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SUPER-ELEVATION ON HIGHWAY CURVES

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The need for super-elevation on road curves, to ensure safety against skidding and overturning with the advent of fast moving traffic, has been felt increasingly.

In the past, roads were constructed without any regard to super-elevation on curves and had generally a cambered section for drainage purposes. It was little realised then that a vehicle moving on a curve had to overcome a centrifugal force to enable it to follow the curved path instead of a straight line, but, in justice to the early designers of roads, it must be said that there was no fast traffic in those days. With animal haulage, curves did not matter so much as the speed was low, hardly exceeding five to ten miles an hour, as against a speed of fifty miles attained at present.

The cambered cross section on roads which is the usual practice on curves is even worse than level rails would be on a railway, since a vehicle travelling on the outside of a cambered road curve must overcome a force which acts at right angles to the transverse slope of the road. The driver, therefore, has to deal with two factors : the slope due to camber, and the force required on a level surface to turn the vehicle round the curve. Except at very slow speeds, a great strain is placed on the steering gear and tyres of the vehicle.

The object of this paper is to emphasize the importance of super-elevation in road construction and to point out that the time has arrived for the principle to be put into practice throughout the country. Super-elevating road surfaces at curves would make the road safe for traffic in both directions, because traffic traversing a right hand bend would automatically keep to the outside in order to secure a better vision, skidding would be less liable to happen, owing to more equal pressure on the inner and outer wheels, the road surface would last very much longer than at present, and corrugation would be less likely to occur. The chief objection to super-elevation is that it would encourage racing round curves. Another and a practical objection is the question of making the outer edge higher than the adjacent ground. Considerable care is required in arranging levels in flat country where building values may be affected. Generally the best way is to super-elevate the road with the centre line as the pivot rather than the outer edge. It is well-known that cycle racing tracks and motor tracks are banked to facilitate passing round the bends at speed. The amount of super-elevation practicable on roads does not compare with that used on such

speedways, and the idea that racing would be encouraged by mild super-elevation may be dismissed. If super-elevation induces traffic to keep well to the left in each direction, the danger of collision will be very largely removed.

When a man rides a bicycle on a curved path he leans towards the centre of the path. By this means the reaction of the ground becomes inclined to the vertical. The vertical component of this reaction supports the weight while the horizontal component supplies the force $\frac{MV^2}{R}$ directed towards the centre and this force is called the centrifugal force.

If the bicycle and the rider are represented by the line AB inclined at an angle ϕ to the vertical the forces acting on the machine are the weight Mg acting vertically downwards at G, the vertical pressures R and F, the force of friction between ground and machine. The resultant of these three forces supplies the horizontal force $\frac{MV^2}{R}$ towards the centre of the path. See Fig. 1.

Since S, the resultant of R and F, must pass through G, we have

$$S \cos\phi = R = Mg$$

$$S \sin\phi = F = \frac{MV^2}{R}$$

$$\text{Tan}\,\phi = \frac{V^2}{Rg}$$

which gives the inclination of the machine to the vertical in terms of the velocity and radius of the path.

It will thus be seen that the inclined position of the machine to the horizontal supplies the necessary force to overcome the centrifugal action. This will apply equally to any other vehicle.

When a railway carriage moves along a curved horizontal path, the force towards the centre of curvature is supplied by the horizontal component of the pressure of the rails on the flanges of the wheels. In the case of a road vehicle this force is supplied by the forces of friction between the tyres of the wheels and the road surface, but these lateral forces are objectionable and even undesirable as they tend to wear away the rails and flanges in the case of a railway carriage and the tyres in the case of a road vehicle as will presently be shown. To overcome these defects the railway track as well as the road surface is banked or super-elevated on the curves so that the position of the carriage becomes inclined to the vertical.

Let ABCD (Fig. 2), be the section of a carriage having the vertical plane perpendicular to the direction of motion through G, its centre of gravity, A and B being the points where the wheels touch the ground.

Let P_1 and P_2 be the resultant vertical components of the pressure of the wheels on the ground and F_1 and F_2 the resultant horizontal component on the wheels on two sides. Also let r be the radius of curvature of the curved path described and V the velocity of the carriage.

The force $\frac{MV^2}{r}$ is the resultant of all the forces acting on the carriage.

Resolving in vertical and horizontal directions we have :—

$$P_1+P_2=Mg$$

$$F_1+F_2=\frac{MV^2}{r}$$

As the force $\frac{MV^2}{r}$ is the resultant of all the forces acting on the car, its moments about any point must be equal to the sum of the forces.

Let the distance AB between the wheels be $2a$, and h the height of G, the centre of mass, above the ground.

Taking moments about B, we have

$$\frac{MV^2}{r}\times h=P_1\times 2a-Mg\times a$$

or $$P_1=\tfrac{1}{2}M\left(g+\frac{V^2h}{ra}\right)$$

And taking moments about A, we have

$$\frac{MV}{r}h=Mg\times a-P_2\times 2a$$

or $$P_2=\tfrac{1}{2}M\left(g-\frac{V^2h}{ra}\right)$$

This shows that P_1 is always positive and increases with V, while P_2 decreases as V increases and vanishes when $V^2=\frac{gra}{h}$ so that the wheels on the inside of the curve are no longer in contact with the road surface and the carriage will upset when $V^2=\frac{gra}{h}$. Thus not only do we get a considerable lateral pressure between the cuter edge of the road surface and the outer tyres which increases rapidly as the speed

increases, but the vertical pressure on the outer surface is considerably greater than that on the inner side and consequently on the wheels which run on the outer side of the curve. This explains why the outer edge of a road on the curve is worn out considerably more than the inner edge.

