COMPUTER-ASSISTED DESIGN METHODOLOGY FOR ARMORING TYPE BRIDGE SCOUR COUNTERMEASURES

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ABSTRACT

COMPUTER-ASSISTED DESIGN METHODOLOGY FOR BRIDGE SCOUR COUNTERMEASURES

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Scour at bridge piers is considered as a significant safety hazard. Hence, scour countermeasure design plays a critical role to hinder the scour potential at bridges. The selection methodology for a scour countermeasure varies with respect to site conditions, economy, availability of material and river characteristics. The aim of this study is to review the literature on this topic to gather universally accepted design guidelines. A user-friendly computer program is developed for decision-making in various sequential steps of countermeasure design against scouring of bridge piers. Therefore, the program is eventually intended to select the feasible solution based on a grading system which deals with comparative evaluation of soil, hydraulic, construction and application aspects. The program enables an engineer to carry out a rapid countermeasure design through consideration of successive alternatives. A case study is performed to illustrate the use of this program.

Keywords: Bridge, pier, scour, scour countermeasure, computer program

ÖZ

KÖPRÜ YEREL OYULMALARINA KARŞI KORUMA PROJELERİNİN BİLGİSAYAR DESTEKLİ TASARIMI

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Köprü ayaklarındaki oyulmalar, köprülerin yapısal güvenliği açısından oldukça önemlidir. Bu nedenle, köprü ayakları yerel oyulmalara karşı uygun koruma projeleri ile korunmalıdır. Köprüler için uygun koruma projelerinin seçimi, köprünün yerel özellikleri, ekonomi, nehrin yatak ve akım karakteri, malzemenin yerel durumu gibi çok sayıda etmene bağlıdır. Bu çalışmada, proje mühendisinin köprü orta ayakları için birçok alternatif koruma projesini yerel hidrolik, zemin ve yapısal kısıtlamalar bakımından puanlama yöntemiyle karşılaştırıp değerlendirebileceği kullanımı kolay bir bilgisayar programı geliştirilmiştir. Aynı zamanda alternatif koruma projelerinin tasarımını hızlı bir şekilde gerçekleştirebilen programın, mevcut bir köprü projesi üzerinde uygulaması gerçekleştirilmiştir.

Anahtar Kelimeler: Köprü, köprü ayağı, oyulma önleyici düzenleme, bilgisayar programı

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A	Length of the riprap stone
ACB	Articulated concrete block
A_n	Net are of the ACB installation
a_o	Angle of bed slope
b	Pier width perpendicular to the flow direction
B	Intermediate axis of riprap stone
C	Thickness of the riprap stone
C_{acb}	Cost of ACB units
C_{at}	Cost of ACB transportation
C_{ex}	Cost of excavation
C_{ext}	Cost of transportation of excavated material
C_f	Cost of filter
C_{fill}	Cost of fill
C_{ft}	Cost of fill transportation
C_{gr}	Cost of grouting
C_r	Cost of riprap stones
C_{rt}	Cost of riprap transportation
C_s	Stability coefficient for rock-filled gabion mattress
CSU	Colorado State University
C_{total}	Total cost
C_u	Coefficient of uniformity
D_{10}	Size of grain for which 10% is finer
D_{50}	Size of grain for which 50% is finer
D_{60}	Size of grain for which 60% is finer
D_{g50}	Median diameter of rock fill in gabion mattress
D_r	Size of riprap
D_{r15}	Size of riprap for which 15% is finer
D_{r50}	Median riprap diameter
D_{r85}	Size of riprap for which 85% is finer
d_s	Depth of scour
d_{se}	Equilibrium scour depth
E_b	Volume of the bank excavation
E_t	Volume of the total excavation
F_d	Drag force
FHWA	Federal Highway Administration
Fr	Frictional resistance to sliding
F_r	Froude number directly upstream of the pier
g	Acceleration of gravity
GFM	Grout filled mattress
K_1	Correction factor for pier nose shape
K_2	Correction factor for angle of attack of flow
K_3	Correction factor for bed condition
K_4	Correction factor for armoring of bed material
K_s	Shape factor representing the effect of shape of pier
K_v	Velocity adjustment factor
LCC	Life – cycle costs
m	Coefficient of static friction
n	Manning's n value
PGR	Partially grouted riprap
Q	Discharge
Q_{100}	Peak discharge corresponding to 100-year return period
S_1	Factor accounting for bed material size and transport
S_2	Factor accounting for severity of debris or ice loading

S_3	Factor accounting for constructability constraints
S_4	Factor accounting for inspection and maintenance requirements
SFs	Safety factor against sliding
S_g	Specific gravity of the riprap
SI	Selection index
t	Time
t_{gm}	Thickness of grouted mattress
u	Velocity
V	Control volume taken at the river bed
V_{avg}	Section average approach velocity
V_{des}	Design velocity regarding the local conditions at the pier
V_{local}	Local available velocity
V_n	Net volume of the riprap installation
W	Weight of riprap stone
y	Flow depth directly upstream of the pier
Y_a	Depth of flow at the toe of the abutment on the overbank or in the channel
γ_g	Specific weight of grout
γ_s	Specific weight of riprap
γ_{sg}	Specific weight of rock-fill in mattress
γ_w	Specific weight of water
τ_0	Bed shear stress
τ_{des}	Design shear stress for local conditions at pier
τ_p	Permissible shear stress
Φ	Angle of side slope

CHAPTER 1

INTRODUCTION

1.1. Statement of the Problem

Bridges should be considered as vital elements of a transportation system so, designing a safe bridge is important for highway safety and lives of people using it. Especially for river-crossing bridges, hydraulic issues hold important place in designing period. Many studies in literature point out the importance of hydraulic issues in bridge design. For instance, bridge damages since 1950 in the USA were investigated and it was found that, about 60% of those damages resulted from local scouring and bed degrading phenomena (Shirhole and Holt, 1991). One must emphasize that designing a safe bridge requires collaborated action of an experienced hydraulic engineer if it crosses an alluvial river (Turan and Yanmaz, 2011).

Beside many hydraulic phenomena, the scouring of the bed in the vicinity of piers and abutments is generally the dominating factor for bridge damages and failures. Basically three types of scouring mechanisms occur at the bridge locations which are contraction scour, local scour and long term degrading of river bed due to river morphology. The last case usually occurs in very long time, usually much longer than the economic life of a bridge. Hence, other scouring mechanisms are found to be critical for bridge design. Generally, scouring occurs due to the contraction effect of the river at the bridge cross-section and vortex systems around piers and abutments. In practice, for implementing an economical bridge design, narrow bridge spans are considered with protruding abutments through the river so the decreased cross-sections yield an increased flow velocity and sediment transport capacity at those cross-sections. Local scouring mechanism around the structural elements of a bridge occurs in the vicinity of the piers and abutments.

In order to achieve a safe bridge design, the total combined effect of all scouring effects must be inside the safety limits. Particularly, if the total scouring depth which is the summation of scouring depths resulted by all types of scouring phenomena occurred at bridge location reaches the footing elevation of bridge structural elements, the critical scour depth is said to be reached and the bridge is identified as scour-critical (Pearson et al., 2002). For the existing bridges, the determination of the scour potential is important for bridge and highway safety. Hence, necessary precautions must be taken to eliminate the scouring at bridge elements. Generally scour countermeasures need to be evaluated and extensively used for scour-critical bridges by monitoring them continuously.

1.2. Objective of the Study

This thesis aims to create a user-friendly computer program for performing scour countermeasure design for a typical bridge pier. The program was designed with a user-friendly graphical interface and can be used by a design engineer to select the most appropriate type of countermeasure among different types of alternatives. After the selection of the most suitable alternative, the specific design of the selected countermeasure can also be performed with the computer program.

The program is applied to a case study and its performance is investigated in finding the most suitable alternative for a typical bridge located on the Taşlıdere Creek in Rize – Turkey. The creek is modeled and water surface computations are performed for various return periods.

The possible scour depths are determined from the model for piers of the bridge considering the 100-year extreme flood and a suitable countermeasure is eventually selected.

1.3. Scope of the Thesis

The scope of the thesis covers the study of the subjects discussed in the previous section. The thesis consists of five chapters with the contents stated below:

- Chapter 1 : Introductory remarks, description of the scope and aim of the study.
- Chapter 2 : Basic concepts of bridge scouring and scour types.
- Chapter 3 : Basic concepts and design aspects of armoring type countermeasures and their selection criterion.
- Chapter 4 : Information about the computer program, applications and functionality.
- Chapter 5:Case study of a specific bridge located on Taşlıdere Creek in Rize – Turkey, implementation of the computer program in designing a suitable countermeasure.
- Cross-sections of the Taşlıdere Creek are shown in Appendix A.
- Source code of the CM Design computer program is shown in Appendix B.

CHAPTER 2

THE MECHANISM OF BRIDGE SCOUR

2.1. General

The scouring mechanism dramatically influences the safety of the bridges due to the transportation of considerable amount of bed material around the bridge footing. As a result of this, structural stability problems emerge. Particularly, several scouring mechanisms influence the stability of river-crossing bridges which are the total long term channel degrading due to the morphological regime of the river, scouring resulted from the contracted cross-section of the bridge and the local scouring around piers and abutments due to vortex actions.

2.2. The Mechanism of Scouring

2.2.1. Contraction Scouring

The scouring mechanism around bridge piers is directly related to the sediment transport mechanism of the river. Generally, rivers consisting of alluvial beds are subject to bed material transportation due to the intensity of the flow regime. This concept can be investigated by the sediment continuity equation which is shown below (Yanmaz, 2002):

$$\frac{dV}{dt}=S_{In}-S_{Out} \qquad (2.1)$$

where V is the control volume taken at the river bed, S_{in} and S_{out} are the incoming and outgoing sediment transport loads considering the specific control volume and t is the time. Basically, a contracted cross-section results in increased flow velocity so bed load transportation increases with the intensity of the flow regime. Therefore, sediment transport capacity of the section increases. For this condition, outgoing bed load will be higher than incoming bed load. Hence, bed degradation occurs until a further stability is established. Furthermore, after the bridge location, the river cross-section expands which yields a decreased flow velocity and bed load transfer capacity because, $S_{in} > S_{out}$ condition governs. For this reason, the transported bed materials accumulate at the locations prior to the bridge (Yanmaz, 2002). Contraction scouring is considered as a secondary scouring mechanism influencing the bridge safety due to its long term characteristics.

2.2.2. Local Scouring

Local scouring results from the increased intensity and irregularities of the stream-flow regime around bridge piers and abutments which are located as obstacles in the stream. These obstacles influence the streamlines of the flow and alter their paths so vortices are formed which are responsible for scouring of bed material in the vicinity of piers and abutments. Specifically, two types of vortices control the scour mechanisms which are horse-shoe and wake vortices. These vortices are shown in Figure 2.1.

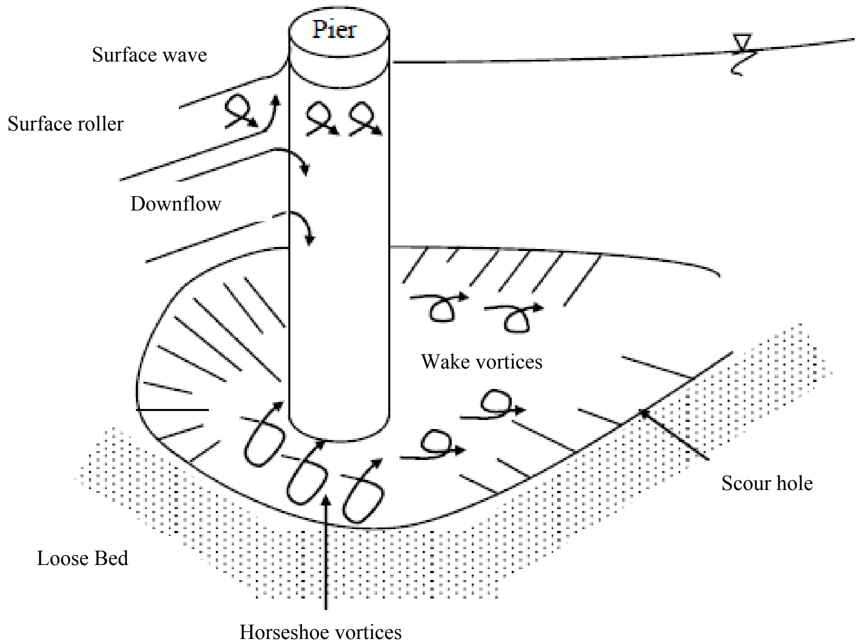


Figure 2.1 Vortex system around a bridge pier (Yanmaz, 2002)

Since the piers are direct obstacles in the flow area, the incoming streamlines collide with the surface of pier and yield an instantaneous stop of the water molecules at the locations called stagnation points. As a result of the governing energy concept, the kinetic energy (velocity head) of the water molecules yields an increased water surface at the front of piers.

The pressure increase at the stagnation points on the pier surfaces are directly related with the intensity of flow. Hence, flow towards the bottom of the pier emerges due to the decreasing pressure gradient with the depth of the flow which is a function of the flow velocity. The emerging down-flow interacts with the approach flow at the base of the pier so horse-shoe vortices are formed (Yanmaz, 2002). The direct effect of down-flow acts as a water-jet on the bed and scouring of the bed material at the front of the pier is initiated. Simultaneously, horse-shoe vortices transport the bed material to downstream of the pier. Wake vortices resulted from the shear stress gradients at the downstream of piers play a secondary role for the local scouring. Also aggradation of the transported material at the downstream of the pier hinders their scouring effect (Yanmaz, 2002). Basically, combination of these two phenomena yields scour mechanism governing around the pier.

2.2.3. Clearwater and Live-Bed Scouring

Bed material transportation directly influences characteristics of local scour mechanism. Clear water scour is observed when there is no bed load transportation with the stream flow. This may occur due to the lower intensity of the flow regime or the characteristics of the bed material so the bed shear stress is lower than the critical value which leads to bed load transportation. When the bed shear stress increases beyond a critical level, live bed condition governs (Yanmaz, 2002).

Clear water scouring yields a gradual increase of the scour depth around the pier (d_s) and a limiting equilibrium scour depth (d_{se}) value is reached. For live bed condition, the scour hole reaches the equilibrium scour depth rapidly due to the more severe flow conditions and variations of the upstream bed load transportation capacity. A variable scour depth is expected to develop due to random amount of the incoming bed load transport. The overall characteristics of both scouring mechanisms with respect to time (t) and velocity (u) can be seen in Figure 2.2 (Yanmaz, 2002).

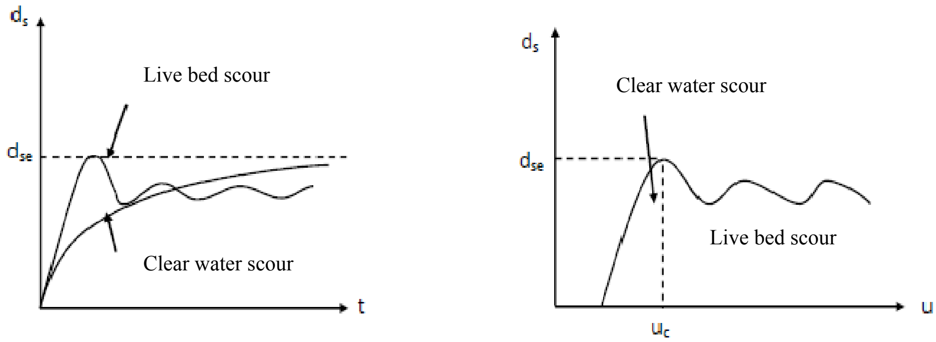


Figure 2.2 Variation of scour depth with time and velocity (Yanmaz, 2002)

2.3. Governing Scouring Parameters

Many researchers have studied the local scouring mechanism around bridge piers and abutments. Because of the complex mechanism of the phenomena, many studies are based on experimental analyses. Therefore, many empirical equations are available in literature. Only two of them will be discussed herein because of their popularity in practical applications. The reader may refer to the recent sources in literature to gain extended knowledge about other scour depth equations and overall concept. See (Melville and Coleman, 2000; Yanmaz, 2002).

HEC-RAS software uses two separate empirical equations to determine the scour depth around bridge piers. The HEC No. 18 report recommends the use of Colorado State University (CSU) equation for the computation of pier scour for live and clear-water conditions. This equation is given below (Richardson and Davis, 2001):

$$d_s = 2.0\, K_1 K_2 K_3 K_4 b^{0.65} y_1^{0.35} F_r^{0.43} \quad (2.2)$$

where;
d_s : Depth of scour
K_1 : Correction factor for pier nose shape
K_2 : Correction factor for angle of attack of flow
K_3 : Correction factor for bed condition
K_4 : Correction factor for armoring of bed material
b : Pier width perpendicular to the flow direction
y_1 : Flow depth directly upstream of the pier
F_r : Froude number directly upstream of the pier

As an alternative, the following equation is used in the HEC-RAS program (Lagasse et al., 2007):

$$d_s = 0.32 K_1 b^{0.62} y_1^{0.47} F_r^{0.22} D_{50}^{-0.99} + b \quad (2.3)$$

HEC-RAS software uses HIRE Equation for calculating the possible scour depth around abutments. The equation is (Richardson et al., 1990):

$$d_s = 4Y_a \left(\frac{K_1}{0.55}\right) K_2 F_r^{0.33} \quad (2.4)$$

where
d_s : Depth of scour
Y_a : Depth of flow at the toe of the abutment on the overbank or in the main channel

CHAPTER 3

BRIDGE SCOUR COUNTERMEASURES

3.1. General

Computation of scouring in bridge vicinity is an important issue for highway safety. The scouring of the bed material around bridge piers and abutments decreases the bridge structural stability and may cause the collapse of the bridge. Therefore, scour depth should not only be computed for new design but also for existing ones to rehabilitate the foundation with relevant countermeasures.

Especially for existing bridges, a structural modification of the bridge is quite difficult so bridge scour countermeasure applications are commonly put in practice. There are various types of countermeasures with specific advantage and disadvantage. A bridge scour countermeasure should perform well under severe flow conditions and be reliable and economical. Moreover, selected countermeasure should be easily constructed, maintained and observed during its lifetime. Although many scour countermeasures have been proposed up to date, only armoring countermeasure types are evaluated in the case study of this thesis since their applications are so common in practice. Particularly, rock riprap, partially grouted riprap are considered as possible armoring type countermeasure alternatives. Articulated Concrete Block system (ACB) is also added to the consideration for cost comparison with armoring type countermeasures.

3.2. Rock Riprap

Rock riprap is one of the most popular scour countermeasures today with the advantageous of being a cheaper solution for many cases. Also, construction and inspection of a rock riprap is relatively easy compared to its alternatives. Rock riprap is a reliable solution for eliminating scour as it behaves flexible under river flows contrary to rigid structures and it can still effectively work even if some of its stones are swept by the flow (Lagasse et al., 2007).

Rock riprap is generally prepared with deposition of stones in the vicinity of a pier or abutment for protecting the river bed against the erosive effects of the river flow. A good riprap structure should consist of rocks having special characteristics, such as individual shape, specific gravity and proper gradation of rocks (Lagasse et al., 2007).

A single rock from a riprap formation should have a specific shape characteristic as the length of the rock must be shorter than 3 times of the thickness. The length (A) and the thickness (C) of a single riprap stone can be found by considering the three specific dimensions as shown in the Figure 3.1 (Lagasse et al., 2007).

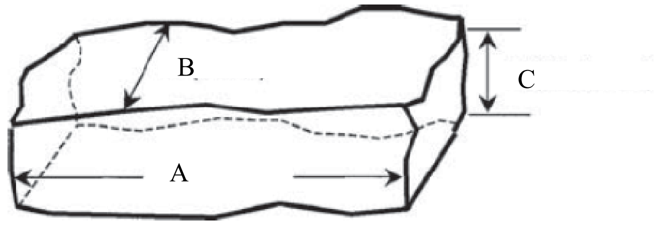


Figure 3.1 Riprap shape described by three axis (Lagasse et al., 2007)

Specific gravity of stones used in riprap should be greater than 2.5. Recommended size and weight relations for riprap stones are determined with the following equation (Lagasse et al., 2007).

$$W=0.85(\gamma_s B^3) \tag{3.1}$$

where

W : Weight of riprap stone

γ_s : Specific weight of riprap

B : Intermediate axis of riprap

For obtaining a good performance from rock riprap, the delivered stones should have a specific size gradation. The recommended size gradations for riprap stones (D_r) are summarized in Table 3.1. This table is prepared by considering a target coefficient of uniformity of 2.0 which has a range between 1.5 to 2.5 (Lagasse et al., 2007).

Table 3.1 Recommended size gradations for standard classes of riprap in cm (Lagasse et al., 2007)

Class	Dr	Dr100	Dr15	Dr15	Dr50	Dr50	Dr85	Dr85
	(cm)	(max)	(min)	(max)	(min)	(max)	(min)	(max)
I	15.2	30.5	9.4	13.2	14.5	17.5	19.8	23.4
II	22.9	45.7	14.0	19.8	21.6	26.7	29.2	35.6
III	30.5	61.0	18.5	26.7	29.2	35.6	39.4	47.0
IV	38.1	76.2	23.4	33.0	36.8	44.5	49.5	58.4
V	45.7	91.4	27.9	39.4	43.2	52.1	59.7	69.9
VI	53.3	106.7	33.0	47.0	50.8	61.0	69.9	82.6
VII	61.0	121.9	36.8	53.3	58.4	69.9	78.7	94.0
VIII	76.2	152.4	47.0	66.0	72.4	87.6	99.1	116.8
IX	91.4	182.9	55.9	80.0	86.4	105.4	119.4	141.0
X	106.7	213.4	64.8	92.7	101.6	123.2	138.4	163.8

The overall design procedure for rock riprap is based on the re-arranged Isbash equation (Lagasse et al., 2001) which yields a median stone diameter. The median diameter is used for selecting the appropriate gradation class ranged from I to X. As a recommendation, one upper class may be selected for the final design characteristics so a slightly overdesigned riprap layer is considered for insuring a higher factor of safety. The Isbash equation is shown below (Lagasse et al., 2001):

$$D_{r50}=\frac{0.692(V_{des})^2}{(S_g-1)2g} \tag{3.2}$$

where

D_{r50} : Median riprap diameter
V_{des} : Design velocity regarding the local conditions at the pier
S_g : Specific gravity of the riprap
g : Acceleration of gravity

The design velocity (V_{des}) plays an important role in determining D_{r50}. Basically, several considerations are taken into account when determining the design velocity like shape of the pier and severity of the flow condition in the vicinity of pier. For piers which have a round-nose face, stream flow easily fluctuates with softer streamlines. However, for squared-edged piers, a severe turbulent flow is observed yielding a more pronounced scour potential. Also as the flow velocity is higher at the center of the channel compared with the banks, the local velocity should be higher than the average channel velocity. As recommended in HEC-23, the section-average approach velocity V_{avg} is multiplied by factors that are a function of the shape of the pier and its location in the channel (Lagasse et al., 2007). The recommended equation is shown below:

$$V_{des}=K_s K_v V_{avg} \tag{3.3}$$

where

K_s : Shape-factor representing the effect of shape of the pier (1.5 for round-nosed piers, 1.7 for square edged piers)
K_v : Velocity adjustment factor for location in the channel (ranges from 0.9 for pier near the bank in a straight reach to 1.7 for pier located in the main current of flow around a sharp bend)
V_{avg} : Section average approach velocity

For the cases where the local velocity (V_{local}) is available from a stream tube or a 1-D or 2-D model, just the pier shape coefficient is sufficient so the general Isbasch equation is modified as shown below (Lagasse et al., 2007):

$$V_{des}=K_s V_{local} \tag{3.4}$$

The riprap layout configuration around a pier is also important. To assure a fine riprap performance, a great care should be taken to keep a good interlocking between stones of riprap formation. Riprap must be placed uniformly and carefully to eliminate any weak area where erosion can start. An optimum countermeasure performance is obtained when the riprap layer is extended a distance of 2 times the pier width in all directions (Lagasse et al., 2007). Characteristic layout details are shown in Figure 3.2.

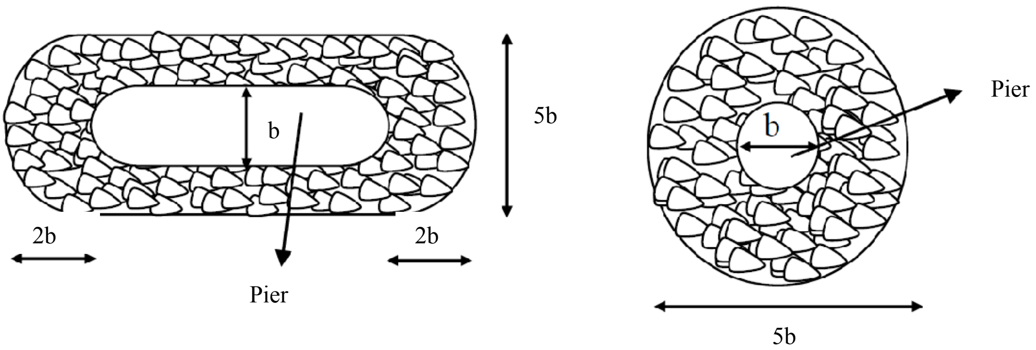


Figure 3.2 Layout details for rock riprap (Yanmaz, 2002)

Thickness of riprap varies from $3D_{r50}$ to $5D_{r50}$ regarding to the severity of hydraulic conditions and it must be placed in an excavated hole or existing scour hole around the pier. When the riprap application is performed under water, the minimum thickness must be increased by 50% (Lagasse et al., 2007).

In the riprap application, a filter is typically required to eliminate the transport of coarser particles underneath and to allow infiltration which is important for the successful long-term performance of an armoring-type countermeasures (Lagasse et al., 2007). Granular and geotextile filters can be used in riprap applications according to bed material characteristics. In some situations, a composite filter consisting of both granular layer and a geotextile can be used. According to Lagasse et al. (2007), for cases where dune-type bed forms may be present, a geotextile filter is recommended.

<u>Granular Filters</u>
According to Brown and Clyde (1989), the minimum thickness of a single layer granular filter should be 15 cm and if the application will be performed in multiple layers, the thickness of each layer can be varied from 10 cm to 20 cm.

<u>Geotextile Filters</u>
Geotextile filter is a material which is placed under the riprap layer. The filter should be carefully installed as it is vulnerable to tearing when it is laid in parts. According to Lagasse et al. (2007), either woven or non-woven, needle-punched fabrics can be used as filter. Placement details of a geotextile filter around a typical bridge pier is shown in Figure 3.3. According to Lagasse et al. (2007), a geotextile filter should be placed all around the pier and it should be extended 3/4 of the width of the riprap layer from the pier face.

