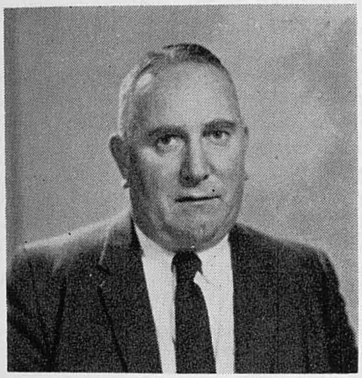
"COMPACTION OF ASPHALTIC CONCRETE"



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Some of the most pressing problems in the field of highway production today involve the compaction of embankments, subgrades, base courses and surface courses. The more one delves into our current standards and procedural requirements for compaction of these various roadway elements, the more complicated the picture becomes.

There is considerable variance in thinking as to what should be the characteristics of the finished product with respect to density or to some measure to which future service behavior can be related. In many instances we are still requiring the same procedures and equipment that were employed years ago, although pavement designs and the character of the traffic using our highways have changed to a considerable extent. Some equipment requirements in construction specifications are either restrictive or obsolete, since provisions are not included for taking advantage of new developments which are capable of superior or more economical performance. If rigid procedural or equipment requirements are used, they tend to stifle the initiative of contractors in developing new methods and to retard the development of improved and more adaptable equipment on the part of manufacturers.

The topic under discussion today is the "Compaction of Asphaltic Concrete." Consideration of the compaction of asphaltic concrete surface courses and their supporting foundations is indeed timely, since about 16,000 miles of this type are now placed each year on the State Highway systems alone.

The National Bituminous Concrete Association has recently adopted a 10-point improvement and quality control program in which the compaction problem has been given a very high priority.

Compaction of Base Courses

While most of these remarks will be directed towards compaction of surface courses, it will be necessary to discuss, to some extent, the compaction of other elements which are part of the total pavement design. As has been pointed out many times before, it is difficult to consider a pavement surface without giving recognition to the base and subbase courses. Needless to say, the base should have sufficient supporting ability to withstand, without deformation, the reaction of tire loads that are imposed on it from the wearing course.

This ability to support involves the characteristics of the materials as well as density and moisture conditions. There seems to be a growing realization that a desirable degree of compaction for all embankment and base materials cannot be expressed as a single percentage of the maximum density at optimum moisture. For example, 95 percent may be too great for materials containing clay and insufficient for granular materials. A few states are using variable percentage requirements depending on the physical characteristics of the material used or its service record over a number of years. A majority of the states, however, are using a single percentage requirement for all materials used in base courses.

In addition to the prevailing ranges of density requirements, there is also a number of methods for the basic determination. We now have two methods under AASHO test procedures for determining maximum densities, and a number of states have adopted their own method. Since each method provides a different answer, there is little opportunity to benefit from the exchange of experience in procedures and equipment application between states.

In addition to the ranges in density requirement and the method of attaining the same, there is a wide spread in the requirements for the maximum thickness of the base course layers to be compacted. It varies from a commonly used 3 to 5 inches to such maximum limits as 8 and 10 inches.

Equipment Requirements

Most of the current construction specifications for base courses provide for or require the use of conventional steel wheel rollers, tamping rollers and pneumatic tired rollers and, in a few instances, the vibratory types.

Most of the pneumatic roller requirements do not provide for the use of the recently developed high pressure tires which appear to offer one solution for the densification of most types of base courses. The Michigan State Highway Department took a desirable step in their 1958 special provision covering test rolling with a heavy compactor by inserting the following requirement:

> "The contractor shall furnish to the engineer, charts or tabulations showing the contact areas and contact pressures for the full range of tire inflation pressures and for the full range of loadings for the tire furnished."

With this information the engineer can determine the effect of varying wheel loads and inflation pressures for the tire size and the prevailing soil conditions. Heretofore, the engineer has been unable to determine the net result of modifying ballast and tire pressures.

Contact areas along with contact pressures are of some importance when compacting or testing deep layers of soils, particularly in elastic materials where Boussinesq's theory[1] of pressure distribution is applicable. Tests conducted by the U. S. Corps of Engineers at Vicksburg, Mississippi, on large compactor size tires tested on lean clay soils show that the loss in pressure due to smaller contact area was not significant at depths of less than 10 inches. When tire contact area was decreased about 18 percent, a pressure loss of about 5 percent under that exerted by the larger tire was experienced at depths of 5 inches below the surface. The pressure intensity of approximately 90 percent of surface contact pressures was experienced at depths of 5 inches below the surface for the tire sizes and surface pressure employed. The smaller size tires may therefore have their place in base compaction. More will be devoted to the subject of tire pressure distribution later in this discussion.