In order, therefore, to counteract the objectionable lateral pressures the plane of the track is banked up. In a railway track this is done by raising the outer rail by a certain amount which is known as super-elevation. The term "Cant" is frequently used as synonymous with super-elevation but properly speaking "Cant " should be used to denote the angle of transverse slope at which the track lies while super-elevation represents the height to which the outer edge of track of road-way is raised above the inner edge.

We now proceed to determine the motion on a banked up track. Let ϕ be the inclination of the floor to the horizontal and R_1 and R_2 be the normal reactions perpendicular to the floor. If there is no lateral thrust along the line AB when the carriage is moving with a velocity V, the force $\frac{MV^2}{r}$ towards the centre of curvature is supplied by the horizontal component of R_1 and R_2 and we have

$$(R_1+R_2) \sin \phi = \frac{MV^2}{r} \qquad (1)$$

$$\text{and } (R_1+R_2) \cos \phi = Mg \qquad (2)$$

$\therefore$ Tan $\phi = \frac{V^2}{rg}$ or slope of banking $= \frac{V^2}{rg}$, which shows that the inclination ϕ depends upon velocity.

When banking up a road, engineers have to adjust the angle ϕ with reference to some velocity. Now the fixing of velocity in the case of a railway track is a comparatively simple affair as only a few kinds of carriages with stated velocities are to be considered. In the case of a road there are all sorts of carriages moving on it from fast cars speeding at forty to fifty m.p.h. down to the slow bullock carts moving at three to five miles per hour. To fix a velocity for banking purposes becomes a difficult problem for the road engineers. A super-elevation convenient for vehicles running at thirty m.p.h. would be unsuitable for those moving at five m.p.h. Therefore whereas steep banking is desirable from the motorist's point of view, limits are imposed by the requirements of slow traffic.

Up to this time no standards have been fixed for the maximum cross slope and for banking for different curvatures and an attempt is made in this paper to indicate the lines along which some standardisation can take place.

The maximum cross slope in a railway track is fixed at 1 : 12, but in the case of road as much as 1:8 could with safety be adopted. The author while engaged on the intensive tarring of the Kangra Valley road during 1932-33 improved the banking on numerous curves by adopting a cant of 1 : 8 on curves of fifty feet radius and less. Driving on them was found to be very comfortable by the motor traffic whereas in the past it experienced unpleasant jerks and tilting on those curves. Hence 1 : 8 could be fixed as the maximum slope for a road. In European countries and in U.S.A. the maximum cross fall ranges from 1 : 12 to 1 : 24 and in the mountain region it is made as much as 1 : 5. In our own country the Assam P.W.D. in 1916 specified 1 : 6 for curves under 25 feet radius, 1 : 12 for curves between 50 and 75 and 1 in 48 for curves between 75 and 100 feet radius. In Burma the cross fall is given 1 in 5 but the surface gets eroded in rains.

From the above it appears that while 1 in 5 is too steep 1 in 10 has been found satisfactory on many roads ; it appears that 1 in 8 may be safely adopted as the limit. Now employing this banking *i.e.*, 1 in 8 on a radius of 50 feet let us find out what velocity there will be according to the above established formula $\tan \phi = \frac{V^2}{gr} = \frac{V^2}{15r}$ approx., where V is in miles per hour.

$$\text{Tan } \phi = \tfrac{1}{8} = \frac{V^2}{15 \times 50} \text{ or } V^2 = \frac{50 \times 15}{8} \text{ or } V = 9{\cdot}7 \text{ miles.}$$

This is rather a low speed and in actual observation I have found cars and lorries negotiate such sharp bends with perfect comfort and safety at 15 m.p.h. Whence does this additional velocity then come in? In working out the previous formula $\tan \phi = \frac{V^2}{gr}$ the force of friction between the wheels and the road surface was neglected. Taking friction (μ) into account it will increase the safe speed for vehicles on banked curves and virtually increase the limiting value of centrifugal force to be resisted by banking and friction. Suppose that the force F acts along AB (Fig. 3) the equation then becomes

$$(R_1 + R_2) \sin \phi \times F \cos \phi = \frac{MV^2}{r}$$

$$(R_1 + R_2) \cos \phi - F \sin \phi = Mg.$$

$$\text{Hence } F = \frac{MV^2}{r} \cos \phi - Mg \sin \phi$$

Now F itself is the frictional force

$$= \text{Coefficient of friction} \times \text{Normal reaction}$$

$$= \mu \times w \cos \phi = \mu \, Mg. \cos \phi$$

Hence $\mu\ Mg \cos\phi = \frac{MV^2}{r} \cos\phi - Mg \sin\phi$

Dividing by $Mg \cos\phi$, we have

$$\mu = \frac{V^2}{gr} - \tan\phi$$

$$\therefore\ \text{Tan}\phi = \frac{V^2}{gr} - \mu \qquad (i)$$

or $$V^2 = (\tan\phi + \mu)\ gr \qquad (ii)$$

Equation (*i*) shows that the slope of banking can be reduced by the amount of the coefficient of friction in order to keep a moving vehicle in perfect equilibrium, and equation (*ii*) shows that the velocity of the vehicle can be increased by an amount μgr on account of the friction which had been neglected in working out the equation $\tan\phi \frac{V^2}{gr}$ on a smooth plane. This therefore explains why velocities were obtained on a curve in excess of the theoretical velocity given by the previous formula.

Now the coefficient of friction varies for different materials in contact, but for the purpose of simplicity it is taken as ·15 for a rubber tyre in contact with a tarred surface, *vide* Punjab Engineering Congress paper No. 64 in 1920 by Mr. A. R. B. Armstrong.

