Granulated filters and geotextile filter stability.

Filter layers are defined as layers that protect the underlying base material or soil from erosion by waves and currents without excessive buildup of pore pressure in the underlying material.

Methods

Filter functions can be achieved using either:

1. one or more layers of granulated material such as gravel or small stone of various grain sizes,
2. geotextile fabric, or
3. a combination of geotextile overlaid with granulated material.

- Design criteria for geotextile filter cloth used in filter application are given in Part VI-4-7, “Geotextiles and Plastics.”
- Design of rubble-mound structure underlayers is covered in Part VI-5-3-e, (1) Filter layer functions.

Design Objectives

Filter layers are designed to achieve one or more of the following objectives in coastal structures:

1. Prevent migration of underlying sand or soil particles through the filter layer voids into the overlying rubble-mound structure layers. Leeching of base material could be caused by turbulent flow within the structure or by excessive pore pressures that can wash out fine particles. Without a filter layer, foundation or underlayer material would be lost and the stones in the structure layer over the filter would sink into the void resulting in differential settlement and decreased structure crest elevation.

2. Distribution of structure weight. A bedding filter layer helps to distribute the structure's weight over the underlying base material to provide more uniform settlement. A leveled bedding layer also ensures a more uniform baseplate load on caisson structures.

3. Reduction of hydrodynamic loads on the structure's outer stone layers. A granular filter layer can help dissipate flow energy whereas a geotextile filter will not be as effective in this regard.

When to Use:

- Granulated filters are commonly used as a bedding layer on which a coastal structure rests, or in construction of revetments where the filter layer protects the underlying embankment.
- Filter layers are also needed in rubble-mound structures having cores composed of fine materials like sand or gravel.
- Stone blankets (used to prevent erosion due to waves and currents) also reduce leeching of the underlying sand or soil, but in this situation stability of the stone
blanket material in waves and currents is an important design concern. Design of stone blankets is covered in Part VI-5-3-f, “Blanket stability in current fields.”

- It is advisable to place coastal structures on a bedding layer (along with adequate toe protection) to prevent or reduce undermining and settlement.

- When rubble structures are founded on cohesionless soil, especially sand, a filter blanket should be provided to prevent differential wave pressures, currents, and groundwater flow from creating an unstable foundation condition through removal of particles.

- Even when a filter blanket is not needed, bedding layers may be used to prevent erosion during construction, to distribute structure weight, or to retain and protect a geotextile filter cloth.

**Bedding layers are not necessary:**
1. where depths are greater than about three times the maximum wave height \( h = 3H_{\text{max}} \),
2. where the anticipated bottom current velocities are below the incipient motion level for the average-size bed material, or
3. where the foundation is a hard, durable material such as bedrock.

**Advantages of Granular over Geotextile Filters**

In some situations granular filters have several advantages over geotextile filters in coastal construction (Permanent International Association of Navigation Congresses (PIANC) 1992).

- The filter elements (stone, gravel, sand, etc.) are usually very durable.
- Granular filters provide a good contact interface between the filter and base material below and between the filter and overlying layers. This is important for sloping structures.
- Granular bedding layers can help smooth bottom irregularities and thus provide a more uniform construction base.
- The porosity of granular filters help damp wave energy.
- Self-weight of the filter layer contributes to its stability when exposed to waves and currents during construction whereas geotextiles may have to be weighted under similar conditions.
- The loose nature of the filter elements allows the filter to better withstand impacts when larger stones are placed on the filter layer during construction or the stones shift during settlement.
- Granular filter layers are relatively easy to repair, and in some instances may be self-healing.
- Filter materials are widely available and inexpensive.
Advantages of Geotextile over Granular Filters

- The major disadvantage of granular filters is the difficulty of assuring uniform construction underwater to obtain the required thickness of the filter layer.
- Placing larger armor stone or riprap directly on geotextile filter cloth is likely to puncture the fabric either during placement or later during armor settlement. Placing a granular filter layer over the geotextile fabric protects it from damage. In this application there is more flexibility in specifying the filter stone gradation because the geotextile is retaining the underlying soil.

Granulated filter failure modes.

Granular filter layers fail their intended function when:
1. The base layer is eroded through the filter layer. Erosion can occur either by outgoing flow washing out particles perpendicular to the base/filter interface or by wave- and current-induced external flows parallel to the interface.
2. The filter layer becomes internally unstable. Instability occurs in filters having a very wide gradation when the finer fraction of the filter grain-size distribution is flushed out of the layer between the coarser material. This could result in compaction of the filter layer, differential settlement of the overlayers, and gradual increase in layer permeability.
3. The interface between adjacent granular layers becomes unstable, and lateral shearing motion occurs between layers constructed on a slope.
4. The filter layer fails to protect the underlying geotextile fabric from punctures and loss of soil through the filter cloth.

Granulated filter design criteria.

- Originally based on the geometry of voids between packed, uniform spheres.
- Allowances for grain-size distributions (and many successful field applications) led to the following established geometric filter design criteria.
  (Design guidance for exposed filter layers must also consider instability due to flow as discussed in Section VI-5-3-f, “Blanket stability in current fields.”)

