TO: Holders of the Geometric Design Guide for Canadian Roads (1999)

FROM: Transportation Association of Canada

SUBJECT: Updates to the Geometric Design Guide for Canadian Roads

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Enclosed please find 54 new and/or revised pages for insertion into your copy of the Geometric Design Guide for Canadian Roads. Revisions in this package will affect the following items:

Title Page – Part 1 and 2
Chapter 1.2 – Design Controls
Chapter 1.4 – Design Consistency
Chapter 4.3 – Index

To update your Guide simply follow these instructions:

Remove the Title Page from Part 1 and Part 2 and insert the new Title Pages.

For Chapter 1.2:

- Remove pages 1.2.i – 1.2.ii, 1.2.3.1 – 1.2.3.6, 1.2.R.1 – 1.2.R.2 from the Guide and insert new pages 1.2.i–1.2.ii, 1.2.3.1 – 1.2.3.9, 1.2.R.1 – 1.2.R.2 from new Chapter 1.2
- Leave pages 1.2.4.1 – 1.2.5.8 in the existing Chapter 1.2 of the Guide, since these are still valid and remain unchanged.

For Chapter 1.4:

- Remove pages 1.4.i – 1.4.R.2 from the Guide and insert new pages 1.4.i – 1.4.R.2 that form the new Chapter 1.4. You should now have a completely new Chapter 1.4 in your Guide.

For Chapter 4.3:

- Remove pages 4.3.1 – 4.3.8 from the existing Index and insert new pages 4.3.1 – 4.3.8.

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Transportation Association of Canada

Geometric Design Guide for Canadian Roads

Part 1

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The Transportation Association of Canada is a national association with a mission to promote the provision of safe, secure, efficient, effective and environmentally and financially sustainable transportation services in support of Canada's social and economic goals. The association is a neutral forum for gathering or exchanging ideas, information and knowledge on technical guidelines and best practices. In Canada as a whole, TAC has a primary focus on roadways and their strategic linkages and inter-relationships with other components of the transportation system. In urban areas, TAC's primary focus is on the movement of people, goods and services and its relationship with land use patterns.

L'ATC est une association d'envergure nationale dont la mission est de promouvoir la sécurité, la sûreté, l'efficience, l'efficacité et le respect de l'environnement dans le cadre de la prestation de services financièrement durables de transport, le tout à l'appui des objectifs sociaux et économiques du Canada. L'ATC est une tribune neutre de collecte et d'échange d'idées, d'informations et de connaissances à l'appui de l'élaboration de lignes directrices techniques et de bonnes pratiques. À l'échelle du pays, l'Association s'intéresse principalement au secteur routier et à ses liens et interrelations stratégiques avec les autres composantes du réseau de transport. En milieu urbain, l'Association s'intéresse non seulement au transport des personnes et des marchandises, mais encore à la prestation de services à la collectivité et aux incidences de toutes ces activités sur les modèles d'aménagement du territoire.

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Design Controls

Chapter 1.2

1.2 DESIGN CONTROLS

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1.2.3 SPEED

1.2.3.1 Introduction

Minimizing travel time is usually one of the most important concerns to a driver in selecting alternate routes. The value of a road in carrying people and goods is judged by its convenience and economy, which are directly related to its travel speed.

The speed of vehicles on a roadway depends, in general, on several conditions:

- vehicle operating capabilities
- driver capability, behaviour and comfort
- physical characteristics of the road and its surroundings
- weather
- roadway conditions
- presence of other vehicles
- posted speed limits

The effects of these conditions are usually combined although, under varying circumstances, one or other of the factors may govern.

The speed of vehicles on a roadway has a significant bearing on safety, particularly in terms of the severity of collisions. However, the relationship of speed to the probability of a collision is not as evident, since collisions are complex events that can seldom be attributed to a single factor. It is now widely believed that collision rate is more directly affected by speed variations than by speed per se, given that intuitively, the probability of conflicts would be lower if all vehicles were travelling at the same speed (this has lead to the introduction of minimum speed limits for some applications).

A recent study[15] showed that both faster and slower drivers are more likely to be involved in collisions. In an analysis of speed variance, the study found that the major contributing factor was the difference between design speed and posted speed limit. For Virginia highways, the minimum speed variance was obtained when the design speed was 10-20 km/h higher than the posted speed. However, this finding is confounded by their other finding that mean speed variance and design speed do not act independently on collision rates since they are correlated.

The designer needs to be cognizant of the general effects of speed on safety. Collision frequency will be reduced on roads that do not require drivers to make large speed adjustments and that promote uniformity of speeds. Collision severity will increase with speed. More severe collisions not only increase the cost to individuals and society of each collision, but result in more collisions being reported, showing an apparent increase in collision rate. A design choice that promotes speed is not necessarily bad since road users value the time savings. However, anticipation of the increase in speed may call for other design improvements to be made that compensate for the expected increase in collision severity.

In designing a road, the features and dimensions chosen must be appropriate for the travel speed. While this is a simple concept, its interpretation is complex, because the relationship between road design and speed is a circular one. While the designer shapes elements of the road by the anticipated speed at which they are intended to be used, the speed at which they will be used depends to some extent on their chosen design. In this, the design of roads differs from the design of most other engineered systems.

1.2.3.2 Desired Speed

Desired speed is the speed at which a driver wishes to travel, determined by a combination of motivation and comfort. Motivation is heavily influenced by the length and urgency of the trip: as these factors increase, desired speed also increases.

Desired speed is influenced, as part of the comfort factor, by the driver's expectations of the characteristics and quality of the road ahead. Expectations are, in turn, based on the driver's perception of the prevailing topographic, environmental, traffic and climatic conditions.

Where severe topographic conditions are encountered, the driver expects to travel at lower speeds and is more likely to adjust to a geometric design consistent with a lower design speed than where there is no apparent reason for it. Drivers do not necessarily adjust their speeds to an arbitrarily chosen design speed for a roadway, but to the physical limitations and the prevailing traffic conditions.

1.2.3.3 Design Speed

Design speed is a speed selected as a basis to establish appropriate geometric design elements for a particular section of road. These design elements include horizontal and vertical alignment, superelevation and sight distance. Other elements such as lane width, shoulder width, sideslope ratio and clearance from obstacles are related indirectly to design speed.

The selected design speed should be a logical one with respect to the character of terrain, anticipated operating speed, adjacent land use (ie. urban or rural in character), and the road classification system as described in the Chapter 1.3 of this guide. As noted elsewhere in this section, urban and rural freeways and primary rural arterials should be designed with the highest practical design speed to promote a desired degree of traffic mobility, safety, and efficiency within the constraints of environmental quality, economics and aesthetics. However, local roads are often subject to speed controls through measures such as traffic calming and hence the design speed is likely to be dictated by a speed management policy.

When planning new facilities, appropriate design speeds should be chosen that are consistent with the road function as perceived by the driver[24]. Redesigning existing roads to achieve greater congruity between driver perceptions of appropriate operating speeds and cues provided by the road itself (e.g. narrowing lanes) has promise. Because of the size of the network, however, road redesign is a long term strategy and more understanding of the overall safety benefits of alternative designs is needed.[27]

When designing a substantial length of road, it is desirable, although it may not be feasible, to assume a constant design speed. Changes in terrain and other physical controls may dictate a change in design speed on certain sections. Each section, however, should be of relatively long length, compatible with the general terrain or development through which the road passes. The justification for introducing a reduced design speed should be obvious to the driver. Moreover, the introduction of a lower or higher design speed should not be effected abruptly but over sufficient distance to encourage drivers to change speed gradually.

Differences in design speed from one segment to another should not be more than 20 km/h. Drivers should be warned well in advance. A transition section allowing for speed reductions, as from 100 to 90 to 80 km/h, should be provided. Thus, the changing condition should comprise extra long (anticipatory) sight distances, speed-zone signs, curve speed signs, and so on.

Roads intended to provide high mobility, such as freeways and expressways, should be designed with the highest practical design speed to promote traffic mobility, efficiency and safety. Pedestrians and cyclists are either discouraged or prohibited from utilizing these types of roads, so provision should be made for a speed that satisfies nearly all drivers (the 85th percentile desired speed is typically used). Only a small percentage of drivers travel at extremely high speed, and it is not economically feasible to design for them.