For a water bound macadam surface this coefficient equals ·25.

Taking ·15 as equal to μ on a curve of 50′ radius, we have,

$$V^2 = (1{\cdot}25 + {\cdot}15) \times g \times 50$$

$$= {\cdot}275 \times 1600 = 440$$

or $$V = 21 \text{ ft. per second}$$

$$= \frac{21 \times 15}{22} = 14{\cdot}3 \text{ m.p.h.}$$

which very nearly accords with the actual velocity observed. The question of the particular speed to be used for calculating the slope of banking now arises. This speed will vary according to the conditions of the locality and the kind of traffic. It can only be taken as the most probable average speed for the traffic passing round the curve.

In the formula $\tan\phi = \frac{V^2}{gr} = \frac{V^2}{15r}$ the average velocity has been taken to be between 5 and 30 m.p.h. *i.e.*, 17·5 m.p.h. and as the frictional forces can be depended upon to counteract about half of the centrifugal force the formula for banking actually becomes

$\frac{V^2}{15r\times 2}=\frac{V^2}{30r}=\frac{17\cdot5\times17\cdot5}{30r}=\frac{306}{30r}=\frac{10}{r}$ approx. This then gives a formula easy to remember for the banking of curves i.e., the banking is the same as ten divided by the radius. As soon as the radius is known the determination of banking is a simple affair and any road inspector or a road *moharrir* can lay it out on the road with the aid of a straight edge template previously marked to various slopes like 1 : 8, 1 : 10, 1 : 20, 1 : 40 and 1 : 50 etc. A banking of 1 in 50 will correspond to a radius of 500 ft. and above this radius a crowned section of the roadway may be adopted in order to prevent very high velocities on such curves. The diagram of the banking template is given in Fig. 4.

By throwing down a plumb bob along any mark any particular slope or corresponding height of super-elevation is obtained. The radius is found by stretching a tape 20 feet long spanning a portion of the curved path left by the wheels of a truck and measuring the offset to the curve in feet. Then the radius is found out by dividing 50 feet by the offset, or $R=\frac{50}{\text{offset}}$ in feet. The following table will give the rate of banking for different radii of curvature :—

Feet.	Banking.	Velocity without taking friction into account.	Velocity taking friction into account.
		m.p.h.	m.p.h.
50	1 : 8	9·7	14·7
100	1 : 10	12·3	19·4
200	1 : 20	12·3	24·5
300	1 : 30	12·3	28·3
400	1 : 40	12·3	31·8
500	1 : 50	12·3	55·4

From the above it will appear that the banking suggested will admirably suit the actual requirements. The determination of banking and its lay-out could be further simplified in the following way. It is known from the properties of a circle that versed sine (*vide* Fig. 5) :

$$S=\frac{C^2}{8r}$$

In order that S may be equal to super-elevation for a 10 feet wide road

$$\frac{C^2}{8r}=\frac{484}{225}\times\frac{V^2}{30r}=10;\ C^2=V^2\times\frac{8}{3}\times\frac{484}{225};\ C=V\sqrt{5\cdot7}=V\times2\cdot4,$$

taking V = 17·5 m.p.h., C = 42 feet. For a 12 feet wide road C = 45 feet.

In actual practice this chord may be taken as 50 feet, the actual length of a tape, and the offset at the centre measured. The offset thus measured gives the amount of super-elevation required for a 12 feet wide road and can easily be laid out by the mate.

An important consideration in connection with super-elevation is the transition from the cross fall on the curve to the normal cross section of the road which is cambered. Transition may be effected in several ways such as

(*a*) Super-elevation before the point of commencement of the curve;

(*b*) Compound curves where an easy curve is used on either side of the principal curve to connect it with the straight;

(*c*) Spiral curves such as employed on railways;

(*d*) Parabolic curve, and

(*e*) the lemniscate.

The simplest transition is the most suitable for road work. Out of the various methods enumerated above the lemniscate is extremely useful and the most scientific as will appear from the following consideration of the problem :—

In order that the raising of the outer edge should be gradual and not sudden it is necessary that the super-elevation should be attempted in a progressive manner. If we pass directly from the straight line to the circular arc we must begin to give this super-elevation while still in the straight causing the vehicle to lurch inwards. This is done by introducing transition curves which start with a radius approaching infinity on joining the straight while at its junction with the circular arc, the radius of its curvature is the same as that of the arc itself. In the ideal curve therefore, the super-elevation should be proportional to the distance from the starting point. As discussed in previous paragraphs super-elevation is also inversely proportional to the radius of curvature. Hence in the ideal curve the radius should be inversely proportional to the distance from the starting point or in other words $\rho r = C$ (a constant) where ρ is the radius of curvature and r the distance from the starting point, *i.e.*, the polar ray in the lemniscate curve.

To satisfy the above conditions Bernouli Lemniscate is an ideal curve from its equation $r^3 V = a^2 P$, where P is the perpendicular from the origin to the tangent at the point and r is the distance of the polar ray from the origin.

Differentiating $r^3=a^2p$, we have $3r^2\times\frac{dr}{dp}=a^2$, substituting $p=r\frac{dr}{dp}$ (in tangential polar co-ordinates) we have $3rp=a^2$; $pr=\frac{a^2}{3}$, a constant. This shows that the lemniscate is the ideal curve for the purpose.

