Technical Report

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Design using geosynthetics —

Part 8:
Surface erosion control

Dimensionnement utilisant des géosynthétiques —
Partie 8: Lutte contre l'érosion de surface

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CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
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Contents

Page

Foreword v

Introduction vi

1 Scope 1

2 Normative references 1

3 Terms and definitions 1

4 Types of erosion 2

4.1 General 2

4.2 Water erosion 2

4.2.1 General 2

4.2.2 Splash 2

4.2.3 Sheet 2

4.2.4 Rill 2

4.2.5 Gully 2

4.2.6 Channel 2

4.3 Wind erosion 3

4.3.1 Suspension 3

4.3.2 Saltation 4

4.3.3 Surface creep 4

5 Design considerations for erosion and sediment control 4

5.1 General 4

5.2 Consideration of soil survey information 4

5.3 Climate and precipitation data 5

5.4 Topography 5

5.5 Design approaches 6

5.5.1 Slope erosion: Revised universal soil loss equation (RUSLE) 6

5.5.2 Channel erosion 7

5.5.3 Sediment control 10

6 Types of geosynthetics for erosion and sediment control 10

6.1 General 10

6.2 Light geogrids and geonets 10

6.3 Geomats 11

6.4 Reinforced geomats 11

6.5 Pre-filled geomats 12

6.6 Geoblankets and natural fibres geotextiles 12

6.7 Geocells 13

6.8 Sediment retention systems 13

6.9 Geotextiles for a silt fence 13

6.10 Georolls 14

6.11 Hard armour systems 14

6.12 Other products for erosion control 15

6.12.1 General 15

6.12.2 Mulches 15

6.12.3 Fibre roving 15

6.12.4 Permanent and temporary applications 15

7 Testing of erosion and sediment control products 16

7.1 General 16

7.2 Index testing 16

7.3 Bench-scale testing 17

7.4 Large-scale performance testing of geosynthetics for erosion control 18

Annex A (informative) **The revised universal soil loss equation (RUSLE)** 20

Annex B (informative) **Detailed design for erosion control with geosynthetics on channel banks** 36

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Foreword

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This document was prepared by Technical Committee ISO/TC 221, *Geosynthetics*.

A list of all parts in the ISO 18228 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

The ISO/TR 18228 series provides information regarding designs using geosynthetics for soils and below ground structures in contact with natural soils, fills and asphalt. The series contains ten parts which cover designs using geosynthetics, including guidance for characterization of the materials to be used and other factors affecting the design and performance of the systems which are particular to each part, with ISO/TR 18228-1 providing general information relevant to the subsequent parts of the series.

The series is written in a limit state format and information is provided in terms of partial material factors and load factors for various applications and design lives, where appropriate.

This document includes information relating to the erosion control function on slopes and river or channel banks. Details of design methodology adopted in current practice are provided.

Erosion is a natural process by which soil and rock material is loosened and transported. Natural erosion occurs primarily on a geologic timescale, but when human activities alter the landscape the process of erosion can be greatly accelerated. Construction site erosion causes serious and costly problems, both on-site and off-site. Fluid borne soil erosion process begins by water or wind detaching particles by mechanical forces and fluid stream over the surface.

When land is disturbed at a construction site, the erosion rate accelerates dramatically. Since ground cover on an undisturbed site protects the surface, the removal of that cover increases the site's susceptibility to erosion. Disturbed land can have an erosion rate 1 000 times greater than the reconstruction rate. Even though the process of construction necessitates that land be left bare for periods of time, proper planning and use of erosion prevention measures can reduce the impact of accelerated erosion caused by land development.

Attempting to quantify the costs of soil erosion is challenging at best. The number of variables contributing to erosion along with the costs for cleaning up the effects are extensive. Soil erosion impairs water resources used for drinking, navigation, recreation or irrigation.

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Design using geosynthetics —

Part 8:
Surface erosion control

1 Scope

This document provides information on the design of geosynthetics for surface erosion control on slopes and river or channel banks.

It does not apply to the design of geosynthetics for the stability of slopes and river or channel banks. It does not apply to coastal protection issues.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10318-1, *Geosynthetics — Part 1: Terms and definitions*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10318-1 and the following terms apply.

