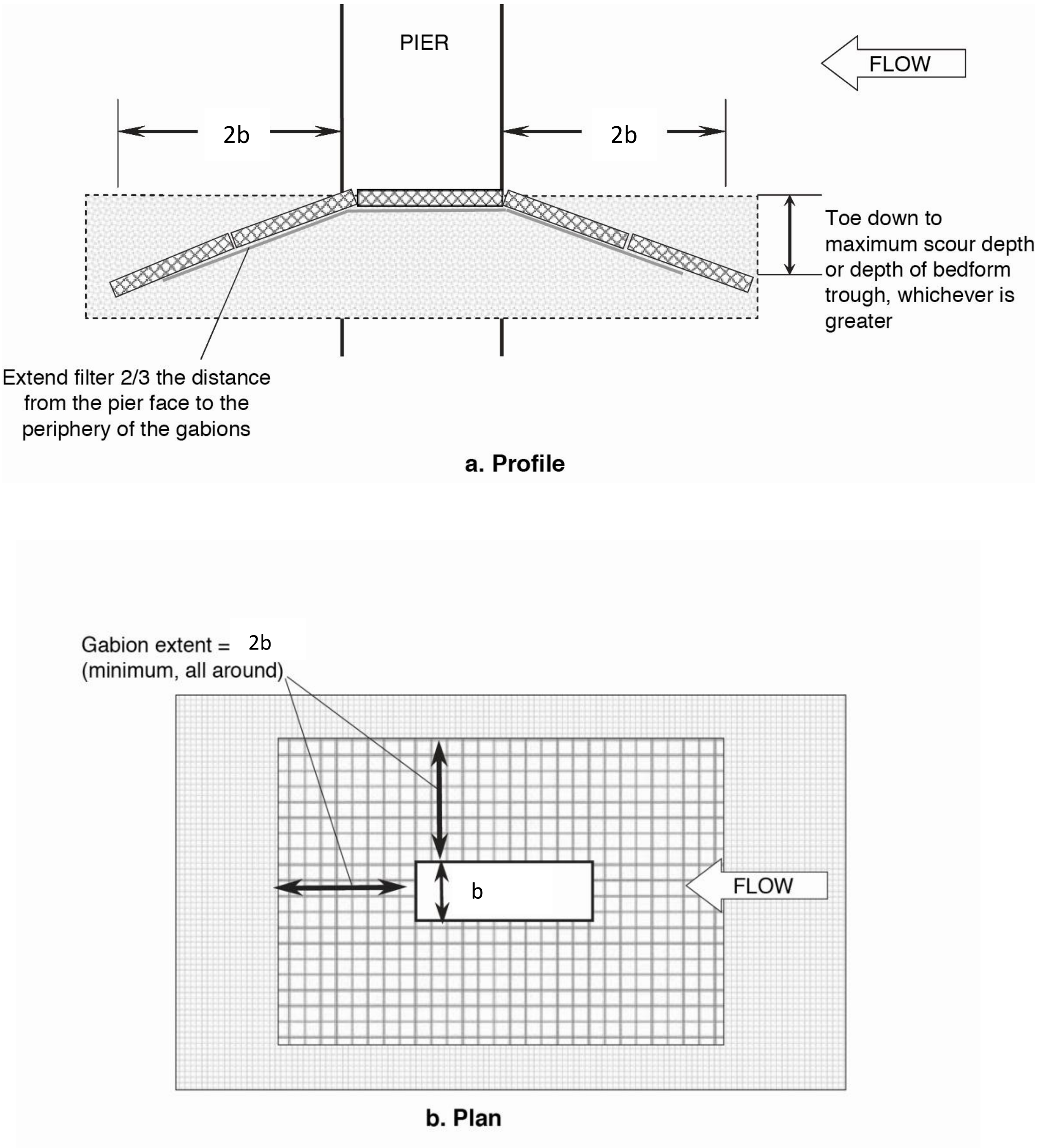


Figure 3.12 Implementation Extent of Gabion Mattresses in Plan and Profile View (Lagasse et al., 2007)

3.1.5 Grout-filled Mattresses

The usage of grout filled mattress system, which is made of double layer strong synthetic fabric, woven nylon or polyester, is still not common as a countermeasure around bridge piers. Grout-filled mattress systems are generally used for protection of shorelines and underwater pipelines as well as channel armoring for abutments and banks (Lagasse et al., 2007).

Mattresses which are found in standard nominal thicknesses of 100, 150 and 200 mm, are connected to a series of pillow – shaped compartments and ducts connect the compartments with them. Before concrete is injected into the fabric form, cables are placed as reinforcement and laced through the mattresses (Lagasse, 2007). Typical picture of grout-filled mattresses is given in Figure 3.13.

Figure 3.13 Typical Grout Filled Mattresses (FHWA, 1989)

The design process of grout-filled mattresses is similar to that of gabion mattresses. Grout filled mattresses are effective only under the clear water conditions. Under dune-type bed form conditions, the mattresses are subject to both undermining and uplift forces. Thus, installation of mattresses is recommended only for clear water conditions. Table 3.4 lists properties of the nominal grout-filled mattress (Lagasse et al., 2007).

Table 3.4 Nominal Grout-Filled Mattress Properties (Lagasse et al., 2007)

Property	**100 mm mattress**	**150 mm mattress**	**200 mm mattress**
Average thickness (mm)	100	150	200
Mass per unit area (kg/m^2)	220	330	440
Mass per block (kg)	40	85	148
Nominal block dimensions (m)	0.5 x 0.36	0.5 x 0.5	0.5 x 0.66
Cable diameter (mm)	6.35	7.94	7.94
Cable breaking strength (kN)	16.5	20	20

For optimum design, two times pier width should be extended in all directions around pier. If the scour possibility is high, lateral extent of the protection must be increased. The slope ratio of the placement of mattresses should be 1V:2H at most. The filter layer under the mattresses should be laid down completely under the grout-filled mattresses in all directions (Lagasse et al., 2007). Figure 3.14, depicts the design criterion for the grout-filled mattresses.

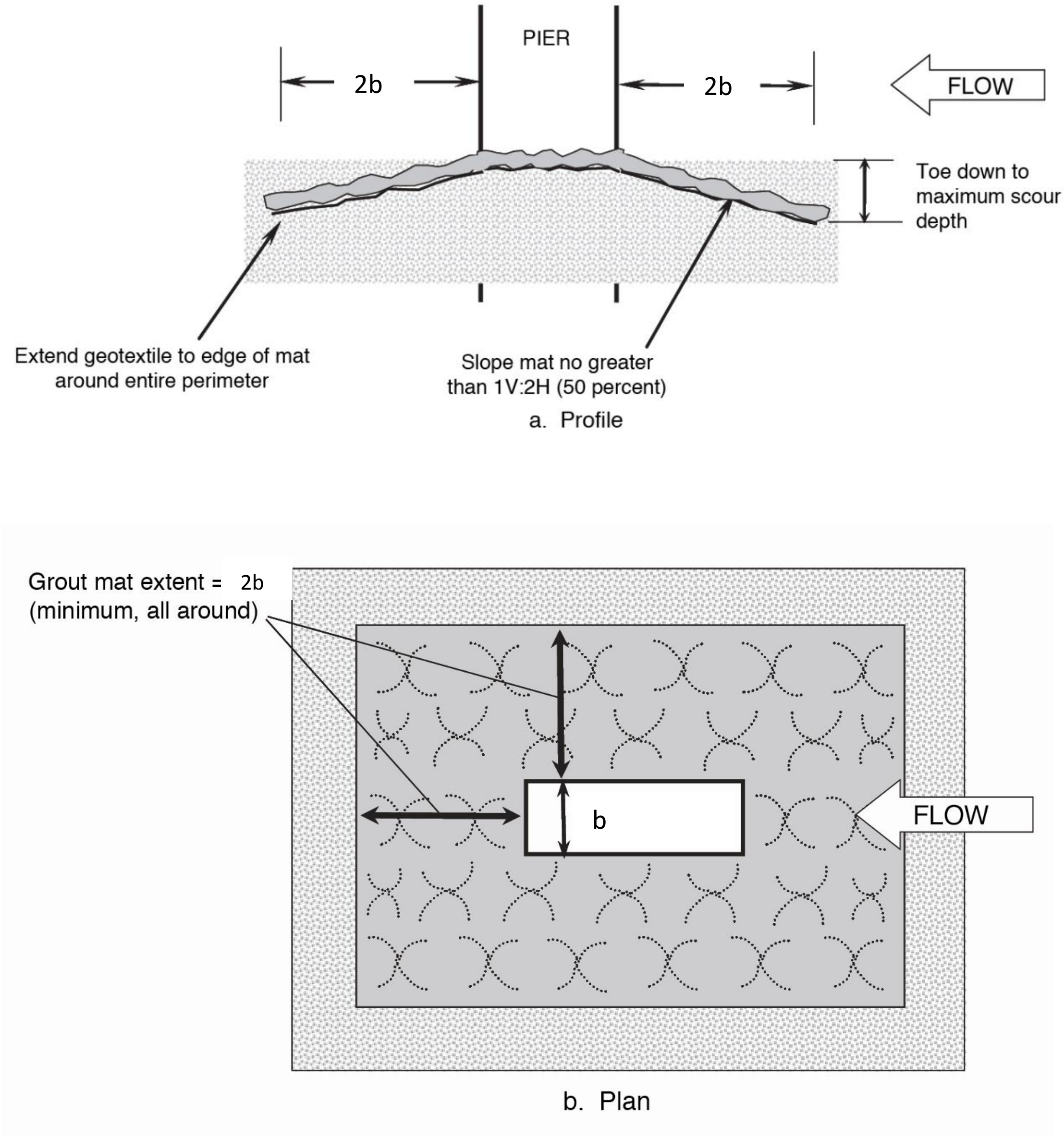


Figure 3.14 Implementation Extent of Grout Filled Mattresses in Plan and Profile View (Lagasse et al., 2007)

3.2 Countermeasure Selection Methodology

3.2.1 General

Implementation of appropriate countermeasure systems is vital while constructing bridges and viaducts. Especially, for pier scour protection, several types of countermeasures, such as rock riprap, partially grouted riprap, articulating concrete block (ACB) systems, grout – filled mattresses, and gabion mattresses should be analyzed and evaluated in terms of structural and economical aspects with site conditions in mind. A selection system based on the risk categories is developed by Johnson and Niezgoda (2004). A similar study is also developed by Lagasse et al. (2007) which presents a selection criterion for armoring type countermeasures.

The selection of the countermeasure system is determined by the five main factors namely, river environment, maintenance, performance, construction considerations, and estimated life-cycle cost. The Selection Index (SI) should be computed for each countermeasure by taking all factors into consideration and the most suitable countermeasure should be selected according to calculated indexes.

The Selection Index (SI) is given by:

$$SI = \frac{S1 \text{ x } S2 \text{ x } S3 \text{ x } S4}{LCC} \qquad (3.7)$$

S1: Factor accounting for bed material size and transport

S2: Factor accounting for severity of debris or ice loading

S3: Factor accounting for constructability constraints

S4: Factor accounting for inspection and maintenance requirements

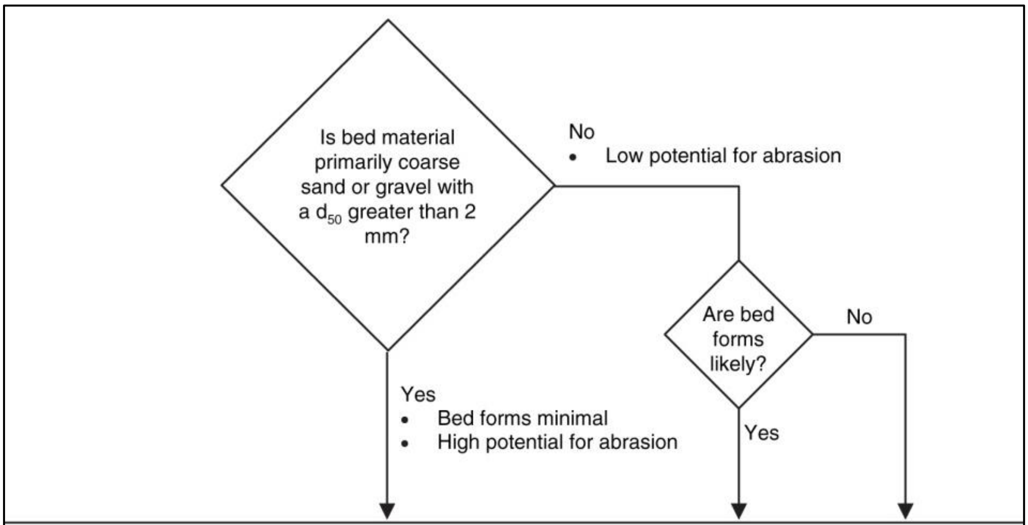
LCC: Life – Cycle Costs

The countermeasure with the highest value of SI should be selected as the most suitable. In Equation (3.7), LCC describes the installation and maintenance costs and this criterion is not taken into consideration by the method of Johnson and Niezgoda (2004).

3.2.2 Factors of the Selection Index (SI)

3.2.2.1 Bed Material

If the bed material is greater than 2 mm in size, transported sediment causes abrasion of the wire mesh. This abrasion weakens the wire mesh and may even cause it to break. Therefore, gabion mattresses are eliminated under such conditions. Similarly, grout filled mattresses are more sensitive at dune type bed form because of progressive propagation of these bed forms, which may alter the bed stability in adverse manner. They are likely to fail under dune type bed form since grout filled mattresses do not articulate as well as other countermeasures. On the other hand, if the bed material size is smaller than 2 mm and bed forms are not likely, whole countermeasure types are treated as equal (Lagasse et al., 2007). The grading system according to the bed material is shown in Figure 3.15.

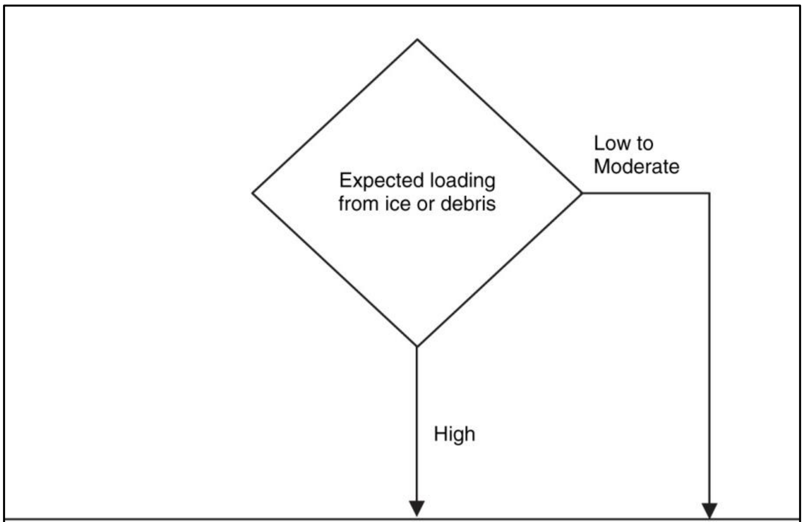


Recommended values for S1			
Riprap	5	5	5
Partially Grouted Riprap	5	4	5
Articulating Concrete Blocks	4	4	5
Grout-Filled Bags	3	3	5
Grout-Filled Mattresses	3	3	5
Gabions, Gabion Mattresses	0	4	5

Figure 3.15 Grading of Bed Material for Selection Index (Lagasse et al., 2007)

3.2.2.2 Ice and Debris Loading

Ice and debris load is accepted as the transported materials, such as wood, logs or man-made materials. Ice and debris loading are generally harmful for the gabion mattresses. When debris loading is high, gabion mattresses are the most affected countermeasure and get the minimum grades. If debris loading is not effective, all countermeasure types are treated as equal. The point scoring system according to the ice and debris loading is given in Figure 3.16.



Recommended values for S2	High	Low to Moderate
Riprap	3	5
Partially Grouted Riprap	4	5
Articulating Concrete Blocks	4	5
Grout-Filled Bags	3	5
Grout-Filled Mattresses	4	5
Gabions, Gabion Mattresses	1	5

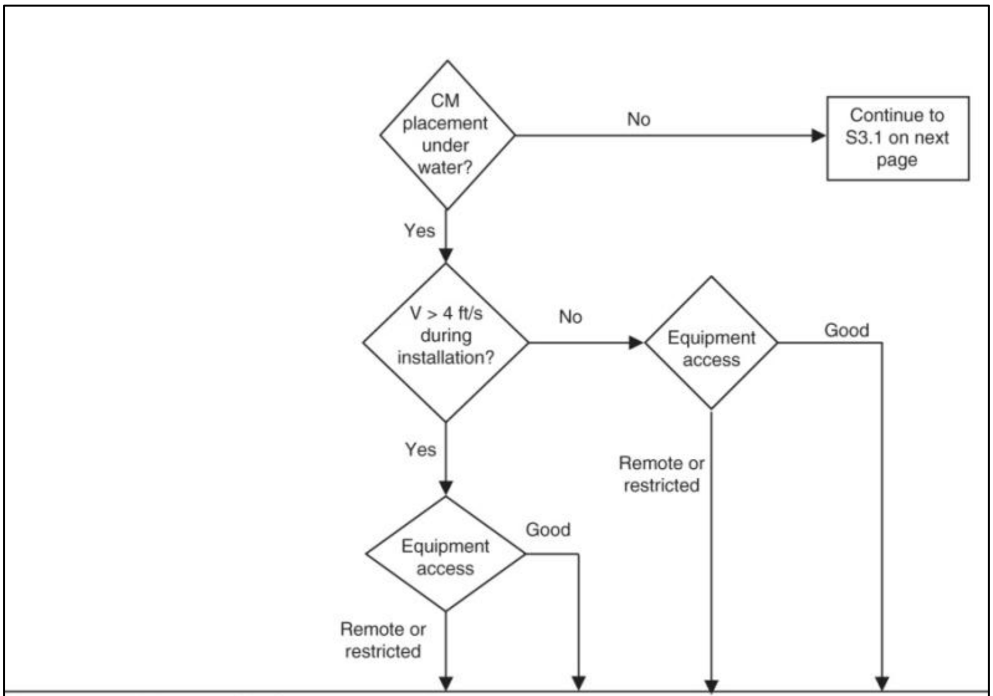
Figure 3.16 Grading of Ice and Debris Loading (Lagasse et al., 2007)

3.2.2.3 Construction Constraints

Another factor in calculating the selection index is the construction constraints. In this part, the footing depth affects the grading. Note that shallow footings and deep footings are evaluated separately.

Other important factors for ratings are equipment, equipment access, and working conditions. For instance; countermeasure placement under water could affect all rating values. Flow velocity also becomes an important factor when the countermeasure system is placed underwater. If flow velocity is greater than approximately 1.3 m/s, some countermeasure systems, such as ACBs, gabion mattresses or grout mattresses are affected negatively (Lagasse et al., 2007).

Figures 3.17 and 3.18 show the grading of construction considerations according to the footing type and place of installation.

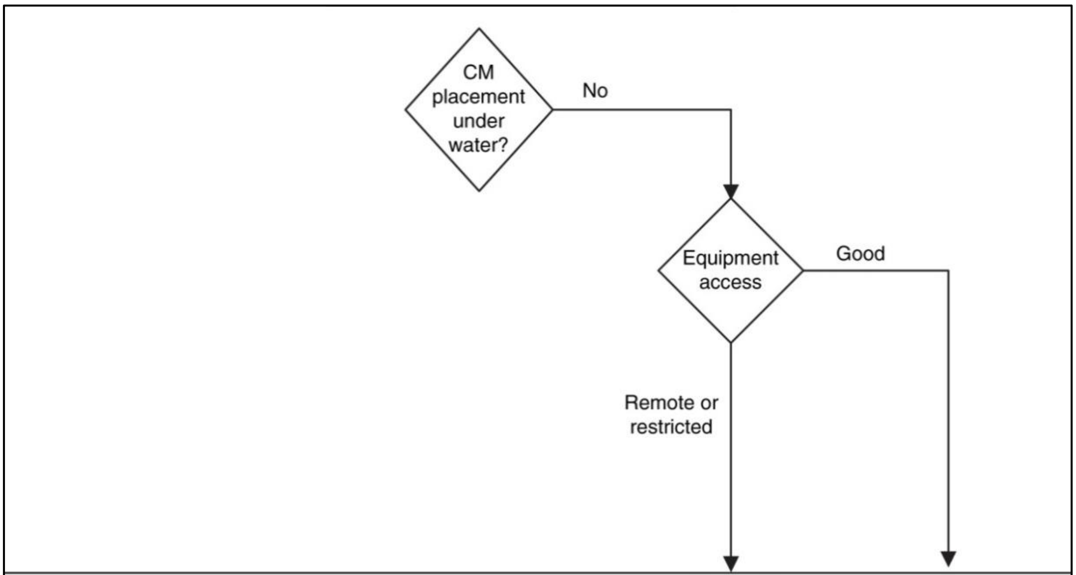


Recommended values for S3	SF*	DF	SF	DF	SF	DF	SF	DF
Riprap	0	2	1	5	1	3	2	5
Partially Grouted Riprap	0	0	0	0	2	4	0	5
Articulating Concrete Blocks	0	0	1	1	2	2	0	4
Grout-Filled Bags	0	1	1	2	1	3	1	5
Grout-Filled Mattresses	0	0	0	0	3	3	0	4
Gabions, Gabion Mattresses	0	0	0	1	1	1	0	3

*Note: Armoring countermeasures not recommended for these conditions.

SF = Shallow Pier, e.g. Spread Footing DF = Deep Footing

Figure 3.17 Grading of Construction Considerations for Underwater Placement (Lagasse et al., 2007)



Recommended values for S3	SF	DF	SF	DF
Riprap	1	3	1	5
Partially Grouted Riprap	2	4	2	5
Articulating Concrete Blocks	2	3	5	5
Grout-Filled Bags	1	4	1	5
Grout-Filled Mattresses	3	4	5	5
Gabions, Gabion Mattresses	1	3	2	5

SF= Shallow Pier, e.g. Spread Footing DF= Deep Footing

Figure 3.18 Grading of Construction Considerations for No Underwater Placement (Lagasse et al., 2007)

3.2.2.4 Inspection and Maintenance

Grading of inspection and maintenance changes with respect to the conditions under which inspection is performed. If the inspection is performed under water, manufactured countermeasure types, such as gabion mattresses, ACBs, and grout mattresses get low grades because of the difficulty in repairing or replacing them. On the other hand, riprap and partially grouted riprap could be repaired and replaced easier than the other countermeasure types. Grading methods of inspection and maintenance are depicted in Figure 3.19.

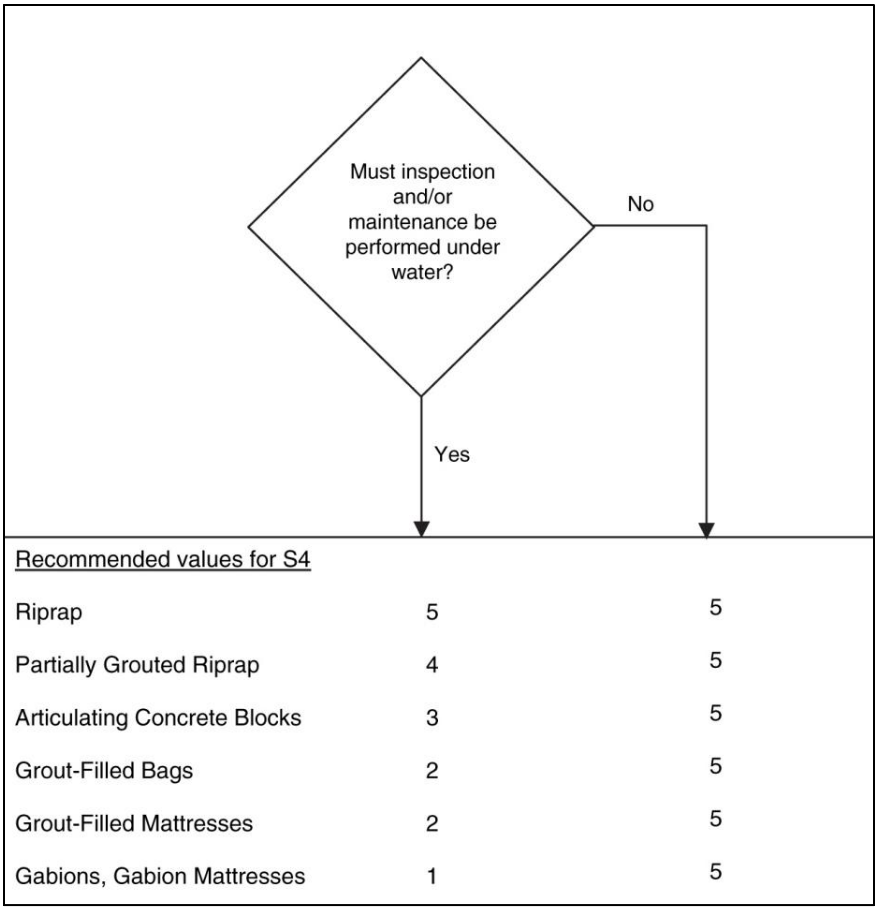


Figure 3.19 Grading of Inspection and Maintenance for Selection Index (Lagasse et al., 2007)

3.2.2.5 Life – Cycle Costs

Life – Cycle costs are the most difficult factor to determine among the aforementioned factors. To calculate life – cycle costs, three major factors should be taken into consideration (Lagasse et al., 2007):

- Delivery costs of initial construction materials.
- Costs of labor and equipment in construction installation.
- Periodic maintenance costs during the installation life.

Above components should be calculated for all countermeasure types separately. Note that they also depend on regional factors and specific project conditions, such as material availability, transportation distance, equipment and labor requirements and rates, habitat situation and endangered species, maintenance frequency, and control of the traffic during the maintenance periods (Lagasse et al., 2007).

To quantify these parameters, engineering judgment and experience are needed. Because of this reason, life – cycle costs can be treated as engineer and site-specific.

CHAPTER IV

CASE STUDY

4.1 Overview of the Case Study

Yanmaz and Arı (2008) conducted a case study for determining riprap size to be placed around infrastructural elements of a number of viaducts in a certain reach of Ankara – Pozantı Highway. That study was performed upon completion of the construction. Therefore, rapid implementation of protective measures was of importance. Regarding ease of application and short duration of implementation, riprap was recommended in that study. In line with the thesis objective, a more comprehensive analysis is conducted for the same study considering possible applications of other types of armoring scour countermeasures and flow reduction capability of the basin upstream of the project area. Following detailed hydraulic analyses, scour potential at piers and abutments of sequential viaducts were re-determined and various types of scour countermeasure were examined in view of the applicability and the feasibility.

Fourteen viaducts crossing Kırkgeçit Creek between 338+355.00 km and 349+660.94 km of Ankara – Pozantı Highway in Kemerhisar – Eminlik – Çiftehan region are inspected. First, the hydrologic characteristics of the study area were investigated to obtain peak flows corresponding to various return periods. Water surface profile computations were then conducted using HEC – RAS program (USACE, 2010). Depths of scour at individual piers and abutments of the viaducts were computed. The effect of channel deepening on the increase of flow carrying ability and hence reduction of scour potential were also investigated using this program. Various armoring type scour countermeasures, which may be adapted to the current Turkish practice, were analyzed in view of practical applicability and economic feasibility. Finally, by comparing the selection indexes of each type, the most suitable type of countermeasure is selected.

4.2 Description of the Project Site

Ankara – Pozantı highway starts from the Central Anatolia Region and reaches up to the Mediterranean Region by crossing over the peak points of Taurus Mountain range which is scattered throughout the entire region. The elevation of the route varies between the range of 770 m and 1450 m. A view of this highway is shown in Figure 4.1.

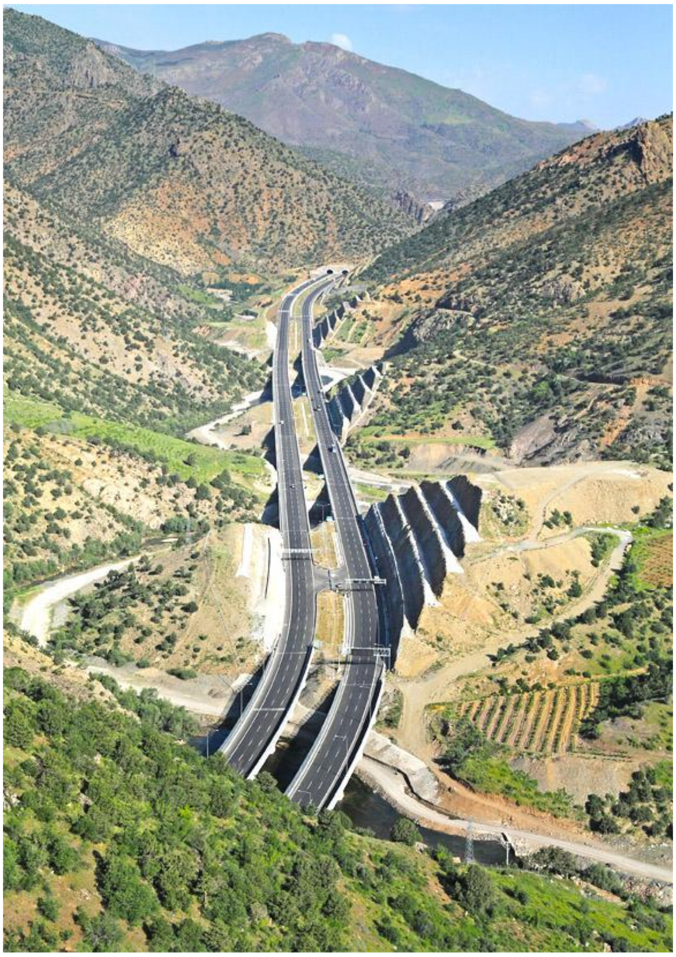


Figure 4. 1 A View of Project Site (www.limak.com.tr)

Total of 14 viaducts over Kırkgeçit Creek are located in the Mediterranean Region (Fig 4.2) and the project site crosses the Taurus Mountains. Gölcük – Niğde –

Kemerhisar Plain, which is the starting point of 14 viaducts, is composed of volcanic ashes of the Mount Melendiz and the plain elevation varies from 1100 m to 1400 m and generally continental climate prevails in the region (Yanmaz and Arı, 2008). Therefore, the meteorological station of Niğde is taken into account while describing the meteorological properties of Niğde – Kemerhisar region.

4.3 Hydrological Evaluations

This case study is conducted on Kırkgeçit Creek Basin which spans over 539 km^2 of land area. There are no stream gaging stations inside the basin. The nearest stream gaging station is located at 50 km downstream of the project site on Çakıtsuyu Creek. The peak discharge at this station has been seen observed in October 5, 1991 as 555 m^3/s. The maximum discharges at the basin outlet are considered for all hydraulic analyses to be on the conservative side.

Hydrological studies are conducted using a 1/25000 scaled map from which various geomorphologic characteristics are determined, such as the length of main stream (56.6 km). The harmonic slope of the study reach is computed as 0.0138 (Yanmaz and Arı, 2008).

Figure 4.2 A Satellite Image of Project Site and 14 Bridges (Google Earth, 2011)

To perform hydrometeorological calculations of Kırkgeçit Creek, the data of Niğde, Ulukışla, Pozantı, and Çamardı meteorological stations are examined. It is concluded that Niğde Meteorological Station can be used as representative meteorological station for the southern part of Central Anatolian Region. In addition, it is concluded that Ulukışla Meteorological Station is found to be representative meteorological station for the southernmost corner of the Central Anatolian Region. Furthermore, Pozantı Meteorogical Station reflects the meteorological characteristics of more southern part of the project. The locations of the meteorological stations can be seen in Figure 4.3. The maximum annual rainfall (P_m) and snow depths (S_m) per stations are given at Table 4.1.

Figure 4.3 Meteorological Stations and Project Site (Google Earth, 2011)

Table 4.1 Rainfall (Pm) and Snow Depths (Sm) at the Projects Site (Yanmaz and Arı, 2008)

Name of the Station	P_m (mm)	S_m (mm)
Niğde	54.5	34
Ulukışla	70.2	55
Pozantı	160.1	38

As it can be seen in Figure 4.4, discharge on the Kırkgeçit Basin is brought by two subbasins namely Toraman and Postallı near the project site. An important contribution is come by Toraman and Postallı Creeks to Kırkgeçit Basin.

According to Cevrem (1998), the flowrate at the outlet of Toraman Creek is 99.58 m^3/s and the area of the Toraman Basin is 132 km^2. Moreover Postallı Creek is joined with Toraman Creek to have a discharge of 156.63 m^3/s in an area of 341 km^2. By those contributions, discharge of 56.6 km length Kırkgeçit Creek is measured at the outlet of the basin as 296.37 m^3/s. All these discharges are computed for 100-year return period.

Cevrem (1998) obtained synthetic unit hydrographs of the sub-basins using rational method for small areas having sizes less than 10 km^2 and DSİ synthetic unit hydrograph techniques for the subbasins having greater areas than this limit. Runoff coefficient was taken as 0.7 for Gölcük – Kemerhisar – Eminlik Region which has non – agricultural and bare lands, whereas it was taken as 0.6 for Eminlik – Pozantı Region which has vegetative permeable soil layer and woodland and partially rocky region.

Since the last viaduct, i.e. Kırkgeçit 14 viaduct is too close to Kırkgeçit Creek Basin outlet, the flowrate at this point can be used as a conservative representative input for calculations of design process. Peak discharges corresponding to various return periods ranging between 2 and 100 years (Q_2 to Q_{100}) are determined using the synthetic unit hydrograph procedure of the Turkish State Hydraulic Works. The relation between those peak discharges (Q) and return periods (T_r) is shown in Figure 4.5. This relation is verified to follow a lognormal probability distribution. Details of synthetic unit hydrograph computations are treated as intermediary steps in the overall design procedure. That is why such information is not presented in the thesis.

Locations and dimensions of viaducts at the project site is given in Table 4.2. In this table abutment to pier and pier to pier distances are represented by Ψ and Ω, respectively. The start and end kilometers, latitude and longitudes, and number of piers are also given in this table. Moreover, to visualize the subject, photos of 14 viaducts are presented in Figures 4.6 through 4.20.

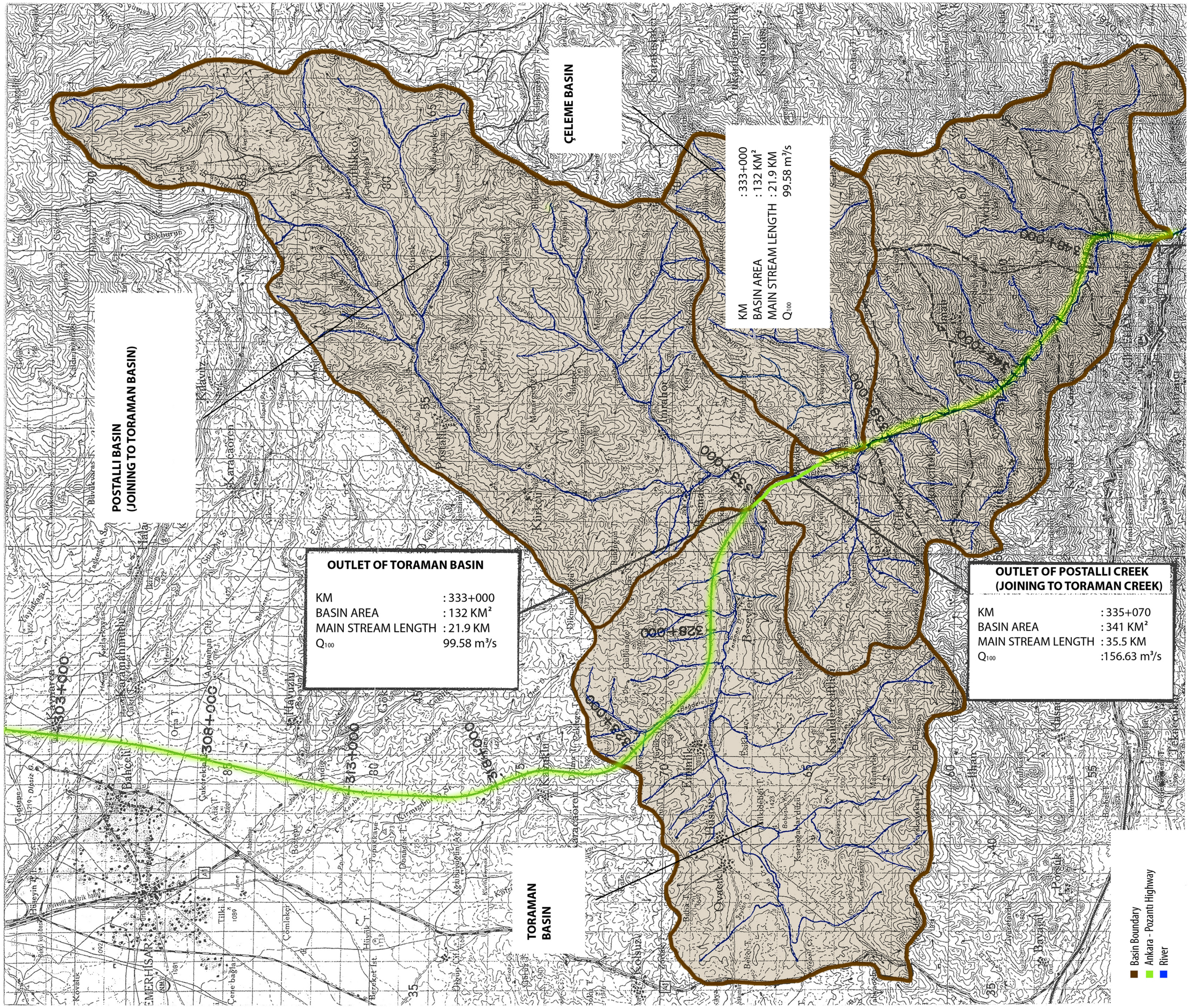


Figure 4.4 - Map of Kırkgeçit Basin (Not to Scale)

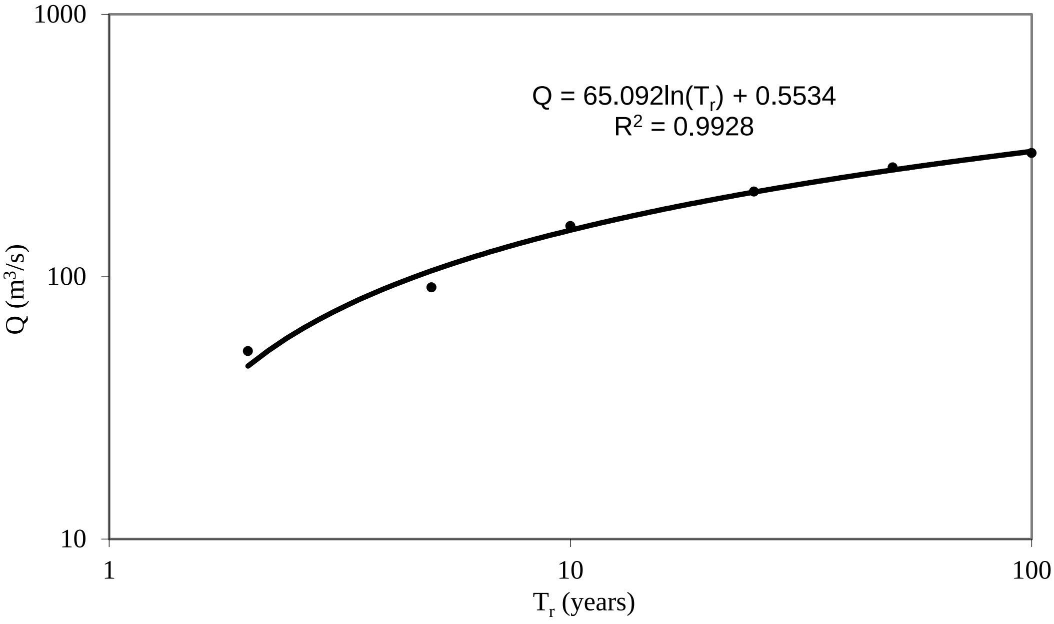


Figure 4.5 Relationship between discharge and return period

Figure 4.6 Çeleme Viaduct

Table 4.2 Location and Dimensions of Viaducts

Bridge		Start (km)	End (km)	Length (m)	Latitude	Longitude	# Piers	Ψ (m)	Ω (m)
Çeleme	Left	338+335.00	338+632.50	297.50	N 37.6033	E 34.7414	7	36.25	37.50
	Right	338+335.00	338+632.50	297.50			7	36.25	37.50
Kırkgeçit-1	Left	340+660.19	340+882.56	222.37	N 37.5851	E 34.7491	5	36.25	37.50
	Right	340+629.29	340+851.80	222.51			5	36.25	37.50
Kırkgeçit-2	Left	342+525.80	342+823.30	297.50	N 37.5672	E 34.7552	7	36.25	37.50
	Right	342.555.78	342+853.28	297.50			7	36.25	37.50
Kırkgeçit-3	Left	343+766.30	343+876.30	110.00	N 37.5594	E 34.7616	2	36.25	37.50
	Right	343+754.30	343+864.30	110.00			2	36.25	37.50
Kırkgeçit-4	Left	344+161.75	344+384.25	222.50	N 37.5559	E 34.7677	5	36.25	37.50
	Right	344+175.90	344+473.40	297.50			7	36.25	37.50
Kırkgeçit-5	Left	344+621.30	344+806.30	185.00	N 37.5548	E 34.7708	4	36.25	37.50
	Right	344+588.30	344+810.80	222.50			5	36.25	37.50
Kırkgeçit-6	Left	344+849.30	344+959.30	110.00	N 37.5544	E 34.7718	2	36.25	37.50
	Right	344+839.30	344+949.30	110.00			2	36.25	37.50
Kırkgeçit-7	Left	345+026.93	345+136.93	110.00	N 37.5532	E 34.7742	2	36.25	37.50
	Right	345+038.30	345+185.80	147.50			3	36.25	37.50
Kırkgeçit-8	Right	345+909.30	346+131.80	222.50	N 37.5492	E 34.7819	5	36.25	37.50
Kırkgeçit-9	Left	346+238.30	346+423.30	185.00	N 37.5455	E 34.7849	4	36.25	37.50
	Right	346+238.30	346+423.30	185.00			4	36.25	37.50
Kırkgeçit-10	Left	347+110.30	347+220.29	109.99	N 37.5409	E 34.7900	2	36.25	37.50
	Right	347+102.30	347+249.80	147.50			3	36.25	37.50
Kırkgeçit-11	Left	348+271.30	348+643.80	372.50	N 37.5339	E 34.8036	9	36.25	37.50
	Right	348+271.30	348+681.30	410.00			3+5	36.25	37.50
Kırkgeçit-12	Left	348+923.30	349+070.80	147.50	N 37.5321	E 34.8080	3	36.25	37.50
	Right	348+885.80	349+033.30	147.50			3	36.25	37.50
Kırkgeçit-13	Left	349+089.30	349+199.30	110.00	N 37.5308	E 34.8097	2	36.25	37.50
	Right	349+086.30	349+233.80	147.50			3	36.25	37.50
Kırkgeçit-14	Left	349+520.36	349+667.86	147.50	N 37.5286	E 34.8143	3	36.25	37.50
	Right	349+475.94	349+660.94	185.00			4	36.25	37.50

Figure 4.7 Kırkgeçit 1 Viaduct

Figure 4.8 Kırkgeçit 2 Viaduct

Figure 4.9 Kırkgeçit 3 Viaduct

Figure 4.10 Kırkgeçit 4 Viaduct

Figure 4.11 Kırkgeçit 5 Viaduct

Figure 4.12 Kırkgeçit 6 Viaduct

Figure 4.13 Pier of Kırkgeçit 7 Viaduct and Historical Bridge

Figure 4.14 Kırkgeçit 8 Viaduct

Figure 4.15 Kırkgeçit 9 Viaduct

Figure 4.16 Kırkgeçit 10 Viaduct

Figure 4.17 Kırkgeçit 11 Viaduct

Figure 4.18 Kırkgeçit 12 Viaduct

Figure 4.19 Kırkgeçit 13 Viaduct

Figure 4.20 Kırkgeçit 14 Viaduct

4.4 Investigation of Flood Volume Reduction Possibility

The project area includes 14 viaducts, over which high-intensity traffic pass. That is why foundation strengthening for these viaducts is of utmost importance. As a preliminary approach, the possibility of flow reduction in the main channel is considered.

Flow reduction can be provided by flood detention dam. Construction of flood detention dam would attenuate the flood volume and may reduce the flood risk significantly. Thus, viaducts on Kırkgeçit Creek Basin can be protected. However, viaducts at the project site occupy a total of 37 km^2 area. Therefore, flood detention dam could not be constructed between viaducts; in other words, the flood detention dam should be built at a proper upstream location of the project site.

Other limiting factors are related to regional, design or economic conditions. Especially those problems that make the flood detention dam construction impossible includes but not limited to the following:

- A possible detention dam, e.g. an earth-fill dam can be constructed near Çeleme Bridge since far north region consists of residential areas, villages, and farms. Based on surveys in Google Earth medium (Google Earth, 2011), the crest length and height from foundation of a nearby dam upstream of Çeleme Viaduct are found to be 205 m and 14 m, respectively. The approximate cost of such a detention dam can be computed using the following equations in terms of 1987 U.S.$ proposed by Akbaş (1987).

- Cost of embankment (C_e) = 17270exp(0.13h_c) = \$ 106558

  Cost of spillway (C_s) = 3700L – 16700 = \$ 168300

Where h_c is dam height and L is spillway crest length, which is taken as 50 m. The total cost is obtained as (C_T) = \$ 274888. Considering the inflation rate, the total cost in 2011 conditions is found as \$ 544305. Excavation for foundation is computed approximately 25687 m^3.

Cost of excavation (C_{ex}) = 8.96 x 25687 = \$ 230156

Overall total cost = 544305 + 230156 = $ 774461. Considering 20% of this amount as possible undefined costs, the total project cost is obtained as $ 929353. Figure 4.21 depicts the location of a possible detention dam.

According to the planned location of the dam, the reservoir volume of the flood detention dam (V_s) is obtained from $V_s = 332.29h^2 + 8517.8h$, where h is the elevation measured from the reservoir bottom. The value of V_s is obtained as 150,000 m^3. The volume of runoff for the design flood hydrograph (V_r) is found as 9,905,000 m^3 (Yanmaz and Arı, 2008). Using the ratio V_s/V_r, the corresponding attenuation ratio, $\alpha = Q_p/I_p$, (Q_p and I_p are peak discharges of inflow and outflow, respectively) can be obtained approximately as 0.93 (Yanmaz, 2006). The effect of attenuation ratio on the dam height and the riprap cost are presented below in Table 4.3.

Table 4.3 The Effect of Attenuation Ratio on the Dam Height and Riprap Cost

α	Q_p (m^3/s)	h_c (m)	Number of Piers influenced	d_s (m)	Max Local Velocity (m/s)	D_{r50} (m)	Cost of Riprap ($)
100%	296.37	-	3	1.97	2.98	0.55	59680
93%	275.62	12	3	1.94	2.92	0.53	57540
90%	266.73	30	2	1.93	2.90	0.52	37648 X
80%	237.10	48	2	1.89	2.81	0.49	35508 X
70%	207.46	64	2	1.85	2.70	0.45	32656 X
60%	177.82	79	2	1.79	2.57	0.41	29804 X

It is observed that for attenuation ratio smaller than 90%, the cost of the dam would be very high. Moreover, increase in water levels due to dam can affect the Gedelözü Bridge, which is 4 km upstream of the Çeleme Viaduct. Therefore, the option of flood volume reduction possibility is ignored.

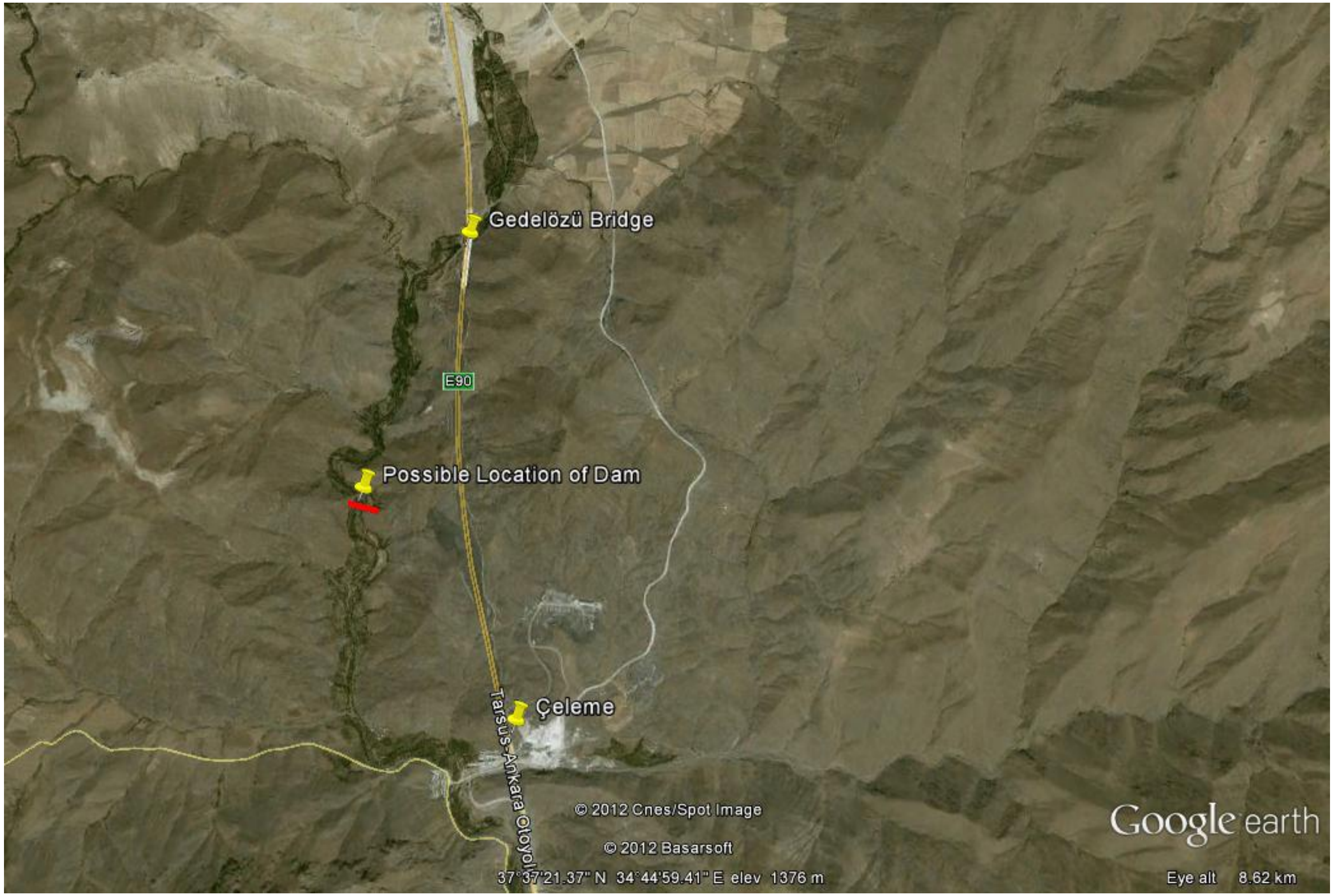


Figure 4.21 Location of the Possible Detention Dam (Google Earth, 2011)

4.5 Determination of Water Surface Profiles

Water surface profiles are determined through HEC – RAS Version 4.1 program (USACE, 2010). Required input data, such as details of the highway and bridges, route of the creek or topographic data, bed material characteristics at viaduct sites and Manning’s roughness coefficient values are extracted from Yanmaz and Arı (2008). The sinuosity of the study reach, which is the ratio of the total length to the bird eye distance, is 1.74. This value represents a meandering river. To apply HEC-RAS program, which performs one dimensional hydraulic computations, the total study reach length is approximately divided into 800 cross-sections. Therefore, the standard step method application by HEC-RAS is conducted by almost one dimensional approach since the river is almost straight in plan between two successive sections, which are apart from each other by 15 - 20 m. The layout of these cross-sections is shown in Appendix A.

To identify the bed material properties, samples were taken from the project area in frequent intervals (See Figure 4.22) to analyze the scouring potential and bed resistance (Yanmaz and Arı, 2008). Those samples show that bed materials are medium to coarse gravels. Therefore, standard deviation of particle size distribution σ_g, which is shown below, is high.

$$\sigma_g = \sqrt{\frac{D_{84}}{D_{16}}} \qquad (4.1)$$

Table 4.4 outlines characteristic information on particle size distributions for the 40 sections. As it can be seen in the table, well graded bed material generates an armoring effect at the river bed, and decreases the scour potential.

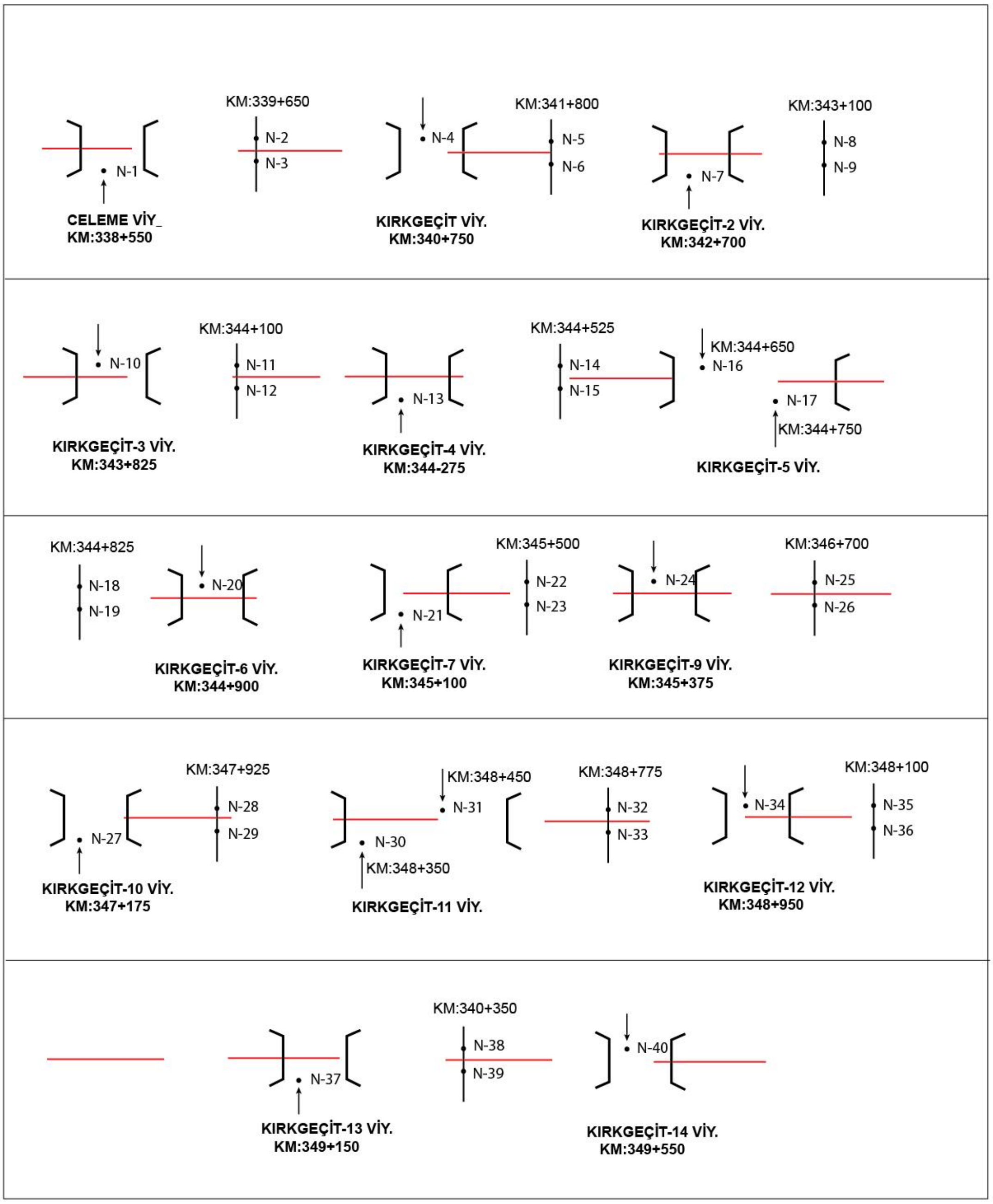


Figure 4.22 Sections of Bed Material Samples

Table 4.4 Properties of the Bed Materials at Sections

Parameter	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
D_{50} (mm)	9	9.5	4.8	12	6.2	4	9	9.5	9.5	6
D_{84} (mm)	24	22	15	26	17	12	23	24	26	20
D_{16} (mm)	0.42	1	0.65	0.14	0.9	0.9	2.5	1.8	0.8	0.9
σ_g	7.6	4.7	4.8	13.6	4.3	3.7	3.0	3.7	5.7	4.7

Parameter	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20
D_{50} (mm)	0.65	8	1.5	3.8	1.8	12	2.5	2.8	0.8	5
D_{84} (mm)	5	21	18	10	10	28	14	11	10	20
D_{16} (mm)	0.12	0.85	0.18	0.8	0.18	2.5	0.1	0.12	0.05	0.55
σ_g	6.5	5.0	10.0	3.5	7.5	3.3	11.8	9.6	14.1	6.0

Parameter	N21	N22	N23	N24	N26	N27	N28	N29	N30	N31
D_{50} (mm)	11	2.6	2.3	5.5	1.3	3.5	7	5.8	5	6
D_{84} (mm)	24	11	7	18	14	16	21	16	20	21
D_{16}(mm)	0.5	0.63	0.7	0.075	0.17	0.05	0.28	0.75	0.9	0.95
σ_g	6.9	4.2	3.2	15.5	9.1	17.9	7	4.6	4.7	4.7

Parameter	N32	N33	N34	N35	N36	N37	N38	N39	N40
D_{50} (mm)	4	8	5.5	1.8	6	9	0.62	1.4	4
D_{84} (mm)	16	18	18	18	25	24	10	20	16
D_{16}(mm)	0.7	0.5	0.2	0.22	0.6	0.65	0.1	0.01	0.3
σ_g	4.8	6.0	9.5	9.0	6.5	6.1	10.0	44.7	7.3

4.5.1 Determination of Manning's Roughness Coefficient

Manning’s roughness coefficient needs to be determined, which characterizes the stream bed resistance to flow. HEC – RAS software requires this input prior to the execution of the program.

Selection of the Manning roughness coefficient should be carried out diligently as it depends on several factors; such as bed material, channel geometry, project site properties, seasonal changes, bed scour and changes in discharge, etc. Definition of the coefficient is stated by Chow (1959) and the required parameters are given in Table 4.5 and Table 4.6 (Lagasse et al., 2001). It is computed from

$$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m \quad (4.2)$$

in which;

n_b: Roughness coefficient due to bed material.

n_1: Roughness coefficient due to cross-sectional variance.

n_2: Roughness coefficient due to channel geometry.

n_3: Roughness coefficient according to undulations at river bed.

n_4: Roughness coefficient due to vegetation.

m: Coefficient due to sinuosity.

Based on the assignment of appropriate values to the variables in Equation (4.2) according to site sections (See Table 4.7) the average roughness coefficient is taken as 0.045 for the main channel. Considering the sections, having floodplains, an average n-value is taken as 0.052 for the floodplains (See Figure 4.23).

