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Modeling of Radial-Ply Tire Contact Length Based on Overall Unloaded Diameter, Inflation Pressure, Vertical Load and Rotational Speed

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Abstract: This study was conducted to model contact length (L) of radial-ply tire based on overall unloaded diameter (d), inflation pressure (P), vertical load (W) and rotational speed (N). For this reason, contact length of three radial-ply tires with different 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 contact length based on overall unloaded diameter, inflation pressure and vertical load, a four-variable linear regression model was suggested and all the data were subjected to regression analysis. The statistical results of study indicated that the four-variable linear regression model L = 552.1 - 0.656 d - 2.930 P + 0.320 W - 0.009 N with R^2 = 0.9711 may be suggested to predict contact length of radial-ply tire based on overall unloaded diameter, inflation pressure, vertical load and rotational speed for a limited range of radial-ply tire sizes.

Key words: Radial-ply tire · Contact length · Overall unloaded diameter · Inflation pressure · Vertical load · Rotational speed · 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]:

$$A = bL \tag{1}$$

where:
A = Contact area of tire (m^2)
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:

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

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

where:
d = Overall unloaded diameter of tire (m)

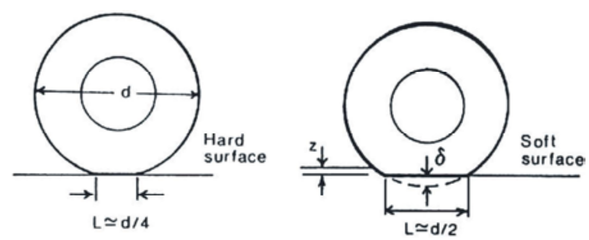

Fig. 1: Contact lengths of tires on hard and soft surfaces, adapted from McKyes [1]

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

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

where:

δ = Deflection of tire (m)

Tire contact length is a key parameter and many equations have been developed based on tire contact length to evaluate the tractive performance of radial-ply and bias-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

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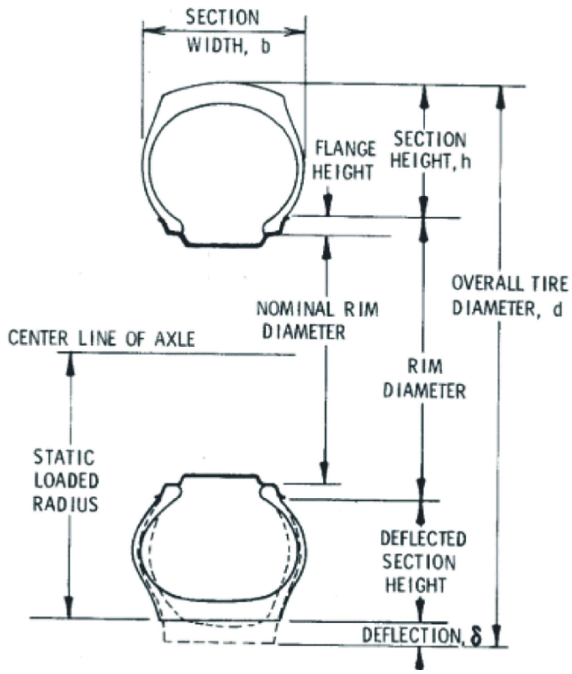

Fig. 2: Tire dimensions, adapted from Brixius [4]

Fig. 3: Tire contact length measurement apparatus

Table 1: Overall unloaded diameter of three radial-ply tires used in this study

Tire No.	Overall unloaded diameter d (mm)
1	578
2	582
3	605

load, tire slip, tire size, tire deflection and tire contact length [4]. Fig. 2 shows the tire dimensions (b, d and δ) used. The tire dimensions can be obtained from tire data book or by measuring the tire. 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 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 contact length for a given tire size, inflation pressure, vertical load and rotational speed may significantly be different between radial-ply and bias-ply tires, this study was conducted to model contact length (L) of radial-ply tire based on overall unloaded diameter (d), inflation pressure (P), vertical load (W) and rotational speed (N) using a linear regression model.

MATERIALS AND METHODS

Tire Contact Length Test Apparatus: A tire contact length test apparatus was designed and constructed to measure contact length of tires with different sizes at diverse levels of inflation pressure, vertical load and rotational speed (Fig. 3).