Ideally, then, design speed should be chosen to reflect the 85th percentile desired speed, and this is often achievable for roads for which the primary function is mobility and where severe physical constraints do not exist. Studies[16] have shown that the 85th percentile desired speed does not generally exceed 120 km/h for unhindered vehicles on a four-lane divided roadway. Use of a design speed of 120 km/h should therefore satisfy driver demands in most areas, although design speeds of 130 km/h are used in some jurisdictions.

The selected design speed should be a logical one with respect to the topography and the functional classification of a road, but careful consideration should also be given to its relationship with other definitions of speed. While no hard relationships have been established, choice of design speed can simultaneously accommodate and influence desired speed, operating speed, running speed and posted speed.

1.2.3.4 Operating Speed

Operating speed is the speed at which a driver is observed operating a vehicle (a "spot" speed at a particular location). For an individual driver, operating speed will generally be lower than desired speed, since operating conditions are not usually ideal. The operating speed of all vehicles at a particular location is reported as either a mean or 85th percentile operating speed.

Where constraints exist, such that the design speed will be less than the desired speed for many drivers, it is important that drivers are given clear advance warning that they should modify their speed desires, as studies[15] have shown that collision rates increase as operating speed of a particular vehicle deviates from the mean operating speed of the other vehicles on the roadway.

The typical driver can recognise or sense a logical operating speed for a given roadway based on knowledge of the system, posted speed limits, appraisal of the ruggedness of the terrain, traffic volumes and the extent, density and size of development. Studies[26] have shown that characteristics such as the number of access points, nearby commercial development, road width, and number of lanes have a significant influence on vehicle speeds. Based on these factors, the driver will adjust speed to be consistent with the conditions expected to be encountered. The driver's initial response is to react to the anticipated situation rather than to the actual situation. In most instances, the two are similar enough that no problems are created. When the initial response is incorrect operation and safety may be severely affected.

Some agencies conduct speed surveys to determine operating speeds at various points along a section of roadway. The results can be compared with the design speed used, and may lead to a policy change in the selection of design speeds.

1.2.3.5 Running Speed

While operating speed is tied to specific locations, running speed is defined[19] as the average or 85th percentile speed of all vehicles along a specific roadway as determined by the distance and the running times (travel times minus involuntary delay stops) between two selected points, usually major intersections. For design purposes, the running speed during off-peak traffic periods and under favourable roadway and weather conditions is an important consideration, since it is helpful to know actual vehicle speeds for traffic en masse to be expected on roadways of different design speeds and various volume conditions. Running speed is one measure of the service that a roadway renders, and it affords a means of evaluating user costs and benefits.

Running speed on a given roadway varies somewhat during the day, depending primarily on the volume of traffic. Therefore, when reference is made to average or 85th percentile running speed it should be clear whether this speed is for peak hours or off-peak hours or whether it is an average for the day. The first two are of concern in design and operation; the latter is of importance in economic analyses.

Running speed is likely to govern the choice of design speed on roads with high traffic volumes, particularly in an urban setting. Local roads, in particular, are designed with consideration for the safety of all users, including pedestrians and cyclists. They are subject to highly conflicting uses and movements, provide a high degree of access and often accommodate parking. Thus, low design speeds are appropriate for local roads with low mobility requirements, frequent access, and significant pedestrian and cyclist activity.

Urban arterial roads should be designated and control devices regulated, where feasible, to permit running speeds of 30 to 70 km/h. Lower speeds in this range are applicable for local and collector roads through residential areas and for arterial roads through the more crowded business areas, while the higher speeds apply to arterials in the outlying suburban areas. For arterial roads through crowded business areas, coordinated signal control through successive intersections generally is necessary to achieve even the lower speeds. Many cities have substantial lengths of roads controlled so as to operate at running speeds of 25 to 40 km/h. At the other extreme, in suburban areas, it is common experience on preferred roads to adopt some form of speed zoning or speed control to prevent high operating speeds. In these areas, the infrequent pedestrian or occasional vehicles on a cross street may be exposed to potential collisions with through drivers, who gradually gain speed as the frequency of urban restrictions are left behind or retain the speed of the open road as they enter the city.

Since much of urban road design is retrofit, the selection of design speed of roads in the urban environment is often an iterative process in which the selection is influenced by the attainable geometric features. An understanding of expected traffic running speeds is important so that the designer can analyse a retrofit project to ascertain the safety and efficiency of the design.

1.2.3.6 Posted Speed

Speed control, aimed at encouraging drivers to travel at an appropriate speed for prevailing conditons, encompasses enforcement, education and engineering techniques. While police enforcement has been the traditional approach to controlling speeds, research[24] has shown that significant increases in enforcement levels are required to influence driver behaviour, and those effects are relatively short lived. The posted speed is a speed limitation, consciously introduced for reasons of safety and economy, traffic control and government regulatory policies. Consequently, the selection of posted speed is a traffic operations consideration rather than a geometric design element. Conversely, however, geometric design elements must be considered in determining posted speed.

Design speed would appear to be the most natural criterion from the road agency's viewpoint in selecting a posted speed limit since by definition it is supposed to be the safe speed at which the road can be negotiated. However, the design speed criterion can be unrealistic from a driver's point of view since speed affects the design of relatively few elements even though it is used to classify an entire road segment. As a result, the speed limit might appear to be unreasonable to the driver and thus lead to substantial speed limit violations.

Further demonstrating the effects of design elements, experience has shown that the collision rates on freeways, which have the highest legislated speed limits, are two to three times lower than two-lane, two-way highways. This safety benefit is in large part due to the design features of the roadway: separation of opposing traffic; dual lanes eliminate passing conflicts; limited access to the roadway; traffic flows are separated at the interchanges; and wide, relatively flat and object free roadsides reduce the severity of collisions when vehicles run off the roadway.

Design speed should not be deduced from anticipated posted speed limits, since these can be changed arbitrarily by policy makers. On the contrary, a posted speed limit should be applied at or below design speed. Where, for reasons of constraints, a design speed is used below anticipated 85th percentile levels of desired or running speeds, continuing enforcement of appropriate speed limits is important in reducing the collision rate on a road.

It should be recognized that, while posted speed can readily be changed after the road is constructed, design speed is reflected in the physical features of the road and cannot be altered without reconstruction. Simply changing the legislated speed limits has little effect on driver behaviour. A recent study[25] investigated the effects of raising and lowering the speed limit at 100 experimental sites on non-limited access highways in 22 U.S. states. A summary of the results indicated that, overall, raising or lowering the speed limits had little effect on the driver's speed choice, and did not lead to any statistically significant changes in either total or severe collisions. Arbitrarily posted reduced speed zones are therefore not likely to operate effectively. To be effective, the posted speed should be consistent with prevailing topographical and development conditions and subject to reasonable enforcement. If a low posted speed is anticipated at the outset of a design, the selected design speed should not be artificially lowered since a well-chosen design speed will produce a safer road and the possibility of a higher posted speed applied after construction should be recognized.

Where a design speed can be selected to match a high percentile desired speed, it appears reasonable to set the posted speed at the design speed, i.e. at the 85th percentile desired or running speed, rounded to the nearest 10 km/h. Speed limits set higher make very few additional drivers “legal” for each 10 km/h increment of speed increased. Conversely, speed limits set lower make a significant number of reasonable drivers “illegal” for each 10 km/h increment of speed decreased, place unnecessary burdens on law enforcement personnel, lead to a lack of credibility of speed limits and lead to increased tolerance by enforcement agencies[14]. Based on studies[16] which showed that the 85th percentile desired speed does not generally exceed 120 km/h for unhindered vehicles on a four-lane divided roadway, it is logical to set the maximum posted speed at 120 km/h, where interchanges are provided and access is controlled.

Situations can arise where the posted speed exceeds the design speed. This is not surprising and is not necessarily unsafe, since traditionally designed geometric components of a road may incorporate considerable margins of safety, particularly for good vehicle and weather conditions. Nevertheless, in order to avoid liability concerns, this situation should give rise to an evaluation of the design of the road and the posting of advisory speed limits at critical locations such as horizontal or vertical curves[13].

