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DESIGN OF UNPAVED ROADS WITH DACE® SOFTWARE

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ABSTRACT

In this article, we introduce DACE® software as an alternative of computational calculation for the design of unpaved roads, using the semi-empirical methods of Giroud, Han and Pokharel, which were published in 2004 and 2015. As a conclusion, the use of the Hypertext Preprocessor (Php) programming language, applied in order to develop DACE®, allows it to be cross-platform software since it is a web application, therefore, it works in all operating systems. Furthermore, the results obtained using DACE®, were satisfactorily validated with the exercise proposed by Han and Pokharel in 2015, therefore, it allows to determine the thicknesses of unreinforced unpaved roads (without geosynthetic), with geotextile (woven geotextile), biaxial geogrid and geocell. Lastly, DACE® is a software that will help estimate the thickness of an unreinforced unpaved road (without geosynthetic), with geotextile (woven geotextile), biaxial geogrid and geocell, whenever the subgrades have a California Bearing Ratio of the sub-grade soil (CBRs) value equal to or less than 3% and a reliability value of 50%. In addition, it is possible to apply similar thicknesses in-situ of the specimens of the CBR and modified proctor tests.

Keywords: software, unpaved, road, design, CBR, unreinforced, woven geotextile, biaxial geogrid, geocell, DACE®.

1. INTRODUCTION

The problem studied is the design of unpaved roads, which is a topic that became important in the 70s with the project 3782-65 "thickness requirements for unsurfaced roads and airfields" of U.S. Army Engineer Waterways Experimental Station [1]. Currently, the semi empirical methods proposed by Giroud, Han and Pokharel in 2004 and 2015 [2] [3] [4] [5] [6] [7] are used.

The design of unpaved roads has evolved from conventional to special, distinguishing the calculation of thicknesses of compacted granular materials without geosynthetic reinforcement from the calculation with reinforcement, such as: woven geotextile, biaxial geogrid, and geocell [8]. Hence, the importance of estimating the design of the thicknesses using a calculation software [9] [10], since the current formulation is nonlinear. The DACE® software was developed for this task, which by its Spanish acronym means -Diseño de Afirmados Convencionales y Especiales DACE®-, which can be executed on a computer, tablet or smartphone, with internet access.

2. METHODS

2.1 Semiempirical methods.

The semiempirical methods are useful for the design of unpaved roads, it has been based on the concepts of bearing failure and an increase of bearing capacity by the use of geosynthetics [11] [12] [6]. Currently, a recent method for calculating the thickness of unpaved roads without reinforcement, with woven geotextile or with biaxial geogrid is shown in Equation (1), as proposed by Giroud and Han in 2004. Furthermore, for unpaved roads with geocell, Equation (2) is applied, which was developed in 2015 by Han and Pokharel, this equation was developed from the calibration of the Equation (1) [7].

Both formulations are used for a subgrade with a California Bearing Ratio of the sub-grade soil (CBR_s) equal to or less than 3%, and a reliability value of 50% [2] [3] [7]. Furthermore, the equations were estimated from the results of accelerated pavement testing of unpaved road sections and large-scale plate loading test in the geotechnical test box [13].

$$\frac{1}{a} = \frac{0.868+\left(0.661-1.006*J_a^2\right)*\left(\frac{a}{h_{base}}\right)^{1.5}*log(N_a)}{f_E} * \left[\sqrt{\frac{P}{\left(\frac{S}{f_{sl}}\right)*\left\{1-0.9*e^{\left[-\left(\frac{a}{h_{base}}\right)^2\right]}\right\}*N_c*Cu*\pi*a^2}} - 1\right] * \frac{1}{h_{base}} \quad (1)$$

$$\frac{1}{a} = \frac{0.868+0.52*\left(\frac{a}{h_{base}}\right)^{1.5}*log(N_a)}{f_E} * \left[\sqrt{\frac{P}{\left(\frac{S}{f_{sl}}\right)*\left\{1-0.9*e^{\left[-\left(\frac{a}{h_{base}}\right)^2\right]}\right\}*N_c*Cu*\pi*a^2}} - 1\right] * \frac{1}{h_{base}} \quad (2)$$