Table 4.5 Manning's n_b Coefficient (Lagasse et al., 2001)

Type of the channel	D_{50} (mm)	n_b
River bed composed of sand	0.2	0.012
	0.3	0.017
	0.4	0.020
	0.5	0.022
	0.6	0.023
	0.8	0.025
	1.0	0.026
Immovable bed channel		
Concrete	-	0.012-0.018
Rock Cuts	-	0.025
Hard Soil (Earth)	-	0.025-0.032
Coarse Sand	1-2	0.026-0.035
Fine Gravel	-	0.024
Gravel	2-64	0.028-0.035
Coarse Gravel	-	0.026
Coarse (Dimension) Stone	64-256	0.030-0.050
Rock	>256	0.040-0.070

Table 4.6 Correction Factors for Manning Roughness Coefficient
(Lagasse et al, 2001)

n_i	Validity Conditions	Value	Notes
n_1	Smooth	0	Smooth Channel
	Minor	0.001-0.005	Excavated channel in good condition
	Moderate	0.006-0.010	Channels with considerable bed roughness and some bank erosion.
	Severe	0.011-0.020	Natural Channels: pools and riffles, exposed tree roots, boulders and/or irregular banks
n_2	Uniform	0	Near – uniform channel sections.
	Gradual	0.001-0.005	Large and small cross sections alternate occasionally.
	Severe	0.010-0.015	Large and small cross sections alternate frequently.
n_3	Negligible	0-0.004	A few scattered obstructions that occupy less than 5% of the channel.
	Minor	0.005-0.015	Obstructions occupy 5–15% of the channel and the obstructions are generally isolated
	Appreciable	0.020-0.030	Obstructions occupy 15–50% of the channel
	Severe	0.040-0.060	Obstructions occupy more than 50% of the channel
n_4	Small	0.002-0.01	y>2*height of vegetation
	Medium	0.01-0.025	y> height of vegetation
	Large	0.025-0.050	y< height of vegetation
	Very Large	0.050-0.100	y<0.5* height of vegetation
m	Minor	1.0	S<1.2
	Appreciable	1.15	1.2≤S≤1.5
	Severe	1.30	S>1.5

Table 4.7 Correction Factors of Manning Roughness Coefficient by Sections

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
n_b	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
n_1	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
n_2	0	0	0	0	0	0	0.005	0	0	0
n_3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
n_4	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
m	1	1.15	1.15	1	1	1	1	1	1	1
n	0.040	0.046	0.046	0.040	0.040	0.040	0.045	0.040	0.040	0.040

	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20
n_b	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
n_1	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
n_2	0.005	0.005	0.002	0	0	0	0	0.002	0.002	0.005
n_3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
n_4	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
m	1.3	1.3	1	1	1	1.3	1.3	1	1	1
n	0.059	0.059	0.042	0.040	0.040	0.052	0.052	0.042	0.042	0.045

Table 4.7 (Contd.)

	N21	N22	N23	N24	N25	N26	N27	N28	N29	N30
n_b	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
n_1	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
n_2	0.002	0.002	0.002	0.005	0.005	0.005	0.002	0.01	0.01	0
n_3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
n_4	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
m	1	1	1	1.15	1	1	1	1	1	1.3
n	0.042	0.042	0.042	0.052	0.045	0.045	0.042	0.050	0.050	0.052

	N31	N32	N33	N34	N35	N36	N37	N38	N39	N40
n_b	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
n_1	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
n_2	0	0	0	0.002	0	0	0.01	0.002	0.002	0
n_3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
n_4	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
m	1.3	1	1	1	1.15	1.15	1.15	1	1	1
n	0.052	0.040	0.040	0.042	0.046	0.046	0.058	0.042	0.042	0.040

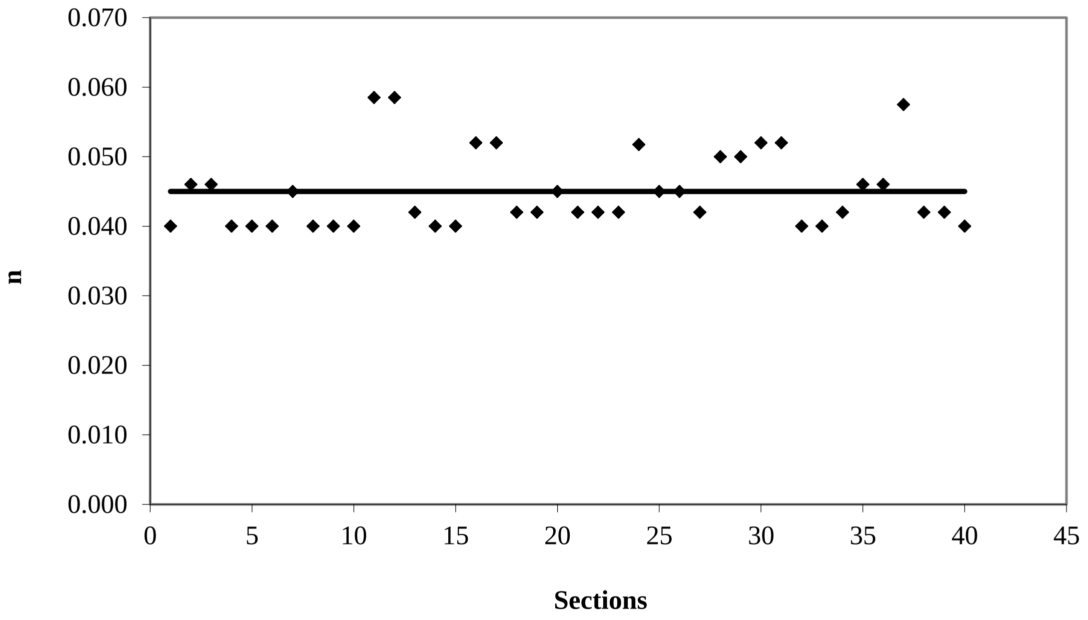


Figure 4.23 Distribution of Manning Roughness Coefficient by Sections

4.5.2 Increasing Flow Carrying Capacity by Dredging

Local velocities are leading to excessive scouring at original cross-sections at Ankara – Pozantı Highway. To protect viaduct piers, economically feasible applications need to be implemented. Increasing the flow carrying capacity is one of the options to provide a tolerable design and application.

Several analyses are carried on the original cross-sections of Ankara – Pozantı Highway and velocity distributions of the viaducts at the upstream part of piers are depicted for original cross-sections in figures in Appendix B. In parallel with those figures, visual presentation of velocity zones i.e. locations of maximum velocities with respect to pier locations, will enable the designer to make rapid comparison among the flow fields of viaducts. Darker zones of those presentations represent the high flow velocity at cross-sections. According to the results given in this appendix, excavations at Çeleme, Kırkgeçit 3, Kırkgeçit 5/1, Kırkgeçit 5/2, Kırkgeçit 10, and Kırkgeçit 11 viaducts lead to economical solution because of reduction in riprap cost. It is also seen that there is no scour at Kırkgeçit 4 left viaduct.

With the increase in flow area, it is intended to decrease the flow velocity throughout the cross-sections of high-velocity regions around the viaducts. Some of the basic implementations consider section dredging (excavation of the channel bed) and section widening. However, section widening is not implemented in this study to limit the water surface width, such that neighboring agricultural areas are not influenced. Various excavation trials are performed as shown in Figure 4.24 in which A_0 is the original cross-section area, Δ_1, Δ_2, and Δ_3 are the excavation depths. Results of the excavation analysis are also presented in Table 4.8.

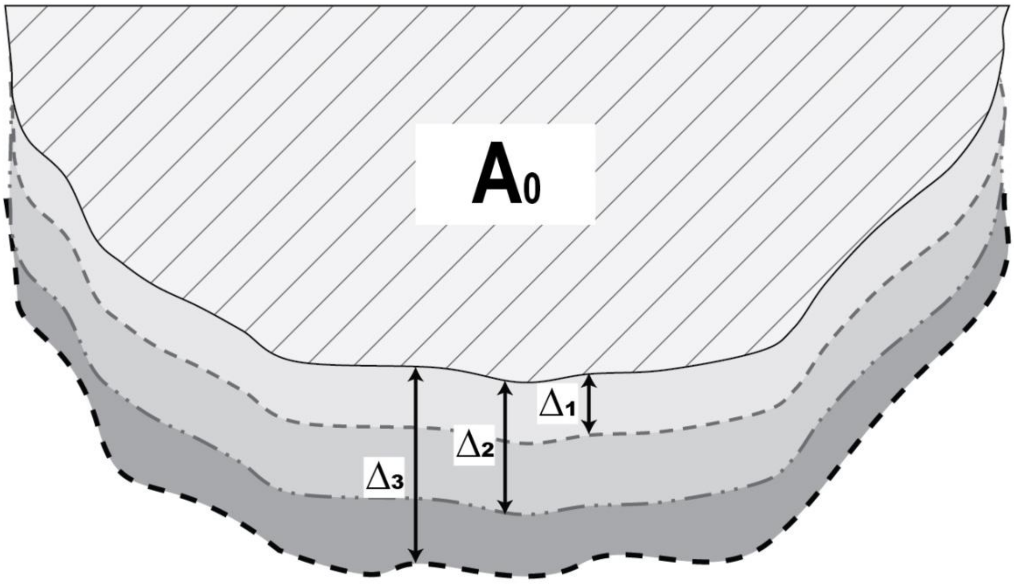


Figure 4.24 Definition Sketch of Excavation (Not to Scale)

In Table 4.8, A_0, $A_{\Delta 1}$, $A_{\Delta 2}$ and $A_{\Delta 3}$ parameters show the original area and the excavation areas by amounts of Δ_1, Δ_2, Δ_3, respectively. In parallel with the areas V_0, $V_{\Delta 1}$, $V_{\Delta 2}$ and $V_{\Delta 3}$ parameters are representing the local maximum velocities. In addition to those parameters, A_{pi} and V_{pd} are symbolized the percentage of increase at the area, and the percentage of decrease at the velocity. As it is seen in the table, main aim of the excavation is to decrease the local velocities by increasing the flow area. However, for Çeleme Left and KG 11/1 Left viaducts, excavations are sometimes caused increase in velocity. This is mainly because of the fact that the rate of increase of flow area is greater than that of the wetted perimeter. The relationship between excavation depths and percentage of velocity for some viaducts are given in Figure 4.25.

Table 4.8 Excavation Trials and Corresponding Parameters

	Original Sections		**Excavation Trial 1 (Δ_1)**					**Excavation Trial 2 (Δ_2)**					**Excavation Trial 3 (Δ_3)**				
NAME	**A_0 (m^2)**	**V_0 (m/s)**	**$\Delta 1$ (m)**	**$A_{\Delta 1}$ (m^2)**	**$V_{\Delta 1}$ (m/s)**	**A_{pi}**	**V_{pd}**	**Δ_2 (m)**	**$A_{\Delta 2}$ (m^2)**	**$V_{\Delta 2}$ (m/s)**	**A_{pi}**	**V_{pd}**	**Δ_3 (m)**	**$A_{\Delta 3}$ (m^2)**	**$V_{\Delta 3}$ (m/s)**	**A_{pi}**	**V_{pd}**
Çeleme Left	6566	2.98	0.30	91.35	2.77	1.39	7.05	0.70	213.15	2.14	3.25	28.19	1.00	14.59	1.71	4.64	42.62
Çeleme Right	6765	2.75	0.50	150.75	6.29	2.23	-	1.00	301.50	2.10	4.46	23.64	1.50	12.57	1.60	6.69	41.82
KG 3 Right	769	2.77	0.50	53.48	2.76	6.95	0.36	1.00	106.97	2.39	13.90	13.72	1.50	7.61	1.86	20.85	32.85
KG 3 Left	737	2.64	0.50	53.86	2.15	7.31	18.56	1.00	107.72	1.83	14.62	30.68	1.50	16.09	1.57	21.94	40.53
KG 5/1 Right	832	2.26	0.10	10.50	2.26	1.26	0.00	0.20	21.01	1.64	2.53	27.43	0.50	13.97	1.53	6.32	32.30
KG 5/1 Left	700	3.28	0.30	27.57	3.20	3.94	2.44	0.50	45.96	1.53	6.56	53.35	0.70	27.03	1.49	9.19	54.57
KG 5/2 Right	837	3.41	0.30	31.49	3.18	3.76	6.74	0.50	52.48	2.92	6.27	14.37	0.70	7.53	2.69	8.78	21.11
KG 10 Left	1651	2.27	0.30	35.00	2.02	2.12	11.01	0.50	58.33	1.82	3.53	19.82	0.70	10.26	1.59	4.95	29.96
KG 10 Right	2691	3.40	0.30	46.37	3.08	1.72	9.41	0.50	77.28	2.86	2.87	15.88	0.70	8.29	2.66	4.02	21.76
KG 11/1 Left	804	3.21	0.50	78.87	6.75	9.82	-	1.00	157.74	2.58	19.63	19.63	1.50	10.56	2.03	29.45	36.76
TOTAL EXC. COST			**$ 127412**					**$ 250973**					**$ 372265**				

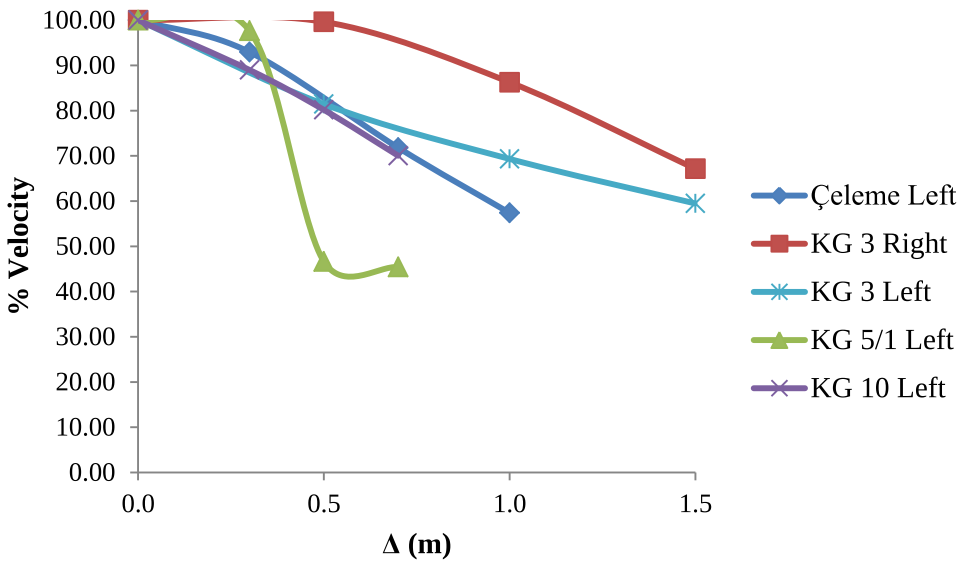


Figure 4. 25 Relationship between excavation depth and percentage of velocity for Some Viaducts

The ordinate of Figure 4.25 represents the percentage of the velocity with respect to no-excavation case. As can be seen in Figure 4.25, average flow velocity at the viaduct openings decreases with respect to excavation depth. It is therefore, clear that section dredging would also reduce the scour depth, and hence the riprap size to be selected.

After several runs, Δ_2 values are found to be economically feasible and selected as a final excavation depths (Δ) as stated in Table 4.9, in which L and R stand for left and right, respectively. As it is seen in Table 4.9, some viaduct foundations are not excavated. Since, it was analyzed that the excavation costs for these viaducts are greater than the profit which is gained by making the riprap smaller.

Table 4.9 Average Excavation at Each Cross Section

	Çeleme		KG1		KG2		KG3		KG4	
	L	R	L	R	L	R	L	R	L	R
Δ (m)	0.70	1.00	-	-	-	-	1.00	1.00	-	-

	KG 5/1		KG5/2		KG6		KG7		KG9	
	L	R	L	R	L	R	L	R	L	R
Δ (m)	0.50	0.20	-	0.50	-	-	-	-	-	-

	KG 10		KG11/1		KG11/2		KG12		KG13		KG14	
	L	R	L	R	L	R	L	R	L	R	L	R
Δ (m)	0.50	0.50	1.00	-	-	-	-	-	-	-	-	-

4.5.2.1 Geometric and Cost Calculation for Excavation

With reference to high velocity zones, excavation is applied to the following viaducts; Çeleme, KG3, KG5, KG10, and KG11. Regarding calculations are presented in Table 4.10. The computation methodology is as follows:

Firstly, coordinates of cross-sections are transferred to a drawing software and are drawn. The average cross-sectional excavation area, A_L, between the upstream and downstream ends, which comprise the river cross-sections needed to be introduced to HEC-RAS immediately before and after the viaduct, is computed for each viaduct by arithmetic averaging.

The sub-reach length, L_s, is computed as the distance between the upstream and downstream cross-sections. The total excavation volume, V_e, is then computed approximately by multiplying L_s by A_L. Cost of excavation, C_{ex}, is equal to unit cost of excavation which is 8.96 $/m^3, multiplied by total excavation volume. Finally, the transportation cost of excavation, C_{ext}, is added to the total excavation cost to obtain the total cost. The value of C_{ext} is computed from

$$C_{ext} (\$) = \text{Unit price } (\$/\text{ton}) \times V_e \times \gamma_r \quad (4.3)$$

where γ_r is unit weight of riprap, which can be taken as 2.65 ton/m^3. The unit price of excavation transport for 2 km is 1.06 $/ton. A sample calculation set for Çeleme-Left viaduct is presented below. The overall calculations due to the channel deepening are given in Table 4.10.

A_L (m^2) = (213.1563 + 213.1535) / 2 = 213.1549

L_s (m) = 17919.050 – 17900.530 = 18.520

V_e (m^3) = 213.1539 x 18.520 = 3947.63

C_{ex} ($) = 8.96 ($/m^3) x 3947.63 (m^3) = 35370.75

C_{ext} ($) = 1.06 ($/m^3) x 3947.63 (m^3) x 2.65 (ton/m^3) = 11088.89

Total Cost ($) = 46459.64

.

Table 4.10 Excavation Calculations of Rearrangement of Cross Sections

Viaduct	Upstream Station (m)	Downstream Station (m)	L_S (m)	A_L (m^2)	V_e (m^3)	C_{ex} (\$/m^3)	C_{ext} (\$/ton) (2 km)	TOTAL COST (\$)
Çeleme Left	17919.050	17900.530	18.520	213.1549	3,947.63	35,370.75	11,088.89	46,459.64
Çeleme Right	17899.020	17880.500	18.520	301.4968	5,583.72	50,030.14	15,684.67	65,714.81
KG 3 Right	9882.760	9861.640	21.120	106.9665	2,259.13	20,241.83	6,345.90	26,587.73
KG 3 Left	9846.545	9826.066	20.479	107.7230	2,206.06	19,766.29	6,196.82	25,963.11
KG 5/1 Right	7481.740	7464.075	17.665	21.0096	371.13	3,325.37	1,042.52	4,367.88
KG 5/1 Left	7440.614	7421.992	18.622	45.9558	855.79	7,667.86	2,403.91	10,071.77
KG 5/2 Right	7293.089	7277.211	15.878	52.4838	833.34	7,466.70	2,340.84	9,807.54
KG 10 Left	3521.491	3500.772	20.719	58.3275	1,208.49	10,828.05	3,394.64	14,222.69
KG 10 Right	3487.005	3466.844	20.161	77.2755	1,557.95	13,959.24	4,376.29	18,335.53
KG 11/1 Left	1928.324	1912.464	15.860	157.7350	2,501.68	22,415.03	7,027.21	29,442.24
				TOTAL COST (\$)		**191,071.25**	**59,901.69**	**250,972.95**

4.5.3 Scour Depth Calculations around Viaduct Piers

In this case study scour depths around viaduct piers are computed through HEC – RAS (USACE, 2010) software. Input parameters, such as geometric data, coefficients, discharges and positions of viaducts are introduced to the program. A return period of 100 years is selected for the design discharge (296.37 m^3/s) to compute scour depths at infrastructural elements of viaducts. Since the stream gaging station is downstream of the sequential viaducts in the project area, it is assumed that the actual return period for this discharge is greater than 100 years at the site of viaducts.

Steady flow analysis is conducted and program is run for mixed flow regime. All the computations are performed for the excavated cross-sections. Hydraulic calculations for water surface profile of this study for a discharge of 100 year return period are given in Appendix C.

HEC – RAS software can compute the scour depth around piers by using Froehlich's method or Colorado State University (CSU) method. In this study CSU method is used in determination of scour depths. Computation screen of bridge scour in HEC – RAS is given in Figure 4.26.

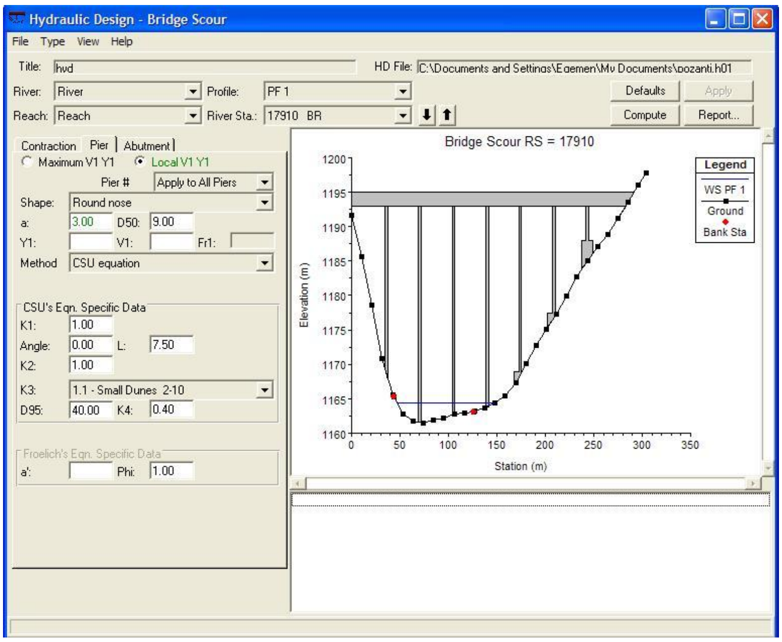


Figure 4.26 Setting of Bridge Scour at HEC - RAS Software

The parameters used in the above screen are defined below (USACE, 2010):

Local V1 Y1: This option gives the velocity (V1) and depth (Y1) at just upstream of the bridge pier.

Method: This menu is used for scour depth calculation methodology selection. The CSU or the Froehlich equations are the options of the menu. According to CSU equation, scour depth is obtained from the Equation (2.3)

Pier #: The data stated in this screen can be applied to all piers or one specific pier from pier dropdown menu. In addition to that, properties about each pier can be observed after the computation from this menu.

Shape: Shape dropdown menu determines the correction factor for pier nose, K_1.

a: This box is the width of the pier perpendicular to flow direction.

D_{50}: This field needs to be filled by bed material median size in mm.

Y1: It represents the flow depth just upstream of each pier. In this study, Y1 values are determined by the program.

V1: This field represents the average flow velocity just upstream of each pier. In this study V1 values are stated automatically as a result of the computation. Determination of the riprap sizes (Dr_{50}) is conducted by using maximum V1 value for each viaduct.

Angle (α): This box directly affects the scour potential of the pier. If the approaching flow angle is zero, this means that the flow direction is perpendicular to the pier nose. Moreover, the greater angle gives the greater scour depths.

L: It corresponds to the length of the pier through the bridge.

K_1: This constant is the correction factor for pier nose shape. Once the shape is selected, K_1 value is automatically appointed.

K_2: This constant is the correction factor for flow angle of attack. This value is determined automatically once the pier width, pier length and angle are specified.

$\underline{K_3}$: This constant is the bed condition correction factor. Determination of K_3 is given in Table 4.11. Determination of bed condition is shown in Table 4.12. According to this table, if the local maximum velocity is greater than the mean threshold velocity, u_c, it corresponds to a live bed condition. If it is smaller than u_c, the bed condition is termed as clear water. Equation (4.4) gives mean threshold velocity for gravels (Melville and Coleman, 2000).

$$\frac{u_c^2}{\Delta_r g D_{50}} = 2.0\left(\frac{D_{50}}{D}\right)^{-\frac{1}{3}} \tag{4.4}$$

where D is the hydraulic depth and Δ_r is the relative density (1.65).

Table 4.11 K3 values stated in Equation (2.3) (Richardson and Davis, 2001)

Bed Condition	K_3
Clear Water Scour	1.1
Plane Bed and Antidunes	1.1
Small Dunes	1.1
Medium Dunes	1.1-1.2
Large Dunes	1.3

$\underline{D_{95}}$: This field needs to be filled by bed material median diameter of which is 95% smaller. The unit of this field is in millimeters.

$\underline{K_4}$: This constant is the correction factor for armoring by D_{95} grain size.

All results about scouring around piers are given in Appendix D.

Table 4.12 Determination of the Bed Condition for Excavated Condition

	Çeleme	**KG1**	**KG2**	**KG3**	**KG4**	**KG5/1**	**KG5/2**	**KG6**	**KG7**	**KG9**	**KG10**	**KG11/1**	**KG11/2**	**KG12**	**KG13**	**KG14**
D_{50} (mm)	9	12	9	6	1.5	12	2.5	5	11	5.5	3.5	5	6	5.5	9	4
D_{84} (mm)	24	26	23	20	18	28	14	20	24	18	16	20	21	18	24	16
D_{16} (mm)	0.42	0.14	2.5	0.9	0.18	2.5	0.1	0.55	0.5	0.075	0.05	0.9	0.95	0.2	0.65	0.3
D_{95} (mm)	40	32	32	27	34	36	24	38	34	30	30	40	30	30	32	30
σ	7.6	13.6	3.0	4.7	10.0	3.3	11.8	6.0	6.9	15.5	17.9	4.7	4.7	9.5	6.1	7.3
D_{max} (mm)	50	37.5	50	37.5	50	50	50	50	50	50	50	50	37.5	37.5	37.5	37.5
D_{50a} (mm)	27.8	20.8	27.8	20.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	20.8	20.8	20.8	20.8
n	0.040	0.040	0.045	0.040	0.042	0.052	0.052	0.045	0.042	0.052	0.042	0.052	0.052	0.042	0.058	0.040
u*c (m/s)	0.161	0.139	0.161	0.139	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.139	0.139	0.139	0.139
D(left) (m)	1.83	1.94	1.145	2.605	1.725	2.875	2.845	3.235	2.58	3.66	2.13	2.115	1.98	2.42	3.345	2.64
D(right) (m)	1.66	2.62	1.535	2.38	2.725	2.83	2.52	4.355	4.235	3.79	2.405	1.94	2.47	2.96	3.27	3.145
u_c (left) (m/s)	1.906	1.748	1.762	1.836	1.887	2.055	2.051	2.096	2.018	2.139	1.955	1.952	1.754	1.814	1.915	1.841
u_c (right) (m/s)	1.875	1.838	1.851	1.809	2.037	2.049	2.010	2.202	2.192	2.152	1.995	1.924	1.820	1.876	1.907	1.895
Regime	LB	CW	LB	LB	CW	LB	LB	CW	LB	LB	LB	LB	CW	CW	LB	CW
α	0	20	45	20	15	30	5	0	10	10	10	0	45	30	0	45
V_{max} (left) (m/s)	2.98	1.8	2.24	2.64	-	3.28	1.57	1.51	2.69	0.99	2.27	3.21	1.56	1.51	1.92	1.16
V_{max} (right) (m/s)	2.75	1.24	2.47	2.77	1.5	2.26	3.41	1.01	1.24	2.69	3.4	2.44	0.93	1.23	0.88	0.89

4.6 Scour Countermeasure Applications

In this case study, 14 viaducts are studied with right (R) and left (L) lanes, each calculated separately. Calculation details of one viaduct for one lane and one pier (Çeleme Left Viaduct) are presented in detail in this part. Similar computations are then performed for all piers and viaducts. Use of gabion mattresses and grout-filled mattresses are excluded in the analyses since they have no applications in environment of river bridges in Turkey.

4.6.1 Application of Rock Riprap

The rock riprap implementation is based on hydrologic, scour and study area analyses. Abrasion, ice, rain and human factors are also effective factors on the bridge resistance. The riprap design starts with the determination of D_{r50} through Equation (3.2). Table 4.13 shows the median stone sizes (D_{r50}) around piers of each viaduct.

Table 4.13 Median Riprap Sizes (D_{r50}) around Piers for Each Bridge

(Excavated Condition)

	Çeleme		KG1		KG2		KG3		KG4	
	L	R	L	R	L	R	L	R	L	R
D_{r50} (m)	0.28	0.27	0.20	0.20	0.31	0.31	0.21	0.35	0.14	0.14

	KG 5/1		KG5/2		KG6		KG7		KG9	
	L	R	L	R	L	R	L	R	L	R
D_{r50} (m)	0.15	0.17	0.12	0.53	0.14	0.14	0.45	0.08	0.32	0.32

	KG 10		KG11/1		KG11/2		KG12		KG13		KG14	
	L	R	L	R	L	R	L	R	L	R	L	R
D_{r50} (m)	0.21	0.51	0.41	0.37	0.15	0.15	0.14	0.14	0.23	0.23	0.08	0.08

There are three types of piers used for rock riprap in this case study. Figure 4.27 depicts the dimensions corresponding areas of piers are calculated through a drawing software. Placement of rock riprap around piers of Çeleme-Left Bridge is also shown in Figure 4.28.

Cost calculation of rock riprap for that viaduct is also conducted in the light of the unit prices given in Table 4.14. Unit prices are taken from the Birimfiyat.com website in TL and converted to the USD by assuming 1 USD = 1.8 TL. Overall cost calculations with the related parameters for excavated and original cross-sections are given in Tables 4.15 throuh 4.18. In these tables, cost of riprap, cost of riprap transportation and cost of geotextile filter are symbolized by C_r, C_{rt} and C_f, respectively.

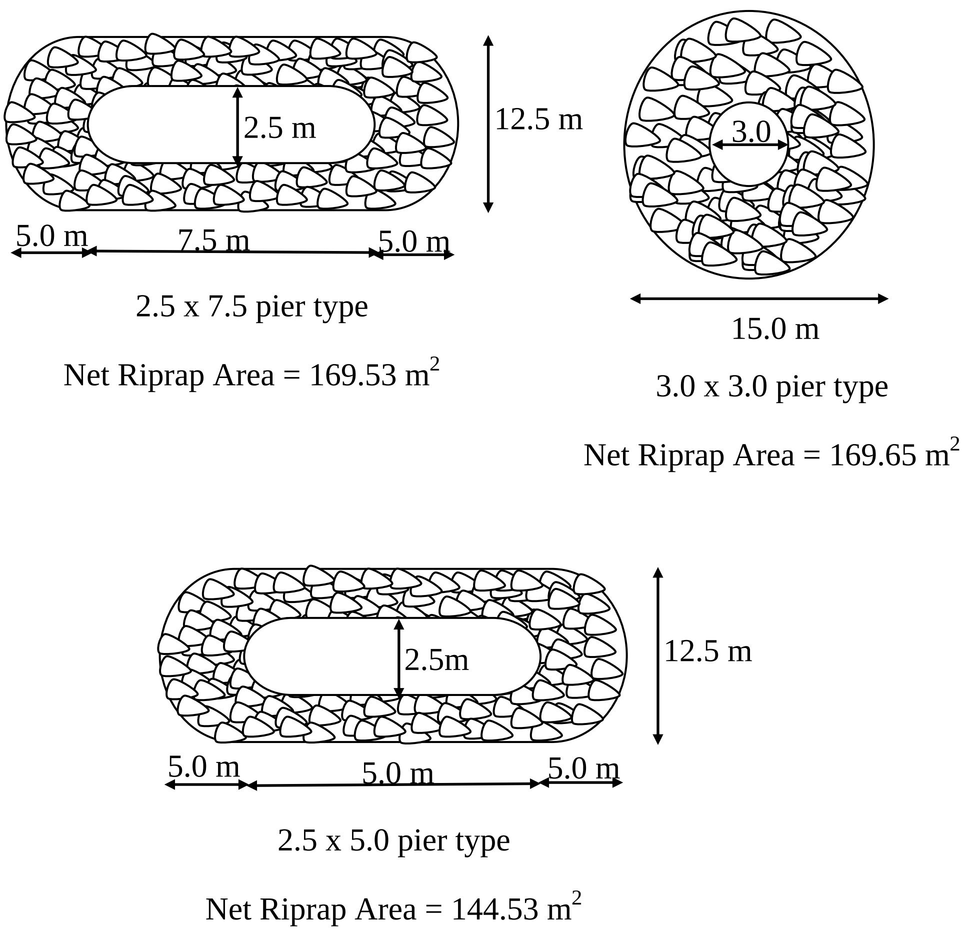


Figure 4. 27 Extent of Piers Used for Rock Riprap

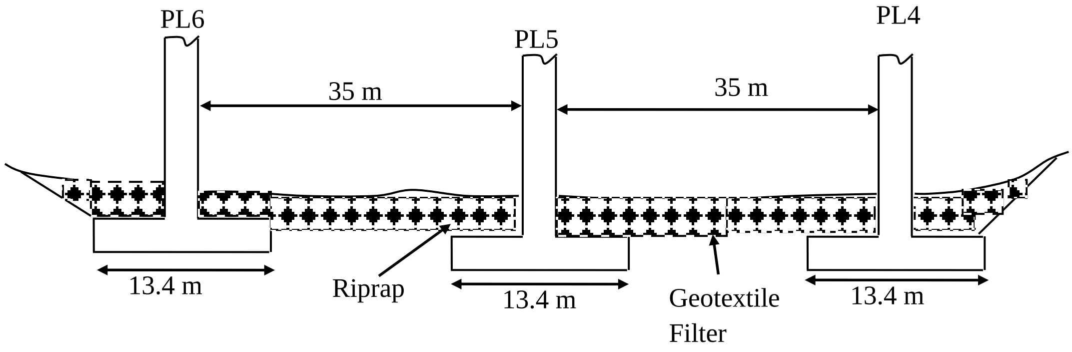


Figure 4.28 Placement of Rock Riprap around piers of Çeleme-Left Bridge

For Çeleme Left Viaduct;

b = 2.5 m, L = 7.5 m

Pier Area = 17.41 m^2

Total Area = 186.94 m^2

Net Riprap Area = 169.53 m^2

Thickness of Rock Riprap = $5Dr_{50}$ = 5 x 0.28 = 1.40 m

Net Volume of Riprap = Net Volume of Excavation = 169.53 x 1.40 = 237.34 m^3

Table 4.14 Unit Prices of Rock Riprap Components (Birimfiyat.com, 2011)

No	**Position No**	**Name of the Component**	**Unit**	**Unit Price (2011, $)**
1	17.081/K	Cost of Riprap	m^3	23.02
2	07.006/35	Cost of Riprap Transportation (11 km)	m^3	7.27
3	14.100	Excavation of any type of soil around bridges manually except rocks	m^3	8.96
4	07.006/14	Transportation of Excavation (2 km)	ton	1.06
5	Special Price	Geotextile Filter	m^2	2.99

C_r = 237.34 (m^3) x 23.02 (\$ / m^3) x 3 (Pier) = \$ 16390.72

C_{rt} = 237.34 (m^3) x 7.27 (\$ / m^3) x 3 (Pier) = \$ 5176.39

C_{ex} = 237.34 (m^3) x 8.96 (\$ / m^3) x 3 (Pier) = \$ 6379.71

C_{ext} = 237.34 (m^3) x 2.65 (ton/m^3) x 1.06 (\$ / ton) x 3 (Pier) = \$ 2000.07

C_f = 169.53(m^2) x (9/16) (The Ratio of Filter) x 2.99 (\$ / m^2) x 3 (Pier) = \$ 855.38

Table 4.15 Median Riprap Sizes and Geometric Parameters for Rock Riprap (According to the Excavated Cross Sections)

Viaduct	D_{r50} (m)	# of Piers	b (m)	L (m)	t_c (m)	Total Area (m^2)	Pier Area (m^2)	Net Area (m^2)	Net Riprap Volume (m^3)
Çeleme L	0.28	3	2.5	7.5	1.4	186.938	17.409	169.5288	237.3403
Çeleme R	0.27	3	2.5	7.5	1.35	186.938	17.409	169.5288	228.8639
KG 1 R	0.20	2	2.5	5	1	155.688	11.159	144.5288	144.5288
KG 1 L	0.20	2	2.5	5	1	155.688	11.159	144.5288	144.5288
KG 2 L	0.31	3	3	3	1.55	176.715	7.0686	169.646	262.9513
KG 2 R	0.31	4	3	3	1.55	176.715	7.0686	169.646	262.9513
KG 3 R	0.35	2	3	3	1.75	176.715	7.0686	169.646	296.8805
KG 3 L	0.21	2	3	3	1.05	176.715	7.0686	169.646	178.1283
KG 4 L	0.14	0	2.5	7.5	0.7	186.938	17.409	169.5288	118.6702
KG 4 R	0.14	4	2.5	7.5	0.7	186.938	17.409	169.5288	118.6702
KG 5/1 R	0.17	2	2.5	5	0.85	155.688	11.159	144.5288	122.8495
KG 5/1 L	0.15	2	2.5	5	0.75	155.688	11.159	144.5288	108.3966
KG 5/2 L	0.12	2	2.5	5	0.6	155.688	11.159	144.5288	86.71728
KG 5/2 R	0.53	2	2.5	5	2.65	155.688	11.159	144.5288	383.0013
KG 6 R	0.14	1	2.5	5	0.7	155.688	11.159	144.5288	101.1702
KG 6 L	0.14	2	2.5	5	0.7	155.688	11.159	144.5288	101.1702
KG 7 L	0.45	1	2.5	5	2.5	155.688	11.159	144.5288	325.1898
KG 7 R	0.08	2	2.5	5	0.4	155.688	11.159	144.5288	57.81152
KG 9 R	0.32	1	2.5	7.5	1.6	186.938	17.409	169.5288	271.2461
KG 9 L	0.32	2	2.5	7.5	1.6	186.938	17.409	169.5288	271.2461
KG 10 L	0.21	1	2.5	5	1.05	155.688	11.159	144.5288	151.7552
KG 10 R	0.51	1	2.5	5	2.55	155.688	11.159	144.5288	368.5484
KG 11/1 R	0.37	2	3	3	1.85	176.715	7.0686	169.646	313.8451
KG 11/1 L	0.41	2	3	3	2.05	176.715	7.0686	169.646	347.7743
KG 11/2 L	0.15	4	3	3	0.75	176.715	7.0686	169.646	127.2345
KG 11/2 R	0.15	4	3	3	0.75	176.715	7.0686	169.646	127.2345
KG 12 R	0.14	3	3	3	0.7	176.715	7.0686	169.646	118.7522
KG 12 L	0.14	3	3	3	0.7	176.715	7.0686	169.646	118.7522
KG 13 L	0.23	2	3	3	1.15	176.715	7.0686	169.646	195.0929
KG 13 R	0.23	3	3	3	1.15	176.715	7.0686	169.646	195.0929
KG 14 R	0.08	3	3	3	0.4	176.715	7.0686	169.646	67.8584
KG 14 L	0.08	3	3	3	0.4	176.715	7.0686	169.646	67.8584

Table 4.16 Cost Calculations of Rock Riprap

(According to the Excavated Cross-sections)

Viaduct	C_r ($)	C_{rt} ($)	Total Excavation for Riprap (m^3)	C_{ex} ($)	C_{ext} ($) (2 km)	C_f ($)
Çeleme L	16390.72	5176.39	712.02	6379.71	2000.07	855.38
Çeleme R	15805.34	4991.52	686.59	6151.86	1928.64	855.38
KG 1 R	6654.11	2101.45	289.06	2589.96	811.96	486.16
KG 1 L	6654.11	2101.45	289.06	2589.96	811.96	486.16
KG 2 L	18159.42	5734.97	788.85	7068.13	2215.89	855.97
KG 2 R	24212.56	7646.62	1051.81	9424.17	2954.52	1141.29
KG 3 R	13668.38	4316.64	593.76	5320.10	1667.87	570.65
KG 3 L	8201.03	2589.99	356.26	3192.06	1000.72	570.65
KG 4 L	0.00	0.00	0.00	0.00	0.00	0.00
KG 4 R	10927.15	3450.93	474.68	4253.14	1333.38	1140.51
KG 5/1 R	5655.99	1786.23	245.70	2201.46	690.17	486.16
KG 5/1 L	4990.58	1576.09	216.79	1942.47	608.97	486.16
KG 5/2 L	3992.46	1260.87	173.43	1553.97	487.18	486.16
KG 5/2 R	17633.38	5568.84	766.00	6863.38	2151.70	486.16
KG 6 R	2328.94	735.51	101.17	906.48	284.19	243.08
KG 6 L	4657.87	1471.01	202.34	1812.97	568.37	486.16
KG 7 L	7485.87	2364.13	325.19	2913.70	913.46	243.08
KG 7 R	2661.64	840.58	115.62	1035.98	324.79	486.16
KG 9 R	6244.08	1971.96	271.25	2430.36	761.93	285.13
KG 9 L	12488.17	3943.92	542.49	4860.73	1523.86	570.25
KG 10 L	3493.41	1103.26	151.76	1359.73	426.28	243.08
KG 10 R	8483.99	2679.35	368.55	3302.19	1035.25	243.08
KG 11/1 R	14449.43	4563.31	627.69	5624.10	1763.18	570.65
KG 11/1 L	16011.53	5056.64	695.55	6232.12	1953.80	570.65
KG 11/2 L	11715.75	3699.98	508.94	4560.08	1429.61	1141.29
KG 11/2 R	11715.75	3699.98	508.94	4560.08	1429.61	1141.29
KG 12 R	8201.03	2589.99	356.26	3192.06	1000.72	855.97
KG 12 L	8201.03	2589.99	356.26	3192.06	1000.72	855.97
KG 13 L	8982.08	2836.65	390.19	3496.06	1096.03	570.65
KG 13 R	13473.12	4254.98	585.28	5244.10	1644.05	855.97
KG 14 R	4686.30	1479.99	203.58	1824.03	571.84	855.97
KG 14 L	4686.30	1479.99	203.58	1824.03	571.84	855.97
TOTAL($)	302911.49	95663.19		117901.26	36962.57	19981.16
GRAND TOTAL ($)		**573419.673**				

Table 4.17 Median Riprap Sizes and Geometric Parameters for Rock Riprap (According to the Original Cross-sections)

Viaduct	D_{r50} (m)	# of Piers	b (m)	L (m)	t_c (m)	Total Area (m^2)	Pier Area (m^2)	Net Area (m^2)	Net Riprap Volume (m^3)
Çeleme Left	0.55	3	2.5	7.5	2.75	186.938	17.409	169.529	466.2042
Çeleme Right	0.55	3	2.5	7.5	2.75	186.938	17.409	169.529	466.2042
KG 1 Right	0.20	2	2.5	5	1	155.688	11.159	144.529	144.5288
KG 1 Left	0.20	2	2.5	5	1	155.688	11.159	144.529	144.5288
KG 2 Left	0.31	3	3	3	1.55	176.715	7.0686	169.646	262.9513
KG 2 Right	0.31	4	3	3	1.55	176.715	7.0686	169.646	262.9513
KG 3 Right	0.47	2	3	3	2.35	176.715	7.0686	169.646	398.6681
KG 3 Left	0.47	2	3	3	2.35	176.715	7.0686	169.646	398.6681
KG 4 Left	0.14	0	2.5	7.5	0.7	186.938	17.409	169.529	118.6702
KG 4 Right	0.14	4	2.5	7.5	0.7	186.938	17.409	169.529	118.6702
KG 5/1 Right	0.66	1	2.5	5	3.3	155.688	11.159	144.529	476.945
KG 5/1 Left	0.66	1	2.5	5	3.3	155.688	11.159	144.529	476.945
KG 5/2 Left	0.72	2	2.5	5	3.6	155.688	11.159	144.529	520.3037
KG 5/2 Right	0.72	2	2.5	5	3.6	155.688	11.159	144.529	520.3037
KG 6 Right	0.14	1	2.5	5	0.7	155.688	11.159	144.529	101.1702
KG 6 Left	0.14	1	2.5	5	0.7	155.688	11.159	144.529	101.1702
KG 7 Left	1.01	1	2.5	5	5.05	155.688	11.159	144.529	729.8704
KG 7 Right	1.01	2	2.5	5	5.05	155.688	11.159	144.529	729.8704
KG 9 Right	0.32	1	2.5	7.5	1.6	186.938	17.409	169.529	271.2461
KG 9 Left	0.32	2	2.5	7.5	1.6	186.938	17.409	169.529	271.2461
KG 10 Left	0.71	1	2.5	5	3.55	155.688	11.159	144.529	513.0772
KG 10 Right	0.71	1	2.5	5	3.55	155.688	11.159	144.529	513.0772
KG 11/1 Right	0.64	2	3	3	3.2	176.715	7.0686	169.646	542.8672
KG 11/1 Left	0.64	2	3	3	3.2	176.715	7.0686	169.646	542.8672
KG 11/2 Left	0.15	4	3	3	0.75	176.715	7.0686	169.646	127.2345
KG 11/2 Right	0.15	4	3	3	0.75	176.715	7.0686	169.646	127.2345
KG 12 Right	0.14	3	3	3	0.7	176.715	7.0686	169.646	118.7522
KG 12 Left	0.14	3	3	3	0.7	176.715	7.0686	169.646	118.7522
KG 13 Left	0.23	2	3	3	1.15	176.715	7.0686	169.646	195.0929
KG 13 Right	0.23	3	3	3	1.15	176.715	7.0686	169.646	195.0929
KG 14 Right	0.08	3	3	3	0.4	176.715	7.0686	169.646	67.8584
KG 14 Left	0.08	3	3	3	0.4	176.715	7.0686	169.646	67.8584

Table 4.18 Cost Calculations of Rock Riprap

(According to the Original Cross Sections)

Viaduct	C_r (\$)	C_{rt} (\$)	Total Excavation for Riprap (m^3)	C_{ex} (\$)	C_{ext} (\$) (2 km)	C_f (\$)
Çeleme Left	32196.06	10167.91	1398.61	12531.57	3928.70	855.38
Çeleme Right	32196.06	10167.91	1398.61	12531.57	3928.70	855.38
KG 1 Right	6654.11	2101.45	289.06	2589.96	811.96	486.16
KG 1 Left	6654.11	2101.45	289.06	2589.96	811.96	486.16
KG 2 Left	18159.42	5734.97	788.85	7068.13	2215.89	855.97
KG 2 Right	24212.56	7646.62	1051.81	9424.17	2954.52	1141.29
KG 3 Right	18354.68	5796.63	797.34	7144.13	2239.72	570.65
KG 3 Left	18354.68	5796.63	797.34	7144.13	2239.72	570.65
KG 4 Left	0.00	0.00	0.00	0.00	0.00	0.00
KG 4 Right	10927.15	3450.93	474.68	4253.14	1333.38	1140.51
KG 5/1 Right	10979.27	3467.39	476.95	4273.43	1339.74	243.08
KG 5/1 Left	10979.27	3467.39	476.95	4273.43	1339.74	243.08
KG 5/2 Left	23954.78	7565.22	1040.61	9323.84	2923.07	486.16
KG 5/2 Right	23954.78	7565.22	1040.61	9323.84	2923.07	486.16
KG 6 Right	2328.94	735.51	101.17	906.48	284.19	243.08
KG 6 Left	2328.94	735.51	101.17	906.48	284.19	243.08
KG 7 Left	16801.62	5306.16	729.87	6539.64	2050.21	243.08
KG 7 Right	33603.24	10612.32	1459.74	13079.28	4100.41	486.16
KG 9 Right	6244.08	1971.96	271.25	2430.36	761.93	285.13
KG 9 Left	12488.17	3943.92	542.49	4860.73	1523.86	570.25
KG 10 Left	11811.04	3730.07	513.08	4597.17	1441.23	243.08
KG 10 Right	11811.04	3730.07	513.08	4597.17	1441.23	243.08
KG 11/1 Right	24993.61	7893.29	1085.73	9728.18	3049.83	570.65
KG 11/1 Left	24993.61	7893.29	1085.73	9728.18	3049.83	570.65
KG 11/2 Left	11715.75	3699.98	508.94	4560.08	1429.61	1141.29
KG 11/2 Right	11715.75	3699.98	508.94	4560.08	1429.61	1141.29
KG 12 Right	8201.03	2589.99	356.26	3192.06	1000.72	855.97
KG 12 Left	8201.03	2589.99	356.26	3192.06	1000.72	855.97
KG 13 Left	8982.08	2836.65	390.19	3496.06	1096.03	570.65
KG 13 Right	13473.12	4254.98	585.28	5244.10	1644.05	855.97
KG 14 Right	4686.30	1479.99	203.58	1824.03	571.84	855.97
KG 14 Left	4686.30	1479.99	203.58	1824.03	571.84	855.97
TOTAL (\$)	**456665.57**	**144220.62**		**177746.46**	**55722.56**	**19254.92**
GRAND TOTAL (\$)		**853610.13**				

4.6.2 Application of Partially Grouted Riprap

Steps of partially grouted riprap application are almost as same as rock riprap application. The only difference is stone classes which are used in the implementation. Class II, class III and class IV type stones are used. Therefore, when it is compared with rock riprap sizes, used stone sizes are a bit smaller in partially grouted riprap. Class of the riprap sizes are controlled and class I stones are shifted to class II. In the same way, ripraps greater than class IV, are lowered to class IV. Class III and class IV stones are also dropped one class. Median riprap sizes used in partially grouted riprap is given in Table 4.19. In this study, porosity between ripraps are accepted as 35%, and the thickness of the riprap layer is taken as $4D_{r50}$.

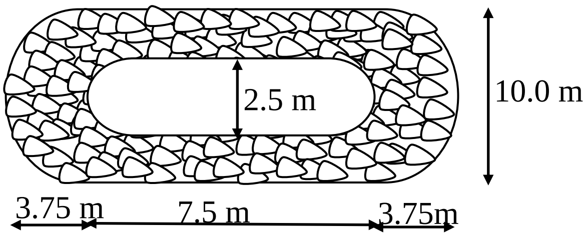
Table 4.19 Median riprap sizes (D_{r50}) used in Partially Grouted Riprap

	Çeleme		KG1		KG2		KG3		KG4	
	L	R	L	R	L	R	L	R	L	R
D_{r50}	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22

	KG 5/1		KG5/2		KG6		KG7		KG9	
	L	R	L	R	L	R	L	R	L	R
D_{r50}	0.22	0.22	0.22	0.37	0.22	0.22	0.37	0.22	0.22	0.22

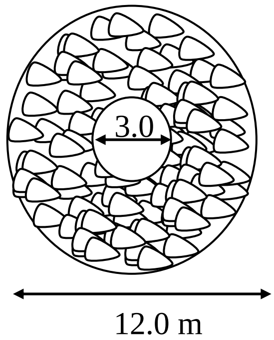
	KG 10		KG11/1		KG11/2		KG12		KG13		KG14	
	L	R	L	R	L	R	L	R	L	R	L	R
D_{r50}	0.22	0.37	0.29	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22

There are three types of piers used for partially grouted riprap. Figure 4.29 gives the dimensions of regarding types and areas of piers are calculated through a drawing software. Unit prices of the components used in partially grouted riprap is given in Table 4.20 and overall cost calculations with the related parameters for excavated and cross-sections are given in Tables 4.21 and 4.22. In those tables, cost of grouting, is shown by $C_{gr.}$



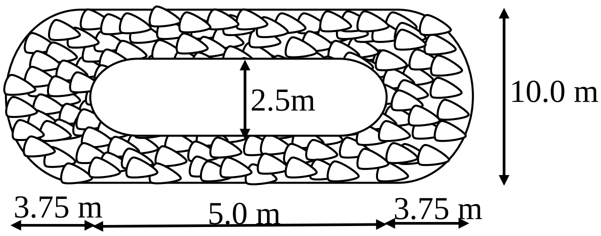
2.5 x 7.5 pier type

Net Riprap Area = 112.83 m^2



3.0 x 3.0 pier type

Net Riprap Area = 106.03 m^2



2.5 x 5.0 pier type

Net Riprap Area = 94.08 m^2

Figure 4.29 Extent of Piers Used in Partially Grouted Riprap

For Çeleme Left Bridge;

b = 2.5 m, L = 7.5 m

Pier Area = 17.41 m^2

Total Area = 130.24 m^2

Net Riprap Area = 112.83 m^2

Thickness of Riprap = $4Dr_{50}$ = 4 x 0.22 = 0.88 m

Net Volume of Riprap = Net Volume of Excavation = 112.83 x 0.88 = 99.29 m^3

Grouting Volume= 99.29 (m^3) x 0.35 (Porosity) x 0.50 (Grouting Ratio) = 17.38 m^3

Table 4.20 Unit Prices of Partially Grouted Riprap Components (Birimfiyat.com, 2011)

No	**Position No**	**Name of the Component**	**Unit**	**Unit Price (2011, $)**
1	17.081/K	Cost of Riprap	m^3	23.02
2	07.006/35	Cost of Riprap Transportation (11 km)	m^3	7.27
3	14.100	Excavation of any type of soil around bridges manually except rocks	m^3	8.96
4	07.006/14	Transportation of Excavation (2 km)	ton	1.06
5	Special Price	Geotextile Filter	m^2	2.99
6	10.022/K	Preparation of Cement Slurry and Grouting	m^3	8.66

Cost Calculation of Partially Rock Riprap for Çeleme Left:

C_r = 99.29 (m^3) x 23.02 (\$ / m^3) x 3 (Pier) = \$ 6856.97

C_{rt} = 99.29 (m^3) x 7.27 (\$ / m^3) x 3 (Pier) = \$ 2165.51

C_{ex} = 99.29 (m^3) x 8.96 (\$ / m^3) x 3 (Pier) = \$ 2668.91

C_{ext} = 99.29 (m^3) x 2.65 (ton/m^3) x 1.06 (\$ / ton) x 3 (Pier) = \$ 836.72

C_f = 112.83 (m^2) x (9/16) (The Ratio of Filter) x 2.99 (\$ / m^2) x 3 (Pier) = \$ 569.30

C_{gr} = 17.38 m^3 x 8.66 (\$ / m^3) x 3 (Pier) = \$ 451.53

Table 4.21 Median Riprap Sizes and Geometric Parameters for Partially Grouted Riprap

Viaduct	**D_{r50} (m)**	**# of Piers**	**b (m)**	**L (m)**	**t_c (m)**	**Total Area (m^2)**	**Pier Area (m^2)**	**Net Area (m^2)**	**Net Riprap Volume (m^3)**
Çeleme Left	0.22	3	2.5	7.5	0.88	130.24	17.41	112.83	99.29
Çeleme Right	0.22	3	2.5	7.5	0.88	130.24	17.41	112.83	99.29
KG 1 Right	0.22	2	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 1 Left	0.22	2	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 2 Left	0.22	3	3	3	0.88	113.10	7.07	106.03	93.31
KG 2 Right	0.22	4	3	3	0.88	113.10	7.07	106.03	93.31
KG 3 Right	0.22	2	3	3	0.88	113.10	7.07	106.03	93.31
KG 3 Left	0.22	2	3	3	0.88	113.10	7.07	106.03	93.31
KG 4 Left	0.22	0	2.5	7.5	0.88	130.24	17.41	112.83	99.29
KG 4 Right	0.22	4	2.5	7.5	0.88	130.24	17.41	112.83	99.29
KG 5/1 Right	0.22	2	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 5/1 Left	0.22	2	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 5/2 Left	0.22	2	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 5/2 Right	0.37	2	2.5	5	1.48	105.24	11.16	94.08	139.24
KG 6 Right	0.22	1	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 6 Left	0.22	2	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 7 Left	0.37	1	2.5	5	1.48	105.24	11.16	94.08	139.24
KG 7 Right	0.22	2	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 9 Right	0.22	1	2.5	7.5	0.88	130.24	17.41	112.83	99.29
KG 9 Left	0.22	2	2.5	7.5	0.88	130.24	17.41	112.83	99.29
KG 10 Left	0.22	1	2.5	5	0.88	105.24	11.16	94.08	82.79
KG 10 Right	0.37	1	2.5	5	1.48	105.24	11.16	94.08	139.24
KG 11/1 Right	0.29	2	3	3	1.16	113.10	7.07	106.03	122.99
KG 11/1 Left	0.37	2	3	3	1.48	113.10	7.07	106.03	156.92
KG 11/2 Left	0.22	4	3	3	0.88	113.10	7.07	106.03	93.31
KG 11/2 Right	0.22	4	3	3	0.88	113.10	7.07	106.03	93.31
KG 12 Right	0.22	3	3	3	0.88	113.10	7.07	106.03	93.31
KG 12 Left	0.22	3	3	3	0.88	113.10	7.07	106.03	93.31
KG 13 Left	0.22	2	3	3	0.88	113.10	7.07	106.03	93.31
KG 13 Right	0.22	3	3	3	0.88	113.10	7.07	106.03	93.31
KG 14 Right	0.22	3	3	3	0.88	113.10	7.07	106.03	93.31
KG 14 Left	0.22	3	3	3	0.88	113.10	7.07	106.03	93.31

Table 4.22 Cost Calculations of Partially Grouted Riprap

Viaduct	C_r ($)	C_{rt} ($)	Total Exc. for Riprap (m^3)	C_{ex} ($)	C_{ext} ($) (2 km)	V_{gr} (m^3)	C_{gr} ($)	C_f ($)
Çeleme Left	6857	2166	297.9	2669	837	17.4	451	569
Çeleme Right	6857	2166	297.9	2669	837	17.4	451	569
KG 1 Right	3812	1204	165.6	1484	465	14.5	251	316
KG 1 Left	3812	1204	165.6	1484	465	14.5	251	316
KG 2 Left	6444	2035	279.9	2508	786	16.3	424	535
KG 2 Right	8592	2713	373.2	3344	1048	16.3	566	713
KG 3 Right	4296	1357	186.6	1672	524	16.3	283	357
KG 3 Left	4296	1357	186.6	1672	524	16.3	283	357
KG 4 Left	0	0	0.0	0	0	17.4	0	0
KG 4 Right	9143	2887	397.2	3559	1116	17.4	602	759
KG 5/1 Right	3812	1204	165.6	1484	465	14.5	251	316
KG 5/1 Left	3812	1204	165.6	1484	465	14.5	251	316
KG 5/2 Left	3812	1204	165.6	1484	465	14.5	251	316
KG 5/2 Right	6411	2025	278.5	2495	782	24.4	422	316
KG 6 Right	1906	602	82.8	742	233	14.5	125	158
KG 6 Left	3812	1204	165.6	1484	465	14.5	251	316
KG 7 Left	3205	1012	139.2	1248	391	24.4	211	158
KG 7 Right	3812	1204	165.6	1484	465	14.5	251	316
KG 9 Right	2286	722	99.3	890	279	17.4	150	190
KG 9 Left	4571	1444	198.6	1779	558	17.4	301	380
KG 10 Left	1906	602	82.8	742	233	14.5	125	158
KG 10 Right	3205	1012	139.2	1248	391	24.4	211	158
KG 11/1 Right	5663	1788	246.0	2204	691	21.5	373	357
KG 11/1 Left	7225	2282	313.8	2812	882	27.5	476	357
KG 11/2 Left	8592	2713	373.2	3344	1048	16.3	566	713
KG 11/2 Right	8592	2713	373.2	3344	1048	16.3	566	713
KG 12 Right	6444	2035	279.9	2508	786	16.3	424	535
KG 12 Left	6444	2035	279.9	2508	786	16.3	424	535
KG 13 Left	4296	1357	186.6	1672	524	16.3	283	357
KG 13 Right	6444	2035	279.9	2508	786	16.3	424	535
KG 14 Right	6444	2035	279.9	2508	786	16.3	424	535
KG 14 Left	6444	2035	279.9	2508	786	16.3	424	535
TOTAL ($)	163241	51554		63538	19920		10747	12765
GRAND TOTAL ($)		**321763.25**						

4.6.3 Application of Articulated Concrete Block (ACB)

In this section, design criteria of ACB's are implemented to one pier of Çeleme Left Bridge. Dimensions of ACB are computed by using the Equations (3.3), (3.4), (3.5) and (3.6). Table 4.23 shows the unit prices used in ACBs. Overall cost calculations are given Tables 4.24 and 4.25. In these tables, cost of ACB, cost of transportation of ACB, cost of fill, and cost of fill transportation are symbolized as C_a, C_{at}, C_{fl}, C_{flt}, respectively.

