RELATIONS BETWEEN CURVATURE AND SPEED

By Merritt L Fox
General Motors Proving Ground

SYNOPSIS

In order to design the curved portions of highways properly it is necessary to study the behavior of cars on curves Both on straight and curved highways the behavior is determined largely by the side forces acting against the wheels and body

Side forces are difficult to measure on a straight highway as they are variable, being caused by road camber and side wind On a curve, the principle side force is due to the centrifugal action which can be controlled by driving the car on a circle of measured radius at constant speed This forms the basis for tests made at the General Motors Proving Ground on a large number of cars Test methods are described and typical curves given

The behavior of cars is determined by the slip angle of the front and rear wheels and the relation between them By evaluating the slip angle to the ratio of side force to weight or cornering ratio, the results of tests become applicable to curves of differing radii and to cars driven at all speeds Difference in understeering and oversteering cars is explained Understeering cars are found to handle better and require less width of lane on curves

Maximum cornering ratio is found by tests to be about 50 per cent This indicates that no highway should be constructed with a radius of curvature which will cause a car traveling at maximum speed to develop a cornering ratio above this value

Modern civilization owes much of its recent progress to more rapid transportation The worker is able to live away from the city and raise his standard of living and the farmer is dealing directly with the consumer and everyone is going somewhere The demand of progress is for increases in both the speed and safety of transportation

Automobile manufacturers have been able to combine this increase in speed with greater safety in their cars However, only in rare instances is the driver justified in using all the speed provided in his car This is due to the condition of the roads and, therefore, it would seem logical to attempt to provide highways which will permit increased driving safety at high speed To do this, a study of the behavior of cars should aid the highway engineer in his designs

Automobiles behave differently on straight or curved courses On a straight course the behavior of an automobile is principally a function of the car and the highway The car is resisted by forces which retard its progress and by other lesser forces which tend to deflect it from its line of travel The retarding forces are ascending grades, air resistance and rolling resistance, while deflecting forces are road camber and side wind

On a curved course the behavior of a car is a function of the car, the highway and the curvature The progress of the car is retarded by forces similar to those that affect it on the straight course, it is deflected by the same side forces as on the straight course plus the force due to centrifugal action As the speed on the curve is increased the centrifugal force soon exceeds the others

Forces which retard the forward progress of the car are important to the owner Any reduction in them will allow the car to be driven farther or faster for the same expenditure Side forces directly affect the handling of the car and its behavior both on curved and straight highways The side forces are therefore important to the car owner, the automobile designer and the highway engineer

The car being driven on straight or

curved highways must resist the side forces in exactly the correct amount so it will not be deflected from its course Rubber tired wheels have good resistance to side force when rolling along a straight path If we could push sidewise against the hub of such a wheel rolling along a pavement, it would require, under ideal conditions, about one hundred pounds of side force to deflect its course one degree

This characteristic of the tire is used to maintain a straight course on the highway Thus, when there is a side force of one hundred pounds acting on the wheel, it must be steered one degree toward the force to maintain its course This angle between the center line of the tread of the tire and the course maintained by the wheel is known as the slip angle

Side thrust developed by the slip angle is affected by the condition of both the tire and the roadway The tire is affected by the weight on the wheel, the tire size, the inflation pressure, the construction of the side walls, the design of the tread and the width of the wheel rim Material and finish of the road surface, the presence of foreign matter, temperature and wet or dry conditions also affect the side thrust

When side forces are encountered it is necessary for the wheels to develop sufficient side thrust to overcome the forces and hold the car on its course To do this the driver must steer toward the side from which the force is coming until the tires have enough slip angle to balance the force The rear wheels are mounted on an axle which is held more or less in alignment with the car This requires the entire body of the car to assume an angle with the course approximately equal to the slip angle of the rear wheels

On a curve the behavior of a car is largely affected by the centrifugal side force A car seldom has equal weight distribution on the front and rear ends The unequal weight will cause a larger centrifugal force at the heavier end This requires the wheels at this end to develop a larger slip angle

The centrifugal side force will cause the car body to lean to the outside of the curve and produce a transfer of weight to the wheels on the outside This will produce uneven loading on the right and left wheels both at the front and rear Since these are held in relative alignment, the side force at the front or rear end is the sum of those produced by the right and left slip angles The sum of these forces at the front or rear wheels must equal the total side thrust against that end of the car

A car in which the front end has more slip angle than the rear requires a greater steering angle than one in which the slip angles are equal This car is said to be understeering A car in which the rear has more slip angle than the front requires less steering angle and is said to be oversteering An understeering car requires the driver to steer toward the side from which the force is coming, and to increase the steering angle as the force grows larger An oversteering car requires the driver to steer away from the force