Actually no such curve is required in practice; for the vehicle, in the case of a road, is not tied down to a particular groove or rail as in the case of a railway but it has got the whole width of road at its disposal and can make its own transition curve as best suits the driver of the vehicle. So in this case the road engineer need not bother about the transition curve. What is required is that super-elevation at the beginning of curve should be reached gradually at a certain easy gradient from the straight portion of the road. This is best done by using a gradient of 1 : 50 or 1 : 100 on a plain road and 1 : 20 on a hill road. This simplification of the problem dispenses with the necessity of making any tedious calculations required for setting out a lemniscate and ensures almost equal comfort to the user of the road. This simplification will also be in conformity with the easy method of determining and setting out the super-elevation so that the whole process could be entrusted to a road inspector or even to an illiterate mate of average intelligence.

The whole process of tackling the super-elevation can be summarized as follows. Where a curve occurs, stretch a tape fifty feet long from one end to another, measure the offset to the curve at the mid-point. This represents the amount of super-elevation by which the outer edge of the road is to be raised above the inner for a 12 feet width. This full amount of super-elevation will begin on the commencement of the curve and will gradually be sloped off on either side to meet the straight in a gradient of 1 : 50 in a plain road and 1 : 20 in a hill road. The main super-elevation will of course be limited to 1 : 8 on the sharpest curves only.

The Cambered Super-Elevated Roads.

This form of section may appeal to some engineers in place of the ordinary cross fall of the super-elevated section. Some time ago it was the practice in certain counties of England to attain improved conditions at curves by moving the crown from the centre to a position two-thirds of the width of the road from the inner edge. This is decidedly better than making the crown at the centre but it still leaves the slope on the outer third unfavourable to the traffic and consequently this portion of the carriage way will hardly be used.

Another method of utilising camber which is occasionally used in America, is the crowning of the super-elevated road section. This gives a quicker slope on the inside edge, which is advantageous for vehicles that necessarily take the shorter radius turn, and a reduced slope

on the outside curve. The inevitable result, however, is that most of the traffic avoids the outer curve and for this reason the method is not recommended.

The importance of banking of curves on hill roads cannot be too strongly urged. The design of hill roads in India, England, America and elsewhere has made super-elevation a sheer necessity.

Another point of importance in the application of super-elevation of curves in hilly districts is the improvement on curves where high ground or rock on the inside makes the widening costly and where the range and vision is very limited. On the outside of the curve widening may be easy and with super-elevation properly applied the curve would be easily negotiated.

Fig. 7 shows a typical case with a centre radius of 100 feet. Beginning with a cross fall of 1 in 24 at a point 50 feet before the commencement of the curve, a maximum super-elevation of 1 : 10 is attained. With this construction a motorist would feel an inducement to keep to the outside of the curve thus obtaining a greater range of vision and leaving sufficient room for the oncoming traffic taking the inside curve. Where curves are sharp and banking is contemplated it is advisable to carry out some widening in order to provide for the extra width required when turning by vehicles with long wheel bases. On sharp curves the rear wheels take a different track from the front wheels, the difference increasing with curvature. It can be shown that the extra width is given by $R-\sqrt{R^2-l^2}$ where R is the radius of the curve taken by the outer front wheel, and l is the wheel base. An average width of four feet is suggested to allow a comfortable margin for vehicles to pass.

It will be shown that by widening on the outside, the radius of the curve is decreased and the curve becomes sharper, hence all the greater necessity for banking. Widening done on the outside of bends without super-elevation is worse than useless and positively dangerous. For this reason widening is sometimes done on the inner side of the curve by the insertion of a curve of larger radius which has the added advantage of increasing the length of vision.

One of the most difficult problems in road engineering is to adjust levels at the junction of one road with another so as to make the surface gradient suitable for the drainage and the traffic. Where a secondary road meets a main road with an easy curve it is possible to introduce banking to facilitate the passage of traffic from one road to the other. In Fig. 8, the gradients are shown with the principal road having a cross fall of 1 in 48 in lieu of the ordinary parabolic or crowned section. As the traffic approaches the main road, speed would be

reduced in approximate proportion to the reduction of banking. Where traffic takes the acute-angled corner to the main road it is clearly a difficult matter to bank the road to any extent. This corner should be cut back as far as possible with a turn of large radius to enable traffic to take the sharp angle without travelling to the centre of the main road.

Another kind of junction may be of a main road bifurcating in two as shown in Fig. 9. In this case it is easy to arrange the cross falls from the crowned section on the main road to super-elevated sections at the commencement of the two branch roads and thence to change to the normal crowned section 50 or 100 feet farther along the road according to the particular circumstances.

Many other kinds of more complicated sorts of junctions, especially in hill roads, will present themselves to the road engineer and he will have to tackle each problem on its own merit and its particular situation but the main guiding principle should be that the super-elevation must be provided even at the cost of the cambered section and that the drainage must not be unduly interfered with.

This paper is submitted with the hope that the principle of banking will be universally accepted as an important part of the practice of road engineering as has been done in railway engineering and that some standard practice of banking will be introduced in the province on roads which are in course of improvement.

PLATE I

BLACK CURVES REPRESENT DIAGRAM OF SAFE SPEEDS ON CURVES HAVING VARIOUS RADII AND SLOPE OF BANKING WHERE CO-EFFICIENT OF FRICTION BETWEEN THE WHEELS AND ROAD = ·15.

DOTTED CURVES REPRESENT DIAGRAM OF $\frac{\text{CENTRIFUGAL FORCE}}{\text{WEIGHT}}$ RATIOS.

