REVITALISATION OF SAN FRANCISCO RIVER IN BRAZIL USING GEOMATS

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Abstract: The main problem, besides the existance of social inequality, faced by the low-income earning Brazilian population are the living conditions. Most of the time this is due to the lack of resources. The San Francisco River, 2830 kilometers long and located between the states of Minas Gerais and Alagoas, is extremely important, both economically and culturally. For this reason, the river is the biggest means of transportation for the agricultural activities of the people who live in that area. Recent studies prove that in many places this important river has been degrading with time. Due to the lateral displacements that have occurred by the constant erosion in the margins, the river is becoming wider and shallower day by day. This reduces the navigability and, consequently, the commercial activities.

The proposal for the "Revitalization of San Francisco River" foresees a search for an effective margin protection system at low cost and using local available technology and resources. This paper introduces the main solution applied in this river using geomats. These are manufactured with an open three dimensional synthetic mat consisting of randomly placed filaments of polypropylene and a double twisted hexagonal mesh. This technique promotes protection against margin erosion and guarantees excellent interaction between soil and material. In addition, the stabilisation of the surface cover and the confinement of soil particles promotes the growth of vegetation. The roots of the vegetation which anchor the geosynthetic material to the slope and the wire mesh increases the resistance of the soil against small displacements.

Keywords: erosion control, geomattress, degradation, polypropylene, revetment, vegetation.

INTRODUCTION

The San Francisco River, affectionately known as “The Old Chico”, is one of the most important hydrographic basins of Brazil. Much more so because of its hydraulic importance than by the development generated for regions where it passes. It contains an area of about 640 thousand km² and occupies 7,40% of the Brazilian territory (Figure 1). Its origins are located in Serra da Canastra in the State of Minas Gerais, located in the southeast of Brazil. Then it continues flowing northwards for 2830 km crossing the State of Bahia, and making it’s northern boundary in the State of Pernambuco, and dividing the States of Sergipe and Alagoas, draining finally in the Atlantic Ocean in the northeast region of the country. In this region is located the Polígono das Secas, which is well-known as a region that has susceptible areas which are annually prone to droughts and possesses the highest concentration and highest rates of social exclusion of the country.

Figure 1. Location of the basin of San Francisco River regarding the Brazilian territory

The San Francisco River, by the aforesaid, is the artery of socioeconomic connection for the southeast to the northeast of Brazil, being the largest single variable responsible for the prosperity of the entire region, and that is currently the largest producer of tropical fruit in the country. Moreover, the channel of distribution of these goods is made through navigational means, supplying a population of about six million habitants who live in that area.

This paper has as the main objective to present the Plan of San Francisco River Revitalization. This plan, whose action of initiation commenced in Barra in the State of Bahia, located in the northeast of Brazil, aimed for a search of feasible and economic options and which would allow for the reduction of the level of erosion of the riverbanks along the river degraded by the action of the rainfall, the stream and the effect of waves, and the stabilization of the fluvial bed.

DESCRIPTION OF THE PROBLEM

Emphasizing the importance of the San Francisco River and what its impact represents to Brazil, recent studies have shown that it has been degrading over time. Examining this river in detail, the width of its bed changes by hundreds of meters (between 10 and 15 meters annually), making it wider and shallower day by day. This progressive degradation is due to the erosive nature of the banks, the transportation of solids and effluents, which form sand banks in the middle of the river, and contribute to the instability of the present islands. This is a continually self-feeding process, what it carries is sensitive prejudices for the sustainability of countless productive activities, and in addition to the reduction of the local navigability. Mostly, this is due to the disordered occupation of the riverbanks of the San Francisco River by the population who live in the region, which provokes the ancillary deforestation and withdraws the additional protection for the surface of the soil to limit erosion.

It is understood that by the process of erosion which occurs, the displacement of soil and the transportation, as well as the redistribution of soil and sediment particles, cause big environmental impacts, inhibiting the water flow and altering the slope of the riverbanks, stimulating an accumulation of sand (Pereira 1999).

