Construction methodology and dimensioning of silt fences: scientific, normative and laboratorial review

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ABSTRACT: This Article features literature review of scientific material and manuals about design, installation, maintenance and singularities of the use of silt fences, defining it and discoursing on the materials that compose it, dynamics of its operation, design procedure and ASTM standards for its use. Presenting the advantages of its application and the disadvantages of its poor installation, or non-use, in places where surface erosion and soil sedimentation occurs for various reasons, presenting parameters for its proper location, aiming to propose more relevant studies for its correct use in Brazil, to thereby, provide better control in the final deposition of sediments, protecting water bodies, sanitation systems and more. This study was carried out with the intention of creating a recommendation of use and installation for silt fences, studying their performance with the use of a variety of geosynthetics to the granulometry of the Brazilian soils in question. In order to perform this study, the ASTM standards were used in tests with the proposed geosynthetics, the data obtained in these analyzes were then arranged in commented tables, indicating which is the best use and in which granulometry each geosynthetic has the best performance. It is hoped, therefore, to ensure the correct use of these temporary barriers in various works, providing consultation and dimensioning material compatible with the accelerated quotidian of construction sites.

Keywords: Silt fence; Surface erosion; Granulometry of the Brazilian soils; Temporary barriers.

1 INTRODUCTION

Despite standards and literature in the area of surface erosion control, there are still flaws and poorly executed projects in Brazil (Rosa et al 2015), culminating in the problem of sediment flow in areas of disturbed soil, letting this event influence the environment, causing great damage to the water bodies and nearby regions, through erosion and consequent sedimentation.

Surface soil erosion affects several regions of the country, from rural to urban, causing a variety of problems with unique gravity. The erosion process has its event bounded by locality characteristics, such as rainfall intensity, land occupation, soil geotechnical characteristics, among others (Vertematti 2015).

The sediment transportation by this flow in places of disturbance of the soil, coming from construction sites and others, is a great problem to the areas where sedimentation will occur. This process causing pollution in water bodies, silting, clogging and reduction of flow in sanitary and rainwater pipes, loss of arable land, destruction or interdiction of roads, streets, canals, buildings and others, thus causing damage in various ways (Maryland 2011).

The use of geosynthetics for erosion control purposes has been very widespread, since they have a good performance in this application when correctly employed (Pilarczky 2000). In Brazil, techniques of continuous coverage, such as geomat and biomat, providing conditions for revegetation and thus combating erosion are used, but they are not suited for every scenario. However, in areas where techniques such as this cannot be applied, such as in construction sites or maintenance sites, another form of protection that prevents sediment leakage is required, such as the silt fence technique.

Silt fence works as a temporary or permanent sediment barrier using geotextile, designed to intercept and reduce sediment flow, allowing the passage of water and retaining the particulate matter carried in the surface runoff (CALTRANS 2003). It is fixed on metal or wood stakes that are installed on the ground, has quick installation and removal (EPA 2012).

Some care must be taken with the use of silt fence, knowing that it is necessary to maintain and inspect them routinely, ensuring their physical and functional integrity. Therefore, if the installation, maintenance and planning specifications are not guaranteed, silt fences may have its intended purpose compromised (EPA 2012).

The design and installation of silt fences should be done according to engineering studies, such as calculation of surface runoff and sedimentation near the fence, thus avoiding application failures and insufficiency (Richardson and Middlebroeks 1991).

The incorrect use of silt fences still persists in Brazil, and it is easy to find works with provisions, materials and installations incompatible with the proposed solution of the technique. For this reason, this article begins a discussion on the subject, aiming to spread the theme in the country and provide clarification on the proposal of silt fence technique.

2 DEFINITION OF SILT FENCE

A silt fence consists of a geotextile attached to vertical stakes to prevent the transport of sediments by surface runoff, preventing them from reaching water bodies, public roads and sanitation systems (Koerner 2005). The geotextile must be anchored in a trench filled with compacted soil and its stakes must reach satisfactory depth for design performance, the geosynthetic must face the increasing inclination and the stakes, behind the geotextile, on the outside of the trench/inclination (IEPA 2012).