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ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
erosion control revegetation mat
ECRM
geomat placed on a slope without being infilled

3.2
reinforced geomat
geocomposite composed of an erosion control product and a reinforcing element

Note 1 to entry: Examples of reinforced geomats include a geogrid, a steel mesh, yarns or other elements.

3.3
prefilled geomat
erosion control product prefilled at factory with a bitumen bound mineral filler of stone chippings, or another filler, affording a sufficiently open structure to allow the vegetation to grow through it

3.4
georoll
GRO
permeable structure of loose, either natural or synthetic, or both, fibres and other elements (natural or synthetic) formed into tubes inserted inside either natural or synthetic, or both, netting

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Note 1 to entry: A georoll is also known as a sediment retention fibre roll (SRFR).

3.5
turf reinforcement mat
TRM
geomat placed on a slope with either topsoil or seeds, or both

4 Types of erosion

4.1 General

Erosion is often described as the detachment of soil particles by some force. This force can be due to rainfall, wind, or other forces. Once detachment occurs, the particles are transported. This is most often caused by water action, although wind can also be a major contributor. The major types of water erosion are covered in 4.2.

4.2 Water erosion

4.2.1 General

The main forms of onsite erosion are splash, sheet, rill and gully (see Figure 1). Offsite erosion includes stream and channel erosion.

4.2.2 Splash

When vegetative cover is stripped away, the soil surface is directly exposed to impact from rainfall. Splash erosion results, when the force of raindrops falling on bare or sparsely vegetated soil, detaches soil particles that can easily be transported by water runoff. This pounding action destroys the soil structure and often a hard crust forms when the soil dries. This crust inhibits water infiltration and plant establishment, increasing runoff and future erosion.

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4.2.3 Sheet

The removal of exposed surface soil can be caused by the action of unchanneled surface runoff. Shallow “sheets” of water flowing over the soil surface cause sheet flow. Sheet flow transports soil particles that have been detached by splash erosion. The shallow surface flow rarely moves as a uniform sheet for more than a few metres before absorption into the surface irregularities.

4.2.4 Rill

As surface flow changes from sheet flow to deeper concentrated flow along the low spots of the soil surface, it creates rivulets, cutting grooves called rills into the soil surface. The energy of this concentrated flow can both detach and transport soil particles. The rills are small but well-defined channels that are, at most, only a few centimetres deep.

4.2.5 Gully

Some gullies are formed when runoff cuts rills deeper and wider or when the flows from several rills come together and form a large channel. If the flow of water is enough, large chunks of soil can fall from a gully headwall in a process called mass wasting. Once a gully is created, it is very difficult to control, and costly to repair.

4.2.6 Channel

When stream bank vegetation is disturbed or when the velocity or volume of a stream is increased, channel erosion can occur. Natural streams have adjusted over time to the quantity and velocity of runoff that normally occurs within a watershed. The vegetation and rocks lining the banks are enough to prevent erosion