Posted speeds may also be established on the basis of specific traffic operation studies. In these studies other elements are often considered including factors such as collision experience, the nature and intensity of adjacent land use, parking practices, access frequency and pedestrian activity.

For all types of roads in an area, it is desirable to provide a reasonable degree of uniformity in the design speeds, operating speeds, and subsequently the posted speeds selected within each classification subgroup or group. For example, the posted speed for all minor arterial roads within a municipality should be identical or near identical. Driver expectations are met in this manner.

1.2.3.7 Limitations of Design Speed Approach

As noted in Subsection 1.2.2.3, consistency of design is fundamental to good driver performance, based on satisfying the driver’s expectations. Design consistency exists when the geometric features of a continuous section of road are consistent with the operational characteristics as perceived by the driver. The traditional approach to achieving design consistency has been through the application of the design speed process. Once selected, the design speed is used to determine values for the geometric design elements from appropriate design domains.

However, application of this procedure alone does not guarantee design consistency. There are several limitations of the design speed concept that should be considered during design:

1. Selection of dimensions to accommodate specified design speed does not necessarily ensure a consistent alignment design. Design speed is significant only when physical road characteristics limit the speed of travel. Thus, a road can be designed with a constant design speed, yet have considerable variation in speeds achievable and therefore to a driver appear to have a wide variation in design basis. For example, to maintain consistency, the design speed of curves within a road section should be uniform, not merely greater than some minimum design speed.

2. For horizontal alignments, design speed applies only to curves, not to the tangents that connect those curves. Design speed has no practical meaning on tangents. As a result, the maximum operating speed on a tangent, especially a long one, can often significantly exceed the design speed of the horizontal curves at either end of the tangent.

3. The design speed concept does not ensure sufficient coordination among individual geometric features to ensure consistency.

It controls only the minimum value of the maximum speeds for the individual features along an alignment. For example, a road with an 80 km/h design speed could have only one curve with a design speed of 80 km/h and all other features with design speeds of 110 km/h or greater. As a result, operating speeds approaching the critical curve are likely to exceed the 80 km/h design speed. Such an alignment would comply with an 80 km/h design speed, but it might violate a driver's expectancy and result in undesirable operating speeds.

4. As discussed previously, vehicle operating speed is not necessarily synonymous with design speed. Drivers normally adjust speed according to their desired speed, posted speed, traffic volumes and the perceived alignment hazards. The perception of hazard presented by the alignment may vary along a road designed with a constant design speed. The speed adopted by a driver tends to vary accordingly and may exceed the design speeds. A report[20] on studies in Australia and the US concluded that 85th percentile operating speeds consistently exceed design speeds, where those design speeds are less than 100 km/h, at horizontal curves on rural two-lane highways.

5. In addition, different alignment elements may have quite different levels of perceived hazard. Entering a horizontal curve too fast will almost certainly result in loss of control, so drivers adjust their speed accordingly. However, the possibility of a curtailed sight distance concealing a hazard is considered as a remote occurrence. Drivers do not generally adjust their speed to compensate for sight distance restrictions.

6. The design speed concept could prevent inconsistent operating-speeds if drivers could be presumed to know the design speed of the road and choose an operating speed less than or equal to that design speed, even though they may be comfortable at higher speeds along most of the alignment. That presumption is unreasonable, even if posted speed is set at design speed. Therefore, the design speed concept does not provide a systematic mechanism for preventing geometric inconsistencies.

In order to help overcome these weaknesses in the use of design speed to design individual geometric elements, speed profiles are used. A speed profile is a graphical depiction (which can be modelled) showing how the 85th percentile operating speed varies along a length of road. This profile facilitates an examination of the design to identify undesirably large differentials in the 85th percentile operating speed between successive geometric elements, e.g. a curve following a tangent.

For an existing road being considered for improvement, actual operating speeds can be measured to create a speed profile, but interpretation of the profile can be difficult, depending on the complexity of geometric and other features which may cause drivers to change speed. For a new road, some prediction of operating speeds is needed to create a speed profile model, and a methodology for doing so is outlined in Chapter 1.4.

1.2.3.8 Design Domain: Design Speed Selection

<u>General Application Heuristics</u>

The following factors influence the choice of design speed and are presented in the form of guidelines only.

- Design speed should be greater than or equal to the legal posted speed. A design speed equal to the posted speed may be warranted by such factors as low traffic volumes, mountainous terrain, or economic considerations. This practice is appropriate for minor collectors, local roads, municipal roads, and some secondary highways

- Design speed choice should reflect the 85th percentile desired speed.

- The overall range in design speeds is 20 km/h to 130 km/h and the design speed increments are 10 km/h.

- A lower design speed should not be automatically assumed for a secondary rural highway or low volume primary rural highway, where the terrain and speed environment are such that drivers are likely to travel at higher speeds.

Rural Highways

Two-lane Locals, Collectors and Arterials

The following operating-speed based approach is recommended for use by designers seeking to establish appropriate design speeds on rural two-lane, two-way highways. This approach is illustrated in Figure 1.2.3.1 and consists of the following steps:

- Select a nominal (trial) design speed.
- Select the design parameters for vertical and horizontal alignment and other highway geometric elements.
- Develop a trial alignment.
- Estimate the 85th percentile speeds on the trial alignment. (See Chapter 1.4)
- Check consistency; does the estimated speed match the design speed?
- If it does finalize the design.
- If the estimated speeds do not match the design speed can the alignment be modified? If so, develop a new trial alignment.
- If the alignment cannot be modified, select another nominal (trial) design speed and repeat the process.

This approach is consistent with basic design consistency principles

Commonly used design speeds for primary rural arterial two-lane highways in Canada vary between 100 and 120 km/h in rolling and level terrain. In mountainous terrain commonly used design speeds are 80 – 100 km/h. A design speed equal to the legal posted speed of 90 – 100 km/h is the normal practice for secondary highways in some jurisdictions. Similarly, a design speed of 80 km/h and a posted speed of 80 km/h is the normal practice for rural municipal roads in some jurisdictions.

Divided Arterials, Expressways, and Freeways

A design speed of 110, 120 or 130 km/h should be used for rural divided arterials, expressways, and freeways.

Urban Roadways

General Application Heuristics for Urban Roadways

- In the urban environment, all users rather than just the motorist should be taken into consideration when selecting the design elements that affect speed along a street. Users other than the motorist include pedestrians, cyclists, and public transit riders[24].
- Speed considerations that may influence design includes design speed, desired speed, and operating speed. A direct relationship between posted speed and design speed is particularly valid for new street facilities in the upper range of the street classification system such as freeways, expressways, and major arterials.
- For design purposes, the average running speed during off-peak traffic periods and under favourable street and weather conditions is an important consideration.
- Where the urban street design is retrofit, the design speed of streets in the urban environment is often an iterative process in which the selection is influenced by the attainable geometric features.
- Unlike rural design providing as high a design speed as practical is not the primary objective.
- Selection of the most appropriate design speed should be made on the basis of the intended service function and needs of the expected users.

- The choice of design speed in the urban environment will also be influenced by the constraints of economics, social impacts, environmental controls, and aesthetics.

- The design speed selected should be consistent with driver expectations along that particular urban roadway. Prevailing conditions that should be considered in this regard include adjacent land-use, intersection spacing, access conditions, and vulnerable road user activity.

Locals and Collectors

- Choosing too high a design speed for an urban local or collector street can induce drivers to travel beyond the safe speed for their surroundings and pose significant risks to vulnerable road users such as pedestrians and cyclists.

- Low design speeds are appropriate for local streets with low mobility requirements, frequent access, and significant pedestrian and cyclist activity. Local streets must be designed with the vulnerable road user in mind, including cyclists and pedestrians.

- The designer's choice of design speed for collectors and local roadways must consider the role and presence of the vulnerable road user. The conventional approach to road design includes design speed choices of 30 – 50 km/h for local roads and 50 – 80 km/h for collector roads.