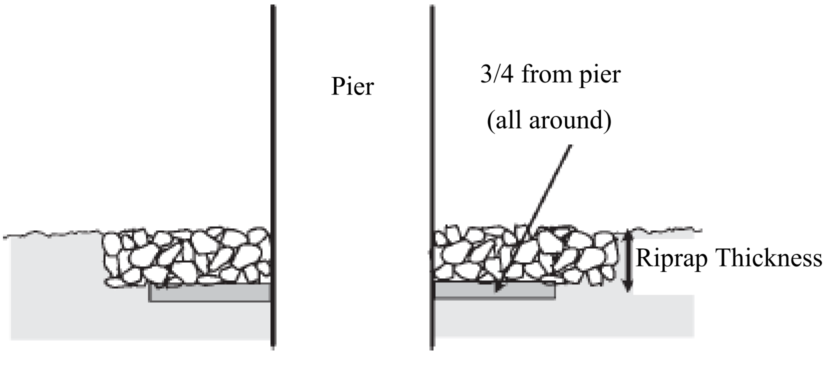


Figure 3.3 Placement details of a filter around pier (Lagasse et al., 2007)

3.3. Partially Grouted Riprap

Partially grouted riprap (PGR) is a specific application of rock riprap which consists of appropriate sized rocks placed in the vicinity of a pier and grouted together with a filling. In this application, 50% or less of the total voids of the riprap volume are filled with the grout filling. Relatively smaller rock diameters can be used with respect to standard so the riprap layer thickness and its extension are decreased. It has also significant advantage as being flexible under the attack by flow and it can be easily repaired and maintained (Lagasse et al., 2007).

The design methodology is similar to regular rock riprap as a median stone diameter D_{r50} is determined. However, only Class II, III and IV riprap rocks are recommended for application while ripraps smaller than Class II contain relatively smaller voids so the grout is not able to penetrate the required depth. Also, ripraps greater than Class IV are not suitable as they have larger voids so grout cannot be retained (Lagasse et al., 2007). The grout fill material is required to be carefully investigated during application as it is applied with sequential layering (Lagasse et al., 2007). A typical view from a partially grouted riprap is shown in Figure 3.4.

Figure 3.4 A typical view from and application of partially grouted (Lagasse et al., 2007)

For partially grouted riprap applications, only Portland cement–based grout is appropriate. The proportions of the recommended grout mix details are shown in Table 3.2.

Table 3.2 Mixture content of 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

According to Lagasse et al. (2007), layer thickness is varied between $2D_{r50}$ and $4D_{r50}$. The filter application is similar to the regular rock riprap system while the filter layer is extended 3/4 of the width of the riprap layer from the pier face (Lagasse et al., 2007). The partially grouted riprap layout diagram is shown in Figure 3.5. Layout details of filter for partially grouted riprap are also shown in Figure 3.6.

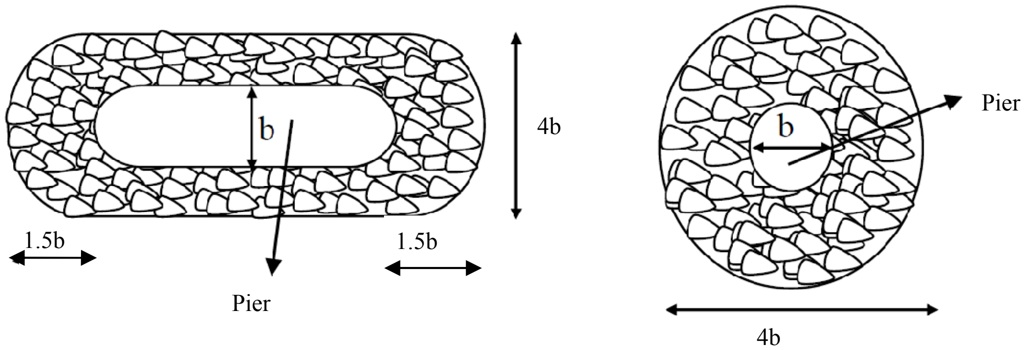


Figure 3.5 Layout details for rock riprap (Yanmaz, 2002)

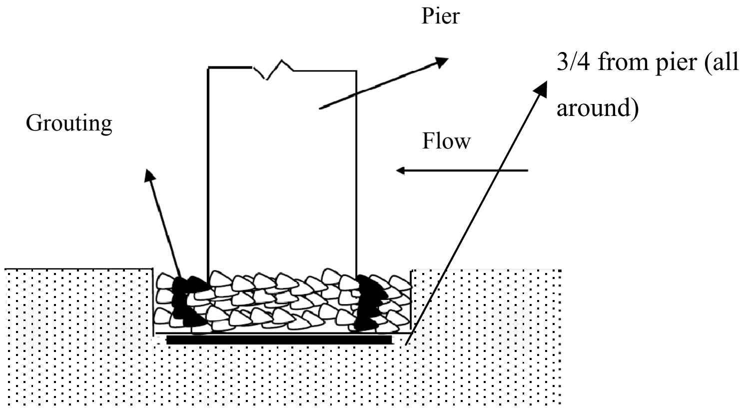


Figure 3.6 Layout details of filter for partially grouted riprap (Lagasse et al., 2007)

3.4. Gabion Mattresses

Gabion mattresses are containers constructed having wire meshes and filled with appropriate sized rocks. Generally, wire is welded or twisted to form gabions and diaphragms are constructed. Angular rocks are preferred for filling the mattress as higher interlocking is obtained. Basically gabions stabilize the rocks against the hydraulic forces and a continuous structure is obtained by connecting the gabions to each other (Lagasse et al., 2007). The application of gabion mattress against pier scouring is not common and there exist limited experience while these systems are widely used for structures, such as check dams, dikes and channel bed stabilization (Lagasse et al., 2007).

The advantage of gabion mattress is its ability to adapt to the changes in bed with a flexible character. Thinner layer and less excavation are sufficient and smaller stone sizes can be used inside the containers. One of the disadvantages of a gabion mattress is difficulty of its application. Also due to the abrasion potential, gabion mattresses are not recommended for gravel bed streams and corrosive waters (Lagasse et al., 2007). A sketch of a typical gabion mattress with its dimensions is shown in Figure 3.7. An application of gabion mattress against scouring at a bridge is shown in Figure 3.8.

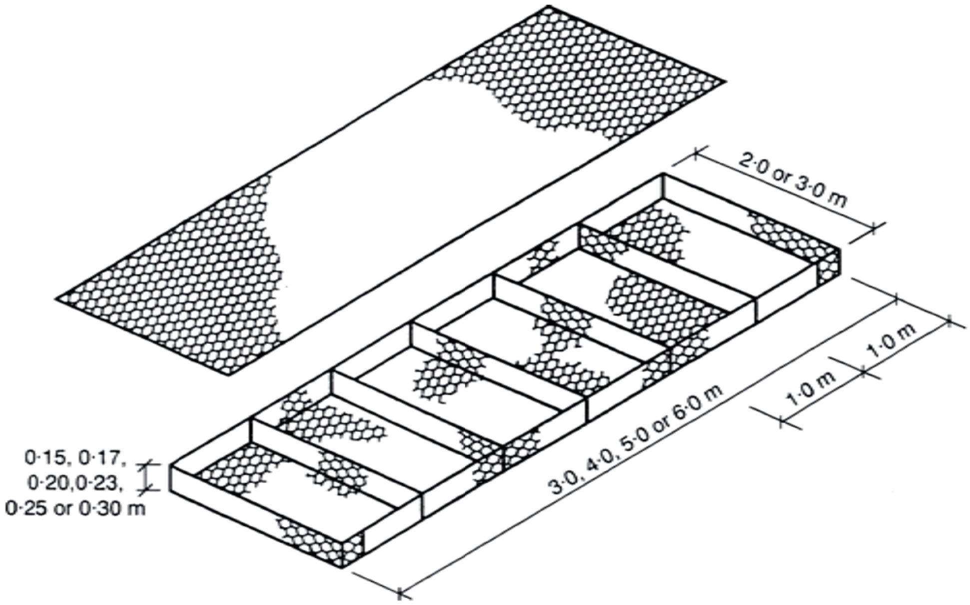


Figure 3.7 Gabion mattress showing typical dimensions (Lagasse et al., 2007)

Figure 3.8 Use of gabion mattress as scour countermeasure at a bridge location
(http://www.tradekorea.com/sell-leads-detail/S00025110/Gabion_Mattress.html, 2012)

The design methodology for gabion mattress is based on determination of median diameter of rock fill in gabion mattress (D_{g50}). For obtaining a stable performance, the delivered stones should have a specific size and also must be hard, dense and durable (Lagasse et al., 2007). The size range of rock for filling the gabion mattress is shown in Table 3.3.

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

Stone sizes should also be evaluated while considering the container properties. Minimum rock size should be at least 1.25 times larger than the aperture size of the wire mesh of the mattress structure (Parker et al., 1998). Moreover, the thickness of the gabion mattress must be at least twice the average diameter of the rock fill and minimum 0.15 m mattress thickness is recommended (Lagasse et al., 2007).

The design progress of a gabion mattress system yields a median stone diameter (D_{g50}). To perform the design, simple flow chart approach developed by Harris County Flood District is recommended (Lagasse et al., 2007). In this approach, the minimum allowable factor of safety for bridge piers is taken as 1.5 and this value is multiplied by two factors which are greater than unity to account for uncertainty and consequence of failure. This chart is modified by Lagasse et al. (2007) and is shown in Figure 3.12. It is used to determine the target factor of safety.

The permissible shear stress for gabion mattress is determined from the following equation provided by HEC-15 report (Kilgore and Cotton, 2005):

$$\tau_p = C_s(\gamma_s - \gamma_w)D_{g50} \qquad (3.5)$$

where

τ_p : Permissible shear stress
C_s : Stability coefficient for rock-filled gabion mattress
γ_s : Specific weight of stone
γ_w : Specific weight of water
D_{g50} : Median diameter of rock fill in mattress

C_s is an empirical coefficient and it is recommended as 0.1 in design (Lagasse et al, 2007). The local velocity and shear stress in the vicinity of pier is used in the design since the hydraulic conditions are more severe than the approach conditions upstream. The determination of the design velocity is the same as that of rock riprap.

The local shear stress is determined from the following equation with the assumption of wide river and under uniform flow conditions (Lagasse et al., 2007):

$$\tau_{des} = (nV_{des})^2 \frac{\gamma_w}{y^{1/3}} \qquad (3.6)$$

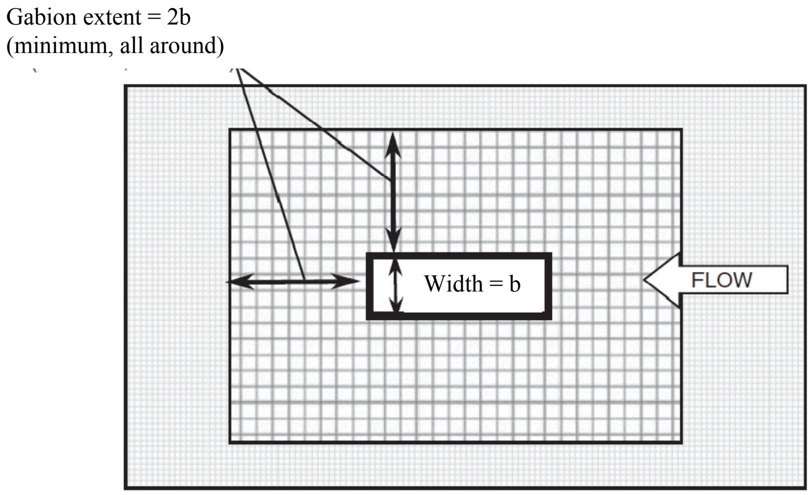
where

τ_{des} : Design shear stress for local conditions at pier
n : Manning's n for the gabion mattress (typical range 0.025–0.035)
V_{des} : Design velocity
γ_w : Specific weight of water
y : Flow depth directly upstream of the pier

The factor of safety of the system is calculated as the ratio of permissible shear stress to local shear stress (Lagasse et al., 2007):

$$F.S = \frac{\tau_p}{\tau_{des}} \qquad (3.7)$$

Placement of the gabion mattresses is also vital for scour countermeasure performance. For the clear water scour case, horizontal alignment of the gabion mattress is required. For other scour cases, mattress must be slopped away in all directions so that the maximum protection depth is greater than probable scour depth, long-term degradation and depth of the bed forms (Lagasse et al., 2007)
.A geotextile filter is also recommended under the mattress. The properties of the filter are same as the other countermeasure types. It is sufficient to extend the filter 2/3 of the gabion extent width from the pier face (Lagasse et al., 2007). The plan and profile views of a specific gabion mattress layout are shown in Figure 3.9 and Figure 3.10.



b. Plan

Figure 3.9 Plan view of the gabion mattress layout (Lagasse et al., 2007)

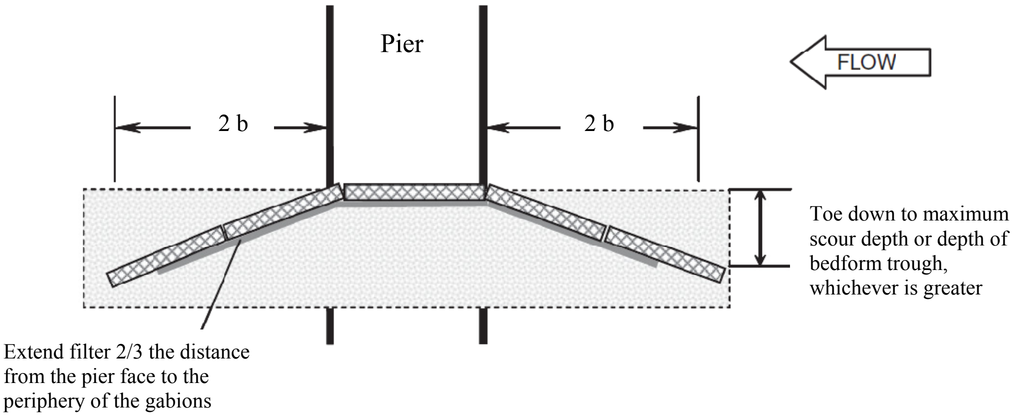


Figure 3.10 Profile view of the gabion mattress layout (Lagasse et al., 2007)

3.5. Articulated Concrete Block (ACB) Systems

Articulated concrete block (ACB) systems consist of concrete blocks that are held together by cables. This provides a flexible armor against scouring (Lagasse et al., 2007). The design methodology of an ACB system is based on the factor of safety, which is defined as the ratio of restraining moments to overturning moments for a single block. The system is analyzed by using Discrete Particle method. The calculated factor of safety must be greater than unity to have a stable structure against hydraulic forces. The target factor of safety of the system is determined with the same flowchart method used for gabion mattress (See Figure 3.12). The factor of safety of a single block is determined by considering the hydraulic conditions (velocity and shear stress), the angle of the inclined surface of the block, weight and the geometry of the block. The forces acting on a concrete block are the lift force, drag force and the submerged weight of the block. The three dimensional view of the forces acting on the block is shown in Figure 3.11 in which the symbols are explained in Table 3.4.

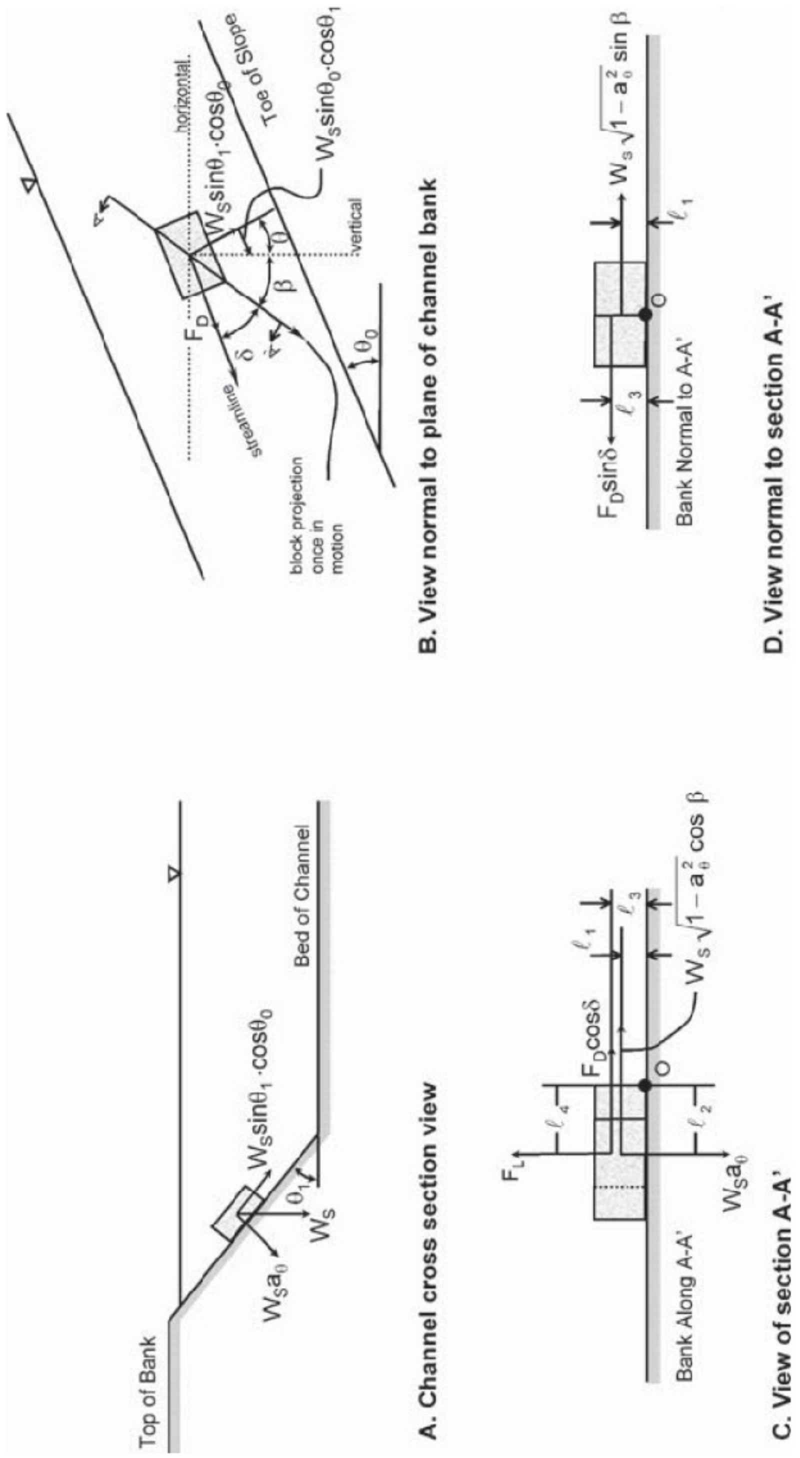


Figure 3.11 Three dimensional view of an ACB unit on a channel side slope (Lagasse et al., 2007)

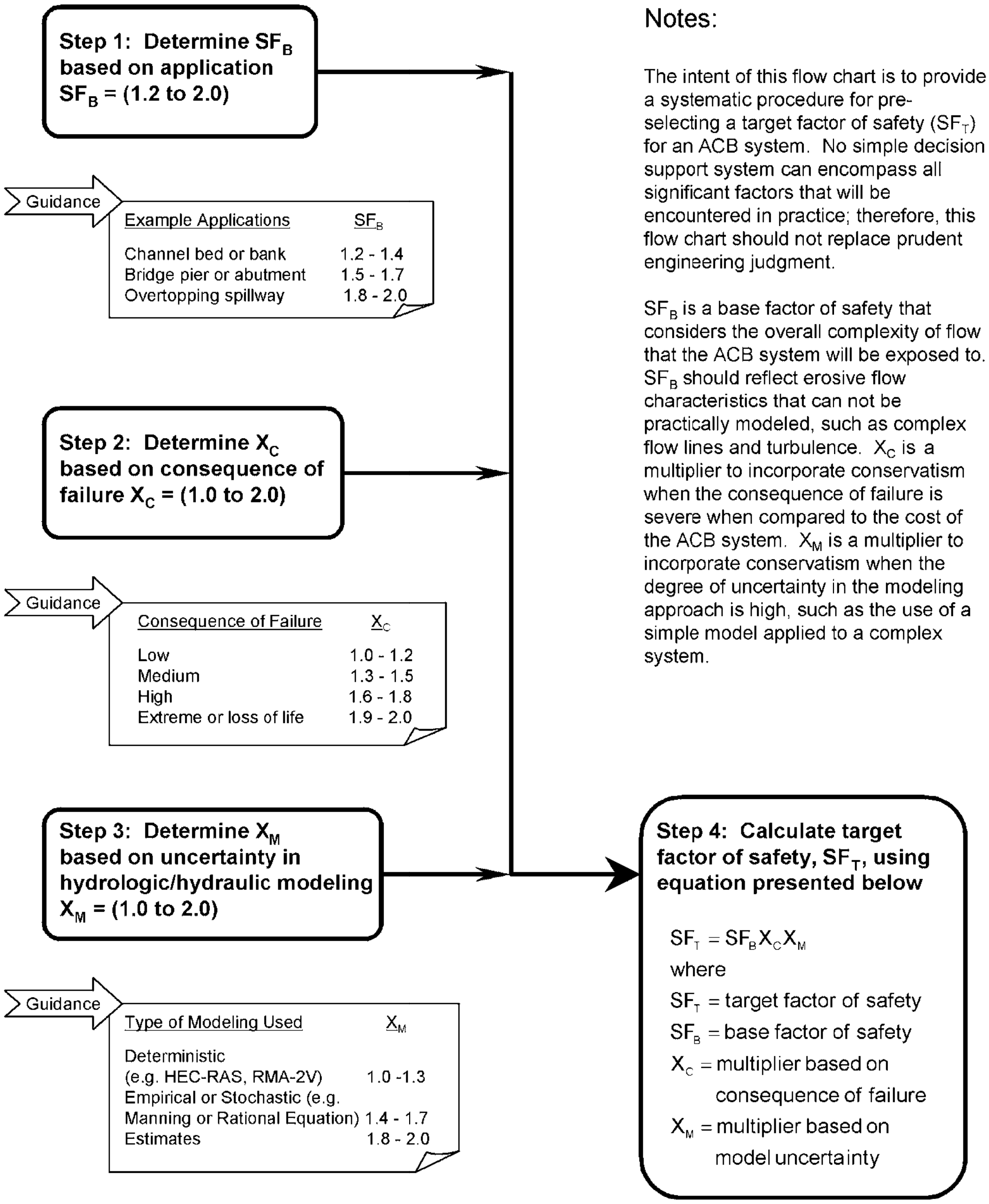


Figure 3.12 Flowchart for determining the target factor of safety for ACB systems (Lagasse et al., 2007)

Determination of the moment arms are described in Figure 3.13. The overturning of the block generally occurs at the downstream corner. So, l_1 and l_4 are used for distance from the center of the block to the corner. Also for l_2, half of the block height is used and for l_3, 8/10 of the block height is used. The equations used for determining the factor of safety of the system is shown in Table 3.4.

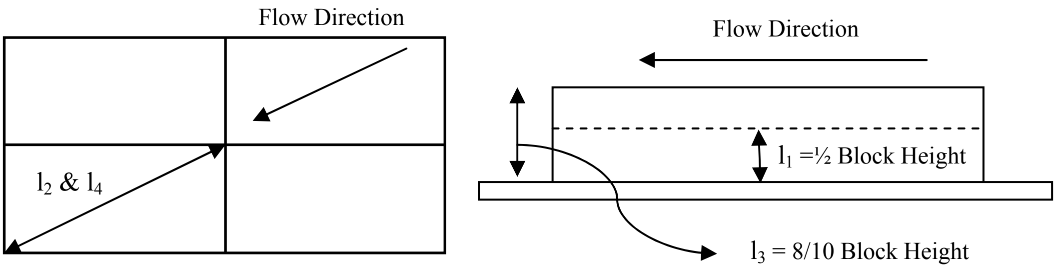


Figure 3.13 Schematic diagram of a block arm showing moment arms (Lagasse et al., 2007)

Like previous countermeasures, design velocity (V_{des}) is determined by multiplication of the section average velocity with shape factor and velocity adjustment factor.

The application details of an ACB system are also important. The dimensions of the system are shown in Figure 3.14. X_1, X_2 and WS are found with Equations (3.8), (3.9) and (3.10) in which d_s is the scour depth and b is the width of the pier.