By driving a car on a circular path at constant velocity, the side force due to the centrifugal action becomes a known quantity While maintaining this velocity, measurements can be made of the steering angle, the angular position of the car on the course and the side roll By driving the car at other velocities, the side force can be controlled Thus, the measurements are made of the desired quantities at increasing values until critical readings are obtained From these measurements the quantities affecting the behavior of the car can be calculated

For the past three years, tests of this type have been made at the General Motors Proving Grounds on practically all models of American cars and the more interesting foreign cars. These tests were performed in order to study the handling charcteristics of cars and obtain data that would enable the General Motors Corporation to make them safer from the handling standpoint. No thought was given in the development of this procedure to the high speed highway. It is believed however, that the results obtained may prove useful to the highway engineer.

and caster are checked against manufacturers' specifications, the car is placed on the alignment equipment and a calibration is made of the steering indicator. To do this the front wheels are advanced to consecutive angular positions and the indicator read. The actual angle of each front wheel is read for each position of the steering indicator. From these readings, curves are plotted for both front wheels using actual angles turned and the corresponding indicator read-

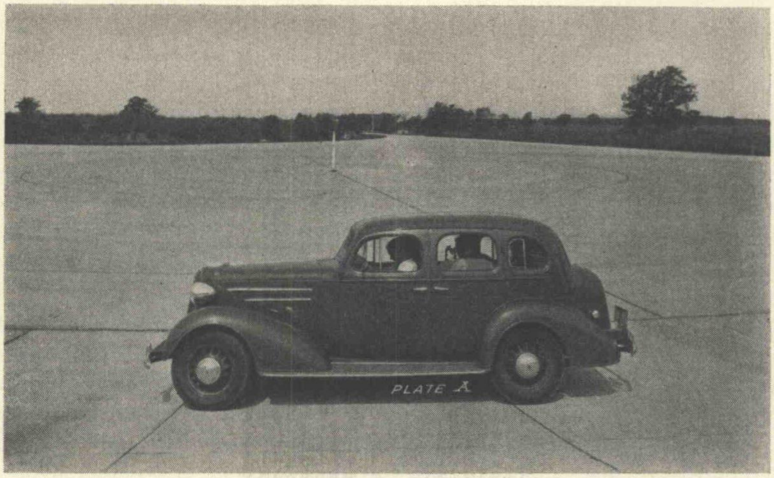

Figure 1

Figure 1 shows a car on the circle ready for the test. Preparations consist in mounting an engineer's transit and stand inside the car between the front and rear seat as near to the center line of the car as possible. An electrical device, making use of a pair of Autosyn motors connected as in signal work, is attached to the steering arm of one front wheel and wiring connections are carried to an indicator in the car. The purpose of this instrument is to indicate to the observer in the car the exact steering angle of the front wheels while the car is being driven around the circle at any given velocity.

After the tire pressure, toe-in, camber

ings. These curves serve as a calibration of the indicator so that its readings, when driving the car in the circular path, give the actual angles of the front wheels.

Some cars are constructed with steering links of unequal length extending from steering gear on the left side of the car to the two steering arms connected to the wheels. This geometry gives unequal steering angles when the car rolls on a curve. To obtain the true steering angles in this case, it is necessary to use two sets of indicating instruments simultaneously, one connected to the right and the other to the left wheel.

In making the test runs, it is necessary to have, besides the driver, two observers in the car, one to read the steering indicator and take the speed readings, the other to set the transit angles This makes the test load equal to about four passengers The car is carefully weighed, each wheel being taken separately and the steering calibration curve made with the full test loads in place

The transit level plate is set with the car on a level portion of pavement The car is rocked from side to side to take out the error due to spring friction The transit vernier plate is set to zero by driving the car in as near a straight course as possible on the center of a straight level roadway and sighting through a telescope on a distant object at the center of the road This is repeated while driving the car at the same speed in the opposite direction The settings of the vernier plate for the two runs are averaged for the true setting Differences in settings are due to paving camber and side wind

Tests are usually made with the tire pressure recommended by the car manufacturers As the car is driven around the circle at higher speeds, the temperatures of the tires on the outside will increase faster than on the inside It is necessary to adjust the pressure as the speed is increased, since cornering power of the tires is affected by an inflation change

At the exact center of the circle to be used in the test, a small pole is erected vertically A marker band is fastened on the pole at the same height as the transit telescope

The car is now ready for the test run on the circle At the Proving Ground a circle of 108-ft radius has been used for the larger part of these tests The car is driven at a uniform speed around the circle as nearly as possible in the same track The driver must keep the speed of the car uniform and at the same time hold it on the circle The car speedometer is used only as a guide to the driver Actual speed is determined by stop watch timing of a complete lap of the circle