Where *Ja* is the aperture stability modulus of geogrid, which is obtained by means of the Standard Test Method for Determining the Aperture Stability Modulus of Geogrids of ASTM D7864 / D7864M - 15 [14], this value is often shown by the manufacturer in the product catalogues [15]. The undrained shear strength of subgrade (*cu*) can be estimated from the Unconfined Compression Test (UCT), from the Unconsolidated-Undrained Triaxial Compression Test, or from an empirical correlation based on the California Bearing Ratio of the sub-grade soil (CBR_s), as shown in Equation (3). *Nc* is the bearing capacity factor of the subgrade which varies according to the type of layer as shown in Table-1. The wheel load (*P*) is half an axle load. *Na* is the number of loading cycles, which is determined by means of traffic counts, converting it to reference axles as applied in the US [16] [17][18] [19] [20] or France [21], defined as the total applied load from an 80 KN or 130 KN single axle, respectively. *S* is the rut depth of the unpaved road. *fsl* is serviceability limit,75 mm as an example. *a* is the radius of the tire contact area which is obtained using Equation (4). h_{base} is the base thickness. f_E is modulus ratio factor obtained by means of Equation (5).

$$cu = 30 * CBR_s \quad (3)$$

$$a = \sqrt{\frac{P}{q_0 * \pi}} \quad (4)$$

q_0 is the tire pressure, which depends on the multiple factors associated to the vehicle characteristics, but in practice in the US, the Asphalt Institute and the AASHTO defined a value, according to these associations, the tire pressure has a value of 493 KPa and 750 KPa [17], respectively. On the other hand, in France, the tire pressure has a value of 662 KPa [21].

Table-1. Bearing capacity factor of the subgrade.

Nc	Condition	Source
3.14	Failure of the subgrade (unreinforced)	[12]
5.14	Failure of the subgrade (geotextile-reinforced roads)	[12]
5.71	Failure of the subgrade (geogrid-reinforced road)	[2] [3]

$$f_E = 1 + 0.204 * (R_E - 1) \quad (5)$$

Where R_E is the modulus ratio of base course to subgrade, which depends on the base course resilient modulus (E_b) and the subgrade resilient modulus (E_s), as shown in Equations (6) and (7).

$$R_E = \frac{E_b}{E_s} = \frac{3.48 * CBR_b^{0.3}}{CBR_s} < 5 \quad (6)$$

$$R_E = MIF * \frac{E_b}{E_s} = MIF * \frac{3.48 * CBR_b^{0.3}}{CBR_s} \leq 7.6 \quad (7)$$

Equation (6) is used for unreinforced unpaved roads, with a woven geotextile, or with a biaxial geogrid. Equation (7) is for unpaved roads with geocell, which is adjusted by means of a Modulus Improvement Factor (MIF), which can have a value of 2. The California Bearing Ratio of the sub-grade soil (CBR_s) and California Bearing Ratio of the base course (CBR_b) [22] can be determined by means of the Standard Test Method for California Bearing Ratio (*CBR*) of Laboratory-Compacted Soils, in accordance with ASTM D1883 - 16 [23]. Lastly, the base course resilient modulus (E_b) and the subgrade resilient modulus (E_s) can be determined by the Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials, in accordance with AASHTO T 307-99 [24].

2.2 DACE®

DACE® is an application developed in Hypertext Pre-processor (Php) programming language. This application is capable to design unpaved roads sections without geosynthetic, with a woven geotextile, with a punch-drawn polypropylene biaxial geogrid, or with a geocell, using semiempirical methods proposed by Giroud, Han and Pokharel in 2004 and 2015.

It has two shared interfaces: 1. A pre-processor and 2. A postprocessor. The first mentioned has data such as Subgrade California Bearing Ratio (CBRs), Axle load of the trucks in kN, Tire Pressure (q_0) in kPa, Allowable Rut Depth (S) in mm and Number of Passes of trucks with single axles (Na). Furthermore, it holds two options for the torsional rigidity (Biaxial Geogrid) value, 0.32 N*m/deg and 0.65 N*m/deg. The pre-processor of DACE® in English and Spanish for computer and smartphone are shown in Figures 1, 2, 3 and 4. The second mentioned a postprocessor, holds the answers of the design of the unpaved road, such as theoretical thickness and construction thickness for an unpaved road section without geosynthetic, with a woven geotextile, with a punch-drawn polypropylene biaxial geogrid, or with a geocell.

