NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1378

DETERMINATION OF THE ELASTIC CONSTANTS OF AIRPLANE TIRES

By Boeckh

Translation of "Ermittlung der elastischen Konstanten von Flugzeugreifen." Focke-Wulf Flugzeugbau GmbH, Bremen/Werkstoff-Versuchsabteilung, Versuchs-Nr. 13 8703.

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SUMMARY

For determination of the elastic constants of airplane tires which are required for the numerical calculations of the shimmy properties of nose and tail wheels, deformation measurements were carried out on four different tires. For this purpose, the tires were loaded in each case with a normal load and then with a lateral force, a tangential force, and a moment.

Moreover, the weight and the mass moment of inertia about a vertical axis were determined for the various tires.

As a basis for the evaluation of the theoretical investigations regarding "The Shimmy of a Wheel With Pneumatic Tire" ("Das Flattern eines mit Luftreifen versehenen Rades") by B. v. Schlippe and R. Dietrich (ZWB-report, vol. 11, issue 2, 1944), the deformation on several airplane tires had to be measured for various load conditions in order to make determination of the elastic constants of the tires possible. It was intended to perform the measurements for three tire inflation pressures.

The following tires were available for the measurements:

560 x 200[1]	685 x 250
630 x 220	700 x 175

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*"Ermittlung der elastischen Konstanten von Flugzeugreifen." Focke-Wulf Flugzeugbau GmbH, Bremen/Werkstoff-Versuchsabteilung, Versuchs-Nr. 13 3703.

[1]NACA reviewer's note: The first and second number given apparently refer to the nominal external diameter and nominal external width, respectively, in millimeters.

The test program provided for the following measurements which are interpreted in more detail by figures 1 to 4.

MEASUREMENT OF THE LENGTH OF THE TIRE CONTACT AREA

The tire, under the prescribed pressure, was loaded by a normal force N acting at the wheel axis. The length of tire contact area 2h was to be measured. The performance of further tests showed that in the case of simultaneous application of a lateral force P the length of tire contact area diminishes. This reduction in the length of tire contact area is practically independent of the tire inflation pressure. Thus, the modified length of tire contact area was given only for the 560 x 200 tire and only for the maximum tire-inflation pressure.

DEFORMATION OF THE TIRE BY THE LATERAL FORCE P

The tire was loaded first by the normal force N. A concrete slab mounted on a roller plate and therefore freely movable in the ground plane served as a bearing surface. The lateral force P deforming the tire toward the side was applied to this ground plate. The lateral deflection of the points on the tire periphery 1 - 8 and of the ground plate was measured. For this purpose, measuring strips with millimeter graduation were fastened at the tire periphery, and their lateral motion was measured with a theodolite.

It was not possible to obtain the motion of the point 1 in all cases. However, in the course of the tests it did appear that the skidding seemed to start already, in the case of the smaller loads, at the outermost tire contact area points AB due to the fact that the surface pressure is smaller here (similar to the case where a moment is applied, as described in section IV). In the cases where the measurement for point 1 could not be carried out, the variation of the deformation between 0 and 1 was faired in the graphs on the basis of the values for point 0.

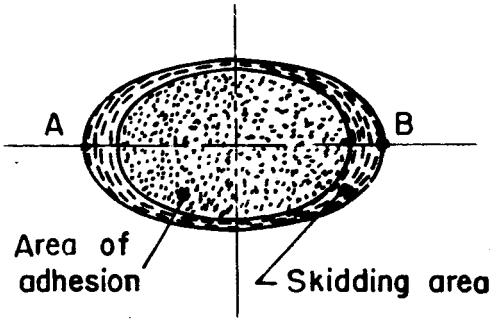
DEFORMATION OF THE TIRE BY THE TANGENTIAL FORCE Q

The braked tire, again loaded by the normal force N, was loaded by a tangential force Q acting in the rolling direction. The quantity to be measured was the displacement λ in the tangential direction of points on the tire circumference; the plane of reference for this was the wheel hub. At the tire points marked by U, O, L, and R, measuring strips

were fastened, the path of which was measured again by means of optical instruments. For further points not lying in the vertical or horizontal, this very accurate method was not applicable. Therefore, the only other quantity measured was the path of the point C; it was measured by means of a frame set up on the wheel axis which marked the original position of the measuring point. The results of these measuring methods which are of different types cannot be immediately compared with one another because of the unavoidable measuring errors. At any rate, the optical measurement results in values of greater accuracy and reliability.

DETERMINATION OF THE SWIVEL ANGLE φ FOR THE MOMENT M

For a given wheel load N, a moment M was introduced into the tire over the ground plate so that the tire contact area underwent a rotation.



We measured, first of all, the angle φ formed by the new position A_1B_1 of the extreme tire contact points with the original position A_oB_o. The two reference points are points on the tire. The angle φ represents, therefore, a pure tire deformation. This deformation increases linearly up to a certain torsional moment and remains constant thereafter. Simultaneously, the angle of rotation φ' of the ground plate was determined. Only in the lowest load ranges do φ and φ' coincide. Afterwards, however, φ' increases more rapidly. A definite skidding moment, at which the tire suddenly starts skidding and beginning from which a further increase in load is no longer possible, does not occur. Skidding of the tire on the ground plate starts at the outermost tire contact area points even for a relatively small torsional moment. With increasing moment, an always larger area of the tire skids. The area of adhesion accordingly decreases. The clearly visible skid marks of the loaded tire provide a reliable confirmation.

First, the investigations were carried out only on the 560 x 200 tire in order to gain experience regarding the usefulness of the measuring methods applied as well as of the measured results obtained. These measurements on the 560 x 200 tire showed that the influence of the tire

inflation pressure is negligibly small. For the sake of economy in work expenditure, the elastic characteristics were determined only for a single inflation pressure in all further tires.

The following graphs contain all measured results. For reasons of simplicity, the individual measured values were connected by straight lines. For the low wheel loads of 500 kg, the measurements did not lead, in all cases, to reliable results. They have therefore only partially been indicated in the graphs.

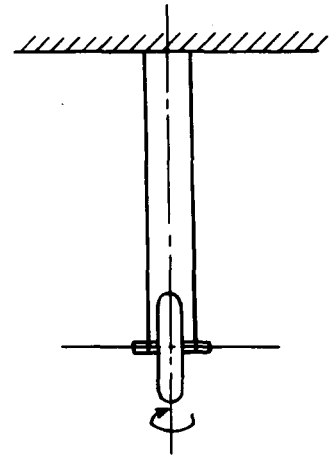
LIST OF THE MEASUREMENTS PERFORMED WITH

CORRESPONDING GRAPH NUMBER

Tire	560 x 200			630 x 220	685 x 250	700 x 175
Gage pressure, atmospheres	4.0	4.5	5.0	4.0	4.5	5.0
2h	5	5	5	24	28	32
P	6-7	8-9	10-11	25	29	33-34
Q	12-13	14-15	16-17	26	30	35
M	18-19	20-21	22-23	27	31	36

DETERMINATION OF THE MASS MOMENTS OF INERTIA ABOUT THE WHEEL AXIS

For the four wheel-tires including the rotating parts of the pertaining wheel centers, the weight and the mass moment of inertia about a vertical axis were determined by oscillation tests using a bifilar suspension.



Wheel-tire	Weights, kg	Moment of inertia, cm-kg-sec^2
560 x 200	15.13	3.13
630 x 220	25.50	7.08
685 x 250	24.96	7.60
700 x 175	25.48	6.93

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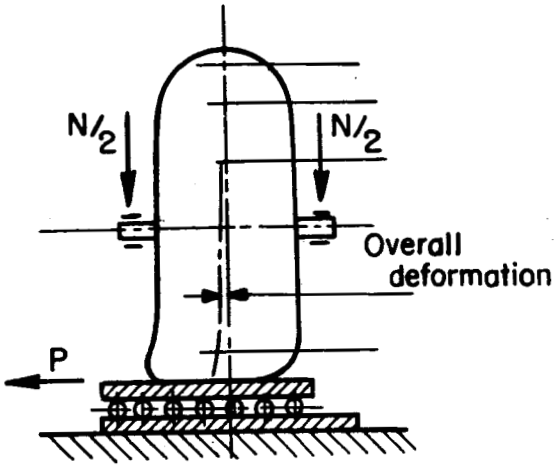


Figure 1.- Determination of the length of the tire contact area.

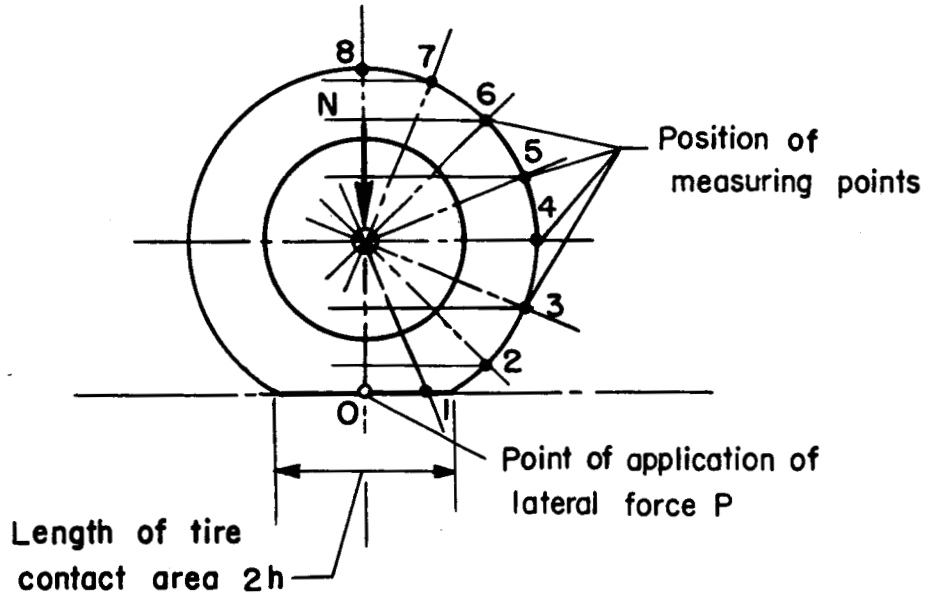


Figure 2.- Lateral deflection of the tire by lateral force P.

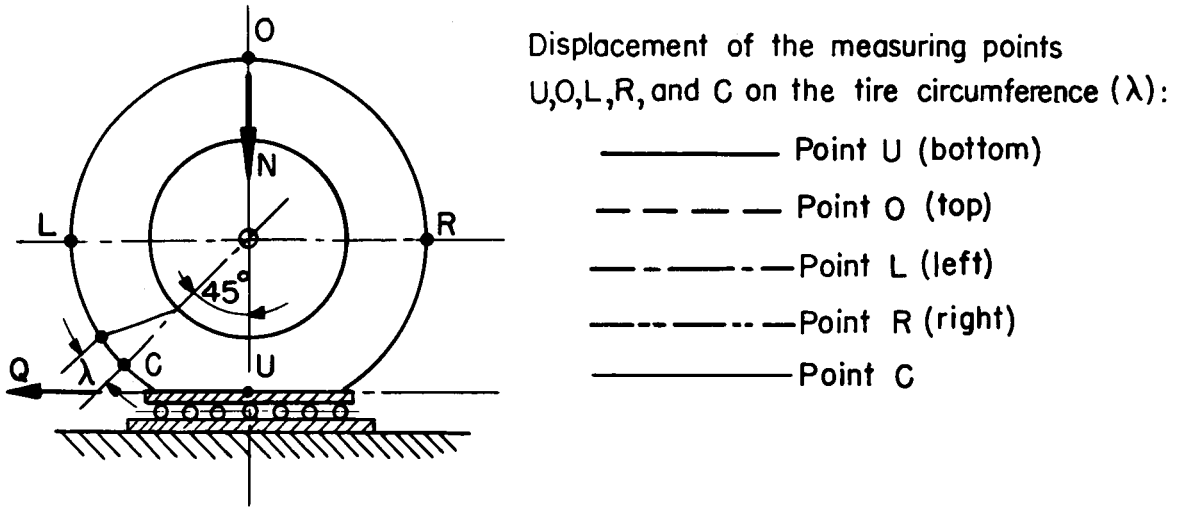
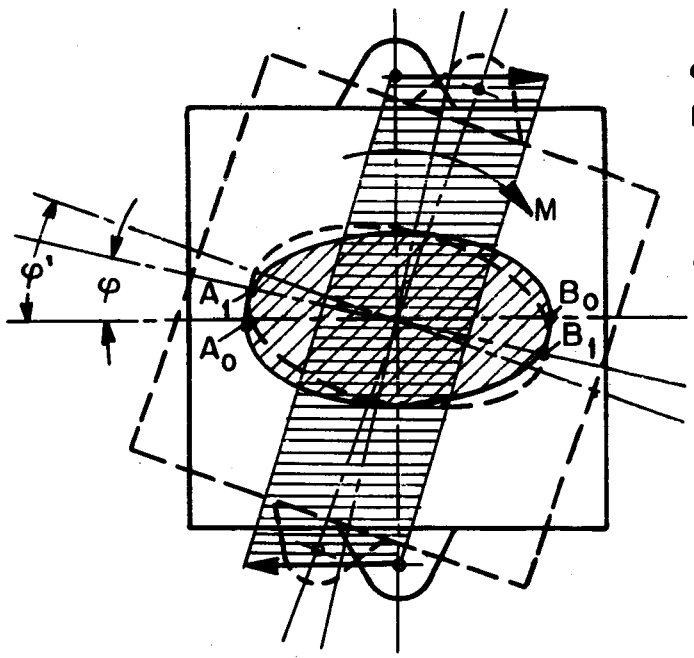
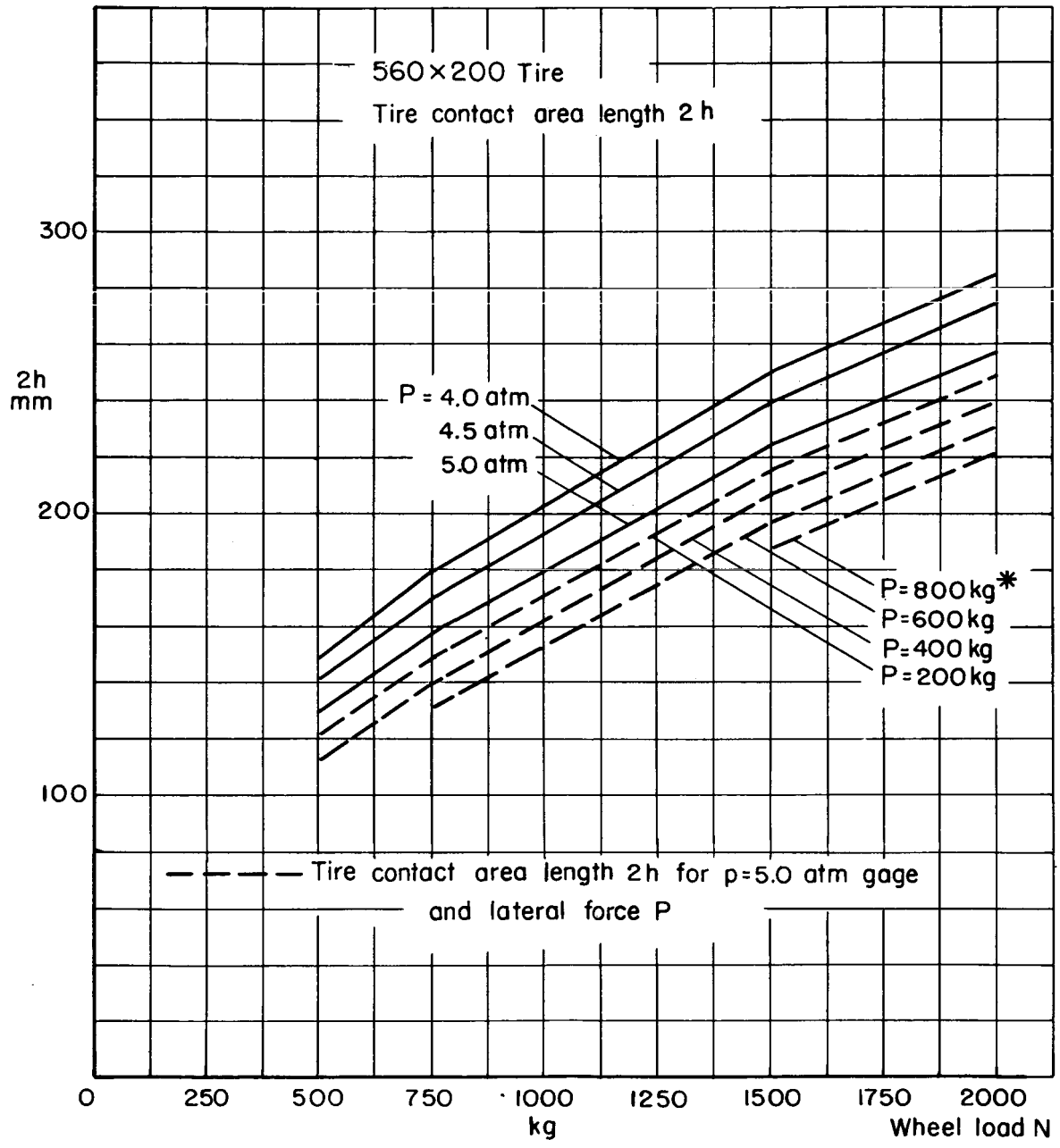


Figure 3.- Deformation of the tire by tangential force Q.



φ = tire deformation: angle between original position A_0B_0 and new position A_1B_1 of the extreme tire contact points.
φ'= angle of rotation between ground plane and wheel axis.

Figure 4.- Determination of the swivel angle φ for moment M.



*Note: The order of listing of these 4 numbers has been reversed from that given in the original German paper because the latter was inconstant with the text and was apparently due to an error in labeling the figure.

