Chapter 3
Characteristics of the Driver, the Pedestrian, the Vehicle and the Road

3-1
Briefly describe the two types of visual acuity.

The two types of visual acuity are static and dynamic. The ability of a driver to identify an object when both the object and the driver are stationary depends on one's static acuity. Some factors that affect static acuity include the background brightness, contrast, and time. The ability of a driver to clearly detect a moving object depends on the driver's dynamic visual acuity.

3-2
(a) What color combinations are used for regulatory signs (e.g. speed limit signs) and for general warning signs (e.g. advance railroad crossing signs)
(b) Why are these combinations used?

Regulatory signs use a color combination of black lettering on white background, and advance warning signs use the color combination of black lettering on yellow background. These color combinations are used because they have been shown to be those to which the eye is most sensitive.

3-3
Determine your average walking speed.
Compare your results with that of the suggested walking speed in the MUTCD.
Which value is more conservative and why?

Pass #	Intersection Width (ft)	Walk Time (sec)	Walking Speed (ft/sec)
1	36	7	5.1
2	36	8.2	4.4
3	36	9.5	3.8
4	36	7.6	4.7
5	36	8	4.5
Average			***4.5***

In this case, the MUTCD value, 4.0 ft/sec, is more conservative than the observed speeds. This value is more conservative because it is a slower speed and it will allow most slower people, such as elderly, individuals with small children, and handicapped individuals to traverse the intersection safely.

3-4
Describe the three types of vehicle characteristics.

The three types of vehicle characteristics are *static*, *kinematic*, and *dynamic*. Static vehicle characteristics include the vehicle's weight and size. Kinematic characteristics involve the motion of the vehicle, and dynamic characteristics involve the force that causes the motion of the vehicle.

3-5
Determine the maximum allowable overall gross weight of WB-20 Design Vehicle.

(The WB-20 is same as WB-65 and WB-67.)

From Table 3.2, the extreme distance between the axle groups is 43.4 – 45.4 ft (use 45.4 in this case). The number of axles in the group is 4.

Use Eq. 3.2,

$$W = 500\left[\frac{LN}{N-1} + 12N + 36\right] = 500 \times \left[\frac{45.4 \times 4}{4-1} + 12 \times 4 + 36\right] = 72267\text{lb}.$$

The maximum allowable overall gross weight is 72267 lb.

3-6
The design speed of a multilane highway is 60 mi/hr. What is the minimum stopping sight distance that should be provided on the road if (a) the road is level and (b) the road has a maximum grade of 4%? Assume the perception-reaction time = 2.5 sec.

The minimum sight distance required in these cases is the stopping sight distance (SSD), given by Equation 3.27:

$$S = 1.47ut + \frac{u^2}{30(\frac{a}{g} \pm G)};$$

where u = design speed (mi/h)
t = perception-reaction time (sec)
a = rate of deceleration (taken as 11.2 ft/sec^2)

g = gravitational acceleration (taken as 32.2 ft/sec^2)
G = grade
Note: the term $\frac{a}{g}$ is typically rounded to 0.35 in calculations.

(a) Determine the minimum sight distance that should be provided for a level roadway.

Since the roadway is level, G = 0.
S = (1.47)(60)(2.5) + (60)^2 / (30)(0.35+0)
S = 220.50 + 345.00
S = 565.50 feet

Therefore, the minimum sight distance for this horizontal roadway is 565 feet.

(b) Determine the minimum sight distance that should be provided for a roadway with a maximum grade of 4 percent.

Since this roadway has a maximum grade of 4 percent, G = -0.04. The downgrade (negative) case provides the most conservative (higher) value for design.

S = 1.47(60)(2.5) + (60)^2 / 30(0.35 – 0.04)
S = 220.50 + 387.10
S = 607.60 feet

Therefore, the minimum sight distance for this roadway should be 608 feet.

3-7
The acceleration of a vehicle can be expressed as:

$$\frac{du}{dt} = 3.6 - 0.06u$$

If the vehicle speed, *u*, is 45 ft/sec at time T_0, Determine:
(a) Distance traveled when the vehicle has accelerated to 55 ft/sec.
(b) Time for vehicle to attain the speed of 55 ft/sec.
(c) Acceleration after 3 seconds.

(a) Determine the distance traveled by the vehicle when accelerated to 55 ft/sec.

