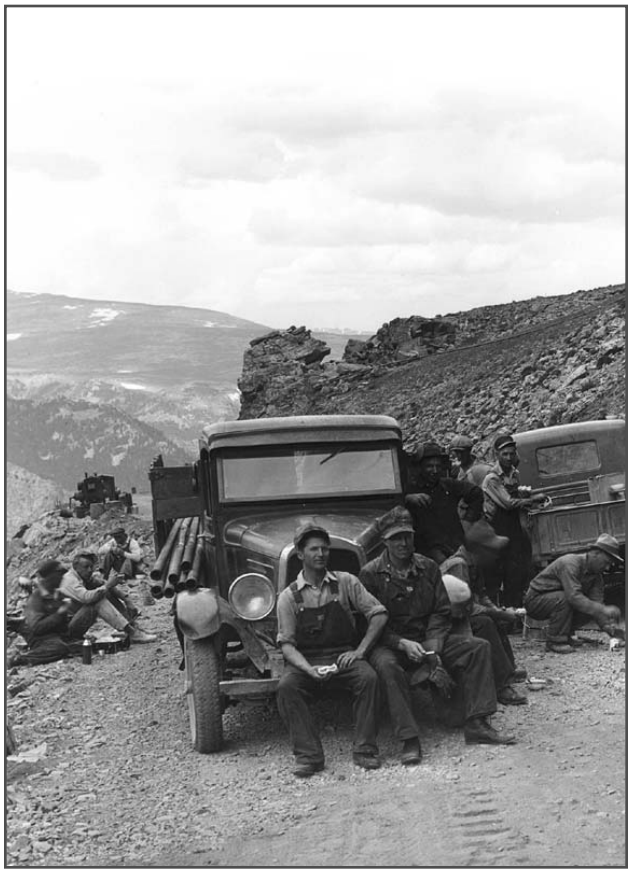
Appendix C
Design Controls and Elements of the Design



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Appendix C — 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 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. The FHWA regulations contained in 23 CFR 625 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.

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) do not fulfill 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 support 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 the proposed project is 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 that are unique to the project area.

In addition, several other design elements contribute to the dimensions of the roadway. Typical section elements, such as the foreslope and the roadside ditch area are discussed as well as the proposed guardrail installations and clear recovery areas. As previously mentioned, the applicable criteria for these features are based on AASHTO and WYDOT design standards.

When design standards cannot be met due to extraordinary cost, adverse environmental impacts, or other reasons, exceptions to a selected design criterion may be used. Typically, the engineering completed as part of this or any other EIS is preliminary in nature. After final design development, all design exceptions would be documented and provided to the maintaining agency for approval. Design exceptions identified during preliminary design are noted in bold.

Context sensitive design techniques have been investigated and applied during the development of alternatives examined in detail in the EIS. The application of these techniques would continue to be applied in final design. These techniques strive to minimize disturbances or blend the proposed design into the natural environment. The techniques include:

- Shifting alignment to affect only one side of the road
- Using existing disturbed areas
- Reducing shoulder widths
- Using design criteria exceptions
- Using paved ditches
- Using retaining walls
- Using slope exceptions
- Reducing foreslope widths
- Adjusting pullouts and parking area

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 USFS. Sections of the Beartooth Highway also are designated an All-American Road by the FHWA.

Based on comments received on the DEIS from the National Park Service, the FHWA evaluated whether segment 4 of the Beartooth Highway could be classified as a special-purpose road. Special-purpose roads are local roads, but are classified differently because of their unique character. Special-purpose roads include recreational roads, resource recovery roads, and local service roads

that are lightly traveled and operate with low traffic speeds. Special-purpose roads are intended to protect and enhance the existing aesthetic, ecological, environmental, and cultural amenities distinguishing the recreational site or area.

One type of a special-purpose road is a recreational road, which serves recreational sites and areas, and is considered to be part of the recreational experience. Visitors to a specific recreational site usually access the general area by a statewide or principal arterial highway, and then access to specific recreational site, by a recreation road classification. Recreational roads can be further categorized as primary access roads, circulation roads, and area roads in the recreation site. Primary access roads are defined as roads that allow through movement into and between access areas. Circulation roads allow movement between activity sites within an access area, whereas area roads allow direct access to individual activity areas, such as campgrounds, park areas, boat launching ramps, picnic groves, and scenic and historic sites. These types of roads are often one-way or two-way single lane roads.