The silt fence filtration begins by an in-suspension particle filtration, meaning to the accumulation of sediments near the fence. That occurs in the first moment by the passage of the water flow and part of the sediments through the geosynthetic and, later, with the accumulation of the sediments and consequent clogging of the geotextile. The heavy particulate tends to be trapped behind the already accumulated sediment and the fine particulate follows reaching higher regions (Koerner 2005), as seen in Figure 1.

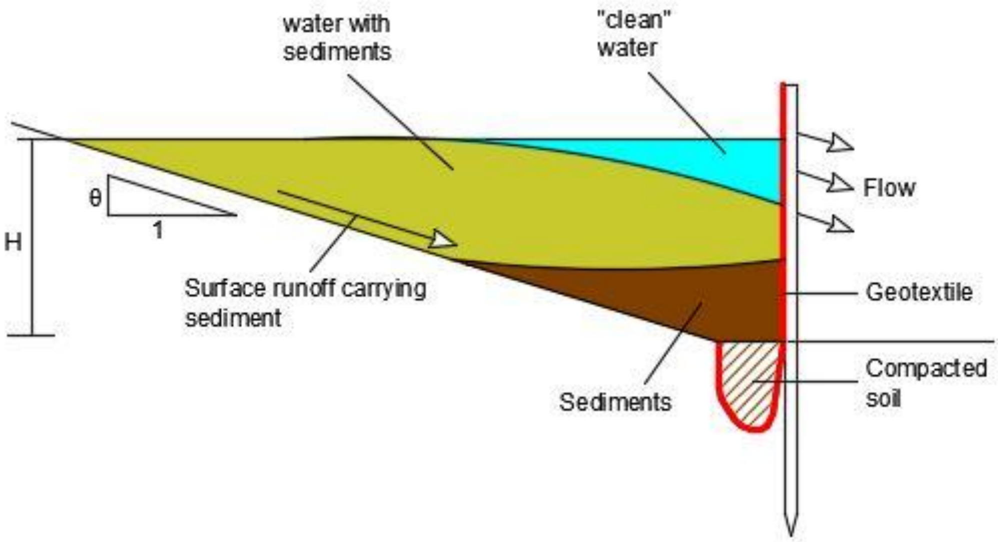

Figure 1. Demonstration of the functioning of a silt fence. Source: author, adapted from Koerner 2005.

CALTRANS (2003) comments that, due to wear and clogging, the life expectancy of a silt fence generally comprises the time of 5 to 8 months, longer periods should receive geotextile replacement or new fence installation downstream of the existing one.

It is emphasized that the use of silt fences is restricted to surface runoff applications without the occurrence of concentrated flows. Therefore, it is necessary that the flow velocity does not exceed a certain limit, being influenced by the slope of the terrain (θ), length of soil and roughness of the soil surface. To ensure the desired runoff, the slope length can be limited by adding slope fence levels (Richardson and Middlebroeks 1991).

3 STANDARDS AND RECOMMENDATIONS

The component materials of a silt fence such as the poles of support and the geotextile, must be designed and specified. To facilitate this process the designer may use standards and recommendations that guarantee its operation as expected in conventional cases.

Approaching about general characteristics regarding materials and methodologies are presented in ASTM D 6461 (2016) - Standard Specification for Silt Fence Materials and ASTM D 6462-03 (2008) - Standard Practice for Silt Fence Installation.

It is also possible to use ASTM D 5141 (2007) - Standard Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device, to test the efficiency of a geotextile for silt fences use.

In addition to ASTM standards there is an AASHTO recommendation, the M288 (2015), for the design of silt fences. This AASHTO recommendation is compatible with the ASTM standards, being even quoted by this.

4 DESIGN & INSTALLATION

For correct installation of the fence, one must ensure certain aspects, such as:

- The size of the fence and the area of action;
- The quality of the materials that will be used;
- How will the geotextile be anchored in the soil; and
- The amount of fence to be allocated.