First, determine the time it took for the vehicle to accelerate to 55 ft/sec.
Using a rearrangement of Equation 3.10:

$-\beta t = \ln [(\alpha - \beta u_t) / (\alpha - \beta u_0)]$ therefore;
$t = (-1/\beta) \ln [(\alpha - \beta u_t) / (\alpha - \beta u_0)]$

t = (-1/0.06) ln [(3.6 - 0.06(55)) / (3.6 - 0.06(45))]
t = 18.33 seconds

Next, determine the distance traveled during this time.
From Equation 3.12:

$x = (\alpha / \beta)t - (\alpha / \beta^2)(1 - e^{-\beta t}) + (u_o / \beta)(1 - e^{-\beta t})$
$x = (3.6 / 0.06)18.33 - [(3.6 /(0.06)^2)(1 - e^{-0.06(18.33)})] + [45 / 0.06 (1 - e^{-0.06(18.33)})]$
x = 933.03 feet.

Therefore, the vehicle traveled 933 feet when accelerating from 45 ft/sec to 55 ft/sec.

(b) Determine the time it takes for the vehicle to attain the speed of 55 ft/sec.

This time was determined in Part (a) of this problem.
Therefore, it took 18.33 seconds for the vehicle to attain the speed of 55 ft/sec.

(c) Determine the acceleration of the vehicle after 3 seconds.
First, determine the velocity of the vehicle after 3 seconds.
From Equation 3.11:

$u_t = (\alpha / \beta)(1 - e^{-\beta t}) + u_o e^{-\beta t}$
$u_t = (3.6 /0.06)(1 - e^{-(0.06)(3)}) + 45e^{-(0.06)(3)}$
u_t = 47.47 ft/sec.

Since acceleration is: $a = du/dt = 3.6 - 0.06u$
$a = 3.6 - 0.06(47.47)$
$a = 0.75$ ft/sec^2
Therefore, the acceleration of the vehicle after 3 seconds is 0.75 ft/sec^2

3-8
The gap between two consecutive automobiles (distance between the back of a vehicle and the front of the following vehicle) is 65 ft. At a certain time the front vehicle is traveling at 45 mph and the following vehicle at 35 mph. If both vehicles start accelerating at the same time, determine the gap between the two vehicles after 15 sec if the acceleration of the vehicles can be assumed to take the following forms:

$$\frac{du}{dt} = 3.4 - 0.07u_t \quad \text{(leading vehicle)}$$

$$\frac{du}{dt} = 3.3 - 0.065u_t \quad \text{(following vehicle)}$$

where u_t is the vehicle speed in ft/sec.

First, determine the distance each vehicle travels during the elapsed time (15 seconds) using Equation 3.12. For the leading vehicle:

$x = (\alpha / \beta)t - (\alpha / \beta^2)(1 - e^{-\beta t}) + (u_o / \beta)(1 - e^{-\beta t})$
$x = (3.4 / 0.07)15 - [(3.4 /(0.07)^2)(1 - e^{-0.07(15)})] + [((45)(1.47) / 0.07)(1 - e^{-0.07(15)})]$
$x = 890$ feet.

Similarly, for the following vehicle:
$x = (3.3 / 0.065)15 - [(3.3 /(0.065)^2)(1 - e^{-0.065(15)})] + [((45)(1.47) / 0.065)(1 - e^{-0.065(15)})]$
$x = 767$ feet.

Since the leading vehicle traveled further, the gap between vehicles increased by the difference in the distances, 890 – 767 = 123 ft
The initial gap was given as 65 ft, so after 15 sec, the gap is 65 + 123 = 188 ft.

3-9

The driver of a vehicle on a level road determined that she could increase her speed from rest to 50 mi/hr in 34.8 sec and from rest to 65 mi/hr in 94.8 sec. If it can be assumed that the acceleration of the vehicle takes the form:

$$\frac{du}{dt} = \alpha - \beta u_t$$

determine the maximum acceleration of the vehicle

First, convert miles/hour to feet/second.
50 mi/h = 73.33 ft/sec
65 mi/h = 95.33 ft/sec
Next, use Equation 3.11 to develop the equation for each case as follows:

Case 1 (50 mi/h)
$u_t = (\alpha / \beta)(1 - e^{-\beta t}) + u_o e^{-\beta t}$
$73.33 = (\alpha / \beta)(1 - e^{-\beta(34.8)}) + 0e^{-\beta(34.8)}$
$73.33 = (\alpha / \beta)(1 - e^{-\beta(34.8)})$ *Equation 1*