The FHWA recognizes that the Beartooth Highway serves the function of providing access to adjacent recreation sites and areas. The FHWA also understands that traveling on the Beartooth Highway is considered to be a recreational experience in and of itself. However, these functions are not sufficient to classify the Highway as a special-purpose recreational road. Based on characteristics of the road and findings from the O-D Survey, which indicate that a high percentage of users were traveling the Highway to access Yellowstone National Park, the primary purpose for the Highway is to provide a link between towns, which is not the function of a special-purpose road. This primary purpose of the Highway is consistent with the original intent of the construction of the roadway, which was to provide access to the Park. In addition, the Highway primarily serves regional travel between Red Lodge, Montana and Yellowstone National Park, consistent with an arterial classification Furthermore, the projected SADT for the Highway by the year 2025 is 1,972 vehicles, which is much greater than the generally light traffic volumes typically found on special-purpose recreation roads. For these reasons, the entire Highway is classified as a rural minor arterial.

Additional consideration must be given to the fact that the segments of the highway in Montana (Segment 1) and the other segments in Wyoming (Segments 2 and 3) have been reconstructed or are proposed for reconstruction using design criteria for rural minor arterial. Additionally, the Montana Department of Transportation has classified all segments in Montana (Segments 1, 5, 6, and 7) as a rural minor arterial. Segment 4 was originally constructed to function like a rural minor arterial and should have similar design criteria based on driver expectancy between adjacent segments.

With respect to the dual function of the Highway (e.g. it acts as a through route as well as providing access to adjacent recreational facilities), this dual nature can be addressed within the range of design standards permitted by the rural minor arterial classification. The implementation of design standards combined with the incorporation of context sensitive design techniques serve to minimize the impacts to the existing aesthetic, ecological, environmental, and cultural amenities distinguishing the Highway.

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.

Traffic counts in the project area 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 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 estimate future traffic, the current ADT, or SADT, is projected using an estimated growth rate to the end of the predicted design period of a facility and rounded 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 percent by analyzing traffic history, past population growth, and Yellowstone National Park visitor data. The projected SADT is 1,972 vehicles in 2025.

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 percent of the traffic on the Beartooth Highway. The truck class includes single unit trucks and truck 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 percent of the traffic on the Beartooth Highway. This recreational traffic is typically over 5.8 m (17 ft) in length and based on the traffic counts conducted on the highway, roughly 3 percent 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 meet these requirements 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, but concluded to be impractical for the project. In the project area, 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. The level of service in 2025 at all intersections was determined to be A.

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 the 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, used for the design of roads within national parks, 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.

Segments 2 and 3 west of Segment 4 were reconstructed using design speeds of 48 km/hr (30 mph) and 65 km/hr (40 mph).

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 percent. (The minimum curvature for specific design speeds is related to the rate of superelevation. See the super-elevation section below for additional information.)

The curve analysis revealed two sections 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 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 the proposed design alignments require a 30 km/hr (19 mph) design speed, which is too low to be considered for the entire project. All switchbacks would therefore be design exceptions. At a design speed of 50 km/hr (31 mph), 17 percent of the existing curves would require a design exception. At 60 km/hr (37 mph), there were 34 percent and at 70 km/hr there were 57 percent requiring design exceptions.

A comparison of the curve data and the results of the spot speed study revealed that the average operating 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 85percent of the project. From the west end of the project to the road closure gate, the average operating 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 either exceptions or improved in order to meet the design speed criteria. Along the eastern portion of the project, in the switchbacks, vehicles have an average running speed of 30 km/hr (19 mph), which matches the design speed exception at those locations. From the Twin Lakes area to the east end of the project the average operating 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.

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 would be below the minimum value recommended by the Green Book, and would be an exception to the design standards**.

Alignments analyzed in the EIS that 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). Options 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, options 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 in this Appendix or Chapter 2 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. Thirteen specific controlling criteria are established for a highway design. Only eleven of these criteria are applicable to the proposed 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 and expectations of the highway users. These criteria include design speed (discussed previously), travel 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). Additionally, information is presented on the roadway foreslope, roadside ditches and guardrail offset to better define the required roadway widths for the project.

