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Overview of Geosynthetics Products for Erosion Control on Slopes and on River/Channel Banks

Pietro Rimoldi

Civil Engineering Consultant and IGS Council Member

pietro.rimoldi@gmail.com

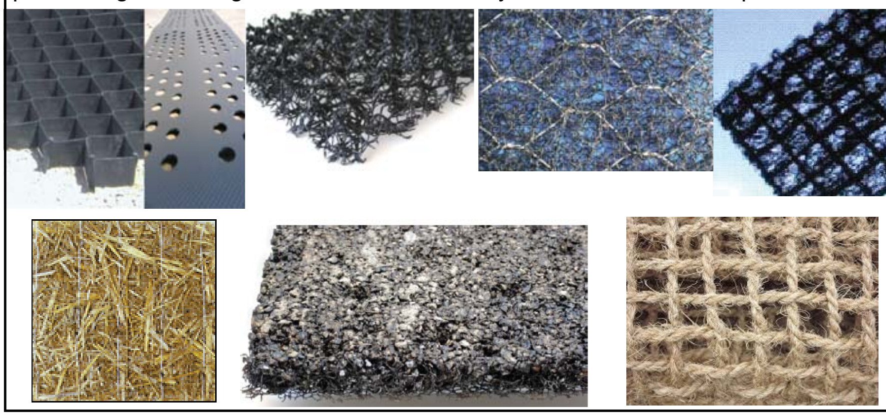
About the lecturer

- Mr Pietro Rimoldi got a degree in Civil Engineering from the Technical University of Milano, Italy, in 1984.
- Since 1986 he has been involved in the development of new Geosynthetic products and in field and laboratory test projects related to geosynthetics and their applications, contributing to the development of new testing apparatus and new testing procedures.
- He has designed several important Geosynthetics projects around the world.
- He is the author of more than 250 national and international publications related to geosynthetics and the author of design manuals for reinforced slopes and walls, road and railway base stabilization, geosynthetic drainage systems and erosion control.
- He is Certified Professional Soil Erosion and Sediment Control Specialist (CPESC) in USA and Chartered Professional Engineer in Italy.
- He is an active member of IGS, ISSMGE TC218 “Reinforced Soil Structures”, ASCE-GI.
- He is an active member of the technical committees CEN TC 189 on Geosynthetics, ISO TC 221 on Geosynthetics, CEN TC 288 - Execution of special geotechnical works, CEN TC250 / SC7 / TG6 on design of Geosynthetic reinforced structures within the structural Eurocodes, CEN TC 217 on Sport surfaces.
- In September 2018 he has been elected by the fourth time as Member of the International Council of the IGS, and from 2015 to August 2020 he has been the Chair of IGS Technical Committee on Hydraulic Applications (TC-H), while he is presently the Chair of IGS Technical Committee on Reinforcement (TC-R). He is Council Member of the Italian Chapter of IGS (AGI-IGS), he has been Council Member of the Italian Geotechnical Association (AGI), and Member of the Board of Directors of the Geosynthetics Institute (GSI) in USA.
- He is presently working as Civil Engineering Consultant, based in Milano (Italy).

EROSION CONTROL ON SLOPES

Erosion on slopes is a natural process caused by the forces of water and wind. It is influenced by a number of factors, such as soil type, vegetation and landscape, and it can be accelerated by various activities that occur on a specific field installation. Uncontrolled erosion processes can cause major damages to existing structures and to the environment.

Geosynthetics for erosion control, if properly designed, are very effective in preventing or limiting the soil loss caused by water erosion on slopes.



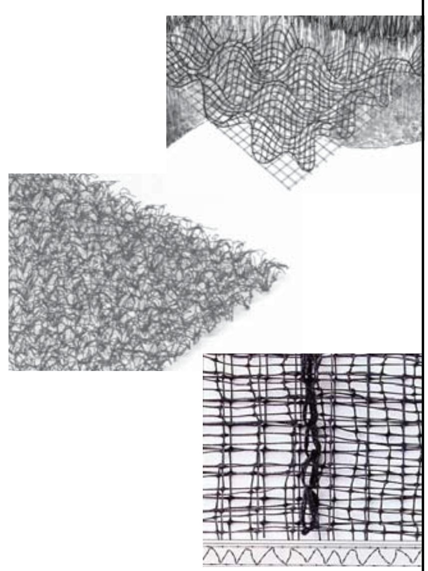
EROSION CONTROL ON SLOPES

MAIN PRODUCTS USED FOR EROSION CONTROL: Geomats

Geomats are generally made of synthetic material filaments or nets, tangled together to form a highly deformable layer 10 - 20 mm thick, featured by a very high porosity (greater than 90% on average).
Geomats can protect the soil against raindrops splash and runoff by keeping in place soil particles; moreover Geomats can increase by several times the shear resistance of the roots system.

They can be used for the following applications:

- erosion protection on slopes caused by the impact of rain drops and runoff
- Lining of river / channel banks with low water velocities



EROSION CONTROL ON SLOPES

MAIN PRODUCTS USED FOR EROSION CONTROL: Geomats

Geomats for erosion control on slopes

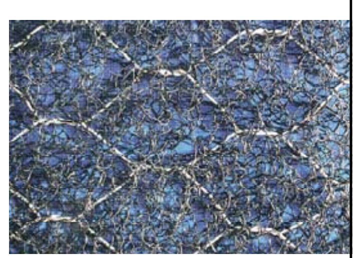
EROSION CONTROL ON SLOPES

MAIN PRODUCTS USED FOR EROSION CONTROL: Reinforced Geomats

Reinforced Geomats are geocomposites produced by factory joining a Geomat and a Geogrid or metallic mesh, having a tensile strength in the range 50 – 300 kN/m.

Reinforced Geomats afford all the characteristics of Geomats, plus they afford high tensile strength.

They can be used on long and steep slopes, along the banks of canals and river courses with relatively high water velocities, where high tensile strength is required.



EROSION CONTROL ON SLOPES

MAIN PRODUCTS USED FOR EROSION CONTROL: Biomats and Bionets

Geosynthetics made up of natural fibers, in the form of a mat of fibers kept together by natural or synthetic low weight meshes (Biomats), or of a woven net (Bionets).
Biosynthetics can protect a slope against rain splash, but the protection against runoff is very limited.
Biosynthetics can absorb high amount of water and, during their natural degradation, can produce nutritious materials for the vegetation.

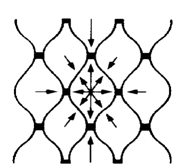
They can be used for temporary erosion control on slopes and along the banks of canals and river courses with low water velocities.

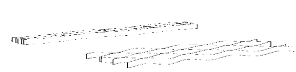
EROSION CONTROL ON SLOPES

MAIN PRODUCTS USED FOR EROSION CONTROL: Geocells

Geocells are honeycomb products manufactured by joining polymeric strips or geotextile strips by welding, gluing or stitching.
The function afforded by geocells is lateral confinment: the lateral movements of the soil infilled in the cells is prevented or limited by the cell walls and by the other surrounding cells.
Geocells can be used to stabilise a soil thickness of 100 - 300 mm, thus avoiding that it slides down the slope.
The top surface have often be protected against erosion by placing a geomat or biomat.

Geocells can be used on arid slopes, when a thick topsoil layer is required for allowing vegetation growth.

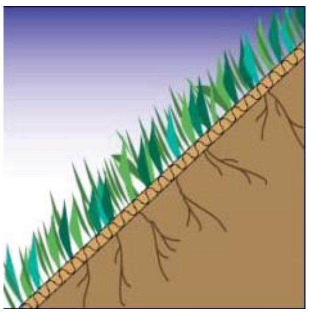




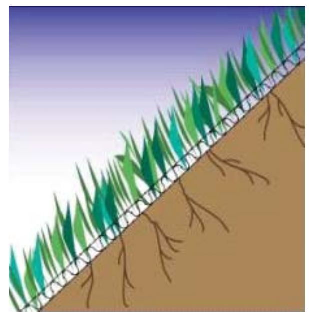
EROSION CONTROL ON SLOPES

Geosynthetics for erosion control, in the form of rolled blankets (Geomats, Reinforced Geomats, etc.), can be used in two main ways:
- TRM: topsoil and seeds are infilled inside the GSY; roots grow through the GSY and get improved resistance to shear stresses
- ECRM: the GSY is laid on the slope without being infilled; it protects the slope against raindrops splash and runoff but it doesn't improve root resistance

The erosion protection capacity is different in the two cases even for the same GSY.



