

Diagnosis and proposal of erosion control downstream of the Park Alfredo Werner Nyffeler, in Maringá – Paraná

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Abstract

The surface runoff role in the urban erosion in Northwest Paraná cities was strengthened by many factors, such as the establishment of the cities often in disaggregated soil areas, vegetation cover removal, soil surface impermeabilization caused by construction and poorly executed embankment areas. In Maringá, Paraná, in a bottom valley located near the park Alfredo Werner Nyffeler, there is an accelerated erosive process, damaging half of the urban drainage pipes, which are located around one meter far from the sidewalk. In that way, it poses a risk to the local population and may lead to a collapse of the drainage structure. Within this context, this work aims to diagnose and identify the possible aspects that caused these issues and to design a gabion wall to stem the significative erosive process occurring in the area. Thus, on-site data survey and laboratory analysis were carried out in order to characterize the soil and, by means of the software GawacWin, a gabion retaining wall in order to use it as a prompt, needed retaining measure was designed. The obtained results showed a lack of awareness by the local population in regard to the solid waste deposition, which accumulates downstream of the park. In addition, the drainage pipes could not cope with the peak flows, causing structural damage, leaks and uncovering the junction box. A silty clay embankment was found in the area, which is an expansive soil, contaminated with rubble and the soil compaction was not properly executed. It was used to level the area for the pipeline passage, contributing to the erosion. A gabion wall, with 6m high and 3m base, showed to be an efficient solution with regard to terrain loads. Furthermore, the price, simple construction and the easy merging with the environment are advantages for the gabion wall, when compared to other structural measures.

Keywords: Urban erosion; Clayey soil; Gabion wall

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1 Introduction

Erosive processes are related to environmental alterations, naturally occurring on Earth's surface during the geological time scale or caused by various land use activities, from deforestation and agriculture to urban development and road systems, which, somehow allow the surface runoff concentration (FENDRICH et al., 1997; SALOMÃO, 1999, BERTONI and LOMBARDI NETO, 1990 apud BRITO, 2012).

The accelerated urbanization, which occurs quite often in a disordered way, as well as improper natural resources exploitation, are long-standing concerns, however, they are being even more intensified in the last decades (BRITO, 2012). Consequently and together with this process, deforestation and impervious surface coverage contribute to soil weakening and increase of surface runoff (TUCCI, 2007).

In order to hinder the outflow, drainage systems are designed using urban drainage network (TUCCI, 2007). Nevertheless, they are designed with fixed geometry and limited capacity. With the rapid urban growth, these drainage networks receive great volumes of water, which, not rarely, exceed the drainage system capacity. It increases the flow velocity and may damage the pipes, not contributing significantly to erosion prevention (ZAMUNER, 2001).

Other factors play a role in the urban erosion, such as unplanned land use, dense occupation, inadequate road systems designs and poor urban drainage system networks, which undermine the drainage network responsible for the stormwater overflow (TUCCI, 2007). In this regard, it is essential to control and, if necessary, recover these eroded areas. To this end, structural and non-structural measures might be implemented.

Non-structural measures aim to mitigate or avoid problems by setting regulations, laws or educational actions, such as land use and urban drainage plan in an urban planning context, sustainable drainage system and environmental education (JACAREÍ, 2010).

Structural measures are physical structures constructed in order to mitigate or even to solve the problem. Detention and infiltration basins, permeable paving, green

roof, sustainable sidewalks and energy dissipators are some examples of structural measures. It may be worth emphasizing that non-structural measures require less investment to be implanted when compared to the structural ones. Nevertheless, they can face limitations regard legal, political and institutional aspects, demanding social and governmental engagement to be accomplished (JACAREÍ, 2010).

Although an urban plan was established for Maringá, which was executed in 1947, erosion in urban bottom valleys is noticed. The urbanization process in the study area took place quickly, causing physical changes as a consequence of impervious surface. After noticing the impacts that it may cause, the municipality installed a park with an artificial reservoir, in order to retain the superficial runoff generated by the crescent impervious surfaces. This reservoir receives stormwater coming from the urban drainage sewers. Over time, this reservoir was not enough – what was clear due to the downstream erosion and destruction of an energy dissipator. Thus, measures to stem the outflow and erosion had to be taken to improve the life quality of the local population.