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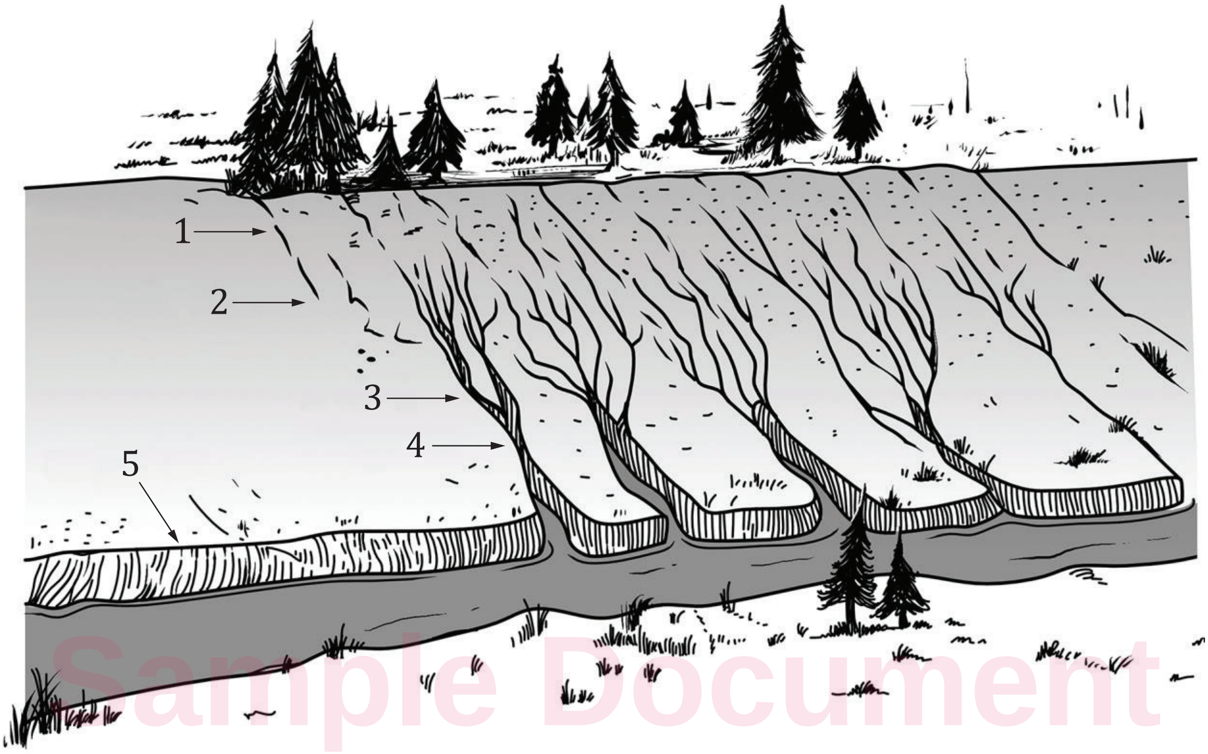
under these steady-state conditions. When a watershed is altered by removing vegetation, by increasing the number of impervious surfaces, or by paving tributaries, stream flows are changed. Increased volume and velocity of runoff can cause expansion of gullies into well-defined channels. These changes can disturb the equilibrium of the stream and cause channel erosion to begin. Channel erosion is commonly found at stream bends, constrictions where installed structures control the stream flow, or discharge points where storm drain culverts release storm water into a stream.



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Key

1 raindrop erosion
2 sheet erosion
3 rill erosion
4 gully erosion
5 channel erosion

Figure 1 — Types of soil erosion

4.3 Wind erosion

Wind erosion is a form of erosion occurring in flat, bare areas with dry, sandy soils, or where the soils are loose, dry, and finely granulated. Wind erosion damages land and natural vegetation by removing soil from one place and depositing it in another. It causes soil loss, dryness, deterioration and desertification of soil structure, nutrient and productivity losses, air pollution and sediment transport and deposition. Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition, there is a minimum velocity to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon particle size, the cloddiness of particles, and wind velocity itself.

4.3.1 Suspension

Suspension occurs when very fine dirt and dust particles are lifted into the wind. They can be thrown into the air through impact with other particles or by the wind itself. Once in the atmosphere, these particles

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can be carried very high and be transported over extremely long distances. Soil moved by suspension is the most spectacular and easiest to recognize of the three forms of movement.

4.3.2 Saltation

The major fraction of soil moved by wind is through the process of saltation. In saltation, fine soil particles are lifted into the air by the wind and drift horizontally across the surface, increasing in velocity as they go. Soil particles moved in the process of saltation cause severe damage to the soil surface and vegetation. They travel approximately four times longer in distance than in height. When they strike the surface again, they either rebound back into the air or knock other particles into the air.

4.3.3 Surface creep

The large particles which are too heavy to be lifted into the air are moved through a process called surface creep. In this process, the particles are rolled across the surface after coming into contact with the soil particles in saltation.

Wind erosion is not addressed in this document.

5 Design considerations for erosion and sediment control

5.1 General

A designer plans for erosion and sediment control measures based upon information provided from resources obtained from local and regional agencies, and a detailed field site visit. In addition, the designer can identify potential erosion and sediment problems, develop design objectives, formulate and evaluate alternatives, select best erosion prevention measures, and develop a plan. A determination is made about what best management practices are appropriate. The stepped process described in Clause 5 is an example of best practice.

