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## EROSION ASSESSMENT AND CONTROL OF EARTHWORKS\*

DR. ING. REIFFSTECK PHILIPPE\*

### ABSTRACT

*Understanding the factors that control superficial stability of earthworks is essential to limit the transport of particles detached by storms in temperate climate. For that, it would be extremely useful to be able, at an early stage of project, knowing the texture of the soil, to foresee its sensitivity to erosion, in order to choose another type of fill or to anticipate adapted anti-erosive techniques installation. The study presented here, based on laboratory tests with a mobile water jets test apparatus tries to answer this need.*

### 1. ERODIBILITY OF SOILS IN CIVIL ENGINEERING

Land developers and construction contractors often worry about the susceptibility of earthworks to erosion (Guiton, 1998)<sup>9</sup>. The empirical relations suggested by the agronomists such as the universal soil-loss equation, are of limited usefulness when extended to the forecast of erosion in earthworks and lands affected by construction activities, because of the difficulty of parameters determination (Wishmeier and Smith, 1971; 1978; Hénensal, 1986; Hénensal, 1987)<sup>13,14,28 & 29</sup>. To be able to use it in projects, it would be necessary to carry out local experiments on trial plots, which is generally unrealistic. These parameters are likely to exhibit a very great regional variability and it seems that erodibility of bare soils and embankments can be estimated starting from characteristics as texture, presence of coarse particles or physicochemical factors, such as plasticity, argilosity, exchangeable sodium content, etc. (Rousseva and al., 2002; Arulanandan and al., 1980, HRB, 1973)<sup>3,6,17</sup>. It would be thus of a great interest to propose an estimate of the erodibility according to parameters resulting from geotechnical classification tests that the engineer usually uses (Hénensal and Duchatel, 1990; Hénensal, 1993)<sup>15,16</sup>.

The communication presents, in a first part, the study of a reproducible erosive attack using an apparatus called " mobile water jets test apparatus ", to judge if it is representative of the erodibility of the soil considered. Tests have been carried out with various ground textures chosen to supplement the panel of tests already carried out. This erodibility is correlated with other characterization parameters of the fine-grained soils,

representative of its sensitivity to water. The results can be used to establish directives supplementing the actual design guides for road or landscape management. These directives will guide land developers and construction contractors towards adapted erosion control techniques.

In a second part, the paper presents the various geosynthetic techniques used in erosion control from the point of view of their function to free itself from too marked specificities of certain products. One presents at this occasion the technical guide published by the Geosynthetics French Chapter (C.F.G.). Within the framework of the sustainable development and of the extensive management of highways shoulders and cut slopes, it is useful to better understand and control the implementation of soil bioengineering technologies to improve the surface and overall stability of slopes. These techniques are indeed cost effective and well perceived by the public. One will present finally the use of these techniques alone or in complement of the geosynthetic techniques.

### 2. TEST METHOD

The laboratory erosion tests proved to be a convenient way to understand how various factors affect the complicated process of soil erosion. It is indeed easy in laboratory to collect runoff water in a measuring tank and to measure eroded solid load. The same measurements as in situ are carried out (Fig. 1):

- \* precipitation,
- \* runoff,
- \* solid matter eroded.

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†Written Comments on this Paper are invited and will be received upto 31st August, 2006.

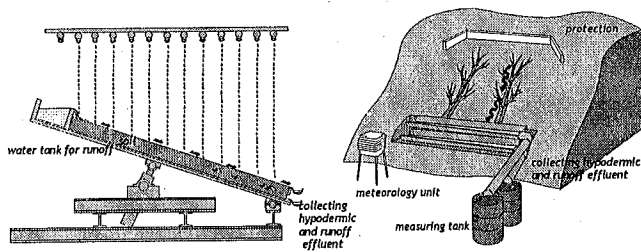


Fig. 1. Laboratory or in situ rainfall simulator

However, these tests can be criticized on several points:

- \* A constant rain replaces the variable time distribution,
- \* The simulated rain is mono-granular whereas the natural rain is spread out.

Because of its many advantages, we have planned a laboratory study while keeping in mind these last remarks.

### 2.1. The Mobile Water Jets Test Apparatus

Many apparatuses able to produce an artificial erosion of soil surface were developed in the past decades. Soil erodability can be measured in either a flume or a rotating cylinder device (with drum or similar to a triaxial cell for example) or a rainfall simulator (see figure 1) (Perry, 1979; Arulanandan et al., 1980; Sanchez et al., 1983; Hanson, 1993; Warlouzel, 1999)<sup>13,12,21,25 & 27</sup>. An apparatus belonging to the second category was developed at LCPC (Hénensal and al., 1990)<sup>15</sup>.

The development of a specific apparatus of rotary type called "mobile water jets test apparatus" (Fig. 2) was the consequence of the research undertaken by LCPC in the nineties. This work completed by Hénensal, aimed partly to correlate the soil erodibility with parameters that can be measurable in laboratory such as the methylene blue value, the activity, the texture and the slope angle, (Hénensal and al., 1990; Hénensal, 1993)<sup>15,16</sup>. This apparatus can be implemented on site or used in laboratory.