TRM: Turf Reinforcement Mattress



ECRM: Erosion Control Revegetation Mattress

EROSION CONTROL ON SLOPES

OVERVIEW OF APPLICATIONS OF GEOSYNTHETICS FOR EROSION CONTROL: Protection of natural slopes

EROSION CONTROL ON SLOPES

OVERVIEW OF APPLICATIONS OF GEOSYNTHETICS FOR EROSION CONTROL: Protection of cut slopes

EROSION CONTROL ON SLOPES

OVERVIEW OF APPLICATIONS OF GEOSYNTHETICS FOR EROSION CONTROL: Road and railway slopes

EROSION CONTROL ON SLOPES

OVERVIEW OF APPLICATIONS OF GEOSYNTHETICS FOR EROSION CONTROL: Landfill capping

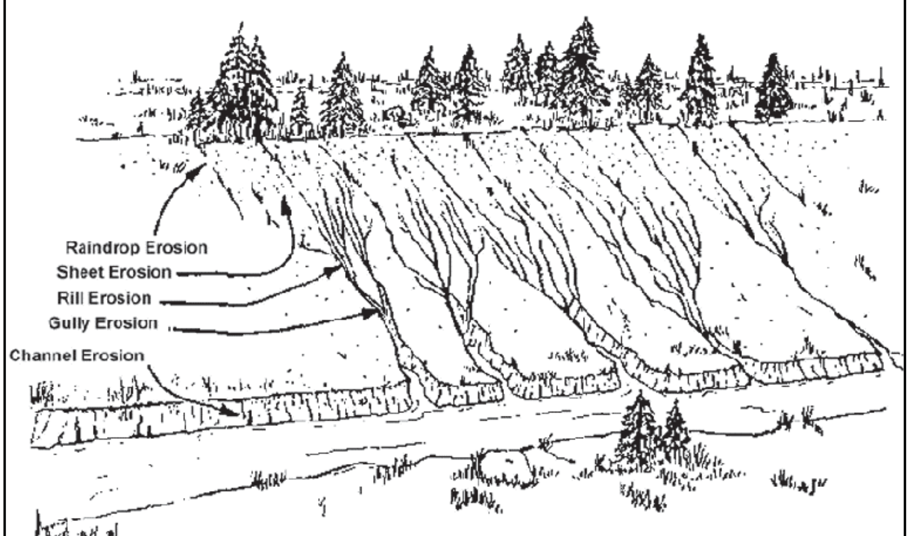
EROSION CONTROL ON SLOPES

OVERVIEW OF APPLICATIONS OF GEOSYNTHETICS FOR EROSION CONTROL: Erosion and sediment control at construction sites

EROSION CONTROL ON SLOPES

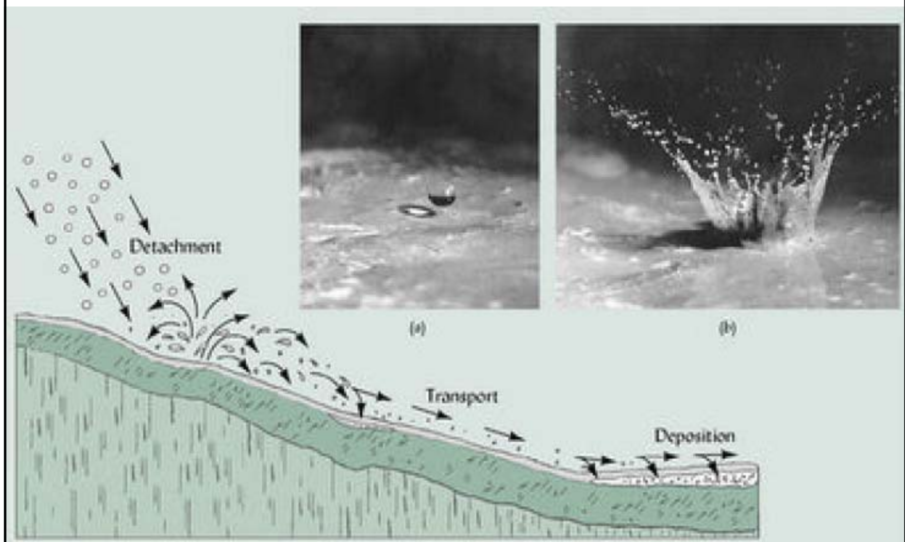
OVERVIEW OF APPLICATIONS OF GEOSYNTHETICS FOR EROSION CONTROL: Revegetation of landslides

EROSION CONTROL ON SLOPES



Types of soil erosion

EROSION CONTROL ON SLOPES



Detachment and downslope soil transport by raindrops impact

EROSION CONTROL ON SLOPES

Erosion on slopes depends on two main factors:

- Erosivity = capacity of erosion (erosive agents on slopes are: water and wind)

  $Ep = f(i, t, d, E_k)$

  i = rainfall intensity;
  t = rain duration;
  d = raindrops diameter;
  E_k = kinetic energy

- Erodibility = susceptibility to be eroded

  $Es = f(F, k, w, \tau, s, a)$

  F = infiltration;
  k = surficial permeability,
  w = lamination capacity,
  τ = shear resistance of soil
  c = type of soil covering
  s = resistance of soil to detachment
  a = abrasion

EROSION CONTROL ON SLOPES

THE REVISED UNIVERSAL SOIL LOSS EQUATION - RUSLE
at present is the most used method for the estimation of soil loss on eroded slopes.
RUSLE is a universal formula, hence it is applicable in any geographical region and socio-economic condition, but it requires a proper data base allowing the estimation of the various factors, which summarize the characteristics of the area and are statistically defined.
In RUSLE all factors influencing the rate of erosion on a given slope are clearly identified.
RUSLE is expressed by the following formula:

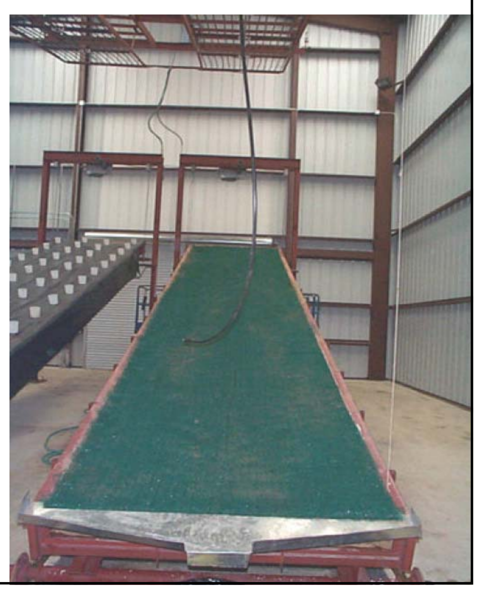
$$A = R \cdot K \cdot LS \cdot C \cdot P$$

where
- **A = estimated average soil loss (tons per acre per year)**
- **R = rainfall-runoff erosivity factor (hundreds of foot·ton·inch/ acre·hour·year)**
- **K = soil erodibility factor (ton·acre·hours / hundred acre·foot·ton·inch)**
- **L = slope length factor**
- **S = slope steepness factor**
- **C = cover-management factor**
- **P = support practice factor**

Geosynthetics for erosion control affect the C factor, which may be reduced even by 100 - 1000 times compared to an unprotected bare slope.

EROSION CONTROL ON SLOPES

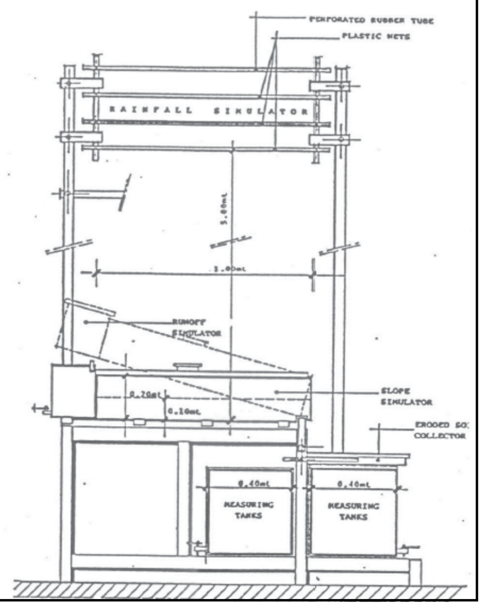
RUSLE is based on a large number of measures, classifications and correlations, referring both to real cases and to situations recreated in the laboratory with rainfall simulators on the standard plot, which is an inclined plane with constant gradient of 9%, with a down slope length of 22.13 m (72 feet) and a width of 1.83 m (6 feet). A rain simulator is placed above the standard plot, producing rainfalls with characteristics (intensity, raindrops diameter, terminal velocity) as close as possible to the real situation that is modeled in the test.



EROSION CONTROL ON SLOPES

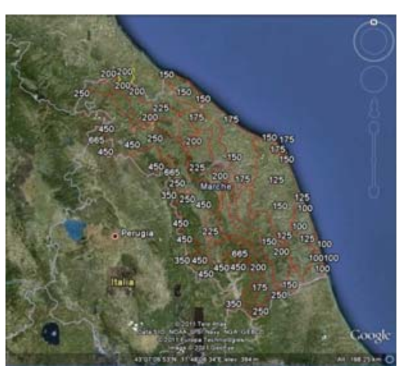
Many test researches on Geosynthetics for erosion control on slopes have been carried out with setups similar to the standard plot (Cancelli et Al, 1990; Weggell and Rustom, 1992; Cazzuffi et Al, 1994).

See the cross section of the rainfall simulator developed by Cancelli, A., Monti, R., and Rimoldi, P. (1990)



EROSION CONTROL ON SLOPES

Many Countries and Regions carried out local measurements of the R factors, and produced regional maps of the R Factor.
As examples:
Right: isoerodent map of California, with R values in US customary units.
Left: isoerodent map of Marche region in Central Italy, with R values in MJ·mm / ha·hr·yr



EROSION CONTROL ON SLOPES

Soil erodibility factor K

The soil erodibility factor (K) is the rate of soil loss per rainfall erosion index on the standard plot.