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5.2 Consideration of soil survey information

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Soil is a product of its environment. A soil's erodibility, or the vulnerability of soil to erosion, is a result of a number of soil characteristics which can be divided into two groups:

— those influencing infiltration, or the movement of water into the ground;

— those affecting the resistance to detachment and transported by rainfall and runoff.

Key factors that affect erodibility are soil texture, amount of organic matter, soil structure, and soil permeability.

Soil texture refers to the size and proportions of the particles making up a particular soil. Sand, silt, and clay are the three major classes of soil particles. Soils high in sand content are said to be coarse-textured. Because water readily infiltrates sandy soils, the runoff, and consequently the erosion potential, is relatively low. Soils high in content of silts and clays are said to be fine-textured or heavy. Clay, because of its stickiness, binds soil particles together and makes a soil resistant to erosion. However, once heavy rain or fast flowing water erodes the fine particles, they will travel great distances before settling.

Organic matter consists of plant and animal litter in various stages of decomposition. Organic matter improves soil structure and increases permeability, water holding capacity, and soil fertility. Organic matter in an undisturbed soil or a mulch covering over a disturbed soil reduces runoff and erosion potential. Mulch on the surface also cushions the soil from the erosive impact of rainfall.

Soil structure is the arrangement of soil particles into a larger structural mass. Soil structure affects the soil's ability to absorb water. When soil is compacted or crusted, water tends to run off rather than infiltrate. Erosion hazard increases with increased runoff. A more granular structure is the most effective against slope erosion since it will more readily absorb and retain water, which reduces runoff and (with sufficient nutrients) encourages plant growth.

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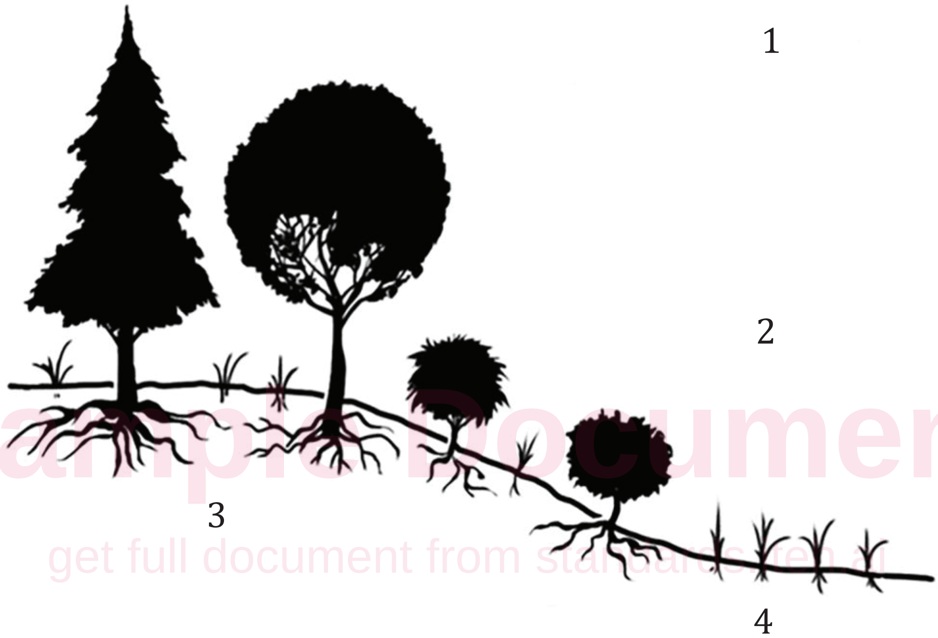
Soil permeability refers to the ability of the soil to allow air and water movement through the soil. Soil texture, structure, and organic matter all contribute to permeability. As noted above, soils that are least subject to erosion from rainfall and shallow surface runoff are those with high permeability rates, such as well graded gravels and gravel-sand mixtures, or those with high cohesion, such as a “fat” clay.

Knowing the type of soil present on the project site helps the designer decide upon the degree of erosion protection required. The soil type will determine its vulnerability to erosion and its ability to support vegetation.

Vegetative cover is an extremely important factor in reducing erosion from a site, see Figure 2. Vegetation can absorb energy of rainfall, bind soil particles, slow velocity of runoff water, increase the ability of a soil to absorb water and remove subsurface water between rainfalls through the process of evapotranspiration. By limiting the amount of vegetation disturbed and the exposure of soils to erosive elements, soil erosion can be greatly reduced.



