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Riverbank Protection with Gabion Structure: Gabion Mattress

Metropolia University of Applied Sciences

Bachelor of Engineering

Sustainable Building Engineering

Bachelor's Thesis

11 May 2019

Author Title Number of Pages Date	Rohit Bhandari Riverbank Protection with Gabion Structure: Gabion Mattress. 50 pages + 2 appendixes 11 May 2019
Degree	Bachelor of Engineering
Degree Programme	Civil Engineering
Professional Major	Sustainable Building Engineering
Instructors	Sunil Suwal, Senior Lecturer. Sudarshan Sedhai, Engineer.

The main goal of this study was to show the usefulness of the gabion retaining structure known as gabion mattress for the protection of a riverbank. Gabion mattress has been widely used in the protection of river banks from soil erosion and scour, and keep the slope stable to maintain channel stability and alignment.

This study aimed to highlight the different types of river bank protection methods, Gabion Mattress as one of them. An overview of some qualities of the gabion mattress was presented in this study, as well as several factors that need to be considered while designing and implementing gabion structures. In addition, this study described the construction and installing techniques of gabion mattress by using a hand-made weaving system.

For achieving the aim, the study was supported by the project work (case study) on the river ‘Kayar khola’ located in Chitwan, Nepal. From the field investigation, it was concluded that the protection work should be applied and different purposed activities were made. After the approval from DDC, the implementation of gabion mattresses along with launching aprons with different dimensions were carried out in the river bank. As a result, local people get benefits to upgrade their farming condition.

The thesis can be used as basic information about the protective measure for the bank of a river using gabion boxes or mattresses. Furthermore, the design presented can be used as a general guideline, but not as a strict code of practice.

Keywords	gabion mattress, riverbank protection, eco-friendly structure

List of Abbreviations

DDC	District Development Committee
VDC	Village Development Committee
RPWC	River Protection Works and Livelihood Improvement in Chitwan, Phase II
PSU	Project Support Unit
CMS	Contract Management Specialist
PVC	Ploy Vinyl Chloride
DoR	Department of Road
NS	Nepal Standard
ASTM	American Society for Testing and Materials
SANS	South Africa National Standard
WECS	Water and Energy Commission Secretariat
Fps	Foot per second

Contents

ACKNOWLEDGEMENT

First, I would like to express my heartfelt gratitude to my family and friends who have been a great source of inspiration and support throughout my journey to complete the thesis. I would like to dedicate this thesis to the memory of my Grandmother Bhimkala Gautam.

I am very thankful to Mr. Sanjeeb Rajbhandari (Team leader), Mr. Sudarshan Sedhai, Mr. Bishnu Maurya and all the other staffs of RPWC II from SILT Consultants (P.) Ltd., for providing an opportunity to complete my internships and the thesis on the project.

It is a pleasure to thank my thesis supervisor, senior lecturer Mr. Sunil Suwal and my language instructor Taija Salminen, for their continuous support and suggestions to make my thesis better.

Finally, yet importantly, I am also pleased to thank Metropolia University of Applied sciences and Sustainable Building Engineering (SBE) department's teachers for teaching and guiding me throughout the years to complete my bachelor's degree in Civil Engineering. Thank You.

Rohit Bhandari
10 May 2019
Helsinki, Finland

1 Introduction

In geography, the word ‘riverbank’ means the land alongside the edge of the river where water meets the shore, and ‘riverbank erosion’ is a natural phenomenon of removing or washing away the bed and edge (bank) soil particles of the river that occurs when the volume of water flowing in the system exceeds the total water holding capacity of the river. [1.]

Riverbank erosion affects not only the nearby land but also the infrastructures like bridges, roads, and buildings. In addition, agricultural land, health and sanitation, and social development are profoundly affected. Many developing countries and even countries that are rich in water resources have been highly affected by the high flow velocity of water especially during the rainy season, and a minimum use of protective measures. This study introduces various types of riverbank protection measures. The most common one is the gabion mattress, also known as a Reno Mattress, used widely as a protection measure around the world. [2.]

A gabion is a rectangular mattress or box-shaped container made of galvanized wire with or without PVC coating, filled with stones and used as a retaining structure for riverbanks or retaining walls. In around 1879, a firm called Maccaferri in Italy introduced the gabion basket. Since then, gabion structures have been in high demand and used because they are inexpensive, durable, stable and flexible. [2.]

This study highlights the importance and the use of gabion hexagonal mesh wire mattresses. The objective of the study is to understand what the soil erosion is, what causes it and what effects it has on the riverbank. Furthermore, the final year project aims at understanding the different measures of riverbank protection. Gabion mattresses, the most commonly used protection measures, and their importance, qualities, and design parameters are discussed along with their design and installing procedures. Finally, a project work (case study) where gabion mattresses are used is studied.

In chapter 2, the thesis briefly describes erosion and scour, and their occurrence due to some internal and external forces. Chapter 3 describes the most common river bank protection measures against erosion and scour. Chapter 4 defines the qualities of the gabion mattress, and chapter 5 describes the major consideration and factors that need to be followed while designing and installing the gabion mattress.

Chapter 6 shows wire properties and construction, as well as the installation procedures of the mattress. To illustrate the utility of the gabion mattress, chapter 7 introduces a project work (case study), including project works, field survey, proposed activities, and the implementation of gabion mattress in the ‘Kayar khola’. Furthermore, chapter 7 shows some useful outcomes from the project work. To conclude, chapter 8 presents the outcomes of this study.

2 Erosion and Scour

2.1 Erosion

In simple words, erosion means that the land is detached or washed away by wind, water or other natural means [1]. Bank erosion means the removal or separation of the banks, bed materials of the river or land due to the action of flowing water as the water washes away the sediment particles of the soil. Also, there is another definition which defines ‘bank erosion’ as the movement of sediment particles from the bed or bank of the rivers after the detachment. As a result, stable or unstable river channels are affected by the bank erosion. [3.]

Generally, there are two types of processes of river bank erosion: fluvial erosion and bank failure. Fluvial erosion carries soil particles directly from the river bank. Soil particles are taken away by fluvial erosion due to the force of flowing water, or the quality or resistance of that particular soil, usually clay, has low resistance than soil. Bank failure occurs when the mass of the river bank exceed the strength of the soil particles. This causes the downfall of the bank. Bank failure is often determined by the force of the internal resistance capacities of soil particles, vegetation and soil-water composition, and occurs as a result of fluvial erosion. [3.]

2.2 Scour

Scour is the hole created when soil particles such as sand, gravel, and other sediments are removed from the bank of land because of the extreme force of flowing water. Moreover, according to the report 97-558 prepared by the U.S. Geological Survey Department, there are different types of scour:

- Scour where the sediment around the bridge's piers or any other rigid structure in a river channel is washed away and create holes around the base of the structures known as local scour.

- Contraction scour is the type of scouring that removes sediment from the depth and bank of the river, causes erosion.

- Degradational scour is a scour that removes the sediment from the depth of the river and causes an increase in depth of the river channel. [4.]

2.3 Causes of erosion

The Minister of Agriculture, Food, and Rural Affairs of ontario pointed out that an increase in rainfall, increases the chances of soil erosion. Continuing rainfall can wash away the top surface soil aggregates, such as organic matter, very fine sand, and clay. As a result, also more massive sand and gravel particles are carried away in the process causing soil erosion. [5.]

Soil erodibility, which means resistance capacities of soils, for example sand, sandy loam, and soil with higher infiltration rates, have higher resistance to absorb raindrops than the organic matters slit, and clay. Low infiltration rates soil leads to soil erosion for low resistance materials. In addition, previous occurence of erosion increases the erodibility of soil. Steep and long slopes have higher chances of soil erosion and landslides. When the soil falls downwards, it makes the slope degree higher, which, in turn, causes more soil erosion. Moreover, a loss of vegetation such as forests, and crops, allows rainfall to impact and splash harder on to the soil. This creates erosion. [5.]

According to Fischenich, there are three modes of riverbank failure:

- A Hydraulic failure occurs when the velocity of flowing water in a channel exerts stress greater than the shear stress of the bed or bank. This type of failure usually occurs with a non-cohesive bank of rivers.

- Geotechnical instability failure occurs when the resistance forces are lower than the gravitational forces of the bank materials, causing a downward movement of the soil materials. The moisture excess in the bank usually affects both stresses and resistances.

- A mixture of hydraulic and geotechnical forces are a common cause of a bank failure. [6.]

3 Methods of Bank Protection

Nowadays, various techniques and methods are used to prevent or control the loss of valuable land. There are three general zones in a river bank: toe zone, bank zone and overbank zone. These zones are affected by the movement of soil or land approaching the surface of the water, causing bank erosion. Protection methods need to be designed to control of erosion with adequately designed filters usually enclosed by large-sized materials such as stones, concrete blocks, and gabion wire netting, to grip the energy of moving water. The stability of land against the river water or soil erosion is prevented by applying protection measures. [7.]

A river bank is usually divided into three sections: embankment section, also called the slanted surface in the direction of the river, upper bank section, which is situated below the shore level and above the low water level and lower bank section, which is below the river surface. Depending the section, various protection measures are executed according to its cost and necessity. [7.]

River banks can be protected with non-structural methods, flexible structures, rigid structures, control structures and vegetation.

3.1 Non-structural methods

Rip-rap methods with stones

The rip-rap method, or shot-rock, rock armor or rubble method, is widely used in construction for soil stabilization, bank protection, stonewall backing, gravity retaining wall, and shoreline erosion protection. The rip-rap method is simple to install and maintain. [8.] For rip-rap installations, the maximum suggested face slope is 1V:2H, where 'V' refers to vertical, and 'H,' refers to horizontal. The primary design parameter for a rip-rap design is the velocity as explained by the tractive force theory. [9.]

Sand filled geo-bags

Geotextile bag or geo-bag, a geo-synthetic product made of polyester; polypropylene or polyethylene or jute is used worldwide for defending riverbanks and hydraulic structures from severe scouring and erosion. In this method, sandbags are placed at the slope below the water level, and the slope above the water level is protected with cement concrete blocks mostly to resist waves. Generally, the sandbags weigh 70 kg, 85 kg, 110 kg, or 230 kg. Sandbags are commonly used for both emergency and permanent shields. [10.]

3.2 Flexible Structures

Blocks and slabs

Blocks and slabs are flexible structures for river bank protection. Block and slabs are mostly use in dry condition rather than wet condition (river bank). They are partially in use for river bank protection. [11.]

Gabion structures

Gabion baskets and mattresses are used as retaining wall structures, and channel linings. They are filled with light to heavy stone without mortar [12]. A gabion mat or basket is a structure made of zinc coated soft temper steel in a shape of hexagonal double twisted wire mesh filled with stones. A gabion basket usually has a height between 0.5m to 1m whereas, a gabion mattress has a height between 0.17m to 0.50m [13]. A non-woven fabrication called a geotextile filter layer is used at the base of the gabion structure to prevent water leakage and wash away button soil particles [14].

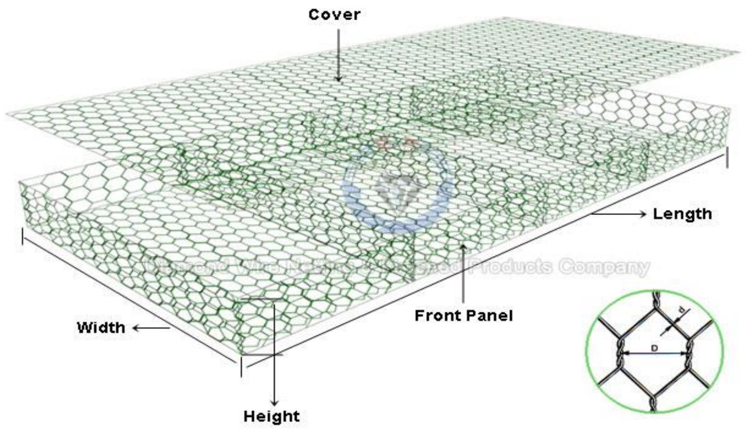


Figure 1. Gabion Mattress, also known as Reno Mattress [15].

Figure 1 shows hexagonal mesh of a gabion mattress. The parts of the gabion as well as the diameter and the width of the wire are marked.

3.3 Rigid Structures

Concrete Paving

A concrete pavement is a covering of an outdoor floor or exterior surface. The covering can be asphalt, stones, concrete on roadsides, patios, courtyards, as well as slope protection against erosion to control the water flow. [16].