Soils high in clay have low K values, approx. from 0.05 to 0.15 in US customary units, because they are resistant to detachment.

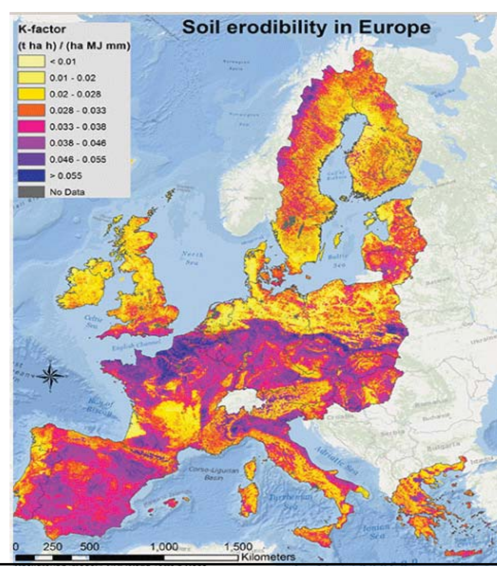
Coarse textured soils, such as sandy soils, have low K values, approx. from 0.05 to 0.2, because of low runoff even though these soils are easily detached.

Medium textured soils, such as silt loam soils, have a moderate K values, approx. from 0.25 to 0.4, because they are moderately susceptible to detachment and they produce moderate runoff.

Soils having a high silt content are most erodible of all soils. They are easily detached; tend to crust and produce high rates of runoff. Values of K for these soils tend to be greater than 0.4.

EROSION CONTROL ON SLOPES

Map of K factor in Europe (in SI units)



EROSION CONTROL ON SLOPES

Slope length and steepness factor LS

S is the slope steepness factor, which represents the effect of slope steepness on erosion. Soil loss increases more rapidly with slope steepness than it does with slope length. S is the ratio of soil loss from the actual field gradient to that from the standard plot having 9 percent slope under otherwise identical conditions.

L factor and S factor are usually considered together as LS factor:

$$LS = L \cdot S = (\lambda / C)^m \cdot (0.065 + 0.0456 \cdot s + 0.006541 \cdot s^2)$$

where:
λ = horizontal length of slope (m for S.I. units or ft for U.S. units)
s = slope steepness (%)
C = 22.13 m (S.I. units)
C = 72.6 ft (U.S. units)

Exponent m as a function of slope steepness s (from Van Remortel et al., 2001).

Slope(°)	m	Slope(°)	m
<0.1	0.01	6.3−7.4	0.37
0.1−0.2	0.02	7.4−8.6	0.40
0.2−0.4	0.04	8.6−10.3	0.41
0.4−0.85	0.08	10.3−12.9	0.44
0.85−1.4	0.14	12.9−15.7	0.47
1.4−2.0	0.18	15.7−20.0	0.49
2.0−2.6	0.22	20.0−25.8	0.52
2.6−3.1	0.25	25.8−31.5	0.54
3.1−3.7	0.28	31.5−37.2	0.55
3.7−5.2	0.32	≥37.2	0.56
5.2−6.3	0.35		

EROSION CONTROL ON SLOPES

Cover-management factor C

The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land, like in the standard plot.
In civil engineering projects the C factor represents the cover and management system; in details the type and density of vegetation on the given slope, and the type of management system in terms of erosion control techniques that are applied, which may consist in Geosynthetics for erosion control.
For a given slope (as example: a road cut with sandy silt surface soil layer) the correct evaluation of the C factor for different Geosynthetics is fundamental for the design of the erosion control system.
The C factor for a specific Geosynthetic product should be obtained by extensive test on real slopes under natural rainfall, and/or laboratory tests with a rain simulator and a standard plot.

For preliminary design, the C factor values in following Tables can be used.

EROSION CONTROL ON SLOPES

Indicative values of the C-Factor for geosynthetics for erosion control (from ISO TR 18228-8)

GEOSYNTHETICS FOR EROSION CONTROL	C min. (s < 0.3 and λ < 6 m)	C max. (s > 0.5 and λ > 30 m)
Geomat	0,005	0,040
Reinforced geomat	0,008	0,030
Geomat + natural fibers matrix	0,001	0,030
Light geogrid and geonet	0,100	0,400
Pre-filled geomat	0,0001	0,005
Geoblanket with synthetic fibers	0,005	0,200
Geoblanket with straw. single net	0,025	0,400
Geoblanket with straw. double net	0,015	0,200
Geoblanket with coconut. single net	0,020	0,300
Geoblanket with coconut. double net	0,010	0,150
Geoblanket with wood wool - Light	0.20	0.30
Geoblanket with wood wool – Heavy	0.25	0.40
Coir geotextile. Light	0,005	0,050
Coir geotextile. Heavy	0,002	0,030
Jute geotextile. Light	0,010	0,030
Jute geotextile. Heavy	0,005	0,020
Geocell	0,400	1,000

EROSION CONTROL ON SLOPES

Supporting Practices Factor P

P is the support practice factor. The RUSLE P factor reflects the impact of support practices on the average annual erosion rate. It is the ratio of soil loss with a supporting practice to that with straight row farming up-and-down slope.
This factor is rarely applicable for construction sites.
Some values are provided in following table.

C AND P FACTOR FOR SOME EROSION CONTROL TREATMENTS

Table 1 Erosion Management Factors

Erosion Control Treatment	C Factor	P Factor
Bare Soil	1.00	1.00
Disked Bare Soil	1.00	0.90
Sediment Basin/Trap	1.00	0.50
Straw Bale Barrier	1.00	0.80
Silt Fence Barrier	1.00	0.50
Asphalt/Concrete Pavement	0.10	1.00
Competant Gravel Layer	0.05	1.00
Established Native Grass (100% coverage)	0.03	1.00
Sod Grass	0.01	1.00
Agricultural Crop	0.45	1.00
Erosion Control Blankets	0.002 to 0.003	1.00
Turf Reinforcement Mats	0.002 to 0.003	1.00

EROSION CONTROL ON SLOPES

DESIGN OF GEOSYNTHETICS FOR EROSION CONTROL

The design of erosion control systems with Geosynthetics, both for temporary and long term applications, can be carried out using the RUSLE.

The procedure for using the RUSLE is the following:

1. Collect rain and soil data for the project area.
2. Determine the R Factor: usually civil and environmental engineering projects cover a relatively small area, hence in general one only R value is applicable.
3. Based on the soil texture, determine the K value. If there is more than one soil type in the project area and the soil textures are not very different, use the soil type that represents the majority of the field. Otherwise repeat for other soil types as necessary.
3. Divide the project area into sections of uniform slope gradient and length. Assign an LS value to each section.

EROSION CONTROL ON SLOPES

DESIGN OF GEOSYNTHETICS FOR EROSION CONTROL

4. Select several options for the erosion control measures to be implemented (as example: no soil coverage during construction; biodegradable Geosynthetics for temporary protection during construction; nondegradable Geosynthetics for long term protection; etc.); for each option select the C Factor from Tables or evaluate it from specific tests.
5. Select the P factor based on the support practice used (in general P = 1.0 for civil and environmental engineering projects).
6. According to RUSLE, multiply the 5 factors together to obtain the soil loss per hectare (acre).
7. Multiply by the total area (in hectares) to obtain the total soil loss in 1 year.

EROSION CONTROL ON SLOPES

Example: design the erosion control system for a construction site final grading

A construction site is comprised of different zones (embankment, road cut, parking, etc.), each one with different area, slope, length, surface soil, vegetation cover.
The construction period is anticipated to be from 1 March to 31 July. In this period the amount of rainfall is 56 % of the annual total rain.

The calculation of the soil loss for the construction period is shown in following Table, where the following notes apply:

1. Annual R = 350 (US units). From 5 March to 31 July:
R_{period} = 56% of annual R; so construction phase partial R = 0.56 $\cdot$ 350 = 196

EROSION CONTROL ON SLOPES

2. K values are obtained from county soil map and anticipated surface soils during the construction phase

3. C factors based on: native good cover for undisturbed areas, temporary erosion control mats for road cuts, planted vegetation or tacked mulches on embankments, and gravel pads for parking, building, and road areas. The vegetation C factor is calculated based on plant growth stages during this construction phase.

EROSION CONTROL ON SLOPES

Example: calculation for unprotected slopes

Site area designation	Area description	Land area (acres)	R for construction period[1]	K soil factor[2]	LS slope length factor	C cover factor[3]	Unit area soil loss (tons/acre/period)	Total area soil loss (tons/period)
1a	Undisturbed area	1.51	196.00	0.15	0.30	0.001	0.01	0.01
1b	Undisturbed area	3.72	196.00	0.17	0.68	0.005	0.11	0.42
2	Road cut	0.54	196.00	0.28	2.67	0.020	2.93	1.58
3	Road cut	1.37	196.00	0.37	4.59	0.020	6.66	9.12
4a	Main embankment	0.84	196.00	0.28	0.40	0.550	12.07	10.14
4b	Main embankment	0.33	196.00	0.37	4.56	0.170	56.22	18.55
4c	Main embankment	1.15	196.00	0.17	3.09	0.070	7.21	8.29
5	Parking area	10.50	196.00	0.28	0.06	0.020	0.07	0.69
6	Building areas	5.53	196.00	0.35	0.06	0.020	0.08	0.46
7a	Road segment	0.26	196.00	0.17	0.57	0.020	0.38	0.10
7b	Road segment	0.95	196.00	0.28	0.22	0.020	0.24	0.23
7c	Road segment	0.37	196.00	0.28	0.10	0.020	0.11	0.04
Total site		27.07						49.64

It is noted that the total soil loss in the construction period is equal to almost 50 tons.
If a sedimentation pond is required to block this amount of sediments, considering a 100 g/liter concentration in the water flowing out the construction site, the pond shall be designed for 500 m^3 of flowing water.