Arterials

- There are important differences between the criteria applicable to low and high-speed designs. In general, because of these distinct differences, the upper limit for low-speed design is 70km/h and the lower limit for high-speed design is 80 km/h.

- Urban arterials generally have running speeds of 30 to 70 km/h. It follows that the appropriate design speeds for arterials should range from 50 to 100 km/h. The design speed selected for an urban arterial will depend largely on the spacing of signalized intersections, the selected type of median cross section, the presence or absence of curb and gutter along the outside edges of the traveled way, and the amount and type of access to the street.

Expressways and Freeways

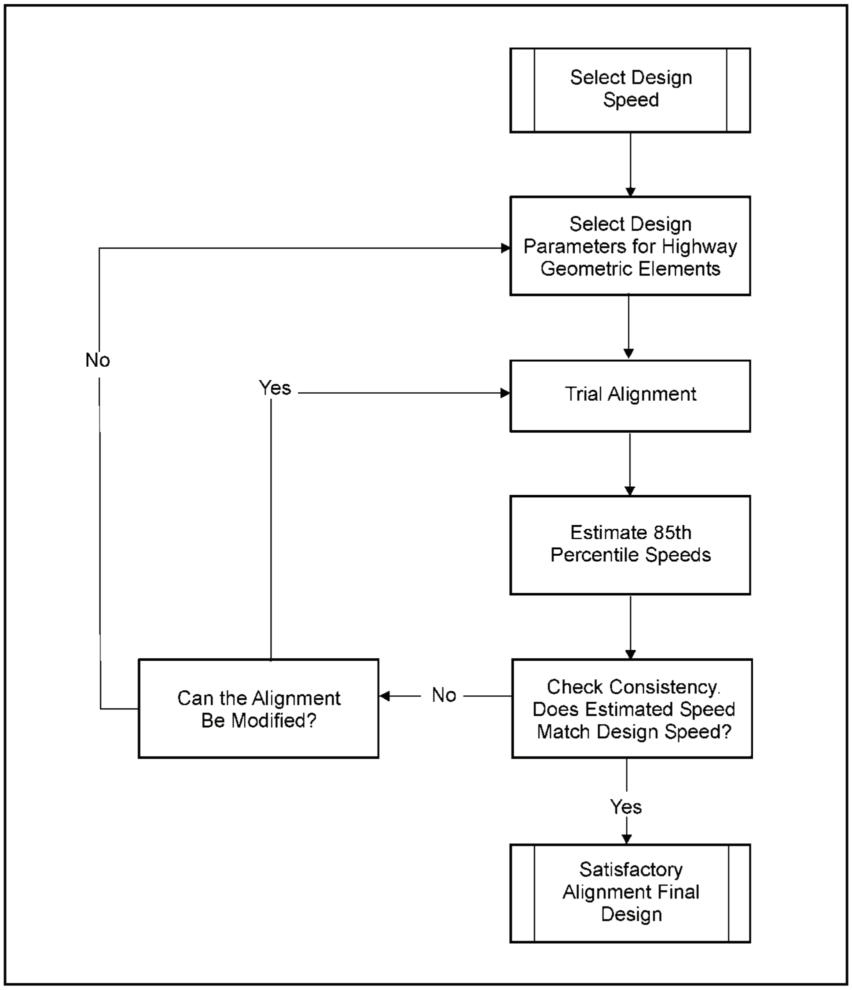
Commonly used design speeds for urban freeways in Canada vary between 90 km/h and 120 km/h.

<u>Design Speed Choices for Rehabilitation Projects</u>

Identifying the design speed is one of the initial steps in the rehabilitation project design process. Rehabilitation projects are often referred to as 3R/4R projects – a term that refers to the various levels of rehabilitation (….) that are embraced by the more general term "rehabilitation". The TAC Guide for 3R/4R[28] notes that there is often a poor relationship between the 85th percentile speed, the original design speed, and the posted speed. In many cases, in particular with older roads that have evolved over time, a design speed may never have been established or is not known. For 3R/4R projects the design speed should reflect actual operating speeds, not necessarily the legal speed limit, since drivers are more apt to accept a lower speed limit where a difficult condition is obvious than where there is no apparent reason for it. In most cases, drivers adjust their speeds to physical limitations and traffic.

The recommended practice for 3R/4R projects is to define the design speed as the existing 85th percentile speed on a roadway. Desirably, the 85th percentile speed should be measured for each project and the operational design speed procedure shown in Figure 1.2.3.1 followed. Where this is not practical, system wide typical values, for specific roadway classifications and other influencing characteristics such as roadway geometry, terrain and adjacent land use can be utilized. In some cases, due to policy or the desire to promote corridor continuity, for example, it may be desirable to define the 3R/4R design speed as a value other than 85th percentile speed.[28, 29] Selection of design speed on this basis is part of context sensitive design[33] or design for ambient conditions.[30, 31, 32, 34]

Figure 1.2.3.1 Operating Speed Approach for Design of Two-lane, Two-way Roadways



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Design Consistency

Chapter 1.4

1.4 DESIGN CONSISTENCY

Tables

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1.4.1 INTRODUCTION

Chapter 1.2 describes how driver reactions are determined in large measure by how well their expectancies are satisfied. Suggestions are made about how designers should respond to reduce/eliminate uncertainty or the unexpected for drivers. An important component of this response is design consistency. The more consistent road designs are over a wide geographic area, the more effective the designer's contribution will be to reducing collision occurrence.

Many different classes of roads are required to serve different purposes, as described in Chapter 1.3. Furthermore, terrain conditions vary widely from one region to another across Canada, requiring different approaches to design. However, the aim of Canadian designers must be to achieve consistency in design of each classification of road, in each type of terrain, regardless of location. This objective is a primary justification for the existence of this guide.

As long ago as 1978, it was pointed out that there was a general lack of explicit criteria for the contiguous combination of basic design elements or for the longitudinal variations of such features as horizontal alignment, vertical alignment, and cross section.[1]

In this chapter, three principles are suggested by which a designer can evaluate consistency of a road design:

- Cross section consistency
- Operating speed consistency
- Driver workload consistency

However, the most valuable tool for evaluating design consistency is actual collision experience, which should, for any existing facility, be used as a basis for the design consistency review.

When inconsistencies cannot be avoided at certain isolated locations because of high construction cost, land use restrictions, or severe environmental impacts, drivers should be given advance warning and other visual cues to alert them to the inconsistency.

Designers should note that the research works on which these consistency measures are based dealt only with two-lane rural highways. The same principles, however, can be applied to other classes of roads.

The same research has also provided valuable guidance to designers regarding the potential road safety performance implications of design consistency considerations. These are summarized in Section 1.4.5 of this Chapter.

1.4.2 CROSS SECTION CONSISTENCY

For a given classification of road in given terrain conditions, cross section elements should desirably be the same everywhere, but certainly on any specific road.

Once cross section dimensions, such as lane and shoulder widths and clear zone configurations have been established, they should be consistently applied. So too should other features of the cross section, such as marker posts and roadside barriers.

A situation to be avoided is the creation of incompatibilities between the road cross section and its horizontal and vertical alignments.[2] In the case of road improvement, for example, upgrading cross section elements without corresponding upgrading of alignment can result in an erroneous and potentially hazardous illusion. This can result in the driver choosing to operate at speeds excessive for the critical alignment conditions.

Sometimes, a sudden change in cross section configurations is unavoidable. One example of this would be where a narrow two-lane road is being reconstructed to four lanes in stages. Staging may be required because of constraints such as funding or property acquisition, but this approach can result in a sudden change in cross section where a newly constructed section ends and the original road cross section is encountered.

Another example could occur through signalized intersections, where the number of traffic lanes is increased or decreased over a comparatively short section of road, for operational and/or capacity reasons. A similar situation can also temporarily exist where a construction detour is introduced with narrower cross section dimensions than the preceding section of road.

Other examples that violate driver's expectancy involve tangential exits and narrow bridges.[3] A tangential exit at the point of curve may cause a driver to be 'pulled-off' the road by following the straight road alignment into the exit. A similar situation is a tangential roadside feature (for example, utility poles) that causes the driver to follow the road feature inadvertently.

