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Analysis of stresses and strains in the structure of the flexible pavements with geotextiles using strain gauges

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ABSTRACT
The investigation with geotextiles in flexible pavements, occurs as a result of analyzing with laboratory tests the stresses and strains. The analysis was done using strain gauges. Then an alternative of technical and economic design in the long term will be developed according to our reality. Laboratory tests were made using two materials as a subbase simulating the configuration of flexible pavements. Beams of 25 x 20 x 80cm were made representing the foundation-subbase ground interface. The analysis of stresses and strains with and without woven and nonwoven geotextiles will be made by using strain gauges located in the interface. These results can be applied with the design methodology, which is based on the analysis of strains and the stresses that arise in the pavement structure. The tensile stresses, originated in the analyzed interface, change according to the material and the geotextile type. It influences the design methodology, because the thickness of the subbase decreases up to 50%. The useful life increases and there can be a savings of up to 40% in costs thanks to the installation of a geotextile as an element of reinforcement and separation in a flexible pavement structure. Finally, with the reduction of the thickness of the granular subbase layer by 50%, the different design alternatives can be evaluated by using a reinforcing geotextile on the subgrade, analyzing the possibilities of improving the properties of the granular materials or the increase in traffic of design or the increase of the useful life of the structure.

Keywords: flexible pavements, geotextile, strain gauge, tensile stresses, strains.

1. INTRODUCTION AND OBJECTIVES

1.1 Introduction

The mechanical properties of geotextiles are defined by the stress - elongation behavior. The lateral strain of the geotextile is restricted. The Grab test method that will be used in the present investigation will allow to obtain the tensile stress in terms of strength and the elongation; obtaining useful values for the survival of geotextiles as reinforcement and separation within a flexible pavement structure. The application of a load on a road is mainly due to vehicular traffic, where the pavement answers to the application of that load, produces a state of stresses and strains, with which the displacements that occur are vertically in very small quantities of the order of hundredths or thousandths of a millimeter. Therefore, it is necessary to understand that, given the application of a vehicular load, although there is a maximum deflection on the point of application, around this area there are also vertical and horizontal displacements that give rise to a state of tensions, which They will be analyzed in the design and evaluation of flexible pavement structures.

1.2 Objectives

- Analyze the influence of the elongation of geotextiles on the stresses in the foundation ground interface - subbase inside of the flexible pavement structure.
- Determine the breaking load and elongation by the Grab Method of a type of woven and nonwoven geotextile using the universal testing machine.

2. DEVELOPMENT

2.1 Hypothesis

The Breaking Load and the Elongation of the geotextiles will directly influence the tensile stresses of the foundation - subbase interface for the design and evaluation of flexible pavements.

2.2 Methodology

The type of research was applied, because is focus to solve practical problems, with a limited generalization margin. Likewise, because the way in which the objects of study will be intervened, a transversal design will be implemented, since the data collection will be done at the given time, that is, in a single time. The Experimental Research Method will be applied, since data will be collected to compare the behavioral measurements of a control group, with the measurements of an experimental group. Control tests of the subbase material (Vicho and Huillque quarry), subgrade and geotextile material, were carried out. Having the following results:

Table 1. Results - Subbase and subgrade material tests.

Description	Huillque´s Quarry	Vicho's Quarry	Subgrade material
SUCS Classification	GP	GP	CH
AASHTO Classification	A – 1 – a (0)	A – 1 – a (0)	A – 7 – 6 (11)
Maximum dry density (gr/cm3)	2.10	2.17	1.83
Moisture content (%)	8.30	7.60	13.60
CBR 100% (%)	53.00	50.00	9.00
CBR 95% (%)	43.00	43.00	8.00
Module resiliency (E=100xCBR) (kg/cm2)	4300	4300	800

Table 2. Results – Geotextile test

Description	Woven geotextile	Non-woven geotextile
Average breaking load (kg)	79.60	95.70
Average elongation (%)	38.03	40.75

Further, a test was performed for the calculation of stresses and strains in the ground foundation interface - subbase with Woven Geotextile, Non-Woven Geotextile and without geotextile; simulating a subgrade configuration - subbase in the form of a beam supported by a subgrade by simulating its continuation. A point load will be applied to the center of the beam. The sensors, in this case strain gauges, will be placed on the ground foundation - subbase interface, where stress and strain data will be obtained.