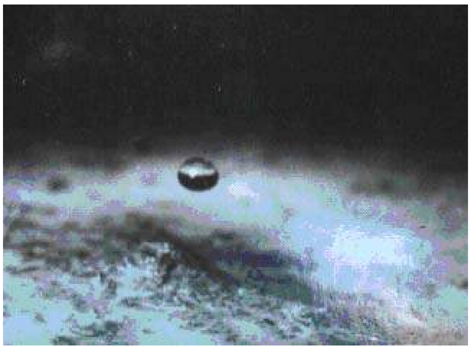
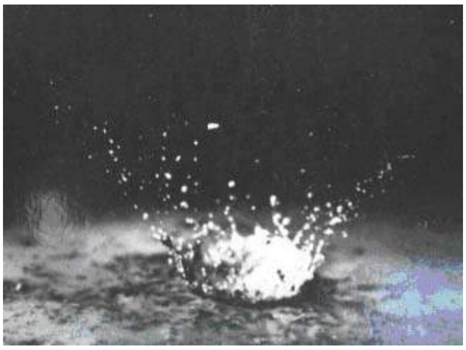
However, the adoption of effective measures of preventative and corrective control of these disordered erosions depends on the correct understanding of the processes related with the dynamics of the hydraulic operation on the ground. The margins or riverbanks of the San Francisco River are destitute of protection, thusly contributing to the erosive processes that occur by natural causes, such as by the action of rainfall, the stream flow or even by the effect of waves.

Erosive process caused by rainfall

This kind of erosive process has a global inclusion, especially in regions with a tropical climate such as is inherent to the northeastern region of Brazil. More importantly, Brazil is a country where the pluviometric indices are much more elevated than in other regions of the planet. The disordered occupation of the margins of San Francisco River provokes the ancillary deforestation, thusly forsaking the riverbanks of the vegetative coverage, and it allows the rain water to directly impact the surface of the ground.

The splash effect

The physical action of a splash (Figures 2 and 3) or splashing (Guerra and Guerra 1997) is the initial phase of the erosive process caused by a drop of rainwater that contacts a particles of soil, which generally are given by the rupture of the aggregate, to be transported by the superficial flow. Moreover, the aggregates enter the pores of the surface of the soil generating the hampering and consequently the decrease of the porosity, increasing the flow of the water. In the same way, the erosion depends on the relations between the erosive capacity of the rainfalls through its kinetic energy and the flows of the surface and sub surface, like the susceptibility of the soil of being eroded.

Figures 2 and 3. Details of a drop of the rain on the surface, causing the splash effect

Kinetic energy of rain

The kinetic energy of the rain determines the erosivity of the terrain, which is the ability of the rain to cause erosion. The determination of the erosive potential depends mostly of the erosivity parameters and also of the characteristics of the drops of the rain, which vary between time and space, among them the total of precipitation, the intensity of the rain, the moment and the kinetic energy of the rain. Moreover, another factor which can generate the erosivity is the aeolian action, mostly if the rain is reached by violent winds.

Rupture of the aggregates

The rupture of the aggregates can be considered the initial stage of the erosive process of the soil. This rupture initiates on the direct impact of the rain drops with the ground, breaking them and forming some very small particles, perforating the existing pores in the soil. With that, the porosity of the soil is reduced and the superficial flow increases. It had been verified through the sounding and batimetries executed in September 2005, that the soil present in the margins of San Francisco River is silt-sandy, characteristic soil of the semi-arid region of Brazil and propitious to action of erosion. According to Wischmeier & Mannering (1969) the soils with these characteristics, used for agriculture and without the care of handling, are more susceptible to erosion when they lose organic matter, and this factor affects directly the rupture of the aggregates. The organic matter incorporated in the soil increases the cohesion between their particles, turning the soil more stable, with powerful retention in a presence of water, and more porous, decreasing the erosive possibility, besides guaranteeing the indispensable nutrition to the growth of the vegetation.