The calculation process was initially proposed by Richardson and Middlebroeks (1991), evaluating the amount of sediment retained next to silt fence in a smooth, vegetation-free terrain and suffering from superficial erosion. The steps that make up this process were later updated by Koerner (2005) and are presented as follow.

4.1 *Maximum slope length*

Assuming the conditions set out above, of smooth, unprotected terrain and suffering from surface erosion, the maximum slope length that can be assigned to a silt fence is described by

$$L_{max} = 36{,}2*^{(e-11{,}1\ *\theta)} \qquad (1)$$

where L_{max} is the length of slope (m), and θ is the declivity of the terrain (dimensionless).

For slopes with lengths greater than those indicated in Equation 01, fence levels are recommended, thus ensuring satisfactory lengths for each fence, which must be individually calculated.

4.2 *Surface runoff flow*

The runoff flow, containing water and sediments, has its calculation method connected to each locality, generally using the rainfall index with return period of 10 years. The surface flow rate, Q (m^3/h) can be obtained by:

$$Q = C*I*A*10^{-3} \qquad (2)$$

where: C is a coefficient of surface flow (dimensionless), I is the precipitation index (mm/h) and A is the area (m^2)

The coefficient of surface runoff is equal to 0.5 for situations where the terrain is smooth and without vegetation.

Typically, a silt fence is designed to support sediment accumulation for up to 3 severe storm events, after which sediment must be removed, removal of older fence and installation of a new one, or new fence installed downstream of existing fence.

4.3 *Estimated amount of sediments*

The fence should be operated in such a way that the sediment accumulation is retained near its base and the "clean" water passes over it.

In order to obtain an estimate of sediments carried by erosion, the Universal Soil Loss Equation, USLE equation, developed by Wischmeier and Smith (1978), is widely used, representing the amount of sediments generated by erosion on slopes.

Although it has a number of limitations, such as not being able to predict erosion in very small areas, very steep slopes, intense and short streams of water, among others.

4.4 *Height of silt fence*

The height of the fence is then calculated by taking into account the amount of runoff flow Q found previously, since this value represents only one precipitation event, a safety factor (FS) should be applied, normally equal to three, representing the number of similar events that the fence will hold. The equation is represented as:

$$V = Q*t = (H/2)*(H/\theta) \quad (3)$$

$$H = (2*\theta*Q*t)^{1/2} \quad (4)$$

where: V = Total volume drained (m3); Q = Surface flow rate (m3 / h); t = Duration of precipitation (h), 1 hour is assumed due to the value of I chosen for the calculation of Q above; H = Height of the fence to withstand a storm event (m); and θ = Declination of the terrain (dimensionless).

4.5 *Pole spacing*

The spacing between the fence posts must be chosen according to relevant regulations. Richardson and Middlebroeks (1991) present graphs on the choosing of poles, that is shown in Figure 2.