Figure 5.-

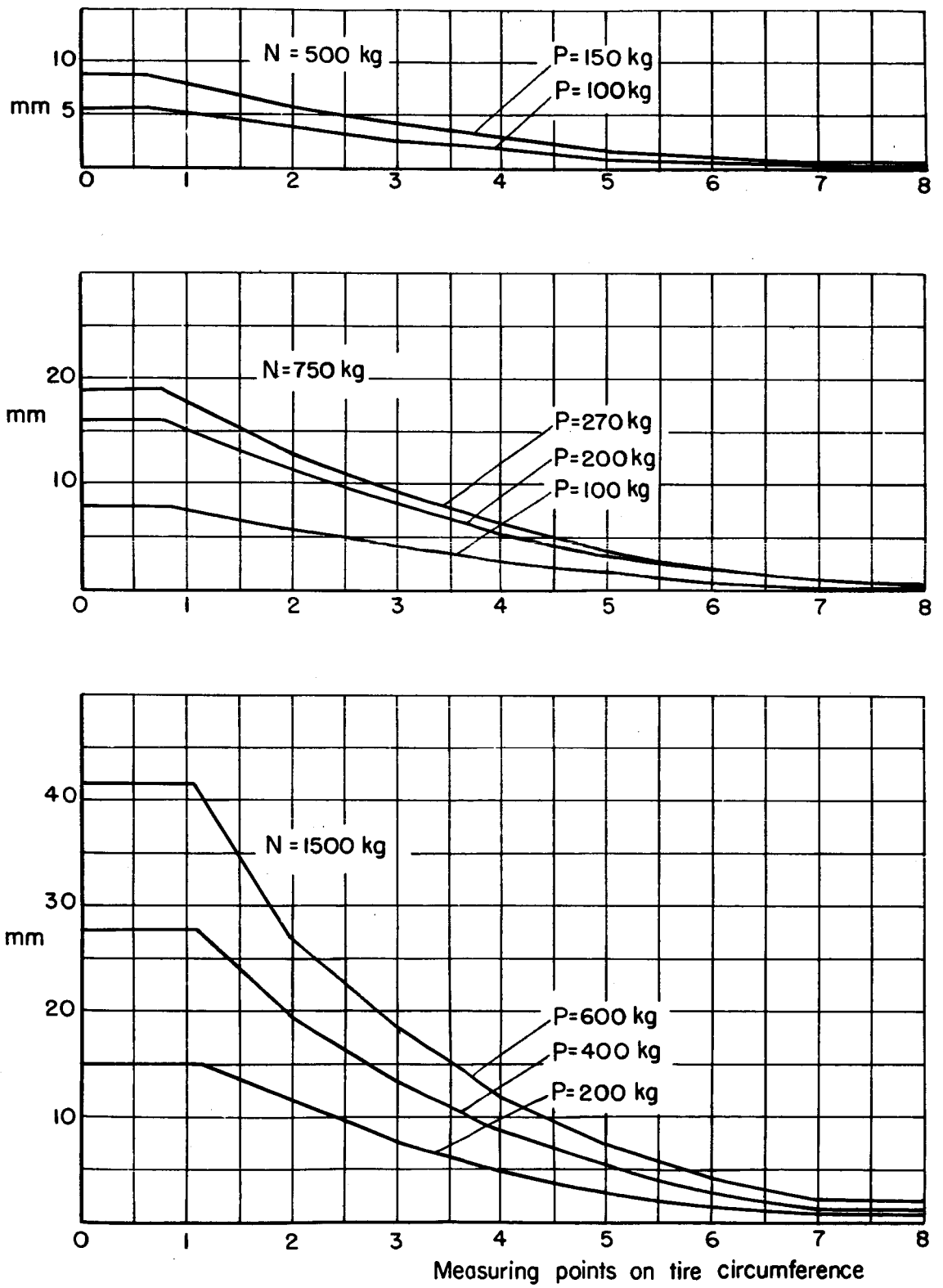


Figure 6.- 560 x 200 tire; p = 4.0 atm gage; lateral deflection by force P.

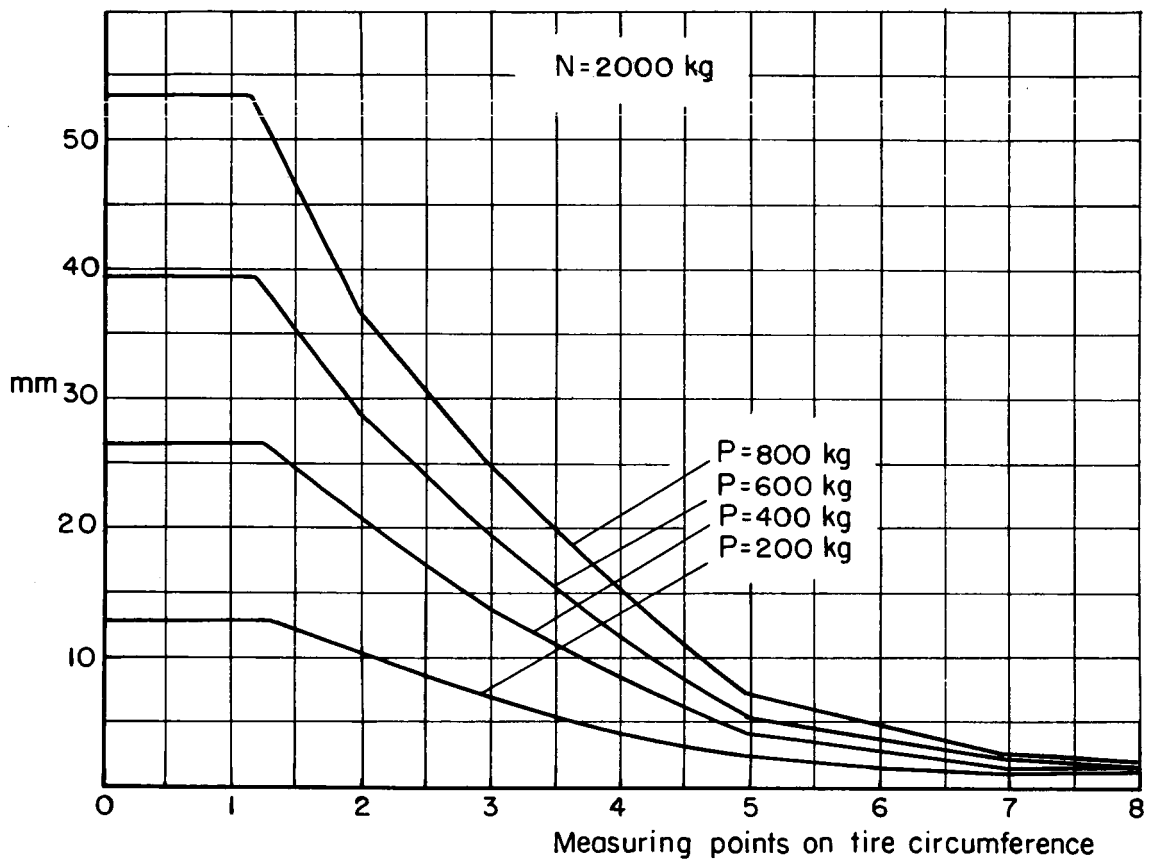


Figure 7.- 560 x 200 tire; p = 4.0 atm gage; lateral deflection by force P.

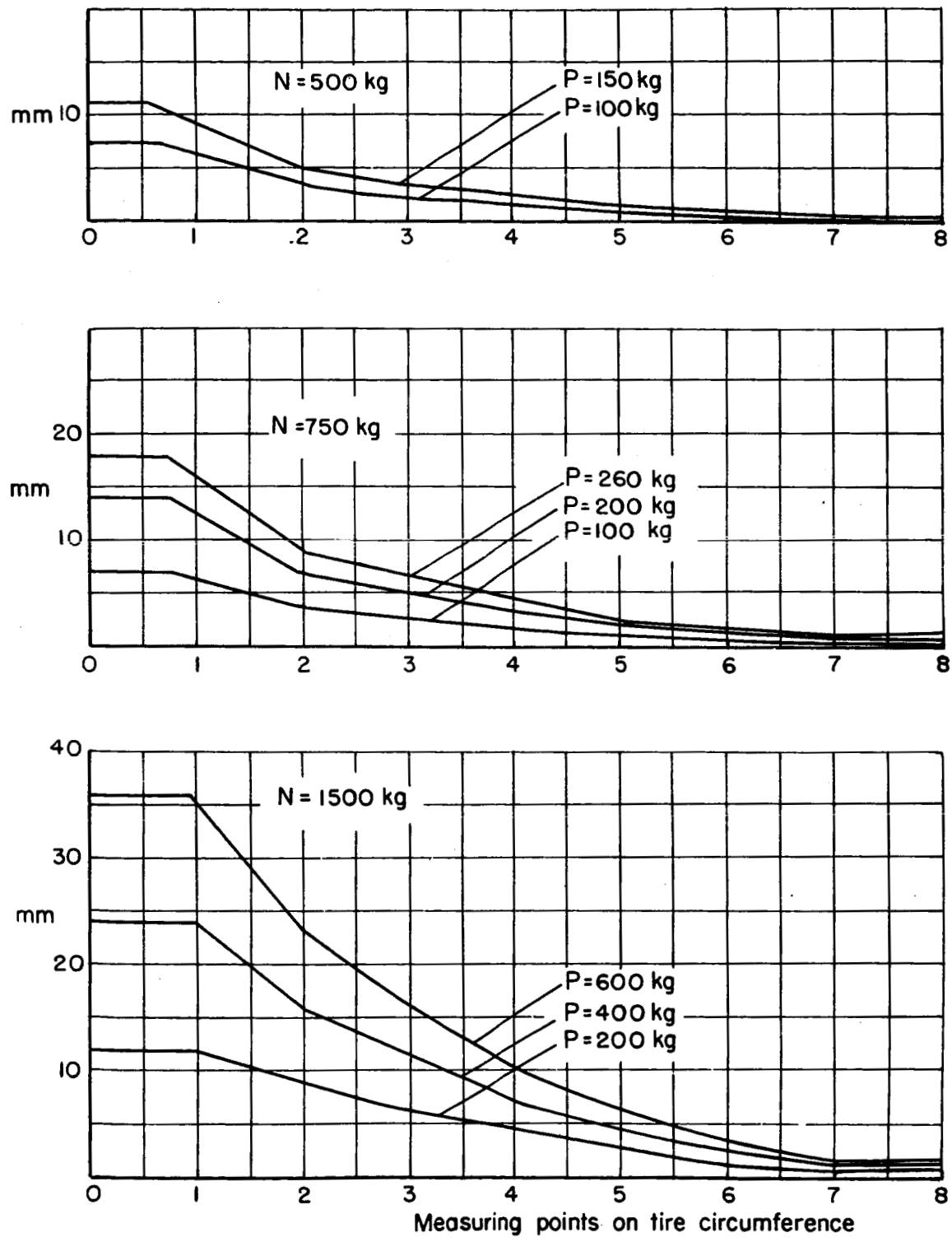


Figure 8.- 560 x 200 tire; p = 4.5 atm gage; lateral deflection by force P.

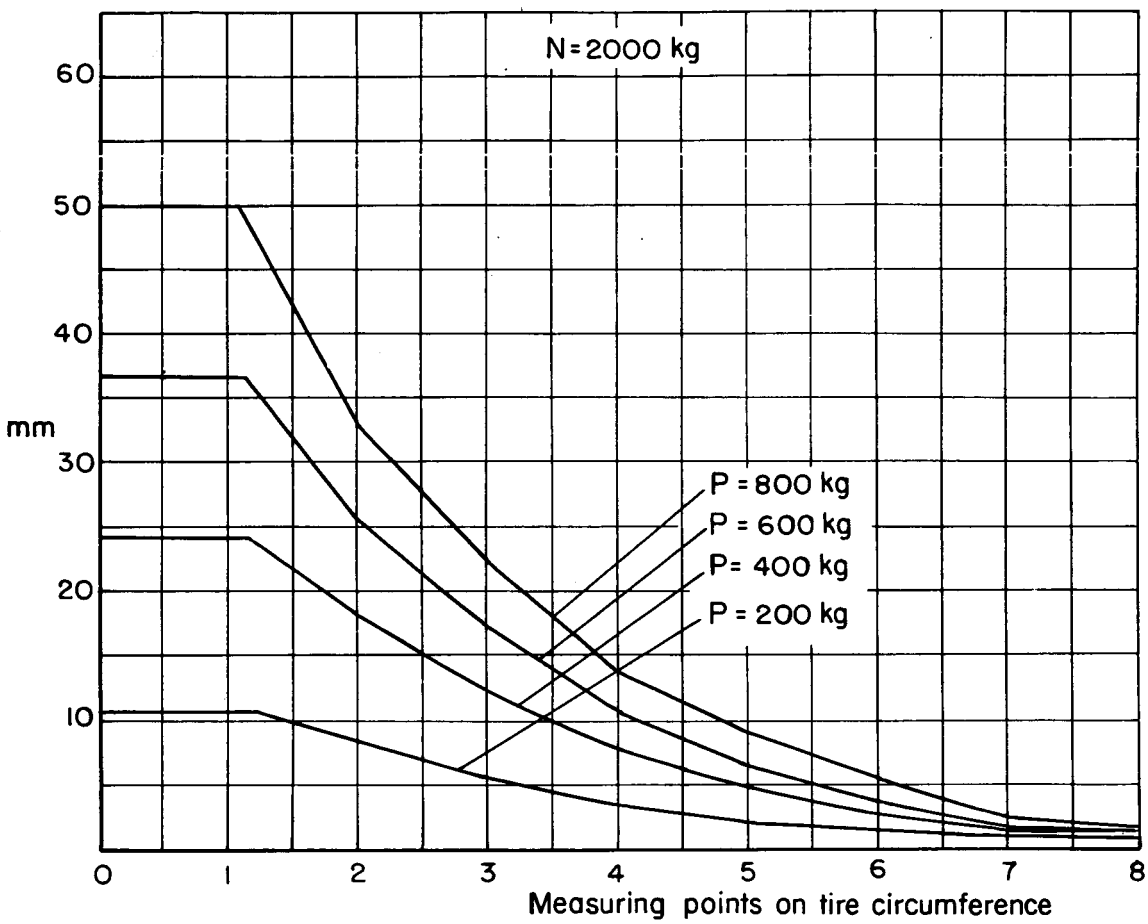


Figure 9.- 560 ×200 tire; p = 4.5 atm gage; lateral deflection by force P.

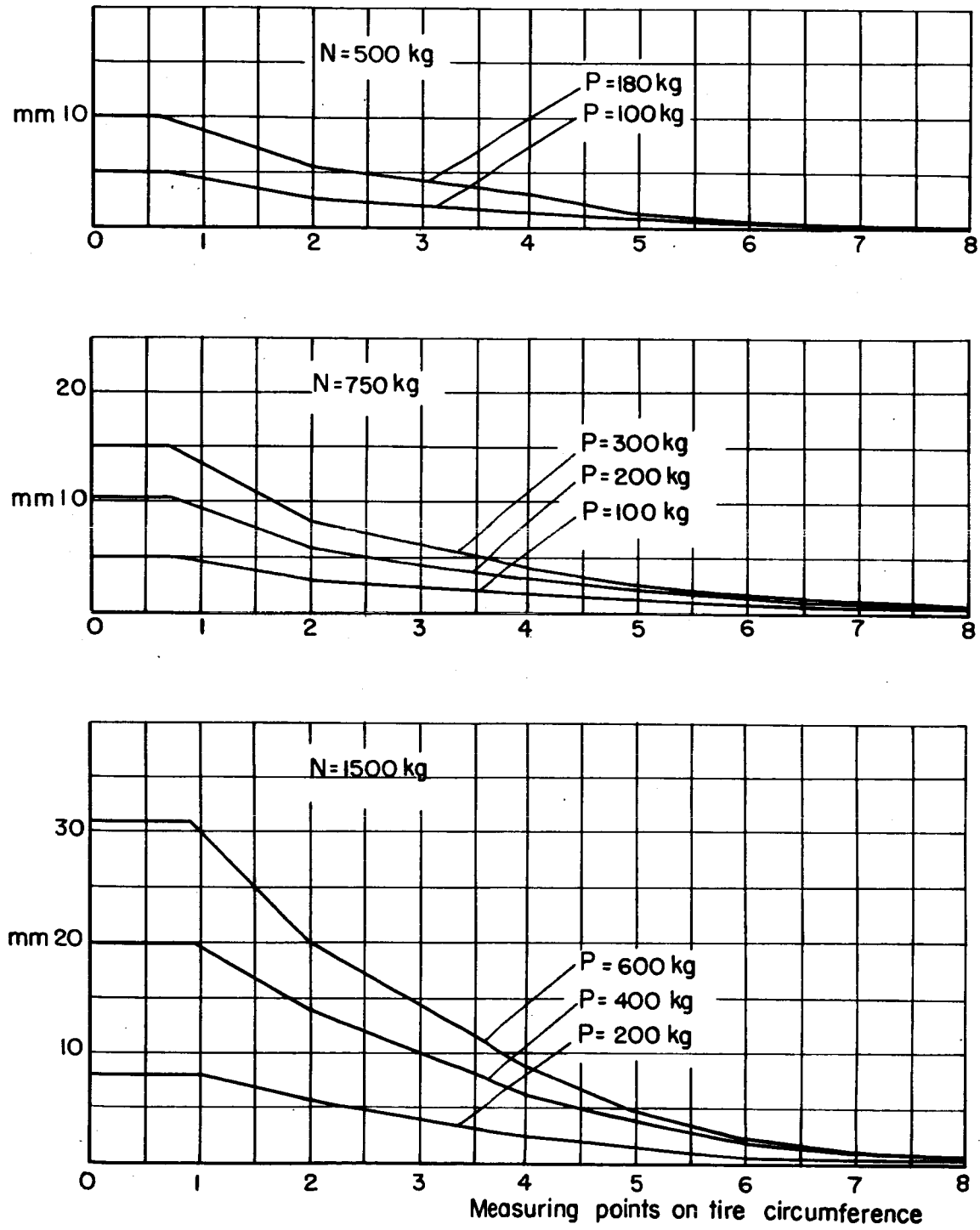


Figure 10.- 560 x 200 tire; p = 5.0 atm gage; lateral deflection by force P.