The mobile water jets test apparatus consists of an active mechanical part, called "eroding unit", of a water tank under controlled pressure, and various additional units. The eroding unit projects, with 0,5

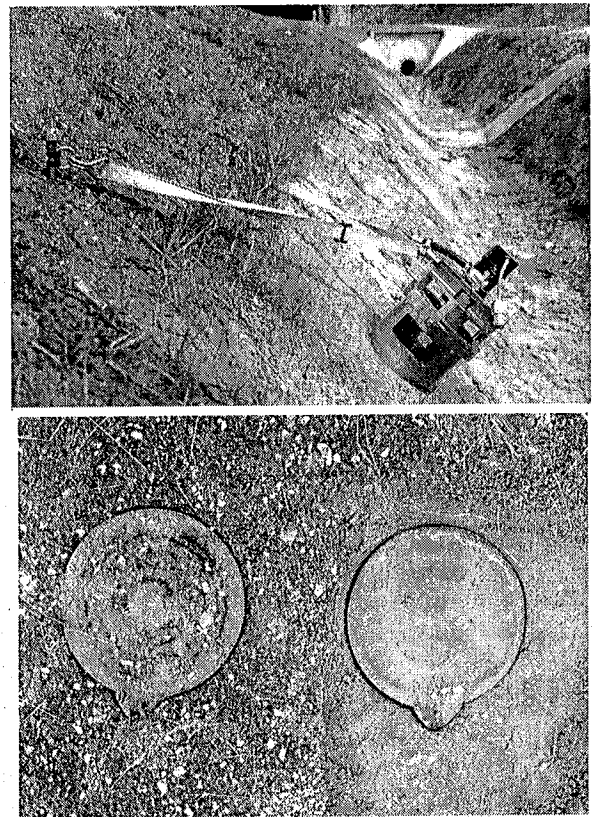


Fig. 2. Mobile water jets test apparatus

mm in diameter nozzles (Fig. 3), perpendicularly on the soil surface or the sample surface of which one wants to measure the erodibility, six water jets of similar and well defined characteristics.

The geometry of this apparatus is quite similar to the submerged jet device developed by Hanson (Hanson, 1993)<sup>12</sup>. However in the LCPC apparatus, the soil is not submerged and the arm of the eroding unit, providing a mount for the six jet nozzles, rotates during the test. Previous studies have shown that salt concentration of the eroding fluid significantly influences the erosion of soil sample (Arulanandan et al., 1980)<sup>3</sup>. As our study concerns mainly the most significant factor of soil erosion from highway construction sites, rainfall, the use of distilled water has only been considered. The estimated erosion will represent an upper bound because as the salt concentration increases, from distilled water to rainfall water or more certainly to river water concentration, the rate of erosion decreases.

**2.1.1. Procedure:** The first stage of the test procedure is to bring the sample to a given density by

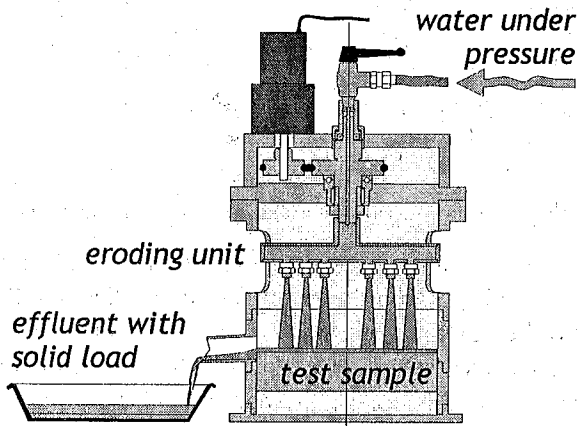
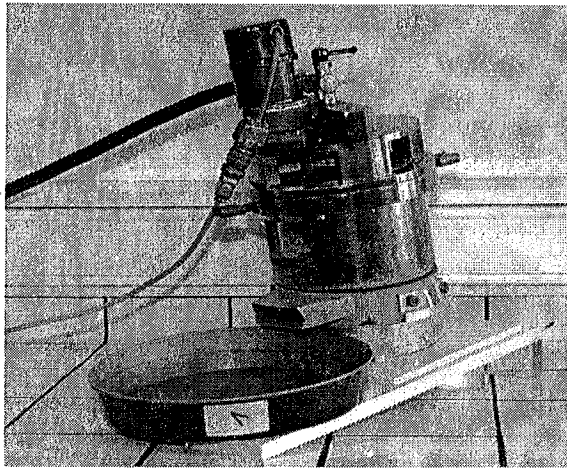


Fig. 3. Mobile water jets test apparatus

static compaction. The sample, in its mould, is then inserted in the apparatus, which is connected with the pressurized water source. The mould is placed on one of the two slopes used for the test. The outfall ring is inserted on the mould while directing the outfall towards the downstream of the slope into the top of the measurement container (Fig. 4). The ground is then subjected to the action of the water jets with the following test parameters:

- water flow of distilled water:  $860 \pm 5 \text{ cm}^3$  for the flat jet nozzle,
- pressure of the compressed air:  $100 \pm 5 \text{ kPa}$ ,
- the energy state of the sample: 95 per cent of the OMC:  $w_{\text{standard Proctor}}$  and  $\gamma_{\text{standard Proctor}}$ ,
- duration of the experiment: 60 seconds.

After test, the sample shows gullies located where the water jets impact its surface. The pluviation chamber of the mobile water jets test apparatus is then rinsed with a washing bottle above an appropriate receiver.

