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Modeling of Deflection for Bias-ply Tire Based on Section Width, Overall Unloaded Diameter, Inflation Pressure, Vertical Load and Rotational Speed

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Abstract: This study was conducted to model deflection (δ) of bias-ply tire based on section width (b), overall unloaded diameter (d), inflation pressure (P), vertical load (W) and rotational speed (N). For this purpose, deflection of three bias-ply tires with different section width and overall unloaded diameter were measured at three levels of inflation pressure, four levels of vertical load and six levels of rotational speed. In order to model deflection based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed, a five-variable linear regression model was suggested and all the data were subjected to regression analysis. The statistical results of study indicated that the five-variable linear regression model δ = 16.602 + 0.0203 b - 0.0006 d - 0.3667 P + 0.0356 W - 0.0050 N with R^2 = 0.952152 may be suggested to predict deflection of bias-ply tire based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed for a limited range of bias-ply tire sizes.

Key words: Bias-ply tire · Deflection · Section width · Overall unloaded diameter · Inflation pressure · Vertical load · Rotational speed · Modeling

INTRODUCTION

In the case of tracked vehicles, the contact area between machine and ground surface is relatively constant for varying sinkage in the soil and is calculated as the length of track on hard ground times track width. However, a flexible tire has a smaller contact area on hard surface than it dose on soft ground. A rule of thumb which can be used for estimation of tire contact area is shown by equation 1 [1]:

$$A=bL \quad (1)$$

Where:

A = Contact area of tire (m^2)
b = Section width of tire (m)
L = Contact length of tire (m)

Wong [2] and Bekker [3] gave an approximate method for calculating contact length of tire as given below in equation 2:

$$L = 2(d\delta - \delta^2)^{0.5} \quad (2)$$

Where:

d = Overall unloaded diameter of tire (m)
δ = Deflection of tire (m)

Tire deflection is a key parameter and many equations have been developed based on tire deflection to evaluate the tractive performance of bias-ply and radial-ply tires operating in cohesive-frictional soils. Gross traction, motion resistance, net traction and tractive efficiency are predicted as a function of soil strength, tire load, tire slip, tire size and tire deflection [4].

Fig. 1 shows the tire dimensions (b, d and δ) used. The tire dimensions can be obtained from tire data book or by measuring the tire [4]. The section width (b) is the first number in a tire size designation. The overall unloaded diameter (d) can be obtained from the tire data handbooks available from off-road tire manufacturers. The tire deflection (δ) on a hard surface is equal to d/2 minus the measured static loaded radius. The static

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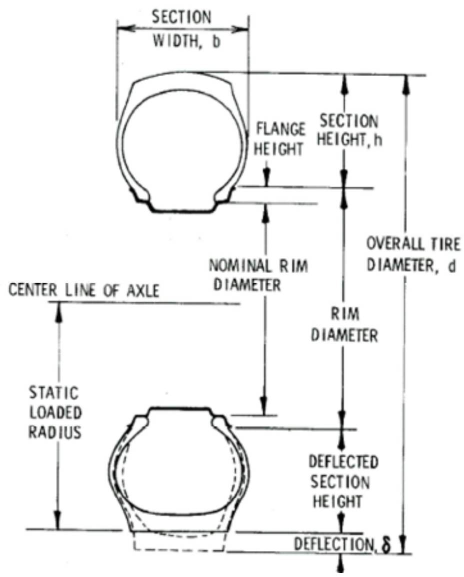

Fig 1: Tire dimensions, adapted from Brixius [4]

Fig 2: Tire deflection test apparatus

loaded radius for the tire's rated load and inflation pressure is standard tire data from the tire data handbooks. It can also be obtained by measuring the tire [4, 5].

As deflections for a given tire size, inflation pressure, vertical load and rotational speed may significantly be different between bias-ply and radial-ply tires, this study was conducted to model deflection (δ) of bias-ply tire based on section width (b), overall unloaded diameter (d), inflation pressure (P), vertical load (W) and rotational speed (N) using a linear regression model.

MATERIALS AND METHODS

Tire Deflection Test Apparatus: A tire deflection test apparatus was designed and constructed to measure deflection of tires with different sizes at diverse levels of inflation pressure, vertical load and rotational speed (Fig. 2).