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Key

1 vegetation absorbs the energy of falling rain

2 vegetation helps to maintain absorptive capacity

3 vegetation slows the velocity of runoff and acts as a filter to catch sediment

4 roots hold soil particles in place

Figure 2 — Benefits of vegetation

5.3 Climate and precipitation data

The frequency, intensity and duration of rainfall and temperature extremes are principle factors influencing the volume of runoff from a given area. As the volume and intensity of rainfall increases, the ability of water to detach and transport soil particles increases. When storms are frequent, intense, and of long duration, the potential for erosion of bare soils is high. Temperature has a major influence on soil erosion. Frozen soils are relatively erosion resistant. However, soils with high moisture content are subject to “spew,” or uplift when frozen and are usually very easily eroded upon thawing.

5.4 Topography

The size, shape and slope characteristics of a watershed influence the amount and duration of water runoff. The greater the slope length and gradient, the greater the potential for both runoff and erosion. Velocities

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of water will increase as the distance from the top of the slope or the gradient of the slope increases. The term “ground cover” refers principally to vegetation, but it also includes surface treatments such as mulches, matting, wood chips, and crushed rock. Vegetation is the most effective means of stabilizing soils and controlling erosion. It shields the surface from the impact of falling rain, reduces flow velocity and disperses flow.

Vegetation provides a rough surface that slows the runoff velocity and promotes infiltration and deposition of sediment. Plants remove water from the soil and thus increase the soil’s capacity to absorb water. Plant leaves and stems protect the soil surface from the impact of rainfall and the roots help maintain the soil structure while holding the soil in place.

5.5 Design approaches

5.5.1 Slope erosion: Revised universal soil loss equation (RUSLE)

In order to properly design retention and erosion control measures, a designer must calculate the quantities of water and sediment that will be managed.

Monitoring and modelling of the erosion processes can help to better understand the causes of soil erosion, make erosion predictions under a range of possible conditions and plan the application of preventive and restorative strategies for erosion. The current most commonly used model for predicting soil loss from water erosion on slopes is the revised universal soil loss equation (RUSLE), developed by the U.S. Department of Agriculture in the 1960s and 1970s.

RUSLE is expressed by Formula (1):

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (1)$$

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where:

A estimated average soil loss (Mg/hectare/year);

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R rainfall-runoff erosivity factor (MJ·mm/ha·hr·yr);

K soil erodibility factor (ton·ha·hours/ha·MJ·mm);

L slope length factor;

S slope steepness factor;

C cover-management factor;

P support practice factor.

The RUSLE equation can be used to predict the amount of soil that can be eroded, for example, from construction sites. Specifically, it enables the most critical source areas to be identified and allows predictions of the benefits of erosion control measures.

RUSLE is based on a very large number of measurements made on the “standard plot" (see Annex A). The plot had a constant gradient of 9 %, with a down slope length of 22,13 m (72 feet) and a width of 1,83 m (6 feet).

Recent research on geosynthetics (GSY) for erosion control on slopes has been carried out with setups of various lengths and steepness for obtaining values of the cover management factor (C) when a slope is protected with a specific GSY. The standardized test method in ASTM D6459 is normally a preferred method for slope erosion performance testing because:

— at present, it is the only international standard that simulates full-scale conditions of rainfall induced erosion on a slope;

— the test procedure has been standardized since 1999 and provides detailed instructions for any labs use in setting up and performing the tests;

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— it has been used to evaluate a wide variety of erosion control products;

— test setup allows an actual installation simulation, including anchor pattern, density, depth and joint overlaps to be examined;

— test setup is large enough to address all relevant erosion issues, including surface drilling;

— test results have demonstrated that ASTM D6459 produces performance results that correlate well with the theoretical results predicted by the RUSLE, as reported by Reference [36];

— thanks to this correlation, the test can provide relevant input to the RUSLE (see Annex A).

For a given slope (for example, a road cut with a sandy silt surface soil layer) the correct evaluation of the C-factor for different GSY is fundamental for the design of the erosion control system.

The C-factor for a specific GSY product can be obtained either by a test on a real slope under calibrated rainfall, or laboratory tests with a calibrated rain simulator, or both, with both working to simulate installation configuration (pin placement and configuration).