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.). 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. In such circumstances, a travel lane width of 3.6 m (12 ft.) is recommended. 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 snowplow blade is 3.0 m (10 ft.). Taking all of the above into account, along with the fact that adjacent sections of the Beartooth Highway that have been reconstructed have travel lane widths of 3.6 m (12 ft.), a minimum 3.6 m (12 ft.) travel lane width was selected for use on the project to provide reasonably efficient and safe operation of the roadway. A travel lane width narrower than 3.6 m (12 ft.) is not sufficient to accommodate the mix of vehicles expected and meet driver expectations consistent with other sections of the Beartooth Highway.

In addition, travel lane widening is needed along certain curves because the rear wheels generally track inside the front wheels (offtracking) causing the design vehicle to require a wider travel lane than the width of the vehicle itself. AASHTO specifies the widening necessary for curves based on the design vehicle, curve radius, roadway width, and the design speed. On simple curves, this widening is applied on the inside edge of the traveled way only. On curves with spiral transitions, widening is divided equally on either side of the centerline. Curve widening would be transitioned over the superelevation runoff length.

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 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.).

For the Beartooth Highway there are three primary considerations that have differing objectives. First, the support of the roadway structural section is essential to extending the life of the pavement over the 20-year design life. Second, minimizing the width of the shoulder would lessen the environmental impacts. Third, comments during the scoping process indicated that bicycle use is increasing and that constructing a wider shoulder should accommodate it. 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 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 needs of the project and that three lesser shoulder widths should be evaluated, 0.6 m (2 ft.), 0.9 m (3 ft.), and 1.2 m (4 ft.) from the Clay Butte turnoff to the road closure gate. To address both the considerable recreation use on the lower section of the highway and the sensitive resources fond in that portion of highway, a 0.9 m (3 ft.) shoulder is proposed. This shoulder width would accommodate a bicyclist but does not meet the AASHTO minimum shoulder width requirements to accommodate a pedestrian or bicyclist. **Based on the proposed shoulder widths, a design exception to the AASHTO standards would be required for both segments.**

Foreslopes

The foreslope is defined as the area from the edge of the surfaced shoulder to the subgrade hinge point (the slope immediately adjacent to the roadway shoulders). The foreslope ensures the stability of the roadway, an opportunity for recovery of an out of control vehicle and provides width for future maintenance operations.

The foreslope improves roadway stability by providing lateral support to the structural section. The depth of the proposed structural section and the required slope ratios defines the width of the foreslope. Foreslopes can be constructed either to meet a specific width (fixed width) or a specific slope (fixed slope). The 2.4 m (8 ft) fixed width foreslope varies in slope as the superelevation (cross-slope) varies, but the width of the foreslope remains constant. The WYDOT design manual states that the foreslopes for new construction on all interstate and two lane roadways should be a 1:8 (vertical: horizontal) slope or flatter. For overlay projects, this criterion is not steeper than 1:6. Additionally, WYDOT recommends that staged construction and maintenance activities such as overlay be taken into consideration when determining foreslope widths. The proposed foreslope of 2.4 m (8 ft) fixed width was selected for the project because it generally provides for the WYDOT recommended slope ratios, provides for future maintenance activities to maintain recoverable slopes, and assists in meeting clear zone requirements. This flatter and wider foreslope provides flexibility for future maintenance operations such as overlays. In addition, a 2.4 m (8

ft) fixed width was selected because the consistent width would simplify construction of the foreslope and subgrade. Also, a minimum clear zone of 3.0 m (10 ft) is required, which is obtained with a 0.6 m (2 ft) shoulder and a 2.4 m (8 ft,) fixed width foreslope. If the foreslope is constructed with a fixed slope (rather than a fixed width), the foreslope width varies and in many instances is less than 2.4 m (8 ft). Therefore, in order to maintain the needed clear zone, the slope would be extended to 2.4 m (8 ft) in the cut or fill slope followed by a steeper slope creating a "barn roof" section. The widening needed to obtain the minimum clear zone offsets any gains made by using steeper foreslopes.

