

## Modeling of Bias-Ply Tire Deflection Based on Tire Dimensions, Tire Inflation Pressure and Vertical Load on Tire

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**Abstract:** This study was conducted to model deflection ( $\delta$ ) of bias-ply tire based on tire dimensions, viz., section width (b) and overall unloaded diameter (d) of tire, tire inflation pressure (P) and vertical load on tire (W). For this purpose, deflection of three bias-ply tires with different section width and/or overall unloaded diameter were measured at five levels of inflation pressure and five levels of vertical load. In order to model deflection based on dimensions, inflation pressure and vertical load, seven multiple variables regression models were suggested and all the data were subjected to regression analysis. The statistical results of study indicated that the multiple variables regression model  $\delta = 51.57 - 0.040 b - 0.019 d - 0.905 P + 3.534 W$  with  $R^2 = 0.983$  may be suggested to predict deflection of bias-ply tire based on tire dimensions (section width and overall unloaded diameter), tire inflation pressure and vertical load on tire for a limited range of bias-ply tire sizes. However, experimental verification of this model is necessary before the model can be recommended for wider use.

**Key words:** Bias-ply tire • Deflection • Dimensions • Inflation pressure • Vertical load • Modeling

### INTRODUCTION

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 = Tire Contact area (m<sup>2</sup>)

b = Section width of tire (m)

L = Contact length of tire (m)

McKyes [1] gave an approximate method for estimating contact length of tire on hard and soft surfaces (Fig. 1) as given below in equations 2 and 3, respectively:

$$L = \frac{d}{4} \text{ (On a hard surface)} \quad (2)$$

$$L = \frac{d}{2} \text{ (On a soft surface)} \quad (3)$$

Where:

d = Overall unloaded diameter of tire (m)

Moreover, Wong [2] and Bekker [3] gave an approximate method for calculating contact length of tire as given below in equation 4:

$$L = 2(d\delta - \delta^2)^{0.5} \quad (4)$$

Where:

$\delta$  = Tire deflection (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. 2 shows the tire dimensions (b, d and  $\delta$ ) 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 (i.e., nominally 18.4 inches for an 18.4-38 tire). The overall unloaded diameter (d) can be obtained from the tire data handbooks available from off-road tire manufacturers. The tire deflection ( $\delta$ ) on a hard surface is equal to d/2 minus the measured static loaded radius. The static loaded radius for the tire's rated load and inflation

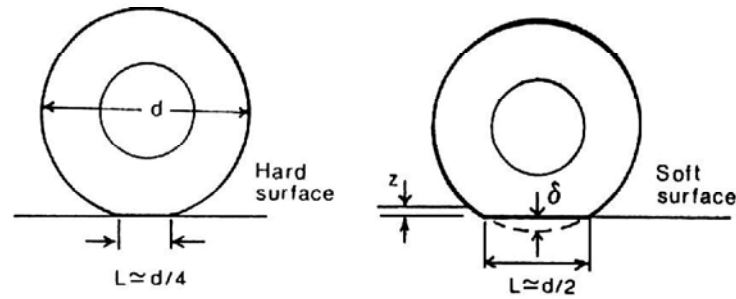


Fig. 1: Contact lengths of tires on hard and soft surfaces, adapted from McKyes [1]

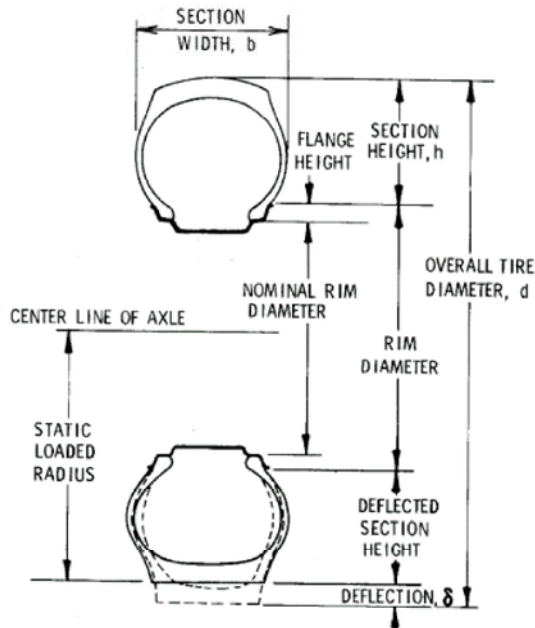


Fig. 2: Tire dimensions, adapted from Brixius [4]