For fallow unprotected ground the C-factor is equal to 1,0; covering the slope with an appropriate GSY for erosion control can reduce the C-factor down to 0,01 – 0,05, or lower, when still unvegetated, and even lower when vegetated.

Table A.9 presents a sample of results from publicly posted ASTM D6459 test reports.

These values of the C-factor provide an immediate impression of the efficacy of GSY in protecting slopes against erosion.

While RUSLE is a tool to estimate the rate of soil loss based on site-specific environmental conditions and a guide for the selection and design of sediment and erosion control systems for the site, it does not estimate gully or stream-channel erosion. RUSLE does not determine when soil loss is excessive at a site, when erosion control systems have failed or sediment yield once it has left the site. The RUSLE user makes such decisions based upon numerous criteria, of which soil-loss and sediment-yield estimates are an important aspect of design.

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The most critical parameter in an engineering design is flow resistance before, during and long after vegetative establishment. Some erosion control materials can be washed away before the vegetation takes hold while others can temporarily exhibit excellent flow resistance only to lose their effectiveness as they degrade or decompose over time.

RUSLE and its application to civil engineering problems is presented in detail in Annex A.

5.5.2 Channel erosion

Erosion on river and channel banks develop from the shear stresses applied by the stream. If not properly addressed, riverine erosion can cause significant issues for navigation and human activities. Moreover, uncontrolled erosion can produce the failure of dikes, with consequent flooding of surrounding areas.

The water flow in rivers and channels produces shear stresses on the bottom and side banks, which are proportional to water depth and velocity. Such shear stresses can remove soil particles and excavate progressively deeper into the channel bottom and sides, which can lead to slope failure. Channel bottom and sides can be protected by lining with different materials (concrete, riprap, GSY, etc.). The calculation (design or verification) of a bank protection can be made using two different methods based on Formula (2) and (3):

— Water velocity: $V < V_{all}$ (2)

— Shear stresses applied by the water stream: $\tau < \tau_{all}$ (3)

V_{all} and τ_{all} are the limit values of velocity and shear stresses just before the movement of soil particles start.

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The design and selection of GSY for protecting river and channel banks require performance tests, in either unvegetated or vegetated configuration, or both, to assess the limit values of water velocity and shear stress when the bank is protected with a specific product.

Two basic design concepts are used to evaluate and define a channel configuration that performs within the accepted limits of stability. These methods are defined as the permissible velocity approach and the permissible tractive force (shear stress) approach. Under the permissible velocity approach, the channel is assumed stable if the adopted velocity is lower than the maximum permissible velocity.

The tractive force (boundary shear stress) approach focuses on stresses developed at the interface between flowing water and the materials forming the channel boundary.[2] The permissible velocity approach uses the Gauckler–Manning formula where, with a given depth of flow, D, the mean velocity of water flow (V) can be calculated as shown in Formula (4):

$$V = (1 / \mathrm{n}) \cdot R_\mathrm{h}^{2/3} \cdot S^{1/2} \tag{4}$$

where:

V	cross-sectional mean velocity (m/s);
n	Gauckler–Manning roughness coefficient (s/m$^{1/3}$);
R_h	hydraulic radius (m);
S	slope of the hydraulic grade line or the linear hydraulic head loss (-), which is equal to the channel bed slope when the water depth is constant.

The hydraulic radius is defined as the ratio of the channel's cross-sectional area of the flow to its wetted perimeter (the portion of the cross-section's perimeter that is "wet") as shown in Formula (5):

$$R_\mathrm{h} = A/P \tag{5}$$

where:

A	cross sectional area of flow (m^2);
P	wetted perimeter (m).

The tractive shear stress applied by the water stream is:

$$\tau = \gamma_\mathrm{w} \cdot D \cdot S \tag{6}$$

where:

τ	tractive shear stress (kPa);
γ_w	unit weight of water (kN/m^3);
D	maximum depth of flow (m);
S	average bed slope (-).

