

Free webinar
November 15 – 17, 2021





Improving the Performance of
Canals with Geosynthetics

Overview of Geosynthetics Products for Erosion Control in Irrigation Channels

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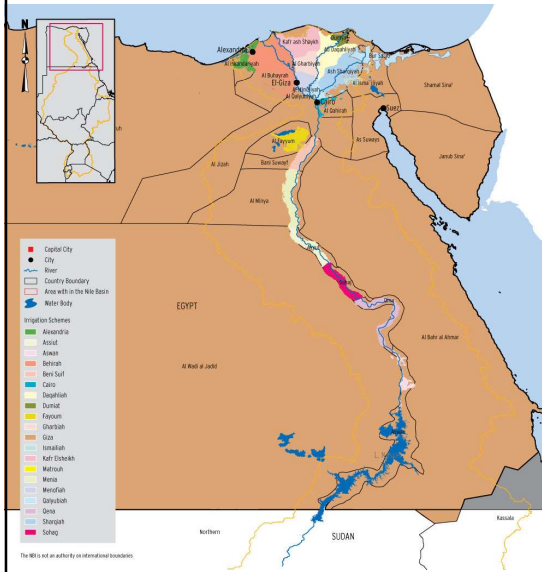
About the lecturer



- 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).

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IRRIGATION SYSTEM IN EGYPT

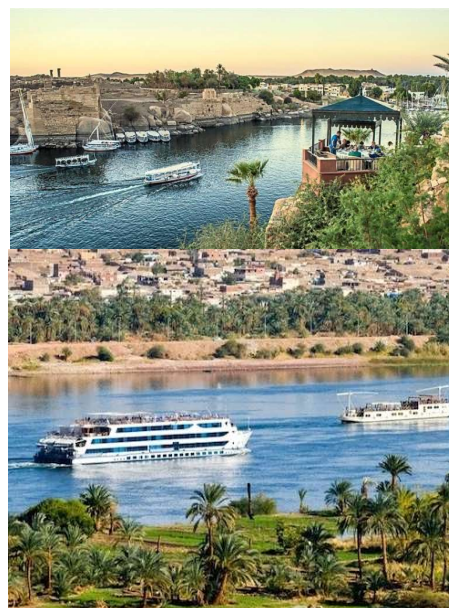


Egypt's irrigation system extends some 1,200 km from Aswan to the Mediterranean Sea and includes **13,000 km of main public canals, 19,000 km of secondary public canals and 100,000 km of tertiary private watercourses (mesqas)** that form the main distributaries to farmer's fields.

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NAVIGATION IN EGYPT

In Egypt the Nile is navigable by sailing vessels and shallow-draft river boats as far south as Aswan



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EXAMPLE OF IRRIGATION IN EGYPT: IBRAHIMIYA CANAL



The **Ibrahimiya Canal** is an irrigation canal built in 1873. It supplied perennial irrigation to 2,300 km² and flood irrigation to another 1,700 km². This 350 kilometer long canal is one of the largest artificial canals in the world, taking water directly from the Nile. It is possible to note that the banks are fully vegetated.

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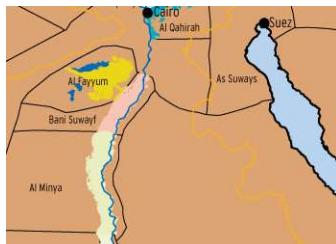
EXAMPLE OF IRRIGATION IN EGYPT: BAHR YUSSEF



The **Bahr Yussef** (the canal of Joseph) is a canal which connects the Nile river with Al Fayyum (South West of Cairo).

The original canal is more than 3,000 years old.

In the picture it can be noted that there are signs of erosion on the right bank, which is not vegetated.