Experimental Procedure: For this purpose, deflection of three bias-ply tires with different section width and overall unloaded diameter were measured at three levels of inflation pressure, four levels of vertical load and six levels of rotational speed. The section width and overall unloaded diameter of three bias-ply tires are given in Table 1. Results of deflection measurement for bias-ply tires No. 1, 2 and 3 are given in Tables 2, 3 and 4, respectively.

Regression Model: A typical five-variable linear regression model is shown in equation 3 [6-9]:

$$Y = C_0 + C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \quad (3)$$

Where:

Y = Dependent variable, for example deflection of bias-ply tire

X_1, X_2, X_3, X_4, X_5 =Independent variables, for example section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed

C_0, C_1, C_2, C_3, C_4, C_5 = Regression coefficients

To model deflection based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed, a five-variable linear regression model was suggested.

Table 1: Section width and overall unloaded diameter of three bias-ply tires used in this study

Tire No.	Section width b (mm)	Overall unloaded diameter d (mm)
1	142	596
2	152	654
3	165	676

Table 2: Section width, overall unloaded diameter, inflation pressure, vertical load, rotational speed and deflection (three replications) for bias-ply tire No. 1

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Rotational speed N (rev/min)	Deflection δ (mm) δ_1	δ_2	δ_3
142	596	30	100	0	12.50	12.50	12.25
				600	9.750	9.250	9.250
				700	9.000	9.000	8.750
				800	8.500	8.500	8.250
				900	8.000	8.000	7.750
				1000	7.500	7.500	7.250
			150	0	14.50	14.50	14.25
				600	11.75	11.25	11.25
				700	11.00	11.00	10.75
				800	10.50	10.50	10.25
				900	10.00	10.00	9.750
				1000	9.500	9.500	9.250
			200	0	16.50	16.50	16.25
				600	13.75	13.25	13.25
				700	13.00	13.00	12.75
				800	12.50	12.50	12.25
				900	12.00	12.00	11.75
				1000	11.50	11.50	11.25
			250	0	18.50	18.50	18.25
				600	15.75	15.25	15.25
				700	15.00	15.00	14.75
				800	14.50	14.50	14.25
				900	14.00	14.00	13.75
				1000	13.50	13.50	13.25
		35	100	0	9.500	9.500	9.250
				600	6.750	6.250	6.250
				700	6.000	6.000	5.750
				800	5.500	5.500	5.250
				900	5.000	5.000	4.750
				1000	4.500	4.500	4.250
			150	0	11.00	11.00	10.75
				600	8.250	7.750	7.750
				700	7.500	7.500	7.250
				800	7.000	7.000	6.750
				900	6.500	6.500	6.250
				1000	6.000	6.000	5.750
			200	0	12.50	12.50	12.25
				600	9.750	9.250	9.250
				700	9.000	9.000	8.750
				800	8.500	8.500	8.250
				900	8.000	8.000	7.750
				1000	7.500	7.500	7.250
			250	0	14.00	14.00	13.75
				600	11.25	10.75	10.75
				700	10.50	10.50	10.25
				800	10.00	10.00	9.750
				900	9.500	9.500	9.250
				1000	9.000	9.000	8.750
		40	100	0	7.500	7.500	7.250

Table 2: Continue

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Rotational speed N (rev/min)	Deflection δ (mm) δ_1	δ_2	δ_3
				600	4.750	4.250	4.250
				700	4.000	4.000	3.750
				800	3.500	3.500	3.250
				900	3.000	3.000	2.750
				1000	2.500	2.500	2.250
			150	0	9.500	9.500	9.250
				600	6.750	6.750	6.250
				700	6.000	6.000	5.750
				800	5.500	5.500	5.250
				900	5.000	5.000	4.750
				1000	4.500	4.500	4.250
			200	0	11.50	11.50	11.25
				600	8.750	8.250	8.250
				700	8.000	8.000	7.750
				800	7.500	7.500	7.250
				900	7.000	7.000	6.750
				1000	6.500	6.500	6.250
			250	0	13.50	13.50	13.25
				600	10.75	10.25	10.25
				700	10.00	10.00	9.750
				800	9.500	9.500	9.250
				900	9.000	9.000	8.750
				1000	8.500	8.500	8.250