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

Regression Model: A typical four-variable linear regression model is shown in equation 5 [6-11]:

$$Y = C_0 + C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 \quad (5)$$

Table 2: Overall unloaded diameter, inflation pressure, vertical load, rotational speed and contact length (three replications) for radial-ply tire No. 1

				Contact length L (mm)		
Overall unloaded diameter d (mm)	Inflation pressure P (psi)	Vertical load W (kg)	Rotational speed N (rev/min)	L_1	L_2	L_3
578	30	100	0	121	121	120
			600	115	115	115
			700	114	114	114
			800	113	113	112
			900	112	112	111
			1000	111	111	111
		150	0	138	138	137
			600	131	131	130
			700	130	130	130
			800	128	128	129
			900	127	127	127
			1000	126	126	126
		200	0	148	148	147
			600	141	141	141
			700	140	140	140
			800	139	139	139
			900	138	138	137
			1000	137	137	137
		250	0	157	157	157
			600	151	151	150
			700	150	150	150
			800	149	149	149
			900	148	148	148
			1000	147	147	147
	35	100	0	104	103	103
			600	97	97	97
			700	96	96	96
			800	95	95	95
			900	94	94	94
			1000	93	93	93
		150	0	122	122	122
			600	116	117	116
			700	115	115	115
			800	113	112	113
			900	111	110	111
			1000	109	109	109
		200	0	139	139	139
			600	135	135	135
			700	134	134	134
			800	133	133	133
			900	132	132	132
			1000	131	132	131
		250	0	151	150	151
			600	146	146	146
			700	145	145	145
			800	144	144	144
			900	143	143	143
			1000	142	142	142

Table 2: Continued

Overall unloaded diameter d (mm)	Inflation pressure P (psi)	Vertical load W (kg)	Rotational speed N (rev/min)	Contact length L (mm) L_1	L_2	L_3
	40	100	0	86	87	86
			600	83	82	83
			700	82	82	82
			800	80	80	80
			900	78	78	79
			1000	77	77	76
		150	0	104	104	105
			600	99	99	100
			700	98	97	97
			800	96	95	95
			900	93	94	93
			1000	91	91	91
		200	0	125	125	125
			600	119	119	119
			700	118	117	117
			800	116	116	116
			900	115	115	115
			1000	114	115	114
		250	0	134	134	134
			600	128	127	128
			700	126	126	126
			800	125	125	125
			900	124	124	124
			1000	123	123	123

Table 3: Overall unloaded diameter, inflation pressure, vertical load, rotational speed and contact length (three replications) for radial-ply tire No. 2

Overall unloaded diameter d (mm)	Inflation pressure P (psi)	Vertical load W (kg)	Rotational speed N (rev/min)	Contact length L (mm) L_1	L_2	L_3
582	30	100	0	110	110	110
			600	104	104	103
			700	102	102	101
			800	100	100	99
			900	99	99	99
			1000	98	98	98
		150	0	129	129	129
			600	125	125	125
			700	124	124	124
			800	123	123	122
			900	122	122	122
			1000	121	121	120
		200	0	151	151	151
			600	148	148	147
			700	147	147	146
			800	147	147	146
			900	146	146	145
			1000	145	145	145
		250	0	168	168	168
			600	164	164	163
			700	163	163	162
			800	162	162	161
			900	161	161	160
			1000	160	160	160

Table 3: Contiued

Overall unloaded diameter d (mm)	Inflation pressure P (psi)	Vertical load W (kg)	Rotational speed N (rev/min)	Contact length L (mm) L_1	L_2	L_3
	35	100	0	95	95	95
			600	90	90	89
			700	89	89	89
			800	87	87	87
			900	86	86	86
			1000	85	84	84
		150	0	114	114	114
			600	100	100	101
			700	98	98	98
			800	97	97	97
			900	96	96	97
			1000	95	95	95
		200	0	130	130	130
			600	126	126	126
			700	125	125	124
			800	124	123	123
			900	123	122	122
			1000	121	121	121
		250	0	140	140	140
			600	137	137	136
			700	136	136	135
			800	135	135	135
			900	135	135	134
			1000	134	134	133
	40	100	0	87	87	87
			600	82	82	81
			700	81	81	80
			800	80	80	79
			900	79	79	78
			1000	78	78	78
		150	0	105	105	105
			600	99	99	98
			700	98	98	97
			800	97	97	96
			900	96	96	95
			1000	95	95	94
		200	0	117	117	117
			600	113	113	112
			700	112	112	111
			800	111	111	110
			900	110	110	109
			1000	109	109	108
		250	0	132	132	132
			600	126	126	126
			700	126	126	125
			800	125	125	124
			900	124	124	123
			1000	123	123	123