Example Computations for Çeleme Left Viaduct

b = 2.5 m, L = 7.5 m & d_s = 1.75 m

WS = 2.5 x 1.75 + 2.5 = 6.875 m

X1 = 1.25 x 1.75 = 2.1875 m

X2 = 3 x 1.75 = 5.25 m

Total Area = (2.1875 + 5.25 + 7.5) x 6.875 = 102.70 m^2 (Includes Pier Area)

Pier Area = 17.41 m^2 (Computed by using ACAD)

Net Area = Total Area – Pier Area = 102.70 – 17.41 = 85.29 m^2

Net Volume = Net Area x 1 = 85.29 m^3

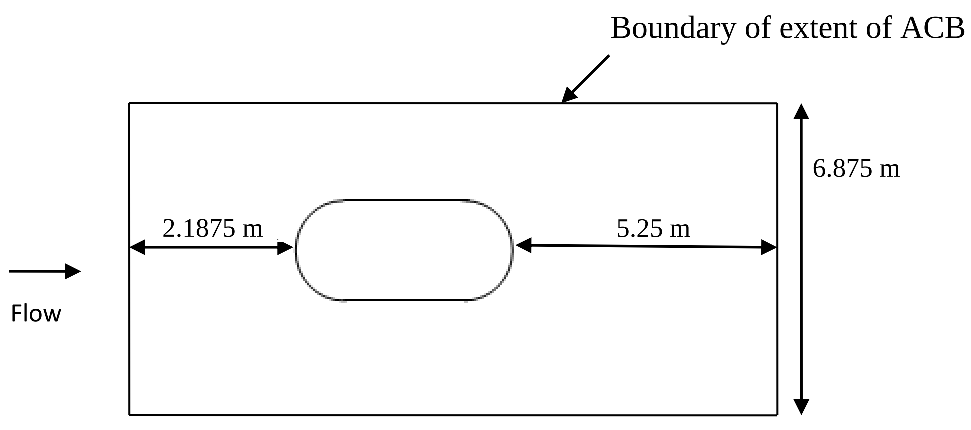


Figure 4.30 Dimensions of ACB Extent in Plan View

Table 4.23 Unit Prices of ACB Systems (Birimfiyat.com, 2011)

No	**Position No**	**Name of the Component**	**Unit**	**Unit Price (2011, $)**
1	Special Price	Cost of ACB	m^2	14.23
2	Special Price	Placement, transportation of ACB	m^2	3.87
3	14.100	Excavation of any type of soil around bridges manually except rocks	m^3	8.96
4	07.006/14	Transportation of Excavation (2 km)	ton	1.06
5	08.003/K2	Cost of fill	m^3	11.57
6	07.006/35	Cost of fill transportation (60 km)	m^3	7.27
7	10.022K	Cost of Grout	m^3	8.66
8	Special Price	Geotextile Filter	m^2	2.99

Cost Calculation of ACB System for Çeleme Left:

C_a = 85.29 (m^2) x 14.23 (\$ / m^2) x 3 (Pier) = \$ 3640.83

C_{at} = 85.29 (m^2) x 3.87 (\$ / m^2) x 3 (Pier) = \$ 990.16

C_{ex} = 85.29 (m^3) x 8.96 (\$ / m^3) x 3 (Pier) = \$ 2292.47

C_{ext} = 226.02 (ton) x 1.06 (\$ / ton) x 3 (Pier) = \$ 718.74

C_{fl} = 85.29 (m^3) x 11.57 (\$ / m^3) x 3 (Pier) = \$ 2960.25

C_{flt} = 85.29 (m^3) x 7.27 (\$ / m^3) x 3 (Pier) = \$ 1860.07

C_f = 85.29 (m^2) x 2.99 (\$ / m^2) x 3 (Pier) = \$ 765.01

Table 4.24 Maximum Scour Depths and Geometric Parameters for ACB

Viaduct	d_s (m)	# of piers	b (m)	L (m)	WS (m)	X1 (m)	X2 (m)	Total Area (m^2)	Pier Area (m^2)	Net Area (m^2)	Net Exc. Vol. (m^3)
Çeleme Left	1.75	3	2.5	7.5	6.88	2.19	5.25	102.70	17.41	85.29	85.3
Çeleme Right	1.69	3	2.5	7.5	6.73	2.11	5.07	98.74	17.41	81.33	81.3
KG 1 Right	2.08	2	2.5	5	7.70	2.60	6.24	106.57	11.16	95.41	95.41
KG 1 Left	2.33	2	2.5	5	8.33	2.91	6.99	124.06	11.16	112.90	112.9
KG 2 Left	5.18	3	3	3	15.95	6.48	15.54	398.99	7.07	391.92	391.9
KG 2 Right	4.19	4	3	3	13.48	5.24	12.57	280.38	7.07	273.31	273.3
KG 3 Right	3.03	2	3	3	10.58	3.79	9.09	167.90	7.07	160.84	160.8
KG 3 Left	2.85	2	3	3	10.13	3.56	8.55	153.01	7.07	145.95	145.9
KG 4 Left	0.00	0	2.5	7.5	2.50	0.00	0.00	0.00	0.00	0.00	0.0
KG 4 Right	5.02	4	2.5	7.5	15.05	6.28	15.06	433.97	17.41	416.56	416.5
KG 5/1 Right	2.86	2	2.5	5	9.65	3.58	8.58	165.55	11.16	154.39	154.3
KG 5/1 Left	8.86	2	2.5	5	24.65	11.1	26.58	1051.5	11.16	1040.3	1040.3
KG 5/2 Left	1.49	2	2.5	5	6.23	1.86	4.47	70.54	11.16	59.39	59.4
KG 5/2 Right	2.08	2	2.5	5	7.70	2.60	6.24	106.57	11.16	95.41	95.4
KG 6 Right	1.19	1	2.5	5	5.48	1.49	3.57	55.06	11.16	43.91	43.9
KG 6 Left	1.39	2	2.5	5	5.98	1.74	4.17	65.17	11.16	54.01	54.0
KG 7 Left	1.73	1	2.5	5	6.83	2.16	5.19	84.31	11.16	73.15	73.2
KG 7 Right	1.58	2	2.5	5	6.45	1.98	4.74	75.56	11.16	64.40	64.4
KG 9 Right	2.33	1	2.5	7.5	8.33	2.91	6.99	144.88	17.41	127.47	127.5
KG 9 Left	1.53	2	2.5	7.5	6.33	1.91	4.59	88.57	17.41	71.16	71.16
KG 10 Left	1.43	1	2.5	5	6.08	1.79	4.29	67.30	11.16	56.14	56.1
KG 10 Right	2.40	1	2.5	5	8.50	3.00	7.20	129.20	11.16	118.04	118.0
KG 11/1 R	1.82	2	3	3	7.55	2.28	5.46	81.05	7.07	73.98	74.0
KG 11/1 L	1.92	2	3	3	7.80	2.40	5.76	87.05	7.07	79.98	80.0
KG 11/2 L	3.56	4	3	3	11.90	4.45	10.68	215.75	7.07	208.68	208.7
KG 11/2 R	2.86	4	3	3	10.15	3.58	8.58	153.82	7.07	146.75	146.8
KG 12 Right	2.87	3	3	3	10.18	3.59	8.61	154.63	7.07	147.57	147.6
KG 12 Left	3.04	3	3	3	10.60	3.80	9.12	168.75	7.07	161.68	161.7
KG 13 Left	1.79	2	3	3	7.48	2.24	5.37	79.29	7.07	72.22	72.2
KG 13 Right	1.27	3	3	3	6.18	1.59	3.81	51.85	7.07	44.79	44.8
KG 14 Right	5.67	3	3	3	17.18	7.09	17.01	465.40	7.07	458.33	458.3
KG 14 Left	3.19	3	3	3	10.98	3.99	9.57	181.72	7.07	174.65	174.7

Table 4.25 Cost Calculations of ACB

Viaduct	C_a ($)	C_{at} ($)	C_{ex} ($)	C_{ext} ($)	C_{fl} ($)	C_{flt} ($) (60 km)	C_f ($)
Çeleme Left	3641	990	2292	719	2960	1860	765
Çeleme Right	3472	944	2186	685	2823	1774	730
KG 1 Right	2715	738	1710	536	2208	1387	571
KG 1 Left	3213	874	2023	634	2613	1642	675
KG 2 Left	16731	4550	10535	3303	13604	8548	3516
KG 2 Right	15557	4231	9796	3071	12649	7948	3269
KG 3 Right	4577	1245	2882	904	3722	2339	962
KG 3 Left	4154	1130	2615	820	3377	2122	873
KG 4 Left	0	0	0	0	0	0	0
KG 4 Right	23710	6448	14929	4680	19278	12113	4982
KG 5/1 Right	4394	1195	2767	867	3573	2245	923
KG 5/1 Left	29607	8052	18642	5844	24072	15126	6221
KG 5/2 Left	1690	460	1064	334	1374	863	355
KG 5/2 Right	2715	738	1710	536	2208	1387	571
KG 6 Right	625	170	393	123	508	319	131
KG 6 Left	1537	418	968	303	1250	785	323
KG 7 Left	1041	283	655	205	846	532	219
KG 7 Right	1833	498	1154	362	1490	936	385
KG 9 Right	1814	493	1142	358	1475	927	381
KG 9 Left	2025	551	1275	400	1647	1035	426
KG 10 Left	799	217	503	158	650	408	168
KG 10 Right	1680	457	1058	332	1366	858	353
KG 11/1 Right	2105	573	1326	416	1712	1076	442
KG 11/1 Left	2276	619	1433	449	1851	1163	478
KG 11/2 Left	11878	3230	7479	2345	9658	6068	2496
KG 11/2 Right	8353	2272	5260	1649	6792	4268	1755
KG 12 Right	6300	1713	3967	1244	5122	3218	1324
KG 12 Left	6902	1877	4346	1363	5612	3526	1450
KG 13 Left	2055	559	1294	406	1671	1050	432
KG 13 Right	1912	520	1204	377	1555	977	402
KG 14 Right	19566	5321	12320	3862	15909	9996	4111
KG 14 Left	7456	2028	4695	1472	6062	3809	1567
TOTAL ($)	131912	35875	83058	26039	107253	67392	27717
GRAND TOTAL ($)		**479248.51**					

4.7 Determination of Selection Index

After all the computations the selection index is determined according to the criteria stated in Chapter 3.

At the rating stage; given points by each factor are stated in the Table 4.26. The points are calculated with respect to followings:

- For factor S1, the bed material is accepted as primarily coarse sand or gravel with D_{50} greater than 2 mm.
- For factor S2, expected ice and debris load is high, because of closeness of the study area to the Taurus Mountains.
- For construction consideration factor S3, countermeasures are placed underwater, velocity during the installation period is smaller than 1.3 m/s (considering application during low flow conditions), equipment access is good and footings are accepted as deep footing.
- For factor S4, inspection and maintenance must be performed underwater.
- For life cycle cost, total installation cost is multiplied with the capital recovery factor for 10% interest rate and 50 years of life time. Özdemir (2003) takes the maintenance and depreciation costs are taken as 0.3% for rock riprap. In the same way, since the strengths of partially grouted riprap and articulated concrete blocks under the same flow conditions are higher than the rock riprap, this ratio is assumed as 0.2% for partially grouted riprap and 0.1% for articulated concrete blocks.

With respect to Table 4.26, partially grouted riprap should be selected since it gives the maximum selection index.

Table 4.26 Selection Index Calculations

		Rock Riprap	Partially Grouted Riprap	Articulated Concrete Blocks
Bed Material		5	5	4
Ice / Debris Load		3	4	4
Construction Considerations		5	5	4
Inspection and Maintenance		5	4	3
Life Cycle Cost	Total Cost ($)	573,419.70	321,763.25	479,248.51
	Annual Maintenance Cost ($/yr)	173.57	64.93	48.36
	Annual Capital Cost ($/yr)	58,031.62	32,530.84	48,404.53
SI INDEX		0.0065	**0.0123**	0.0040

All the calculations are performed for the excavated cross-sections. Therefore, excavation costs are not included to the selection index computations. In order to analyze the benefits of excavation, total costs are compared in Table 4.27. As it is seen in this table, excavated cross-sections are more profitable than the original cross-sections.

Table 4.27 Total Cost Comparison between Original and Excavated Cross-sections

	Original Cross-sections	**Excavated Cross-sections**		
	Rock Riprap	**Rock Riprap**	**Partially Grouted Riprap**	**Articulated Concrete Blocks**
Countermeasure Cost ($)	853,610.13	573,419.7	321,763.25	479,248.51
Excavation Cost ($)	-	250,972.95	250,972.95	250,972.95
Total Cost ($)	853,610.13	824,392.65	572,736.20	730,221.46

Rock riprap installation at excavated cross-sections is $29,217.48 more profitable than the one at original cross-sections. Partially grouted riprap is not only the most economically feasible, but also suitable countermeasure due to the selection index concept among the all countermeasure types at excavated cross-sections. Therefore, it is recommended to protect the piers of the viaducts in the study area by partially grouted ripraps.

When the costs of armoring countermeasures are compared with the total cost of viaducts, it can be seen that the applications of countermeasures are relatively feasible. As an example, the total cost of Çeleme Left Viaduct is obtained as $ 4,650,000 (Turan and Yanmaz, 2011). Application costs of countermeasures for this viaduct for rock riprap, partially grouted riprap and ACBs are $ 31000, $ 13550, $ 13300, respectively. The cost of partially grouted riprap is only 0.29% of the total cost of viaduct. With the allocation of a relatively small additional budget for countermeasure implementation, the safety of the viaduct will be improved significantly.

CHAPTER V

CONCLUSIONS

This study deals with the evaluation of design criteria for armoring type scour countermeasures for bridges. A case study is performed to illustrate the applicability of the related design criteria for sequential viaducts that cross Kırkgeçit River. The study area covers Kemerhisar – Eminlik – Çiftehan section of Ankara – Pozantı Highway. The basic steps performed in this study and the conclusions derived throughout the thesis can be summarized as follows:

1. Hydrologic characteristics of the basin are identified to obtain flow rates corresponding to different return periods. The scour countermeasure design is performed for a return period greater than 100 years, which is assumed to be conservative for the highway located in a rural area.

2. Water surface profile computations and scour depth determinations around piers of viaducts are performed using HEC-RAS program. Several possibilities are tested to observe the effect of channel dredging on scour depths at some sections having high velocity zones.

3. Riprap, partially grouted riprap, and articulated concrete blocks are tested for applicability around piers of viaducts using the design and implementation guidelines proposed by National Cooperative Highway Research Program of The United States Transportation Research Board. Economic analyses are carried out to obtain the most feasible solution.

4. Possibility of flood detention dam is analyzed. Due to the attenuation ability of the possible dam reservoir and construction cost of dam, this possibility is thought as infeasible.

5. The decision making is done according to the selection index, which is based on joint consideration of bed material, ice - debris load, construction aspects, inspection – maintenance conditions, and life cycle costs. Partially grouted riprap implementation is proposed according to the highest value of the selection index. The cost of partially grouted riprap is only 0.29% of the total cost of Çeleme Left Viaduct. Similar costs are also obtained for the other viaducts. Therefore, it is concluded that with the allocation of a relatively small additional budget for countermeasure implementation, the safety of the viaducts will be improved significantly.

6. As a future study, it is recommended to carry out a hydroeconomic analysis to determine the optimum return period of the flows. Such a study is based on determination of capital costs, flood damage risk cost, and total costs on annual basis for various return periods.

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APPENDIX A

LAYOUT OF THE STATIONS IN HEC-RAS

HEC – RAS software was executed by using 800 stations in Kırkgeçit Creek. The layout of the stations is given in Figure A.1 generally.

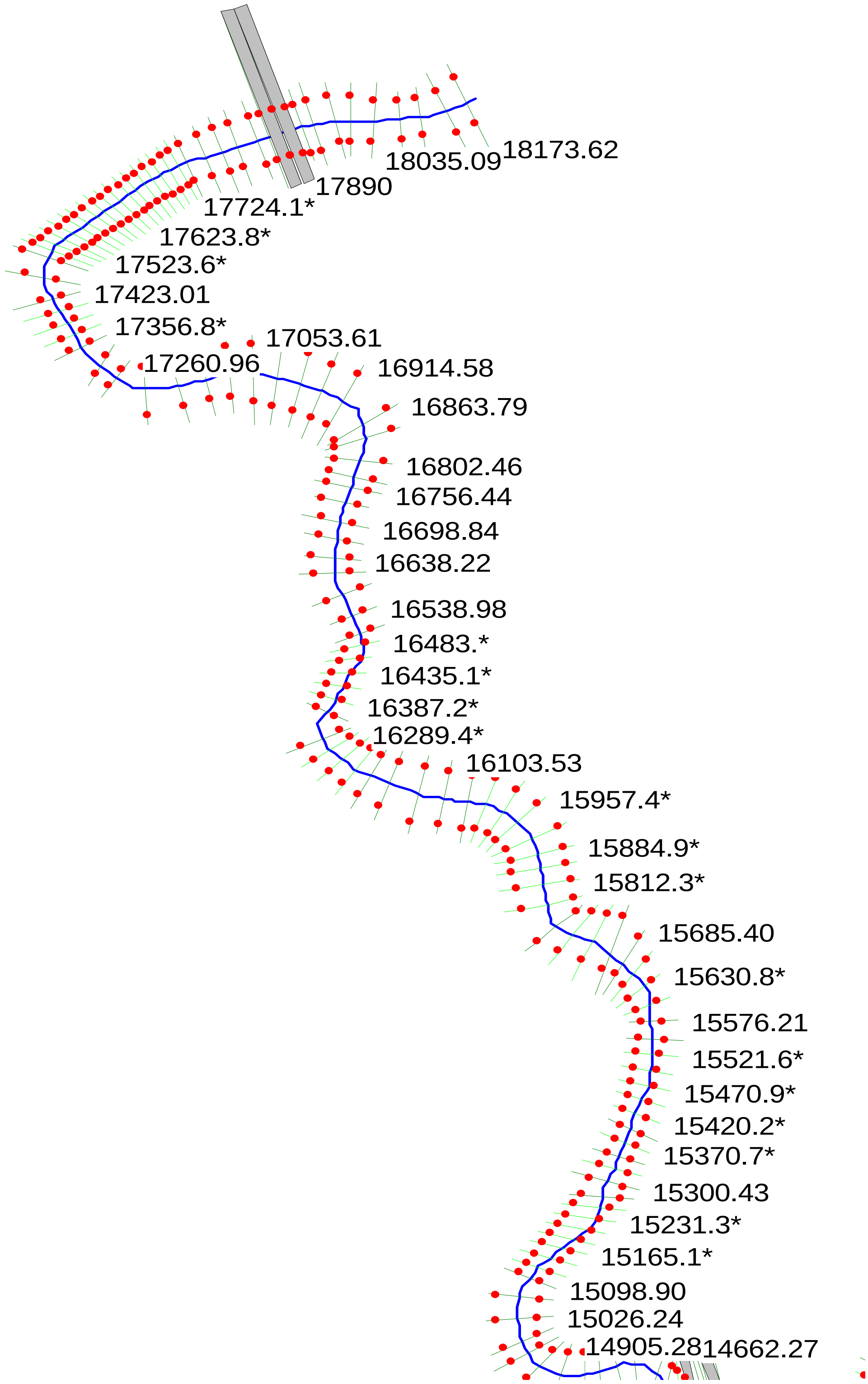


Figure A. 1 Stations of the Used Cross-sections in HEC - RAS

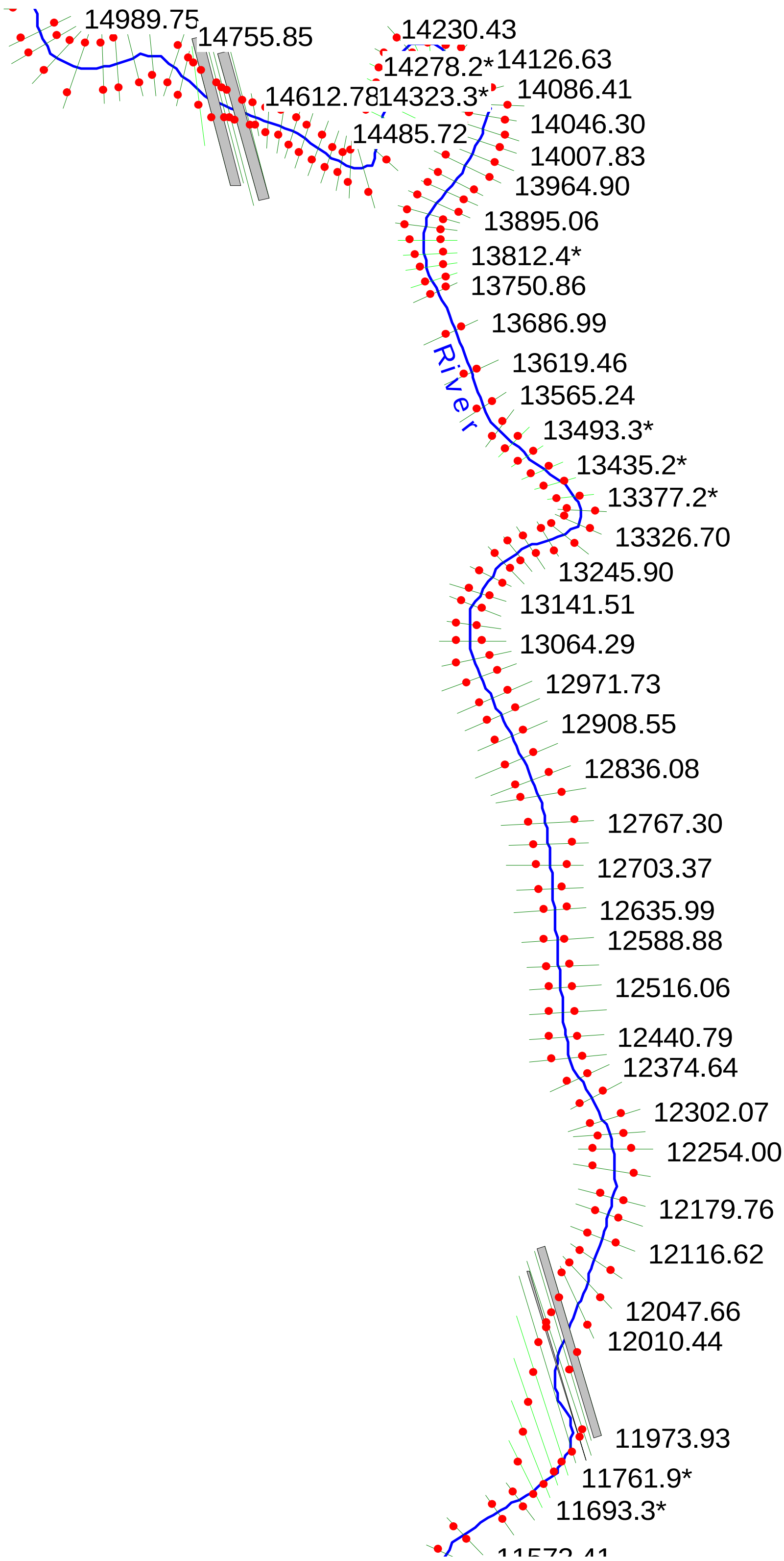


Figure A. 1 (Continued)

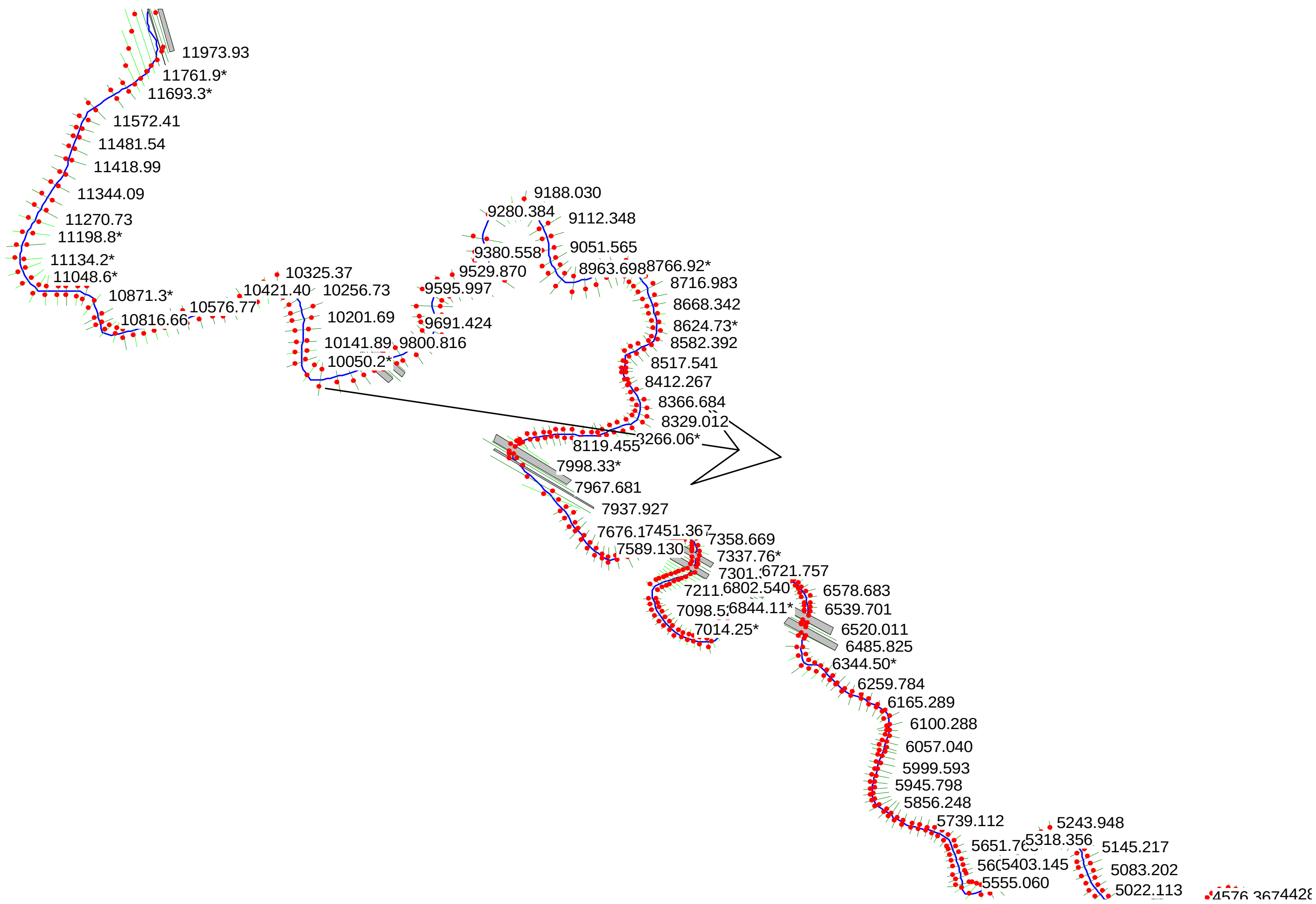


Figure A. 1 (Continued)

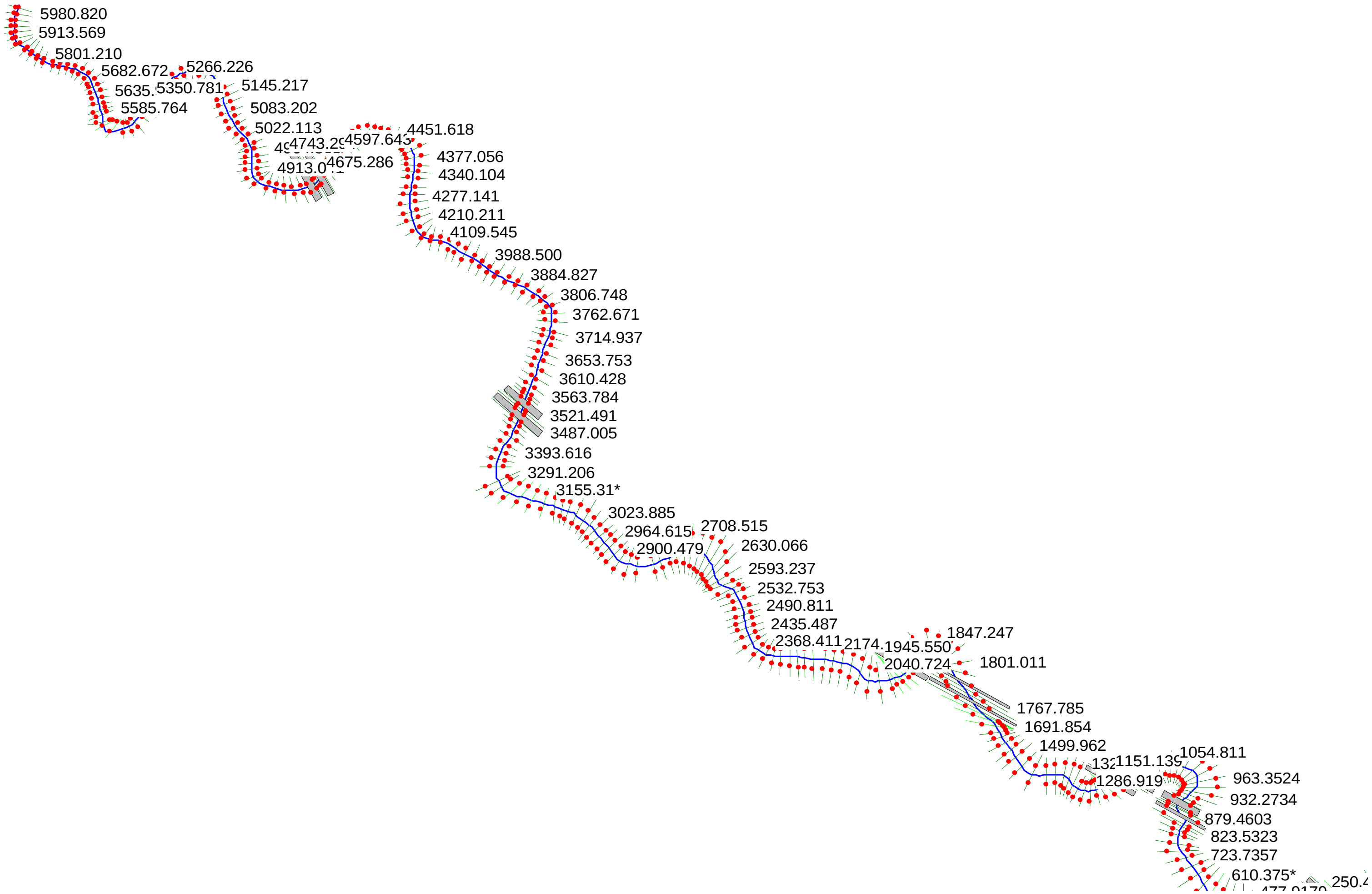


Figure A. 1 (Continued)

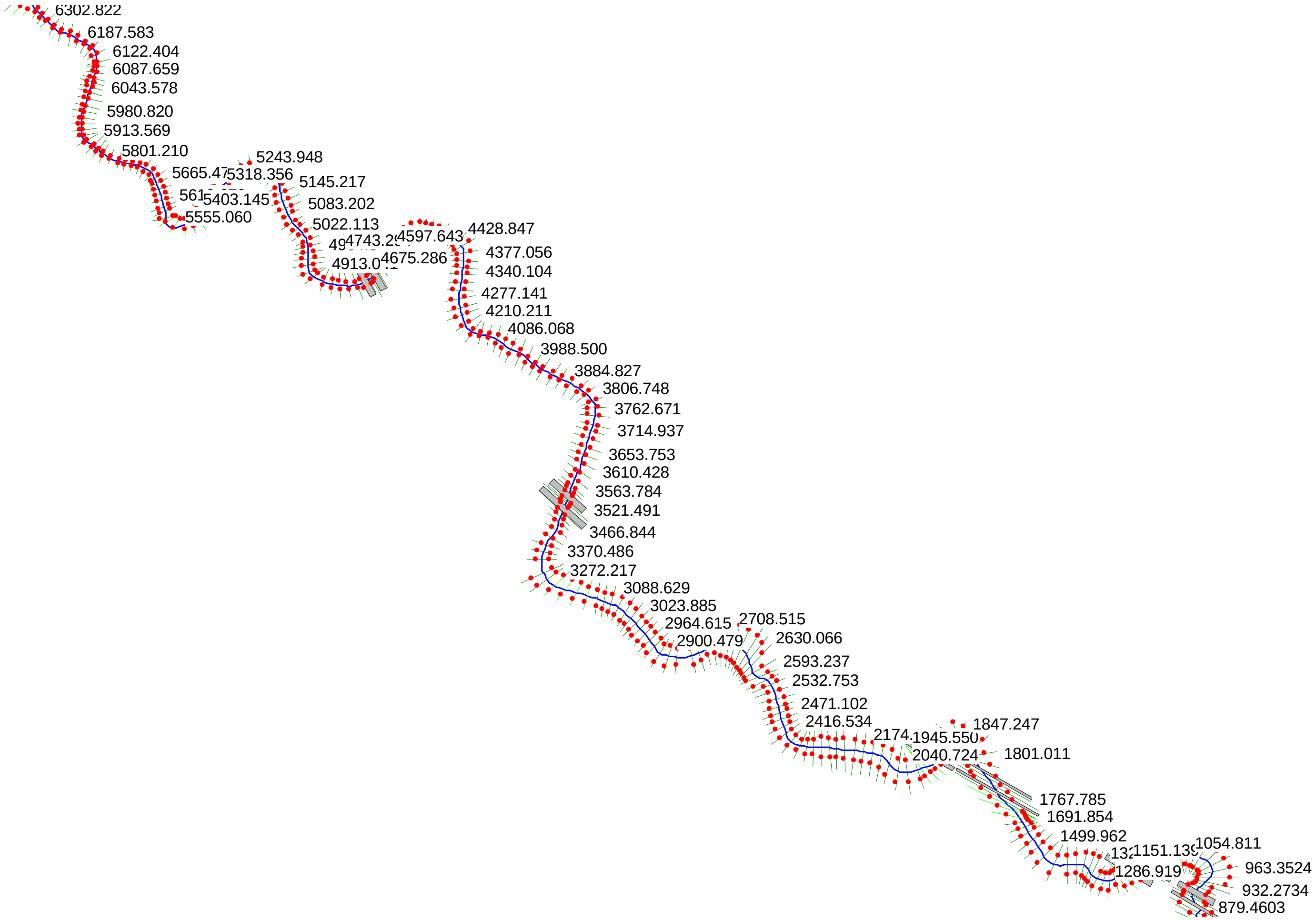


Figure A. 1 (Continued)

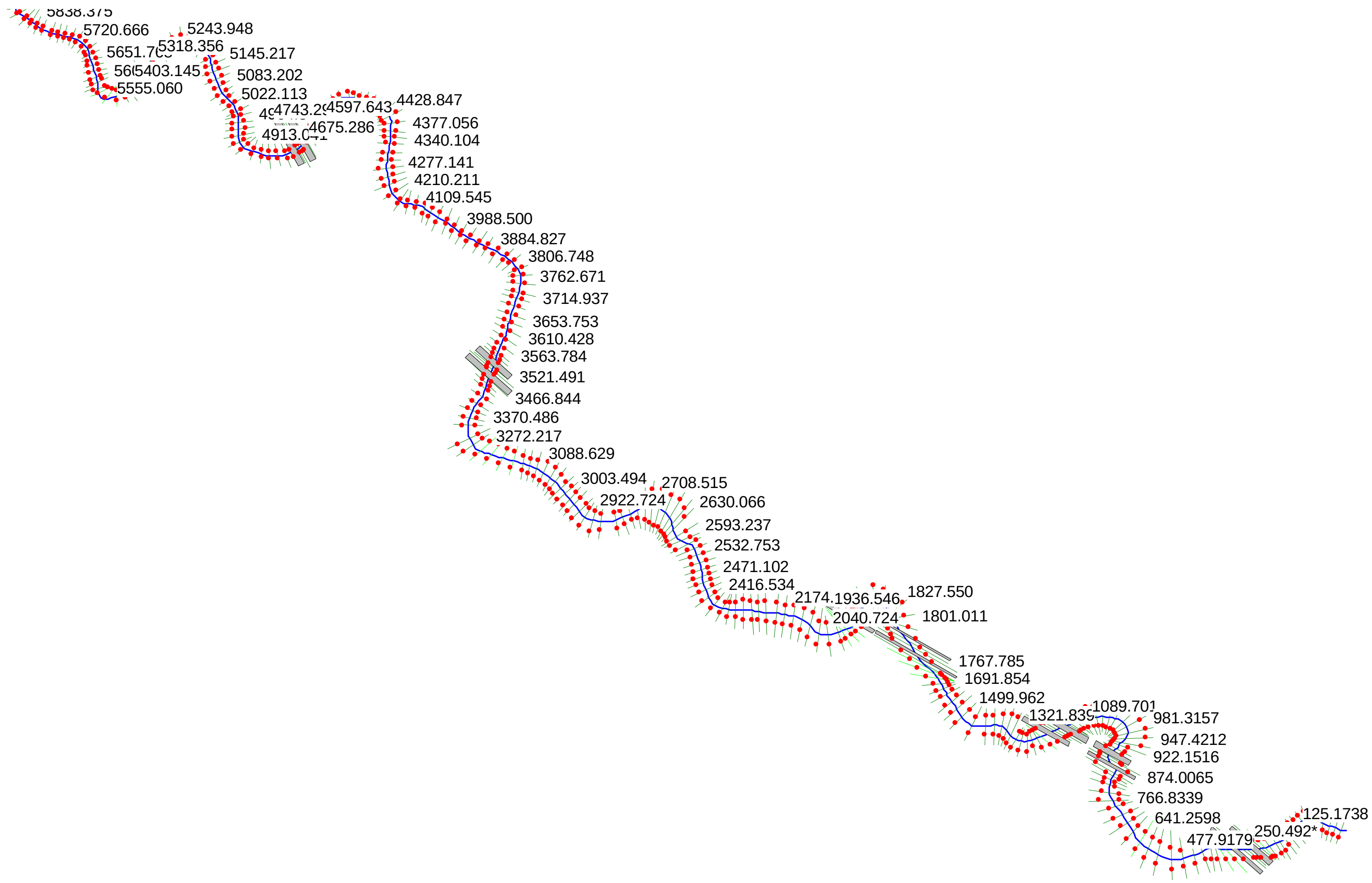


Figure A. 1 (Continued)

APPENDIX B

VELOCITY ZONES AND VELOCITY PROFILES AT ORIGINAL CROSS-SECTIONS WITH THE RELATED PARAMETERS

To determine the local maximum velocities and median riprap sizes before the excavation, velocity zones and velocity profiles are computed.

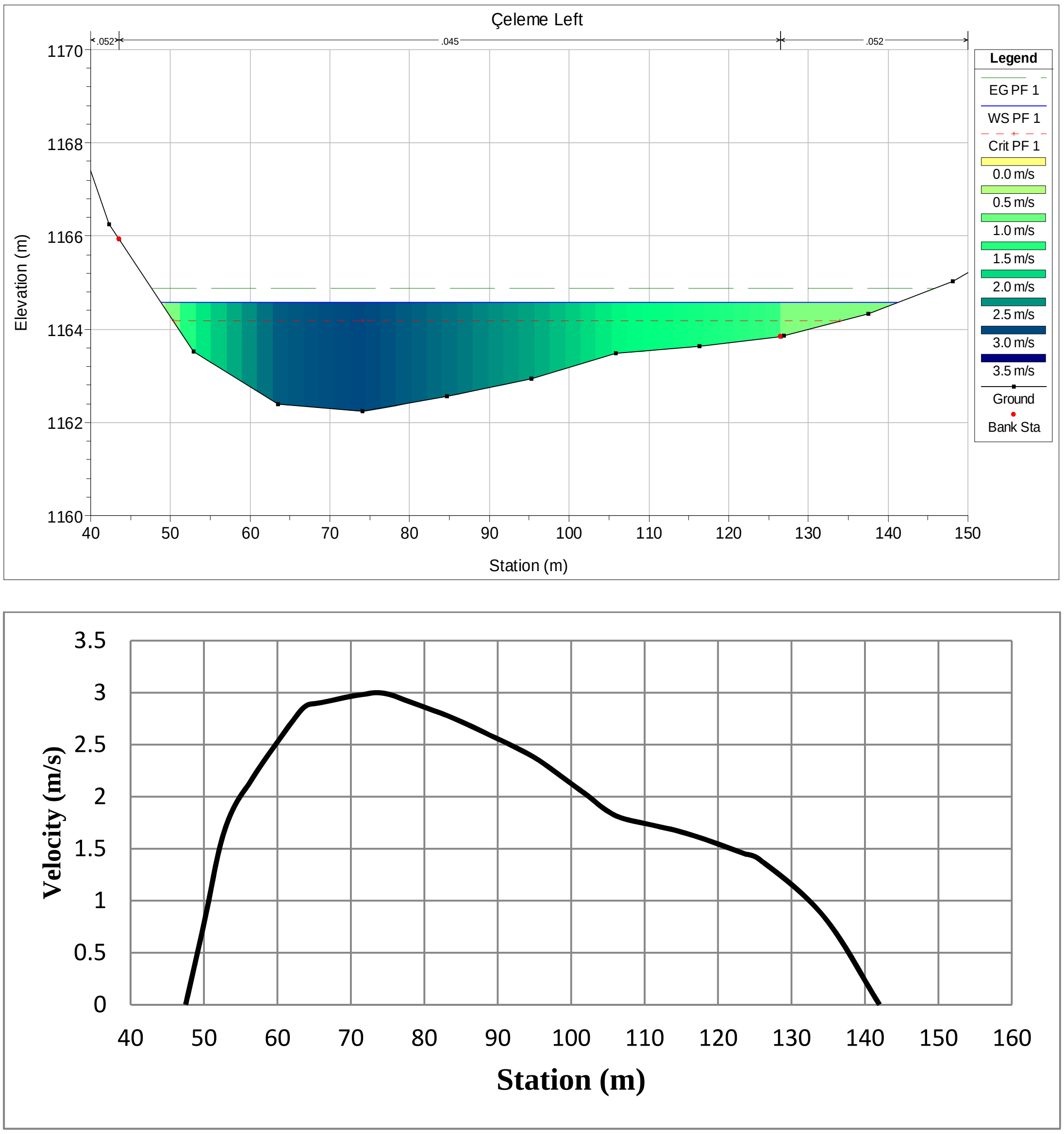


Figure B.1 Velocity Distribution for Çeleme Left Viaduct

Table B.1 Local Velocities, Scour Depths and Median Riprap Sizes for Çeleme Left

<table>
<tr><th>Station Coordinate (m)</th><th>Local Velocity(m/s)</th><th>Scour Depth (m)</th><th rowspan="2">Local Max Velocity (m/s)</th><th rowspan="2">Median Riprap Size (m)</th></tr>
<tr><td>70.75</td><td>2.98</td><td>1.97</td></tr>
<tr><td>105.25</td><td>1.89</td><td>1.47</td><td rowspan="2">2.98</td><td rowspan="2">0.55</td></tr>
<tr><td>139.75</td><td>0.86</td><td>0.75</td></tr>
</table>

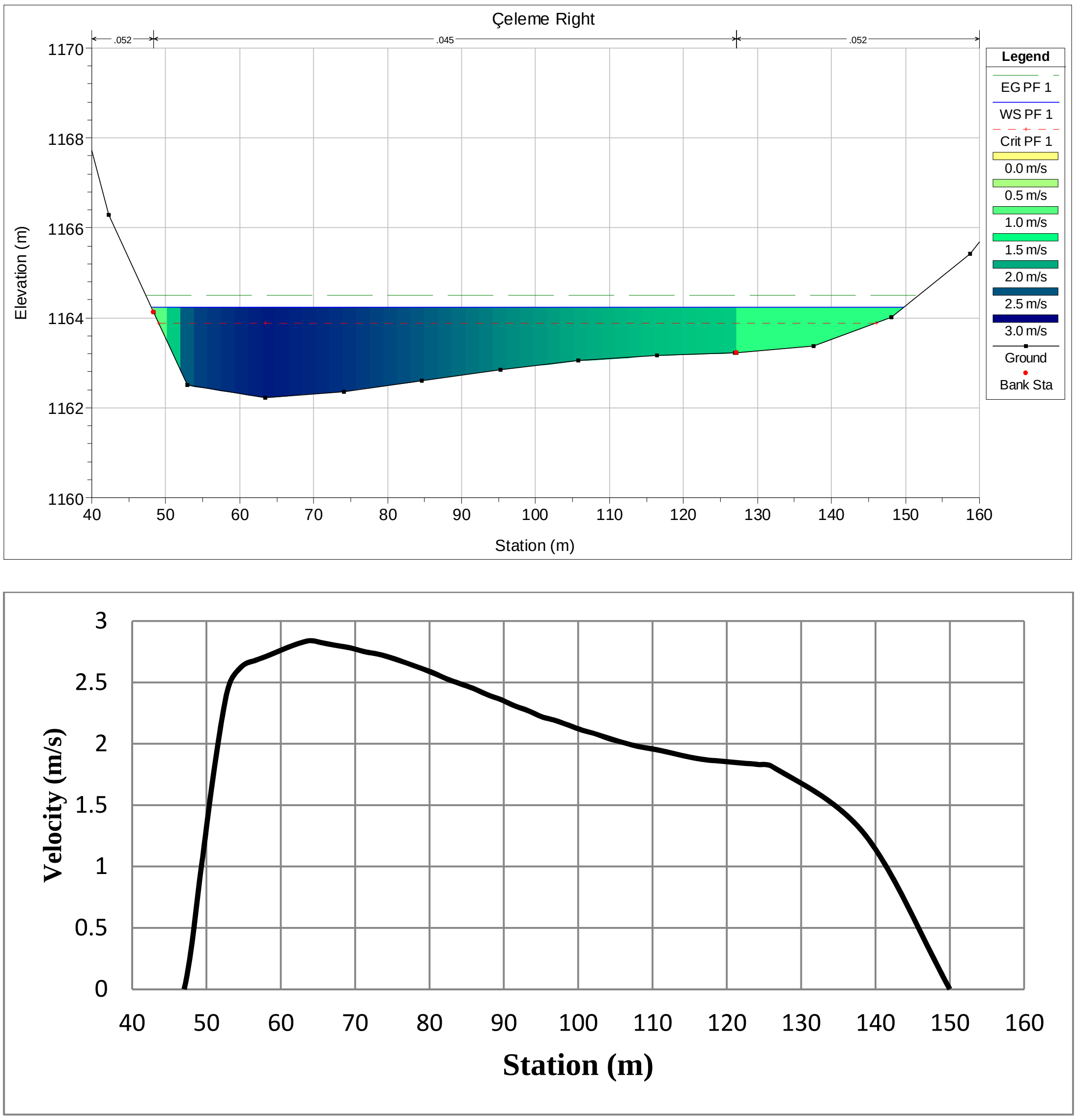


Figure B. 2 Velocity Distribution for Çeleme Right Viaduct

Table B. 2 Local Velocities, Scour Depths and Median Riprap Sizes for Çeleme Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
70.75	2.75	1.86		
105.25	2.01	1.52	**2.75**	**0.47**
139.75	1.26	1.16		

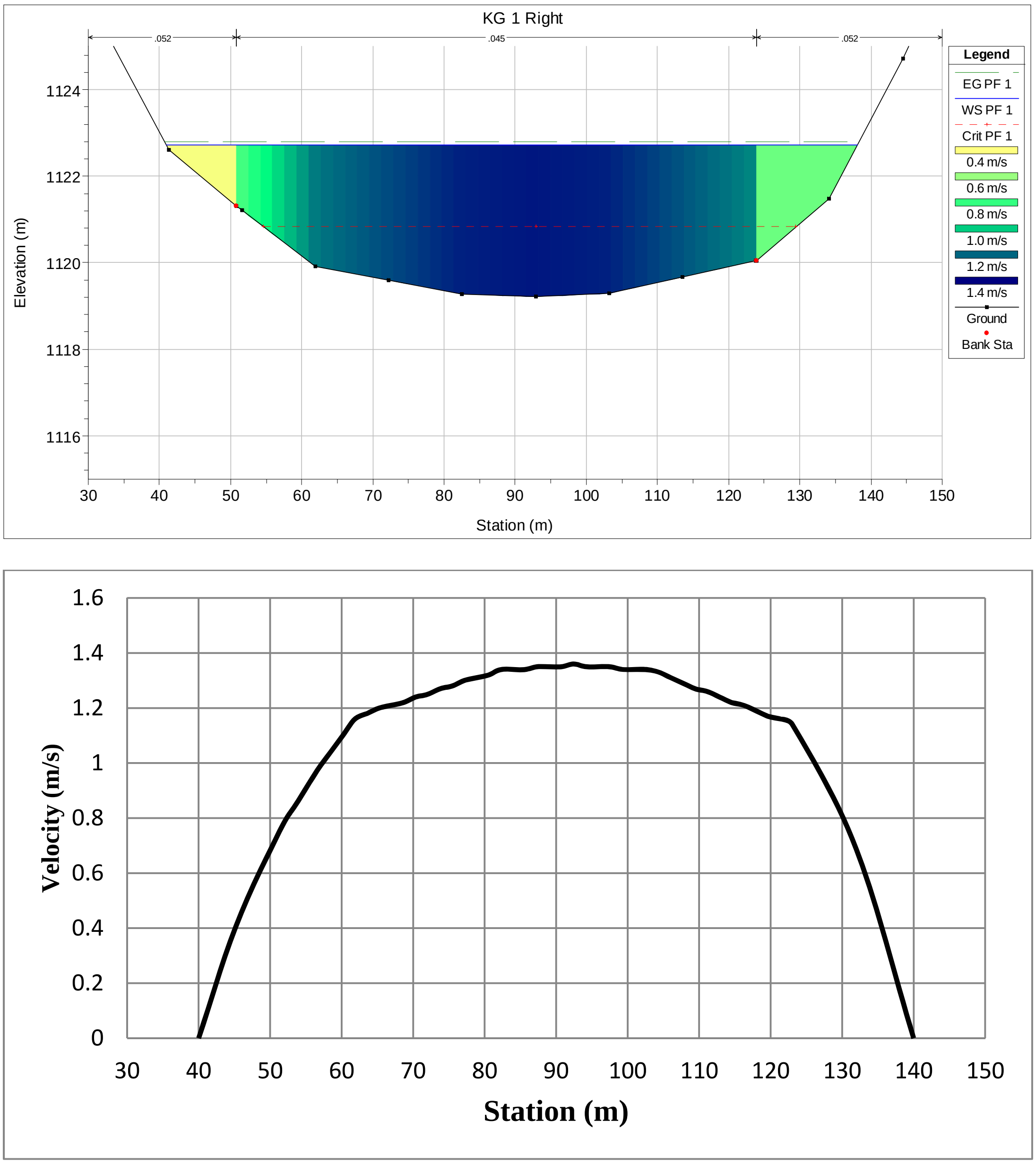


Figure B. 3 Velocity Distribution for KG1 Right

Table B.3 Local Velocities, Scour Depths and Median Riprap Sizes for KG1 Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
70.75	1.24	2.08		
105.25	1.31	2.16	**1.31**	**0.10**

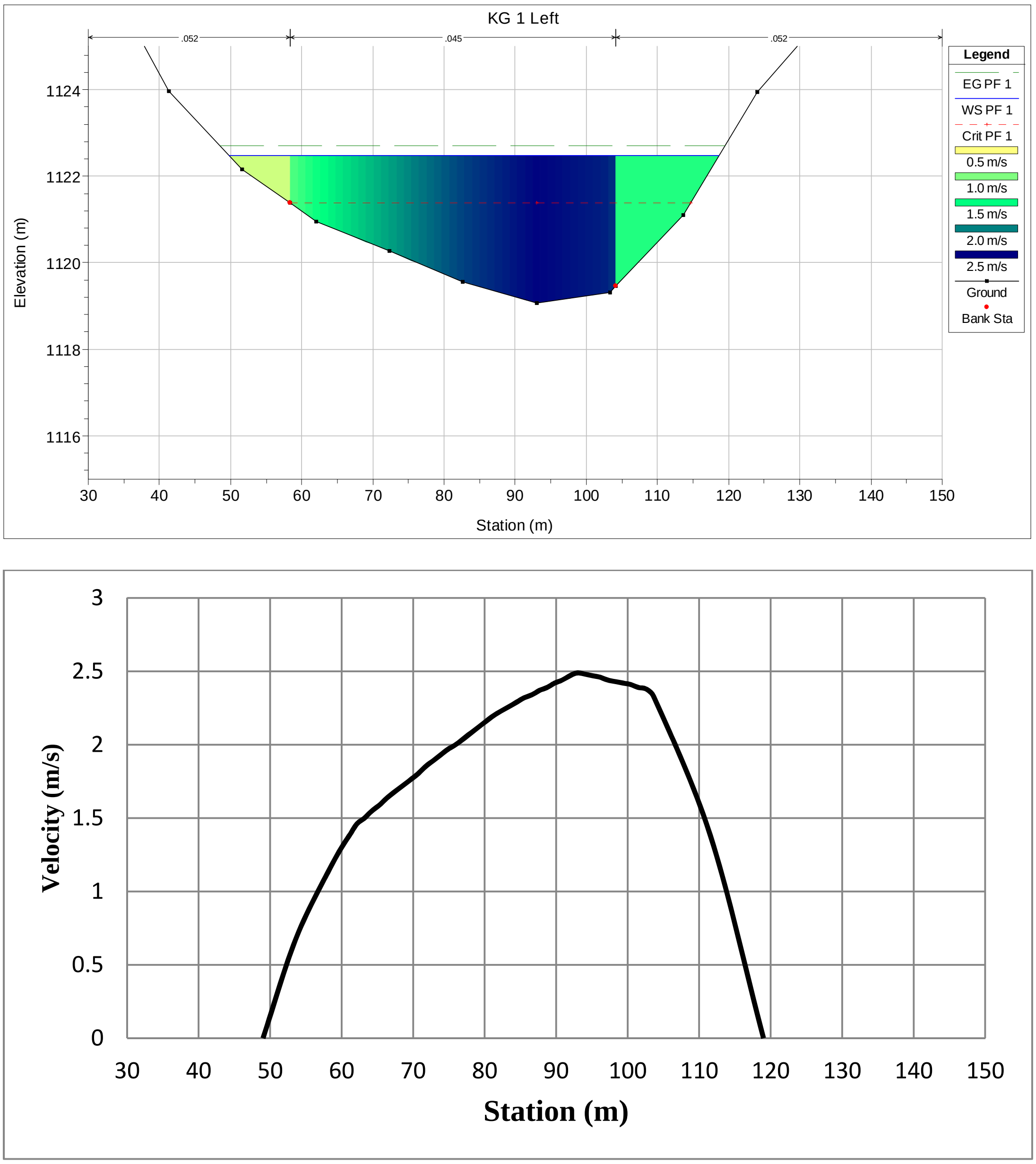


Figure B. 4 Velocity Distribution for KG1 Left

Table B. 4 Local Velocities, Scour Depths and Median Riprap Sizes for KG1 Left

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
70.75	1.80	2.33		
105.25	1.38	2.15	**1.80**	**0.20**

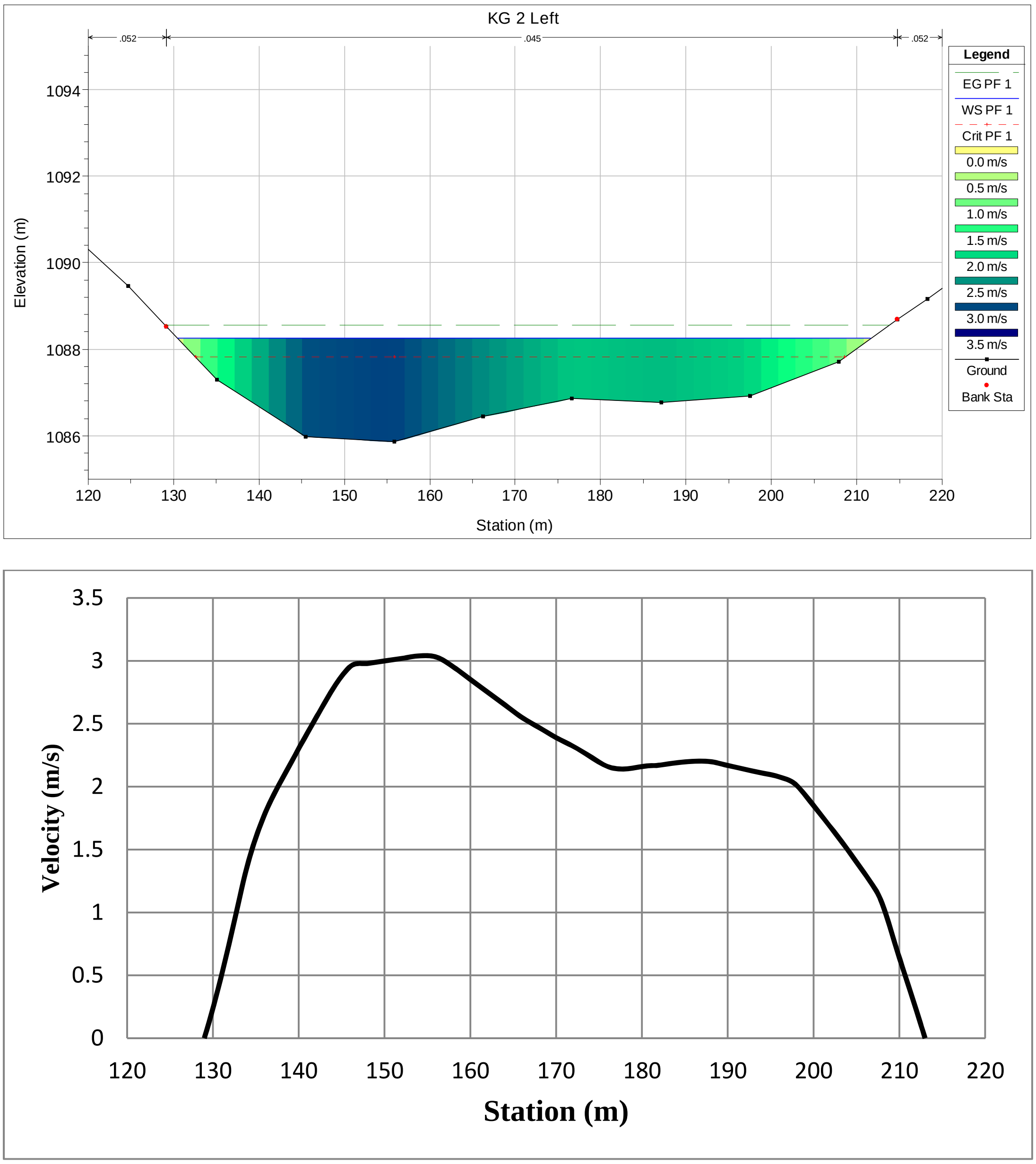
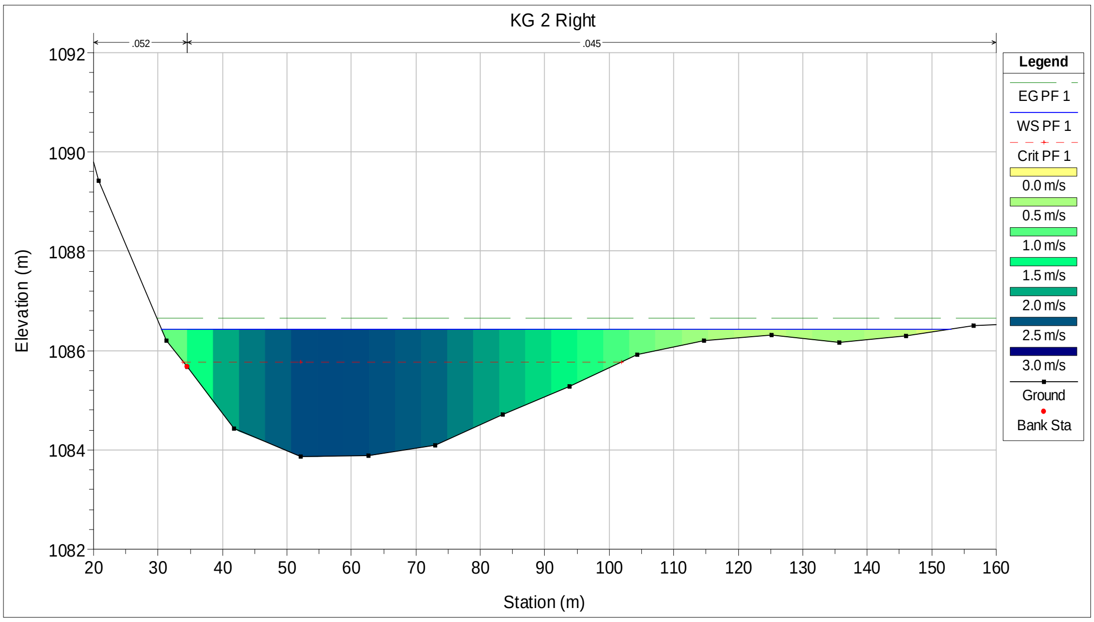