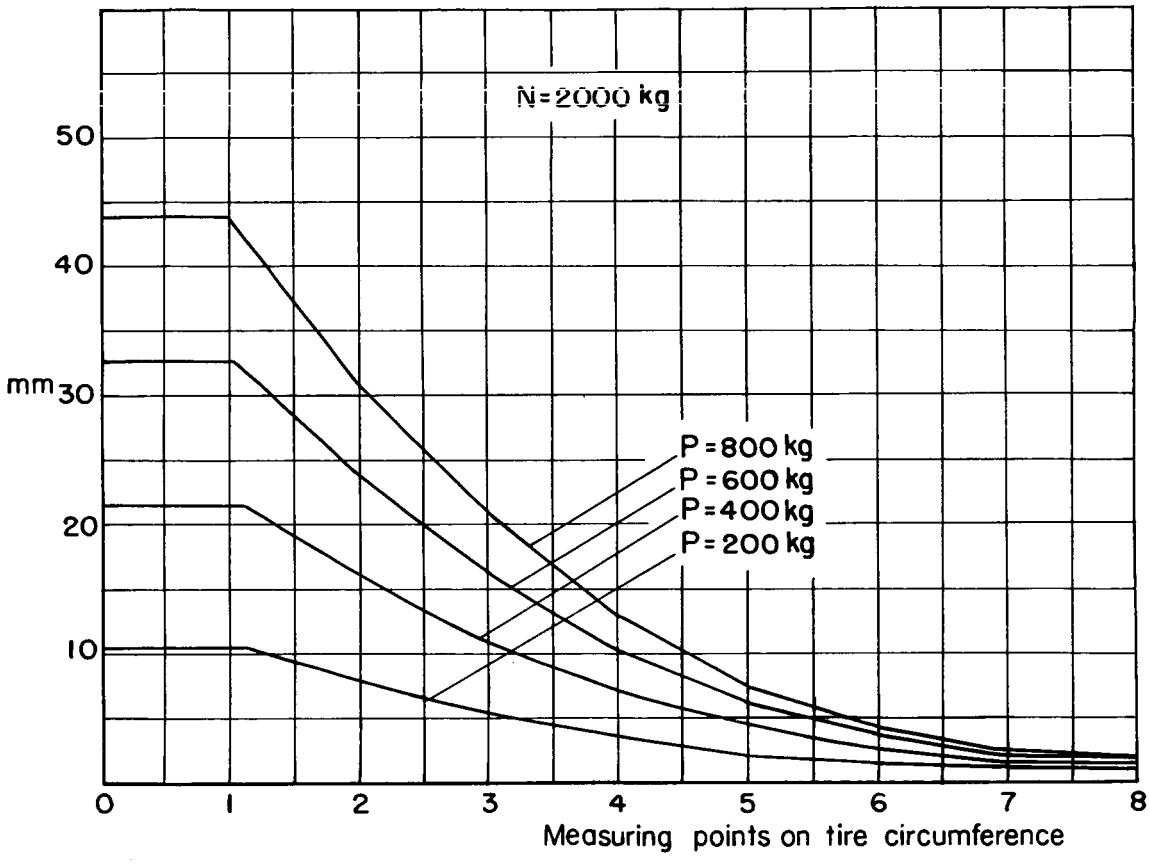


Figure 11.- 560 x 200 tire; p = 5.0 atm gage; lateral deflection by force P.

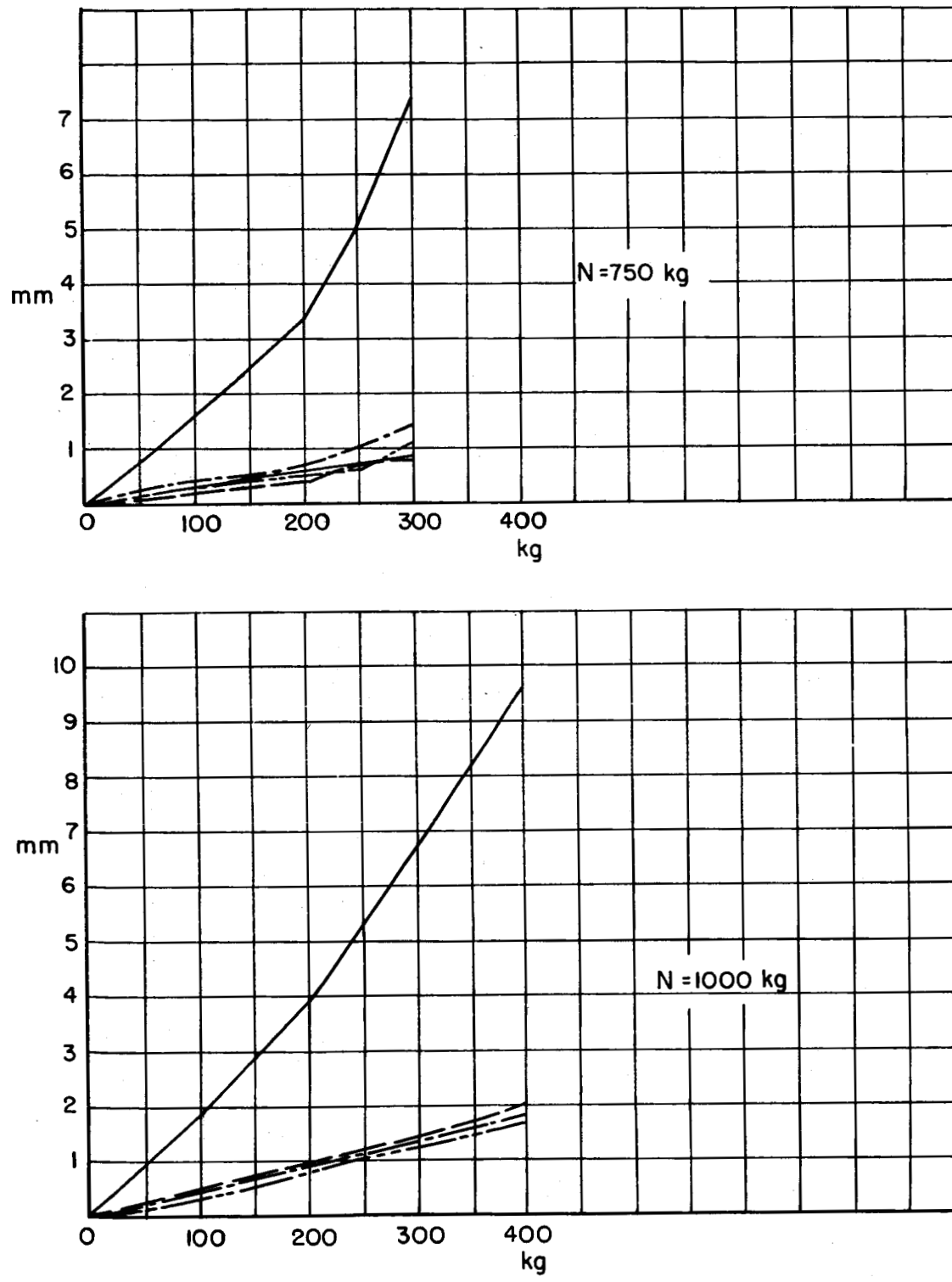


Figure 12.- 560 x 200 tire; p = 4.0 atm gage; tire deformation by tangential force Q.

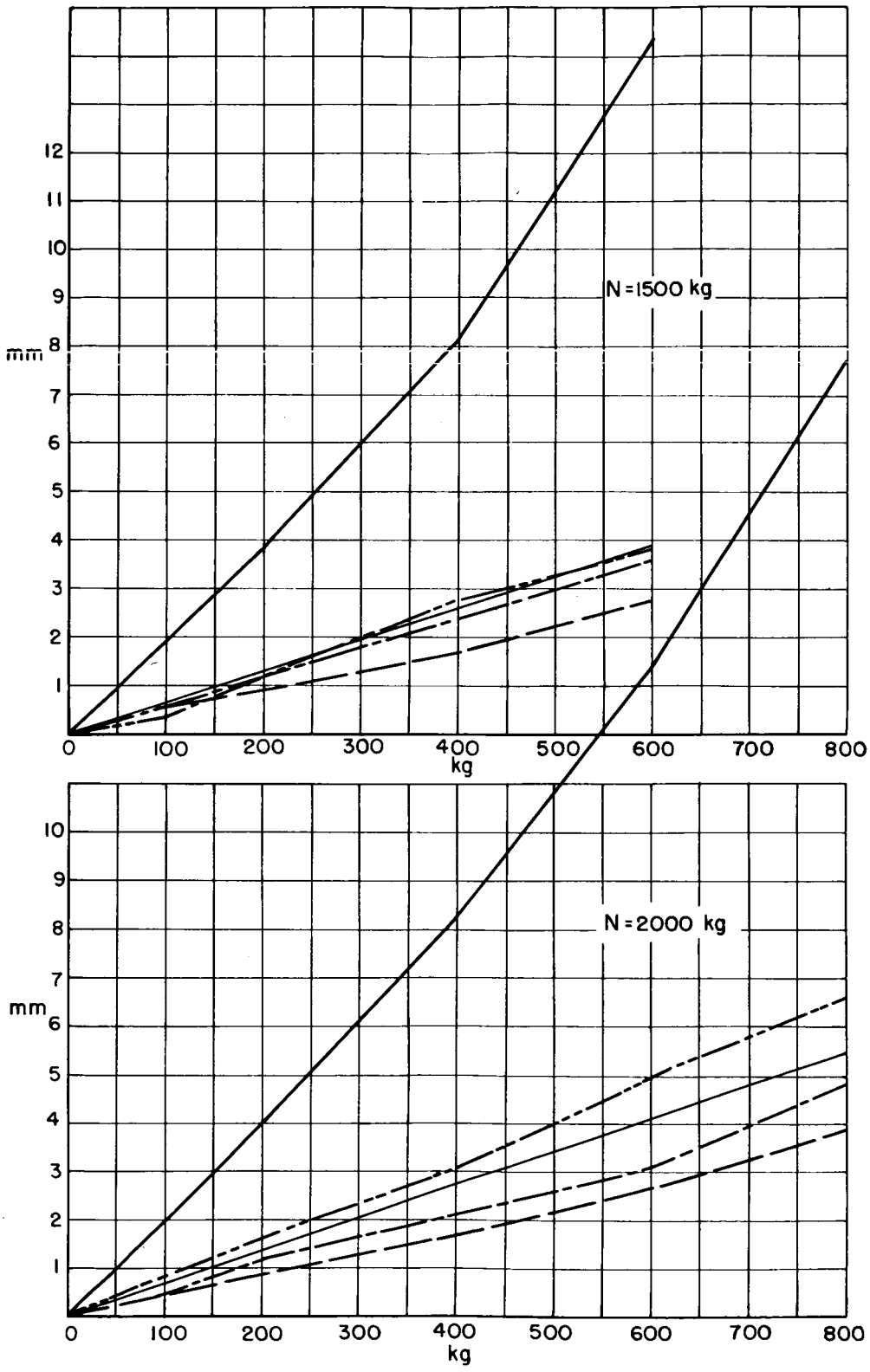
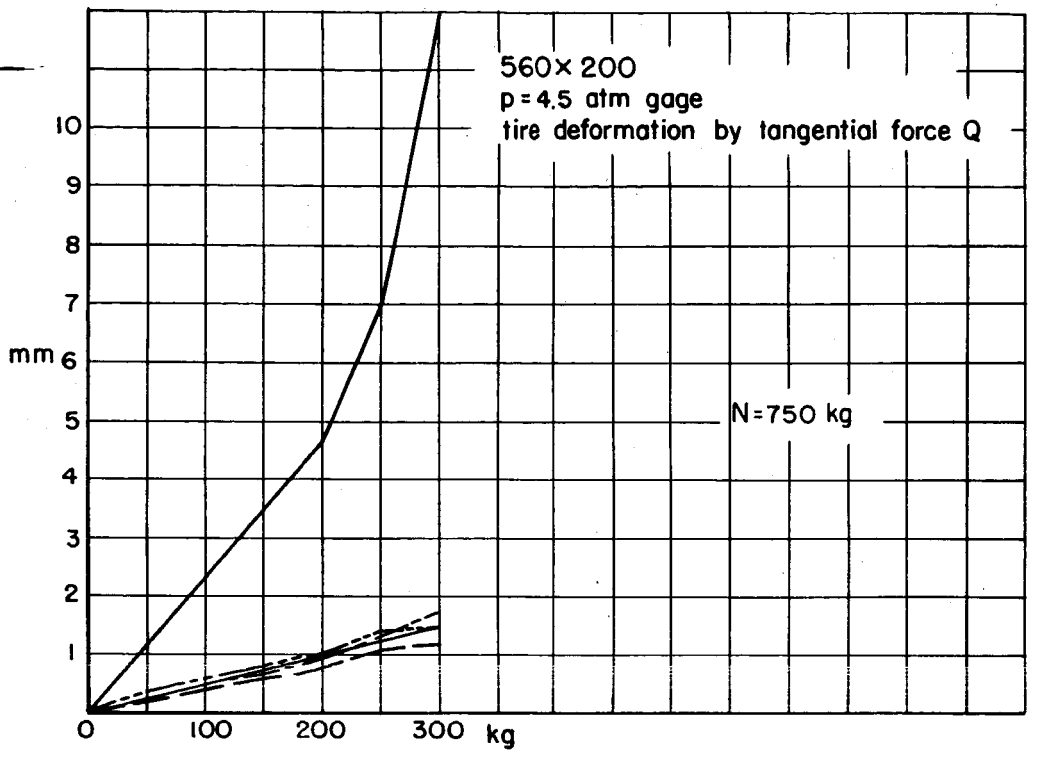


Figure 13.- 560 x 200 tire; p = 4.0 atm gage; tire deformation by tangential force Q.


560×200
p=4.5 atm gage
tire deformation by tangential force Q
N=750 kg
mm
10
9
8
7
6
5
4
3
2
1
0
100
200
300
kg

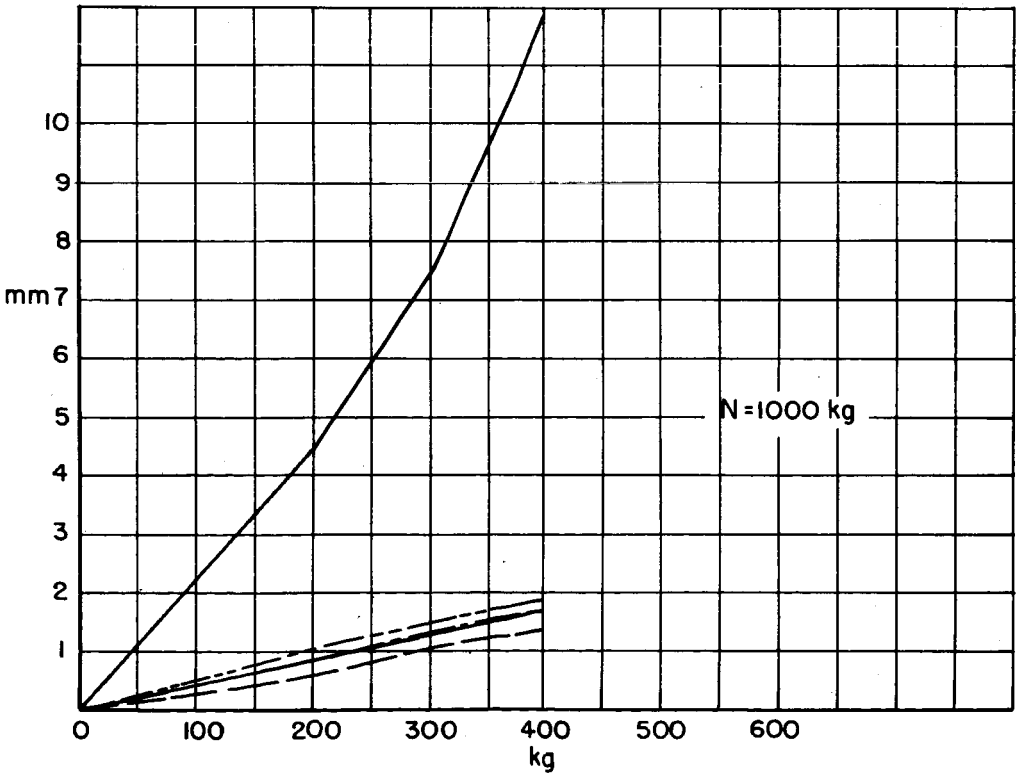

N=1000 kg
mm
10
9
8
7
6
5
4
3
2
1
0
100
200
300
400
500
600
kg

Figure 14.-

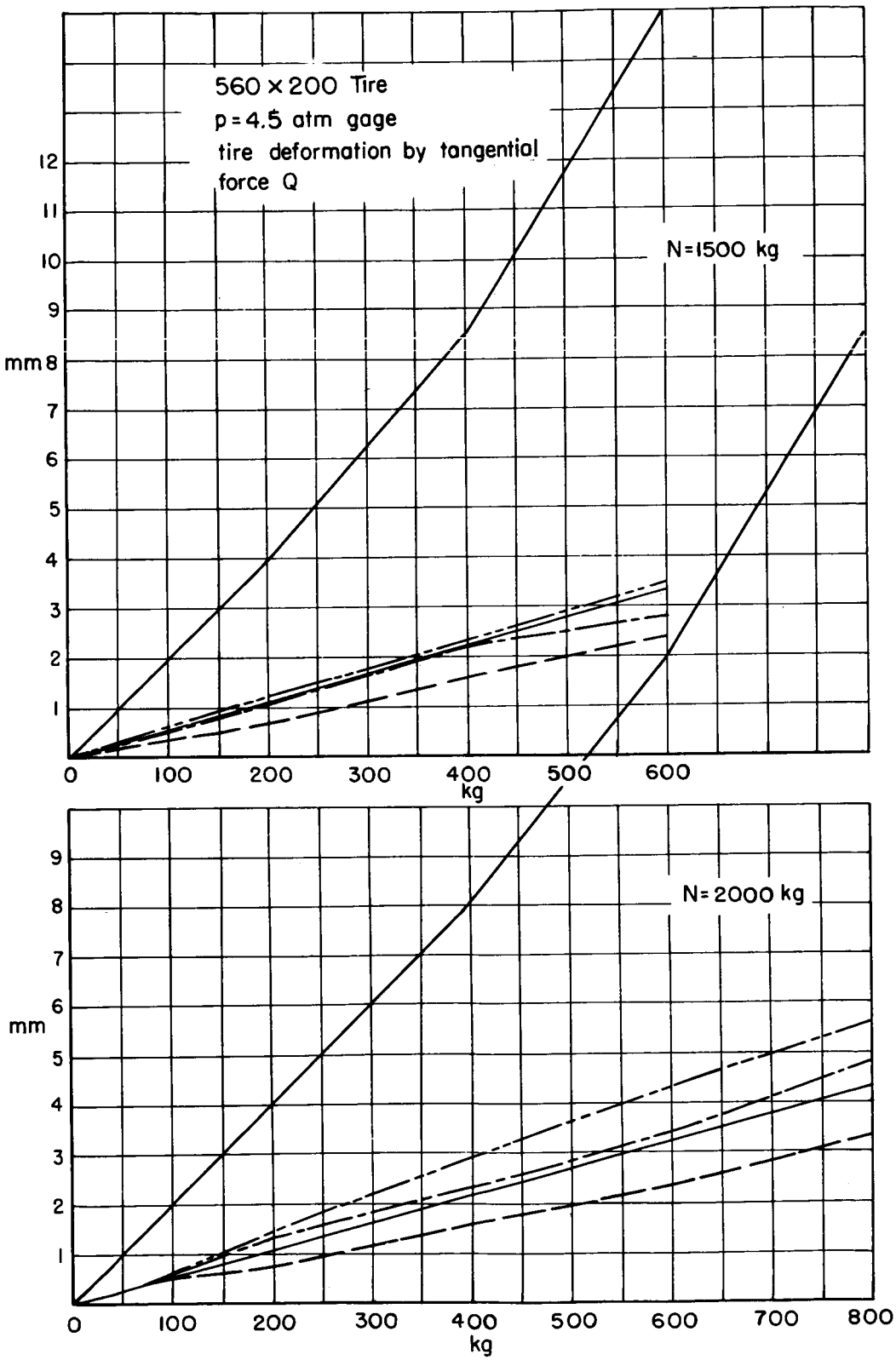

560 x 200 Tire
p = 4.5 atm gage
tire deformation by tangential force Q
N=1500 kg
mm
kg
N=2000 kg
mm
kg