One observer rides beside the driver reads the steering indicator and takes the stop watch readings The second observer rides in the rear and adjusts the transit until, as seen in the telescope, the cross hairs average the travel of the band on the pole at the center of the circle By repeatedly informing the other observer and the driver as to whether the course of the car is inside or outside the exact circle as seen through the transit telescope, it is possible for the two observers to agree on the correct settings when the car is exactly on the circle

Since it is impossible to read the transit scales when the car is running, it is stopped after each run Readings of the speed and steering indicator, as well as the horizontal and vertical angle of the transit are then made and entered on the data Runs have been made at approximately $2\frac{1}{2}$ mile increments of speed, starting at five miles per hour and increasing to as high a speed as possible, consistent with holding the car on the circle and taking readings After making the test the actual speed in miles per hour is figured from the stop watch time

The actual steering angle values are taken from the calibration curve of the steering indicator

The roll angle is given by the transit vertical scale The attitude angle of the car is the angle between its longitudinal axis and a tangent to its course It is found from the horizontal angle read by the transit and the transit position angle as shown in Figure 2 The rear slip angle is the same as the attitude angle if the rear axle of the car remains truly lateral to the car as it rolls on the curve

Due to the rear spring changing position when roll occurs and one side of the car rising as the other falls, the axle moves laterally In some cars this movement of the axle is unequal at the two ends, thus causing the rear axle to steer through a small angle which either adds to or subtracts from the effective steering angle of the car The steering of the rear axle due to roll angle is found from another test in which the car is rolled to measured angles and the change in the position of the axle is measured In the figures shown in this report, the rear axle is assumed to remain lateral to the axis of the car

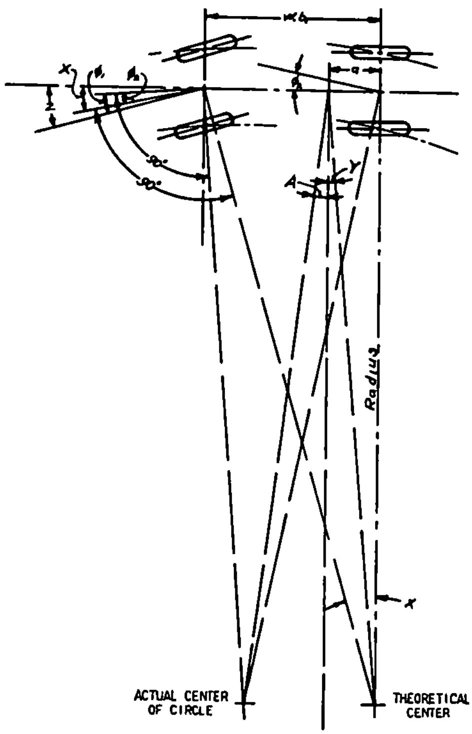

Figure 2

Z = Steering Angle Found from Tests

X = Wheelbase Angle

$$\text{Tan } X = \frac{W\ B}{\text{Radius}}$$

Y = Transit Position Angle

$$\text{Tan } Y = \frac{A}{\text{Radius}}$$

A = Angle Read by Transit

ϕ_2 = Rear Slip Angle

$$\phi_2 = Y + A$$

ϕ_1 = Front Slip Angle

$$\phi_1 = Z + \phi_2 - X$$

Figure 2 indicates the angular relations of a car on a circular path The theoretical center of the circle is located in line with the rear axle at a distance equal to the radius of the circle The wheelbase is denoted by w b The actual center of the circle about which the car is being driven is ahead of the theoretical center

The transit is located in the car a distance "a" ahead of the rear axle The transit vernier plate is set to read zero when the telescope points toward the inside of the circle and 90 degrees from the longitudinal axis of the car

Let A be the angle read by the transit It is negative when the line of sight is toward the rear and positive when ahead of the zero reading

Let Y be the transit position angle, the tangent of which equals the distance the transit is ahead of the rear axle divided by the radius of the circle

Then ϕ_2, the rear slip, is the sum of the angles indicated by the transit A, and the transit position angle Y

$$\phi_2 = A + Y$$

The front slip angle ϕ_1 equals the sum of the steering angle Z and the rear slip angle ϕ_2 minus the wheelbase Angle X

$$\phi_1 = Z + \phi_2 - X$$

The steering angle Z has been found from the readings of the steering indicator and the calibration curve

The wheelbase angle X is the angle at the theoretical center of the circle between lines drawn to the wheelbase (w b) of the car Its tangent is the wheelbase divided by the radius of the circle When considering the slip angle of the wheels separately, those on the outside of the circle will have the smaller wheelbase angles