Narrow bridges, where the width of the preceding section of road is not reduced, also represent an expectancy violation for the driver. This is especially true when the bridges are located on curves or dips, where they are difficult to perceive.

In these circumstances, the designer should do everything possible to mitigate the impact of the unexpected features or realign the road to eliminate the inconsistency. For example, cross section change should be introduced gradually, with tapers as long as practically possible, and advance signing should be used to warn approaching drivers of what to expect.

1.4.3 OPERATING SPEED CONSISTENCY

The safety of a road is closely linked to variations in the speed of vehicles travelling on it. These variations are of two kinds:

1. Individual drivers vary their operating speeds to adjust to features encountered along the road, such as curves, intersections, and accesses in the alignment. The greater and more frequent are the speed variations, the higher is the probability of collision.

2. Drivers travelling substantially slower or faster than the average traffic speed have a higher risk of being involved in collisions.

A designer can therefore enhance the safety of a road by producing a design that encourages operating speed uniformity.

As noted in the discussion of speed profiles in Chapter 1.2, simple application of the design speed concept does not prevent inconsistencies in geometric design. Traditional North American design methods have merely ensured that all design elements meet or exceed minimum standards, but have not necessarily ensured operating speed consistency between elements.

Practices used in Europe and Australia have supplemented the design speed concept with methods of identifying and quantifying geometric inconsistencies in horizontal alignments of rural two-lane highways. In addition, recent research work in Canada and the United States has addressed design consistency for combined (horizontal and vertical) alignments. The focus of this work is on two-lane rural highways. These methods have not been perfected, particularly in predicting the performance of a newly designed road. Their effectiveness is greater in evaluating existing roads and identifying priority improvements to reduce collision rates.

1.4.3.1 Prediction of Operating Speeds

In order to establish consistency of highway alignment design for a proposed new road, it is necessary to predict operating speeds associated with different geometric elements, including isolated horizontal and vertical curves, and horizontal-vertical curve combinations. Limited information for Canadian conditions is generally available to assist designers with predicting operating speed, but the material presented in this chapter may help, noting the limited database used. As an alternative, some jurisdictions have local data on which to base speed predictions.

Two distinct approaches to the assessment of operating speed design consistency are presented here.

- The first – based on research carried out in the US – considers only the horizontal alignment, and as a result, is somewhat simpler to apply, but has been shown to provide consistent and relevant results. This method may have its best application at the planning and preliminary design stages, when the vertical alignment may not be well defined. It may also have good application at the detailed design stage in situations of relatively flat (non-rolling, non-mountainous) terrain. Software is available to assist in this type of design consistency analysis.

- The second – also based on US data – considers both horizontal and vertical alignment. It is somewhat more complex to apply, but has also been shown to provide consistent and relevant results. This approach may be most applicable at the detailed design stage when the vertical alignment is well defined, and where the terrain is rolling or mountainous. In such areas - where elevation changes are substantial - this technique may provide somewhat more realistic predictions of operating speed than the method noted immediately above.

Both methodologies have merit and are deemed to be applicable in the Canadian road design context.

Horizontal alignment approach: Introduction

In this approach, researchers collected data from five US states, measuring 85th percentile operating speeds, under free flowing traffic conditions, on long tangents and horizontal curves on rural two-lane highways. Long tangents (250m or more) are those lengths of straight road on which a driver has time to accelerate to the desired speed before approaching the next curve. The mean 85th percentile speed on long tangents was found to be 99.8 km/h on level terrain and 96.6 km/h in rolling terrain. It was noted that these speeds were probably constrained by the 90 km/h posted speed in force at the time.

On horizontal curves, the research found consistent disparities between 85th percentile speeds, with the greater disparity on tighter radius curves. The 85th percentile speed exceeded the design speed on a majority of curves in each 10 km/h increment of design speed up to a design speed of 100 km/h. At higher design speeds, the 85th percentile speed was lower than the design speed.

Using regression techniques, a relationship was found between 85th percentile speeds and the characteristics of a horizontal curve.

$$V_{85} = 102.45 + 0.0037L - (2741.75 + 1.75L) / R \quad (1.4.1)$$

Where V_{85} = 85th percentile speed on curve (km/h)

L = length of curve (m)

R = radius of curvature (m)

Speed Profile Model 1: The technique

The findings outlined in Subsection 1.4.3.1 support the conclusion that there is no strong relationship between design speed and operating speed on horizontal curves. Consistency of horizontal alignment design cannot therefore be assured by using design speed alone. A further check can be carried out by constructing a speed profile model, using predicted 85th percentile operating speeds for new road and measured 85th percentile speeds for existing roads.

For the predictive model, it is necessary to calculate the critical tangent length between curves as follows:

$$TL_c = \frac{2V_f^2 - V85_1^2 - V85_2^2}{25.92\,a} \quad (1.4.2)$$

Where: TL_c = critical tangent length (m)

V_f = 85th percentile desired speed on long tangents (km/h)

$V85_n$ = 85th percentile speed on curve n (km/h)

a = acceleration/deceleration rate, assumed to be 0.85 m/s^2

The calculation assumes that deceleration begins where required, even if the beginning of the curve is not yet visible.

Each tangent is then classified as one of three cases, as shown on Figure 1.4.3.1, by comparing the actual tangent length (TL) to the critical tangent length (TL_C).

Having found the relationship between each tangent length (TL) and the critical tangent length (TL_C), the equations in Table 1.4.3.1 can then be used, as appropriate, to construct the speed profile model.

The speed profile model is used to estimate the reductions in 85th percentile operating speeds from approach tangents to horizontal curves, or between curves. Designers should note that the research[6,9] on which the model is based dealt only with two-lane rural highways. The same principles, however, can be applied to design of other classes of roads.

Horizontal and vertical alignment approach: Introduction

In this approach, researchers[4] collected data in six states at 176 sites, again measuring operating speed (85th percentile speed) for different types of curves on two-lane rural highways, and developing regression equations predicting 85th percentile speeds for passenger cars for most combinations of horizontal and vertical curves. The significant difference in this research, was the inclusion of vertical alignment characteristics in the predictive equations.

Table 1.4.3.1 summarizes the regression equations for various types of curves. The radius was the only significant variable in predicting operating speed for all alignment combinations that included a horizontal curve on grade. The best form of the independent variable in regression equation is $1/R$, where R is curve radius.

Operating speeds on horizontal curves are very similar to speeds on long tangents when the radius is greater than about 800 m. When this condition occurs, the grade of the section may control the selection of operating speed and the contribution of the horizontal curve radius is negligible. For radii less than 800 m, operating speeds decrease as the radius decreases, and drop sharply when the radius is less than about 250 m.

For horizontal curve combined with either sag curve or crest curve with limited sight distance (LSD), the radius of the horizontal curve was the best predictor of speed. For nonlimited sight distance (NLSD) crest curves combined with horizontal curves, the lower of the speed predicted using the equation for horizontal curves on grades or the desired speed should be used.

For LSD crest curve on horizontal tangent, operating speed is predicted using the rate of vertical curvature as the independent variable. The best form of the independent variable in the regression equation is $1/K$, where K is rate of vertical curvature.

The regression equations for vertical curves are based on data collected on crest vertical curves with initial upgrades followed by downgrade and sag vertical curve with initial downgrades followed by upgrades. Although these are the typical vertical curves, other types of crest and sag curves exist and it is assumed that they have similar speed relationships. Where available, local data for these types of curves should be used.

The analysis[4] found that the use of spiral curves did not result in a significant difference in speed compared with similar sites without spirals.

In addition, the analysis indicated that the trend for trucks and recreational vehicles is generally similar to that for passenger cars. Therefore, a design consistency evaluation based on passenger cars is recommended.

Speed-Profile Model 2: The technique

The model used in this approach for establishing the speed profile along a continuous alignment involving both horizontal and vertical geometry is shown in Figure 1.4.3.1. The supporting equations are presented in Table 1.4.3.2. The model is based on earlier research work[5] and subsequent modifications.[6]

The speed-profile model uses the operating speeds predicted in Subsection titled Horizontal and Vertical Alignment: Introduction on page 1.4.3.2 for individual curves to determine the operating speeds on the speed-change (acceleration and deceleration) segments between the curves. The speeds are then used to establish the speed profile along the road and evaluate design consistency.