Figure 15

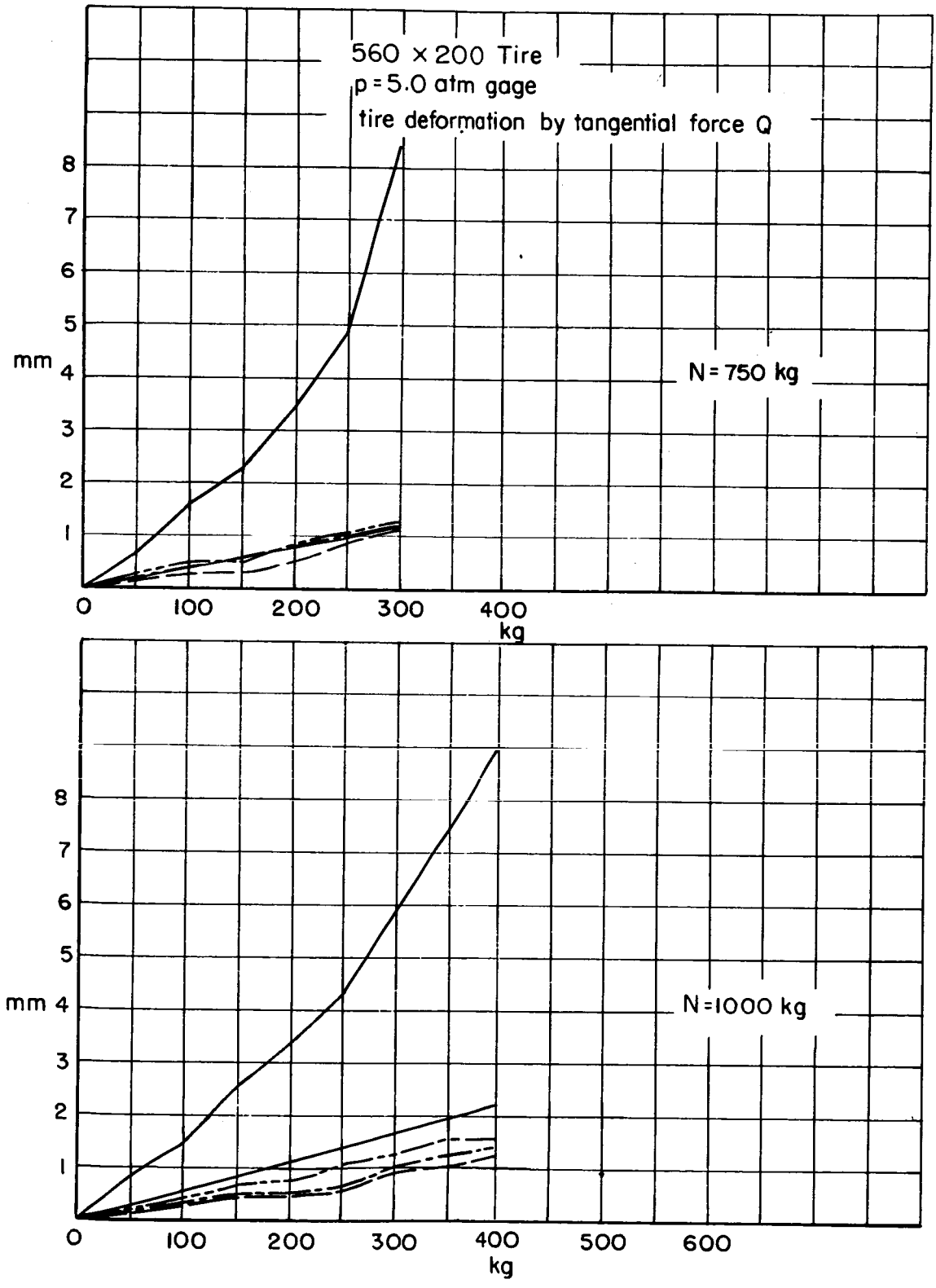

560 × 200 Tire
p = 5.0 atm gage
tire deformation by tangential force Q
N = 750 kg
mm
0
100
200
300
400
kg
N = 1000 kg
mm
0
100
200
300
400
500
600
kg

Figure 16

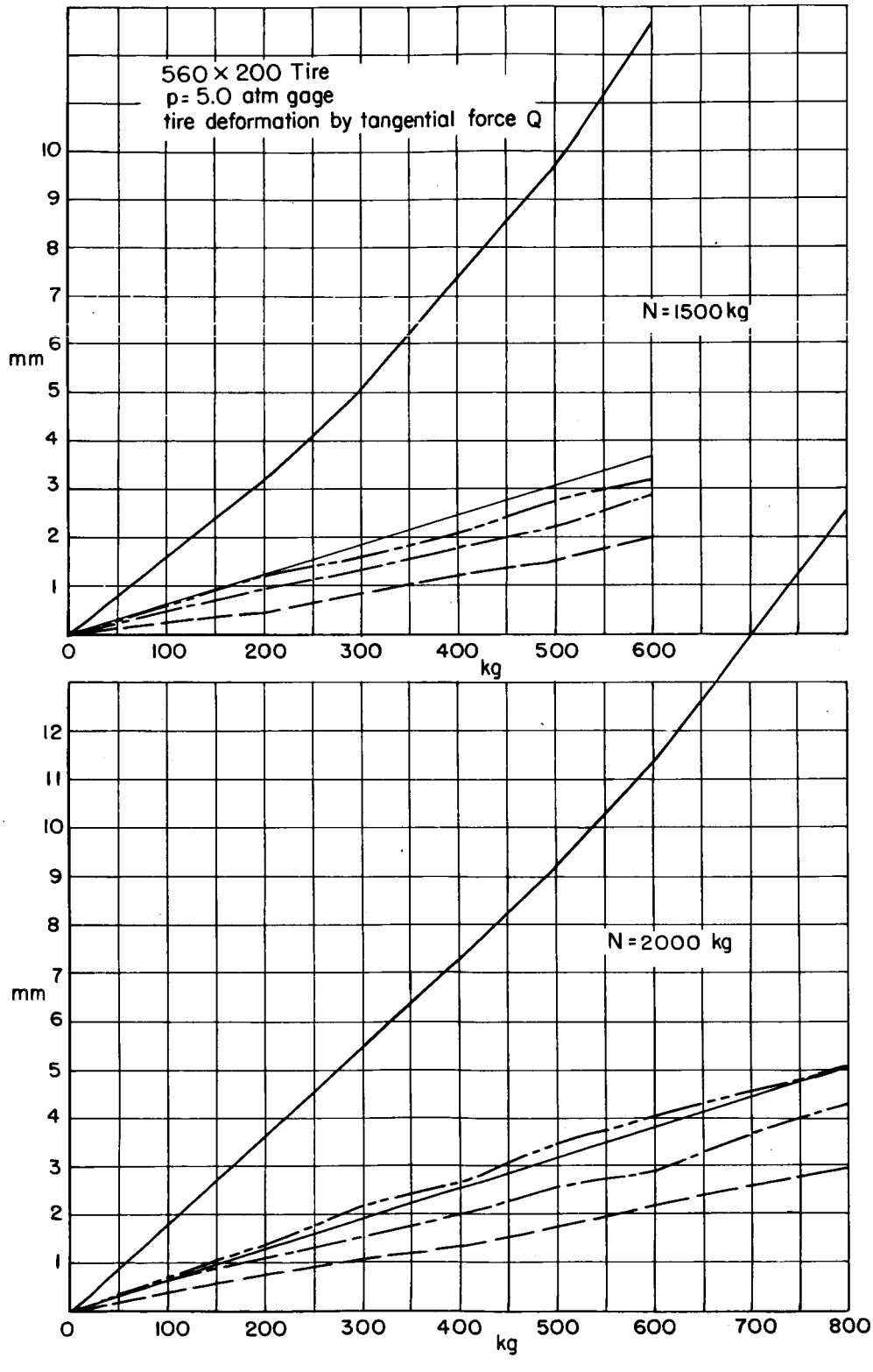
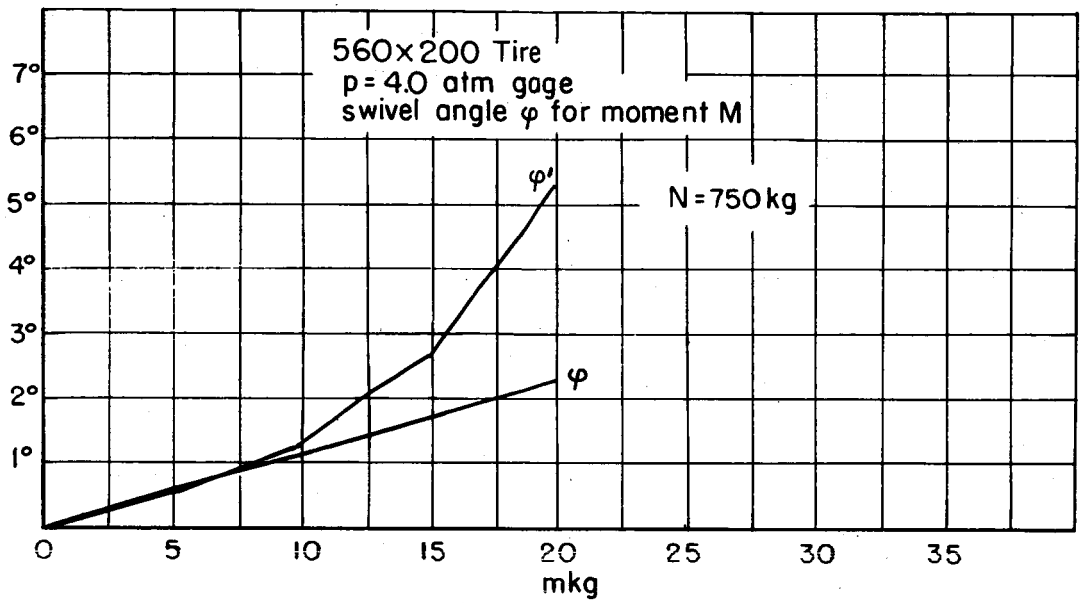

560 × 200 Tire
p = 5.0 atm gage
tire deformation by tangential force Q
N = 1500 kg
mm
kg
N = 2000 kg
mm
kg

Figure 17


560x200 Tire
p = 4.0 atm gage
swivel angle φ for moment M
N = 750 kg
φ'
φ
7°
6°
5°
4°
3°
2°
1°
0
5
10
15
20
25
30
35
mkg

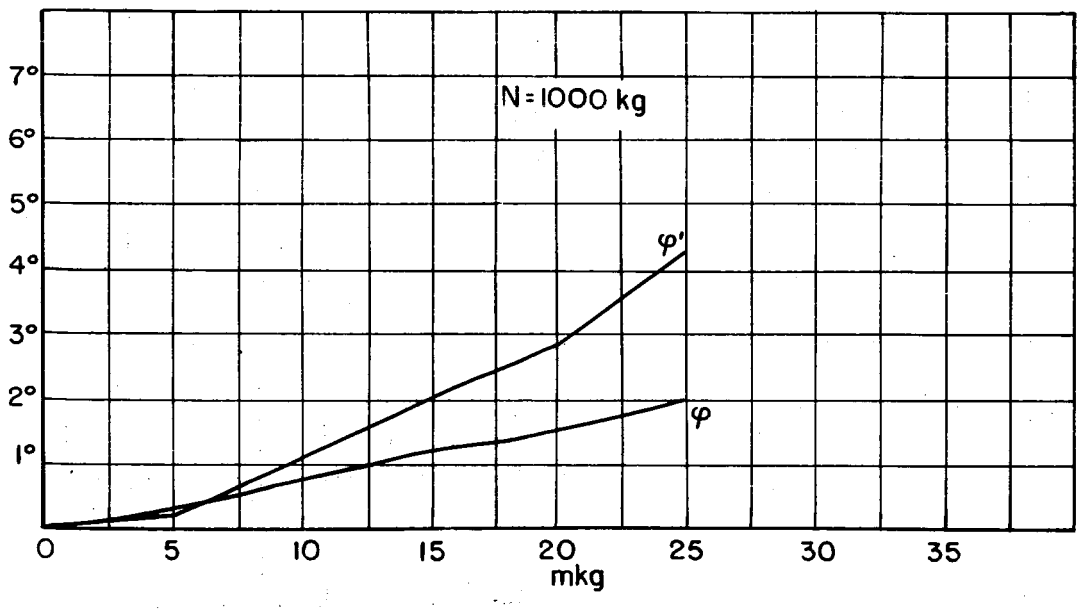
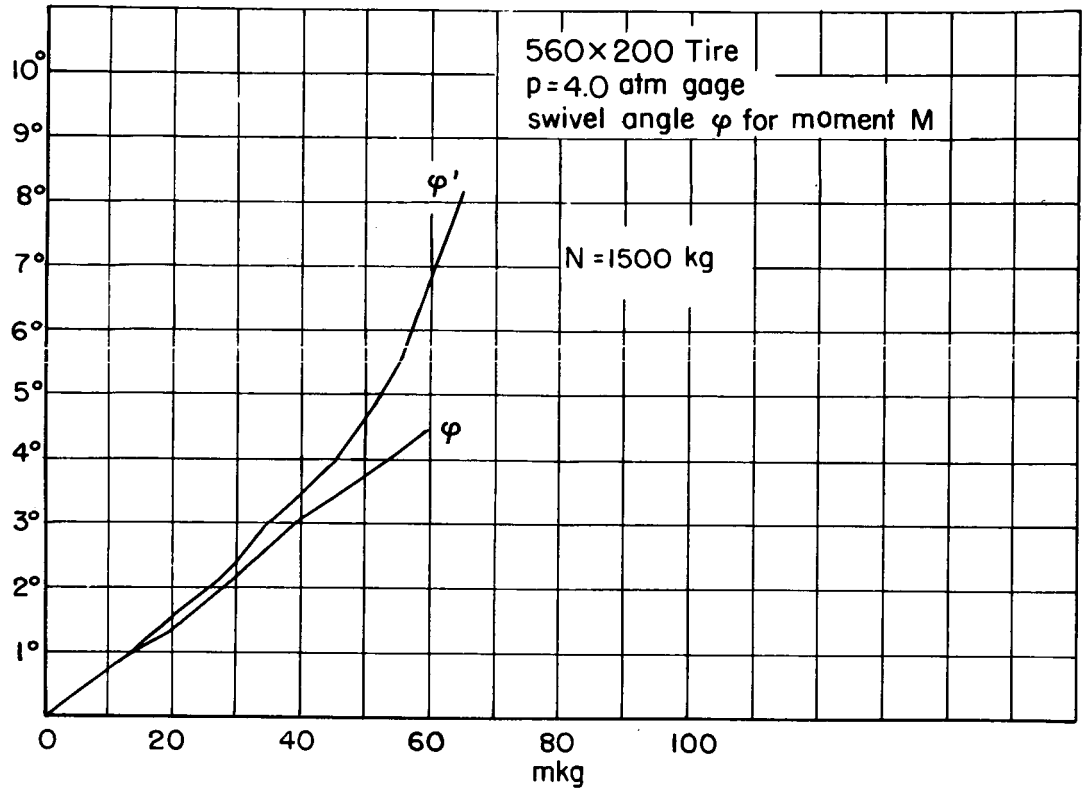

N = 1000 kg
φ'
φ
7°
6°
5°
4°
3°
2°
1°
0
5
10
15
20
25
30
35
mkg

Figure 18


560×200 Tire
p=4.0 atm gage
swivel angle φ for moment M
φ'
φ
N=1500 kg
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
0
20
40
60
80
100
mkg