The construction thickness is needed for quality control in situ, it is recommended to use 10 cm as a minimum construction thickness for an unpaved road section without geosynthetic, with a woven geotextile or with a punch-drawn polypropylene biaxial geogrid. On the other hand, it is recommended to use 22cm as a minimum construction thickness for an unpaved road section with geocell, whenever the geocell reinforcement has a thickness of 12 cm. These standards are used in the CBR and modified proctor tests, since the specimens are similar, both have thickness of 10 cm [23] [25].

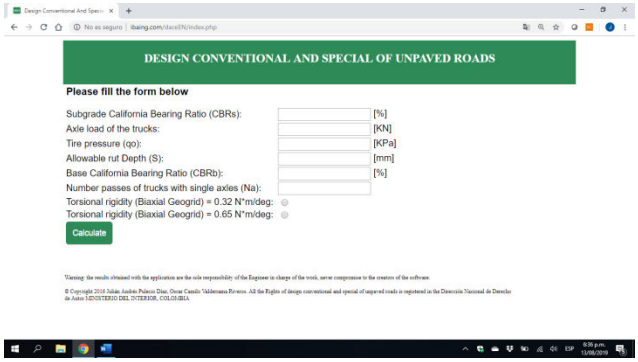

Figure-1. Preprocessor of DACE® in English for computer.

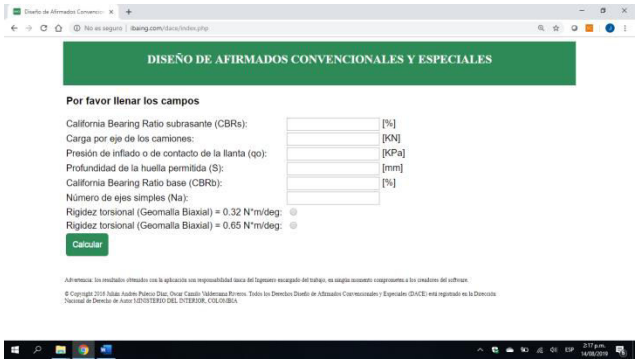

Figure-2. Preprocessor of DACE® in Spanish for computer.

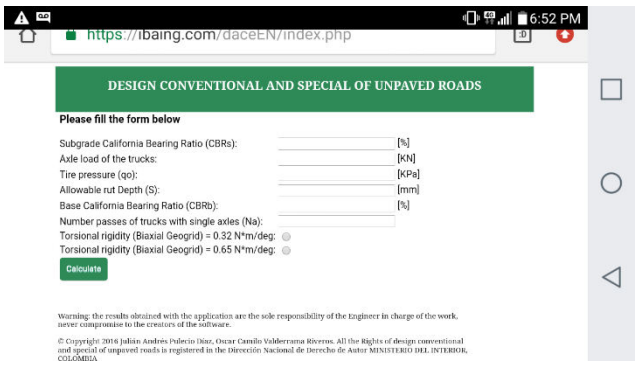

Figure-3. Preprocessor of DACE® in English for smartphone.

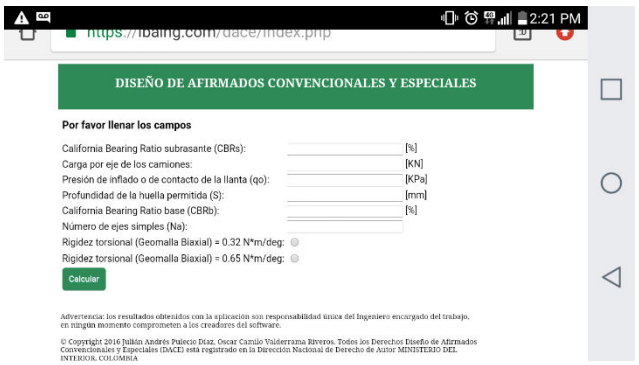

Figure-4. Preprocessor of DACE® in Spanish for smartphone.

Currently, DACE® can be accessed on Internet by typing the URL ibaing.com/daceEN/index.php for English, or ibaing.com/dace/index.php for Spanish. Contact daceengineering@gmail.com for further information.

2.3 Using DACE®

In order to validate the results of DACE®, an exercise proposed by Han and Pokharel in 2015 [6] [7] is solved.

An unpaved haul road needs to be designed for 1000 passes of trucks with single axles (the front axle is ignored due to light load). The axle load of the trucks used on this site is 72 kN and the tire pressure is 552 kPa. The clayey subgrade CBR_s is 1.5% and the base CBR_b is 20%. The allowable rut depth is 75 mm. Design this unpaved road section without geosynthetic, with a geotextile, and punch-drawn polypropylene geogrid (Ja = 0.32 N*m/deg) using the Giroud and Han method [6].