Table 3: Section width, overall unloaded diameter, inflation pressure, vertical load, rotational speed and deflection (three replications) for bias-ply tire No. 2

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Rotational speed N (rev/min)	Deflection δ (mm) δ_1	δ_2	δ_3
152	654	30	100	0	11.50	11.50	11.25
				600	8.750	8.250	8.250
				700	8.000	8.000	7.750
				800	7.500	7.500	7.250
				900	7.000	7.000	6.750
				1000	6.500	6.500	6.250
			150	0	13.00	13.00	12.75
				600	10.25	9.750	9.750
				700	9.500	9.500	9.250
				800	9.000	9.000	8.750
				900	8.500	8.500	8.250
				1000	8.000	8.000	7.750
			200	0	14.50	14.50	14.25
				600	11.75	11.25	11.25
				700	11.00	11.00	10.75
				800	10.50	10.50	10.25
				900	10.00	10.00	9.750
				1000	9.500	9.500	9.250
			250	0	16.00	16.00	15.75
				600	13.25	12.75	12.75
				700	12.50	12.50	12.25

Table 3: Continue

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Rotational speed N (rev/min)	Deflection δ (mm) δ_1	δ_2	δ_3
				800	12.00	12.00	11.75
				900	11.50	11.50	11.25
				1000	11.00	11.00	10.75
		35	100	0	10.00	10.00	9.750
				600	7.250	6.750	6.750
				700	6.500	6.500	6.250
				800	6.000	6.000	5.750
				900	5.500	5.500	5.250
				1000	5.000	5.000	4.750
			150	0	12.00	12.00	11.75
				600	9.250	8.750	8.750
				700	8.500	8.500	8.250
				800	8.000	8.000	7.750
				900	7.500	7.500	7.250
				1000	7.000	7.000	6.750
			200	0	14.00	14.00	13.75
				600	11.25	10.75	10.75
				700	10.50	10.50	10.25
				800	10.00	10.00	9.750
				900	9.500	9.500	9.250
				1000	9.000	9.000	8.750
			250	0	16.00	16.00	15.75
				600	13.25	12.75	12.75
				700	12.50	12.50	12.25
				800	12.00	12.00	11.75
				900	11.50	11.50	11.25
				1000	11.00	11.00	10.75
		40	100	0	8.500	8.500	8.250
				600	5.750	5.250	5.250
				700	5.000	5.000	4.750
				800	4.500	4.500	4.250
				900	4.000	4.000	3.750
				1000	3.500	3.500	3.250
			150	0	10.50	10.50	10.25
				600	7.750	7.250	7.250
				700	7.000	7.000	6.750
				800	6.500	6.500	6.250
				900	6.000	6.000	5.750
				1000	5.500	5.500	5.250
			200	0	12.50	12.50	12.25
				600	9.750	9.250	9.250
				700	9.000	9.000	8.750
				800	8.500	8.500	8.250
				900	8.000	8.000	7.750
				1000	7.500	7.500	7.250
			250	0	14.50	14.50	14.25
				600	11.75	11.25	11.25
				700	11.00	11.00	10.75
				800	10.50	10.50	10.25
				900	10.00	10.00	9.750
				1000	9.500	9.500	9.250

Table 4: Section width, overall unloaded diameter, inflation pressure, vertical load, rotational speed and deflection (three replications) for bias-ply tire No. 3

