Appendix B

Design Controls and Elements of Design

Appendix B — Design Controls and Elements of the Design

Background

Many considerations influence the determination of the design for highway reconstruction projects. They include the intended function of the road (based in part on approved land management plans), the volume and type of vehicles to be accommodated, the type of terrain traversed, environmental constraints, the capabilities of the typical driver using the facility, and the desired user experience. The American Association of State Highway and Transportation Officials (AASHTO) has developed these considerations into a comprehensive matrix of design guidelines that represent current industry practice in their publication entitled *A Policy on Geometric Design of Highways and Streets* (AASHTO 2001). This publication is commonly referred to as the "Green Book." The policy is a compilation of guidelines based on established engineering practices and recent research developed through the continuing work of long-standing committees made up of the leading highway engineering professionals nation-wide. The intent of the policy is to provide guidance to the highway designer by referencing a recommended range of design values for various types of highways, ranging from local roads to interstate freeways, and for various types of conditions. The compendium of design values and guidelines in the Green Book are commonly referred to as design standards. The term "design standards" is not intended to connote a rigid set of design criteria for all conditions, superceding the need for application of sound engineering principles by a knowledgeable design professional. The recommended ranges in design values allow for flexibility to that can be exercised by an experienced engineering professional in the selection of the applicable design standards to be used applied under a specific set of conditions for a particular road.

The WYDOT and the FHWA have adopted the policy as a basis for making design decisions. FHWA regulations contained in 23CFR625 require that federally funded roads not on the National Highway System, such as the Beartooth Highway (U.S. 212), must be designed constructed, and maintained to state standards. The NPS and the FHWA have adopted a separate document, *Park*

Road Standards, 1984, as the policy for making design decisions on National Park Service roads.

When selecting design standards for any type of highway, the design should strive for the highest practical level of performance, within economic and environmental constraints, to allow for a margin of error in the design assumptions, provide additional tolerance for unanticipated conditions, and extend the function and service life of the facility. The roadway should provide a design and environment consistent with the driving tasks required. Design consistency is recognized as critical to safety and operations, and is defined in the AASHTO publication *Highway Safety Design and Operations Guide, 1997* as "the avoidance of abrupt changes in geometric features for contiguous highway elements and the use of design elements in combinations that meet driver expectations." Design consistency is best achieved by selecting design criteria for all critical elements (roadway width, design speed, gradient) on a corridor rather than individual location basis. Drivers' experiences with the highway, roadside, and operational features (intersections, pullouts, signs, markings) along the road are the factors that establish their expectations and influence their behavior. Consistent highway design is extremely important to drivers because through past experiences they have learned how to react to common situations. Drivers will react in a consistent manner to familiar situations; conversely, if drivers experience new situations or situations they are not expecting, their responses are delayed and can be improper or detrimental. Inconsistencies in the design of such features as highway alignment, roadway width (including shoulders), intersection layout, roadside access and roadside hardware (such as signs, guardrail) violate driver expectations and contribute to indecision or error. Coordinating the various design elements and roadway features to the driver's expectations and avoiding abrupt changes in the design criteria greatly supports the driving task. Driver's expectations for the Beartooth Highway have been largely established by the design of previous reconstruction projects along the route. While consistency with the previous projects was used as a base, a goal of this project was to balance the needs of the driver and the design criteria with other constraints, such as avoidance of wetlands, preservation of the scenic character and special viewsheds, preservation of natural landforms and historic features, and consideration of adjacent land uses which are unique to this section of highway.

BEARTOOTH HIGHWAY DESIGN STANDARDS

The basic elements of highway design standards are separated in the Green Book into highway functions, design controls and criteria, elements of design, and cross-section elements. For ease of understanding the sections, elements of design and cross-section elements, have been combined into the heading of design features in this text.

Functional Classification

The first step in the transportation planning process is to determine the functional classification of the roadway. Functional classifications group streets and highways according to the character of service they are intended to provide. The first step in functional classification is to define the roadway as urban or rural. The Beartooth Highway is located within a rural area. Both urban and rural roads are separated into classifications of arterials, collectors, and local roads. The Green Book states:

> "Arterials are expected to provide a high degree of mobility for the longer trip length. Therefore,,, they should provide a high operating speed and level of service.