Case 2 (65 mi/h)
$u_t = (\alpha / \beta)(1 - e^{-\beta t}) + u_o e^{-\beta t}$
$95.33 = (\alpha / \beta)(1 - e^{-\beta(94.8)}) + 0e^{-\beta(94.8)}$
$95.33 = (\alpha / \beta)(1 - e^{-\beta(94.8)})$ *Equation 2*

Solve for α in equation 1 and substitute into equation 2.
$\alpha = 73.33\beta / (1 - e^{-\beta(34.8)})$ *Equation 3*
Substitute this into Equation 2.
$95.33 = [(73.33\beta / (1 - e^{-\beta(34.8)})) / \beta] * (1 - e^{-\beta(94.8)})$

$95.33 = (73.33 / (1 - e^{-\beta(34.8)})) * (1 - e^{-\beta(94.8)})$
$(95.33 / 73.33) * (1 - e^{-\beta(34.8)}) = (1 - e^{-\beta(94.8)})$
$1.30 * (1 - e^{-\beta(34.8)}) = (1 - e^{-\beta(94.8)})$
$1.30 - 1.3e^{-\beta(34.8)} = (1 - e^{-\beta(94.8)})$
$1.3e^{-\beta(34.8)} - e^{-\beta(94.8)} = 0.30$

The above equation can be solved by assuming a value for β, evaluating the left hand side of the equation, and comparing the result to 0.3 as follows.

β	$1.3\, e^{-\beta(34.8)} - e^{-\beta(94.8)}$
0.02	**0.5**
0.03	**0.4**
0.04	**0.3**

As can be seen, the solution is:

$\beta = 0.04$

Substituting into Equation 3 gives:

$\alpha = 73.33 * 0.04 / (1 - e^{(-0.04 * 34.8)})$
$= 3.90 \text{ ft/sec}^2$

Since the maximum acceleration is achieved when the velocity of the vehicle is 0, the value for α determined above is the maximum acceleration.

3-10

If the vehicle in Problem 3-9 is traveling at a speed of 40 mph, how long will it take after the driver starts accelerating for the vehicle to achieve a speed of 45 mph?

The acceleration model found in Problem 3-9 was

$du/dt = 3.90 – 0.04\, u_t$

The values α=3.90 and β=0.04 can then be substituted in Equation 3.10:

$t = (-1/\beta) \ln [(\alpha - \beta u_t) / (\alpha - \beta u_0)]$
$t = (-1/0.04) \ln [(3.9 – ((0.04)(40)(1.47)) / (3.9 – ((0.04)(45)(1.47))]$
$t = 5.2$ seconds

3-11

Determine the horsepower developed by a passenger car traveling at a speed of 60 mph on an upgrade of 4% with a smooth pavement. The weight of the car is 4500 lb and the cross-sectional area of the car is 45 ft^2.

First, determine all of the resistive forces, air, rolling, and grade, acting on the vehicle, and then determine its horsepower requirement.

The air resistance is (using Equation 3.13):

$R_a = 0.5 * [(2.15 p C_D A u^2) / g]$

$R_a = 0.5 * [(2.15(0.0766)(0.4)(45)(60)^2 / 32.2]$

$R_a = 165.7$ lb

The rolling resistance is (using Equation 3.14):

$R_r = (C_{rs} + 2.15 C_{rv} u^2) * W$

$R_r = (0.012 + 2.15(0.65*10^{-6})(60)^2) * 4500$

$R_r = 76.6$ lb

The grade resistance is:

$R_G = WG$

$R_G = (4500)(0.04)$

$R_G = 180.0$ lb

Since these are the only forces acting on the vehicle, one can now determine the horsepower requirement. Use Equation 3.17.

$P = 1.47 Ru / 550$

$P = [(1.47(165.7 + 76.6 + 180)(60)) / 550]$

$P = 67.5$ hp

3-12

Repeat Problem 3-11 for a 24,000-lb truck with a cross-sectional area of 100 ft^2 and coefficient of drag of 0.5 traveling at 50 mi/hr.

First, determine all of the resistive forces, air, rolling, and grade, acting on the vehicle, and then determine its horsepower requirement.

