

# Behavior of granular rubber waste tire reinforced soil for application in geosynthetic reinforced soil wall

## *Comportamento de solo reforçado com resíduo granular de borracha de pneu para aplicação em parede de solo reforçada com geossintético*

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### Abstract

Large quantities of waste tires are released to the environment in an undesirable way. The potential use of this waste material in geotechnical applications can contribute to reducing the tire disposal problem and to improve strength and deformation characteristics of soils. This paper presents a laboratory study on the effect of granular rubber waste tire on the physical properties of a clayey soil. Compaction tests using standard effort and consolidated-drained triaxial tests were run on soil and mixtures. The results conveyed an improvement in the cohesion and the angle of internal friction the clayey soil-granular rubber mixture, depending on the level of confining stress. These mixtures can be used like backfill material in soil retaining walls replacing the clayey soil due to its better strength and shear behavior and low unit weight. A numerical simulation was conducted for geosynthetic reinforced soil wall using the clayey soil and mixture like backfill material to analyzing the influence in this structure.

**Keywords:** triaxial tests, granular rubber, waste, reinforced soil.

### Resumo

Uma grande quantidade de resíduo de pneu é descartada no meio ambiente de forma indesejada. O potencial de uso deste resíduo em aplicações geotécnicas podem contribuir para a redução do problema de descarte e melhorar as características de resistência e deformação dos solos. Este artigo apresenta um estudo laboratorial dos efeitos da aplicação dos resíduos granulares de pneus nas propriedades físicas de solos argilosos. Foram desenvolvidos testes de compactação usando esforços padrão e ensaios triaxiais consolidados drenados em amostras de solo e suas misturas. Os resultados apresentam uma melhoria na coesão e no ângulo de atrito do solo argiloso e a mistura com borracha granular, dependendo do confinamento das tensões. Estas misturas podem ser utilizadas como material de aterro em paredes de contenção em substituição de solos argilosos devido a um melhor desempenho na resistência ao cisalhamento e baixo peso unitário. Uma simulação numérica foi realizada para parede de solo reforçada com geossintético utilizando solo argiloso e misturas para materiais de aterro com a finalidade de analisar a influência nesta estrutura.

**Palavras-chave:** ensaios triaxiais, borracha granular, resíduo, reforço de solo.

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## 1. Introduction

Scrap tires are increasing every year and their disposal is a major environmental problem. Particles of rubber tires are been using in landfill engineering as subgrade reinforcement for construction roads over soft soil and others researches suggest their application in civil engineering because of their low density, high durability, high thermal insulation and low cost compared with other fill materials (Cetin, [1]; SZELIGA, [2], RAMIREZ, [3]). In Brazil is being using a specific granular rubber of scrap tires mixed with asphalt for the cap asphaltic road.

This research aimed to understand the viability of this granular rubber as reinforcement material in geotechnical works (layers of landfills, embankments on soft soils and temporary landfills), obtaining a first knowledge of the behavior of reinforced clayey soil with this granular rubber from scrap tires. Finally, use of this alternative material would decrease the demand of natural resources, reducing the environmental impact and adding value to this waste.

## 2. Materials

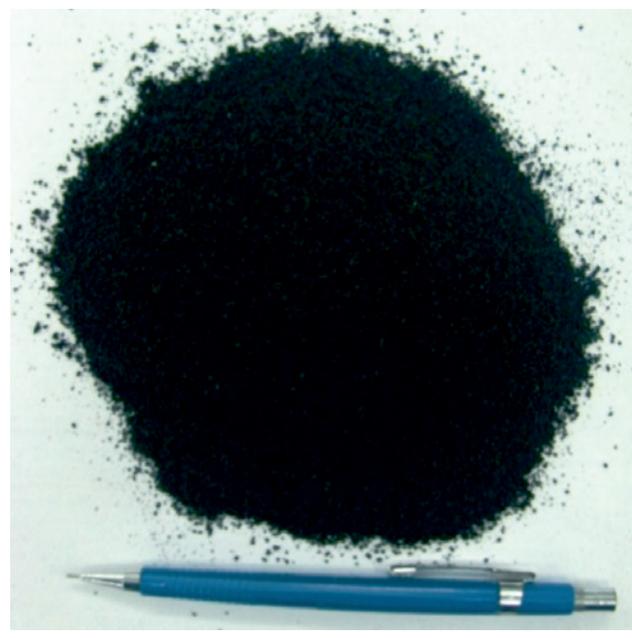
### 2.1 Clayey soil

The clayey soil used in this study is a residual tropical soil (Figure 1) with a limit liquid of 53%, a limit plastic of 39% and specific gravity 2.72. It was collected in the Experimental Field II located in the PUC-Rio Campus. The grain size distribution curve is shown in Figure 3. This clayey soil is classified as MH according to SUCS. This soil has a micro-granular texture, constituted by quartz, altered garnet, clay minerals (mainly kaolinite) and iron and aluminum oxides.