Beneath of an ACB system, both granular and geotextile filters are recommended. In Netherlands, 1 m thick granular filer is used (Lagasse et al., 2001). A small amount of grouting is also recommended around pier. According to the studies of Özdemir (2003), the cost of the grouting job is negligibly small so it is not considered in the economic analysis. Some types of ACB units and systems are shown in Figure 3.15

$$WS=2.5d_s+b \tag{3.8}$$

$$X_1=1.25d_s \tag{3.9}$$

$$X_2=3d_s \tag{3.10}$$

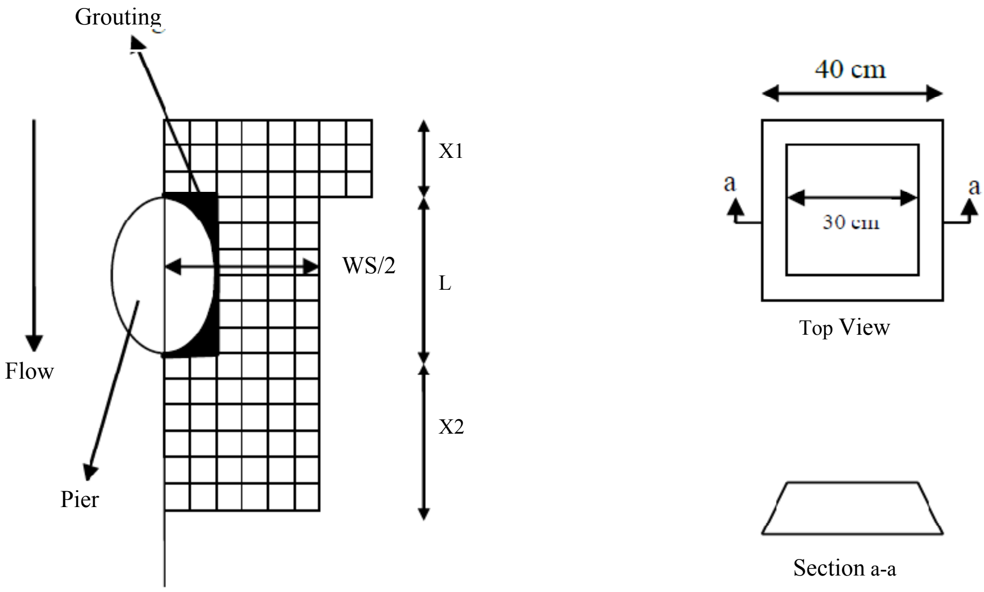


Figure 3.14 Layout details of an ACB system application (Lagasse et al., 2001)

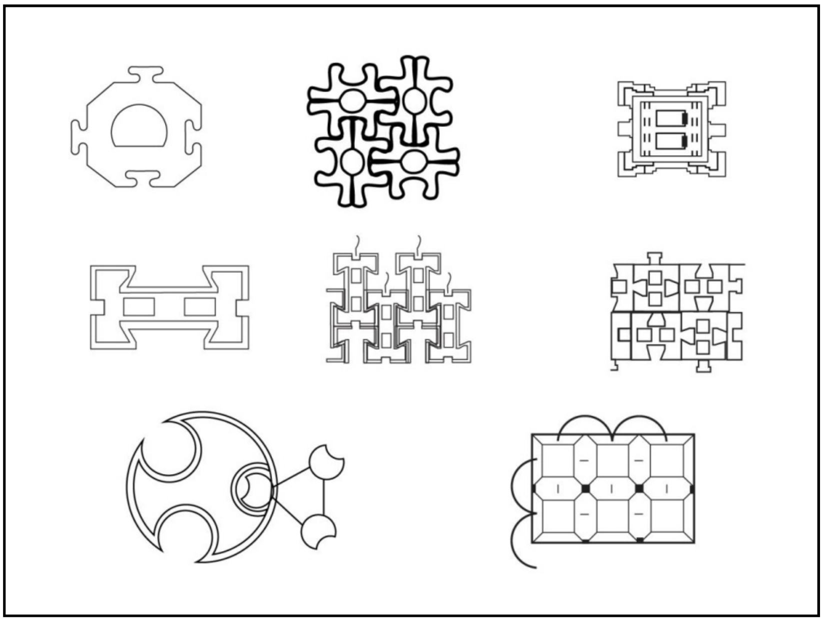


Figure 3.15 Some types of ACB units and systems (Scholl, 2010)

Table 3.4 Design equations for ACB system (Lagasse et al., 2007)

Equation	
$F_L' = F_D' = 0.5\rho b(\Delta z)(V_{des})^2$	(E1.2)
$\eta_0 = \frac{\tau_{des}}{\tau_C}$	(E1.3)
$\theta = \arctan\left(\frac{\tan\theta_0}{\tan\theta_1}\right)$	(E1.4)
$a_\theta = \sqrt{(\cos\theta_1)^2 - (\sin\theta_0)^2}$	(E1.5)
$\beta = \arctan\left(\frac{\cos(\theta_0+\theta)}{\left(\frac{\ell_4}{\ell_3}+1\right)\left(\frac{\sqrt{1-a_\theta^2}}{\eta_0(\ell_2/\ell_1)}\right)+\sin(\theta_0+\theta)}\right)$	(E1.6)
$\delta = 90^o - \beta - \theta$	(E1.7)
$\eta_1 = \eta_0\left(\frac{(\ell_4/\ell_3)+\sin(\theta_0+\theta+\beta)}{(\ell_4/\ell_3)+1}\right)$	(E1.8)
$W_s = W\left(\frac{\gamma_c-\gamma_w}{\gamma_c}\right)$	(E1.9)
$SF = \frac{(\ell_2/\ell_1)a_\theta}{\cos\beta\sqrt{(1-a_\theta)^2}+\eta_1(\ell_2/\ell_1)+\frac{(\ell_3F'_D\cos\delta+\ell_4F'_L)}{\ell_1W_s}}$	(E1.10)

Term Definitions	
a_θ =	Projection of W_S into plane of subgrade
b =	Block width normal to flow (ft)
F'_D, F'_L =	added drag and lift forces due to protruding block (lb)
ℓ_x =	Block moment arms (ft)
γ_c =	Concrete density, lb/ft^3
γ_w =	Density of water, lb/ft^3
V_{des} =	Design velocity (ft/s)
W =	Weight of block in air (lb)
W_S =	Submerged block weight (lb)
Δz =	Height of block protrusion above ACB matrix (ft)
β =	Angle between block motion and the vertical
δ =	Angle between drag force and block motion
η_0 =	Stability number for a block on a horizontal surface
η_1 =	Stability number for a block on a sloped surface
θ =	Angle between side slope projection of W_S and the vertical
θ_0 =	Channel bed slope (degrees)
θ_1 =	Side slope of block installation (degrees)
ρ =	Mass density of water (slugs/ft^3)
τ_c =	Critical shear stress for block on a horizontal surface (lb/ft^2)
τ_{des} =	Design shear stress (lb/ft^2)
SF =	Calculated factor of safety

Note: The equations cannot be solved for $\theta_1 = 0$ (i.e., division by 0 in Equation E1.4); therefore, a very small but non-zero side slope must be entered for the case of $\theta_1 = 0$.

3.6. Grout-filled Mattresses

Grout-filled mattresses (GFM) are scour countermeasures which are composed of strong synthetic fabrics such as woven nylon or polyester. These are sewn into pillow-shaped compartments and connected with each other (Lagasse et al., 2007).

Concrete grout is used to fill the pillow-shaped compartments. Mattresses are generally connected to each other by sewing. The grout-filled mattresses act as a mat made of interconnected rigid blocks so the river bed is protected against scouring.

Lagasse et al. (2007) indicated that flexibility and permeability should be considered important for GFM systems. Hence, filter points which allow pressure relief through mat are recommended. Mattresses which are available in nominal thickness of 100, 150 and 200 mm used in GFM applications are shown in Table 3.5.

Table 3.5 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

There has been very limited experience of using GFM systems in bridge environment as they are generally used for shore protection, channel armoring and pipeline projects (Lagasse et al., 2007). GFM has various advantages. It can be deployed rapidly and also dewatering is not necessary. One of the disadvantageous of GFM is that it is suitable only for clear water conditions. For dune-type bed form conditions, both undermining and uplift forces are expected (Lagasse et al., 2007). A basic sketch of a GFM system is shown in Figure 3.16.

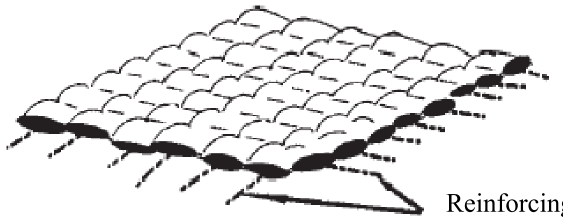


Figure 3.16 Basic sketch of a GFM system (Fotherby, 1995)

3.7. Countermeasure Selection Methodology

3.7.1. General

Choosing the appropriate countermeasure type is vital for protection of bridges against scouring. Several types of countermeasures, such as rock riprap, partially grouted riprap, articulating concrete block (ACB), grout–filled mattresses and gabion mattresses are evaluated considering structural and economical aspects which are unique for each project. Lagasse et al. (2007) recommended a methodology based on selection factors that consider river environment, construction considerations, maintenance, performance, and estimated life-cycle cost. The Selection Index (SI) is determined for each countermeasure by considering those factors and the countermeasure having the highest (SI) value is considered to be the most appropriate for a given project.

The Selection Index (SI) is given by (Lagasse et al., 2007):

$$SI=\frac{S_1 x S_2 x S_3 x S_4}{LCC} \tag{3.11}$$

where

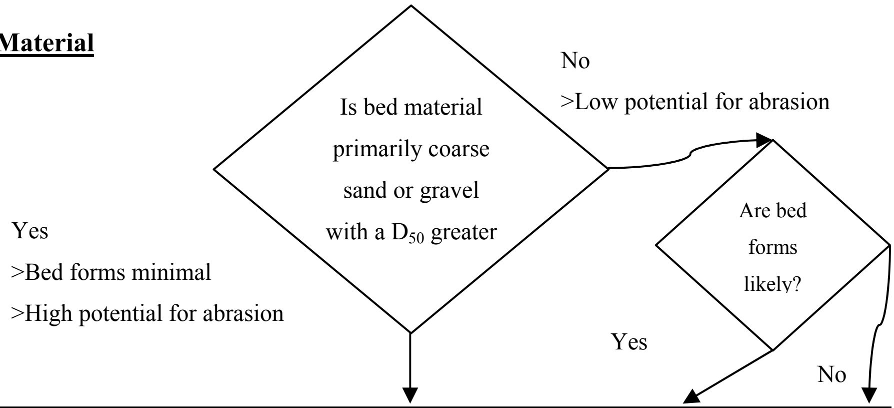
S_1 : Factor accounting for bed material size and transport
S_2 : Factor accounting for severity of debris or ice loading
S_3 : Factor accounting for constructability constraints
S_4 : Factor accounting for inspection and maintenance requirements
LCC : Life – Cycle Costs

3.7.2. Factors of the Selection Index (SI)

3.7.2.1. Bed Material

For a bed material greater than size of 2 mm, gabion mattresses are not applicable as sediment causes abrasion of the wire mesh. Grout filled mattresses are also vulnerable to dune type bed forms. On contrary, if bed material size is smaller than 2 mm and there exist no bed forms, all countermeasure types are treated equal considering S1 factor (Lagasse et al., 2007). The bed material grading system is shown in Figure 3.17.

Factor S1: Bed Material



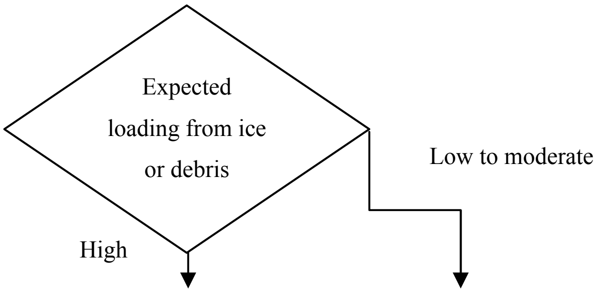
Recommended values for S1			
Riprap	5	5	5
Partially Grouted Riprap	5	4	5
ACB	4	4	5
Grout-Filled Bags	3	3	5
Grout-Filled Mattress	3	3	5
Gabions, Gabion Mattress	0	4	5

Figure 3.17 Grading of bed material (S1) (Lagasse et al., 2007)

3.7.2.2. Ice and Debris Loading

Ice and debris (woods, logs, etc.) loads are the transported materials to the direction of downstream. Ice and debris transportation is basically destructive for the gabion mattresses so they are considered with lowest SI points. If debris loading is low, all countermeasure types are treated as equal. The grading system is given Figure 3.18.

Factor S2: Ice/Debris Load



Recommended values for S1		
Riprap	3	5
Partially Grouted Riprap	4	5
ACB	4	5
Grout-Filled Bags	3	5
Grout-Filled Mattress	4	5
Gabions, Gabion Mattress	1	5

Figure 3.18 Grading of ice and debris loading (S2) (Lagasse et al., 2007)

3.7.2.3. Construction Constraints

Foundation type o the bridge is an important aspect affecting the scour potential. For the deep foundations such as long piles there exist low scouring risk by the way, shallow foundations such as spread footings, short piles, mud sills are considered with high scour risk as scour mechanism can easily reach the footing depth. For determining the selection index regarding the construction constraints, shallow footings and deep footings are evaluated separately. Equipment access and site conditions during application are important factors. 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 while placing, some countermeasure systems, such as ACB, gabion mattresses or grout mattresses are not recommended (Lagasse et al., 2007). Grading criterion for construction considerations are given in Figure 3.19 and Figure 3.20.

3.7.2.4. Inspection and Maintenance

If the inspection is performed under water, countermeasure types such as gabion mattresses, ACB and grout mattresses get lower grades because of repairing difficulty. By the way, riprap and partially grouted riprap could be cared easily (Lagasse et al., 2007). Grading criterion for inspection and maintenance are summarized in Figure 3.21.

3.7.2.5. Life – Cycle Costs

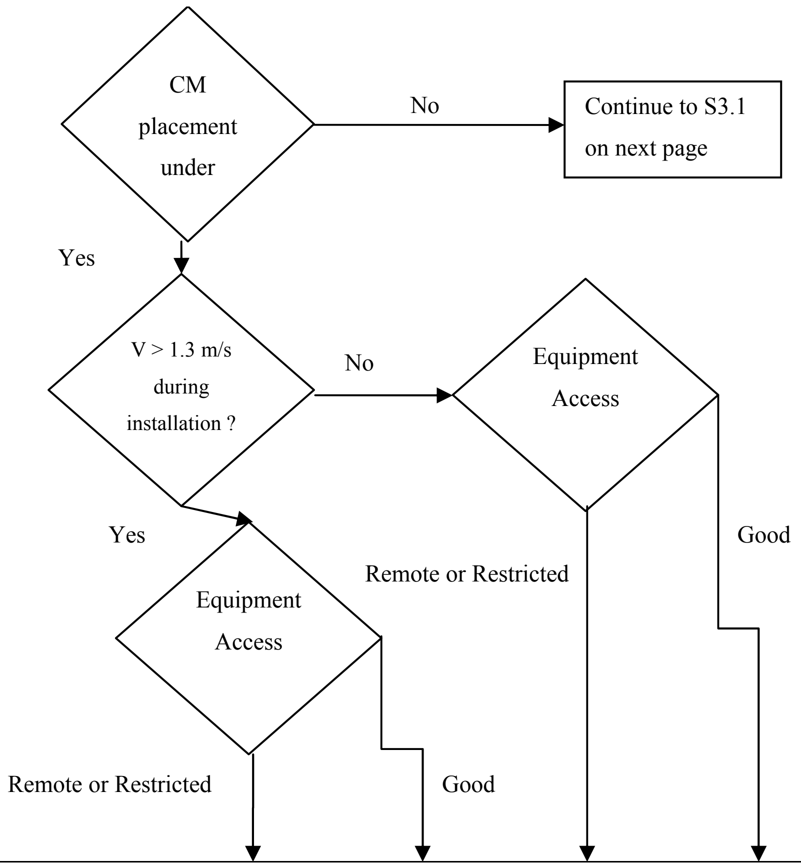
Life-cycle costs are the most difficult factors to determine among the aforementioned factors due to regional viabilities. (Lagasse et al., 2007) state that, due to regional availability of materials, site conditions and construction constraints, life-cycle cost information is difficult to determine.

To calculate life–cycle costs, three major factors are taken into consideration (Lagasse et al., 2007):

- Initial construction materials and delivery costs
- Initial construction installation costs associated with labor and equipment
- Periodic maintenance during the life of the installation

These three factors should be considered for all countermeasure types separately depending on regional factors and specific project conditions such as material availability, transportation distance, equipment, labor requirements and rates, habitat situation and endangered species, maintenance frequency, control of the traffic during the maintenance periods (Lagasse et al., 2007).

Factor S3: Construction Considerations



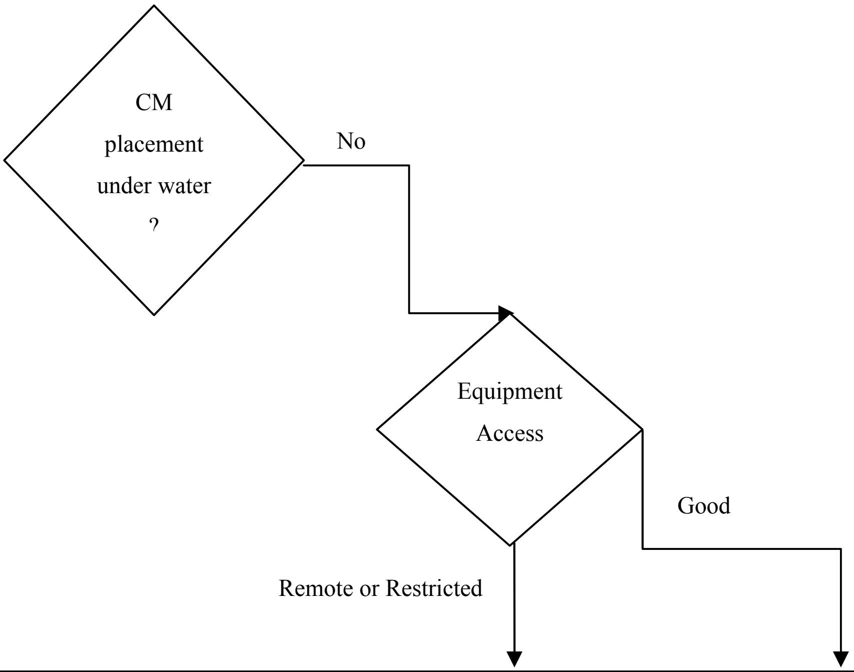
Recommended values for S1	SF*	DF	SF	DF	SF	DF	SF	DF
Riprap	0	2	1	5	1	3	2	5
Partially Grouted Riprap	0	0	0	0	2	4	0	5
ACB	0	0	1	1	2	2	0	4
Grout-Filled Bags	0	1	1	2	1	3	1	5
Grout-Filled Mattress	0	0	0	0	3	3	0	4
Gabions, Gabion Mattress	0	0	0	1	1	1	0	3

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

*Note: Armoring countermeasures not recommended for these conditions.

Figure 3.19 Grading of construction considerations (S3) (Lagasse et al., 2007)

Factor S3.1: Construction Considerations
No Underwater Placement

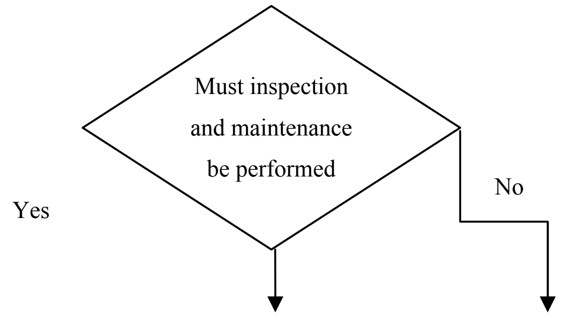


Recommended values for S1	SF	DF	SF	DF
Riprap	1	3	1	5
Partially Grouted Riprap	2	4	2	5
ACB	2	3	5	5
Grout-Filled Bags	1	4	1	5
Grout-Filled Mattress	3	4	5	5
Gabions, Gabion Mattress	1	3	2	5

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

Figure 3.20 Grading of bed material (S3.1) (Lagasse et al., 2007)

Factor S4: Inspection and Maintenance



Recommended values for S1		
Riprap	5	5
Partially Grouted Riprap	4	5
ACB	3	5
Grout-Filled Bags	2	5
Grout-Filled Mattress	2	5
Gabions, Gabion Mattress	1	5

Figure 3.21 Grading of inspection and maintenance (S4) (Lagasse et al., 2007)

CHAPTER 4

COMPUTER PROGRAM FOR DESIGNING ARMORING TYPE PIER SCOUR COUNTERMEASURES

4.1. General

Bridge pier scouring is one of the most important safety issues regarding river-crossing bridges. Application of countermeasures around bridge piers and abutments are generally considered as effective solutions for eliminating scouring by establishing an effective protection. Since there exist several countermeasures, such as rock ripraps, partially grouted ripraps, ACB, gabion and grout filled mattresses, the appropriate selection of a suitable and cost effective countermeasure system is vital. Each river-crossing bridge needs to be cared specifically since bridge and the crossed river has unique characteristics, such as span length, shape, size, numbers of piers, depth of the pier foundation, characteristics of flow regime, characteristics of bed materials, etc. These issues make the design stage of a countermeasure usually a repetitive procedure to search within the alternatives. At this point, a computer program can help an engineer to perform the time consuming calculations and evaluate several alternatives easily.

4.2. About the Program

A user-friendly computer program named "CM Design" is developed for performing armoring scour countermeasure design calculations. Despite the console-based computer software likewise MS-DOS environment, the graphical interface of the software creates a simplified medium for design engineer. The computer software is developed in VB.Net (VisualBasic.Net) which is an object-oriented computer programming language.

4.3. Programming Language

In the market, there exist several computer languages for software development. For the CM Design application, VB.Net environment is found suitable considering various alternatives, such as FORTRAN, C and C++. VB.Net is a user friendly software development environment among the alternatives. It is also capable of performing calculations and routines of design algorithm in a satisfactory time. As an alternative, "Fortran" is a much faster but it is not a user-friendly computer language. VB.Net is an object-oriented computer language so it has advantages of developing the software more efficiently.

All editions of Win7, Windows XP, Windows ME and Win 98 should be able to run the software without any problems. The CM Design demands little system resources. 128 MB RAM and an old class Pentium-M processor type (Pentium 533MHz) is sufficient to run the software without any problems.

4.4. Program Functionality

4.4.1. General

CM Design has the capabilities of performing the selection and design of a bridge pier scour countermeasure. The overall design and selection methodology is performed according to Lagasse et al. (2007). CM Design has two separate user interfaces. The main interface is the first appeared window when the program is initiated and it has basic capabilities of performing countermeasure design for rock-riprap, partially-grouted riprap, gabion-mattress, and ACB system (See Figure 4.1). User can select the design option from the radio-box controls of the interface. The required tabs are enabled while the unnecessary tabs are disabled. User needs to fill all the information required. After clicking the start button, program performs the required calculations for a particular countermeasure type and outputs the design specifications in a text file which can be automatically displayed prior to the program execution. User is also able to make a logical selection of a proper CM system among the alternatives.

4.4.2. Countermeasure Selection

CM Design is able to perform the selection methodology for a feasible countermeasure. The selection methodology provides a quantitative assessment of the six countermeasure types. The CM Selection tab is opened by clicking CM Selection button on the main interface (See Figure 4.1). A view from the CM Selection tab is shown in Figure 4.2. The user needs to enter the necessary logical information for S1, S2, S3 and S4 factors and life cycle costs of each typical countermeasure system. Life cycle cost is directly entered into the green parts of the output summary table. After clicking the start button, selection indexes (SI) for each alternative are shown in the output table.

