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Evaluation of the Impact of Truck Overloading on Flexible Compacted Gravel Lateritic Soil's Pavements by FEM with Cast3M©

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Abstract

Within the framework of a FEM of the nonlinear behavior of lateritic pavement of Senegal, the effect of truck overloading is studied to estimate its impact on the deformability of road pavement on compacted gravel lateritic soils. For that purpose, various loading conditions were tested to measure the impact on the critical response parameters of road pavement design. The implementation of the models was realized with Cast3M©. This study allowed us to point out that the observed variations are linear and would help to plan in advance the impact of axle overloads for a better evaluation within the framework of the mechanistic (M. E.) design of pavements.

Keywords

FEM, Axle Overload, Nonlinear Behavior, Gravel Lateritic Soil

1. Introduction

The regulation number 14/2005/*CM*/*UEMOA* of WAEMU (*West African Economic and Monetary Union*) of December 16th, 2005 concerning the harmonization of standards and control procedures of truck volumes, weights and axle loads of heavy goods vehicles in the member states of the Union, set the axle load to 12 tons for a single axle with dual-wheels (Uemoa, 2005 [1]). However, recent studies showed that this recommended official load is far from being respected. Indeed, 60% - 70% of heavy trucks are overloaded and have significant

contribution in the degradation of roads. The objective of this study is to determine the critical response parameters of lateritic roads materials submitted to various conditions of axle overload. The standard axle load is 130 kN (13 tons) for a single axle with dual-wheels (Bceom-Cebtp, 1984 [2]). The reference load is uniformly distributed on two circles whose centers are from 37.5 cm away from each other. The calculation of the stresses and the strains is done for a typical load of 6.5 tons exercising a vertical pressure q uniformly distributed on two circles with: $a = 12.5$ cm; $l = 3 \times a = 37.5$ cm and $q = 6.62$ bars. The reference load for the calculations is represented by the **Figure 1**.

The reference axle is varied from 13 to 20 tons to take into account the overloading. The effect of a single wheel is tested with a tire pressure of 0.662 MPa for the load of 13 tons and respectively 0.764 MPa, 0.917 MPa and 1.019 MPa respectively for axle loads of the 15, 18 and 20 tons (Samb, 2014 [3]).

2. Geometry, Materials and Algorithm of Calculations

The structure consists of a 80 mm thick bituminous concrete, a 200 mm thick base layer of lateritic gravels treated or not, a 250 mm thick subbase of untreated lateritic gravels and of a sandy subgrade of infinite thickness. The materials of the asphalt and subgrade layer are considered linear elastic. The base and the subbase has a nonlinear elastic behavior. To take into account this non-linearity, the elastic modulus is replaced by a resilient modulus which depends on the stress level. Several formulations were suggested by using various terms of stresses (Lekarp, Isacsson, and Dawson, 2000 [4]; Kim, 2007 [5]) and showed that the models proposed by Uzan (1985) [6] and the NCHRP (2004) [7] allow to take into account the behavior of granular soils as well as fine soils. Triaxial test results on the gravel lateritic soils of Ngoundiane showed that Uzan model give the best correlations and so, the model parameters was determined for these soils.

The Uzan model expresses the resilient modulus according to the bulk stress and the deviatoric stress, which allows us to take into account the effect of the shear behavior:

$$M_r = k_1 \left(\frac{\theta}{p_a} \right)^{k_2} \left(\frac{\sigma_d}{p_a} \right)^{k_3} \tag{1}$$

with,

$\theta = (\sigma_1 + 2\sigma_3) = (\sigma_d + 3\sigma_3)$ = bulk stress;

$\sigma_d = \sigma_1 - \sigma_3$ = deviatoric stress;

k_1, k_2 and k_3: model parameters.

For the Young modulus, the maximal values of the unconfined compression tests are chosen, by considering that the gravel lateritic soils are perfectly compacted in 95% of the Optimum Modified Proctor (OMP). For the asphalt layer and the subgrade (Young modulus (E) and Poisson's ratio (v)), these values are chosen in reference to Fall, Senghor and Lakhoune (2002) [8]. The materials parameters are given in **Table 1**. The horizontal movements are blocked in the transverse directions (*flexible boundary*) and the vertical and horizontal movements are blocked in the bottom of the subgrade (*stiff boundary*).