The slip angles both front and rear as found by this method are the angles between the tangent to the circle and the center line of the tire at the point of contact The rear slip angle as found assumes that the rear wheels remained parallel to the longitudinal axis of the car

Figure 3 has been prepared from the readings of a test run on a standard 1937 sedan, designated as Car A The horizontal scale of speed is in miles per hour

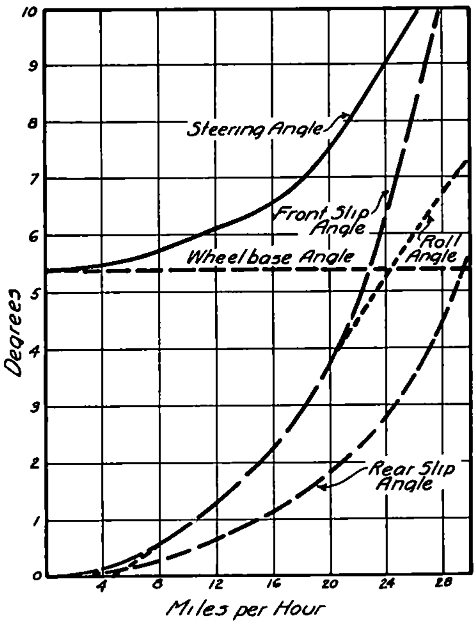

Figure 3 Angular Relations Versus Speed Car A Driven in a Circle of 108-Ft Radius

on the 108-ft radius circle The vertical scale is in degrees and applies to the different relations shown in the curves

The average steering angle of the front wheels starts near the wheelbase angle and increases with speed

Front and rear average slip angles have been extended back to zero speed The lowest test readings are made at 5 miles per hour

The roll angle crosses zero at about 4½ miles per hour This is due to the circular course having a slight side slope At this speed, the side component from the slope angle balances the centrifugal force

The curves show that the front slip angle increases faster than the rear This requires the steering angle to increase with speed in this test circle and the car is decidedly understeering

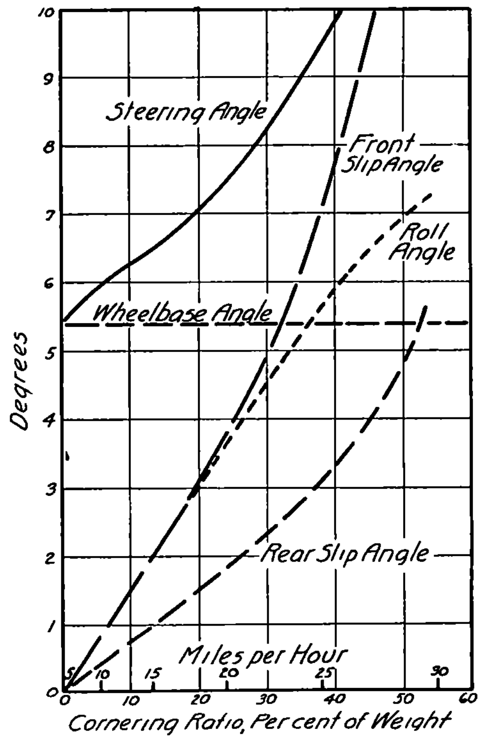

Figure 4 Angular Relations Versus Side Force Expressed as Per Cent of Weight Car A Driven in a Circle of 108-Ft Radius

Figure 4 is a replot of the quantities shown in Figure 3, but with the horizontal scale changed When the car is driven about the circle a side thrust is set up due to the centrifugal force This thrust becomes greater with increase in speed and would increase as the square of the speed except for a small slope toward the center of the circle for drainage

The formula for side force when the roadway has side elevation is

$$\text{Side Force} = \frac{W(V^2 \cos S - \sin S)}{gR}$$

In which, W equals weight in pounds
R equals radius of the circle in feet
V equals velocity of car in feet per second
g equals acceleration of gravity
S equals bank angle of the curve

In the test runs, R=108 ft, g=32 16, and S=0°21-½′

Substituting quantities

$$\text{Side Force (lbs)} = W(\ 0002875\ V^2 - \ 00625)$$

If the curves were plotted to the values of side force found by this formula, the scale would apply to cars tested on curves of equal radii These would not have as universal application as when plotted to values of cornering ratio expressed as percentage of weight

$$\text{Cornering Ratio (per cent of Weight)} = \frac{\text{Side Force}}{\text{Weight} \times 100}$$

This is the same type of ratio that Professor R A Moyer called "Coefficient of Friction" in his tests of skidding characteristics

Figure 4 uses the same vertical scale of angular values as Figure 3 with side forces expressed as cornering ratio