Within this context, this work aims to diagnose and identify the possible aspects that caused these issues and to design a gabion wall to hold the significative erosive process occurring in the area.

Gabions were chosen as constructive material for the gravity wall. As gabions have a high permeability and allow drainage and water percolation through them, relieving forces caused by water; high flexibility, what allows structure's adaptation to terrain movement, following soil consolidation without compromising the stability and structural efficiency; present high resistance to soil loads and traction stress, due to its monolithic design by gravity. Gabions' wire coating assures the material durability for many years. They are an ecological alternative, which integrates easily with the environment, due to the water passage without barriers and the inert material allows a quick recovery of fauna and flora (ONODERA, 2005).

Thus, on-site data survey and laboratory analysis were carried out in order to characterize the soil and, by means of the software GawacWin, a gabion wall was designed in order to use it as a possible retaining measure.

2 Materials and Methods

2.1 Study area description

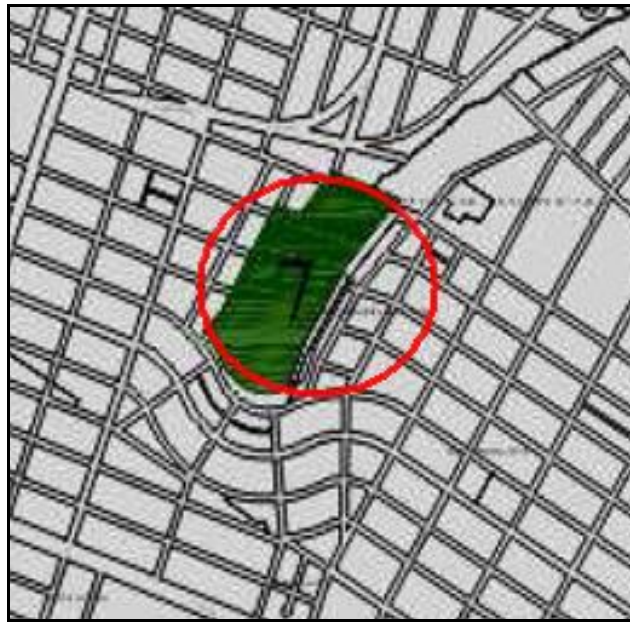
The city of Maringá, located in the North of Brazil, has 357.077 inhabitants and an area of 487,73km² (IBGE, 2010). The city was planned by Jorge de Macedo Vieira, following the "Garden-city" movement, proposed by Ebenezer Howard. The public squares, parks and streets were designed taking into account the local relief (FIGUEIREDO, 2005).

The study area is located in Maringá, PR, located at the street Bogotá, with latitude 23°24'46"S and longitude 51°55'05'W, an altitude of 520 meters and area of 104.967,82 m² (BOVO, AMORIM, 2011).

The municipal park was established in 1988, known as "Parque do Buracão". It is the outcome of a high slope terrain recovery, with a progressive erosion and degradation process. At this time, large amounts of solid waste generated by the city, including civil construction waste and pieces of furniture, were deposited in the area (BOVO, AMORIM, 2011).

With the purpose of mitigating the problem, a detention basin was constructed to store surface runoff and stormwater, which arrives in a large amount and velocity in the terrain lowest point. This detention basin permanently holds a pool of water, used as recreation by the locals. Therefore, the park Alfredo Wener Nyffeler arose. However, some of the issues were transferred downstream to the park, area which the present paper will stick to. Figure 01 and 02 show the park location and the detention basin located inside the park Alfredo Wener Nyffeler, respectively.

Figure 1 – Location of the Park Alfredo Werner Nyffeler, in Maringá



Source: Menezes (2008)

Figure 2 – Detention basin located in the park Alfredo Werner Nyffeler, in Maringá - PR



Source: http://www.taximaringa.com.br/hotel_turismo.php?c=turismo

2.2 Methods

The area was studied through a photographic survey, in order to identify and clarify the issues found there.