For nonlinear analysis, an incremental iterative procedure is used, the tangent constitutive matrix is updated after and during each load increment (NCHRP, 2004). For this implementation, a direct incremental method of the resilient modulus with very small time steps is used. A first test showed that, for the linear method, 24 time-steps were sufficient to reach a constant result. Besides, for the nonlinear model, the tests showed that the

q = 6.62 bars
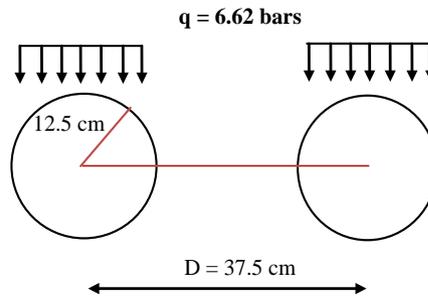
Figure 1. Schematization of the loading.

results vary very widely according to the compulsory number of steps. From 300 steps, the values stabilize, which explains that the value of the number of steps *n* was set to these aforesaid values. For every interval of load, the resilient modulus is given with the average of the values found for two successive stages. This algorithm is summarized in **Figure 2**.

Table 1. Characteristics of the axisymmetric linear and nonlinear models for the lateritic gravel soils of Ngoundiane (Samb, 2014 [3]).

Pavement layers	Thickness	Linear model		Nonlinear model		
	h_i (mm)	v	E (MPa)	k_1 (kPa)	k_2	k_3
Asphalt	80	0.35	1.300	-	-	-
Base (*untreated*)	200	0.25	62	837.275	0.13	−0.33
Base 2%	200	0.25	84	279.074	0.65	−0.50
Base 3%	200	0.25	137	170.052	0.88	−0.56
Subbase (*untreated*)	250	0.25	62	837.276	0.13	−0.33
Subgrade	17.500	0.25	30	-	-	-
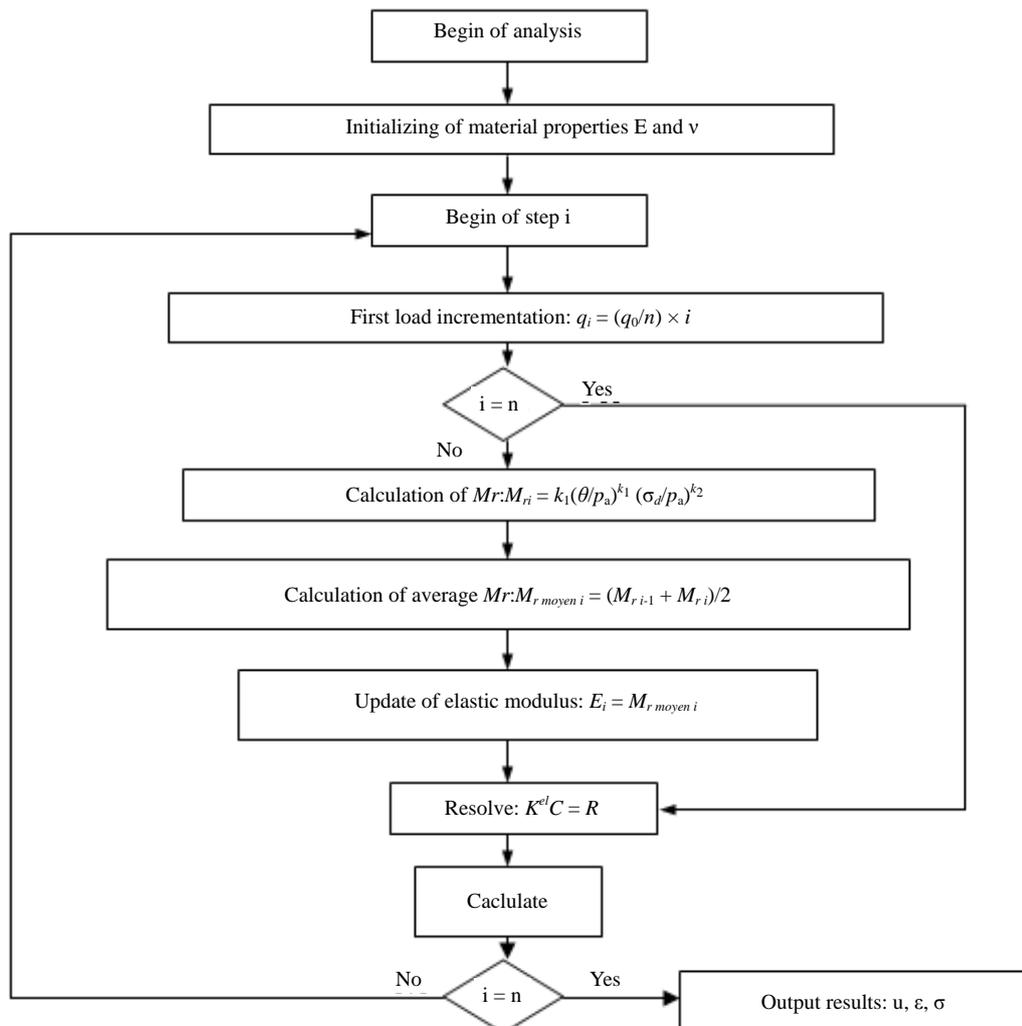
Figure 2. Calculation algorithm used in Cast3M© (Samb, 2014 [3]).