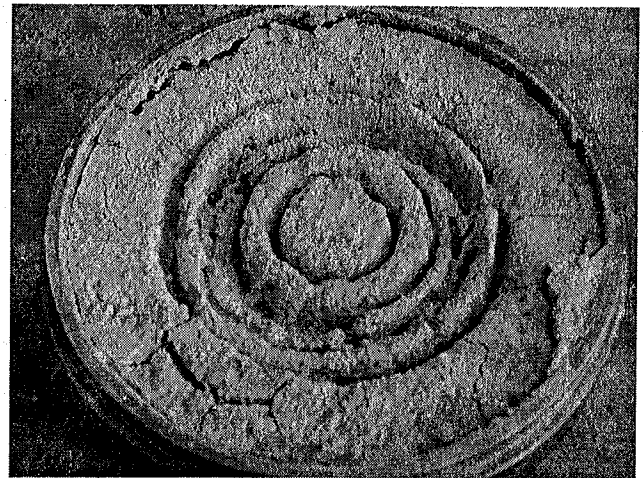


Fig. 4. Example of test result

The quantity of effluent collected is measured and passed to the drying oven to determine the mass of dry material eroded. This solid load will be used to perform qualitative evaluations of erosion. To establish correlations between the amount of soil erosion and the geotechnical properties and to make comparisons between the various soils, it is absolutely necessary to keep the preceding parameters constant.

2.1.2. **Choice of textures:** The choice of studied textures was carried out within the framework of the USCS/LCPC textural classification, which is the usual French classification (Fig. 5).

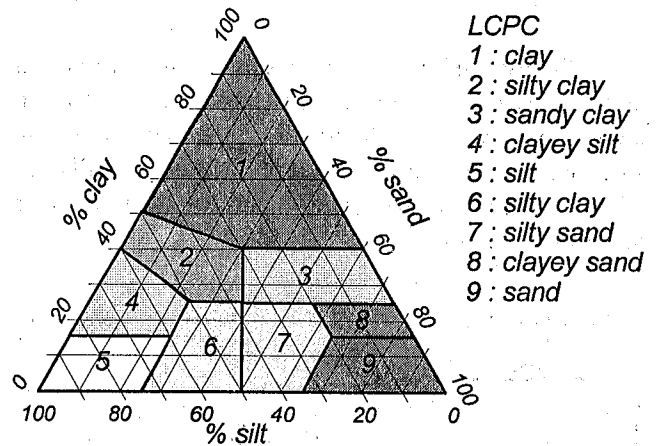


Fig. 5. Textural soil classification in a ternary diagram with LCPC denomination

This classification differentiates materials using only the particle size distribution of their components. In order to be able to differentiate them according to plasticity, it is thus necessary to use in parallel the

plasticity chart (Fig. 7). We thus decided to test mixtures of original and altered grounds, which would correspond as much as possible to a class of textural classification of Fig. 5.

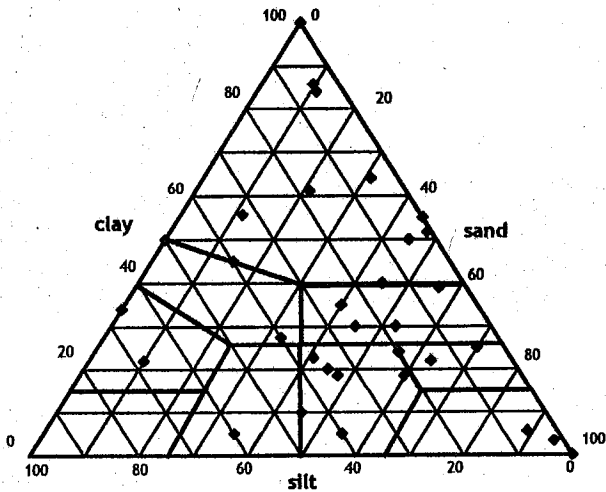


Fig. 6. Soils tested in the ternary diagram

We have tried to place the points near the centers of the various zones of the diagram (Figs. 5 and 6). We made this choice because the aim of the study is to connect under conventional test conditions in laboratory or on site, the erodibility of a soil to the classification of the GTR design guide (i.e. Technical Guidelines on Embankment and Capping Layers Construction) familiar for French public works actors (LCPC and SETRA, 1992)<sup>19</sup>.

Finally, we have 35 test results on soils of varied textures, with a range of plasticity index up to and including 35 per cent. Practically, for economic reason soils with higher plasticity are rarely re-employed without treatment. The study made for treated soil is not presented herein.

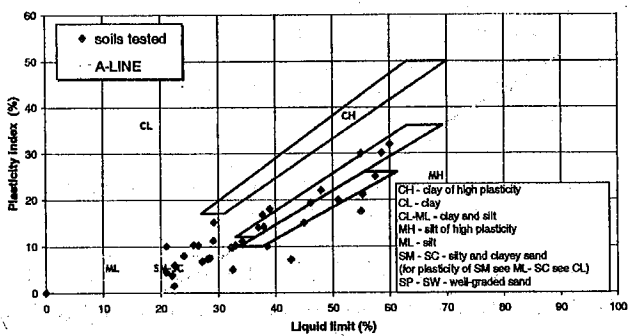


Fig. 7. Soils tested in the plasticity chart

2.1.3. **Results:** During the analysis of the tests results, the variation of volumes of eroded matter, with the particle size distribution and the sensitivity of the clayey fraction are of primary interest. The shear stress on the surface of the sample is indeed not measurable in a pluviator. Fig. 8 gathers the dry masses of eroded material (noted  $E_{\text{slope per cent}}$ ) by the mobile water jets test apparatus for two slopes: 10 and 67 per cent, put in connection with the plasticity index.