Figure 1 - Clayey soil



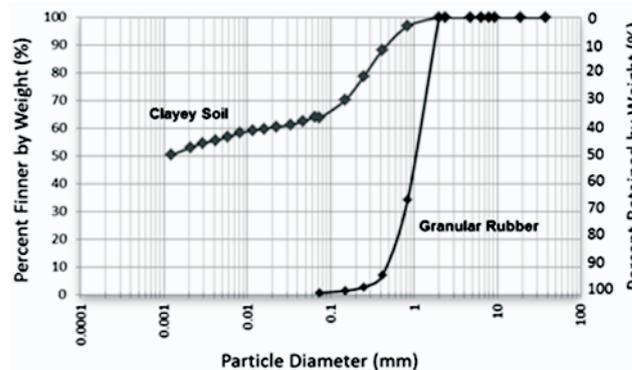
Figure 2 - Granular rubber



### 2.2 Granular rubber

The granular rubber used for reinforced the clayey soil (Figure 2) is by-products of the tire retread process. The specific gravity of this material is 1,12. Its middle diameter is 1,0 mm, varying between 0,2 mm and 2,0 mm. The particle size distribution is shown in Figure 3. This material is composed of 50% by weight of particular cars tire and 50% by weight of trucks tire. In Brazil this granular rubber is mainly used in road construction area. A mixture of asphalt and granular rubber is being used as an efficient technology to achieve Brazilian road requirements.

Figure 3 - Particle size distribution curve of granular rubber and clayey soil



**Table 1 – Symbols used to denote the soil and mixtures**

Material / Mixture	Soil (%)	Granular rubber (%)	Symbol
Clayey soil	100	0	S100
Mixture 1	95	5	S95/B5
Mixture 2	90	10	S90/B10
Mixture 3	80	20	S80/B20

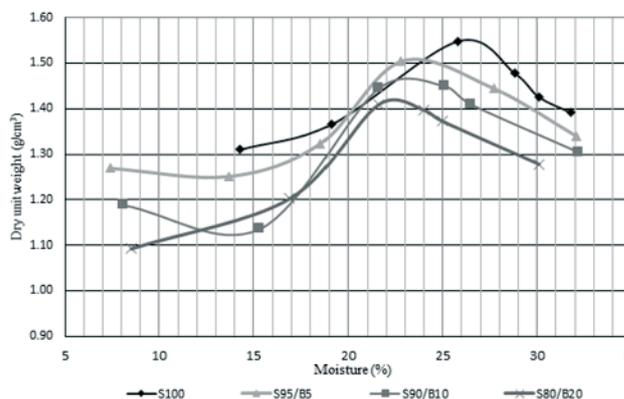
### 2.3 Mixtures

Clayey soil was mixed with 5%, 10% and 20% of granular rubber by dry weight of soil. Water was added according to the optimum moisture and the maximum dry density obtained from Standard Proctor Test (standard compactive effort) performed on each material (S100, S95/B5, S90/B10 and S80/B20). The abbreviations used to denote the soil and mixtures are shown in Table 1.

## 3. Experimental procedure

In order to obtain the optimum rubber content was performed triaxial tests on samples with 5%, 10% and 20% of granular rubber by dry weight of clayey soil (S100). Physical characterization and standard proctor tests were run on clayey soil and mixtures.

**Figure 4 – Standard proctor test curves**



solids, particle size analysis, liquid limit and plastic limit tests were performed using the material finer than size #40 (0,425 mm). An important step to obtain the specific gravity of soil solids is removing the entrapped air in the soil with a vacuum pump. Then was added water to the pycnometers until complete its capacity. Four pycnometers were used to calculate an average value of G<sub>s</sub>. The particle size analysis for coarse soil was done according to the standards by sieving, while the distribution of particle size for fine soil was determined by sedimentation process using a hydrometer.

**Table 2 – Clayey soil physical characterization**

G <sub>s</sub>	Sand (%)	Clay (%)	LL (%)	LP (%)	IP (%)	SUCS
2.72	36.4	10.8	53	39	14	MH

### 3.1 Physical characterization tests

Characterization tests were performed to determine the index properties of clayey soil samples, from the Experimental Field II. The soil was prepared according to the Brazilian technical standard (Brazilian Association of Technical Standards – ABNT). The performed tests followed next standards:

- NBR 6457/1986 – Samples of Soil – Preparations for using in Proctor Test and Characterization.
- NBR 7181/1984 – Soil – Particle Size Analysis.
- NBR 6508/1984 – Soil – Specific Gravity of Soil Solids.
- NBR 6459/1984 – Soil – Liquid Limit.
- NBR 7180/1984 – Soil – Plastic Limit.

The specific gravity of soil

### 3.2 Standard proctor tests

Standard proctor tests were conducted on the clayey soil (S100) and mixtures (S95/B5, S90/B10 and S80/B20) to determinate the optimum moisture (w<sub>opt</sub>) and the maximum dry density (γ<sub>dmax</sub>) of all materials. These tests were made according to NBR 7182, using the standard compactive effort.

The compaction was made in a small cylindrical mold (internal diameter 10 cm and height 12,7 cm). It applied 26 blows in each layer (three layer in total) with a manual rammer, of 2,5 kg of weight, falling 30,5 cm of height. Carefully was trimmer the top of the compacted specimen until to form a plane surface with the top of the mold. Then was determined the mass of the specimen inside the mold using a balance and subtracting the mold weight.