The air resistance is (using Equation 3.13)::

$R_a = 0.5 * [(2.15 p C_D A u^2) / g]$

$R_a = 0.5 * [(2.15(0.0766)(0.5)(100)(50)^2 / 32.2]$

$R_a = 319.7$ lb

The rolling resistance is (using Equation 3.15):

$R_r = (C_a + 1.47 C_b u) * W$

$R_r = (0.02445 + 1.47(0.00044)(50)) * 24,000$

$R_r = 1361$ lb

The grade resistance is:

$R_G = WG$

$R_G = (24,000)(0.04)$

$R_G = 960.0$ lb

Since these are the only forces acting on the vehicle, one can now determine the horsepower requirement. Use Equation 3.17.

$P = 1.47Ru / 550$
$P = [(1.47(319.7 + 1361 + 960)(50)) / 550]$
$P = 352$ hp

3-13
A 2500-lb passenger vehicle originally traveling on a straight and level road gets onto a section of the road with a horizontal curve of radius=850 ft. If the vehicle was originally traveling at 55 mi/h, determine (a) the additional horsepower on the curve the vehicle must produce to maintain the original speed, (b) the total resistance force on the vehicle as it traverses the horizontal curve, and the total horsepower. Assume that the vehicle is traveling at sea level and has a front cross-sectional area of 30 ft^2.

First, determine all of the resistive forces, air and rolling, acting on the vehicle while it is traveling straight and then determine its horsepower requirement.

The air resistance is (using Equation 3.13):
$R_a = 0.5 * [(2.15pC_DAu^2) / g]$
$R_a = 0.5 * [(2.15(0.0766)(0.4)(30)(55)^2 / 32.2]$
$R_a = 92.74$ lb

The rolling resistance is (using Equation 3.14):
$R_r = (C_{rs} + 2.15C_{rv}u^2) * \mathrm{W}$
$R_r = (0.012 + 2.15(0.65*10^{-6})(55)^2) * 2500$
$R_r = 40.57$ lb

Since these are the only forces acting on the vehicle, one can now determine the horsepower requirement on the straight segment. Use Equation 3.17.

$P = 1.47Ru / 550$
$P = [(1.47(92.74 + 40.57)(55)) / 550]$
$P = 19.60$ hp

Now determine the additional resistive force acting on the vehicle due to the curve.

The curve resistance is (using Equation 3.16):
$R_c = 0.5 * [(2.15u^2\mathrm{W}) / gR]$
$R_c = 0.5 * [(2.15(55)^2(2500) / (32.2)(850)]$
$R_c = 297.03$ lb

Now determine the total additional horsepower for the curve section of roadway.
$P = 1.47Ru / 550$

$P = [(1.47(297.03)(55)) / 550]$
$P = 43.66$ hp

Determine the additional required for the vehicle to maintain its original speed

$hp_{required} = hp_{curve} + hp_{straight}$
$hp_{required} = 43.66 + 19.60$
$hp_{required} = 63.26$ hp

Therefore, the vehicle will need to produce 63.26 more horsepower to traverse the curve at its original velocity.

The total resistive force acting on the vehicle while in the curve is:

$R_{total} = R_a + R_r + R_c$
$R_{total} = 92.74 + 40.57 + 297.03$
$R_{total} = 430.34$ lb

Therefore, the total resistive force acting on the vehicle in the curve is 430 pounds.

3-14

A horizontal curve is to be designed for a section of a highway having a design speed of 60 mi/hr.

(a) If the physical conditions restrict the radius of the curve to 500 ft, what value is required for the superelevation at this curve?

(b) Is this a good design?

(a) Determine required superelevation

First, determine the coefficient of side friction, f_s, from Table 3.3.

$$f_s = 0.12$$

Next, use equation 3.34 and solve for the superelevation value.

$$R = u^2 / 15(e + f_s)$$
$$e = [u^2 / 15R] - f_s$$
$$e = [(60)^2 / 15(500)] - 0.12$$
$$e = 0.36$$

(b) Is this a good design?

The superelevation for this curve would be 0.36. Since $e = 0.36 > 0.10$ (allowable maximum superelevation, this would NOT be a good design.

3-15

Determine the minimum radius of a horizontal curve required for a highway if the design speed is 70 mi/hr and the superelevation rate is 0.08.

Determine the minimum radius required for this section of roadway.