Crusts formation and hampering of the soils

From the rupture of the aggregates caused by the impact of the drops of the rain, there occurs a formation of crusts on the surface of the soil and it happens almost instantaneously generating hampering of the soil, complicating the infiltration of water and, as a consequence, increasing the superficial flow and the possibility of soil loss. According to Thornes (1980) the infiltration occurs quicker in the aggregate of larger and granulometricly stable, decreasing the action of the superficial flow. When the aggregates broke and the surface of the soil is stamped, these crusts offer larger resistance to the action of splash, however the speed of the superficial flow increases and it could cause significant damages in the contacted areas of the ground. From the moment that the infiltration indices are reduced, it contributes to the formation of puddles on the surface of the soil.

Infiltration and puddle formation on the surface of the soil

When the deriving waters of rainfall enter in direct contact with the soil, they are stored in small furrows or directly in the soil. During a torrential rain, the blank spaces between particles are perforated by water turning the rates of infiltration lower that given in the original saturated soil which carries to the loss of the apparent cohesion, producing an exceeding flow and after a certain time, it does not manage to absorb more water. All of these factors give origin to the last phase that precedes the superficial flow: the puddle formation in the surface of the soil.

Superficial flow of water

After the desegregation of the particles, the saturation of the soil and the consequent formation of the puddles, it's given the superficial flow, where the water realizes a relatively fast trajectory and is able to transport materials of the soil by means of the hydraulics force of its flow. Depending on the force of this flow, two kinds of erosion are possible: laminate, when caused by intensity of the drops of the rain resulting in progressive removal of the present soil in the surface of the terrain and lineal of channels, when caused by flow lines of this flow. It can even be faster in slopes with high river bad gradient (above 34°), disintegrating the particles presents in the soil causing the cited erosions.

Figure 4 shows the entire trajectory that the rainfall water runs through just after its impact in the surface, exemplifying the beginning of the process of the ravines, which are the erosions caused by concentration of the superficial flow in a same point. After that, the total amount of the erosive processes caused by the accumulation of the superficial and subsuperficial flow (groundwater) originate the erosions with larger dimensions, which demand a more effective solution and eliminate associated elevated costs, making many times over the intervention works impracticable.

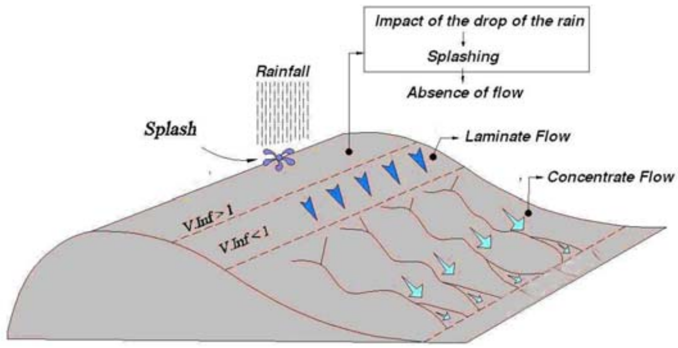


Figure 4. Mechanism of the erosion caused by action of the rainfall

Erosive process caused by flow stream

In spite of the fact that the San Francisco River does not have flow rates of water that causes great impact when in contact with its banks or margins, the flow stream is one of the major items responsible for depriving the present vegetable covering. With the slope unprotected, the flow of water causes drag of the particles for percolation that can occur by collapse of the soil silt-sandy which compose the margins of the river and after that the erosions are imminent.

Erosive process causes by the effect of waves

Besides the erosive processes previously cited, the margins of San Francisco River are always subject to the wave impact sometimes generated by the aeolic action, sometimes generated by local navigation. Like the erosive process generated by the drops of water originating due to rainfall, the collision of the waves in the margins of the river, provoke the mass movement in a large quantity of big blocks, promoting its destabilization. This adds to this fact, the deforestation of the ancillary woods which, besides forsaking the local margins, it affects directly the everyday life of the people who lives in that region.