EROSION CONTROL ON SLOPES

Example: calculation for slopes protected with geomats

Let's lay polypropylene geomats on road cut and embankment slopes: let's assume that, from Table 10, the C Factor for this type of erosion control Geosynthetic is C = 0.003.
The calculation of soil loss becomes as shown in Table 14, where the annual value of R has been considered: the total annual soil loss is reduced to 7.67 tons/year, that is 1/7 of the soil loss during the 5 months construction period.

Site area designation	Area description	Land area (acres)	Annual R	K soil factor[2]	LS slope length factor	C cover factor[3]	Unit area soil loss (tons/acre/period)	Total area soil loss (tons/period)
1a	Undisturbed area	1.51	350.00	0.15	0.30	0.001	0.02	0.02
1b	Undisturbed area	3.72	350.00	0.17	0.68	0.005	0.20	0.75
2	Road cut	0.54	350.00	0.28	2.67	0.003	0.78	0.42
3	Road cut	1.37	350.00	0.37	4.59	0.003	1.78	2.44
4a	Main embankment	0.84	350.00	0.28	0.40	0.003	0.12	0.10
4b	Main embankment	0.33	350.00	0.37	4.56	0.003	1.77	0.58
4c	Main embankment	1.15	350.00	0.17	3.09	0.003	0.55	0.63
5	Parking area	10.50	350.00	0.28	0.06	0.020	0.12	1.23
6	Building areas	5.53	350.00	0.35	0.06	0.020	0.15	0.81
7a	Road segment	0.26	350.00	0.17	0.57	0.020	0.68	0.18
7b	Road segment	0.95	350.00	0.28	0.22	0.020	0.43	0.41
7c	Road segment	0.37	350.00	0.28	0.10	0.020	0.20	0.07
Total site		27.07						7.67

EROSION CONTROL OF CANAL AND RIVER BANKS

Floods are the second most destructive type of natural disaster, after earthquakes. Nearly 30 % of all the natural disasters consist of flood events.
Rivers and canals need to be managed and controlled to decrease the hydraulic risks.
Erosion control on river and canals banks can be achieved with geosynthetic technology.

Erosion control on river / channel banks

- Erosion on river and channel banks is produced by the shear stresses applied by the stream. If not properly addressed, erosion may cause significant issues for navigation and human activities. Moreover uncontrolled erosion may 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 may lead to slope failure.
- Channel bottom and sides can be protected by lining with different materials (particularly with Geosynthetics).

PROTECTION AGAINST EROSION

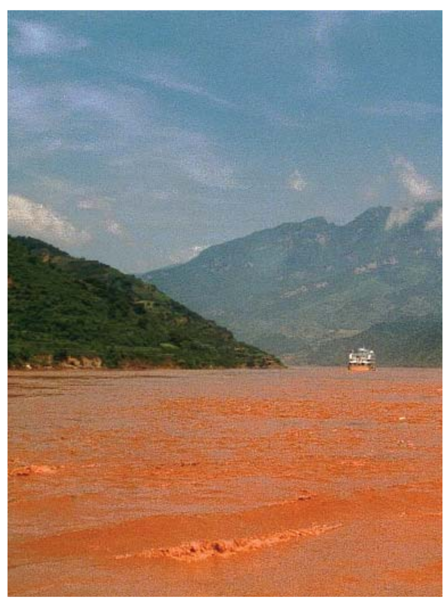
Erosion protection is essential for watercourses for two main reasons :

1) the necessary cross-section must be guaranteed for easy navigation and for the safe discharge of design flow; therefore, no deposit of material in the water course due to the transport of sediments or slope instability shall be allowed to obstruct the regular water flows;
2) streams often cross densely populated areas, so the stability of the banks of rivers and canals is of particular importance. Therefore it is necessary to foresee potential situations of instability and to provide protection measures in good time.

EROSION BY NORMAL WATER FLOW

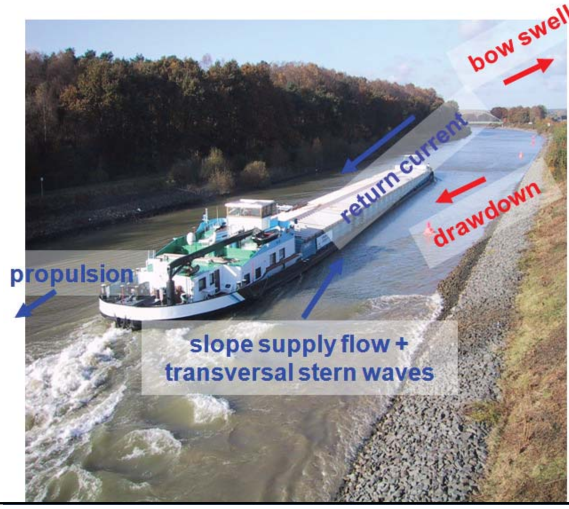
EROSION DURING EXTREME METEOROLOGICAL EVENTS

EROSION BY VESSELS



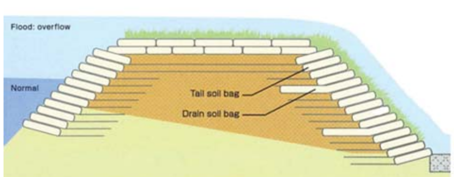
EROSION BY VESSELS

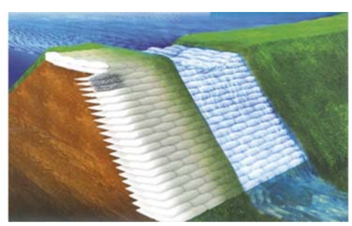
In canals, the dominating hydraulic load often results from ship induced currents and waves, intensified by the fact that the cross section of the waterway can be small compared to the immersed part of the vessel.
From these loads, the drawdown needs extra attention regarding bank stability, if there is an interaction of groundwater and canal water.



Passive protection

- Passive protection consists with increasing resistance to water action and often it is the only possible measure if no alteration of the actions can be achieved.
- Comparison of costs can also lead to such a decision.
- The passive protection may include an increase in the overall stability of an earth structure and / or an increase in the resistance of the surface affected by the hydraulic action, by means of layers of materials for protection and/or reinforcement.
- Geosynthetics are particularly suited for passive protection of river / channel banks





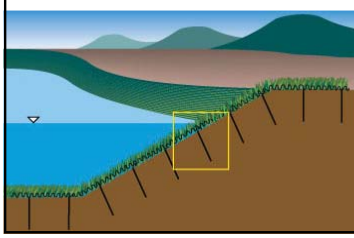
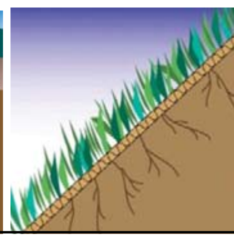
Geosynthetics for erosion control on river/channel banks

Vegetation provides protection to a bank in two functional ways:

- protection of the soil surface by reduction of velocities and stresses at the embankment boundary as a result of the coverage provided by stems and leaves that lay down in the flow and blanket the surface;

- reinforcement of the underlying soil due to the presence of roots.

Geosynthetic reinforced vegetation can resist significantly higher flow velocities compared to unreinforced vegetation; moreover the time before failure occurs is extended when vegetation is reinforced.

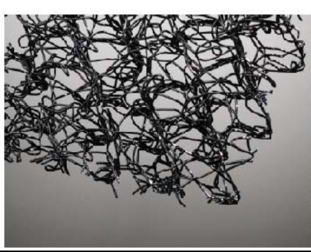
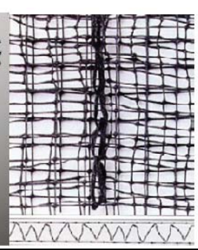

Geosynthetics for erosion control on river/channel banks

- **Geomats** are generally made of synthetic filaments or nets, tangled together to form a highly deformable layer 10 - 20 mm thick, featured by a very high porosity (greater than 90% on average); Geomats can protect the soil against raindrops splash and runoff by keeping in place soil particles; moreover Geomats can increase by several times the shear resistance of the roots system. They can be used for the following applications:

- erosion protection on slopes caused by the impact of raindrops and runoff

- lining of river / channel banks with low water velocities

Examples of geomats


Geosynthetics for erosion control on river/channel banks

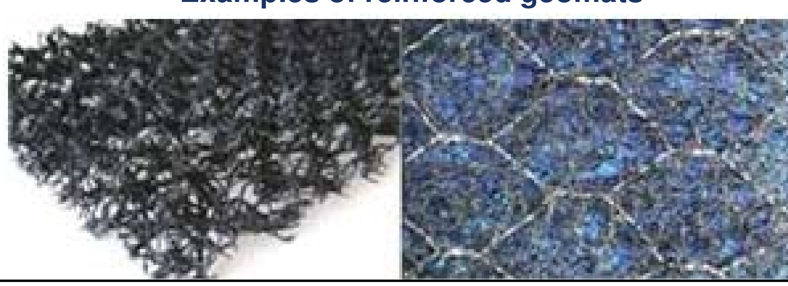
Examples of geomats used for erosion control on river/channel banks

Geosynthetics for erosion control on river/channel banks

Reinforced Geomats are geocomposites produced by factory joining a Geomat and a Geogrid or metallic mesh, having a tensile strength in the range 50 – 300 kN/m.