A land survey was carried out in the area of study using a total station, an electronic instrument used to measure angles and distances, allowing plotting the terrain profile.

In the studied area, disturbed and undisturbed soil samples were collected for laboratory analysis. The following tests were performed:

- Grain size distribution, following the Brazilian standard NBR 7181 (ABNT, 1995), in order to classify the soil particles by their size;
- Soil compaction test, following the Brazilian standard NBR 7182 (ABNT, 1988), with the purpose of obtaining the correlation of moisture content and the dry specific weight and determine the dry unit weight and the compaction curve;
- Direct shear test, according to the British standard BS-1377-7 (BSI 1990), which aims to assess the soil cohesion and the friction angle;
- Soil plasticity test, following the Brazilian standard NBR 7180 (ABNT, 1984);
- Liquid limit test, according to the Brazilian standard NBR 6459 (ABNT, 1984), in order to determine the soil type.

The retaining structure adopted for this work was a gravity gabion wall. This structure is designed to provide stability against rupture of the rocks or soil massif, giving support and avoiding sliding caused by its own weight or by external loads. The gravity structures use their own weight and, in many situations, the weight of the soil incorporated to them to increase the stability against the pressure caused by the retained soil.

To analyze the chosen retaining structure, the software GawacWin, developed by Maccaferri was used. This software makes use of limit equilibrium methods (adapted from Coulomb theories), Rankine, Meyerhof and Bishop (optimized by the algorithm SIMPLEX) and based on the technical report "Analysis and design of gabion walls", by Prof. Dr. Eng. Persio Leister de Almeida Barros.

Structural projects, in general, in order to keep safety against rupture and excessive deformation, set limit states. Limit states are defined as a state beyond which the structure does not meet the stability and usability requirements imposed

by the project. These limit states are classified as ultimate limit state and serviceability limit state.

To this end, security criteria specified by the Brazilian standards NBR 9061 (Safety in open-air excavations), NBR 11682 (Slope stability); e NBR 8044 (Geotechnical project), that advice a safety factor of 1,5 for excavation works.

3 Results and discussion

The lack of awareness of the population towards the solid waste deposition persisted and, nowadays, there is a solid waste accumulation downstream of the park.

The urban drainage pipes installed with the purpose of transport the runoff flow from the detention reservoir during the flood season became insufficient for the flow peaks. Therefore, the existing junction box broke (Figure 3.a, Figure 3.b) together with the pipes. Leakages (Figure 3.c) and patches with mortar (Figure 3.d) are present as temporary solutions.

Figure 3 – Current state of the drainage system downstream of the park Alfredo Werner Nyffler



By means of a visual and tactile analysis, it was possible to notice that the most superficial soil layer is formed by an embankment, put there in order to level the surface to allow the pipeline passage until the discharge point, located upstream of the water body.

As result of all these mentioned incidences, the erosive process in the area was accelerated. The erosion compromised part of the drainage system, putting it in danger of collapse (Figure 4.a). Furthermore, the erosion is increasingly closer to the sidewalk, putting at risk the safety of people, especially children, passing through the area (Figure 4.b).