The scale in miles per hour on the circle of 108-ft radius has been added to retain the relationship between speed and side force from the test

Figure 5 shows the steering angles of five 1937 cars plotted in the same manner as used in Figure 4 The initial steering angle is larger for cars with longer wheelbases as will be noted from the curves

From these curves the car with the shortest wheelbase shows the greatest amount of oversteering and that with the longest wheelbase shows the largest understeering This relationship depends on the slip angles in the front and rear and not on the wheelbase Of the cars chosen for the tests, those with short wheelbases had front axles and these usually show more tendency toward oversteering

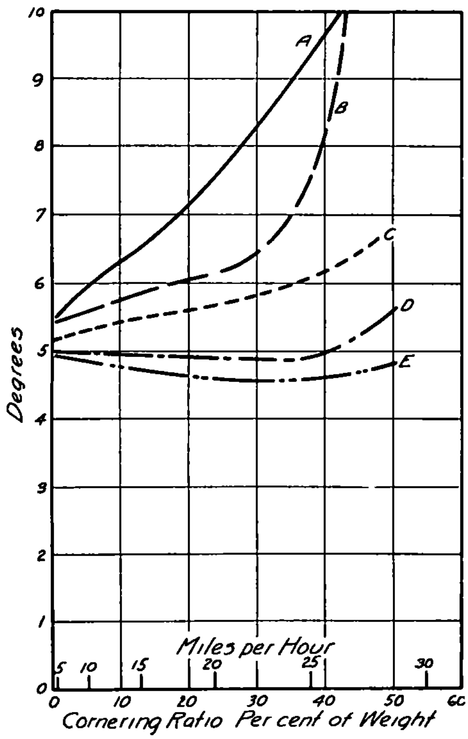

Figure 5 Comparison of Steering Angles of 5 Cars

Those with the longer wheelbases had independently sprung front wheels

Figure 6 shows the average front and rear slip angles of Cars A and E Figure 5 shows that Car A has the most understeering and Car E has the greatest oversteering This is because, in Car A, the front slip angle is larger than the rear and, in Car E, the rear slip angle is larger than the front The slip angles of Cars A and E were selected from those of the 1937 cars since these had the greatest difference between the front and rear Slip angles of other cars will plot between them

As previously stated, the values of the slip angles are affected by changes in tire characteristics and condition of the roadway as well as by the geometry of the car By plotting slip angles against values of

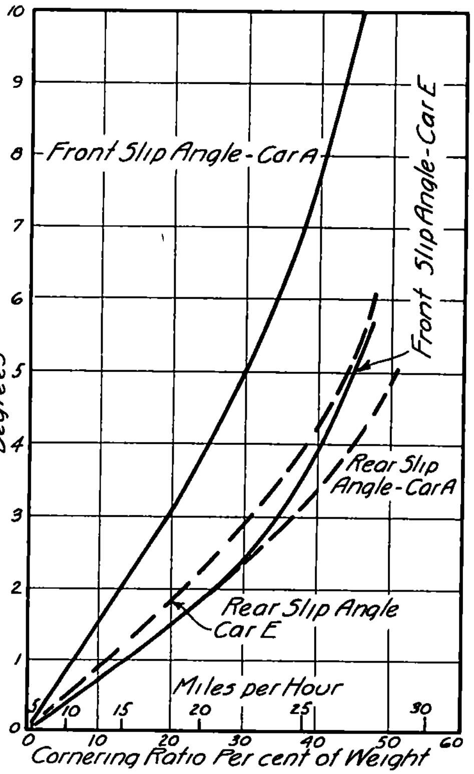

Figure 6 Comparison of Front and Rear Slip Angles on Cars A and E

side force expressed as cornering ratio, test results can be compared

Thus, a car traveling at 20 miles per hour on a flat curve of 100-ft radius has about the same centrifugal side force as one traveling at 60 miles per hour on a 1,000-ft radius

On these curves the front and rear slip angles will be much alike at the two speeds Due to the different curvature the wheelbase angle is very different, being approximately ten times as large on the curve with the small radius The steering angle will be the wheelbase angle plus the difference in the front and rear slip angles In all cases these relations may be altered somewhat In the front the steering geometry of the car may change at different radii of curvature and with greater values of rolling resistance