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EXAMPLE OF IRRIGATION IN EGYPT: MEDIUM CHANNELS



In some cases the banks are vegetated, in other cases the banks are unvegetated (hence totally exposed to the erosive action of water flow)

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EXAMPLE OF IRRIGATION IN EGYPT: SMALL CHANNELS

In some cases the banks are vegetated, in other cases the banks are unvegetated (with clear signs of erosion)



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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).



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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.



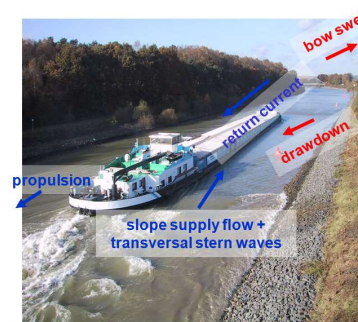
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Erosion of the banks of waterways

The erosion of embankments and banks of canals and rivers can be produced by two main actions: the natural hydraulic forces originating from currents and waves and the hydraulic loads induced by navigation.

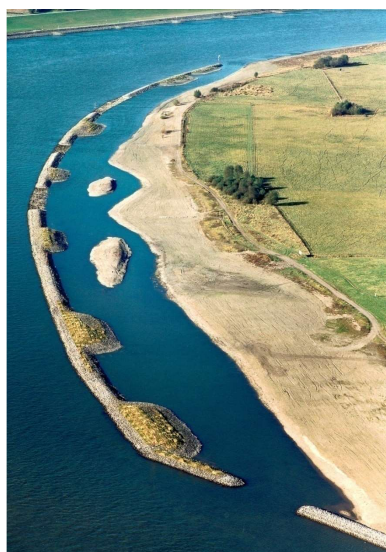
In navigable channels, the dominant hydraulic load often derives from the currents and waves induced by the boats, intensified by the fact that the cross section of the watercourse is often small compared to the submerged part of the ship.

In natural waterways, the maximum hydraulic loads are reached during extreme weather events.



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Active protection of waterways consists with structures for reducing the effects of the water flow



longitudinal embankments

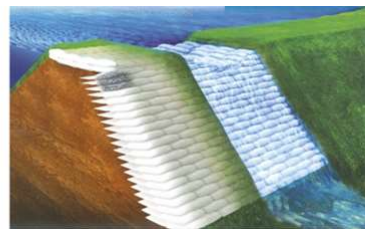
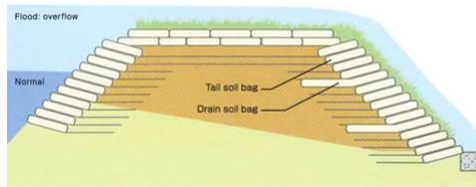


perpendicular groins

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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



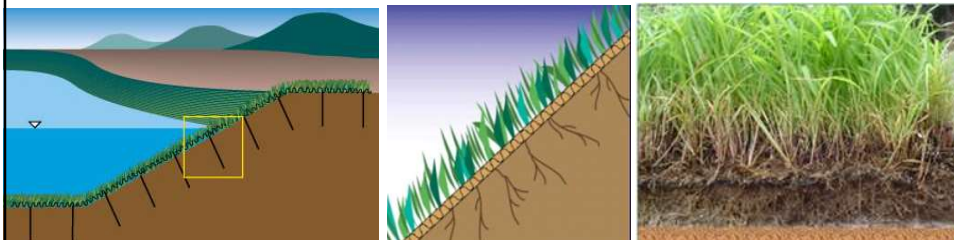
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Geosynthetics for erosion control on river/channel banks

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.