> Since access to abutting property is not their major function, some degree of access control is desirable to enhance mobility. The collectors serve a dual function in accommodating the shorter trip and feeding the arterials. They should provide some degree of mobility and also serve abutting property. Thus an intermediate design speed and level of service is appropriate. Local roads and streets have relatively short trip lengths, and because property access is their main function, there is little need for mobility or high operating speeds. This function is reflected by use of a lower design speed and level of service."

Using the Green Book criteria the Beartooth Highway is classified as a rural minor arterial. According to the Green Book rural minor arterials provide a link among cities, larger towns, and other traffic generators (such as major resort areas) and are capable of attracting travel over long distances. Rural minor arterials also integrate interstate and intercounty service. The Beartooth Highway primarily serves regional travel between Red Lodge, Montana and Yellowstone National Park, consistent with an arterial classification. The Highway also provides local access to the National Forest, primarily for recreation, which is consistent with a collector classification. This duality was considered in the selection of the range of design standards.

In addition to serving the functions discussed in the Green Book, the Beartooth Highway also carries the designations of a Scenic Byway by both Wyoming and the Forest Service. In 2000, the Beartooth Highway in Wyoming was also designated an All-American Road by the FHWA.

Design Controls and Criteria

Design controls and criteria are those characteristics of vehicles, pedestrians, and traffic that are used in the design of streets and highways. These include the existing and design-year traffic demands to be placed on the facility (e.g., daily and hourly traffic volumes, the mix of passenger cars and trucks on the facility), the design vehicle, the level of service, and the design speed. These controls establish the basic parameters used to determine the design features.

Traffic Volumes

After the functional classification, the single factor that most influences the determination of design standards is the traffic volume, generally measured as the average daily traffic (ADT). The Green Book defines the ADT "as the total volume during a given time period (in whole days), greater than one day and less than one year, divided by the number of days in that time period." Some roadways, such as the Beartooth Highway, have time periods in which the traffic is much greater than the yearly ADT, or are open only for a portion of the year. For these roadways traffic volumes are often expressed in terms of seasonal ADT or SADT.

On the Beartooth Highway traffic counts were conducted during various weeks in the summers of 1998, 1999, and 2000. The counts were then averaged to compute the current SADT for the project, which was calculated to be 942 vehicles.

The standard of practice by transportation agencies is to design a highway facility that not only meets current traffic volumes, but future volumes as well. To accomplish this the current ADT, or SADT, is projected using an estimated growth rate to the end of the predicted design period of a facility and averaged to the next five-year increment, e.g., 2020, 2025. The design period is influenced by the level of investment and long-term life cycle costs of the facility. For reconstruction projects the design period is typically 20 to 25 years. The growth rate for the Beartooth Highway was estimated to be 3% by analyzing traffic history, past population growth, and Yellowstone National Park visitor data. The projected SADT is 1,972 vehicles in 2025.

Another key measure for determining traffic volume on rural arterials is the peak hour traffic. The Green Book states, "traffic volumes for a time period shorter than one day more appropriately reflect the operating conditions that should be used for design if traffic is to be properly served." The selection of the design hourly volume (DHV) is the 30th highest hourly volume of the year, abbreviated by 30 HV. This volume meets a compromise in neither over designing nor under designing certain features of the facility. The 30 HV, or DHV, for the Beartooth Highway is 296 vehicles and was computed based on the traffic counts.