Retaining wall system

Retaining walls are a rigid structure, made of stone, concrete, steel-reinforced, wood planks or other substantial and rigid materials. Retaining structures are typically used to support the soil, water, coal, and land on a steep slope, near vertical slope or in areas where there are chances of erosion. Retaining walls are classified according to their stability. The most common wall systems are gravity walls, cantilever retaining walls, and anchored walls as shown in figure 2. [17.]

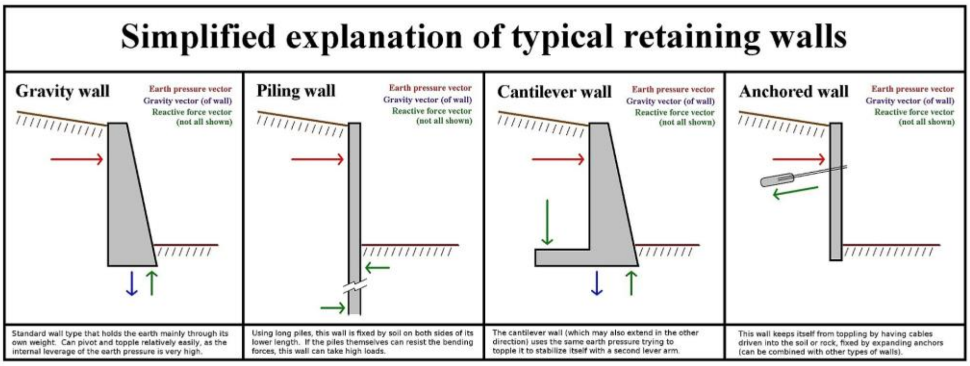


Figure 2. Most common types of retaining walls structures [18].

Figure 1 shows that gravity wall can hold their stability mostly through their own weight and soil resting on the wall. The lower length of the piling wall is fixed by soil on both sides and can resists higher loads if the bending force is not applied. Cantilever wall is most commonly used retaining wall because its individual parts work as a function of strength for the stability. Anchored wall keeps itself from falling by having cables driven into the soil or rock, fixed by expanding anchors.

3.4 Control Structures

Check dams

Check dams are constructed in different shapes and sizes, and as permanent or temporary structures with various materials such as stones, clay, sandbags, and cement. The installation method of a check dam is depends upon the location. The best use of a check dam is to regulate the surface water during and after monsoon periods to prevent erosion by reducing the velocity of running water, and to trap transported sediments, and prevent further transport downstream. Specific maintenance is needed to avoid any damage to check dams. [19.]

Durable obstructions

Durable obstructions contain large- or small-scale materials, and techniques, such as the use of natural vegetation, for example woods, leaves, and grasses to prevent or control the land from being eroded for specific time periods. [19].

Use of Vegetation on Riverbank Stability

Bio-engineering uses live vegetation and woody materials to prevent erosion. It requires some time to establish vegetation, but once establish, a plant will ultimately sprout, providing enlarged resistance to erosion and steadying the bank over a long term. Bio engineering supports the river bank by reducing the impact of raindrops by absorbing the energy formed by the rainfall. [3.]

There are many examples and a lot of evidence about the use of vegetation to prevent or control soil erosion, especially in sloppy areas. furthermore, research has shown that the use of grasses and trees provides stability to the riverbank due to the variation in the root size. Especially, forested vegetation whose root thickness is more than 0.5 mm in diameter offers improved stability against riverbank erosion compared to thin roots. [3.]

4 Qualities of Gabion Mattress Structures

Gabion wall structures, such as double twist mesh gabion and reno mattresses, in rivers and channels have been extensively used in water ways, road and civil projects [20]. A gabion mattress prevents soil erosion and it is flexible, sustainable, stable and durable.

4.1 Flexibility

Gabion mattress structures are easy to construct and install. Gabion mattress do not require very skilled manpower, large mechanized construction equipment, or complected technical ways. The structure can be made on site. Gabion mattress with low carbon steel mesh wire have a high level of capabilities to bear unexpected and localized stress. [20.]

A gabion structure tolerates differential settlement and prevents loss of structural efficiency. However, in case of a simple mistake such as small lacing, unsuitable stones, or a defective geotextile filter, the structure may fail. [21.] The flexibility increases the use of gabion in rockfall barriers. Gabion structures are not only a rural solution, they are also widely used in modern building and wall-retaining structures. The gabion structure is fast to construct and can be used immediately in both wet and dry conditions. The gabion mattress does not have any hydrostatic pressure problems and have free draining. [20.]

In addition, it is possible to replace the stones by sand-bags. However, precautionary measures should be taken with sand-filled gabions because there are no proper holes for water drainages and sand-bags will lose sand if penetrated. Therefore, the use of sand-bag gabions is not common in hydraulic applications. [22.]

4.2 Sustainability

Gabions are sustainable, they have a low carbon footprint, whereas concrete structures have a high carbon footprint. The comparison of a concrete retaining wall with a gabion solution of the same height shows that up to 80% of CO2 emissions can be reduced by using gabion structures. A gabion wall built using rocks taken from the perimeter of around 100Km has a carbon footprint of about 5,000kg CO2 eq., and if the rocks are brought from a distant quarry, the carbon footprint is about 8,000kg CO2 eq. However, both are better than the carbon footprint of 53,000kg CO2 eq. for an equivalent concrete structure. Therefore, the gabion structure has a small carbon footprint compared with alternative structures. A gabion structure regulates the climate and humidity of its environment. [22.]

According to an article by APEC Group, the gabion structure’s materials are cheap and easy to construct without vast experience in a short period. Furthermore, they are greener than concrete. With passing time, the stability and strength of a gabion structure will develop with the subsequent growth of re-vegetation that can take place when plants colonies the interstitial spaces between the rock fill. The rockfill enhances the ecosystem as it allows the free flow of water as well as the growth of plants through the structure. Therefore, the structure is also beneficial for nature. However, vast woody vegetation should not be allowed to grow in the gabions because it may break the wire and damage the gabion for further use. [23.]

Gabion structures, made of stone and wire, are less expensive than other construction materials. Stones used in the gabion structure are usually locally available, and wires are easily accessible in the market at low cost. Unskilled labor can easily construct the structure by simply following the instructions. Because of its simple construction, local or unemployed people get employment during the project period. Pilings, underwater drainage systems or excavation are not necessary to implement the gabion structures.

After the completion, the gabion structure is ready to take its full load immediately without the 1-2 month wait that concrete structures require. [23.]

After the implementation, a gabion structure prevents the effect of flood and increases the productive infrastructure like an irrigation system. A proper irrigation system increases the production of harvest in agricultural field. Also, the value of land increases, thus improving the livelihood of local communities. [36; 37.]

4.3 Stability

According to research conducted by Army Engineer Research and Development Center in Vicksburg, the critical shear stress and the critical velocity calculations are the two common methods used to determine the stability of gabion structures [14]. Additional drainage is not required to release the hydrostatic pressure because the stones that fill the gabion box release water through the structure and, thus, maintain the stability of soil [25].

According to the article on the stability of gabion walls for earth retaining structures, the interlocking configuration should be used as an alternative to the conventional stack-and-pair system. A hexagonally shaped gabion shows better strength capabilities then the traditional rectangular shaped gabion. Zinc-coated steel wire mesh filled with stones can resist much more sorts of stress, especially tension and shear, and provide a board reinforcement throughout to structure. [24.] Another test was conducted where gabion mattress known as reno mattress were found to be more stable than the rip-rap method under the same flow level of turbulence [21].

4.4 Durability

Generally, a gabion mattress has a long period of use, about 30-50 years, but only with proper maintenance. Unlike reinforced concrete structures, gabion structures do not have steel cast and good cover to protect them from the elements for example damage, theft, and corrosion. So, the wire is exposed to the elements, and after 30-50 years of use, the zinc coating in the wires slowly disappears, thus becoming the thinner in diameter. However, they can still be in use for some years. Research has shown that zinc galvanizing with aluminum-enhanced alloys has an estimated life expectancy of up to 50 years before the zinc coating is lost. Even in case of a break of any single wire, the double twisted mesh wire prevents the breaking of the whole wire and the movement of stones out of the gabion. Even if a wire is broken, soil and plant roots present between the stones grow, thus forming a uniform solid structure of the gabion. [22.]

For additional protection, a polymer sleeve of PVC or nylon is extruded over the wire to protect it from elements, resist mechanical or chemical effects to the wire, and increase the life-span of the wire. Usually appropriate geotextile fiber cloths are placed behind and under the gabion structure on all soil-gabion interfaces, which also improves the durability. [22.] Gabion structures have a wide range of uses; the most common areas where utilization of gabion is in high demand are:

- mass gravity walls
- architectural applications
- hydro-chambers
- biofilters
- river protection structures
- bridge base protection
- rock wall mesh netting
- river diversion structure
- river canal lining
- reinforced soil walls [26].

5 Design Consideration for Gabion Mattress

There are design constraints and important design criteria that should be considered when designing and installing gabion mattresses. Rivers are dynamic units in which the hydraulic and channel boundaries are regularly changing and vary with time. The design of a river bank protection cross section should consider the dynamic environment in which the designed works are constructed. [38.] The most important design constraints and design criteria for gabion mattresses are discussed below.

5.1 Design Constraints

5.1.1 Scour Depth

Riverbank protection works are designed to resist scour. Scour occurs when the flood water passes around an obstruction and has to change its velocity and direction. As a result, soil erosion occurs. There are different types of scouring such as bend scour and constriction scours. If river protection works fail, it is usually due to an underestimation of the depth of scour, so it is important to consider the expected scour near the structure during the design phase. To account for scour and morphological changes, there are two options are available.

- Structure foundation constructed sufficiently deep at or below the estimated maximum scour level.
- Structure foundation constructed above the estimated maximum scour level but with launching apron.

Scour depth can be calculated by using Lacey's formula,

$$\boldsymbol{R = 0.47\ (Q/f)^{1/3}} \tag{1}$$

where
R is depth of scour below High Flood Level(HFL)
Q is Discharge intensity (m³/sec).
f *is Lacey's silt factor,* $1.76(d)^{1/2}$ *where d is the average diameter of the material in the river bed section in mm. [27.]*

5.1.2 River Morphology

Riverbank protection works have an impact on the river morphology, but they are also affected by the morphological changes of the river. A well-designed protection structure should resist erosion during its period of use. Proper maintenance increases the life of the structure. However, protection measures are localized and not able to constrain the whole cross-section of the river or channel. Non-protected areas usually face the migration of channel bed and bank materials. The movement of bed and bank materials is generally taken into consideration when the protection works are done nearby the boundaries of the area, such as the toe of the revetment. Concerning this, sediment transport is not an issue to be considered when designing the river protection works. However, the migration and the deposition of the sediment carried away from the bed, and a bank of the river should be studied with reference to

- Long-term degradation and aggradations due to changes in the boundary condition and upstream river works.
- Channel relocation upstream and downstream of the river training works.
- Channel cross-section changes due to seasonal or day to day variation in sediment transport and flow rate.
- Location of existing revetments or other forms of river training works. [28.]

5.1.3 Hydrology and Flow Regulation

The hydrology of the river controls the hydraulic conditions to which the structure will be exposed. The hydrology of the river might change because it is dynamic and reliance on the historical situation may cause an actual change in the flow conditions before and after the construction. An increase of urban developments, climatic changes, changes to land use in the catchment or implementation of river works upstream, all have a potential to increase the hydraulic load on river works. Such activities lead to the rise of currents, and higher flood levels. The rapidly changing water levels may influence the design works because

- an increased flow of currents, which leads to an increased size of the stones in the armor layer and, as a result, an increased thickness of the structure.
- increased flood levels cause increased crest level of the river bank protection works, e.g., bank protection, spur, dyke or guide bund.
- the fluctuated level of water, or fall of water leads to a decrease in the stability of the river bank protection works, especially at slope areas. [28.]

5.1.4 Local Currents and Turbulence

Current velocity is the primary factor determining the size of armor stone. However, seasonal rises or falls of the water level cause the large variation in the current speed in the river. The presence of structures, obstructions, bends, and roughness in the bed and bank of the channel affect the current, creating eddies and turbulence. Eddies and turbulence are capable of imposing more loads on the river bank protection works than currents alone. That is why it is essential to study the series of current velocities as well as the degree of turbulence that might appear and increase due to the obstruction created by the river protection works. [28.]