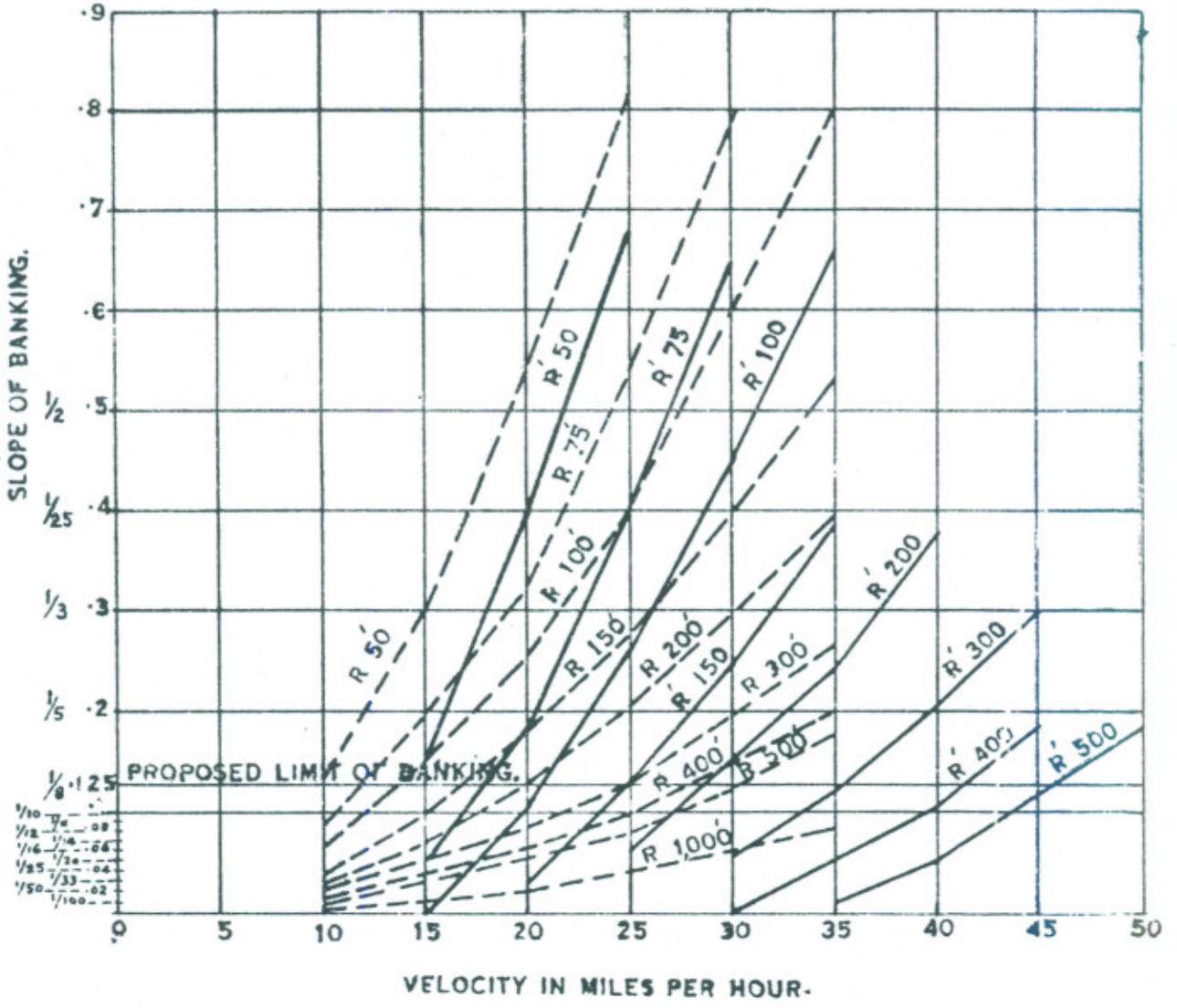


FIG: 1

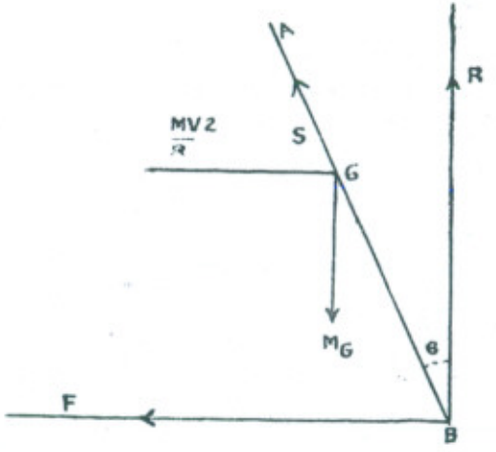


FIG: 2

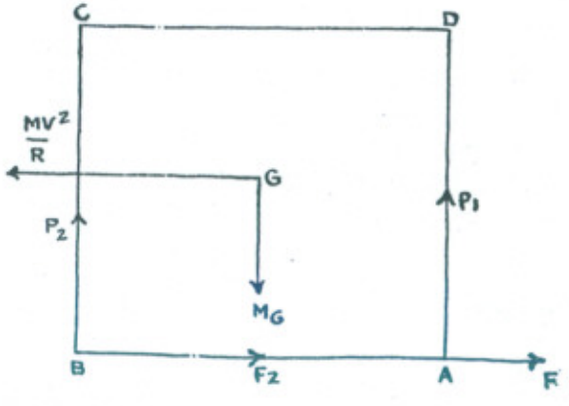


FIG: 3

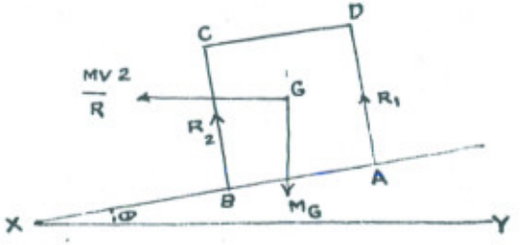


FIG: 4

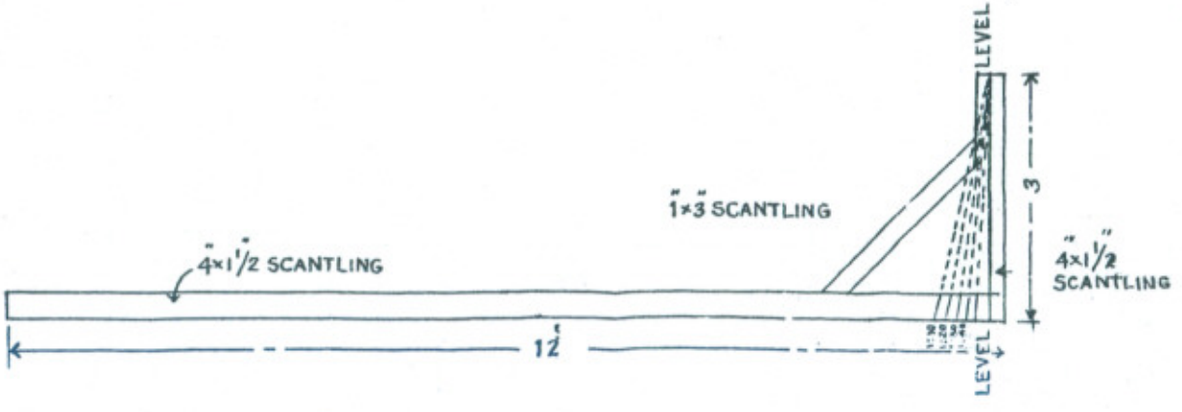


FIG: 3

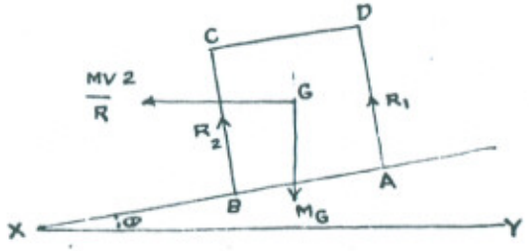


FIG: 5

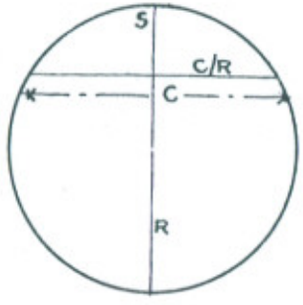


FIG: 4

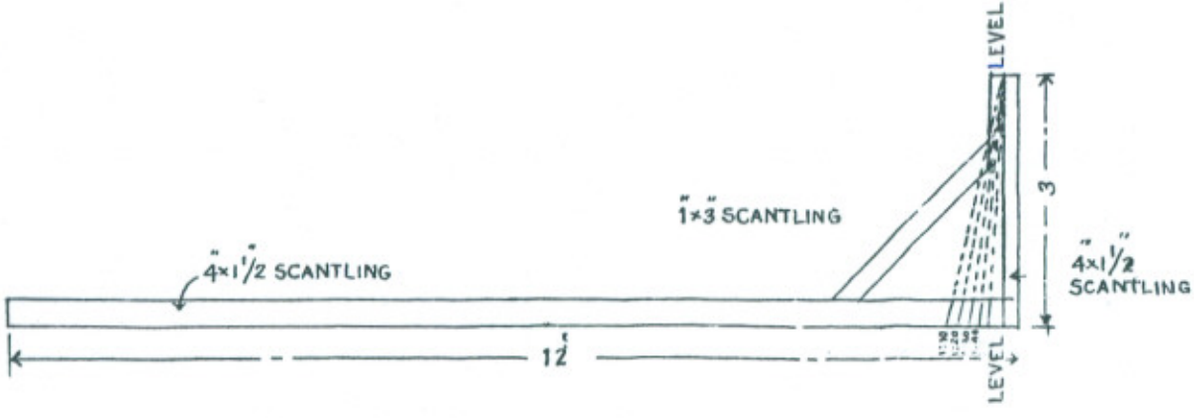


FIG: 6

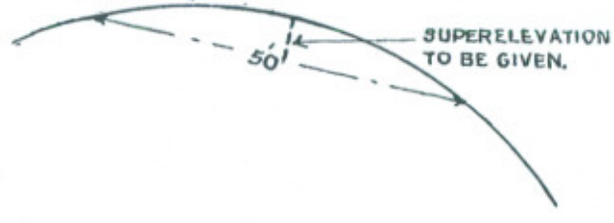


PLATE II

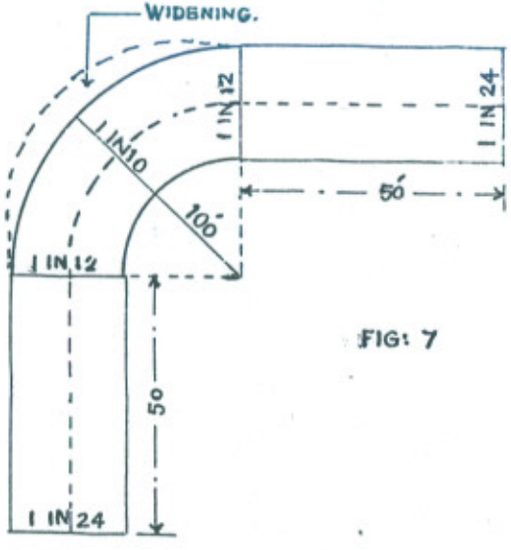


FIG: 7

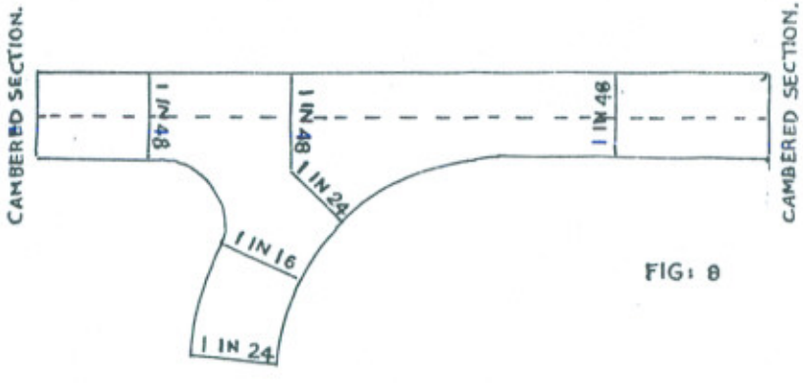
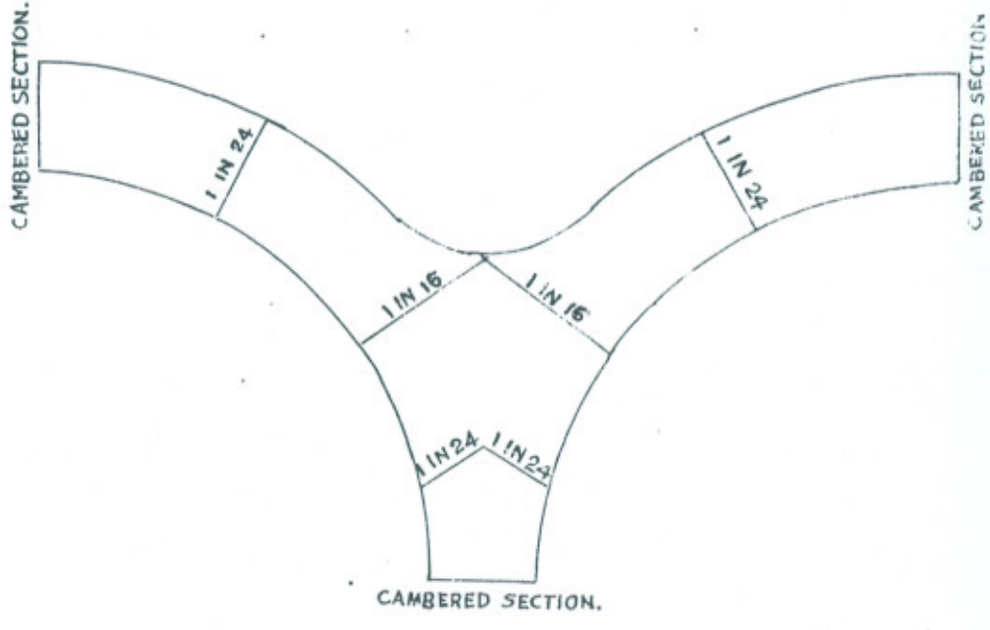


FIG: 8

FIG: 9



DISCUSSION.

The **Author** introducing his paper, observed that he made no pretension to the discovery of any new principle but what had been attempted in the paper was to find a simple process by which the super-elevation on arterial roads could be provided in an easy, systematic and regular way.

He thought that it was too late in the day to emphasize the importance of super-elevation, for, where it was not provided, cases had not been wanting where motor tyres had been twisted and torn, the car had skidded or even over-turned and other accidents had happened. The need for super-elevation had never been so great as it is now.