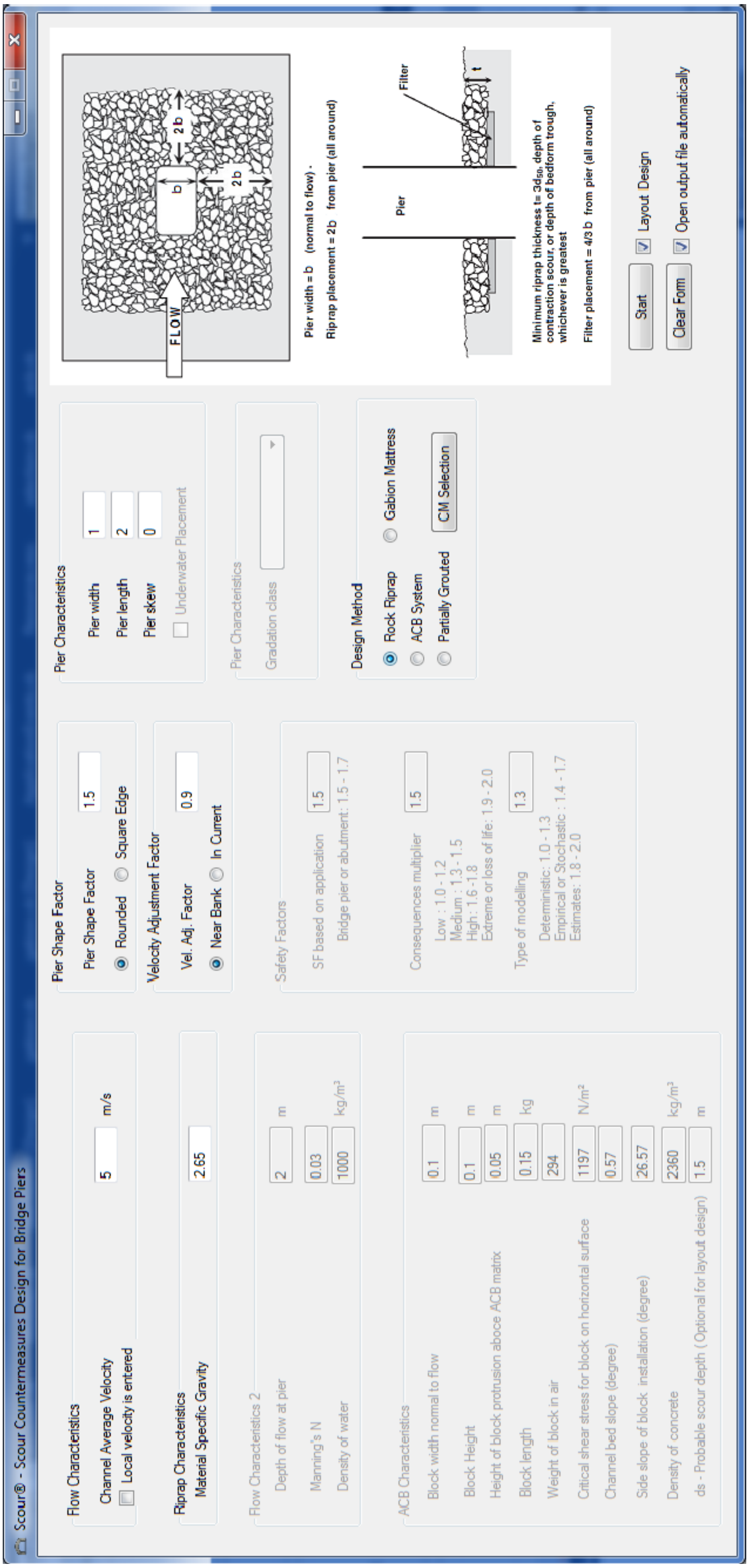


Figure 4.1 The main interface of the program

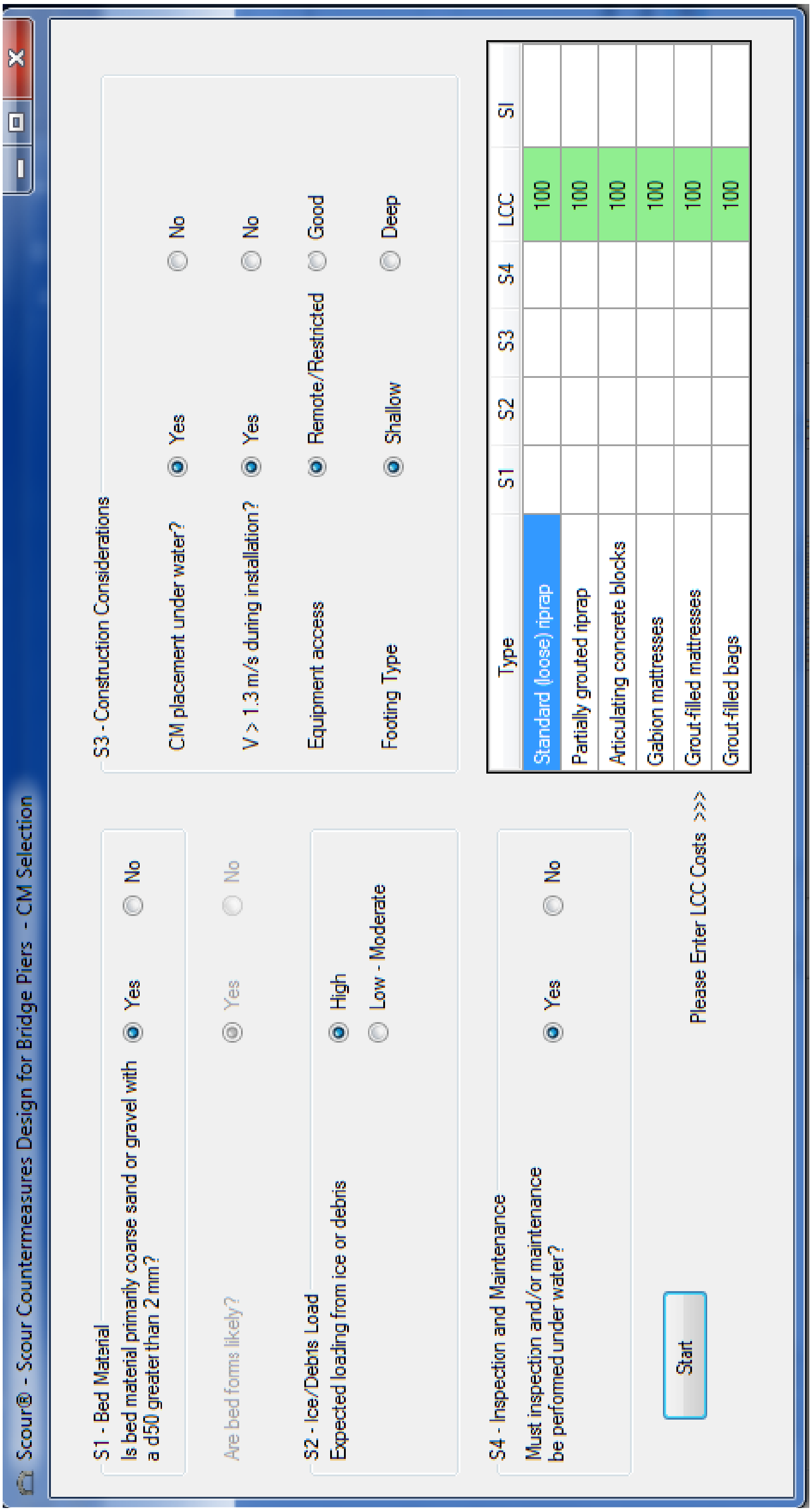
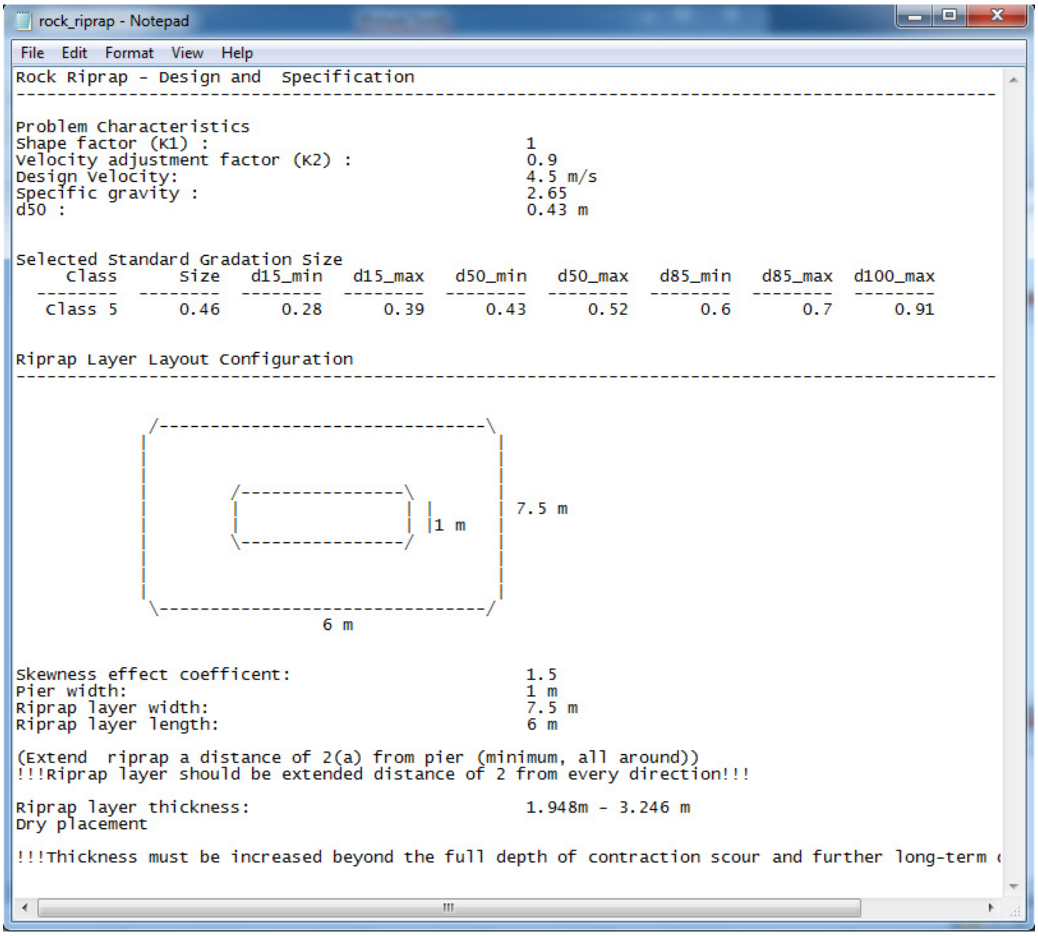


Figure 4.2 A view from the CM Selection tab of the program

4.5. Program Execution

Design for a specific countermeasure is performed by selecting the radio-box option from the “Design Method” section located upper left of the main program window. The enabled input boxes are filled with the required information. For instance, if 1-D or 2-D model is used for river modeling, “Local velocity is entered” option is required to be checked.

The layout design of the rock riprap is also available and can be determined by checking the “Layout Design” checkbox from the main window. The design calculations are executed by clicking the start button. The design output is automatically opened as a text file. In Figure 4.3, a view from a specific design output is shown for a rock riprap.



```
rock_riprap - Notepad
File  Edit  Format  View  Help
Rock Riprap - Design and  Specification
---------------------------------------------------------------------------------------------------

Problem Characteristics
Shape factor (K1) :                                   1
Velocity adjustment factor (K2) :                     0.9
Design Velocity:                                      4.5 m/s
Specific gravity :                                    2.65
d50 :                                                 0.43 m


Selected Standard Gradation Size
     Class      Size   d15_min   d15_max   d50_min   d50_max   d85_min   d85_max  d100_max
  --------  --------  --------  --------  --------  --------  --------  --------  --------
   Class 5      0.46      0.28      0.39      0.43      0.52       0.6       0.7      0.91


Riprap Layer Layout Configuration
---------------------------------------------------------------------------------------------------


             /---------------------------------\
             |                                 |
             |                                 |
             |                                 |
             |        /-----------------\      |
             |        |                 | |    | 7.5 m
             |        |                 | |1 m |
             |        \-----------------/      |
             |                                 |
             |                                 |
             |                                 |
             \---------------------------------/
                              6 m

Skewness effect coefficent:                           1.5
Pier width:                                           1 m
Riprap layer width:                                   7.5 m
Riprap layer length:                                  6 m

(Extend  riprap a distance of 2(a) from pier (minimum, all around))
!!!Riprap layer should be extended distance of 2 from every direction!!!

Riprap layer thickness:                               1.948m - 3.246 m
Dry placement

!!!Thickness must be increased beyond the full depth of contraction scour and further long-term (
```

Figure 4.3 A view from the design output text file

CHAPTER 5

CASE STUDY

5.1. Overview of the Case Study

CM Design computer program was used in a case study for a specific bridge project. For this study, Taşlıdere Creek located in Rize –Turkey was selected. Basically, pier scouring potential was determined for the bridge with a river modeling software. Several countermeasure types were investigated in view of feasibility and applicability by using the CM Design software.

Firstly, hydrological assessment of the creek was investigated using peak flow values corresponding to several return periods. The creek was modeled in HEC-RAS software which is able to perform 1-D water surface profile calculations. The output from the model was used to evaluate the necessary countermeasures for bridge piers. At this point, CM Design was used for evaluating the alternative countermeasures and performing their design calculations. Probable scour depths were also determined from the HEC-RAS software and they were used for countermeasure evaluation of the bridge.

5.2. Description of the Project Site

Taşlıdere Creek is located in the vicinity of Engindere district in Rize - Turkey. Taşlıdere Creek is formed by the junction of two creeks namely Güneysu and Potomya. As Taşlıdere Creek was investigated, it is seen that, the flood plains were narrowed due to excessive land usage and flood protection walls. The Northern Black Sea region of Turkey is always under the risk of floods due to its typical topographical and hydro-meteorological characteristics. Not only the regional characteristics but also the land usage practices are responsible for floods occurred in the Black Sea Region (Önsoy, 2002). Taşlıdere shows similar characteristics with other regional creeks as it can convey extremely large flows during floods. Especially, narrowing the river net flow area, changing the river flow location, excavation of bed materials beyond the limits and excessive degradation are responsible for bridge failures in this region. The considered bridge is located 300 m upstream of the Creek outlet location and it is used for general transportation having significant traffic load. Upstream view of the bridge is seen in Figure 5.1. Satellite image of the project site is shown in Figure 5.2.

Figure 5.1 Upstream view of the bridge

5.3. Hydrological Evaluations

Hydrological studies of the corresponding basin were performed by Trabzon Regional Directorate of State Hydraulic Works (DSİ) by using a 1/25,000 scaled map. The peak discharge values for various return periods between 5 and 500 years are shown in Table 5.1. Details of the performed flood frequency analyses are not discussed in this thesis. The total drainage area was found to be 327 km^2. The peak discharge values for the bridge location were determined by the DSİ officials (See Table 5.1).

Table 5.1 Peak discharge values for the bridge location

Return Period (yr)	Q (m^3/s)
5	356.5
10	432.6
25	545.2
50	642.2
100	750.3
500	970.1
1000	1064

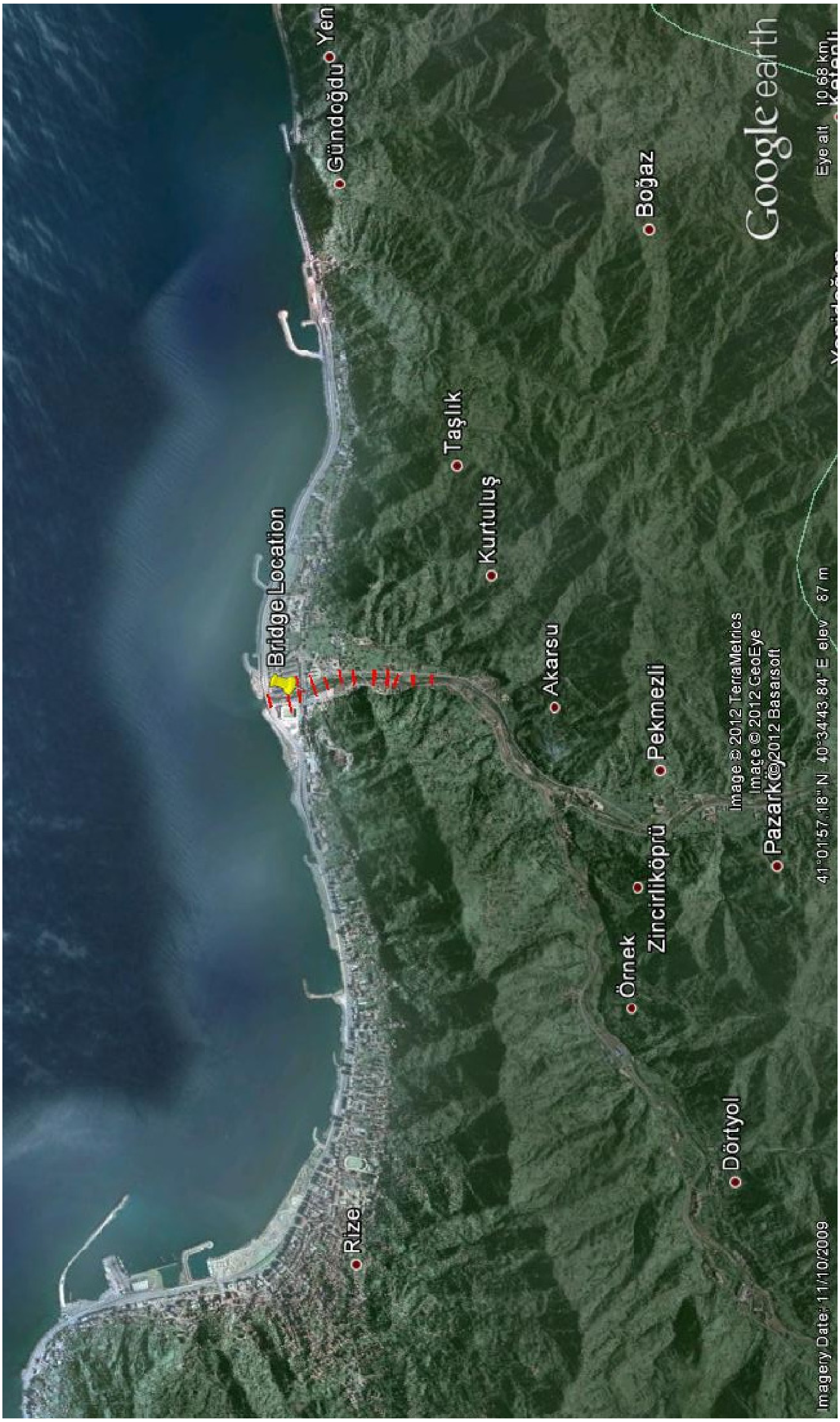


Figure 5.2 Satellite image of project site (Google Earth, 2012)

5.4. HEC-RAS Methodology

5.4.1. General

HEC-RAS program was used for modeling the river and determining the characteristics of the flow for various return periods. The output from the model was used to evaluate the countermeasures for bridge piers. At this point CM Design program was employed for evaluating the alternative countermeasures and performing their design calculations. Expected scour depths were also determined by the HEC-RAS software and used for countermeasure evaluation of the bridge.

The median diameter of the bed material is an important parameter for live bed modeling. To determine the bed material characteristics, a considerable amount of sample was taken from the vicinity of the bridge location. The gradation curve of the bed material is shown in Figure 5.3.

For creating the model, input parameters for HEC-RAS, such as geometrical data, regional coefficients and hydrological information were obtained. From the outlet of the Creek, 12 cross-sections were obtained by using total station equipment by DSİ field team. The distances between each successive cross-sections were about 100 m to 150 m. The general layout of the Taşlıdere Creek is shown in Figure 5.4 on a regional 1/25,000 scaled map. Bridge location from the outlet of the creek is shown in Figure 5.5.

HEC-RAS considers the energy losses with contraction and expansion coefficients of the sections and Manning's coefficients. Determination of Manning's coefficients are important for the reliability of the software output. Typically, main channel and flood plains of the creek were considered separately and two different Manning's values were determined for each cross-section. According to the regional characteristics, DSİ officials decided a Manning's coefficient as 0.07 for the left and right river banks and 0.065 for the main channel.

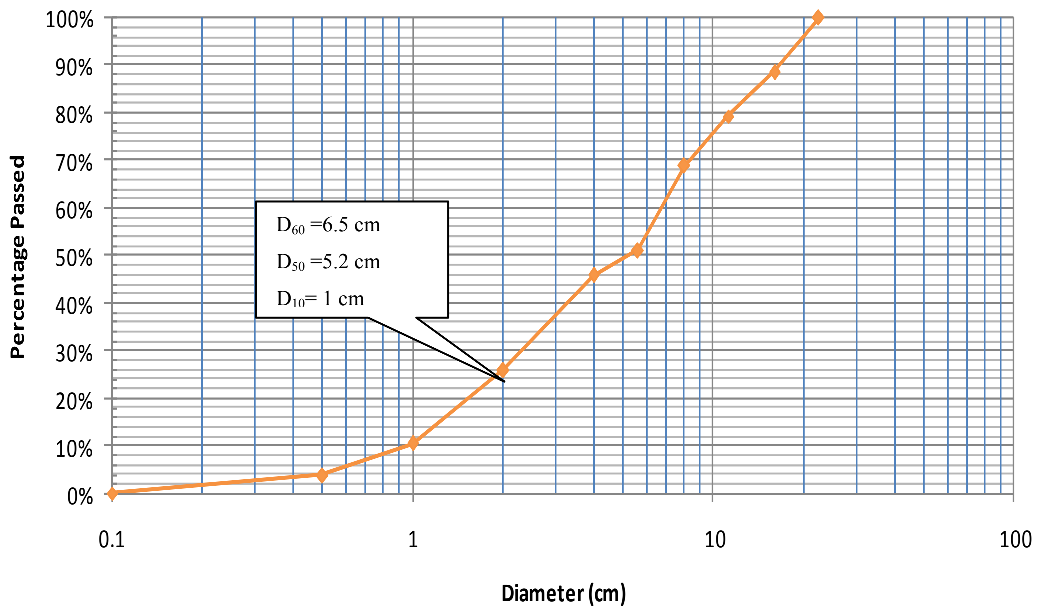


Figure 5.3 Gradation curve of the bed material at bridge site

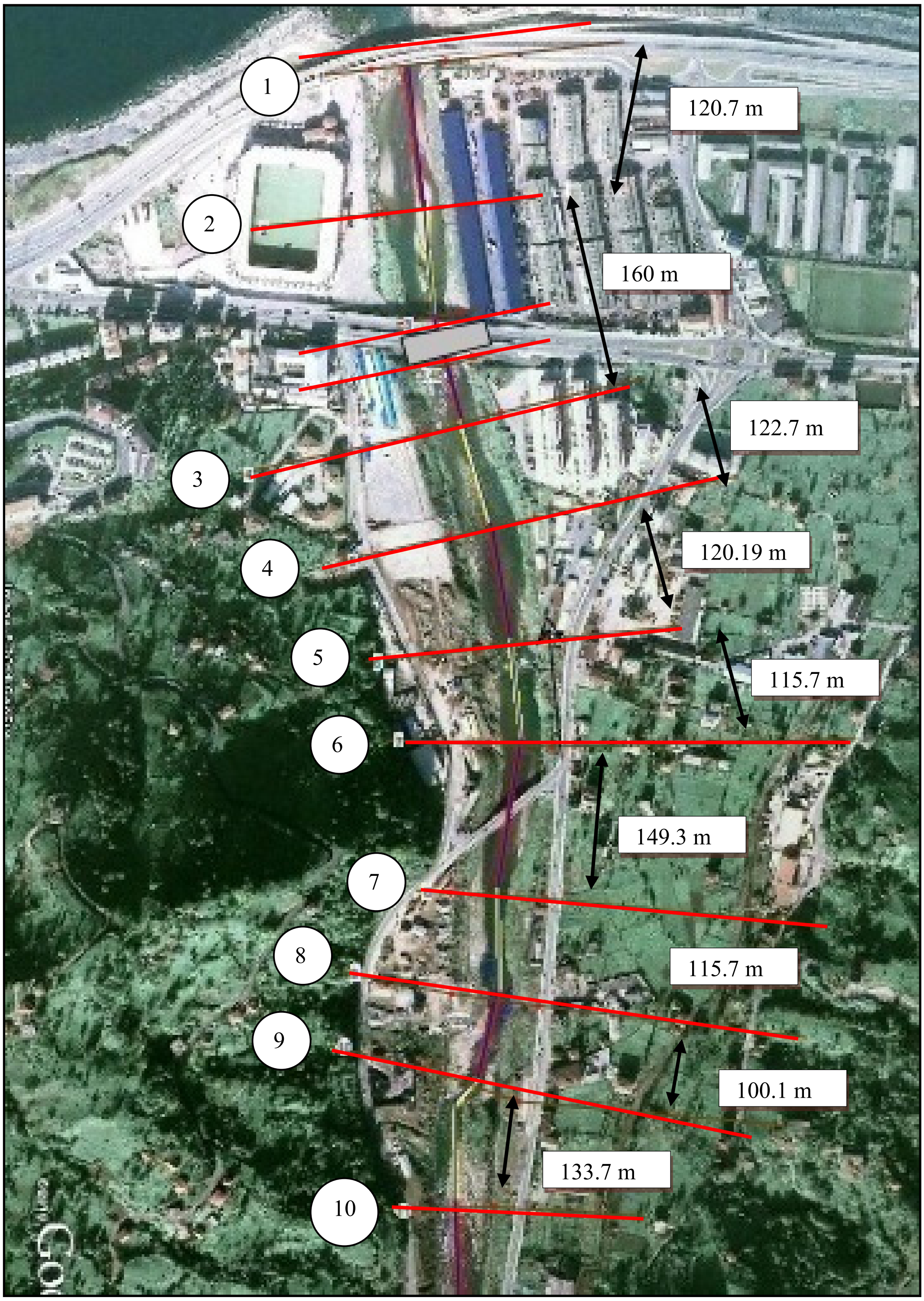


Figure 5.4 Satellite image of project site, bridge location and cross-sections (Google Earth, 2012)

Figure 5.5 Location of the bridge from the outlet of the creek (Google Earth, 2011)

From the Figure 5.3, the value of D_{50} was determined as 5.2 cm. Coefficient of uniformity C_u was found as 6.8. As C_u was greater than 3.0, the bed material was found to be well graded (Yanmaz, 2002).

5.4.2. Preparation of the Model

After entering all the necessary data, HEC-RAS program was executed for steady flow analysis with mixed flow regime. The output of the program was used for calculating the potential scour depths around the bridge piers. Hydraulic calculations summary for a discharge of 100-year-return-period is shown in Table 5.2.

5.4.3. Scour Depth Calculations

In this thesis, scour depths around bridge piers were computed using HEC–RAS program with the hydraulic design functions tab. A return period of 100-years which is a standard criterion used by FHWA was selected for computing the scour depths. This flow value was calculated for Taşlıdere Creek sea-outlet location in the vicinity of bridge location.

In this thesis, CSU Method was used in HEC-RAS program for determining the scour depths. The scouring mechanism was identified as live-bed from HEC-RAS.

The Hydraulic Design section of the HEC-RAS software was used for calculating the probable pier scour depths for live bed conditions. A view from the program interface is shown in Figure 5.6.

Table 5.2 HEC – RAS water surface profile outputs for Q_{100}

Station	Minimum Channel Elevation	Water Surface. Elevation	Energy Grade Line Elevation	Energy Grade Line Slope	Channel Average Velocity	Flow Area	Top Width	Froude Number
	(m)	(m)	(m)	(m/m)	(m/s)	(m^2)	(m)	
12	13.1	17.51	18.22	0.0116	3.72	201.56	58.66	0.64
11	12.3	15.62	16.4	0.016	3.9	192.27	66.28	0.73
10	10.31	15.11	15.36	0.0032	2.21	339.59	82.4	0.35
9	9.99	14.61	14.95	0.0049	2.58	290.69	77.72	0.43
8	9.36	14.3	14.5	0.0026	1.97	381.23	95.1	0.31
7	9.13	12.7	13.53	0.0161	4.04	185.74	61.17	0.74
6	7.48	11.94	12.37	0.006	2.89	259.79	66.58	0.47
5	7	11.22	11.56	0.0058	2.61	287.53	84.84	0.45
4	6.1	10.34	10.78	0.007	2.04	258.96	69.61	0.45
3.48	5.75	10.11	10.37	0.0042	2.22	337.61	95	0.38
3.3	Bridge							
3	5.6	9.47	9.81	0.0068	2.58	291	95	0.47
2	4.95	9	9.22	0.0033	2.11	355.97	93.23	0.34
1	4.6	6.83	7.91	0.0334	4.6	163.14	76.44	1

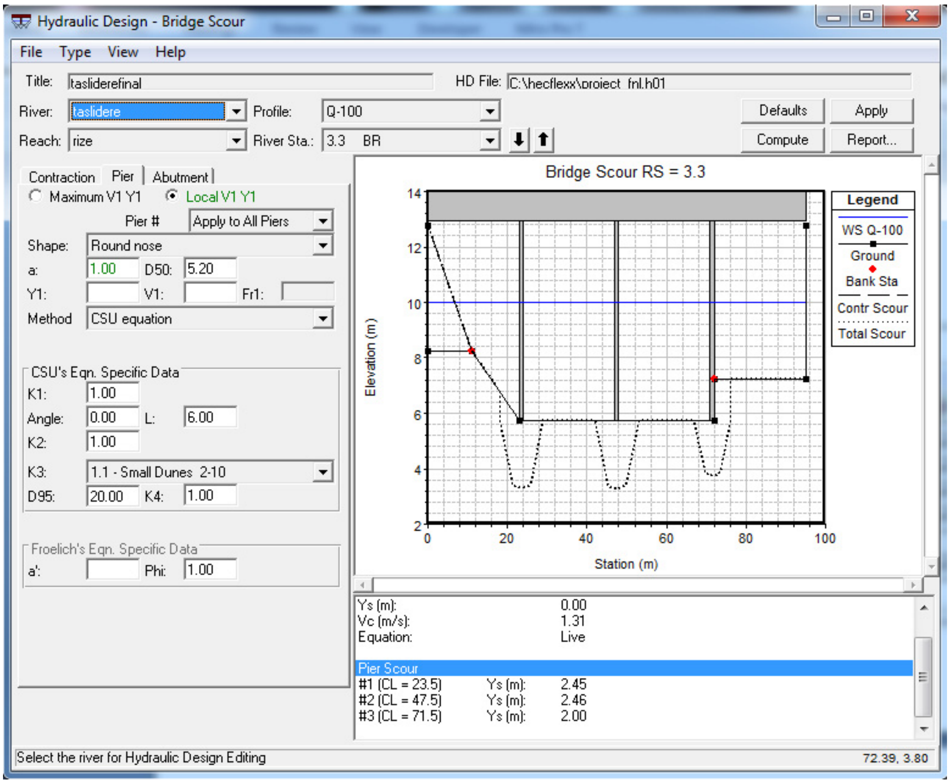


Figure 5.6 Hydraulic design tab of HEC-RAS software

The bridge was constructed as two lanes. A schematic description of cross-section of the bridge is shown in Figure 5.7. As the piers were located along the same axis in the flow direction, the bridge was considered with a single pier with a length of 28.5 m in the HEC-RAS program. The pier configuration of the bridge is shown in Figure 5.8. The possible scour depths obtained from the HEC-RAS program for 100-year return period flood are shown in Table 5.3 for each pier.