The reinforcement increases the tensile strength of the geomat so that it can be used on long and steep slopes, along the banks of canals and river courses with relatively high water velocities, where high tensile strength is required.

Examples of reinforced geomats



Geosynthetics for erosion control on river/channel banks

Pre-filled Geomats are produced by filling the geomat at factory with sand - gravel and bitumen, for increasing the weight and the resistance to shear stresses.

Other products consists of geomats pre-filled with topsoil and seeds

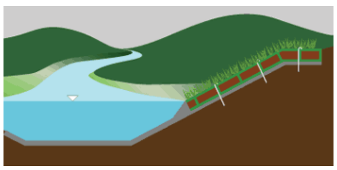
Examples of pre-filled geomats

Geosynthetics for erosion control on river/channel banks

Geocells are honeycomb products manufactured by joining polymeric strips.

Geocells can be used to stabilize a soil thickness of 100 - 300 mm, when a thick topsoil layer is required for allowing vegetation growth or to ballast geomembranes.

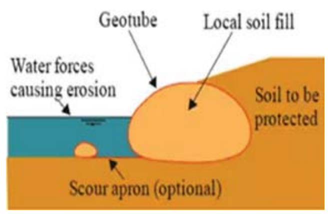
The top surface may be protected against erosion by placing a Geomat or Biomat.

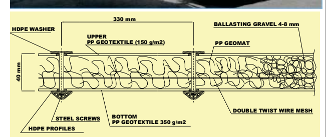


Geocontainers for erosion control on river/channel banks

Geosynthetic containers (Geocontainers) are geocomposite assembled from geotextiles and/or other geosynthetics, able to contain soil or other loose materials, totally closed by stitching, bonding, or other methods, for segregating the loose particles while allowing water or other fluids to escape.
Geocontainers include:

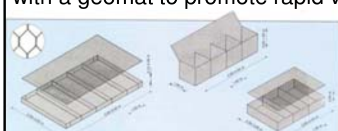
geobags **geosynthetic tubes** **ballasted mattresses**





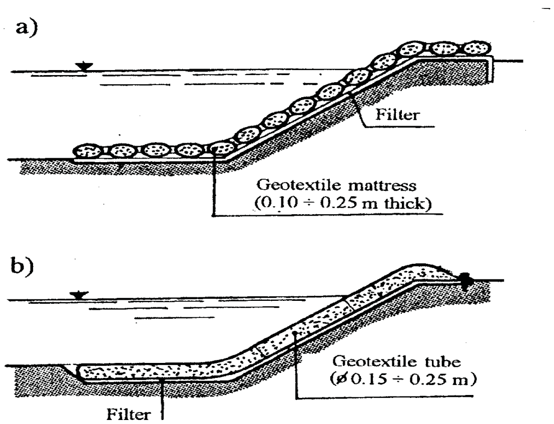
Geocontainers for erosion control on river/channel banks

Steel wire mesh products, such as gabions and mattresses, are usually implemented in rivers / canals when high water flow velocity occurs and high shear stresses are applied to canal banks.
These products are manufactured by assembling in factory different double twisted wire mesh panels to form boxes of different sizes that, once on the job site, can be filled with rocks of a specific grade.
When rocks are not available on the job site or nearby, it is possible to internally line a mattress with a nonwoven geotextile and fill it with sand or vegetative soil and cover it with a geomat to promote rapid vegetation.



GEOSYNTHETICS USED FOR COASTAL PROTECTION

Concrete Filled Geocontainers



Geocontainers for erosion control on river/channel banks

Columnar geocontainers, filled with concrete or sand

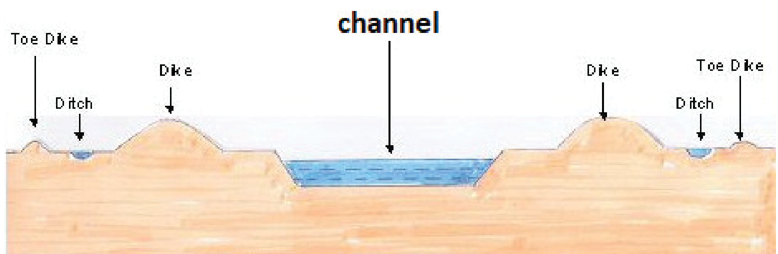
Geobags filled with sand for protection of the bank in a curve

Geocontainer mattress, filled with concrete

Choice of geosynthetics for erosion control

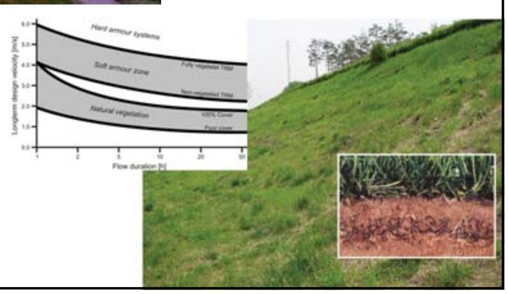
In a channel the following are usually distinguished:
- the bed, composed of the bottom and the banks, which is almost permanently under water;
- the upper part of the bank, submerged for about half the year and subject to periodic variations between the normal water level and the maximum;
- the floodplain area, between the bed and the main dike, flooded only during limited periods.

The bed and banks are the areas of greatest erosive stress, while the higher areas are only periodically exposed to erosive flow and wave motion.



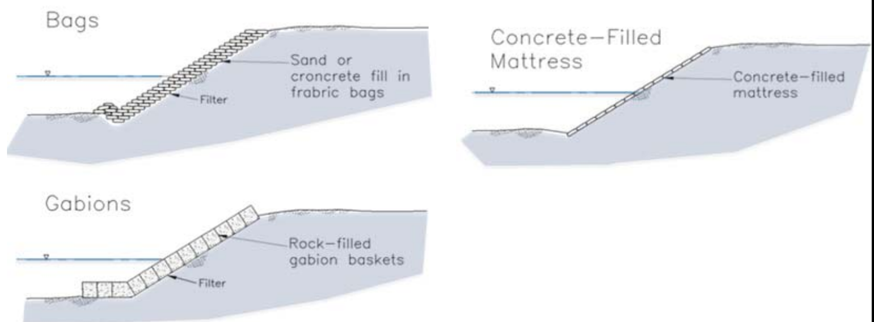
Choice of geosynthetics for erosion control

To avoid erosion, it is necessary to ensure adequate resistance to the speed and shear stresses generated by the water current on the bank.
The combination of vegetation and geosynthetics provides the best and strongest resistance to erosion.



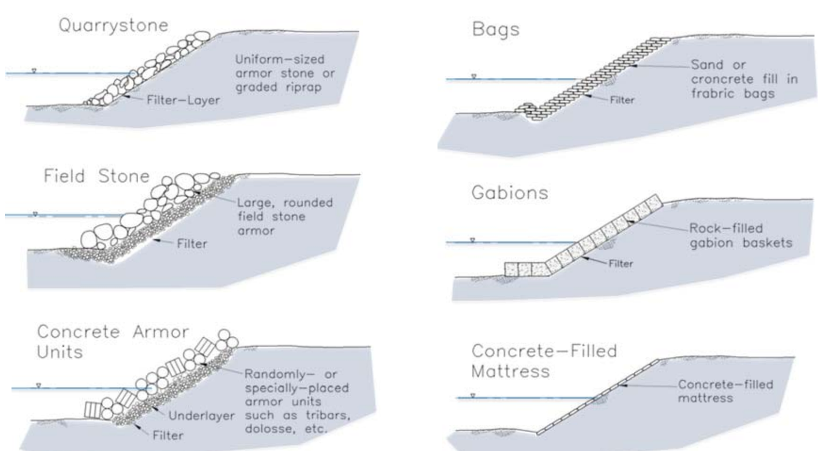
Choice of geosynthetics for erosion control

If greater resistance to water stream actions is required, geocontainers can provide the necessary stability thanks to the weight of the fill.
Geocontainers offer an added benefit, as the local material may be used as infill and there may be no need to import additional material.



APPLICATIONS OF GEOSYNTHETICS FOR COASTAL PROTECTION

Revetments and geotextile filters



PROTECTION OF BANKS BY VEGETATED GEOCONTAINERS:

Many bioengineering techniques combine vegetation and geosynthetics.
The protection of banks and dikes with living plant components can only be carried out permanently at a water depth of about 70 - 80 cm in clear waters, less so in turbid environments.
An example are geocontainers with already grown vegetation that can withstand even high hydraulic forces, with similar or even greater performance than stone riprap.