Figure B. 5 Velocity Distribution for KG2 Left

Table B. 5 Local Velocities, Scour Depths and Median Riprap Sizes for K2 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
139.00	2.07	3.64		
173.25	2.24	3.79	**2.24**	**0.31**
207.5	1.10	5.18		



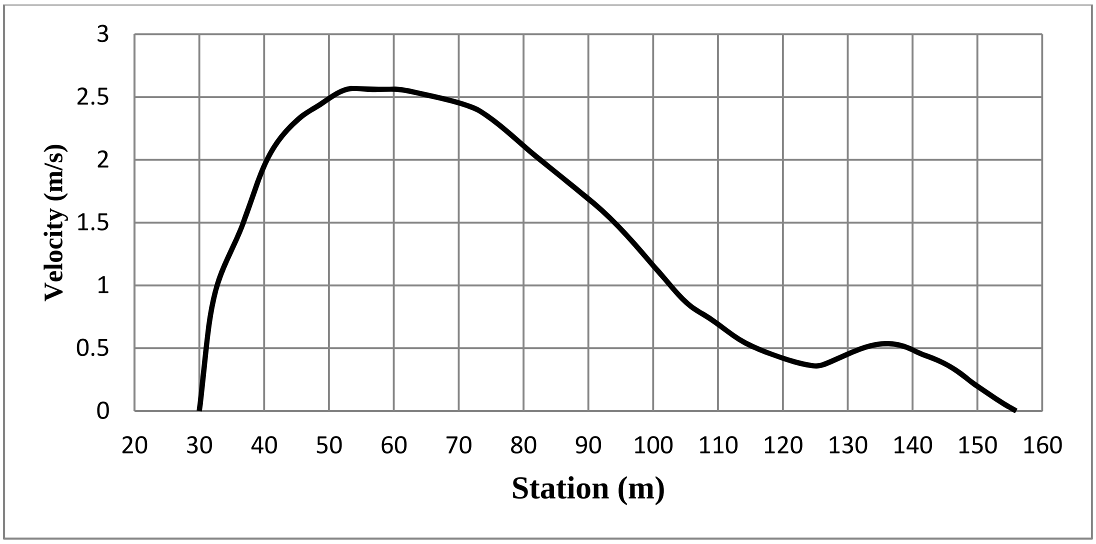


Figure B. 6 Velocity Distribution for KG2 Right

Table B. 6 Local Velocities, Scour Depths and Median Riprap Sizes for KG2 Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
36.25	1.46	3.00		
70.75	2.47	4.19	**2.47**	**0.38**
105.25	0.86	2.16		
139.75	0.45	1.45		

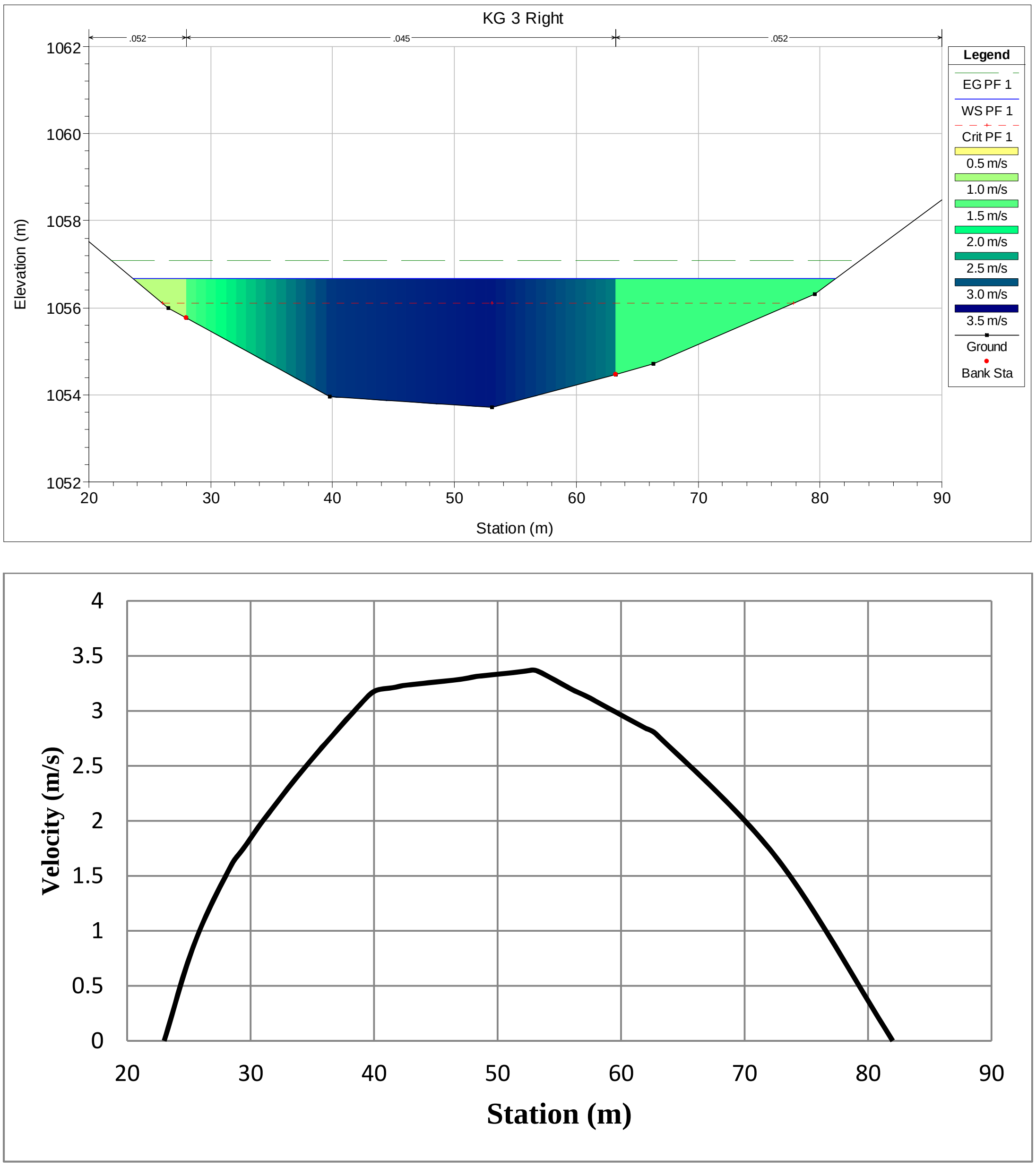


Figure B. 7 Velocity Distribution for KG3 Right

Table B. 7 Local Velocities, Scour Depths and Median Riprap Sizes for KG3 Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
36.25	2.77	3.16		
70.75	1.66	2.40	**2.77**	**0.47**

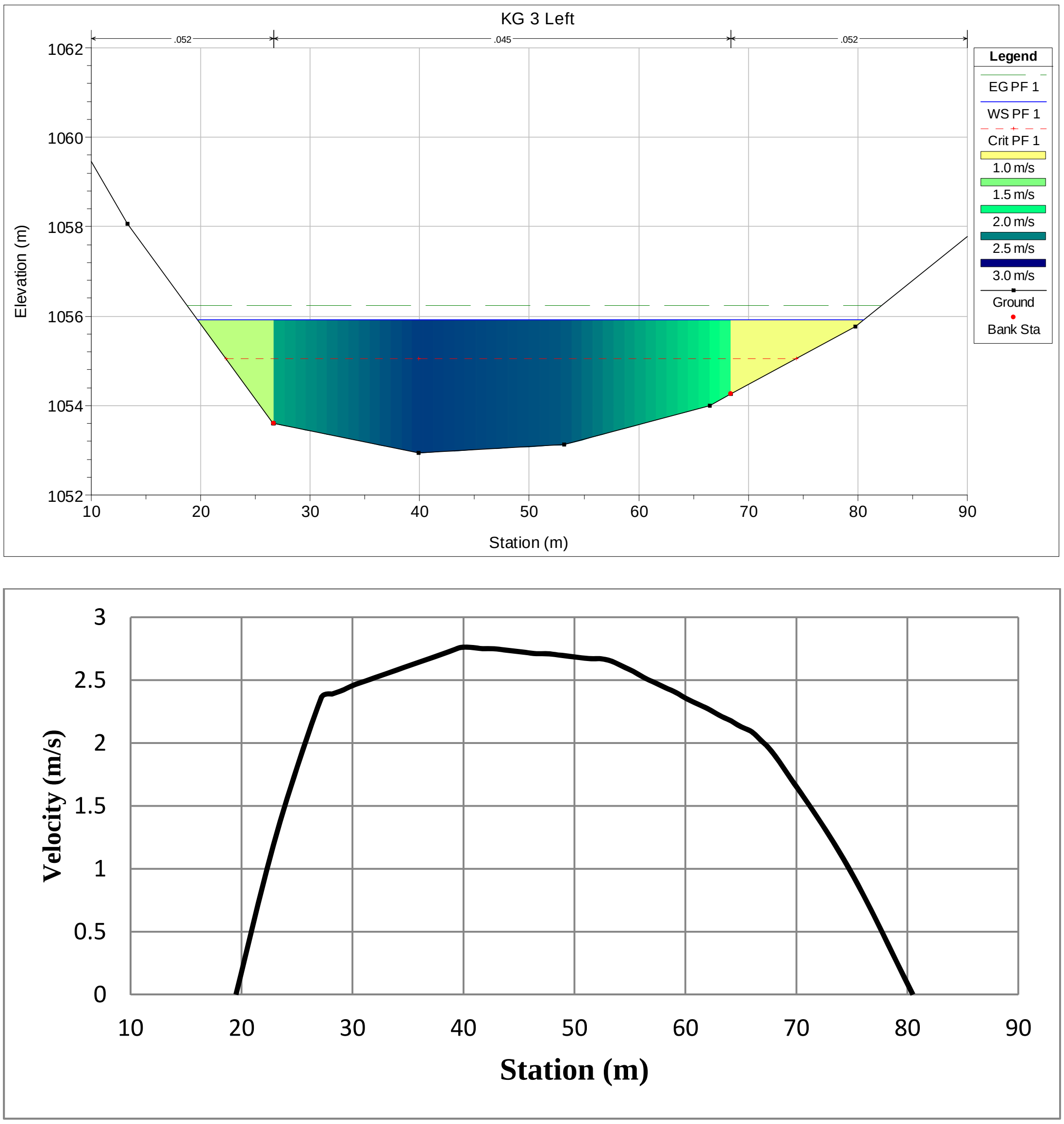


Figure B. 8 Velocity Distribution for KG3 Left

Table B. 8 Local Velocities, Scour Depths and Median Riprap Sizes for KG3 Left

<table>
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<tr><td>36.25</td><td>2.64</td><td>3.21</td></tr>
<tr><td>70.75</td><td>1.05</td><td>1.95</td><td>2.64</td><td>0.43</td></tr>
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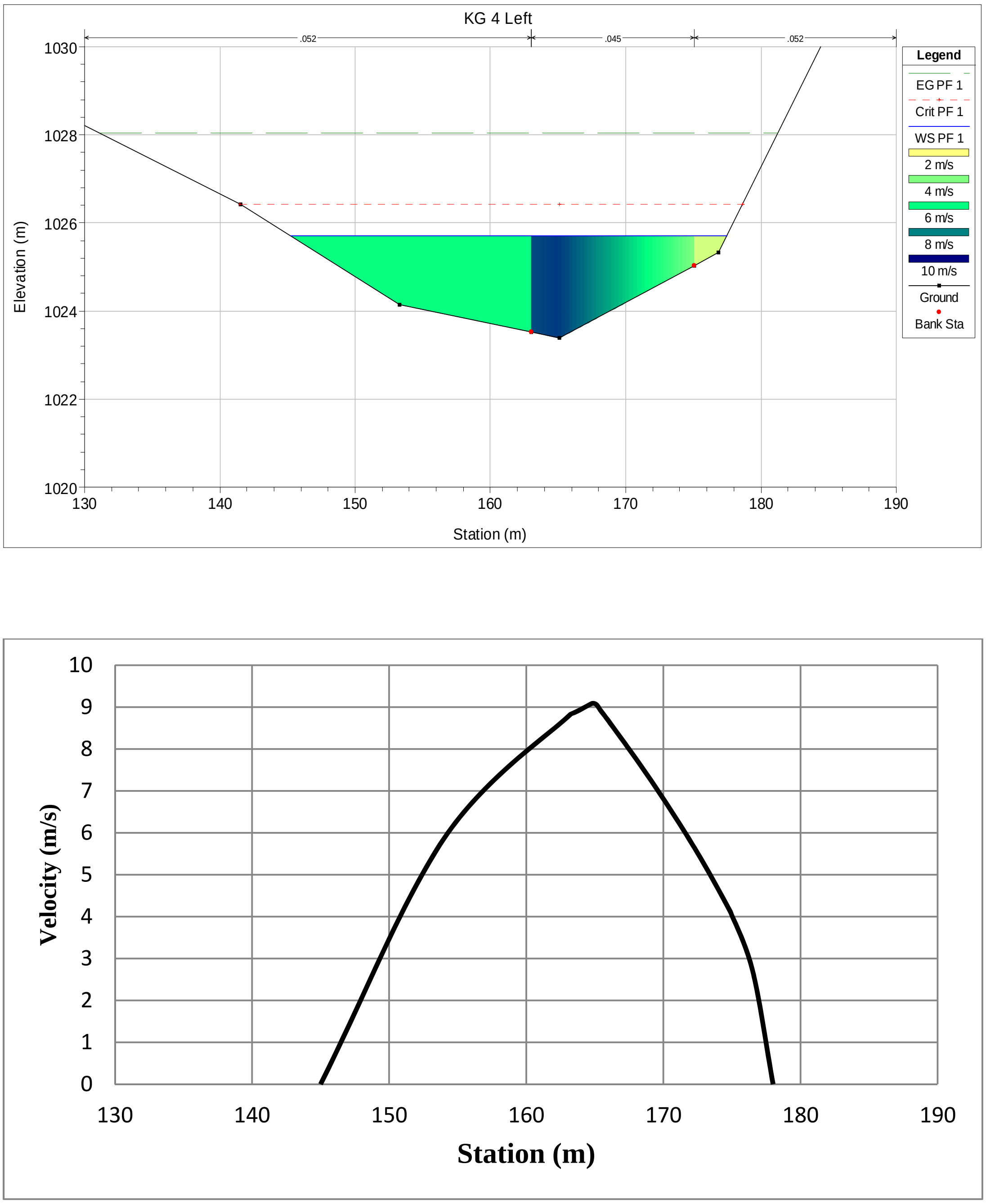

Figure B. 9 Velocity Distribution for KG4 Left

There is no scour in the Kırkgeçit 4 Left Bridge

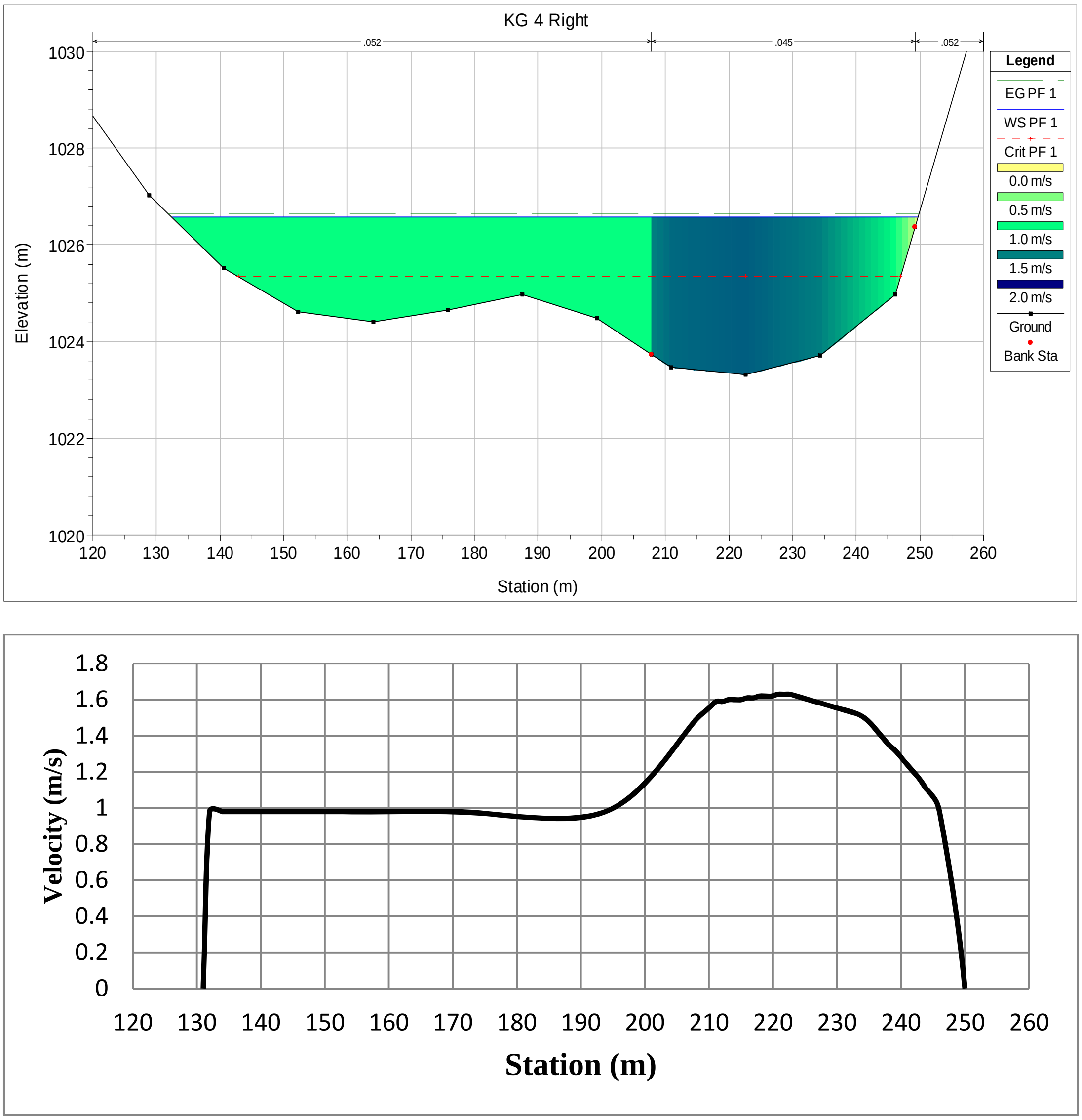

Figure B. 10 Velocity Distribution for KG4 Right

Table B.9 Local Velocities, Scour Depths and Median Riprap Sizes for KG4 Right

<table>
<tr><th>Station Coordinate (m)</th><th>Local Velocity(m/s)</th><th>Scour Depth (m)</th><th>Local Max Velocity (m/s)</th><th>Median Riprap Size (m)</th></tr>
<tr><td>139.75</td><td>0.98</td><td>1.44</td><td rowspan="4">1.50</td><td rowspan="4">0.14</td></tr>
<tr><td>174.25</td><td>0.98</td><td>1.59</td></tr>
<tr><td>208.75</td><td>1.50</td><td>2.02</td></tr>
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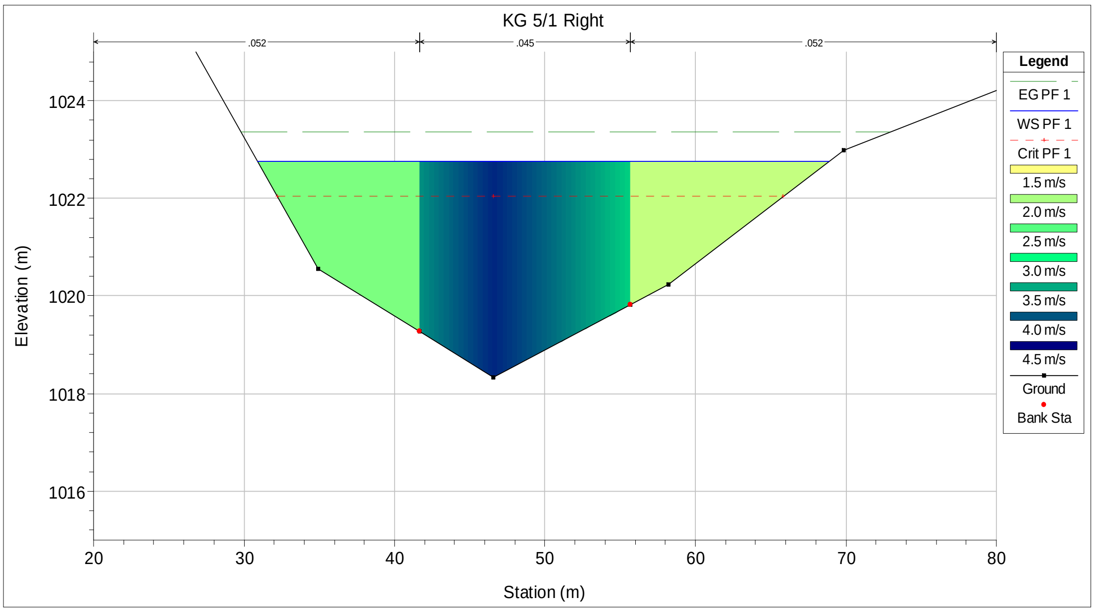


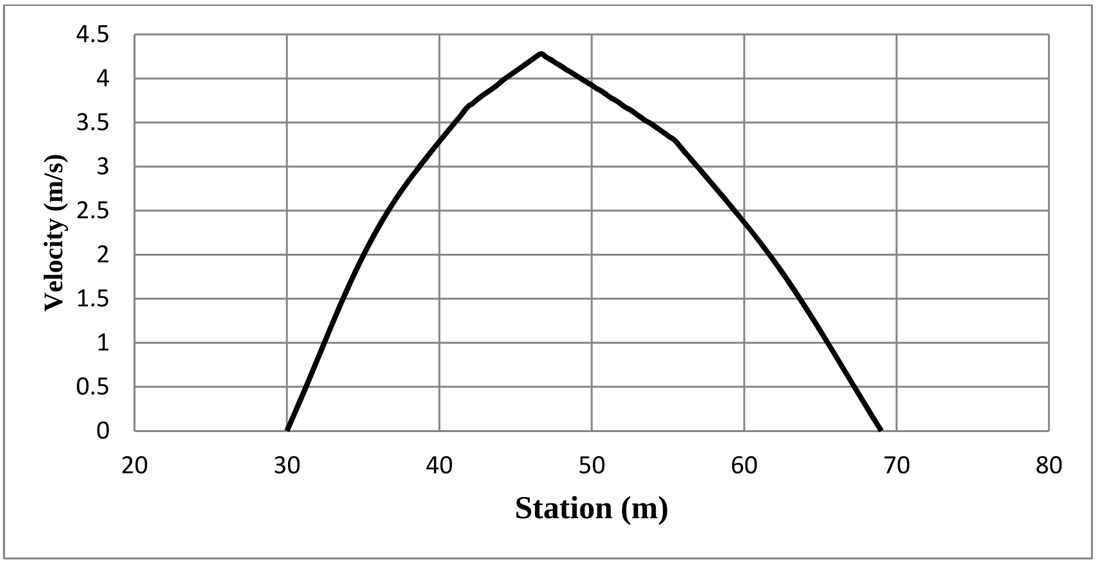
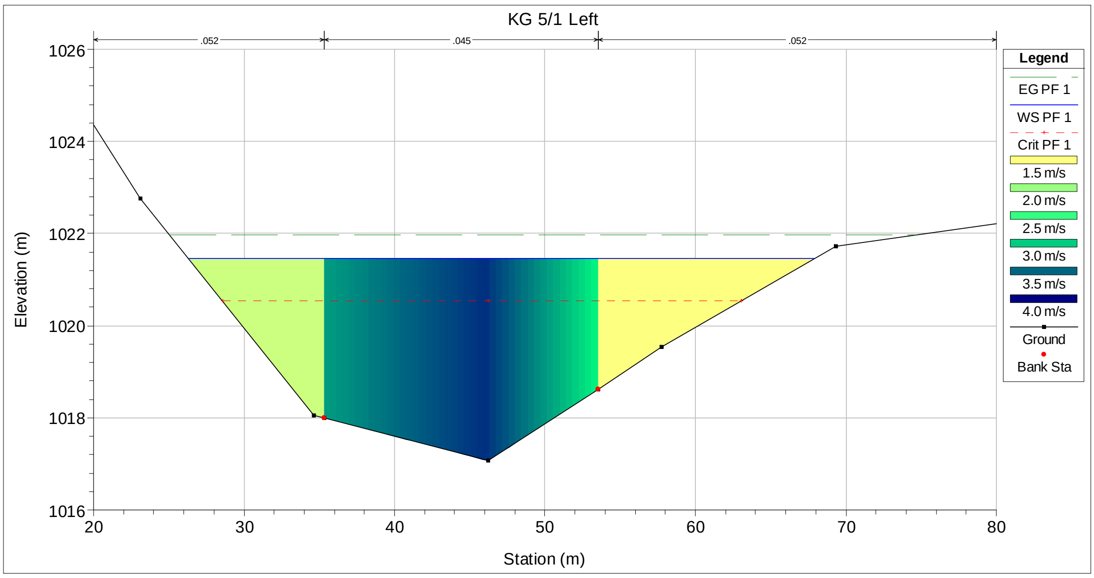


Figure B. 11 Velocity Distribution for KG 5/1 Right

Table B.10 Local Velocities, Scour Depths and Median Riprap Sizes for KG 5/1 Right

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
36.25	2.26	3.13	**2.26**	**0.32**



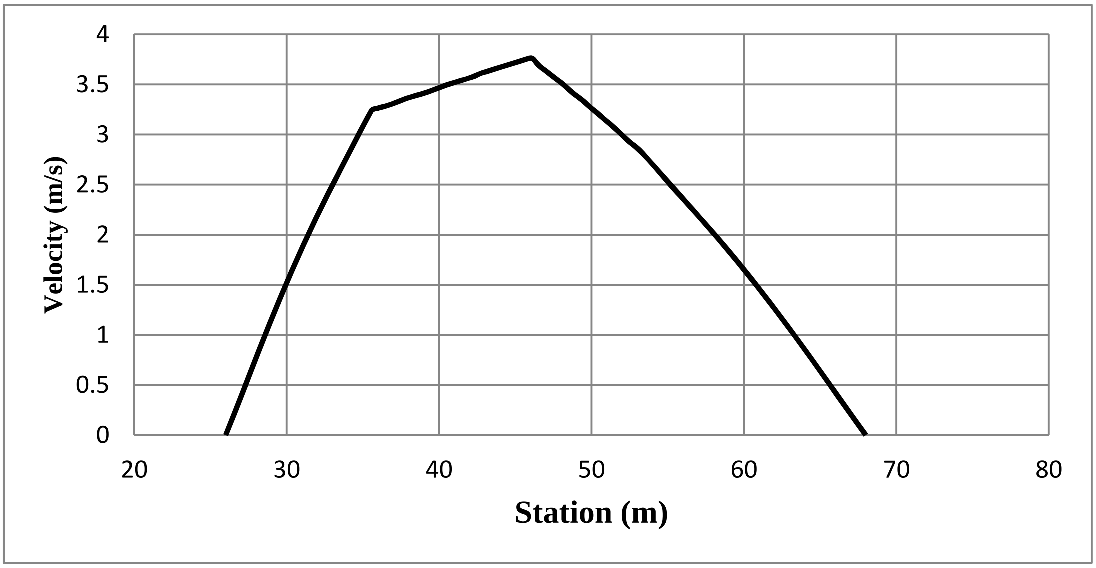


Figure B. 12 Velocity Distribution for KG 5/1 Left

Table B.11 Local Velocities, Scour Depths and Median Riprap Sizes for KG 5/1 Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
36.25	3.28	11.39	**3.28**	**0.67**

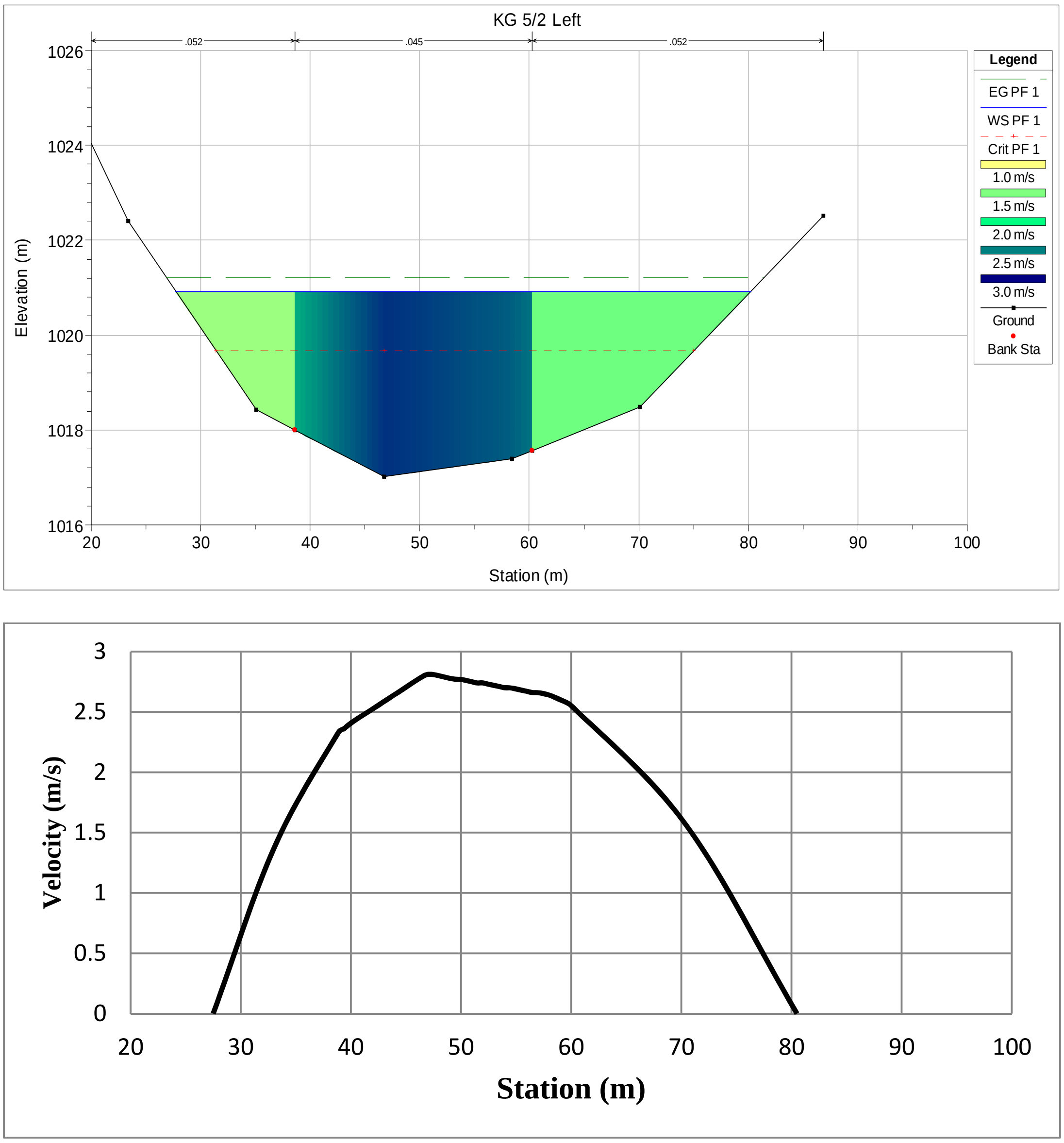


Figure B. 13 Velocity Distribution for KG 5/2 Left

Table B.12 Local Velocities, Scour Depths and Median Riprap Sizes for KG 5/2 Left

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
36.25	1.38	1.50		
70.75	1.57	1.55	**1.57**	**0.15**

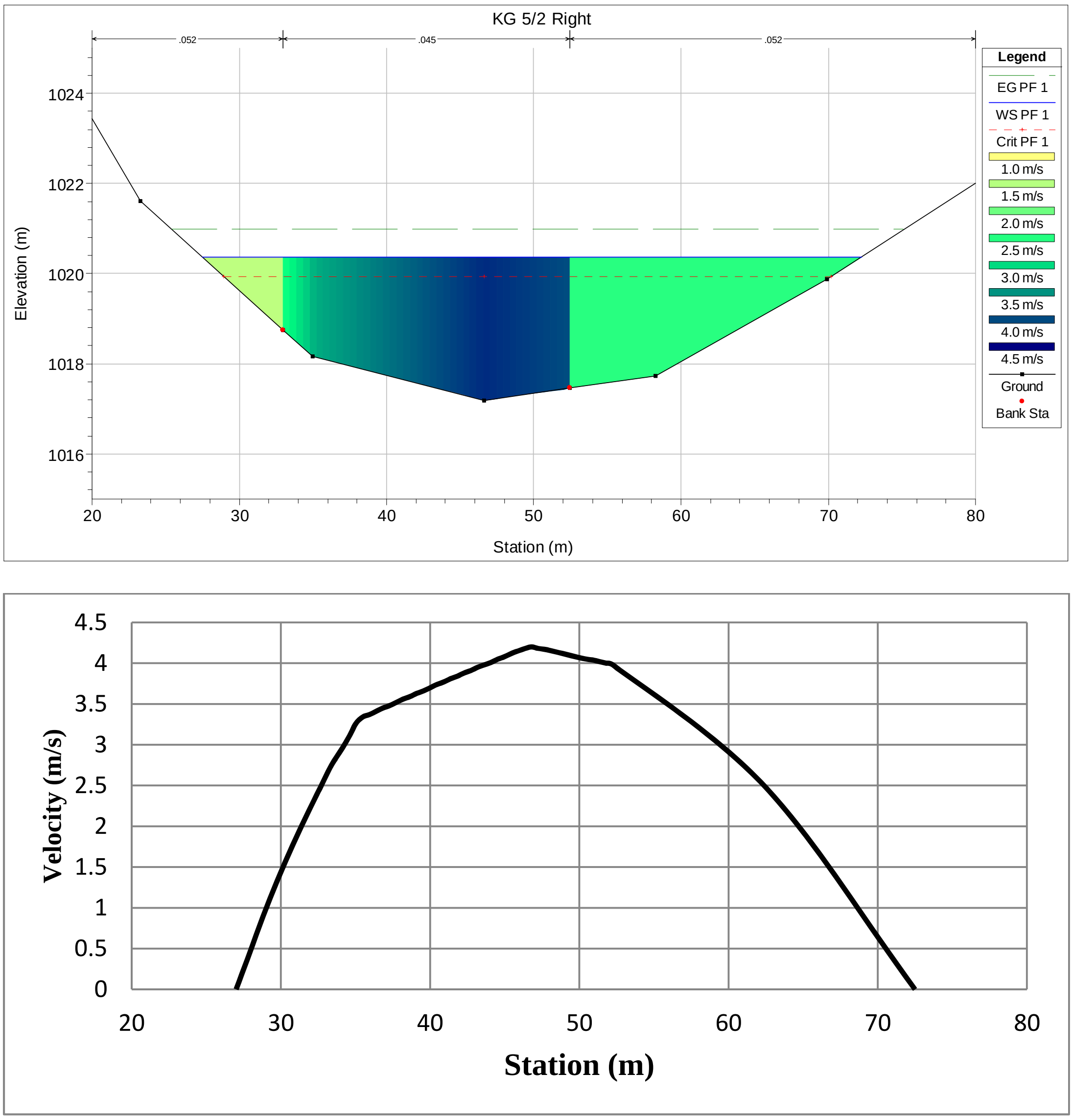
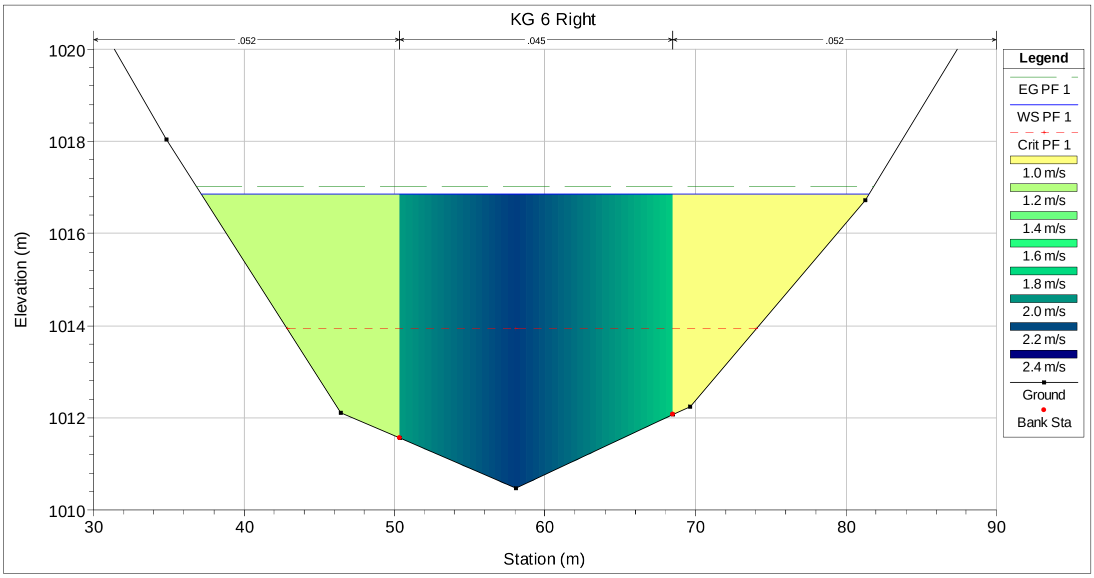


Figure B. 14 Velocity Distribution for KG 5/2 Right

Table B.13 Local Velocities, Scour Depths and Median Riprap Sizes for KG 5/2 Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
36.25	3.41	2.17		
70.75	2.48	1.45	**3.41**	**0.72**



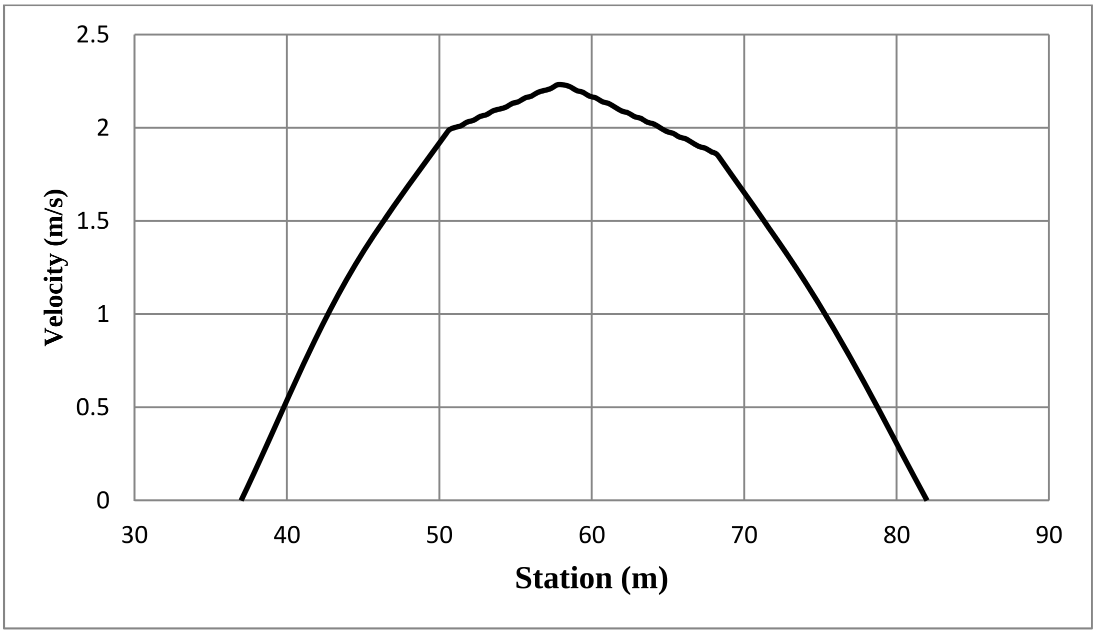
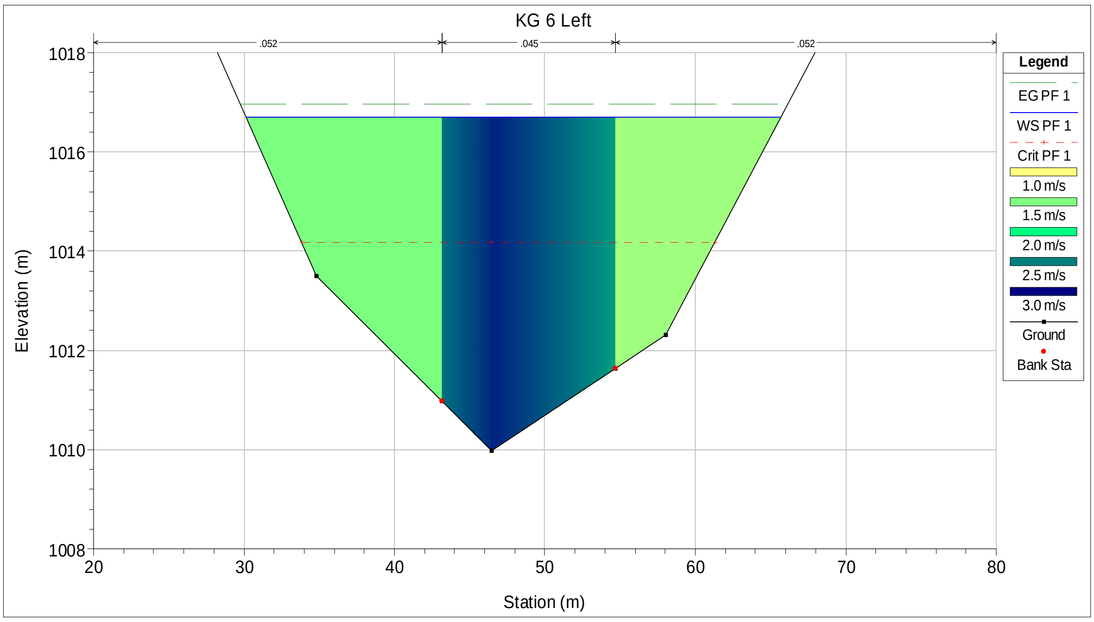


Figure B. 15 Velocity Distribution for KG 6 Right

Table B.14 Local Velocities, Scour Depths and Median Riprap Sizes for KG 6 Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
70.75	1.01	1.19	**1.01**	**0.06**



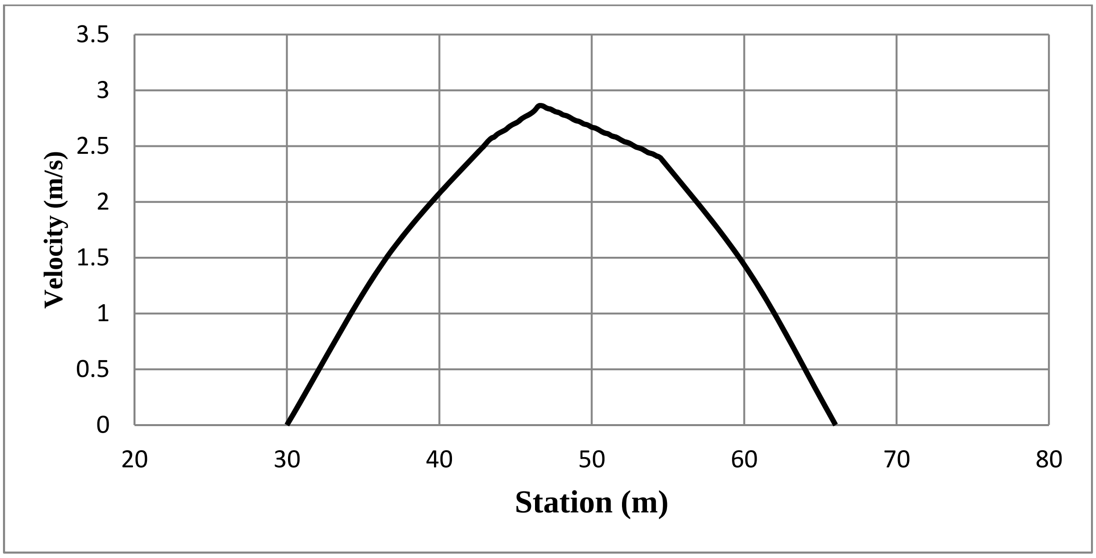
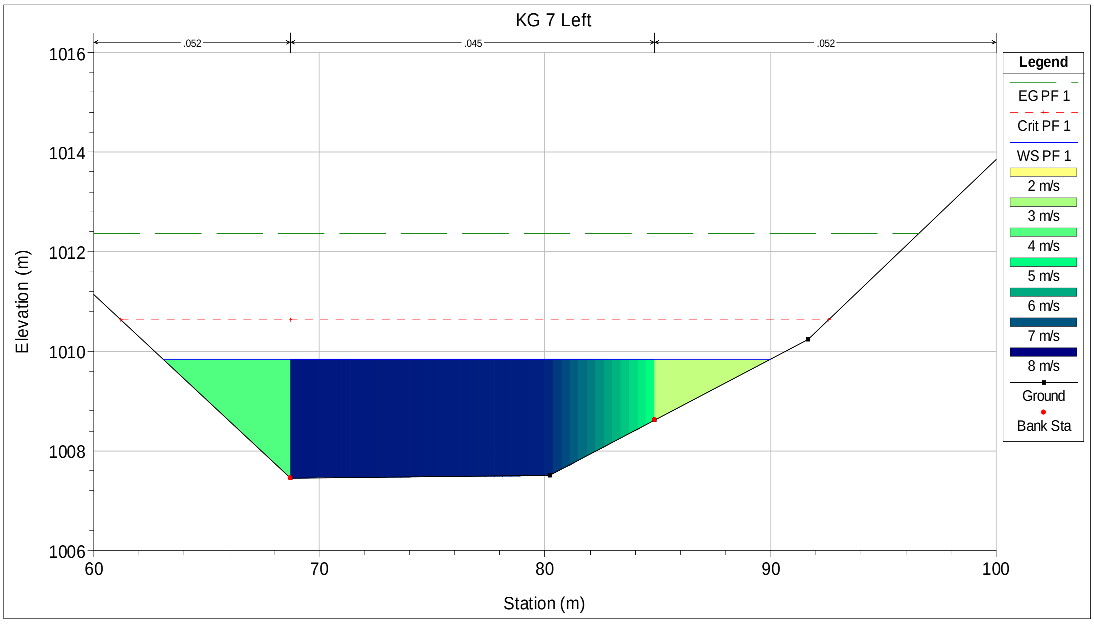


Figure B. 16 Velocity Distribution for KG 6 Left

Table B.15 Local Velocities, Scour Depths and Median Riprap Sizes for KG 6 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
36.25	1.51	1.39	**1.51**	**0.14**



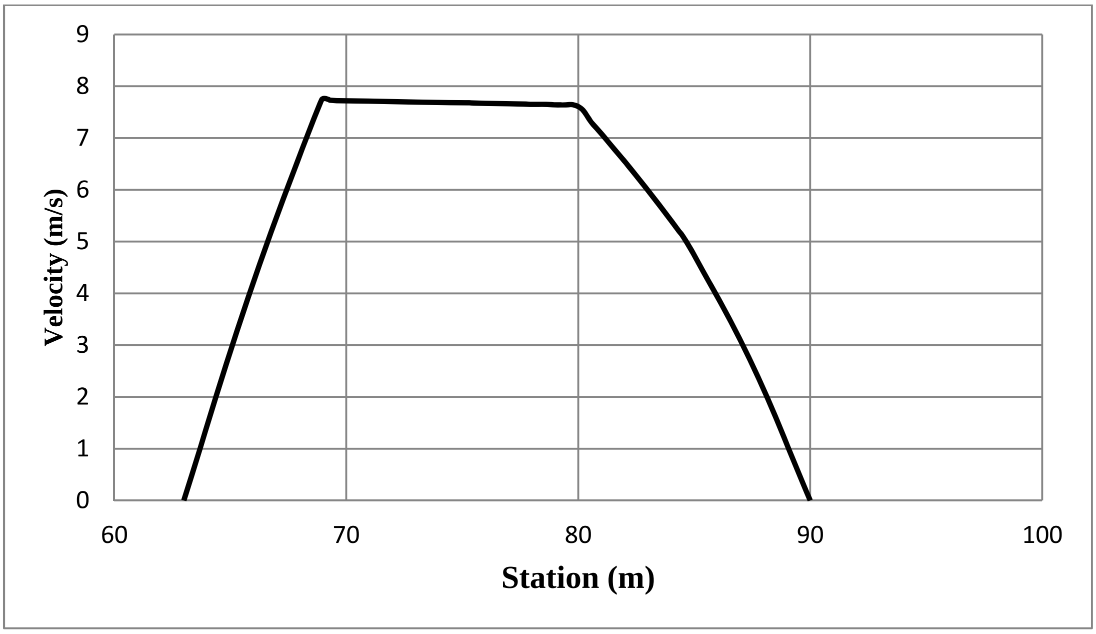


Figure B. 17 Velocity Distribution for KG 7 Left

Table B.16 Local Velocities, Scour Depths and Median Riprap Sizes for KG 7 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
87.99	2.69	1.80	**2.69**	**0.45**

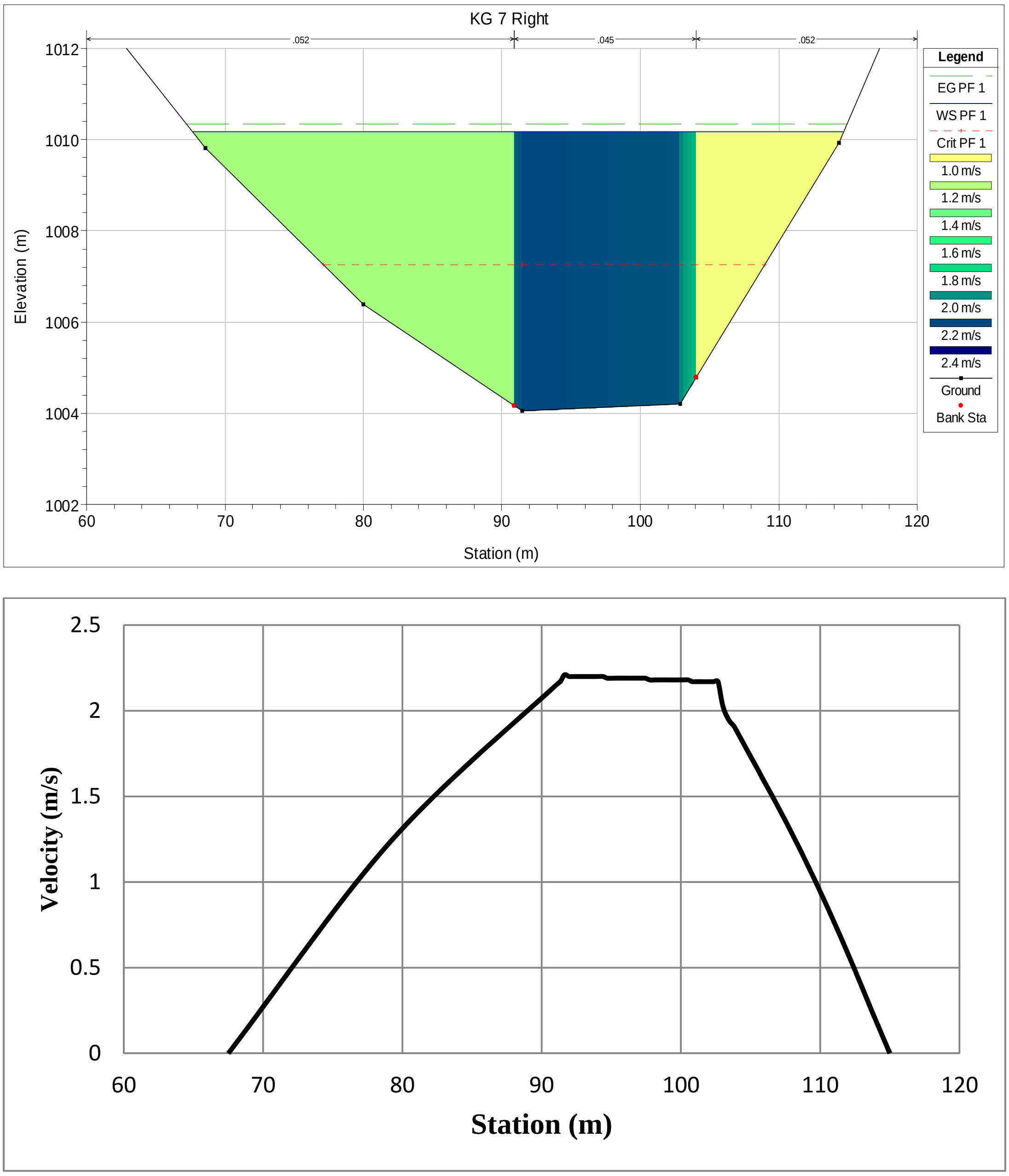
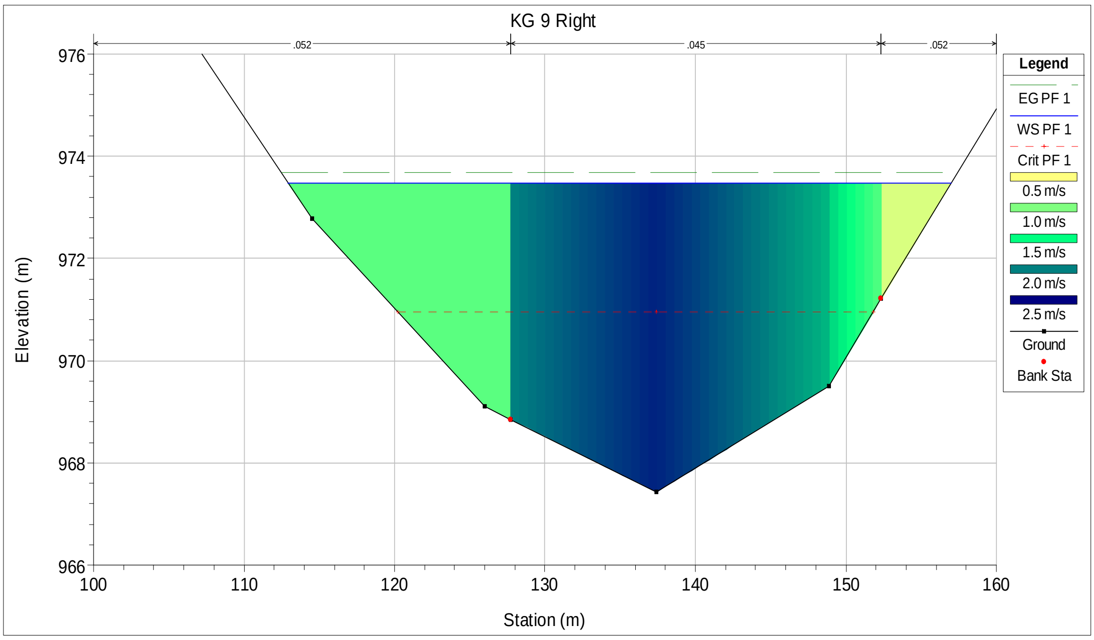


Figure B.18 Velocity Distribution for KG 7 Right

Table B.17 Local Velocities, Scour Depths and Median Riprap Sizes for KG 7 Right

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
36.25	1.24	1.43		
105.25	1.03	1.63	**1.24**	**0.10**



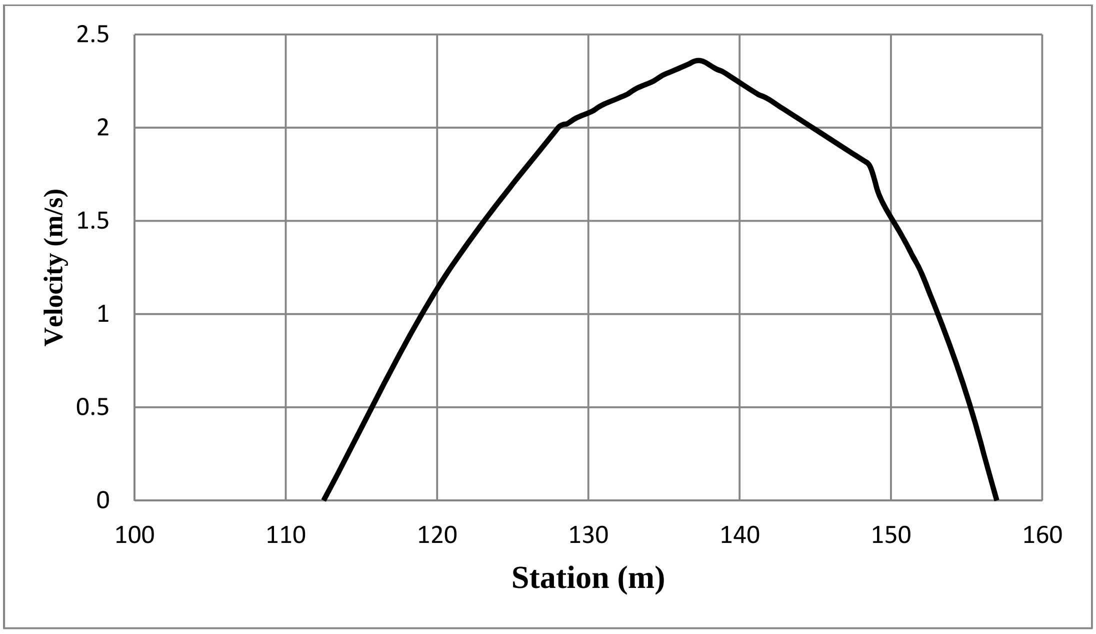


Figure B.19 Velocity Distribution for KG 9 Right

Table B.18 Local Velocities, Scour Depths and Median Riprap Sizes for KG 9 Right

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
139.75	2.27	2.33	**2.27**	**0.32**