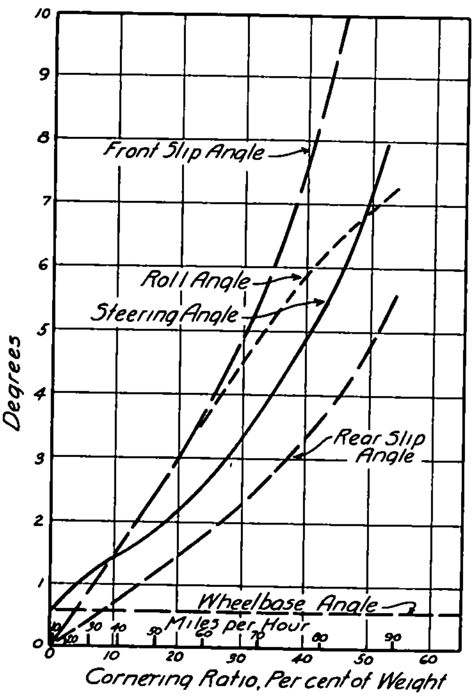

Figure 7 Angular Relations Versus Side Force Expressed as Percentage of Weight of Car A Driven in a Circle of 1,000-Ft Radius

In the rear the greater driving torque will increase the slip angle of the rear wheels by a small amount

These relations are shown in Figure 7

By the use of this method and test runs made on a curve of known radius, the handling characteristics of the car on any other curve and at any speed can be predicted

Every car will have typical curves of front and rear slip angles and of steering angle These typical curves will be repeated by the car when all the conditions of the car and the roadway are duplicated

The circular path used in making these tests is equipped with a sprinkler system Thus, a car can be run with the paving wet and other conditions as in previous tests

On wet paving the slip angles are influenced to a greater degree by the condition of the tire tread than on dry pavement A new tire will show only slightly greater slip angles up to a cornering ratio of about 40 per cent A smooth tire will show a larger slip angle on wet pavement, the amount depending on the condition of the tread The smoother the tread, the greater the slip angle will be

A car being driven from a straight into a circular course has an increasing amount of side force applied at a rate depending on the abruptness of the transition In this case, the speed is kept constant and the angle of curvature is changed

Thus, the slip angles will increase in a manner similar to our test curves

When the attitude angle equals ½ of the wheelbase angle the front and rear wheels will track At lower speed on the curve the front wheels will track outside the rear and at higher speeds they will track inside the rear From Figures 3 and 4 these conditions can be found for Car A The wheelbase angle is plotted at 5° 23′

The wheelbase is then

$$1{,}296 \sin 5^\circ 23' = 1{,}296 \times 0938 = 122 \text{ in}$$

The front and rear wheels will track at 2° 41′, which corresponds to a cornering ratio equal to 34 per cent of its weight This is produced by driving at 24 miles per hour on the test circle

At approximately 30 miles per hour, the attitude equals the wheelbase angle At this speed the rear will track 5¾ in outside the front

This is on Car A which is understeering On Car E, which is somewhat oversteering, the attitude equals the wheelbase angle on the test circle when the car is driven at 26 miles per hour At 30 miles per hour, the attitude angle will be about double the wheelbase angle and the rear will track about 11 in outside the front

An understeering car will require less width of highway on a curve Including the overhang of the body beyond the wheelbase, Car E will require a lane 17 in wider than its body Car A requires only 8½ in extra width although its wheelbase is 10 in longer

Motor busses, freight trucks, and house trailers have long wheelbases and require a greater width of highway than passenger cars

An understeering car such as Car A is safer than one that is oversteering This is because the front has more slip angle than the rear and the driver has control of this end When the front starts to skid, the driver has warning and can correct the condition The rear end of this car will not skid before the front nor go into a spiral spin An oversteering car may do this before the driver is aware of the dangerous condition

From Figures 6 and 7, it is evident that the slip angles are increasing very rapidly when the cornering ratio reaches 50 per cent It has been found impossible to drive any car above this value of side force, hold it in its course and take readings with the instruments

At this value of side force, the tire has started side skidding, making the behavior of the car erratic A good driver will still guide the car around the curve without trouble provided there is no traffic in the other direction

The surface of the roadway used in the tests is somewhat smoother than the average pavement However, with so definite a value established in many tests, it seems advisable that no curves should be constructed on main highways where a driver will exceed this value of side force when traveling at the highest speed he will attain

The tests described are made by driving a car on a circular path The speed is controlled to give constant centrifugal forces of known value In this way the angular relations and the behavior of a car on a curved roadway can be studied

A car on a straight roadway and traveling from a straight to a curved path behaves differently In this case, the forces are variable and change direction rapidly This sets up secondary reactions between the members of the car The mass of the parts are carried on springs and tires which give them characteristic vibration frequencies

The study of the behavior of cars on straight roadways is a matter requiring an entirely different test procedure, a discussion of which must be left to some future time

CONCLUSIONS

The examples of behavior of cars on curves shown in Figures 3 to 6 were taken from tests of typical 1937 cars In these tests the condition of the cars and their tires were carefully checked