In this respect, it is not practical to use different sizes and shapes of the protection structures because the river morphology changes at every chainage. Hence, the river channel is divided in various reaches to optimize the values of the protection structures and launching apron. [28.]

5.1.5 Geotechnical Boundary Conditions

The geotechnical stability of a structure includes the safe slope angle, the primary geotechnical factor together with depth and the slope angle of the local scour holes at the toe. These are essential factors that influence the design boundary conditions of river a bank protection work. The stability of bank protection works should be designed according to the sliding of the slope and subsoil foundation, and settlement and bearing capacity. Some stability problems such as local scour, internal erosion or piping, hydraulic gradient forces or rainfall runoff above the water line are considered as failure factors, but such problems are reduced by conducting proper geotechnical investigations, adequate compaction of the subsoil, and geotechnical design. [28.]

It is important to use of under-layer geotextile filter fiber since it provides proper drainage from the foundation and locks up the soil particles from being washed away. The use of earthen dams, also known as levees or dykes, is also another essential structure which should be placed at a suitable place that limits a river flood within the cross-section available between the dams, thus allowing no spill to the floodplains, a typical problem in many rivers as shown in figures 3 and 4. [28.]

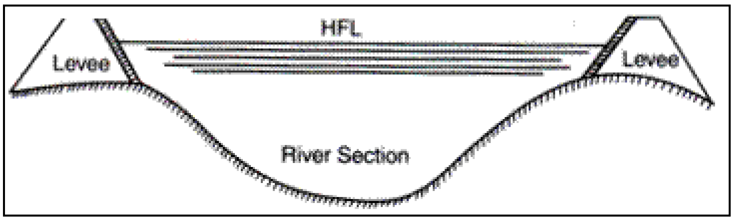


Figure 3. Marginal Embankment or levees/dykes [29].

Figure 3 shows the high flood level (HFL) between levees on the river section. Levees or dykes limit a river flood within the river section.

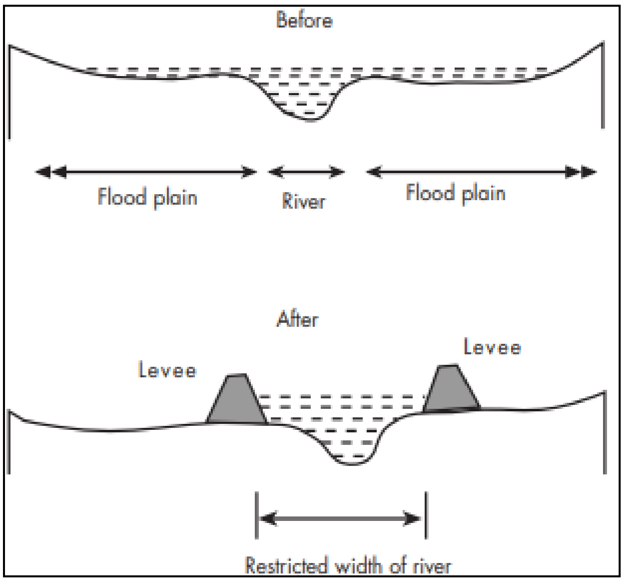


Figure 4. A river cross section before and after building levees [29].

However, the use of such embankments has an undesired long run effect as they deposit the sediments over the years, thus rising the river bed level. This can lead to floods. [28.]

5.2 Design Criteria for Gabion Mattress

5.2.1 The Thickness of Pitching and Size of Stone

According to Freeman and Fischenich, the largest diameter sized of filling material stones, should not be more than about two times the diameter of the smallest sized stones, and the height of the mattress should be at least twice the depth of the largest stone size [14]. Another important factor that needs to be taken into consideration is that a structure placed in sloping areas of a river has to withstand the high force of flowing water. Gabion mattresses face higher velocities of water than gabion baskets, are much shallower, and move, so care should be taken to design so that a mattress can resist the forces applied by the velocity of water. The slope must be pitched manually with gabion mattresses. [30.] The medium size of stones used for gabion mattresses can be determined by the equation 2 [14].

$$d_m = S_f\, C_s C_v d \left[\left(\frac{\gamma_w}{\gamma_s-\gamma_w}\right)^{0.5} \frac{V}{\sqrt{gdK_1}}\right]^{2.5} \tag{2}$$

Where the variables are:
C_s*= stability coefficient (use 0.1)*
C_v*= velocity distribution coefficient*
= 1.283-0.2 log (R/W) (minimum of 1.0) and equals 1.25 at the end of dikes and concrete channels
d_m*= average rock diameter in gabions*
d*= local flow depth at V*
g*= acceleration due to gravity*
K_1*= side slope correction factor (Table 1)*
R*= centerline bend radius of main channel flow*
S_f*= safety factor (1.1 minimum)*
V*= depth-averaged velocity*
W*= water surface width of the main channel*
γ_s*= unit of the weight of stone*
γ_w*= unit of the weight of water*

Table 1 below describes the value of K1 for equation 2. '1V' is the vertical height and '1H' is the horizontal length. Equation 2 was developed to prevent the movement of the stones from the gabion, and it also removes the deformation of stones when the stone sizes are not sufficient to resist the high velocity of water.

Table 1. Shows side slope angle vs. side slope correction factor [14]

Slide Slope	**K1**
1V : 1H	0.46
1V : 1.5H	0.71
1V : 2H	0.88
1V: 3H	0.98
<1V : 4H	1.0

However, in some situations, regardless equation 2, different round, irregular sizes and shapes of stones with a dimension of 2 to 2.5 times larger than the mesh's opening of the gabion structure are used in gabion mattresses. By doing so, the filled stone should not come out from the hexagonal mesh diameter of the gabion. Stones or rocks can range from 75mm to 150mm, and upto 2/3 of the thickness of the mattress, and to make the structure compact, small stones are palced to fill the gaps in the structure. In the marine environment, the minimum size of stone should be 150mm. An oversize of 5% and/or an undersize of 5% in the sizes of stones are acceptable and can make layers of stones, but care should be taken when placing stones to evade the damage to the wire coating. [13; 35.]

Moreover, Maccaferri, an Italian family-owned multi-national civil engineering company that provides services in retaining structures and other soil protection solutions, offers materials information on sizing the stones, the size of gabions, and allowable velocities for gabion baskets and gabion mattresses as seen in table 2 [30].

Table 2. Reference values of stone sizes and acceptable velocities for gabions [14]

Type	Thickness (m)	Filling Stone Range (m)	D50	Critical* Velocity (m/s)	Limit** Velocity (m/s)
Reno Mattress	0.15	0.07- 0.10	0.08	3.50	4.20
	0.15	0.07 – 0.15	0.10	4.20	4.51
	0.22	0.07- 0.10	0.08	4.51	4.87
	0.22	0.07 – 0.15	0.11	4.51	6.10
	0.30	0.07 – 0.12	0.10	4.14	5.49
	0.30	0.10 – 0.15	0.12	4.99	6.40
Basket	0.45	0.10 – 0.20	0.15	5.79	7.59
	0.45	0.12 – 0.25	0.19	6.40	7.98

*critical velocity is the velocity at which a gabion mattress or basket stays steady. *limit velocity is the acceptable velocity at which there is some deformation of the mattress or basket due to slight movement of filling stones in internal compartments or cells.

A report prepared by Gary E. Freeman and J. Craig Fischenich on Gabions for streambank erosion control, shows that when the data in table 2 is compared to Equation 2, if V = 3.50, Cs = 1.0, K1 = 0.71, γ_w = 150 and S_f = 1.1, then to get the depth of local flow in a range of 7.6 m, the diameter of 0.086 m as shown in table 2, should be placed in equation 2. However, table 2 just shows the reference values for the general guidelines for the size of the filling stone and allowable velocities [14].

Moreover, Maccaferri also provides an equation of shear stress to calculate the stability of gabions. In the open channel flow, shear stress is a measure of the force of moving water against the bed of the channel.

5.2.2 Shear Stress Analysis at Bed and Bank Materials

Shear stress analysis at bed and bank materials is a necessary part of design. Usually, projects follow the previous shear stress results at the areas for the shear stress analysis. However, some local projects are done with a normal calculation for shear stress. The equations below are used to calculate the shear stress of the river and the results show whether a structure is stable or not after the implementation.

Shear stress is calculated as [31]

$$\tau_b = \gamma . d . S_w \tag{3}$$

Where
τb= Shear Stress (N/m^2 or lb/ft^2)
γ= Weight Density of Water (N/m^3 or lb/ft^3)
d = Average water depth (m or ft)
Sw = Water Surface slope (m/m or ft/ft)

Along with the bank shear, τm is considered as 75 percent of the bed shear, i.e. the maximum shear stress acting on the bank

$$\tau_m = 0.75\, \gamma . d . S_w \tag{4}$$

The above equation (4) is then related to the critical stress for the bed which is calculated as:

$$\tau_c = C(\gamma_s - \gamma_w). d_m \tag{5}$$

Finally, the critical shear stress for the banks is calculated as

$$\tau_s = \tau_c \sqrt{1 - \frac{sin^2\theta}{0.4304}} \tag{6}$$

Where
τ_c = Critical shear stress on inverts in lb/ft2
τ_s = Critical shear stress on banks and side slopes in lb/ft2
*C * = Shield's parameter (0.10 for gabions and mattresses)*
γ_s = The it weight of the stones in lb/ft3

d_m= Median size of stone rocks in ft.
θ = Bank side slope angle in degree
ϕ = Internal friction angle of stone fill in degree

As a result of the above equations, the design is acceptable if the following conditions are achieved:

1) The design of the structure is stable and acceptable if the shear stress (τ_b) is equal to or smaller than 1.2 times critical stress $(\tau_{c)}$ $i.e.\ \tau_b \leq 1.2\,\tau_c$
2) The bank or side slope of the channel is stable if the maximum shear stress is less or equal to critical (permissible) shear stress i.e. $\tau_m \leq \tau_s$
3) With limited deformation, it may also be acceptable if the maximum shear stress is less or equal to 1.2 times the critical (permissible) shear stress i.e. $\tau_m \leq 1.2\,\tau_s$. [31.]

5.2.3 Velocity at Underlying Bed and Stability of Bank Materials

One of the primary considerations is the stability of gabion structures, i.e. the stability in the foundation of a gabion mattress or gabion basket. This stability can be determined by achieving the appropriate values of the velocity of water that passes through the gabions to the base soil of the gabions. [31.]

By using the Manning equation (equation 7), the velocity of water at the base soil or underlying the filter interface to the gabions can be calculated as

$$\boldsymbol{V_b} = \frac{\mathbf{1.486}}{\boldsymbol{n_f}} . \left(\frac{\boldsymbol{dm}}{\mathbf{2}}\right)^{\frac{2}{3}} . \boldsymbol{S}^{\frac{1}{2}} \qquad (7)$$

Where
n_f is the Manning's roughness coefficient i.e. 0.02 for geotextile filter, 0.025 for gravel filter,
S is water surface slope (m/m or ft/ft),
d_m is the medium size of filling stones,
V_b is the velocity in the mattress/filter interface. [31.]

To accept the design, the calculated value of the velocity of water at the base soil or underlying the filter interface to the gabions (V_b) must be equal to or less than the allowable velocity of soils at the river bed as shown in table 3.

Table 3. Reference values of acceptable velocities of soils at river bed [31].

Soil Materials	Velocity (ft/sec)	
	No material carried in suspension	Colloidal material carried in suspension
Fine sand (non-colloidal)	1.5	2.5
Sandy clay (non-colloidal)	1.7	2.5
Soft clay	2.0	3.0
Mud	2.5	3.5
Coarse sand	2.5	5.0
Stiff clay	3.7	5.0
Gravel	4.0	6.0
Shingle	5.0	5.5
Very Stiff Clay	6.0	6.0

The report prepared by Simons et al. recommended that the water velocity under the filter fabric through the gabions should be one-fourth (1/4) to one-half (1/2) of the value of V_b given in euqation 5. If the stability of soil underneath the filter fabric at the filter and soil interface is not achieved, it is essential to add extra filter fabric under the gabion structure to gain soil stability. [31.]