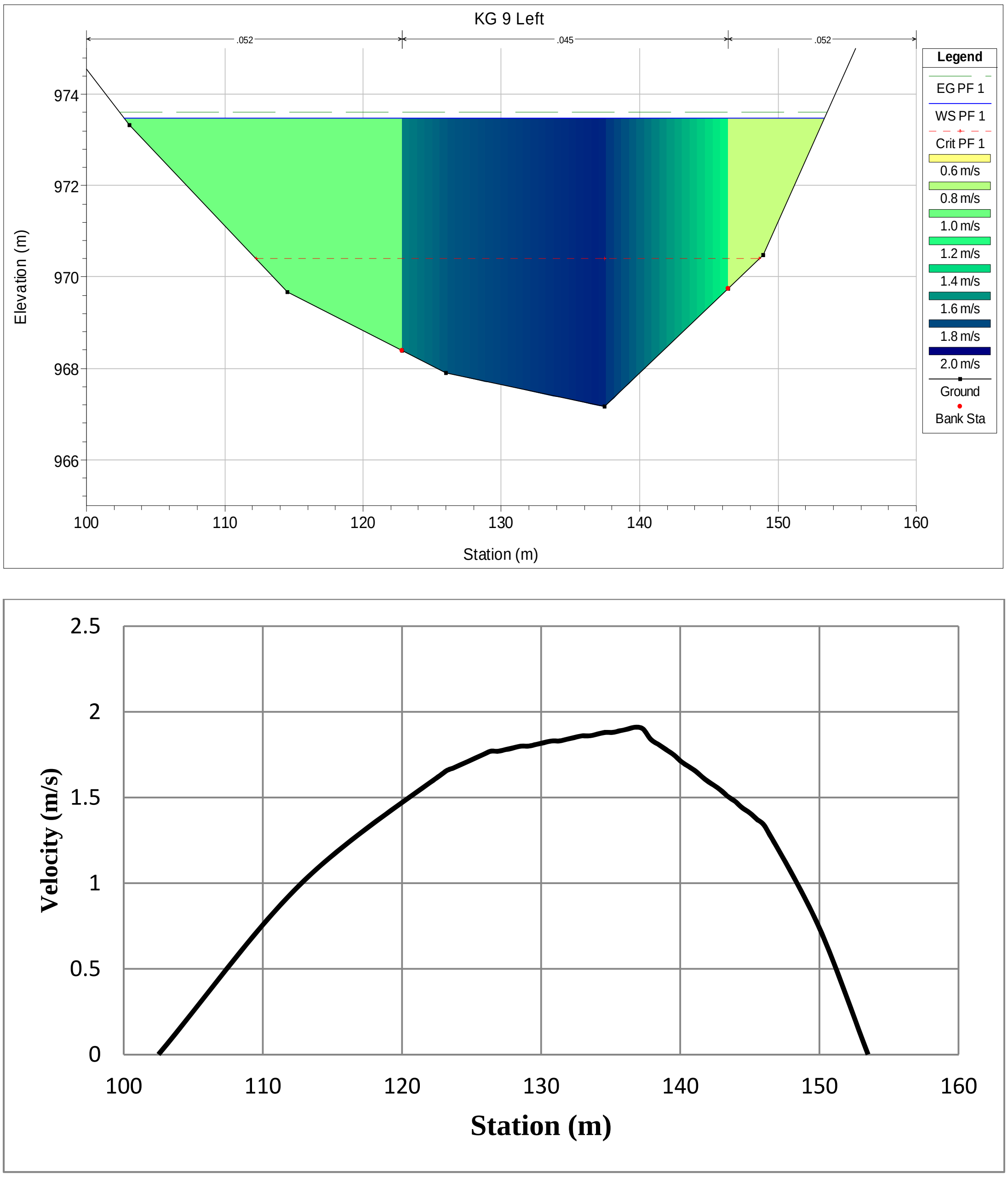


Figure B.20 Velocity Distribution for KG 9 Left

Table B.19 Local Velocities, Scour Depths and Median Riprap Sizes for KG 9 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
113.88	0.99	1.53		
148.38	0.75	1.34	**0.99**	**0.06**

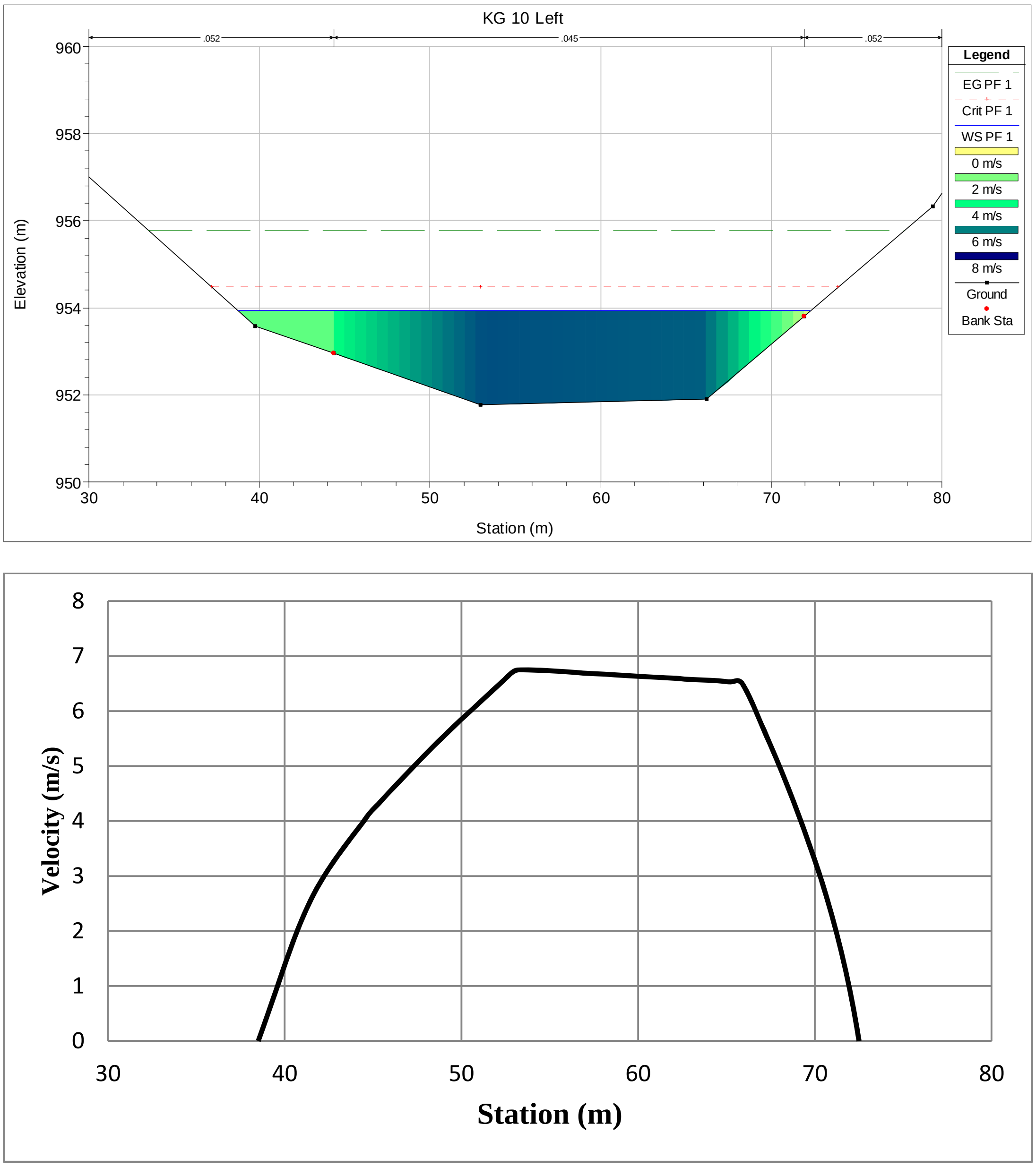


Figure B.21 Velocity Distribution for KG 10 Left

Table B.20 Local Velocities, Scour Depths and Median Riprap Sizes for KG 10 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
70.75	2.27	1.69	**2.27**	**0.32**

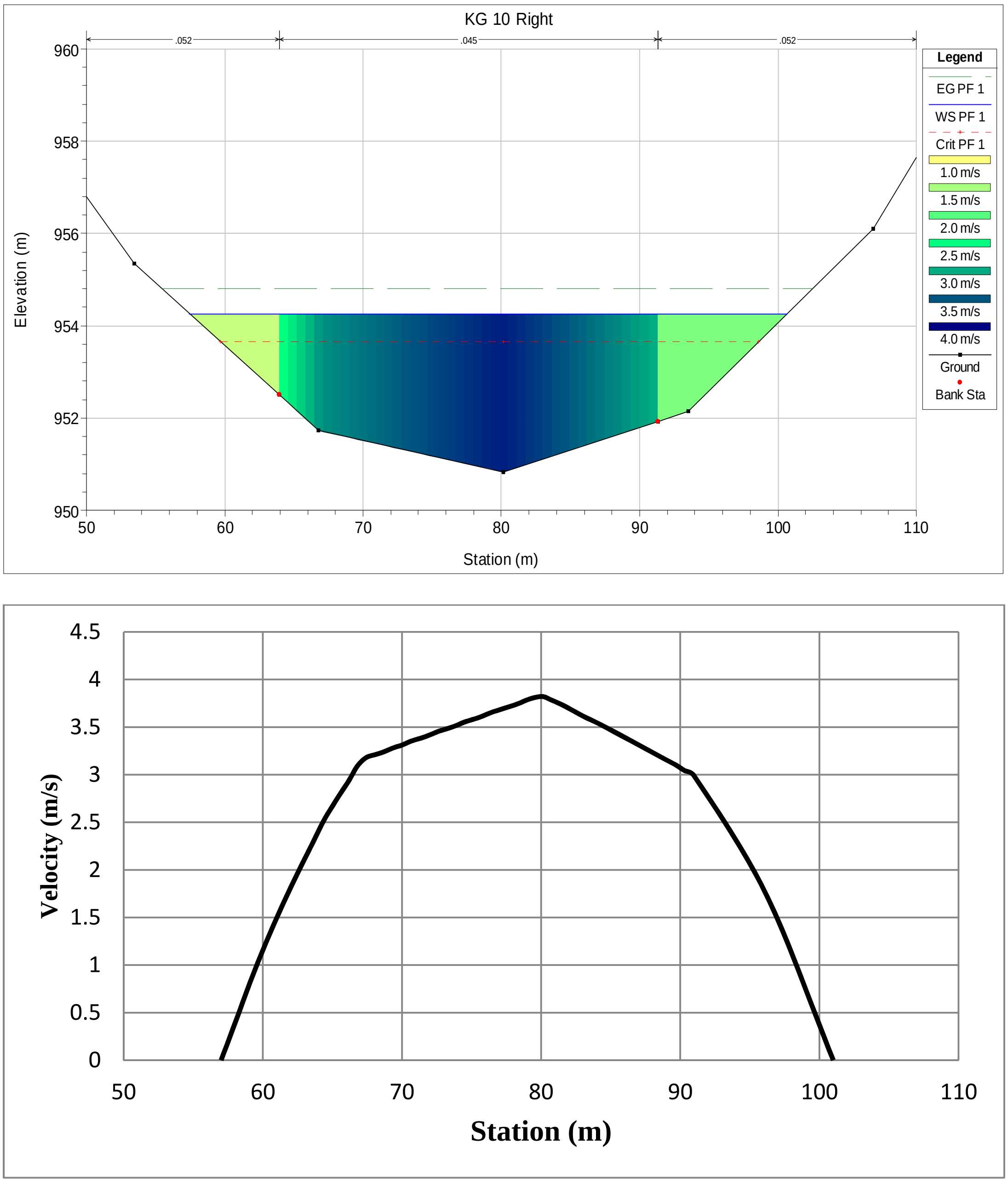


Figure B. 22 Velocity Distribution for KG 10 Right

Table B.21 Local Velocities, Scour Depths and Median Riprap Sizes for KG 10 Right

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
85.75	3.40	2.54	**3.40**	**0.71**

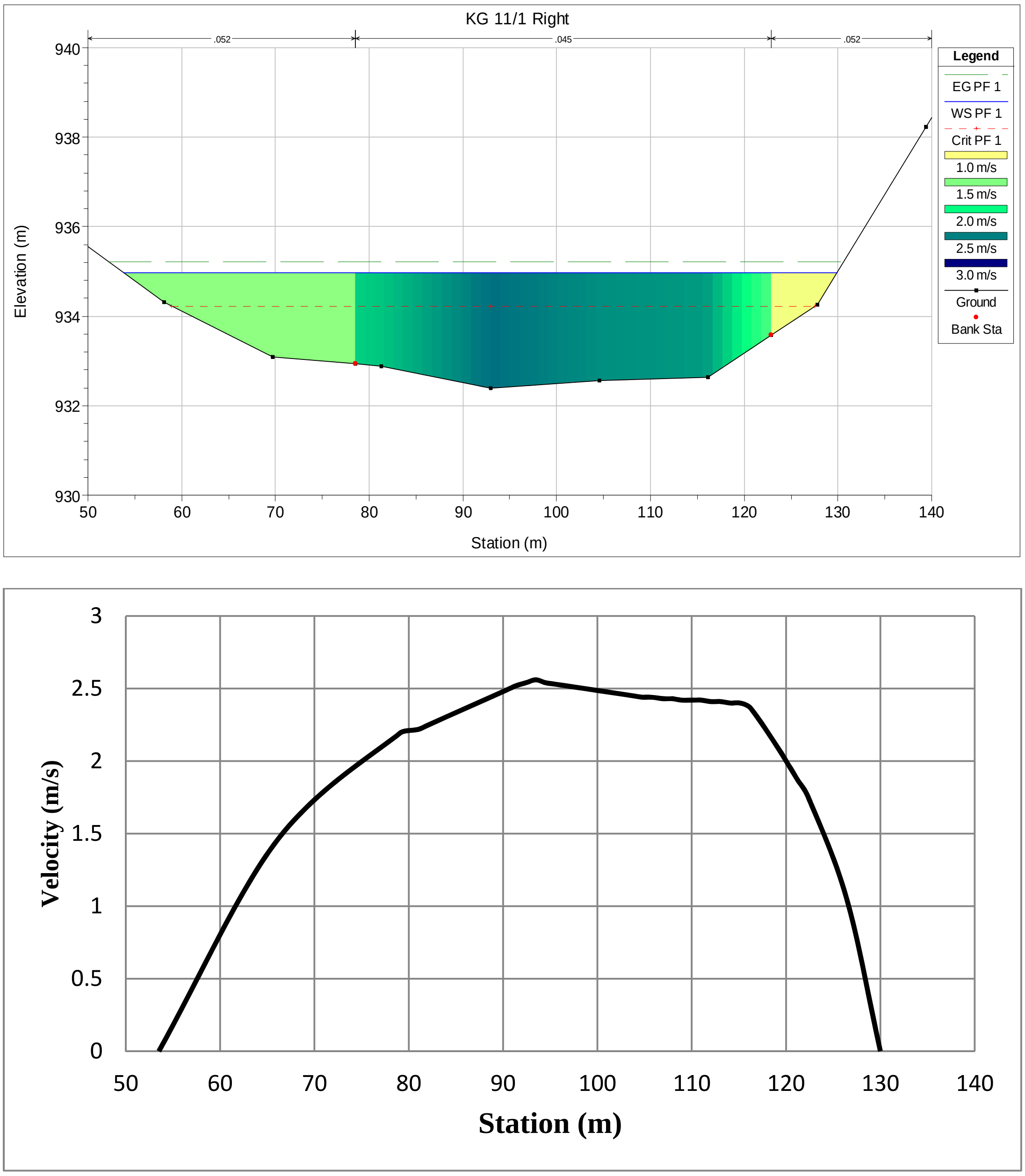
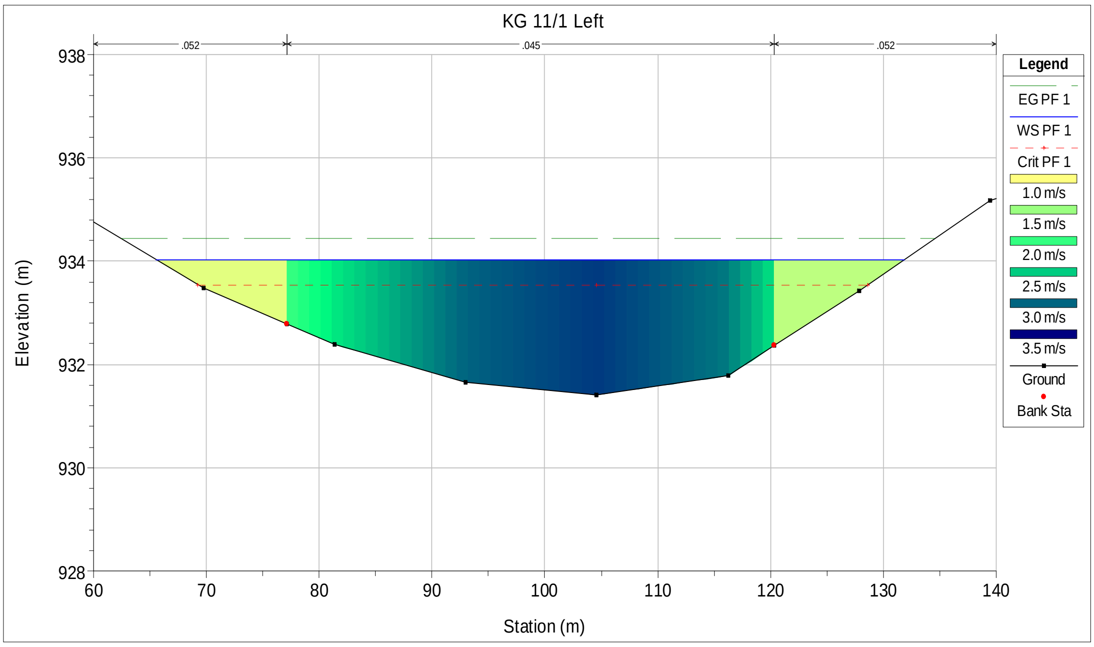


Figure B.23 Velocity Distribution for KG 11/1 Right

Table B.22 Local Velocities, Scour Depths and Median Riprap Sizes for KG11/1 Right

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
70.75	1.45	1.40		
105.25	2.44	1.82	**2.44**	**0.37**



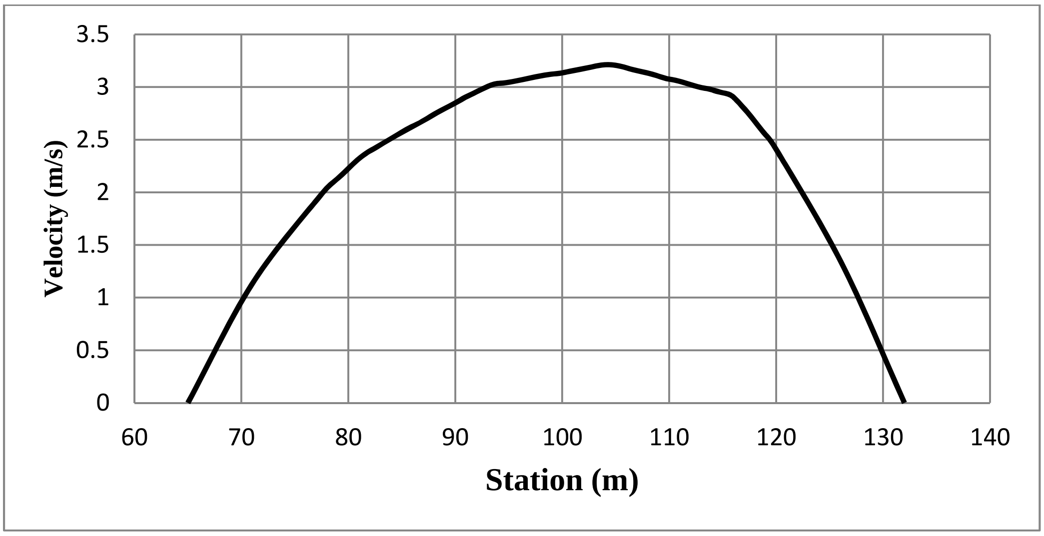
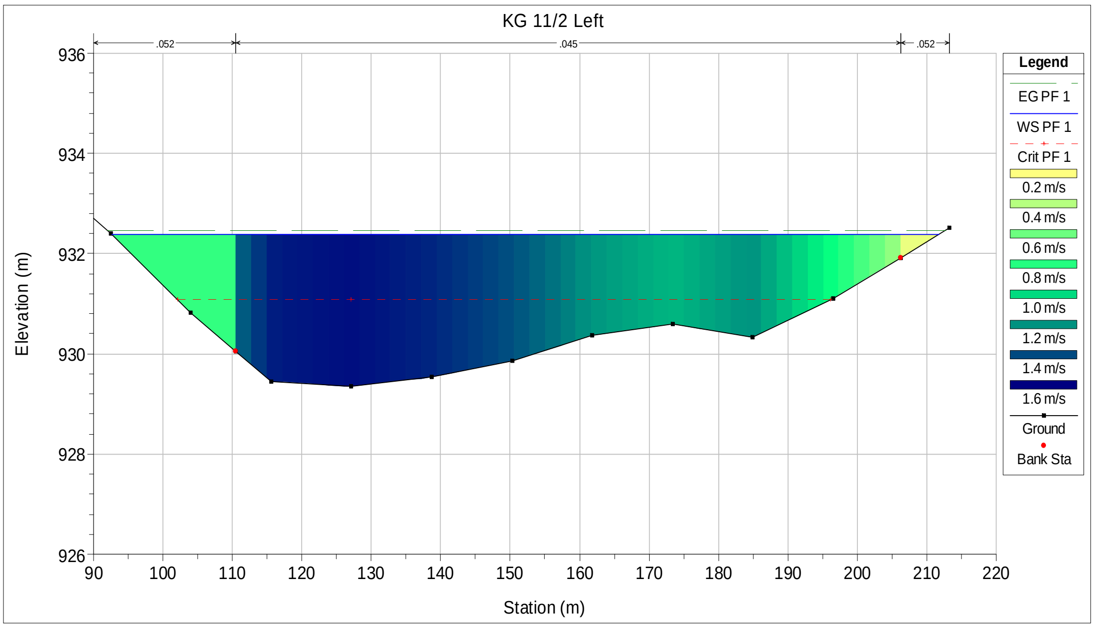


Figure B.24 Velocity Distribution for KG 11/1 Left

Table B.23 Local Velocities, Scour Depths and Median Riprap Sizes for KG 11/1 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
70.75	1.14	1.10		
105.25	3.21	2.07	**3.21**	**0.64**



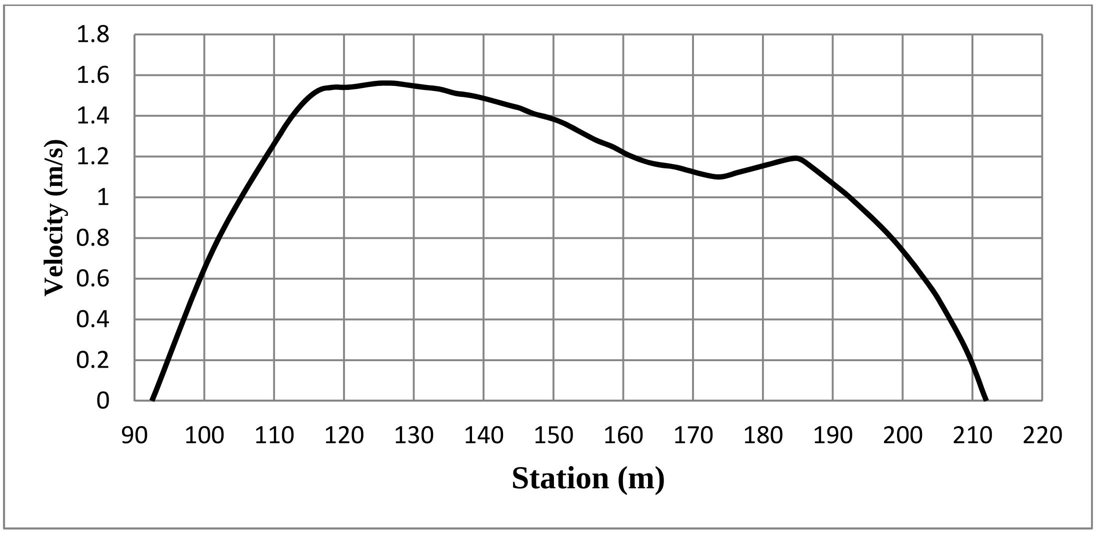


Figure B.25 Velocity Distribution for KG 11/2 Left

Table B.24 Local Velocities, Scour Depths and Median Riprap Sizes for KG 11/2 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
93.50	0.76	1.69		
128.00	1.56	3.56	**1.56**	**0.15**
162.50	1.18	2.98		
197.00	0.88	2.47		

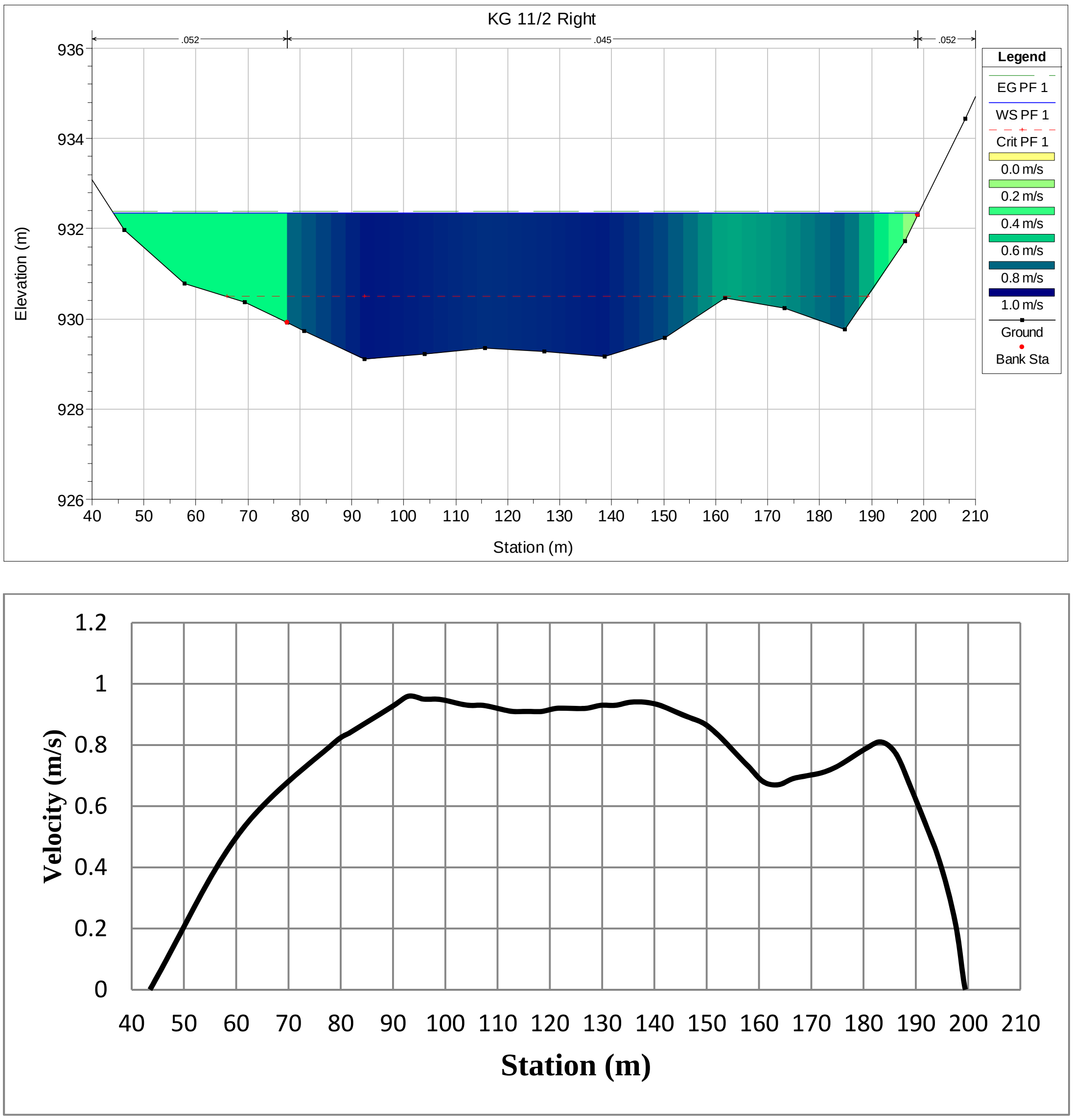
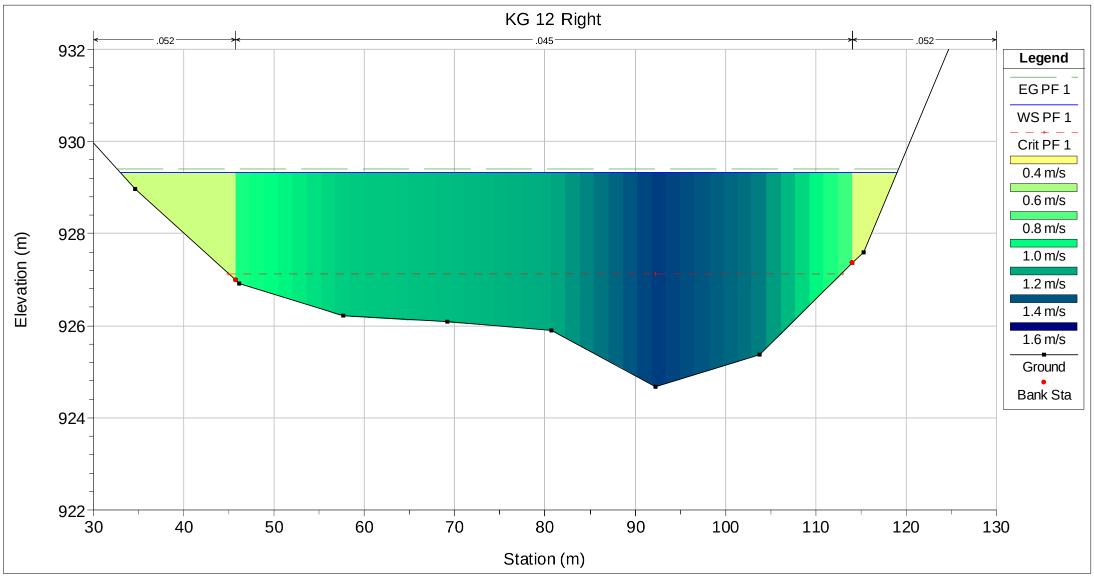


Figure B.26 Velocity Distribution for KG 11/2 Right

Table B.25 Local Velocities, Scour Depths and Median Riprap Sizes for KG 11/2 Right

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
93.50	0.51	2.09		
128.00	0.93	2.86	**0.93**	**0.05**
162.50	0.93	2.86		
197.00	0.73	2.45		



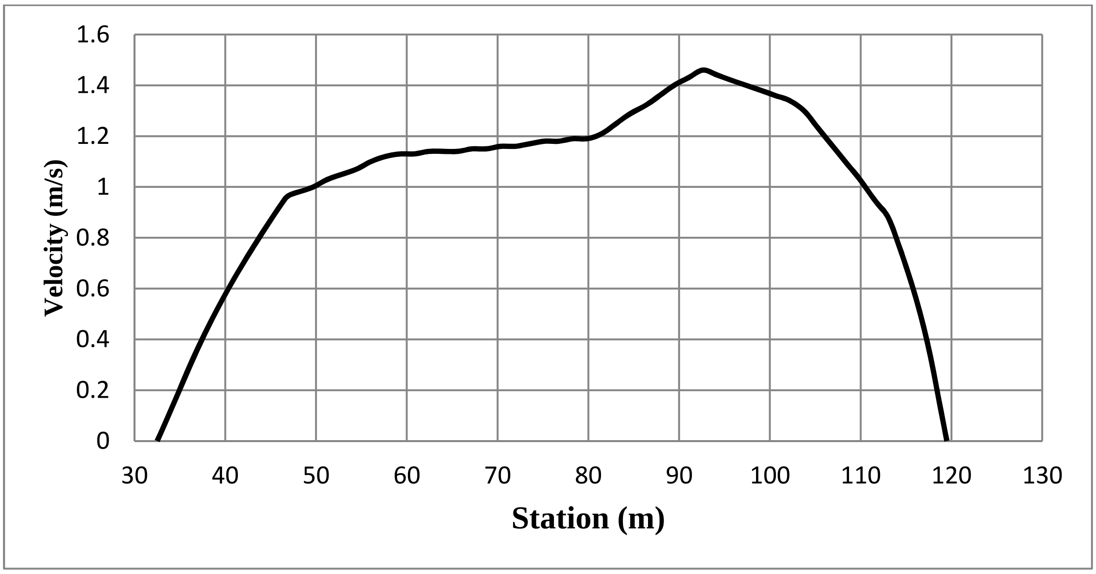


Figure B.27 Velocity Distribution for KG 12 Right

Table B.26 Local Velocities, Scour Depths and Median Riprap Sizes for KG 12 Right

<table>
<tr><th>Station Coordinate (m)</th><th>Local Velocity(m/s)</th><th>Scour Depth (m)</th><th rowspan="2">Local Max Velocity (m/s)</th><th rowspan="2">Median Riprap Size (m)</th></tr>
<tr><td>36.25</td><td>0.52</td><td>1.57</td></tr>
<tr><td>70.75</td><td>1.16</td><td>2.75</td><td rowspan="2">1.23</td><td rowspan="2">0.09</td></tr>
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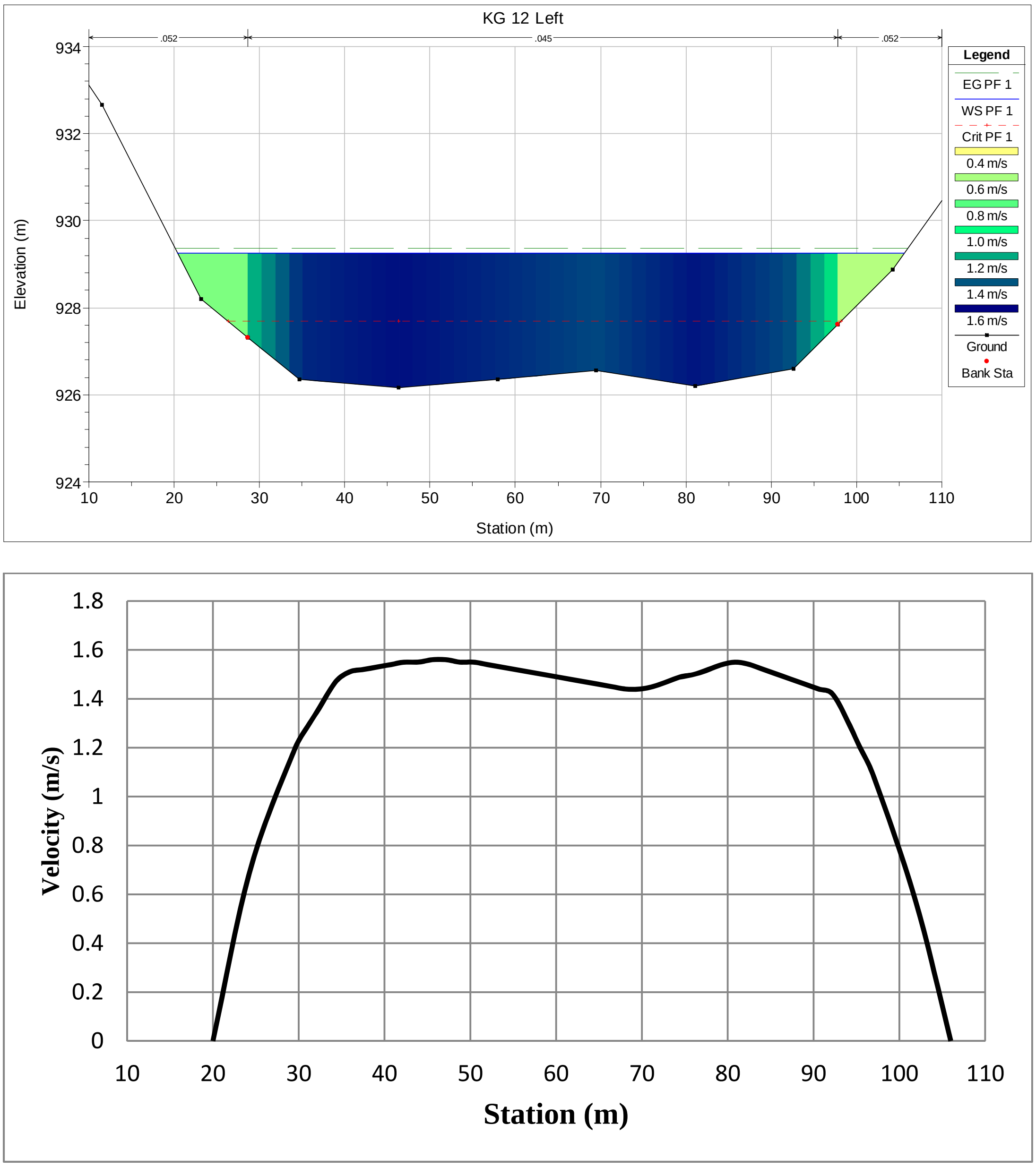


Figure B.28 Velocity Distribution for KG 12 Left

Table B.27 Local Velocities, Scour Depths and Median Riprap Sizes for KG 12 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
36.25	1.51	3.04	**1.51**	**0.14**
70.75	1.45	2.96		
105.25	0.57	1.26		

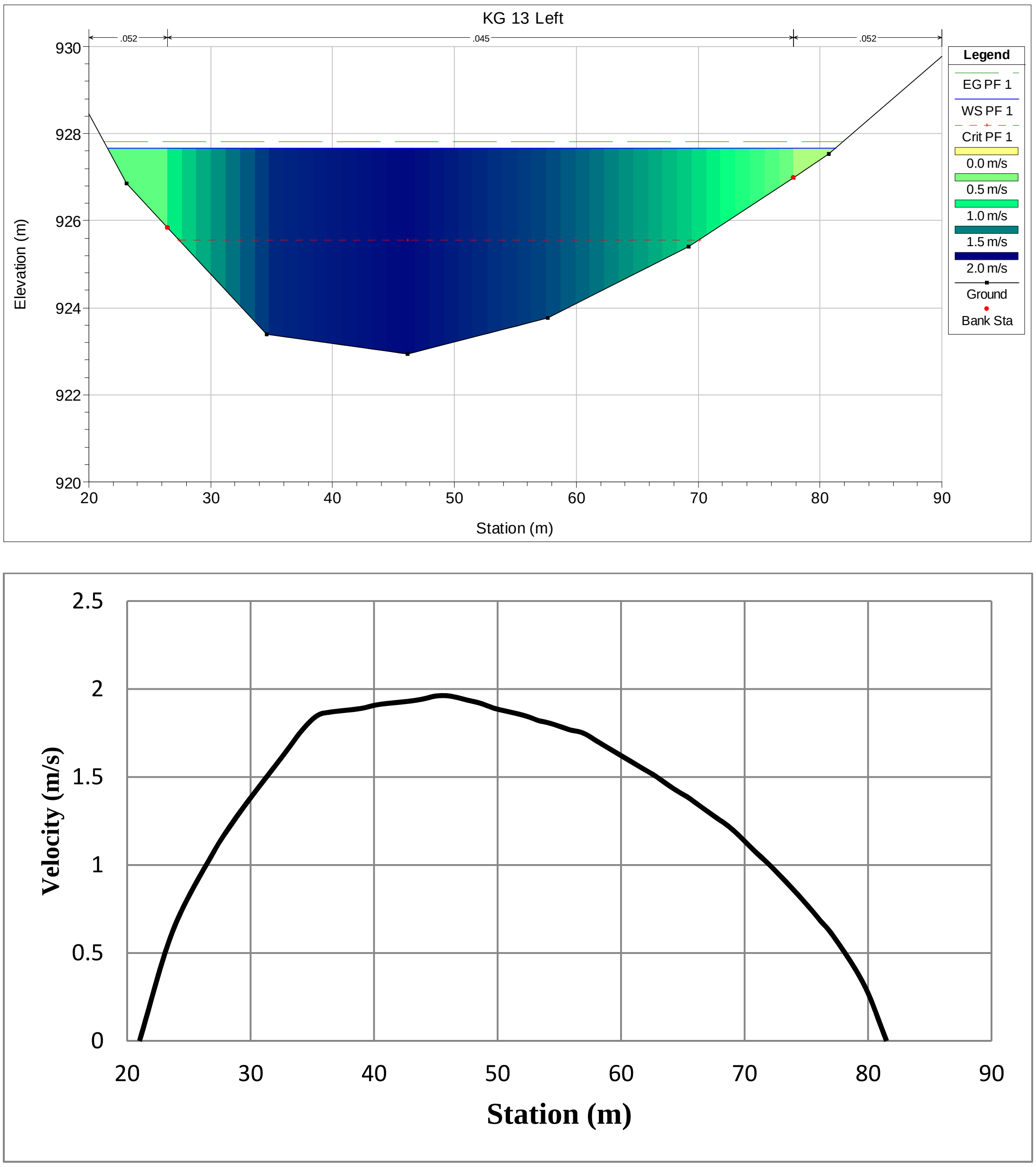
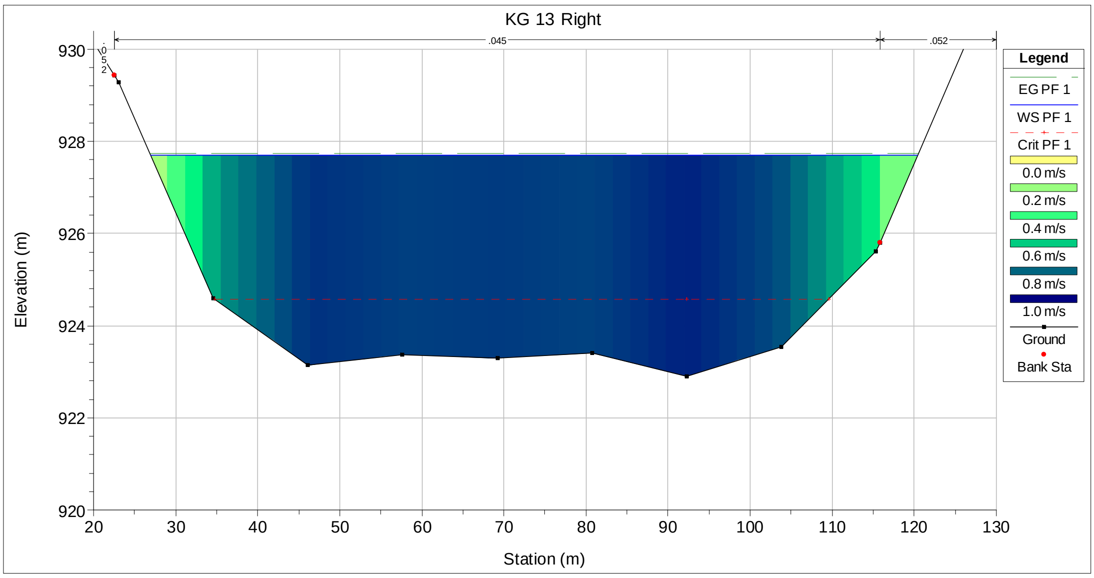


Figure B.29 Velocity Distribution for KG 13 Left

Table B.28 Local Velocities, Scour Depths and Median Riprap Sizes for KG 13 Left

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
41.25	1.92	1.79		
75.75	0.69	0.95	**1.92**	**0.23**



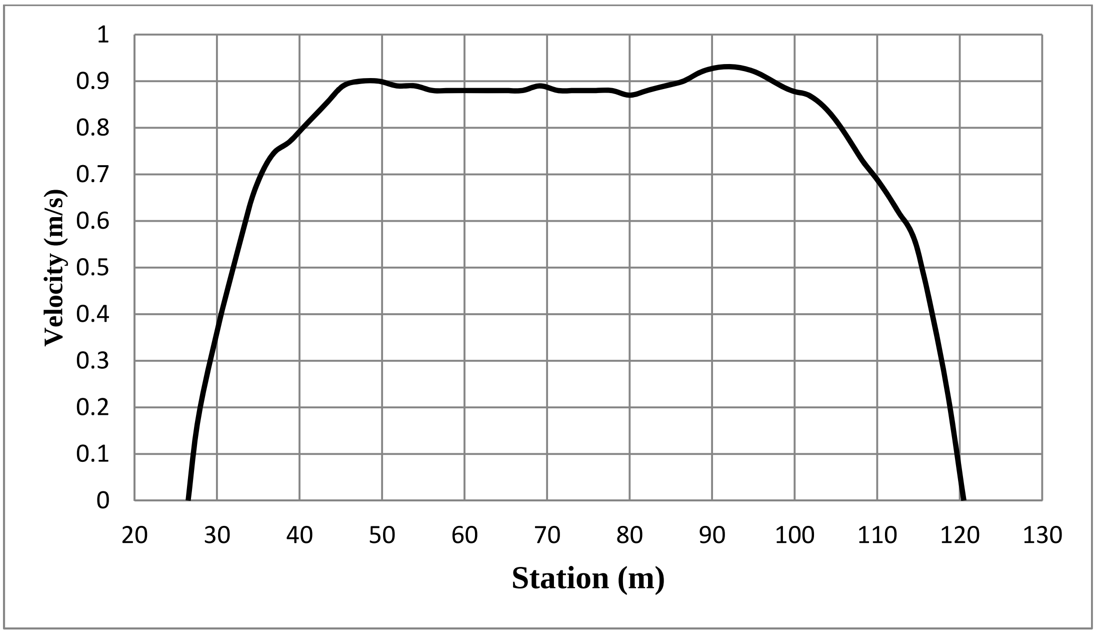
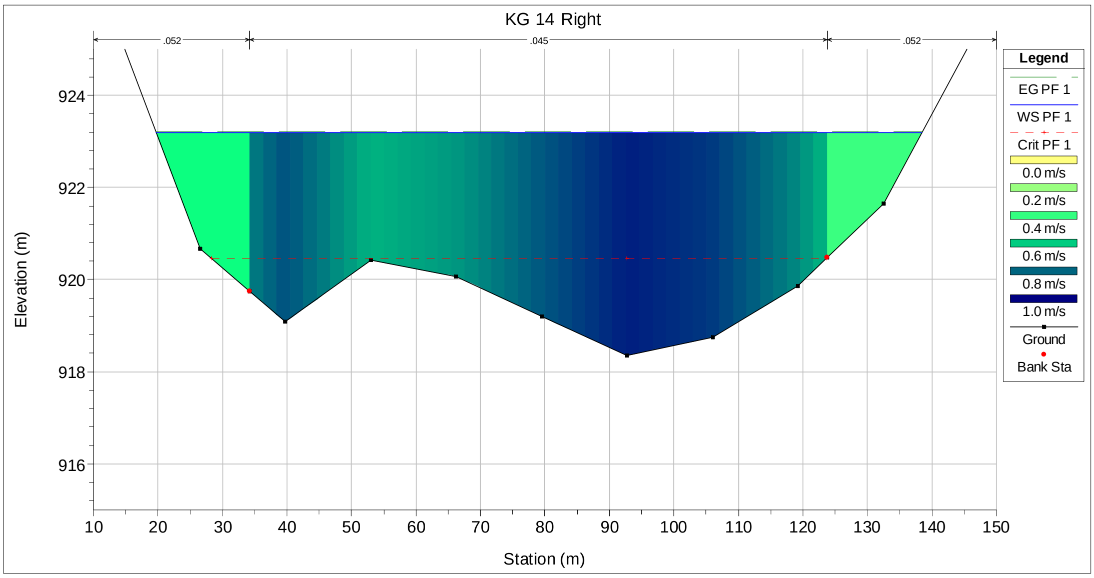


Figure B.30 Velocity Distribution for KG 13 Right

Table B.29 Local Velocities, Scour Depths and Median Riprap Sizes for KG 13 Right

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
40.25	0.81	1.21	**0.88**	**0.05**
74.75	0.88	1.27		
109.25	0.73	1.12		



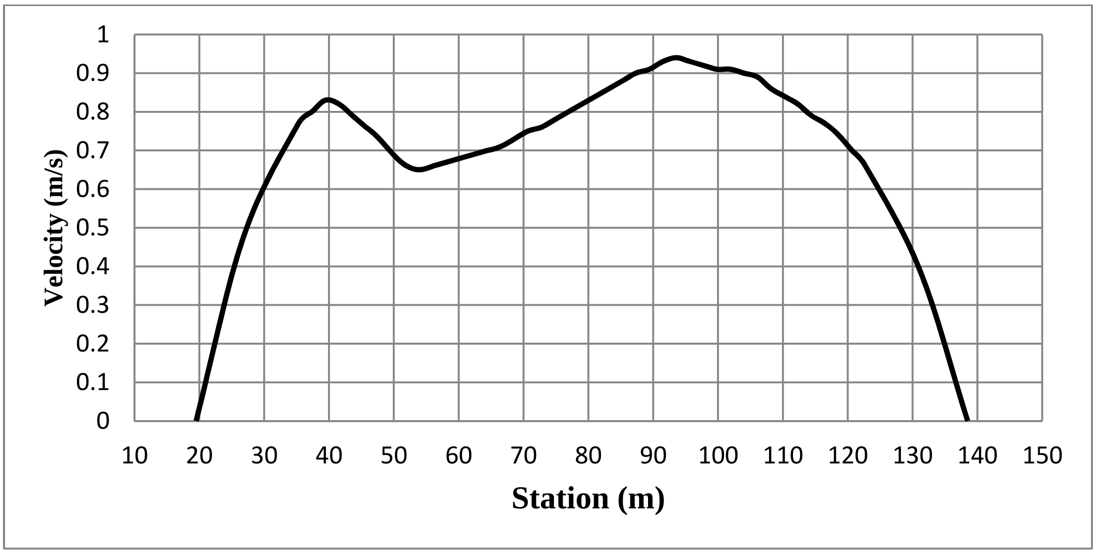
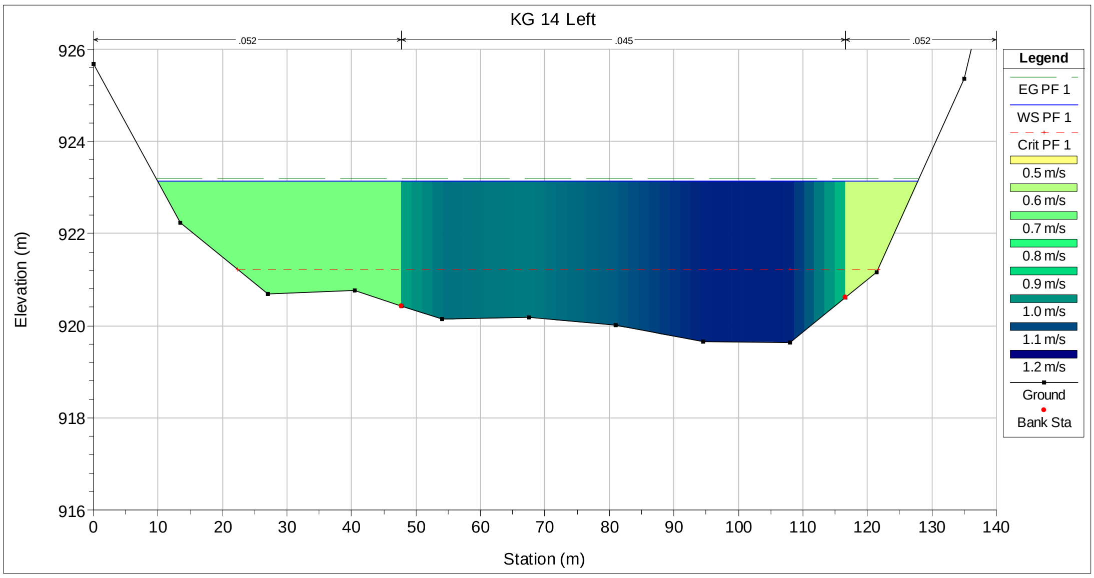


Figure B. 31 Velocity Distribution for KG 14 Right

Table B.30 Local Velocities, Scour Depths and Median Riprap Sizes for KG 14 Right

Station Coordinate (m)	Local Velocity(m/s)	Scour Depth (m)	Local Max Velocity (m/s)	Median Riprap Size (m)
36.25	0.77	2.69	**0.89**	**0.05**
70.75	0.75	2.63		
105.25	0.89	5.67		



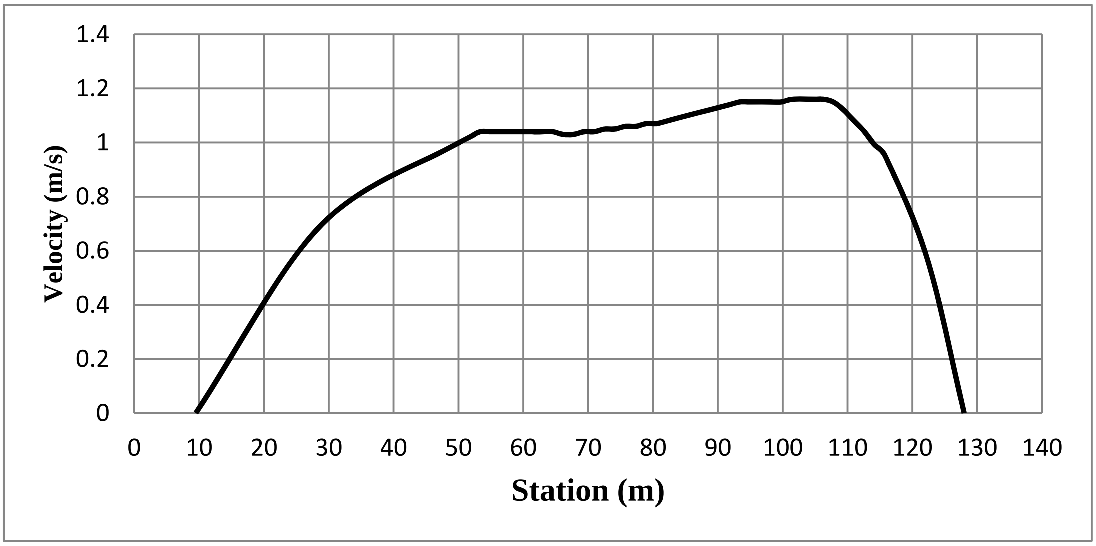


Figure B.32 Velocity Distribution for KG 14 Left

Table B.31 Local Velocities, Scour Depths and Median Riprap Sizes for KG 14 Left

Station Coordinate (m)	**Local Velocity(m/s)**	**Scour Depth (m)**	**Local Max Velocity (m/s)**	**Median Riprap Size (m)**
36.25	0.69	2.42		
70.75	1.04	2.99	**1.16**	**0.08**
105.25	1.16	3.19		

APPENDIX C

HEC – RAS WATER SURFACE PROFILE OUTPUTS

FOR KIRKGEÇİT CREEK

HEC – RAS software was executed in mixed flow regime for Kırkgeçit Creek. 100 year discharge is used in computations to find location of river station, minimum channel elevation, water surface elevation, critical water surface elevation, energy grade line elevation, energy grade line slope (Sf), channel velocity, flow area, top width, hydraulic depth and Froude numbers of 800 stations in Kırkgeçit Creek.

