

Impact of Multi-Axle Wheelbases on Longitudinal and Transverse Deformations at the Bottom of Bituminous Pavement Layers

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Received February 10, 2024; Revised March 12, 2024; Accepted March 19, 2024

Abstract The multiplication of heavy vehicle axles is a growing phenomenon in the WAEMU (West African Economic and Monetary Union) community. The wheelbases of these new axle configurations differ from one vehicle to another. This article evaluates the impact of axle wheelbases on longitudinal and transverse deformations at the bottom of the road surface and the base layer of a roadway. To achieve this, models of the pavement structure and different axle configurations were made using ALIZE LCPC 2.3.1 software. The results obtained at the end of the numerical simulation show that the maximum deformations under stress of the wide and isolated wheels are greater than those of the twin wheels. Longitudinal deformations in contraction and extension at the bottom of the asphalt concrete (BB) road surface and the gravel bitumen (GB) base layer vary slightly depending on the wheelbases of the dual or insulated wheel axles. This variation is due to the superposition of the contraction and extension deformations of the successive wheels. As for transverse deformations, they are strongly influenced by axle wheelbases. These transverse deformations, at the bottom of the road surface, decrease during contraction and increase during extension when the axle wheelbase increases. But at the bottom of the base layer, they increase during the contraction cycle and remain almost invariable in an extension phase with the evolution of wheelbases. During the study, it was also found that the addition of axles impacts the peaks of the different deformations.

Keywords: Wheelbases, transverse deformations, longitudinal deformations, contraction, extension

Cite This Article: Kokoro Kobori, Doua Allain Gnabahou, B. Kossi Imbga, and Vincent Sambou, "Impact of Multi-Axle Wheelbases on Longitudinal and Transverse Deformations at the Bottom of Bituminous Pavement Layers." *American Journal of Materials Science and Engineering*, vol. 12, no. 1 (2024): 13-24. doi: 10.12691/ajmse-12-1-2.

1. Introduction

Roads are the main highway of the national economy. In particular, it promotes the development of trade and facilitates the movement of people [1]. In recent years, the increasing flow of goods has led to the emergence of several types of heavy vehicles on the WAEMU (West African Economic and Monetary Union) road network [2], [3]. Although the gauge, weight, and axle load of heavy vehicles are governed by WAEMU Regulation 14 [4], it is clear that the phenomenon of silhouette modifications continues and is growing.

These new types of heavy duty vehicles (HGV) are characterized by the multiplication of their rear axles with variable wheelbases [3]. The repeated passage of these multi-axle vehicles through pavements leads to progressive degradation of structures and/or materials [5,6].

Damage to pavement structures is mainly caused by fatigue of the material due to the repeated passage of heavy vehicles [7]. Given the increased demands

generated by these vehicles, it is necessary to question the ability of roads to support such loads over the long term. It therefore appears necessary to carry out more in-depth studies on the mechanical stresses generated by the multi-axle HGV circulation.

This article deals with the longitudinal and transverse deformations induced by these multi-axles on bituminous pavement.

The aim is to evaluate these deformations due to variable axle wheelbases, also considering the increase in the number of axles, at the bottom of the road surface and the base layer of the bituminous structure.

The problem of axle wheelbases in deformations has been addressed by several authors. However, most of these existing studies in the literature have been limited to the evaluation of deformations in tandem and tridem and generally at the bottom of a single layer. These studies are also conducted in the majority cases with two wheelbase variables. This is the case, for example, of Zoa AMBASSA [5] who worked on a tridem axle with wheelbases of 1.35 and 1.62 m and F. HOMSI [7] who also carried out a study in tandem with wheelbases of 1.4

and 2.8 m. These two authors evaluated the deformations only at the base of the GB3 layer. This work simultaneously evaluates these deformations on the road surface and the base layer with wheelbases of three to four variables and is carried out on several groups of axles ranging from tridem to 6-axles. It will allow you to fully appreciate the influence of the wheelbases on the deformations of all the bituminous layers and the impact of axle multiplication on these deformations.

To carry out this study, the manuscript is structured as follows. Following this Section 1, the material and methodology will be described in Section 2, followed by the analysis of the results and the discussion in Section 3. Section 4 is devoted to the conclusion.

2. Materials and Methodology

2.1. Material

The pavement structure chosen to simulate is a structure composed of a bituminous concrete coating, a gravel bitumen base layer, a crushed enhanced lateritic gravelly foundation layer and a lateritic gravelly shape layer, all resting on a PF3 type support platform. The test structure is shown in Figure 1. The characteristics of these layers are recorded in Table 1.

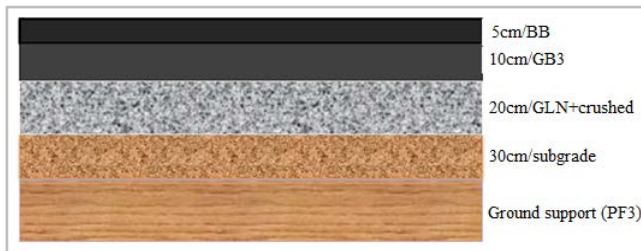


Figure 1. Test structure

Table 1. Characteristic of the materials of the structure tested

Layer	Thickness (cm)	Modulus (MPa)	Poisson's ratio coefficient
Rollover: BBSG	5	1300(30°C)	0.35
Base: GB3	12	2700 (30°C)	0.35
Foundation: GLAC	20	700	0.35
Shape layer	30	200	0.35
Floor support (PF3)	Infinite	120	0.35

This structure is assumed to have a homogeneous and isotropic linear elastic behavior with standard parameters for all of its materials. This behavioral hypothesis is used by several authors [8,9,10].

The axle types chosen for this work are tandems or 3-axles, 4-axles, 5-axles and 6-axles. These axles can be dual wheels or insulated with wide tires. The different applied loads are shown in Table 2 below. The charges applied are those authorized by the Burkina Faso National Road Safety Office (NRSO) according to the WAEMU space communiqué of the Ministers of Transport of 21 October 2022 [11].

The wheel-road contact area is considered circular with a radius equal to 0.125 m for dual wheels and 0.14625 m

for wide and insulated wheels commonly known as super single tires (Figure 2) [12,13,14].

Table 2. Loading of different axle groups

Axle	Axle load (T)	Total load (T)
Tridem	11.33	34
Quad	10.75	43
Quint	11	66
Six	11	55

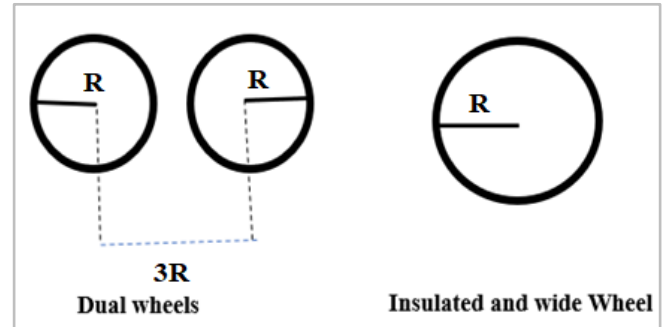


Figure 2. Dual wheels and insulated wheel

The tool used for pavement modeling and axle loading is the ALIZE LCPC version 2.3.1 software. Since all the axles under study have symmetry on the longitudinal axis, modeling is done on half axles.

2.2. Methodology

The methodology consists of making a mesh of the tested pavement structure. This mesh is illustrated in Figure 3 and all simulations were performed under the same climatic conditions [15].