The process involves the following four steps:

- Selecting a desired speed along the roadway.
- Predicting an operating speed for each curve.
- Calculating operating speeds on speed-change segments.
- Evaluating the design consistency.

Step 1: The desired speed, V_f, is the speed which drivers select when not constrained by the grade on a horizontal or vertical curve. The speeds observed on long tangents can serve as an assumed desired speed. A long tangent is one that is long enough for the driver to accelerate to, and for some distance sustain, a desired speed. The 85^{th} percentile speed observed on long tangents of two-lane rural highways ranges from 94 to 104 km/h. Therefore, a rounded value of 100 km/h is a good estimate for the desired speed on long tangents of two-lane rural highways with a speed limit of 90 km/h.

Step 2: The operating speeds for various types of curves are predicted using the equations of Table 1.4.3.1. These speeds correspond to the midpoint of the curve. Based on a study in Canada for combined alignments,[7] operating speeds at the point of curve (PC) and the point of tangent (PT) were found to be greater than the speed at the middle point for both horizontal curve-sag curve and horizontal curve-crest curve combinations. The average difference was about 2.0 km/h. This value is recommended for estimating operating speeds at the beginning and end of the combined curves.

For isolated horizontal curves, a constant speed along the curve is assumed because data have not shown a defined pattern of how speed varies through the curves.[5] If the predicted speed on a curve is greater than the desired speed, the desired speed should be used.

Step 3: Calculation of the operating speed on speed-change segment, *TL*, involves determining the following:

- Length of road for acceleration from curve *n* speed to desired speed, X_{1a}
- Length of road for deceleration from desired speed to curve *n+1* speed, X_{1d}
- Length of road for deceleration from curve *n* speed to curve *n+1* speed, X_{2d}
- Length of road for acceleration from curve *n* speed to curve *n+1* speed, X_{3a}
- Critical length of road needed to accommodate full acceleration and deceleration, TL_c
- Length of road available for speed changes, *TL*

The critical length for speed changes between curves, TL_c, is the distance required to accelerate from a curve speed to the desired speed and then decelerate to the next curve speed. Thus,

$$TL_c = X_{1a} + X_{1d} \qquad (1.4.1)$$

As noted in Table 1.4.2.2, the distances X_{1a} and X_{1d} are functions of the 85^{th} percentile speeds on curves *n* and *n+1*, V_n and V_{n+1} (km/h), respectively [predicted in Subsection titled Horizontal and Verticval Alignment: Introduction on page 1.4.3.2], V_f, *a*, and *d*, where *a* = acceleration rate (m/s^2) and *d* = deceleration rate (m/s^2). Values of *a* and *d* equal to 0.54 m/s^2 and 1.00 m/s^2, respectively, are assumed. These values represent the comfortable, observed levels on two-lane rural highways.

The speed-change segment, *TL*, is a critical component of the speed-profile model. In the case of an alignment with no vertical curves, *TL* is simply the tangent distance between PT of one horizontal curve and PC of the next curve. For combined alignments, however, *TL* is the distance between the speed-limiting curves shown in Table 1.4.3.1. These curves are the horizontal curves (whether on tangents or combined with vertical curves) and the LSD crest curves on horizontal tangents.

The findings to date[4] demonstrate that speed on NLSD crest curves on horizontal tangents and sag curves on horizontal tangents is not substantially influenced by the characteristics of the curve. Therefore, these types of vertical curves should be included in the length of road available for speed changes. The operating speed on these curves equals desired speed.

By comparing the actual speed-change length *TL* and the critical length TL_c, and curve speeds V_n and V_{n+1}, each length of speed-change segment is classified as one of the five cases shown in Figure 1.4.3.1.

Note that in Case 2b, when the actual length equals X_{2d}, the driver will decelerate at the assumed value of 1.00 m/s^2. When the actual length is less than X_{2d}, the driver will have to use greater deceleration to reach the speed of the next curve. In this case, the designer should ensure that the resulting deceleration rate (*d’* in Table 1.4.3.2) does not exceed the maximum practical rate (2.0 m/s^2).

Similarly, in Case 3b when the actual length equals X_{3a}, the driver will accelerate at the assumed value of 0.54 m/s^2. When the actual length is less than X_{3a}, a driver may use higher acceleration rate than the assumed rate to reach the predicted curve speed V_{n+1} or will enter the next curve at a speed, V_{n+1}^{a}, lower than that predicted by the regression equation. It would be unusual for a driver to accelerate past the comfortable rate simply because of the geometry. Therefore, the adjusted speed V_{n+1}^{a} should be used in establishing the speed profile.

Step 4: To evaluate design consistency, the speed profile established in the previous step is used to estimate the reductions in 85th percentile speeds between speed-change segment and horizontal curves, or between curves. Large differences in operating speeds of successive elements would indicate that inconsistencies exist in the alignment.

Some studies[18] suggested that a difference of 10 km/h or less represents good design and a difference between 10 km/h and 20 km/h represents fair design. A difference greater than 20 km/h indicates the need for improvement. The research to date illustrated that predicting operating speed for combined alignments is complex, and requires further studies.

Horizontal and Vertical Model Special Aspects

The speed-profile model assumes that deceleration begins where required, which implies that sight distance is always large enough for the beginning of the next curve to be visible. The model also assumes that all acceleration and deceleration take place before or after the speed-limiting curve.

In some situations, the speeds predicted with the regression equations are higher than the assumed desired speed on the tangent. For consistency within the speed-profile model, the maximum speed on curves should be set equal to the desired speed on the tangent.

The smallest radius in the field data used for developing operating speed equations was 100 m. For smaller radii, the regression may produce very small or negative speeds. Therefore, when the radius of a horizontal curve is less than 100 m, set the speed equal to 60 km/h.

Overlapping horizontal and vertical curves require special attention. If the curves completely or significantly overlap, then they represent a single element for which one of the regression equations is used to predict speed. If the curves partially overlap, the designer should make a judgement regarding whether the overlapped curves should be treated as two or more adjacent elements. For example, if a vertical curve begins after PC and ends before PT, three predicted speeds will result from this alignment configuration. A suggested method is to use the lowest speed predicted for any condition throughout the horizontal curve.