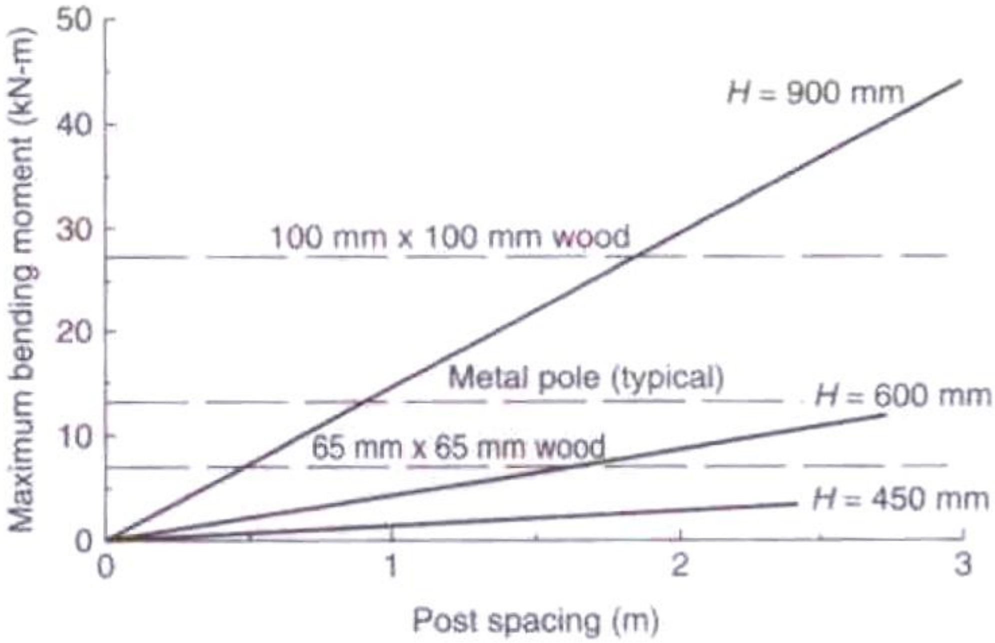

Figure 2. Maximum moment by spacing between stakes by height of silt fence. Source: Koerner 2005.

It should be noted that, in accordance with ASTM D 6462-03 (2008), poles should reach a depth of at least 0.45 m in the ground and have a free 1.00 m outside the ground for geotextile fixation. The poles can be made of wood or metal, as long as they meet the required standardization.

4.6 *Choice of geotextile*

The geotextile should be chosen according to its ultimate tensile strength, in the sense of lower strength, and a reduction factor may be included. Figure 3, presented by Koerner (2005) shows the relationship between geotextile strength and staked spacing.

It should be noted that the apparent aperture of the geotextile pores is not a governing factor, taking into account that their clogging will occur. The tensile strength is more relevant to silt fences.

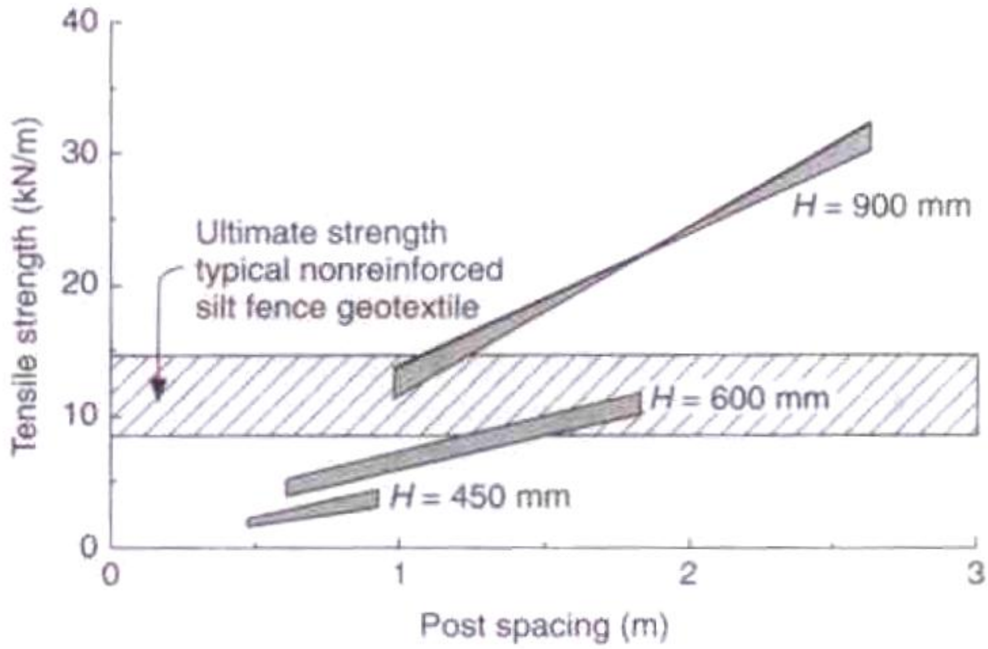

Figure 3. Resistance to traction of the geotextile by spacing between stakes by height of silt fence. Source: Koerner 2005.