Many current base construction specifications also exclude the use of the dynamic type compactors including the pad or plate types on which reports indicate very good results in compacting granular type bases including macadam courses. Engineers have misgivings with regard to some types of equipment attachments. Tests, however, have shown that the addition of a trailing vibratory compacting unit to a 3-wheel roller enabled the equipment to obtain a higher density than could be obtained with the static roller regardless of the number of passes made.

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[1] A series of equations expressing stress components caused by perpendicular, point, surface force, at points within an elastic isotropic homogeneous mass which extends infinitely in all directions from a level surface.

Vibratory steel wheel rollers are being used to a greater extent in compacting base courses. Most of the models used are of the towed type, although one small self-propelled roller of German manufacture was introduced in this country during the last two years and has demonstrated its ability to compact soil bases and asphaltic binder courses with a minimum number of passes.

There is a need for more performance information on many of the new roller and compactors, particularly on the dynamic types, for various materials and conditions. A wide variance exists in the frequency of vibrations of the several vibratory models and in many of the manufacturers' claims on effective compaction depths and number of passes required for given density requirements. A considerable amount of basic research has been done on pad or plate type vibration by the California Institute of Technology with laboratory models in cooperation with the U.S. Navy Civil Engineering Corps. There have been no comprehensive tests made, however, with commercial models.

Good results have also been reported in the compaction of base courses with grid rollers and with segmented pad type rollers, but here again we need more information on performance for various materials and conditions.

The problems associated with the compaction of base courses certainly deserve more consideration than has been given them in the brief remarks contained in this paper. It will be necessary, however, to move on to the main topic of discussion—the compaction of asphaltic concrete surface courses. Some of the remarks made will also be applicable to base course compaction.

Compaction of Surface Courses

Surface Stability Requirements

First of all, it would be well to analyze what is being sought for in the stability of the final product. Based on available information, twenty-six of the forty-nine states and the territory of Hawaii have density requirements for finished asphaltic concrete pavements. Twenty-seven states and Hawaii have specific requirements, and one state establishes the density after the job mix is established. Here in Kentucky, specifications require a "satisfactory density as determined by method of test designated by the engineer." Of the twenty-eight states and territories having specific density requirements, fifteen jurisdictions relate the requirement to a percentage of theoretical density or a voidless mixture. The other thirteen states base their percentage on the density of a laboratory mix. Not all these states identify the test for the laboratory design method used, but three indicated the Marshall method and another two the Hubbard-Field while several others indicated the California or Hveem method.

The range of requirements based on theoretical density varies from 85 percent for binder courses to 99 percent for surface courses. The range of requirements based on the density of laboratory mixes varies from 92 to 98 percent. One state increases their percentage requirement of laboratory density from 93 to 95 percent after September 1. Even when variances in mixes are considered, both ranges appear to be too great for products which are to be subjected to comparable truck tire loads.

With regard to the method of basing the density requirements, both the Asphalt Institute and our Bureau recommend a percentage based on a laboratory mix. This is because it is not always possible to attain a specified percentage of a voidless mixture without crushing the aggregate particles and thereby changing the character of the mix. A laboratory mix, on the other hand, always contains sufficient voids to allow for bleeding and for some degree of densification under traffic. A range of from 95 to 98 percent of laboratory density would be a desirable goal in the compaction of asphaltic concrete surfaces.

Equipment Requirements

Practically all of the states have requirements for approved type rolling equipment for compacting asphaltic concrete surfaces. This includes those states which have also adopted an "end result" requirement in the form of a minimum density. The advantages of end result features are largely nullified, however, by specifying the equipment to be used and the method to be employed.

Steel Wheel Rollers

Steel wheel rollers which have changed little from a capacity standpoint for several decades remain the more commonly used units for compacting asphaltic concrete. A majority of the states require the use of tandem rollers for finish rolling and permit either tandem or 3-wheel on the breakdown rolling.

On the finish or final rolling, several states may require diagonal and/or cross rolling of the surface with tandem rollers. A number of asphalt technicians advocate this procedure to guard against undue post construction densification that often occurs under heavy traffic. Some of the objections to the steel wheel types, however, are their tendency to bridge over low spots and to confine the final degree of compaction achieved to a thin layer near the surface.