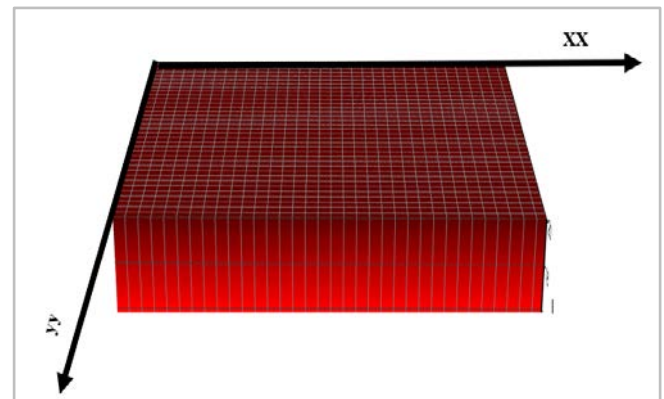


Figure 3. Mesh of the tested pavement structure

Calculating deformations, which is traditionally carried out considering isotropic linear elastic multilayers with static loading, first requires in the first place knowledge of Young's moduli and also Poisson's ratio coefficients of the different materials that make up the pavement [16,17,18]. It is precisely from these two parameters that the Burmister ALIZE software based on the model (1943) allows the solution of the problem considered linear elastic and isotropic [17,19,20]. These parameters are recorded in Table 1.

The Burmister model implemented in the ALIZE software is represented by Equation 1.

$$\phi_i = pa \int_0^\infty \frac{J_0(mr) J_1(ma)}{m} \left[A_i e^{mz} - B_i e^{-mz} + Z C_i e^{mz} - Z D_i e^{-mz} \right] dm \quad (1)$$

It is from this equation that the results for stresses and displacements are drawn.

Equations 2, 3 and 4 show the normal stresses.

$$\sigma_z = pa \int_0^\infty J_0(mr) J_1(ma) \left[A_i m^2 e^{mz} + B_i m^2 e^{-mz} - C_i m(1 - 2\nu_i + mz) e^{mz} + D_i m(1 - 2\nu_i - mz) e^{-mz} \right] dm \quad (2)$$

$$\sigma_r = -pa \int_0^\infty J_0(mr) J_1(ma) \left[A_i m^2 e^{mz} + B_i m^2 e^{-mz} + C_i m(1 - 2\nu_i + mz) e^{mz} - D_i m(1 - 2\nu_i - mz) e^{-mz} \right] dm$$

$$pa \int_0^\infty \frac{J_0(mr) J_1(ma)}{m} \left[A_i m^2 e^{mz} + B_i m^2 e^{-mz} + C_i m(1 + mz) e^{mz} - D_i m(1 - mz) e^{-mz} \right] dm \quad (3)$$

$$\sigma_\theta = -pa \int_0^\infty J_0(mr) J_1(ma) \left[C_i m e^{mz} - D_i m e^{-mz} \right] 2\nu_i dm$$

$$+ pa \int_0^\infty \frac{J_1(mr) J_1(ma)}{m} \left[A_i m^2 e^{mz} - B_i m^2 e^{-mz} + C_i m(1 + mz) e^{mz} - D_i m(1 - mz) e^{-mz} \right] dm \quad (4)$$

Equation 5 shows the tangential stresses.

$$\tau_{rz} = -pa \int_0^\infty J_1(mr) J_1(ma) \left[A_i m^2 e^{mz} - B_i m^2 e^{-mz} + C_i m(2\nu_i + mz) e^{mz} + D_i m(2\nu_i - mz) e^{-mz} \right] dm \quad (5)$$

Equations 6 and 7 show vertical displacements.

$$w = \frac{1 + \nu_i}{E_i} pa \int_0^\infty \frac{J_0(mr) J_1(ma)}{m} \left[A_i m^2 e^{mz} - B_i m^2 e^{-mz} + Z C_i m(2 - 4\nu_i - mz) e^{mz} - Z D_i m(2 - 4\nu_i - mz) e^{-mz} \right] dm \quad (6)$$

$$\mu = \frac{1 + \nu_i}{E_i} pa \int_0^\infty \frac{J_1(mr) J_1(ma)}{mr} \left[A_i m^2 e^{mz} + B_i m^2 e^{-mz} + C_i m(1 + mz) e^{mz} - D_i m(1 - mz) e^{-mz} \right] dm \quad (7)$$

Equation (8) transfers the stresses from the cylindrical frame (r, θ , z) to the Cartesian frame (x, y, z).

$$\begin{pmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \end{pmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} \sigma_r \\ \sigma_\theta \\ \sigma_{zz} \end{pmatrix} \quad (8)$$

Using Hooke's law, in linear and isotropic elasticity, Equation 9 yields deformations from stresses [19], [20].

$$\begin{pmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \end{pmatrix} = \left(\frac{1}{E} \right) \begin{bmatrix} 1 - \nu - \nu \\ -\nu & 1 - \nu \\ -\nu & -\nu & 1 \end{bmatrix} \begin{pmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \end{pmatrix} \quad (9)$$

a: Radius of circular loading surface (m)

p: Charge pressure (evenly distributed) (MPa)

r: Radial distance in cylindrical cordata (m)

Z: Depth(m)

σ_z : Vertical stress (MPa)

σ_r : Radial stress (MPa)

σ_θ : Circumferential stress (MPa)

σ_x : Longitudinal stress (MPa)

σ_y : Transverse stress (MPa)

ε_x : Longitudinal deformations (μdef)

ε_y : Transverse deformations (μdef)

ε_z : Vertical deformations (μdef)

τ_{rz} :

Vertical shear stress (MPa)

W: Vertical displacement (m)

u: Radial displacement (m)

E_i : Young's modulus of the i-th layer (MPa)

ν_i : Poisson ratio coefficient of the the i-th layer (-)

A_i, B_i, C_i, D_i : Unknown parameters, determined by boundary conditions (-)

J_0 : Bessel function of the first kind of order 0 (-)

J_1 : Bessel function of the first kind of order 1 (-)

m: Integration parameter (-)

The mechanical loads considered for the simulation come from multiple axle loads. The axles considered in this study are the tridems, 4-axles, 5-axles and 6-axles commonly encountered in the road network.

The loads applied to the various axles with twin or single wheels are those defined in WAEMU Regulation 14 and according to the Minister of Transport recommendations dated October 21, 2022 on the tolerance of road overloads [11].

Figure 4 shows the modeling of a tridem with dual wheels (Figure 4. a) and wide and isolated wheels (Figure 4. b).

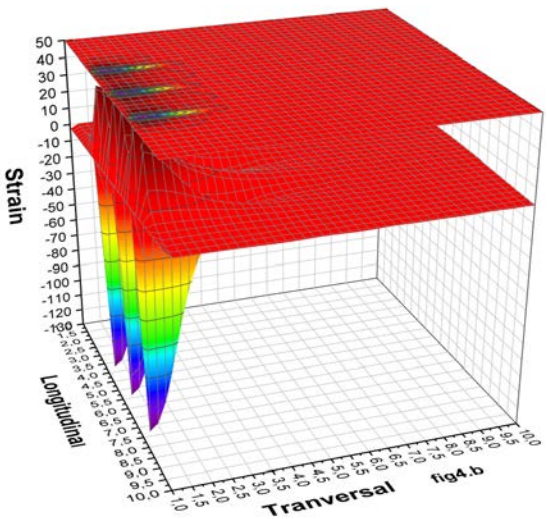
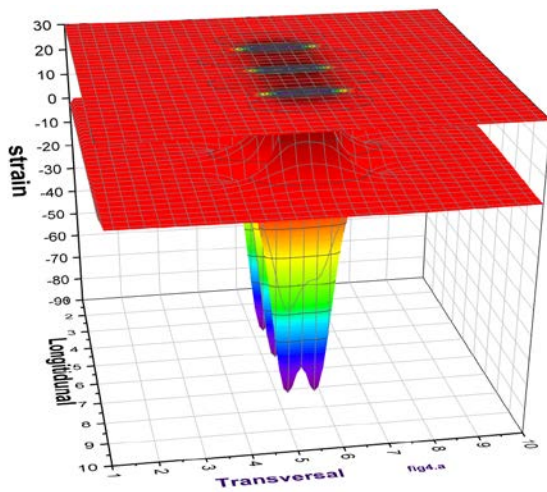


Figure 4. Tridem modeling: a) dual wheel; b) insulated and wide wheel

Figure 5 shows the modeling of a four-axle with dual wheel (Figure 5.a) and wide and isolated wheel (Figure 5.b).