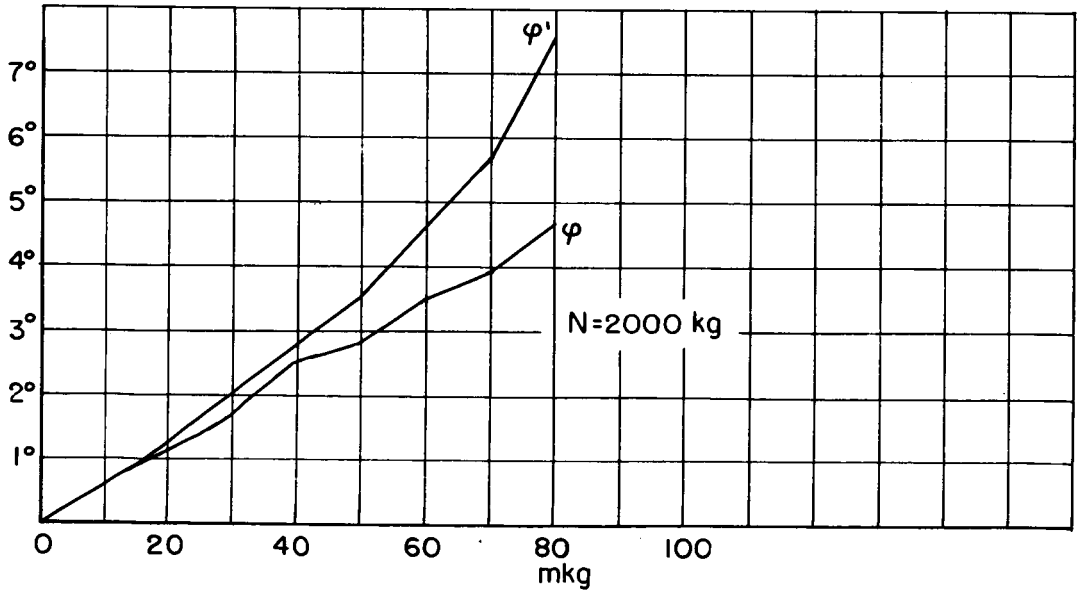

φ'
φ
N=2000 kg
7°
6°
5°
4°
3°
2°
1°
0
20
40
60
80
100
mkg

Figure 19

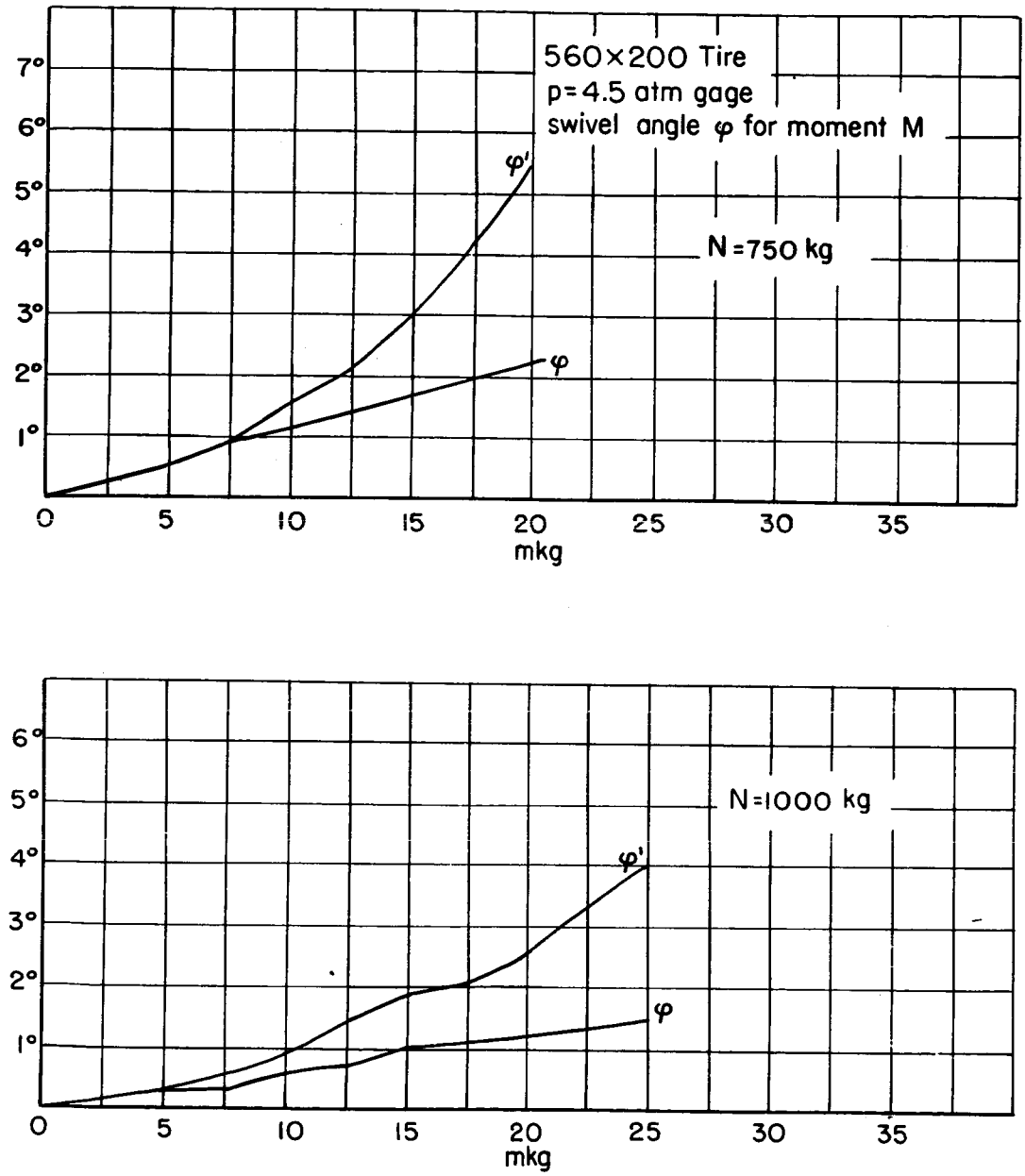
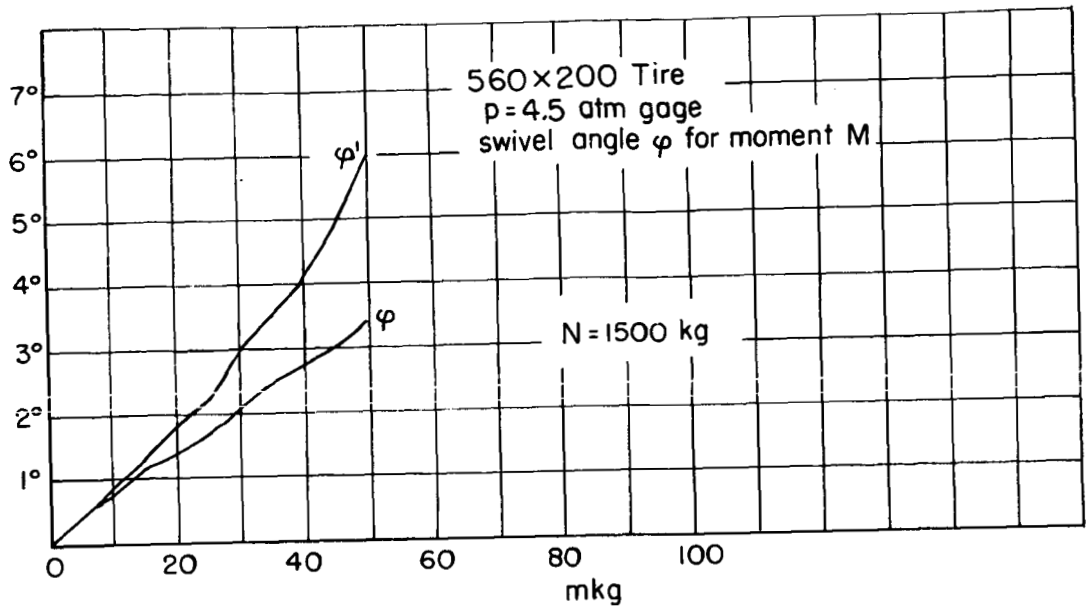

560×200 Tire
p=4.5 atm gage
swivel angle φ for moment M
N=750 kg
φ'
φ
7°
6°
5°
4°
3°
2°
1°
0
5
10
15
20
25
30
35
mkg
N=1000 kg
φ'
φ
6°
5°
4°
3°
2°
1°
0
5
10
15
20
25
30
35
mkg

Figure 20


560×200 Tire
p = 4.5 atm gage
swivel angle φ for moment M
N = 1500 kg
φ'
φ
7°
6°
5°
4°
3°
2°
1°
0
20
40
60
80
100
mkg

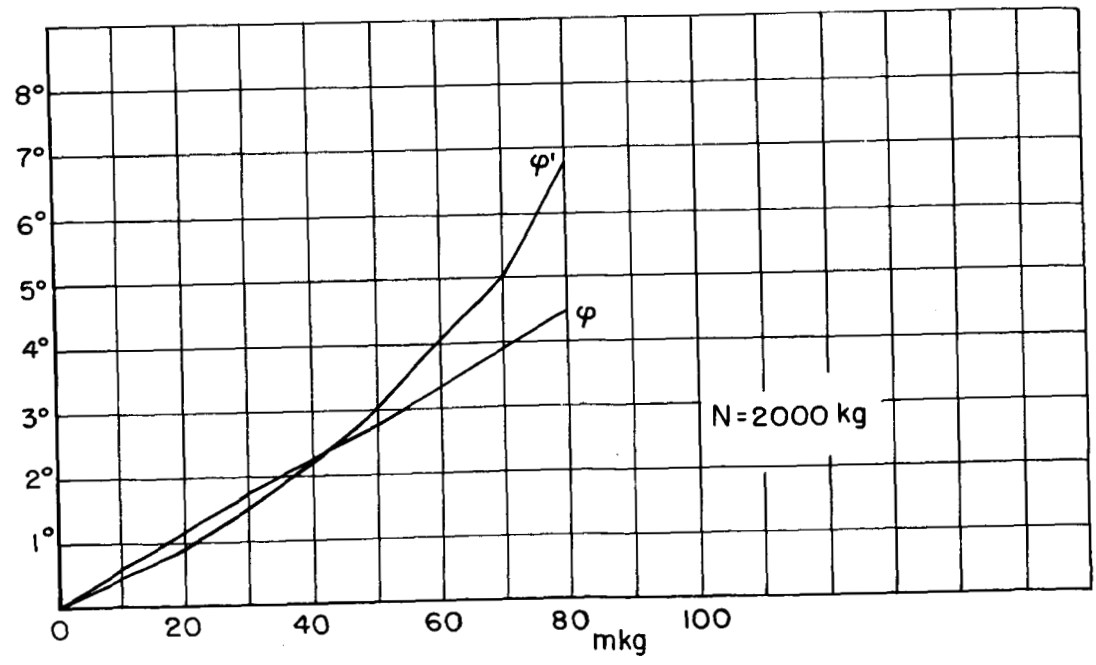
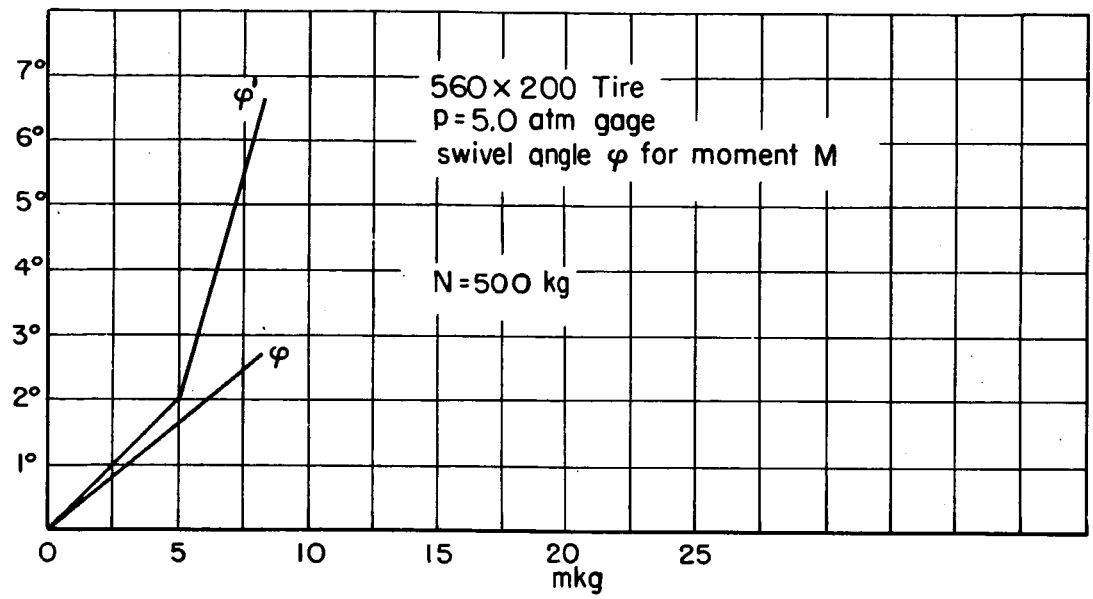

N = 2000 kg
φ'
φ
8°
7°
6°
5°
4°
3°
2°
1°
0
20
40
60
80
100
mkg

Figure 21


560 x 200 Tire
p = 5.0 atm gage
swivel angle φ for moment M
N = 500 kg
φ'
φ
7°
6°
5°
4°
3°
2°
1°
0
5
10
15
20
25
mkg

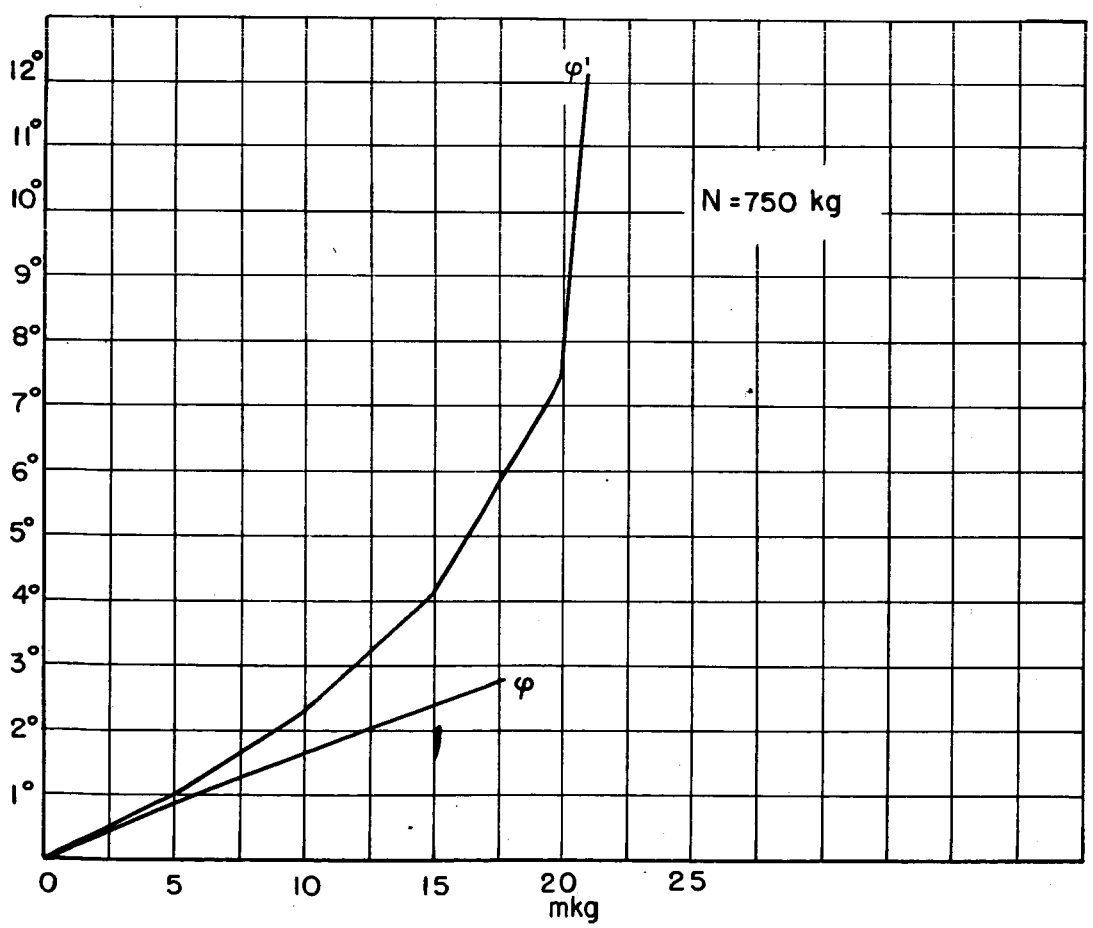
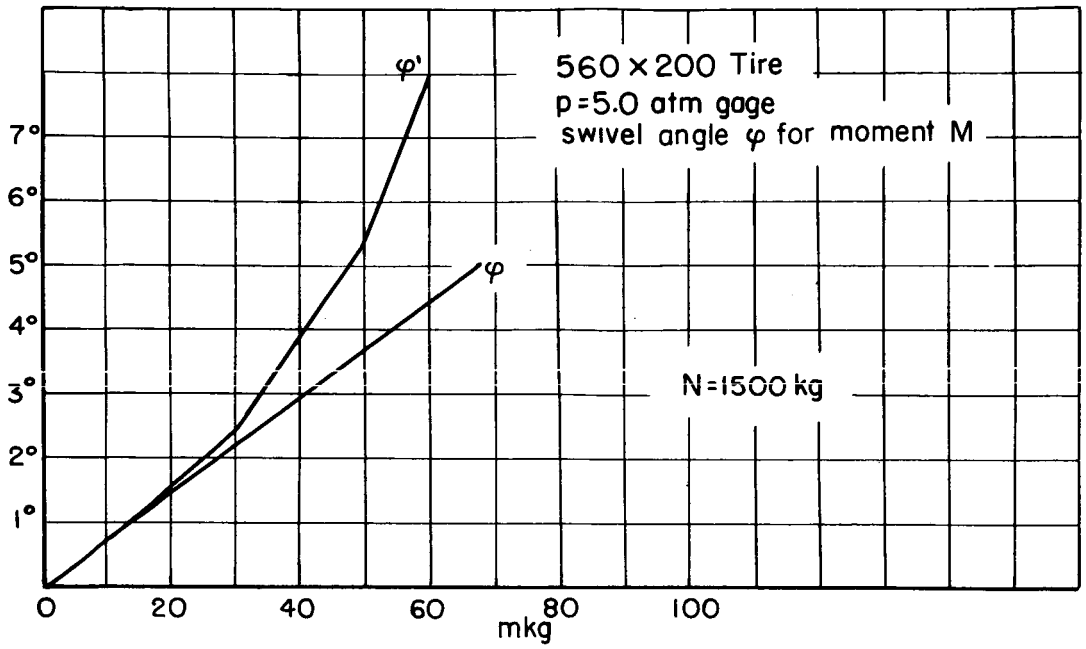

N = 750 kg
φ'
φ
12°
11°
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
0
5
10
15
20
25
mkg

Figure 22


560 x 200 Tire
p = 5.0 atm gage
swivel angle φ for moment M
φ'
φ
N = 1500 kg
7°
6°
5°
4°
3°
2°
1°
0
20
40
60
80
100
mkg

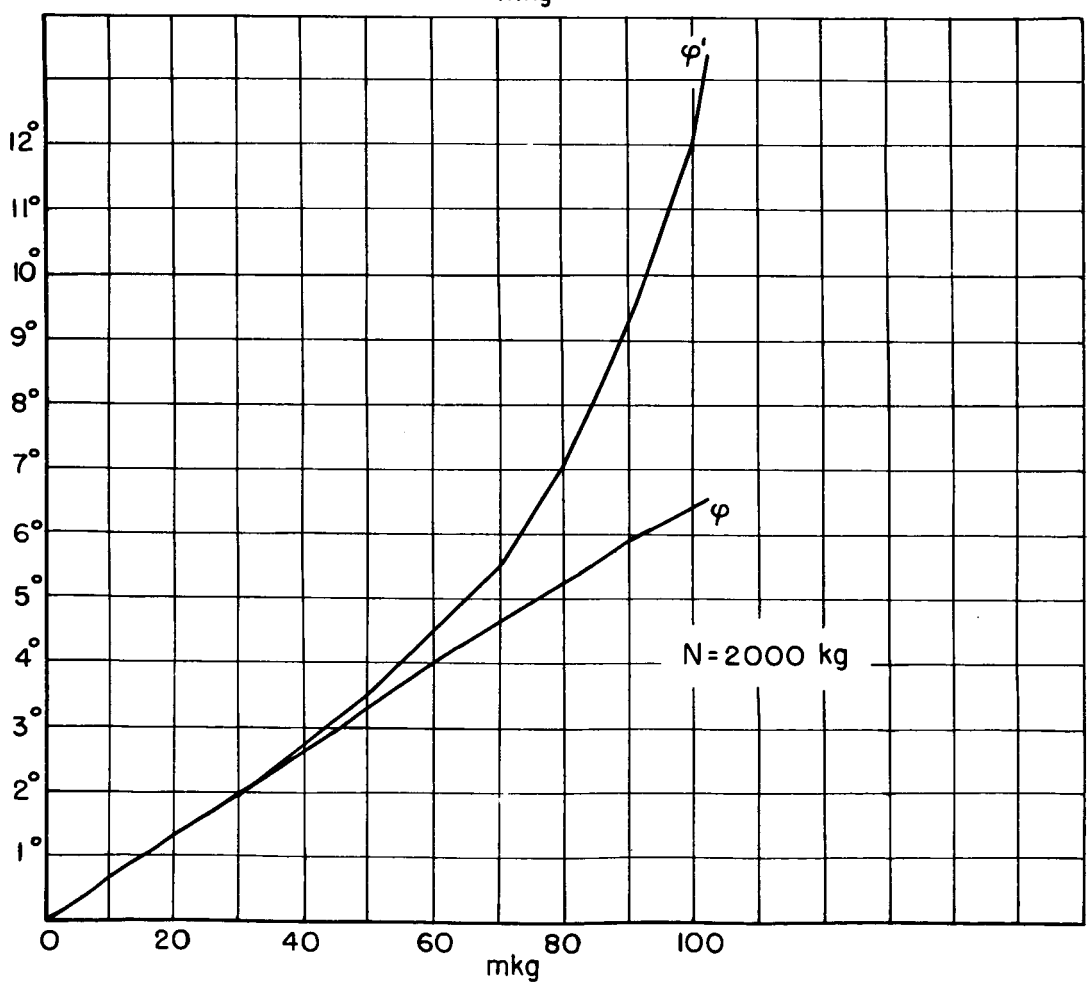

φ'
φ
N = 2000 kg
12°
11°
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
0
20
40
60
80
100
mkg