While there is reasonable uniformity in the general types of steel wheeled rollers required, there is a wide variation in the capacities as expressed in tons and minimum compression per inch of driving rolls. The tonnage requirements for tandems vary from 5 to 10 tons and on 3-wheel rollers from 8 to 12 tons. For 3-wheel rollers the minimum compression varies from 200 to 350 pounds per inch of driving wheel. For tandem rollers the variance is from 160 to 400 pounds per inch of driving wheel or a range of 150 percent between the low and the high requirements.

There is no correlation between the density requirements and the above minimum roller capacities. For example, a state which specifies 90 percent of theoretical density of the wearing course requires a greater compression (250 pounds) on the driving wheel than a State (200 pounds) which requires up to 98 percent of theoretical density.

Torque converters are often desirable on tandem rollers which do the finish rolling due to the ease of reversing direction without scuffing the surface. Such rollers should be equipped with two-speed transmission if compaction on steep grades (6 percent and over) is contemplated.

Pneumatic Tired Rollers

One of the most significant developments in the field of asphaltic concrete compaction has been recent improvements in pneumatic rolling equipment, particularly with the advent of torque converters and high pressure tires.

Many highway departments have discovered the potency of heavy truck tires in the densifying of asphaltic concrete pavements subsequent to construction. This post-construction densification occurs when the wearing surface softens under extreme summer heat with rutting often prevalent in the wheel tracks. Wheel rutting from truck traffic is not confined to isolated projects on our primary and secondary highways, but has been experienced on some of our well known and better engineered expressways, especially where flexible bases have been used.

Past experience seems to infer that where rutting of the asphaltic concrete surface has occurred in the wheel tracks, the base or surface courses or both were compacted during construction with equipment that was not capable of exerting the pressures produced by the heavier truck tires used today.

Early last year the Goodyear Tire and Rubber Company furnished our Bureau with information on contact area on truck tires for manufacturer's recommended inflation pressures and rated wheel loads. From this information it was possible to compute the average contact pressure for the various sizes. The term *average* contact pressure is used because the pressure is not constant throughout the elliptical contact pattern of the tire. The average contact pressure is obtained by dividing the contact area into the wheel load to obtain pounds per square inch or "p.s.i." Contact areas are obtained for different wheel loads and inflation pressures by tracing the contract patterns on a glass or steel plate with the tire in a static position. The following is a tabulation showing this data for the more popular sizes used on the heavier truck combinations.

TABLE I

CONTACT AREAS OF HIGHWAY TIRES AT LOADS AND INFLATIONS SHOWN

Truck Tire Size	Ply	Inflation Pressure (psi)	Wheel Load (lbs)	Contact Area (sq in)	Computed Av. Contact Pressure (psi)
7.50x20	8	65	2740	48.4	56.6
8.25x20	10	70	3330	50.5	65.9
9:00x20	10	70	3960	60.6	65.3
10.00x20	12	75	4580	71.8	63.8
11.00x20	12	80	4850	67.4	72.0
11.00x22	12	70	4750	75.3	63.1

There are several other tires, notably in the 7.50x15—12 ply and 14.00x20—18 ply sizes, which produce contact pressures up to 93.4 p.s.i. and 82.5 p.s.i., respectively. However, these tire sizes are used to only a limited extent.

A study[1] made by the Division of Highway Transport of our Bureau of the air inflation pressures in operating truck tires revealed that the current practice was to operate at average hot inflation pressures of about 10 percent above the tire manufacturers recommendation. While this would increase the average contact pressures shown in Table I, the study also revealed that maximum wheel loads were seldom used in actual operations. Accordingly, it is believed that the contact pressure shown on Table I may be considered the maximums to be expected in normal use. In the compacting or densifying of asphaltic concrete at the intermediate or semifinal stage with pneumatic tired rollers, it is believed that the rollers used should be capable of exerting an average cotact pressure *of at least 80 p.s.i.* The maximum required will depend to some extent on the characteristics of the mix.

All of the three currently manufactured smooth compactor tire sizes of the ply ratings indicated below are capable of exerting average contact pressures of 80 p.s.i. and over.

