**MOTOR VEHICLE SPEED AND SAFETY – TRAFFIC CONTROL EVALUATION**

**Introduction:**

Traffic calming utilises physical design and other measures to improve the safety for motorists, pedestrians and cyclists. There are numerous traffic controlling devices that have developed over decades including: speed humps, speed tables, raised crosswalks, raised intersections, textured pavement, traffic circles, roundabouts, chicanes, neckdowns, centre island narrowings and chockers.

Speed humps and tables are raised areas placed across the roadway which are very effective in slowing travel speeds. Raised crosswalks are similar except they are outfitted with crosswalk markings and signage to channelize pedestrian crossings. Therefore, raised crosswalks improve the safety for both pedestrians and vehicles.

Textured pavement is utilised to emphasise either an entire intersection or a pedestrian crossing. They can reduce vehicle speeds over an extended length and placed at an intersection can calm two streets at once. Similarly, traffic circles are raised islands placed in intersections around which traffic circulates and are very effective in moderating speeds and improving safety within neighbourhoods.

In addition to this, neckdowns and centre island narrowings focus on improving pedestrian safety. Neckdowns create protected on-street parking bays, through and left-turn movements are easily negotiable by large vehicles while centre island narrowings along with chockers can reduce traffic speeds and volumes.

Furthermore, arguably one of the most successful traffic calming devices are roundabouts. They’re main purpose is to moderate traffic speeds on an arterial and enhance safety as an alternative to traffic signals. In comparison to traffic signals, roundabouts are also less expensive to operate and they can minimise queuing at the approaches to an intersection.

**Physics Principles**

In most cases, friction acts at the contact point between two surfaces and acts to resist the relative motion of these two surfaces. However, static friction is also able to facilitate movement in the form of grip and traction. The size of a frictional force is given by where N is the magnitude of the normal reaction force between the two surfaces and *μ* is the coefficient of friction between the two surfaces. For example, friction acts as a car’s tyre and the surface which it is travelling on. There are two types of friction; kinetic and static. The force of static friction is a force between two surfaces that prevents those surfaces from sliding or slipping across each other and is represented by the equation:

 Where;

The force of kinetic friction always opposes the sliding motion and tries to reduce the speed at which the surfaces slide across each other. The equation follows the form:

 Where;

Acceleration is a vector quantity. Therefore, a turning car is accelerating even if its speed it constant since it is changing direction. This known as centripetal acceleration. Since Newton’s second law states that the acceleration of an object is directly proportional to the force applied and dependent upon the mass, there must be a force on the car while it is turning. This force is the inward pointing centripetal force and is equivalent to the net turning force acting on the car. It is represented by the equation;

Where; m = mass of the vehicle (kg)
 v = velocity of the vehicle (m s-1)
 r = radius of the curve (m)
 = centripetal acceleration (m s-2)

For a car going around an unbanked (level) curve, there are three force acting. The downward force labelled “mg” is the weight of the car (the earth pulling downward on the car). The upward force, labelled "N" (normal) is the force the road exerts on the car perpendicular to the surface of the road. The car is not accelerating vertically, so Newton's First Law tells us that these two forces must cancel exactly which means the *vertical* net force on the car is zero. There must be a *horizontal* net force on the car. In the diagram, the horizontal force "F" represents the horizontal friction force that the road exerts on the car's tyres. This force must be the centripetal force which points toward the centre of the turn and is responsible for turning the car. In an unbanked turn, the force responsible for turning the car is the friction force between the tires and the road.

If a car is on a level (unbanked) surface, the forces acting on the car are its weight, mg, pulling the car downward, and the normal force, N, due to the road, which pushes the car upward. Both of these forces act in the vertical direction and have no horizontal component. If there is no friction, there is no force that can supply the centripetal force required to make the car move in a circular path and there is no way that the car can turn. However, if the car is on a banked turn, the normal force (which is always perpendicular to the road's surface) is no longer vertical. The normal force now has a horizontal component, and this component can act as the centripetal force on the car. The car will need move with just the right speed so that it achieves a centripetal force equal to this available force.
If a car is going around a banked turn, the centripetal force *needed* to turn the car () depends on the speed of the car (since the mass of the car and the radius of the turn are fixed) - more speed requires more centripetal force and vice versa. The centripetal force *available* to turn the car is fixed. Therefore, it is logical to assume that if one particular speed was found at which the centripetal force needed to turn the car equals the centripetal force supplied by the road, this is the "ideal" speed, videal, at which the car the car will negotiate the turn - even if it is covered with perfectly-smooth ice. Any other speed, v, will require a friction force between the car's tires and the pavement to keep the car from sliding up or down the embankment:

v > videal(right diagram attached): If the speed of the car, v, is greater than the ideal speed for the turn, videal, the horizontal component of the normal force will be less than the required centripetal force, and the car will "want to" slide up the incline, away from the centre of the turn. A friction force is required to oppose this motion up the incline. This friction force will act down the incline, in the general direction of the centre of the turn.

v < videal (left diagram attached): If the speed of the car, v, is less than the ideal (no friction) speed for the turn, videal. In this case, the horizontal component of the normal force will be greater than the required centripetal force and the car will "want to" slide down the incline toward the centre of the turn. A friction force is required to oppose this motion down the incline. This friction force will act up the incline, away from the general direction of the centre of the turn.