Figure 23

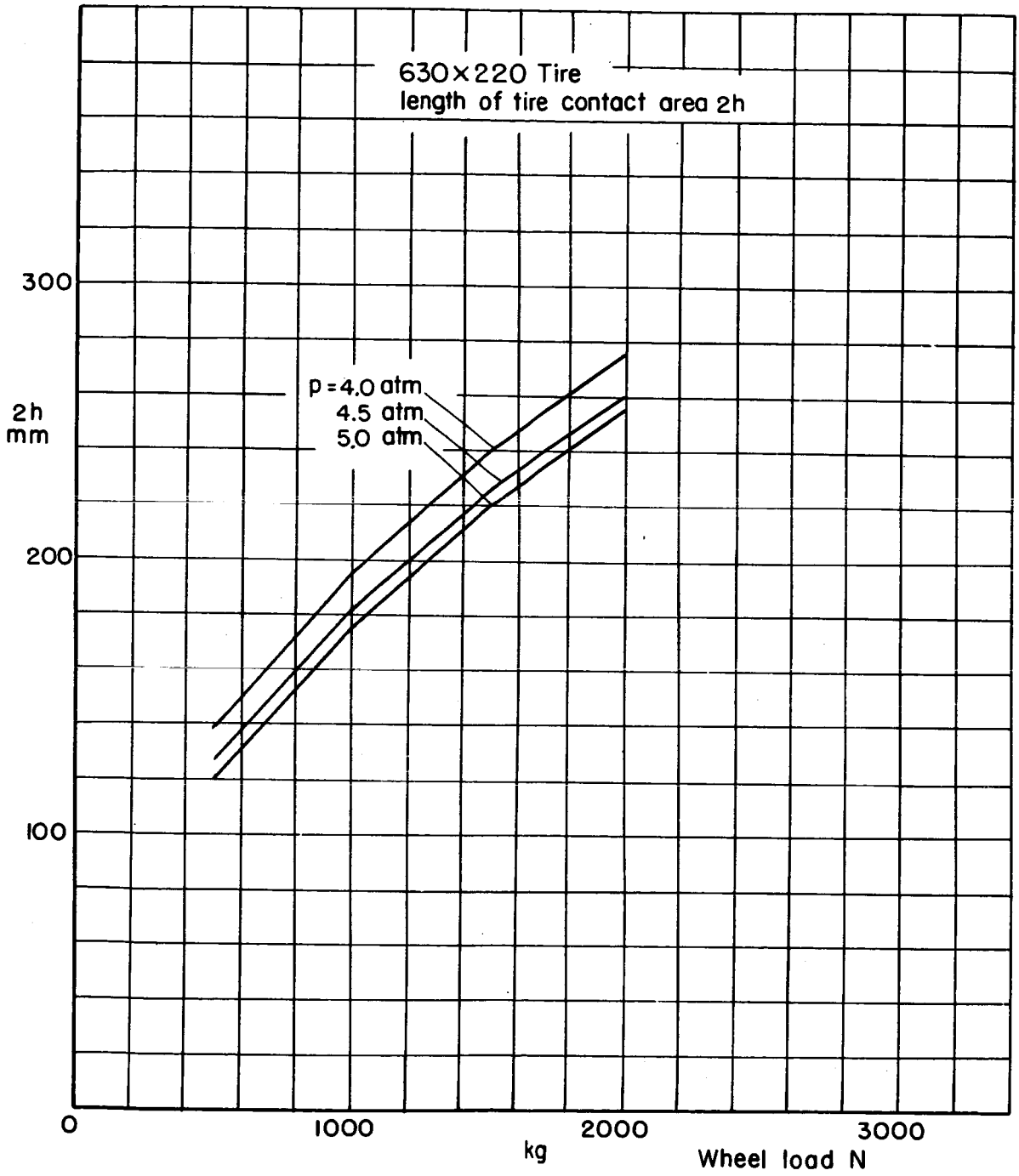

630×220 Tire
length of tire contact area 2h
p = 4.0 atm
4.5 atm
5.0 atm
2h
mm
300
200
100
0
1000
2000
3000
kg
Wheel load N

Figure 24

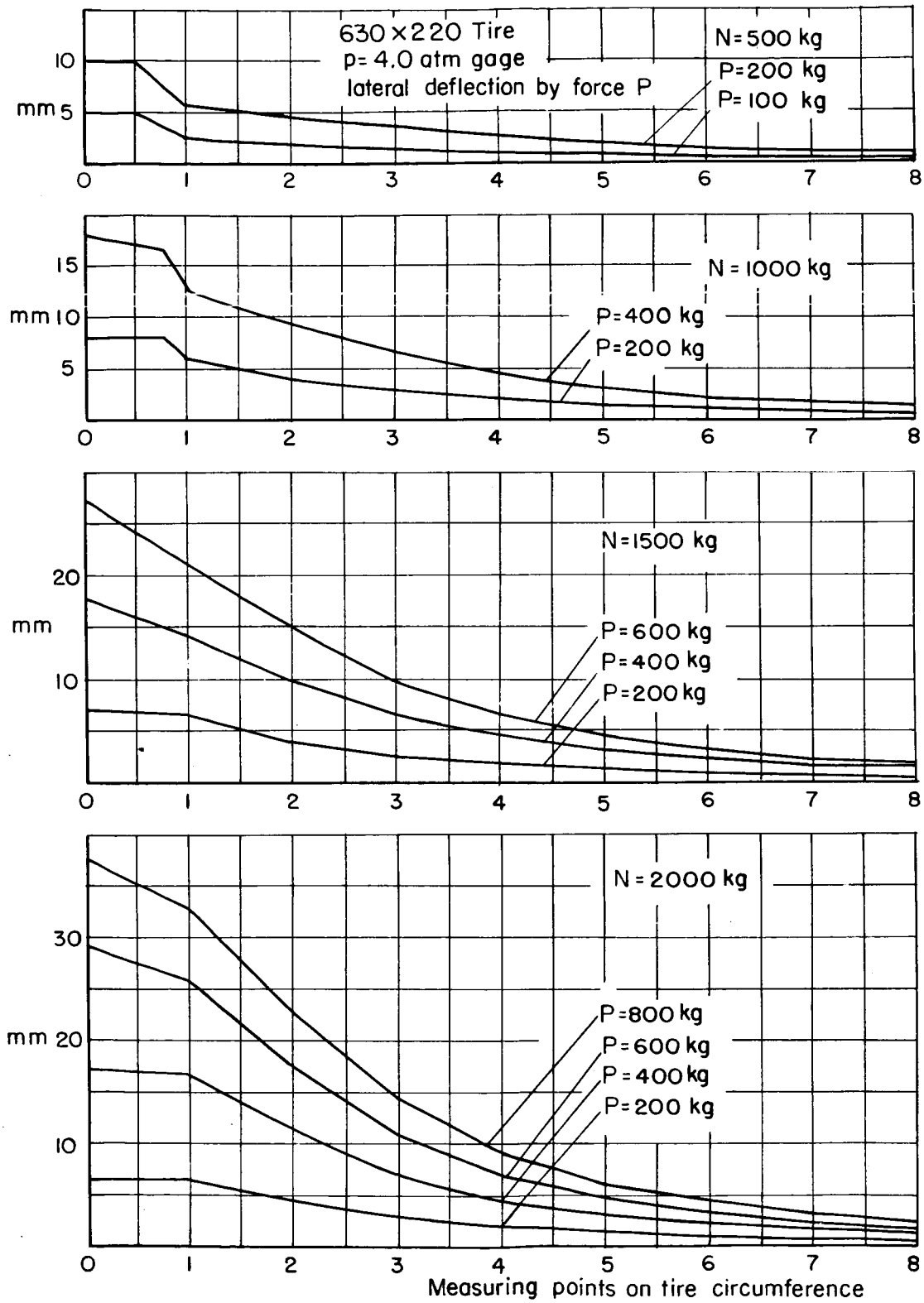

630×220 Tire
p= 4.0 atm gage
lateral deflection by force P
N=500 kg
P=200 kg
P=100 kg
mm
N=1000 kg
P=400 kg
P=200 kg
N=1500 kg
P=600 kg
P=400 kg
P=200 kg
N=2000 kg
P=800 kg
P=600 kg
P=400 kg
P=200 kg
Measuring points on tire circumference

Figure 25

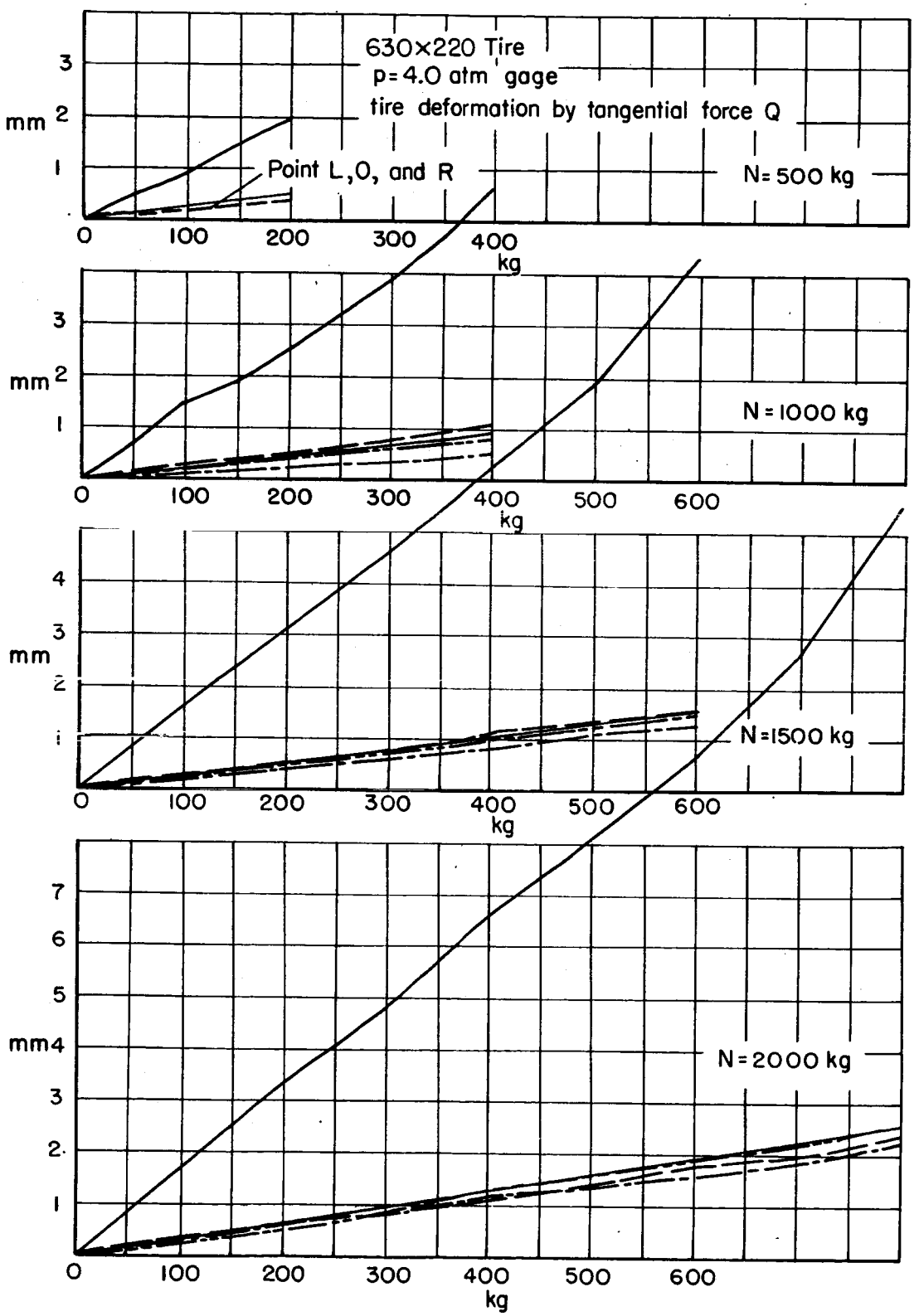
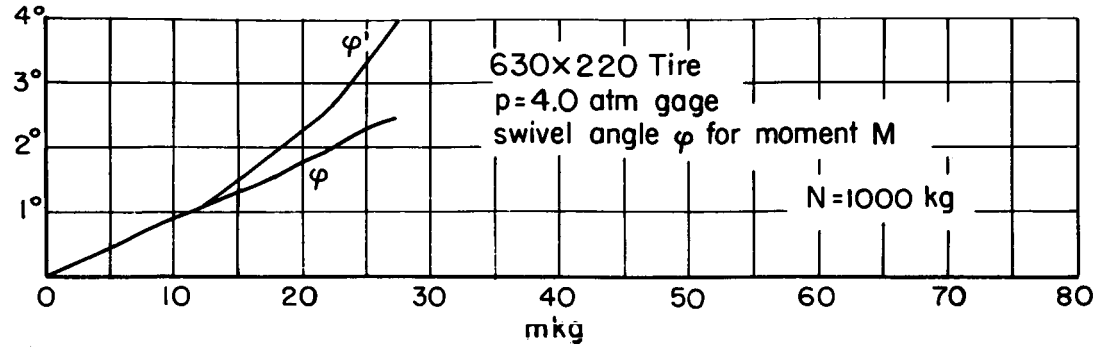
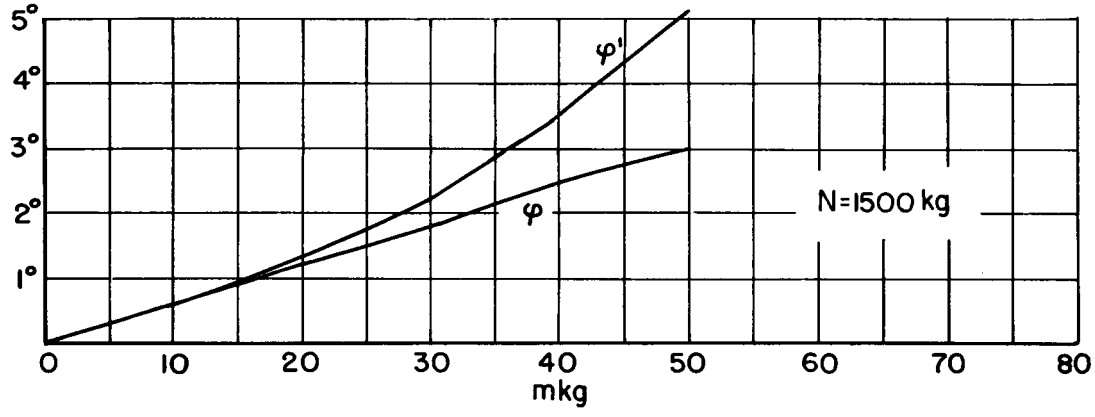

630×220 Tire
p=4.0 atm gage
tire deformation by tangential force Q
Point L,O, and R
N=500 kg
N=1000 kg
N=1500 kg
N=2000 kg
mm
kg
0
100
200
300
400
500
600

Figure 26


4°
3°
2°
1°
φ'
φ
630×220 Tire
p=4.0 atm gage
swivel angle φ for moment M
N=1000 kg
0
10
20
30
40
50
60
70
80
mkg