Figure 4 – Erosive process downstream the park Alfredo Werner Nyffler

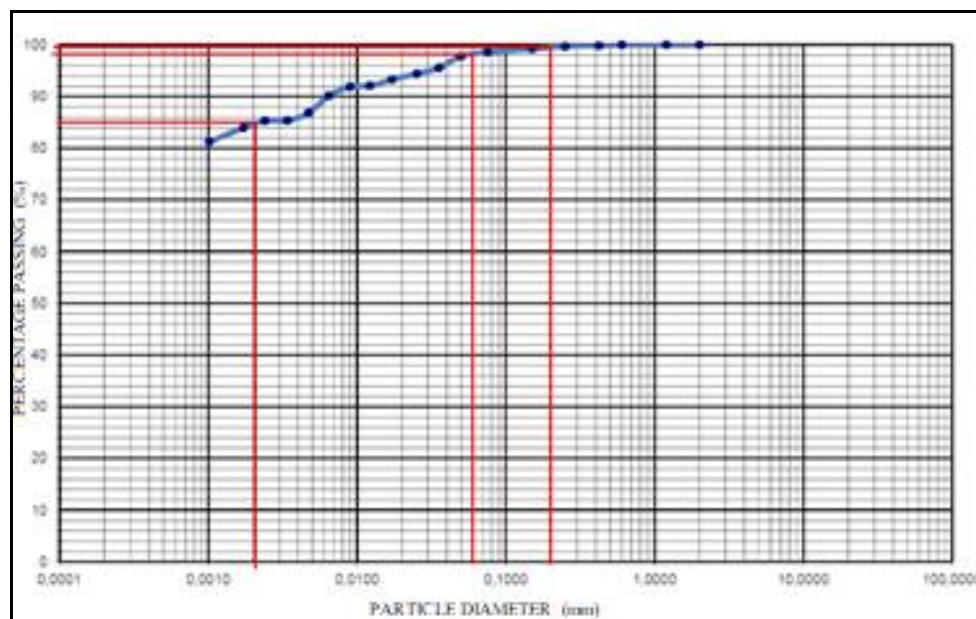


There are many factors contributing to the erosive process in this area, as observed through a local survey. In this way, many measures have to be taken in order to truly solve the problem and not only cover it up. Even temporary actions would not be enough in this case, since the erosion process is recurrent and often showing up again in short period of time.

According to a planialtimetric survey, it was noticed that the erosion has U and D-shaped cross-section profiles, with a depth of 5,144 meters and it is not under the influence of the water table, as there is no a permanent water line in the erosion base. Therefore, it is classified as a ravine, in accordance with CASTRO, XAVIER (2004), IWASA ET AL (2004) and BERGSMA ET AL (1996).

Gradation tests showed that there is a fraction of 85% of clay (particles with dimension smaller than 0,002mm), 13% of silt (particles with dimension between 0,002 mm and 0,06 mm), 1% of fine sand (between 0,06 mm and 0,2 mm) and 1% of medium sand (between 0,2 mm and 0,6 mm). Thus, the analyzed soil is classified as silty clay (Figure 5).

Figure 5 - Grain size distribution graph, with cumulative percent passing (%) x grain diameters (mm)



Through laboratory tests, according to the Brazilian standard NBR 7180 (ABNT, 1984) for plasticity limit determination and NBR 6459 (ABNT, 1984) for liquid limit determination, the results for liquid limit, plasticity limit and plasticity index were obtained. The liquid limit (LL) was 85 and the plasticity limit (LP) was 52. With these results, the plasticity index (IP) was calculated, obtaining the value of 33. Based on these Atterberg limits, the soil is considered clayey.

In order to execute the embankment and identify the optimal compaction conditions, the compaction curve in normal energy was plotted, following the Brazilian standard NBR 7182 (ABNT, 1988) (Figure 6). The optimum water content found was 43,4% and the maximum dry unit weight, 12,42 KN/m³ (Table 1).