The test is about the manufacture of beams with subgrade and subbase material, these have dimensions of 80cm x 20cm x 25cm and are supported on a compacted material of 10cm thick that simulates the continuation of the foundation ground. The thicknesses of the subgrade and subbase were determined by locating the neutral axis of the two stacked beams, that way we will know where we can locate the geotextile. Being one of the objectives to calculate and analyze the tensile stress, we will place the geotextile in the traction zone, therefore the configuration of our beam will be 15 cm of subgrade and 20 cm of subbase, as shown in Figure 1.

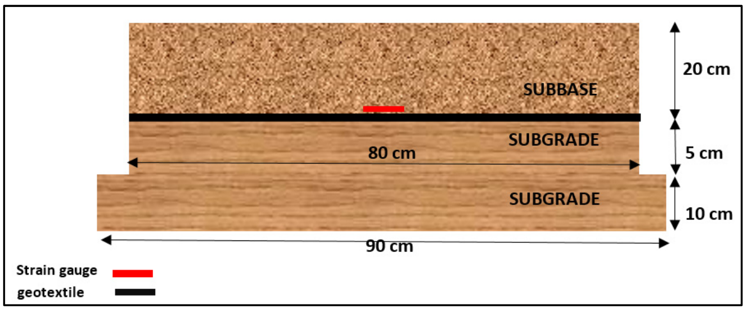


Figure 1. Subgrade - Subbase configuration, with geotextile.

To determine the kind of strain gauge to be used in the test, a multilayer analysis was previously performed to calculate the stresses, deformations and strains at a specific point; and thus obtain strain gauges with technical specifications useful for the test. This analysis was performed with the Kenlayer Software, the software has tools that provide us with a more complete analysis of stresses, strains and deflections at specific points and in turn you can enter parameters of different kinds of terrain; which favors the analysis. Taking into account that the CBR values at 95% of the Huillque and Vicho quarries are the same, then we do a single analysis. The results of the analysis are as follows:

Table 3. Results – Stresses with Kenlayer Software

Stresses	
Vertical stress (kg/cm^2)	0.860 kg/cm2
Radial stress (kg/cm^2)	-0.940 kg/cm2
Tangential stress (kg/cm^2)	-2.040 kg/cm2
Shear stress (kg/cm^2)	-0.426 kg/cm2

Table 4. Results – Strains with Kenlayer Software

Strains	
Vertical strain	0.0004486
Radial strain	-0.0001188
Tangential strain	-0.0004810
Shear strain	-0.000268

Having as preliminary data the stresses and strains, we choose a kind of Strain Gauge that has the sensitivity to measure this data. For this type of application, gauges are normally used with a measuring grid with 10mm or greater. The Strain Gauges data log and strains dials, is a recording device consisting of sensors (micrometers, strain gauges, load cells) in a modular way, the development includes the recording device and the necessary software for the visualization and storage of the information collected on an excel spreadsheet. This device was designed only for this test by an electronic engineer.

3. STRESS AND STRAIN TEST ANALYSIS IN FLEXIBLE PAVEMENT STRUCTURE

The purpose of this test is to obtain results of stresses and strains in the subgrade subbase interface through the use of strain gauge located in said interface, to do the laboratory tests, analyzes or investigations required by a project. It can be applied with the design methodology that is based on the analysis of strains and the stresses presented in the pavement structure.

3.1 Equipment:

We use: Universal Testing Machine, Device for measuring strains by strain gauge and Manual key with metal tripod.

3.2 Materials:

We use: Subgrade material, Subbase material, Woven and non-woven geotextile, Wooden formwork (90cm x 30cm x 15cm), Metallic formwork (80cm x 20cm x 25cm), Strain gauges, Pison and compaction plate.