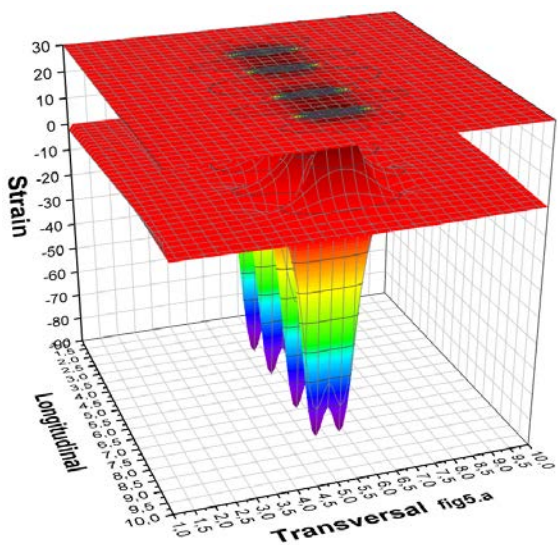


Figure 5. 4-axle modeling: a) dual wheel; b) insulated and wide wheel

Figure 6 shows the modeling of a 5-axle with dual wheels (Figure 6. a) and wide and isolated wheels (Figure 6.b).

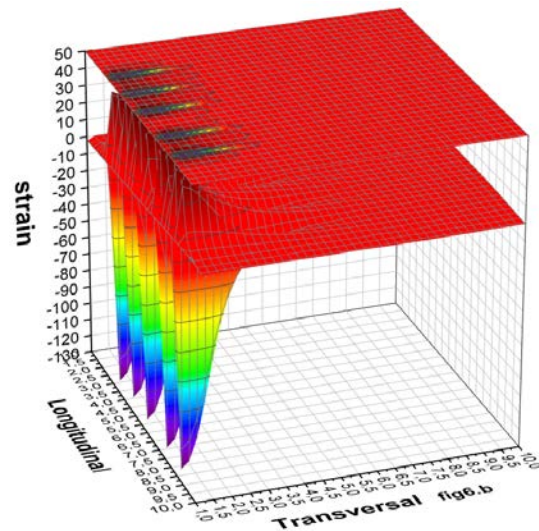
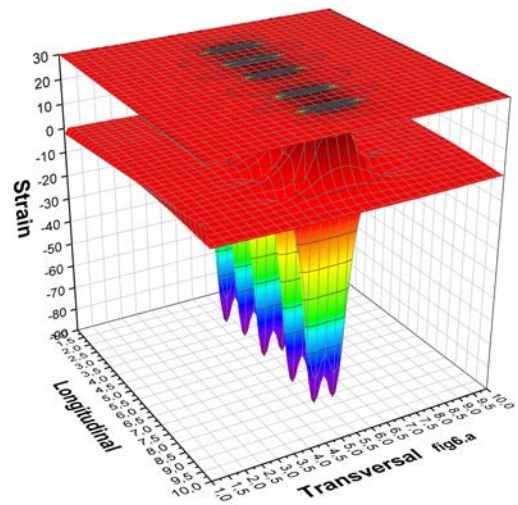
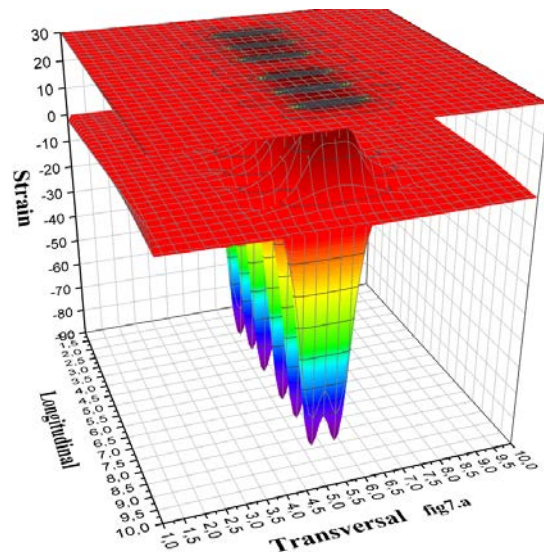


Figure 6. 5-axle modeling: a) dual wheel; b) insulated and wide wheel

Figure 7 shows the modeling of a 5-axle with dual wheels (Figure 7. a) and wide and isolated wheels (Figure 7.b).



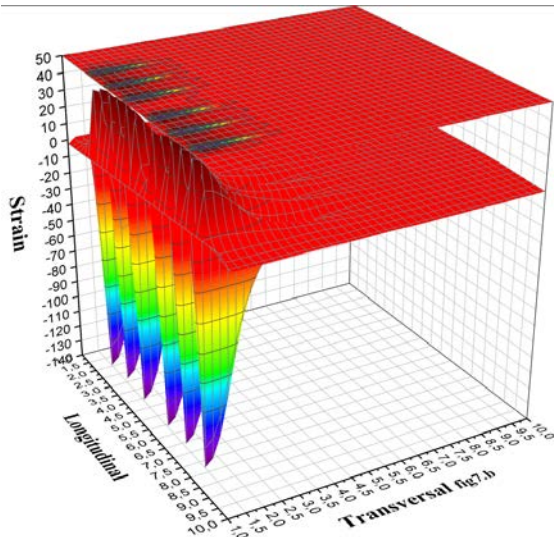


Figure 7. Tridem modeling: a) dual wheel; b) insulated and wide wheel

For each group of axles, the wheelbase must be varied and transverse and longitudinal deformations must be studied. These deformations are calculated at the bottom of the bituminous concrete (BB) layer and at the bottom of the gravel bitumen (GB) seam. The different wheelbases used in this manuscript are those commonly encountered in the road network of the WAEMU community space. It is also a question of determining the impact of the increase in the axles on these deformations.

3. Results and Discussions

When designing or rehabilitating a roadway, the parameters of longitudinal and transverse deformations in maximum contraction or extension at the base of the pavement or in the base layer of bituminous materials shall be taken into account in the rational design method [22,23]. It should be noted that the maximum values of these calculated deformations are always lower than the deformations allowed for a given traffic [18,24].

3.1. Effect of Wheelbase on Longitudinal Deformations

3.1.1. Longitudinal Deformations on Asphalt Concrete (BB)

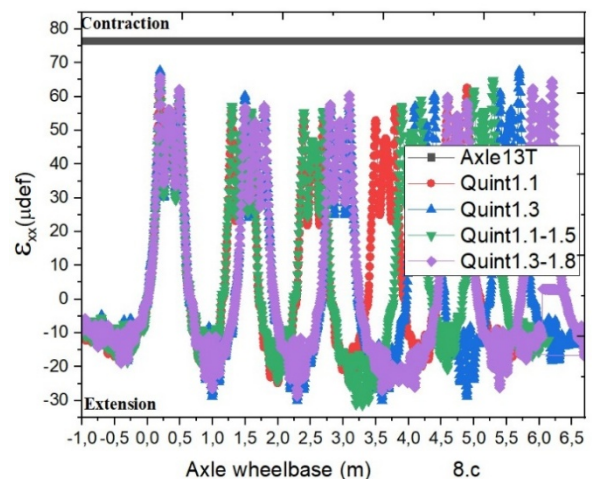
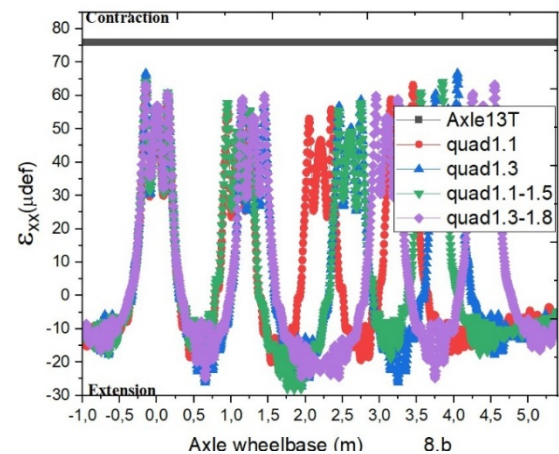
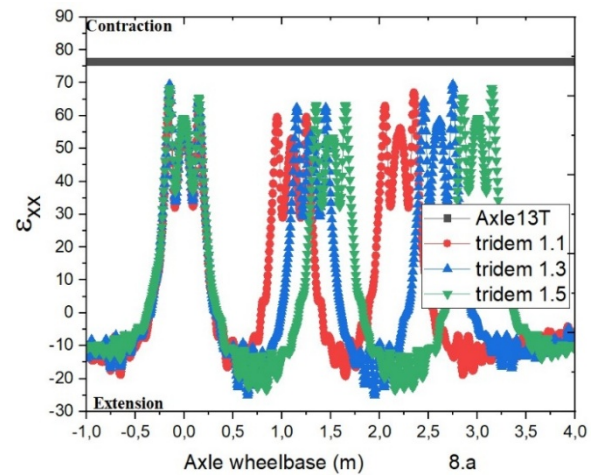
Case of dual-wheeled axles

Figure 8.a, Figure 8.b, Figure 8.c and Figure 8.d illustrate the longitudinal deformations at the bottom of the bituminous concrete road surface under a static load with dual wheels of different axles.