Figure 6 – Compaction curve

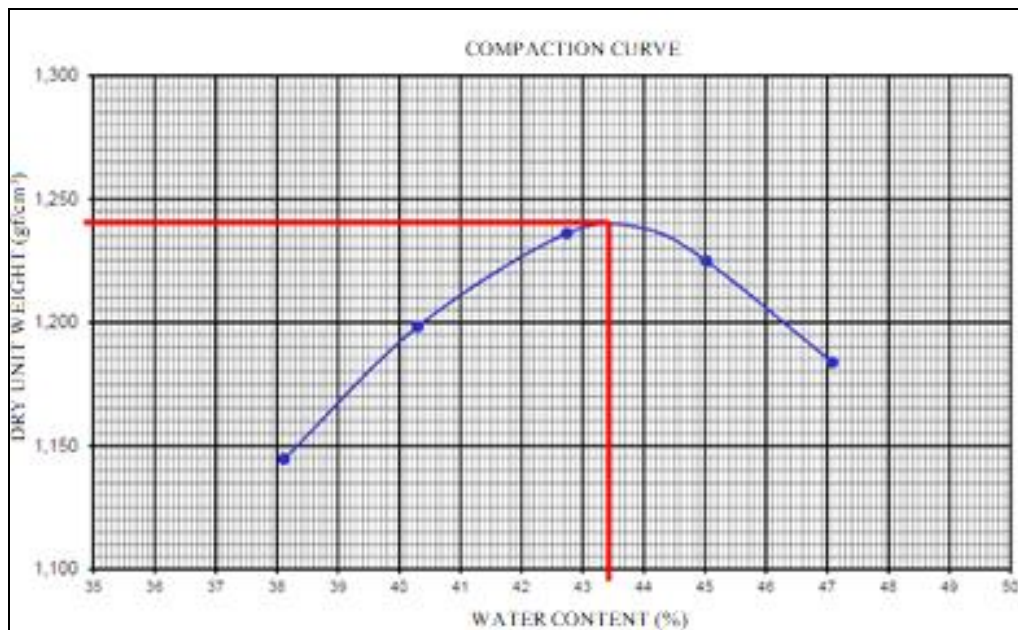


Table 1 – Results found using the compaction curve

Results	
Water content (%)	43,4
Dry unit weight (KN/m ³)	12,40

Based on the compaction test results, it was observed that the optimum moisture content was 43,4% and maximum dry unit weight, 12,10 KN/m³. These parameters must be taken into account when executing the embankment in the study area since it aims for a higher erosion resistance.

The shear resistance was determined through the shear resistance test. Three rupture values for each state were used to plot the circles of stress for the soil in natural conditions (Figure 7), with optimal moisture content in the maximum unit weight in the normal compaction effort (Figure 8) obtained from the compaction curve and 90% of the maximum unit weight (Figure 9). The graphs show the Mohr-Coulomb resistance limit, in which any point above these values, for each given soil and state, represents soil rupture. The cohesion and friction angles were determined by the Mohr-Coulomb failure criterion equation.

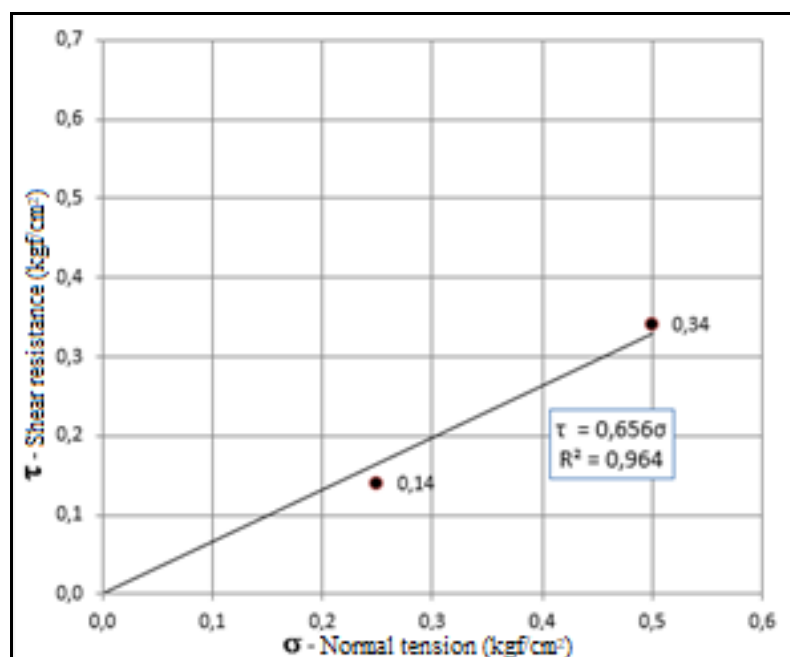
Soils can be considered cohesive and non-cohesive. However, as noticed in the particle size distribution test, previously mentioned, the given soil is classified as a silty clay. Therefore, the results obtained for the shear resistance test in cohesive soils will be analyzed.