Table 5.3 Possible scour depths for piers for Q_{100}

Piers	d_s (m)
L	2.42
C	2.44
R	2.00

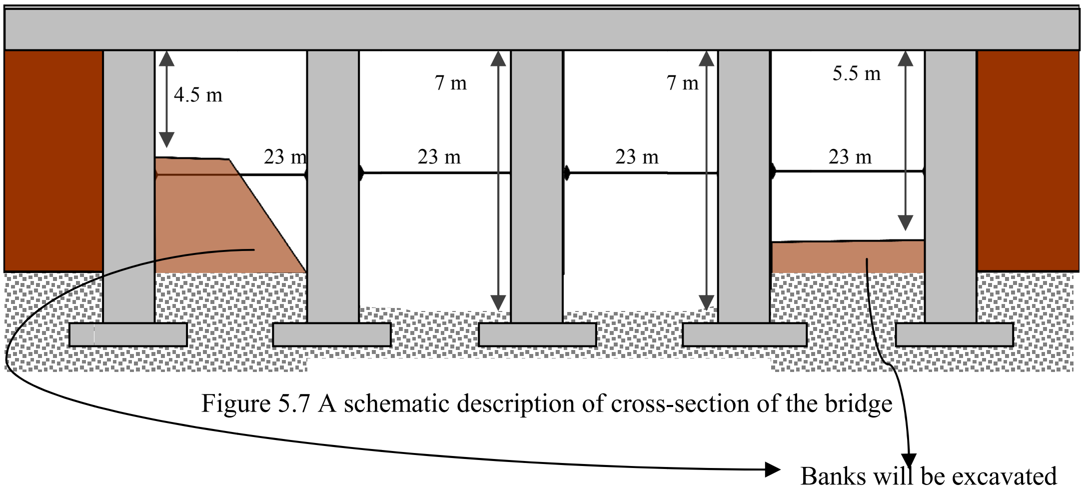


Figure 5.7 A schematic description of cross-section of the bridge

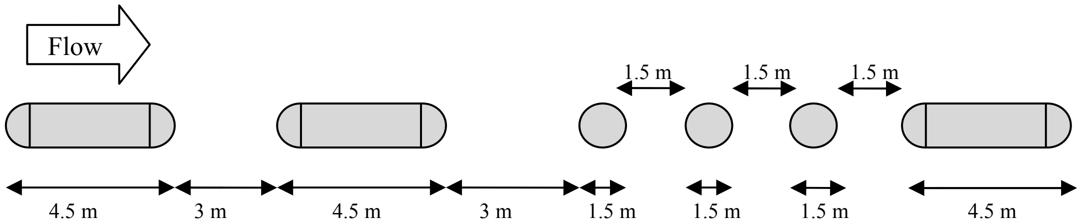


Figure 5.8 Pier configuration of the bridge

5.5. Scour Countermeasure Applications

In this study, CM Design program was used for designing the bridge scour countermeasures. As the use of gabion and grout-filled mattresses have no application practices in Turkey, rock riprap, partially grouted riprap and ACB systems were investigated. Although, application of ACB system is not performed in Turkey, it was also considered in this thesis for cost comparison purpose. Basically, cost analysis for each countermeasure alternative was performed and the most economical countermeasure was selected. Further design of the countermeasure system was performed by using CM Design program.

5.5.1. Application of Rock Riprap

The rock riprap design is based on the determination of the D_{r50} which is the median diameter of the riprap stones used. The design specifications for rock riprap are shown in Table 5.4. Corresponding to the $D_{r50,}$ riprap classes were also determined. By considering the severe conditions of the Black Sea Region, greater factor of safety is obtained by selecting Class III riprap types with reference to the recommendation of Lagasse et al. (2007). Therefore, D_{r50} = 31 cm is used in the protection zone.

Table 5.4 Design specifications for rock riprap

Pier	Location	Width (m)	Length (m)	Velocity (m/s)	D_{r50} (m)	Riprap Class	Thickness $5D_{r50}$ (m)
1	Left	1	28.5	2.47	0.31	Class III	1.55
2	Center	1	28.5	2.50	0.31	Class III	1.55
3	Right	1	28.5	1.60	0.31	Class III	1.55

Cost calculation for the riprap application for each pier was performed. The sketch of the layout of the rock riprap application is seen in Figure 5.9. The layout was also determined with CM Design program.

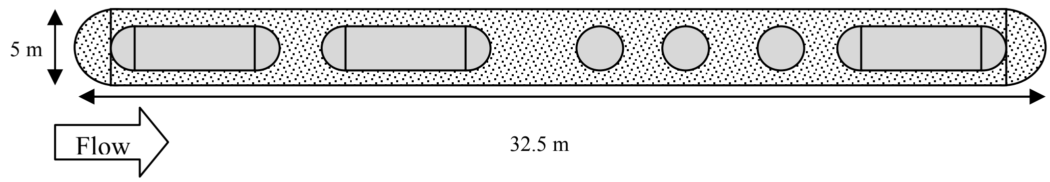


Figure 5.9 Layout of the rock riprap application for left pier

For each pier, Net Riprap Area = Total Area – Pier Area
For left pier:
b = 1 m, Length = 28.5 m

Total Riprap Area = 162.13 m^2
Total Pier Area = 18.15 m^2
Net Riprap Area= 143.97 m^2
Thickness of Rock Riprap = $5Dr_{50}$
Left : 5 x 0.31 = 1.55 m

For calculating the excavation volume, the net volume of the riprap installation was calculated. The closer banks of the piers were also excavated for ease of installation.

Volume of Bank Excavation
Pier(Left): 2 x 2.5 x 0.5 x 28.5= 71.25 m^3 (riprap + right bank)
Pier(Center): 0 (No need for bank excavation)
Pier(Right): 1.5 x 2 x 28.5= 85.5 m^3 (riprap + left bank)

Cost calculation for the rock riprap system was based on the unit prices of the year 2012 as shown in Table 5.5. The unit prices were taken from the "BirimFiyat.com" website and converted to USD by taking 1 USD = 1.8 TL.

Table 5.5 Unit prices for the rock riprap (birimfiyat.com, 2012)

Unit Prices - Rock Riprap				
No	Name of component	Unit	Unit Price (TL)	Unit Price ($)
17.081/K	Riprap cost	m^3	17.09	9.49
07.006/35	Cost of riprap transportation (18 km)	m^3	4.30	2.39
14.100	Excavation of soil around bridges by hand except rocks	m^3	18.01	10.01
07.006/14	Transportation of excavated material (2 km)	Ton	2.09	1.16
Special Price	Geotextile filter	m^2	NA*	3.40

NA* : Not available

Cost calculation for the riprap application for each pier was performed. Riprap layout configurations around piers are shown in Figure 5.10. Riprap cost, cost of transportation, cost of excavation and cost of transportation of excavated material were found by multiplying each unit price with the net riprap volume. Cost of filter was determined by considering the riprap protection area.

Cost calculations for the rock riprap installation are summarized in Table 5.6. Basically, V_n is the net volume of riprap installation, E_b is the volume of the bank excavation, E_t is the volume of the total excavation, C_r is the cost of riprap stones obtained from the quarry, C_{rt} is the cost of riprap transportation, C_{ex} is the cost of excavation, C_{ext} is the cost of transportation of excavated material, C_f is cost of filter and C_{total} is the total cost.

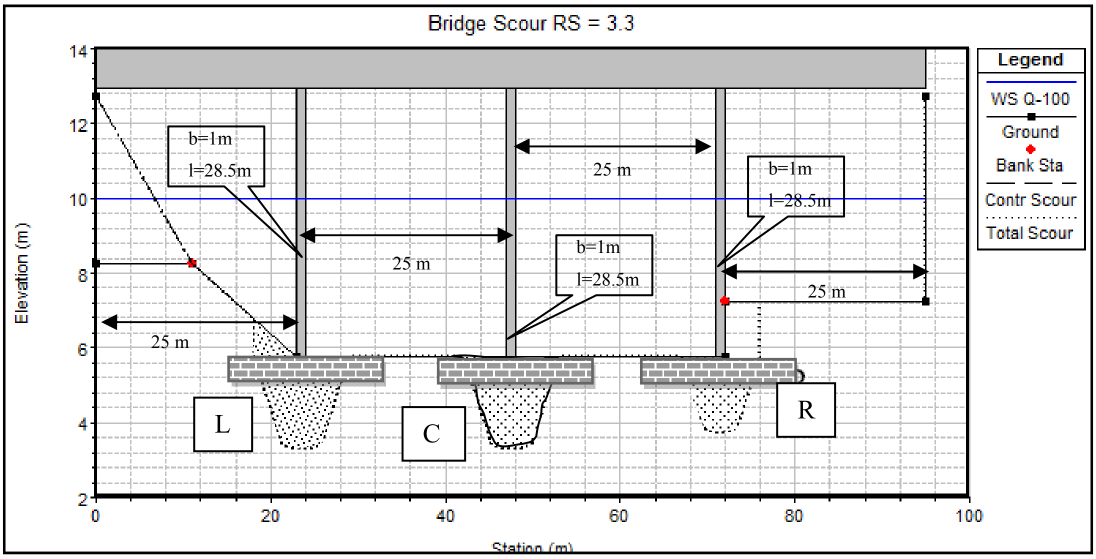


Figure 5.10 Schematic description of bridge with riprap installation

Table 5.6 Cost calculations for the rock riprap

V_n (m^3)	E_b (m^3)	E_t (m^3)	C_r ($)	C_{rt} ($)	C_{ex} ($)	C_{ext} ($)	C_f ($)	C_{total} ($)
223.16	71	294.41	2,119	533	2,946	906	275	6,779
223.16	0	223.16	2,119	533	2,233	687	275	5,847
223.16	86	308.66	2,119	533	3,088	950	275	6,965
					Total Cost ($):			19,591

5.5.2. Application of Partially Grouted Riprap

To identify the rock classes for partially grouted riprap, the rock riprap sizes are considered. Class II is selected for partially grouted riprap installation. The design specifications for partially grouted riprap are shown in Table 5.7.

Table 5.7 Design specifications for partially grouted riprap (birimfiyat.com, 2012)

Pier	Location	Riprap Class	D_{r50} (m)	Thickness $4D_{r50}$ (m)	Total Area (m^2)	Pier Area (m^2)	Net Area (m^2)
1	Left	Class II	0.23	0.92	126.56	18.15	108.41
2	Center	Class II	0.23	0.92	126.56	18.15	108.41
3	Right	Class II	0.23	0.92	126.56	18.15	108.41

The sketch of a partially grouted riprap layout around a typical pier was shown in Figure 5.11.

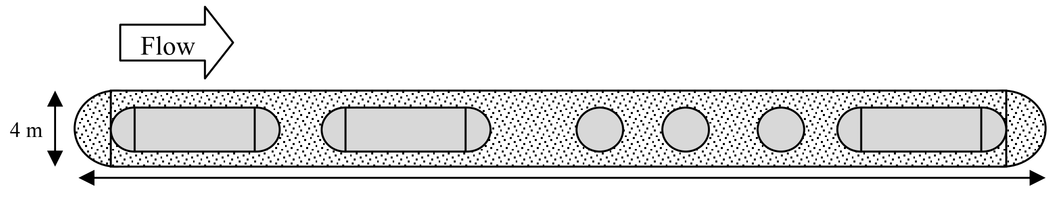


Figure 5.11 Layout of the partially grouted riprap application for left pier

For calculating the excavation volume, the net volume of the riprap installation was calculated. The closer bank of the pier was also excavated for ease of installation.

Volume of Bank Excavation
Pier (Left): 1.5 x 2.5 x 0.5 x 28.5= 53.43 m^3 (riprap + right bank)
Pier (Center): 0 (No need for bank excavation)
Pier (Right): 1.5 x 1.5 x 28.5= 64.13 m^3 (riprap + left bank)

Cost calculations for the rock riprap system were based on the unit prices for the year 2012 given in Table 5.8. The unit prices are taken from "BirimFiyat.com" website and converted to USD by taking 1 USD = 1.8 TL

Table 5.8 Unit prices for the partially grouted riprap

Unit Prices – Partially Grouted Riprap				
No	Name of component	Unit	Unit Price (TL)	Unit Price ($)
17.081/K	Riprap cost	m^3	17.09	9.49
07.006/35	Cost of riprap transportation (18 km)	m^3	4.30	2.39
14.100	Excavation of soil around bridges by hand except rocks	m^3	18.01	10.01
07.006/14	Transportation of excavated material (2 km)	Ton	2.09	1.16
Special Price	Geotextile filter	m^2	NA*	3.40
10.022/K	Preparation of cement slurry and grouting	m^3	13.73	7.63

NA* : Not available

Cost calculations for the partially grouted riprap installation are shown in Table 5.9. Basically, C_{gr} is cost of grouting application which was found by multiplying the riprap volume with 0.35 (porosity) and 0.50 (grouting ratio).

Table 5.9 Cost calculations for the partially grouted riprap

V_n (m^3)	E_b (m^3)	E_t (m^3)	C_r (\$)	C_{rt} (\$)	C_{ex} (\$)	C_{ext} (\$)	C_f (\$)	C_{gr} (\$)	C_{total} (\$)
99.73	53	152.73	947	238	1,528	470	207	133	3,524
99.73	0	99.73	947	238	998	307	207	133	2,830
99.73	64	163.73	947	238	1,638	504	207	133	3,668
					Total Cost ($) :				10,022

5.5.3. Application of Articulated Concrete Block (ACB) System

The dimensions of the ACB installation X1, X2 and WS were found by using CM Design program. The layout of the ACB system is shown in Figure 5.12. The design specifications for ACB system is shown in Table 5.10.

For Pier 1 (L)
Possible scour depth is 2.42 m
Ws = 2.5xd_s+b = 2.5x2.42+1 = 7.05 m
X1=1.25d_s = 1.25x2.42 = 3.03 m
X2=3d_s=3x2.42 = 7.26 m
Total area of the system 273.4m^2
Pier area = 18.15 m^2
Net area= 255.28 m^2

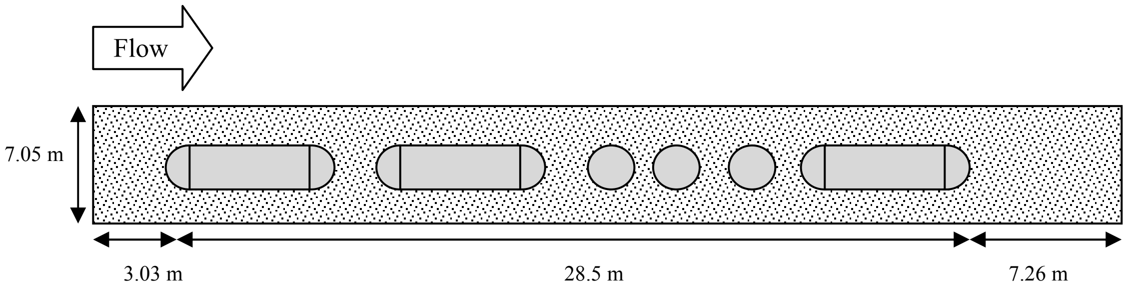


Figure 5.12 Layout of the ACB system for left pier

Table 5.10 Design specifications for ACB system

L (m)	b (m)	Pier	d_s (m)	W_S (m)	X_1 (m)	X_2 (m)	Total area (m^2)	Pier area (m^2)	Net Area (m^2)
28.5	1	L	2.42	7.05	3.03	7.26	273.43	18.15	255.28
28.5	1	C	2.44	7.10	3.05	7.32	275.98	18.15	257.82
28.5	1	R	2.01	6.03	2.51	6.03	223.18	18.15	205.03

For calculating the excavation volume, the net volume of the ACB installation was calculated. ACB thickness was taken as 1 meter. For calculating the bank excavation volume, the closer bank of left and right piers were excavated for ease of installation.

Volume of Bank Excavation
Pier(Left): 2.5 x 4 x 0.5 x 28.5= 142.5 m^3 (right bank)
Pier(Center): 0 (No need for bank excavation)
Pier(Right): 3.5 x 1.5 x 28.5= 149.5 m^3 (left bank)
Cost calculations for the ACB installation is shown in Table 5.11.

Table 5.11 Unit prices for the ACB system

ACB System				
No	Name of component	Uni t	Unit Price (TL)	Unit Price ($)
17.081/K	Cost of ACB	m^3	NA*	15.65
07.006/35	Placement, transportation	m^2	7.66	4.26
14.100	Excavation of soil around bridges by hand except rocks	m^3	18.01	10.01
07.006/14	Transportation of excavation (2 km)	Ton	2.09	1.16
Special Price	Geotextile filter	m^2	NA*	3.40
07.006/35	Cost of fill transportation	m^3	7.15	3.97
08.003/K2	Cost of fill	m^3	8.97	4.98

NA* : Not available

Cost calculations for the ACB installation is shown in Table 5.12 Basically, A_n is the net area of ACB installation, E_b is the volume of the bank excavation, E_t is the volume of the total excavation, C_{acb} is cost of ACB system, C_{at} is cost of ACB transportation, C_{fill} is cost of fill, C_{ft} is cost fill transportation, C_f is cost of filter.

Table 5.12 Cost calculations for the ACB system

A_n (m^2)	E_b (m^3)	E_t (m^3)	C_{acb} ($)	C_{acb} ($)	C_{at} ($)	C_{ex} ($)	C_{ext} ($)	C_{fill} ($)	C_{ft} ($)	C_f ($)	C_{total} ($)
255.28	255.28	143	397.78	3,996	1,086	3,980	1,224	1,272	1,014	868	13,440
257.82	257.82	0.0	257.82	4,036	1,097	2,580	793	1,285	1,024	877	11,691
205.03	205.03	150	354.65	3,209	873	3,548	1,091	1,022	814	697	11,255
								Total Cost ($):	36,387		

5.5.4. Determination of Selection Index

Selection indexes for the countermeasures were evaluated with using the CM Design program. Firstly, life cycle costs were determined by multiplying the total cost of each countermeasure with the capital recovery factor for 50 years and 10% interest rate. Maintenance and depreciation costs were added to the annual capital cost. Çam (2012) considers maintenance and depreciation costs as 0.3% for rock riprap, 0.2% for partially grouted riprap and 0.1% for ACB system. Life cycle cost calculations are summarized in Table 5.13.

Table 5.13 Life cycle cost calculations for each countermeasure type

	Rock Riprap	Partially Grouted	ACB
Total Cost ($)	19,591	10,022	36,387
Annual Maintenance Ratio (%)	0.3	0.2	0.1
Annual Maintenance Cost ($)	59	20	36
Design Life (yr)	50	50	50
Interest Rate (%)	0.1	0.1	0.1
Capital Recovery Factor	0.1009	0.1009	0.1009
LCC ($)	2,035	1,031	3,706

The Selection Indexes for each countermeasure were determined using the CM Selection tab of the CM design (See Figure 5.13). In CM Selection tab, SI index was determined according to the following considerations.

Factor S_1:The Bed material was accepted as primarily coarse sand or gravel with D_{50} greater than 2 mm.
Factor S_2:Expected ice and debris load was selected as high as the rivers in Black Sea Region of Turkey are capable of conveying large debris.
Factor S_3: The application will not be performed under water (application in summer, low flow conditions). Equipment access is good as bridge is located in the urban area. Footings were considered as deep footings with the information taken by DSİ officials.
Factor S_4: Inspection and maintenance will be performed under water.
The output of the program is shown in Table 5.14. As partially grouted riprap has the highest SI value, it was selected as the most appropriate countermeasure.

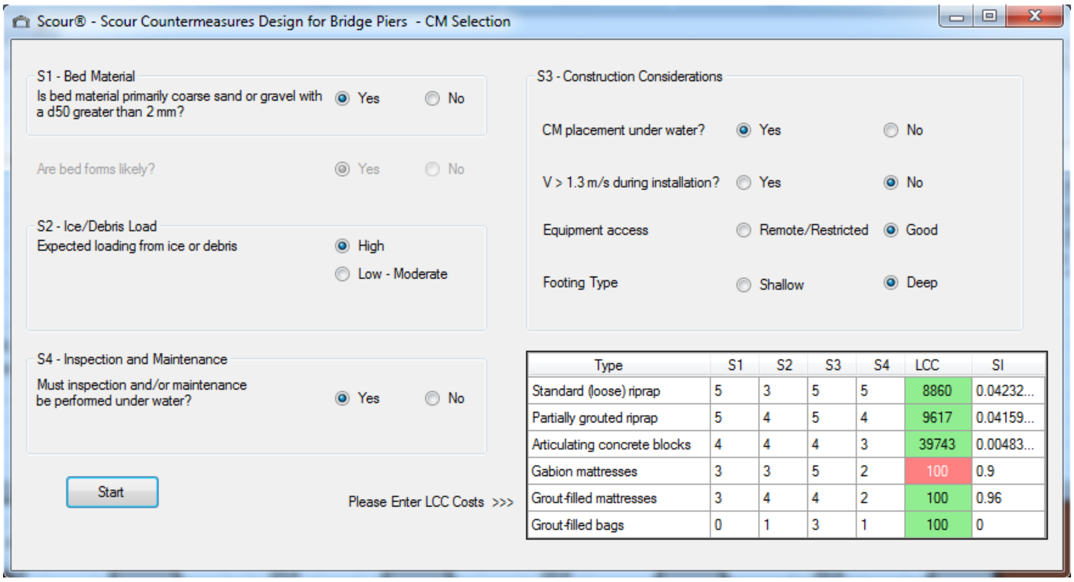


Figure 5.13 CM Selection tab of CM Design program

Table 5.14 Output of the CM Design program

Type	S1	S2	S3	S4	LCC	SI
Standard (loose) riprap	5	3	5	5	2035	0.18427...
Partially grouted riprap	5	4	5	4	1031	0.38797...
Articulating concrete blocks	4	4	5	3	3706	0.06475...

5.5.5. Sensitivity Analysis for the Effect of Return Period

The cost analysis is also performed for Q_{500} and Q_{1000} discharge values to compare the results with those of Q_{100} value. This analysis is of worth since the Black Sea Region of Turkey is more to prone to severe floods due to its regional characteristics and the bridge concerned is located on the coastal highway. The cost calculations of riprap for all discharges i.e. Q_{100}, Q_{500} and Q_{1000} are presented in Table 5.15 and Table 5.16. Similar information for partially grouted riprap case is given in Table 5.17 and Table 5.18 and for ACB case is given in Table 5.19 and Table 5.20.

Table 5.15 Determination of riprap size for Q_{100}, Q_{500} and Q_{1000} values

Case	Location	Q (m^3/s)	Local velocity (m/s)	D_{r50} (m)	Selected D_{r50} (m)	Class	Thickness $5D_{r50}$ (m)
Q_{100}	Left	750.31	2.47	0.29	0.31	3	1.55
Q_{100}	Center	970	2.50	0.30	0.31	3	1.55
Q_{100}	Right	1064	1.60	0.12	0.31	3	1.55
Q_{500}	Left	750.31	2.72	0.36	0.38	4	1.90
Q_{500}	Center	970	2.75	0.36	0.38	4	1.90
Q_{500}	Right	1064	1.78	0.15	0.31	3	1.55
Q_{1000}	Left	750.31	2.82	0.38	0.38	4	1.90
Q_{1000}	Center	970	2.85	0.39	0.38	4	1.90
Q_{1000}	Right	1064	1.85	0.16	0.31	3	1.55

Table 5.16 Cost comparison of riprap for various discharges

Case	Total Area (m^2)	Pier Area (m^2)	Net Riprap Area (m^2)	Net Volume (m^3)	Bank Excv (m^3)	Total Excv (m^3)	C_r ($)	C_{rt} ($)	C_{ex} ($)	C_{ext} ($)	C_f ($)	C_{total} ($)
Q_{100}	162.13	18.15	143.97	223.16	71	294.41	2,119	533	2,946	906	275	6,779
Q_{100}	162.13	18.15	143.97	223.16	0	223.16	2,119	533	2,233	687	275	5,847
Q_{100}	162.13	18.15	143.97	223.16	86	308.66	2,119	533	3,088	950	275	6,965
									Total Cost ($):			19,591
Q_{500}	162.13	18.15	143.97	273.55	71	344.55	2,597	653	3,447	1,060	275	8,033
Q_{500}	162.13	18.15	143.97	273.55	0	273.55	2,597	653	2,737	842	275	7,105
Q_{500}	162.13	18.15	143.97	223.16	86	309.16	2,119	533	3,093	951	275	6,972
									Total Cost ($):			22,110
Q_{1000}	162.13	18.15	143.97	273.55	71	344.55	2,597	653	3,447	1,060	275	8,033
Q_{1000}	162.13	18.15	143.97	273.55	0	273.55	2,597	653	2,737	842	275	7,105
Q_{1000}	162.13	18.15	143.97	223.16	86	309.16	2,119	533	3,093	951	275	6,972
									Total Cost ($):			22,110

Table 5.17 Determination of partially grouted riprap size for Q_{100}, Q_{500} and Q_{1000} values

Case	Location	Local velocity (m/s)	Q (m^3/s)	Class	Selected D_{r50} (m)	Thickness $4D_{r50}$ (m)
Q_{100}	Left	2.47	750.31	2	0.23 m	0.92 m
Q_{100}	Center	2.50	970	2	0.23 m	0.92 m
Q_{100}	Right	1.60	1064	2	0.23 m	0.92 m
Q_{500}	Left	2.72	750.31	3	0.31 m	1.24 m
Q_{500}	Center	2.75	970	3	0.31 m	1.24 m
Q_{500}	Right	1.78	1064	2	0.23 m	0.92 m
Q_{1000}	Left	2.82	750.31	3	0.31 m	1.24 m
Q_{1000}	Center	2.85	970	3	0.31 m	1.24 m
Q_{1000}	Right	1.85	1064	2	0.23 m	0.92 m

Table 5.18 Cost comparison of partially grouted riprap for various discharges

Case	Net Riprap Area ($m^{2)}$	Net Volume (m^3)	Total Excv (m^3)	C_r ($)	C_{rt} ($)	C_{ex} ($)	C_{ext} ($)	C_f ($)	C_{gr} ($)	C_{total} ($)
Q_{100}	108.41	99.73	152.73	947	238	1,528	470	207	133	3,524
Q_{100}	108.41	99.73	99.73	947	238	998	307	207	133	2,830
Q_{100}	108.41	99.73	163.73	947	238	1,638	504	207	133	3,668
							Total Cost ($):			10,022
Q_{500}	108.41	134.42	187.42	1,276	321	1,875	577	207	179	4,436
Q_{500}	108.41	134.42	134.42	1,276	321	1,345	414	207	179	3,743
Q_{500}	108.41	99.73	163.73	947	238	1,638	504	207	133	3,668
							Total Cost ($):			11,847
Q_{1000}	108.41	134.42	187.42	1,276	321	1,875	577	207	179	4,436
Q_{1000}	108.41	134.42	134.42	1,276	321	1,345	414	207	179	3,743
Q_{1000}	108.41	99.73	163.73	947	238	1,638	504	207	133	3,668
							Total Cost ($):			11,847

Table 5.19 Determination of dimensions of ACB- protection area for Q_{100}, Q_{500} and Q_{1000} values

Case	Location	Q (m^3/s)	d_s (m)	W_s (m)	X_1 (m)	X_2 (m)	Total area (m^2)	Pier area (m^2)	Net Area (m^2)
Q_{100}	Left	750.31	2.42	7.05	3.03	7.26	273.4	18.15	255.28
Q_{100}	Center	970	2.44	7.10	3.05	7.32	276.0	18.15	257.82
Q_{100}	Right	1064	2.01	6.03	2.51	6.03	223.2	18.15	205.03
Q_{500}	Left	750.31	2.57	7.43	3.21	7.71	292.7	18.15	274.56
Q_{500}	Center	970	2.58	7.45	3.23	7.74	294.0	18.15	275.86
Q_{500}	Right	1064	2.14	6.35	2.68	6.42	238.7	18.15	220.57
Q_{1000}	Left	750.31	2.63	7.58	3.29	7.89	300.6	18.15	282.40
Q_{1000}	Center	970	2.64	7.60	3.30	7.92	301.9	18.15	283.72
Q_{1000}	Right	1064	2.19	6.48	2.74	6.57	244.8	18.15	226.65

Table 5.20 Cost comparison of ACB system for various discharges

Case	Net Volume (m^3)	Total Excv (m^3)	C_{acb} ($)	C_{at} ($)	C_{ex} ($)	C_{ext} ($)	C_{fill} ($)	C_{fill_t} ($)	C_f ($)	C_{total} ($)
Q_{100}	255.28	397.78	3,996	1,086	3,980	1,224	1,272	1,014	868	13,440
Q_{100}	257.82	257.82	4,036	1,097	2,580	793	1,285	1,024	877	11,691
Q_{100}	205.03	354.65	3,209	873	3,548	1,091	1,022	814	697	11,255
							Total Cost ($):			36,387
Q_{500}	274.56	417.06	4,298	1,168	4,173	1,283	1,368	1,091	933	14,315
Q_{500}	275.86	275.86	4,318	1,174	2,760	849	1,375	1,096	938	12,509
Q_{500}	220.57	370.20	3,453	939	3,704	1,139	1,099	876	750	11,960
							Total Cost ($):			38,784
Q_{1000}	282.40	424.90	4,420	1,202	4,251	1,307	1,407	1,122	960	14,670
Q_{1000}	283.72	283.72	4,441	1,207	2,839	873	1,414	1,127	965	12,866
Q_{1000}	226.65	376.27	3,548	965	3,765	1,158	1,129	900	771	12,235
							Total Cost ($):			39,771

Total implementation costs for riprap, partially grouted riprap, and ACB system are outlined for Q_{100}, Q_{500} and Q_{1000} discharge values in Table 5.21 for comparison purpose. The results are also presented in a bar chart in Figure 5.14. The flow area in bridge section is relatively large. Therefore, increase in discharge from Q_{100} to Q_{500} value i.e.from 750.31 m^3/s to 970 m^3/s would not result in significant increase in local velocity. Since riprap size is directly proportional to the square of velocity, the corresponding riprap sizes for the larger discharges do not change considerably. That is why the same riprap class is selected for riprap and partially grouted riprap for both 500 and 1000-year return periods. Therefore, it is recommended to design the pier-scour countermeasures as partially grouted riprap for 1000-year return period.