Table C. 1 HEC – RAS Water Surface Profile Outputs for Q_{100}

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. Water Surf. Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
18173.6	1166.96	1168.80	1168.95	1169.52	0.030029	3.78	79.35	87.54	0.91	1.22
18141.7	1165.39	1168.31	1167.94	1168.65	0.007526	2.58	118.38	84.78	1.40	0.66
18102.1	1164.95	1167.56	1167.56	1168.18	0.017114	3.53	86.54	73.11	1.18	0.97
18073.3	1163.06	1167.40	1166.94	1167.74	0.006825	2.61	115.13	73.34	1.57	0.64
18035.1	1163.90	1167.21		1167.50	0.005123	2.40	125.43	76.36	1.64	0.56
18002.9	1163.47	1166.64	1166.64	1167.20	0.017153	3.34	91.30	87.60	1.04	0.96
17978.0	1162.44	1164.59	1165.17	1166.40	0.048572	5.97	49.61	36.46	1.36	1.63
17947.6	1161.75	1164.60	1163.92	1164.92	0.005802	2.54	116.71	63.62	1.83	0.60
17928.9	1162.21	1164.14	1164.14	1164.72	0.019004	3.38	87.81	75.71	1.16	1.00
17919.1	1161.54	1164.38	1163.47	1164.53	0.002623	1.80	173.65	101.76	1.71	0.41
17910.0	Bridge									
17900.5	1161.51	1164.34		1164.45	0.001552	1.50	212.84	109.34	1.95	0.32
17899.8	1162.22	1163.90	1163.90	1164.41	0.017807	3.22	96.37	96.35	1.00	0.96
17899.0	1161.23	1163.61	1162.88	1163.77	0.003131	1.86	170.06	105.55	1.61	0.44
17890.0	Bridge									
17880.5	1160.86	1163.53		1163.67	0.002705	1.75	180.80	106.04	1.71	0.41
17862.0	1159.83	1163.18		1163.56	0.01011	2.74	109.31	86.23	1.27	0.75
17830.2	1160.22	1163.13		1163.33	0.003361	1.99	152.77	87.24	1.75	0.46
17807.3	1160.82	1162.55	1162.55	1163.14	0.017935	3.42	87.62	76.03	1.15	0.98
17781.8	1160.54	1162.03	1162.08	1162.65	0.020717	3.52	86.51	80.86	1.07	1.04
17752.8	1159.60	1161.61	1161.42	1162.04	0.011357	2.99	104.60	80.83	1.29	0.80
17738.4*	1159.40	1161.42		1161.87	0.011653	3.04	102.50	78.85	1.30	0.81
17724.1*	1159.21	1161.24		1161.70	0.0119	3.08	100.74	77.16	1.31	0.82
17709.8*	1159.01	1161.05	1160.90	1161.53	0.012213	3.11	99.00	75.68	1.31	0.83
17695.5*	1158.81	1160.85	1160.71	1161.35	0.012549	3.16	97.19	74.34	1.31	0.84
17681.1*	1158.61	1160.65		1161.16	0.012861	3.20	95.51	73.17	1.31	0.85
17666.8*	1158.41	1160.45		1160.98	0.013158	3.24	94.03	72.22	1.30	0.86
17652.5*	1158.21	1160.25	1160.14	1160.79	0.01339	3.27	92.87	71.51	1.30	0.87
17638.2*	1158.01	1160.04	1159.95	1160.59	0.013647	3.30	91.80	71.03	1.29	0.88
17623.8*	1157.81	1159.83	1159.75	1160.40	0.013961	3.33	90.79	70.78	1.28	0.89
17609.5*	1157.61	1159.63	1159.54	1160.19	0.014173	3.36	90.19	70.65	1.28	0.90
17595.2*	1157.41	1159.41	1159.34	1159.99	0.014674	3.40	89.26	70.91	1.26	0.91
17580.9*	1157.21	1159.19	1159.14	1159.78	0.014962	3.42	89.06	71.56	1.24	0.92
17566.5*	1157.01	1158.98	1158.93	1159.56	0.01495	3.42	89.76	72.84	1.23	0.92
17552.2*	1156.81	1158.72	1158.71	1159.33	0.01663	3.52	87.83	74.84	1.17	0.96

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
17537.9*	1156.61	1158.49	1158.49	1159.09	0.016439	3.49	90.23	78.71	1.15	0.96
17523.6*	1156.41	1158.18	1158.24	1158.82	0.01981	3.67	87.04	81.06	1.07	1.04
17509.2*	1156.21	1157.88	1157.97	1158.52	0.02158	3.72	87.69	85.68	1.02	1.08
17495.0	1156.01	1157.53	1157.64	1158.18	0.025397	3.81	86.03	87.87	0.98	1.15
17462.8	1155.03	1156.27	1156.47	1157.12	0.036348	3.73	73.12	70.97	1.03	1.31
17423.0	1153.48	1155.86	1155.61	1156.39	0.013039	3.19	91.72	56.40	1.63	0.86
17400.9*	1153.14	1155.59		1156.09	0.011907	3.16	95.01	58.41	1.63	0.83
17378.8*	1152.80	1155.44		1155.84	0.007847	2.95	107.66	61.84	1.74	0.69
17356.8*	1152.46	1155.39		1155.68	0.004398	2.56	129.98	66.84	1.94	0.54
17334.8	1152.12	1155.38		1155.58	0.002383	2.15	159.37	70.55	2.26	0.41
17290.7	1152.46	1154.56	1154.56	1155.30	0.014089	4.02	83.99	58.97	1.42	0.94
17261.0	1151.44	1153.83	1153.99	1154.80	0.018305	4.51	73.20	54.96	1.33	1.06
17213.2	1151.07	1153.68	1153.08	1153.96	0.005488	2.35	126.20	76.35	1.65	0.57
17165.2	1150.77	1153.51		1153.74	0.003389	2.14	143.81	79.12	1.82	0.47
17123.7	1151.03	1152.82	1152.82	1153.43	0.018327	3.46	86.22	73.25	1.18	0.99
17088.0	1150.31	1151.85	1152.00	1152.61	0.02839	3.87	76.50	72.55	1.05	1.20
17053.6	1149.42	1150.86	1151.01	1151.60	0.029836	3.83	77.48	77.79	1.00	1.22
17019.1	1148.76	1150.74	1150.28	1151.01	0.006482	2.28	129.77	89.78	1.45	0.61
16983.0	1147.99	1150.69		1150.83	0.002401	1.68	176.86	93.00	1.90	0.39
16950.2	1148.56	1150.50		1150.72	0.004795	2.11	144.31	94.27	1.53	0.53
16914.6	1148.56	1149.90	1149.89	1150.39	0.019097	3.11	96.00	98.01	0.98	0.98
16863.8	1147.34	1149.67		1149.89	0.004606	2.08	142.68	88.03	1.62	0.52
16840.7	1146.66	1149.66		1149.79	0.001991	1.64	182.74	89.55	2.04	0.36
16802.5	1146.88	1149.49		1149.69	0.003203	2.00	150.54	78.13	1.93	0.45
16775.7	1146.58	1149.32		1149.59	0.004509	2.29	130.25	71.39	1.82	0.53
16756.4	1146.36	1149.25		1149.50	0.003773	2.23	134.41	69.40	1.94	0.49
16730.8	1146.24	1149.06		1149.38	0.005157	2.57	119.96	63.42	1.89	0.57
16698.8	1146.16	1148.94		1149.23	0.003907	2.46	128.19	63.35	2.02	0.51
16669.2	1146.23	1148.85		1149.11	0.003642	2.38	138.88	72.16	1.92	0.49
16638.2	1146.46	1148.34	1148.22	1148.88	0.013941	3.36	92.35	66.52	1.39	0.89
16613.9	1145.58	1147.88	1147.88	1148.50	0.016025	3.57	88.81	73.99	1.20	0.95
16575.6	1144.37	1146.29	1146.63	1147.52	0.039182	4.92	60.49	52.27	1.16	1.44
16539.0	1142.77	1146.52	1145.74	1146.92	0.004562	2.86	112.04	54.20	2.07	0.56
16506.9	1143.57	1146.11		1146.69	0.009893	3.56	93.60	58.28	1.61	0.79
16483.*	1143.37	1145.86		1146.45	0.010041	3.61	93.29	59.07	1.58	0.80
16459.0*	1143.17	1145.60		1146.20	0.010197	3.64	93.16	59.85	1.56	0.81

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
16435.1*	1142.96	1145.35		1145.96	0.010305	3.67	93.42	60.85	1.54	0.81
16411.2*	1142.76	1145.11	1144.95	1145.71	0.010227	3.66	94.55	62.22	1.52	0.81
16387.2*	1142.56	1144.89	1144.70	1145.46	0.009731	3.59	97.42	64.22	1.52	0.79
16363.4	1142.36	1144.45	1144.45	1145.16	0.014004	4.03	86.74	62.90	1.38	0.93
16313.1	1140.88	1142.41	1142.87	1143.83	0.055263	5.32	56.75	58.29	0.97	1.67
16289.4*	1140.73	1143.21	1142.73	1143.52	0.006407	2.52	122.02	79.93	1.53	0.62
16265.7*	1140.59	1143.05		1143.37	0.006896	2.54	121.25	79.73	1.52	0.64
16242.1*	1140.44	1142.88		1143.20	0.007239	2.58	119.63	79.68	1.50	0.65
16218.5	1140.30	1142.69		1143.02	0.007749	2.63	117.45	79.79	1.47	0.67
16185.5	1139.78	1142.00	1142.00	1142.62	0.019067	3.52	86.11	71.92	1.20	1.01
16141.2	1139.02	1141.48	1141.09	1141.86	0.008157	2.79	110.00	72.00	1.53	0.70
16103.5	1138.90	1141.08		1141.51	0.010539	2.96	103.98	73.38	1.42	0.78
16066.2	1138.93	1140.72		1141.08	0.011649	2.72	114.12	100.05	1.14	0.79
16029.9*	1138.51	1140.29		1140.65	0.011685	2.75	112.69	97.92	1.15	0.79
15993.7*	1138.08	1139.85		1140.23	0.011721	2.78	111.32	95.85	1.16	0.80
15957.4*	1137.65	1139.41		1139.80	0.011734	2.81	110.08	93.85	1.17	0.80
15921.1*	1137.23	1138.97		1139.37	0.011784	2.83	108.79	91.93	1.18	0.80
15884.9*	1136.80	1138.54		1138.94	0.011762	2.85	107.81	90.18	1.20	0.80
15848.6*	1136.37	1138.10		1138.51	0.011845	2.87	106.57	88.45	1.20	0.81
15812.3*	1135.94	1137.67		1138.08	0.011663	2.87	106.22	86.96	1.22	0.80
15776.1*	1135.52	1137.32		1137.69	0.009633	2.71	112.43	87.04	1.29	0.73
15739.8	1135.09	1136.62	1136.62	1137.19	0.018503	3.37	89.62	80.71	1.11	0.99
15729.9*	1134.45	1136.12	1136.29	1136.94	0.030789	4.01	74.10	72.65	1.02	1.25
15720.1*	1133.80	1135.70	1135.93	1136.61	0.033583	4.22	70.25	66.46	1.06	1.31
15710.2	1133.16	1135.21	1135.50	1136.26	0.035636	4.53	65.46	58.16	1.13	1.36
15685.4	1132.95	1135.35	1135.15	1135.85	0.011527	3.12	95.59	66.88	1.43	0.81
15658.1*	1132.51	1135.08		1135.56	0.009339	3.09	98.60	63.15	1.56	0.75
15630.8*	1132.06	1134.87		1135.32	0.00732	3.02	104.53	61.50	1.70	0.68
15603.5*	1131.61	1134.70		1135.12	0.006032	3.00	108.32	55.89	1.94	0.63
15576.2	1131.16	1134.44		1134.93	0.006542	3.31	99.65	46.00	2.17	0.66
15546.9	1131.30	1133.89	1133.80	1134.64	0.013244	4.03	80.52	46.96	1.71	0.91
15521.6*	1130.92	1133.52	1133.45	1134.29	0.013658	4.07	79.54	46.80	1.70	0.92
15496.2*	1130.53	1133.14	1133.10	1133.93	0.013971	4.11	78.75	46.65	1.69	0.93
15470.9*	1130.15	1132.74	1132.73	1133.56	0.014737	4.19	77.06	46.31	1.66	0.96
15445.5*	1129.77	1132.45	1132.35	1133.19	0.012444	3.96	81.47	47.04	1.73	0.89
15420.2*	1129.38	1132.33		1132.88	0.008142	3.43	94.35	49.29	1.91	0.73

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
15394.9	1129.00	1132.29		1132.68	0.004796	2.89	112.61	52.36	2.15	0.57
15370.7*	1129.09	1132.13		1132.55	0.005631	3.01	109.26	55.58	1.97	0.61
15346.7	1129.17	1131.51	1131.51	1132.30	0.015204	4.09	79.37	52.98	1.50	0.96
15323.5*	1128.88	1130.89	1131.08	1131.86	0.022752	4.44	70.50	52.96	1.33	1.15
15300.4	1128.60	1130.63	1130.65	1131.37	0.016842	3.88	79.86	57.44	1.39	0.99
15275.5	1127.30	1130.24	1129.59	1130.58	0.005326	2.65	119.89	64.92	1.85	0.58
15253.4*	1127.22	1130.11		1130.45	0.005654	2.70	118.13	64.81	1.82	0.60
15231.3*	1127.14	1129.97		1130.32	0.006015	2.75	116.43	64.79	1.80	0.62
15209.2*	1127.07	1129.82		1130.18	0.006418	2.79	114.80	64.97	1.77	0.63
15187.2*	1126.99	1129.67		1130.04	0.006697	2.82	113.44	65.08	1.74	0.65
15165.1*	1126.91	1129.50		1129.88	0.006738	2.88	112.45	65.63	1.71	0.65
15143.0*	1126.83	1129.35		1129.73	0.006549	2.90	113.52	66.11	1.72	0.65
15120.9*	1126.76	1129.23		1129.59	0.006041	2.86	117.32	67.23	1.75	0.63
15098.9	1126.68	1129.13		1129.45	0.005186	2.75	124.95	69.22	1.81	0.58
15063.1	1126.23	1129.00		1129.27	0.004213	2.30	129.76	67.25	1.93	0.52
15026.2	1125.83	1128.95		1129.14	0.002105	1.92	158.66	67.48	2.35	0.38
14989.8	1126.15	1128.21	1128.21	1128.92	0.016993	3.74	80.75	58.40	1.38	0.98
14966.8	1125.47	1127.07	1127.42	1128.30	0.038713	4.97	61.67	57.92	1.06	1.44
14940.3	1123.36	1125.02	1125.60	1126.90	0.069661	6.13	49.45	48.43	1.02	1.89
14905.3	1122.77	1125.12	1124.72	1125.51	0.008248	2.77	106.90	66.08	1.62	0.70
14869.5	1122.53	1124.98		1125.25	0.004735	2.33	129.92	71.55	1.82	0.54
14847.8	1122.87	1124.40	1124.40	1125.04	0.01869	3.53	84.04	66.96	1.26	1.00
14821.6	1121.59	1123.56	1123.73	1124.45	0.02515	4.17	71.44	56.78	1.26	1.17
14792.5	1120.91	1123.88	1123.03	1124.15	0.004088	2.37	131.42	65.57	2.00	0.51
14755.9	1121.01	1123.08	1123.08	1123.82	0.016394	3.83	79.28	54.64	1.45	0.98
14733.0	1120.41	1122.32	1122.53	1123.32	0.027314	4.43	66.83	50.10	1.33	1.23
14710.0*	1119.81	1122.65	1121.69	1122.86	0.00307	2.05	147.65	73.24	2.02	0.45
14687.1	1119.21	1122.71	1120.83	1122.79	0.000722	1.25	251.56	97.11	2.59	0.23
14674.7	Bridge									
14662.3	1119.05	1122.62		1122.74	0.001189	1.59	203.15	79.74	2.55	0.29
14652.8	1118.99	1122.59		1122.73	0.001496	1.73	186.44	75.45	2.47	0.33
14644.8	1119.08	1122.48	1121.39	1122.70	0.002648	2.17	149.08	68.85	2.17	0.43
14644.5	Bridge									
14624.1	1119.36	1122.06		1122.51	0.006555	3.09	106.67	62.21	1.71	0.66
14612.8	1119.46	1121.65	1121.65	1122.38	0.014227	3.98	84.44	60.23	1.40	0.94
14592.1	1118.88	1121.18	1121.24	1122.04	0.017846	4.24	74.90	49.52	1.51	1.03

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
14572.2	1118.16	1121.17	1120.64	1121.59	0.006028	2.96	109.29	58.03	1.88	0.63
14551.3	1117.22	1121.24		1121.46	0.002098	2.10	151.96	62.23	2.44	0.39
14532.0	1117.68	1121.14		1121.40	0.00319	2.37	135.93	61.75	2.20	0.47
14508.5	1117.00	1121.14		1121.33	0.001582	1.97	165.85	63.58	2.61	0.34
14485.7	1117.93	1120.82		1121.24	0.005542	3.04	111.76	59.97	1.86	0.61
14467.4	1118.25	1120.34	1120.34	1121.05	0.015055	4.00	85.01	61.80	1.38	0.96
14452.7	1117.49	1120.20	1119.37	1120.44	0.003316	2.25	145.18	77.16	1.88	0.47
14432.1	1116.67	1120.27		1120.36	0.00088	1.34	225.96	85.38	2.65	0.25
14396.0	1116.77	1120.00		1120.28	0.003852	2.38	125.83	58.86	2.14	0.50
14368.4	1117.31	1119.46		1120.08	0.012311	3.55	87.22	55.01	1.59	0.86
14345.8*	1117.03	1119.15	1119.04	1119.79	0.013166	3.66	86.19	55.95	1.54	0.89
14323.3*	1116.75	1118.80	1118.75	1119.48	0.014507	3.79	84.86	57.37	1.48	0.93
14300.7*	1116.46	1118.53	1118.43	1119.14	0.013595	3.70	89.09	60.65	1.47	0.90
14278.2*	1116.18	1118.42		1118.85	0.008533	3.16	107.82	67.84	1.59	0.73
14255.7	1115.90	1118.41		1118.66	0.004289	2.48	138.68	73.29	1.89	0.53
14230.4	1114.93	1117.60	1117.60	1118.40	0.016885	4.30	78.03	49.37	1.58	1.01
14210.2*	1114.49	1117.02	1117.17	1117.98	0.020841	4.64	71.90	48.98	1.47	1.12
14190.1*	1114.05	1116.50	1116.70	1117.52	0.021724	4.70	70.01	49.11	1.43	1.14
14169.9*	1113.61	1115.94	1116.19	1117.04	0.023533	4.79	67.14	48.53	1.38	1.18
14149.8	1113.16	1115.34	1115.63	1116.52	0.026303	4.90	63.81	46.84	1.36	1.24
14126.6	1113.03	1115.28	1115.26	1116.06	0.013861	4.05	80.70	53.13	1.52	0.93
14108.8	1112.87	1115.17	1115.01	1115.79	0.010313	3.68	91.82	58.51	1.57	0.81
14086.4	1112.64	1114.77	1114.77	1115.51	0.014129	4.02	83.32	57.76	1.44	0.94
14066.2	1112.07	1113.56	1113.98	1114.95	0.047202	5.29	57.93	56.72	1.02	1.58
14046.3	1111.10	1114.28	1113.26	1114.50	0.002978	2.15	144.45	68.61	2.11	0.45
14026.8	1110.72	1114.21		1114.45	0.003005	2.14	140.34	62.44	2.25	0.45
14007.8	1111.14	1114.05		1114.36	0.005148	2.50	118.78	60.21	1.97	0.57
13986.0	1110.24	1114.12		1114.25	0.001461	1.61	187.27	74.90	2.50	0.32
13964.9	1110.81	1113.92		1114.19	0.00413	2.30	128.83	62.54	2.06	0.51
13937.9	1110.67	1113.86		1114.09	0.002934	2.14	141.51	65.56	2.16	0.44
13916.2	1111.06	1113.15	1113.15	1113.91	0.017617	3.84	77.08	51.50	1.50	1.00
13895.1	1110.18	1111.43	1111.94	1113.14	0.073802	5.79	51.16	54.31	0.94	1.90
13873.2	1109.31	1112.31	1111.35	1112.54	0.003114	2.19	143.83	68.19	2.11	0.46
13853.4	1108.91	1112.27		1112.48	0.002396	2.05	152.34	66.95	2.28	0.41
13832.9*	1108.83	1112.19		1112.42	0.002706	2.18	144.33	63.17	2.28	0.43
13812.4*	1108.75	1112.10		1112.36	0.003083	2.36	134.95	59.48	2.27	0.46

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
13791.8*	1108.66	1111.97		1112.29	0.003728	2.61	124.01	55.66	2.23	0.51
13771.3*	1108.58	1111.78		1112.19	0.004989	2.99	110.40	51.49	2.14	0.59
13750.9	1108.50	1111.08	1111.08	1111.97	0.015176	4.44	74.41	43.43	1.71	0.98
13687.0	1107.60	1110.75	1110.16	1111.21	0.0054	3.27	106.78	49.54	2.16	0.62
13619.5	1106.89	1110.62		1110.92	0.002702	2.68	134.35	51.42	2.61	0.45
13565.2	1106.90	1110.10		1110.67	0.006946	3.51	93.48	42.59	2.19	0.69
13522.4	1107.08	1109.52	1109.35	1110.26	0.01165	4.07	81.76	43.84	1.86	0.87
13493.3*	1106.58	1109.12	1109.01	1109.91	0.012475	4.13	79.40	43.73	1.82	0.90
13464.3*	1106.09	1108.71	1108.65	1109.53	0.013353	4.16	77.38	43.85	1.76	0.92
13435.2*	1105.59	1108.28	1108.24	1109.13	0.014367	4.19	75.43	43.60	1.73	0.95
13406.2*	1105.10	1107.87	1107.83	1108.70	0.014666	4.14	75.20	43.78	1.72	0.95
13377.2*	1104.61	1107.50	1107.41	1108.28	0.013738	3.98	77.39	44.61	1.73	0.92
13348.2	1104.11	1106.98	1106.98	1107.83	0.016534	4.15	73.47	43.93	1.67	1.00
13326.7	1102.84	1107.00	1105.85	1107.32	0.003484	2.54	120.91	47.72	2.53	0.49
13298.3	1103.55	1106.36	1106.27	1107.10	0.014365	3.82	77.70	45.60	1.70	0.93
13273.7	1102.67	1106.60		1106.85	0.002038	2.23	140.89	49.94	2.82	0.39
13245.9	1103.20	1105.78	1105.78	1106.66	0.014887	4.22	73.81	43.68	1.69	0.96
13224.0	1102.22	1104.20	1104.76	1106.03	0.046961	6.01	50.06	38.62	1.30	1.62
13200.3	1101.45	1104.58	1104.58	1105.53	0.014948	4.47	71.63	38.66	1.85	0.98
13171.0	1100.93	1104.81	1103.63	1105.14	0.003081	2.56	120.56	46.44	2.60	0.47
13141.5	1101.35	1104.59		1105.01	0.004765	2.99	107.96	48.13	2.24	0.58
13120.2	1101.53	1104.31		1104.88	0.007111	3.45	94.68	47.07	2.01	0.70
13091.1	1101.14	1103.65	1103.65	1104.55	0.014672	4.36	73.78	43.15	1.71	0.97
13064.3	1100.15	1102.20	1102.70	1103.84	0.044655	5.79	53.17	41.07	1.29	1.58
13036.7	1099.85	1102.32	1102.32	1103.15	0.016526	4.06	74.02	45.16	1.64	0.99
13007.1	1098.64	1102.14	1101.31	1102.48	0.004481	2.61	116.94	53.97	2.17	0.54
12971.7	1098.74	1101.64	1101.32	1102.23	0.009864	3.51	88.49	46.53	1.90	0.79
12942.7	1098.77	1101.02	1101.02	1101.85	0.016166	4.04	74.67	46.55	1.60	0.98
12908.6	1098.26	1100.93	1100.35	1101.36	0.006122	2.96	104.54	51.65	2.02	0.63
12870.8	1097.75	1100.43		1101.05	0.010144	3.49	86.21	48.68	1.77	0.80
12836.1	1097.27	1100.43		1100.74	0.004142	2.46	122.23	58.74	2.08	0.52
12808.2	1096.85	1100.48		1100.63	0.001635	1.74	179.17	75.51	2.37	0.34
12767.3	1096.58	1100.44		1100.56	0.001218	1.53	197.72	78.07	2.53	0.29
12733.7	1097.33	1100.33		1100.50	0.002093	1.89	165.07	72.09	2.29	0.38
12703.4	1096.95	1100.21		1100.43	0.002284	2.12	152.86	68.00	2.25	0.40
12665.7	1097.08	1099.89		1100.29	0.004989	2.95	114.88	60.01	1.91	0.59

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
12636.0	1097.26	1099.25	1099.25	1100.01	0.015869	4.06	80.66	55.37	1.46	0.98
12588.9	1095.98	1098.14	1098.26	1099.15	0.019356	4.61	69.00	43.57	1.58	1.09
12548.1	1093.22	1095.62	1096.32	1097.83	0.049667	6.64	45.61	31.10	1.47	1.69
12516.1	1093.30	1096.25	1096.16	1097.13	0.013113	4.17	72.69	37.85	1.92	0.91
12478.5	1093.23	1096.12	1095.67	1096.67	0.00736	3.31	92.70	46.71	1.98	0.70
12440.8	1093.07	1095.41	1095.41	1096.25	0.016194	4.07	73.74	45.25	1.63	0.98
12409.0	1091.04	1095.10	1093.63	1095.32	0.00208	2.09	144.20	53.45	2.70	0.39
12374.6	1091.23	1094.82		1095.21	0.003819	2.84	113.34	47.65	2.38	0.52
12339.4	1091.29	1094.05	1094.05	1094.92	0.016203	4.18	72.87	43.70	1.67	0.99
12302.1	1090.65	1092.51	1092.93	1093.95	0.040815	5.36	56.70	46.30	1.22	1.50
12277.1	1090.86	1092.61	1092.61	1093.26	0.015268	3.79	88.34	68.64	1.29	0.95
12254.0	1090.44	1092.48	1092.00	1092.79	0.006339	2.57	124.50	80.27	1.55	0.62
12222.0	1089.05	1092.26		1092.59	0.006203	2.60	118.43	71.46	1.66	0.62
12179.8	1089.24	1091.44	1091.44	1092.16	0.014913	3.95	83.74	59.53	1.41	0.95
12152.7	1088.78	1091.29	1090.92	1091.76	0.007356	3.18	103.97	62.12	1.67	0.69
12116.6	1088.90	1090.67	1090.67	1091.36	0.016647	3.80	83.68	63.42	1.32	0.98
12081.7	1086.94	1089.53	1089.76	1090.55	0.030609	4.48	66.93	57.38	1.17	1.28
12047.7	1087.24	1088.99	1088.99	1089.62	0.018932	3.53	84.03	67.54	1.24	1.01
12010.4	1086.65	1088.52	1088.21	1088.85	0.008726	2.53	117.61	89.89	1.31	0.70
11973.9	1085.86	1088.25	1087.82	1088.55	0.007036	2.44	121.65	81.14	1.50	0.64
11961.3	Bridge									
11948.7	1086.24	1087.53	1087.53	1087.93	0.021749	2.96	108.12	137.09	0.79	1.02
11926.4	1084.94	1086.64	1086.80	1087.25	0.045207	3.47	85.60	137.16	0.62	1.40
11917.2	1083.86	1086.43	1085.76	1086.65	0.007035	2.09	142.69	122.42	1.17	0.61
11851.0	Bridge									
11784.9	1082.75	1086.24		1086.33	0.001462	1.32	225.80	119.05	1.90	0.30
11761.9*	1082.54	1086.22		1086.29	0.001419	1.22	242.51	138.27	1.75	0.29
11739.1*	1082.32	1086.19		1086.26	0.000966	1.17	254.30	120.59	2.11	0.25
11716.2*	1082.10	1086.16		1086.24	0.00087	1.27	238.83	97.19	2.46	0.25
11693.3*	1081.89	1086.08		1086.21	0.00122	1.64	190.29	71.09	2.68	0.30
11670.5	1081.67	1085.48		1086.11	0.007501	3.67	88.48	39.30	2.25	0.71
11635.8	1081.41	1085.52		1085.87	0.002887	2.74	122.82	45.68	2.69	0.47
11572.4	1080.88	1085.42		1085.70	0.001949	2.44	139.76	47.24	2.96	0.39
11533.9	1081.24	1085.33		1085.61	0.002242	2.51	135.90	48.47	2.80	0.42
11506.0	1081.21	1085.11		1085.52	0.003863	3.26	116.76	46.58	2.51	0.55
11481.5	1081.15	1084.75		1085.37	0.007012	4.09	93.95	41.31	2.27	0.72

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
11451.0	1079.17	1084.98		1085.18	0.001158	2.30	170.91	49.41	3.46	0.32
11419.0	1080.36	1084.77		1085.11	0.002855	3.01	130.66	48.87	2.67	0.48
11379.8	1080.73	1083.88	1083.88	1084.84	0.012283	4.80	76.68	41.55	1.85	0.93
11344.1	1078.63	1080.84	1081.72	1083.74	0.078267	7.79	40.31	31.06	1.30	2.09
11305.0	1078.46	1080.84	1081.02	1081.85	0.018807	4.56	70.86	51.04	1.39	1.07
11270.7	1077.53	1079.86	1080.19	1081.08	0.02566	4.97	63.23	48.23	1.31	1.23
11234.7*	1077.28	1079.79	1079.79	1080.47	0.011892	3.90	91.99	72.23	1.27	0.87
11198.8*	1077.04	1079.05	1079.23	1079.90	0.020393	4.54	81.87	72.81	1.12	1.11
11162.8	1076.79	1078.56	1078.56	1079.16	0.017621	3.96	92.55	77.77	1.19	1.01
11134.2*	1076.02	1077.77	1077.87	1078.52	0.022936	4.38	81.59	69.68	1.17	1.15
11105.7*	1075.24	1077.14	1077.17	1077.85	0.019497	4.20	83.30	64.46	1.29	1.07
11077.1*	1074.47	1076.40	1076.48	1077.20	0.021837	4.41	77.73	58.42	1.33	1.13
11048.6*	1073.69	1075.75	1075.79	1076.55	0.020354	4.37	77.16	53.94	1.43	1.09
11020.0*	1072.92	1075.06	1075.11	1075.91	0.020596	4.45	74.54	49.40	1.51	1.10
10991.5*	1072.15	1074.41	1074.44	1075.28	0.019851	4.47	73.10	45.38	1.61	1.09
10963.0	1071.37	1073.77	1073.79	1074.68	0.019159	4.54	71.34	41.53	1.72	1.08
10935.3*	1070.86	1073.12	1073.27	1074.13	0.02052	4.73	70.33	47.20	1.49	1.12
10907.8	1070.34	1072.50	1072.72	1073.55	0.020974	4.70	69.84	52.84	1.32	1.13
10871.3*	1069.59	1072.33	1072.21	1073.06	0.010675	3.99	85.94	53.09	1.62	0.84
10835.0	1068.85	1071.65	1071.65	1072.56	0.015389	4.55	74.09	43.87	1.69	0.99
10816.7	1067.82	1069.90	1070.59	1072.00	0.040703	6.97	51.44	38.69	1.33	1.60
10790.6*	1067.37	1070.31	1070.25	1071.23	0.011648	4.64	77.30	41.23	1.87	0.90
10764.5*	1066.92	1069.97	1069.85	1070.92	0.011229	4.58	74.13	35.52	2.09	0.88
10738.5	1066.47	1069.42	1069.42	1070.57	0.01406	4.91	65.57	30.16	2.17	0.98
10712.1*	1065.88	1068.41	1068.80	1070.02	0.027086	5.75	54.31	30.63	1.77	1.30
10685.8*	1065.29	1067.97	1068.20	1069.29	0.02199	5.19	59.79	33.43	1.79	1.17
10659.4*	1064.69	1068.03	1067.64	1068.71	0.008458	3.73	83.80	38.76	2.16	0.75
10633.1*	1064.10	1068.09		1068.47	0.003767	2.81	112.22	44.81	2.50	0.52
10606.8	1063.51	1068.12		1068.36	0.001919	2.21	144.65	52.75	2.74	0.38
10576.8	1063.77	1068.07		1068.30	0.001825	2.19	148.92	52.76	2.82	0.37
10541.9	1064.10	1067.07	1067.07	1068.08	0.014903	4.61	69.11	36.63	1.89	0.98
10510.6	1062.97	1065.48	1066.00	1067.30	0.03791	5.98	49.69	30.94	1.61	1.49
10479.7	1062.79	1066.30	1065.47	1066.73	0.005272	3.09	106.56	44.47	2.40	0.60
10457.2	1062.83	1065.59	1065.59	1066.48	0.015997	4.41	73.68	41.62	1.77	1.00
10421.4	1061.50	1063.43	1064.05	1065.41	0.051387	6.31	48.78	39.07	1.25	1.69
10389.3*	1061.30	1063.85	1063.72	1064.56	0.011969	3.83	83.18	50.07	1.66	0.87

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
10357.3*	1061.10	1063.49	1063.35	1064.17	0.011967	3.77	85.03	53.11	1.60	0.86
10325.4	1060.89	1062.97	1062.97	1063.73	0.015207	3.99	80.72	56.54	1.43	0.96
10286.8	1059.51	1061.65	1061.97	1062.87	0.031266	4.91	60.37	42.90	1.41	1.32
10256.7	1058.95	1060.91	1061.12	1061.92	0.028114	4.43	66.87	51.31	1.30	1.24
10225.5	1058.57	1061.07	1060.55	1061.41	0.006207	2.61	115.63	68.69	1.68	0.62
10201.7	1058.06	1060.77		1061.24	0.007543	3.07	100.67	60.45	1.67	0.69
10173.3	1057.29	1060.79		1061.05	0.002846	2.42	139.74	61.92	2.26	0.45
10141.9	1057.23	1059.95	1059.95	1060.82	0.013551	4.31	76.54	46.38	1.65	0.94
10115.3*	1056.98	1059.90	1059.45	1060.41	0.006841	3.40	101.10	53.23	1.90	0.68
10088.8	1056.74	1059.94		1060.22	0.003203	2.60	136.45	61.30	2.23	0.48
10050.2*	1056.83	1059.62		1060.05	0.005511	3.00	109.38	56.74	1.93	0.61
10011.7	1056.92	1058.95	1058.95	1059.68	0.01581	3.86	80.91	56.82	1.42	0.96
9969.9	1055.53	1057.15	1057.58	1058.60	0.040294	5.45	57.98	51.70	1.12	1.50
9934.9	1053.68	1055.91	1056.28	1057.28	0.034104	5.18	57.18	39.96	1.43	1.38
9908.4	1053.18	1055.91	1055.91	1056.81	0.015542	4.23	72.10	43.08	1.67	0.98
9882.8	1052.72	1056.02	1055.10	1056.33	0.003472	2.57	130.35	60.90	2.14	0.49
9872.2	Bridge									
9861.6	1051.98	1056.01		1056.17	0.001422	1.92	175.79	67.13	2.62	0.33
9854.1	1052.98	1055.66		1056.12	0.006654	3.10	102.88	57.03	1.80	0.66
9846.5	1051.94	1055.86	1054.06	1056.01	0.00119	1.78	187.59	68.42	2.74	0.30
9836.3	Bridge									
9826.1	1052.10	1055.76		1055.94	0.00169	1.97	167.05	67.65	2.47	0.35
9800.8	1052.80	1054.97	1054.97	1055.78	0.015986	4.08	76.32	49.11	1.55	0.98
9765.1	1052.07	1054.29	1054.37	1055.15	0.019311	4.23	74.29	52.75	1.41	1.07
9738.0	1051.38	1053.96	1053.87	1054.70	0.013318	3.95	81.16	49.38	1.64	0.91
9714.8	1051.16	1053.56	1053.56	1054.36	0.015174	4.03	77.79	52.65	1.48	0.96
9691.4	1050.70	1052.40	1052.80	1053.73	0.046583	5.12	57.91	52.37	1.11	1.55
9651.7	1049.97	1052.08	1052.08	1052.80	0.017722	3.76	78.77	54.64	1.44	1.00
9624.8	1048.92	1051.80	1050.67	1052.00	0.002556	1.99	150.61	67.12	2.24	0.41
9596.0	1048.47	1051.75		1051.93	0.001929	1.89	163.03	69.02	2.36	0.37
9564.2	1048.77	1051.08	1050.95	1051.75	0.013869	3.62	81.78	49.80	1.64	0.90
9529.9	1048.43	1050.45	1050.45	1051.21	0.016916	3.87	77.37	52.28	1.48	0.99
9500.6	1047.35	1049.51	1049.72	1050.59	0.02415	4.63	65.23	45.14	1.45	1.18
9465.4	1046.72	1050.12	1048.75	1050.30	0.002043	1.91	159.13	65.56	2.43	0.38
9428.8	1046.15	1050.17		1050.23	0.000493	1.04	287.36	98.57	2.92	0.19
9380.6	1047.15	1049.38	1049.33	1050.10	0.01574	3.88	80.80	52.70	1.53	0.97

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
9344.0	1046.61	1048.68	1048.68	1049.36	0.017525	3.98	84.55	61.08	1.38	1.01
9280.4	1043.87	1046.32	1046.73	1047.73	0.033478	6.07	60.48	44.14	1.37	1.42
9249.6*	1043.55	1046.23	1046.23	1047.05	0.015642	4.47	78.87	50.38	1.57	1.00
9218.81*	1043.23	1045.87	1045.72	1046.54	0.01203	3.90	86.15	52.80	1.63	0.87
9188.0	1042.91	1045.80		1046.20	0.005742	2.95	111.18	58.67	1.90	0.62
9150.9	1042.63	1045.31		1045.91	0.008765	3.48	89.95	49.89	1.80	0.75
9112.3	1041.48	1044.46	1044.46	1045.45	0.013921	4.48	70.62	39.03	1.81	0.95
9082.1	1040.86	1044.21	1043.84	1044.89	0.007941	3.84	87.83	42.82	2.05	0.74
9051.6	1040.90	1043.64	1043.64	1044.54	0.015243	4.38	73.46	42.53	1.73	0.98
9017.6	1039.79	1042.20	1042.64	1043.72	0.035752	5.47	54.54	37.96	1.44	1.43
8993.0	1039.28	1042.78	1042.22	1043.27	0.006988	3.19	98.35	47.46	2.07	0.68
8963.7	1038.20	1042.86		1043.09	0.001918	2.17	141.70	49.09	2.89	0.38
8930.2	1038.13	1042.86		1043.02	0.001245	1.84	172.17	56.76	3.03	0.31
8901.0	1038.41	1042.80		1042.98	0.00148	1.92	159.90	53.71	2.98	0.33
8873.1	1037.34	1042.83		1042.93	0.000604	1.42	219.26	59.85	3.66	0.22
8846.0	1037.03	1042.81		1042.91	0.000517	1.47	224.26	58.22	3.85	0.21
8821.9	1037.19	1042.80		1042.90	0.000526	1.44	230.66	62.46	3.69	0.21
8791.9	1037.06	1042.82		1042.88	0.000298	1.14	297.32	76.00	3.91	0.16
8766.92*	1036.92	1042.81		1042.87	0.000272	1.11	302.14	73.58	4.11	0.15
8741.95*	1036.77	1042.81		1042.86	0.000249	1.09	307.68	71.59	4.30	0.15
8717.0	1036.62	1042.80		1042.85	0.000227	1.07	313.71	69.91	4.49	0.14
8691.7	1036.57	1042.80		1042.85	0.000239	1.12	323.06	77.38	4.17	0.15
8668.3	1038.12	1042.63		1042.82	0.001442	2.15	167.10	55.31	3.02	0.34
8646.53*	1038.17	1042.52		1042.78	0.002097	2.50	143.90	51.57	2.79	0.41
8624.73*	1038.23	1042.32		1042.71	0.003329	3.00	119.37	47.30	2.52	0.50
8602.9	1038.29	1041.49	1041.49	1042.52	0.011929	4.71	72.38	37.69	1.92	0.91
8582.4	1037.85	1040.25	1040.78	1042.06	0.033274	6.61	54.16	34.67	1.56	1.46
8562.0	1036.53	1040.84	1039.92	1041.40	0.005006	3.77	98.47	36.57	2.69	0.62
8539.5	1035.57	1040.96		1041.26	0.001663	2.53	136.33	40.57	3.36	0.37
8517.5	1034.59	1041.02		1041.19	0.000911	1.98	173.24	45.85	3.78	0.28
8496.8	1034.51	1040.90		1041.16	0.001406	2.48	148.81	43.16	3.45	0.34
8475.6	1034.82	1040.65		1041.10	0.003104	3.60	111.21	31.84	3.49	0.51
8459.8	1035.76	1040.14	1039.67	1040.99	0.007595	4.74	81.46	30.35	2.68	0.77
8447.4	1035.60	1039.56	1039.56	1040.83	0.01256	5.76	66.71	26.96	2.47	0.97
8426.2	1034.20	1037.46	1038.34	1040.23	0.042294	8.94	45.76	26.15	1.75	1.71
8412.3	1032.14	1033.91	1035.18	1038.98	0.159799	11.6	31.15	25.76	1.21	3.01

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
8391.8	1032.90	1035.50	1035.72	1036.74	0.025484	5.22	60.91	35.56	1.71	1.24
8366.7	1030.60	1032.12	1033.01	1035.39	0.110659	8.16	38.15	36.97	1.03	2.41
8347.0	1030.10	1032.84	1033.00	1034.05	0.017922	4.97	63.65	35.37	1.80	1.08
8329.0	1028.98	1033.37	1031.72	1033.62	0.001901	2.31	141.14	47.50	2.97	0.38
8313.3	1028.45	1033.38		1033.58	0.001223	2.03	162.61	49.61	3.28	0.31
8288.0	1027.50	1033.40		1033.54	0.000646	1.70	198.06	48.98	4.04	0.24
8266.06*	1027.45	1033.34		1033.52	0.00087	1.94	174.81	44.58	3.92	0.27
8244.12*	1027.40	1033.27		1033.49	0.001169	2.22	154.06	40.45	3.81	0.31
8222.2	1027.36	1033.16		1033.45	0.001564	2.54	135.56	36.46	3.72	0.36
8205.4	1027.88	1032.88		1033.39	0.003866	3.68	103.47	32.57	3.18	0.56
8187.2	1028.34	1032.19	1032.01	1033.22	0.011628	4.69	68.83	27.69	2.49	0.88
8164.0	1027.33	1032.56		1032.91	0.002375	2.86	121.97	35.69	3.42	0.44
8140.0	1027.19	1032.64		1032.83	0.001049	2.11	167.83	43.17	3.89	0.30
8119.5	1028.48	1032.02		1032.73	0.007667	3.89	83.74	36.23	2.31	0.73
8101.6	1027.93	1031.30	1031.30	1032.50	0.014251	5.04	64.00	28.63	2.24	0.98
8085.9	1027.50	1030.54	1030.92	1032.17	0.02327	6.41	57.29	29.41	1.95	1.26
8068.4	1026.61	1029.23	1029.98	1031.61	0.033176	7.37	48.02	27.47	1.75	1.49
8048.2	1024.17	1027.08	1028.15	1030.60	0.06226	8.54	37.50	23.63	1.59	1.95
8029.4	1025.02	1028.26	1028.26	1029.43	0.014969	5.14	65.14	29.65	2.20	1.00
8008.9	1024.51	1027.56	1027.85	1029.03	0.021171	6.58	60.85	30.34	2.01	1.23
7998.33*	1023.94	1026.58	1027.27	1028.64	0.037696	7.50	51.44	31.97	1.61	1.57
7987.7	1023.38	1025.71	1026.43	1028.04	0.061501	7.58	45.33	32.30	1.40	1.89
7977.7	Bridge									
7967.7	1023.82	1026.45	1025.68	1026.77	0.005918	2.71	119.05	58.18	2.05	0.61
7959.5	1022.93	1026.52	1025.10	1026.71	0.002464	2.25	163.02	70.79	2.30	0.42
7937.9	1023.32	1026.56	1025.34	1026.65	0.001224	1.49	244.10	117.17	2.08	0.29
7898.1	Bridge									
7858.3	1021.45	1026.56		1026.59	0.000186	0.80	415.29	123.05	3.37	0.12
7813.21*	1021.45	1026.52		1026.58	0.00039	1.17	299.58	94.92	3.16	0.18
7768.1	1021.45	1026.16		1026.51	0.002532	2.88	124.39	41.21	3.02	0.45
7745.6	1019.60	1026.26		1026.43	0.000777	1.91	178.10	44.01	4.05	0.26
7720.8	1021.43	1025.18	1025.05	1026.28	0.011089	4.86	68.33	28.79	2.37	0.88
7700.6	1020.67	1025.25		1026.02	0.006248	4.32	84.12	29.36	2.87	0.69
7676.1	1021.02	1024.65	1024.65	1025.78	0.012059	5.20	70.13	31.98	2.19	0.93
7649.7	1020.32	1024.54	1023.86	1025.29	0.006833	4.14	82.83	30.34	2.73	0.70
7627.2	1020.76	1024.45		1025.11	0.006907	3.96	88.06	35.17	2.50	0.71

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS. Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
7605.9	1018.30	1024.50		1024.95	0.002885	3.44	110.71	30.87	3.59	0.49
7589.1	1018.71	1024.15		1024.85	0.006915	4.03	82.31	25.92	3.18	0.68
7566.7	1017.72	1024.38		1024.66	0.001604	2.74	138.74	34.53	4.02	0.36
7542.0	1019.45	1023.99		1024.57	0.004284	3.68	96.92	32.37	2.99	0.58
7519.4	1018.68	1023.20	1023.08	1024.36	0.010587	5.21	68.54	27.03	2.54	0.88
7499.8	1018.67	1023.36		1024.08	0.005638	4.34	89.00	30.30	2.94	0.67
7481.7	1018.14	1023.60	1021.84	1023.90	0.002012	2.82	141.03	47.60	2.96	0.41
7472.9	Bridge									
7464.1	1019.32	1023.56		1023.80	0.002421	2.71	148.35	54.94	2.70	0.44
7451.4	1018.02	1023.58		1023.77	0.001227	2.24	176.26	53.88	3.27	0.32
7440.6	1016.57	1023.64	1020.03	1023.73	0.00042	1.57	263.11	70.35	3.74	0.20
7431.3	Bridge									
7422.0	1020.21	1023.00		1023.54	0.007387	3.69	99.10	49.40	2.01	0.72
7409.04*	1019.83	1022.46	1022.46	1023.37	0.013867	4.64	76.30	43.32	1.76	0.96
7396.09*	1018.95	1021.20	1021.72	1022.98	0.038154	6.32	52.04	34.17	1.52	1.52
7383.1	1018.07	1020.45	1021.02	1022.39	0.04342	6.50	48.59	29.30	1.66	1.60
7358.7	1017.21	1020.72	1020.02	1021.29	0.005767	3.64	94.66	37.35	2.53	0.65
7348.21*	1017.15	1020.73		1021.20	0.004745	3.35	105.24	42.41	2.48	0.59
7337.76*	1017.08	1020.73		1021.13	0.003914	3.09	116.15	46.96	2.47	0.54
7327.3	1016.52	1020.83	1019.17	1021.05	0.001731	2.32	159.22	55.44	2.87	0.37
7319.4	Bridge									
7311.6	1016.42	1020.76		1020.98	0.001852	2.44	156.80	55.58	2.82	0.38
7301.4	1017.23	1020.09	1019.92	1020.88	0.012319	4.48	80.34	42.14	1.91	0.91
7293.1	1016.69	1020.29	1019.44	1020.71	0.004608	3.22	112.04	48.18	2.33	0.58
7285.2	Bridge									
7277.2	1016.21	1020.29		1020.57	0.00251	2.66	137.43	50.76	2.71	0.44
7266.20*	1016.66	1019.99		1020.51	0.005833	3.51	101.15	45.62	2.22	0.65
7255.19*	1016.61	1019.90		1020.44	0.006021	3.55	99.36	44.96	2.21	0.66
7244.19*	1016.56	1019.81		1020.37	0.006238	3.59	97.48	44.30	2.20	0.67
7233.18*	1016.51	1019.71		1020.29	0.006508	3.63	95.42	43.63	2.19	0.68
7222.17*	1016.45	1019.61		1020.22	0.006858	3.68	93.12	42.95	2.17	0.70
7211.17*	1016.40	1019.50		1020.14	0.007337	3.75	90.44	42.25	2.14	0.72
7200.16*	1016.35	1019.37	1019.00	1020.05	0.008076	3.85	87.19	41.85	2.08	0.75
7189.2	1016.30	1018.93	1018.93	1019.90	0.014045	4.55	71.73	38.77	1.85	0.96
7173.7	1014.26	1019.00	1017.22	1019.26	0.001774	2.45	145.59	47.60	3.06	0.38
7140.9	1014.95	1018.43		1019.11	0.00688	3.98	89.48	38.80	2.31	0.71

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
7127.0	1013.88	1018.59		1018.96	0.002547	2.93	118.62	35.99	3.30	0.45
7114.8	1013.84	1018.54		1018.93	0.00262	2.86	116.51	37.92	3.07	0.45
7098.5	1014.72	1018.02	1017.71	1018.82	0.00864	4.13	80.57	36.78	2.19	0.78
7081.3	1013.00	1018.31		1018.61	0.001932	2.70	136.52	42.32	3.23	0.40
7064.3	1012.53	1018.28		1018.57	0.001756	2.62	139.08	41.51	3.35	0.38
7049.0	1014.02	1017.37	1017.37	1018.44	0.012861	5.12	71.64	34.44	2.08	0.96
7030.1	1012.10	1015.59	1016.30	1017.93	0.034782	7.13	46.37	25.12	1.85	1.49
7014.25*	1012.00	1016.88	1016.05	1017.52	0.005392	3.87	90.49	32.29	2.80	0.64
6998.45*	1011.91	1016.87		1017.41	0.004334	3.56	98.48	33.78	2.92	0.57
6982.64*	1011.82	1016.86		1017.33	0.003525	3.29	106.64	35.26	3.02	0.52
6966.8	1011.72	1016.86		1017.25	0.002899	3.05	114.95	36.77	3.13	0.48
6947.7	1010.18	1016.95		1017.17	0.001036	2.16	155.88	37.40	4.17	0.30
6930.44*	1010.06	1016.95		1017.14	0.000912	2.08	163.76	38.59	4.24	0.28
6913.17*	1009.95	1016.94		1017.12	0.000804	2.00	172.08	39.75	4.33	0.26
6895.91*	1009.83	1016.94		1017.11	0.000708	1.92	180.81	40.83	4.43	0.25
6878.64*	1009.72	1016.94		1017.09	0.000625	1.85	189.92	41.89	4.53	0.24
6861.37*	1009.61	1016.94		1017.08	0.000552	1.78	199.41	42.95	4.64	0.22
6844.11*	1009.49	1016.94		1017.06	0.000488	1.71	209.25	44.01	4.75	0.21
6826.8	1009.38	1016.94		1017.05	0.000432	1.65	219.47	45.06	4.87	0.20
6811.8	1010.00	1016.89		1017.04	0.000671	1.92	192.02	44.28	4.34	0.25
6802.5	1010.47	1016.86	1013.93	1017.03	0.000874	2.08	178.00	44.39	4.01	0.28
6792.7	Bridge									
6782.9	1009.36	1016.83		1017.00	0.000694	2.05	186.13	39.62	4.70	0.25
6776.5	1009.30	1016.79		1016.99	0.000862	2.28	172.17	38.22	4.50	0.28
6770.0	1009.98	1016.71	1014.18	1016.97	0.001364	2.66	146.65	35.57	4.12	0.35
6760.2	Bridge									
6750.3	1011.95	1015.57	1015.57	1016.80	0.013159	5.63	67.05	28.59	2.35	0.99
6738.4	1010.95	1014.46	1015.04	1016.51	0.025665	7.00	52.08	26.24	1.98	1.33
6721.8	1008.92	1014.85	1013.35	1015.34	0.002928	3.39	106.38	30.12	3.53	0.49
6704.2	1009.82	1014.87		1015.26	0.002449	3.03	119.72	35.26	3.40	0.45
6686.7	1010.67	1013.94	1013.94	1015.10	0.01288	5.08	67.61	30.61	2.21	0.96
6670.4	1009.75	1013.39	1013.60	1014.83	0.016868	6.21	62.18	28.11	2.21	1.11
6652.3	1009.16	1013.32	1012.77	1014.14	0.00743	4.64	81.10	28.88	2.81	0.76
6635.3	1008.26	1013.03		1014.00	0.008152	5.20	76.22	26.00	2.93	0.79
6621.01*	1008.26	1013.06		1013.84	0.006296	4.60	84.52	28.17	3.00	0.70
6606.70*	1008.25	1013.08		1013.72	0.00503	4.12	92.95	30.56	3.04	0.63

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
6592.4	1008.24	1013.10		1013.62	0.004108	3.71	101.71	33.12	3.07	0.57
6578.7	1008.02	1013.20		1013.52	0.002026	2.78	131.90	39.06	3.38	0.41
6565.5	1007.63	1013.12		1013.48	0.002238	2.79	120.14	35.96	3.34	0.42
6550.0	1008.28	1012.12	1012.12	1013.33	0.01366	5.24	65.15	28.40	2.29	0.97
6539.7	1008.24	1011.37	1011.76	1013.10	0.021269	6.24	54.64	26.09	2.09	1.20
6528.6	1007.41	1010.24	1010.99	1012.71	0.039185	7.37	45.64	26.30	1.74	1.59
6520.0	1006.96	1009.16	1010.13	1012.25	0.052964	8.12	40.61	25.77	1.58	1.82
6509.8	Bridge									
6499.6	1003.73	1010.11	1007.84	1010.37	0.001647	2.63	144.12	40.21	3.58	0.37
6492.9	1004.42	1010.12	1007.87	1010.36	0.001523	2.54	151.79	42.85	3.54	0.36
6485.8	1003.55	1010.19	1006.76	1010.32	0.000623	1.92	209.83	49.11	4.27	0.24
6475.4	Bridge									
6465.0	1003.26	1010.17		1010.29	0.000607	1.91	217.93	51.88	4.20	0.24
6455.2	1004.30	1010.18		1010.28	0.00063	1.59	211.44	48.21	4.39	0.23
6430.0	1004.05	1010.14		1010.26	0.000751	1.77	200.15	50.04	4.00	0.25
6408.73*	1003.04	1010.18		1010.24	0.000274	1.22	288.98	60.03	4.81	0.16
6387.5	1002.03	1010.19		1010.22	0.000121	0.90	389.71	67.57	5.77	0.11
6365.98*	1002.31	1010.16		1010.22	0.000206	1.18	312.95	59.40	5.27	0.14
6344.50*	1002.60	1010.12		1010.21	0.000339	1.50	253.08	50.93	4.97	0.18
6323.0	1002.88	1010.07		1010.20	0.000513	1.81	210.90	42.28	4.99	0.22
6302.8	999.50	1010.09		1010.18	0.000272	1.58	248.96	37.44	6.65	0.16
6283.6	1004.10	1008.77	1008.77	1010.05	0.011396	5.82	68.19	27.12	2.51	0.93
6259.8	999.31	1006.86	1003.19	1007.06	0.000921	2.53	168.60	34.17	4.93	0.30
6236.8	1001.50	1005.65	1005.65	1006.90	0.013031	5.70	66.32	27.17	2.44	0.98
6209.7	996.91	999.46	1000.99	1005.57	0.148503	11.6	28.13	19.46	1.45	2.89
6187.6	995.95	1002.45	1000.49	1002.82	0.00311	2.90	112.15	29.31	3.83	0.46
6165.3	996.16	1001.46		1002.63	0.008363	5.40	69.67	21.24	3.28	0.80
6143.2	994.76	1000.76	1000.76	1002.36	0.01248	6.07	59.01	19.65	3.00	0.90
6122.4	995.64	998.58	999.57	1001.75	0.044686	7.99	38.50	17.34	2.22	1.65
6100.3	991.74	995.10	996.62	1000.26	0.077057	10.9	31.90	16.34	1.95	2.25
6087.7	992.43	998.11	996.78	998.74	0.004015	4.14	96.25	27.64	3.48	0.59
6074.2	992.28	998.29		998.62	0.001845	3.07	130.34	31.55	4.13	0.41
6057.0	989.65	998.37		998.56	0.000618	2.09	176.24	31.10	5.67	0.24
6043.6	991.20	998.25		998.54	0.001324	2.49	136.34	31.49	4.33	0.33
6032.4	993.19	997.14	997.14	998.40	0.012884	5.30	64.34	26.74	2.41	0.96
6017.5	991.35	994.09	995.25	997.81	0.055545	8.88	36.75	19.88	1.85	1.87

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
5999.6	989.55	992.79	994.02	996.75	0.060406	9.39	35.33	17.51	2.02	1.92
5980.8	988.43	991.91	993.09	995.67	0.048394	9.37	38.51	19.98	1.93	1.80
5963.7	989.19	993.10	993.26	994.56	0.015206	6.09	61.65	25.49	2.42	1.06
5945.8	989.05	992.27	992.77	994.18	0.02226	6.88	54.12	25.59	2.11	1.26
5929.1	987.34	992.27	991.05	992.75	0.003772	3.64	107.66	35.41	3.04	0.55
5913.6	987.92	992.08		992.67	0.005552	4.18	95.79	34.01	2.82	0.66
5897.3	987.45	991.25	991.25	992.47	0.013991	5.66	66.02	27.71	2.38	1.01
5879.7	984.86	991.56	989.58	991.98	0.00245	3.26	115.39	30.01	3.85	0.45
5856.2	986.22	990.44	990.44	991.77	0.012431	5.61	64.29	25.23	2.55	0.96
5838.4	985.12	988.11	989.09	991.22	0.043275	8.53	41.69	21.84	1.91	1.71
5820.8	984.91	989.62	988.47	990.22	0.004306	3.96	96.79	30.42	3.18	0.59
5801.2	984.97	988.76	988.76	990.02	0.011695	5.46	66.86	27.88	2.40	0.94
5775.9	983.98	988.44	987.58	989.06	0.00495	4.00	94.82	33.36	2.84	0.63
5757.3	984.18	987.74	987.74	988.87	0.01281	5.40	69.93	31.45	2.22	0.97
5739.1	984.03	987.44	987.49	988.62	0.01444	5.50	67.51	31.17	2.17	1.02
5720.7	983.09	985.47	986.28	988.05	0.042243	7.56	45.25	28.34	1.60	1.64
5703.4	981.12	986.42	984.78	986.76	0.002198	2.76	127.36	41.22	3.09	0.42
5682.7	981.62	986.26		986.70	0.003476	3.19	110.45	38.03	2.90	0.52
5665.5	980.93	986.27		986.62	0.002258	2.72	121.90	39.15	3.11	0.42
5651.8	982.28	985.34	985.34	986.48	0.01363	4.79	65.04	30.36	2.14	0.95
5635.9	981.86	984.12	984.69	986.08	0.034424	6.23	48.96	29.49	1.66	1.45
5619.7	980.89	984.96	983.75	985.38	0.003324	2.95	108.89	38.93	2.80	0.50
5603.3	981.38	984.22	984.22	985.22	0.014321	4.47	68.73	36.64	1.88	0.96
5585.8	981.59	983.72	983.93	984.90	0.021859	4.88	63.57	40.41	1.57	1.15
5573.1	980.61	984.22	983.11	984.55	0.003108	2.68	123.56	48.63	2.54	0.48
5555.1	979.24	984.35		984.46	0.000725	1.59	211.65	60.72	3.49	0.24
5532.51*	979.18	984.29		984.44	0.000882	1.77	189.61	55.35	3.43	0.27
5509.97*	979.12	984.23		984.41	0.001085	1.98	168.80	49.75	3.39	0.30
5487.42*	979.06	984.15		984.38	0.001356	2.20	149.63	43.44	3.44	0.33
5464.9	978.99	984.05		984.34	0.001777	2.48	131.70	37.79	3.49	0.38
5447.7	979.05	983.99		984.30	0.002264	2.53	125.11	38.37	3.26	0.42
5424.8	977.76	984.05		984.24	0.000844	1.97	171.07	41.98	4.08	0.27
5403.1	979.59	983.05	983.05	984.10	0.014333	4.69	67.83	32.37	2.10	0.97
5377.1	977.58	982.44	980.71	982.74	0.002053	2.59	130.25	40.79	3.19	0.40
5350.8	978.95	981.56	981.56	982.56	0.017362	4.64	68.11	35.56	1.92	1.04
5318.4	977.28	979.52	980.17	981.57	0.047622	6.63	48.19	34.20	1.41	1.67

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS. Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
5291.6	976.54	979.24	979.48	980.53	0.020857	5.44	63.24	36.59	1.73	1.16
5266.2	976.44	978.71	978.96	979.90	0.026141	5.41	64.56	43.08	1.50	1.27
5243.9	975.10	977.28	977.80	979.04	0.045674	6.34	51.35	34.80	1.48	1.62
5222.5	973.43	978.49	976.33	978.68	0.001214	2.07	163.42	46.56	3.51	0.31
5203.8	973.27	978.48		978.65	0.001178	1.83	172.15	55.92	3.08	0.30
5183.5	973.79	978.46		978.62	0.001123	1.87	173.19	50.61	3.42	0.30
5145.2	974.60	977.45	977.45	978.43	0.014805	4.66	71.35	38.09	1.87	0.98
5123.9	973.78	977.67	976.55	978.06	0.003292	2.85	114.52	43.67	2.62	0.49
5105.3	973.54	977.69		977.98	0.002331	2.42	128.88	44.91	2.87	0.42
5083.2	974.00	976.84	976.84	977.81	0.01607	4.36	68.17	36.74	1.86	1.00
5063.3	971.91	976.72	975.18	977.03	0.002179	2.56	129.43	41.88	3.09	0.41
5041.7	972.26	976.37		976.93	0.005738	3.41	93.27	38.44	2.43	0.63
5022.1	971.84	975.59	975.59	976.71	0.013461	4.77	66.13	31.35	2.11	0.95
5001.9	971.13	975.58	975.13	976.42	0.008054	4.13	76.15	29.82	2.55	0.75
4979.2	971.92	975.12	975.12	976.15	0.015232	4.74	68.58	33.73	2.03	0.99
4964.9	970.98	974.83	973.95	975.34	0.004351	3.38	103.19	40.75	2.53	0.57
4947.9	970.77	974.76		975.25	0.004966	3.16	98.05	37.98	2.58	0.59
4930.4	969.30	974.92		975.13	0.001351	2.04	150.61	43.13	3.49	0.32
4913.0	969.49	974.84		975.09	0.001864	2.29	138.49	41.35	3.35	0.37
4894.3	969.68	974.87		975.04	0.001101	1.90	169.83	47.96	3.54	0.29
4876.0	970.69	974.15		974.93	0.010435	4.16	78.45	34.64	2.26	0.83
4848.4	969.88	974.29		974.66	0.00303	2.97	118.43	39.59	2.99	0.48
4824.6	970.06	973.39	973.39	974.45	0.015813	4.87	67.10	31.56	2.13	1.01
4804.1	969.20	973.37	972.43	973.93	0.004318	3.48	97.42	35.35	2.76	0.57
4782.0	968.87	973.35		973.82	0.003469	3.23	106.34	36.89	2.88	0.52
4758.6	967.11	973.53		973.69	0.000755	1.97	183.90	44.30	4.15	0.26
4743.3	967.43	973.48	970.95	973.68	0.001102	2.08	162.80	44.09	3.69	0.30
4733.4	Bridge									
4723.5	967.68	973.46		973.62	0.000918	1.89	180.44	46.43	3.89	0.27
4716.1	967.15	973.48		973.61	0.000634	1.72	203.56	49.34	4.13	0.23
4709.9	967.16	973.47	970.40	973.60	0.000651	1.75	204.07	50.61	4.03	0.24
4697.6	Bridge									
4688.4	968.23	973.30		973.54	0.001801	2.38	145.58	44.28	3.29	0.38
4675.3	967.18	973.30		973.51	0.001266	2.20	156.57	42.79	3.66	0.32
4655.5	967.24	973.27		973.48	0.001177	2.26	158.91	41.09	3.87	0.32
4635.2	968.37	973.16		973.45	0.002147	2.62	133.57	40.45	3.30	0.41