First, determine the coefficient of side friction, f_s, from Table 3.3. $f_s = 0.10$

Next, use Equation 3.34 to solve for R.

$$R = u^2 / 15(e + f_s)$$
$$R = [(70)^2 / 15(0.08 + 0.10)$$
$$R = 1{,}814.81 \text{ feet.}$$

The minimum radius for this curved section of roadway was found to be approximately 1,815 feet.

3-16

The existing posted speed limit on a section of highway is 55 mph and studies have shown that that the current 85th percentile speed is 65 mph. If the posted speed limit is to be increased to the current 85th percentile speed, what should be the increase in the radius of a curve that is just adequate for the existing posted speed limit? Assume a superelevation rate of 0.08 for the existing curve and for the redesigned curve.

For the existing curve, use Equation 3.34 to determine the radius.

$$R = u^2/15(e+f_s)$$
$$R = (55)^2/15(0.08+0.13)$$
$$R = 960 \text{ ft}$$

Similarly, determine the radius for the curve to be redesigned.

$$R = (65)^2/15(0.08+0.11)$$
$$R = 1482 \text{ ft}$$

The increase should then be 1482 – 960 = 522 ft

3-17

The radius of a horizontal curve on an existing highway is 750 ft. The superelevation rate at the curve is 0.08 and the posted speed limit on the road is 65 mi/h. Is this a hazardous location? If so, why? What action will you recommend to correct the situation?

Assume that the design speed of this section of roadway is 70 mi/h (5 mi/h above the posted speed limit.

Next, determine the coefficient of side friction, f_s, from Table 3.3. $f_s = 0.10$

Next, determine the maximum permissible speed on this existing curve by using Equation 3.34.

$$R = u^2 / 15(e + f_s)$$
$$u^2 = 15(R)(e + f_s)$$
$$u = [15(750)(0.08 + 0.10)]^{1/2}$$
$$u = 45 \text{ mi/h}$$

This curve is hazardous since the speed limit is posted at 65 mi/h yet the maximum safe speed in the curve is 45 mi/h. One low cost measure to increase the safety of this curve would be to reduce the speed limit to 45 mi/h, or to post a curve warning sign with an advisory (maximum safe) speed of 45 mi/h. A long-term solution to improve safety would be to increase the radius of curvature to permit safe operation at the speed limit. This can be accomplished by using the above equation (equation 3.34):

$$R = (65)^2 / 15(0.08 +0.10)$$
$$R = 1{,}564.81 \text{ ft.}$$

Therefore, to permit safe travel at the maximum speed limit, the radius of the curve should be increased to 1,565 feet.

3-18

A section of highway has a superelevation of 0.05 and a curve with a radius of only 300 ft. What speed limit will you recommend at this section of the highway?

A trial value for u must be assumed and the corresponding f_s found and then checked for safety. Using Equation 3.34, solve for the value of f_s associated with u = 35 mi/h

$$R = u^2 / 15(e + f_s)$$
$$300 = 35^2 / 15(0.05 + f_s)$$
$$f_s = 0.22$$

Interpolating in Table 3.3, for u =35 mi/h, f_s = 0.18 should be assumed. Therefore, try a lower speed of u = 30 mi/h. Using Equation 3.34, f_s = 0.15, which is less than the assumed to be provided value of 0.20. Therefore, the speed limit that should be posted on this roadway is 30 mi/h.

3-19

A curve of radius 250 ft and *e* = 0.08 is located at a section of an existing rural highway, which restricts the safe speed at this section of the highway to 50% of the design speed. This drastic reduction of safe speed resulted in a high accident rate at this section. To reduce the accident rate, a new alignment is to be designed with a horizontal curve. Determine the minimum radius of this curve if the safe speed should be increased to the design speed of the highway. Assume f_s = 0.17 for the existing curve, and the new curve is to be designed with *e* = 0.08.

First, determine the safe speed on the existing curve, using Equation 3.34.

$$R = u^2 / 15(e + f_s)$$
$$u^2 = 15(R)(e + f_s)$$
$$u = [15(250)(0.08 + 0.17)]^{1/2}$$
$$u = 30.62 \text{ mi/h}$$

Next, determine the design speed of the existing roadway. (Remember, the existing speed is the design speed reduced by 50%.)

