LECTURE A3 – SUPERELEVATION & TRANSITION CURVES

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INTRODUCTION

At a time when cars could only travel at a brisk walking speed and trucks had yet to be invented there was no need for superelevation.

Brooklands was a famous racing circuit built in the 1930's, and one of its claims to fame was the heavy banking provided on the curves. It did not take all that long for designers to realise that something similar could, with advantage, be provided on public roads and superelevation was born.

INTRODUCTION

Two advantages were foreseen, being that

tighter radii could be employed without adversely affecting the selection of design speed

drivers could perhaps be persuaded to stay on their side of the road

With regard to the latter, it should be borne in mind that, at this time, South Africa made one of its greatest contributions to highway engineering because it was here that the painted centre line was invented. Drivers thus no longer had any excuse for not knowing where, relative to the road surface, they should be.

INTRODUCTION

As far as the driver is concerned, there is actually no need for superelevation. All he wants to do is to effect a change of direction without having to change his selected speed and in comfort. A sufficiently large radius can achieve this state of affairs and has the added benefit that the route between two points is shortened in the process when compared to the equivalent of two tangents with a short intervening curve.

THE MECHANICS OF THE PROBLEM

Acceleration is normally understood as being an increase in speed. This is however a very limited understanding because deceleration is simply a negative acceleration. Furthermore, in the mathematical scheme of things, acceleration is defined as any change to a vector of translation and, to properly define a vector, two characteristics have to be described being its magnitude and its bearing. Negotiating a curve at unaltered speed is thus also an acceleration. And the acceleration of a moving mass requires a force. The extent of the required force is a function of the speed of the moving object and the radius of the curve it is negotiating.

THE MECHANICS OF THE PROBLEM

The force that results in a change of direction is known as centripetal. Because every action comes complete with an opposing reaction, a force seeking to resist the change of direction comes into being and this is known as the centrifugal force. If the designer thus wishes to impose a change of direction, this is the force that he must overcome.

There is only one naturally occurring force available without the intervention of the designer and this is the centripetal force which is a product of mass and the coefficient of friction. The coefficient of friction is known as the side force factor and, in theory, this should be independent of speed.

THE MECHANICS OF THE PROBLEM

In practice, air passing rapidly under a vehicle is compressed and this exerts a lifting force, effectively reducing the mass of the vehicle that can be brought to bear on the development of side force. The lifting effect is, for convenience built into the side force factor so that this is not entirely a pure coefficient of friction and reduces with increasing speed. Values of side friction that are used in design are given by the relationship

$$f = 0{,}19 - V/1\,600$$

where V = Speed (km/h)

THE MECHANICS OF THE PROBLEM

If the vehicle is located on a lateral slope, the vertical force of gravity can be split into vectors, one of which is parallel to the slope and the other at right angles to it. The force parallel to the slope can be represented by a further set of vectors, one vertical and one horizontal, and it is the latter which assists the side force in overcoming the centrifugal force involved in the change of direction. This force, F_g, is expressed as

$$F_g = M g \sin \theta \cos \theta$$

The angle, θ, is very small. Its cosine is thus close to 1 and its sine is well approximated by the tan. The expression, g sin θ cos θ, can thus conveniently be replaced by g tan θ and the latter is simply the magnitude of the slope presented in percentage form as a gradient, "e".

THE MECHANICS OF THE PROBLEM

If the centrifugal coefficient of acceleration is balanced by the combination of side force and slope coefficients of acceleration, the combination of forces is stable and this stability is recognised in the relationship

$$e + f = V^2 / 127 R$$

where V = speed (km/h)

R = radius (m)

The designer, armed with the relationships given above, can thus select his design speed and hence calculate the side force coefficient available. Thereafter, he can select a radius of curvature and derive the required superelevation required to balance the forces to zero.

THE MECHANICS OF THE PROBLEM

Theoretically, and apart from the approximations implicit in the trigonometrical ratios, something approaching a Wall of Death would be perfectly acceptable. Constraints are however always with us.

The most obvious of these is that very steep superelevations would require the vehicle speed to match the design speed to fairly close tolerances. A heavily loaded truck on a steep up grade would obviously have a problem. If the load, in addition to being heavy, is also high there is a distinct possibility that it either would drop its load all over the road or roll.

THE MECHANICS OF THE PROBLEM

In the early Sixties, the maximum gradient for use on primary rural roads was 1 : 16 or 6,25 % and the maximum rate of superelevation was 12 %. The combination of these two maxima was found to be adequate to dislodge bales of fodder. The maximum rate of superelevation for rural roads was thereafter reduced to 10 %

Urban situations are seldom plagued by trucks loaded to great heights, but other restraints come into play. Few urban streets have a total control of access and property access requires that the street should be fairly close to natural ground level at all times.

THE MECHANICS OF THE PROBLEM

A 10 % superelevation would be inimical to this requirement. Intersections are also closely spaced and it can occur that an intersection may coincide with a curve. Treating vehicles to an adverse superelevation of 10 % is an open invitation to disaster.