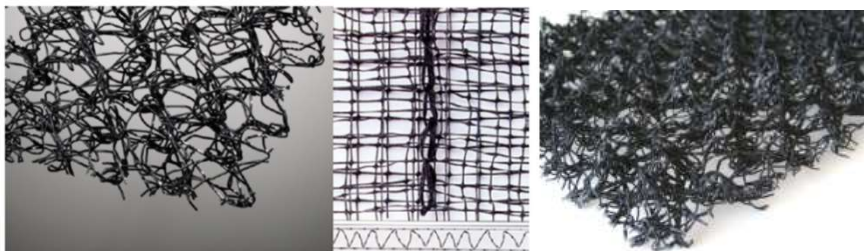


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Geosynthetics for erosion control on river/channel banks

- **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



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Geosynthetics for erosion control on river/channel banks

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



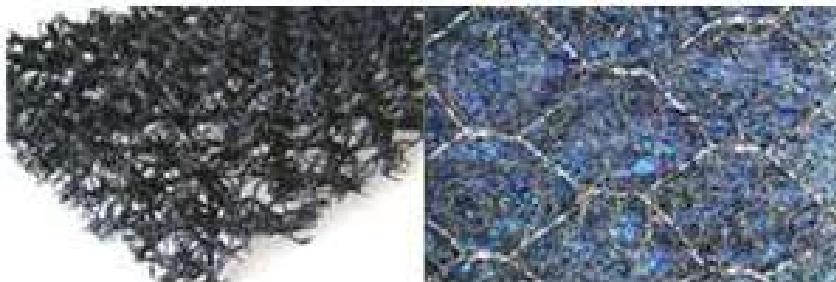
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Geosynthetics for erosion control on river/channel banks

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



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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

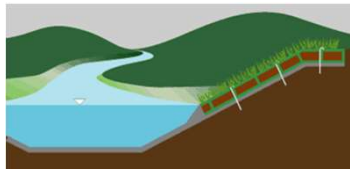
Examples of pre-filled geomats



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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.



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Geosynthetics for erosion control on river/channel banks

- **Biomats and Bionets** provide temporary erosion control and are either degradable after a given period or they function only long enough to facilitate vegetative growth.

Biomats and Bionets are made up of natural fibers, in the form of a mat of fibers kept together by natural or synthetic low weight meshes (Biomats), or in the form of a woven net (Bionets).

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

Examples of Biomats and Bionets



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Geocontainers for erosion control on river/channel banks

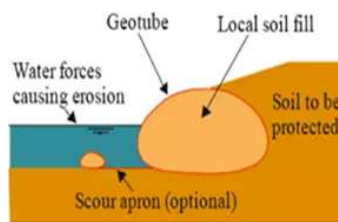
Geosynthetic containers (Geocontainers) are geocomposite assembled from geotextiles and/or other geosynthetics, able to contain soil or other loose materials, totally closed by stitching, bonding, or other methods, for segregating the loose particles while allowing water or other fluids to escape.

Geocontainers include:

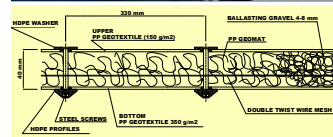
geobags



geosynthetic tubes



ballasted mattresses



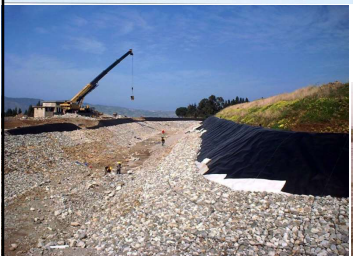
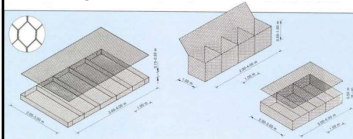
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Geocontainers for erosion control on river/channel banks

Double twisted wire mesh products, such as gabions and mattresses, are usually implemented in irrigation canals when high water flow velocity occurs and high shear stresses are applied to canal banks.

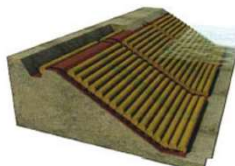
These products are manufactured by assembling in factory different double twisted wire mesh panels to form boxes of different sizes that, once on the job site, can be filled with rocks of a specific grade.

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.