**Table 3 – Optimum moisture and maximum dry unit weight**

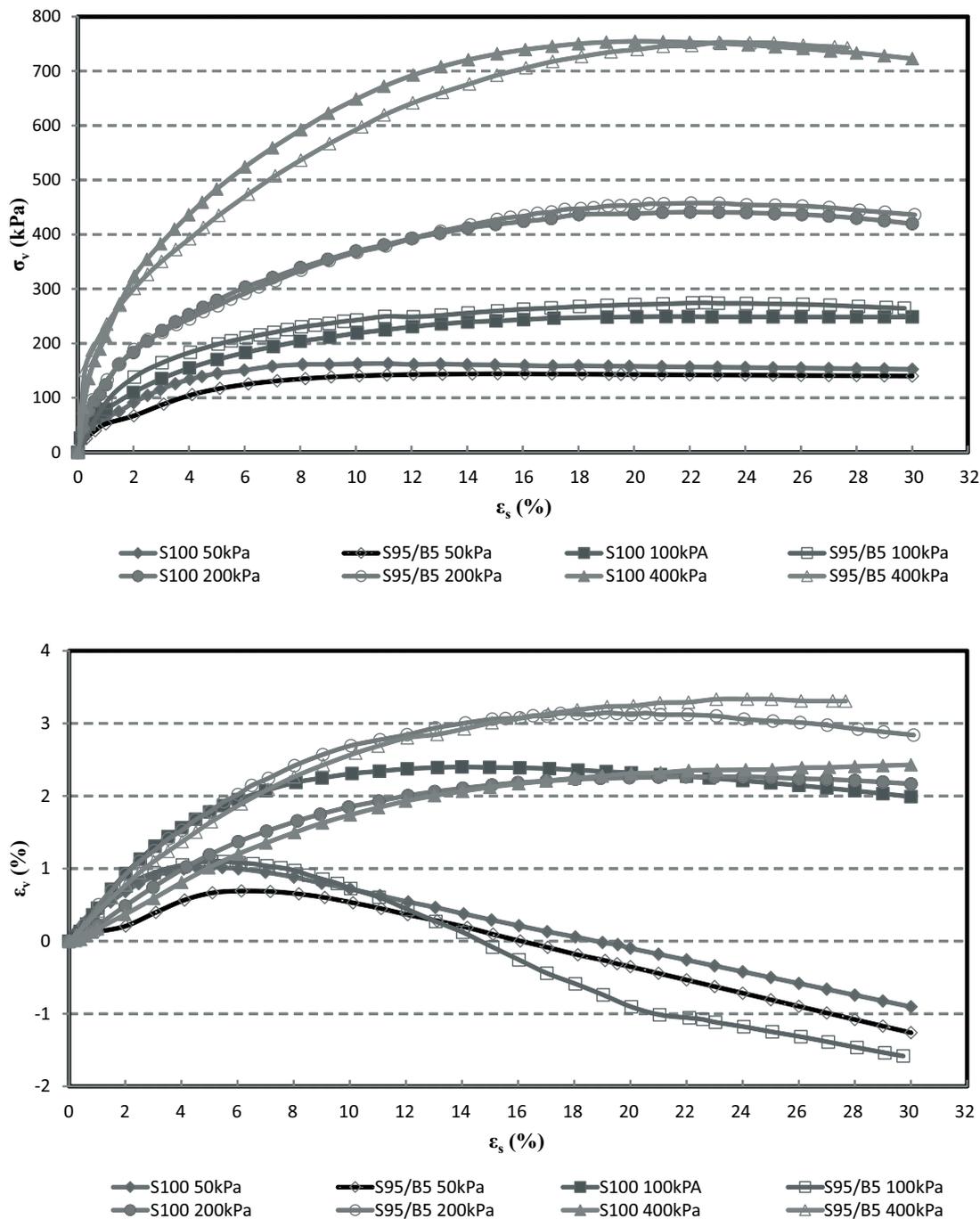
Material / Mixture	W <sub>opt</sub> (%)	γ <sub>dmax</sub> (%)
S100	26.3	1.56
S95/B5	23.5	1.51
S90/B10	23.1	1.47
S80/B20	22.5	1.42

The material was removed from the mold to obtain a specimen for moisture. Then, with each moisture and dry density was plotted the points of the compaction curve. At least were used two molding water content points in each side of the curve (wet and dry side).

### 3.3 Triaxial tests

Standard triaxial testing procedures were followed. The specimens were saturated using backpressure and percolation of

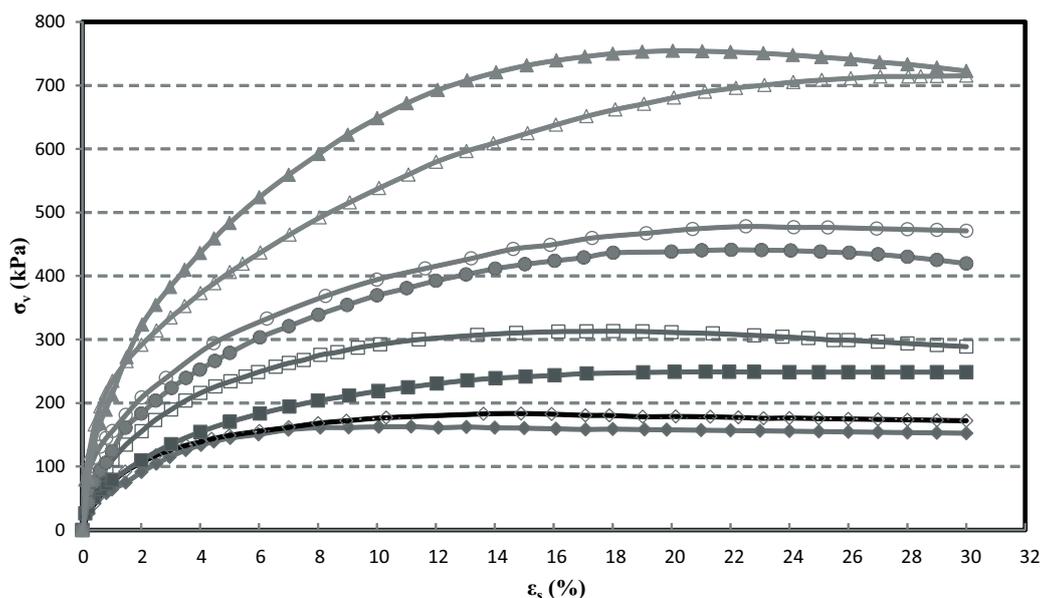
Figure 5 - Results of drained triaxial tests for clayey soil (S100) and mixture (S95/B5)