**Analysis and Evaluation**

Referring to stimulus 1, the traffic calming device is a chicane. As mentioned in the question, the centre of curvature of a bend can be estimated by creating two or more lines perpendicular to the bend to find their intersection point (refer to lined paper attached).

Using a protractor, the circumferences of the circle was drawn based on the approximated centre of curvature. This allowed the radius of the circle to be determined through measuring the distance from the centre of curvature to the outside of the circle. Then, the scale at the bottom of the picture will be used to determine the actual radius in metres of the chicane.

Prior to any calculations, an uncertainty margin will be implemented to account for any inequities in determining the values for each variable. The radius was measured using a centimeter ruler for which the lowest increment is 0.1 cm which will be the absolute uncertainty margin for the radius.

The ratio becomes:

3cm = 10m
The measured radius was 6.5

Convert to relative uncertainty percentage:

This equates to; 6.5

 (the relative uncertainty does not multiply by the constant)

The final answer for radius should always be rounded up, even if this goes against the normal rounding rules. This is because rounding down will result in the calculated answer exceeding the rounded value for the minimum safe radius, which means that the car will not be able to safely negotiate the corner. Therefore, the minimum safe radius for a car negotiating the bend is;

22 m

The question specifies to substantiate whether the maximum speed without sliding is a major design influence on this device. Although the car is travelling through a bend, it remains on a horizontal flat surface and therefore the following free body force diagram can be obtained (on lined paper attached).

Equating the forces vertically, it is found that;

Where the centripetal acceleration is provided by the static friction between the tyres and the road.

The mass of the car can be cancelled out because it appears on both sides of the equation:

Within this scenario, it can be assumed that the coefficient of friction will need to be between dry asphalt and rubber. According to various tables on the internet, the coefficient for these specifications is 0.9. Therefore, the velocity can be calculated as follows:

Since the coefficient of friction and gravitational acceleration are constants, uncertainty margins do not require implementation for this calculation.

This answer suggests that the maximum speed without sliding around the chicane is
50 km h-1  which could be either be 49.3 km h-1 or 51 km h-1 (both values rounded up). The purpose of a chicane is to prevent congestion but allow cars to obtain a maximum speed around this curve which means it is a major design influence on this device. If the bend is tighter (i.e. the radius is smaller), the maximum speed would be less and vice versa.

This relationship can be represented in greater detail below:

The relationship between radius and maximum velocity on an unbanked curve. (assuming road is dry)

Radius = 10, 15, 20, 25 metres

Substitute these values into the equation above for maximum speed resulted in the table below:

|  |  |
| --- | --- |
| Radius (m) | Velocity (km h-1) |
| 10 | 33.8 |
| 15 | 41.4 |
| 20 | 47.8 |
| 25 | 53.4 |

The graph validates the previous assumption of how there is a direct relationship between the radius and maximum speed around a curve for the above equation. The two variables for the equation are directly proportional to each other. Therefore, the greater the radius, the large the maximum speed that can be achieved when traversing around a curve or roundabout. However, the relationship between radius and velocity is known as centripetal acceleration for which the formula is; . This formula suggests that there is an inverse relationship between the two variables. However, the two formulas are considerable different and it is likely that they would produce differing outcomes due to the differences in their arrangement of variables. In this case, the gradient of this graph would be equal to . Whereas, for the second equation, the equation for centripetal acceleration is where:

However, this only applies if the surface between the car tyres and the road is dry. If the conditions of the road are wet, the coefficient of friction is 0.25. Repeating the same process on wet asphalt, the results are as follows;

The maximum speed without sliding for wet asphalt is 26 km h-1, this is almost half the speed of dry asphalt. Uncertainty margins included, the velocities are; 25.9 and 26.8 km h-1. This is an expected case because if the road is wet, the rubber on the tyres are more slippery when initiating contact with the asphalt and it would be unsafe to travel at a greater speed than dry asphalt. The original maximum speed determined when the road was dry was 50 km h-1 which is the same value as the region speed limit. This is a desirable outcome because if the velocity is greater than the region speed limit, then the driver of the vehicle could be tempted to increase its speed. Whereas, if the maximum speed around the bend is a significant amount less than the region speed limit, this will create congestion if a car is travelling too slow when negotiating the roundabout, worrying about increasing the speed in case the vehicle slips off the roundabout.