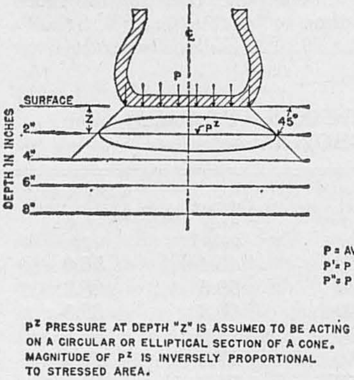
TABLE II

Tire Size	Ply	Inflation Pressure (psi)	Wheel Load (lbs)	Average Contact Pressure (psi)
7.50x15	10	90	5130	82.6
9.00x20	10	90	8000	83.0
13.00x24	18	90	12000	88.2 (Approx.)

The above tabulation does not show the maximum contact pressure which can be exerted by each tire size, but serves to illustrate that all sizes are capable of exerting at least 80 p.s.i. The two smaller sizes are also manufactured in 12 ply sizes which along with the 13.00x24—18 ply size can be inflated to a maximum of 100 p.s.i. with standard rims and thereby obtain contact pressures approaching and exceeding 100 p.s.i.

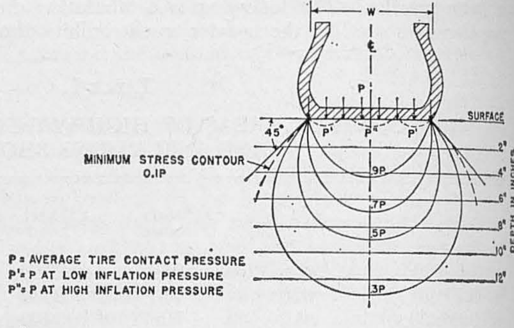
Compactor tires are rated for given wheel loads and inflation pressures (such as for the 7.50x15 and 9.00x20 sizes listed above), and the tire pressures and

[1] Public Roads, Vol. 28, No. 22, Feb. 1958.



CONE OF PRESSURE
(AS ASSUMED FROM BOUSSINESQ'S FORMULAS)

FIG. 1



TYPICAL PRESSURE BULBS
SHOWING STRESS DISTRIBUTION AS INFLUENCED BY TIRE CONTACT PRESSURES

FIG. 2

wheel loads may be reduced or increased within limits of deflection. As inflation pressure is increased or decreased, tire manufacturers recommend that ballast be adjusted accordingly. A typical tabulation showing the allowable ranges of inflation pressures and corresponding wheel loads for a compactor tire is included in the appendix.

During the past year there have been some discussions relative to the pressure distribution of wheel loads below the surface. At least one group holds that the Bossinesq theory is applicable to all materials and conditions and the surface contact pressure is assumed to be distributed below the surface in the shape of a cone radicating at an angle of 45 degrees from the perimeter of the tire contact pattern. (See Figure 1.)

Under this assumption, for which we do not find substantiating evidence, some of the smaller compactor tires would lose 30 percent of their compacting effort 1 inch below the surface, about 50 percent about 2 inches below the surface, etc. I am sure that flexible pavement designers would appreciate the dissipation of heavy truck tire loads at such rates. Actually, Boussinesq's theory is applicable only for certain elastic materials of a homogeneous character which have constant properties of displacement in all directions. Very few highway materials are in this category.

The subsurface influence of a given contact pressure on a circular or elliptical tire pattern appears more likely to take on the form of pressure bulbs in which the points of equal stress below the surface are shown as contours. Figure 2 exemplifies typical pressure bulb distributions of stress influence lines for a single homogeneous layer of materials.

In examining the contours of equal pressures in Figure 2, it is to be noted that the apex or center of the bulbs is located on an axis through the center of the tire both for normal tire pressures and for high inflations where the contact pressure at the center of the tire (P″) would greatly exceed that under the sidewalls. Conversely, under a low inflation the maximum pressure (P′) would be at the edges where the tire receives structural support from the sidewalls. Under these conditions the material being processed receives additional horizontal pressures as well as the vertical pressures.

Work done in both the highway and agriculture fields as well as in the transportation industry with pressure distribution on elastic materials for circular and strip loads indicates that pressure equal to 0.9 of the surface contact (0.9 P) can be expected to depths of at least 3 inches below the surface. This pressure influence of 0.9 would act on approximately two-thirds of the tire width. To get complete coverage of an area to 0.9 P at a depth of 3 inches in a single pass, it would be necessary to have at least some overlap of the front tire tracks with the tires on the rear axle.

Concentrated loads which are applied by truck tires when the highway is in service will not exceed the maximum pressures now obtainable with the smaller compactor tires on or below the roadway surface. In view of the foregoing, it is believed that compactor tire size is not significant in the compaction of asphaltic concrete courses to the depths of 2½ and 3 inches if the roller tires are properly spaced for overlap.