The low permeability in clays is directly linked to the water presence and the influence in the soil behavior. Due to this fact, when in the presence of water, the excessive pore-pressure caused by the load dissipates slowly. Thus, the pore-pressure originated by the load continues to act, even years after the construction's end. The point instantly after the load application, when little or no pore-pressure dissipation occurred, is known as an undrained or short-term condition.

The presence of water influences the retaining structures' behavior in many ways. The soil shear resistance parameters decrease when the water content increases, particularly the cohesion. Another consequence is an increment in the soil unit weight, which increases due to the voids filled with water.

In this way, the shear resistance test was performed under undrained conditions, in a saturated soil sample. The most critical circumstances (with the lowest resistance) were considered due to the pore-pressure forces acting in the soil, which may cause a loss of cohesion and an increase in unit weight.

Figure 7 – Coulomb resistance envelope for the soil in natural conditions



$$\tau = c + \sigma_n \operatorname{tg}(\varphi)$$

$$\tau = 0 + \sigma_n 0,656$$

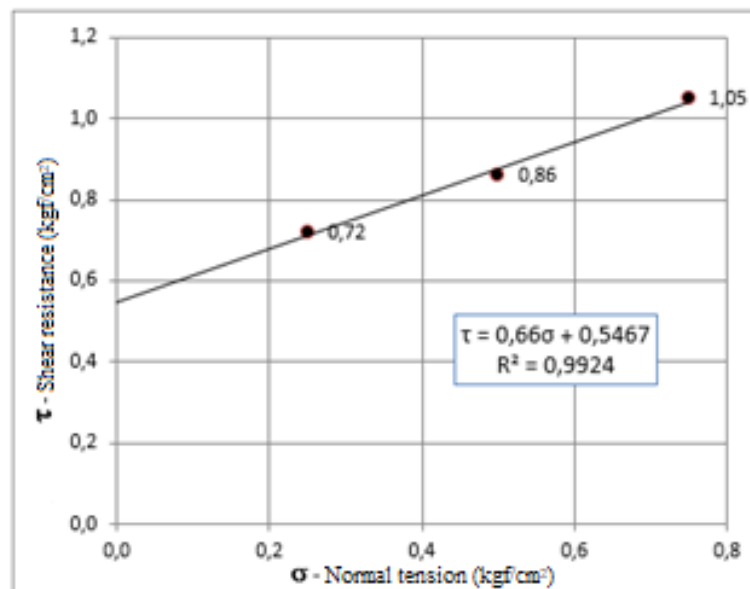
$$c = 0 \text{ (cohesion)}$$

$$\varphi = 33,26^\circ \text{ (friction angle)}$$

According to the results, it was observed that the soil cohesion is zero, meaning that the clayey soil has a non-cohesive behavior.

The non-cohesive soils are represented by sand and boulder, also known as granular soils. However, some clays, when in presence of water or saturated soils, may present a similar behavior towards granular soils. This is due to the fact that, the water in the voids increases the distance between particles, decreasing cohesion. In some cases, clay can even behave as a non-cohesive soil. These soils are more prone to erosion, as the non-cohesive soils have lower shear resistance.

Figure 8 – Coulomb resistance envelope for the soil in conditions of maximum unit weight and optimum water content