According to ASTM D 6462-03 (2008) the geotextile must have a minimum width of 0.60 m above the ground and 0.15 m of anchorage buried in the trench.

Comparing the ASTM standard and the AASHTO recommendation with the graphical methodology proposed by Koerner (2005), it is possible to realize that for the typical geotextile ultimate strength for unreinforced silt fences, both techniques present very similar results. But, also, differently from the standards and recommendations, Koerner (2005) predicts the use of greater spacing between posts for stronger geotextiles.

Furthermore, the method proposed by Koerner (2005) enables a more refined design for the pole specification concerning material and spacing, considering the bending moment acting in the poles.

4.7 *Methods of fixation (trenches)*

There are two commonly used methods for the installation of silt fences: one uses specific equipment, corresponding to a tractor or similar with a coupled blade, called the Static Slicing Method, the other is the trench method, corresponding to the excavation of a trench using equipment or manually.

Vertical compaction should be performed on both sides of the silt fence, for example by being driven by the wheels of a tractor on the side of the 2 to 4-fold side, thus generating similar or greater soil compaction before being disturbed (EPA 2012).

The vertical compaction reduces the voids between soil particles, reducing the infiltration. Without this compaction, infiltration can saturate the soil and the water flow may find the path under the fence to escape as prescribed by the EPA (2012). It also warns that for situations where the fence is retaining large amounts of accumulated sediment and water, soil compaction, poles depth and geotextile fixation are fundamental to its proper functioning.

4.8 *Fitting quantity and suitability*

As stated by Richardson and Middlebroeks (1991), the slope drainage area corresponding to a silt fence should not be greater than 1000 m^2 for linear 33.4 m of fence. Also, the surface runoff velocity in the area should be controlled.

In addition to the linear length by drainage area, a very important aspect to the installation of the fence is its location, being recommended the division of the terrain into segments, making it easier to manage the sediments, defining areas for its accumulation with independent silt fences (EPA 2012).

It should be emphasized that the allocation of the fence should be such that the center of the fence is always lower in the ground than its ends, thus avoiding leakage of flow from the fence at the ends of the fence. It is also necessary to consider the passage of water over the fence in a critical event, resizing the fence, subdividing it and creating smaller drainage areas if this is a recurrent problem (EPA 2012).

5 TESTS WITH BRAZILIAN SOILS

For laboratory analysis, soil samples were taken from Institute of Aeronautical Technology (ITA), in the city of São José dos Campos, southeast of Brasil. These samples, were named red and brown, are shown in Figure 4.

To allow comparing tested soil with typical Brazilian soils, Figure 5 illustrates granulometric curves of erodible soils, presented by Angulo (1983) and the tested soils. Tests were also performed with standard soil stated in ASTM D5141-11, indicated as “ASTM LI” in Figure 5. This standard soil was prepared by the mixture of different granulometry of quartz grains.

Figure 4. Red and brown Brazilian soils.