Design Vehicle

The design vehicle is the largest vehicle that is likely to use the facility with considerable frequency, e.g. multiple daily use or, over 1 percent of the total. Three general classes of design vehicles have been selected by AASHTO to represent nearly all of the vehicles using the road. They are passenger cars, trucks, and buses/recreational vehicles. The passenger car class includes all cars plus all light vehicles (such as compact SUVs), and light delivery trucks (vans and pickups). This class accounts for 95% of the traffic on the Beartooth highway. The truck class includes single unit trucks and truck tractor-semi trailer combinations. On the Montana segment of the Highway between Red Lodge and the Montana/Wyoming stateline all commercial vehicles are prohibited which eliminates almost all tractor-semi trailer combinations. The bus/recreational vehicle class includes single-unit buses, school buses, motor homes, and passenger cars or motor homes pulling trailers or boats. The last two categories make up approximately 5% of the traffic on the Beartooth Highway. Based on the traffic counts conducted on the highway roughly 3% of the vehicles are greater than 10 m (30 ft.) in length. The single-unit bus was used as the design vehicle on the route because of the number of tour buses and recreational vehicles that use the route on a daily basis. In 2025, an average of 100 buses/recreational vehicles is predicted to use the route daily.

Level of Service

The level of service is a letter value grading system used to characterize the amount of congestion. It uses the letter A to represent the least amount of congestion and F to refer to the greatest amount. The level of service is measured at the peak hour traffic volumes and only serves as a controlling factor for a small number of highways, usually in urban areas. The level of service on the Beartooth Highway was not analyzed, but meets the requirements for Level of Service A in most cases. The only cases when it does not are when vehicles cannot pass slower vehicles with little or no delay. In many portions of the Beartooth Highway, the opportunities to pass slower moving vehicles are not frequently available. This situation can be addressed through the use of passing lanes, which were considered to be impractical for this project. On the Beartooth Highway, occasional roadside pullouts can provide opportunities for very slow-moving vehicles to momentarily pull over, out of the travel lane, to let another vehicle to pass. Using highway capacity software the level of service in 2025 at all intersections was analyzed and determined to be A, by MK Centennial.

Design Speed

Design speed is an important criterion because it is used to determine critical design features such as stopping sight distance and minimum rate of curvature. The Green Book defines design speed as, "a selected speed used to determine the various geometric design features of the roadway." To determine appropriate design speeds for this project, the FHWA completed the following work: 1) a review of the Green Book criteria, 2) a spot speed study, 3) an analysis of the existing curvature, and 4) a review of previously completed projects on adjacent sections of the route.

According to the Green Book, the recommended range of speeds for a rural minor arterial is 60 to 120 km/hr (37 to 75 mph). Design speeds in the higher range, 100 to 120 km/hr (62 to 75 mph), are normally used in level terrain, design speeds of 80 to 100 km/hr (50 to 75 mph) are normally used in rolling terrain, and design speeds of 60 to 80 km/hr (37 to 50 mph) are used in mountainous terrain.

For comparison, the 1984 Park Road Standards recommends a preferred design speed of 72 km/hr (45 mph) in rolling terrain and 64 km/hr (40 mph) in mountainous terrain and a minimum design speed of 56 km/hr (35 mph) in rolling terrain and 48 km/hr (30 mph) in mountainous terrain, for principle park roads with daily design volume of 1,000 to 4,000 vehicles.

The analysis of the existing roadway curvature consisted of counting the number of existing curves requiring design exceptions (i.e., the radius of the existing curves were less than the minimum curvature for the design speed) for speeds ranging from 30 to 70 km/hr (19 to 44 mph) for a maximum superelevation rate of 6%. (The minimum curvature for specific design speeds is related to the rate of superelevation. See the superelevation section below for additional information.)

The curve analysis revealed two segments along the project with distinctly different existing horizontal alignment characteristics. The first is from the west end of the project to just east of Little Bear Lake. This section contains 31 curves (most are relatively flat (large radius)) and several long tangent sections. A design speed of 50 km/hr (31 mph) results in 13 percent of the total number of existing curves requiring design speed exceptions. At 60 km/hr (37 mph) there were 16 percent and at 70 km/hr (44 mph) there were 29 percent. The second section from Little Bear Lake to the east end of the project, contains a total of 82 curves, twelve of which are switchbacks, and proceeds over both the east and west summits of the Beartooth Plateau. For analysis purposes the switchbacks were excluded because they require a 30 km/hr (19 mph) design speed, which is too low to be considered for the entire project. All switchbacks will therefore be design exceptions. At a design speed of 50 km/hr (31 mph) 17 percent of the existing curves would require design speed exception. At 60 km/hr (37 mph) there were 34 percent and at 70 km/hr there were 57 percent requiring design speed exceptions.