3.3 Soil Sample

The soil sample (subgrade and subbase) and specimens for compaction should be prepared with the moisture content. The soil sample used must pass the 19mm (3/4”) sieve, all the gradation must be used to prepare the soil samples to be compacted without modification.

3.4 Process

- According to the density and moisture content of each of the materials, whether for the subgrade or subbase, we calculate the necessary weight for the manufacture of our beams. All this calculated weight should be compacted in the predetermined volume.
- Compact 10cm of the subgrade material in the wooden formwork. The compaction will be done in 5 layers, 56 strokes at each compaction point.
- Assemble the metal formwork on top of the compacted subgrade
- Within the metal formwork, 5 cm of subgrade is compacted.
- The geotextile is laid on top of the compacted subgrade, and slightly tensioned longitudinally.
- The strain gauge is placed on top of the compacted geotextile, located in the central part, covering an area of approximately 40x 20cm.
- Next, 20cm of subbase material is compacted (05 layers, 56 strokes at each compaction point)

3.5 Estimations

Weight required for compaction like equation 1 shows:

$$W = \gamma\ (1+ \omega)\ V \qquad [1]$$

The strain and stress readings will be made using the strain gauge reading device and the universal testing machine. The results of the laboratory test were obtained from two sources:

3.5.1 From Universal Testing Machine

With the Universal Testing Machine, we could control the speed (200 kg/min) and the contact pressure "q" (8.443 kg/cm2). The data we obtained were the load at the breaking point, the stress at the breaking point and the position.

3.5.2 From Device for measuring strains by strain gauge

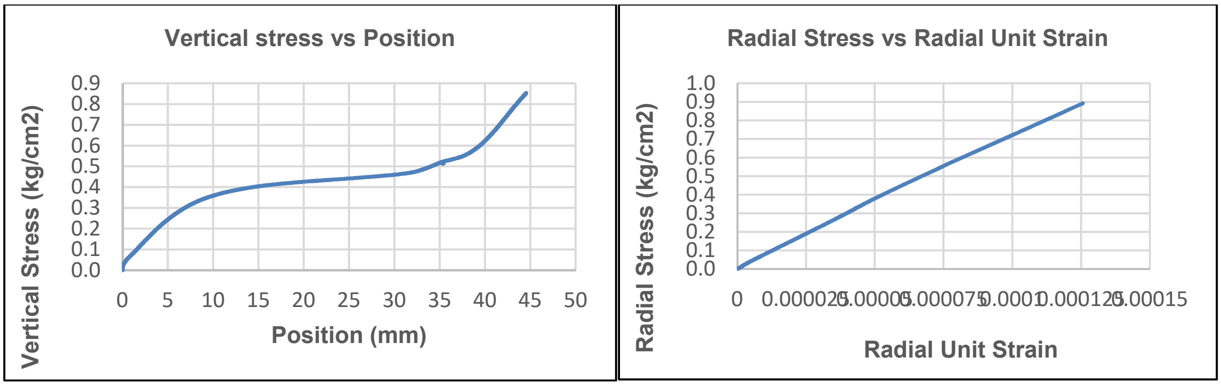
With the Device for measuring strains, we could control the stress force, the vertical and horizontal deformation. From the data of vertical stress (σz) and radial stress (σr), we obtain the values of radial deformation (εr), with the Eq.2.

$$\varepsilon r = 1/E\,(\sigma r - \mu\,(\sigma t + \sigma z)) \qquad [2]$$

4. RESULTS OF LABORATORY STRESS AND STRAIN ANALYSIS TESTS

Two types of graph obtained during the test are shown, then a summary will be presented with the results for each situation.

a) b)



- Maximum Vertical Stress (σz) = 0.882 kg/cm2
- Maximum Vertical Position = 44.7 mm

- Maximum Radial Stress (σr) = 0.892 kg/cm2
- Maximum Radial Strain = -0.0001256

Figure 2. a) Vertical Stress vs. Position – Vicho´s Quarry Without Geotextile. b) Radial Stress vs. Radial Unit Strain – Vicho´s Quarry with Woven Geotextile