Design criteria based on flow velocity can be limited because maximum velocities vary widely with channel length (L), shape (R_h), and roughness coefficients (n). In reality, it is the force developed by the flow, not the flow velocity itself, that challenges the performance of erosion control systems. Tractive forces caused by flowing water over the ground surface create shear stresses which can be used as a design parameter independent of channel shape and roughness. Moreover, the higher stresses developed in channel bends or other changes in stream channel geometry can be quantified by simplified shear stress calculations, providing a higher level of design confidence than otherwise possible (see Reference [37]).

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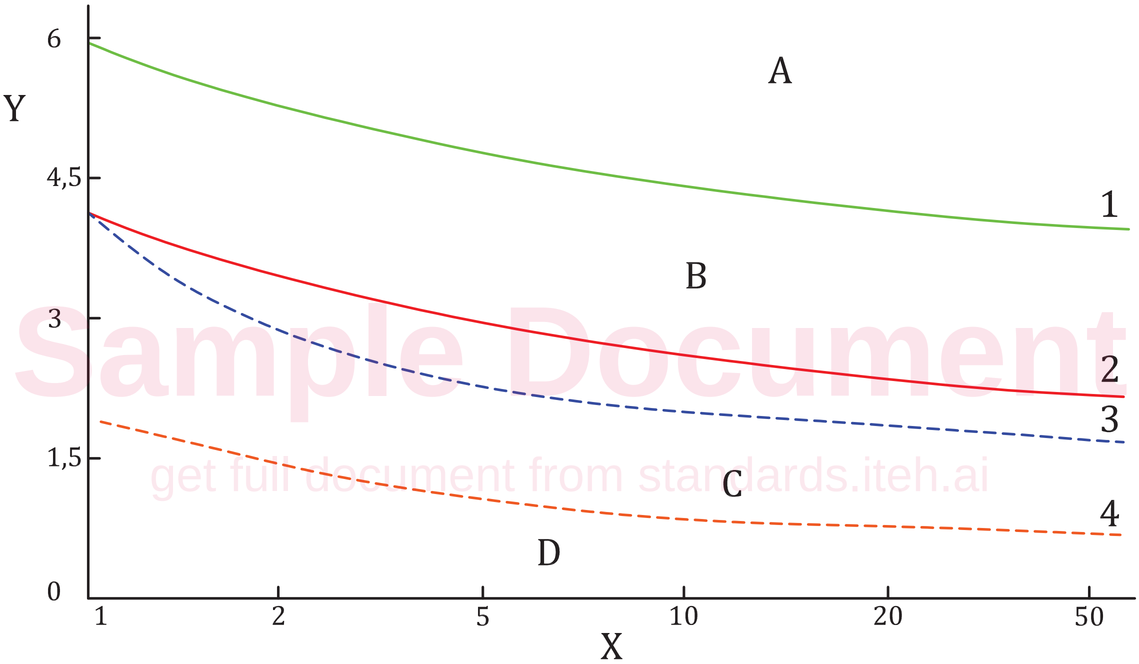
Critical shear stress determinations are meant to be used with velocity calculations for pre-screening of channel lining designs. Manning's equation remains the primary hydraulic research and design tool. However, as everyday practice has determined, a simplified screening criterion such as maximum shear stress is necessary to ensure properly engineered design of channel lining erosion control systems.

The duration of flow is of some importance. In general, the design of erosion control materials is based on relatively short flow durations during testing, e.g. 30 minutes for unvegetated and 60 minutes for vegetated conditions. Though flow velocities decrease over time, it has been assumed in standard testing protocols that soil loss does not continue to increase with flow duration. Thus, manufacturers of geosynthetics for erosion control often express the erosion resistance of their materials in terms of maximum allowable flow velocity that has been determined by relatively short-term testing. This erosion resistance does not reflect any additional erosion damage resulting from flows continuing over a period of several hours. It can be important for a designer to consider flow duration in appropriate design.

Design examples for erosion control with geosynthetics in channel applications is presented in Annex B.

Figure 3 shows the allowable design water velocity, V_{allow}, for various classes of erosion control materials.



Key

X flow duration (h)

Y long term allowable velocity (m/s)

1 fully vegetated TRM

2 non-vegetated TRM or ECRM

3 100 % cover

4 poor cover

A hard armor systems

B soft armor zone

C limits of natural vegetation

D bare soil erosion

[SOURCE: Reference [3], reproduced with the permission of the authors.]

Figure 3 — Allowable design water velocity V_{allow}

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