A comparison of the curve data and the results of the spot speed study revealed that the average running speeds of vehicles using the highway closely match the design speeds (50 to 60 km/hr (31 to 37 mph)) of curves in portions of the road that represent approximately 85 percent of the project. From the west end of the project to the road closure gate the average running speed ranged from 56 to 67 km/hr (35 to 42 mph). As stated above, a design speed of 60 km/hr (37 mph) would require approximately 16 percent of the curves to be improved in order to meet the design speed criteria. In the switchbacks, vehicles have an average running speed of 30 km/hr (19 mph), which matches the design speed at those locations. From the Twin Lakes area to the east end of the project the average running speeds were 51 to 55 km/hr (32 to 34 mph). With a design speed of 50 km/hr (31 mph) from Little Bear Lake to the west end of the project, 17 percent of the curves would require improvements in order to meet the design speed criteria, or result in a design exception.

Previous projects completed along the route in the vicinity of this project were reconstructed using design speeds of 48 km/hr (30 mph) and 65 km/hr (40 mph).

Based on the information presented above a design speed of 60 km/hr (37 mph) was selected for the section of roadway from the west end of the project to Little Bear Lake and a speed of 50 km/hr (31 mph) was selected from Little Bear Lake to the east end of the project. The 50 km/hr (31 mph) design speed will be below the minimum value recommended by the Green Book, and will be an exception to the design standards. Alignments have been generated which meet the design criteria along the entire length of the project, except at switchback locations where the roadway could not be practically realigned (i.e. without realignment of extensive portions of the route on to entirely new locations). Alternatives have been developed in several locations using criteria for various design speeds, which result in alignments that deviate from the existing roadway. For example, at the Beartooth Ravine area, alternatives for design speeds of 40 km/hr (25 mph), 50 km/hr (31 mph), and 60 km/hr (37 mph) have been developed. (See the alternatives section for more information.)

DESIGN FEATURES

Design features are elements of the roadway that define the physical characteristics of the roadway section and much of the requirements for the horizontal and vertical alignment. Design features are primarily determined using the established criteria (functional classification, ADT, design speed, etc.) that have been discussed previously. In the Green Book, guidelines for the selection of design criteria are provided for each functional classification. There are thirteen specific controlling criteria that are established for a highway design. Only eleven of these criteria are applicable to this project. (Two of them, vertical clearance and horizontal clearance are related to tunnels and overpasses and do not apply.) These criteria are the features that are the most critical in designing a safe roadway that meets the needs of the highway users. These criteria include design speed (discussed previously), lane width, shoulder width, bridge width, structural capacity, rate of horizontal curvature, rate of vertical curvature, grade, stopping sight distance, cross slope, superelevation, vertical clearance, and horizontal clearance (not including clear zone).

Travel Lane Width

The travel lane width is defined as the portion of the roadway provided for the movement of vehicles, exclusive of the shoulders. It is usually identified on the roadway as the location between the yellow centerline stripe and the white edge line. The minimum roadway width for arterial highways is primarily dependent on the design traffic volume, the design speed, and the mix of vehicle size and use. The Green Book provides guidelines for two lane widths on rural arterials. For an SADT between 1500 and 2000 vehicles and a design speed of 60 km/hr (37 mph) it recommends a minimum lane width of 3.3 m (11 ft.). Adjacent sections of the Beartooth Highway that have been reconstructed have travel lane widths of 3.6 m (12 ft.). For comparison, the 1984 Park Roads