The amount of slip angle necessary to develop a required side thrust depends on the car maintaining its alignment, and the tires being in good condition and having the correct inflating pressures The cars on the highways seldom meet these conditions The front end geometry usually has been neglected and the tire pressure allowed to drop

The behavior of cars in 1937 is better than in previous years and next year it will be still better However, allowance must be made in highway design for cars with poorer behavior than those shown in the test curves There are cars on our highways having more oversteering than Car E, and these require more than the 17 in extra width of lane

All rubber tired vehicles get their cornering power from the development of slip angles in the same way as cars The passenger bus and freight truck have characteristic curves which are on the understeering side until the rear tires become overloaded In this condition, the rear slip angle increases much faster than the front and the rear wheel will track a greater distance outside the front

At least one foot should be added to the lane on curves for each 10 per cent of the maximum cornering ratio that can be developed

In all except the most southern part of the country, sleet and ice at times may cover the highways In this part of the country no highway should have enough superelevation so that a car will side slip into the lower lane A reasonable coefficient of friction for ice has been suggested at 10 per cent, which corresponds to a superelevation of approximately $1\frac{1}{4}$ in per foot

As indicated by test results, a cornering ratio of 50 per cent is the maximum value that can be obtained under good conditions The total cornering ratio which can be used is then the sum of that due to maximum superelevation and friction or 60 per cent It is obviously impossible to build a highway on which it would be safe to drive a car at maximum speed when the surface is slippery Assuming, however, that the maximum speed of 100 miles per hour is used only when the conditions are ideal, a minimum radius of 1,100 feet and a superelevation of one in ten will allow a good driver to bring the car safely around the curve

DISCUSSION ON CURVATURE AND SPEED

Mr W C Johnson, *Goodyear Tire and Rubber Company* The work of this nature performed by Goodyear is in complete accord with Mr Fox's results This is particularly true as regards the value for maximum side skid coefficient of friction

Mr Fox has mentioned several of the factors that affect the development of side force by the pneumatic tire In view of the vital importance of the part played by the tire in this problem, I would like to amplify the description of the cornering properties of tires

Mr R D Evans, of the Goodyear Tire & Rubber Company, presented, at the January 1935 meeting of the Society of Automotive Engineers, a Paper on this subject from which I would like to quote in part

Figure 1 shows the fundamentad relation of cornering force to slip angle for a given tire and for a given set of conditions The straight portion of the curve represents that used in the normal handling of the car, and leads to the designation of the slope as the cornering power of the tire for the set of conditions indicated In this illustration the cornering power is 126 pounds per degree of slip angle

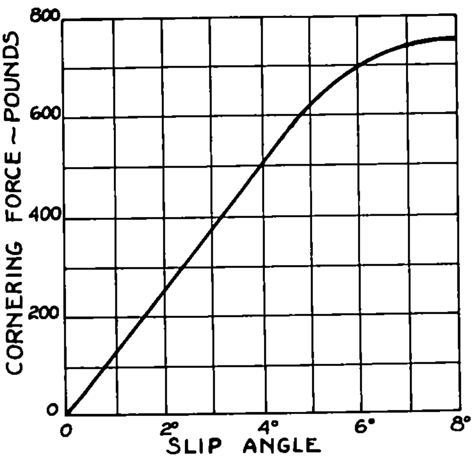

Figure 1 Tire Size 7 50-17 6 Ply Load 1500 lbs Inflation 30 lbs Camber 0°

Figure 2 gives the effect of load This is an interesting relation showing a maximum in the region of the tire's rated load The ideal and most effective tire would be one in which the ratio of cornering power to load remains a constant Then shifting loads would find the tire always able to deliver its share of cornering power This ratio has been termed the cornering coefficient

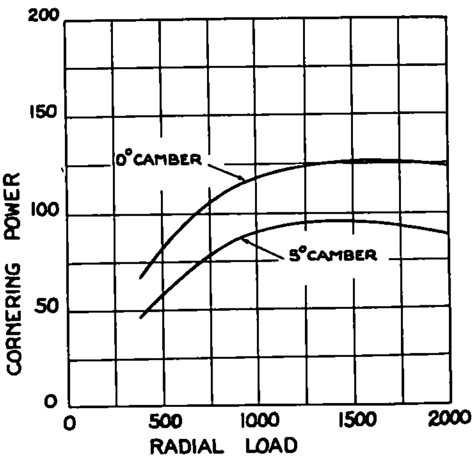

Figure 2 Tire Size 7 50-17 6 Ply Inflation 30 Lbs Per Sq In

Figure 3 shows the data of Figure 2 replotted in these terms There is now no maximum, but instead a discouraging falling off of cornering coefficient with increasing load