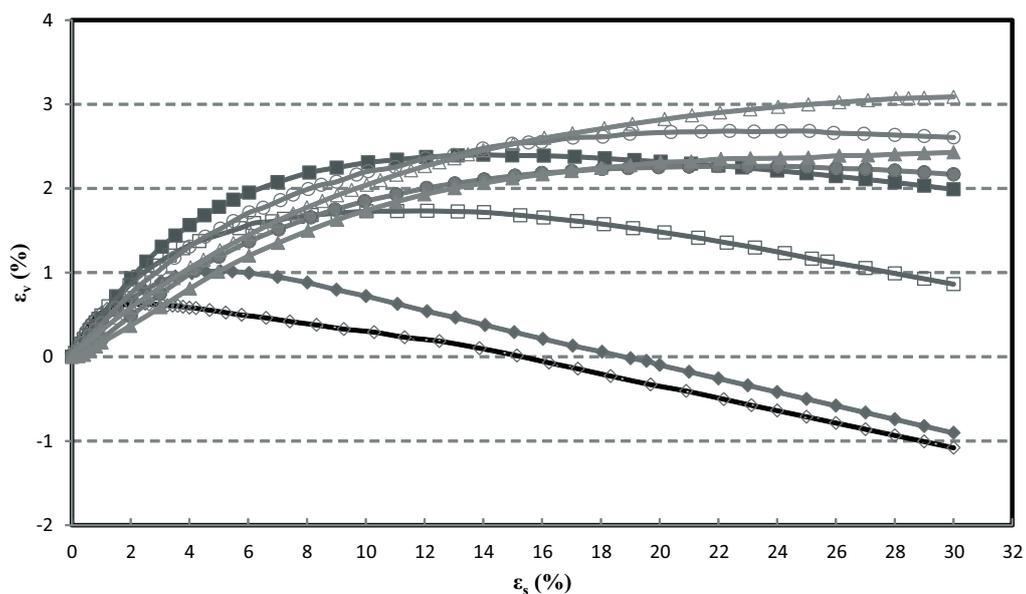
water through the samples. The final saturation was estimated with Skempton parameter ( $B = 0,97$ ). Consolidated-drained (CD) tests were conducted on clayey soil and mixtures. According to HEAD [5], the maximum rate of deformation was

determined using the minimum time of failure 8,5t100. The rate of deformation used in the shear phase was 0,022 mm/min for all samples. After compact the clayey soil and the mixtures with their optimum moistures and maximum dry densities were

Figure 6 – Results of drained triaxial tests for clayey soil (S100) and mixture (S90/B10)



S100 50kPa     
  S90/B10 50 kPa     
  S100 100kPa     
  S90/B10 100kPa  
 S100 200kPa     
  S90/B10 200kPa     
  S100 400kPa     
  S90/B10 400kPa



S100 50kPa     
  S90/B10 50 kPa     
  S100 100kPa     
  S90/B10 100kPa  
 S100 200kPa     
  S90/B10 200kPa     
  S100 400kPa     
  S90/B10 400kPa

molded samples with 3,8 cm of diameter and 7,2 cm of height.

### 4. Results and analysis

The results of specific gravity (Gs), liquid limit (LL), plastic limit (LP) and a resume of particle size are shown in Table 2. According with

SUCS this soil is classified as a silt high plasticity (MH), but in this research it is named clayey soil due to it has more than 50% of clay. The soil particle size distribution curve is shown in Figure 3. The compaction results showed the maximum dry unit weights and the optimum moistures of mixtures are lower than those for clayey soil (S100). This decrease is mainly due to lower specific gravity

Figure 7 - Results of drained triaxial tests for clayey soil (S100) and mixture (S80/B20)