1. **Retention criterion.** To prevent loss of the foundation or core material by leeching through the filter layer:

\[
\frac{D_{15} \text{(filter)}}{d_{85} \text{(foundation/base)}} < 4 \text{ to } 5
\]

   \[d_{85} = \text{dia. exceeded by the coarsest } 15\% \text{ of the base mat'l}
   \]

   \[D_{15} = \text{dia. exceeded by the coarsest } 85\% \text{ of the filter mat'l}
   \]

   a. Important for breakwater design.
   b. The coarser particles of the foundation or base material are trapped in the voids of the filter layer, thus forming a barrier for the smaller sized fraction of the foundation material.
c. The same criterion can be used to size successive layers in multilayer filters that might be needed when there is a large disparity between void sizes in the overlayer and particle sizes in the material under the filter.

d. Filter layers overlying coarse material like quarry spall and subject to intense dynamic forces should be designed similar to a rubble-mound structure underlayer with
\[
\frac{W_{50}(\text{filter})}{W_{50}(\text{foundation/base})} < 15 \text{ to } 20
\]

2. Permeability criterion. Adequate permeability of the filter layer is needed to reduce the hydraulic gradient across the layer (i.e. prevent pore pressure build-up). The accepted permeability criterion is
\[
\frac{D_{15}(\text{filter})}{d_{15}(\text{foundation/base})} > 4 \text{ to } 5
\]

   a. Important for embankment design.

3. Internal stability criterion. If the filter material has a wide gradation, there may be loss of finer particles causing internal instability (i.e. well sorted material is preferred). Internal stability requires
\[
\frac{D_{60}}{D_{10}} < 10
\]

   a. Poorly sorted material is not suitable for filters \( \Rightarrow \frac{D_{60}}{D_{10}} \geq 20 \Rightarrow \) internally unstable \( \Rightarrow \) too much washes out.

4. Layer thickness.
   a. Filter layers constructed of coarse gravel or larger material should have a minimum thickness at least two to three times the diameter of the larger stones in the filter distribution to be effective.
   b. Smaller gravel filter layer thickness should be at least 20 cm, and sand filter layers should be at least 10 cm thick (Pilarczyk 1990).
   c. These thickness guidelines assume controlled above-water construction. In underwater placement, bedding layer thickness should be at least two to three times the size of the larger quarrystones used in the layer, but never less than 30 cm thick to ensure that bottom irregularities are completely covered.
   d. Considerations such as shallow depths, exposure during construction, construction method, and strong hydrodynamic forces may dictate thicker filters, but no general rules can be stated.
   e. For deeper water the uncertainty related to construction often demands a minimum thickness of 50 cm.
5. **Extent.**
   a. It is common practice to extend the bedding layer beneath **rubble-mound structures** at least 1.5 m (5 ft) beyond the toe of the cover stone to help reduce toe scour.
   b. Rubble-mound structures with no core (i.e. composed entirely of armor layer and underlayers as are some low rubble-mound structures) should have a bedding layer that extends across the full width of the structure.

6. **Bedding layer over geotextile fabric.**
   a. In designs where a geotextile fabric is used to meet the retention criterion, a covering layer of quarry spalls or crushed rock (10-cm minimum and 20-cm maximum) should be placed to protect against puncturing by the overlying stones.
   b. Recommended minimum bedding layer thickness in this case is 60 cm, and filtering criteria should be met between the bedding layer and overlying stone layer.

- The previous geometric granular filter criteria are widely accepted in practice, and they are recommended in cases when an appreciable pressure gradient is expected perpendicular to the soil/filter interface.
- These rules may be somewhat conservative in situations without significant pressure gradients and when flow is parallel to the filter layer.
- When a good understanding of the character of flow within the filter layer exists and if the erosion of base material is caused by shear stresses rather than groundwater pressure gradients; the geometric filter requirements can be relaxed. A method based on research by Delft Hydraulics Laboratory can be used. Their hydraulic filter criteria is based on an expression for critical hydraulic gradient parallel to the filter/soil interface. The guidance is in terms of the filter $D_{15}$, base material $d_{50}$, filter porosity, and critical shear velocity of the base material; and acceptable values for the critical gradient were given by graphs for each of the flow cases.

**Granulated filter construction aspects.**
- Granular filter construction above water creates no special problems, and accurate placement is straightforward.
- Constructing a filter beneath the water surface is somewhat more problematic.
  o If small-size filter material with a wide gradation is dropped into place, there is a risk of particle segregation by size. This risk can be decreased by using more uniform material and minimizing the drop distance.
  o Another problem is maintaining adequate layer thickness during underwater placement. This has led to the recommended layer thickness being greater than required by the geometric filter criteria.
  o Finally, filter or bedding layers placed underwater are exposed to eroding waves and currents until the overlayers are placed. Depending on site-specific conditions, this factor may influence the construction sequence or the time of year chosen for construction.