Below is a summary with the results of the tests performed:

Table 5. Results – Huillque's Quarry

	Huillque's Quarry			
	Maximum Vertical Stress (σz)	Maximum Vertical Position (mm)	Maximum Radial Stress (σr)	Maximum Radial Strain
Without Geotextile	0.854	44.6	0.907	-0.00020585
With Woven geotextile	0.816	35	0.836	-0.00015535
With Non Woven geotextile	0.843	44.4	0.73	-0.00013231

Table 6. Results – Vicho's Quarry

	Vicho's Quarry			
	Maximum Vertical Stress (σz)	Maximum Vertical Position (mm)	Maximum Radial Stress (σr)	Maximum Radial Strain
Without Geotextile	0.882	44.7	0.92	-0.00020892
With Woven geotextile	0.795	43.3	0.892	-0.0001256
With Non Woven geotextile	0.855	44.6	0.724	-0.00010054

5. BENEFIT-COST RELATIONSHIP ANALYSIS USING WOVEN AND NON-WOVEN GEOTEXTILES IN THE SUBGRADE-SUBBASE INTERFACE

5.1 Benefit-cost analysis with woven geotextile Huillque´s Quarry and Vicho´s Quarry

Below are two cases where the cost benefit relationship using woven and nonwoven geotextiles in the Vicho and Huillque quarry will be analyzed. It's important to highlight that the woven geotextile allows to increase the conditions of support of the pavement structure as a whole, however, in the design methodology, the contribution of the geotextile in the bearing capacity of the subgrade soil must be evaluated to compare the results of the Road design without geotextile and design with geotextile. For this benefit - cost analysis, an initial design of the pavement structure is presented with the following characteristics:

- Design Traffic: N = 1.5 x 106 equivalent axes of 8.20 ton
- Design Period: 20 years
- CBR of the subgrade: 9%

We use the design methodology of AASHTO 93, for which we need the following data:

Table 7. Input data for SN calculation

Characteristics	Values
Reliability (R)	85%
Zr	-1.037
Standard Deviation (So)	0.45
Initial Serviceability	4
Final Serviceability	2.50
Subgrade Resilient Module	2555*CBR0.64 = 10426 PSI
Design Traffic - W18	1490000

So, the SN is 3.21. Now, if the structural coefficients (a_i), the drainage coefficients (m_i) and the thicknesses (D_i) are: a_1= 0.125/cm, a_2=0.052/cm, a_3=0.047/cm, m_2=0.8, m_3=0.8.

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \tag{3}$$

Then the thicknesses of each layer will be: Asphalt layer = 0.05m, Granular base = 0.25m, Granular Subbase = 0.40m and subgrade with CBR = 9%

So, initially, for the calculation of stresses and strains we use the kenlayer software, with which we obtain the following results:

Table 8. Stress and strain results with Kenlayer software

	Stress (kg/cm^2)	Strain
Vertical	0.184	0.0001431
Radial	-1.112	-0.0001871
Tangential	-0.529	-0.00003857
Shear	-0.072	-0.0000365

The approach is made with the reduction of granular soils and analysis of the alternative.

Alternative N°01: Granular subbase thickness 30cm. The results obtained after to do a model in the Kenlayer Software are:

Table 9. Results of Stresses and Strains - Alternative 1

	Stress (kg/cm^2)	Strain
Vertical	0.170	0.0001205
Radial	-0.846	-0.0001382
Tangential	-0.494	-0.00004855
Shear	-0.062	-0.0000315

The normal stress applied is σz = 0.170 kg/cm2 = 0.017 MPa = 17 kPa. The Stress is distributed horizontally, in a flat area, we get 17 kPa x 1.0 m = 17 kN/m; T_{req} = 17 kN/m (T_{req}: Stress required). For this case, the Woven Geotextile was previously worked is chosen, with the following characteristics:

- Last Stress (Td): 39 kN/m (data calculated based on the average breaking load of the GRAB test)
- Available Stress (Tr): 21.67 kN/m (This data is obtained from the Design Manual with Geosynthetics, 8th Edition)

Now we calculate the global safety factor (FSG): FSG = Td/Tr; FSG = 21.67/17: FSG = 1.275 < 1.3.