5.2.4 Determination of Filter Requirement

According to Simons et al., filter fibers are easy to install and effective in use when the interface velocity is low, but in case of larger forceful velocity, gravel filter material is highly recommended. Simons et al, suggest that geo-textile filter fibers, including gravel filter fibers, are the most important thing that needs to be placed before installing gabion mattresses or gabion boxes on the ground to eliminate leakage water into the gabion structures. [31.] Furthermore, It is also noted that,

$$V_f = \frac{1.486}{n_f} . \left(\frac{dm}{2}\right)^{\frac{2}{3}} . SVa^{\frac{1}{2}} \quad (8)$$

Where
V_f *is a residual velocity on the bed, i.e. under the gabion mattress and under the filter fabric,* Va *is the average channel velocity and* V_b *can be determined from equation 7.*

For noncohesive soil,

$$\boldsymbol{V_e = 16.1\, d^{\frac{1}{2}}} \quad (9)$$

where
V_e *is erosion velocity for loose soil.*
d *is diameter of stone in mm.*

For cohesive soil,

$$\boldsymbol{V_e = \sqrt{\frac{8\tau}{f\rho}}} \quad (10)$$

Where
τ *can be determined from equation (2),* f *is the Darcy-Weisbach friction factor. In general,* f *varies from 0.02 to 0.05 depending on surface roughness, channel slope and Reynolds number (Chow, 1959). For equation 10,* f *= 0.025 is suggested. p is the density of water.*

If the residual velocity is smaller than the erosion velocity i.e. $V_f < V_e$, simons at al. suggested the use of geotextile filter, but if the residual velocity is two or four times higher erosion than erosion velocity i.e. $V_f > (2\ or\ 4\ times)\, V_e$, then a gravel filter is used until the residual velocity (V_f) is in an acceptable range.

To check an acceptability filter use the average diameter of the stone (d_m) in equation 8. If still the value of V_f is too high, then the stone size should be reduced to obtain an acceptable value for V_f.

Simons et al. also suggested that to achieve a stable structure between the mattresses, filter, and base soil, a combined geotextile and gravel filter should be used under high intense water velocity. The test result of Simon et al. indicated that the use of gabion mattresses is very beneficial due to them being more stable and economical than the rip-rap structure. [31.]

5.2.5 Determining Deformation, Launching Apron and Wire

Deformation occurs when the shear stress in the gabion mattress increases and reaches a critical value that causes movement of stones in the units, as shown in figure 5.

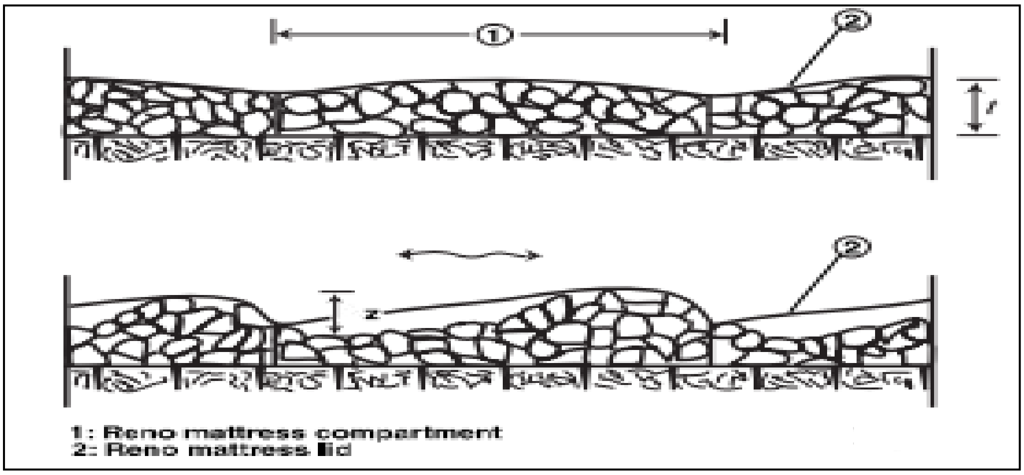


Figure 5. Undeformed gabion above and deformation of stones under a mattress due to high velocities of current below [31].

According to Simons et al., a mattress with a thickness equal to or larger than nine inches would still be effective to protect base materials in a mild slope channel bed under a velocity up to 20 fps (equal to 6.096 m/s). However, either gravel filter or geo-textile or a combination of both filters should be utilized to reduce the velocity of the water at the interface between mattress and filter that attacks the base materials. [31.]

To stabilize the gabion mattress on slope areas, a launching apron is commonly used. A launching apron has a similar shape as the gabion mattress that is made of a flexible double twisted mesh wire and filled with stones. A launching apron is an important and a necessary structure placed at the end of the gabion mattresses to protect the structure from failure due to scouring at the toe of the structure. Scouring is a process of removing the bed or bank of the river by the actions of waves. Scouring often occurs near the structure during construction where the construction works obstruct the flowing water and change the its velocity.

The launching apron is highly flexible due to the round natural river stones. Its minimum depth is 0.20 m to 0.30 m. The length of a launching apron shall spread beyond the base of the gabion mattress minimum two times the estimated depth of scour. If the apron needs to be placed in deep water, it is practical way to prefabricate the apron on a barge, and then put it into the water. However, the size of the apron depends upon the deck size of the barge.

Wire plays a vital role in determining the durability and flexibility of a gabion mattress. Gabion mattress is all about stones and wire used in it. Types of steel wire used in gabion mattresses include galvanized steel, PVC coated steel, galfan steel and stainless-steel wire. These wire types are colorful and have a high level of corrosion resistivity, UV protection, and high tensile capacities. Wire properties are discussed more in chapter 6.2 below.

6 Design of Gabion mattress

6.1 Gabion Mattress

A gabion mattress, also known as a Reno mattress or revet mattress, designed in a hexagonal mesh with double or triple twisted structure is used as retaining wall structure and channel linings. All physical and mechanical properties of gabion mattresses are manufactured according to various standards, such as SANS 1580:2005 (South African National Standard), ASTM A975-97(American Society for Testing Materials), BS EN 10223-3:2013 (British-Adopted European Standard), BS EN 10218-2:1997 (British Standard). The standards are briefly discussed to indicate their differences. The Nepalese standard NS 169-2045 is discussed in chapter 7 for the case study.

A gabion mattress is not high compared with a gabion basket filled with stone or rock at a project site. The mattress is divided into cells with internal diaphragms. The mattress forms a flexible, permeable, monolithic structure used widely in erosion control, riverbank protection, coastal protection, channel linings and also to promote the eco-system by the growth of natural vegetation. [32.]

There are different forms of gabion mattresses having their specific part of the role in different areas.

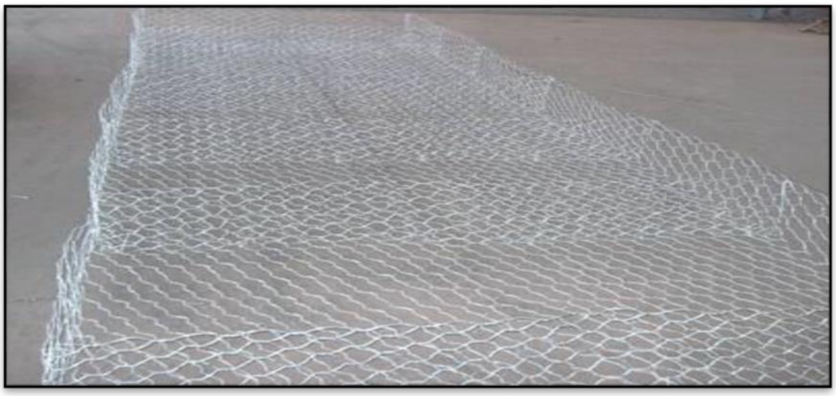


Figure 6. Woven mesh hexagonal gabion mattress [32].

Woven gabion mattress is a reno mattress used widely for river bank protection, slope protection, coastal protection, channel lining, revetment, and other protective measures as shown in above figure 6.

Figure 7. Welded mesh gabion mattress [32].

Welded gabion mattress is a reno mattress used for decoration, like landscape construction, fire-place, and retaining wall structures. Also, it can be used for slope protection, the same way as a woven reno mattress, as shown in above figure 7. [32.]

6.2 Materials Charastictis of Gabion Mattress

Wire Properties

Manufacture companies develop various types and sizes of gabion boxes as well as gabion mattress. According to the given standards, for example double twisted hexagonal woven steel wire mesh (type 60) have a nominal mesh dimension of 60mm x 80mm, and other one (type 80) have a nominal mesh dimension of 80mm x 100mm of the opening of mesh, where the first number denotes the width ‘b’ of the mesh as shown in table 4. The types 60 and 80 reno mattresses are widely used in riverbank protection, depending upon the river morphology. The steel wire used in a gabion mattress is PVC coated, heavily zinc coated soft tempered steel (Class A), according to the standards. The PVC coating provides additional protection against corrosion. Hexagonal mesh wire gabion usually has a wire diameter of 2.7 mm or 3.0 mm [33].

The PVC coating of the galvanized wire provides durable protection against corrosion. According to SANS 675:1997, the tensile strength of the wire should be between 350-575 N/mm². The properties and tolerances of the steel wire and mesh are taken from Diamond Wire Netting and Finished Products Company as shown in tables 4 and 5. [13.]

Figure 8. PVC Coated, Galvanized, and Combination of both used as Gabion mattress [31].

Figure 8 above shows the different types of mesh used for making gabion structures. Galvanized wire (Zinc coating) is manufactured with a hot-dip process with iron (Fe) and Zinc (Zn), and further coating with PVC (Polyvinyl chloride) provides higher corrosion resistance, UV resistance, colors, and makes the mesh easy to assemble [13].

Table 4. Standard mesh-wire of type 60 and type 80 gabion mattress [13]

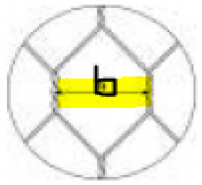
STANDARD MESH PROPERTIES			
Mesh Type 60 60 x 80 (mm)	b (mm)	Tolerance (mm)	Nominal wire diameter (mm)
Galvanised + PVC	60	-4 +10	2.2 / 3.2
Mesh Type 80 80 x 100 (mm) Galvanised + PVC	80	-4 +10	2.7 / 3.7
	Mesh tolerance: The tolerance on the opening of mesh `b' being the distance between the axis of two consecutive twists according to SANS 1580:2005.		

Table 4 above shows that as the mesh opening size increases, the nominal wire diameter is also increases. PVC coated galvanised wire has bigger wire diameter than a ordinary wire.

Table 5. Properties of wire of gabion mattress [13].

PROPERTIES OF WIRE				
Characteristic	Units	Lacing	Mesh	Selvedge
**Galvanised+PVC	$\emptyset\ mm$	2.2 / 3.2	2,7 / 3.7	3.4 / 4.4
Wire Tolerance*	$\emptyset\ mm$	±0.08	±0.08	±0.1
Quantity of zinc*	g/m^3	245	275	275
Tensile strength*	N/mm^2	350 - 575		
**according to SANS 1580:2005 and SANS 675:1997 *according to SANS 675:1997				

In the gabion structure, a wire with the greater diameter than the mesh wire is used to selvedge the edges of all mesh panels. Gabion mattresses are divided into separate compartments situated at approximately 1m from the center. The sizes and dimensions are shown in table 6. The standard mesh wire types, tolerance, and diameters are shown in table 7, according to ASTM A975.

Table 6. Standard Gabion Mattress Sizes of Type 60, according to SANS 675:1997 [13].

GABIONS						
Nominal Dimensions			Number of Cells	Capacity (m^3)	Units/Bundle	
Length (m)	Width (m)	Height (m)			Zinc	PVC
* 2,0	1,0	0,30	2	0,60	80	60
* 3,0	1,0	0,30	3	0,90	60	40
6,0	2,0	0,17	6	2,04	25	20
6,0	2,0	0,23	6	2,76	25	20
6,0	2,0	0,30	6	3,60	25	20
Binding Wire: Sufficient wire should be supplied for lacing and bracing operations.						

As seen in table 6, gabion structures with different nominal dimensions have different number of cells and their capacity as described in SANS 675:1997.

Table 7. Standard Mesh-Wire, according to ASTM A975

Type (mm)	'D' (mm)	Tolerance	Internal Wire Diameter (mm)
80 x 100 Zinc coated	83	±10%	3.05

In according to SANS 675:1997 and EN 10223-3, the minimum mesh properties for the strength and flexibility that the wire manufacture should follow are listed below [13].