From these figures, it appears that the longitudinal deformations in contraction are very high compared to those in extension. The appearance of these deformation signals is similar to the signals obtained by T. Diffiné [20] using longitudinal gauges on a pavement and those of BREYSSE et al. [25].

Each longitudinal contraction deformation signal has three peaks for each pair of wheels. The presence of these three peaks is consistent with the full-scale work of P  ret et al. in tandem [17,19].

Examination of these figures also shows that the two extreme axles have slightly higher maximum deformations than the intermediate axles, regardless of the wheelbase. But in the direction of extension, these intermediate axles have the highest deformation values. The work of A. CHABOT et al. [26] on a tridem reveal the same observation.



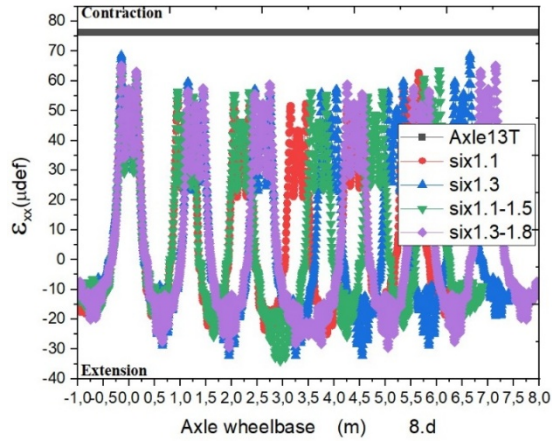


Figure 8. Longitudinal deformations at the bottom of the BB: a) Tridem twinned; (b) 4-twin axles; c) 5-twin axles; (d) 6-twin axles

Figure 8.a shows the longitudinal deformations at the bottom of the road surface under static stress of a tridem with dual wheels with wheelbases of 1.1 m, 1.3 m and 1.5 m. According to this figure, the increase in wheelbases slightly increases the maximum amplitudes of these deformations in contraction. On the other hand, in the direction of extension, the 1.3 m wheelbase has the highest deformations at the intermediate extension peaks and at the extremes it is the 1.1 m wheelbase that gives the highest deformation signals. This is consistent with the work of Homsí et al. on a 1.4 m and 2.8 m wheelbase tandem [7].

The 4-axes, 5-axes, and 6-axes respectively of Figures 8.b, 8.c, and 8.d are studied on the same wheelbases of 1.1 m, 1.3 m, 1.1-1.5 m and 1.3-1.8 m and depending on the authorized load for each type of axle in use. From these figures, it appears that the deformations resulting from the 1.1-1.5 m wheelbases have the highest extended values at the intermediate axles, while the highest 1.3 m wheelbases give the values, in contraction, at the extremes.

The increase in the axles slightly influences the longitudinal deformation in contraction. A more detailed analysis of these figures shows that the maximum longitudinal deformations in extension increase with increasing axle numbers. This confirms the interaction between the different axles. This interaction should be considered in determining the aggressiveness coefficients of the axle.

Case of wide and insulated wheeled axles

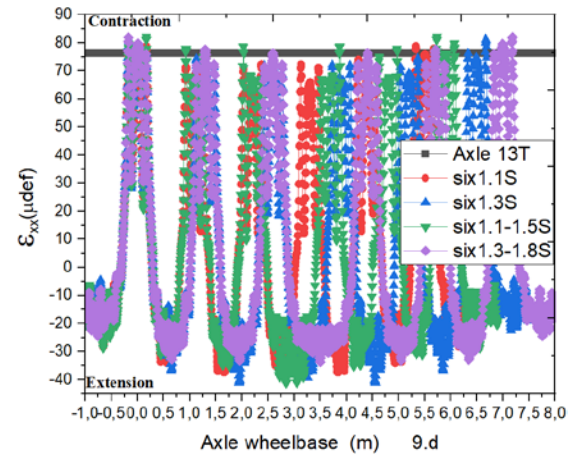
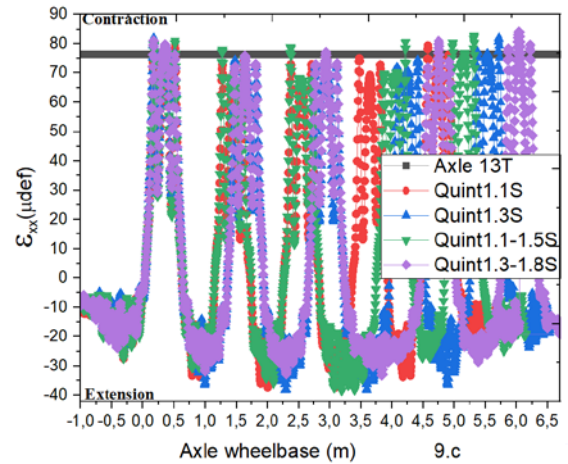
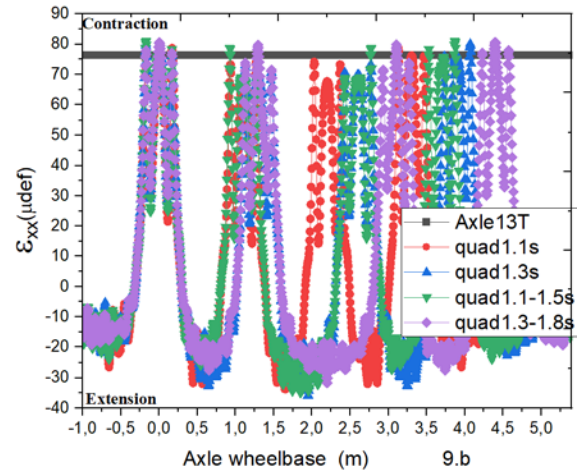
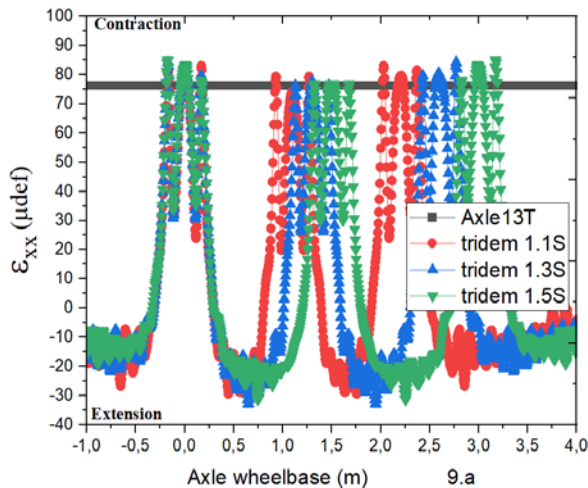


Figure 9. Longitudinal deformations at the bottom of the BB: (a) isolated Tridem; (b) 4-axes insulated; c) 5-axes insulated; (d) insulated 6-axes

Figure 9.a, Figure 9.b, Figure 9.c and Figure 9.d show the longitudinal deformations at the bottom of the asphalt concrete road surface under static loads of the tridems, 4-axes, 5-axes and 6-axes, respectively. All these axles are wide-wheeled and insulated with variable wheelbases. The longitudinal deformations of these axles have higher peaks than those of dual-wheel axles. Figure 8 for twin axles shows maximum values for longitudinal deformations of around 70 micro-deformations, while these maximum values for isolated axles in Figure 9 reach 80 micro-deformations slightly higher than those of the standard

axle of 13T. These results are in line with the experimental results of Péret et al. 2001, 2003 [17]. As with twin axles, insulated axles have the same similarities in terms of the influence of wheelbases and the increase of axles on longitudinal deformation.