In addition to the high pressure pneumatic rolling of asphaltic concrete, there is some thinking among asphalt technicians that a pneumatic roller with low pressure inflation should be used for the breakdown rolling. When compactor tires are inflated at a low range, 30 to 40 p.s.i., the tire contact pattern is concave and the horizontal forces exerted assist in particle placement and the kneading itself.

1) Most pneumatic roller specifications are either meaningless or are restrictive because they have been written around a single model.
2) There has been a lack of basic technical information on which a non-restrictive specification could be based. (This includes such information as ground or contact pressures for allowable compactor tire inflation ranges and wheel loads.)[1]

Only in the last several years has it been recognized that the average ground pressure exerted by pneumatic tires is not limited to or necessarily equal to inflation pressure.

Let's examine some of the current methods used to rate the capacity of pneumatic rollers in construction specifications by the twelve states in which their use on asphaltic concrete is mandatory and an additional twelve states which permit or may require their use:

1. *Gross Weight*

Several states rate the pneumatic rollers approved for asphaltic concrete compaction by gross weight, and in one instance the number of tires is specified. Neither of these ratings is conclusive without information on the tire size and ply rating. The same applies to the so-called 50-ton compactor which for all practical purposes is a 30-ton compactor when ballasted for this weight. Several manufacturers advertize on the basis of maximum gross weight.

2. *Wheel or Tire Loads*

A number of states specify minimum wheel or tire loads varying from 1,000 to 8,000 pounds. This criteria is also meaningless without tire size and ply rating data. Several of the minimum wheel loads as now specified are well below the minimum of the smallest compactor tire manufactured and must be termed obsolete. Wheel loads in the lower ranges (2,000 to 2,500 pounds) would be suitable for breakdown rolling purposes, but would be of little or no value for densification purposes in intermediate or semifinal rolling.

3. *Weight Per Inch of Tire Width*

Quite a number of states rate the required pneumatic rollers by the "weight per inch of tire width." This rating has little or no significance because the tires make an elliptical pattern and the weight per linear inch varies both for tire sizes and within the pattern itself. This rating seems to be a carry-over from the rating of steel wheel rollers which actually produce rectangular contact patterns under

[1] A considerable amount of such information has been developed recently by tire manufacturers.

most conditions. If the "weight per inch of tire width" requirements were converted into wheel loads on the basis of tire contact width for various tire sizes, it would represent a sizeable range in the contact pressure exerted. For example, a requirement of 600 pounds "per inch of tire width" could convert into a contact pressure of 62.0 p.s.i. for one size tire and into a contact pressure of 81.6 p.s.i. for another size tire. This is a differential of over 30 percent in compacting effort.

4. *Inflation Pressure*

If tire inflation pressure is specified, it could represent a considerable range in contact pressure due to tire sizes and wheel loads (see appendix for contact pressure ranges for only one tire size).

It can be seen from the foregoing that of all the current roller requirements those used for pneumatic rollers are the least expressive of the equipment's ability to perform.

The ability of smooth compactor tires to exert a given contact or ground pressure is dependent on the following factors:

a) Tire size
b) Ply rating
c) Wheel load
d) Tire inflation pressure

It would be possible to specify all of the above factors and still have a restrictive specification because rollers equipped with other size tires under different wheel loads would be capable of exerting comparable contact pressures.

It is our belief that the contact pressure range should be the principal criteria in rating the pneumatic rollers to be used in compacting asphaltic concrete courses and thin layers of base materials.

Until now we have pointed out some of the apparent deficiencies in rating pneumatic rollers. On the positive side it might be worth while to suggest some preliminary guides for describing desirable overall characteristics of pneumatic tired rollers to be used in compacting asphalt concrete courses and thin layers of base materials pending the development of suitable performance criteria. First of all, a minimum width of about 6′6″ would be desirable from a production standpoint. The unit should be equipped with smooth wide tread compactor tires capable of exerting an average contact pressure variable from 60 to 95 p.s.i. uniformly over the surface by adjusting ballast and tire inflation pressure. The wheels should be so mounted as to prevent scuffing of the surface during rolling or turning with provisions for wetting and cleaning tires.

The mentioning of desirable pneumatic roller characteristics in this paper is not necessarily a recommendation for their inclusion in a construction specification. While a number of current models could measure up to these suggested guides, a new model might be introduced this year or next year which would make these features obsolete or restrictive. As you know, the revision and reprinting of construction specifications is a time-consuming procedure. It would seem preferable to develop an "end result" specification where density or other finished characteristics, in addition to profile and crown tolerances would be specified.