Although, it could be considered a relatively large value for the respective condition because the region speed should not be equal to the maximum speed around the bend. The bend appears to be considerably tight and it would be extremely difficult, if not impossible, to travel around the bend at this speed without losing control of the vehicle. This could be used to explain why the structure was removed. Knowing that the apparent maximum speed around the chicane was 50 km h-1, drivers would then attempt to maintain stability while travelling this speed. This could have resulted in numerous crashes or congestion if others cars decided not to do so.

In addition to this, the maximum velocity around the chicane is not completely accurate because when a vehicle travels around a roundabout, it does not maintain the same distance from the centre the entire way round. It could tighten closer to the inside or move further outwards before exiting depending on the person in the vehicle. This in turn would slightly affect the direction of travel, acceleration and therefore the maximum velocity.

Also, the maximum speed would not be the same in both directions. This is because the bend appears to be considerably tighter than the opposite direction. The radius for the opposing bend was measured to be 3cm; the equivalency of 10m (according to the scale). The velocity can be determined utilizing the same process above:

This can be rounded up towards the next general speed limit; 40 km h-1. This is a more suitable value for vehicle traversing the bend. However, it needs to be the same in both direction to allow for consistency and less confusion. The reasoning behind this is that a vehicle might travel 50 km h-1 in the first direction and attempt to travel the same speed in the opposite direction without realising that this would theoretically result in the vehicle sliding off the bend. Thereby, resulting in a greater amount of crashes on the road.

Stimulus 2 is the roundabout at intersection of Main Street and Boat Harbour drive where the region speed limit is 60 km h-1. The camber (superelevation) on this roundabout varies considerably due to the surrounding terrain and services under/around it. At the steepest section of the roundabout, the outside edge of the roundabout roadway is about 600mm lower than the inside edge of the roadway.

The minimum curve radius is a limiting value of curvature for a given design speed. In the design of the horizontal alignment, smaller than the calculated boundary value of minimum curve radius cannot be used. Thus, the minimum radius of curvature is a significant value in alignment design. For a given speed, the curve with the smallest radius is also the curve that requires the most centripetal force.

The same uncertainty margin for stimulus 1 will be utilised for the radius of stimulus 2 because the smallest increment on a ruler still remains at 0.1 cm.

The scale for the roundabout is:

4.6 cm = 30 m

The measured radius is 3.5 cm

4.6 cm = 30 m

The measured radius is 2 cm

23 – 14 = 9 m 1.54%.

The reason the two radius values were subtracted from each other is because the initial radius is measured from the inside to the total outside of the roundabout. Whereas, the second radius is determined by measuring the outside lane to the centre of the roundabout. The resulted value of 9 metres represents the distance where the superelevation occurs.

As a vehicle traverses a circular curve, it is subject to forces associated with the circular path. According to the principle of inertia, in the absence of forces, a moving body will travel in a straight line. A force must be applied to change direction. For a circular change of direction, the force is called centripetal force and, in road design, this is provided by side friction developed between the tyres and the pavement, and by superelevation. Superelevation is inclined roadway cross section that employs the weight of a vehicle in the generation of the necessary centripetal force for curve negotiation. This situation can be depicted on a right-angle triangle and the angle can be determined using Pythagoras theorem.

 9 m

0.6 m

 x

Find the width of the road between these two points:

x =

This almost the same as the value of the radius. This is to be expected because the superelevation is very small and when squared, created an ever smaller value.

A free force diagram will be drawn (on lined paper attached) for a vehicle on an incline to determine the maximum velocity.

Equating vertically:

Equate horizontally:

Rearrange equation 1 for m

Substitute equation 3 into equation 2:

But,

The normal force can cancel itself out because it enters every term:

Substitute

The angle of superelevation was 3.82 and this produced a velocity of 33 km h-1. With the uncertainty margin included, the results are; 31.2 and 34.8. Therefore, the maximum speed that a vehicle can travel around the bend without sliding is 33 km h-1. The region speed limit is 60 km h-1 so it appears this is a reasonable value as it is significantly less than the region speed limit. Well-designed roundabouts achieve a lower potential relative speed of vehicles on the cross roads primarily because of the presence of entry curvature. Entry curvature limits the speed at which drivers can enter the circulating carriageway. Conversely, a poorly designed roundabout with little entry curvature or deflection results in high speeds through the roundabout creating high potential relative speeds between vehicles.