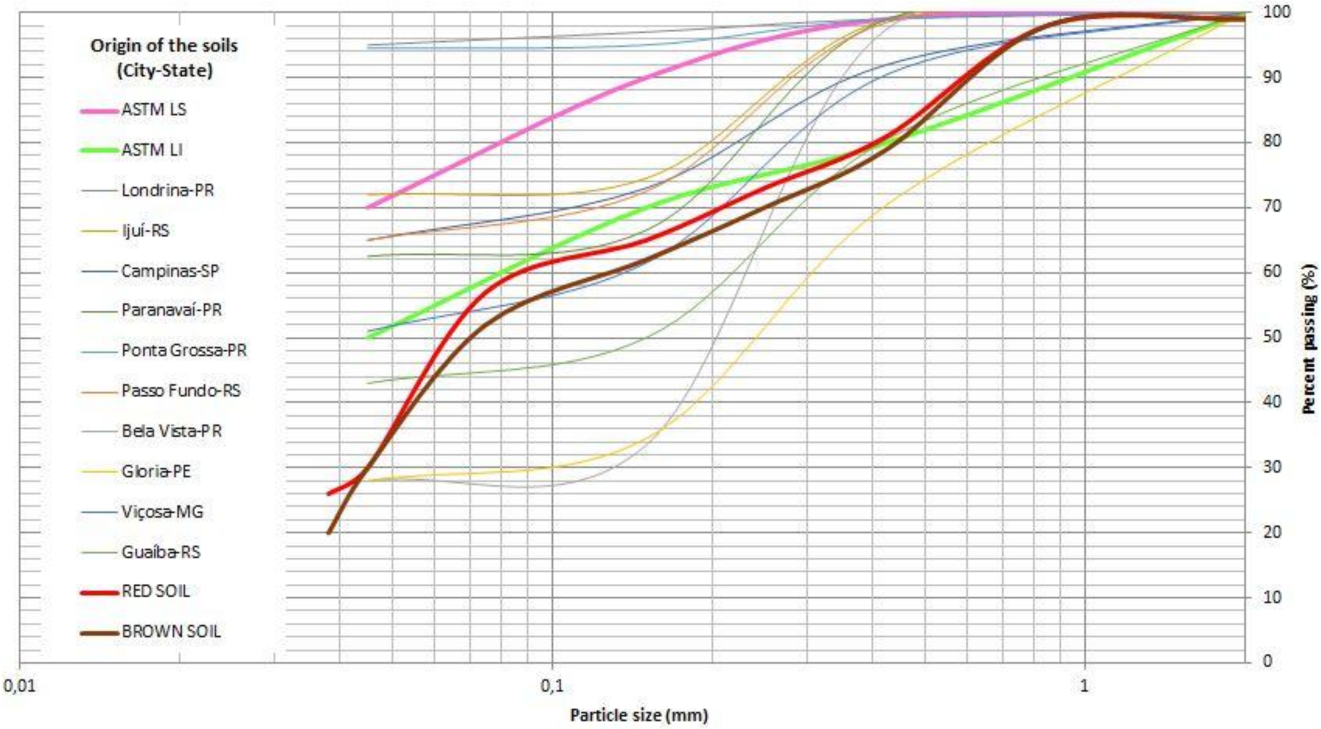

Figure 5. Granulometric Curve of Brazilian soils used in the tests compared to other typical Brazilian soils.

All tests were performed according to ASTM D5141, in the ITA geosynthetics laboratory, using woven polypropylene geotextile shown in Figure 6. The geotextile used was found to be acceptable by the values described in the ASTM D6461 Standard. Its properties are described in Table 1.

Table 1. Properties of the geotextile.

Polypropylene Woven Geotextile	
Tensile Strength MD/CMD (ISO 10319)	25kN/m
Strain at nominal Tensile Strength (ISO 10319)	15%
Characteristic Opening Size (ISO 12956)	450µm
Permeability (ISO 11058)	35.10^{-3} m/s

Tests results according to the ASTM D5141 standard performed on the soils are shown in Table 2.

Table 2. Test results.

	Ss - suspended soils (ppm)	FE - Filtering Efficiency (%)	Flow rate ($m^3/m^2/s$)
ASTM 5141 Soil	1.05	100	0.30
Brown Brazilian Soil	0.38	100	0.25
Red Brazilian Soil	0.49	100	0.19

The tested soils were retained with relative success, when compared to the standard soil, but at the expense of the longer time required for filtration, resulting in low flow rates.

It was possible to observe, in the second half of the test, for the Brazilian soils, a significant clogging of the geotextile pores. This is shown in Figure 6.

The clogging of the lower portions of the geotextile generates the accumulation of sediments behind the filter, which forces the flow of water and soil to run over this accumulated mass. In this way, it prevents the passage of grains that settle before reaching the geotextile.

Figure 6. Upstream clogged pores of geotextile during the test made on the red Brazilian soil.

6 CONCLUSIONS

Silt fences for sediment control has been largely used in the world, however, in Brazil there is not a standardized use of this technique, making room for a multitude of improper uses, thus generating diverse problems.