Design speed = Existing speed / 0.50
Design speed = 30.62 / 0.50
Design speed = 61.24 mi/h

Next, determine the coefficient of friction, f_s, from Table 3.3 using the new design speed.

$$f_s = 0.12$$

Now, determine the new radius for this curve.

$$R = u^2 / 15(e + f_s)$$
$$R = (61.24)^2 / 15(0.08 + 0.12)$$
$$R = 1{,}250.11 \text{ feet.}$$

Therefore, to permit the safe speed of the curve to be raised to the overall design speed, the curve's radius must be increased to 1,250 feet.

3-20

What is the distance required to stop an average passenger car when brakes are applied on a 2% downgrade if that vehicle was originally traveling at 40 mi/hr?

Use equation 3.25 to determine the braking distance.

$$D_b = \frac{u^2}{30(\frac{a}{g} \pm G)}$$

Note that *a* is taken as 11.2 ft/sec^2; therefore, *a/g* is equal to 0.35.

$$D_b = 40^2 / 30(0.35 - 0.02)$$

$D_b = 161.62$ feet

The braking distance required to stop the vehicle is 162 feet.

3-21

A driver on a level two-lane highway observes a truck completely blocking the highway. The driver was able to stop her vehicle only 20 ft from the truck. If the driver was driving at 60 mph, how far was she from the truck when she first observed it?

Use equation 3.35 to determine the stopping sight distance used. Use AASHTO recommended values, t = 2.5 seconds, a/g = 0.35

$$SSD = 1.47ut + \frac{u^2}{30(\frac{a}{g} \pm G)} = 1.47(60)(2.5) + \frac{(60)^2}{30(0.35)} = 563 \text{ ft}$$

Therefore, the distance from the point at which the driver observed the stopped truck to the truck is 20 + 563 = 583 ft.

3-22

A temporary diversion has been constructed on a highway of +4% gradient due to major repairs that are being undertaken on a bridge. The maximum speed allowed on the diversion is 10 mi/hr. Determine the minimum distance from the diversion that a road sign should be located informing drivers of the temporary change on the highway.

Maximum allowable speed on highway = 70 mi/hr

Letter height of road sign = 4"

Perception-reaction time = 2.5 sec

Use equation 3.35 to determine the stopping sight distance.

$$SSD = 1.47ut + \frac{u^2}{30(\frac{a}{g} \pm G)}$$

While the first term in this equation is simply the distance traveled during the perception-reaction time, second term is the distance traveled during braking. *a/g* is taken as 0.35. Since the vehicle is not stopping (the final speed is not equal to zero), the equation needs to be modified to take this into consideration. The second term of equation 3.35 is replaced by equation 3.26 as follows (in which u_1 is the initial velocity and u_2 is the final velocity):

$$SSD = 1.47ut + \frac{u_1^2 - u_2^2}{30(\frac{a}{g} \pm G)}$$

SSD = 1.47(70)(2.5) + (70^2 - 10^2) / (30 (0.35 + 0.04))
SSD = 256.67 + 410.26
SSD = 666.93 feet.

Next, determine the readability of the roadway sign.

Readability = (Letter height in inches) * 40 feet / inch of letter height
Readability = 4 inches * 40 feet / inch
Readability = 160 feet

The sign can be read at a distance of 160 feet.

Next, determine the distance from the diversion the sign should be placed.

x = SSD – readability distance
x = 666.93 – 160.00
x = 506.93 feet

The sign should be placed approximately 510 feet prior to the diversion to alert drivers of the change on the highway.

3-23

Repeat Problem 3-22 for a highway with a down grade of -3.5% and the speed allowed on the diversion is 15 mph. Assume that a driver can read a road sign within his or her area of vision at a distance of 40 ft for each inch of letter height.

Use equation 3.35 to determine the stopping sight distance.

$$SSD = 1.47ut + \frac{u^2}{30(\frac{a}{g} \pm G)}$$

While the first term in this equation is simply the distance traveled during the perception-reaction time, second term is the distance traveled during braking. *a/g* is taken as 0.35. Since the vehicle is not stopping (the final speed is not equal to zero), the equation needs to be modified to take this into consideration. The second term of equation 3.35 is replaced by equation 3.26 as follows (in which u_1 is the initial velocity and u_2 is the final velocity):

$$SSD = 1.47ut + \frac{u_1^2 - u_2^2}{30(\frac{a}{g} \pm G)}$$

SSD = 1.47(70)(2.5) + (70^2 – 15^2) / (30 (0.35 – 0.035))
SSD = 256.67 + 494.71
SSD = 751.37 ft

Next, determine the readability of the roadway sign.
Readability = (Letter height in inches) * 40 feet / inch of letter height
Readability = 4 inches * 40 feet / inch
Readability = 160 feet

The sign can be read at a distance of 160 feet.