The distance available to develop superelevation is, in any event, invariably restricted. For this reason, urban superelevation rates are limited desirably to 4 % or to a maximum of 6 %.

Having decided what the maximum allowable value of e is, it is a simple matter to calculate what minimum radius can be used for any given design speed and these values were listed in the previous lecture.

SELECTION OF SUPERELEVATION FOR RADII GREATER THAN MINIMUM

The values of e and f referred to above are maxima and apply to the minimum radius. For a radius greater than the minimum, it follows that less than maximum values of e and f would be utilised. They thus become semi-independent variables in the sense that they both can be varied but their sum must match the centrifugal coefficient.

There are five recognised methods for distributing superelevation and friction for radii greater than the minimum. These are

SELECTION OF SUPERELEVATION FOR RADII GREATER THAN MINIMUM

e and f are increased uniformly and proportionally to the degree of curve

f only is used until a further decrease of radius would require the introduction of e

e only is used until e_{max} has been reached and then further reductions of radius are balanced by increasing f

as for the third method but based on average running speed rather than design speed

both e and f are increased in a curvilinear relationship with degree of curve

SELECTION OF SUPERELEVATION FOR RADII GREATER THAN MINIMUM

South African design practice has opted for the fourth of the methods given above, whereas the American favour the fifth. The South African selection implies that driving at the average running speed, generally about 85 % of design speed, will cause the curve to be negotiated with a "hands off" level of control, which seems to suit most South African drivers.

SUPERELEVATION DEVELOPMENT

Discussion so far has purely indicated what the superelevation for a given radius at a selected design speed should be. It is therefore necessary to consider how, from a normal cross-section, this superelevation would be achieved. The usual cross-section of an undivided road has a central high point (crown) with the lanes falling away either side towards the shoulder breakpoints (camber or crossfall).

Superelevation implies a constant road surface crossfall, greater in magnitude than the normal camber/crossfall, between shoulder breakpoints.

SUPERELEVATION DEVELOPMENT

This condition can be achieved by holding the one lane edge at a constant height relative to the centreline and rotating the other around the centreline until the camber has been replaced by a cross-fall. Both edges are then rotated around the centreline until the desired extent of superelevation has been achieved.

Rotation, in the case of a two-lane road, is typically around the centreline. However, there is no requirement that this has to be the case and rotation can be around any point of the cross-section that is convenient to the designer.

SUPERELEVATION DEVELOPMENT

In the case of a dual carriageway, rotation is often around the inner shoulder breakpoint.

For purposes of calculation, superelevation development is split into two components being crown runoff and superelevation runoff. Crown runoff is the distance required to rotate the outside lane to the point where the lane edge and the centreline are at a common height, ie the adverse camber has been removed. Superelevation runoff is the distance needed to rotate the outside lane from level to full superelevation.

SUPERELEVATION DEVELOPMENT

The rate of rotation is measured by the relative slope between the carriageway edge and the axis of rotation. The relative slope factors quoted in applicable design guidelines (an example of which is given in Table A3.1) have been found in practice to give acceptable lengths of run-off.

The length of run-off is thus calculated as:-

$$L = w.e.s.l/100$$

Where:-

SUPERELEVATION DEVELOPMENT

w = lane width

e = extent of superelevation

s = slope factor (reciprocal of relative slope)

l = lane factor

The last mentioned factor calls for explanation. Where the rotated surface is wider than one lane, the additional width would automatically result in an increase in the distance required to achieve the development of superelevation. And, very often, this additional distance is simply not available.

SUPERELEVATION DEVELOPMENT

In the case of undivided roads, runoff length is calculated on the basis of that required for a two-lane road and a lane correction factor applied. Lane factors are given in applicable design guidelines, an example of which is presented in Table A3.2.

The length of crown run-off is calculated using the same formula but with the value of superelevation, e, replaced by the normal camber, typically 2 %.

Where the superelevation required for a particular radius is relatively low, blind adherence to the recommended relative slopes would result in a short developmental section that would inevitably create the appearance of a kink in the road edge.

SUPERELEVATION DEVELOPMENT

To avoid this effect, minimum runoff lengths are given in the appropriate design guidelines, an example of which is presented in Table A3.3

While a preferred minimum length of superelevation run-off is quoted , no maximum lengths are suggested. The designer should however be aware of the fact that a long run-off might cause drainage problems at the commencement of the run-off section.

A preferred method for avoiding kinked road edges is to grade the road edges separately.

LOCATION OF SUPERELEVATION RUN-OFF

The location of the position of the superelevation run-off is somewhat of a compromise. The driver should have the full superelevation on reaching the start of the circular horizontal curve. On the other hand, having the full superelevation while still on the tangent preceding the curve is operationally awkward, to say the least. The compromise achieved is to have two-thirds of the runoff on the tangent and one-third on the curve. This more-or-less matches the transitional path that the vehicle follows in moving from the tangent to the curve.