3. RESULTS AND DISCUSSIONS

Table-2 shows the results of the exercise proposed by Han and Pokharel in 2015, which was used for validation, and the results obtained using DACE®. The thicknesses found using DACE® are equal to the solution by Han and Pokharel in 2015, which demonstrates that DACE® is accurate. The results of DACE® are shown in Figures 5, 6, 7 and 8, both in Spanish and English, for computer and smartphone.

Table-2. Validation of results- DACE®.

Pavement	Theoretical thickness		Variation [%]
	Han and Pokharel, 2015	DACE®	
Unreinforced	33.22 cm	33.21 cm	0.03 %
With Geotextile	21.15 cm	21.14 cm	0.04 %
With biaxial geogrid	16.34 cm	16.33 cm	0.06 %

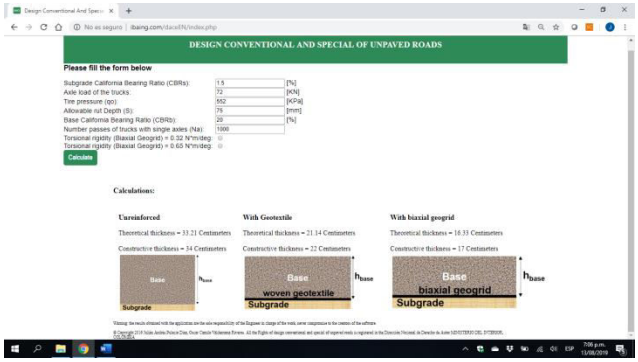

Figure-5. Post processor of DACE® in English for computer.

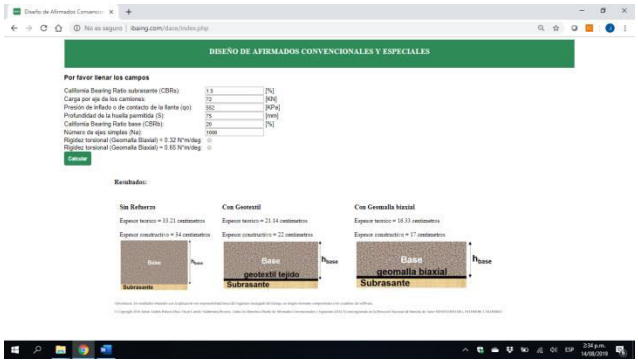

Figure-6. Post processor of DACE® in Spanish for computer.

DACE® generates the results of the construction thicknesses for unreinforced unpaved roads (without geosynthetic), with geotextile (woven geotextile), with biaxial geogrid or geocell. Table-3 shows the results of construction thicknesses found using DACE®.

The thicknesses values depend on the height of the specimens of the CBR and Modified Proctor tests, therefore, if the thickness found using DACE® is greater than the thickness in the tests, an in-situ compaction of more layers is needed.