Next, determine the distance from the diversion the sign should be placed.

x = SSD – readability distance
x = 751.37 – 160
x = 591 ft

The sign should be placed approximately 591 feet prior to the diversion to alert drivers of the change on the highway.

3-24

An elevated expressway goes through an urban area, and crosses a local street as shown in Figure 3.10. The partial cloverleaf exit ramp is on a 2% downgrade and all vehicles leaving the expressway must stop at the intersection with the local street. Determine (a) minimum ramp radius and (b) length of the ramp for the following conditions:

Maximum speed on expressway = 60 mi/hr

Distance between exit sign and exit ramp = 260 ft

Letter height of road sign = 3"

Perception-reaction time = 2.5 sec

Maximum superelevation = 0.08

Expressway grade = 0%

Assume that a driver can read a road sign within his or her area of vision at a distance of 50 ft for each inch of letter height, and the driver sees the stop sign immediately on entering the ramp.

First, determine the readability of the roadway sign.
Readability = (Letter height in inches) * 50 feet / inch of height
Readability = 3 inches * 50 feet / inch
Readability = 150 feet

Next, determine the speed of the vehicle just prior to it entering the exit ramp (u_{exit}). Modify equation 3.27 by replacing the second term (braking distance) with equation 3.26. a/g is taken as 0.35.

$$SSD = 1.47ut + \frac{u_1^2 - u_2^2}{30(\frac{a}{g} \pm G)} - \text{readability distance}$$

$260 = 1.47(60)(2.5) + [(60^2 - u^2_{exit}) / 30\ (0.35 + 0)] - 150$
$410 = 220 + (60^2 - u^2_{exit}) / 10.5$
$60^2 - u^2_{exit} = 1995$
$u_{exit} = (1605)^{1/2}$
$u_{exit} = 40.06$ mi/h

Next, determine the minimum radius required for this exit ramp, using Equation 3.34. For exit speed of 45 mi/h, the new coefficient of side friction should be f_s = 0.14.

$R = u^2_{exit} / 15(e + f_s)$
$R = (40.06)^2 / 15(0.08 + 0.14)$
R = 486.35 feet.

Next, determine the length required for this exit ramp.

$S = 1.47u_{exit}t + u^2_{exit} / 30\ ((a/g) \pm G)$
$S = 1.47(40.06)(2.5) + (40.06)^2 / 30(0.35 - 0.02)$
S = 147.23 + 162.10
S = 309.33 feet.

Therefore, the minimum radius for this exit ramp is approximately 490 feet and the minimum length of the exit ramp was found to be approximately 310 feet.

3-25

Calculate the minimum passing sight distance required for a two-lane rural roadway that has a posted speed limit of 45 mi/hr. The local traffic engineer conducted a speed study of the subject road and found the following: average speed of the passing vehicle was 47 mi/hr with an average acceleration of 1.43 mi/hr/sec, and the average speed of impeder vehicles was 40 mi/hr.

Time to initiate maneuver, t_1 = 4.0 sec

Determine the minimum passing sight distance for this roadway.

First, determine the distance traversed during the perception-reaction time.

$d_1 = 1.47t_1(u - m + (at_1 / 2))$
$d_1 = 1.47(4.0)[47 - 7 + ((1.43(4.0)) / 2)]$
$d_1 = 251.44$ feet

Determine the distance traveled while passing the vehicle. Table 3.6, t_2 = 10.0 sec.

$d_2 = 1.47ut_2$
$d_2 = 1.47(47)(10)$
$d_2 = 689.33$ feet

Now determine the distance between the passing vehicle and the opposing vehicle from Table 3.6.

$d_3 = 180$ feet.

Now determine the distance moved by the opposing vehicle.

$d_4 = (2 / 3)\ d_2$
$d_4 = (2 / 3)\ 689.33$
$d_4 = 459.55$ feet

The minimum passing distance can be found by adding all above distances together.

$d_1 + d_2 + d_3 + d_4 =$ Minimum sight distance
Sight distance = 251.44 + 689.33 + 180 + 459.55
Sight distance = 1,580.32 feet

Therefore, the minimum passing sight distance required for this roadway is approximately 1,600 feet.