As the value of the FSG gave a value below 1.3, we proceed to optimize the design by proposing new structure alternatives. So that this value is above and close to 1.3 as indicated in the Design Methology with Geotextiles in the Design Manual with Geosynthetics, 8th Edition.

Alternative N°02: Granular subbase thickness 25cm. The results obtained after to do a model in the Kenlayer Software are:

Table 10. Results of Stresses and Strains - Alternative 02

	Stress (kg/cm^2)	Strain
Vertical	0.158	0.0001025
Radial	-0.639	-0.0001003
Tangential	-0.463	-0.00005567
Shear	-0.056	-0.0000282

The normal stress applied is $\sigma z = 0.158$ kg/cm2 = 0.0158 MPa = 15.18 kPa. The Stress is distributed horizontally, in a flat area, we get 15.18 kPa x 1.0 m = 15.18 kN/m; T_{req} = 15.18 kN/m (T_{req}: Stress required). For this case, the Woven Geotextile was previously worked is chosen, with the following characteristics:

- Last Stress (Td): 39 kN/m (data calculated based on the average breaking load of the GRAB test)
- Available Stress (Tr): 21.67 kN/m (This data is obtained from the Design Manual with Geosynthetics, 8th Edition)

Now we calculate the global safety factor (FSG): FSG = Td/Tr; FSG = 21.67/15.18: FSG = 1.37 < 1.3.

This last structure is taken as a design recommendation:

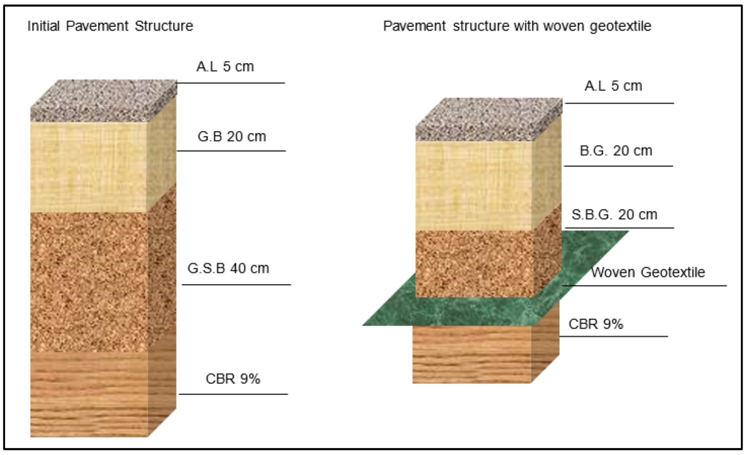


Figure 3. Pavement structure with reinforcement (woven geotextile), subbase decreased 15cm (from 40cm to 25cm)

Finally, we calculate the decrease in thickness with reinforcement geotextile. The Unit Price analysis of Granular Subbase compacted on site, with the S10 Software and the cost for m^3 is 21.50 USD. So:

- Granular subbase compacted on site: 21.50USD / m3
- Cost of reduced thickness of granular subbase = 0.15m x 21.50USD / m3 = 3.225USD / m2
- The m2 of woven geotextile has a value of: 1.5USD
- The saving, for m^2 is given by = 3.225USD / m2 - S /. 1.50USD / m2 = 1.725USD / m2

In a kilometer of road with a roadway of 7m wide and with these characteristics of thicknesses the saving is: 12,075.00 USD equivalent to a saving of 47%.