Table 5.21 Summary of the cost calculations for all countermeasure types

Countermeasure	Q_{100}	Q_{500}	Q_{1000}
Riprap ($)	19,591	22,110	22,110
PGR ($)	10,022	11,847	11,847
ACB ($)	36,387	38,784	39,771

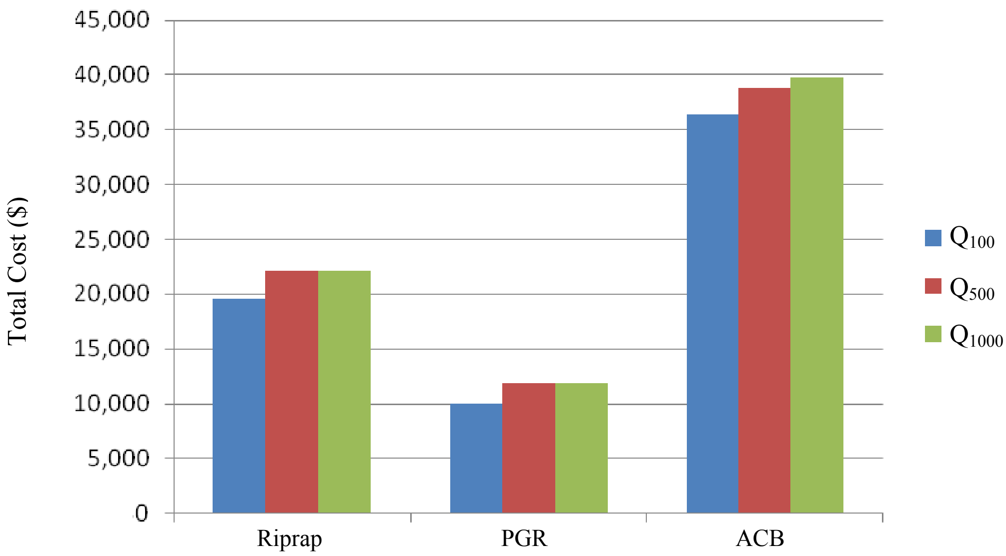


Figure 5.14 Summary of the cost calculations for all countermeasures

CHAPTER 6

CONCLUSION

This study deals with the development of a user-friendly computer program for designing a suitable armoring-type scour countermeasure for bridge piers. It also guides the designer to select the most feasible alternative using selection index criterion. The program was used in a case study and its performance was investigated in finding the suitable and feasible countermeasure for a highway bridge located in Rize – Taşlıdere Region. The conclusions derived throughout the thesis can be summarized as follows:

1. The Creek was modeled in HEC-RAS program and probable scour depths around bridge piers were computed from HEC-18 procedure. The output from the model was used to evaluate the countermeasure alternatives for the bridge.

2. Riprap, partially grouted riprap, and ACB system were tested in the program for suitability around piers of the bridge using the design and implementation guidelines considered in the program. It must be noted that, this study considers only pier scouring. Computation of scouring and countermeasure design at abutments are not covered in the scope of the study. Therefore, extension of this program for abutment countermeasure design is recommended in a future study.

3. Most appropriate countermeasure alternative was determined by using CM Design program based on the 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. By using a smaller class of rock type and thinner protection layer, partially grouted riprap has significantly thinner protection layer. Therefore, this results in reduction in the total cost of implementation. ACB system was the most expensive solution as unit cost of ACB blocks are high and it has a large protection area.

4. In a sensitivity analysis, cost comparisons between Q_{100}, Q_{500} and Q_{1000} discharge values were also performed and the following results are obtained:

    a. The width of Taşlıdere Creek is relatively large i.e. around 100 m, which results in slight differences in local velocities and hence riprap sizes for Q_{100}, Q_{500} and Q_{1000} flows. To this end, the same riprap class is selected (Class IV) for Q_{500} and Q_{1000} flows.

    b. For PGR, riprap value of Class IV decreased for one class and Class III is used. For the pier 3, there is no significant difference in local velocity for all discharge values. So the same cost is obtained for Q_{500} and Q_{1000} flows with that of Q_{100}.

    c. ACB cost is sensitive to the local velocities because its layout configuration such as width and length of the protection area is directly related with local scour depth which is the function of local velocity.

d. Considering the severity of the flow conditions in the region and the critical importance of the bridge concerned, partially grouted riprap for 1000-year return period is proposed for the appropriate countermeasure.

REFERENCES

Birimfiyat.com. (2011). Retrieved November 26, 2011, from http://www.birimfiyat.com

Brown, S.A., and Clyde, E.S. (1989). "Design of Riprap Revetment," Hydraulic Engineering Circular No. 11 (HEC-11), FHWA-IP-016, Federal Highway Administration,Washington, D.C.

Çam, U. E. (2012). *" Scour Countermeasure Design for Sequential Viaducts on Ankara – Pozanti Highway ",MSc Thesis.* Middle East Technical University, Ankara.

Fotherby, L.M. (1995). "Scour Protection at Bridge Piers: Riprap and Concrete Armor Units," Ph.D. Dissertation, Colorado State University, Fort Collins, CO.

Google Earth (2012, December 5). Google Inc.

Kilgore, R.T., and Cotton, G.K. (2005). "Design of Roadside Channels with Flexible Linings" Hydraulic Engineering Circular No. 15, Third Edition, Washington D.C.

Lagasse, P. F, Clopper, P. E., Zevenbergen, L. W. and Girard L. G. (2007). *"Countermeasures to Protect Bridge Piers from Scour", NCHRP Report 593* Transportation Research Board, Washington, D.C.

Lagasse, P. F., Zevenbergen, L. W., Schall, J. D., and Clopper, P. E. (2001). *"Bridge Scour and Stream Instability Countermeasures - Experience, Selection, and Design Guidelines", Hydraulic Engineering Circular (HEC) No. 23, Second Edition. FHWA Report No. FHWA NHI 01-003.* Washington, D.C.: Federal High way Administration.

Melville, B. W. and Coleman, S. E. (2000). "Bridge Scour". Colorado: Water Resources Publications.

Önsoy, H. (2002). "Doğu Karadeniz'de Kıyılara ve Dere Yataklarına Müdahaleler ve Beklenen Taşkınlar", *Türkiye Mühendisilik Haberleri*, *Vol. 420 No: 4 145-147*

Özdemir, C. E. (2003). "A Feasibility Study on Bridge Scour Countermeasures", MSc Thesis. Middle East Technical University, Ankara.

Parker, G., Toro-Escobar, C., and Voigt, R.L., Jr. (1998). "Countermeasures to Protect Bridge Piers from Scour," Users Guide (revised1999) and Final Report, NCHRP Project 24-7, prepared for Transportation Research Board by St. Anthony Falls Laboratory, University of Minnesota, MN, 360 p.

Pearson, D,, Stein, S., and Jones, J. S. (2002). "HYRISK Methodology and User Guide". FHWA Report No. FHWA-RD-02-XXX. Virginia: Federal Highway Administration.

Richardson, E.V., and Davis, S.R. (2001). “Evaluating Scour at Bridges,” Hydraulic Engineering Circular No. 18(HEC-18), Fourth Edition, FHWA NHI 01-004, Federal Highway Administration, Washington, D.C.

Richardson, E.V., Simons, D.B. and Julian, P.Y.(1990). "Highways in the River Environment,"Design and Training Manual, U.S. Department of Transportation, Federal Highway Administration, Washington D.C, (Civil Engineering Department Report, Colorado State University, 1987)

Scholl, B. N. (2010). Articulated Concrete Block Design, Research Paper,Contech Construction Products Inc.

Shirhole A.M. and Holt R.C. (1991). Planning for a Comprehensive Bridge Safety Program. Transportation Research Record 1290, Vol. 1. Transportation Research Board, National Research Council, Washington DC. 39-50

Tradekorea marketplace. (2012). Retrieved December 10, 2012 from http://www.sun-gabion.com/Reno-Mattresses/products-83-Reno-Mattress.htm

Turan and Yanmaz, A. M. (2011). “Reliability-based optimization of river bridges using artificial intelligence techniques”, *Canadian Journal of Civil Enginering, Vol.38, No:10*, 1103-1111

Yanmaz, A. M. (2002). "Köprü Hidroliği". Ankara: METU Press.