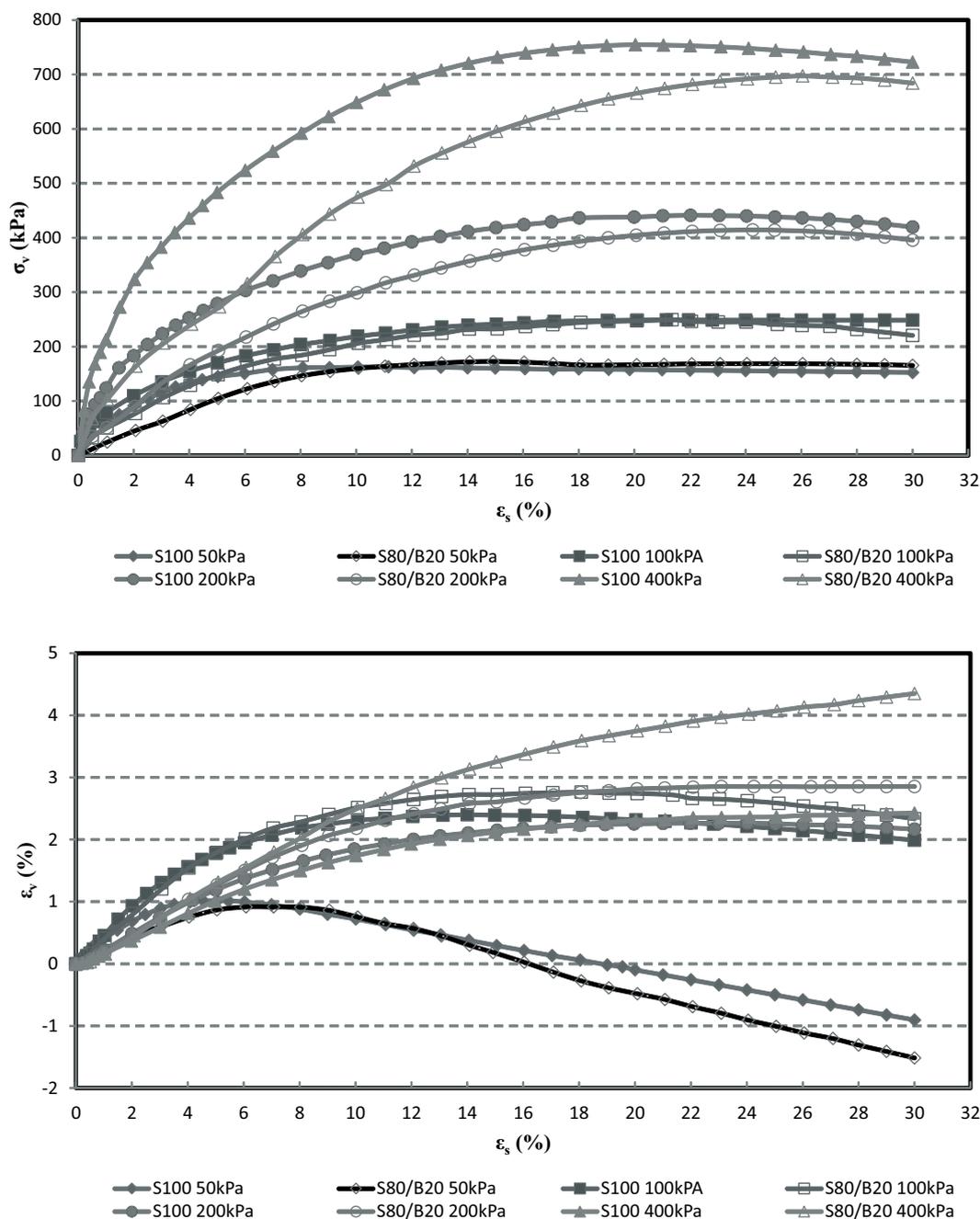
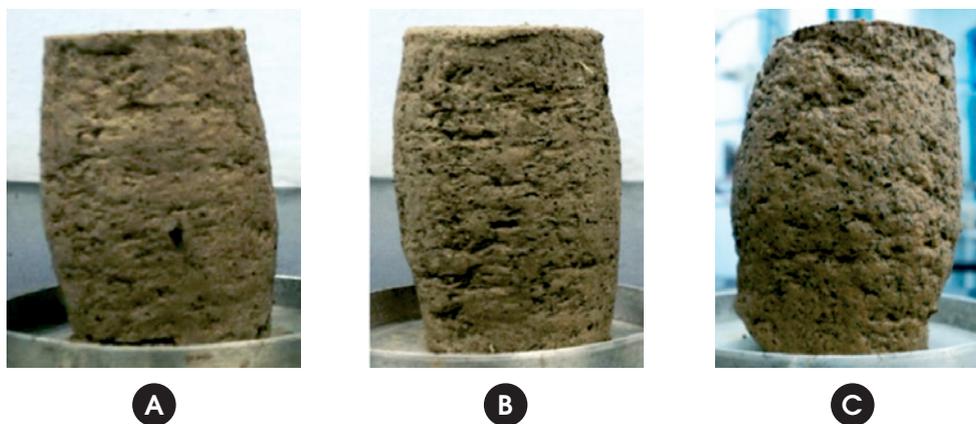


Figure 8 – Sheared mixture specimens. Confining stress: (a) 100 kPa, (b) 200 kPa and (c) 400 kPa



of the rubber. The Figure 4 and Table 3 show the results of the standard compaction tests performed on clayey soil and mixtures. The triaxial tests showed that exist a positive influence of granular rubber reinforcement on the shear strength behavior of the clayey soil. The mixture with 10% of rubber has the better behaviour compared with the others mixtures (See Figures 5, 6 and 7). The shear strength of the mixture (S90/B10) increase in relation to clayey soil (S100), this occur until 200 kPa of effective confine stress, beyond of this confine stress the presence of granular rubber

degrade the shear strength of the clayey soil. The shear strength of clayey soil reached 162, 250, 440 kPa at 50, 100 and 200 kPa of confinement stress, respectively. On the other hand, the shear strength of S90/B10 mixture attained 184, 312, 478 kPa at same confining stresses. The increases of strength were 52%, 124% and 10% for 50, 100 and 200 kPa of confinement stress, showing clearly the influence of confining stress on shear strength. In large strain, the shear strength of the mixture maintains larger that strength of the clayey soil. Only for 400 kPa of effective confinement stress, the