In the case of the Vicho´s quarry, the analysis is similar to Huillque´s quarry previously detailed, the only difference is that at the time of making the unit price analysis the cost for m^3 is: 23.20USD. So:

- Granular subbase compacted on site: 23.20USD / m3
- Cost of reduced thickness of granular subbase = 0.15m x 23.20USD / m3 = 3.48USD / m2

- The m2 of woven geotextile has a value of: 1.5USD
- The saving, for m^2 is given by = 3.48USD / m2 - S /. 1.50USD / m2 = 1.98USD / m2

In a kilometer of road with a roadway of 7m wide and with these characteristics of thicknesses the saving is: 13,860.00 USD equivalent to a saving of 43%.

5.2 Benefit-cost analysis with non-woven geotextile Huillque´s Quarry and Vicho´s Quarry

In the case of non-woven geotextiles, the reduction of the serviceability index will be evaluated in function of the equivalent loads without the installation of a geotextile as a separation element, and we will determine the increase in costs due to the effects of the pollution presented in a main road that was designed with the same structure previously calculated. Performing the calculation of SN, with the thicknesses shown in the Figure 08, a value of 3.17 is obtained. It is then, that we calculate the number of equivalent axes. So, the W18 is 1.41E+06.

The new structural number is calculated considering the contamination of the subbase. In order to quantify the reduction in the structural coefficient of the subbase layer, the phrase "5 kilos of stone placed on 5 kilos of mud was taken as a reference results in 10 kilos of mud" cited by Robert Koerner in his book "Design with Geosynthetics. " Taking into account the above, the aforementioned coefficient is reduced by 50% and the new SN of the road structure is calculated. Therefore, the structural coefficient of the subbase (a_3) is reduced by 50%.

So, a_1= 0.125/cm, a_2=0.052/cm, a_3=0.0235/cm, m_2=0.8, m_3=0.8, D_1=5cm, D_2=25cm, D_3=40cm. We apply the "Eq.3", and as a result we have SN=2.42. The reduced structural number of the road is 2.42, with this value the new number of equivalent axes is calculated, keeping the values recommended by AASHTO. To evaluate the benefit of geotextile as a separation element, the additional material necessary is calculated to maintain the initial conditions of the road (SN = 3.17), having a structural coefficient of the subbase reduced by 50%. So, a_1= 0.125/cm, a_2=0.052/cm, a_3=0.0235/cm, m_2=0.8, m_3=0.8, D_1=5cm, D_2=25cm, and SN=3.17, Then, clearing the value "D_3" we have, D_3=40cm.

To verify if the geotextile that we use in the Tension Grab test is appropriate, the following procedure is performed:

- T_u = 939 N (Breaking Load Data - Grab Test)
- ε = 41% (Elongation Data - Grab Test)
- $f(\varepsilon)$ = 0.51 (see table N°4.1 of the Geosynthetic Design Manual)
- d_a = 38.1 mm = 1 1/2'' (maximum diameter)
- p'= 120 PSI = 827.40kPa (contact pressure, data from our initial pavement design)
- FS_p = 1.525 (FRID * FRDQB) (Security factors, see table N°3.1 of the Geosynthetic Design Manual)

So, FSG = T_u / (FS_p x p' x (0.33 x d_a)2 x f(ε)), FSG = 939 / (1.525 x 827.40 x 10-3 x (0.33 x 38.10)2 x 0.51), FSG = 9.23 > 1 ok.

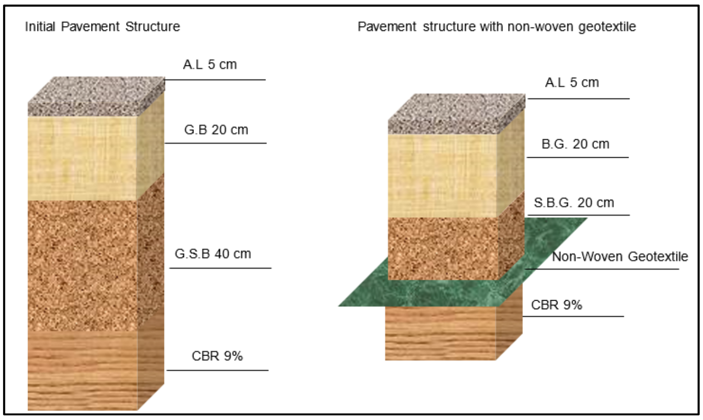


Figure 4. Pavement structure with non-woven geotextile

Making the cost comparison of the two structures of the road considering only the reduction of the granular subbase, we have:

Table 11. Huillque´s Quarry, with non-woven geotextile

Layers of the road structure	Unit.	Thickness (m)	Unit price (USD)	Price for layer (USD)
Granular Subbase	m^3	0.40	21.40	8.56
Geotextile	m^2			1.50
Total				10.10

Table 12. Huillque´s Quarry, without non-woven geotextile

Layers of the road structure	Unit.	Thickness (m)	Unit price (USD)	Price for layer (USD)
Granular Subbase	m^3	0.80	21.40	17.12
Total				17.12

The cost savings thanks to the installation of a geotextile as a separation element in this structure is 41%.

In the case of the Vicho's quarry, the analysis is similar to that of the Huillque quarry previously detailed, the only difference is that at the time of making the unit price analysis the cost for m^3 is: 23.30USD. Making the cost comparison of the two structures of the road considering only the reduction of the granular subbase, we have:

Table 13. Vicho's Quarry, with non-woven geotextile

Layers of the road structure	Unit.	Thickness (m)	Unit price (USD)	Price for layer (USD)
Granular Subbase	m^3	0.40	23.30	9.32
Geotextile	m^2			1.50
Total				10.82

Table 14. Vicho's Quarry, without non-woven geotextile

Layers of the road structure	Unit.	Thick ness (m)	Unit price (USD)	Price for layer (USD)
Granular Subbase	m^3	0.80	23.30	18.64
Total				18.64

The cost savings thanks to the installation of a geotextile as a separation element in this structure is 42%

6. RESULTS

6.1 Results of the test for the calculation of stresses and strains in the laboratory

6.1.1 Quarry Analysis

Table 15. Results of stresses and strains- Huillque's quarry

	Without Geotextile	With woven geotextile	With non-woven geotextile
Vertical Stress (kg/cm^2)	0.854	0.816	0.843
Vertical Position (mm)	44.60	35.00	44.40
Radial Stress (kg/cm^2)	0.907	0.836	0.730
Radial Strain	-0.00020585	-0.00015535	-0.00013231

If we consider the stress and strain values Without Geotextile as the base, that is, 100%, then we see that when using Woven and Nonwoven Geotextiles, they vary as follows:

Table 16. Results of stresses and strains- Vicho's quarry

	Without Geotextile	With woven geotextile	With non-woven geotextile
Vertical Stress (kg/cm^2)	0.882	0.795	0.855
Vertical Position (mm)	44.70	43.30	44.60
Radial Stress (kg/cm^2)	0.920	0.892	0.724
Radial Strain	-0.00020892	-0.0001256	-0.00010054

If we consider the stress and strain values Without Geotextile as the base, that is, 100%, then we see that when using Woven and Nonwoven Geotextiles, they vary as follows:

6.1.2 Analysis by kind of geotextile

Table 17. Results of stress and strain with woven geotextile

	Huillque´s Quarry	Vicho’s Quarry
Vertical Stress (kg/cm^2)	0.816	0.795
Vertical Position (mm)	35.00	43.30
Radial Stress (kg/cm^2)	0.836	0.892
Radial Strain	-0.0001554	-0.0001256

When using Woven Geotextile, with the Huillque and Vicho Quarry, it is observed that the stresses and strain vary as follows:

Table 18. Variation of stresses and strains (Woven Geotextile)

Woven Geotextile	
Vertical Stress	Varies in 2.57%
Vertical Position	Varies in 19.17%
Radial Stress	Varies in 6.28%
Radial Strain	Varies in 19.18%

Table 19. Results of stress and strain with non-woven geotextile

	Huillque´s Quarry	Vicho’s Quarry
Vertical Stress (kg/cm^2)	0.843	0.855
Vertical Position (mm)	44.40	44.60
Radial Stress (kg/cm^2)	0.730	0.724
Radial Strain	-0.00013231	-0.00010054