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
4615.9	967.85	973.12		973.41	0.001634	2.64	140.58	40.36	3.48	0.37
4597.6	967.49	973.09		973.38	0.001767	2.52	132.79	36.51	3.64	0.38
4576.4	968.37	972.91		973.32	0.002947	2.94	112.14	36.16	3.10	0.48
4560.4	967.08	973.04		973.23	0.000922	2.06	169.56	42.20	4.02	0.28
4540.9	967.35	973.03		973.21	0.000953	2.05	172.94	45.38	3.81	0.29
4521.0	967.09	973.03		973.18	0.000762	1.89	185.39	44.91	4.13	0.26
4506.3	968.13	972.73		973.14	0.002986	2.98	113.64	38.36	2.96	0.48
4491.5	968.73	971.94	971.94	972.99	0.016638	4.77	66.79	32.40	2.06	1.03
4472.4	967.74	969.52	970.32	972.23	0.075369	7.45	41.58	33.02	1.26	2.04
4451.6	966.76	969.21	969.69	970.85	0.036837	6.01	53.39	33.51	1.59	1.48
4428.8	964.24	966.04	966.99	969.31	0.104	8.40	37.77	31.40	1.20	2.37
4414.8	963.68	965.95	966.56	967.91	0.049352	6.37	49.04	36.31	1.35	1.67
4397.4	963.54	966.91	966.28	967.37	0.006175	3.08	101.39	47.52	2.13	0.64
4377.1	963.49	966.22	966.22	967.13	0.015543	4.38	72.24	39.71	1.82	0.99
4356.6	962.62	965.88	965.23	966.38	0.005853	3.22	97.61	42.63	2.29	0.63
4340.1	962.56	965.27	965.21	966.20	0.01326	4.37	71.85	37.37	1.92	0.93
4322.1	961.87	965.14		965.93	0.01178	4.15	77.36	36.66	2.11	0.88
4298.0	961.71	964.88	964.60	965.68	0.009183	4.05	78.77	35.95	2.19	0.79
4277.1	961.02	964.92		965.46	0.005125	3.30	94.94	38.27	2.48	0.60
4254.9	961.53	964.68		965.31	0.008544	3.52	86.07	41.51	2.07	0.74
4230.9	959.96	964.92		965.12	0.001318	2.01	158.51	50.03	3.17	0.32
4210.2	960.41	964.80		965.07	0.002164	2.41	135.55	47.94	2.83	0.40
4183.5	959.25	964.85		965.00	0.000854	1.88	195.10	55.75	3.50	0.27
4155.4	958.37	964.84		964.97	0.000774	1.89	201.50	50.55	3.99	0.26
4132.6	960.39	964.56		964.91	0.004112	3.00	116.41	43.88	2.65	0.54
4109.5	958.63	964.52		964.84	0.001896	2.79	134.13	39.16	3.43	0.39
4086.1	960.00	963.97		964.71	0.007856	3.86	79.74	32.33	2.47	0.73
4064.7	960.74	963.44	963.44	964.47	0.013712	4.61	69.16	35.57	1.94	0.95
4040.1	959.99	963.00	963.07	964.09	0.016428	4.64	65.15	34.59	1.88	1.02
4013.8	958.21	962.49	961.64	963.04	0.00437	3.64	100.55	36.43	2.76	0.58
3988.5	957.52	962.60		962.89	0.002032	2.70	135.45	41.88	3.23	0.41
3963.7	957.13	962.60		962.83	0.001505	2.44	151.12	40.99	3.69	0.35
3939.5	956.89	962.59		962.79	0.001276	2.30	165.13	45.98	3.59	0.33
3910.5	957.08	962.58		962.74	0.001066	2.10	179.56	47.81	3.76	0.30
3884.8	957.06	962.45		962.70	0.001609	2.53	147.44	42.14	3.50	0.36
3858.5	957.79	961.99		962.59	0.006388	3.61	90.06	35.44	2.54	0.67

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
3829.1	958.06	961.95		962.41	0.003734	3.17	106.97	37.91	2.82	0.53
3806.7	957.90	961.14	961.14	962.20	0.013743	4.92	69.59	34.01	2.05	0.97
3782.0	957.47	960.22	960.59	961.72	0.022935	5.86	59.74	35.33	1.69	1.23
3762.7	956.43	958.41	959.17	960.90	0.070699	7.16	43.22	34.68	1.25	1.98
3741.4	955.90	958.88	958.89	959.87	0.014477	4.47	69.85	37.55	1.86	0.97
3714.9	953.48	958.67	956.74	958.93	0.001686	2.32	139.11	41.53	3.35	0.36
3699.0	955.12	957.81	957.81	958.80	0.015065	4.48	69.04	36.20	1.91	0.98
3678.2	953.81	956.16	956.78	958.20	0.041752	6.33	46.97	28.88	1.63	1.56
3653.8	952.43	956.91	955.54	957.27	0.002679	2.84	120.08	40.29	2.98	0.46
3632.9	953.20	956.33	956.10	957.13	0.01051	4.22	78.72	37.73	2.09	0.84
3610.4	953.08	955.86	955.86	956.85	0.013602	4.51	70.67	37.37	1.89	0.95
3586.0	952.10	955.93	955.13	956.45	0.004636	3.58	103.95	41.48	2.51	0.60
3563.8	951.26	956.10		956.31	0.001417	2.19	158.48	50.33	3.15	0.34
3543.2	952.24	955.73		956.23	0.005419	3.26	100.53	43.65	2.30	0.62
3531.7	952.28	955.15	955.15	956.09	0.014427	4.45	71.98	37.92	1.90	0.96
3521.5	951.28	953.22	953.97	955.68	0.057755	7.00	43.66	32.31	1.35	1.81
3511.1	Bridge									
3500.8	950.10	954.45	952.91	954.75	0.002151	2.48	132.80	45.56	2.91	0.41
3493.9	950.75	954.11	953.55	954.69	0.006298	3.49	92.51	41.48	2.23	0.66
3487.0	950.33	954.22	953.15	954.60	0.003417	2.87	116.81	46.46	2.51	0.50
3476.9	Bridge									
3466.8	950.81	954.08		954.45	0.00396	2.91	119.79	52.10	2.30	0.54
3454.4	951.11	953.67	953.47	954.34	0.00976	3.83	87.87	49.15	1.79	0.80
3439.1	950.56	953.79		954.16	0.00415	2.96	119.65	53.76	2.23	0.55
3416.9	949.36	953.80		954.07	0.001849	2.34	140.02	47.40	2.95	0.38
3393.6	949.79	952.90	952.90	953.90	0.014304	4.61	70.54	37.49	1.88	0.97
3370.5	949.52	951.53	952.08	953.31	0.039695	6.07	52.76	40.83	1.29	1.53
3349.8	948.94	950.80	951.25	952.33	0.045958	5.74	55.53	45.70	1.22	1.59
3328.4	949.04	951.05	951.05	951.82	0.01743	4.11	78.70	53.94	1.46	1.02
3291.2	948.48	950.13	950.29	950.94	0.027613	4.17	76.25	68.86	1.11	1.21
3272.2	947.74	950.34	949.69	950.62	0.005105	2.45	128.80	72.71	1.77	0.56
3242.99*	947.55	950.19		950.47	0.004808	2.44	129.50	70.98	1.82	0.55
3213.76*	947.36	950.05		950.33	0.004528	2.43	130.18	69.24	1.88	0.54
3184.54*	947.17	949.92		950.20	0.004188	2.43	130.60	67.37	1.94	0.52
3155.31*	946.97	949.80		950.08	0.003896	2.46	130.28	65.33	1.99	0.51
3126.1	946.78	949.67		949.97	0.003765	2.52	128.87	63.11	2.04	0.51

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
3107.0	946.71	949.57		949.89	0.004054	2.59	124.05	60.86	2.04	0.52
3088.6	946.77	949.40		949.79	0.005896	2.84	109.66	59.08	1.86	0.62
3066.0	945.97	949.48		949.66	0.00193	1.91	164.94	70.05	2.35	0.37
3042.8	945.54	949.48		949.61	0.001204	1.65	191.44	72.63	2.64	0.30
3023.9	945.95	949.42		949.58	0.001567	1.82	178.31	73.08	2.44	0.34
3003.5	946.22	949.28		949.53	0.003097	2.26	139.06	65.64	2.12	0.46
2984.3	946.52	948.64	948.64	949.36	0.016887	3.82	80.20	56.45	1.42	0.99
2964.6	946.01	947.65	947.98	948.85	0.036885	4.87	62.20	55.72	1.12	1.41
2944.5	945.00	946.56	946.99	947.98	0.047589	5.30	56.71	54.30	1.04	1.58
2922.7	943.55	945.32	945.80	946.87	0.053155	5.56	54.36	51.23	1.06	1.67
2900.5	943.28	945.90	945.39	946.25	0.006653	2.73	115.20	66.99	1.72	0.64
2876.4	943.09	945.62		946.06	0.007853	3.04	103.46	59.65	1.73	0.70
2853.8	942.87	945.55		945.89	0.004983	2.69	118.25	60.41	1.96	0.57
2812.9	942.67	944.81	944.78	945.52	0.01471	3.86	82.51	56.07	1.47	0.94
2793.9	942.19	944.49	944.47	945.24	0.014019	3.91	81.14	57.23	1.42	0.93
2770.8	941.66	944.14	944.14	944.92	0.013696	3.99	81.07	57.54	1.41	0.92
2749.2	941.07	942.62	943.14	944.29	0.058857	5.76	52.81	55.86	0.95	1.75
2727.5	940.85	942.91	942.71	943.38	0.011596	3.05	99.10	72.40	1.37	0.81
2708.5	940.73	942.83		943.16	0.0075	2.52	118.97	82.67	1.44	0.66
2687.9	940.92	942.69		942.99	0.007845	2.42	122.56	91.79	1.34	0.66
2668.4	940.78	942.64		942.85	0.004754	2.02	148.00	102.90	1.44	0.52
2647.9	940.70	942.54		942.75	0.004655	2.01	149.37	102.14	1.46	0.52
2630.1	940.39	942.33		942.63	0.007889	2.43	123.70	94.66	1.31	0.66
2613.3	940.03	941.92	941.81	942.44	0.014198	3.19	93.17	71.79	1.30	0.88
2593.2	939.26	941.90		942.22	0.004985	2.51	121.74	66.56	1.83	0.56
2576.2	939.02	941.95		942.12	0.002217	1.88	168.53	83.22	2.03	0.39
2551.4	938.76	941.85		942.05	0.002871	2.06	151.23	75.57	2.00	0.44
2532.8	938.47	941.76		942.00	0.002488	2.27	146.65	65.15	2.25	0.42
2512.5	938.89	941.08	941.08	941.84	0.015479	4.07	81.10	55.93	1.45	0.97
2490.8	938.21	940.06	940.41	941.31	0.035333	5.12	61.67	50.09	1.23	1.40
2471.1	937.10	940.51	939.48	940.79	0.003144	2.40	132.45	58.00	2.28	0.47
2453.9	936.64	940.48		940.73	0.002612	2.23	139.31	54.43	2.56	0.43
2435.5	937.18	940.08		940.62	0.008324	3.26	91.84	48.22	1.90	0.73
2416.5	936.69	940.13		940.46	0.003497	2.57	120.25	50.67	2.37	0.49
2394.8	936.70	940.08		940.37	0.003189	2.45	126.58	52.77	2.40	0.47
2368.4	936.44	939.68		940.23	0.006919	3.34	95.33	48.49	1.97	0.68

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
2345.0	936.91	939.13	939.13	939.97	0.015454	4.18	76.32	47.39	1.61	0.97
2326.4	936.48	938.14	938.51	939.49	0.036255	5.20	58.98	47.21	1.25	1.42
2307.6	935.95	938.59	938.12	939.05	0.006732	3.11	102.35	54.82	1.87	0.66
2285.8	934.67	938.67		938.90	0.002551	2.11	143.69	60.85	2.36	0.42
2265.3	934.79	938.36		938.79	0.00719	2.90	102.93	56.24	1.83	0.67
2247.1	935.46	938.30		938.66	0.005392	2.70	114.71	60.55	1.89	0.59
2226.0	935.28	937.85	937.72	938.46	0.013596	3.46	85.85	56.01	1.53	0.88
2197.9	935.35	937.68		938.12	0.008063	2.99	102.68	61.82	1.66	0.70
2174.9	935.10	937.10	937.10	937.83	0.017504	3.80	78.42	55.35	1.42	1.00
2152.2	934.27	936.11	936.41	937.25	0.035244	4.72	62.76	51.87	1.21	1.37
2125.9	933.23	936.70	935.55	936.91	0.002684	2.02	147.09	65.51	2.25	0.42
2098.3	933.40	936.45		936.79	0.005794	2.57	115.39	61.30	1.88	0.60
2066.6	933.34	935.68	935.68	936.45	0.017173	3.89	76.29	50.29	1.52	1.00
2040.7	932.63	934.42	934.80	935.76	0.038994	5.14	58.50	48.06	1.22	1.45
2013.4	931.06	935.04	933.63	935.25	0.002139	2.08	149.81	59.74	2.51	0.39
2000.01*	931.39	934.92		935.21	0.003495	2.42	130.76	60.81	2.15	0.49
1986.65*	931.73	934.76		935.14	0.005875	2.80	114.30	62.81	1.82	0.61
1973.29*	932.06	934.29	934.29	934.98	0.01628	3.80	84.22	62.35	1.35	0.97
1959.9	931.89	934.47	933.72	934.72	0.003796	2.38	141.08	76.09	1.85	0.50
1952.7	Bridge									
1945.6	931.40	934.38		934.61	0.002881	2.26	148.20	73.11	2.03	0.45
1936.5	931.69	933.77	933.77	934.51	0.014466	3.90	82.15	58.78	1.40	0.94
1928.3	930.41	933.45	932.54	933.71	0.003129	2.36	141.55	72.38	1.96	0.47
1920.4	Bridge									
1912.5	930.13	933.49		933.60	0.0012	1.55	216.89	95.34	2.27	0.29
1890.7	930.96	933.34		933.54	0.00415	2.02	147.30	89.74	1.64	0.50
1866.1	930.84	933.27		933.45	0.003184	1.88	157.98	86.50	1.83	0.44
1847.2	930.63	933.14		933.38	0.003865	2.13	139.08	72.74	1.91	0.49
1827.6	929.80	933.17		933.30	0.001499	1.59	186.39	74.53	2.50	0.32
1816.6	930.21	933.08		933.27	0.002521	1.94	153.38	67.29	2.28	0.41
1801.0	930.50	932.44	932.44	933.14	0.017863	3.71	79.98	57.67	1.39	1.00
1784.6	930.17	932.26	931.82	932.58	0.006783	2.51	120.74	79.63	1.52	0.63
1767.8	929.35	932.38	931.08	932.47	0.001246	1.33	233.54	119.08	1.96	0.29
1747.6	Bridge									
1727.4	928.95	932.35		932.41	0.000809	1.13	282.74	141.38	2.00	0.23
1708.7	929.06	932.35		932.39	0.000521	0.95	331.84	143.47	2.31	0.19

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
1691.9	929.11	932.35	930.50	932.38	0.000418	0.86	365.78	154.99	2.36	0.17
1673.2	Bridge									
1654.6	928.75	932.33		932.36	0.000351	0.83	374.67	145.08	2.58	0.16
1635.93*	928.81	932.30		932.35	0.000528	1.00	308.90	122.29	2.53	0.19
1617.25*	928.88	932.25		932.33	0.000844	1.27	243.94	99.26	2.46	0.24
1598.58*	928.95	932.15		932.30	0.001648	1.76	177.09	75.50	2.35	0.34
1579.9	929.02	931.68		932.21	0.007205	3.27	95.03	49.15	1.93	0.69
1565.2	928.46	931.73		932.08	0.003509	2.65	116.59	47.12	2.47	0.50
1547.9	928.36	931.72		932.01	0.002929	2.44	128.52	51.82	2.48	0.46
1524.6	928.28	931.60		931.93	0.003554	2.59	121.17	51.80	2.34	0.50
1500.0	927.91	930.90	930.90	931.72	0.015994	4.05	75.17	46.07	1.63	0.98
1471.2	927.94	930.12	930.31	931.12	0.026379	4.44	66.93	49.78	1.34	1.21
1436.2	926.79	930.21	928.73	930.38	0.001676	1.88	166.10	65.56	2.53	0.35
1399.3	926.24	930.17		930.32	0.001292	1.76	174.40	60.66	2.88	0.31
1376.9	926.38	930.15		930.29	0.001134	1.67	186.96	64.94	2.88	0.29
1356.1	925.63	930.15		930.26	0.000976	1.49	206.13	72.35	2.85	0.27
1338.9	926.18	930.15		930.24	0.000811	1.34	228.60	79.16	2.89	0.24
1321.8	926.68	930.12		930.22	0.001022	1.40	216.16	82.07	2.63	0.27
1303.5	926.62	930.01		930.19	0.001705	1.92	167.50	67.94	2.47	0.35
1286.9	926.49	929.94		930.15	0.002275	2.12	150.55	65.18	2.31	0.40
1271.2	926.56	929.55	929.13	930.06	0.007742	3.19	96.03	52.02	1.85	0.70
1257.8	926.56	929.05	929.05	929.89	0.01582	4.10	75.05	47.43	1.58	0.98
1244.4	925.53	929.26	928.05	929.48	0.0024	2.11	145.28	62.11	2.34	0.41
1230.55*	925.11	929.31		929.43	0.001116	1.57	196.77	73.41	2.68	0.28
1216.7	924.68	929.33	927.12	929.41	0.000581	1.22	255.81	86.09	2.97	0.21
1204.3	Bridge									
1192.1	925.17	929.30		929.38	0.000615	1.21	250.82	85.00	2.95	0.21
1183.8	925.53	929.27		929.37	0.000918	1.38	221.75	83.62	2.65	0.26
1174.9	926.17	929.25	927.68	929.36	0.001125	1.48	209.83	85.18	2.46	0.28
1163.0	Bridge									
1151.1	925.76	929.18		929.31	0.001392	1.60	192.77	81.09	2.38	0.31
1141.9	925.79	929.16		929.29	0.001406	1.67	188.54	76.71	2.46	0.32
1128.9	926.12	929.10		929.27	0.001954	1.86	168.52	75.00	2.25	0.37
1110.2	926.25	928.92		929.20	0.004329	2.41	130.32	70.91	1.84	0.53
1089.7	926.72	928.76		929.09	0.005918	2.62	120.54	74.65	1.61	0.61
1073.5	926.37	928.21	928.21	928.91	0.016713	3.75	82.08	61.81	1.33	0.98

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
1054.8	925.08	927.49	927.71	928.48	0.027798	4.44	67.52	53.11	1.27	1.24
1037.8	924.08	927.91	927.17	928.23	0.005131	2.51	119.58	64.83	1.84	0.57
1020.0	925.14	927.74		928.12	0.007189	2.71	110.17	68.01	1.62	0.66
998.7	925.08	927.75		927.96	0.003612	2.08	146.49	82.16	1.78	0.48
981.3	923.96	927.82		927.90	0.00064	1.21	253.45	90.52	2.80	0.22
963.4	922.35	927.85		927.88	0.00017	0.78	395.60	101.91	3.88	0.12
947.4	922.28	927.85		927.88	0.000143	0.73	418.05	104.05	4.02	0.11
932.3	922.24	927.83		927.87	0.000227	0.88	341.52	88.08	3.88	0.14
922.2	923.14	927.73		927.86	0.000984	1.63	197.70	69.36	2.85	0.27
910.1	923.14	927.64		927.84	0.001617	1.97	156.92	56.47	2.78	0.34
900.2	922.94	927.67	925.56	927.81	0.001131	1.68	181.02	59.79	3.03	0.29
889.8	Bridge									
879.5	922.70	927.69		927.75	0.000369	1.10	281.25	76.93	3.66	0.17
874.0	922.52	927.70		927.75	0.000295	1.00	308.84	82.60	3.74	0.15
860.2	922.91	927.70	924.58	927.74	0.000238	0.85	352.94	93.41	3.78	0.14
841.9	Bridge									
823.5	923.71	927.61		927.70	0.000778	1.28	236.71	85.81	2.76	0.24
814.5	924.42	926.75	926.75	927.60	0.015234	4.12	74.30	46.03	1.61	0.97
801.8	923.42	925.45	925.97	927.21	0.040081	5.99	51.67	35.92	1.44	1.52
788.4	922.63	926.60	925.11	926.85	0.002028	2.31	142.96	50.98	2.80	0.39
766.8	923.15	926.57		926.79	0.002453	2.11	147.92	63.22	2.34	0.41
745.9	923.52	926.54		926.73	0.002255	1.97	160.16	69.45	2.31	0.39
723.7	923.31	925.93		926.58	0.010442	3.60	84.72	46.66	1.82	0.81
697.5	923.27	925.99		926.32	0.004384	2.56	117.76	55.49	2.12	0.54
671.7	922.82	925.21	925.21	926.07	0.016501	4.11	72.50	43.55	1.66	0.99
641.3	920.64	924.50	923.22	924.75	0.002556	2.21	135.76	52.45	2.59	0.42
610.375*	920.39	924.50		924.66	0.00148	1.81	167.34	59.52	2.81	0.33
579.5	920.14	924.50		924.61	0.000869	1.48	204.93	66.56	3.08	0.26
549.1	920.30	924.48		924.58	0.0008	1.42	214.48	67.48	3.18	0.24
509.6	920.28	924.39		924.54	0.001413	1.73	173.54	61.84	2.81	0.32
477.9	920.71	924.27		924.48	0.001798	2.04	150.04	51.88	2.89	0.36
447.0	921.08	923.43	923.43	924.29	0.016588	4.11	72.84	43.88	1.66	1.00
422.7	919.38	923.06	922.44	923.49	0.005996	2.91	103.08	48.21	2.14	0.62
400.1	919.01	923.06		923.34	0.003591	2.35	127.33	55.53	2.29	0.48
387.5	917.51	923.15		923.27	0.000996	1.54	194.76	61.59	3.16	0.27
371.708*	917.79	923.17		923.25	0.000605	1.23	246.10	77.02	3.20	0.21

Table C. 1 (Contd.)

River Station	Min Chnl Elev	Water Surf. Elev.	Crit. WS Elev.	EGL Elev.	EGL Slope (Sf)	Chnl Vel. (u)	Flow Area (A)	Top Width (T)	D	Fr
355.951*	918.07	923.18		923.23	0.00037	1.00	307.97	95.55	3.22	0.17
340.2	918.36	923.19	920.46	923.22	0.000227	0.81	391.65	118.68	3.30	0.13
325.1	Bridge									
310.0	918.66	923.17		923.20	0.000306	0.91	366.84	122.77	2.99	0.15
298.3	919.52	923.15		923.20	0.000469	1.04	326.12	122.48	2.66	0.19
287.6	919.64	923.14	921.22	923.19	0.000513	1.08	309.73	117.94	2.63	0.19
274.9	Bridge									
262.2	919.10	923.12		923.17	0.000562	1.10	298.12	112.53	2.65	0.20
250.492*	918.82	923.04		923.16	0.001216	1.55	206.89	87.89	2.35	0.29
238.8	918.54	922.92		923.13	0.002281	2.02	149.18	62.71	2.38	0.40
221.2	919.54	922.69		923.05	0.005489	2.70	112.01	58.45	1.92	0.59
208.7	919.98	922.17	922.17	922.90	0.01869	3.90	78.97	55.18	1.43	1.03
193.2	916.20	918.49	919.50	921.99	0.113722	8.81	36.04	28.00	1.29	2.47
176.5	913.55	915.59	916.79	919.90	0.108706	9.51	33.49	25.49	1.31	2.48
159.3	912.91	914.53	915.44	917.71	0.105499	7.91	37.49	32.35	1.16	2.34
143.1	912.82	916.40	915.63	916.83	0.005134	2.94	103.42	43.88	2.36	0.59
125.2	913.36	915.92	915.76	916.66	0.012597	3.84	78.08	43.34	1.80	0.88
108.9	913.42	915.92		916.43	0.008145	3.18	95.01	49.96	1.90	0.71
88.1	912.76	915.25	915.25	916.16	0.016702	4.20	70.49	39.13	1.80	1.00
66.3	908.92	914.30	912.92	914.64	0.003531	2.59	114.41	39.95	2.86	0.49
47.1	909.84	914.21		914.57	0.003897	2.65	111.96	40.98	2.73	0.51
30.4	910.46	913.45	913.45	914.39	0.016665	4.30	68.90	36.68	1.88	1.00
13.1	909.97	913.03	913.10	914.08	0.018509	4.54	65.32	34.65	1.89	1.05

APPENDIX D

CROSS-SECTIONS OF VIADUCTS ON KIRKGEÇİT CREEK

AND

CALCULATIONS ABOUT SCOUR DEPTH

Scour calculations are conducted in in HEC – RAS, and scour depths, local maximum velocities and median riprap sizes (Dr_{50}) are given by tables in this part. Moreover viaduct scour is also shown in figures.

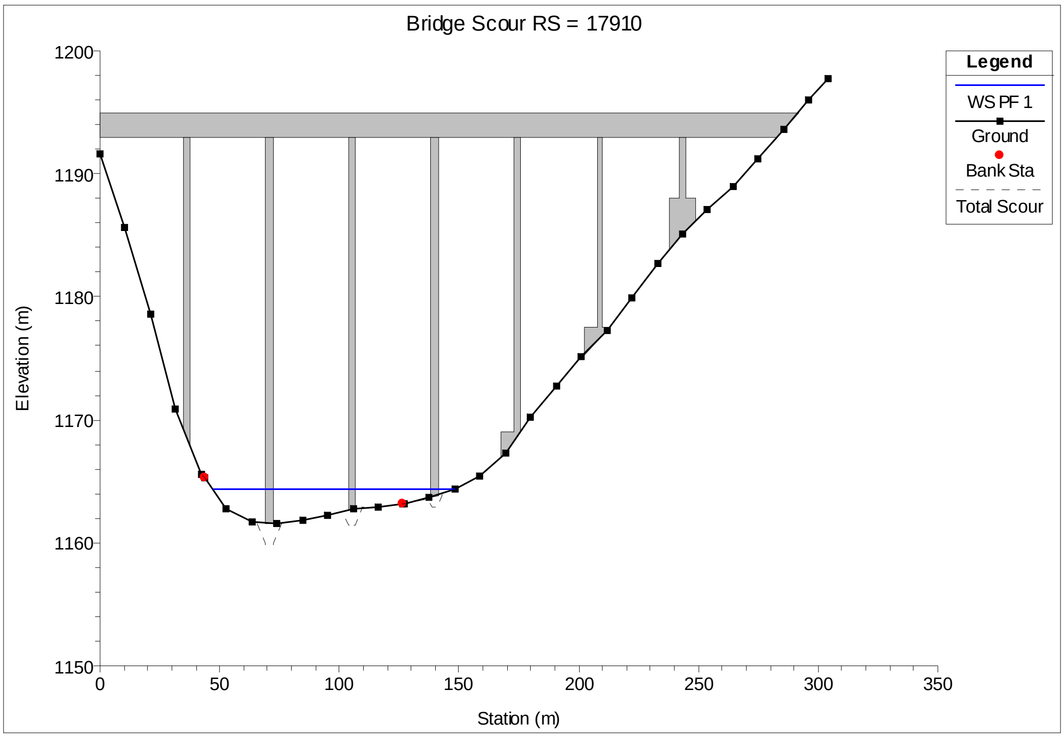


Figure D. 1 Scouring at Çeleme Left Viaduct in Cross-sectional View

Table D. 1 Scour Depths, Local Max. Velocity and Median Riprap Size for Çeleme Left

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	-
#2 (CL = 70.75)	1.75
#3 (CL = 105.25)	1.40
#4 (CL = 139.75)	0.91
#5 (CL = 174.25)	-
#6 (CL = 208.75)	-
#7 (CL = 243.25)	-

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.14	0.29

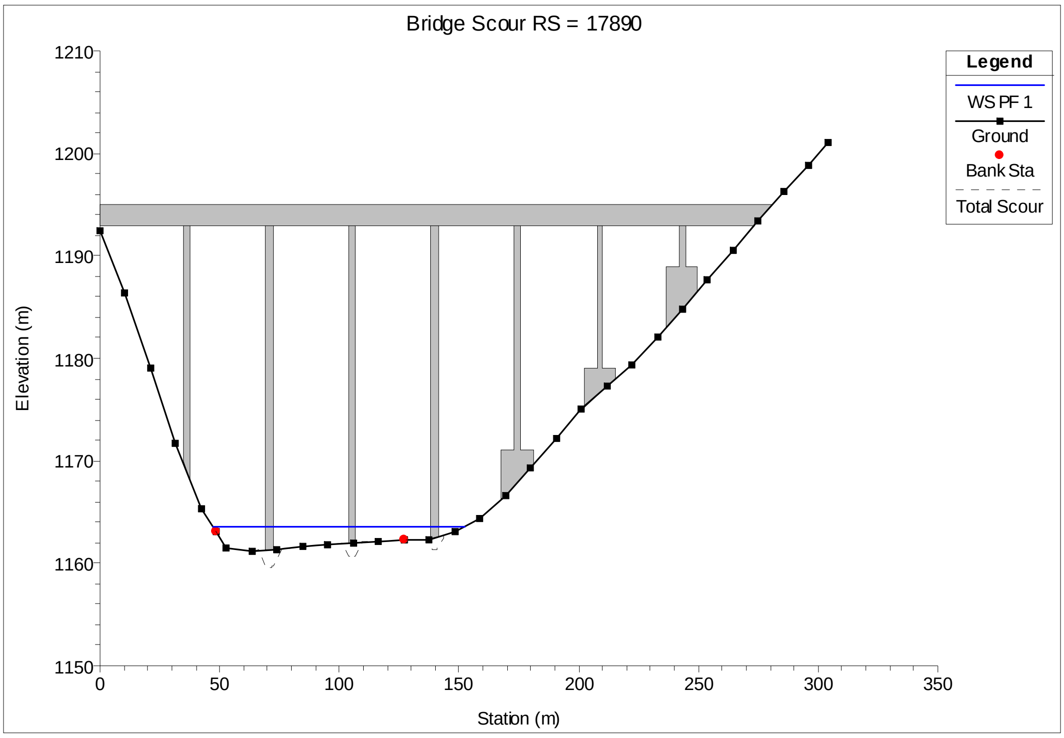


Figure D. 2 Scouring at Çeleme Right Viaduct in Cross-sectional View

Table D. 2 Scour Depths, Local Max. Velocity and Median Riprap Size for Çeleme Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	-
#2 (CL = 70.75)	1.69
#3 (CL = 105.25)	1.44
#4 (CL = 139.75)	1.14
#5 (CL = 174.25)	-
#6 (CL = 208.75)	-
#7 (CL = 243.25)	-

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.10	0.27

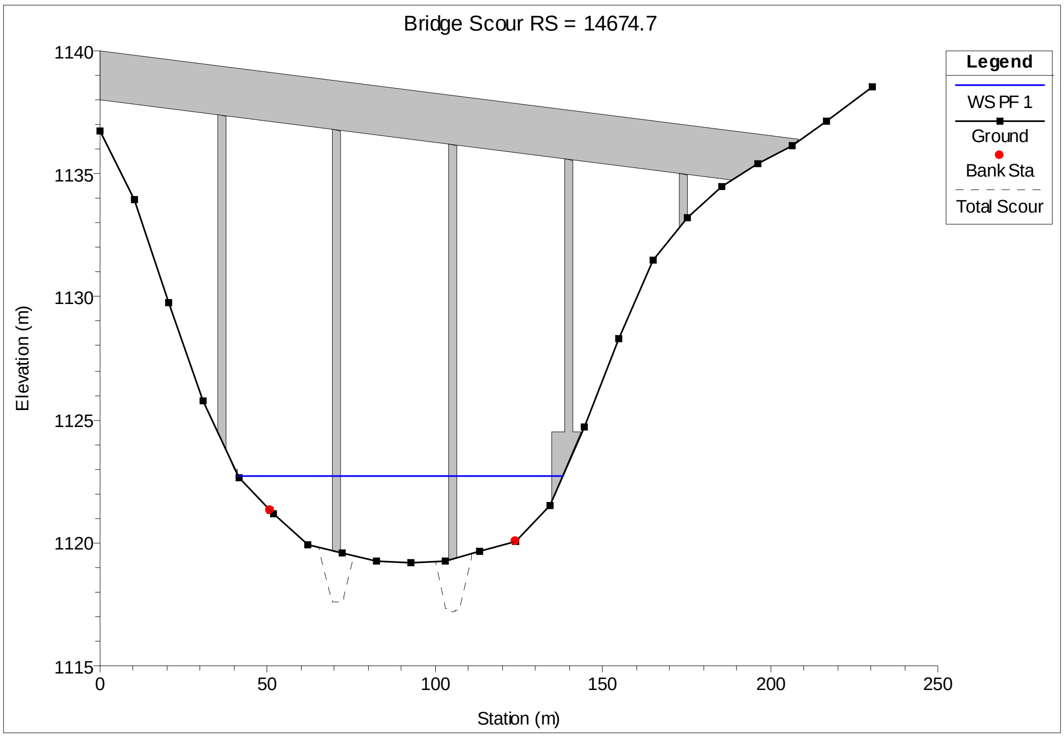


Figure D. 3 Scouring at Kırkgeçit 1 Right Viaduct in Cross-sectional View

Table D. 3 Scour Depths, Local Max. Velocity and Median Riprap Size for KG1 Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	-
#2 (CL = 70.75)	2.08
#3 (CL = 105.25)	2.16
#4 (CL = 139.75)	-
#5 (CL = 174.25)	-

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.31	0.10

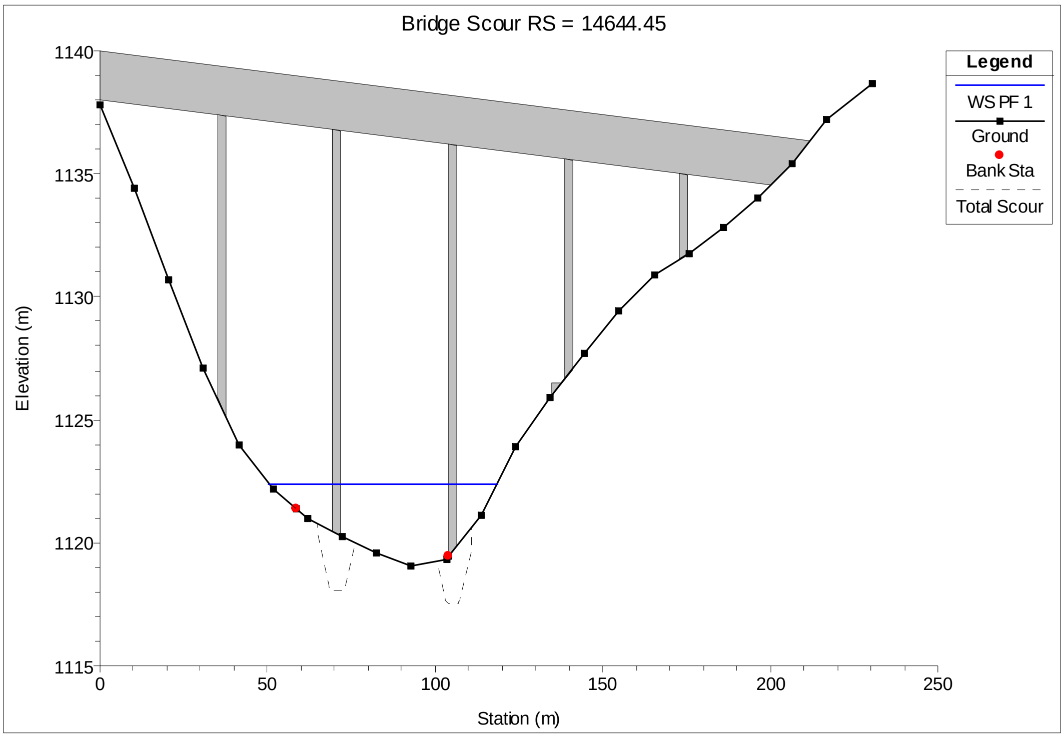


Figure D. 4 Scouring at Kırkgeçit 1 Left Viaduct in Cross-sectional View

Table D. 4 Scour Depths, Local Max. Velocity and Median Riprap Size for KG1 Left

Name of the Pier	d_s (m)
#1 (CL = 36.25)	
#2 (CL = 70.75)	2.33
#3 (CL = 105.25)	2.15
#4 (CL = 139.75)	
#5 (CL = 174.25)	

Local Maximum Velocity V (m/s)	Median riprap size (m)
1.8	0.20

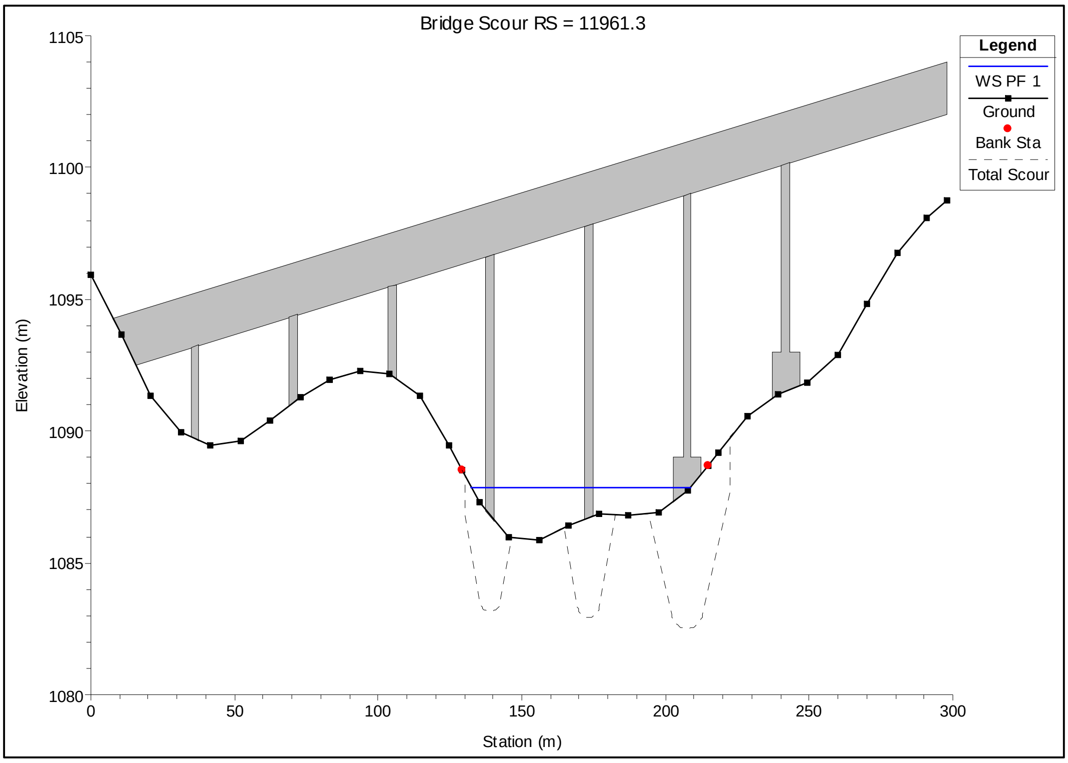


Figure D. 5 Scouring at Kırkgeçit 2 Left Viaduct in Cross-sectional View

Table D. 5 Scour Depths, Local Max. Velocity and Median Riprap Size for KG2 Left

Name of the Pier	**d_s (m)**
PL7 (CL = 36.25)	-
PL6 (CL = 70.5)	- (Piled)
PL5 (CL = 104.75)	- (Piled)
PL4 (CL = 139)	3.64 (Piled)
PL3 (CL = 173.25)	3.79 (Piled)
PL2 (CL = 207.5)	5.18
PL1 (CL = 241.75)	-

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.24	0.31

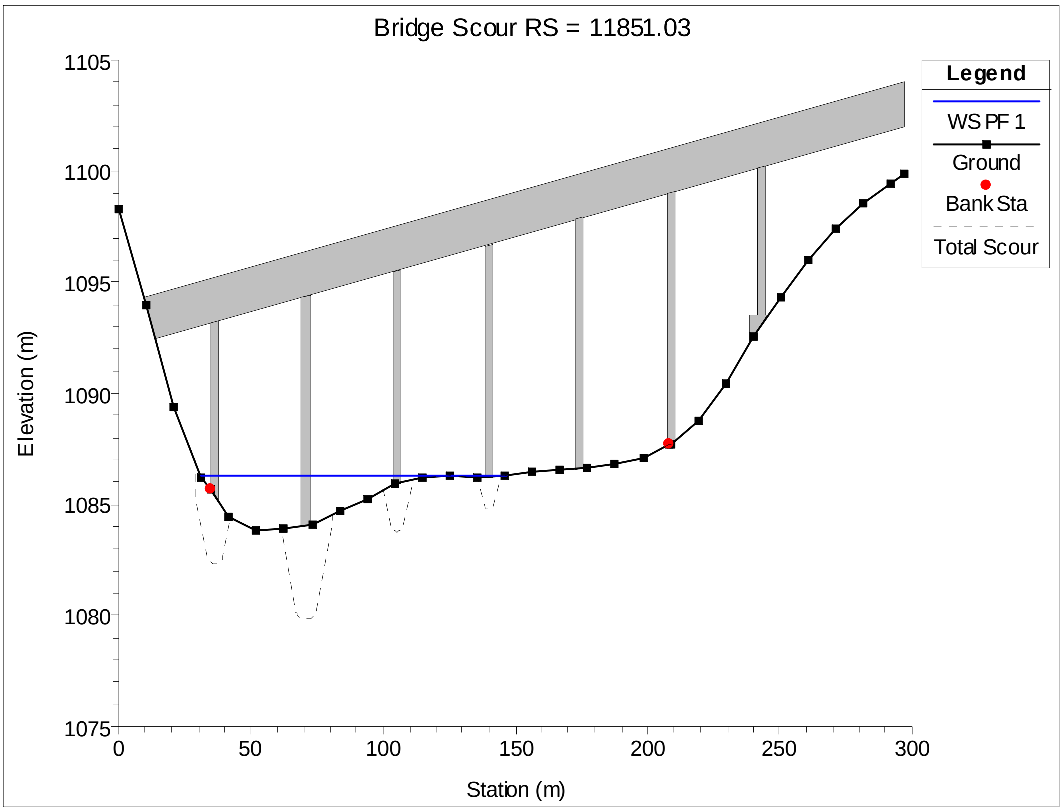


Figure D. 6 Scouring at Kırkgeçit 2 Right Viaduct in Cross-sectional View

Table D. 6 Scour Depths, Local Max. Velocity and Median Riprap Size for KG2 Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	3.00
#2 (CL = 70.75)	4.19
#3 (CL = 105.25)	2.16
#4 (CL = 139.75)	1.45
#5 (CL = 174.25)	
#6 (CL = 208.75)	
#7 (CL = 243.25)	

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.47	0.38

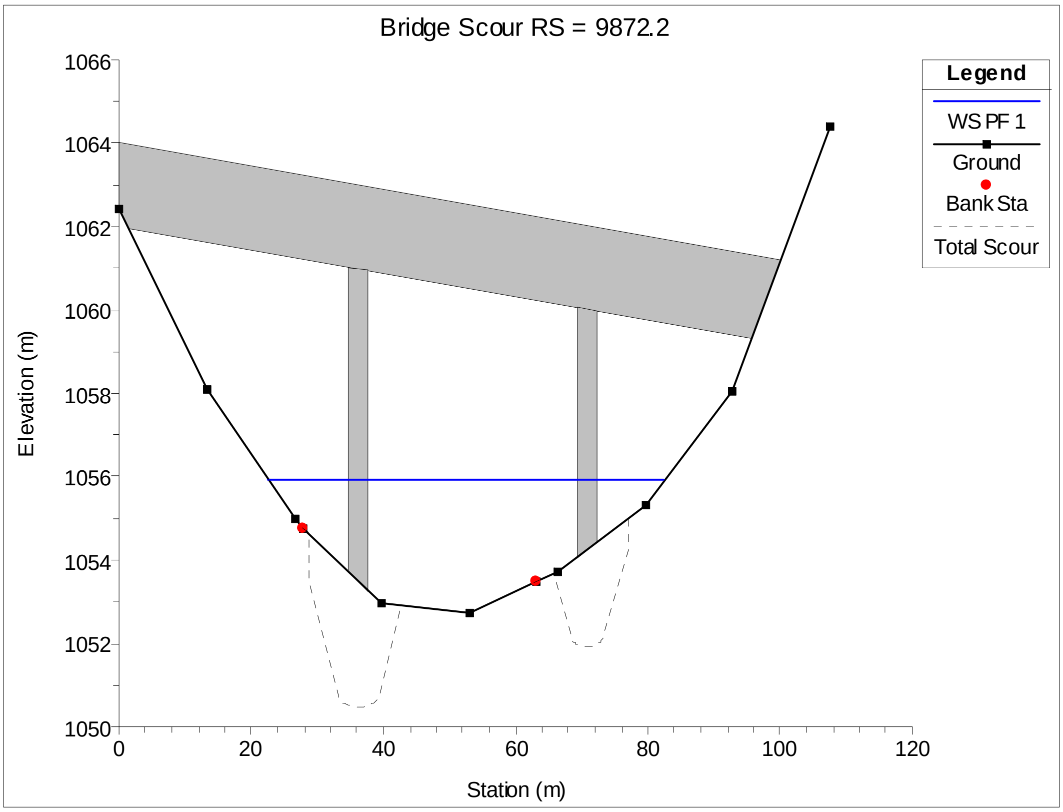


Figure D. 7 Scouring at Kırkgeçit 3 Right Viaduct in Cross-sectional View

Table D. 7 Scour Depths, Local Max. Velocity and Median Riprap Size for KG3 Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	3.03
#2 (CL = 70.75)	2.33

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.39	0.35

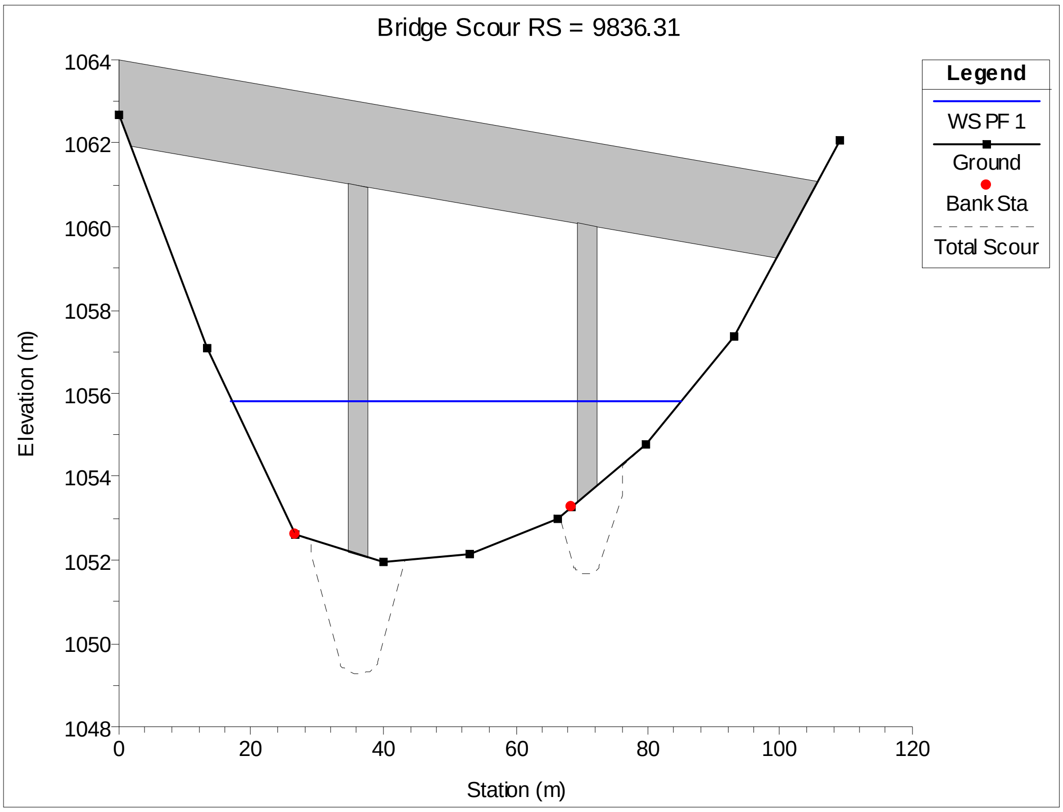


Figure D. 8 Scouring at Kırkgeçit 3 Left Viaduct in Cross-sectional View

Table D. 8 Scour Depths, Local Max. Velocity and Median Riprap Size for KG3 Left

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	2.85
#2 (CL = 70.75)	1.90

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.83	0.21

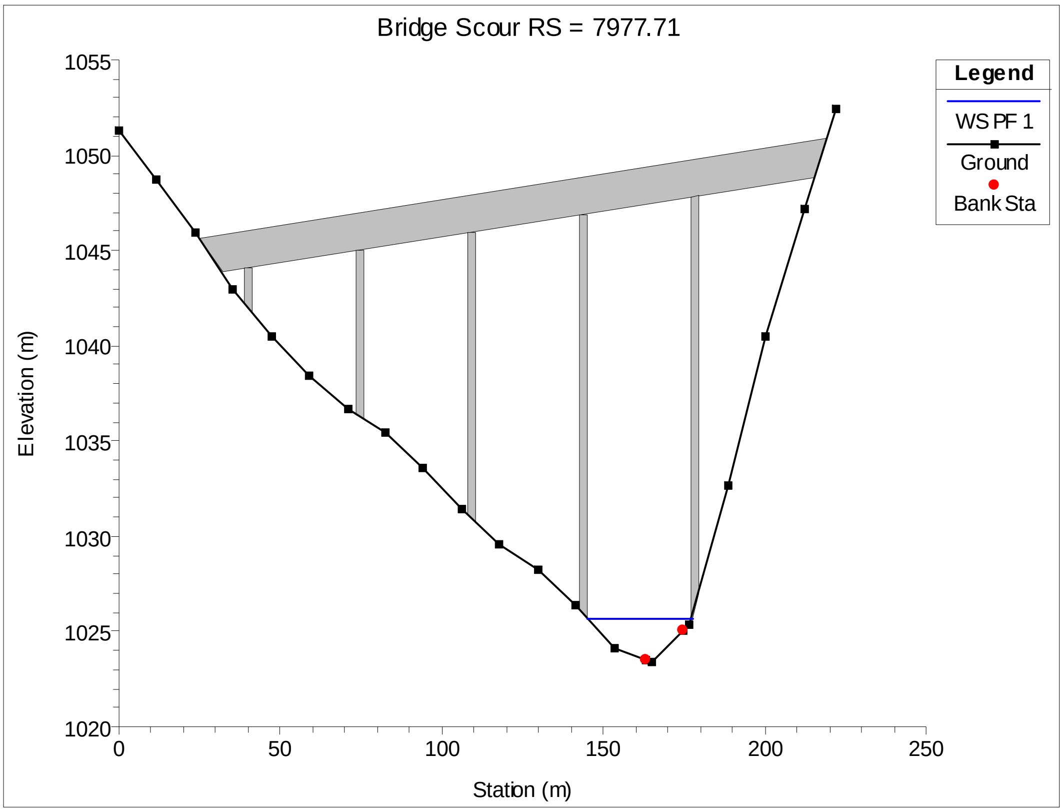


Figure D. 9 Scouring at Kırkgeçit 4 Left Viaduct in Cross-sectional View

There is no scour in the Kırkgeçit 4 Left Viaduct

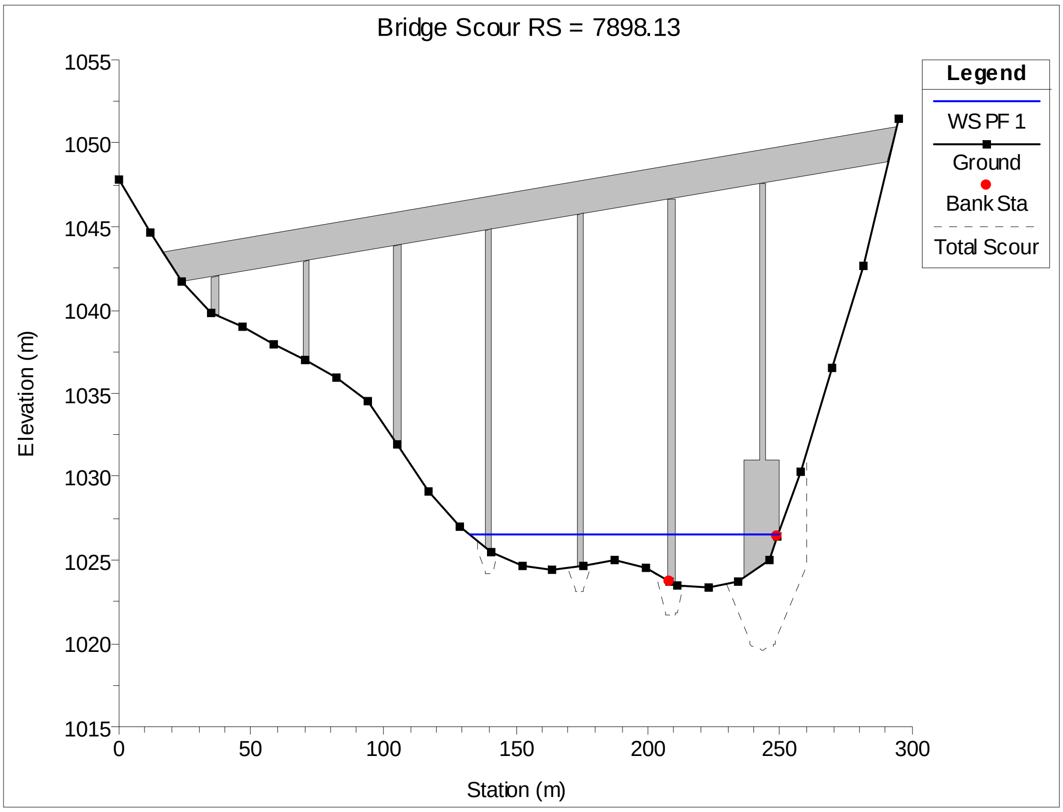


Figure D. 10 Scouring at Kırkgeçit 4 Right Viaduct in Cross-sectional View

Table D. 9 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 4 Right

Name of the Pier	d_s (m)
#1 (CL = 36.25)	
#2 (CL = 70.75)	
#3 (CL = 105.25)	
#4 (CL = 139.75)	1.44
#5 (CL = 174.25)	1.59
#6 (CL = 208.75)	2.02
#7 (CL = 243.25)	5.02

Local Maximum Velocity V (m/s)	Median riprap size (m)
1.50	0.14

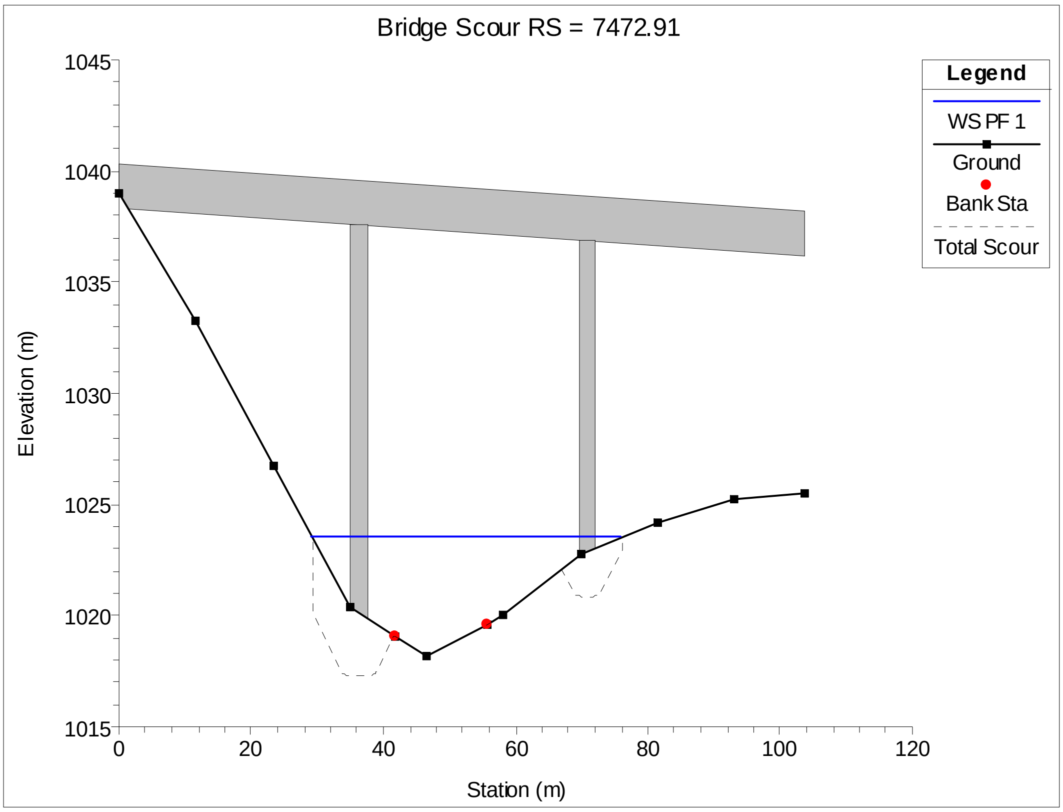


Figure D. 11 Scouring at Kırkgeçit 5/1 Right Viaduct in Cross-sectional View

Table D. 10 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 5/1 Right

Name of the Pier	d_s (m)
#1 (CL = 36.25)	2.86
#2 (CL = 70.75)	2.06

Local Maximum Velocity V (m/s)	Median riprap size (m)
1.64	0.17

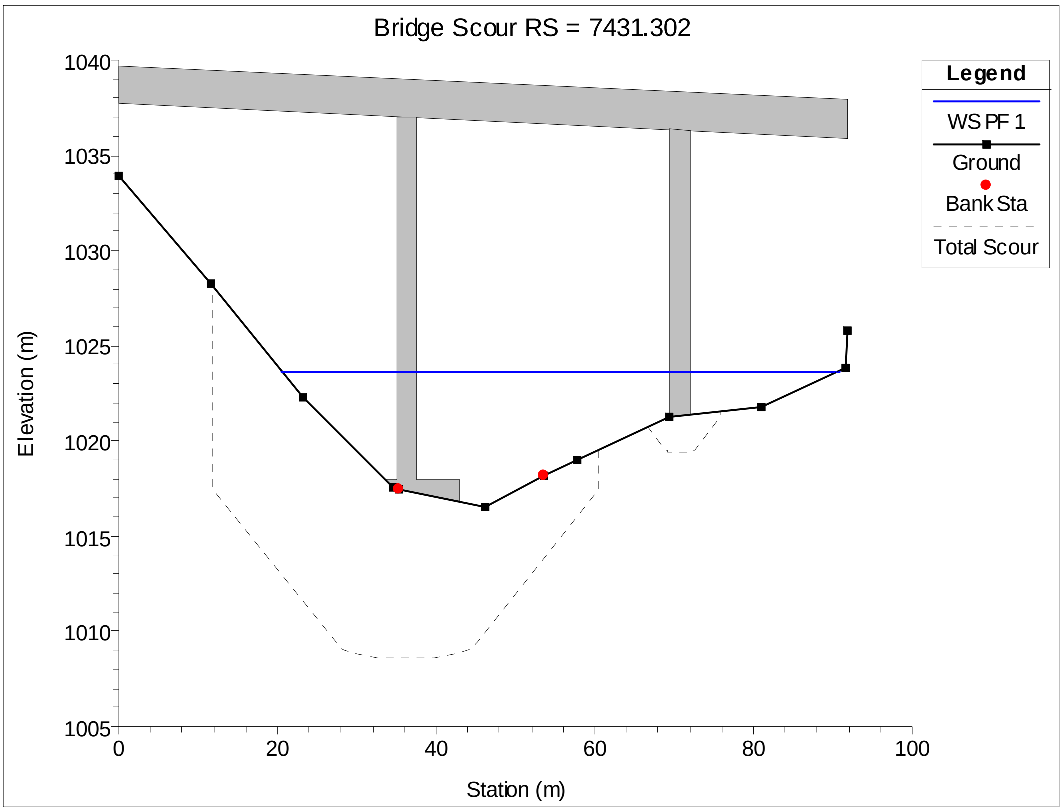


Figure D. 12 Scouring at Kırkgeçit 5/1 Left Viaduct in Cross-sectional View

Table D. 11 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 5/1 Left

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	8.86
#2 (CL = 70.75)	1.92

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.53	0.15

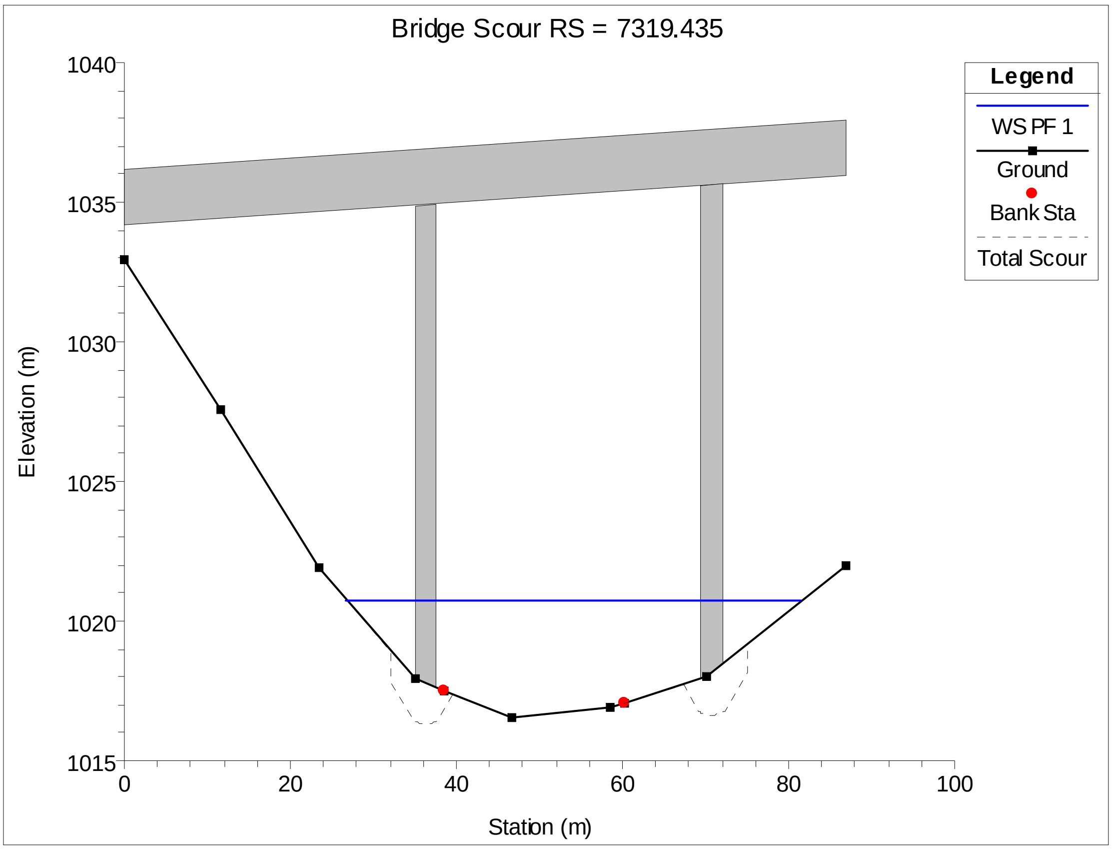


Figure D. 13 Scouring at Kırkgeçit 5/2 Left Viaduct in Cross-sectional View

Table D. 12 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 5/2 Left

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	1.44
#2 (CL = 70.75)	1.49

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.57	0.15

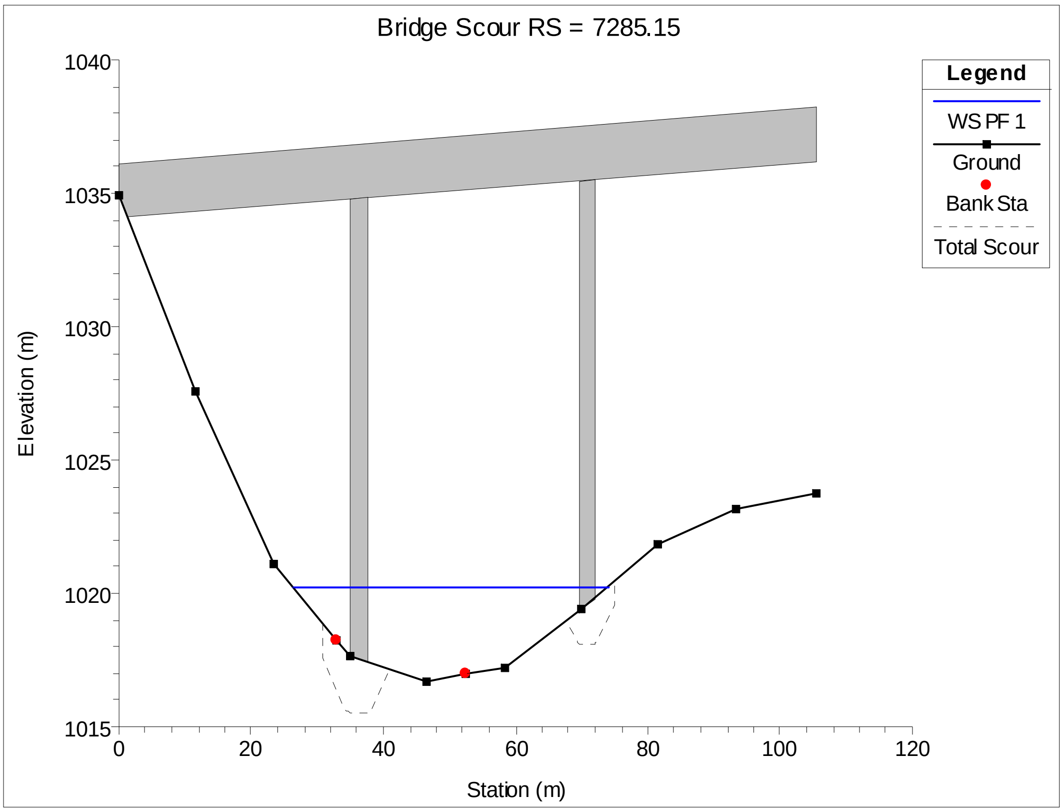


Figure D. 14 Scouring at Kırkgeçit 5/2 Right Viaduct in Cross-sectional View

Table D. 13 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 5/2 Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	2.08
#2 (CL = 70.75)	1.50