Tensile strength: The tensile strength of a gabion wire should be between 350-575 N/mm^2.

Ductility: The zinc-coated wire used in a gabion should be ductile, which means that when the wire is wrapped around a wire with the same diameter at least eight times at a rate of not more than 15 turns per minute, and then unwrapped at the same rate, it doesn't indicate any signs of fracture on the original steel wire.

Elongation: When testing a 25 cm long wire, the elongation should not be less than 10% in accordance with European standard (EN 10223-3).

Adhesion of Zinc: The adherence of zinc to the steel wire should be so strong that rubbing with bare hands does not flake or crack the zinc coating.

6.3 Making of Gabion Mattress

In the context of Nepal, both hand woven gabion systems and machine-made woven gabion systems are used. According to CMS (Contract Management Specialist) in Nepal, machine woven gabion boxes are better than hand woven systems regarding tightness of twisting, uniform manufacture, and thickness (shown in table 8), but due to poor availability of machines and the more costly production, some areas are use a hand-woven systems. The hand-woven gabion boxes require extra thickness to compensate for equivalent retaining force (shown in table 9). [39.] The project work presented in chapter 7 follows the specification of DoR (Department of Roads, Nepal) for hand-woven systems. The making procedures presented below are the common procedures of making the hand-woven system for the manufacture of gabion mattress.

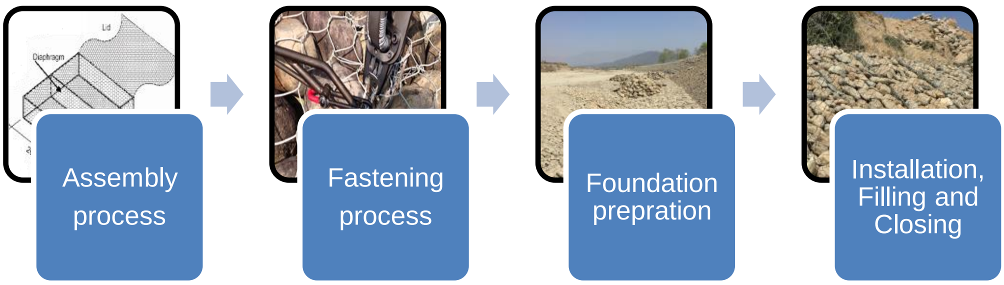


Figure 9. Making process of gabion mattress.

Figure 9 shows the making process of a gabion mattress, starting from assembly process to installation, filling and closing.

Table 8. The diameter of wires in DoR (Hand-made and Machine-made) specifications [39].

Mesh Opening	DoR specification (Hand-made specification)			Machine made specification		
100mmx120mm	Selvedge Wire	Mesh Wire	Binding Wire	Selvedge Wire	Mesh Wire	Binding Wire
	7 swg (4.47mm)	10 swg (3.25mm)	12 swg (2.64mm)	3.9mm	3.0mm	2.64mm

*swg- Standard Wire Gauge

As seen in table 8, the result for the mesh opening of 100mm x 120mm shows that the hand weaving gabion require extra thickness of the wires to compensate for equivalent retaining force than compare to machine weaving gabion.

Table 9. Weight of Wires for Machine made woven and Hand-made woven gabion boxes [39].

Gabion box L x b x h	Weight in Kg per box for Hand-made woven	Weight in Kg per box for Machine made woven
3 x 1 x 1 m	39.41	29.64
2 x 1 x 1 m	27.26	20.96
1.5 x 1 x 1 m	19.88	15.73

As seen in table 9, hand woven gabion boxes are heavier than machine woven ones. It means that machine woven systems are easy to carry and economically beneficial in use. Additionally, machine woven systems have better tightness of twisting, uniformity of mesh which is good for uniform load distribution and have high productivity, etc.

Assembly

At first, open and unfold the folded units of the gabions into their original shape from the initial bundle and placed on the hard-rigid surface. Then, to form an open box shape, lift up the front, back and end panels in a vertical position (remember to check that the height of both sides is the same). The end panel should be folded and cover the mattress, and all the edges and diaphragms of the panels are tied or fastened by either using lacing wire or ring fasteners. Use of pliers to tying the panels with the lacing wire that provided with gabion is usually recommended as shown in Figure 10.

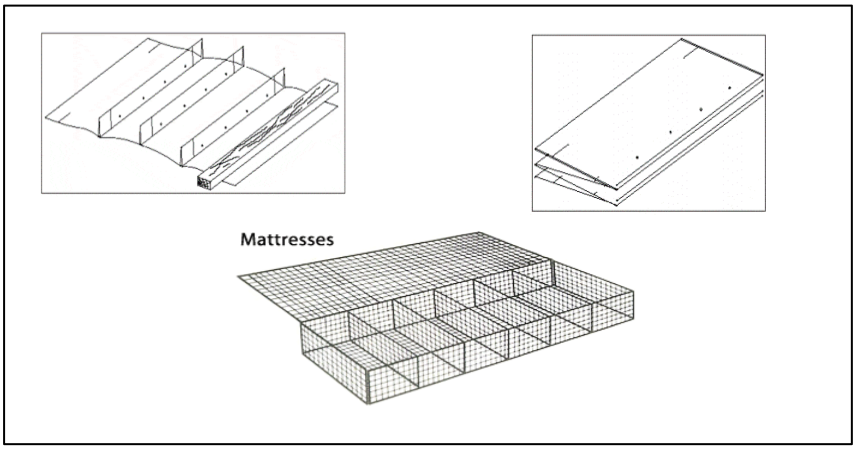
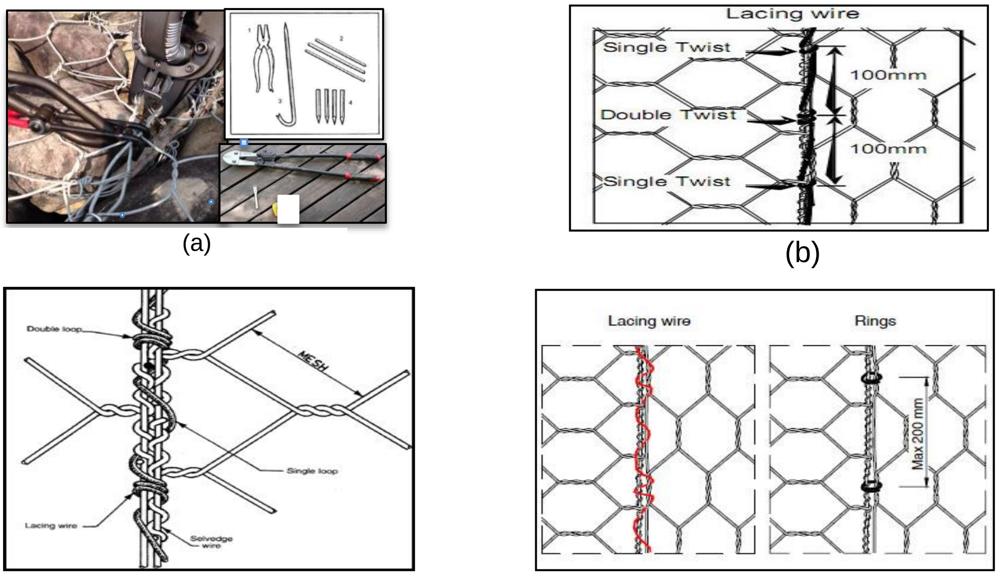


Figure 10. Assembly of Gabion mattress [35].

The assembly of a gabion mattress is usually done close to the site, for example in a local home, space, or a clear space by the river, and transported to the installation location. [35.]

Fastening

To tying or attaching the edges of a gabion mattress, ring fasteners should be installed at a maximum spacing of 100mm apart (figure11b) with a special tool such as a Manual Spenax tool (figure11 a). When using lacing wire, cut a necessary length of wire nearly 1.5 times the length of the edge to be tied if needed several lengths of wire can be attached. Firstly, start twist or loop the lancing wire with the mesh wire, and then twisting or looping can be done through a single twist and double twists in an alternative way in approximately every 100mm (figure 11). Secoundly, Pulling each loop or twist tightly till the end of the edge of the panel and finally securing the end with a proper twist with the mesh wire as shown in figure 11. [13; 35.]



(a) (b)

(c) (d)

Figure 11. Fastening instruments (a), lacing wire with 100mm space bwtween loops (b), installation of lacing wire and rings in the mattress (c), and double and single twisted loops of the wire (d) [13.]

Foundation Preparation

The foundation where gabion mattresses are to be placed should not have irregularities on its surface, loose material, or any vegetation and the location and slope elevation should follow the project drawing. Filter fabric (geo-textile) should be used appropriately, and any other additional gravel filter is fitted according to the plan to prevent the movement of soil and bed materials under the gabion mattress. Geotextiles, gabions or bedding are only placed once the foundation work is finished and approved by the engineer or site supervisor. [13; 35.]

Figure 12. (Left) Foundation preparation on slope and (Right) Installing of geotextile fiber below the gabion mattress on slope area.

As seen in figure 12, foundation is prepared at first and then the geo-textile cloth is placed. Afterward, gabion mattresses are placed on the geo-textile cloth.

Installation, Filling and Closing of Matress

After the assembly, the gabion mattresses should be placed in the proper location and connected to each other, as well as lined up before filling them with stones. The edges of empty cells should be connected with lacing wire and ring fasteners at their contact surface to form a continuously connected unit. It is important to make sure that all adjacent gabions are well laced together to protect the structure from failure due to the loss of a compartment. In case of river bank protection, gabion mattresses are placed with the width perpendicular to the slope, except for small ditches. In a slope area, the gabion mattresses are secured with hardwood pegs driven about 2 m at the center under the ground or as deep as the project requirements define. [13; 35.]

Generally, mattresses can bend up to a radius of 18 m to 21m without alternations, and they can be placed on curvature for filling. Mattresses may be cut into parts diagonally in a sharp curve area and overlap each other to obtain proper shape. After the assembly, the mattresses are placed on the geo-textile fiber material, and filled with appropriate size of stones, according to the project descriptions. The stones or rocks have to be hard, round or angular in shape, long-lasting, and of a quality that can withstand the pressure of water throughout the life of the structure. [13;35.]

Stones are placed by hand or mechanically. In slope areas the stones are placed from the bottom up. The stones or rocks can range from 75mm to 150mm, and upto 2/3 of the thickness of the mattress. However, in marine environments, the minimum size of a stone should be 150mm. Rhe stones can be 5% over or undersized and make layers of stones, but care should be taken when placing stones to evade any damage to wire coating. [13;35.]

Small stones are also used to fill the spaces or gaps between large stones. The filling of stones are placed one after another unit. The units should be ready at first place so that the filling of stones are made afterwards. The placement of the stones should be in compact form with eachother in the mattress. The top surface of the units should be uniformly formed and easily reachable for a connection as shown in figure 13. [13;35.]

Figure 13. Stone in a gabion mattress (left), and placement of gabion mattress on the geotextile (right).

In the closing section, thing to remember is to level up the top surface uniformly. Firstly, fold the lid cover and pull the edges. Then, tie strongly the edges to the top mesh of the diaphragm by using lacing wire with appropriate tools such as a lid closer. Follow the same procedures used while assembling the panel. The cover should be tightly laced all the edges, ends and diaphragm of the mesh. Lacing can be performed by making single and double loops alternatively along with steel ring fasteners. Sometimes in cases where many adjacent bases are needed to cover at one time, they be replaced by the rolls of mesh in place of single size lid. [13; 35.]

Figure 14. Completed installation of gabion mattress for the river bank protection.

Figure 14 shows the completed installation of gabion mattresses. The top surfaces are in unifrom and smooth form. The stones are placed in a compact form and small stones are used in filling the gaps between the large stones.

7 Project Work at Kayar khola

The Kayar khola, where ‘khola’ means for ‘river’, originates from the southern and western parts of Korak VDC (Village Development Committee). The river flows from the hilly region towards the foot hills. It then flows towards south up to the confluence of Budhi Rapti Nadi. This river transports a high amount of sediment during the flood season and deposits that sediment after the foothills around 2.5 km upstream from the East-West Highway. The flood water causes soil erosion. Kayar khola is located in Chitwan district, which has historically experienced a series of floods in 1965, 1979, 1993, and 2002. The floods were devastating and destroyed 2000 to 5000 houses and swept away over 5000 livestock and public infrastructure in 1993. Past projects, supported by Asian Development Bank, and later by the Swiss Agency for Development Cooperation (SDC) have planned to decrease the effects of the disaster and have succeeded in improving people's livelihoods, contributing towards better watershed management. For a long-term solution, research has indicated the need for river training programs to be integrated with good watershed management. [37.]