When using Non-Woven Geotextile, with the Huillque and Vicho Quarry, it is observed that the stresses and strain vary as follows:

Table 20. Variation of stresses and strains (Non-Woven Geotextile)

Non-Woven Geotextile	
Vertical Stress	Varies in 1.40%
Vertical Position	Varies in 0.45%
Radial Stress	Varies in 0.82%
Radial Strain	Varies in 24.01%

6.2 Results of the benefit - cost analysis with the use of geotextiles in the subgrade interface - subbase

Table 21. Benefit - cost analysis with woven geotextile

	Huillque’s Quarry	Vicho´s Quarry
Subbase Thickness Reduction (cm)	15	15
Savings for m^2	1.70USD /m2	2.00USD /m2
Savings in 1km of road with 7m wide (USD)	11,847.00	13,785.00

Table 22. Benefit - cost analysis with non-woven geotextile

	Huillque’s Quarry	Vicho´s Quarry
Subbase Thickness Reduction (cm)	20	20
Savings for layer (USD)	7.10	7.80
Savings in 1km of road with 7m wide (USD)	10,334.00	13,464.00

7. CONCLUSSIONS

- The influence of the Breaking Load is reflected in the design methodology with either Woven and Nonwoven Geotextiles, this data being essential for the calculation of the Available Tension and consequently for the calculation of the Global Safety Factor and thus to optimize the design with geotextile, in terms of the influence on stress efforts, it is concluded that Nonwoven Geotextiles absorb the stresses in greater proportion unlike Woven Geotextiles.

- The influence of Elongation on the tensile stress that occur in the subgrade – subbase interface, is reflected in the design methodology with Non-Woven Geotextiles, since it is part of the calculation of the Global Security Factor, being one of the values that define the compliance or not of a type of geotextile in the separation function.

- The design methodology used to define the reduction of the thickness of the granular subbase layer in a flexible pavement structure, based on an analysis of the strains and stresses that occur in each layer of the structure and in a theory of the deformation of the geotextile on soft soils under the application of the load.

- With the result of reducing the thickness of the granular subbase layer by 50%, different design alternatives can be evaluated by using a reinforcement geotextile on the subgrade, evaluating the possibilities of improving the properties of granular materials or the increase in design traffic or the increase in the useful life of the structure.

- With respect to the savings for m^2 with the use of Woven Geotextile, both in the Huillque and Vicho quarry, this represents a saving of 45% on average, while with the use of Non-Woven Geotextile, the savings It is 41%. Both figures determine that the use of geotextiles in the ground-based interface - subbase optimizes costs by more than 40%.

- To give correct use to woven and non-woven geotextiles, it is necessary to have granular subbase soils, according to the SUCS and AASHTO classification, the Huillque´s Quarry and the Vicho´s Quarry are classified as Bad Graded Soils, therefore These materials are suitable for the use of woven and non-woven geotextiles.

- The initial design without geotextile is essential to define the structural contribution of the geotextile in the pavement and the variables that are assumed for the design are the same that are used in the reinforcement methodology, therefore an evaluation of the conditions must be made of each project to have a design alternative that works correctly during the design period of the road.

- More research should be carried out that covers another type of geosynthetic, such as the case of geogrids, or failing to propose the use of a type of natural geosynthetic, that way there will also be savings in the geosynthetic.

- Being the impact deflectometer, the only standard means to measure the strains that the subgrade presents, it is recommended to use the strain gauge to measure stresses and strains, placing them above the subgrade in the initial stage of a road project. In order to be able to continuously monitor the conditions in which the subgrade is.

- This research is unprecedented, investigations were carried out regarding the resistance of the subgrade and the structural capacity of a pavement structure with information from the impact deflectometer, but never before were stresses or strains analyzed with the use of geotextiles in the study interface, that is why it is recommended to continue investigating the efforts that occur in the pavement structure with the use of Strain gauge or another type of sensor capable of recording measurements of that magnitude, in order to include a new alternative of construction of long-term economic technical roads.

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