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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

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Geosynthetics for erosion control on river/channel banks

Geosynthetic Cementitious Composite Mat GCCMs are a class of geosynthetic material with a wide range of geotechnical applications. They are flexible concrete impregnated fabrics that harden on hydration to form a thin, durable, water proof and fire resistant concrete layer.

Examples of GCCM



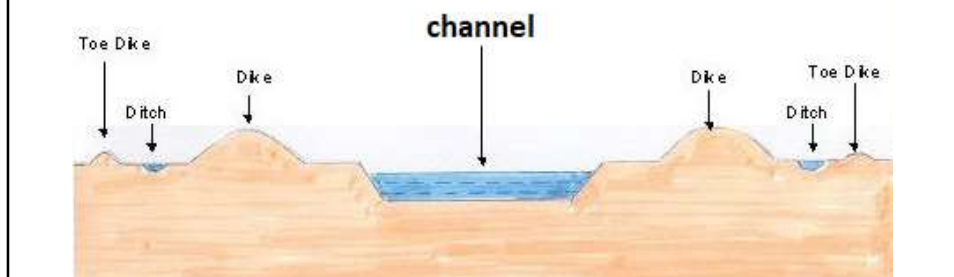
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Choice of geosynthetics for erosion control

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.

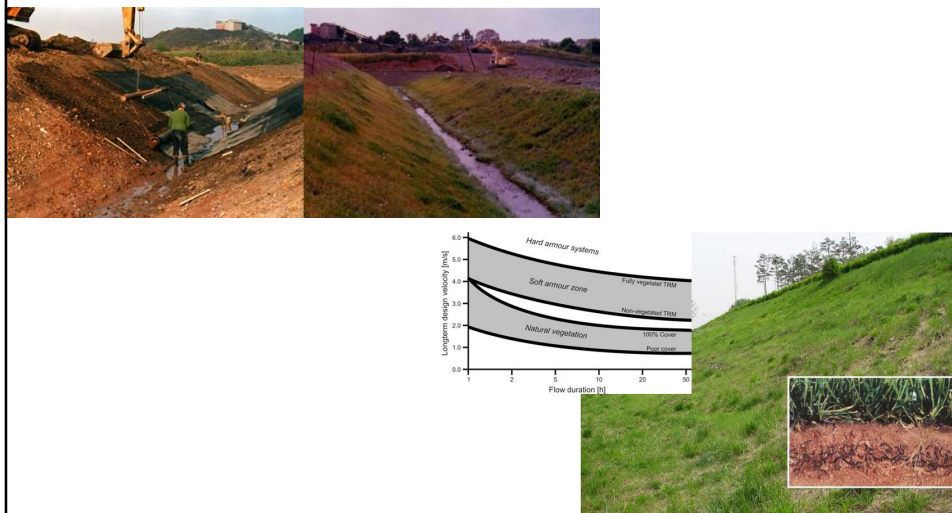


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Choice of geosynthetics for erosion control

To avoid erosion, it is necessary to ensure adequate resistance to the speed and shear stresses generated by the water current on the bank.

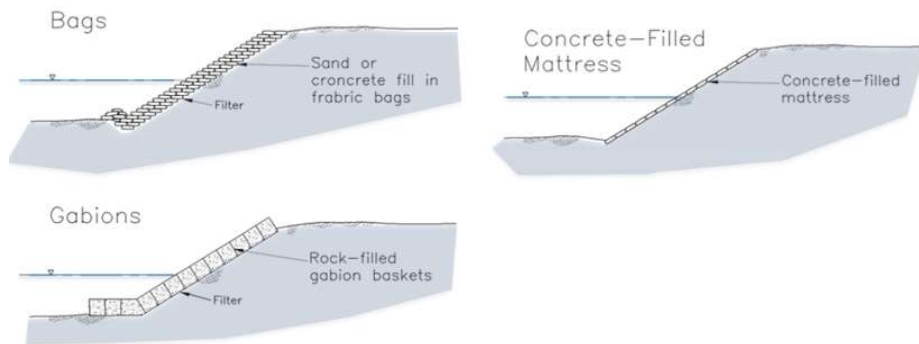
The combination of vegetation and geosynthetics provides the best and strongest resistance to erosion.