7.1 Project Description

River Protecting Works and Livelihood Improvement in Chitwan, Nepal Phase II (RPWC) is a river training and livelihood improvement project funded by the bilateral agreement between the Government of Nepal and the Swiss Agency for Development Cooperation in Eastern Chitwan. The project is implemented by SILT Consultant (P) Ltd, Nepal, as the project support Unit (PSU) for RPWC. PSU ran the phase II of the project from December 2014 to November 2018, after a successful implementation of Phase I. At present, the closing of Phase II is going on, and soon it will be ended, as reported by the project's manager. [37.]

There have been several projects whose aim has been to improve the water management in Chitwan district. The bodies and organizations that have participated are:

- the Swiss agencies
- the Nepalese government agencies: District Forest Office (DFO), District Agricultural Development Office (DADO)
- MoFALD/DoLIDAR. etc. [37.]

The project work presented in this study is a small part of the second phase of the RPWC. The project has outcomes in term of environment protection, social development, and economic improvement. According to the authorities, the purpose of the project Phase II was to enhance the livelihoods of people and to control natural disasters, like floods. Additionally, the project helps the agricultural production to generate income sources for farmers. Therefore, this project had unique multi-sectoral areas which focused on safeguarding and providing better management of land, water supply to agricultural fields, forest resources and, as a result, economic growth and poverty reduction.

A small portion, 166 m (see appendix 1), of the Kayar river was taken as a project task because it required bank protection measures. To prevent riverbank erosion in that area, gabion mattresses with hand-made woven mesh were designed with sizes defined according to the design parameters, relying on the past experience of the river training works in Nepal by SILT Consultants (P) Ltd.

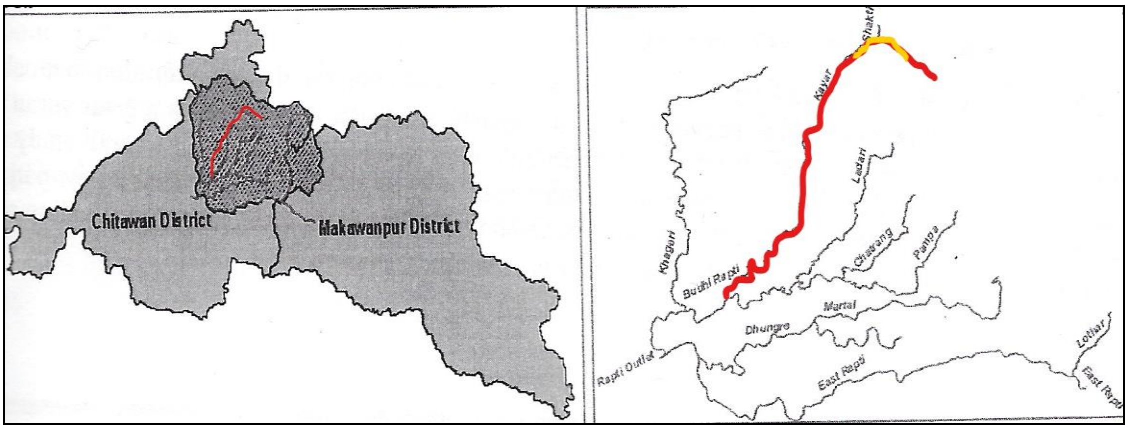


Figure 15. Kayar khola (Red line), and the part of the case study (yellow line) [37].

Figure 15 illustrates the zone of Kayar Khola located in the Chitwan district. The red line shows the perimeter of Kayar Khola and the yellow line shows the case study area within Kayar Khola.

Table 10. Hydrological Analysis; Flood forecast for 50, 100, and 200 years return periods for Kayar khola [36].

Flood Frequency for different rivers at various return period (Q in Cumecs)			
River	RP 50 Yrs	RP 100 Yrs	RP 200 Yrs
Kayar Khola	446.9	532.3	622.0

Table 10 above shows the chances of the occurance of a flood in a certain period of time, such as 50 years, 100 years, and 200 years. The WECS methods were used for discharge calculation of engaged river as shown in table 10. However, Dicken's Method or Gumbel Method is also being used to calculate the discharge.

The morphology of the kayar khola changes at every chainage. Therefore it is not practical to have different size and shapes of protection structures at every chainage. Hence, the river stretch has been divided in various reaches to optimize the sizes of the protective structures and launching aprons. [37.]

7.2 Design Criteria and Proposed Activities

In the RCWP project, hand-made woven mattresses were installed in the Kayar Khola. Cross-sectional data about the location, areas where the gabion mattresses were installed, and measurements were collected for the work. Measurement with a tape measure were made every 25 meters, starting from chainage (ch0+000 m) to a point (ch0+166 m). The figure 0+000 stands for 0 km and 0+166 m for 0 km and 166 meters. This way of length measurement was used in the RCWP project.

Chapter 5 above discussed various design consideration factors and equations for the design and installation of gabion mattresses. The actual calculations had been done in a previous study by the RCWP. Only some of those findings are discussed in this case study. The design criteria that are included in this case study are scour depth, the dimension of gabion mattress, wire properties, the thickness of the infill stone, geo-textile, launching apron and the stability of bank materials. Each are discussed below.

<u>Scour depth</u>

The study from the river Kayar Khola as shown table 11 revealed that the water discharge volume per sec. from Ch0+000 to Ch21+350 is 489.00 m^3/sec which means a constant discharge throughout the river. The coefficient of 1.5 and 2.25 are the estimations of scour depth for bank reventment and spur, respectively. However, the scour depth and the length of the launching apron vary according to the chainage of the river between 2.957 m to 3.108 m for the scour depth, and 7.00 m to 8.00 m for the launching apron. Although table 8 was used during the design and installation processes of gabion mattresses in the Kayar Khola, the length of the mattress for launching and slope in that particular section were minimized, as shown in table 12.

Table 11. Adopted river parameters for the Kayar Khola [28].

River	River Streacth	Discharge, m³/sec.	Scour Depth, below river bed in Meter (m)		Length of Lunching apron at Lowest Bed level in Meter (m)	
			Bank Protection	Spur Nose	Bank Protection	Spur Nose
Kayar Khola	Ch 0+000 to Ch 5+850	489.00	2.957	6.581	7.00	13.00
	Ch 5+850 to Ch 14+300	489.00	3.500	7.166	8.00	15.00
	Ch 14+300 to Ch21+350	489.00	3.108	7.667	7.00	14.00

<u>The dimension of Gabion mattress</u>

The project work observed the DoR (Department of Road, Nepal) specification (as of July 2001), for the hand-made woven gabion system rather than for the machine-made woven system. With the DoR specification, the hand-made woven gabion mattresses were used in the Kayar Khola. The DoR described the dimension of the mattress as shown in table 12.

Table 12. The dimension of a mattress according to its placement at the slope angle.

Mesh type	Dimensions (l x b x h) m	Placement	Slope angle at the junction
100x120 (mm)	3 x 1 x 0.30 3 x 1 x 0.50	On the slope For launching apron	1H:1.5V

Table 12 above illustrates that the mesh diameter of 100mmx120mm has two different dimensions of mattresses placed on the slope, and on the bed level as a launching apron as defined in the DoR specification. The thickness (height) of the mattress was more for the launching apron than on the slope because the launching apron has to resist more flow velocity of water in the river. The slope angle ratio at the junction was 1H:1.5V, which means 1.5 times in vertical direction for 1 in the horizontal direction, means the angle between the slope mattress and launching apron (mattress). The total quantity of weaving gabion box/mattress and diaphragms having mattress size 3 x 1 x 0.3 m per box weaving (9 m^2) on the slope is 2490 m^2 (see appendix 1)

Wire properties

The project followed the DoR specification for the wire properties as shown in table 13.

Table 13. The diameter of wires as specified by DoR.

Mesh Opening (type)	DoR Specification		
100mm x 120mm	Selvedge Wire	Mesh Wire	Binding wire
	7 SWG (4.47 mm)	10 SWG (3.25 mm)	12 SWG (2.64 mm)

Table 13 shows that 12 SWG gabion wire, where SWG is Standard wire gauge (12 SWG = 2.642 mm) is to be used for the binding and lacing of gabion mattresses of 3 m x 1 m x 0.30 m and 3 m x 1 m x 0.50 m, whereas 10SWG (3.25 mm) wire is to be used for mesh wire diameter and 7SWG (4.47 mm) gabion wire for the fabrication of gabion mattresses with a mesh size 100mm x 120mm.

Wires used in the project were zinc-coated galvanized mild steel wires complying with the NS 169-2045 standsrd. The tolerance of diameter of wire is ± 2.5 % and the tensile strength is 380 to 500 N/mm^2.

The thickness of infill stone

As seen in table 14 below, the natural stones used in the gabion mattress as specified in DoR are in the area of 249.00 m^3, whereas the supply and place of dry stone that are pitching on the embarkment slope are in an area of 49.80 m (see appendix 1). The equations to determine the size of the infill stone, explained in chapter 5 above were not used in the project. Instead, irregular, round shapes and sizes of stones with 1.5 times to 2.5 times the size of the hexagonal mesh opening of the gabion, which is 120 mm to 160 mm in dimension of the stone were used. Some stones were broken into small parts to fill the gaps between large stones, whereas inflated stones were used to make a uniformly distributed top surface on the gabion mattresses.

Use of gro-textile

In the project, to maintain the geotechnical stability of the underlayer geotextile (MXC 30, 220m x 4.0 m size) was used on the slope of embarkment below the gabion mattresses in an area of 913 m^3 (see appendix 1) . The reason of using geotextile instead of gravel fiber was the condition shown in euqation 8 in chapter 5.2.4.

Launching apron:

In the project, the launching apron was 3 m in length, 1 m in width and 0.50 m in thickness. The total quantity of weaving gabion box/mattress and diaphragms having launching apron size 3 x 1 x 0.5 m per box weaving (11 m^2) is 1826 m^2 (see appendix 1). It was used to protect and provide stability for the gabion mattress located on the slope. The suitable length for a launching apron for that particular scour depth is shown in table 11. However, in the project, a different size was used as shown in table 12.

Stability of bank materials

The shear stress analysis, the velocity at the bed and bank level, and scour depth, were calculated by a previous study, and are not calculated in this one. The project authority had taken the shear stress into account when designing the gabion structure. The project took local stability problem such as local scour, internal erosion, instability effects on bank erosion due to hydraulic gradient forces, and rainfall runoff above the water line into account in the project work.

Besides this design consideration, past experiences, assumptions and the site visit (investigation) of the location have helped to determine the design and installation of gabion structure at Kayar Khola.

For the transportation of gabion materials to the site or location, a wider road was constructed beside the river bank. All the supplies were carried with local transportation from the project office to site location. The construction like lacing of wire to form gabion mattresses was done in an area close to the river bank, and then carried by vehicle to the exact location.

Table 14. Summary list of activities along with its quantities used in Kayar khola (case study) in Chainage 0+000 m to 0+166 m length at Simalghari. Reprinted from a technical report prepared by SILT Consultants (P) Ltd [37].