Figure 9 – Strength envelopes of clayey soil (S100) and mixture (S90/B10)

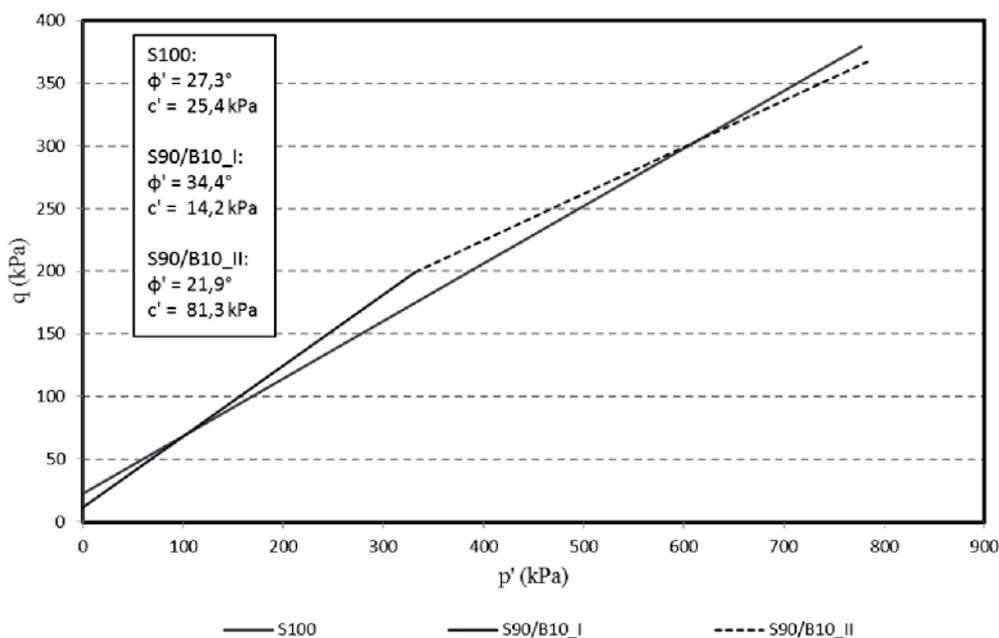


Figure 10 - Geosynthetic reinforced soil wall model

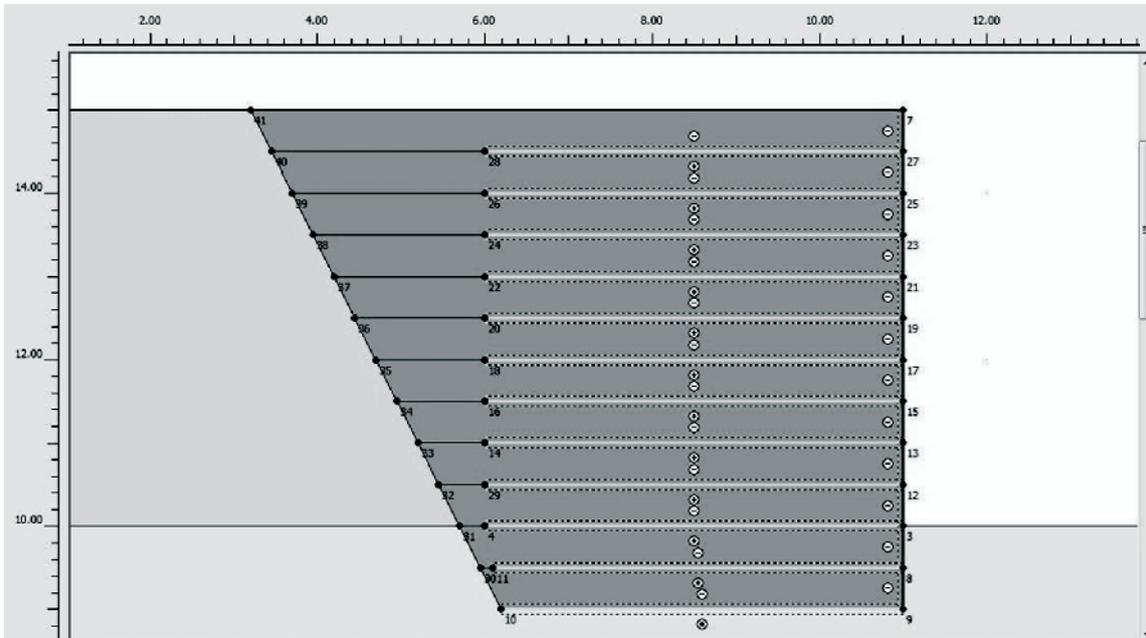
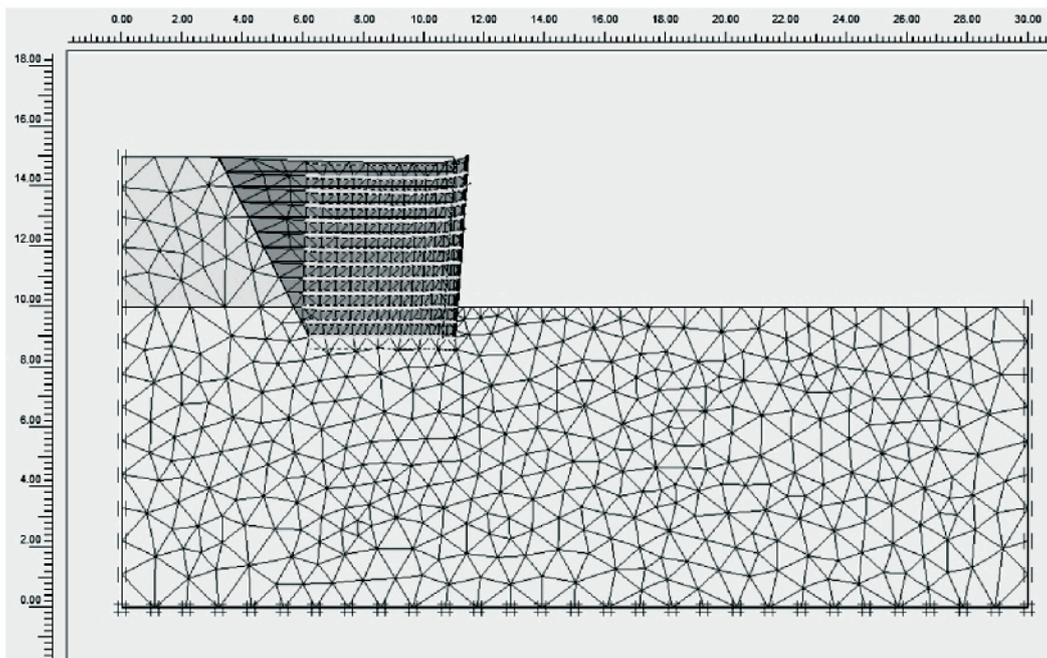
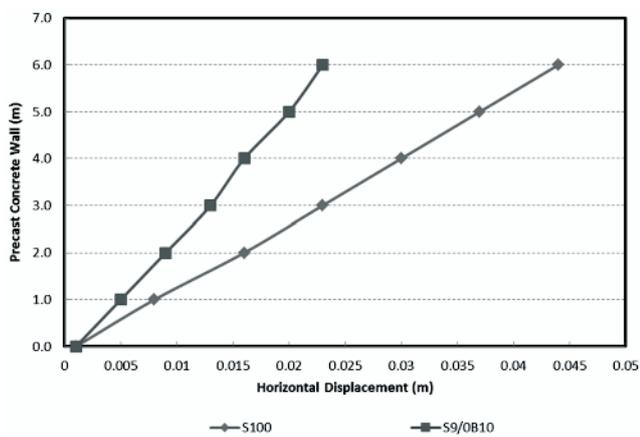