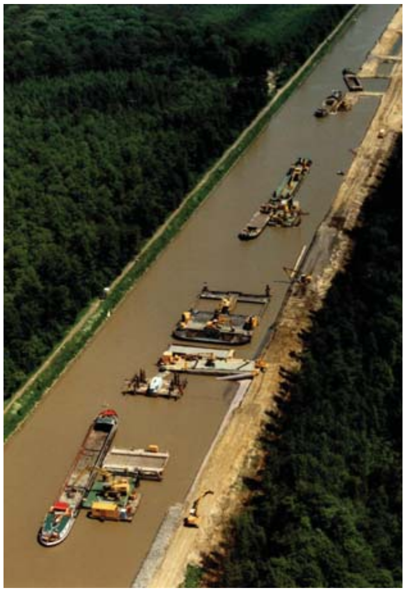
Choice of geosynthetics for erosion control

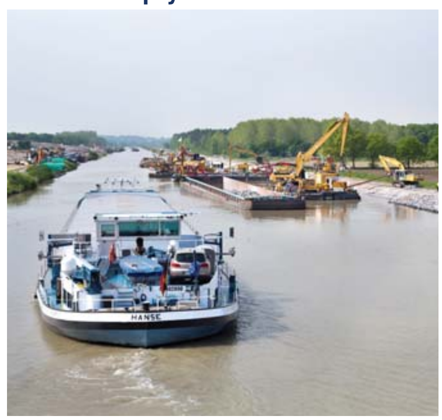
A highly effective erosion protection can be obtained with reinforced slopes with a wrap-around facing, often integrated with the insertion of willow cuttings.
The reinforcing elements (geogrids, geotextiles, steel meshes with polymeric coating), wrapped around the face, ensure protection from erosion while the roots of the plants serve as deep anchors in the ground.
The vegetation in turn provides protection of the geosynthetics from atmospheric agents.
Willows can be introduced into the reinforced soil body during construction; once grown, willows will provide high erosion resistance and high CO_2 segregation.

FAILURE OF BANK PROTECTION MAY OCCUR DUE TO LACK OF FILTRATION AND SEPARATION:
destabilisation is indicated by downward soil movement under the armour, even if the armour in itself is stable due to interlocking or cable connections like in many concrete revetments. Such soil movement is due to erosion and piping of soil particles produced by reverse flow.

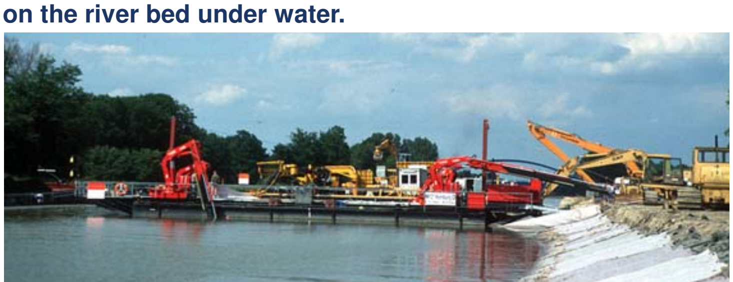
A GEOTEXTILE PREVENTS FAILURE OF BANK PROTECTION DUE TO LACK OF FILTRATION AND SEPARATION

INSTALLATION IS DIFFICULT UNDER WATER:
the installation of erosion protection is complicated by the fact that all work has to be done under water, since often it is not possible to allow for an interruption of navigation and we can't empty a river.

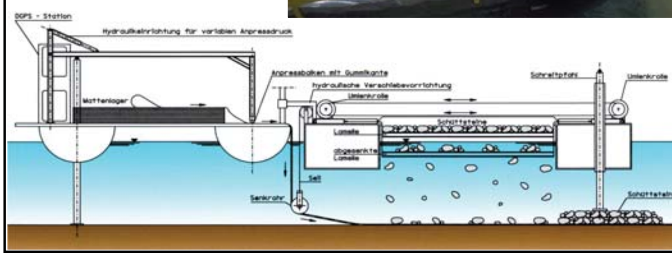




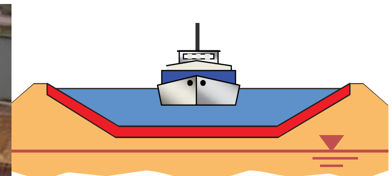
SPECIAL EQUIPMENT HAS BEEN DEVELOPED FOR INSTALLATION UNDER WATER:
some installation systems roll the geosynthetic on a steel tube and unroll it on the river bed under water.

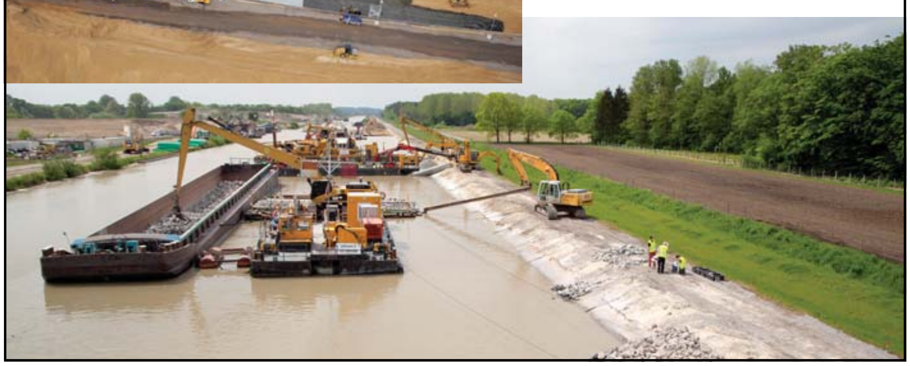


Other methods guide the fabric from a pontoon to the bottom around a cross-beam. It is essential that the geosynthetic is ballasted, otherwise it would float



Erosive interaction of water and ground can be avoided if the water course is confined by an impervious lining. Usually natural clay is used for such lining, but clay needs erosion protection itself, which is provided for in the usual way: a geotextile as filter and separation, and an armour for structural stability.





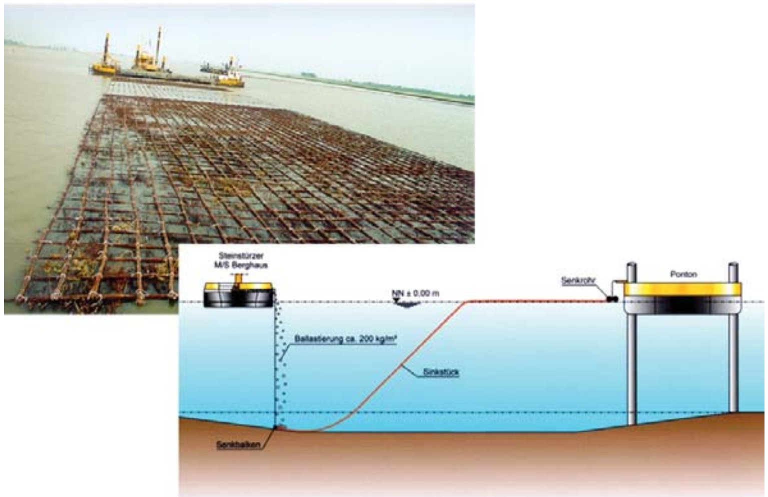
LINING OF RIVER BANKS WITH GCL PROTECTED BY CONCRETE LINING:
with GCL, impervious clay and erosion protection is combined in one product. Nevertheless, also a GCL needs protection against mechanical impact, e.g. a thin concrete layer or a concrete filled geosynthetic mattress

ACTIVE PROTECTION OF RIVER BANKS WITH TRAINING STRUCTURES (GROINS AND DIKES):
in rivers there is the possibility to reduce the erosive forces on the banks caused by water flow by installing river training structures like groins and longitudinal dikes. These structures need themselves sufficient strength, provided usually by heavy rocks and/or geosynthetic containers

USE OF GEOBAGS AND GEOCONTAINERS FOR GROINS AND DIKES:
geocontainers can be used to build the core or the whole body of a groin or dike. One great advantage is the possibility to use local soil that would never be used for hydraulic structures without confinement, like silt or sand. In this way construction costs can be greatly limited.

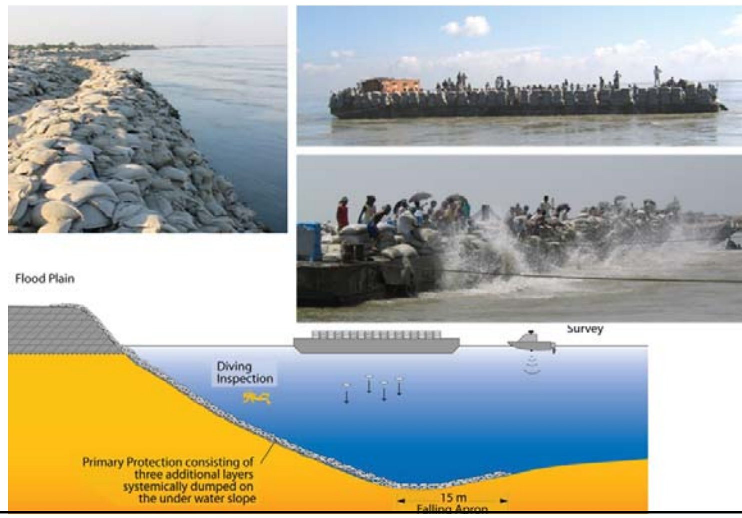
USE OF GABIONS AND MATTRESSES FOR PROTECTION AGAINST SHIP INDUCED AND WATER STREAM EFFECTS:
we can't influence the water load, but we can provide sufficient strength against flow forces.
To increase the strength, since we have ship induced plus natural hydraulic effects, we can use gabions or mattresses, always with an appropriate geotextile filter underneath.