Standards, recommends a travel lane width of 3.3 m (11 ft.) for ADTs of 1,000 to 4,000 vehicles, except where tour buses are allowed or the proportion of recreation vehicles exceeds 5 percent of the design volume, additional travel lane width of 3.6 m (12 ft.) should be considered. Approximately 5% (100 per day in 2025) of the vehicles that use the Beartooth Highway are over 5.8 m (17 ft.) in length. Vehicles of this length are typically up to 2.6 m (8.5 ft.) wide, excluding the mirrors. Including the mirrors, which extend approximately 0.3 m (1 ft.) on each side of the vehicle, the total width is 3.2 m (10.5 ft.). The remaining portion of the travel way left to accommodate movements of the large size vehicles within the travel lane is approximately 0.4 m (1 ft. 4 in.). Snow plowing activities along the Highway occur throughout the year when the highway is open. The width of a standard snow plow blade is 3.0 m (10 ft.). Taking all of the above into account, a minimum 3.6 m (12 ft.) travel lane width was selected for use on the Beartooth Highway to provide reasonably efficient and safe operation of the roadway. A travel lane width narrower than 3.6 m (12 ft.) is not considered to be sufficient to accommodate the mix of vehicles expected and meet driver expectations consistent with other sections of the Beartooth Highway.

Shoulder Width

A shoulder is the portion of the roadway adjacent to the travel lane. Adequate shoulders are needed on the Beartooth Highway for vehicles to maneuver or recover, to escape encroachment of oncoming vehicles and avoid potential crashes or reduce their severity; provide space for pedestrian and possibly bicycle traffic; accommodate temporarily stopped or disabled vehicles; improve sight and stopping distance; provide lateral clearance for signs and guardrails, provide storage space for plowed snow and maintenance operations; provide lateral support of the base and pavement; and remove drainage from the travel lanes. The Green Book recommends a shoulder width of 1.8 m (6 ft.) on rural arterials with an SADT of 1500 to 2000 vehicles and a width of 2.4 m (8 ft.) with a SADT over 2000 vehicles. For comparison, the 1984 Park Road Standards, recommends a shoulder width of 0.9 m (3 ft.) for roads with ADT of 1,000 to 4,000 vehicles. The adjacent sections of the Beartooth Highway that have been reconstructed have shoulder widths ranging from 0.6 m (2 ft.) to 1.2 m (4 ft.). When considering the shoulder width for this portion of the Beartooth Highway there are three primary considerations that have differing objectives. First the support of the roadway structural section is considered essential on this project in extending the life of the pavement during the design period. Second, minimizing the width of the shoulder would lessen the environmental impacts. Third, while bicycle use currently is minimal, comments during the scoping process indicated that the use is increasing and that it should be accommodated by constructing a wide shoulder. The minimum shoulder width suggested by the Green Book, for any use, including providing support to the structural pavement section is 0.6 m (2 ft.). The Green Book recommends the absolute minimum shoulder width necessary to safely accommodate bicyclists is 1.2 m (4 ft.). It was determined that the recommended shoulder widths in the Green Book for the anticipated SADT would not be compatible with other goals of the project and that two lesser shoulder widths should be evaluated, 0.6 m (2 ft.) and 1.2 m (4 ft.). Regardless of which shoulder width is ultimately selected for construction, a design exception to the AASHTO standards will be required.

Bridge Width

Bridges are expected to have a physical life expectancy longer than the design period for the roadway, typically up to 75 years. Due to their high initial cost, bridges are designed to accommodate traffic for a much longer period than the roadway. The Green Book recommends that the full roadway width be provided for the approach roadways across all new bridges at a minimum and that on long bridges, over 60 m (200 ft.), offsets to the parapet or rail shall be at least 1.2 m (4 ft.) measured from the edge of the nearest travel lane on both sides of the roadway. The approach roadway width is defined as the travel lanes, shoulders, and the normal offset to a roadside barrier on the roadway. For comparison, the 1984 Park Road Standards, recommends that bridges should be designed in accordance with the AASHTO standards, and that the clear widths for new and reconstructed bridges should desirably be a minimum of the traveled lane plus shoulders plus 1.2 m (4 ft.), or 0.6 m (2 ft.) on each side. On this project there are two proposed bridge structures that are longer than 60 m. The structures are identified as the Beartooth Ravine and the Fen Mitigation bridges. In addition to the 1.2 m (4 ft.) the Green Book also recommends an additional 0.6 m (2 ft.) offset from the edge of the shoulder to the face of the bridge guardrail as a safety precaution. This is also recommended in the publication titled the AASHTO Roadside Design Guide. The publication provides guidance on offsets to guardrail and other fixed object hazards such as trees. The design width for the structures on the Beartooth Highway project is selected at 11 m (36 ft.). This includes 3.6 m (12 ft.) travel lanes, 1.2 m (4 ft.) shoulders, and an additional offset width to the bridge guardrail of 0.6 m (2 ft.). This width is recommended for all alternatives. For comparison, the Lake Creek Bridge on the adjacent reconstructed section of the Beartooth Highway is 12 m (40 ft.) wide.