By providing a flatter and wider foreslope and shoulders, several needs are met. A flatter and wider foreslope provides flexibility for future maintenance operations such as overlays. The minimum foreslope ratios can generally be maintained and provide for future overlays. If foreslope widths are reduced to minimums at the outset, then in order to overlay the roadway in the future, the maintaining agency would have to reconstruct the roadway section and roadside ditches, increasing environmental impacts.

When a road with 3.6 m (12 ft.) lanes requiring a new surface has shoulder widths greater than 0.9 m (3 ft.), the edges of a 50-mm (2-in.) overlay would be tapered at the required 1:6 foreslope, reducing the effective shoulder width by 0.3 m (1 ft.), while maintaining the 3.6 m (12 ft.) lanes. Such an overlay would be completed without disturbing the adjacent revegetated foreslopes, ditches, or cut and fill slopes. The minimum shoulder width standard of 0.6 m (2 ft.) and the existing foreslope ratio of 1:6 would be maintained. This scenario could be applied on the lower section of the Beartooth Highway, from the beginning of the project to the road closure gate. However, this operation would reduce the available width of the shoulder by 0.3 m (1ft.) on each side of the roadway, thus reducing the available width for pedestrian and bicycle use. If 0.9 m (3 ft.) shoulders are maintained, then there are two options available. The foreslope ratios can be steepened or the pavement taper can be flattened to acceptable ratios after the overlay operation. This impact would be minimal on the revegetated foreslopes.

For the upper section of the project, from the road closure gate to the state line, to complete construction of a 50 mm (2 in.) overlay on a roadway with 3.6 m (12 ft.) lanes, with minimum shoulders 0.6 m (2 ft.) or less, the resulting foreslope would be 1:4.4. If the foreslope was flattened to 1:6, minor reconstruction of the foreslopes and disturbance to the vegetation on the foreslope would be required. Again, if a width of 2.4 m (8 ft.) is provided, only minor foreslope flattening or reconstruction is required to achieve a 1:6 slope by flattening the paved taper. In both circumstances, the 2.4 m (8 ft.) width would eliminate the need to remove pavement and dispose waste of the old pavement material off site, and would reduce resurfacing costs substantially.

A flatter foreslope provides a "clear zone" area where an errant vehicle could safely return to the road within a clear zone of 3.0 m (10 ft.). Flatter foreslopes also provide for a higher chance of revegetation.

By providing a 2.4 m (8 ft.) wide foreslope the future environmental impacts are minimized, while the roadway stability, "clear zone", and future maintenance concerns are considered.

Roadside Ditches

Roadside ditches collect and convey runoff from the highway. Therefore, these ditches should have adequate capacity to handle the expected flows or the "design runoff." In addition, the depth of the

ditch must be sufficient to remove the runoff without saturating the subgrade of the roadway. The ditches on the highway would also serve the additional function of providing a snow storage area. Ditch geometry should be such that safety and maintenance considerations are addressed.

Two ditch types are proposed for the project, a graded ditch and a paved ditch. Graded ditches are used in areas of gentler terrain and where the roadway profile is not as steep. Paved ditches are used where ditch flow velocities are expected to be high or to minimize or avoid significant impacts. On the proposed project, those areas include the rock cut areas and the long steep grade to the Top of the World Store.

Due to the severe winter weather in the project area, a graded ditch sideslope of 1:6 is preferable to reduce snow drifting. The depth of the ditch should be a minimum of 300 mm (1 ft.) from the bottom of the ditch to the bottom of the base course. This depth provides capacity to handle expected drainage flows without saturating the base course layer under the pavement. To obtain this required depth, the necessary ditch width is 1.8 m (6 ft.). In some locations, where the existing terrain provides for a clear recovery area, a graded ditch slope of 1:4 would be investigated.

Where applicable, paved ditches are proposed. The recommended width of the paved ditches is 1.5 m (5 ft.). When paved ditches are provided, neither foreslopes or graded ditches are required, thus reducing the overall width of impacts by 2.4 m (8 ft.). Additionally, in areas of paved ditch the "clear zone" is reduced because of the use of curb. The curb would act as a barrier to an out-of-control vehicle.