Figure 11 - Deformation generated after the last construction phase



**Figure 12 – Horizontal Displacements on precast concrete wall**



shear strength of the mixture was shorter than strength of clayey soil, however from 30% of strain can it appreciate that the shear strength of clayey soil has a tendency to be shorter than mixture and the shear strength of the mixture tend to arise. Volume changes caused by shearing differ for clayey soil and mixtures. S90/B10 mixture shows less contraction comparing with S100 for 50, and 100 kPa confining stress. Furthermore, these both specimens show higher rate of dilatation than other mixtures and higher shear

strength than the clayey soil. Dilatation could mobilize the tensile stress on rubber, adding strength during shear stage. The tested S90/B10 mixture specimens are shown in Figure 8.

In the Figure 9 are shown the strength envelopes of the clayey soil and the mixture 2 (S90/B10). This envelope were plotted in  $p':q$  space. The strength envelope of the mixture shows bilinearity due to confining stress influence. For high levels of confinement the strength decrease and can be less than strength of clayey soil. The first part of the mixture strength envelope has a friction angle of  $34,4^\circ$  and the second parte decreases to  $21,9^\circ$ . In the other hand, the cohesion of the first part of the envelope is 14,2 kPa, arising in the second part to 81,3 kPa.

### 5. Numerical simulation of a geosynthetic reinforced soil wall

It was performed a numerical simulation of a geosynthetic reinforced soil wall. This structure was formed with layer of compacted soil (backfill) reinforced with geogrids. A precast concrete face completed the structure. It was considered 6,0 m of height and 12 layer of 0,5 m of thickness (See Figure 10).

It was using the finite element program PLAXIS to run this example. The purpose of this simulation was to compare the behaviour of the geosynthetic reinforced soil wall when the backfill is constituted for clayey soil (S100) or mixture 2 (S90/B10). There were defined points in the precast concrete face to know the horizontal displacements generated for the backfill. The Hardening soil model was used for the backfill materials and the Mohr Coulomb model was assigned to foundation soil. Horizontal displacement on top