Impact of Overloading on the Deflection and the Vertical Strain of the Subgrade

The effect of overloading was studied with regard to the normalized axle load of calculation (13 tons). **Figure 3(a)** and **Figure 3(b)** and **Figure 4(a)** and **Figure 4(b)** give the variation of deflections and strains for the linear and nonlinear models. The results show a linear variation of the axle overload for both models. This proves that it is possible to know in advance the impact of the axle overload on deflections and strains of the pavement layers. We notice that the values of strains and deflections decrease according to the depth. Indeed, the values noticed at the subgrade are lower than those noticed for the other layers.

On the other hand, the impact of the axle overload seems to have more effect on deflection at the top layers (asphalt layer and base layer) than for the lower layers. It is necessary to note that the effect of a single wheel was tested. To know the total deflection and strain, it is necessary to take into account the effect of the dual-wheels. Besides, the variation of deflection and deformation for a variation of the axle overload of 1, 2, 3, 5 and 10 tons is given for the linear model (**Table 2**). These results show the possibilities of forecasting the response parameters values by analyzing loading scenarios. For a calculated estimation, **Table 3** gives a comparison of
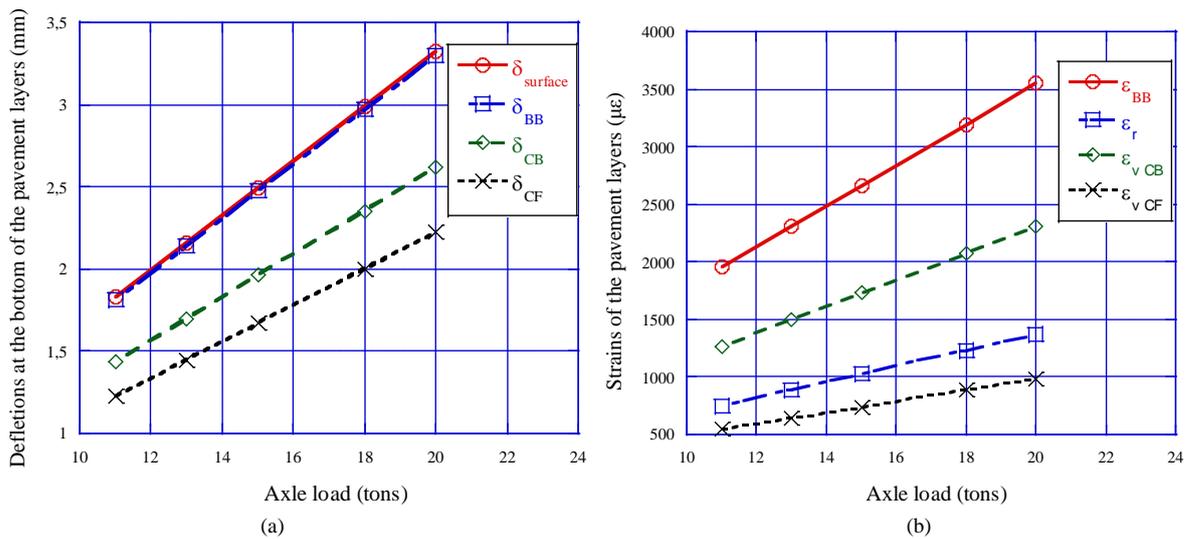
Figure 3. Variation of deflections and strains of the pavement layers (in absolute value) of the load for the 2D linear model: (a) Deflections; (b) Strains (Samb, 2014 [3]).
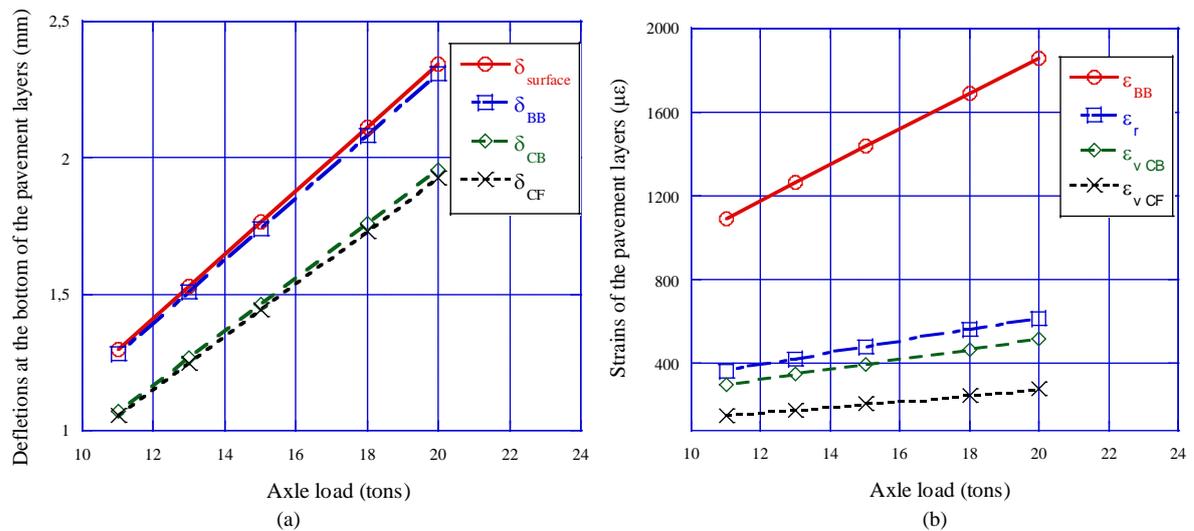
Figure 4. Variation of deflections and strains of the pavement layers (in absolute value) of the load for the 2D nonlinear model: (a) Deflections; (b) Strains (Samb, 2014 [3]).