Guardrail Offset Widths (Lateral Offset)

According to the Green Book, the guardrail should be placed as far from the traveled way as conditions permit. This placement provides the errant motorist with the best chance of regaining control without having an accident and provides additional sight distance. In addition, barriers should be located beyond the edge of the shoulder to ensure the full shoulder width may be used. However, based on the unique environmental setting of the project area, the minimum lateral offset for guardrail from the edge of traveled-way would be implemented in the design.

The minimum lateral offset should be the distance needed for the guardrail to not be perceived as an obstacle to the driver, which causes the driver to reduce speed or change position on the road. According to the Roadside Design Guide, the minimum lateral offset for a design speed of 60 km/hr (37 mph) is 1.4 m (5 ft. (4.6 ft to be exact)) from the edge of traveled-way. The proposed shoulder width in this section of the roadway is 0.9 m (3 ft.) so an additional offset of 0.6 m (2 ft.) from the shoulder to the guardrail is required. The minimum lateral offset for a design speed of 50 km/hr (31 mph) is 1.1 m (4 ft.) from the edge of traveled way. The shoulder width in the upper segment of the roadway is 0.6 m (2 ft.) so the offset from the shoulder to the guardrail would be 0.6 (2 ft.).

Bridge Width

Due to their initial high cost, bridges are designed to have a physical life expectancy for 75 years, which is 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 be a minimum of the traveled lane plus shoulders plus 1.2 m (4 ft.), or 0.6 m (2 ft.) on each side. Two bridge structures in various alternatives, Beartooth Ravine and the Little Bear Creek fen, would be longer than 60 m (200 ft.). 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 Roadside Design Guide. The Roadside Design Guide provides guidance on offsets to guardrail and other fixed object hazards such as trees. The design width for the structures on 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 build 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, retaining 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 semi-trailer. 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 project would 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 the proposed 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 the proposed project, two minimum curve criteria were 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.). In some locations along the project, such as at switchbacks, curves would 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 would be marked with curve warning and reduced speed advisory signs as a part of the reconstruction project. **Based on the proposed horizontal curvature, an exception to the AASHTO design standard would be required.**

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 the proposed 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. **Based on the horizontal alignment proposed for the project, an exception to the AASHTO standard would be required for the proposed SSD.**

Clear Recovery Area (Clear Zone)

Use of an appropriate clear-zone distance amounts to a compromise between maximum safety and minimum environmental impacts. A clear-zone starts at the edge of the traveled way and consists of the area safe for errant vehicles. The Roadside Design Guide determines the necessary clearance for the clear zone based on the design speed, design SADT, and the slope ratio for both cut and fill. The Roadside Design Guide displays guidelines to illustrate the process that may be used to determine if a fixed object or non-traversable terrain feature warrants relocation, modification, removal, shielding, or no treatment. Roadside channels are not obstacles and need not be constructed at or beyond the clear-zone distance for a specific roadway. On the other hand, drainage features should be designed and built with consideration given to the safety of an errant vehicle. As discussed above in the foreslope section, a flatter

foreslope provides an additional clear-zone area where an errant vehicle could safely return to the road within a clear-zone. The clear-zone on a curved alignment is determined by adjusting the value obtained for a tangent section of highway by a curve correction factor in the Roadside Design Guide based on the degree of curvature, the design speed, and the roadside width. AASHTO specifies that for low-speed rural collectors and rural local roads, a minimum clear-zone width of 3.0 m (10 ft.) should be provided. Based on the balance of the clear-zone safety guidelines and environmental impact concerns, a clear zone of 3.0 m (10 ft.) was selected. The proposed foreslope width of 2.4 m (8 ft.) and the shoulder width of 0.6 – 0.9 m (2 – 3 ft.) generally provide the necessary area to meet the project standards for a minimum allowable clear-zone of 3 m (10 ft.)

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. Two different K-values are used in design of vertical alignments; one for crest vertical curves (K_{crest}) and one for sags (K_{sag}). For the proposed 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

Grade is a measure of the vertical slope of the roadway. Grades are expressed in percentages, 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 was selected for the proposed project. For the majority of the project, existing grades would be under 6 percent. The maximum gradients in switchbacks should typically be 4 percent, 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 the proposed project, a 2 percent typical cross-slope was selected.

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