APPENDIX A

CROSS-SECTIONS OF THE STATIONS OF HEC-RAS MODEL

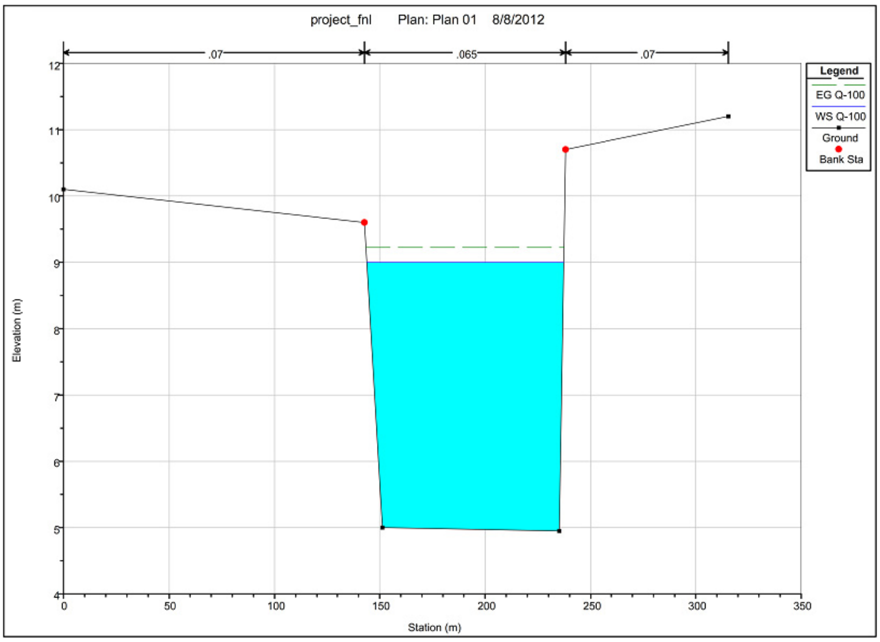


Figure A.1 Geometric details of Section 1 in HEC-RAS model

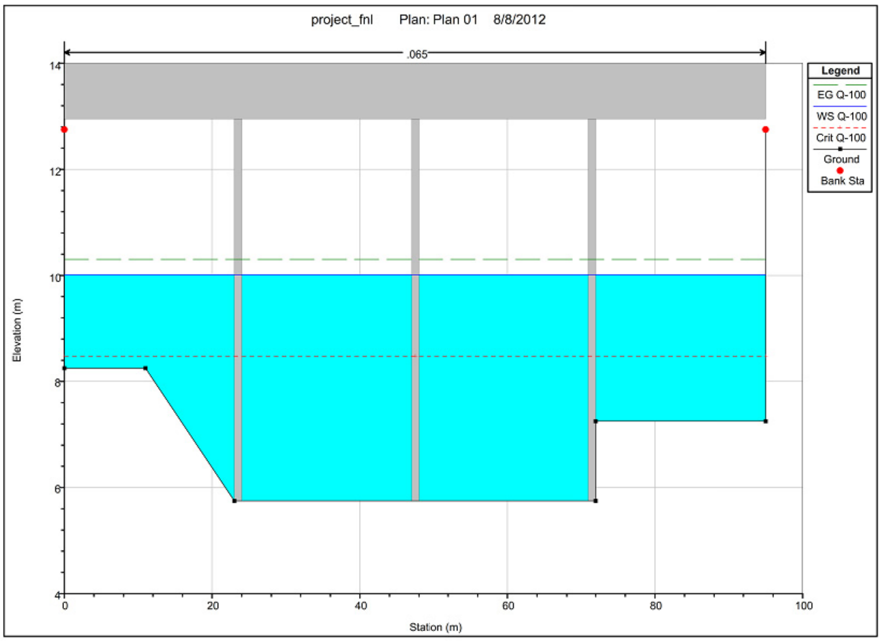


Figure A.2 Geometric details of Section 2 in HEC-RAS model

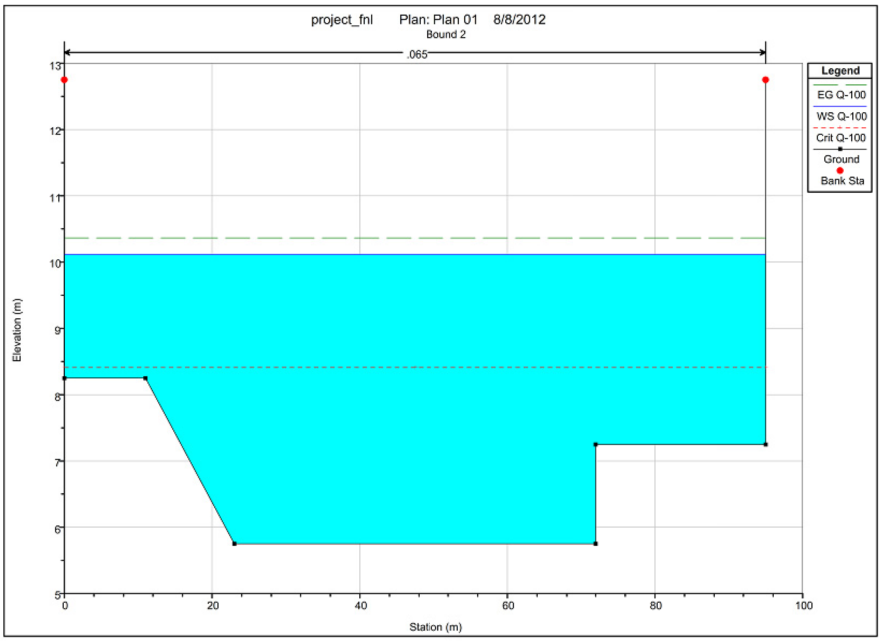


Figure A.3 Geometric details of Section 3 in HEC-RAS model

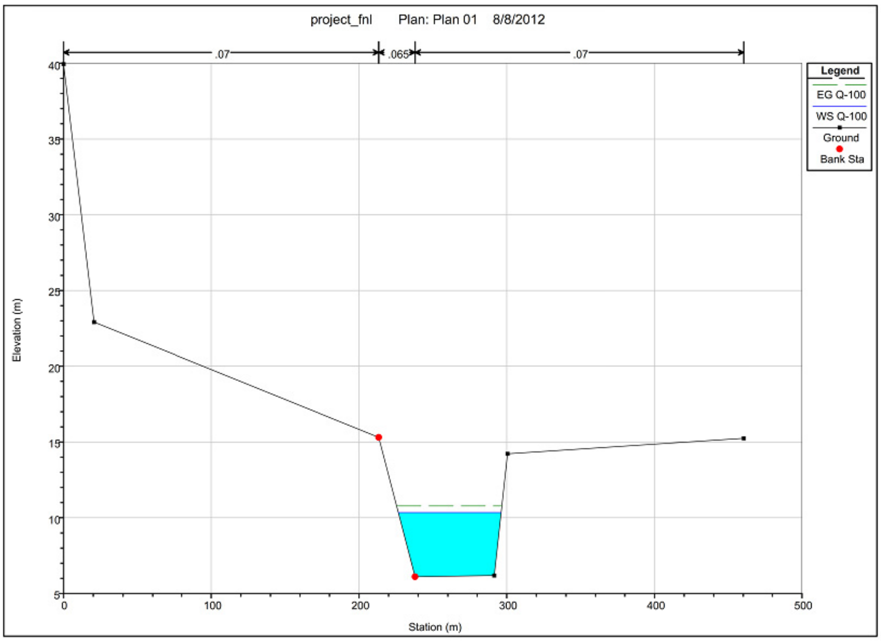


Figure A.4 Geometric details of Section 4 in HEC-RAS model

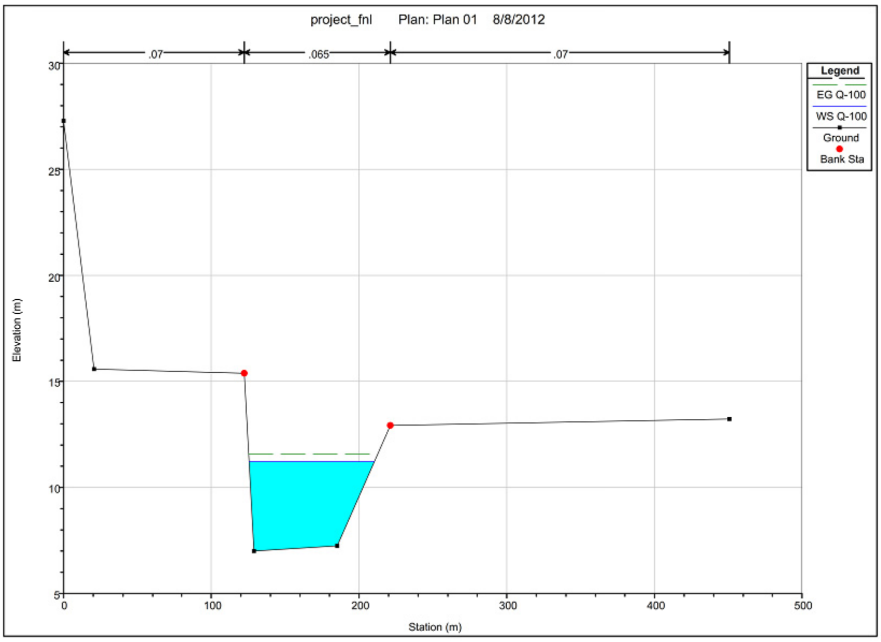


Figure A.5 Geometric details of Section 5 in HEC-RAS model

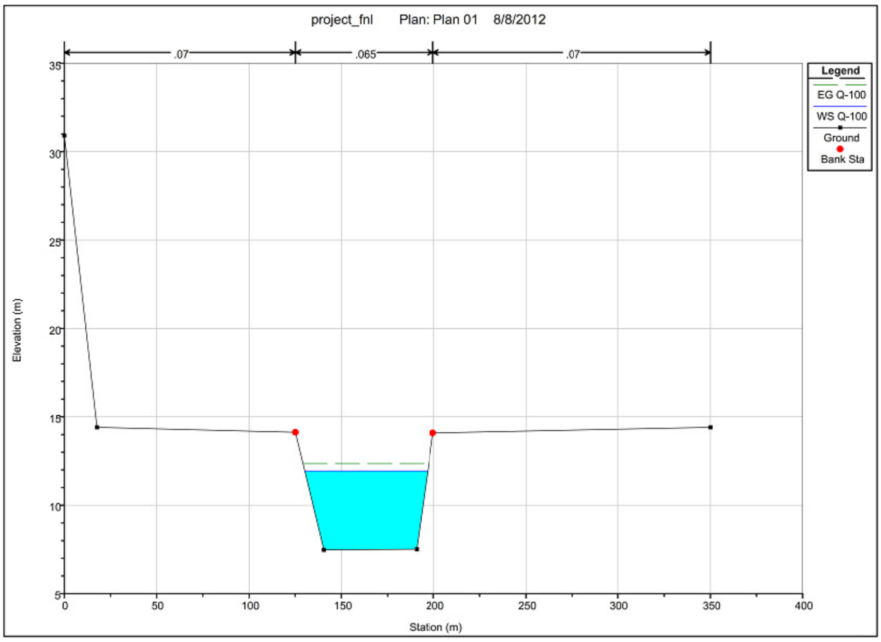


Figure A.6 Geometric details of Section 6 in HEC-RAS model

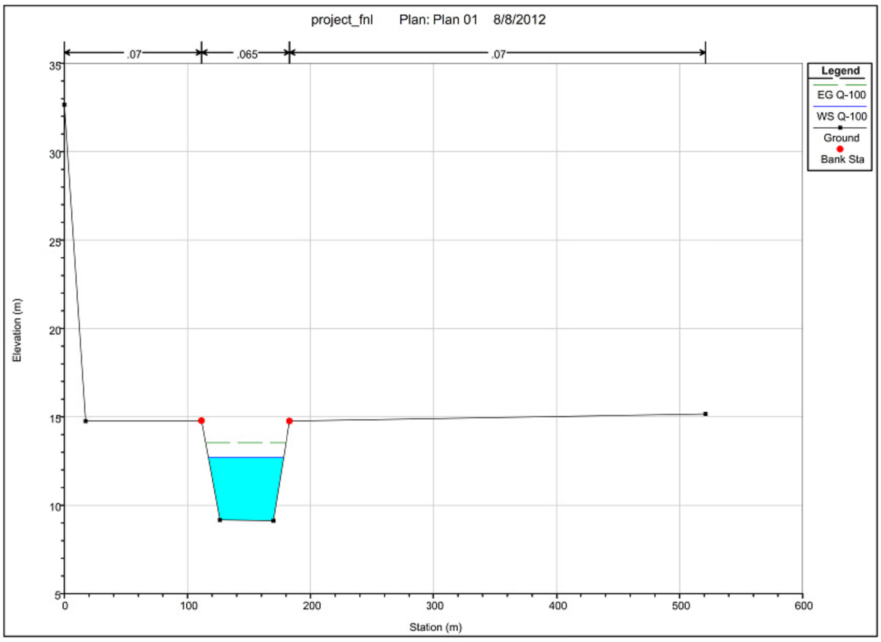


Figure A.7 Geometric details of Section 7 in HEC-RAS model

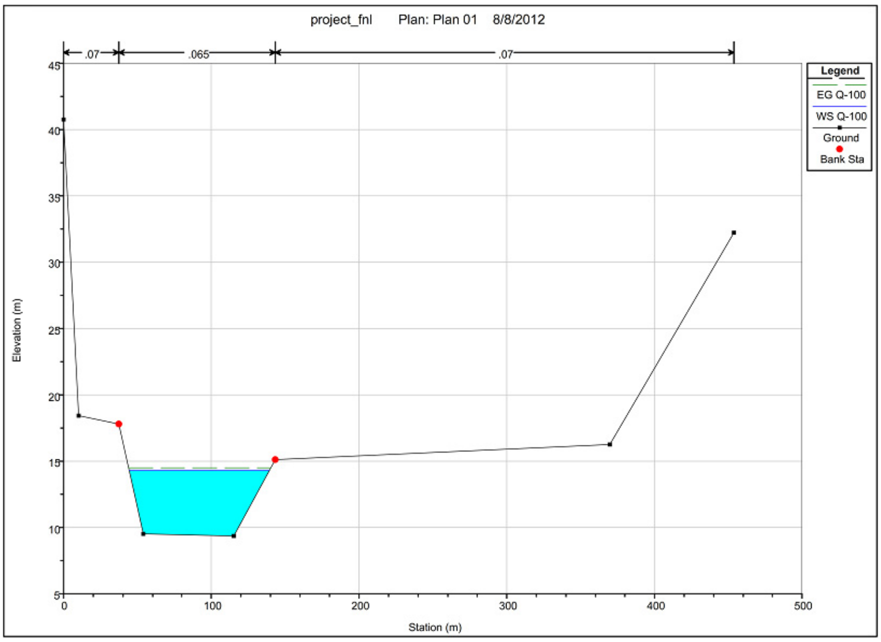


Figure A.8 Geometric details of Section 8 in HEC-RAS model

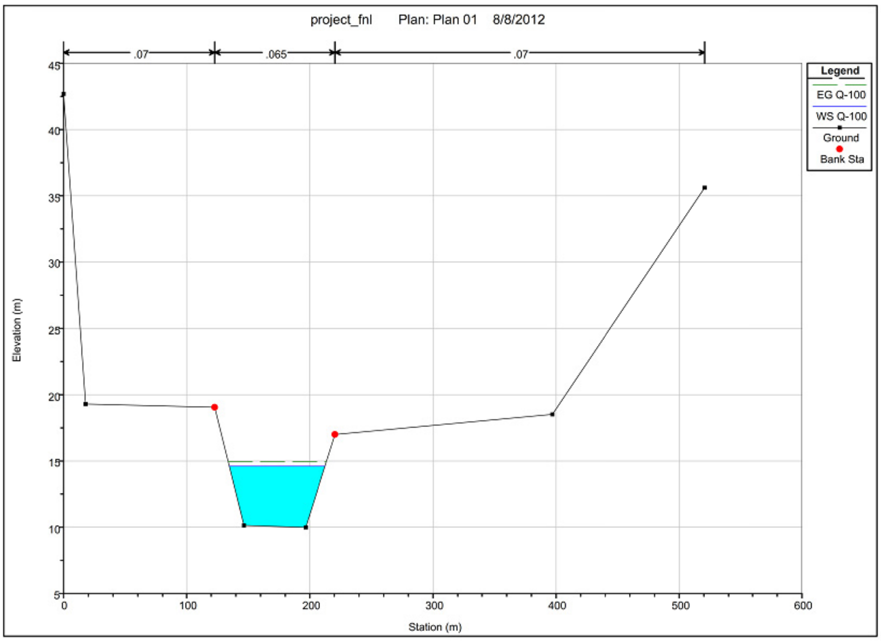


Figure A.9 Geometric details of Section 9 in HEC-RAS model

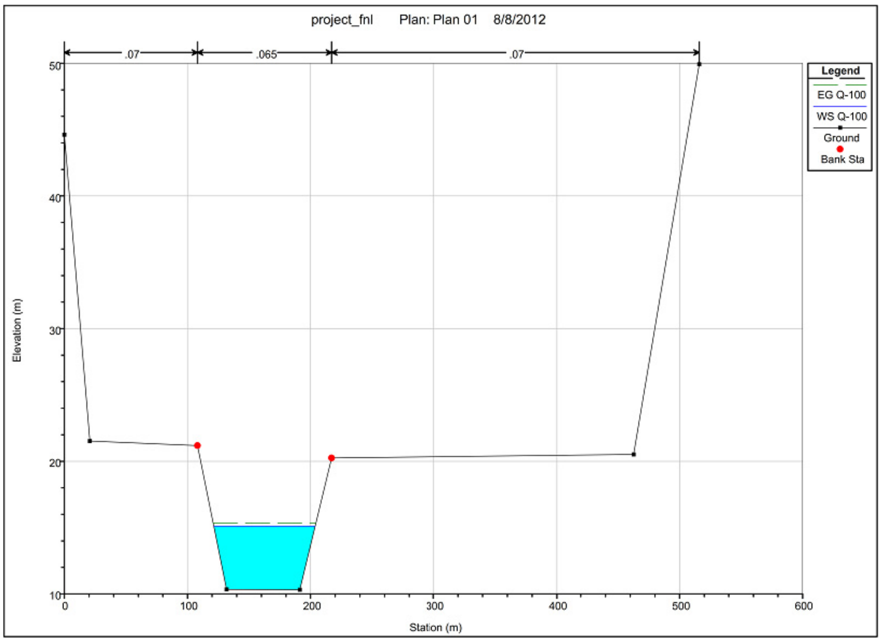


Figure A.10 Geometric details of Section 10 in HEC-RAS model

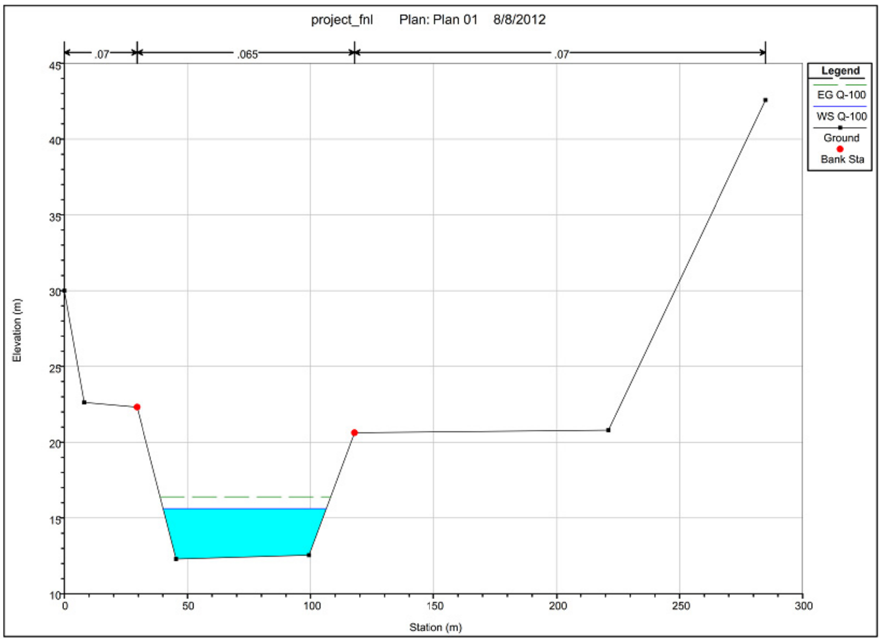


Figure A.11 Geometric details of Section 11 in HEC-RAS model

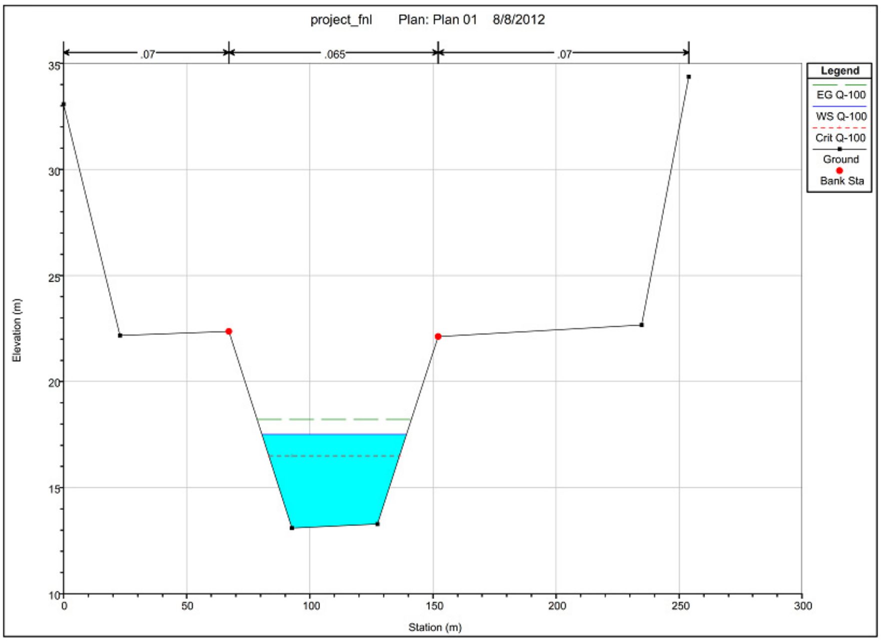


Figure A.12 Geometric details of Section 12 in HEC-RAS model

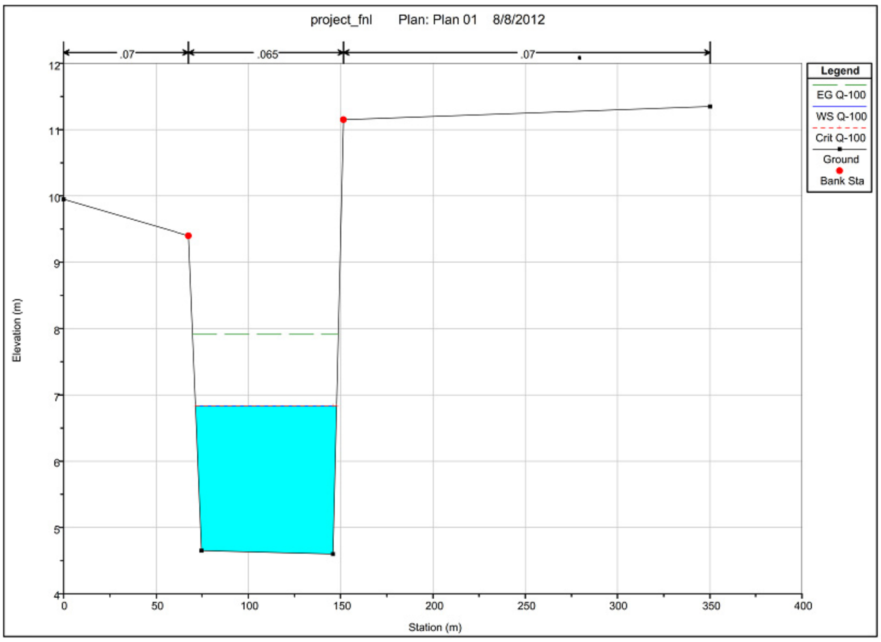


Figure A.13 Geometric details of Section 13 in HEC-RAS model

APPENDIX B

COMPUTER PROGRAM SOURCE CODE

```
Module Module1

 Public Sub acb_design()

  ' v_des calculation

  Dim vavg As Double
  Dim vloc As Double
  Dim k1 As Double
  Dim k2 As Double
  Dim sg As Double
  Dim vdes As Double
  Dim fd As Double
  Dim fl As Double

  Dim dens As Double
  Dim b_blk As Double
  Dim p_blk As Double
  Dim w_blk As Double
  Dim d0 As Double
  Dim d1 As Double
  Dim dx As Double
  Dim a0 As Double
  Dim nman As Double
  Dim y As Double
  Dim Tdes As Double
  Dim h_blk As Double
  Dim ds As Double
  Dim e2, e3, e4, e5, e6, e7, e8, SF As Double
  Dim l1, l2, l3, l4 As Double
  Dim Tc, m_blk, d_con, d_Water As Double
  Dim sfb, xc, xm As Double

  vavg = CDbl(flow_panel4.Vavg.Text)
  d_Water = CDbl(flow_panel4.d_Water.Text)
  y = CDbl(flow_panel4.y.Text)
  nman = CDbl(flow_panel4.nman.Text)
  b_blk = CDbl(flow_panel4.b_blk.Text)
  h_blk = CDbl(flow_panel4.h_blk.Text)
  m_blk = CDbl(flow_panel4.m_blk.Text)
  w_blk = CDbl(flow_panel4.w_blk.Text)
  Tc = CDbl(flow_panel4.Tc.Text)
  d0 = CDbl(flow_panel4.d0.Text)
  d1 = CDbl(flow_panel4.d1.Text)
  d_con = CDbl(flow_panel4.d_con.Text)
  k1 = CDbl(flow_panel4.K1.Text)
  k2 = CDbl(flow_panel4.K2.Text)
  sfb = CDbl(flow_panel4.sfb.Text)
```

```
        xc = CDbl(flow_panel4.xc.Text)
        xm = CDbl(flow_panel4.xm.Text)
        p_blk = CDbl(flow_panel4.blk_pr.Text)
        ds = CDbl(flow_panel4.ds.Text)

        If flow_panel4.vloc.Checked = True Then
            vdes = k1 * vavg
        Else
            vdes = k1 * k2 * vavg
        End If

        Tdes = (nman * vdes) ^ 2 * (d_Water * 9.81) / (y ^ (1 / 3))


        dx = 180 * Math.Atan(Math.Tan(d0 / 180 * Math.PI) / Math.Tan(d1 / 180 * Math.PI)) / Math.PI


        'block parameters
        l1 = h_blk / 2
        l4 = ((w_blk / 2) ^ 2 + (b_blk / 2) ^ 2) ^ (1 / 2)
        l2 = l4
        l3 = h_blk * 8 / 10
        fd = 0.5 * (d_Water) * b_blk * p_blk * (vdes ^ 2)
        fl = fd
        e2 = Tdes / Tc

        e3 = Math.Atan(Math.Tan(d0 / 180 * Math.PI) / Math.Tan(d1 / 180 * Math.PI)) / Math.PI * 180

        e4 = ((Math.Cos(d1 / 180 * Math.PI)) ^ 2 - (Math.Sin(d0 / 180 * Math.PI)) ^ 2) ^ (1 / 2)

        Dim par1, par2, par3, par4 As Double

        par1 = Math.Cos((d0 + e3) / 180 * Math.PI)
        par2 = (l4 / l3 + 1)
        par3 = ((1 - e4 ^ 2) ^ (1 / 2)) / (e2 * l2 / l1)
        par4 = Math.Sin((d0 + e3) / 180 * Math.PI)

        e5 = Math.Atan(par1 / (par2 * par3 + par4)) / Math.PI * 180
        e6 = 90 - e5 - e3
        e7 = e2 * ((l4 / l3) + Math.Sin((d0 + e3 + e5) / 180 * Math.PI)) / ((l4 / l3) + 1)
        e8 = m_blk * ((d_con - d_Water) / d_con)



    Dim p1, p2, p3, p4, p5 As Double
        p1 = l2 / l1 * e4
        p2 = (Math.Cos(e5 / 180 * Math.PI)) * (((1 - e4) ^ 2) ^ (1 / 2))
        p3 = e7 * l2 / l1
        p4 = l3 * fd * Math.Cos(e6 / 180 * Math.PI) + l4 * fl
        p5 = l1 * e8
        SF = p1 / (p2 + p3 + (p4 / p5))
        Dim sft As Double

        sft = CDbl(flow_panel4.sfb.Text) * CDbl(flow_panel4.xc.Text) * CDbl(flow_panel4.xm.Text)
        If sft < SF Then
            flow_panel4.acb_alert.Text = "SAFE DESIGN - F.S > TARGET F.S"
        Else
```

```
        flow_panel4.acb_alert.Text = "UNSAFE DESIGN - F.S < TARGET F.S"
    End If
    Dim o As System.IO.StreamWriter
    o = IO.File.CreateText("acb.txt")
    o.WriteLine("ACB - Design and  Specification")
    o.WriteLine("------------------------------------------------------------------------------------------")
    o.WriteLine("")
    o.WriteLine("Problem Characteristics")
    o.WriteLine("Shape factor (K1): " & k1)

    If flow_panel4.vloc.Checked = False Then
        o.WriteLine("Velocity adjustment factor (K2):" & k2)
    End If

    o.WriteLine("Design Velocity: " & Math.Round(vdes, 3) & " m/s")
    o.WriteLine("Depth of flow at pier: " & y & " m")
    o.WriteLine("Manning’s roughness coefficient: " & nman)
    o.WriteLine("Width of ACB unit in the direction of flow: " & b_blk & " m")
    o.WriteLine("Height of block protrusion above ACB matrix:" & p_blk & " m")
    o.WriteLine("Block length: " & w_blk & " m")
    o.WriteLine("Block height: " & h_blk & " m")
    o.WriteLine("Mass of block (In air): " & m_blk & " kg")
    o.WriteLine("Channel bed slope (Degrees): " & d0)
    o.WriteLine("Side slope of block installation (Degrees): ", d1 & "")
    o.WriteLine("Concrete density: ", d_con & " kg/m³")
    o.WriteLine("")
    o.WriteLine("Details of calculations")
    o.WriteLine("Block Parameters:")
    o.WriteLine("l1: " & l1 & " m")
    o.WriteLine("l2: " & l2 & " m")
    o.WriteLine("l3: " & l3 & " m")
    o.WriteLine("l4: " & l4 & " m")
    o.WriteLine("")
    o.WriteLine("FL: " & fl & " N")
    o.WriteLine("FD: " & fd & " N")
    o.WriteLine("Stability Num: " & e2 & " m")
    o.WriteLine("Angle btw s.slope proj. of Ws" & e3)
    o.WriteLine("Projection of Ws into plane of subgrade " & e4)
    o.WriteLine("Angle between block motion and vertical :" & e5)
    o.WriteLine("Angle between drag force and block motion : " & e6)
    o.WriteLine("Stability number for block on sloped surface : " & e7)
    o.WriteLine("Submerged block weight : " & e8 & " N")


o.WriteLine("")
    o.WriteLine("Factor of Safety Calculations")
    o.WriteLine("Target Factor of Safety: ", sft & "")
    o.WriteLine("Calculated Factor of Safety: ", Math.Round(SF, 3) & "")
    o.WriteLine("")
    o.WriteLine("")
    If SF > sft Then
        o.WriteLine("Because the calculated factor of safety EXCEEDS the target,")
        o.WriteLine("the proposed ACB system is STABLE against loss of intimate contact.")
    Else
        o.WriteLine("Because the calculated factor of safety DOESNT EXCEEDS the target,")
        o.WriteLine("the proposed ACB system is NOT STABLE  against loss of intimate contact.")
        o.WriteLine("")
```

```
        End If

        If flow_panel4.lay_design.Checked = True Then
            ' acb layer dimensions
            Dim ka As Double
            Dim pa As Double
            Dim skew As Double
            Dim pleng As Double

            pleng = CDbl(flow_panel4.pleng.Text) ' take pier length
            pa = CDbl(flow_panel4.pa.Text) 'take pier width
            skew = CDbl(flow_panel4.pskew.Text) '  river attack angle for pier
            ka = ((pa * Math.Cos(skew / 180 * Math.PI) + pleng * Math.Sin(skew / 180 * Math.PI)) / pa) ^
(0.65)

            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("ACB System Layout Configuration")
            o.WriteLine("-------------------------------------------------------------------------------------------
")
            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("           /-------------------------------\   ")
            o.WriteLine("           |                              | ")
            o.WriteLine("           |                              | ")
            o.WriteLine("           |                              | ")
            o.WriteLine("           |       /----------------\ _      | ")
            o.WriteLine("           WS      |                | |     | " & Math.Round(2.5 * ds + pa, 2) & " m ")
            o.WriteLine("           |       |                ||" & pa & " m   | ")
            o.WriteLine("           |       \----------------/ _      | ")
            o.WriteLine("           |                              | ")
            o.WriteLine("           |                              | ")
            o.WriteLine("           |                              | ")
            o.WriteLine("           \--X2------------L-------------X1-/  ")
            o.WriteLine("                          " & Math.Round((1.25 * ds + 3 * ds + pleng), 2) & " m ")
            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("Skewness effect coefficent: " & Math.Round(ka, 2))
            o.WriteLine("Pier width: " & pa & " m ")
            o.WriteLine("ACB layer WS: " & Math.Round(2.5 * ds + pa, 2) & " m ")
            o.WriteLine("ACB layer X1: " & Math.Round((1.25 * ds), 2) & " m ")
            o.WriteLine("ACB layer X2: " & Math.Round((3 * ds), 2) & " m ")


            o.WriteLine("Filter Notes")
            o.WriteLine("Both geotextile and granular filter is required")
            o.WriteLine("Ex : 1 m thick granular filter is recomended!!!")
            o.WriteLine("Geotextile filter area depends on th surface are of ACB installation")

            If flow_panel4.plc_uwater.Checked = True Then
                o.WriteLine("Wet Placement - Granular filter layer thickness increased by 50%")
            End If
        End If

        o.Close()

        If flow_panel4.autof.Checked = True Then
```

```
            System.Diagnostics.Process.Start("acb.txt")
        End If

    End Sub

    Public Sub grout_riprap()


        Dim i As Integer
        If flow_panel4.class_s.Text = "Class II" Then
            i = 1
        ElseIf flow_panel4.class_s.Text = "Class III" Then
            i = 2
        ElseIf flow_panel4.class_s.Text = "Class IV" Then
            i = 3
        Else
            MsgBox("No gradation class is selected")
            Exit Sub
        End If


        Dim clas(9) As Integer
        Dim size(9), d15_min(9), d15_max(9), d50_min(9), d50_max(9), d85_min(9), d85_max(9),
d100_max(9), d50 As Double

        clas = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10}
        size = {0.15, 0.23, 0.3, 0.38, 0.46, 0.53, 0.61, 0.76, 0.91, 1.07}
        d15_min = {0.09, 0.14, 0.19, 0.23, 0.28, 0.33, 0.37, 0.47, 0.56, 0.65}
        d15_max = {0.13, 0.2, 0.27, 0.33, 0.39, 0.47, 0.53, 0.66, 0.8, 0.93}
        d50_min = {0.14, 0.22, 0.29, 0.37, 0.43, 0.51, 0.58, 0.72, 0.86, 1.02}
        d50_max = {0.18, 0.27, 0.36, 0.44, 0.52, 0.61, 0.7, 0.88, 1.05, 1.23}
        d85_min = {0.2, 0.29, 0.39, 0.5, 0.6, 0.7, 0.79, 0.99, 1.19, 1.38}
        d85_max = {0.23, 0.36, 0.47, 0.58, 0.7, 0.83, 0.94, 1.17, 1.41, 1.64}
        d100_max = {0.3, 0.46, 0.61, 0.76, 0.91, 1.07, 1.22, 1.52, 1.83, 2.13}
        d50 = size(i)


        'type the gradation of the selected aggregate class
        Dim o As System.IO.StreamWriter





        o = IO.File.CreateText("partiallygrout.txt")
        o.WriteLine("Partially Grouted Riprap - Design and  Specification")
        o.WriteLine("-------------------------------------------------------------------------------------------")
        o.WriteLine("")
        o.WriteLine("")
        o.WriteLine("Selected Standard Gradation Size ")
        o.WriteLine("-------------------------------------------------------------------------------------------")
        o.WriteLine("{0,10}{1,10}{2,10}{3,10}{4,10}{5,10}{6,10}{7,10}{8,10}", "Class", "Size",
"d15_min", "d15_max", "d50_min", "d50_max", "d85_min", "d85_max", "d100_max")
        o.WriteLine("{0,10}{1,10}{2,10}{3,10}{4,10}{5,10}{6,10}{7,10}{8,10}", "--------", "--------",
"--------", "--------", "--------", "--------", "--------", "--------", "--------")
        o.WriteLine("{0,10}{1,10}{2,10}{3,10}{4,10}{5,10}{6,10}{7,10}{8,10}", "" &
```

```
flow_panel4.class_s.Text, size(i), d15_min(i), d15_max(i), d50_min(i), d50_max(i), d85_min(i), 
d85_max(i), d100_max(i))
        o.WriteLine("")
        o.WriteLine("")

        'calculation of mixture for 1 m3 of grout
        o.WriteLine("!!!Mixture for 1m3 of grout!!!")
        o.WriteLine("-----------------------------------------------------------------------------------------------")
        o.WriteLine("Ordinary portland cement: 441 - 453 kg")
        o.WriteLine("Fine concrete aggregate (sand) dry: 703 - 715 kg")
        o.WriteLine("1/4 crusher chips (very fine gravel), dry: 703 - 715 kg")
        o.WriteLine("Water: 250 - 268 kg")
        o.WriteLine("Anti-washout additive: 3,6 - 4,8 kg")
        o.WriteLine("Air entrained: 5%  - 7%  kg")
        o.WriteLine("")
        ' riprap layer size

        'layout dimesions

        If flow_panel4.lay_design.Checked = True Then
            ' riprap layer diemsions
            Dim ka As Double
            Dim pa As Double
            Dim skew As Double
            Dim pleng As Double

            pleng = CDbl(flow_panel4.pleng.Text) ' take pier length
            pa = CDbl(flow_panel4.pa.Text) 'take pier width
            skew = CDbl(flow_panel4.pskew.Text) '  river attack angle for pier

            ka = ((pa * Math.Cos(skew / 180 * Math.PI) + pleng * Math.Sin(skew / 180 * Math.PI)) / pa) ^
(0.65)

            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("Riprap Layer Layout Configuration")
            o.WriteLine("-----------------------------------------------------------------------------------------------
")
            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("           /--------------------------------\   ")
            o.WriteLine("          |                         | ")



            o.WriteLine("          |                         | ")
            o.WriteLine("          |                         | ")
            o.WriteLine("          |      /----------------\ _      | ")
            o.WriteLine("          |      |              | |     | " & Math.Round((1.5 * pa * ka) * 2 + pa, 2) & " m
")
            o.WriteLine("          |      |              | |" & pa & " m   | ")
            o.WriteLine("          |      \----------------/ _      | ")
            o.WriteLine("          |                         | ")
            o.WriteLine("          |                         | ")
            o.WriteLine("          |                         | ")
            o.WriteLine("           \-------------------------------/  ")
            o.WriteLine("                          " & Math.Round((3 * pa + pleng), 2) & " m ")
```

```
            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("Skewness effect coefficent: " & Math.Round(ka, 2))
            o.WriteLine("Pier width: " & pa & " m ")
            o.WriteLine("Riprap layer width: " & Math.Round((1.5 * pa * ka) * 2 + pa, 2) & " m ")
            o.WriteLine("Riprap layer length: " & Math.Round((3 * pa + pleng), 2) & " m ")

            If flow_panel4.plc_uwater.Checked = True Then
              o.WriteLine("Wet Placement - Suggested Riprap Thickness: " & Math.Round(1.5 * 4 * d50,
2) & " m")
            Else
              o.WriteLine("Dry Placement - Suggested Riprap Thickness: " & Math.Round(4 * d50, 2) &
" m")
            End If
            o.WriteLine("")

            o.WriteLine("Filter Requirements")
            o.WriteLine("Filter Layer Width: " & Math.Round((3 / 4 * 1.5 * pa * ka) * 2 + pa, 2))
            o.WriteLine("Filter Layer Length: " & Math.Round((3 / 4 * 1.5 * pa) * 2 + pleng, 2))
            o.WriteLine("")
            o.WriteLine("Granular Filter Notes")
            o.WriteLine("Minimum Granular Stone Filter Layer Thickness: maximum of 4 x d50 of the
granular filter or 15 cm")
            o.WriteLine("Granular filter layer thickness increased by 50% for wet placement.")


        End If

        o.Close()
        If flow_panel4.autof.Checked = True Then
            System.Diagnostics.Process.Start("partiallygrout.txt")
        End If
    End Sub
    Public Sub find_riprap_d50()

        Dim d50 As Double 'min allowable stone size ( median diameter )
        Dim Vdes As Double 'design velocity
        Dim K1 As Double 'shape factor
        Dim K2 As Double 'velocity adjustment factor
        Dim sg As Double 'specific gravity
        Dim vavg As Double
        Dim clas(9) As Integer
        Dim i As Integer


        Dim size(9), d15_min(9), d15_max(9), d50_min(9), d50_max(9), d85_min(9), d85_max(9),
d100_max(9) As Double
        clas = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10}
        size = {0.15, 0.23, 0.3, 0.38, 0.46, 0.53, 0.61, 0.76, 0.91, 1.07}
        d15_min = {0.09, 0.14, 0.19, 0.23, 0.28, 0.33, 0.37, 0.47, 0.56, 0.65}
        d15_max = {0.13, 0.2, 0.27, 0.33, 0.39, 0.47, 0.53, 0.66, 0.8, 0.93}
        d50_min = {0.14, 0.22, 0.29, 0.37, 0.43, 0.51, 0.58, 0.72, 0.86, 1.02}
        d50_max = {0.18, 0.27, 0.36, 0.44, 0.52, 0.61, 0.7, 0.88, 1.05, 1.23}
        d85_min = {0.2, 0.29, 0.39, 0.5, 0.6, 0.7, 0.79, 0.99, 1.19, 1.38}
        d85_max = {0.23, 0.36, 0.47, 0.58, 0.7, 0.83, 0.94, 1.17, 1.41, 1.64}
        d100_max = {0.3, 0.46, 0.61, 0.76, 0.91, 1.07, 1.22, 1.52, 1.83, 2.13}
```

```
vavg = CDbl(flow_panel4.Vavg.Text)
K1 = CDbl(flow_panel4.K1.Text)
K2 = CDbl(flow_panel4.K2.Text)
sg = CDbl(flow_panel4.sg.Text)
Dim j As Integer
If flow_panel4.vloc.Checked = False Then
   Vdes = K1 * K2 * vavg
Else
   Vdes = K1 * vavg
End If

d50 = 0.692 * (Vdes ^ 2) / ((sg - 1) * 2 * 9.81)

j = 0
For i = 0 To 8
   If size(i) < d50 And d50 < size(i + 1) Then
      i = i + 1
      j = 1
      Exit For
   End If
Next


Dim o As System.IO.StreamWriter
o = IO.File.CreateText("rock_riprap.txt")
o.WriteLine("Rock Riprap - Design and  Specification")
o.WriteLine("------------------------------------------------------------------------------------------------")
o.WriteLine("")
o.WriteLine("Problem Characteristics")
o.WriteLine("Shape factor (K1): " & K1)

If flow_panel4.vloc.Checked = False Then
   o.WriteLine("Velocity adjustment factor (K2): " & K2)
   o.WriteLine("Design Velocity: " & Math.Round(Vdes, 2) & " m/s ")
Else
   o.WriteLine("Design Velocity: " & Math.Round(Vdes, 2) & " m/s ")
End If


o.WriteLine("Specific Gravity : " & sg)
o.WriteLine("d50 : " & Math.Round(d50, 2) & " m ")
o.WriteLine("")
o.WriteLine("")



If Not j = 1 Then
   o.WriteLine("d50 is so large, no dimension range is determined!!!")
Else
   o.WriteLine("Selected Standard Gradation Size ")
   o.WriteLine("{0,10}{1,10}{2,10}{3,10}{4,10}{5,10}{6,10}{7,10}{8,10}",   "Class",   "Size",
"d15_min", "d15_max", "d50_min", "d50_max", "d85_min", "d85_max", "d100_max")
   o.WriteLine("{0,10}{1,10}{2,10}{3,10}{4,10}{5,10}{6,10}{7,10}{8,10}", "--------", "--------
", "--------", "--------", "--------", "--------", "--------", "--------", "--------")
   o.WriteLine("{0,10}{1,10}{2,10}{3,10}{4,10}{5,10}{6,10}{7,10}{8,10}", "Class " & clas(i),
size(i), d15_min(i), d15_max(i), d50_min(i), d50_max(i), d85_min(i), d85_max(i), d100_max(i))
```

```
        End If

        If flow_panel4.lay_design.Checked = True Then
            ' riprap layer diemsions
            Dim ka As Double
            Dim pa As Double
            Dim skew As Double
            Dim pleng As Double

            pleng = CDbl(flow_panel4.pleng.Text) ' take pier length
            pa = CDbl(flow_panel4.pa.Text) 'take pier width
            skew = CDbl(flow_panel4.pskew.Text) '  river attack angle for pier
            'MsgBox(Math.Cos(30 / 180 * Math.PI))
            ka = ((pa * Math.Cos(skew / 180 * Math.PI) + pleng * Math.Sin(skew / 180 * Math.PI)) / pa) ^
(0.65)

            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("Riprap Layer Layout Configuration")
            o.WriteLine("-------------------------------------------------------------------------------------------
")
            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("          /--------------------------------\   ")
            o.WriteLine("          |                                | ")
            o.WriteLine("          |                                | ")
            o.WriteLine("          |                                | ")
            o.WriteLine("          |      /----------------\ _      | ")
            o.WriteLine("          |      |             | |    | " & Math.Round((2 * pa * ka) * 2 + pa, 2) & " m ")
            o.WriteLine("          |      |             | |" & pa & " m   | ")
            o.WriteLine("          |      \----------------/ _      | ")
            o.WriteLine("          |                                | ")
            o.WriteLine("          |                                | ")
            o.WriteLine("          |                                | ")
            o.WriteLine("          \--------------------------------/  ")
            o.WriteLine("                          " & Math.Round((4 * pa + pleng), 2) & " m ")
            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("Skewness effect coefficent: " & Math.Round(ka, 2))
            o.WriteLine("Pier width: " & pa & " m ")
            o.WriteLine("Riprap layer width: " & Math.Round(2 * pa * ka * 2 + pa, 2) & " m ")
            o.WriteLine("Riprap layer length: " & Math.Round((4 * pa + pleng), 2) & " m ")



            If flow_panel4.plc_uwater.Checked = True Then
                o.WriteLine("Wet Placement - Suggested Riprap Thickness: " & Math.Round(1.5 * 3 *
size(i), 2) & " m to " & Math.Round(1.5 * 5 * size(i), 2) & " m ")
            Else
                o.WriteLine("Suggested Riprap Thickness: " & Math.Round(3 * size(i), 2) & " m to " &