3.1.2. Longitudinal Deformations on Gravel Bitumen (GB)

Case of dual-wheeled axles

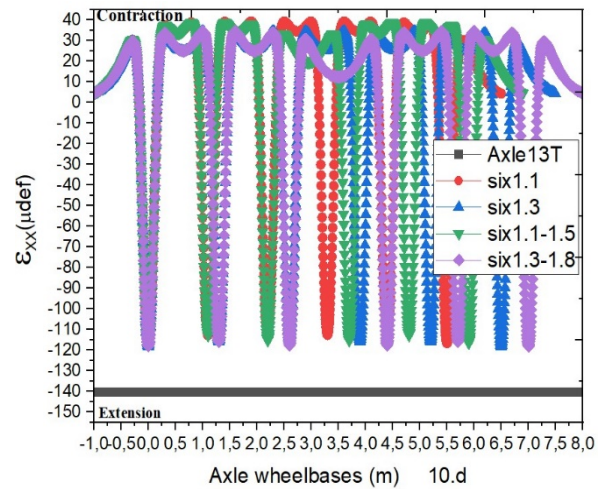
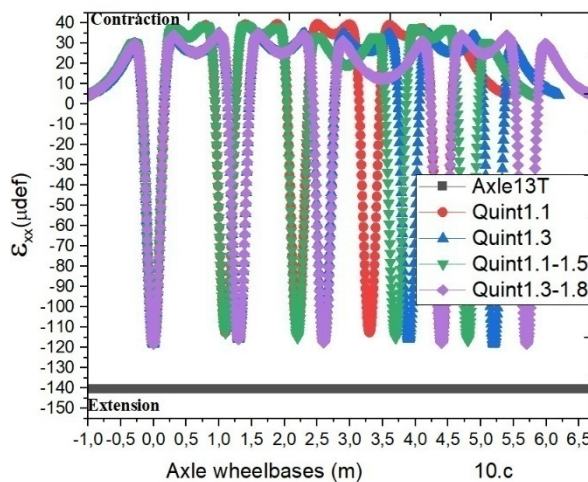
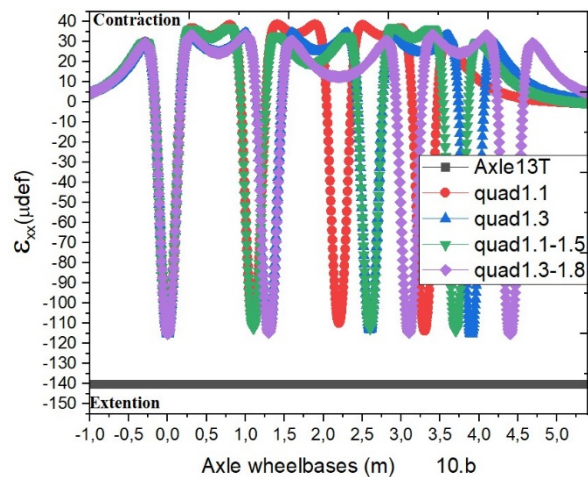
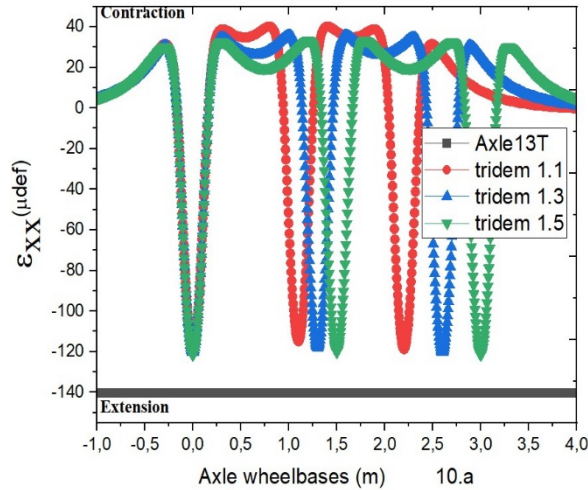


Figure 10. Longitudinal deformations at the bottom of the GB: a) Tridem twinned; (b) 4-twin axles; c) 5-twin axles; (d) 6-twin axles

Figure 10 shows the longitudinal deformations at the bottom of the bitumen gravel seam caused by tridem, 4-axes, 5-axes and 6-axes with dual wheels. In contrast, at the bottom of the bituminous concrete layer, at the level of the severe bitumen, the longitudinal stresses in extension are greater than those in contraction. These results are consistent with those of Péret et al. [17] and M. Badiane [22].

Figure 10.a shows that the shrinking deformations peaks decrease as the axle wheelbase increases. This shows that the interaction between the axles decreases with increasing wheelbase.

In Figure 10.b, Figure 10.c and Figure 10.d, the wheelbase of 1.1 m of the axles has the highest values of deformations in contraction, while the wheelbases 1.3-1.8 m for the 4-axes, 5-axes and 6-axes have the lowest ones. When extended, the intermediate axles of the 1.1 m wheelbase show the lowest deformation values. It should be noted that in extension, the deviations of the deformations due to the wheelbase of the axles are not as pronounced as in contraction.

The addition of axles does not significantly influence longitudinal deformations at the base of the GB layer.

Case of wide and insulated wheeled axles

Figure 11.a, Figure 11.b, Figure 11.c and Figure 11.d show the longitudinal deformations at the bottom of the bitumen the base layer of gravel under the respective stresses of the tridem, the 4-axes, the 5-axes and the 6-axes with wide and insulated wheels. Compared to twin axles, the longitudinal deformations induced by wide and insulated wheeled axles are much greater in contraction and extension. - This difference in deformation between the twin and insulated wheels was also noted by J. M BALAY and J. M PIAU [27].

The maximum values of longitudinal deformations in the extension of these insulated wheel axles are also higher than those generated by the 13T reference axle.

In the direction of the wheelbases and the increase in the number of axles, these deformations show the same evolutions as those of the twin axles in Figure 10.

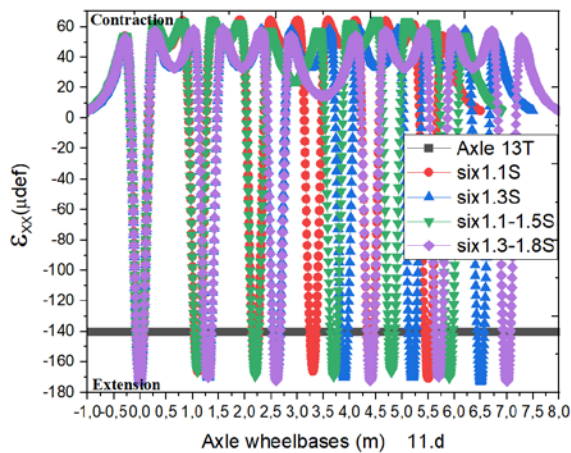
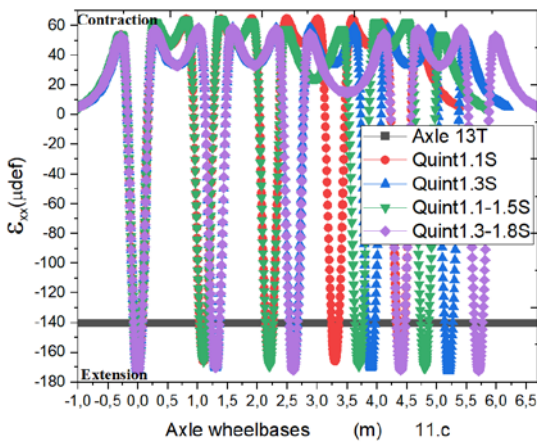
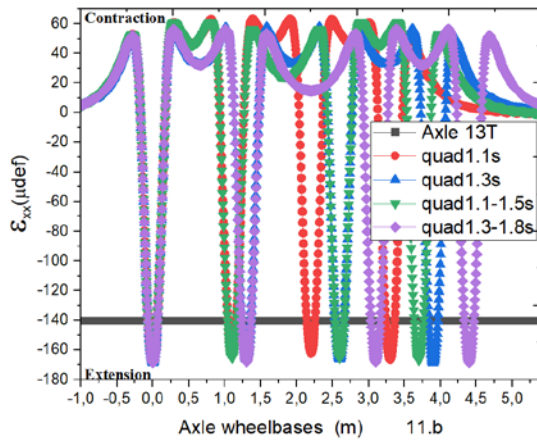
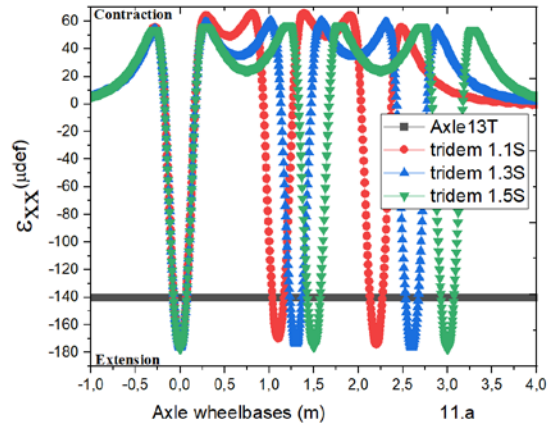