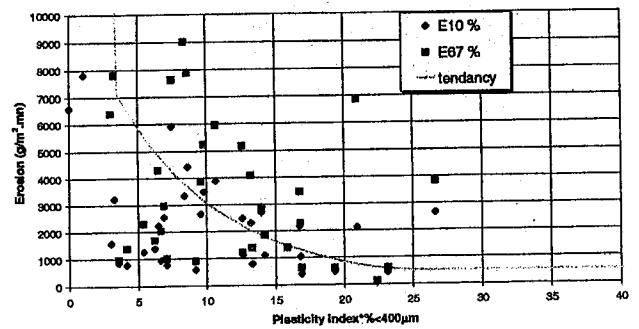


Fig. 8. Relation rate of erosion - index of plasticity

For this analysis, the Atterberg limits of the soils are normalized with the tested soil mass, they are thus multiplied by the percentage of the 0/400  $\mu\text{m}$  fraction, like the activity parameter proposed by Skempton. One observes a rather great dispersion of the values of erosion. It seems difficult to determine a tendency or a spindle on this type of graph (Fig. 9).

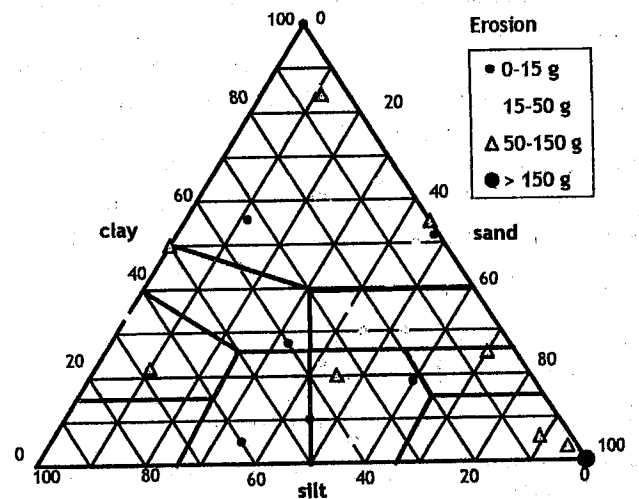


Fig. 9. Grounds tested in the ternary diagram

If the results are superimposed on the plasticity chart, the trend is apparent (Fig. 10). We separated the results by classes from limits: 15, 50 and 150 g of soil load.

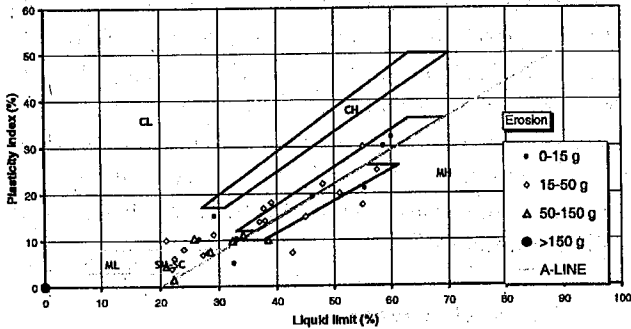


Fig. 10. Grounds tested in the plasticity chart

Solid loads higher than 150 g (circle) and 50 g-150 g (triangles) are located in the low and moderate resistance to erosion zones proposed by previous studies (Fig. 11) (Arlanandan et al.,1980)<sup>3</sup>. The origin of the scatter distribution of the 0-15g (small circles) is probably an argument to discuss the choice of the range of the erosion classes determined by Hénensal.

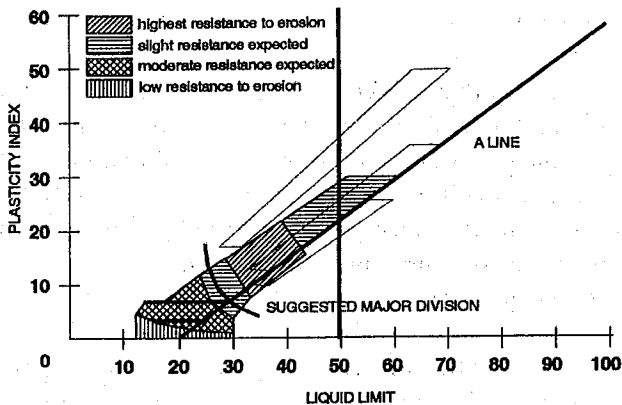


Fig. 11. Soil erodability in the plasticity chart

A more accurate presentation of engineering classes in the triangular form can be made by substituting the plasticity index for percentage of clay and liquid limit for percentage of silt (Handy et al., 1977)<sup>10</sup>. In this diagram, the percentage of sand is ignored below 50 per cent (Fig. 12).

The results represented in this diagram show a rather coherent organization with the soil classes. The sandy soils and clayey soils not very plastic are the most erodible ones followed by the more plastic silts.

However, in order to propose the use within the GTR framework, we superimposed our results with

- USCS  
 1 : CH - clay of high plasticity  
 2 : CL - clay  
 3 : CL-ML - clay and silt  
 4 : MH - silt of high plasticity  
 5 : ML - silt  
 6 : SM - SC - silty and clayey sand  
 (for plasticity of SM see ML- SC see CL)  
 SP - SW - well-graded and