5°
4°
3°
2°
1°
φ'
φ
N=1500 kg
0
10
20
30
40
50
60
70
80
mkg

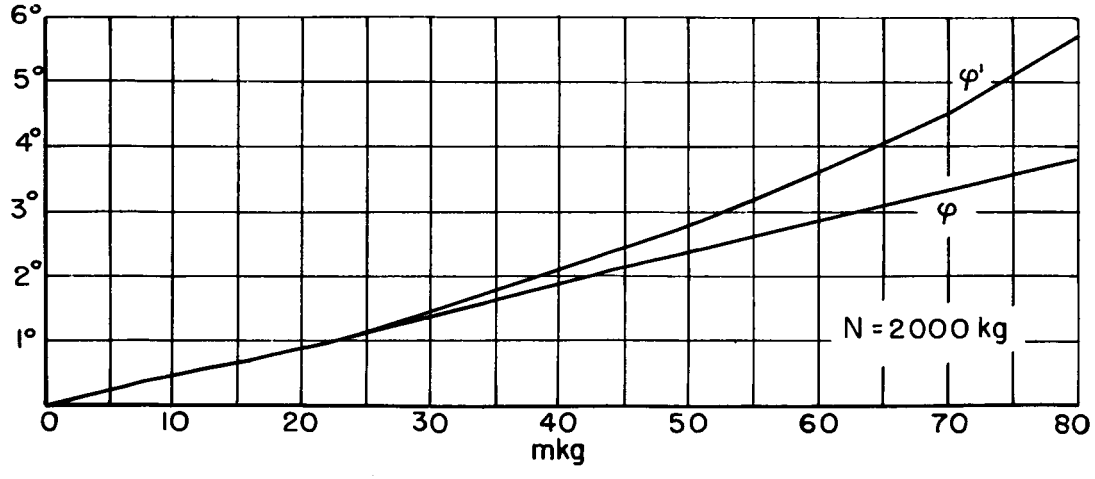

6°
5°
4°
3°
2°
1°
φ'
φ
N=2000 kg
0
10
20
30
40
50
60
70
80
mkg

Figure 27

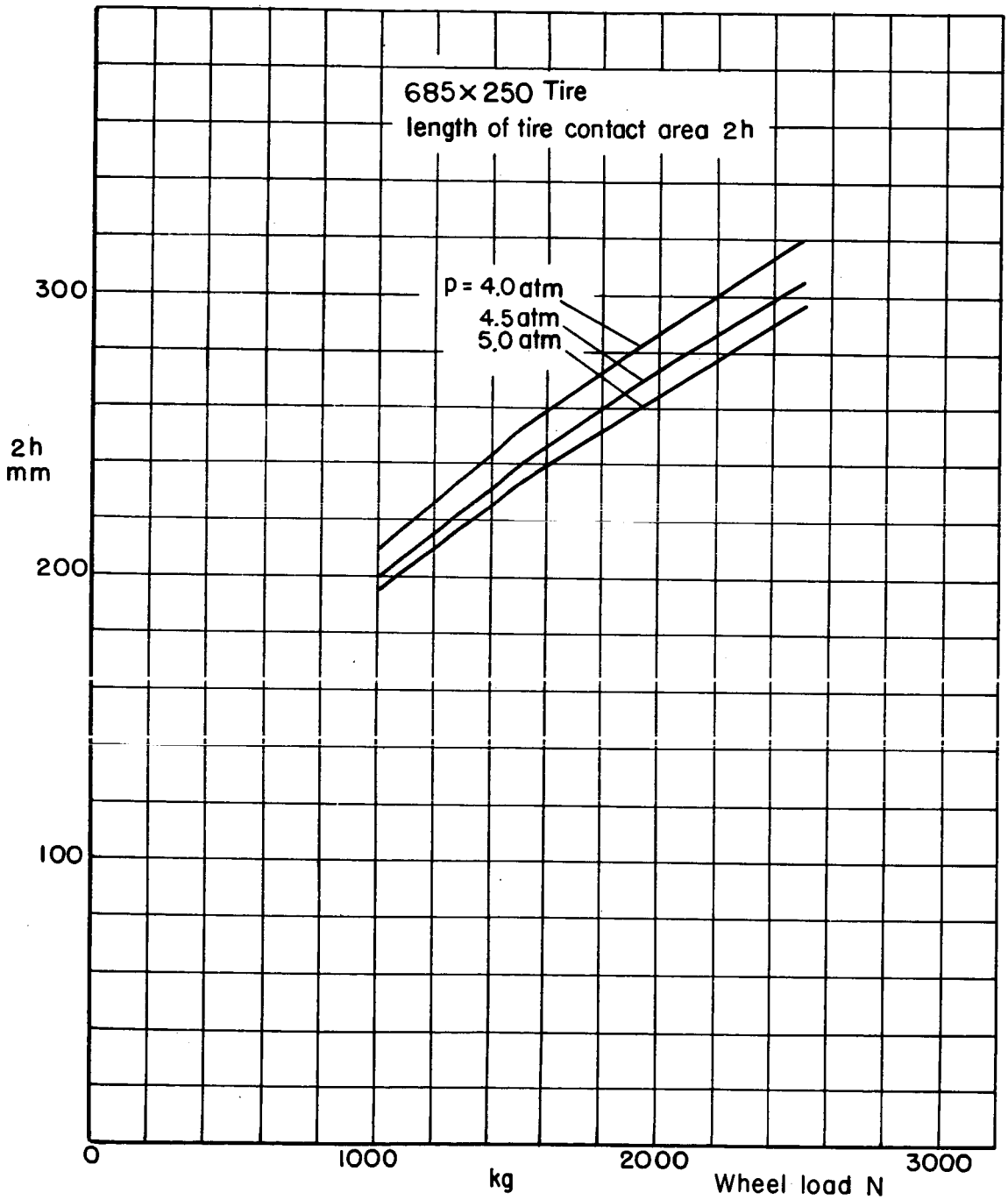

685×250 Tire
length of tire contact area 2h
p = 4.0 atm
4.5 atm
5.0 atm
2h
mm
300
200
100
0
1000
2000
3000
kg
Wheel load N

Figure 28

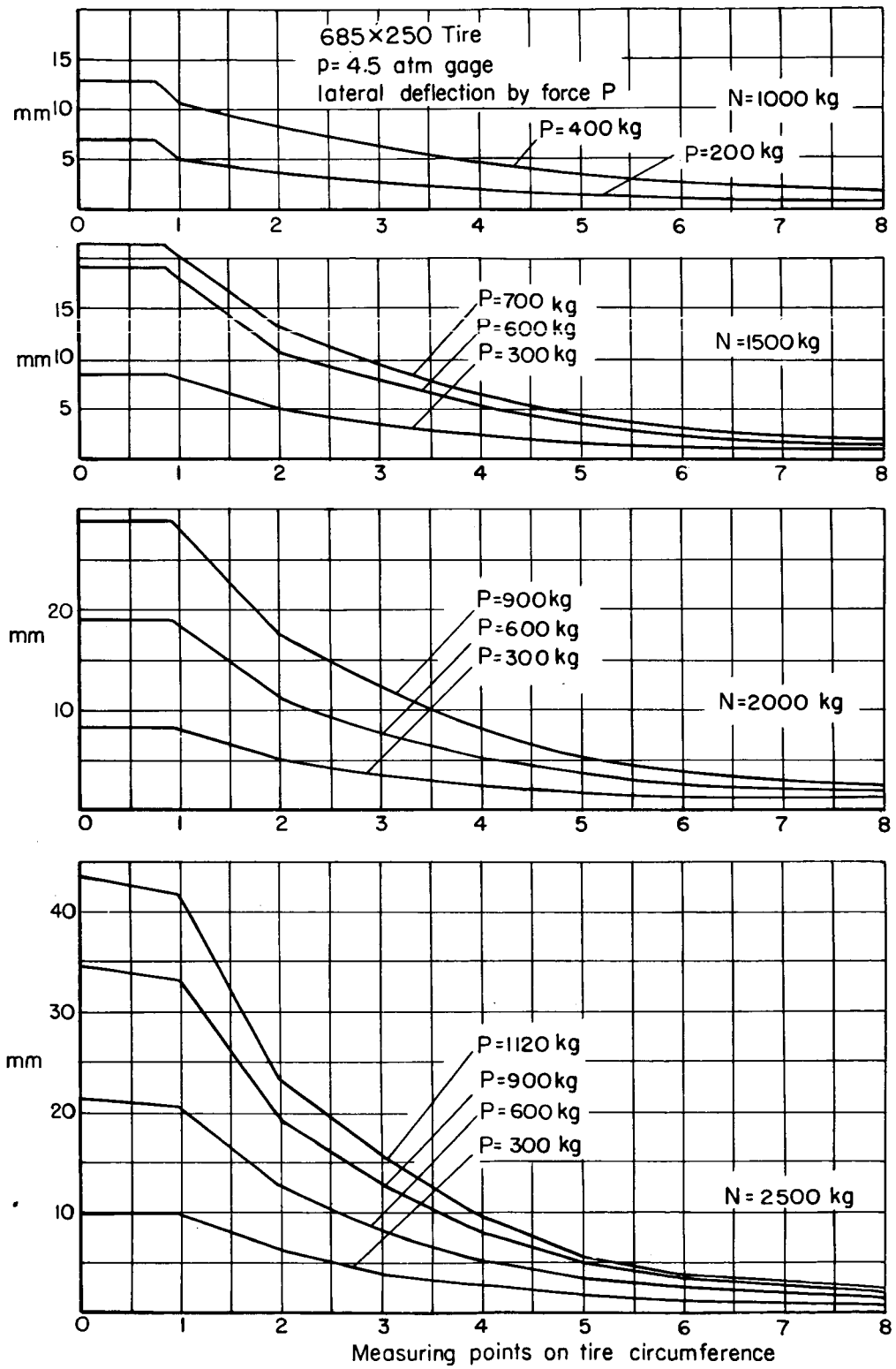

685×250 Tire
p= 4.5 atm gage
lateral deflection by force P
N=1000 kg
P=400 kg
P=200 kg
mm
15
10
5
0 1 2 3 4 5 6 7 8
P=700 kg
P=600 kg
P=300 kg
N=1500 kg
mm
15
10
5
0 1 2 3 4 5 6 7 8
P=900kg
P=600 kg
P=300 kg
N=2000 kg
mm
20
10
0 1 2 3 4 5 6 7 8
P=1120 kg
P=900kg
P=600 kg
P= 300 kg
N= 2500 kg
mm
40
30
20
10
0 1 2 3 4 5 6 7 8
Measuring points on tire circumference

Figure 29

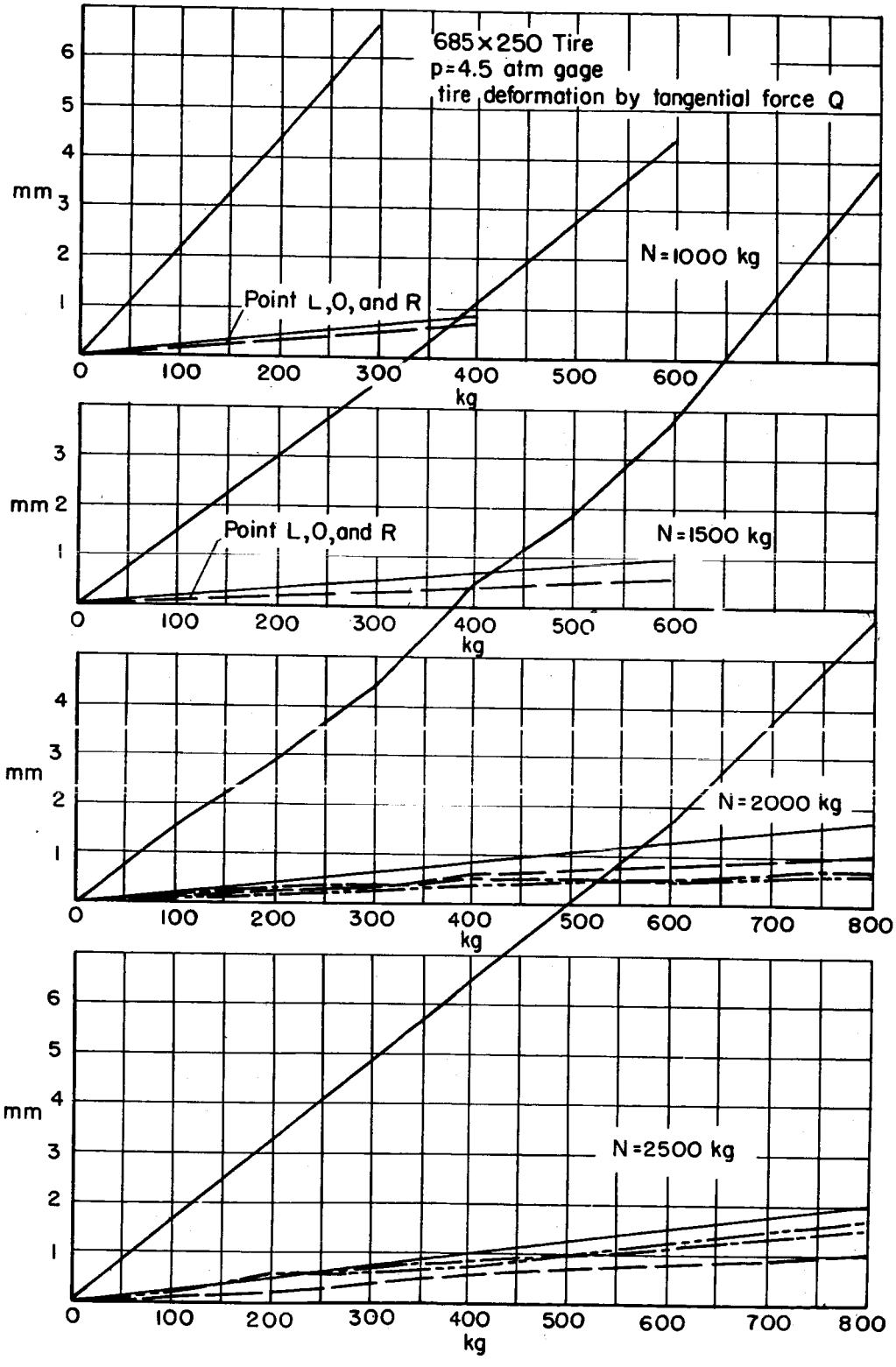

685×250 Tire
p=4.5 atm gage
tire deformation by tangential force Q
N=1000 kg
Point L,O,and R
N=1500 kg
Point L,O,and R
N=2000 kg
N=2500 kg
mm
kg
0
100
200
300
400
500
600
700
800

Figure 30

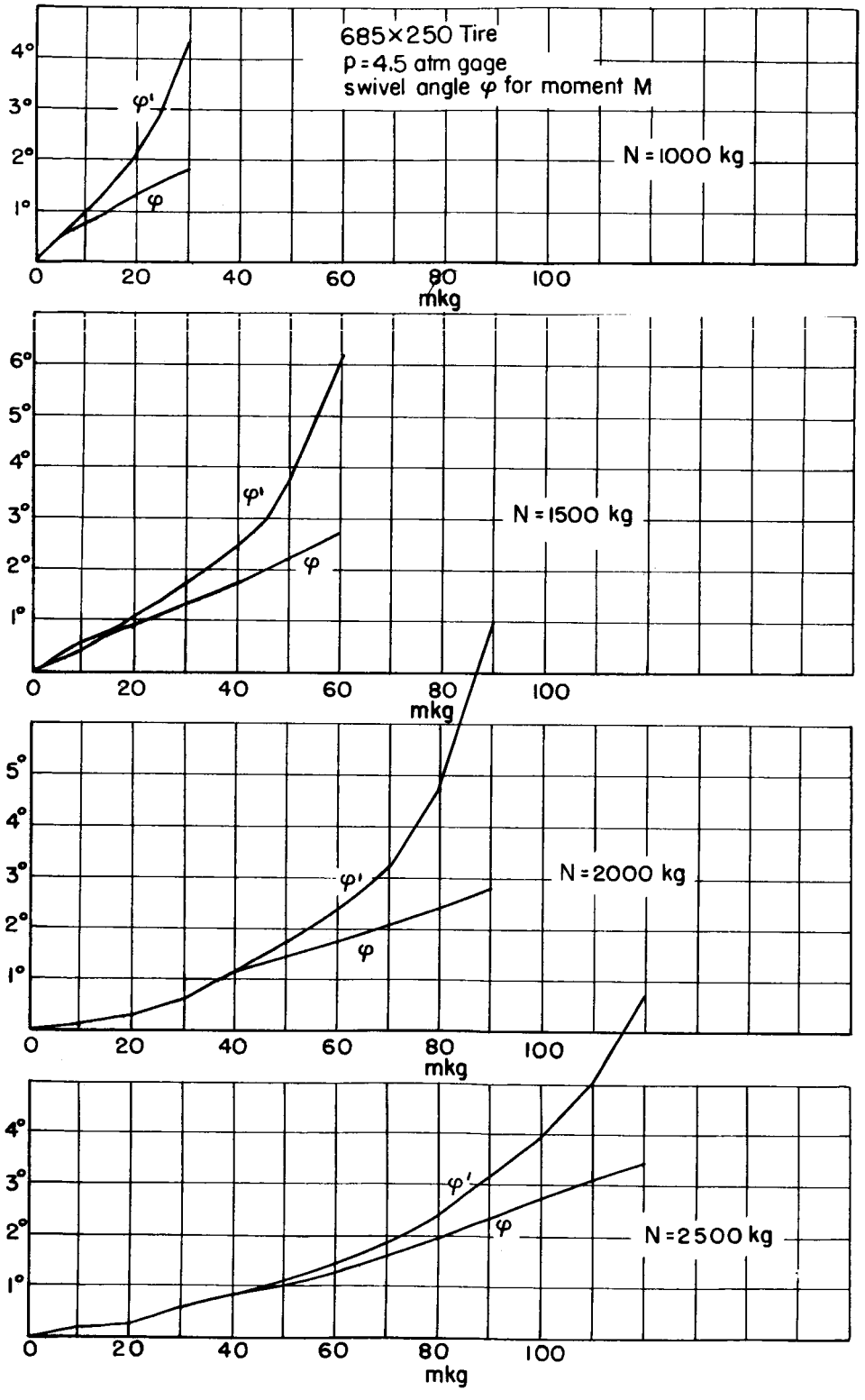

685×250 Tire
p = 4.5 atm gage
swivel angle φ for moment M
N = 1000 kg
N = 1500 kg
N = 2000 kg
N = 2500 kg
φ'
φ
mkg
0
20
40
60
80
100
1°
2°
3°
4°
5°
6°