Figure 11. Longitudinal deformations at the bottom of the gravel bitumen (GB): a) isolated tridem, b) 4-insulated axles, c) 5-insulated axles, d) 6-insulated axles

3.2. Effect of the Wheelbase of a Tridem on Transverse Deformations

3.2.1. Transverse Deformations in Bituminous Concrete (BB)

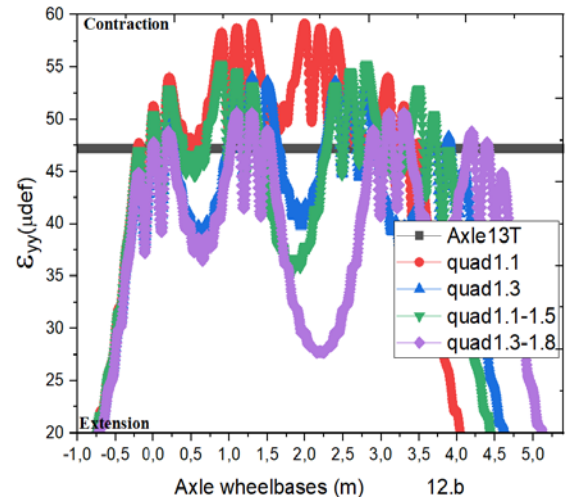
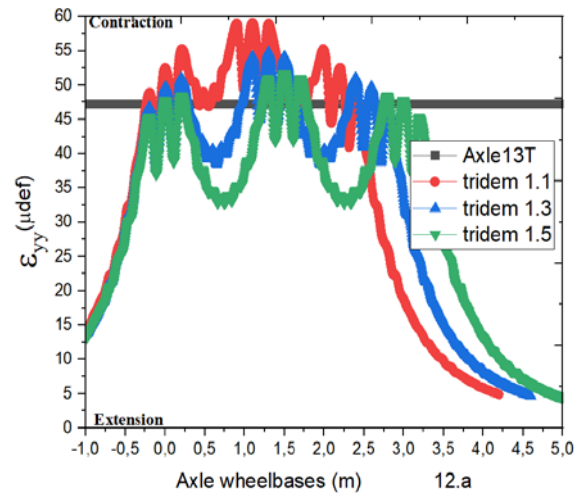
Case of dual-wheeled axles

Figure 12.a to Figure 12.c show the transverse deformations at the bottom of the bituminous concrete road surface under loading of the dual axles. From these figures, it appears that the maximum transverse deformations in contraction are greater than those in extension. Several authors have found similar results [16,19,27].

On each wheel, the presence of three peaks of deformations of the same level was found. In fact, the transverse deformation peaks of all axles are much higher than those generated by the reference axle 13T. Among these axles, the intermediate ones have the highest deformation values.

Contrary to the longitudinal deformations shown in Figure 8 and Figure 9 of the same layers, here the impact of the wheelbases and the number of axles is clearly visible. These results are consistent with the work of F. HOMSI et al. [7].

In Figure 12.a, the maximum contraction deformations decrease as the wheelbase of the tridem increases from 1.1 to 1.5 m. These results confirm the work of A. ZOA [5]. The opposite effect is observed in the direction of extension.



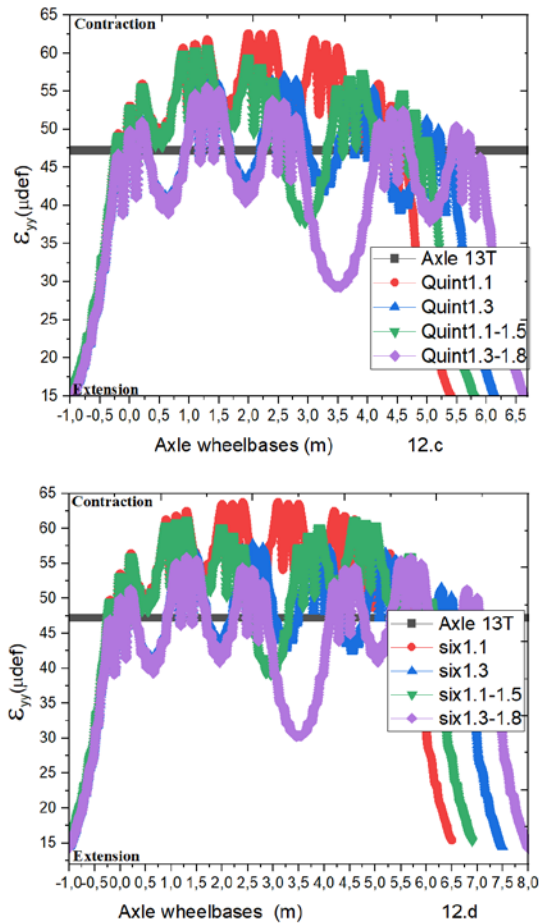


Figure 12. Transverse deformations at the bottom of the BB: a) Tridem twinned; b) 4-twin axles; c) 5-twin axles; d) 6-twin axles

According to Figure 12.b, Figure 12.c and Figure 12.d, the transverse deformations in the contraction of the road structure under the 1.1 m stress of the wheelbase axles are the highest, followed respectively by the wheelbase axles of 1.1-1.8 m, 1.3 m and 1.3-1.8 m. If under the stresses of the 1.3-1.8 m wheelbase axles, the transverse deformations in contraction are the smallest compared to other wheelbase types, it was found that during a contraction-extension-contraction cycle, these 1.3-1.8 m wheelbase axles have the highest peaks of extension deformations.

From these figures, it also emerges that the number of axles has an influence on the peaks of these deformations.

Case of wide and insulated wheeled axles

The figure below shows the transverse deformations at the bottom of the road surface test under static loading of the various insulated axles under study.

The transverse deformations of the wide and isolated wheel axles in Figure 13.a to Figure 13.d are much greater than those of the dual wheel axles in Figure 12.

Contrary to dual wheels, the intermediate deformation peak of the three peaks of each wheel is greater than those extreme of the same wheel. All these results are consistent with the work of several authors, including [7] [19-27].

In the succession of contraction-extension-contraction ranges shown in Figure 13.a to Figure 13.d; It appears that the maximum transverse deformations in contraction decrease and those in extension increase with increasing

wheelbase of the axles. The intermediate wheels of these axles have the highest transverse deformation values.