Bank Protectection of Kayar Khola at Simalghari, Pani Tanki

Place **Kharani Municipality, Ward No.:-2**

S.no.	Proposed Activity	Unit	Quantity
2	**Bank Protection of Kayar Khola**		
2.2	Earthwork excavation for foundation using equipment.	m^3	872.06
2.3	Embankment Filling .(900)	m^3	506.86
2.4	Supply and fabrication of Gabion mattress of different size with diapharagms including rolling, cutting and weaving as per specification having hexagonal mesh type 100mm*120mm and mesh wire 10SWG, Selvedge wire 7SWG and binding wier 12SWG		
	For Box Size 3*1*0.50m Matress		
(a)	Supply of 10SWG+7SWG gabion wire for fabrication of gabion box/mattress having mesh size 100mm*120mm and box size 3*1*0.50.	kgs	4,464.57
(b)	Supply of 12 SWG gabion Wier for binding and lacing of Gabion Box/Mattress having mesh size 100mm*120mm and box size 3*1*0.50m.	kgs	156.87
(c)	Fabrication (weaving) of gabion matress of size 3*1*0.50m with diapharagms having mesh size 100mm*120mm, using Employer supplied mesh weir 10SWG, selvedge wire 7SWG all complete.	m^2	1,826.00
(d)	Supply and filling of Stone/Boulder in Gabion box/mattress including assembas per specification all complete.	m^3	249.00
	For 3*1*0.30m Matress		
(a)	Supply of 10SWG+7SWG gabion wire for fabrication of gabion box/mattress having mesh size 100mm*120mm and box size 3*1*0.30.	kgs	6,197.61
(b)	Supply of 12 SWG gabion Wier for binding and lacing of Gabion Box/Mattress having mesh size 100mm*120mm and box size 3*1*0.30m.	kgs	249.00
(c)	Fabrication (weaving) of gabion matress of size 3*1*0.30m with diapharagms having mesh size 100mm*120mm, using Employer supplied mesh weir 10SWG, selvedge wire 7SWG all complete.	m^2	2,490.00
(d)	Supply and filling of Stone/Boulder in Gabion box/mattress including assembling gabion box/mattress, placing in position, stretching, forming compartment, tying with Employer supplied 12SWG binding wire as per specification all complete.	m^3	249.00
2.5	Supply and Place dry stone work as per specification and instruction all complete	m^3	49.80
2.6	Supply and place Geotextile on slope of embankment below gabion mattress.(MXC 30, 220m*4.0m size)	m^2	913.00
2.7	Provide and place Project Sign Board (Flex Print) with two bamboo post as per instruction.	nos.	2.00
2.8	Transportation of Gabion Wier from PSU, Simaltadi Chitwan to Construction Site.	Quintal	110.68

The summary Table 14 illustrated above shows the activities in bank protection of Kayar Khola. Table 14 illustrated the summary list of different parts of works, type of gabion mattresses, calculated values, and its units were needed to protect the river bank of Khyar Khola at Simalghari, Pani Tanki in a range of Chainage 0+000 m to 0+166 m. This part of the protection work was carried out up to 166 meters (m).

In the initial stage at the location, earthwork excavation for foundation, and embarkment filling using equipment were done. Then the supply of fabrication of gabion mattress of different size with diaphragms including rolling, cutting and weaving. For hexagonal mesh type 100 mm x 120 mm, mesh wire 10SWG, selvedge wire 7SWG and binding wier 12SWG are used to construct gabion mattress as defined in the DoR specification as shown in table 13.

7.3 Implementation of Proposed Activities

As shown in table 14, the summary list of proposed activities in the protection of the bank of the Kayar Khola (river) in the chainage of 0+000 m to 0+166 m length was approved by the District Development Committee (DDC), Chitwan. After the approval, the activities were started and finished within the given time frame. There was a cost estimation of the project collected through the group contribution by local, national as well as international agencies. However, those cost estimations are not included in this study. According to the project support unit (PSU), the use of gabion mattresses is the cheapest method and provides service for a long period compared to other protection measures. This is why gabion mattresses were chosen for the bank protection.

Figures 16 and 17 present drawings of the designed gabion mattresses by SILT Consultants (P) Ltd. Pictures (see appendix 2) show the initial phase, implementation phase, and completion phase of the project.

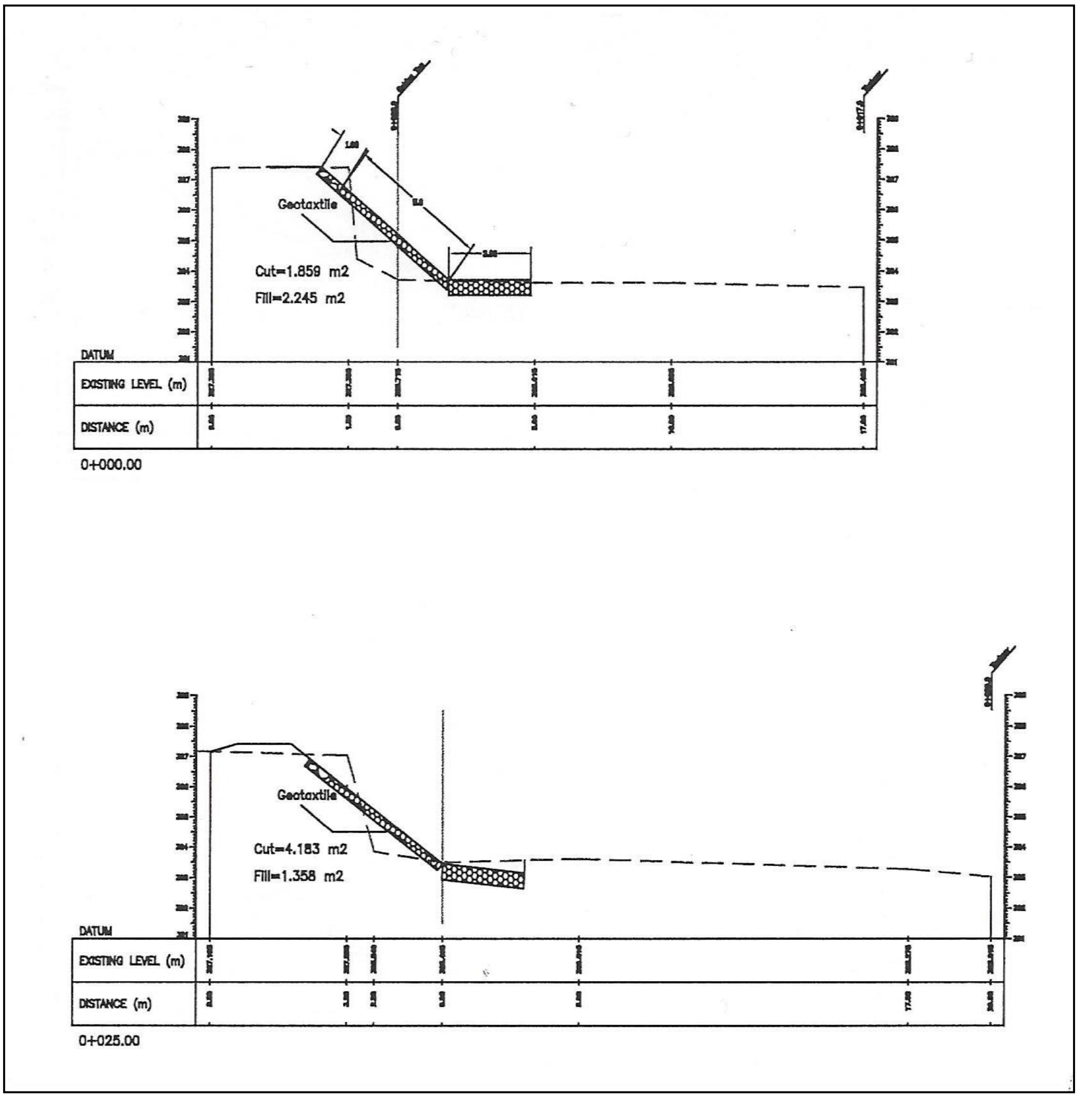


Figure 16. Drawing of gabion mattress and launching apron in a chainage between 0+000 m to 0+025 m [37].

Figure 16 above illustrates the design of a gabion mattress and launching apron in the cross-section CH 0+000 and CH 0+025. CH 0+000 had a cut equal to 1.859 m² and fill equal to 2.245 m² of land whereas CH 0+025 had a cut equal to 4.183 m² and fill equal to 1.358 m² of the land. The cuts and fills of the land were done in order to maintain uniformly distributed slope and base surface.

Geotextile (MXC 30, 220m x 4.0 m) was used on the slope of the embankment below the gabion mattresses.

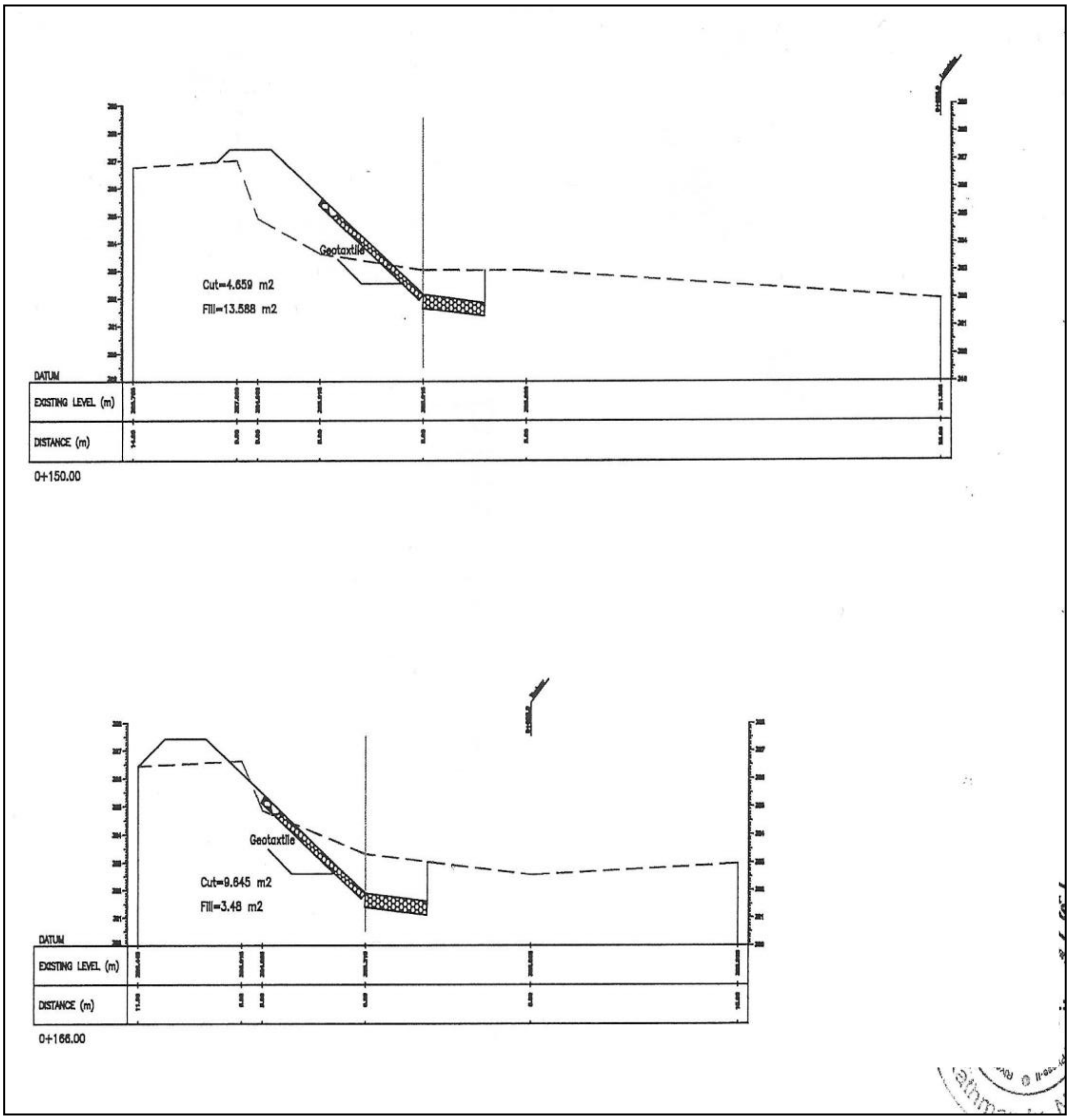


Figure 17. Drawing of gabion mattress and launching apron in a chainage between 0+150 m to 0+166 m [37].

Likewise, figure 17 above illustrates the design of a gabion mattress and launching apron in the cross-section CH 0+150 and CH 0+166. CH 0+150 had a cut equal to 4.659 m² and fill equal to 13.588 m² of the land, whereas CH 0+166 had a cut equal to 9.645 m² and fill equal to 3.48 m² of the land.

Also, Geotextile (MXC 30, 220m x 4.0 m) was used on the slope of the embankment below the gabion mattresses.

7.4 Outcomes of the project work

The project activities implemented in the Kayar khola bring some outcomes in terms of environmental protection, social development, and economic improvement due to the project. The project

- improves the economic growth and reduces poverty by focusing on safeguarding and better management of water and land.