Structural Capacity

The structural capacity of a roadway refers to the weight that the structural elements of the road can handle. The elements include bridges, culverts, walls, and other structures along the roadway. AASHTO has established a loading system based on classes. There are four classes of highway loading: M18 (H20), (M13.5) H15, (MS18) HS 20, and MS13.5 (HS 15). These classes are designations of vehicles that will use the highway. The minimum loading for a rural arterial in the Green Book is MS18 (HS20). This load rating simulates a tractor truck with a semitrailer. While commercial vehicles (usually a truck hauling a semi-trailer) are restricted from the Beartooth Highway, other vehicles, including buses, do use the Highway and are limited by this criterion if they are to be considered a legal highway load. For this reason all structures on the Beartooth Highway will be designed for MS18 (HS20) loading.

Superelevation Rate

Superelevation is the downward slope (banking) of the roadway toward the inside of a curve. When a vehicle is moving through a curve, two main forces are acting on it: an outward radial force (centrifugal force) and a counter-acting inward radial force. The outward radial force is due to the tendency that the vehicle will travel in a straight line. The inward radial force is due to the friction between the tires and the roadway resulting from a change in direction of the vehicle. Vehicles traveling through curves at higher speeds can create a larger outward force than an inward force, especially in sharper curves (smaller radius). When the outward force exceeds the inward force the vehicle slides across the roadway. An indicator that the outward force is just exceeding the inward force is when tires squeal around corners of a paved road. When the roadway is inclined towards the center of the curve an additional force, resulting from the weight of the vehicle, is created to further counteract the outward force. In very slick conditions such as when the pavement is covered with ice and snow, the roadway slope and superelevation can cause slow-moving vehicles to slide across the roadway toward the inside of the curve. The Green Book recommends that in locations where ice and snow conditions are present, the superelevation rate should not exceed 8 percent. For highways with seasonal snow and ice conditions, the FHWA typically uses a maximum superelevation rate of 6 percent and has selected it for this project.

Rate of Horizontal Curvature (Horizontal Alignment)

The horizontal alignment consists of straight sections of road, defined as tangents, connected by horizontal curves. A curve is a segment of a circle, with a continuous defined radius. The minimum radius (i.e. the maximum rate of horizontal curvature), which can be used in the design of the highway, is determined by the established design speed and the maximum superelevation rate of the roadway. Because two design speeds were selected for use on this project there will be two minimum curve criteria selected. For the design speed of 60 km/hr (37 mph) the minimum curve radius is 135 m (440 ft.). The minimum curve radius for the 50 km/hr (31 mph) design speed is 90 m (300 ft.). There are locations along the project, such as at switchbacks, that curves will be less than the minimum curve radius. The curve radius at most switchbacks is 30 m (100 ft.), which corresponds to a design speed of 30 km/hr (19 mph). These locations will be marked with curve warning and reduced speed advisory signs as a part of the reconstruction project.