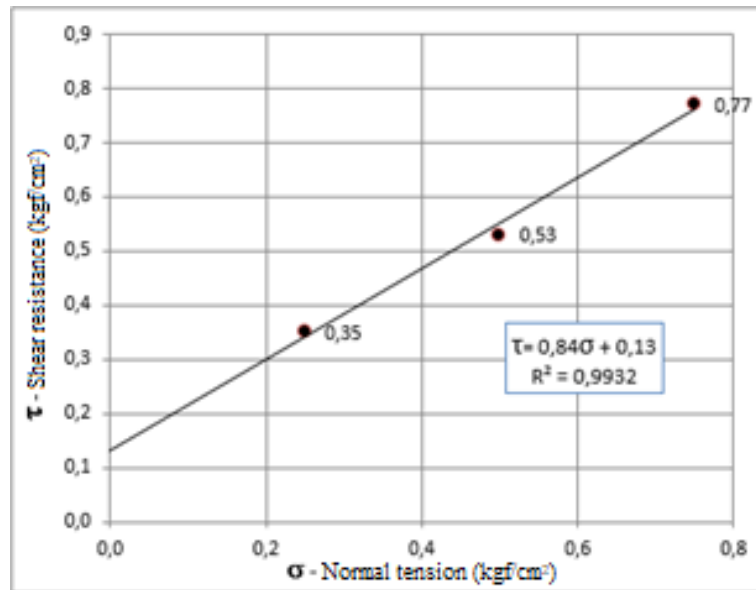
$$\tau = c + \sigma_n \operatorname{tg}(\varphi)$$

$$\tau = 0,5467 + \sigma_n 0,66$$

$$c = 0,5467 \text{ (cohesion)}$$

$$\varphi = 33,42^\circ \text{ (friction angle)}$$

Figure 9 – Coulomb resistance envelope for the soil with 90% of maximum dry unit weight and optimum water content



$$\tau = c + \sigma_n \operatorname{tg}(\varphi)$$

$$\tau = 0,13 + \sigma_n 0,84$$

$$c = 0,13 \text{ (cohesion)}$$

$$\varphi = 40,03^\circ \text{ (friction angle)}$$

The shear resistance test in the optimal compaction conditions, that is, optimum water content and maximum dry unit weight, and optimal water content and 90% of the dry unit weight are performed using undisturbed soil samples. Analyzing the results, one can notice that this soil, after compaction and in non-drained conditions, still presents cohesion, which means that there was an increase in the soil shear resistance after compaction.

In the optimal compaction conditions, the value found for cohesion was 0,5467 and for friction angle, 33.42°. In the optimal water content and 90% of the dry unit weight, the cohesion was 0,13 and friction angle, 40,03%. After obtaining these laboratory results, it was possible to choose the better contention method.

Using the software GawacWin, developed by Maccaferri, an analysis was performed regarding the gabion wall stability. The most critical section was analyzed.

Thus, the embankment starts in the lowest point of the terrain, at the base of the retaining wall, not considering the embedment of 0,85m. The geometry of the wall section and soil massif is shown in Figure 10.

For the optimization of the wall design, what means decrease the material costs, there are two limiting factors: geographic limitation and wall stability limitation. For the latter, the Brazilian standards specify a safety factor for retaining structures in excavations of 1,50. This factor has to be satisfied in all instability situations.

The terrain unevenness is 5,144m, which corresponds to the necessary wall height. However, as an initial attempt, the wall embedment depth was considered approximately 0,85m, which was tested in the Gawacwin and a report was generated. The total wall height will be, therefore, 6,0 meters.

An overload of 1 KN/m² was adopted in order to represent the terrain vegetation. In addition, a slope of 10° for the wall was considered, so its own weight contributes to the structural stability against slide and toppling.

The gabion is composed of a net of 8 x 10 @ 2,7 mm CD, filled by rocks with a unit weight of 24,20 KN/m² and porosity of 30%.

The embankment soil has a unit weight of 11,16 KN/m², angle of internal friction 40,03° and cohesion $c = 13,00$ KN/m². The natural soil, which also composes the structure foundation, has a unit weight of 11,80 KN/m², friction angle of 33,26° and cohesion $c = 0$.

With this data as input for the software, the results were analyzed according to the safety coefficients. Remembering that, according to the Brazilian standards, the minimum safety factor in this situation is 1,5. The values found by the software for the stability factors were: safety factor for sliding = 2,76; safety factor for toppling = 2,11; global failure safety factor = 1,52. All the safety factors are lower than 1,50. Thus, the retaining structure resists against the tension exerted by the soil with efficiency and stability.