Vibratory Compaction Equipment

The principle of vibratory compaction has been incorporated in the asphaltic concrete lay-down process for some time. An American manufacturer has recently introduced a 3-wheel tandem roller with vibration on the middle roll. This roller may have application in the compaction of both binder and surface courses of asphaltic concrete. The vibratory roll is retractable which will allow the roller to be used as a statis unit for finish rolling.

As previously mentioned, a small self-propelled vibratory roller with vibration on the driving wheel of the tandem was introduced in this country about two years ago. It has demonstrated its ability to compact granular bases and asphaltic binder courses to required densities with a minimum number of passes. More performance information is needed on both of these vibratory rollers.

Although the use of vibratory compacting equipment on asphalt concrete courses has been limietd, there is a feeling in some quarters that application of the dynamic principles offers one of the solutions to the compaction of asphaltic concrete.

It has been a pleasure to appear here today to give you some of our ideas on the compaction of asphaltic concrete pavements. While some progress has been made recently in obtaining a better understanding of the problem, much remains to be accomplished, particularly in obtaining unbiased appraisals of equipment performance and in narrowing down the wide spread in other procedural or end result requirements.

APPENDIX

Contact Areas and Ground Pressures

9.00-20 12 Ply Smooth Compactor Tire on 7.00L Rim
at Various Loads & Inflations

Load	55 psi Contact Area	55 psi Press.	65 psi Contact Area	65 psi Press.	75 psi Contact Area	75 psi Press.	80 psi Contact Area	80 psi Press.	95 psi Contact Area	95 psi Press.	105 psi Contact Area	105 psi Press.
4500	70.0	64.4										
4750	72.0	66.0										
5000	73.9	67.8	68.5	73.0								
5250	77.4	68.0	71.0	74.0								
5500	79.5	69.3	73.0	75.4								
5750	81.5	70.6	74.5	77.3	70.5	81.6						
6000	84.5	71.0	77.3	77.6	72.2	83.1	70.0	85.7				
6250	87.0	72.0	79.6	78.2	73.7	84.8	71.3	87.2				
6500	89.5	72.6	81.6	79.6	75.7	85.8	73.0	89.0				
6750	91.5	73.8	83.7	80.6	77.6	87.0	74.6	90.3				
7000	94.8	74.0	85.8	81.6	79.6	87.8	76.5	91.5	69.5	100.0		
7250	97.0	74.9	88.0	82.5	81.5	89.0	78.0	93.0	71.1	102.0		
7500	99.0	75.6	90.0	83.3	83.1	90.1	80.1	93.5	73.0	102.8		
7750			92.1	84.0	86.0	90.2	81.6	95.0	74.3	104.2	70.5	110.0
8000			94.5	84.6	89.0	89.8	83.4	96.2	76.0	105.2	71.6	115.5
8250			96.5	85.5	91.2	90.5	85.4	96.8	77.5	106.5	73.1	112.8
8500			98.6	86.1	93.0	91.4	87.4	97.4	78.7	108.0	74.4	114.3
8750			101.4	86.2	95.0	92.2	88.4	99.3	80.5	108.6	75.7	115.5
9000					96.5	93.3	90.6	99.4	81.8	111.0	77.3	116.5
9250					98.5	94.0	92.5	100.0	83.4	111.1	78.5	117.9
9500					100.6	94.5	94.0	101.1	85.0	112.7	80.0	119.0
9750							95.5	102.0	86.5	112.8	81.5	119.5
10000							97.1	103.0	88.0	113.7	82.6	121.0
10250							99.0	103.5	89.7	114.1	84.1	121.9
10500							101.0	105.0	91.0	115.5	85.6	122.6
10750									92.5	116.1	87.0	123.4
11000									94.0	117.0	88.3	124.7
11250									95.6	117.6	90.0	125.0
11500									97.0	118.6	91.3	126.1
11750									98.5	119.7	92.5	127.2
12000									100.0	120.0	94.1	127.6
12250											95.5	128.5
12500											97.0	128.9
12750											98.5	129.6
13000											99.4	130.0

Underscoring denotes load and inflation for normal deflection of tire
Minimum deflection for above figures is 1.41″
Maximum deflection for above figures is 2.35″

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Courtesy of Goodyear Tire and Rubber Company.