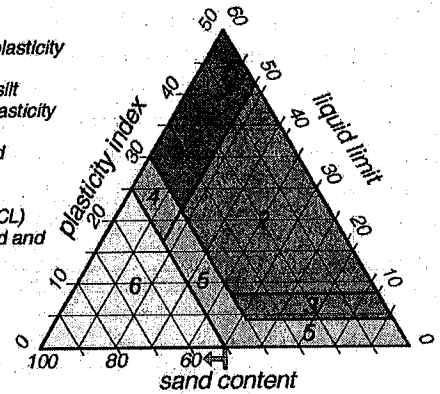


Fig. 12. Ternary diagram including plasticity

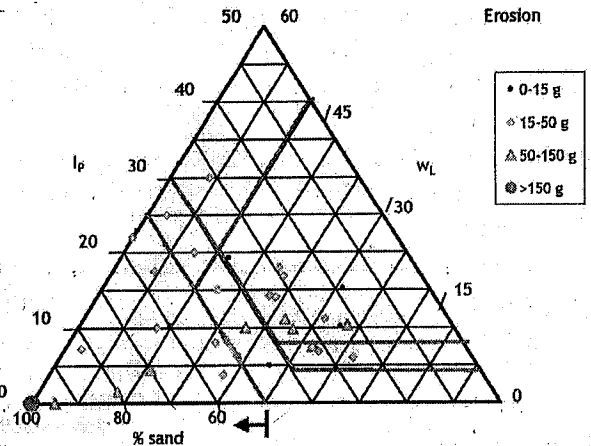


Fig. 13. Measured erosions with 10 per cent of slope in the modified ternary diagram

the classification diagram of fine materials of the GTR (Fig. 14). It will be noted that this diagram differs also from the one used in the guide by ignoring the methylene value scale.

This Fig. 14 confirms that the erosion process is more aggressive for fine granular soils or low plastic

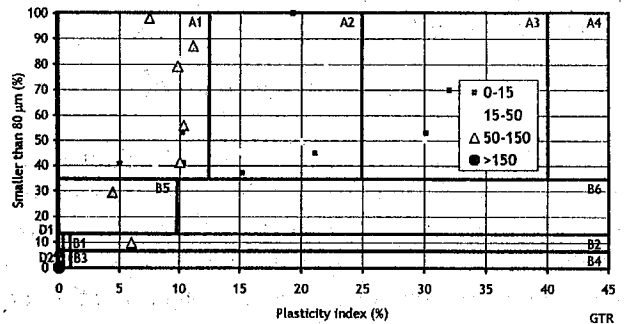


Fig. 14. Measured erosions with 10 per cent of slope in GTR diagram

silt: A1 soils, B1, B2 and D1 of the Technical Guidelines on Embankment and Capping Layers Construction (LCPC et. al., 1992)<sup>19</sup>. The risk decreases when the proportion of clay and/or the organic content increases (soils A2, B4, B5 > A3, B3, B6, C1 > A4), when the void ratio of the soil or sodium adsorption ratio in the soil decreases or when the ionic force of eroding fluid increases. The less erodible soils are the C2, C3, D2, D3 and D4 soils.

### 3. DISCUSSION OF RESULTS

This test program results confirm that:

- the most resistant texture is clay and the least resistant is sand (this last has a particular behaviour because it gives only isolated points on graphs)
- erosion decreases with the clay fraction and increases with the percentage of granular materials,
- erosion decrease with the plasticity index IP and thus the nature of the clayey fraction of the ground (Fig. 8).

The representation of our results in a diagram only based on particle size distribution (Fig. 9) or on plasticity (Fig. 10) does not allow classifying the soils according to their erodibility. The use of the modified ternary diagram of Fig. 13 seems more promising. The GTR diagram represented Fig. 14 has the advantage of being familiar with the experts however its use requires to supplement the tests by tests on materials with more varied plasticity indexes.

The results of this study did not yield at the present time to draw precise conclusions. Complementary studies will be carried out to specify the nature of the parameters of influence.

### 4. USES OF GEOSYNTHETICS

From a practical point of view, the limitation of the soil erodibility implies the reduction in the sensitivity to water and the conservation of texture. Current method for controlling water erosion from construction areas will thus intend to drain, protect, confine and even reinforce the bare soil surface. One of the preferred solutions in Europe landscape management is the installation of anti-erosive techniques including

geosynthetics during the settlement of a dense cover of low-growing grassy vegetation, which is recommended because it will provide the best protection from surface erosion. For these reasons, there is a need for a document based on the knowledge presented above to explain the way to design a geosynthetic erosion control technique adapted to the soil encountered.

#### 4.1. Background

Erosion does not involve the devastating effects of natural disasters like seism, big landslides, tsunamis, floods, but it is often a worsening factor and causes as many large expenditures for the community (CCR, 1999; Guiton, 1998)<sup>4,9</sup>. Fortunately, it is possible to fight effectively against this phenomenon using tested techniques. These techniques resulting from the collaboration of the chemical and textile industry with public works companies were to be described in a didactic work. The Geosynthetics French Chapter (C.F.G.) has undertaken the redaction of a guide for this purpose.

**4.1.1. The readers:** This guide is intended to help the Building Owners and Project superintendents when they encounter problems of erosion and that they seek a practical solution. As they are, in most cases, not geotechnical engineer, a presentation of the concepts on soil erosion presented above had to be made in a preliminary chapter.

**4.1.2. The objective:** The objective of this guide is to present, the functions implemented by the geosynthetic techniques answering the problems that can be encountered in practise. This guide was written with the three following major goals:

- To avoid passing beside the problem,
- To be able to judge stakes,
- To know how to call upon experts.

**4.1.3. Orientation of the reader:** To achieve these goals, the guide is structured in the following way: a first rather didactic part, which is used as reference to the reader to apprehend the technical elements developed in the body of the guide, i.e. mechanism of soils erodability, tests used to check erodability. This first part also exposes geosynthetics developed for erosion control from the point of view

of their function to avoid too clear references to the specificities of given products. The guide then describes, in five chapters, the geosynthetic techniques available for each type of erosion according to the phenomena brought into play:

- rainfall erosion,
- river erosion,
- coastal erosion,
- wind erosion,
- anthropic and animal erosions.