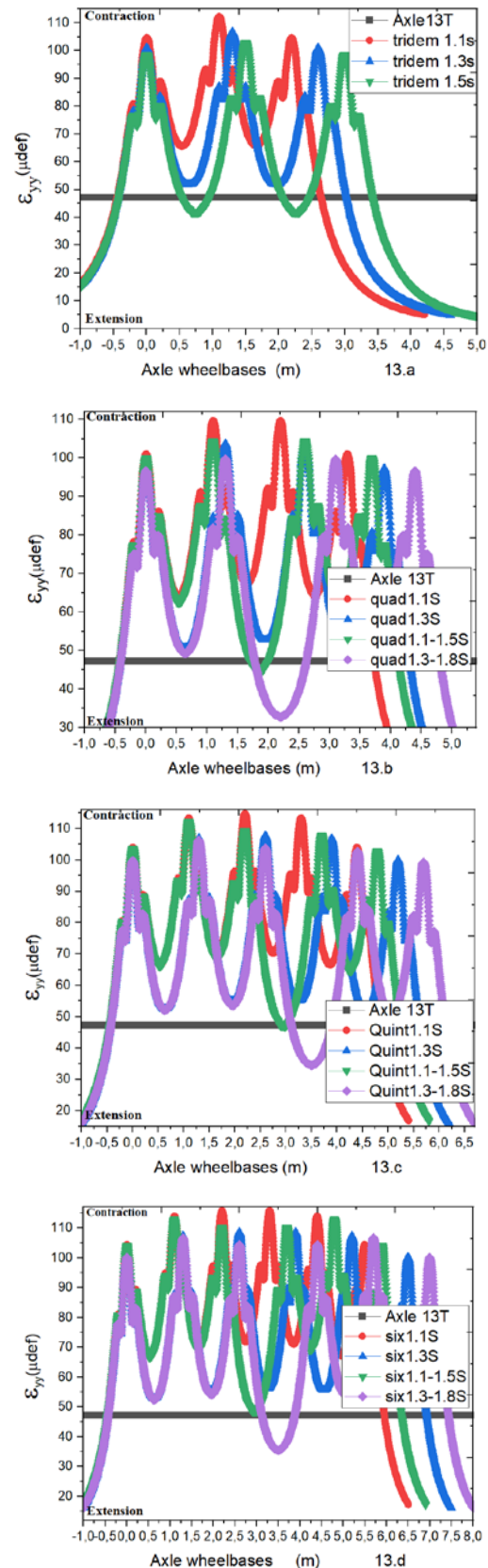


Figure 13. Transverse deformations at the bottom of the BB: a) isolated tridem, b) 4-axle insulated, c) isolated axles, d) 6-axles insulated

3.2.2. Transverse Deformations in Gravel Bitumen (GB)

Case of dual-wheeled axles

Figure 14 shows the transverse deformations at the bottom of the bitumen gravel layer under the stress of the four types of double-wheeled axle. From these figures, it appears that the transverse deformations in extension are greater than those in contraction, which confirms the work of some authors, including [17,19,20].

Figure 14.a shows that the axle spacing on the tridem axle has no effect on the extended transverse deformation, but in the contraction direction, these deformations increase with increasing axle spacing.

As for Figure 14.b, Figure 14.c and Figure 14.d, which illustrate the transverse deformations obtained at the level of the 4-axes, 5-axes, and 6-axes, as for the case of the tridem of Figure 14.a, these figures show that the maximums of these deformations in contraction increase when the wheelbase of these axles increases. This is most noticeable with intermediate axles.

These contraction deformations are influenced by the addition of axles. But in the direction of extension, the impact of adding the axles is negligible.

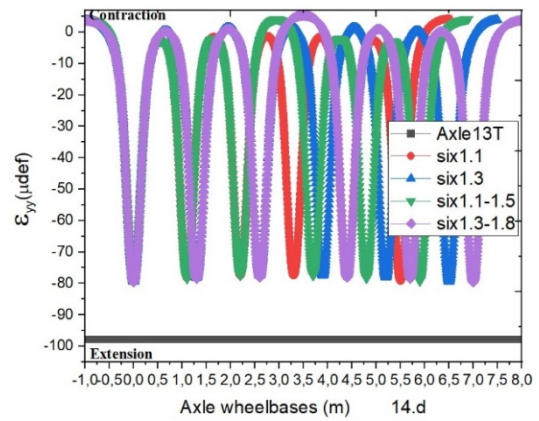
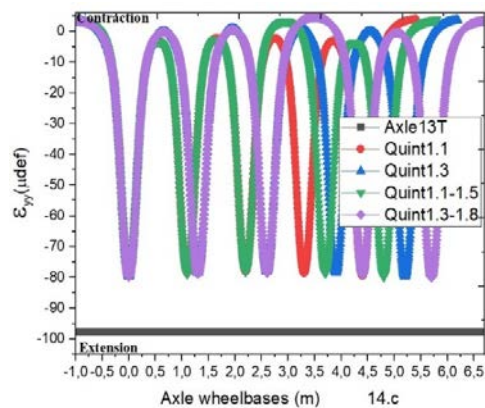
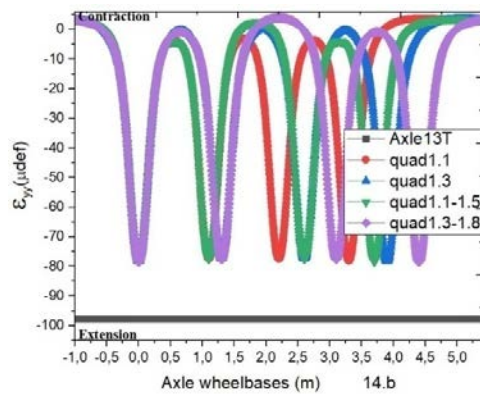
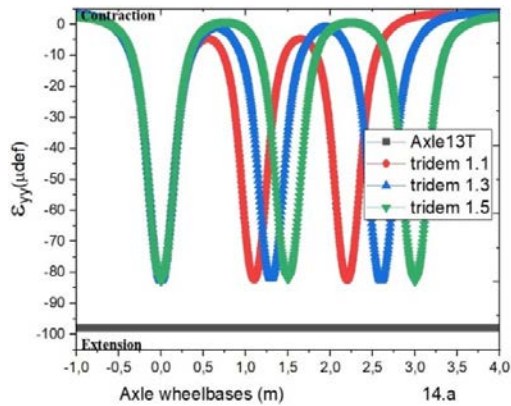
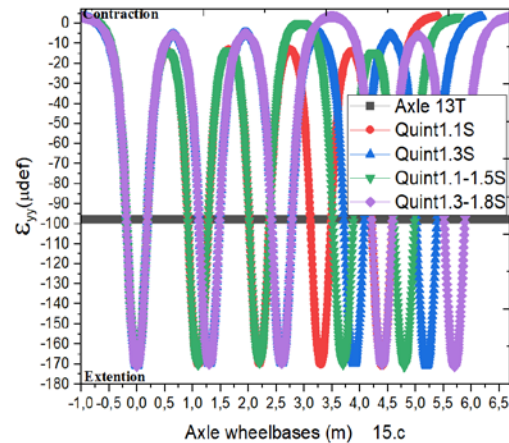
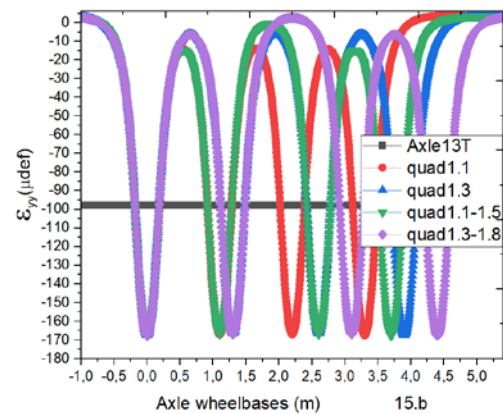
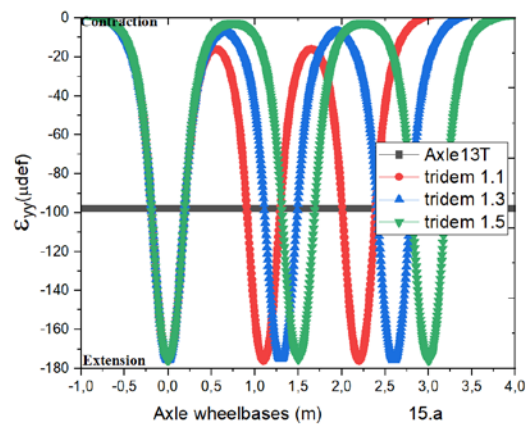