USE OF FASCINES COVERED WITH DUMPED BALLAST FOR LARGE RIVERS OR ESTUARIES:
in rivers with high flow velocities, placement of a geotextile filters is even more complicated. Therefore in large rivers or estuaries, fascine or willow mats are used to protect against erosion. Placement is started by lowering one end of the mattress with a steel cross beam and then by dumping ballast on it

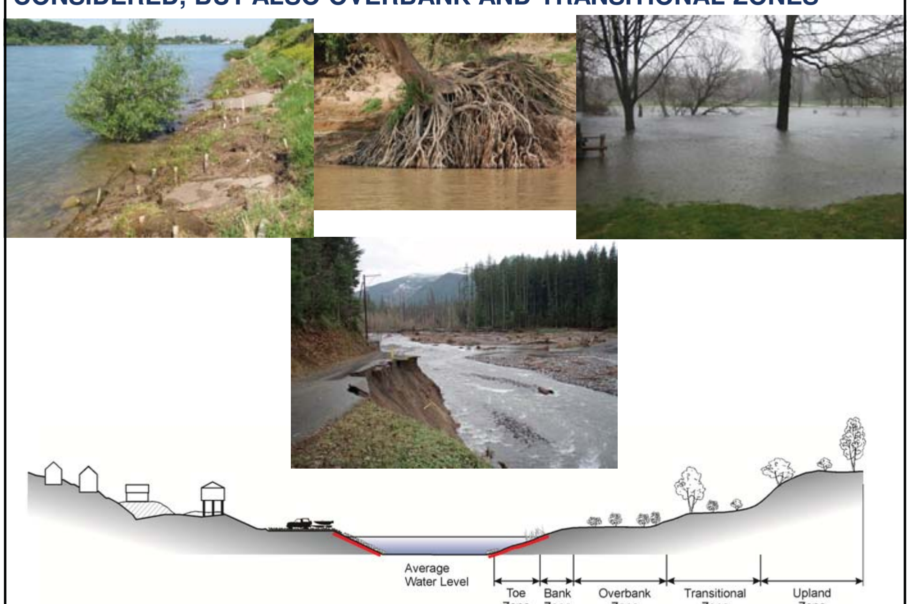


USE OF GEOTEXTILES BELOW FASCINES COVERED WITH DUMPED BALLAST FOR LARGE RIVERS OR ESTUARIES: ù
for standard fascine mattresses, willow bundles are tied on a geotextile. If extra protection of the geotextile is needed because of the size of the armour, a brushwood layer is added. Often a composite fabric is used, made up of a woven gtx for strength and a nonwoven gtx for filtration.

USE OF GEOCONTAINERS FOR FILTER AND BANK STABILITY UNDER WATER: another possibility to allow for placing a filter and bank stability system in flowing water is the use of geosynthetic containers, which afford filter function and bank stability thanks to fill weight.



IN RIVERINE AREAS, NOT ONLY THE RIVERBANKS HAVE TO BE CONSIDERED, BUT ALSO OVERBANK AND TRANSITIONAL ZONES

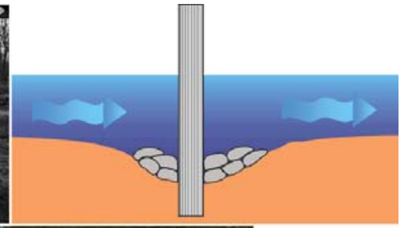


Choice of geosynthetics for erosion control

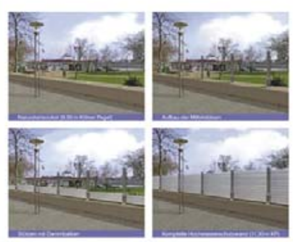
With turbulent flow, there is always a risk of scouring where water velocities are high, typically around structures such as bridge piers and foundations.

Geocontainers filled with sand are an ideal solution to prevent scouring or to repair existing scoured cavities in river or channels beds.

The geocontainers can be filled with local sandy material under dry conditions and placed in the desired position with appropriate equipment.

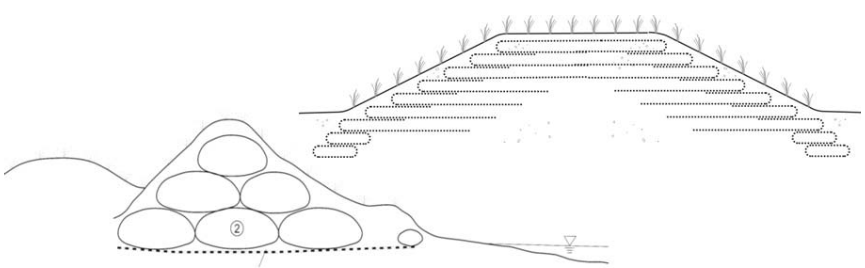


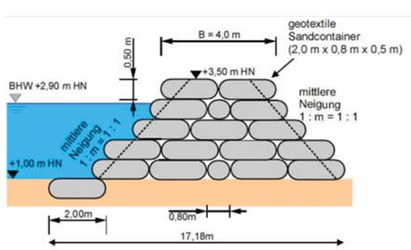
FLOOD CONFINING STRUCTURE FOR WIDE RIVER VALLEYS:
if a river valley is very wide, often flood confining structures are built. In rural areas, dikes or levees retain the flood water. In urban areas, flood walls, either permanent or temporary, protect the area from being flooded. Earth dikes or levees need to be protected against erosion both on water side and valley side.

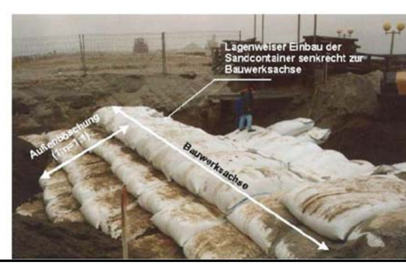


DIKES SHALL BE PROTECTED AGAINST OVERTOPPING:
a very specific issue is the protection of the downstream side of dikes or levees against erosion caused by overtopping water. In such cases, the slope can have to withstand flow velocities up to 10 m/s. Often the usual grass cover is not able to withstand such velocities. If regressive gully erosion develops, dike failure becomes very likely.
Therefore increasing the erosion resistance of vegetation by geomats or other bioengineering measures is often required.

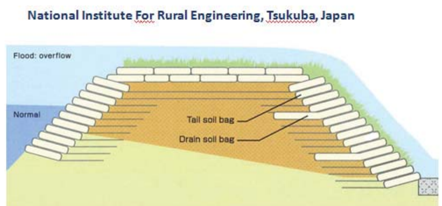
STRENGTHENING THE WHOLE DIKE BODY WITH GEOSYNTHETIC REINFORCEMENTS AND GEOCONTAINERS:
another possibilitiy is to strenghten the whole dike body with geosynthetic reinforcements, or to build the body of the dike with geosynthetic containers.

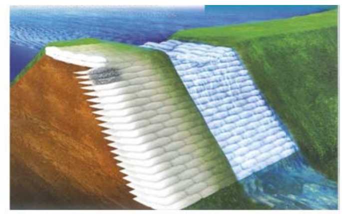


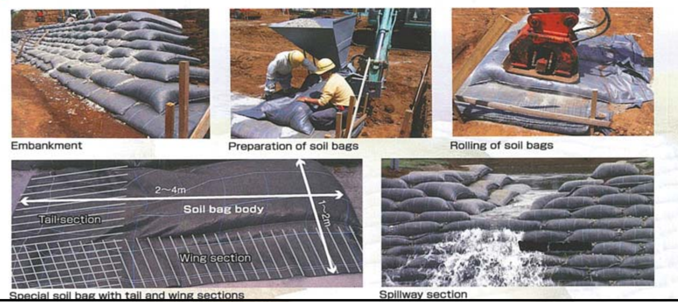




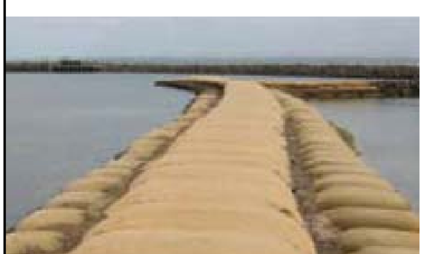
STRENGTHENING THE WHOLE DIKE BODY WITH GEOCONTAINERS :
in Japan a system was developed using geobags with tails and wings, which allows to get increased strength to enable controlled overtopping in a purposely designed spillway section.