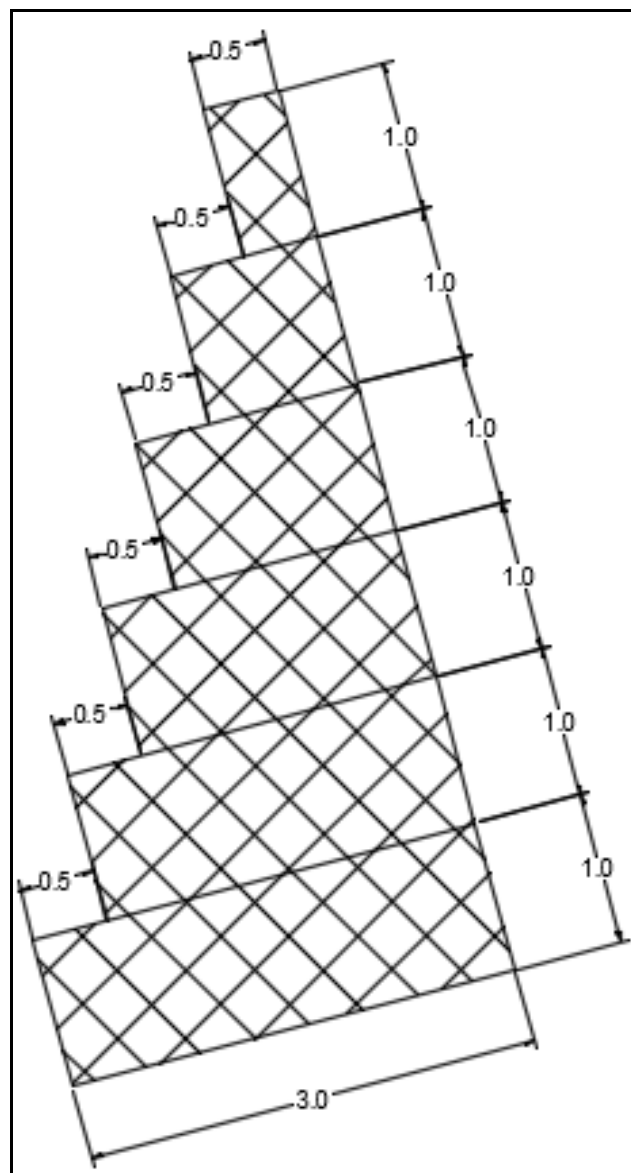
The safety factor for global failure is quite close to 1,50, which means that the wall dimensions cannot be decreased and the structure sizing is optimized.

As a confirmation, the embedment depth was reduced to 0,35 m (0,85m – 0,50m (height of one gabion box)). The software GawacWin analyzed the new structure and the safety factor for slide (FSd) was 2,62, for toppling (FSt), 2,10 and global stability factor, 1,39.

Analyzing the results obtained in the software GawacWin, one can notice that the structure does not have an adequate safety coefficient. The safety factor for slide (FSd = 2,62) and toppling (FSt = 2,10) were higher than 1,50, however, the safety factor related to global stability was 1,39, which is lower than the minimum of 1,50.

Therefore, the gabions wall is proposed as one of the erosion retaining measures, as the scheme shown in Figure 10.

Figure 10 – Scheme of the gabion wall



4 Final considerations

This study sought to evaluate the downstream conditions of the park Alfredo Werner Nyffeler, in order to propose measures to control, recover and stem the erosive process occurring in the area.

The diagnose showed that only one contention work would not be enough to stabilize the soil mass. The sources of the erosion, which accelerate the erosive process, need to be controlled and sorted out to avoid future problems.

Therefore, a new drainage system is needed, since the existing one cannot deal with the high flows. Moreover, an embankment, compacted in optimal conditions mentioned in this work, public awareness of the problem and environmental education to reduce the solid waste disposal downstream the park and a gabion wall to stabilize the soil are some of the proposed measures for the problem.

The gathered data supports the implementation of an embankment in optimal conditions and the gabion wall design. However, not enough data was collected to design a new urban drainage system, thus new studies need to be carried out to accomplish this project.

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