Table 4: Overall unloaded diameter, inflation pressure, vertical load, rotational speed and contact length (three replications) for radial-ply tire No. 3

				Contact length L (mm)		
Overall unloaded diameter d (mm)	Inflation pressure P (psi)	Vertical load W (kg)	Rotational speed N (rev/min)	L_1	L_2	L_3
605	30	100	0	99	99	99
			600	93	93	92
			700	92	92	91
			800	91	91	90
			900	90	90	89
			1000	89	89	88
		150	0	116	116	116
			600	111	111	110
			700	110	110	109
			800	109	109	108
			900	108	108	107
			1000	107	107	106
		200	0	130	130	130
			600	127	127	126
			700	126	126	125
			800	125	125	124
			900	124	124	123
			1000	123	123	124
		250	0	149	149	149
			600	144	144	143
			700	143	143	142
			800	142	142	141
			900	141	141	140
			1000	140	140	139
	35	100	0	80	80	80
			600	76	76	75
			700	75	75	74
			800	74	74	73
			900	73	73	72
			1000	72	72	72
		150	0	100	100	100
			600	94	94	93
			700	93	93	92
			800	92	92	91
			900	91	91	90
			1000	90	90	89
		200	0	118	118	118
			600	113	113	112
			700	112	112	111
			800	111	111	110
			900	110	110	109
			1000	109	109	108
		250	0	131	131	131
			600	128	128	128
			700	128	128	128
			800	127	127	127
			900	127	127	127
			1000	126	126	126

Table 4: Continued

Overall unloaded diameter d (mm)	Inflation pressure P (psi)	Vertical load W (kg)	Rotational speed N (rev/min)	Contact length L (mm) L_1	L_2	L_3
	40	100	0	73	73	73
			600	67	67	66
			700	66	66	65
			800	65	65	64
			900	64	64	63
			1000	63	62	63
		150	0	87	87	87
			600	84	84	84
			700	84	84	83
			800	83	83	83
			900	83	83	82
			1000	82	82	82
		200	0	98	98	98
			600	95	95	95
			700	94	94	94
			800	94	94	93
			900	93	93	93
			1000	93	93	92
		250	0	109	109	109
			600	108	107	107
			700	107	107	106
			800	106	106	106
			900	106	106	105
			1000	105	105	105

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

Model	p-value d	P	W	N	R^2
L = 552.1 - 0.656 d - 2.930 P + 0.320 W - 0.009 N	3.2E-222	0	0	2.18E-65	0.9711

where:

Y = Dependent variable, for example contact length of radial-ply tire
X_1, X_2, X_3, X_4 = Independent variables, for example overall unloaded diameter, inflation pressure, vertical load and rotational speed
C_0, C_1, C_2, C_3, C_4 = Regression coefficients

To model contact length based on overall unloaded diameter, inflation pressure, vertical load and rotational speed, a four-variable linear regression model was suggested.

RESULTS AND DISCUSSION

In order to model contact length of radial-ply tire based on overall unloaded diameter, inflation pressure, vertical load and rotational speed, a four-variable linear regression model was suggested and all the data were subjected to regression analysis using the Microsoft Excel 2007. The four-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 0.9711, indicating good agreement of the experimental data. In addition, the p-value of independent variables (d, P, W and N) is as follows: 3.2E-222, 0, 0 and 2.18E-65, respectively. Thus, based on the statistical results, this model is initially accepted, which is given by equation 6:

$$L = 552.1 - 0.656\,d - 2.930\,P + 0.320\,W - 0.009\,N \quad (6)$$

In this model, contact length of radial-ply tire can be predicted using a four-variable linear regression of overall unloaded diameter, inflation pressure, vertical load and rotational speed.

CONCLUSION

It can be concluded that the four-variable linear regression model L = 552.1 - 0.656 d - 2.930 P + 0.320 W - 0.009 N with R^2 = 0.9711 may be suggested to predict contact length of radial-ply tire based on overall unloaded diameter, inflation pressure, vertical load and rotational speed for a limited range of radial-ply tire sizes.

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