Table 2. Deflections and deformations caused by the pressure of a tire by tons of axle overload for the linear model and for respectively: 2, 3, 5 and 10 tons (Samb, 2014 [3]).

Deflections		Deflections according to the axle overload (mm)			
	Per tons (mm)	2 tons	3 tons	5 tons	10 tons
δ_{surface}	−0.04877	−0.09754	−0.14631	−0.24385	−0.4877
δ_{BB}	−0.04877	−0.09754	−0.14631	−0.24385	−0.4877
δ_{CB}	−0.0227465	−0.045493	−0.0682395	−0.1137325	−0.227465
δ_{CF}	−0.008193	−0.016386	−0.024579	−0.040965	−0.08193
Deformations		**Deformations according to the axle overload ($\mu\varepsilon$)**			
	Per tons ($\mu\varepsilon$)	2 tons	3 tons	5 tons	10 tons
ε_{BB}	−137.42	−274.84	−412.26	−687.1	−1374.2
ε_{r}	56.0705	112.141	168.2115	280.3525	560.705
ε_{CB}	−81.526	−163.052	−244.578	−407.63	−815.26
ε_{CF}	−27.518	−55.036	−82.554	−137.59	−275.18

Notations: BB: asphalt layer; CB: base layer; CF: subbase layer.

Table 3. Variation of the critical response due to the pressure of a tire by tons of road overload (Samb, 2014 [3]).

	Variation per tons of overload	
	2D Linear	2D Nonlinear
δ_{surface} (mm)	−0.166	−0.116
δ_{BB} (mm)	−0.165	−0.115
δ_{CB} (mm)	−0.131	−0.098
δ_{CF} (mm)	−0.111	−0.097
ε_{vBB} ($\mu\varepsilon$)	−177.370	−87.685
ε_{r} ($\mu\varepsilon$)	68.291	28.778
ε_{vCB} ($\mu\varepsilon$)	−115.200	−24.440
ε_{vCF} ($\mu\varepsilon$)	−49.345	−14.245
σ_{r} (MPa)	0.065	0.019
σ_{CB} (MPa)	−0.008	−0.013
σ_{CF} (MPa)	−0.002	−0.001

the variation of deflections and strains for the linear and nonlinear models by tons of axle overload. We can thus notice that the linear model gives higher strain and deflection variations and lower stress variations than for the nonlinear model.

3. Conclusion

The results show a linear variation of deflections and deformations at the road layers according to the variation of the axle overload. This overload seems to have more effects on deflections for the top layers level (asphalt layer and base layer) than the lower layers. It is however necessary to note that the effect of a single wheel is tested. To know total deflections and deformations, it is necessary to take into account the dual tires. These results reveal the possibility of obtaining the response values of roads by analyzing real scenarios of load as well as forecasting the impact of the axle overload on deflections and deformations of road pavements.

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