Before proceeding with the paper the author wished to point out certain mistakes. These are :—

Page 27, line 16 insert "of the moments of all the forces about the same point" after "sum."

Page 27 line 23, $\frac{MV}{r}$ should read $\frac{MV^2}{r}$.

Page 31, last line should read,

$$\frac{c^2}{8r} = \frac{484}{225} \times \frac{V^2}{30r} \times 10.$$

Page 32, last para, in the equation of lemniscate

$r^3v = {}^2apv$ is redundant and should be omitted.

Page 33, line 28, instead of "main super-elevation" read "maximum super-elevation."

The author said that the first four pages dealt with the mathematics of the problem and it had been shown that in determining the required super-elevation it was necessary to take into account the coefficient of friction between the tyre and the road surface. This, he said, had been assumed by him as ·15. It had since found corroboration from certain experiments made in the United Provinces, *vide* article in "Indian Roads" of June 1934, by Mr. Jagdish Prasad.

Without the help of the coefficient of friction, the slope of banking derived from the simple formula $\tan \phi = \frac{V^2}{15r}$ would be excessive and quite unnecessary, with its help the formula would become $\tan \phi + U = \frac{V^2}{15r}$ and would thereby reduce the slope by an amount equal to the coefficient of friction.

If no super-elevation was given and the road surface was horizontal, curves of the following radii could be negotiated with corresponding velocities with the help of friction only.

Velocity:	10 mile/hour	..	Radies	45 ft.
,,	20 mile/hour	..	,,	178 ft.
,,	30 miles/hour	..	,,	400 ft.
,,	40 mile/hour	..	,,	711 ft.

As velocity was the chief factor in determining the super-elevation, and as it had a very wide range from that of a slow moving bullock to the fast omnibus, 17·5 miles has been taken as the average velocity. From this assumption a simple formula for arriving at the slope of banking had been derived, *i.e.*, slope of banking was equal to ten divided by the radius of curve.

The author pointed out, that another simpler process was worked out and was as follows.

Where a curve occurs, stretch a tape 50′ long from one end to another, measure the offset to the curve at the midpoint. This represents the amount of super-elevation by which the outer edge of the road is to be raised above the inner edge for a 12′ wide road.