Figure 14. Transverse deformations at the bottom of the GB: a) Tridem twinned; (b) 4-twin axles; c) 5-twin axles; (d) 6-twin axles

Case of wide and insulated wheeled axles



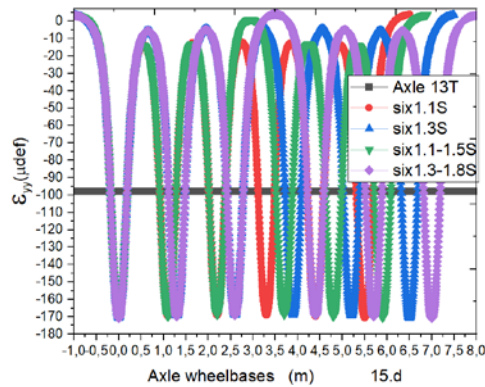


Figure 15. Transverse deformations at the bottom of the GB: a) Isolated tridem, b) insulated with 4-axes, c) Isolated axles, d) insulated with 6-axes

Figure 15.a to Figure 15.d show the transverse deformations in the bitumen gravel base layer of the test structure caused by the different groups of wide and insulated wheel axles mentioned in this work. From these figures, it appears that the amplitudes of these transverse deformations induced by these wide and isolated wheeled axles (Figures 15.a to 15.d) are almost double those generated by the double wheeled axles (Figure 14.a to Figure 14.d).

These signs are similar to those in the bibliography, which are intended to reproduce deformations on the roadway.

These deformations are also higher than those of the 13T reference axle.

The influence of the different wheelbases of these wide and insulated wheelbases is identical to that of those with dual wheels. The only difference found is in the maximum deformations. This difference can be explained by the fact that a wide wheel carries the same load as two twin wheels.

4. Conclusion

The article discusses the influence of axle wheelbases on longitudinal and transverse deformations at the bottom of the bituminous layers of a roadway. For the study, four groups of axles were used for simulation with variable wheelbases. The results obtained show that the deformations caused by the static loads of the wide and insulated wheels are qualitatively greater than those induced by the axles with dual wheels. From these results, it appears that the longitudinal deformations at the bottom of the road surface induced by the different axles are weakly influenced in contraction and extension by the variation of the wheelbases. However, in the base layer, the effect of the wheelbase on these deformations was observed only in the contraction phase. Regarding transverse deformations, they are strongly influenced by the different wheelbases of the axles. These transverse deformations in contraction decrease with increasing wheelbases of the axles at the bottom of the road surface, but at the level of the base layer, these deformations in contraction increase with increasing spacing between axles.

Isolated axle configurations resulted in longitudinal deformations, at the bottom of the two bituminous layers, greater than that generated by the 13T reference axle.

The transverse deformations of all axle configurations at the bottom of the tread are greater than those produced

by the standard reference axle. At the base layer, the wide and insulated wheeled axles that give transverse deformations greater than those of the reference axle. This observation shows that a carriageway sized with the reference axle will not operate for long under traffic consisting of the multi-axes studied.

Analysis of all deformation signals also shows that the reduction of the axles influences these signals.

Given that these deformations play a role in the assessment of pavement damage, it is necessary to supplement this work with a study of the influence of the distance between the rear and front axles of a heavy vehicle on these deformations and assess the associated damage.

Statement of Competing Interests

The authors declare no conflicts of interest regarding publication of this paper.

List of Abbreviations

- Axle 13 T: Standard reference axle of 13 T
- Tridem 1.1: Group of three axles with twin wheels with wheelbases of 1.1 m
- Tridem 1.3: Group of three axles with twin wheels with wheelbases of 1.3 m
- Tridem 1.5: Group of three axles with twin wheels with wheelbases of 1.1 m
- Tridem 1.1S: Group of three axles with wide and insulated wheels with wheelbases of 1.1 m
- Tridem 1.3S: Group of three axles with wide and insulated wheels with wheelbases of 1.3 m
- Tridem 1.5S: Group of three axles with wide and insulated wheels with wheelbases of 1.5 m
- Quad 1.1: Group of four dual-wheeled axles with 1.1 m wheelbases
- Quad 1.3: Group of four axles with dual wheels with wheelbases is 1.3 m
- Quad 1.1-1.5: Group of four axles with twin wheels with wheelbases of 1.1 m between the 1st and 2nd and between the 3rd and the 4th and 1.5 m between 2nd and 3rd
- Quad 1.3-1.8: Group of four axles with twin wheels with wheelbases of 1.3 m between the 1st and 2nd and between the 3rd and the 4th and 1.8 m between 2nd and 3rd
- Quad 1.1S: Group of four axles with wide and insulated wheels with a wheelbase of 1.1 m
- Quad 1.3S: Group of four axles with wide and insulated wheels with a wheelbase of 1.3 m
- Quad 1.1-1.5S: Group of four axles with wide and insulated wheels with wheelbases of 1.1 m between the 1st and 2nd and between the 3rd and 4th and 1.5 m between 2nd and 3rd
- Quad 1.3-1.8S: Group of four axles with wide and insulated wheels with wheelbases of 1.3 m between the 1st and 2nd and between the 3rd and the 4th and 1.8 m between 2nd and 3rd
- Quint 1.1: Group of Five dual wheel axles with a wheelbase of 1.1 m

Quint 1.3: Group of five dual-wheel axles with a wheelbase of 1.3 m

Quint 1.1-1.5: Group of five axles with twin wheels with wheelbases of 1.1 m between the 1st, 2nd and 3rd and between the 4th and 5th and 1.5 m between 3rd and 4th

Quint 1.3-1.8: Group of five axles with twin wheels with wheelbases of 1.3 m between the 1st, 2nd and 3rd and between the 4th and 5th and 1.8 m between 3rd and 4th

Quint 1.1S: Group of five axles with wide and insulated wheels with wheelbases is 1.1 m

Quint 1.3S: Group of five axles with wide and insulated wheels with wheelbases is 1.3 m

Quint 1.1-1.5S: Group of five axles with wide and isolated wheels with wheelbases of 1.1 m between the 1st, 2nd and 3rd and between the 4th and the 5th and 1.5 m between 3rd and 4th

Quint 1.3-1.8S: Group of five axles with wide and isolated wheels with wheelbases of 1.3 m between the 1st 2nd and 3rd and between the 4th and 5th and 1.8 m between the 3rd and 4th

SIX 1.1: Group of six dual-wheel axles with a wheelbase of 1.1 m

SIX 1.3: Group of six dual-wheel axles with a wheelbase of 1.3 m

SIX 1.1-1.5: Group of six axles with twin wheels with wheelbases of 1.1 m between the 1st, 2nd and 3rd and between the 4th, 5th and the 6th and 1.5 m between the 3rd and 4th

SIX 1.3-1.8: Group of six axles with twin wheels with wheelbases of 1.3 m between the 1st, 2nd and 3rd and between the 4th, the 5th and the 6th and 1.8 m between the 3rd and 4th

SIX 1.1S: Group of six axles with wide and insulated wheels with a wheelbase of 1.1 m

SIX 1.3S: Group of six axles with wide and insulated wheels with a wheelbase of 1.3 m

SIX 1.1-1.5S: Group of six axles with wide and insulated wheels with wheelbases of 1.1 m between the 1st, 2nd and 3rd and between the 4th, 5th and 6th and 1.5 m between the 3rd and 4th

SIX 1.3-1.8S: Group of six axles with wide and insulated wheels with wheelbases of 1.3 m between the 1st, 2nd and 3rd and between the 4th, 5th and 6th and 1.8 m between the 3rd and 4th

BBSG: Semi-Grained Bituminous Concrete

GB: Gravel Bitumen

def: Micro-deformations

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