Figure 1.4.3.1 Variable Definitions for Speed-Profile Model

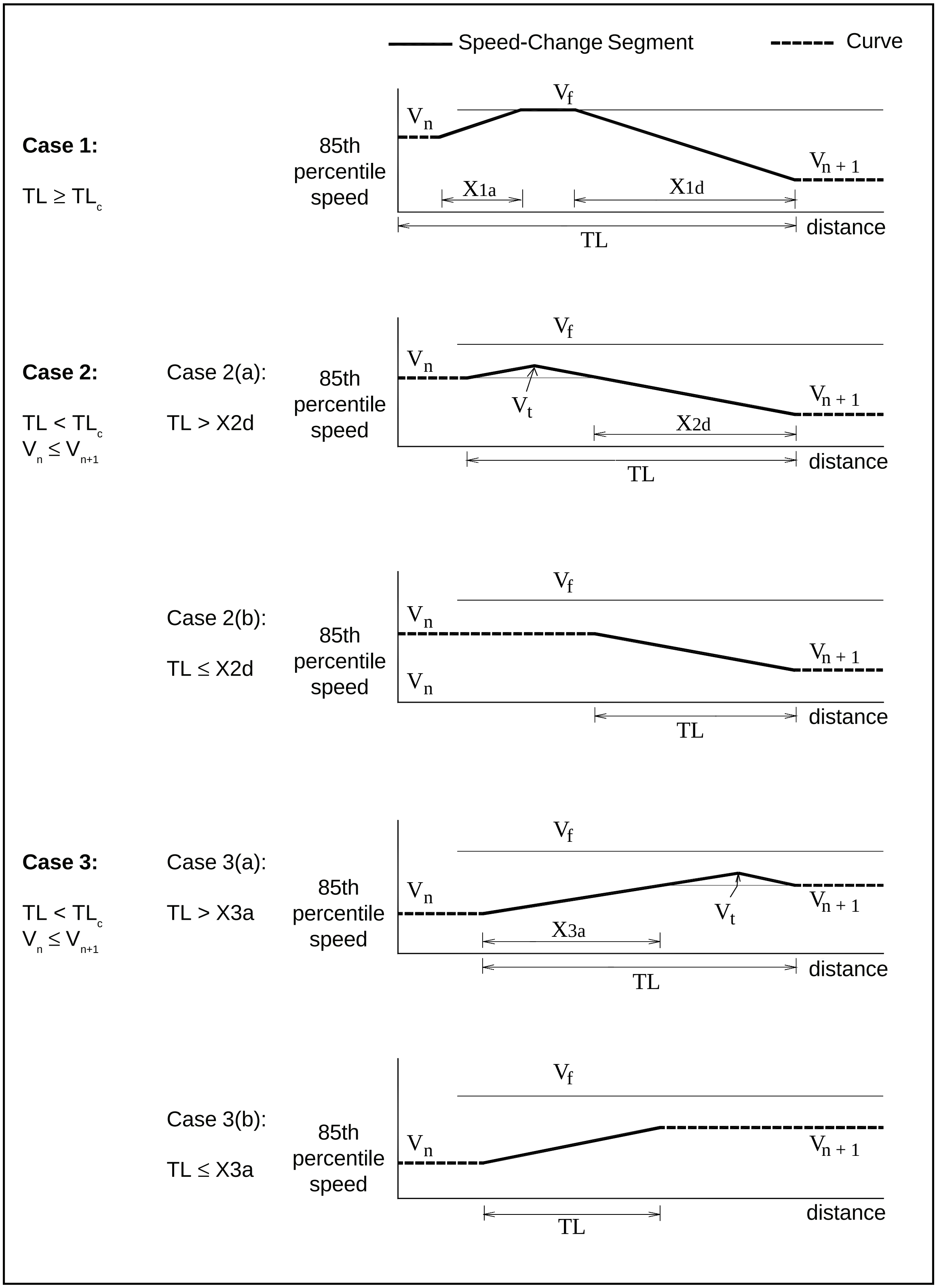


Table 1.4.3.1 Equations for Estimating Operating Speed on Various Types of Speed-Limiting Curves[5]

Type	Alignment Condition	Equation[a]
1	Horizontal curve on grade: -9% ≤ G < -4%	$V_{85} = 102.10 - \frac{3077.13}{R}$
2	Horizontal curve on grade: -4% ≤ G < 0%	$V_{85} = 105.98 - \frac{3709.90}{R}$
3	Horizontal curve on grade: 0% ≤ G < 4%	$V_{85} = 104.82 - \frac{3574.51}{R}$
4	Horizontal curve on grade: 4% ≤ G < 9%	$V_{85} = 96.91 - \frac{2752.19}{R}$
5	Horizontal curve combined with sag vertical curve	$V_{85} = 105.32 - \frac{3438.19}{R}$
6	Horizontal curve combined with non limited sight distance crest vertical curve	-[b]
7	Horizonal curve combined with limited sight distance crest vertical curve (i.e., K ≤ 43m/%)[c]	$V_{85} = 103.24 - \frac{3576.51}{R}$
8	Vertical crest curve with limited sight distance (i.e., K > 43 m/%) on horizontal tangent	$V_{85} = 105.08 - \frac{149.69}{K}$

[a] V85 = 85th percentile speed of passenger cars (km/hr), K = rate of vertical curvature, R = radius of curvature (m), and G = grade (%).
[b] Use lowest speed of the speeds predicted from Type 1 or 2 (for the upgrade) and Type 3 or 4 (for the downgrade).
[c] In addition, check the speed predicted from Type 1 or 2 (for the upgrade) and Type 3 or 4 (for the downgrade) and use the lowest speed. This will ensure that the speed predicted along the combined curve crest vertical curve results in a higher speed.

Table 1.4.3.2 Equations for Speed-Profile Model

Case and Condition	Sub-Condition	Equation[a]
Case 1: $TL \geq TL_c$	N.A.	$X_{1a} = (V_f^2 - V_n^2)/25.92\ a$ $X_{1d} = (V_f^2 - V_{n+1}^2)/25.92\ d$ $TL_c = X_{1a} + X_{1d}$
Case 2: $TL < TL_c$ $V_n {}^{3} V_{n+1}$	Case 2(a) $TL > X_{2d}$	$X_{2d} = (V_n^2 - V_{n+1}^2)/25.92\ d$ V_t = {Vn2 + 25.92 [ad/(a + d)] (TL – X2d)} $^{1/2}$
	Case 2(b) $TL \leq X_{2d}$	For $TL < X_{2d}$, d' + $(V_n^2 - V_{n+1}^2)$ (25.92 TL)
Case 3: $TL < TL_c$ $V_n \leq V_{n+1}$	Case 3(a) $TL > X_{3a}$	$X_{3a} = (V_{n+1}^2 - V_n^2)/25.92\ a$ $V_t = \{V_{n+1}^2 + 25.92\ [ad/(a + d)]\ (TL - X_{3a})\}^{1/2}$
	Case 3(b) $TL \leq X_{3a}$	For $TL < X_{3a}$, $V_{n+1}^{a} = [V_n^2 + 25.92\ a\ TL]^{1/2}$

[a] V_n and V_{n+1} = 85[th] percentile speeds for curve n and n+1 (predicted using equations in Table 1.4.2.1)

1.4.4 DRIVER WORKLOAD CONSISTENCY

Driver workload represents the demands placed on a driver by the road. If the workload a driver experiences drops too low or rises too high, the collision rate can increase. If workload is too low, for example on long straight, flat stretches of road in a rural setting, drivers may become bored or tired. Their responses to unexpected situations may then be inappropriate or slow. At the other end of the scale, drivers may become confused by situations that require very high workload, such as fast-moving, heavy traffic in an urban setting that presents a plethora of signs and advertisements or construction work zones. In these situations drivers may overlook or misinterpret an unexpected occurrence and either not respond until too late or respond inappropriately.

Driver workload quantifies the criticality of individual features and the interacting effects of combination of features along road alignment. Consistent road geometry allows a driver to predict the correct path while using very little visual information processing, thus allowing attention to be dedicated to navigation and obstacle avoidance.

Some general principles have been established that should be considered when an unusual design feature or combination of features is being contemplated[11]. Abrupt increases in driver workload increase collision potential. Such increases can be caused by:

- The criticality of the feature being approached (an intersection or lane drop is more critical than a change in shoulder width, for example)
- Limited sight distance on the feature
- Dissimilarity of the feature to the previous feature (that might cause surprise to the driver)
- Large percentages of drivers unfamiliar with the road (for example, on a major arterial as opposed to a local road)
- A high demand on the driver's attention after a period of lesser demand (for example, a sharp curve at the end of a long stretch of straight road).

Situations where most or all of these factors are encountered simultaneously should be avoided.

Various methods[8,11,12,13,14,15] have been proposed by which driver workload can be used to evaluate design consistency, however these research approaches have yet to mature to the point where they can be considered to be sufficiently robust for application in the design environment.

1.4.5 SAFETY AND CONSISTENCY

As noted in Chapter 1.2, there is evidence that the risk of a collision is lowest near the average speed of traffic and increases for vehicles travelling much faster or slower than the average speed. While this is true in relation to the general distribution of speeds in a stream of traffic, it has also been found to apply when there is a variation in speed caused by the effects of reduction in speed from one geometric design element to the next.

This particular form of speed variation may be experienced in situations such as the transition from a tangent to a curve, or between curves. In the first of the design consistency research projects previously mentioned, researchers found that the mean collision rate increased in direct proportion to the mean speed difference caused by the transition from one geometric element to the other. The results are noted in Figure 1.4.5.1[1].

The numerical values from Figure 1.4.5.1 should be used with caution, because of the database used. However, the principles show the effect of a lack of horizontal alignment consistency on increasing collision potential. Figure 1.4.5.1 should not be interpreted to mean that collision rate decreases as speed decreases.