**Figure 13 – Effective relative stresses (S100 backfill)**

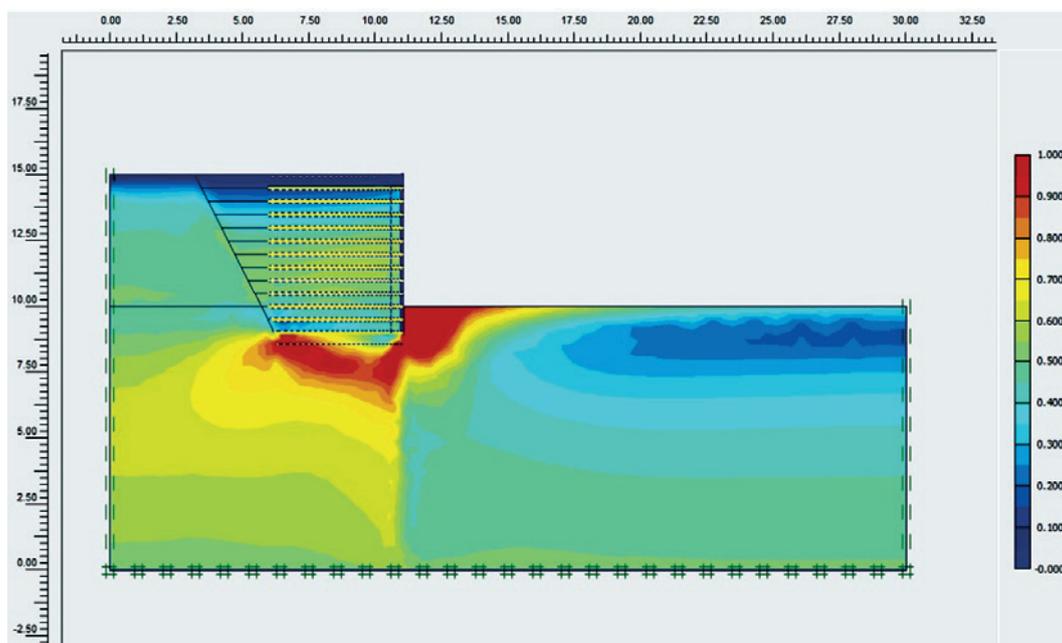
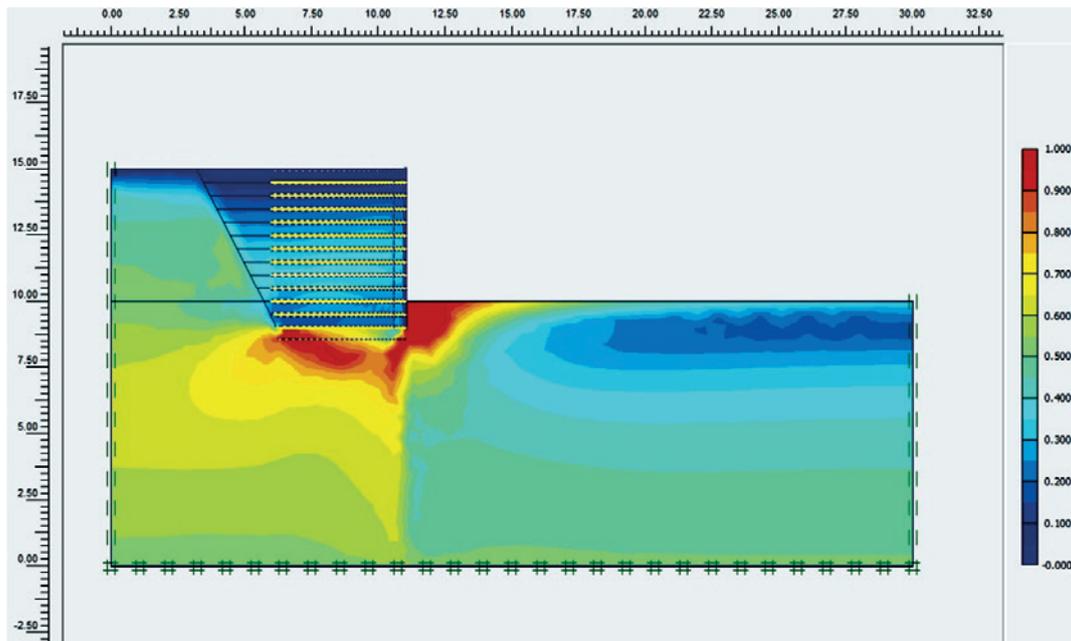


Figure 14 – Effective relative stresses (S90/10 backfill)



wall was 4.4 cm for clayey soil backfill. Moreover, S90/B10 backfill induced 2.3 cm of horizontal displacement on top wall. The horizontal displacement along the wall was less when S90/B10 material was used as backfill. The Figure 11 show the deformations generated after the last construction phase.

In addition, when it was used S90/B10 backfill the effective relative stresses were less than the effective relative stresses registered when S100 backfill was used. See Figures 13 and 14.

## 6. Conclusions

- Addition of granular rubber enhances the clayey soil behavior improving its shear strength.
- For large deformation, the shear strength of mixture is higher than clayey soil and the development of strength has a better behavior than clayey soil.
- The influence of the confinement in the mixture behavior is important. Exist a limiting confining pressure beyond which the presence of the granular rubber degrades the strength of the clayey soil. This could be explained because of the excessive confinement that restricts dilatation, in consequence the granular rubbers cannot mobilize tensile stress. Thus, this mixture will have a better performance than clayey soil under low confinement levels (Özkul and Baykal,[6]).
- Results of the numerical simulation showed minors horizontal displacements in the precast concrete wall when the mixture S90/B10 was used as backfill.
- Low effective stresses were generated when S90/B10 backfill was used in the retaining wall.
- This mixture is an adequate material to be used in some geotechnical application as layers of landfills, backfill in retaining walls, small embankments on soft soils, temporary landfills, subgrade reinforcement for construction roads over soft soil. In these projects the presence of low confinement stresses enable the use of this material.
- An important contribution to the environmental, low cost of the

projects and major quality of this geotechnical structures would be possible with more researches in non-conventional material particularly with waste (Ramirez and Casagrande, [4]).

## 7. References

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