- prevents the erosion of the river bank and prevents scours for the next few decades. Under proper maintenance by the local authorities, the protection measures last for 30-50 years.

- prevents the effects of flood, and encourage investment in productive irrigation system by putting irrigation canals for the agricultural land. Farmers can irrigate their harvests for 8 to 9 months a year.

- Eliminates the danger of erosion, and the around 300 to 500 houses located near the project area are safe now. People can again cultivate their lands, which increases the value and the productivity of the land as well.

- Improves the water supply, and proper sanitation around the area, the existing bridges and roads and other resources get better and safer from the activity.

- employed people for the protection works.

8 Conclusions

This study shows an overview of different types of river bank protection methods. Especially, this study describes the effectiveness of the gabion mattress method of protecting river banks. This study discusses the qualities of the gabion mattress in terms of stability, flexibility, durability, and sustainability. This study has shown various aspects of design where the hydrological and meteorological analysis of a particular river or stream is an essential part to conduct before designing and installing of gabion mattress. Likewise, scour depth estimation, current velocity, geotechnical boundary conditions, wire and stone properties, and geotechnical stability of the underlayer with appropriate geotextile filters are considered as major factors.

The literature review of this study has shown different design consideration factors along with various equations in which the design and installation of gabion mattress are constructed. The actual result of those calculation values was done in a previous study and are not included in the case study. Only some findings are considered in the case study.

The final year project concluded that although various protection methods are available to protect the river bank from erosion, gabion structures are often choosen due to their low-cost production, flexibility, durability, stability and sustainability. It was established that PVC coated and galvanized (Zn coated) wires have higher tensile strength and durability than the ordinary steel wire. Tensile strength (N/mm^2) of the wires depends upon respective standards.

Hand-made weaving mess can provide more employment to the people in comparison to machine-made weaving systems. However, the machine-made system is better than the hand-made system. The cost of production is higher in the machine-made system due to the machine cost, and the transportation from the manufacturing company to the location of use. The weight of wires for hand-made woven gabion boxes is slightly higher than those of the machine made woven boxes as shown in table 9.

Different standards of specification for gabion structure are available in the world, but in the project the Nepalese standard (NS), together with the DoR specification were followed. The sizes of the wires specified in the DoR specification (Hand-made system) were large than the sizes of the machine-made system as shown in table 8.

Although the scour depth of the Kayar khola is higher, about three meters, the implementation of a gabion structure from the base of the scour depth was not done at the particular location of the project. Instead, the structure foundation was constructed above the estimated scour level but with a launching apron at the bed level (150 mm - 200 mm below). This indicates that a structure foundation can be constructed above the estimated scour level, not necessary from the base of it, but under proper field investigation.

Shear stress analysis and velocity at the underlying bed of the river was infrequently considered in the project. However, previous field data, information and survey reports were helpful in the design and installation of gabion mattresses at the location.

Although there are methods of calculation to determine the size of the infill stone in the mattress as shown in chapter 5, in this project, the stone sizes were determined in terms of tightness, so that the infill stones must not come out through the mess openings of the gabion mattresses.

The morphology of the Kayar khola changes at every chainage. Therefore, the use of the dimensions of the gabion mattress was not possible in a practical way at every chainage. Hence, the river stretch has been divided in various reaches to optimize the values of the size of the protection structure and launching apron.

To further summarize the chapters above, the study showed the following.

Environmental Protection

As mentioned in chapters 3 and 4, a gabion mattress has a wide range of environmental benefits due to its stability, flexibility, durability, and sustainability. In comparison to concrete retaining structures, the gabion structure has a relatively low carbon (CO_2) footprint. In addition to other sustainable qualities, the gabion structure has an excellent stability quality, i.e., the structure can allow the growth of plants or re-vegetation within the structure’s frame. The growth of roots actually helps the structure to become more stable. Hence, the process enhances the eco-system. Also, a gabion structure regulates the environment relating to climate and humidity. A good structure can efficiently regulate the current velocity of the flowing water, thus minimizing the chances of flood.

Social Development

Considering the outcomes of the case study, the structure helps to lead towards better livelihood and social infrastructural development. In addition, the economic improvement and environmental protection further help to improve the quality of social life that creates social development.

Economic Improvement

Chapters 4 and 6 present the qualities of a gabion mattress and their manufacture. The materials used in a gabion structure are wire and stone. Wire and stone are easily available practically everywhere at a cheap cost. One can easily follow the procedure to construct small scale gabion mattresses with less experience in low budget. Also, such type of protection measures increase the productivity of the land through the supply of an irrigation system that helps to boost the economic development further.

Design considerations, construction technique and procedures, and implementation of the gabion mattress presented in this study can be further used as a guideline, but not interpreted as a strict code of practice.

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Survey data of the project work at the Kayar khola.

River Protection Works and Livelihood Improvement in Chitwan (RPWC-II)

DISTRICT DEVELOPMENT COMMETTE, CHITWAN

Bank Protectection of Kayar Khola at Simalghari, Pani Tanki

Quantity Estimate

SN	Description	Chainage	Unit	Length (m)	X-sectional Area (m^2)	Min area (m^2)	Qnantity (m^3)	Remarks
2	**Bank Protection of Kayar Khola**							
2.3	E/W Filling							
		0+000	m^3	0.00	2.25	0.00	0.00	
		0+025	m^3	25.00	1.36	1.80	45.04	
		0+050	m^3	25.00	0.07	0.72	17.90	
		0+075	m^3	25.00	0.52	0.30	7.48	
		0+100	m^3	25.00	1.59	1.06	26.43	
		0+125	m^3	25.00	3.35	2.47	61.75	
		0+150	m^3	25.00	13.59	8.47	211.73	
		0+166	m^3	16.00	3.48	8.53	136.54	
						Total quantity of Earth Filling =	506.86	m^3

River Protection Works and Livelihood Improvement in Chitwan (RPWC-II)

DISTRICT DEVELOPMENT COMMETTE, CHITWAN

Bank Protectection of Kayar Khola at Simalghari, Pani Tanki

Quantity Estimate

SN	Description	Chainage	Unit	Length (m)	X-sectional Area (m^2)	Min area (m^2)	Qnantity (m^3)	Remarks
2	**Bank Protection of Kayar Khola**							
2.2	E/W excavation for foundation using equipment							
		0+000	m^3	0.00	1.86	0.00	0.00	
		0+025	m^3	25.00	4.18	3.02	75.53	
		0+050	m^3	25.00	5.07	4.63	115.64	
		0+075	m^3	25.00	6.53	5.80	144.99	
		0+100	m^3	25.00	5.08	5.81	145.15	
		0+125	m^3	25.00	6.18	5.63	140.80	
		0+150	m^3	25.00	4.66	5.42	135.53	
		0+166	m^3	16.00	9.65	7.15	114.43	
						Total quantity of Earth Work Excavation =	872.06	m^3

River Protection Works and Livelihood Improvement in Chitwan (RPWC-II)

DISTRICT DEVELOPMENT COMMETTE, CHITWAN

Bank Protectection of Kayar Khola at Simalghari, Pani Tanki

Quantity Estimate

SN	Description	Chainage	Unit	Length (m)	Breadth (m)	Height (m)	Qnantity (m^3)	Remarks
2	**Bank Protection of Kayar Khola**							
2.4(a)	Gabion Works							
	Weaving, placing in position including tightening of gabion box of Gabion Matress 3m*1m*0.30m for On Slope							
		0+000	m^3	0.00	5.00	0.30	0.00	
		0+025	m^3	25.00	5.00	0.30	37.50	
		0+050	m^3	25.00	5.00	0.30	37.50	
		0+075	m^3	25.00	5.00	0.30	37.50	
		0+100	m^3	25.00	5.00	0.30	37.50	
		0+125	m^3	25.00	5.00	0.30	37.50	
		0+150	m^3	25.00	5.00	0.30	37.50	
		0+166	m^3	16.00	5.00	0.30	24.00	
						Total quantity of Gabion =	249.00	m^3
						Total quantity of Gabion Wier 10SWG+7SWG for weaving in KGs @ 24.89KGs =	6197.61	KGs
						Total quantity of Gabion Wier 12SWG for Lacing in KGs @ 1.0KGs =	249.00	KGs
						Total quantity of Stone Filling in Gabion Box =	249.00	m^3
						Total quantity of weaving gabion box/mattress and diaphragms having box size 3*1*0.3m per box weaving is $9m^2$ =	2490.00	m^2

River Protection Works and Livelihood Improvement in Chitwan (RPWC-II)

DISTRICT DEVELOPMENT COMMETTE, CHITWAN

Bank Protectection of Kayar Khola at Simalghari, Pani Tanki

Quantity Estimate

SN	Description	Chainage	Unit	Length (m)	Breadth (m)	Height (m)	Qnantity (m^3)	Remarks
2	**Bank Protection of Kayar Khola**							
2.4(b)	Gabion Works							
	Weaving, placing in position including tightening of gabion box of Gabion Matress 3m*1m*0.50m for Lanching							
		0+000	m^3	0.00	3.00	0.50	0.00	
		0+025	m^3	25.00	3.00	0.50	37.50	
		0+050	m^3	25.00	3.00	0.50	37.50	
		0+075	m^3	25.00	3.00	0.50	37.50	
		0+100	m^3	25.00	3.00	0.50	37.50	
		0+125	m^3	25.00	3.00	0.50	37.50	
		0+150	m^3	25.00	3.00	0.50	37.50	
		0+166	m^3	16.00	3.00	0.50	24.00	
						Total quantity of Gabion =	249.00	m^3
						Total quantity of Gabion Wier 10SWG+7SWG for weaving in KGs @ 17.93KGs =	4464.57	KGs
						Total quantity of Gabion Wier 12SWG for Lacing in KGs @ 0.63KGs =	156.87	KGs
						Total quantity of Stone Filling in Gabion Box =	249.00	m^3
						Total quantity of weaving gabion box/mattress and diaphragms having box size 3*1*0.5m per box weaving is $11m^2$ =	1826.00	m^2

River Protection Works and Livelihood Improvement in Chitwan (RPWC-II)

DISTRICT DEVELOPMENT COMMETTE, CHITWAN

Bank Protectection of Kayar Khola at Simalghari, Pani Tanki

Quantity Estimate

SN	Description	Chainage	Unit	Length (m)	Breadth (m)	Height (m)	Qnantity (m3)	Remarks
2	**Bank Protection of Kayar Khola**							
2.5	Dry Stone Piching							
	Dry Stone Pitching on Embankment Slope							
		0+000	m^3	0.00	1.00	0.30	0.00	
		0+025	m^3	25.00	1.00	0.30	7.50	
		0+050	m^3	25.00	1.00	0.30	7.50	
		0+075	m^3	25.00	1.00	0.30	7.50	
		0+100	m^3	25.00	1.00	0.30	7.50	
		0+125	m^3	25.00	1.00	0.30	7.50	
		0+150	m^3	25.00	1.00	0.30	7.50	
		0+166	m^3	16.00	1.00	0.30	4.80	
	Total quantity of Dry Stone Pitching =						49.80	m^3

River Protection Works and Livelihood Improvement in Chitwan (RPWC-II)

DISTRICT DEVELOPMENT COMMETTE, CHITWAN

Bank Protectection of Kayar Khola at Chitrasari

Quantity Estimate

SN	Description	Chainage	Unit	Length (m)	Breadth (m)	Height (m)	Qnantity (m^2)	Remarks
2	**Bank Protection of Kayar Khola**							
2.6	Geotextile							
	Supply and place Geotextile in embankment slope as per instruction all complete.							
		0+000	m^2	0.00	5.50		0.00	
		0+025	m^2	25.00	5.50		137.50	
		0+050	m^2	25.00	5.50		137.50	
		0+075	m^2	25.00	5.50		137.50	
		0+100	m^2	25.00	5.50		137.50	
		0+125	m^2	25.00	5.50		137.50	
		0+150	m^2	25.00	5.50		137.50	
		0+166	m^2	16.00	5.50		88.00	
	Total quantity of Geotextile =						913.00	m^2

Pictures of the project work at Kayar khola.

Figure 1. Observation of slope before installing gabion mattress.

Figure 2. Geotextile installing below gabion mattress at slope.

Figure 3. Inspection of work at slope area.

Figure 4. Installed Launching apron.

Figure 5. Installed Gabion mattress and launching apron in a bank of the Kayar khola.