Math.Round(5 * size(i), 2) & " m ")
            End If

            o.WriteLine("Filter Requirements")
            o.WriteLine("Filter Layer Width: " & Math.Round((3 / 4 * 2 * pa * ka) * 2 + pa, 2))
            o.WriteLine("Filter Layer Length: " & Math.Round((3 / 4 * 2 * pa) * 2 + pleng, 2))
            o.WriteLine("")
```

```vb
        o.WriteLine("Granular Filter Notes")
        o.WriteLine("Minimum Granular Stone Filter Layer Thickness: maximum of 4 x d50 of the granular filter or 15 cm")
        o.WriteLine("Granular filter layer thickness increased by 50% for wet placement.")

    End If
    ' en son hal bu 10.48 24 eylül


    o.Close()

    If flow_panel4.autof.Checked = True Then
        System.Diagnostics.Process.Start("rock_riprap.txt")
    End If

End Sub
Public Sub gabion_mat()

    'definition of variables
    Dim Vdes As Double 'design velocity
    Dim K1 As Double 'shape factor
    Dim K2 As Double 'velocity adjustment factor
    Dim sg As Double 'specific gravity
    Dim vavg As Double
    Dim d_water As Double
    Dim nman As Double
    Dim y As Double
    Dim Tdes As Double
    Dim sft As Double
    Dim d50 As Double

    'variable fills
    vavg = CDbl(flow_panel4.Vavg.Text)
    K1 = CDbl(flow_panel4.K1.Text)
    K2 = CDbl(flow_panel4.K2.Text)
    sg = CDbl(flow_panel4.sg.Text)
    y = CDbl(flow_panel4.y.Text)
    nman = CDbl(flow_panel4.nman.Text)
    d_water = CDbl(flow_panel4.d_Water.Text)

    Dim j As Integer
    If flow_panel4.vloc.Checked = False Then
        Vdes = K1 * K2 * vavg


    Else
        Vdes = K1 * vavg
    End If


    Tdes = (nman * Vdes) ^ 2 * (d_water * 9.81 / (y ^ (1 / 3)))
    sft = CDbl(flow_panel4.sfb.Text) * CDbl(flow_panel4.xc.Text) * CDbl(flow_panel4.xm.Text)
    d50 = sft * Tdes / (0.1 * (CDbl(flow_panel4.sg.Text) - 1) * 1000 * 9.81)
    Dim o As System.IO.StreamWriter
    o = IO.File.CreateText("gabion_mattress.txt")
    o.WriteLine("Gabion Mattress - Design and  Specifications")
    o.WriteLine("---------------------------------------------------------------------------------------------")
```

```
        o.WriteLine("")
        o.WriteLine("Problem Characteristics")
        o.WriteLine("Shape factor (K1) : " & K1)

        If flow_panel4.vloc.Checked = False Then
            o.WriteLine("Velocity adjustment factor (K2): " & K2)
            o.WriteLine("Design Velocity: " & Math.Round(Vdes, 2) & " m/s ")
        Else
            o.WriteLine("Design Velocity: " & Math.Round(Vdes, 2) & " m/s ")
        End If


        o.WriteLine("Specific Gravity :" & sg)
        o.WriteLine("d50 : " & Math.Round(d50, 3) & " m")
        o.WriteLine("Minimum Mattress Thickness : " & 2 * Math.Round(d50, 3) & " m")
        o.WriteLine("Minimum Allowable Wire Mesh Size : " & Math.Min(2 * Math.Round(d50 / 1.25,
3), 0.15) & " m")
        o.WriteLine("")
        o.WriteLine("")
        o.WriteLine("Size Ranges for Rocks to Fill Gabion Mattress")
        o.WriteLine("-----------------------------------------------------------------------------------------------")
        o.WriteLine("")
        o.WriteLine("{0,5}{1,22}", "Mattress Thickness (cm)", "Range of Stone Size ")
        o.WriteLine("{0,5}{1,24}", "--------", "--------")
        o.WriteLine("{0,5}{1,30}", "15", "7.6 to 12.7")
        o.WriteLine("{0,5}{1,30}", "23", "7.6 to 12.7")
        o.WriteLine("{0,5}{1,30}", "30", "10 to 20   ")
        o.WriteLine("")

        'layout configurations

        If flow_panel4.lay_design.Checked = True Then
            ' riprap layer diemsions
            Dim ka As Double
            Dim pa As Double
            Dim skew As Double
            Dim pleng As Double

            pleng = CDbl(flow_panel4.pleng.Text) ' take pier length
            pa = CDbl(flow_panel4.pa.Text) 'take pier width
            skew = CDbl(flow_panel4.pskew.Text) '  river attack angle for pier

            ka = ((pa * Math.Cos(skew / 180 * Math.PI) + pleng * Math.Sin(skew / 180 * Math.PI)) / pa) ^
(0.65)

            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("Gabion Mattress  Layout Configuration")
            o.WriteLine("-----------------------------------------------------------------------------------------------
")
            o.WriteLine("")
            o.WriteLine("")
            o.WriteLine("          /-------------------------------\  ")
            o.WriteLine("          |                               | ")
            o.WriteLine("          |                               | ")
            o.WriteLine("          |                               | ")
            o.WriteLine("          |       /----------------\ _      | ")
```

```
        o.WriteLine("           |       |              | |     | " & Math.Round(2 * pa * ka * 2 + pa, 2) & " m ")
        o.WriteLine("           |       |              | |" & pa & " m  | ")
        o.WriteLine("           |       \---------------/ _      | ")
        o.WriteLine("           |                            | ")
        o.WriteLine("           |                            | ")
        o.WriteLine("           |                            | ")
        o.WriteLine("            \-------------------------------/  ")
        o.WriteLine("                         " & Math.Round((4 * pa + pleng), 2) & " m ")
        o.WriteLine("")
        o.WriteLine("")
        o.WriteLine("Skewness effect coefficent: " & Math.Round(ka, 2))
        o.WriteLine("Pier width: " & pa & " m ")
        o.WriteLine("Gabion layer width: " & Math.Round(2 * pa * ka * 2 + pa, 2) & " m ")
        o.WriteLine("Gabion layer length: " & Math.Round((4 * pa + pleng), 2) & " m ")

        o.WriteLine("Filter Requirements")
        o.WriteLine("Filter Layer Length: " & Math.Round(2 / 3 * 2 * pa + pleng, 2))
        o.WriteLine("Filter Layer Width: " & Math.Round(((2 * pa * ka) * 2 / 3 * 2) + pa, 2))
        o.WriteLine("")
        o.WriteLine("Granular Filter Notes")
        o.WriteLine("Minimum Granular Stone Filter Layer Thickness: maximum of 4 x d50 of the
granular filter or 15 cm")
        o.WriteLine("Granular filter layer thickness increased by 50% for wet placement.")


      End If
      o.Close()


      If flow_panel4.autof.Checked = True Then
        System.Diagnostics.Process.Start("gabion_mattress.txt")
      End If
    End Sub

    Public Sub grout_fill()

      Dim Vdes As Double 'design velocity
      Dim K1 As Double 'shape factor
      Dim K2 As Double 'velocity adjustment factor
      Dim sg As Double 'specific gravity
      Dim vavg As Double
      Dim d_water As Double
      Dim nman As Double


      Dim y As Double
      Dim Tdes As Double
      Dim sft As Double
      Dim d50 As Double
      vavg = CDbl(flow_panel4.Vavg.Text)
      K1 = CDbl(flow_panel4.K1.Text)
      K2 = CDbl(flow_panel4.K2.Text)
      sg = CDbl(flow_panel4.sg.Text)
      y = CDbl(flow_panel4.y.Text)
      Dim j As Integer
      If flow_panel4.vloc.Checked = False Then
        Vdes = K1 * K2 * vavg
```

```
        Else
            Vdes = K1 * vavg
        End If


        nman = CDbl(flow_panel4.nman.Text)
        d_water = CDbl(flow_panel4.d_Water.Text)

        Tdes = (nman * Vdes) ^ 2 * (d_water * 9.81 / (y ^ (1 / 3)))

        sft = CDbl(flow_panel4.sfb.Text) * CDbl(flow_panel4.xc.Text) * CDbl(flow_panel4.xm.Text)
        d50 = sft * Tdes / (0.1 * (CDbl(flow_panel4.sg.Text) * 1000 * 9.81 - 9.81 *
CDbl(flow_panel4.d_Water.Text)))



        Dim o As System.IO.StreamWriter
        o = IO.File.CreateText("gabion_mattress.txt")
        o.WriteLine("Gabion Mattress - Design and  Specifications")
        o.WriteLine("------------------------------------------------------------------------------------------------")
        o.WriteLine("")
        o.WriteLine("Problem Characteristics")
        o.WriteLine("{0,0}{1,31}", "Shape factor (K1) : ", K1)

        If flow_panel4.vloc.Checked = False Then
            o.WriteLine("{0,20}{1,20}", "Velocity adjustment factor (K2) :", K2)
            o.WriteLine("{0,0}{1,40}", "Design Velocity: ", Math.Round(Vdes, 3) & " m/s")
        Else
            o.WriteLine("{0,0}{1,38}", "Design Velocity: ", Math.Round(Vdes, 3) & " m/s")
        End If
        o.WriteLine("{0,0}{1,36}", "Specific Gravity :", sg)
        o.WriteLine("{0,0}{1,51}", "d50 : ", Math.Round(d50, 3) & " m")
        o.WriteLine("")
        o.WriteLine("")
        o.WriteLine("Size Ranges for Rocks to Fill Gabion Mattress")
        o.WriteLine("{0,10}{1,10}", "Mattress Thickness (cm)", "Range of Stone Size ")
        o.WriteLine("{0,10}{1,10}", "--------", "--------")
        o.WriteLine("{0,10}{1,10}", "15", "7.6 to 12.7")
        o.WriteLine("{0,10}{1,10}", "23", "7.6 to 12.7")
        o.WriteLine("{0,10}{1,10}", "30", "10 to 20")

        If flow_panel4.lay_design.Checked = True Then
            ' riprap layer diemsions


            Dim ka As Double
            Dim pa As Double
            Dim skew As Double
            Dim pleng As Double

            pleng = CDbl(flow_panel4.pleng.Text) ' take pier length
            pa = CDbl(flow_panel4.pa.Text) 'take pier width
            skew = CDbl(flow_panel4.pskew.Text) '  river attack angle for pier

            ka = ((pa * Math.Cos(skew / 180 * Math.PI) + pleng * Math.Sin(skew / 180 * Math.PI)) / pa) ^
(0.65)
```

```
        o.WriteLine("")
        o.WriteLine("")
        o.WriteLine("Gabion Mattress Layout Configuration")
        o.WriteLine("")
        o.WriteLine("")
        o.WriteLine("          /-------------------------------\   ")
        o.WriteLine("         |                               | ")
        o.WriteLine("         |                               | ")
        o.WriteLine("         |                               | ")
        o.WriteLine("         |       /----------------\ _       | ")
        o.WriteLine("         |       |               | |     | " & Math.Round(4 * pa * ka, 2) & " m")
        o.WriteLine("         |       |               | |" & pa & " m   | ")
        o.WriteLine("         |       \----------------/ _       | ")
        o.WriteLine("         |                               | ")
        o.WriteLine("         |                               | ")
        o.WriteLine("         |                               | ")
        o.WriteLine("          \-------------------------------/  ")
        o.WriteLine("                         " & Math.Round((4 * pa + pleng), 2) & " m")
        o.WriteLine("")
        o.WriteLine("")
        o.WriteLine("{0,10}{1,25}", "Skewness effect coefficent: ", Math.Round(ka, 3))
        o.WriteLine("{0,10}{1,35}", "Pier width:      ", pa & " m")
        o.WriteLine("{0,10}{1,35}", "Mattress layer width: ", Math.Round(4 * pa * ka, 3) & " m")
        o.WriteLine("{0,0}{1,32}", "Mattress layer length: ", Math.Round((4 * pa + pleng), 3) & " m")
        o.WriteLine("")
        o.WriteLine("(Extend  riprap a distance of 2(a) from pier (minimum, all around))")
        o.WriteLine("!!!Riprap layer should be extended distance of " & 2 * pa & " from every direction!!!")
        o.WriteLine("")


        o.WriteLine("Granular Filter Notes")
        o.WriteLine("Minimum  granular stone filter layer thickness" & Math.Max(4 * d50, 0.15) & "m")

        If flow_panel4.plc_uwater.Checked = True Then
            o.WriteLine("{0,0}{1,41}", "Granular filter layer thickness: ", Math.Round(3 * d50, 3) & "m -" & Math.Round(5 * d50, 3) & " m")
            o.WriteLine("Wet Placement")
            o.WriteLine("The granular filter layer thickness should be increased by 50% when placing under water")



        Else
            o.WriteLine("{0,0}{1,42}", "Granular filter layer thickness: ", Math.Round(1.5 * 3 * d50, 3) & "m - " & Math.Round(1.5 * 5 * d50, 3) & " m")
            o.WriteLine("Dry placement")
        End If

        o.WriteLine("")
        o.WriteLine("!!!Thickness must be increased beyond the full depth of contraction scour and further long-term degradation!!!")
        o.WriteLine("Filter Requirements")
        o.WriteLine("The filter should not be extended fully beneath the gabions; instead, it should be terminated two-third of the distancefrom the pier to the edge of the gabion mattress.")
```

```
        End If
        o.Close()


        If flow_panel4.autof.Checked = True Then
            System.Diagnostics.Process.Start("gabion_mattress.txt")
        End If
    End Sub
End Module

Public Class flow_panel4

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button1.Click

        If rockriprap_r.Checked = True Then
            find_riprap_d50()

        End If

        If acb_r.Checked = True Then
            acb_design()

        End If

        If pargr_r.Checked = True Then

            grout_riprap()

        End If
        If gabion_r.Checked = True Then
            gabion_mat()
        End If

    End Sub

    Private Sub d1_TextChanged(ByVal sender As System.Object, ByVal e As System.EventArgs)
        If d1.Text <= 0 Then
            MsgBox("The equations cannot be solved for  0  therefore, a very small but non-zero side
slope must be entered for the case of 1 = 0.")
        End If
    End Sub


    Private Sub GroupBox2_Enter(ByVal sender As System.Object, ByVal e As System.EventArgs)

    End Sub

    Private Sub RadioButton4_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs)
        If Me.RadioButton4.Checked = True Then
            Me.K1.Text = 1.5
        Else
            Me.K1.Text = 1.7
        End If
    End Sub
```

```
    Private Sub RadioButton2_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs)
        If Me.RadioButton2.Checked = True Then
            Me.K2.Text = 0.9
        Else
            Me.K2.Text = 1.7
        End If
    End Sub



    Private Sub RadioButton7_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles rockriprap_r.CheckedChanged
        Dim g As Control
        For Each g In Me.Controls
            If TypeOf g Is Panel Then
                g.Enabled = False
            End If
        Next

        flow_panel.Enabled = True
        r_panel.Enabled = True
        pier_shape_panel.Enabled = True

        'check for underwater placement
        If rockriprap_r.Checked = True And lay_design.Checked = True Or pargr_r.Checked = True And
lay_design.Checked = True Then
            plc_uwater.Enabled = True
        Else
            plc_uwater.Enabled = False
        End If
        PictureBox.Image = My.Resources.rockriprap
        man_label.Hide()
        riprap_panel.Text = "Riprap Characteristics"

    End Sub

    Private Sub RadioButton8_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles acb_r.CheckedChanged
        Dim g As Control
        For Each g In Me.Controls


            If TypeOf g Is Panel Then
                g.Enabled = False
            End If
        Next
        acb_panel.Enabled = True
        flow_panel.Enabled = True
        flow_panel2.Enabled = True
        pier_shape_panel.Enabled = True
        sf_panel.Enabled = True
        acb_alert.Show()
        acb_alert.Text = ""
```

```
        'check for underwater placement
        If rockriprap_r.Checked = True And lay_design.Checked = True Or pargr_r.Checked = True And
lay_design.Checked = True Then
            plc_uwater.Enabled = True
        Else
            plc_uwater.Enabled = False
        End If
        PictureBox.Image = My.Resources.acb

        man_label.Show()
        man_label.Text = "ACB System"
        GroupBox3.Text = "ACB Characteristics"

    End Sub

    Private Sub vloc_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles vloc.CheckedChanged
        If vloc.Checked = True Then
            vel_adj_box.Enabled = False
        Else
            vel_adj_box.Enabled = True
        End If
    End Sub

    Private Sub lay_design_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles lay_design.CheckedChanged
        If lay_design.Checked = True Then
            Layout_Des.Enabled = True
            plc_uwater.Enabled = False
            If rockriprap_r.Checked = True Or pargr_r.Checked = True Then

            End If
        Else
            Layout_Des.Enabled = False
        End If
    End Sub


    'Grout radiobax a tıklandığında
    Private Sub pargr_r_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles pargr_r.CheckedChanged
        Dim g As Control
        For Each g In Me.Controls


            If TypeOf g Is Panel Then
                g.Enabled = False
            End If
        Next

        grout_panel.Enabled = True

        'check for underwater placement
        If rockriprap_r.Checked = True And lay_design.Checked = True Or pargr_r.Checked = True And
lay_design.Checked = True Then
            plc_uwater.Enabled = True
        Else
```

```
        plc_uwater.Enabled = False
      End If

      man_label.Hide()
      PictureBox.Image = My.Resources.grouted

   End Sub

   Private Sub acb_Load(ByVal sender As Object, ByVal e As System.EventArgs) Handles Me.Load
      rockriprap_r.Checked = True
      plc_uwater.Enabled = False
      acb_alert.Hide()


   End Sub

   Private Sub class_s_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles class_s.SelectedIndexChanged

   End Sub

   Private Sub RadioButton4_CheckedChanged_1(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles RadioButton4.CheckedChanged
      If Me.RadioButton4.Checked = True Then
        Me.K1.Text = 1.5
      Else
        Me.K1.Text = 1.7
      End If
   End Sub

   Private Sub RadioButton3_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles RadioButton3.CheckedChanged

   End Sub

   Private Sub RadioButton2_CheckedChanged_1(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles RadioButton2.CheckedChanged
      If Me.RadioButton2.Checked = True Then
        Me.K2.Text = 0.9
      Else
        Me.K2.Text = 1.7
      End If
   End Sub


   Private Sub gabion_r_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs)
      Dim g As Control
      For Each g In Me.Controls
        If TypeOf g Is Panel Then
          g.Enabled = False
        End If
        flow_panel.Enabled = True
        flow_panel2.Enabled = True
        pier_shape_panel.Enabled = True
        sf_panel.Enabled = True
```

```
        Next
    End Sub

    Private Sub ToolStripButton1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)

    End Sub

    Private Sub ToolStripMenuItem1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)

    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Button3.Click
        selection.Show()
    End Sub

    Private Sub grnflt_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs)
        If lay_design.Checked = True Then
            plc_uwater.Enabled = True
        Else
            plc_uwater.Enabled = False
        End If
    End Sub

    Private Sub GroupBox6_Enter(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles GroupBox6.Enter

    End Sub

    Private Sub RadioButton10_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles gabion_r.CheckedChanged
        man_label.Show()
        man_label.Text = "Gabion Matt. (Range 0.025–0.035)"
        riprap_panel.Text = "Gabion Mattress Characteristics"

        'GABION MATTRESS CASE
        Dim g As Control
        For Each g In Me.Controls
            If TypeOf g Is Panel Then
                g.Enabled = False


            End If
        Next

        r_panel.Enabled = True
        pier_shape_panel.Enabled = True
        flow_panel.Enabled = True
        sf_panel.Enabled = True
        flow_panel2.Enabled = True

        'check for underwater placement
        If rockriprap_r.Checked = True And lay_design.Checked = True Or pargr_r.Checked = True And lay_design.Checked = True Then
```

```
            plc_uwater.Enabled = True
        Else
            plc_uwater.Enabled = False
        End If
        PictureBox.Image = My.Resources.gab
    End Sub

    Private Sub plc_uwater_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles plc_uwater.CheckedChanged

    End Sub
End Class

Public Class selection

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button1.Click
        cselect()
    End Sub

    Private Sub Form1_Load(ByVal sender As Object, ByVal e As System.EventArgs) Handles
Me.Load
        Me.DataGridView1.Rows.Add(6)
        Me.DataGridView1.Rows(0).Cells(0).Value = "Standard (loose) riprap"
        Me.DataGridView1.Rows(1).Cells(0).Value = "Partially grouted riprap"
        Me.DataGridView1.Rows(2).Cells(0).Value = "Articulating concrete blocks"
        Me.DataGridView1.Rows(3).Cells(0).Value = "Gabion mattresses"
        Me.DataGridView1.Rows(4).Cells(0).Value = "Grout-filled mattresses"
        Me.DataGridView1.Rows(5).Cells(0).Value = "Grout-filled bags"

        Me.DataGridView1.Rows(0).Cells(5).Value = 100
        Me.DataGridView1.Rows(1).Cells(5).Value = 100
        Me.DataGridView1.Rows(2).Cells(5).Value = 100
        Me.DataGridView1.Rows(3).Cells(5).Value = 100
        Me.DataGridView1.Rows(4).Cells(5).Value = 100
        Me.DataGridView1.Rows(5).Cells(5).Value = 100

    End Sub

    Private Sub RadioButton2_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles s11_2.CheckedChanged

    End Sub



    Private Sub s11_1_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles s11_1.CheckedChanged

        If s11_1.Checked = True Then
            s12_1.Enabled = False
            s12_2.Enabled = False
            s12_label.Enabled = False

        Else
            s12_1.Enabled = True
            s12_2.Enabled = True
```

```
        s12_label.Enabled = True

      End If

    End Sub

    Private Sub RadioButton12_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles s31_1.CheckedChanged
      If s31_1.Checked = True Then
        s32_1.Enabled = True
        s32_2.Enabled = True
        s32_label.Enabled = True
      Else
        s32_1.Enabled = False
        s32_1.Checked = False
        s32_2.Enabled = False
        s32_2.Checked = False
        s32_label.Enabled = False

      End If
    End Sub

    Private Sub Panel2_Paint(ByVal sender As System.Object, ByVal e As System.Windows.Forms.PaintEventArgs) Handles Panel2.Paint

    End Sub
End Class
```