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.92	0.53

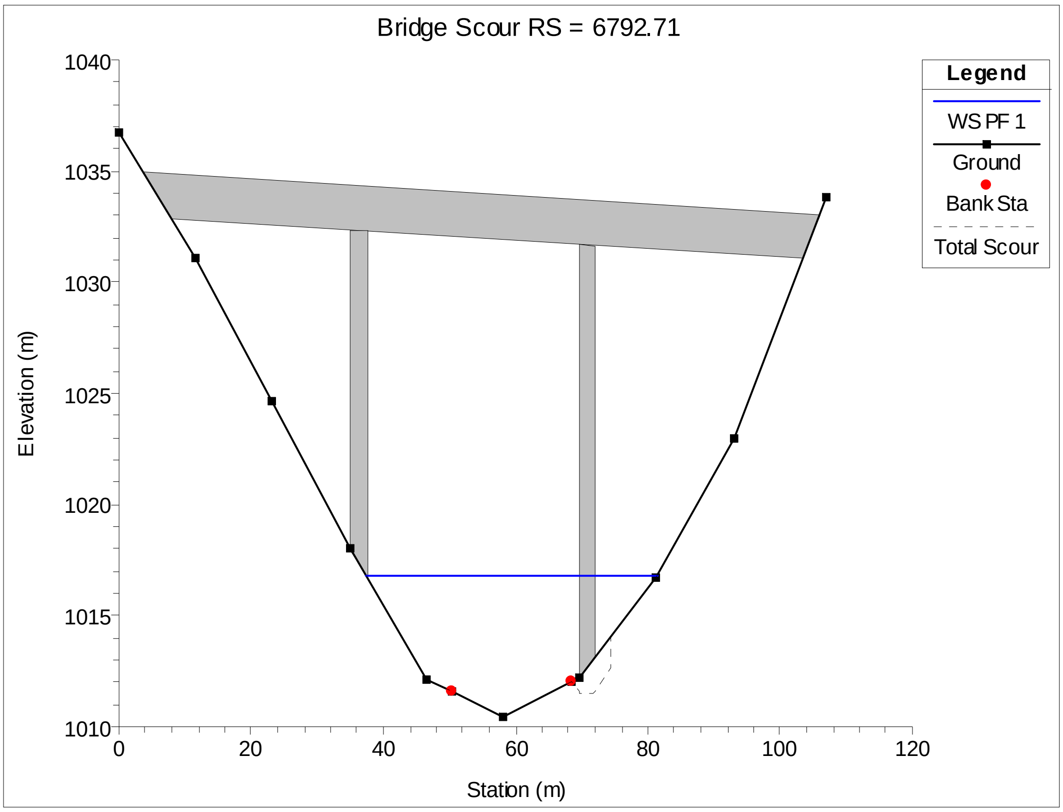


Figure D. 15 Scouring at Kırkgeçit 6 Right Viaduct in Cross-sectional View

Table D. 14 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 6 Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	
#2 (CL = 70.75)	1.19

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.01	0.06

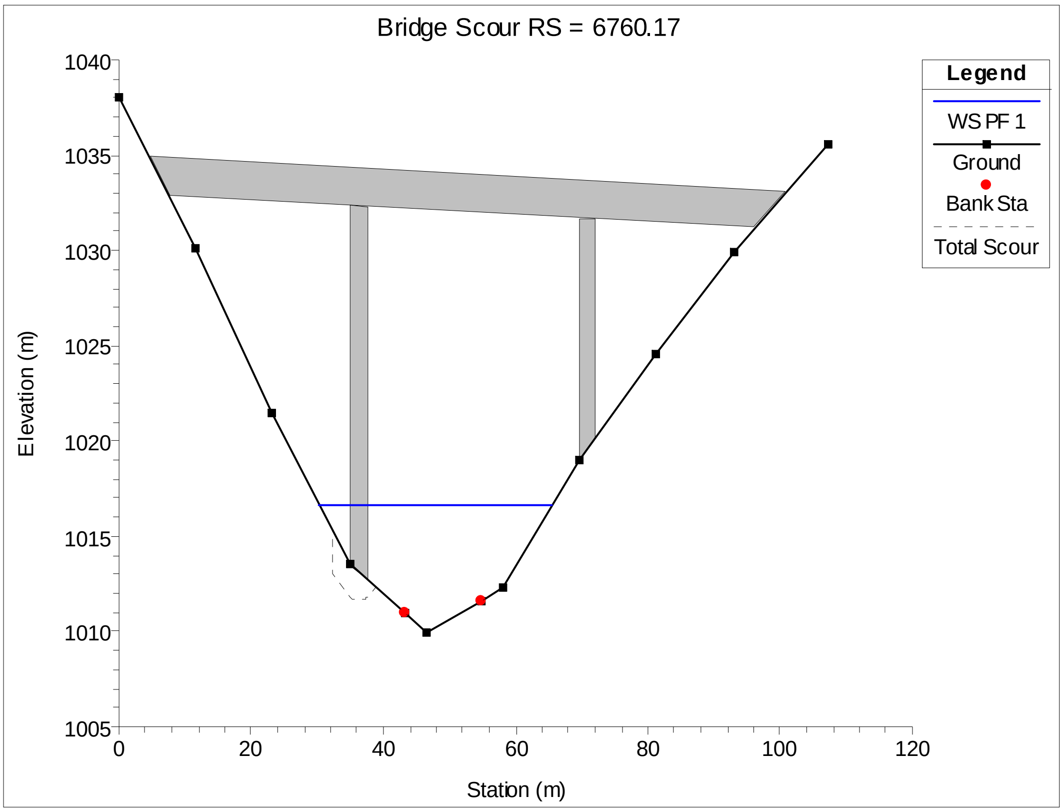


Figure D. 16 Scouring at Kırkgeçit 6 Left Viaduct in Cross-sectional View

Table D. 15 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 6 Left

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	1.39
#2 (CL = 70.75)	

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.51	0.14

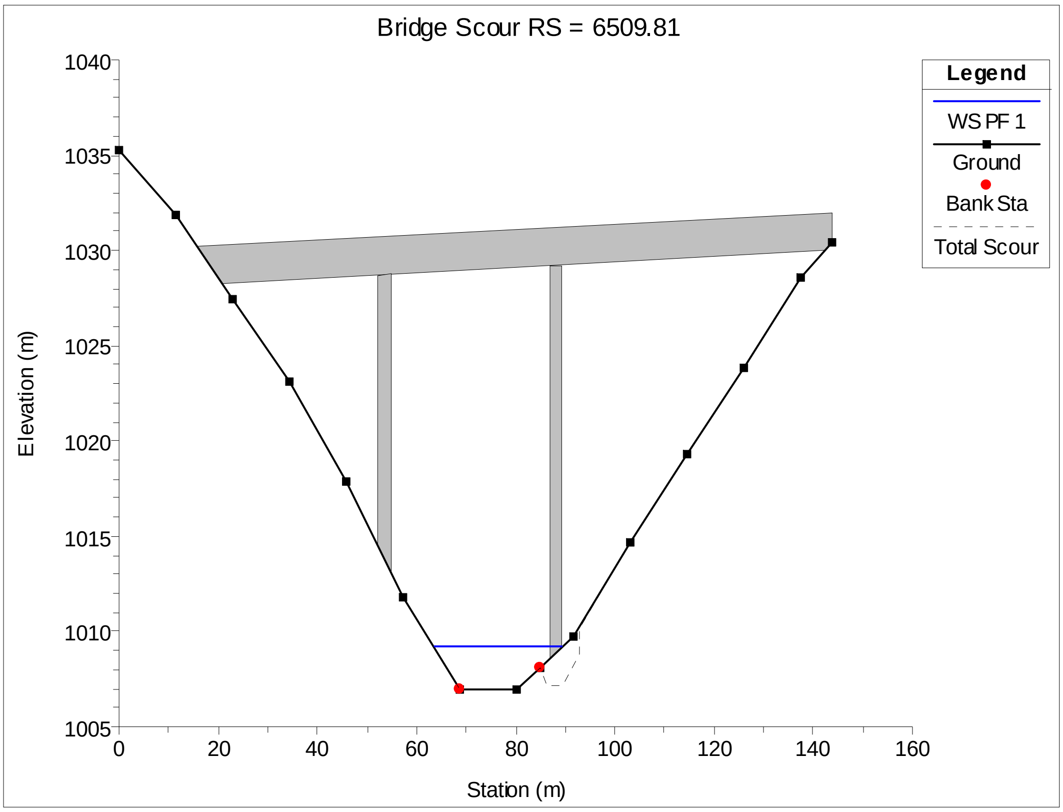


Figure D. 17 Scouring at Kırkgeçit 7 Left Viaduct in Cross-sectional View

Table D. 16 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 7 Left

Name of the Pier	**d_s (m)**
#1 (CL = 53.49)	
#2 (CL = 87.99)	1.80

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.69	0.45

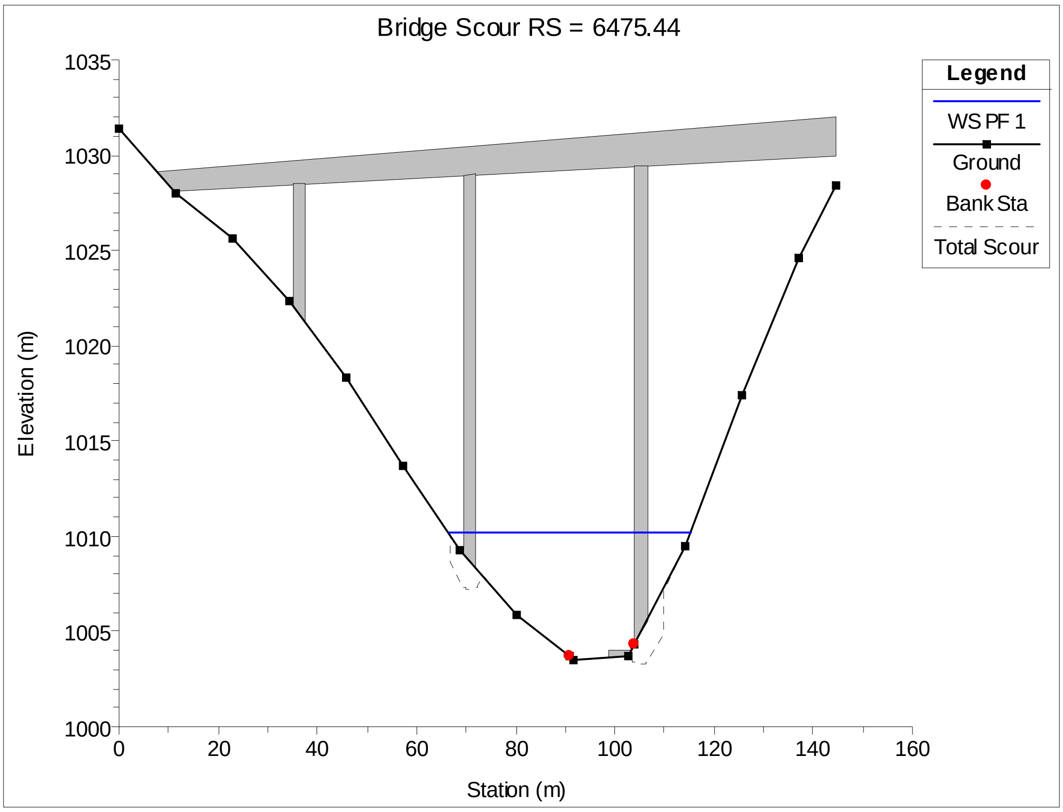


Figure D. 18 Scouring at Kırkgeçit 7 Right Viaduct in Cross-sectional View

Table D. 17 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 7 Right

Name of the Pier	d_s (m)
#1 (CL = 36.25)	
#2 (CL = 70.75)	1.43
#3 (CL = 105.25)	1.63

Local Maximum Velocity V (m/s)	Median riprap size (m)
1.24	0.10

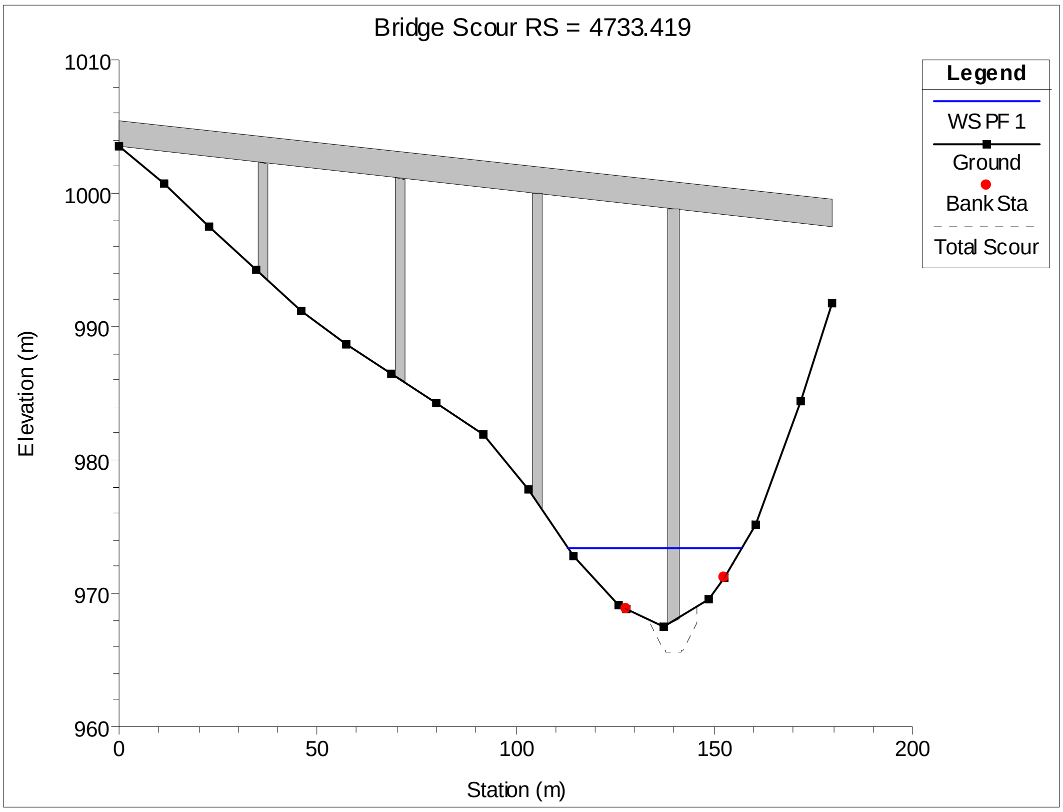


Figure D. 19 Scouring at Kırkgeçit 9 Right Viaduct in Cross-sectional View

Table D. 18 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 9 Right

Name of the Pier	d_s (m)
#1 (CL = 36.25)	
#2 (CL = 70.75)	
#3 (CL = 105.25)	
#4 (CL = 139.75)	2.33

Local Maximum Velocity V (m/s)	Median riprap size (m)
2.27	0.32

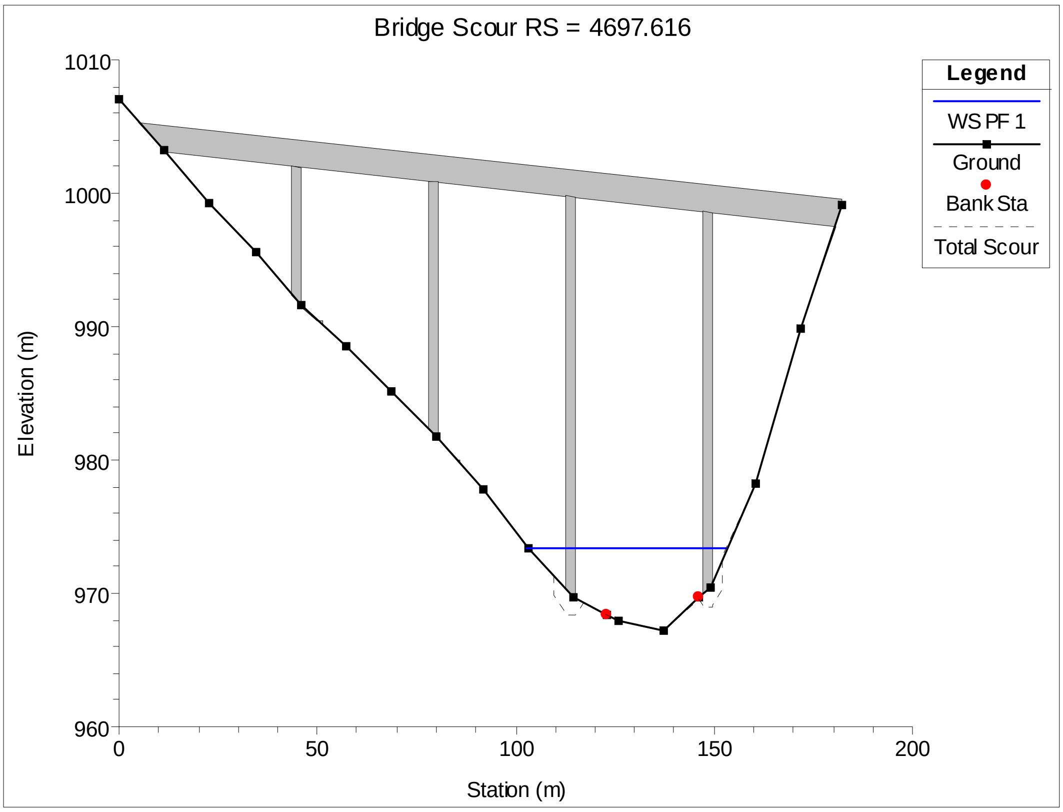


Figure D. 20 Scouring at Kırkgeçit 9 Left Viaduct in Cross-sectional View

Table D. 19 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 9 Left

Name of the Pier	**d_s (m)**
#1 (CL = 44.88)	
#2 (CL = 79.38)	
#3 (CL = 113.88)	1.53
#4 (CL = 148.38)	1.34

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
0.99	0.06

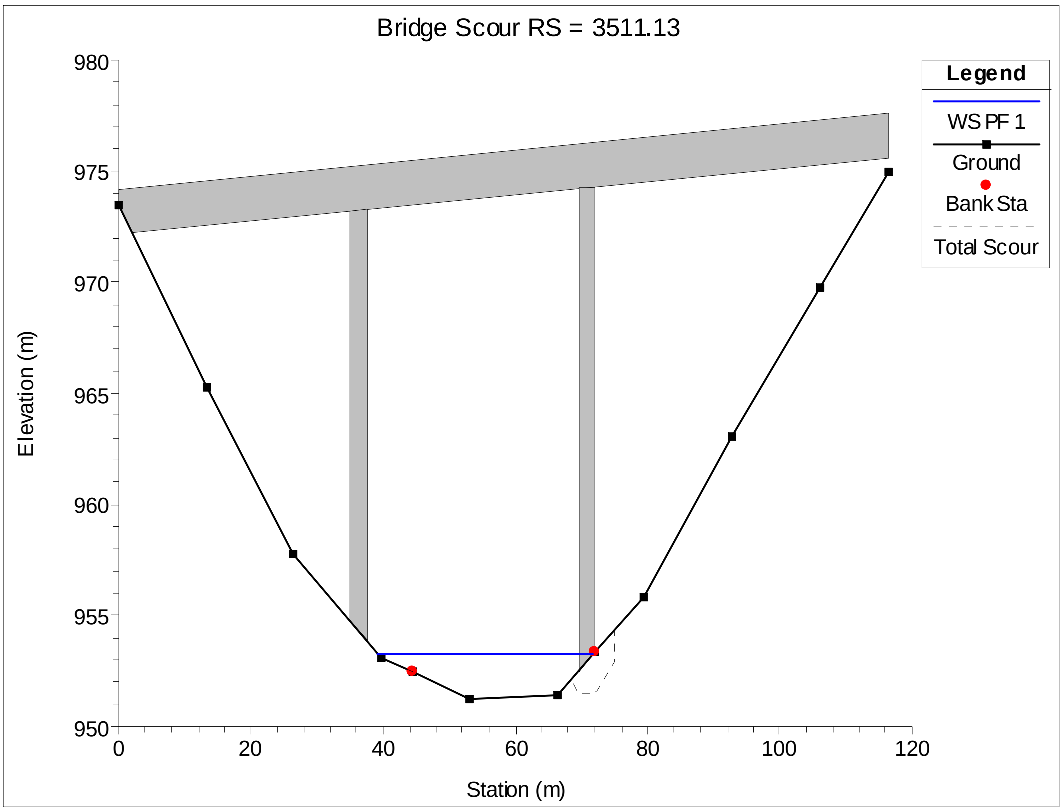


Figure D. 21 Scouring at Kırkgeçit 10 Left Viaduct in Cross-sectional View

Table D. 20 Scour Depths, Local Max. Velocity and Median Riprap Size for KG10 Left

Name of the Pier	d_s (m)
#1 (CL = 36.25)	
#2 (CL = 70.75)	1.43

Local Maximum Velocity V (m/s)	Median riprap size (m)
1.82	0.21

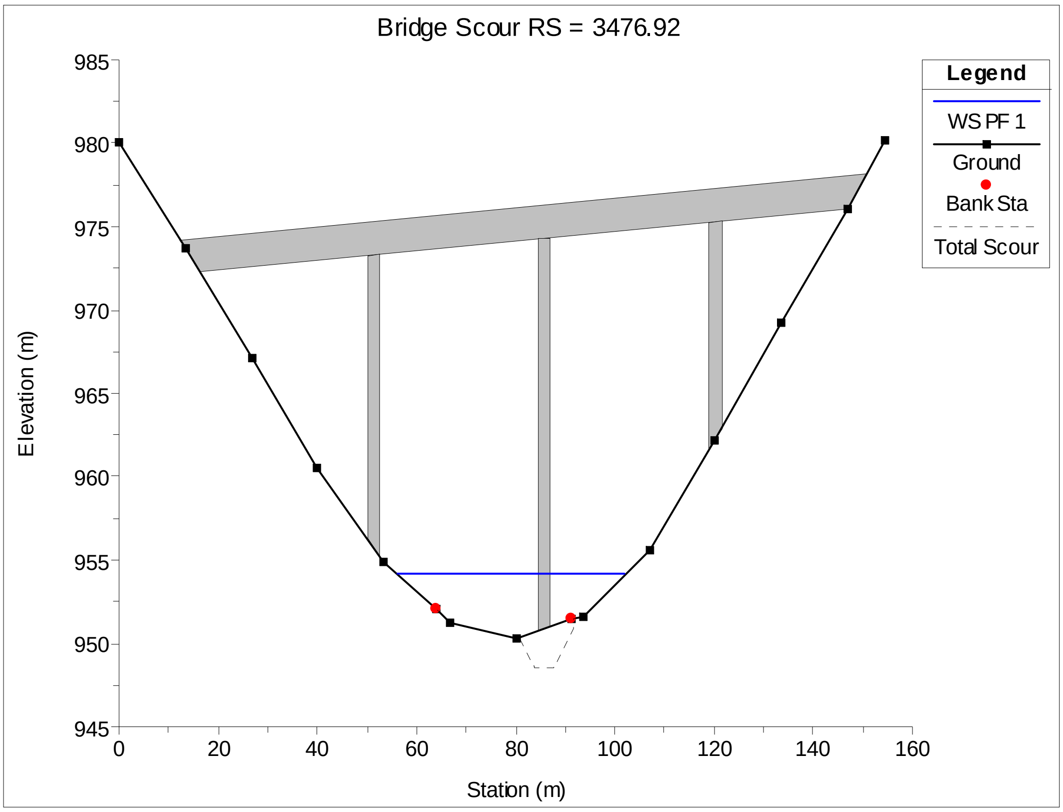


Figure D. 22 Scouring at Kırkgeçit 10 Right Viaduct in Cross-sectional View

Table D. 21 Scour Depths, Local Max. Velocity and Median Riprap Size for KG10 Right

Name of the Pier	**d_s (m)**
#1 (CL = 51.25)	
#2 (CL = 85.75)	2.40
#3 (CL = 120.25)	

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
2.86	0.51

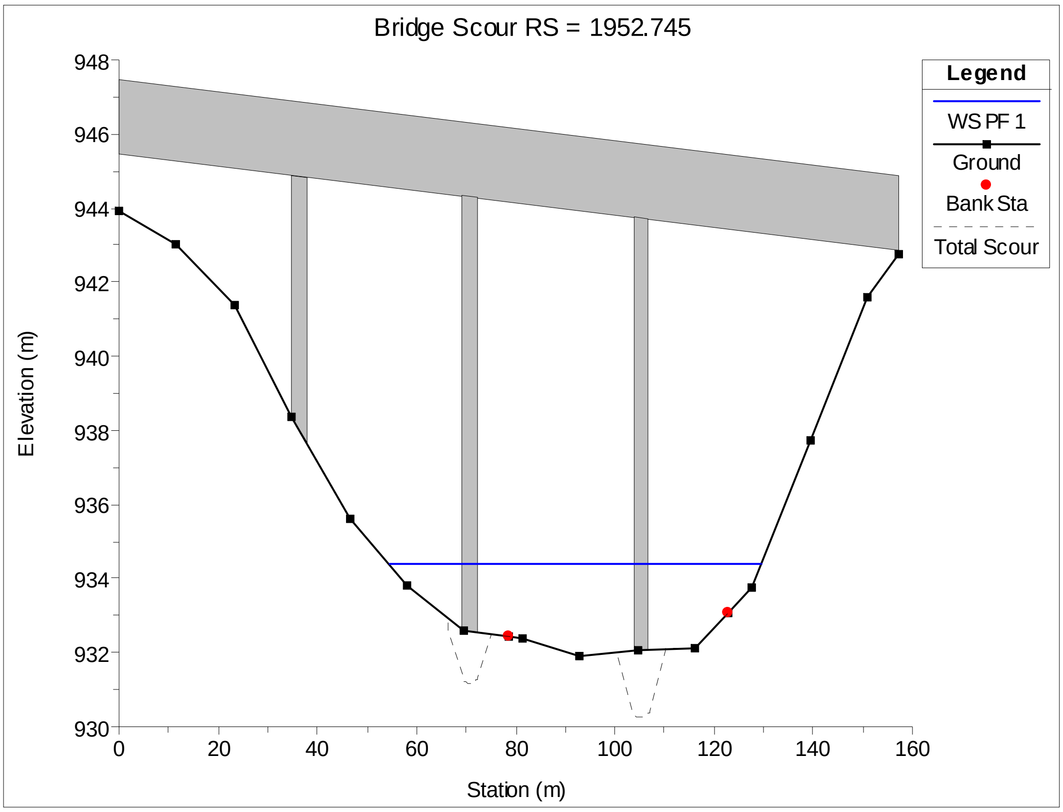


Figure D. 23 Scouring at Kırkgeçit 11/1 Right Viaduct in Cross-sectional View

Table D. 22 Scour Depths, Local Max. Velocity and Median Riprap Size for KG11/1 Right

Name of the Pier	d_s (m)
#1 (CL = 36.25)	
#2 (CL = 70.75)	1.40
#3 (CL = 105.25)	1.82

Local Maximum Velocity V (m/s)	Median riprap size (m)
2.44	0.37

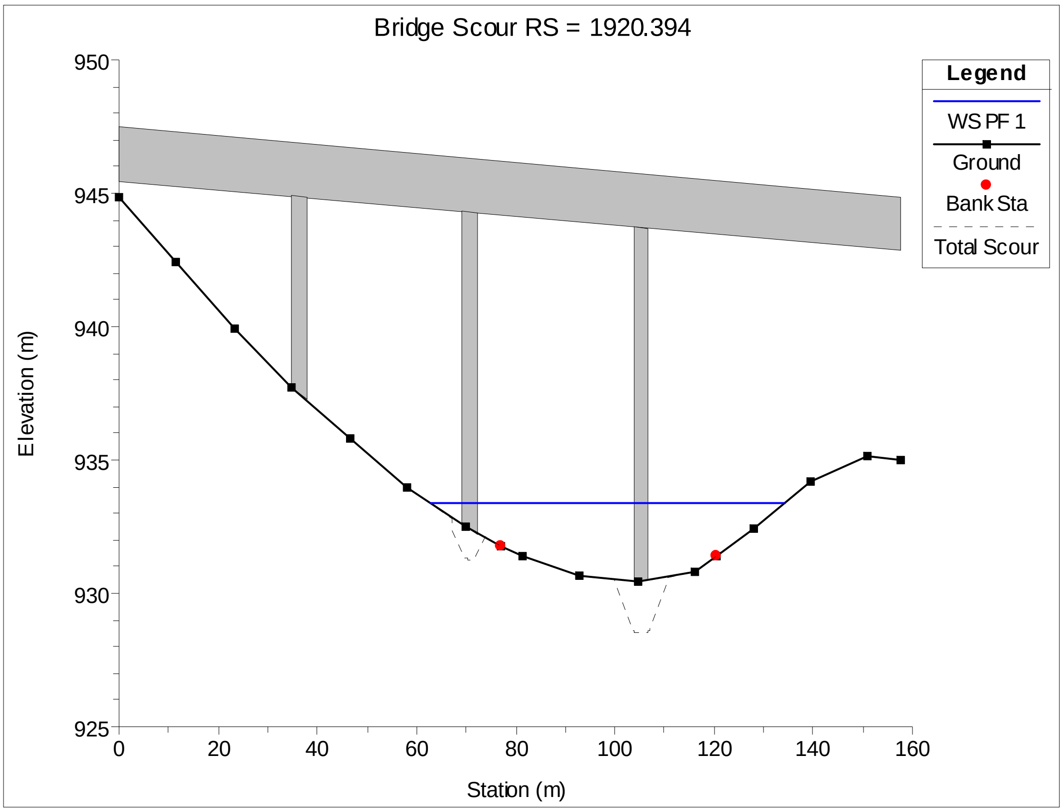


Figure D. 24 Scouring at Kırkgeçit 11/1 Left Viaduct in Cross-sectional View

Table D. 23 Scour Depths, Local Max. Velocity and Median Riprap Size for KG11/1 Left

Name of the Pier	d_s (m)
#1 (CL = 36.25)	
#2 (CL = 70.75)	1.11
#3 (CL = 105.25)	1.92

Local Maximum Velocity V (m/s)	Median riprap size (m)
2.58	0.41

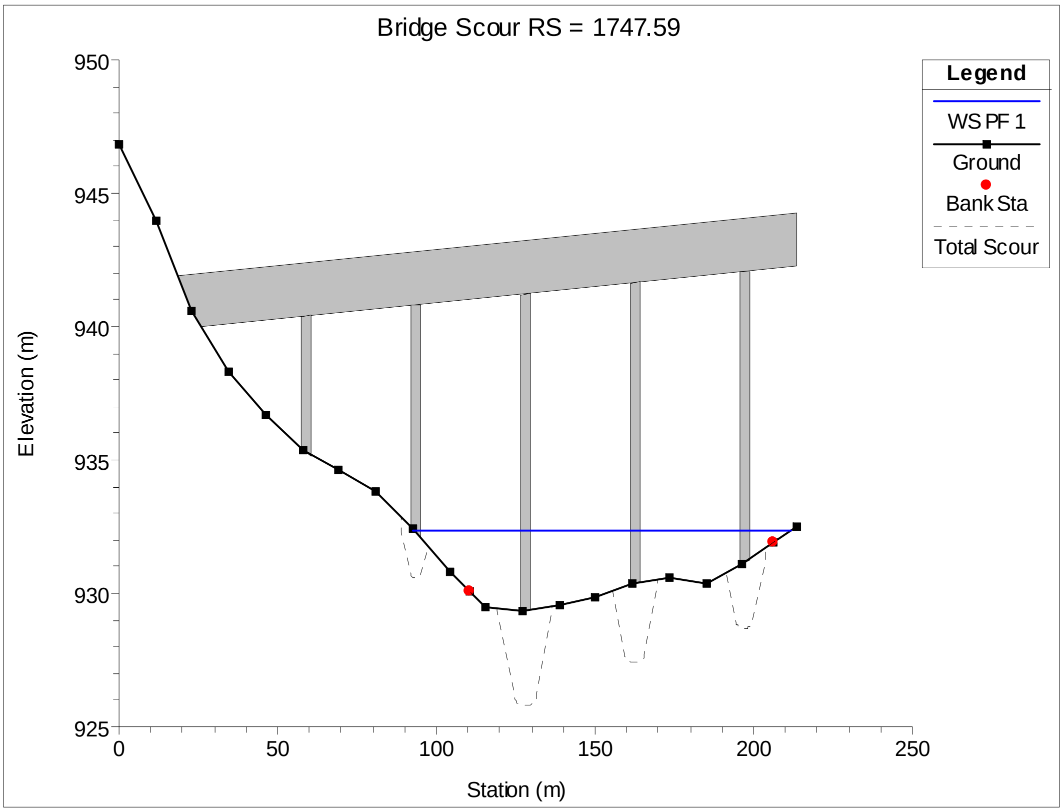


Figure D. 25 Scouring at Kırkgeçit 11/2 Left Viaduct in Cross-sectional View

Table D. 24 Scour Depths, Local Max. Velocity and Median Riprap Size for KG11/2 Left

Name of the Pier	**d_s (m)**
#1 (CL = 59)	
#2 (CL = 93.5)	1.69
#3 (CL = 128)	3.56
#4 (CL = 162.5)	2.98
#5 (CL = 197)	2.47

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.56	0.15

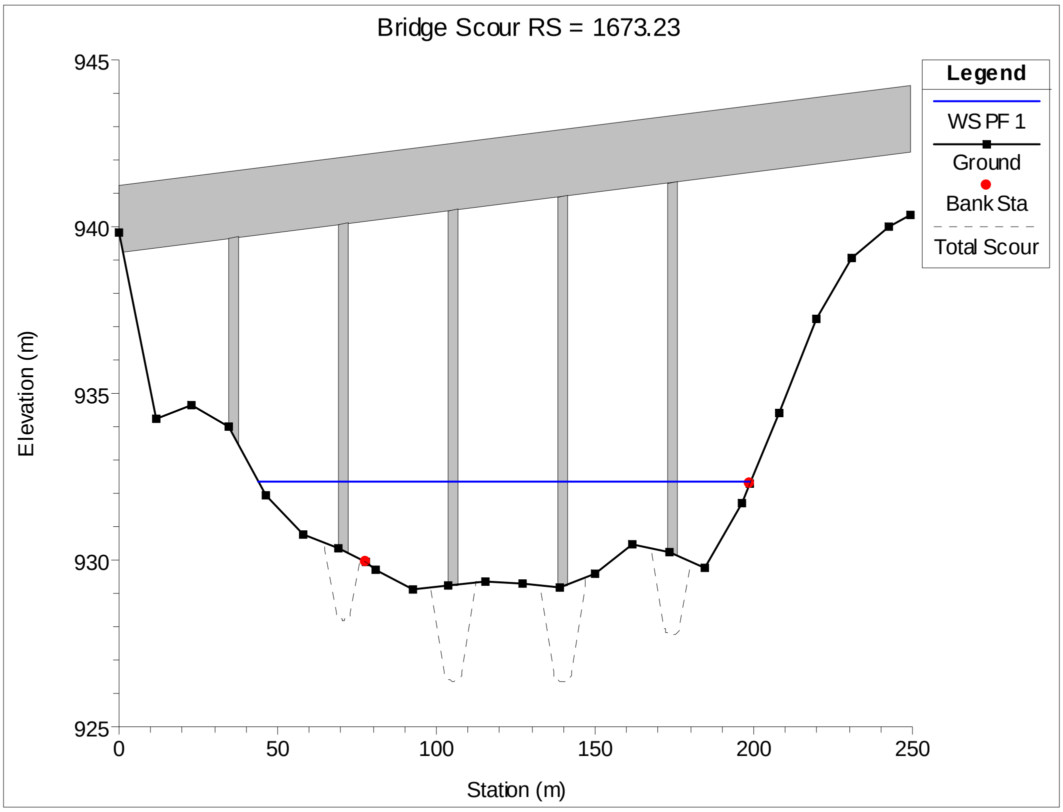


Figure D. 26 Scouring at Kırkgeçit 11/2 Right Viaduct in Cross-sectional View

Table D. 25 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 11/2 Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	
#2 (CL = 70.75)	2.09
#3 (CL = 105.25)	2.86
#4 (CL = 139.75)	2.86
#5 (CL = 174.25)	2.45

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
0.93	0.05

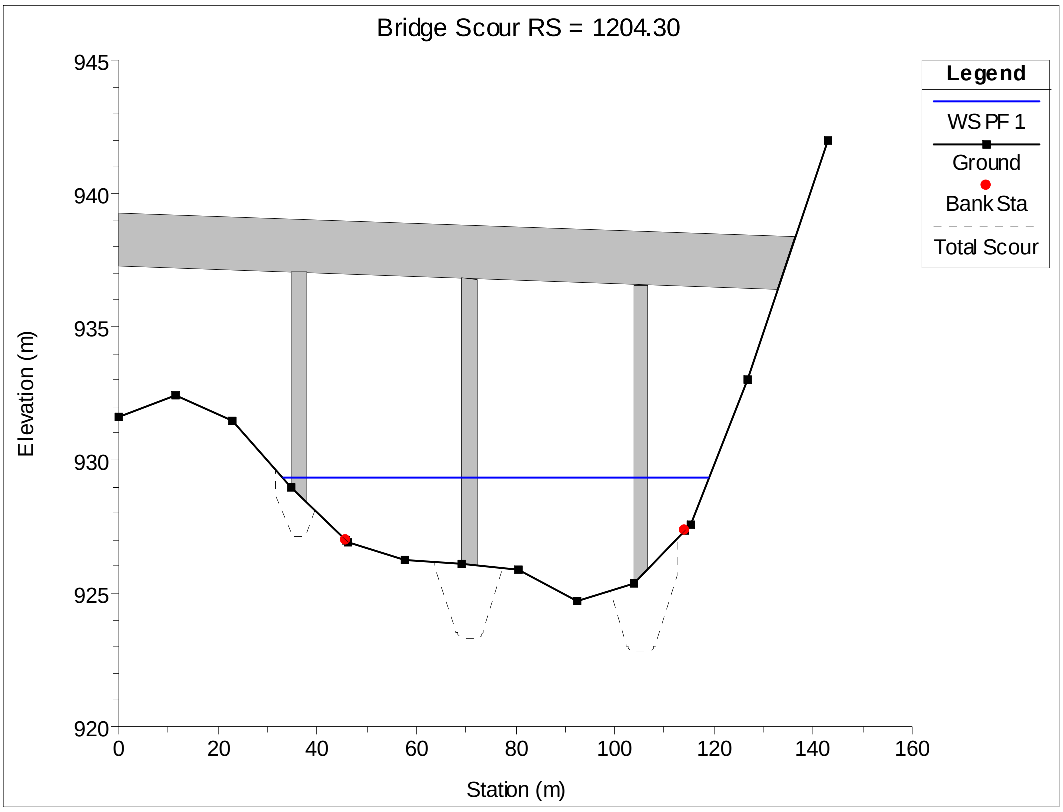


Figure D. 27 Scouring at Kırkgeçit 12 Right Viaduct in Cross-sectional View

Table D. 26 Scour Depths, Local Max. Velocity and Median Riprap Size for KG12 Right

Name of the Pier	**d_s (m)**
#1 (CL = 36.25)	1.57
#2 (CL = 70.75)	2.75
#3 (CL = 105.25)	2.87

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.23	0.09

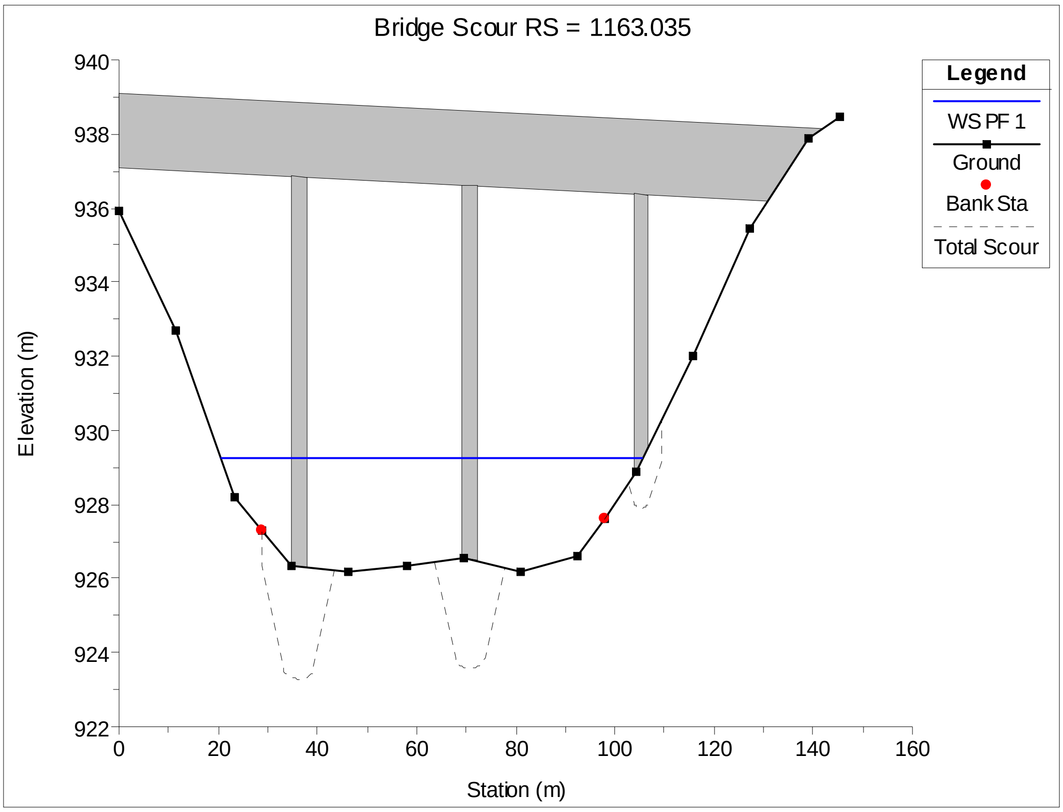


Figure D. 28 Scouring at Kırkgeçit 12 Left Viaduct in Cross-sectional View

Table D. 27 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 12 Left

Name of the Pier	d_s (m)
#1 (CL = 36.25)	3.04
#2 (CL = 70.75)	2.96
#3 (CL = 105.25)	1.26

Local Maximum Velocity V (m/s)	Median riprap size (m)
1.51	0.14

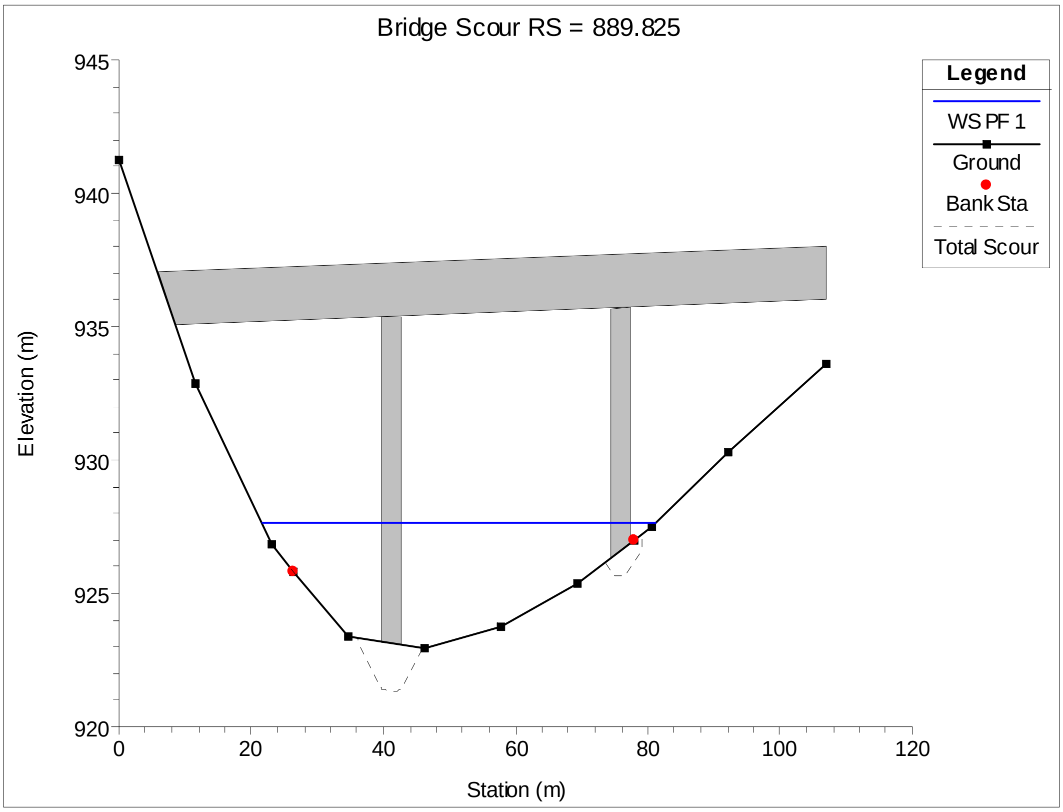


Figure D. 29 Scouring at Kırkgeçit 13 Left Viaduct in Cross-sectional View

Table D. 28 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 13 Left

Name of the Pier	**d_s (m)**
#1 (CL = 41.25)	1.79
#2 (CL = 75.75)	0.95

Local Maximum Velocity V (m/s)	**Median riprap size (m)**
1.92	0.23

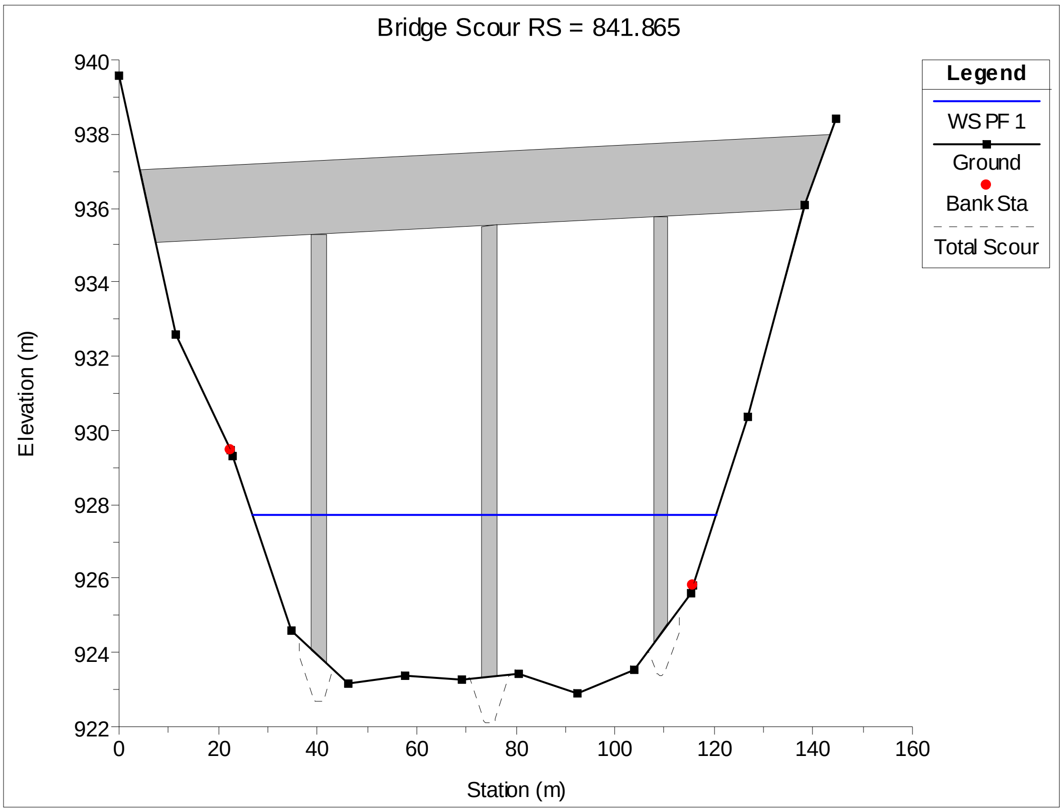


Figure D. 30 Scouring at Kırkgeçit 13 Right Viaduct in Cross-sectional View

Table D. 29 Scour Depths, Local Max. Velocity and Median Riprap Size for KG13 Right

Name of the Pier	d_s (m)
#1 (CL = 40.25)	1.21
#2 (CL = 74.75)	1.27
#3 (CL = 109.25)	1.12

Local Maximum Velocity V (m/s)	Median riprap size (m)
0.88	0.05

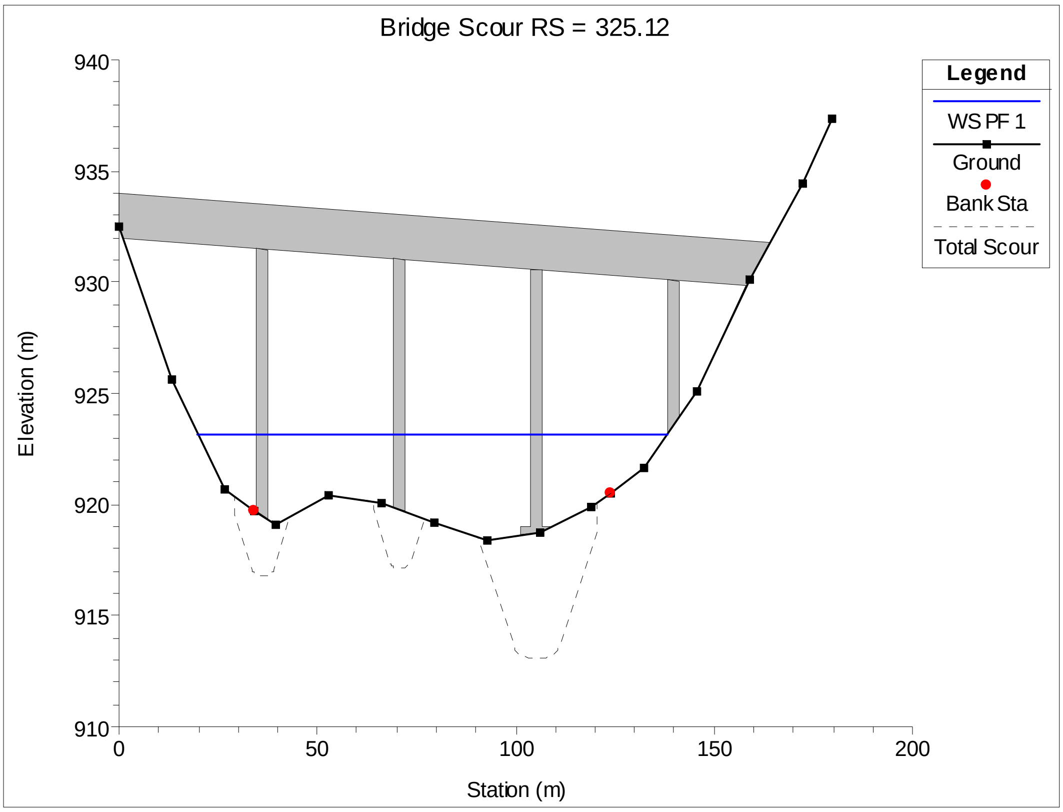


Figure D. 31 Scouring at Kırkgeçit 14 Right Viaduct in Cross-sectional View

Table D. 30 Scour Depths, Local Max. Velocity and Median Riprap Size for KG14 Right

Name of the Pier	d_s (m)
#1 (CL = 36.25)	2.69
#2 (CL = 70.75)	2.63
#3 (CL = 105.25)	5.67
#4 (CL = 139.75)	

Local Maximum Velocity V (m/s)	Median riprap size (m)
0.89	0.05

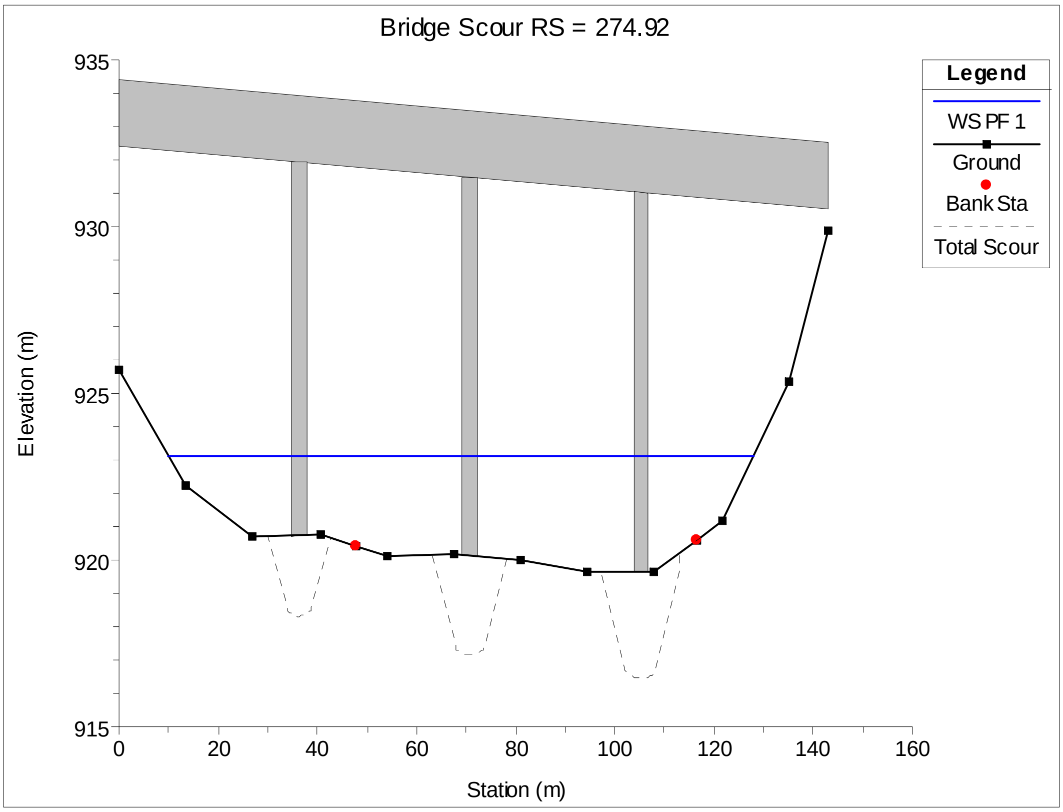


Figure D. 32 Scouring at Kırkgeçit 14 Left Viaduct in Cross-sectional View

Table D. 31 Scour Depths, Local Max. Velocity and Median Riprap Size for KG 14 Left

Name of the Pier	d_s (m)
#1 (CL = 36.25)	2.42
#2 (CL = 70.75)	2.99
#3 (CL = 105.25)	3.19

Local Maximum Velocity V (m/s)	Median riprap size (m)
1.16	0.08