Here 12′ width of road is specified but the process admits of a general application for any width of road if we read the offset to the curve in feet and take that as so many inches for the cross slope per foot width of road. This is a simple method. All that the road inspector or mate has to do is to measure the offset and, with the aid of a straight edged template and a plumb bob, mark the required height of elevation on the ground. In Plate II Fig. 4, such a template has been shown but in this figure slopes such as 1 : 10, 1 : 20 etc. have been marked on the template. Heights such as 2″×3″ etc. could also similarly be marked. This method has actually been adopted in the Gurgaon Division and it is hoped it will find an application elsewhere too.

The author stated that he had done away with the necessity of providing transition curves on roads which were already made because it did not appear to be a necessity, but where entirely new roads were to be constructed transition curves, preferably the lemniscate, would be an advantage and a refinement.

In order, however, to attain the super-elevation in a progressive manner it was necessary that the full amount of super-elevation be reached gradually in an easy gradient from the horizontal surface. Where the road is already on a gradient, as in the hills, the new gradient for

the super-elevation would have to be superimposed on the existing one and in order that the total of two gradients be not excessive, the new gradient should be as flat as possible. In hill roads, where the curves were numerous and the road on the gradient, the gradual approach to meet the super-elevation could be made in a gradient 1 : 50 and in the case of plain road this could be done at 1 : 100. For simplicity a tape length, *i.e.* 50 ft., could be taken as the transition length which would meet almost all requirements of approach to the super-elevation.

Mr. Bikramjit furnished a table showing the velocities on curves of varying radius similar to that given by the author in his introductory remarks. The author's calculations were based on a speed of 17·5 miles per hour, and for such a speed the speaker pointed out that there was no need to provide any banking on a curve of a radius 150 feet or more.

On roads in the plains it was seldom necessary to adopt a curve of a radius less than 150 feet and therefore the problem of super-elevation had but little application to such roads. This problem might therefore be confined almost entirely to the roads in the hills such as were in the Kangra Valley, and he hoped that while the author was in the plains he would not attempt to improve the roads in his charge in the light of his deductions.

It stood to reason that on hill roads too no super-elevation needed to be provided on a curve of a radius 100 feet or more. On curves of smaller radii super-elevation was necessary only if the speed could not be reduced by a corresponding figure. In such cases, a cross slope of 1 in 8 might be provided.

Looking at the problem in another way, nature had provided in terms of the coefficient of friction (which is 0·15 in this case) a cross slope which could be depended upon to the figure 0·15, or 1 in 6·2/3 (*i.e.*, 15 in 100) and it did not appear worth while to supplement it artificially by an additional cross slope of 1 in 40 or 1 in 50 (*i.e.* 2 in 200) (*see* Plate III) which would not appreciably enhance the one provided by nature.

Mr. G. R. Sawhney remarked that the paper was merely of academic interest. In his opinion the curves suggested were not practicable in this province. Before talking about applying these curves the necessary arrangements must be made for giving bullock carts a separate roadway, otherwise he was afraid the practices suggested would cause more trouble than is being faced at present.

The author of the paper should see the roads made by the Military in the N. W. F. Province and he would find that the curves have been satisfactorily derived without using these formulas.

The Author replying to the discussions said that it is surprising that the opposition to providing super-elevation on roads in the plains should have come from a young Engineer of Buildings & Roads Branch.

The author further said that Mr. Bikramjit had not followed the calculations. If he had done so he need not have taken the trouble of working out his own table of velocities and radii, for a very similar one was given by the author while introducing the paper. For the purpose of these calculations it is assumed that the road surface is horizontal, but the road surface is never horizontal. On the other hand it is cambered to allow for drainage. It thus becomes a sub-elevation or negative elevation instead of super-elevation and thus all the more dangerous on curves. This point was brought out in the introductory pages of the paper. It is therefore evident that neither a cambered section nor a horizontal section of road on the curves will be satisfactory. The curve must have a sloping section or, in other words, a banked-up surface.

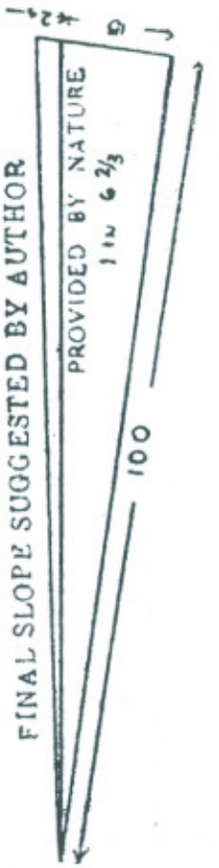
It is true that lateral pressures are brought into play when negotiating a curve without banking and it is for this reason that banking has beeh suggested.

If the coefficient of friction has to be depended upon entirely for the purpose of counteracting the centrifugal force on curves a severe strain will be caused on the tyres and the road surface due to lateral pressures. The author said that this point has been made sufficiently clear and the necessity for super-elevation is established beyond doubt.

The author further said that Mr. G. R. Sawhney observed that the paper was more of academic interest and the mathematics needs to be translated into practice. If Mr. Sawhney will read the paper carefully he will find that the aim and object of the paper is to reduce theory to practice and work out an easy practical process which can be followed by even an illiterate person.

As regards his objection to the super-elevation on the ground of inconvenience to bullock carts it can safely be asserted that the prescribed maximum slope of banking 1 in 8 will not be found inconvenient by animal traffic and will amply meet the requirements of fast traffic thus providing a common road equally useful for both.

PLATE III.


FINAL SLOPE SUGGESTED BY AUTHOR
PROVIDED BY NATURE
1 in 6 2/3
100