The working group "Geosynthetics and erosion" thus wanted to bring a better knowledge of erosion for the actors of public works and land management and to propose a methodology, as well as tools to implement a strategy of erosion control integrating geosynthetic techniques. Two important concepts are defined:

- The concept of scale,
- The concept of functions.







#### 4.2. Concept of Scale

For a slope (slope, bank, coast), one is confronted with two problems of stability: the first relates to the stabilization a significant thickness of soil (several centimetres) on steep slope. This soil horizon is a layer of topsoil or soil in a loose state. We define this problem as a problem of meso-stability to distinguish it from the macro-stability, which relates to overall slope stability. The second problem relates to the stability of the soil particles on the surface. We speak then about micro-stability. Whereas meso-stability is related to static gravitating forces, micro-stability is related to the solicitation corresponding for example in the case of rainfall erosion, the effect of raindrop and the effect of runoff. This micro-stability is directly related to the soil properties as illustrated in the previous paragraph.

#### 4.3. Geosynthetic Functions

The geosynthetic products have to achieve various functions, which can schematically be divided into six roles: containment, reinforcement, separation, protection, filter and drain (Table 1). These functions are defined in NF EN ISO 10318 standard. As the functions do not include containment, we propose a specific symbol for this function.

TABLE 1. DEFINITION OF THE FUNCTIONS

Functions	Symbol	Definition
Reinforcement		Improving the mechanical properties of soil
Containement		Wrapping and maintaining in a given volume a soil or fill materials
Separation		Preventing from intermixing of adjacent dissimilar soils or/and fill materials
Protection		Preventing or limiting the local damage to a given element
Filtration		Restraining movements of soil or other particles while allowing the passage of water
Drainage		Collecting and transporting of precipitation or groundwater

These functions can be present in one geosynthetic or several geosynthetics assembled in a geocomposite in order to be complementary. Generally, geosynthetics have a principal function to which can be added other functions considered as secondary. It will be noted that the symbol of erosion control lay in standard NF EN ISO 10318, is not included in this list, because it was considered to be too generic. These symbols are used in the decision tables or flow charts that we set up (Fig. 15).

These flow charts takes implicitly into account for each type of project, that the fill used will be chosen and compacted in accordance with the Technical Guidelines on Embankment and Capping Layers Construction (LCPC et. al., 1992)<sup>19</sup>. The flow chart combined with the scale defined for the problem as in 4.2 then integrates the results of the study presented in paragraph 2. The only exception is for natural slope for which the soil needs to be identified and the erodability to be evaluated.

At the beginning of each chapter, a flow chart allows to make a fast choice of the techniques according to desired functions. This flow chart is available for each type of erosion: rainfall, river, coastal, wind, anthropic and animal. These flow charts are intended to guide the reader for a fast choice.

The other tool used throughout this guide to present the functions filled by the geosynthetic is a table comprising two lines. The first comprises the list of the functions and the second an indicator of relevance represented by crosses.

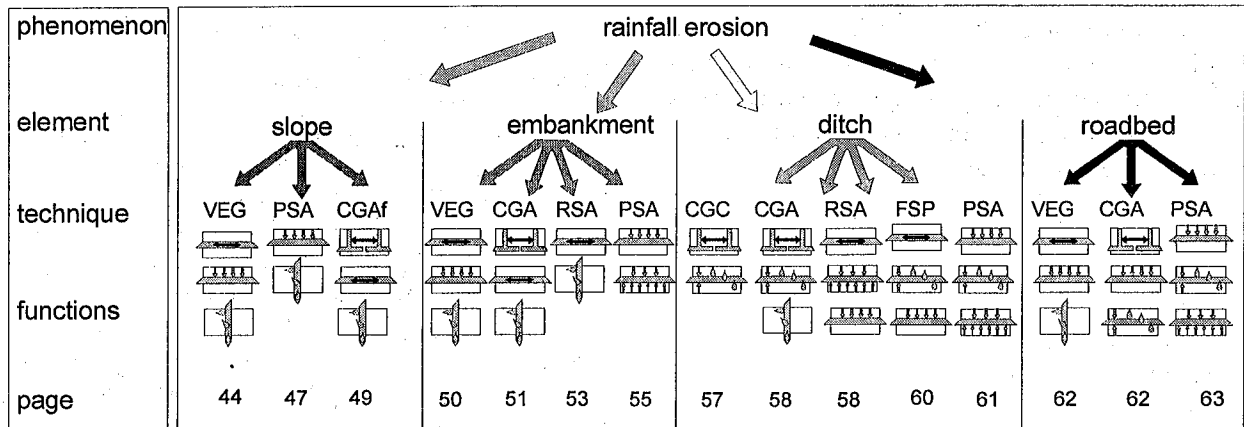


Fig. 15. Flow chart for rainfall erosion

#### 4.4. Geosynthetic Techniques

The range of geosynthetics available for the designer during a project is vast. In this range one can define the three main families according to the geometry of the geosynthetic product:

- One-dimensional, it is presented in the form of strip or tube,
- Two-dimensional, it constitutes a sheet,
- Three-dimensional, it contains soil or a material.