PLAN OF SAN FRANCISCO RIVER REVITALIZATION

The problems of San Francisco River in its margins (Figures 5 and 6) and riverbed were identified after several expeditions realized with cultural character and mostly of environmental understanding, looking to the necessity of interventions. Also it had been noticed that the erosive process isn't generalized along the whole fluvial course and is conditioned by the demographic density, along with the geotechnical and hydrographic characteristics in all places studied.

Figures 5 and 6. Erosion in the margins of San Francisco River

Every study performed through these expeditions that had been initiated in 1998, the year in which the Government of the State of Bahia made a formal contract with CESP – Companhia Energética de São Paulo – with the purpose of accomplishing interventions and the consequent revitalization in the margins of San Francisco River. The initial idea was to perform such interventions of a similar form than used on Paraná and Tietê Rivers; both located in the State of São Paulo and demonstrated multiple cases of enormous success in Brazil. In December 2001, it was signed, a covenant among the Environment Department, National Agency of Waters, and the Government of the State of Bahia with the aim of the elaboration of the Plan of San Francisco River Revitalization by a Field Test. To execute this work, it contracted the company FUNDESPA – Fundações de Pesquisas e Estudos Aquáticos.

This Field Tests (Figure 7), is located between the cities of Barra and Xique-Xique, in the State of Bahia, with an extension of 12 km in distance, that aims to test in real scale, some realistic applicable alternatives to the eroded margins with the object to stabilize and revitalize them environmentally, using low cost options, little maintenance and mostly where it can be applied, technologies and available resources in the location, and generating employment for the people who lives in that region. These interventions have the objective for the total revitalization of the fluvial flow and will increase the depth of San Francisco River guaranteeing the continuous navigation of the embarkations which transport all the agricultural goods produced by the local habitants.

By this way, the measures for the protection of these margins include the slope construction with low inclination (between 15 and 27 degrees) protected by geosynthetics materials, biodegradable or not allied to the planting of specific vegetation for several kinds of situations regarding to the level of water. Other purpose of San Francisco River Revitalization is to implant a World Network of Transport, converting the San Francisco River in an axis of effective integration among Southeastern and Northeastern region of Brazil, attending to the economic expansion of the west of Bahia that since the start of the erosions in the margins was prevented.

Figure 7. Location of the Field Tests.

TECHNICAL CONSIDERATIONS

The process of superficial erosion that affects constantly the margins of San Francisco River contributing to the ravines and big erosions are motivated by the disordered occupation of the population who live in that area, devastating the local vegetation and consequently, the ground that is totally unprotected against the impact of the drops of the rainfall, the stream and impact of the waves. With that, the Plan of Rio San Francisco River Revitalization foresees a search of solutions of low environmental impact with the objective of providing the fast growth of the vegetation.

Importance of the vegetation

Vegetation has been used as the prevention and control of erosion for centuries, beginning with the Chinese, Roman and Incas civilizations as the pioneers. The vegetative coverage and of the present of soils in slopes contribute to attenuate its erodibility rate, maintaining the humidity and facilitating the infiltration of waters in the terrain. It propitiates several effects of the geotechnical, ecological, economic or even aesthetic point of view; however each one has its particularities.

Geotechnical

- Protection of the margins against the erosion caused by impact of the drops of rain, of the stream flow, or of the waves;
- Increase the stability of the slope by the establishment of a soil-root matrix and by modifications in the humidity proportion;
- Protection against the action of the wind and displacement of the soil;
- Enrichment of the organic material of the soil, decreasing its shear;
- Reduction of the speed of water.

Ecological

- It soothes temperature and humidity ends of the air close to the surface of the soil;
- Optimization of the hydraulic relations in the system soil-plant-atmosphere;
- Reduction of the extra-transpiration rates;
- Improve the quality of water;
- Create refuges for micro-faunas and insects.

Economic

- Reduction of the execution and maintenance costs;

Aesthetic

- Harmonization and improvement of the landscape;
- Reduction of the visual impact with the increase of the green area.