In the second research study mentioned earlier, researchers[4,10] found that the number of collisions that occurred on a horizontal curve in a three year period increased exponentially with the increase in the speed reduction (SR) caused by the transition from one geometric element to the next (Figure 1.4.5.2)[2].

The collision rate also increased in direct proportion to the exposure, M. The exposure was defined as the product of curve length (m) and AADT (veh/day) during a three-year period, a common exposure measure for road sections. The exposure is expressed in terms of millions of vehicle-kilometres of travel.

The results of Figure 1.4.5.2 show that the predicted collision experience is clearly sensitive to speed reduction on a horizontal curve. This sensitivity lends support to the use of speed reduction estimates as a design consistency measure.

Similar caveats apply to Figure 1.4.5.2 as were noted for Figure 1.4.5.1 – including the fact that the numerical values from Figure 1.4.5.2 should be used with caution, because of the database used. Wherever possible, designers should use local data.

Figure 1.4.5.1 Mean Collision Rate versus Mean Speed Difference between Geometric Elements[9]

(i.e. reduction in speed from one geometric element to the next, e.g. tangent to curve)

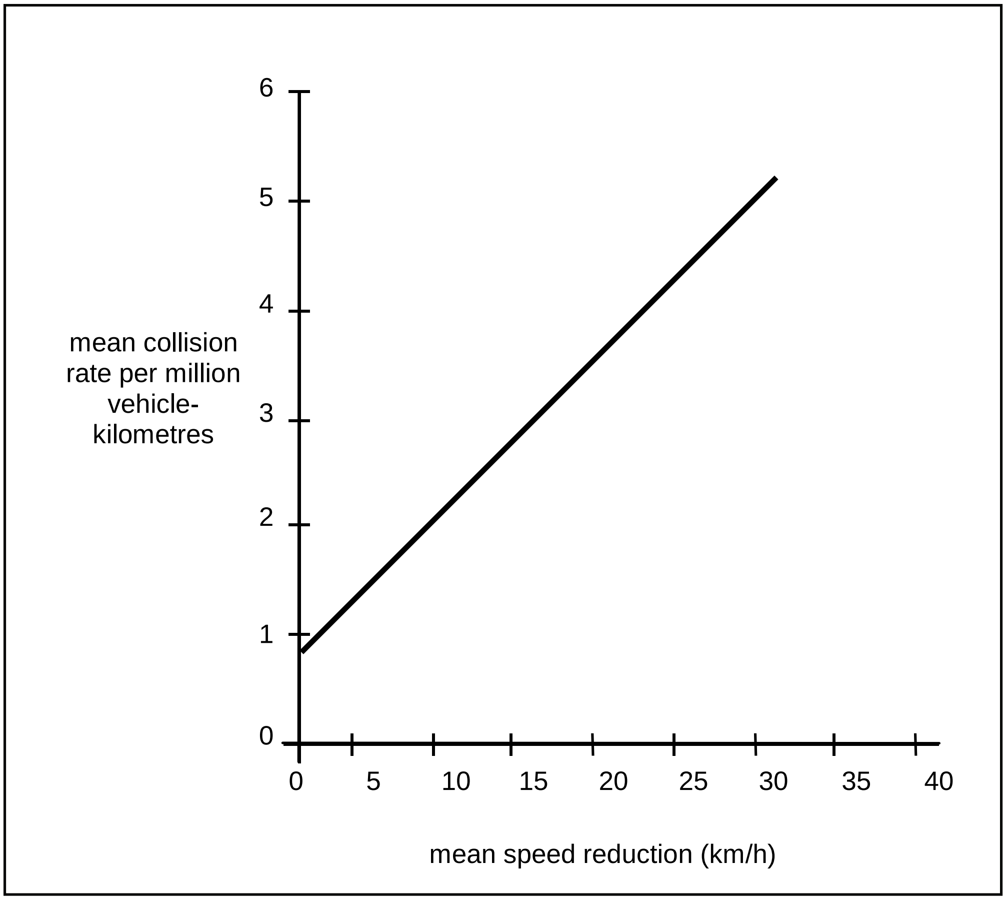
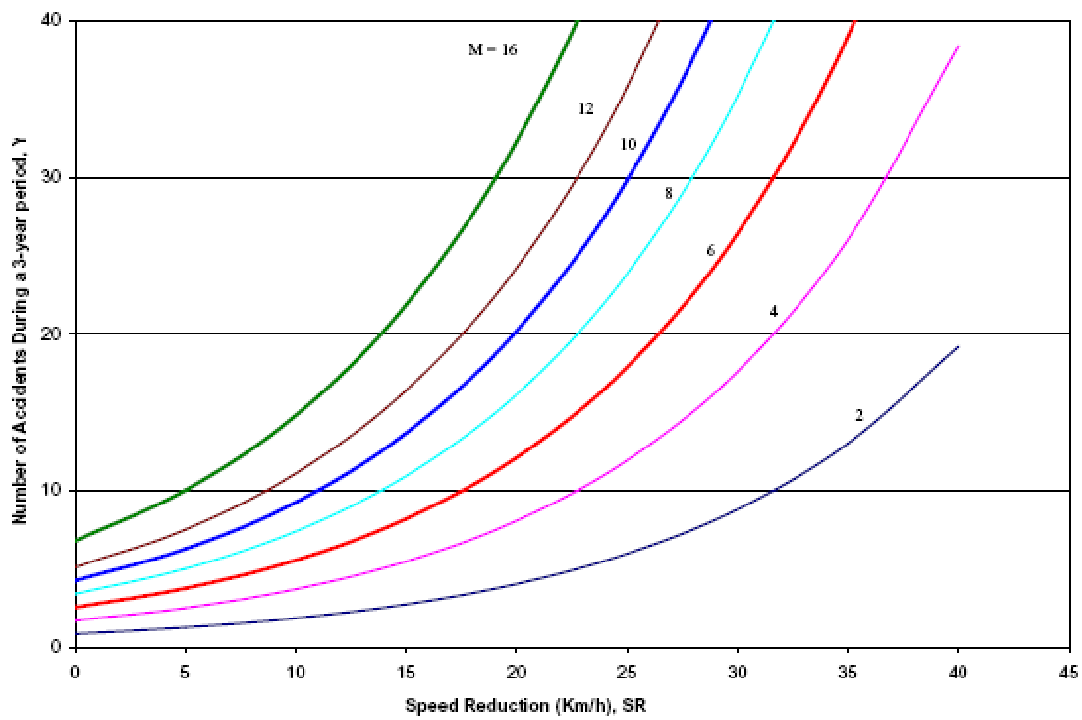


Figure 1.4.5.2 **3-year Collision Frequency versus Mean Speed Reduction Between Geometric Elements**
Y = exp(-0.8571) M exp(o.0780 SR)



M = million veh-km of travel during a 3 year period

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Transportation Association of Canada

Geometric Design Guide for Canadian Roads

Part 2

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The Transportation Association of Canada is a national association with a mission to promote the provision of safe, secure, efficient, effective and environmentally and financially sustainable transportation services in support of Canada's social and economic goals. The association is a neutral forum for gathering or exchanging ideas, information and knowledge on technical guidelines and best practices. In Canada as a whole, TAC has a primary focus on roadways and their strategic linkages and inter-relationships with other components of the transportation system. In urban areas, TAC's primary focus is on the movement of people, goods and services and its relationship with land use patterns.

L'ATC est une association d'envergure nationale dont la mission est de promouvoir la sécurité, la sûreté, l'efficience, l'efficacité et le respect de l'environnement dans le cadre de la prestation de services financièrement durables de transport, le tout à l'appui des objectifs sociaux et économiques du Canada. L'ATC est une tribune neutre de collecte et d'échange d'idées, d'informations et de connaissances à l'appui de l'élaboration de lignes directrices techniques et de bonnes pratiques. À l'échelle du pays, l'Association s'intéresse principalement au secteur routier et à ses liens et interrelations stratégiques avec les autres composantes du réseau de transport. En milieu urbain, l'Association s'intéresse non seulement au transport des personnes et des marchandises, mais encore à la prestation de services à la collectivité et aux incidences de toutes ces activités sur les modèles d'aménagement du territoire.

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