Stopping Sight Distance

The stopping sight distance (SSD), for design purposes, is the minimum sight distance required for a driver to react and stop a vehicle after seeing an object in the vehicle's path before hitting that object. The distance is the sum of the distance the vehicle travels during the time it takes the driver to identify the object and react to the object by beginning to apply the brakes, and the distance required for the vehicle to stop. The distance is based on driver performance data and the coefficient of friction of tires on wet pavements. The minimum SSD provided in the design of a roadway is defined in the Green Book dependent on the design speed of the roadway. For this project the minimum SSD is 65 m (213 ft.) at 50 km/hr (31 mph) and 85 m (279 ft.) at 60 km/hr (37 mph). Stopping sight distance is primarily used as a control in the vertical alignment, as the crest of hills and headlight illumination of the pavement at night diminish the sight distance. Stopping sight distance is also affected by the gradient of the roadway at specific locations.

Rate of Vertical Curvature (Vertical Alignment)

A vertical alignment consists of straight continuous gradients along the highway, defined as tangent grades, connected by vertical curves. The vertical curves provide a uniform transition from one tangent grade to another. There are two types of vertical curves, sag and crest. A sag vertical curve is a vertical curve with a low-point, for example when a roadway crosses a valley. A crest vertical curve is a vertical curve with a high point, for example when a roadway goes over a hill. The design controls for vertical curvature relate to how far ahead a driver can see objects. For crest vertical curves, the distance is based on the driver's eye height, 1.08 m (3.5 ft.) and the object height 0.6 m (2.0 ft.) . For sag vertical curves, the distance is based on the projection of the vehicle headlights to a point on the road surface, which is diminished in vertical curves. This criterion is expressed as the K-value. The K-value is a measure of the rate of change of the gradient over distance along the roadway in the horizontal direction. In mathematical terms it is computed by dividing the horizontal length of the vertical curve by the algebraic difference in the two tangent roadway grades it connects, which results in the rate of changing gradient. The Green Book requires a minimum K-value based on the stopping sight distance. The stopping sight distance is based on the design speed of the roadway. After the minimum stopping sight distance is established a minimum K-value is mathematically determined that provides this distance. There are two different K-values used in design of vertical alignments; one for crest vertical curves (K_{crest}) and one for sags (K_{sag}). For this project the minimum K_{crest} is 7 and the minimum K_{sag} is 13 for the 50 km/hr (31 mph) design speed. For the 60 km/hr design speed the minimum K_{crest} is 11 and the minimum K_{sag} is 18.

Grades

Grades are a measure of the vertical slope of the roadway. Grades are expressed as percent, e.g., 4 percent, 5 percent, etc, of the change in elevation in relation to the length of the roadway in the horizontal direction. The selection of maximum grades for a highway depends on the design speed, the design vehicle, the functional classification established, with consideration for operation during snow and ice conditions. The selected maximum grade should not be exceeded except possibly on very short sections, less than 150 m (500 ft.). Grades of 4 to 5 percent generally have little effect on passenger cars or trucks. As the grade increases above 5 percent both cars and trucks travel slower on uphill sections of roadway and faster on downhill sections. As the grades become steeper the effect becomes markedly greater. On very steep grades, approaching 8 percent, trucks and/or recreation vehicles traveling at very slow speeds uphill can become hazards by suddenly slowing traffic and resulting passing maneuvers. On steep downhill sections it becomes more difficult to control vehicle speed and the braking ability of the vehicle is markedly diminished. In snow and ice conditions, it is difficult to control vehicle traction when gradients exceed 9 percent on tangents and at lower gradients in horizontal curves, where superelevation is also provided. In the Green Book a maximum grade of 8 percent is recommended for arterials in mountainous terrain with a design speed of 60 km/hr (37 mph), or less. This maximum grade is selected for this project. For the majority of the project existing grades are under 6 percent. The maximum gradients in switchbacks should typically be 4 percent maximum, to facilitate braking and vehicle control.

Cross Slope

Cross slope is defined as the slope of the pavement from the centerline to the edge of the roadway on straight, or tangent horizontal alignment sections. The primary purpose of cross slope is to drain water off of the pavement surface. Two-lane rural paved roadways are normally designed with crowned (sloping downward on each side of the centerline) cross slopes ranging from 1.5 to 2 percent. The Green Book recommends a value at the upper range. For this project, a 2 percent typical cross-slope is selected.

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