Geosynthetics used for prevention and control of superficial erosions

Geosynthetics can be defined as polymeric industrialized products, whose properties contribute for geotechnical improvements, in which they perform mostly functions of: reinforcement, filtration, drainage, protection, and separation, flow control (impermabilization) and superficial control (Vidal 2002).

Their utilization in this specific field of application has experienced a significant advance since 1990 decade, providing an adequate protection of the soils even though the local terms (river bed gradient, geotechnical characteristics, pluviometric indices, use and occupation of the terrain, etc) show adverse and potentially deflagrated of erosive processes. Basically, geosynthetics should act as retainer of the fines coming from the underlying soils or of the edodible material transported, besides having the function of resisting to the flow speeds and to the tangential efforts generated by the flow of waters and to absorb the energy of the impact of the drops of the rain. Currently, geosynthetic products and applications range from prevention to control of superficial erosions and are very vast in application with new solutions being developed every day. It suggests clearly that any kind of solution with erosion prevention and control purposes constituted by synthetic materials should be installed on a stable geotechnical slope.

According to Theisen (1990) geosynthetics for erosion prevention and control are classified as temporary (TERMs, temporary erosion and vegetation materials) that are wholly or partly degradable elements and they have the function of preventing and controlling erosion of the protected location until the vegetable coverage can be established, and in addition promoting the germination of the seeds for the fast development of the vegetation. Theoretically, TERMs are subdivided in two groups: ECMNs (erosion control meshes and nets) constituted by geogrids or geonets, both constructed with biaxial orientation and ECBs (erosion control blankets) constituted by blankets of biodegradable vegetable fibers.

A second group of geosynthetics with the same function are denominated as permanent (PERMs, permanent erosion and revegetation materials) which are polymeric elements not-degradable with good tensile strength and aid not only as reinforcement of the root system of the vegetation, but in vegetative growth. PERMs are subdivided in two distinct categories: geosynthetics biotechnical-related, TRMs (turf reinforcement mats) which are blankets of three-dimensional matrix of polymeric fibers used for the reinforcement of the vegetation already developed against the action of the speed of water and against the strength efforts above of the maximum supported by it, besides help it to grow. Aligned to the previous concept are ECRMs (erosion control and revegetation mats) which are blankets with the same characteristics of the aforesaid material, however with the soil added to accelerate the development of the vegetation. The second PERMs category is the biologically active materials hard armor-related like geocellular, concrete block system, wood, stone riprap or gabions. In the Table 1 can be checked a summary of this classification.

Table 1. Geosynthetic erosion control material (after Theisen 1990)

TERMs	PERMs	
	Biotechnical-related	**Hard armor-related**
Erosion control meshes and nets (ECMNs)	Erosion control revegetation mats (ECRMs)	Geocellular
		Concrete block system
Erosion control blankets (ECBs)	Turf reinforcement mats (TRMs)	Wood
		Stone riprap
		Gabions

GEOCOMPOSITE PROTECTION

During the study of the Plan of San Francisco River Revitalization many solutions have been proposed to cure definitively the erosive problems in the margins of the river, however due to the terms imposed by the location, neither of all of them could be installed.

Geocomposite protection exemplified at this paper (Figures 8 and 9) is manufactured with an open three dimensional synthetic mat consisting of randomly placed filaments of polypropylene welded in all of their points of contact and joined in a double twisted hexagonal metal mesh with a plastic coating that inhibits its corrosion when in contact with water. Aligned to the TRM concept, this geomat avoids the direct contact of splash with the surface creating a propitious environment to the growth of the vegetation. After that, with the stabilization of the surface covered and the particles of the soil confined, it promotes the growth of the vegetation. The roots of the vegetation, which anchor the geosynthetic material at the slope and the wire mesh, increase the resistance of the soil against small displacements. Besides these characteristics, this geomat also has as function to reduce the speed of the fluvial flow and it reduces sensibly the erosive risks of the margins. Each component of this geomat owns its individual function and the result obtained by the entire set is excellent.