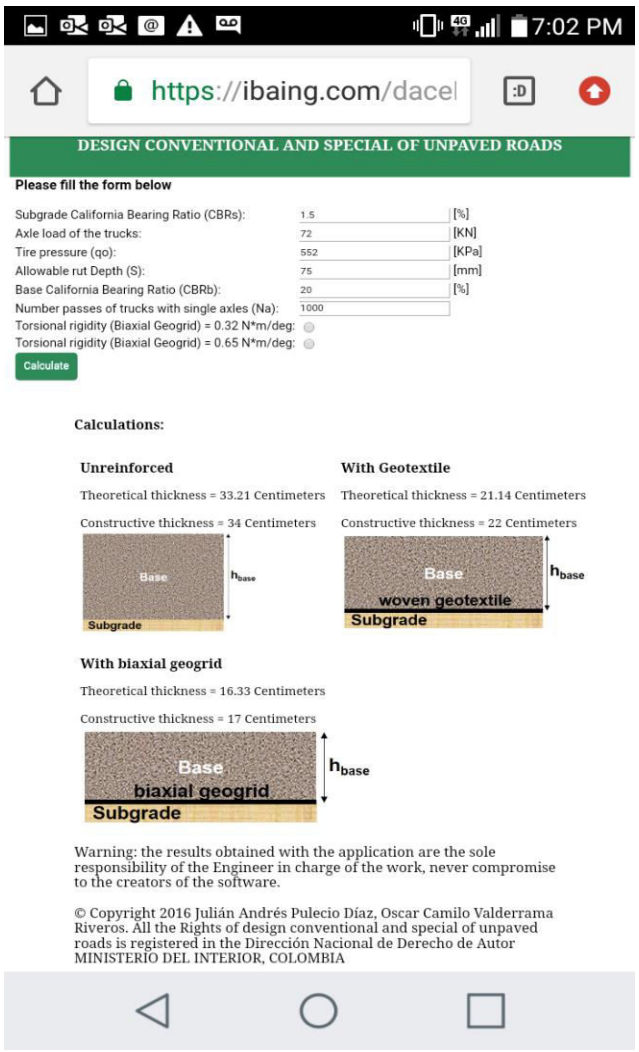

Figure-7. Post processor of DACE® in English for smartphone.

Table-3. Construction thicknesses - DACE®.

Pavement	Construction thicknesses
Unreinforced	34 cm
With Geotextile	22 cm
With biaxial geogrid	17 cm

Lastly, the performance of the thickness should be evaluated in-situ with advanced equipment such as the Light Weight Deflectometer (LWD), or Falling Weight Deflectometer (FWD). Further information about these tests can be found in the ASTM E2583 - 07 [26] and ASTM D4694 - 09 [27] standards.

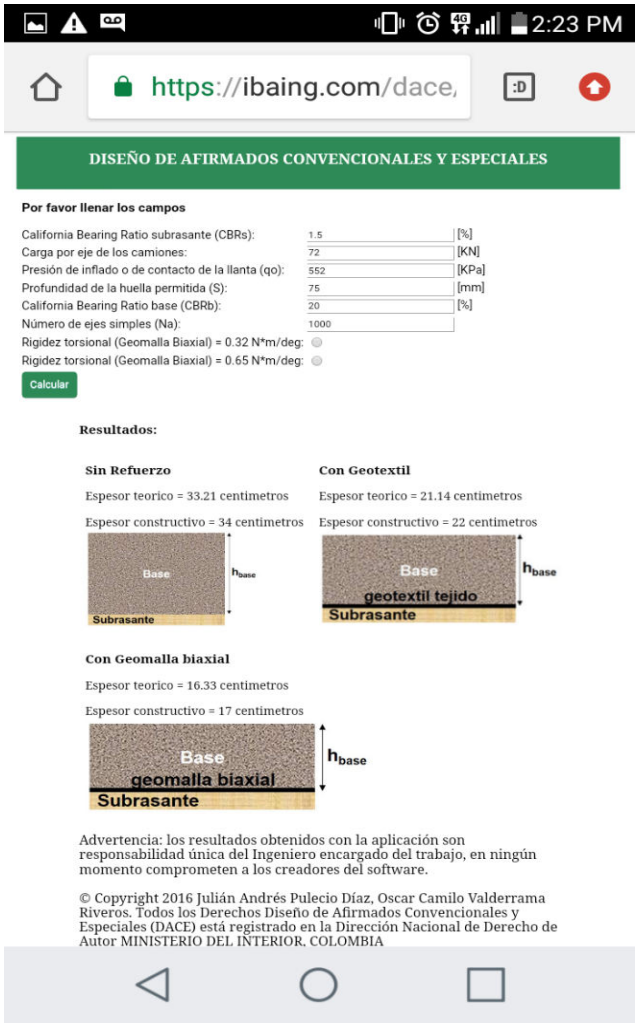

Figure-8. Post processor of DACE® in Spanish for smartphone.

4. CONCLUSIONS

- The use of the Hypertext Preprocessor (Php) programming language, applied in order to develop DACE®, allows it to be cross-platform software since it is a web application; therefore, it works in all operating systems.
- The results obtained using DACE® were satisfactorily validated with the exercise proposed by Han and Pokharel in 2015, therefore, it allows to determine the thicknesses for unreinforced unpaved roads (without geosynthetic), with geotextile (woven geotextile), biaxial geogrid and geocell.
- DACE® is a software that helps to estimate the thickness of unreinforced unpaved roads (without geosynthetic), with geotextile (woven geotextile), with biaxial geogrid and geocell, whenever the subgrades have a California Bearing Ratio of the sub-grade soil (CBRs) value equal to or less than 3% and a reliability value of 50%. In addition, it is possible to apply similar thicknesses in-situ of the specimens of the CBR and modified proctor tests.

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