Regarding the tests performed for this study, they showed a reasonable applicability of the test method and the geotextile chosen for filtration of the Brazilian soils studied.

It is important to emphasize that the tests are performed with loose soil, free of roots, leaves and lumps, which must, obviously, lead to significant differences in the silt fence performance. This effect can be clearly observed by the significant difference between the tests on the standard soil and the Brazilian ones, due to the behavior of quartz grains, which do not form agglomerates of particles. Therefore, it is highly recommended to use the local soil in the tests for a best selection of the geotextile for each specific situation. Thus, the test is only performed as a comparative and qualitative tool to assess the suitability of the chosen geotextile for the specific soil.

It is not adequate to design the silt fence based only on the flow rates obtained in this test. The other recommendations and standards mentioned in this article can provide the tools for adequate design. For that matter, one purpose of this article was to add pertinent bibliographic information about the use of silt fences in a single document, generating ease in obtaining information about the subject and providing relevant material to research and future work.

Despite the lack of standardization for the use of silt fences in the country, its correct use implies great value, representing great savings in measures related to sedimentation, considering that its use prevents problems caused by the accumulation of sediments in undesired places. The international standards and recommendations mentioned in this article may be applied in Brazil, while more detailed studies must be carried out to adapt the specifications of silt fences to the Brazilian reality, such as climate, typical soils, precipitation and material availability.

REFERENCES

AASHTO: American Association of State Highways and Transportation Officials. AASHTO M 288-05 (2005). Geotextile Specification for Highway Applications. 20p.

ANGULO, R. J. Relações Entre a Erodibilidade e Algumas Propriedades de Solos Brasileiros. Universidade Federal do Paraná. Curitiba, 1983

ASTM: American Society for Testing and Materials ASTM D5141-11 (2011). Standard Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device. 6p.

ASTM: American Society for Testing and Materials ASTM D6461 (2016). Standard Specification for Silt Fence Materials. 3p.

ASTM: American Society for Testing and Materials ASTM D6462-03 (2008). Standard Practice for Silt Fence Installation. 3p.

Caltrans Storm Water Quality Handbooks. Construction Site Best Management Practices Manual. California: Caltrans, 2003, 6 p.

EPA, United States Environmental Protection Agency. Stormwater Best Management Practice: Silt Fences. EUA, 2012. 6 p.

IEPA, Illinois Environmental Protection Agency. Illinois Urban Manual Practice Standard: Silt Fence. Illinois, EUA, 2012. 4 p.

KOERNER, R.M. Designing with Geosynthetics. 5. Ed. Upper Saddle River, NJ: Pearson, 2005. 796 p.

MARYLAND. Maryland Standards and Specifications for Soil Erosion and Sediment Control. 1. Ed. Baltimore, MD, 2011, 292 p.

PILARCZYK, K.W. Geosynthetics and Geosystems in Hydraulic and Costal Engineering. 1. Ed. Netherlands: A.A.Balkema, 2000. 913 p.

RICHARDSON, G.R.; MIDDLEBROEKS, P. A simplified Design Method for Silt Fences, Geosynthetics '91 Conf., IFAI, St. Paul, MN, p. 879-885, 1991.

ROBICHAUD, P.R.; BROWN, R.E. Silt Fences: An Economical Technique for Measuring Hillslope Soil Erosion, U.S. Department of Agriculture, USA, 28 p., 2002.

ROSA, F.A.; VIDAL, D.; HEMSI, P. Aspectos do Dimensionamento e Eficiência das Barreiras de Sedimentos, ReGeo Conf., Brasília, BR, 8 p., 2015.

WISCHMEIER, W.H.; SMITH, D.D. Predicting rainfall erosion losses: A guide to conservation planning, U.S. Department of Agriculture, USA, 58 p., 1978.

VERTEMATTI, J.C. Manual brasileiro de geossintéticos. 2. Ed. São Paulo: Blucher, 2015. 570 p.