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Rotational speed N (rev/min)	Deflection δ (mm) δ_1	δ_2	δ_3
165	676	30	100	0	12.00	12.00	11.75
				600	9.250	8.750	8.750
				700	8.500	8.500	8.250
				800	8.000	8.000	7.750
				900	7.500	7.500	7.250
				1000	7.000	7.000	6.750
			150	0	14.00	14.00	13.75
				600	11.25	10.75	10.75
				700	10.50	10.50	10.25
				800	10.00	10.00	9.750
				900	9.500	9.500	9.250
				1000	9.000	9.000	8.750
			200	0	16.00	16.00	15.75
				600	13.25	12.75	12.75
				700	12.50	12.50	12.25
				800	12.00	12.00	11.75
				900	11.50	11.50	11.25
				1000	11.00	11.00	10.75
			250	0	18.00	18.00	17.75
				600	15.25	14.75	14.75
				700	14.50	14.50	14.25
				800	14.00	14.00	13.75
				900	13.50	13.50	13.25
				1000	13.00	13.00	12.75
		35	100	0	10.50	10.50	10.25
				600	7.750	7.250	7.250
				700	7.000	7.000	6.750
				800	6.500	6.500	6.250
				900	6.000	6.000	5.750
				1000	5.500	5.500	5.250
			150	0	12.00	12.00	11.75
				600	9.250	8.750	8.750
				700	8.500	8.500	8.250
				800	8.000	8.000	7.750
				900	7.500	7.500	7.250
				1000	7.000	7.000	6.750
			200	0	13.50	13.50	13.25
				600	10.75	10.25	10.25
				700	10.00	10.00	9.750
				800	9.500	9.500	9.250
				900	9.000	9.000	8.750
				1000	8.500	8.500	8.250
			250	0	15.00	15.00	14.75
				600	12.25	11.75	11.75
				700	11.50	11.50	11.25
				800	11.00	11.00	10.75
				900	10.50	10.50	10.25
				1000	10.00	10.00	9.750
		40	100	0	9.000	9.000	8.750
				600	6.250	5.750	5.750

Table 4: Continue

Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Rotational speed N (rev/min)	Deflection δ (mm) δ_1	δ_2	δ_3
				700	5.500	5.500	5.250
				800	5.000	5.000	4.750
				900	4.500	4.500	4.250
				1000	4.000	4.000	3.750
			150	0	10.50	10.50	10.25
				600	7.750	7.250	7.250
				700	7.000	7.000	6.750
				800	6.500	6.500	6.250
				900	6.000	6.000	5.750
				1000	5.500	5.500	5.250
			200	0	12.00	12.00	11.75
				600	9.250	8.750	8.750
				700	8.500	8.500	8.250
				800	8.000	8.000	7.750
				900	7.500	7.500	7.250
				1000	7.000	7.000	6.750
			250	0	13.50	13.50	13.25
				600	10.75	10.75	10.25
				700	10.00	10.00	9.750
				800	9.500	9.500	9.250
				900	9.000	9.000	8.750
				1000	8.500	8.500	8.250

Table 5: Five-variable linear regression model, p-value of independent variables and coefficient of determination (R^2)

Model	p-value b	d	P	W	N	R^2
δ = 16.602 + 0.0203 b - 0.0006 d - 0.3667 P + 0.0356 W - 0.0050 N	0.019269	0.795949	9.7E-253	0	5.2E-272	0.952152

RESULTS AND DISCUSSION

In order to model deflection of bias-ply tire based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed, a five-variable linear regression model was suggested and all the data were subjected to regression analysis using the Microsoft Excel 2007. The five-variable linear regression model, p-value of independent variables and coefficient of determination (R^2) of the model are shown in Table 5. As it is shown in Table 5, this model has a high R^2 value at 0.952152, indicating good agreement of the experimental data. In addition, the p-value of independent variables (b, d, P, W and N) is as follows: 0.019269, 0.795949, 9.7E-253, 0 and 5.2E-272, respectively. Thus, based on the statistical results, this model is initially accepted, which is given by equation 4:

$$\delta = 16.602 + 0.0203\, b - 0.0006\, d - 0.3667\, P + 0.0356\, W - 0.0050\, N \quad (4)$$

In this model, deflection of bias-ply tire can be predicted using five-variable linear regression of section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed.

CONCLUSIONS

It can be concluded that the five-variable linear regression model $\delta = 16.602 + 0.0203\, b - 0.0006\, d - 0.3667\, P + 0.0356\, W - 0.0050\, N$ with $R^2 = 0.952152$ may be suggested to predict deflection of bias-ply tire based on section width, overall unloaded diameter, inflation pressure, vertical load and rotational speed for a limited range of bias-ply tire sizes.

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