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, tire inflation pressure and vertical load on tire are significantly different between bias-ply and radial-ply tires [4], this study was conducted to model deflection ( $\delta$ ) of bias-ply tire based on tire dimensions, i.e. section width ( $b$ ) and overall unloaded diameter ( $d$ ) of tire, tire inflation pressure ( $P$ ) and vertical load on tire ( $W$ ).

## MATERIALS AND METHODS

**Tire Deflection Test Apparatus:** A tire deflection test apparatus (Fig. 3) was designed and constructed to measure deflection of tires with different sizes at diverse



Fig. 3: Tire deflection test apparatus



Fig. 4: Measuring static loaded radius

levels of inflation pressure and vertical load. As deflection on a hard surface is equal to  $d/2$  minus the measured static loaded radius [4, 5], the static loaded radius was obtained by measuring as shown in Fig. 4.

Table 1: Dimensions of the three bias-ply tires used in this study

Tire No.	Tire size designation	Section width b (mm)	Overall unloaded diameter d (mm)
1	5.50-13	160	585
2	6.50-14	185	690
3	6.00-16	155	725

Table 2: Section width, overall unloaded diameter, inflation pressure, vertical load and deflection for bias-ply tire No. 1

Tire No.	Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Deflection $\delta$ (mm)
1	160	585	30	5.8690	24.0
				7.8250	33.0
				9.7810	41.0
				11.738	48.0
				13.694	60.0
			32	5.8690	24.0
				7.8250	31.0
				9.7810	40.0
				11.738	47.0
				13.694	53.0
			34	5.8690	23.0
				7.8250	30.5
				9.7810	38.0
				11.738	45.5
				13.694	51.0
			36	5.8690	23.0
				7.8250	29.0
				9.7810	35.0
				11.738	41.0
				13.694	49.0
			38	5.8690	20.0
				7.8250	29.0
				9.7810	36.0
				11.738	42.0
				13.694	50.0

Table 3: Section width, overall unloaded diameter, inflation pressure, vertical load and deflection for bias-ply tire No. 2

Tire No.	Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Deflection $\delta$ (mm)
2	185	690	30	5.8690	24.0
				7.8250	31.0
				9.7810	38.0
				11.738	45.0
				13.694	52.0
			32	5.8690	24.0
				7.8250	30.0
				9.7810	37.0
				11.738	43.0
				13.694	49.5
			34	5.8690	22.0
				7.8250	28.0
				9.7810	35.0
				11.738	41.0
				13.694	47.0
			36	5.8690	20.0
				7.8250	27.0
				9.7810	32.0
				11.738	39.0
				13.694	46.0
			38	5.8690	20.0
				7.8250	27.0
				9.7810	31.0
				11.738	37.0
				13.694	42.0

Table 4: Section width, overall unloaded diameter, inflation pressure, vertical load and deflection for bias-ply tire No. 3

Tire No.	Section width b (mm)	Overall unloaded diameter d (mm)	Inflation pressure P (kPa)	Vertical load W (kN)	Deflection $\delta$ (mm)
3	155	725	30	5.8690	23.0
				7.8250	32.0
				9.7810	40.0
				11.738	47.0
				13.694	54.0
				5.8690	23.0
			32	7.8250	31.0
				9.7810	37.0
				11.738	46.0
				13.694	52.0
				5.8690	23.0
			34	7.8250	28.0
				9.7810	35.0
				11.738	43.0
				13.694	47.5
				5.8690	19.0
			36	7.8250	27.0
				9.7810	33.0
				11.738	41.0
				13.694	47.0
			38	5.8690	17.0
				7.8250	24.0
				9.7810	29.0
				11.738	37.0
				13.694	45.0