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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.



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Choice of geosynthetics for erosion control

The use of vegetation with or without structural elements – the so-called bioengineering – is increasingly being proposed to replace "hard materials" while continuing to provide protection from erosion.

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.



Geocontainers with pre-cultivated vegetation in gabions or mattresses

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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 CO₂ segregation.



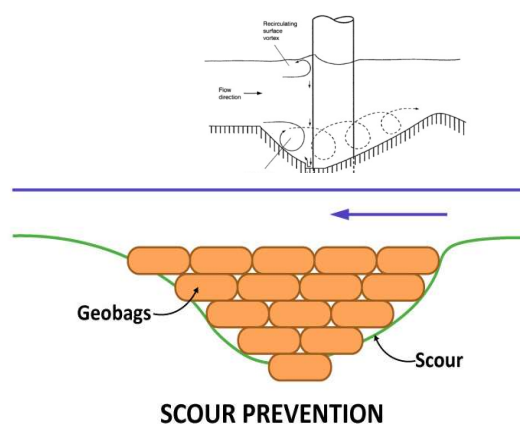
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Choice of geosynthetics for erosion control

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.



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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.

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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:

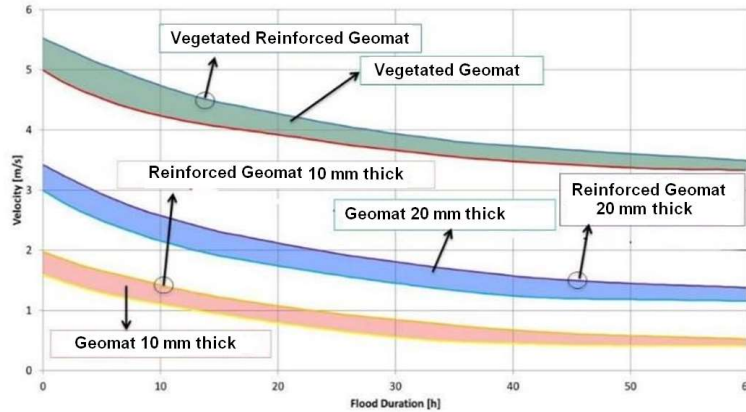
- End of the works: at the very end of the works, the section is able to convey the maximum capacity and the resistant shear stresses are minimal: this is usually the critical condition for the coating materials, therefore it is the most critical situation to be taken into consideration for the protection of the embankment.

- Fully grown vegetation: when the vegetation has fully grown, both the roughness and the resistant cutting 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 Q_d .

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Design of erosion protection systems

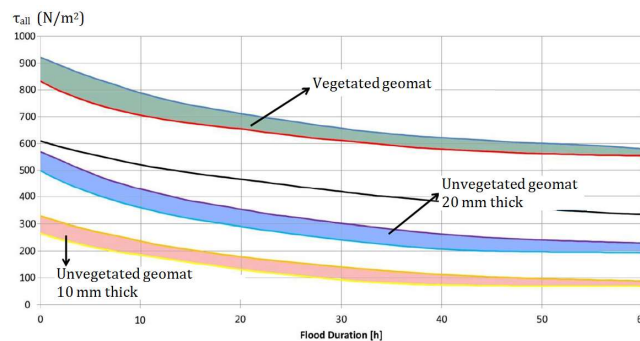
The Figure shows an example, taken from several sources, of a V_{all} graph as a function of the duration of the flood event flow for a family of geomats, from tests according to ASTM D6460: the graph is divided into zones, where the lower zones they refer to non-vegetated geomats and the upper zone 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.



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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.



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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.

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Benefits of Geosynthetics in channel projects

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 in rivers and 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 on the banks of waterways, 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.

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