Of course, that does not mean that the number of dimensions of geosynthetic corresponds to the number of size present in the studied work. In fact, the larger the number of dimensions of geosynthetic is, the more it is able to deal with in-depth problems. The difficulty for the development of the suggested methodology is that some geosynthetic have two-dimensional and three-dimensional characteristics according to the scale they are observed. In addition it is possible to realize many combinations to create composites benefiting from the characteristics of the geosynthetic component (for example, cells of geocells can be closed with geosynthetic sheet to create a geomat). The traditional classification of geosynthetics used in erosion protection is generally done according to the type of structure and manufacture, geogrids and geomesh, geonets, bionets, geocells. A classification according to their function appeared to us however more adapted:

- Mattress and tube confinement system (CGC)
- Cellular confinement system (CGA)
- Turf reinforcement mat (RSA)

- Erosion control blanket (PSA)
- Filtration of soil under hard armor systems (FSP)
- Vegetalisation (VEG).

The cards of the guide are thus structured with this classification as with the scale at which the functions act. On two access levels, the guide, could either be used as a vulgarisation document on erosion control techniques, or a day to day reference for the designer who will get in there by rapid reading of the diagram. This guide does not provide however information on the implementation, jointly with the geosynthetic techniques, of the soil bioengineering techniques which combine a structural resistance with the aesthetic contribution.

#### 5. SOIL BIOENGINEERING TECHNIQUES

The soil bioengineering techniques consist of the use of living plants to solve in an ecological way the problems of slopes stability, of riverbanks or reservoirs and unstable and eroded road or railway embankment. Contrary to other techniques for which the plants are mainly aesthetic components of the project, in the soil bioengineering techniques, plants are important structural components (Fig. 16). The techniques, called now soil bioengineering techniques, were first developed in the early years after world war two in Germany and Austria. Many developments also took place in the United States of America and were the object of outstanding publications, which promote these techniques in our profession (Gray et. al., 1989)<sup>8</sup>. However, there are still reluctances in many countries, to use this technique.

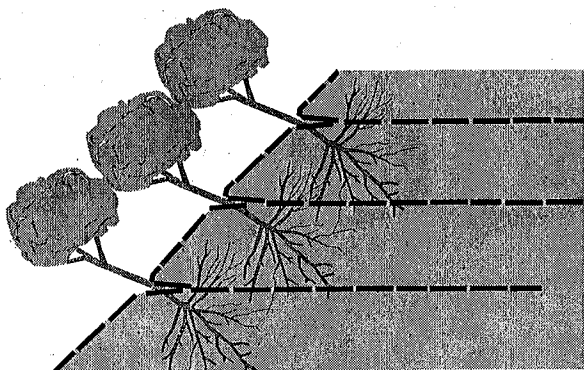


Fig. 16. Example of slope stabilized with soil bioengineering technique

If apparatuses like mobile water jets test apparatus can estimate the erodability of the bare soil before settlement of vegetation, it does not work anymore when the vegetation covers the soil surface. Specific design can lead to special field experiments using rainfall simulators for example.

5.1. Herbaceous Vegetation

The herbaceous vegetation influences positively the effect of rainfall impact and runoff by protecting the ground superficially. From a geotechnical viewpoint, one can say that the vegetalisation provides on the slope face:

- A reinforcement of the soil by the roots, which is equivalent to an apparent cohesion,
- A modification of soil water regime due to a soil moisture depletion mechanism.

These two mechanisms involve an increase in the shear strength of the soil.

5.2. Woody Vegetation

The stabilizing action of the trees acts at various levels. The canopy interception reduces the rainfall impact. In addition to evapotranspiration, the decrease of water content due to tree roots increases the shear strength of the soil.

The tree roots mostly concentrated in the first meter below the soil surface, are characterized by a positive hydrotropism, which leads them to grow in direction of the wettest zones (up to 30 m for a oak and 40 m for a willow radially and 4 to 5 m in-depth)

(Ziemer, 1981; Keppeler and al., 1994)<sup>18,30</sup>. This root system also reinforces the soil, the most important roots anchoring the ground.

5.2.1. Contribution of stability: Anchoring effect of a tree is ensured by the counterweight of the ground ball fixed by the fine root system whose weight is about 6 to 8 times that of the aerial parts of the tree. The size of the root ball depends on the species, the age and the general health of the trees and the competition. Anchoring is ensured by side main roots (more than a few cm in diameter), which prolong the action of the counterweight of the root ball.

It could be considered that deeper rooting species e.g. oak and Douglas fir are better anchored than shallow species e.g. spruce but no quantitative studies have yet been carried out.

Of the three root systems (tap, sinker, in heart, see Fig. 17), the last one is the more efficient one as far as anchoring is concerned because it results in fixing a more important bulk of ground by roots (Fig. 17). The contribution of resistance is done in two manners (Fig. 18a):

- increase in the shear strength of the soil in the sheared zone,
- anchoring of the active wedge by the roots.

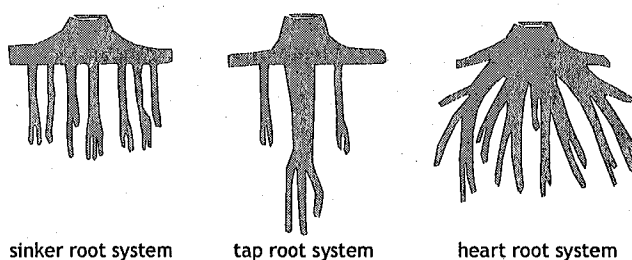


Fig.. 17. Three basic types of root system of trees

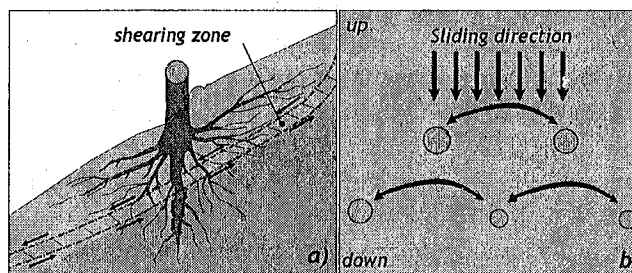


Fig. 18. Stabilization of the slope with the root system of trees

**5.2.2. Increase in the shear strength:** The presence of roots improves significantly the shear strength of the ground surface. The roots create an apparent cohesion in the sandy grounds having little or not intrinsic cohesion. Laboratory and in situ tests indicate a shear strength increase per unit root content ranging from 3.2 to 3.7 kPa per kilogramme of root per cubic meter of soil (Abe et. al., 1991a and 1991b)<sup>1,2</sup>. One noted masses of root per volume of varied ground from 2.5 to 7.5 kg/m<sup>3</sup>.