Table 5: Seven multiple variables regression models and their relations

Model No.	Model	Relation
1	$\delta = C_0 + C_1 b + C_2 d + C_3 P + C_4 W$	$\delta = 51.57 - 0.040 b - 0.019 d - 0.905 P + 3.534 W$
2	$\delta = C_0 + C_1 b + C_2 P + C_3 W$	$\delta = 40.54 - 0.051 b - 0.905 P + 3.534 W$
3	$\delta = C_0 + C_1 d + C_2 P + C_3 W$	$\delta = 45.67 - 0.020 d - 0.905 P + 3.534 W$
4	$\delta = C_0 + C_1 (bd) + C_2 P + C_3 W$	$\delta = 42.13 - 0.00009 (bd) - 0.905 P + 3.534 W$
5	$\delta = C_0 + C_1 (b/d) + C_2 P + C_3 W$	$\delta = 26.80 + 20.98 (b/d) - 0.905 P + 3.534 W$
6	$\delta = C_0 + C_1 (d/b) + C_2 P + C_3 W$	$\delta = 36.80 - 1.173 (d/b) - 0.905 P + 3.534 W$
7	$\delta = C_0 + C_1 (bd)^{0.5} + C_2 P + C_3 W$	$\delta = 52.13 - 0.060 (bd)^{0.5} - 0.905 P + 3.534 W$

Table 6: The p-value of independent variables and coefficient of determination ( $R^2$ ) for the seven multiple variable regression models

Model No.	p-value						P	W	$R^2$
	b	d	bd	b/d	d/b	$(bd)^{0.5}$			
1	0.001734	6.69E-10	---	---	---	---	3.35E-25	1.26E-62	0.983
2	0.002050	---	---	---	---	---	2.75E-19	3.00E-55	0.971
3	---	6.35E-10	---	---	---	---	7.57E-24	2.30E-61	0.981
4	---	---	7.90E-11	---	---	---	1.56E-24	3.09E-62	0.982
5	---	---	---	0.009443	---	---	7.09E-19	1.16E-54	0.970
6	---	---	---	---	0.012512	---	8.41E-19	1.48E-54	0.970
7	---	---	---	---	---	5.33E-11	1.16E-24	2.11E-62	0.982

**Experimental Procedure:** Deflection of three bias-ply tires with different dimensions was measured at five levels of inflation pressure and five levels of vertical load. The dimensions 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 multiple variables regression model is shown in equation 5 [6-13]:

$$Y = C_0 + C_1 X_1 + C_2 X_2 + \dots + C_n X_n \quad (5)$$

Where:

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

$X_1, X_2, \dots, X_n$  = Independent variables, for example section width, overall unloaded diameter, inflation pressure and vertical load

$C_0, C_1, C_2, \dots, C_n$  = Regression coefficients

To model deflection based on dimensions, inflation pressure and vertical load, seven multiple variables regression models were suggested.

## RESULTS AND DISCUSSION

In order to model deflection of bias-ply tire based tire dimensions (section width and overall unloaded diameter of tire), tire inflation pressure and vertical load on tire, seven multiple variables regression models were suggested and all the data were subjected to regression analysis using the Microsoft Excel 2007. All the multiple variables regression models and their relations are shown in Table 5.

In addition, the p-value of the independent variables and coefficient of determination ( $R^2$ ) for the seven multiple variables regression models are shown in 6. Among the seven models, model No. 1 had the highest  $R^2$  value (0.983). Moreover, this model totally had the lowest p-value of independent variables among the seven models. Based on the statistical results model No. 1 was selected as the best model, which is given by equation 6:

$$\delta = 51.57 - 0.040 b - 0.019 d - 0.905 P + 3.534 W \quad (6)$$

In this model, deflection of bias-ply tire can be predicted using multiple variables regression of section width, overall unloaded diameter, inflation pressure and vertical load.

## CONCLUSIONS

It can be concluded that the multiple variables regression model  $\delta = 51.57 - 0.040 b - 0.019 d - 0.905 P + 3.534 W$  with  $R^2 = 0.983$  may be suggested to predict deflection of bias-ply tire based on tire dimensions (section width and overall unloaded diameter of tire), tire inflation pressure and vertical load on tire for a limited range of bias-ply tire sizes. However, experimental verification of this model is necessary before the model can be recommended for wider use.

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