Figures 8 and 9. Details of the geomat applied in the San Francisco River

For its dimensions and whereby represents the Brazilian territory, the San Francisco River Basin does not present alarming numbers regarding its water flow. According to the statistics of the Government of the State of Bahia, its average flow is approximately 2700 m³/s having average speed varied among 2.7 and 3.5 m/s, numbers which, and according to Figure 10 they are enough for the installation of the TRM geocomposite protection, which after vegetated, tolerates admissible speed up to 4.50 m/s.

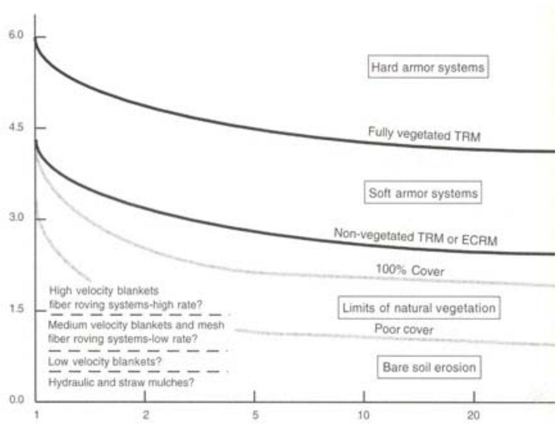


Figure 10. Admissible speeds of the geomat

Installation of the geosynthetic material at the Field Tests

Before the beginning of the execution of the Field Tests, many cares had been taken regarding the kind of vegetation that would be developing there. Being this way, native's vivariums have been installed strategically in easy access location to provide for the interventions of ancillary reforestation of the margins of the San Francisco River.

Due to the previous erosion in the margins of the river, initially it had been planned for the preparation of the slopes with mechanical equipment and an inclination of 27 degrees with the purpose of obtain an uniform surface and without irregularities. The second stage consisting of a trench displaced 1.00m below the top of the slope with dimensions of 0.50m x 0.50m to anchor the geomat and to allow for local drainage, thus preventing the rainwater from infiltrating subsuperficially causing the formation of ravines below the protection.

The steel pegs in form of an "L" were installed for fixation. The geocomposite protection had been anchored at the trenches previously, opened and unrolled (Figure 11), it had been installed along the slope with same peg configuration characteristics respecting the average distribution of 4 (four) pegs per square meter due to its inclination. The objective of the anchorage of the material in the slope is due to the guarantee of the adhesion of the blanket to the surface, preventing the export of the materials through the superficial flow. Moreover, to avoid open points in the geocomposite, a overlapping joining seam was made to pass over 0.15 m in all amendments, longitudinal and transversal (revetment to the upstream superimposing the revetment to downstream), respecting the flow sense of water. On the geomat, there was a hand sowing of a variety of seeds properly prepared with native plant seeds and fertilizers.

Figure 11. Geomat being unrolled in the slope

Figure 12. Geocomposite protection installed in the slope

Tactically, Field Tests had been planned for execution in the driest period of the San Francisco River Basin (between June and October 2007), in other words, the geocomposite protection had been totally installed (Figure 12) on dry soil and with the use of sprinklers the points of contact with the slope allowed coverage of the slope itself with water. The result was exceptional and vegetation has been developed in just two months (Figures 13 and 14). In addition to the vegetation that normally developed, the plants extracted from the natural vivarium seeds that had been planted along the geocomposite revetment in the openings of the double twisted hexagonal mesh showed a result that had also had been very satisfactory.

Figures 13 and 14. Vegetation developed in two months

CONCLUSIONS

The execution of the initial part of the Field Tests of Plan of San Francisco River Revitalization has been, therefore, a success. Thusly being possible to observe several methodologies used in the margins of this important Brazilian river, for example the geocomposite protection, which presented the best results in the evaluated extension. It can be possible to affirm categorically that, this is the beginning of several studies which are still to be performed on Brazilian rivers whose lack of environmental recuperation and the continuing search for a low cost solution, as well as an opportunity for greater productivity that can generate, above all, employment to the low income population.

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