Figure 4 shows the extremely small effect of speed on cornering power The dotted line represents the demand on the tire by centrifugal force, which increases as the square of the speed, while the cornering power of the tire is essentially unchanged with speed This demonstrates why a tire having adequate cornering power at a low speed, may be seriously lacking in this property at a much higher speed

Figure 5 shows that increasing inflation is beneficial, tho definitely affected by the law of diminishing returns

The question of major importance is, what can be done to improve the cornering power of tires? Mr Evans in his SAE paper has referred to the "Tripod of Tire Performance" The three factors referred to are, cornering, cushioning, and durability, the tire being a compromise of all three In other words, improvement

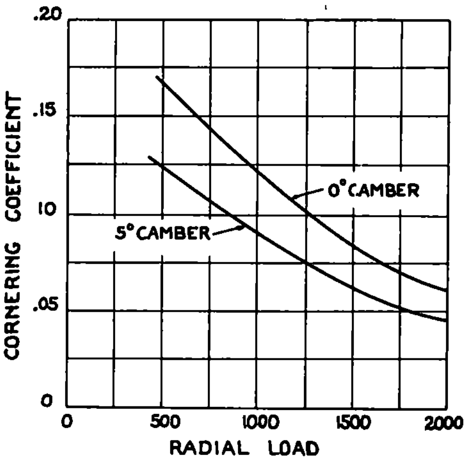

Figure 3 Tire Size 7 50-17 6-Ply Inflation 30 Lbs

of one is almost always at the expense of one or both of the others One illustration of this is the increase of cornering power gained by increasing the tire inflation This is obviously at the expense of cushioning

Larger cars require larger tires to carry the load from a durability standpoint, but larger tires are less capable of supplying cornering power in proportion to their load than smaller tires The cornering coefficients of a 5 25-17 4-ply and a 7 50-16 6-ply tire, both at their rated load and inflation, are 0 115 and 0 085 respectively

From these considerations, it appears that when heavy vehicles must be cornered at high speeds, and large tires otherwise adequate for the service lack sufficient cornering power, the substitution of dual smaller tires will result in improved handling

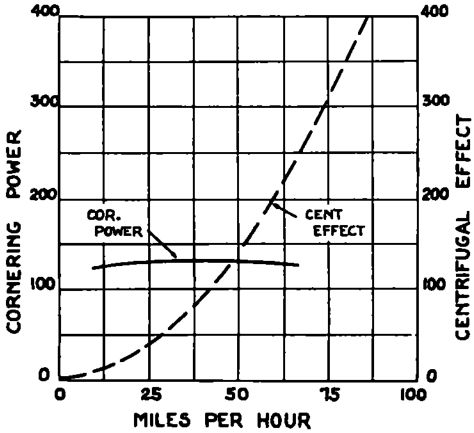

Figure 4

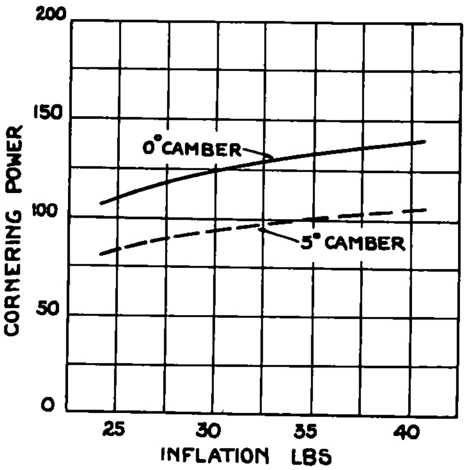

Figure 5 Tire Size 7 50-17 6 Ply Load 1500 Lbs, Rim 4 19 F

The selection of tire equipment for any automobile vehicle requires careful consideration and technical study A tire that meets the requirements of suitable durability may not be a satisfactory tire for directing and cushioning the vehicle

PROF R A MOYER, *Iowa State College* As Chairman of the Committee on "Relations Between Curvature and Speed" I should like to say how pleased I am to bring to this group Mr Fox of the General Motors Proving Ground and Mr Johnson of the Goodyear Company Too frequently designers have made assumptions that were not warranted on the basis of facts In the design of a highway, the designer should consider four distinct factors—the car, the tire, the road and the driver, and each of these factors must be studied very carefully In the work of this committee we desire to present the facts concerning the critical conditions and critical values in car operation on curves, just as the structural engineer in designing a building needs to know the critical behavior and the ultimate forces that will cause failure That is the procedure which we are now following We are trying to determine the critical behavior of the car, of the tire, of the road and of the driver, and I believe after we have examined all of those factors we will find that this matter of driving on curves is far more complicated than many of us thought it to be We also believe that after the designer has all of the facts before him, he really will be in a position to design safely for higher speeds than we are designing for now