**5.2.3. Anchoring effect:** Russian studies show that for a ground reinforced by 0.5 per cent on the surface on a section of linden roots, 75 to 95 per cent of the ultimate force is necessary to break the roots. The poplar has the most resistant roots followed by birch, oak, linden and fir trees with a difference of 40 per cent between the poplar and the fir trees. The roots of trees are 1.5 to 3 times more resistant than the roots of grassy plants of the same diameter. With equivalent section, the roots of bush are twice as strong as those of conifers trees.

**5.2.4. Buttressing and arching:** Buttressing is the action by which the trunk of a well established tree prevents a soil horizon which is immediately upstream him, from slipping downward (Fig. 18a). The arching occurs when a superficial soil mass in imbalance is retained by a series of tree trunk sufficiently close to each other so that the soil mass cannot creep between the trunks (Fig. 18b).

**5.2.5. Evolution in time and durability:** More important than their depth, the health of the roots is determining on stability. Fraser (1962)<sup>7</sup> by means of tensile tests on Douglas firs and spruces of Sitka park (Alaska) shows that the failure stress (by washing away) was 1/3 weaker in the event of roots decay or attacked by fungi than for healthy trees. It takes approximately 15 years of decay to be 50 per cent of maximum resistance and 25 years for totality. The small roots resistance decreases quickly (for example: Douglas fir 50 per cent in 3 years) whereas largest (diameter >15cm) can remain during decades. Approximately, 50 per cent of resistance are lost in the 2 years after the cut and 90 per cent in the 9 years (Ziemer, 1978)<sup>31</sup>. The tensile strength of a root ball is a function of the shearing strength of the roots, which is proportional to their surface. The loss of resistance of the tree roots after cut is one of the important mechanisms, which

lead to depressions of slope and landslides. The cavity left after root decay can be, for embankment, dam and dikes, a major cause for initiation of internal erosion and can produce a piping failure. The phenomenon cannot be studied with mobile water jet apparatus but by the recently proposed Hole Erosion Test (Wan et Fell, 2004)<sup>26</sup>.

### 5.3. Synthesis

These solutions are often used for the reorganization of a location, conclusion of a landscape study followed by a geotechnical analysis. Because of the difficulty of apprehending the evolution of the resistance provided by vegetation, they are often housed in geosynthetic structures adapted to limit the erodability of the soil (Gray et al., 1989; Di Pietro et al., 2002)<sup>6,8</sup>. The introduction of the soil bioengineering techniques into geotechnical calculation is thus done in a simple way. The cohesion brought by the root system is introduced into the behaviour law of the soil, for example an elastic-ideally-plastic model with a Mohr Coulomb criterion. The extension of the reinforced zone (soil-roots fabric) is evaluated according to the depth of ground and weathered rock as well as planted species. One can assimilate the anchoring effect to stabilization by piles. This effect can be estimated by a simple calculation of laterally loaded piles. These piles are loaded vertically by the weight of the trees considered. The calculations carried out with the Prosper-LCPC software or finite elements software CESAR-LCPC, provide results in agreement with the studied cases.

The use and choice of safety factors in these calculations should be related to the structural integrity and the flexibility of the system projected. Since the performance of an erosion protection system is normally based on its serviceability limit, it would, therefore, be advisable to assume higher safety factors when performance and material failure represent the ultimate system's resource.

## 6. CONCLUSION

The choice of an erosion control technique must pass by a detailed preliminary study. The current concerns of environment preservation and erosion control impose the following approach:

- a landscape study to define the new morphology of the landscape or stream banks or littoral coast, so that they are harmonized with the surrounding relief, and the appropriate plant species to restore balance with the local vegetation. This point is well described in detailed technical works (for example METL and SETRA, 1994)<sup>20</sup>;
- an impact study to specify the influence of the structures implemented on local fauna and flora;
- the implementation of techniques to stabilize the slopes i.e. inert material before the establishment of the vegetation i.e. living system if the erodability estimated from its classification is judged to be unsafe. It will take many years indeed before this one reaches its ecological balance and is sufficiently developed to protect the ground surfaces.

We briefly presented the guide "Recommendations for the use of geosynthetics in erosion control" proposed by the CFG. This guide is intended to bring a better knowledge of erosion for the actors of public works and land management and to propose a methodology to implement a strategy of erosion control integrating geosynthetics. It can be downloaded on the CFG Web site (CFG, 2004)<sup>5</sup>.

Finally, we must emphasize on the fact that there does not exist at the present time, general and reliable quantitative design method of erosion control techniques and that the methods suggested for a given process are not transposable with the other processes. This is accentuated by the diversity of the processes as well as the specificity of each erosive phenomenon. Only the experimentation is at the present time a reliable means to determine the potentialities of a new product and to integrate it in the techniques presented in this guide.

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