Figure 31

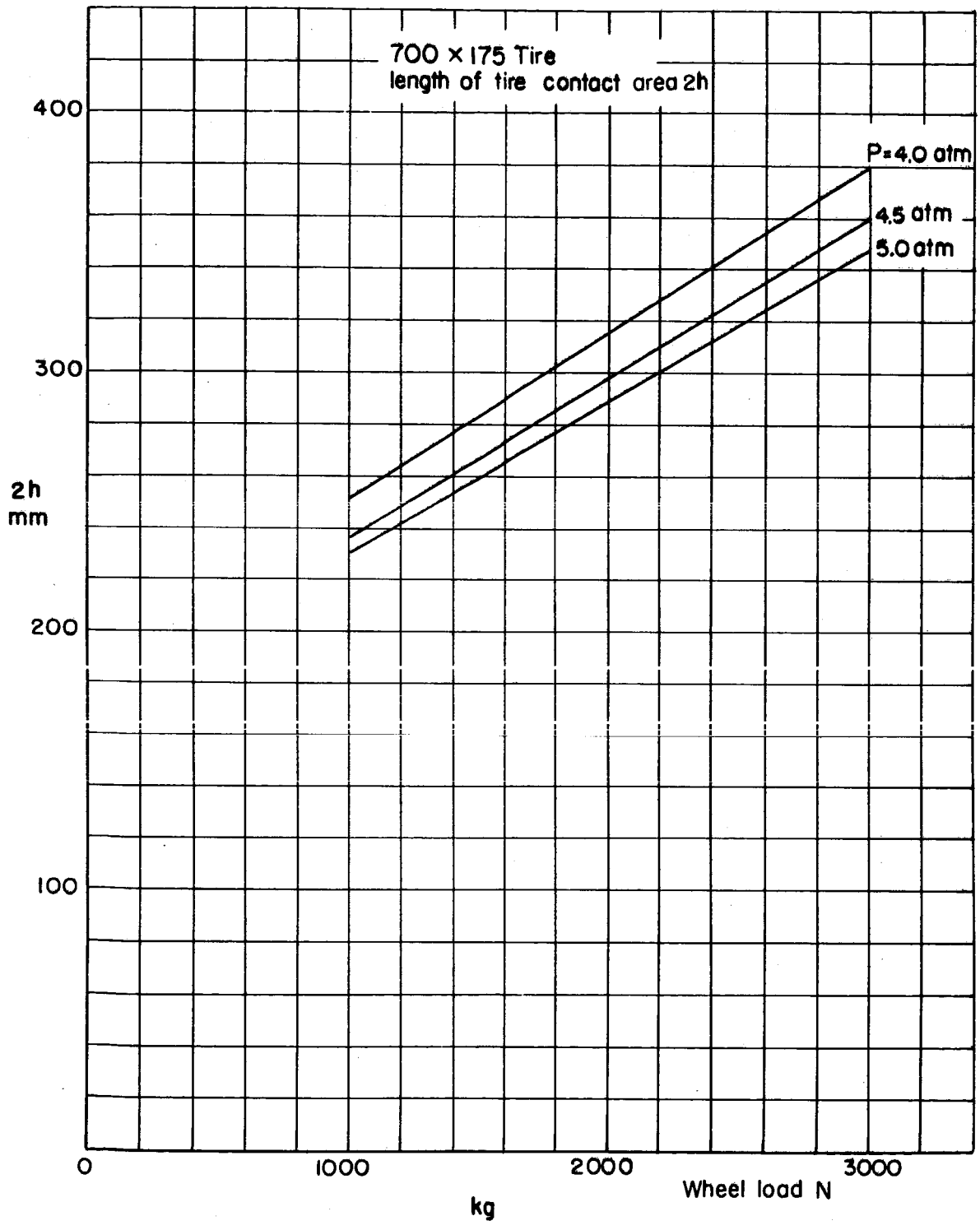

700 × 175 Tire
length of tire contact area 2h
P=4.0 atm
4.5 atm
5.0 atm
400
300
200
100
2h
mm
0
1000
2000
3000
kg
Wheel load N

Figure 32

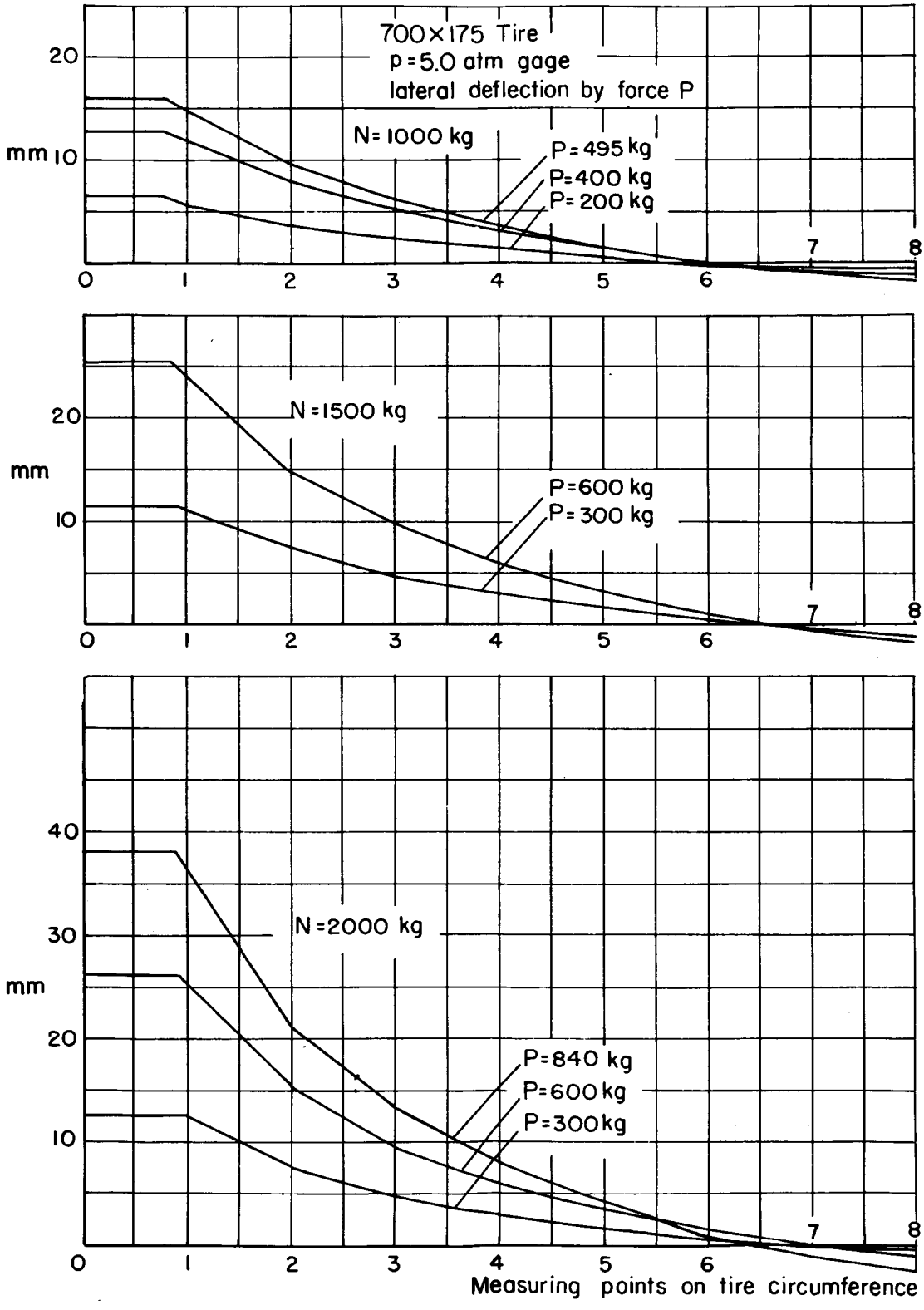

700×175 Tire
p = 5.0 atm gage
lateral deflection by force P
N = 1000 kg
P = 495 kg
P = 400 kg
P = 200 kg
mm
20
10
0 1 2 3 4 5 6 7 8
N = 1500 kg
P = 600 kg
P = 300 kg
mm
20
10
0 1 2 3 4 5 6 7 8
N = 2000 kg
P = 840 kg
P = 600 kg
P = 300 kg
mm
40
30
20
10
0 1 2 3 4 5 6 7 8
Measuring points on tire circumference

Figure.33

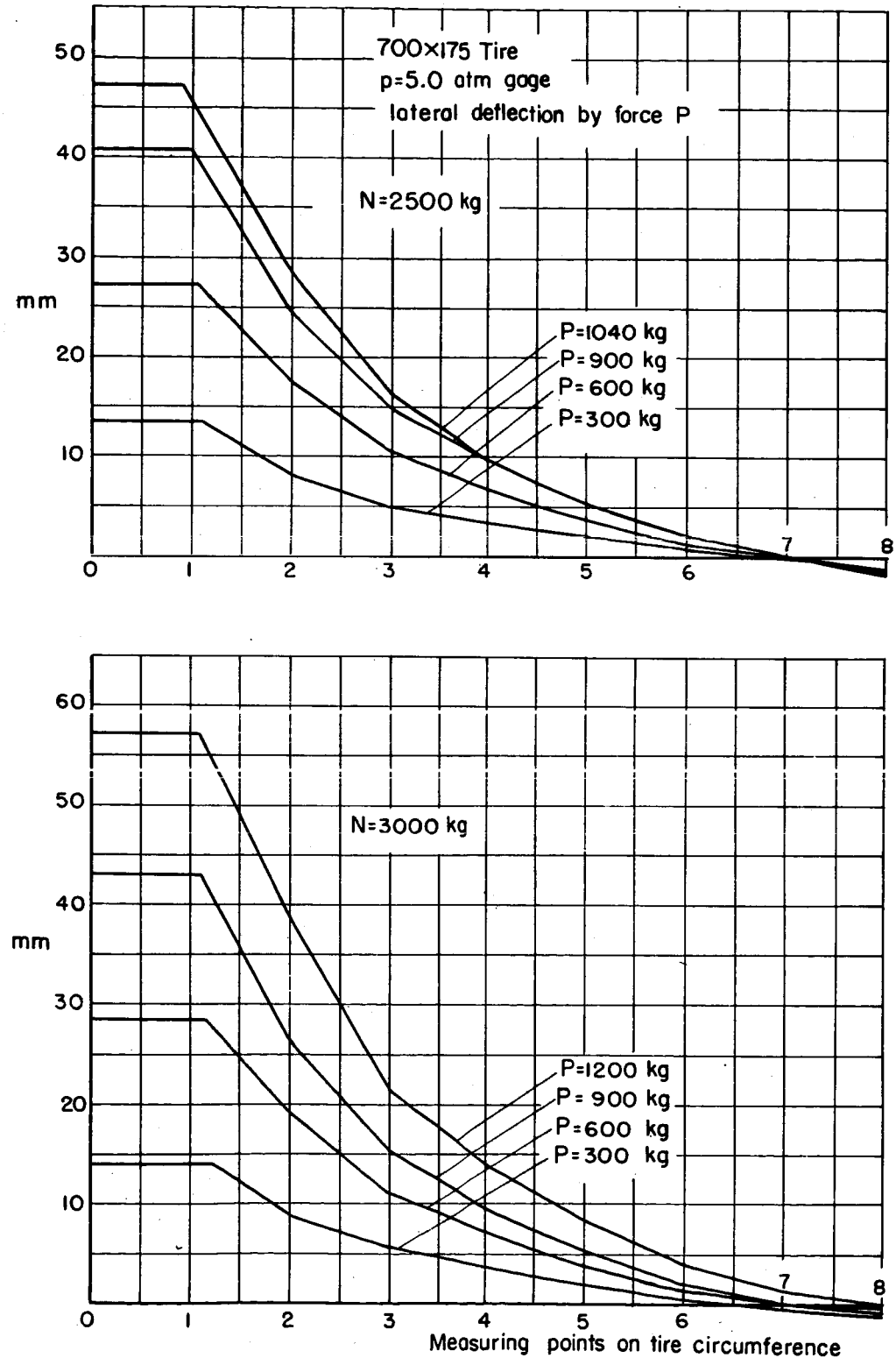

700×175 Tire
p=5.0 atm gage
lateral deflection by force P
N=2500 kg
P=1040 kg
P=900 kg
P=600 kg
P=300 kg
mm
50
40
30
20
10
0
1
2
3
4
5
6
7
8
N=3000 kg
P=1200 kg
P=900 kg
P=600 kg
P=300 kg
mm
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
Measuring points on tire circumference

Figure 34

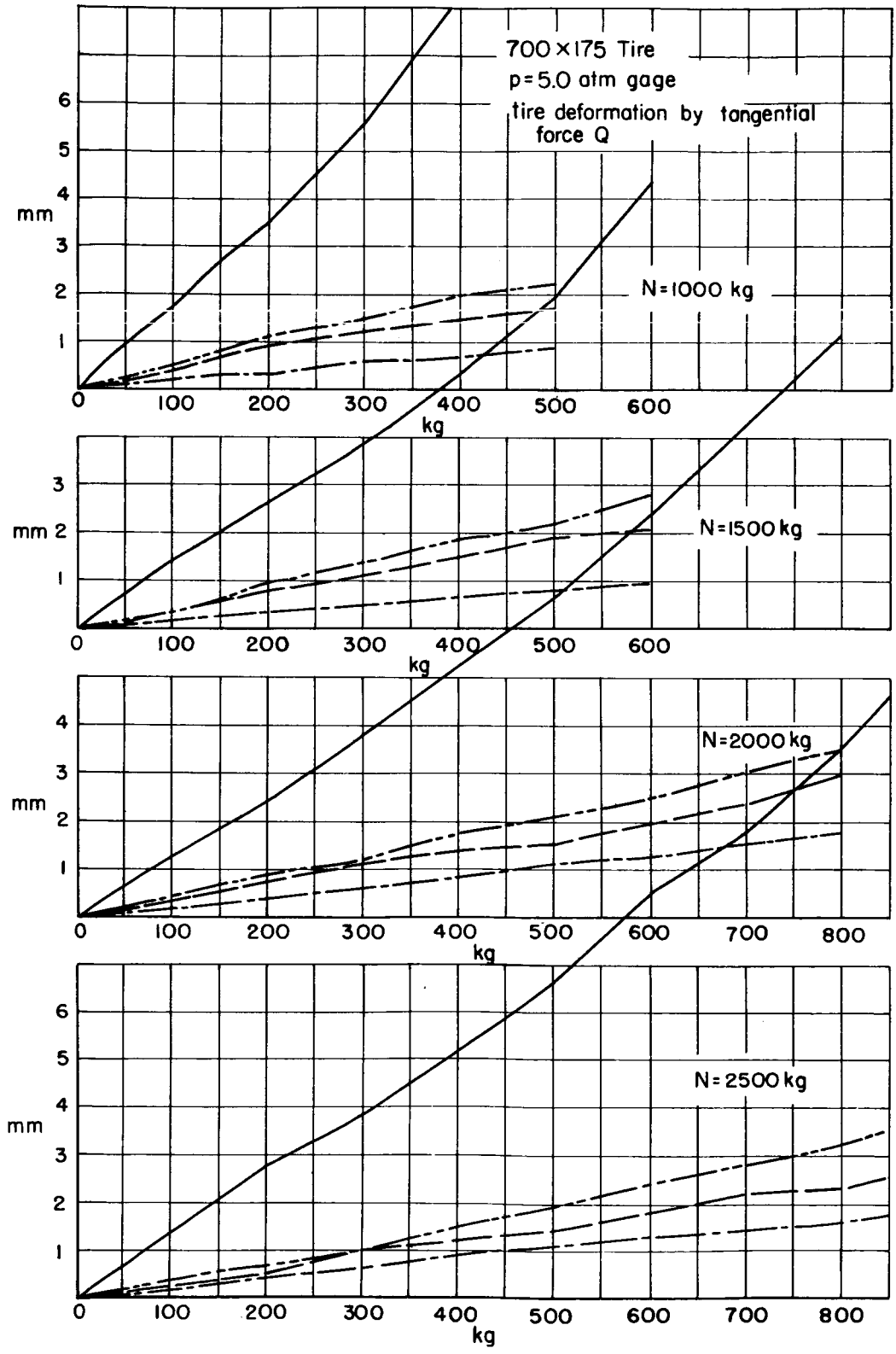

700×175 Tire
p=5.0 atm gage
tire deformation by tangential force Q
N=1000 kg
N=1500 kg
N=2000 kg
N=2500 kg
mm
kg
0
100
200
300
400
500
600
700
800
1
2
3
4
5
6

Figure 35

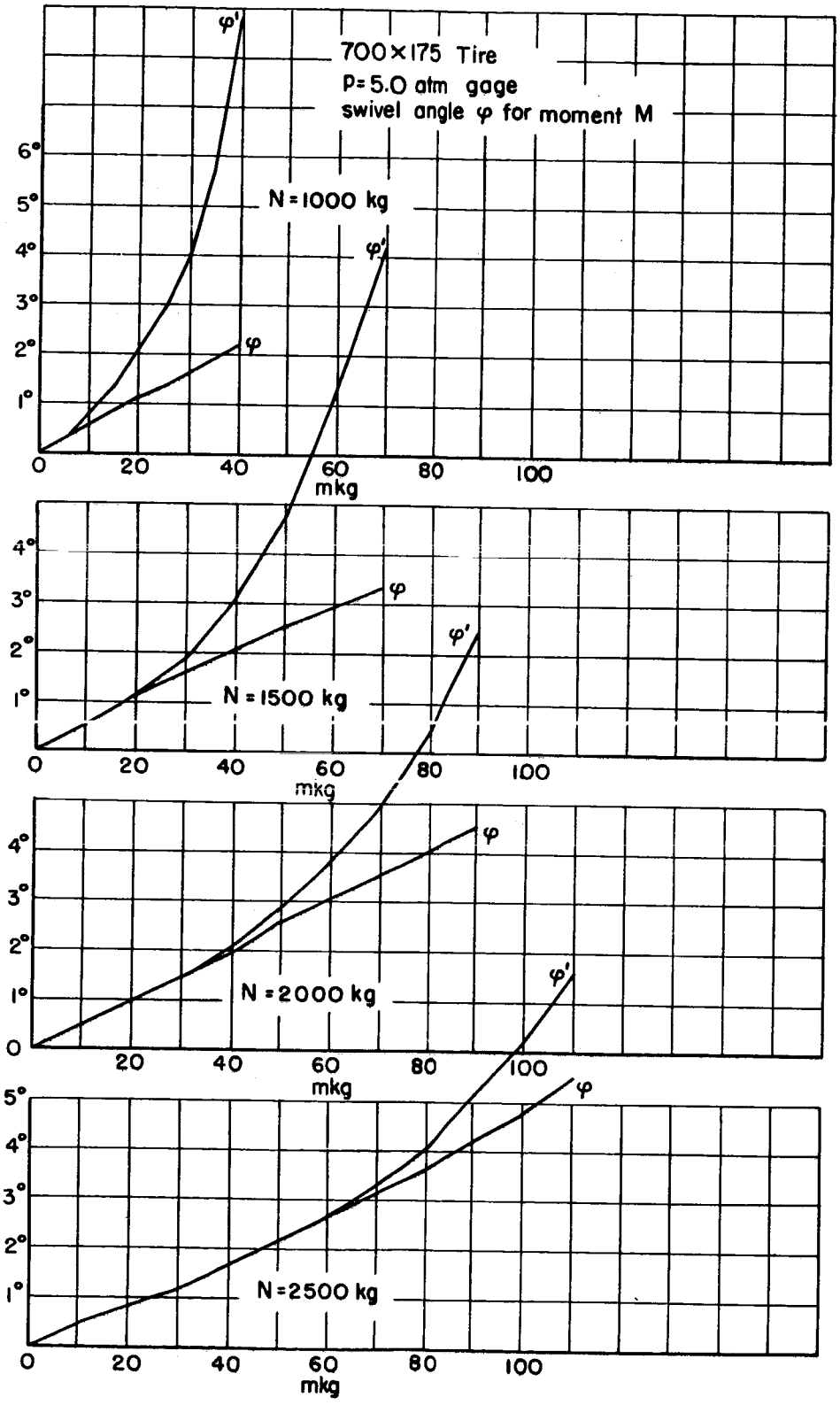

700×175 Tire
p=5.0 atm gage
swivel angle φ for moment M
N=1000 kg
N=1500 kg
N=2000 kg
N=2500 kg
φ'
φ
mkg
0
20
40
60
80
100
1°
2°
3°
4°
5°
6°

Figure 36