GEOSYNTHETIC BAGS (GEOBAGS) APPLICATIONS

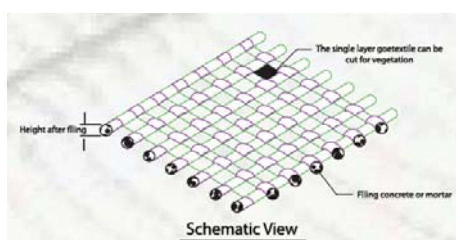


GEOSYNTHETIC BAGS (GEOBAGS) INSTALLATION

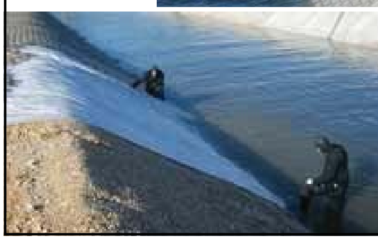
GEOSYNTHETIC BAGS (GEOBAGS) INSTALLATION

Plastic gabions and mattresses

CONCRETE FILLED GEOCONTAINER MATTRESSES



CONCRETE FILLED GEOCONTAINERS

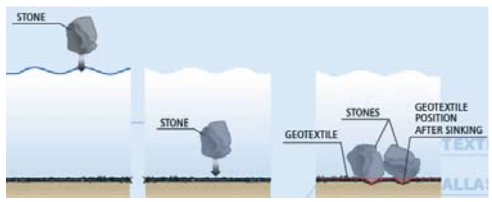


CONCRETE FILLED GEOCONTAINERS

INSTALLATION

Concrete filled geocontainers are supplied in rolls. The filling site should be prepared to be flat and free of debris or protruding objects. Each sectors of the Geocontainer is filled with an appropriate mix of concrete. The filling time is about 10 minutes for each unit. Once the Geocontainer is installed, it provides protection for areas subject to heavy erosion. The structure shall be UV resistant. It is possible to lift the Geocontainer and change location thanks to lifting loops and high tenacity seams. Geocontainer can be lifted and placed in position under water.

Ballasted filtering mattresses (BFM)

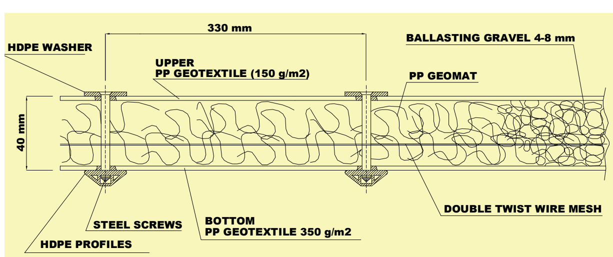


Ballasted filtering mattresses (BFM)

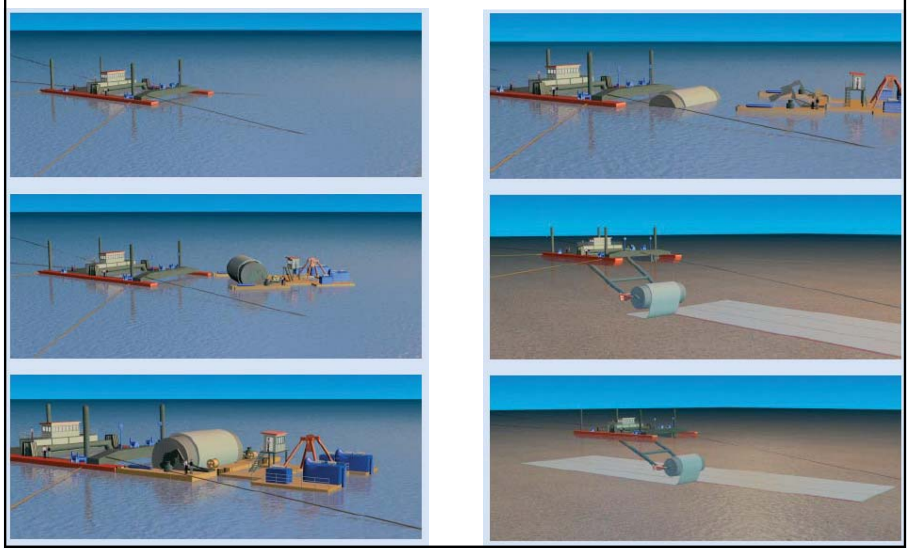
BALLASTED FILTERING MATTRESSES

The BFM (weight 50 kg/m2, ±10%), is a geocomposite of nominal thickness equal to 40 - 50 mm constituted by:

- **filtering geotextile for bottom and closure**
- **reinforcement with metallic wire mesh**
- **PP three-dimensional geomat**
- **quilting**
- **side band**



Ballasted filtering mattresses (BFM) installation



Ballasted filtering mattresses (BFM) installation

Design of erosion protection systems

The design calculation or verification of a bank protection can be carried out using two different methods: the first takes into consideration the admissible speed of the water, and the second the admissible shear stresses:

- speed: $V < V_{all} / FS$

- shear stresses: $\tau < \tau_{all} / FS$

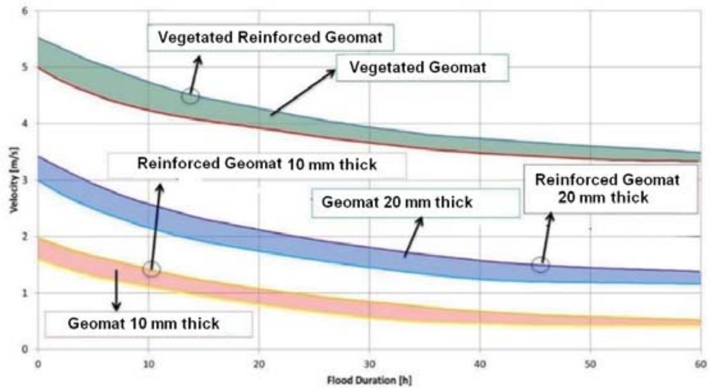
where τ_{all} and V_{all} are respectively the shear stress produced by the current and the water velocity at which the movements of the solid particles begin, and FS is the required Safety Factor.

Design of erosion protection systems

The stability checks shall be performed in two design conditions, which represent the two limit states, to take into account the evolution of the vegetation over time:
- End of the works: at the very end of the works, the section is able to convey the maximum capacity and the resistant shear stresses are minimal: this is usually the critical condition for the coating materials, therefore it is the most critical situation to be taken into consideration for the protection of the embankment.
- Fully grown vegetation: when the vegetation has fully grown, both the roughness and the resistant shear forces are maximum; in fact when the vegetation is completely developed (generally after 1 - 3 years) the resistance to erosion is greater due to the effect of the root system, but at the same time there is an increase in roughness; this is usually the critical condition for conveying the design flow Qd.

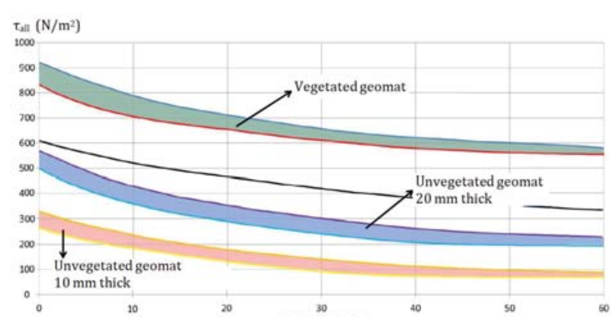
Design of erosion protection systems

The Figure shows an example, taken from several sources, of a V_{all} graph as a function of the duration of the flood event flow for a family of geomats, from tests according to ASTM D6460: the graph is divided into zones, where the lower zones they refer to non-vegetated geomats and the upper zone refers to vegetated geomats; the upper limit of each zone indicates V_{all} for reinforced geomats. These charts can be provided by manufacturers for each specific product family.



Design of erosion protection systems

The permissible resistant shear stress τ_{all} can be evaluated by means of channel tests according to the ASTM D6460 standard. The tests are generally carried out for a maximum duration of 60 hours. The permissible resistant shear stress τ_{all} is evaluated when an average erosion depth of 12.5 mm below the coating is reached. The figure shows an example (taken from several sources) of a τ_{all} graph as a function of the flow duration for a family of geomats, typically obtained with tests according to the ASTM D6460 standard. These charts can be provided by manufacturers for each specific product family.



Design of erosion protection systems

For the design of geocontainers for protection against hydraulic erosion, some design approaches are available, a collection of which was published by Pilarczyk (2000) and by Bezuijen, A. and Vastenburg E.W. (2013).

The design of geosynthetics, both for single products such as geomats and for geocontainers and naturalistic engineering systems, must take into account the projections of the hydraulic conditions expected in the coming decades.

Therefore, the calculation methods must be used with the application of appropriate amplification factors of the hydraulic actions and evaluating the resistances for the amplified conditions of flow rate, depth of the watercourse and duration of the floods as a function of the design life of the project.

Benefits of Geosynthetics for erosion control

Based on 40 years of positive experience, geosynthetics are nowadays well accepted and broadly used in hydraulic projects, like dams and canals.
The components of the geosynthetic system selected for use in a hydraulic structure are highly project specific and site specific. If properly specified and installed, geosynthetics can be cost effective and increase the service life of a hydraulic structure.
The design and execution of erosion protection works on slopes and in rivers / canals must take into account loads that are caused by the interaction between water and soil.
Wave action and natural current must be taken into account, as well as hydraulic loads on banks and embankments during flood events.
All defenses against erosion require adequate engineering design. Geosynthetics can provide an optimal solution to the problem of erosion, both in simple forms, such as geomats, and in the form of engineered geocontainers, and as components of naturalistic engineering systems.
The design of geosynthetics against erosion on the banks of waterways must be carried out taking into account the projections of the hydraulic conditions expected in the coming decades, depending on the design life of the project.