TRANSITION CURVES

The transition curve is a spiral that commences at an infinite radius (ie straight) and terminates with a radius matching that of the tangential circular curve.

Transition curves have distinct advantages:

1. the curve leads the driver into the circular curve and causes increases and decreases in centrifugal force to occur gradually.

2. without this leading action, the driver typically has already entered the curve before realising it and thus follows a circular path tighter than that of the selected curve radius.

TRANSITION CURVES

3. the length of the spiral curve is used for superelevation run-off.

4. the length of the spiral curve can be used to incorporate the transition to a wider section of the roadway around the curve.

5. the transition enhances the appearance of the highway by removing the noticeable breaks at the beginning and end of circular curves

As a rule of thumb, transition curves should be considered if the radius selected is such that the superelevation required is about 80 % of whatever e_{max} has been selected.

TRANSITION CURVES

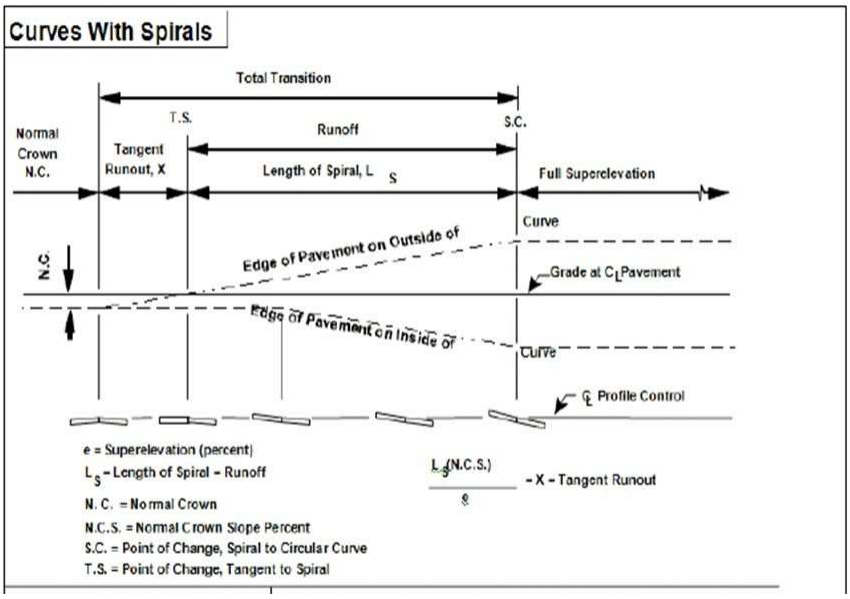
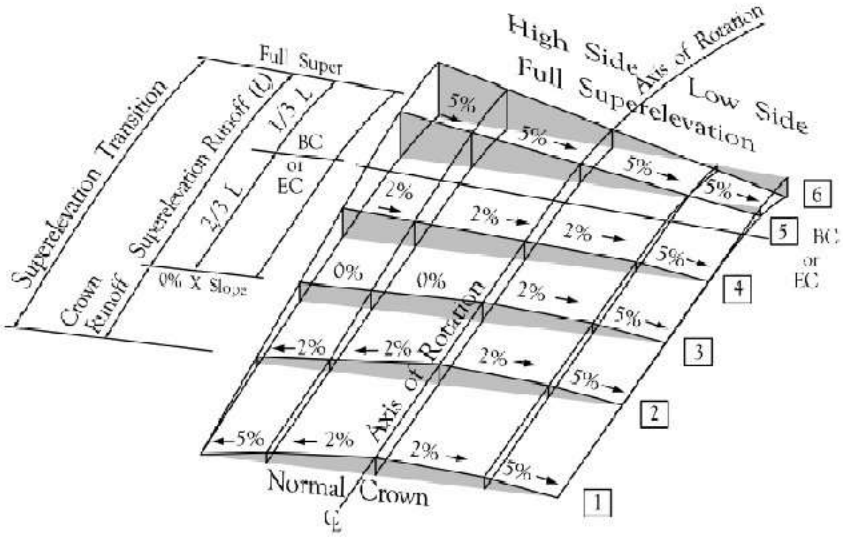
Various curves can be employed as transitions. Whatever form of curve is selected, it should satisfy the conditions that:

- it is tangential to the straight
- its curvature should be zero (ie infinite radius) on the straight
- the curvature should increase (ie radius decrease) along the transition at the same rate that e increases
- its length should be such that at its junction with the circular curve, full superelevation has been attained
- it should join the circular arc tangentially
- the radius of the transition curve at its end should be the same as that of the circular curve

TRANSITION CURVES

Curves which can be used as transitions are the Euler Spiral, the Lemniscate and Froude's Spiral otherwise known as the cubic parabola. The lemniscate requires an unacceptable length of arc to achieve the desired radius and the Euler Spiral is the preferred form.

In practice, superelevation is developed at a uniform rate, specifically as expressed by the relative slope factor, so that the radius of the transition curve at any point is proportional to its distance from the origin.



Super-elevation Transition