

## Modeling of Radial-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 radial-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 radial-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  $\delta = 75.67 + 0.104 b - 0.107 d - 0.758 P + 3.519 W$  with  $R^2 = 0.986$  may be suggested to predict deflection of radial-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 radial-ply tire sizes. However, experimental verification of this model is necessary before the model can be recommended for wider use.

**Key words:** Radial-ply tire • Deflection • Dimensions • Inflation pressure • Vertical load • 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 does 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)

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:

L = Contact length of tire (m)  
 d = Overall unloaded diameter of tire (m)  
 $\delta$  = 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. 1 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 pressure is standard tire data from the tire data handbooks. It can also be obtained by measuring the tire [4, 5].

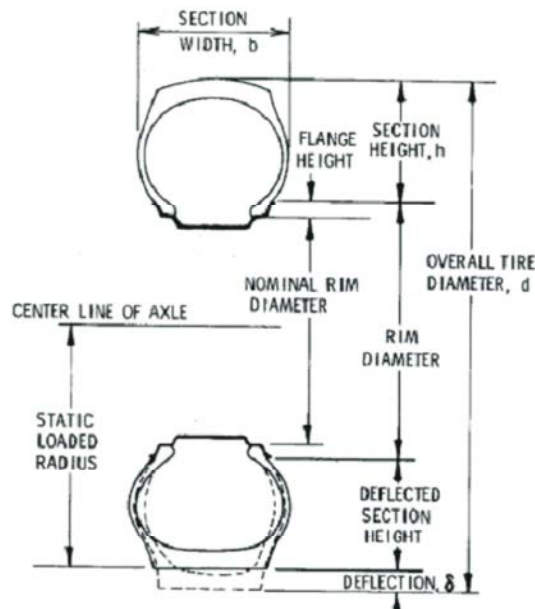


Fig. 1: Tire dimensions, adapted from Brixius [4]

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 radial-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. 2) was designed and constructed to measure deflection of tires with different sizes at diverse 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. 3.

**Experimental Procedure:** For this purpose, deflection of three radial-ply tires with different dimensions were measured at five levels of inflation pressure and five levels of vertical load. The dimensions of three radial-ply tires are given in Table 1. Results of deflection measurement for radial-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 3 [6-13]:



Fig. 2: Tire deflection test apparatus



Fig. 3: Measuring static loaded radius

$$Y = C_0 + C_1X_1 + C_2X_2 + \dots + C_nX_n \quad (3)$$

Where:

$Y$  = Dependent variable, for example deflection of radial-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.

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

Tire No.	Tire size designation	Section width b (mm)	Overall unloaded diameter d (mm)
1	R13-165/65	165	535
2	R14-185/65	185	580
3	R15-185/65	185	610

Table 2: Section width, overall unloaded diameter, inflation pressure, vertical load and deflection for radial-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	165	535	30	5.8690	31.0
				7.8250	39.0
				9.7810	47.5
				11.738	55.0
			32	13.694	62.0
				5.8690	28.5
				7.8250	38.0
				9.7810	47.0
				11.738	53.0
			34	13.694	60.0
				5.8690	29.0
				7.8250	36.5
				9.7810	44.5
				11.738	51.5
			36	13.694	58.0
				5.8690	27.5
				7.8250	36.0
				9.7810	43.0
				11.738	49.0
			38	13.694	55.0
				5.8690	26.5
				7.8250	35.0
				9.7810	42.5
				11.738	49.0
				13.694	55.0

Table 3: Section width, overall unloaded diameter, inflation pressure, vertical load and deflection for radial-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	580	30	5.8690	29.5
				7.8250	38.0
				9.7810	44.5
				11.738	50.5
			32	13.694	58.0
				5.8690	28.5
				7.8250	35.5
				9.7810	43.0
				11.738	48.0
			34	13.694	55.0
				5.8690	28.0
				7.8250	35.0
				9.7810	41.5
				11.738	47.5
			36	13.694	54.0
				5.8690	26.5
				7.8250	33.0
				9.7810	44.5
				11.738	46.0
			38	13.694	51.5
				5.8690	26.0
				7.8250	31.5
				9.7810	40.5
				11.738	43.5
				13.694	50.5

Table 4: Section width, overall unloaded diameter, inflation pressure, vertical load and deflection for radial-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	185	610	30	5.8690	26.0
				7.8250	35.0
				9.7810	42.0
				11.738	48.0
				13.694	54.5
			32	5.8690	28.0
				7.8250	35.0
				9.7810	40.5
				11.738	47.5
				13.694	53.5
			34	5.8690	22.5
				7.8250	31.5
				9.7810	37.0
				11.738	45.0
				13.694	52.0
			36	5.8690	22.0
				7.8250	30.5
				9.7810	36.0
				11.738	42.5
				13.694	49.5
			38	5.8690	21.0
				7.8250	26.5
				9.7810	34.5
				11.738	41.5
				13.694	47.5

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 radial-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 Table 6. Among the seven models, model No. 1 had the highest  $R^2$  value (0.986). 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 4:

Table 5: Seven multiple variables regression models and their relations

Model No.	Model	Relation
1	$\delta = C_0 + C_1 b + C_2 d + C_3 P + C_4 W$	$\delta = 75.67 + 0.104 b - 0.107 d - 0.758 P + 3.519 W$
2	$\delta = C_0 + C_1 b + C_2 P + C_3 W$	$\delta = 71.38 - 0.219 b - 0.758 P + 3.519 W$
3	$\delta = C_0 + C_1 d + C_2 P + C_3 W$	$\delta = 77.43 - 0.078 d - 0.758 P + 3.519 W$
4	$\delta = C_0 + C_1 (bd) + C_2 P + C_3 W$	$\delta = 54.83 - 0.0002 (bd) - 0.758 P + 3.519 W$
5	$\delta = C_0 + C_1 (b/d) + C_2 P + C_3 W$	$\delta = -9.675 + 135.7 (b/d) - 0.758 P + 3.519 W$
6	$\delta = C_0 + C_1 (d/b) + C_2 P + C_3 W$	$\delta = 76.20 - 13.58 (d/b) - 0.758 P + 3.519 W$
7	$\delta = C_0 + C_1 (bd)^{0.5} + C_2 P + C_3 W$	$\delta = 76.28 - 0.137 (bd)^{0.5} - 0.758 P + 3.519 W$

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					$(bd)^{0.5}$	P	W	$R^2$
	b	d	bd	b/d	d/b				
1	0.009716	2.50E-13	---	---	---	---	4.24E-23	4.10E-65	0.986
2	1.33E-14	---	---	---	---	---	2.49E-15	2.05E-54	0.970
3	---	4.61E-25	---	---	---	---	2.69E-22	1.64E-64	0.985
4	---	---	1.53E-20	---	---	---	4.29E-19	3.77E-60	0.979
5	---	---	---	0.005114	---	---	1.20E-09	1.09E-43	0.938
6	---	---	---	---	0.003795	---	1.07E-09	8.48E-44	0.938
7	---	---	---	---	---	3.02E-20	6.81E-19	7.32E-60	0.979

$$\delta = 75.67 + 0.104 b - 0.107 d - 0.758 P + 3.519 W \quad (4)$$

In this model, deflection of radial-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  $\delta = 75.67 + 0.104 b - 0.107 d - 0.758 P + 3.519 W$  with  $R^2 = 0.986$  may be suggested to predict deflection of radial-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 radial-ply tire sizes. However, experimental verification of this model is necessary before the model can be recommended for wider use.

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