Therefore, this is a good roundabout because it allows vehicles to travel a safe speed around the roundabout without endangering the lives of other vehicles on the road. Also, approaching a roundabout, particularly a busy roundabout such as this, will require a vehicle to usually slow down to approximately 25 – 35 km h-1 depending on how busy it is. However, very rarely a vehicle will encounter no traffic when going straight or turning.

Stimulus 3 is a roundabout on Boat Harbour Drive between Nissen Street and Old Maryborough Road and is reasonably similar to stimulus 2 except there is no superelevation. The same process for the previous two stimuli will be used to determine the radius of the roundabout.

The ratio becomes:

4.1cm = 30m
The measured radius was 2.9 cm.

The radius was not rounded to the nearest metre because this would mean that the estimated radius would be the same value as stimulus one which would not reflect the results.

Using the 21.3 metre value for the radius, the maximum velocity can be determined shown below:

The value for the maximum velocity is 49 km h-1. The speed limit within this area is 60 km h-1. Therefore, this appears to be a reasonable value for the maximum speed because it does not exceed the speed limit. However, if a vehicle is travelling below the speed limit but exceeds the estimated maximum speed limit, the vehicle would be slipping off the road. This is providing that the calculations are correct and there is very little or no traffic on the roundabout during this period of time. The circumstances above would not hinder the roundabout from being considered “good” because roundabouts are in place to reduce the amount of congestion; implying that they are usually very busy. Thus, a vehicle would not have the opportunity to travel at this speed because most vehicles either come to a complete stop or slow to approximately 20 km h-1 approaching a roundabout.

If circumstances should occur when the road is wet (wet asphalt), the velocity becomes:

As previously seen through question 1, it is appropriate for the maximum speed on wet asphalt to differ considerably from dry asphalt because the surface will be slippery which increases the chance for the vehicle to slide off the road.

Stimulus 4 is a roundabout at Hervey Bay-Maryborough Rd and Booral Rd (right) and Torbanlea Rd (left). The speed limit on these roads is 100 km h-1 but reduces to 80 km h-1 approaching the roundabout. The radius is determined again as follows:

The ratio becomes:

1.9cm = 20m
The measured radius was 4 cm.

Using the 43 metre value for the radius, the maximum velocity can be determined shown below:

While approaching the roundabout, the speed reduces to 80 km h-1. If the calculations are correct, the maximum speed at which vehicle can travel around the roundabout without sliding is 70 km h-1. This value allows vehicle to stay safe on the road, because it will maintain a safe speed when traversing the roundabout, as it will not exceed the region speed limit. This produces similar results to the previous stimulus and would therefore be considered a good example of a roundabout.

Stimulus 5 is a very large roundabout in Canberra. It is at the intersection of Yamba Drive, Melrose Drive and Yarra Glen.

The shape of the roundabout is not circular so three radius values will be estimated for each of the bends. There are rounded points at 3 sections of the roundabout. The radius and consequently the velocity will be calculated for all three sections. This is because the region speed limits are different depending on which exit is being used.

**Ratio:
4.5cm = 82m**

Yamba Drive; Melrose Drive; Yarra Glen;

Measured radius is 6.3 cm Measured radius is 5.6 cm Measured radius is 6 cm

The separate exits will be analysed for each of the velocities.

Yamba Drive; Melrose Drive; Yarra Glen;

All of the above maximum speeds greatly exceed their region speed limits. The speed limit is 80 km h-1 on Yamba Drive and Yarra Glen and 60 km h-1 on Melrose Drive but increases to 80 km h-1 before reaching the roundabout. It is clearly depicted throughout all the stimuli that the larger the roundabout (increased radius), the greater the maximum speed that can be achieved when negotiating the curve. However, the coefficient has remained the same during all the calculations as the road was assumed to be dry and this correlated with a value of 0.9. Contrarily, if the road surface was not asphalt and it was concrete, the coefficient of friction would be equivalent to 0.6 and the results would be as follows:

Yamba Drive; Melrose Drive; Yarra Glen;

These results are carry greater acceptability because although they exceed the region speed limits, their values are 20 km h-1 less than when the surface was assumed to be dry asphalt. This stimulus follows the same principles as stimulus 2 in terms of being viewed as neither a good or bad roundabout because the vehicles could only potentially slide off the roundabout if the vehicle is exceeding the speed limit.

**Conclusion:**

The five stimuli were analysed by measuring the radius from the diagram and calculating the velocity and in one circumstance; the super elevation.

Horizontal curves on which high values of coefficient of friction are likely to be demanded should be provided with a pavement surfacing capable of providing good skid resistance. This is particularly important on horizontal curves in constrained areas. The following treatments will help decrease the likelihood of skidding which can eliminate the need of a slower speed around a bend which could in turn reduce congestion.

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**Appendix**