2 - VEHICULAR CHARACTERISTICS AND PERFORMANCE

Highway Design and Vehicular Performance

- Vehicular characteristics and their effects on design:
  - Performance to accelerate, decelerate and stopping
    (Acceleration and deceleration lanes, highway grades, minimum stopping and passing sight distances)
  - Dimensions,
    (Highway features Layout, i.e. lane widths, shoulder widths etc.),
  - Weights
    (Pavement design, design of bridges)
  - Turning performance
    (Highway curves, ramps, layout of intersections)

Tractive Effort and Resistance

- The acceleration, deceleration and stopping performance of vehicles depends on two primary opposing forces.

  - Tractive effort

    (Force generated by the engine)

  - Resistance

    (1) Aerodynamic resistance (R_a),

    (2) Rolling resistance (R_{rl}),

    (3) grade resistance (R_g).

Tractive Effort and Resistance

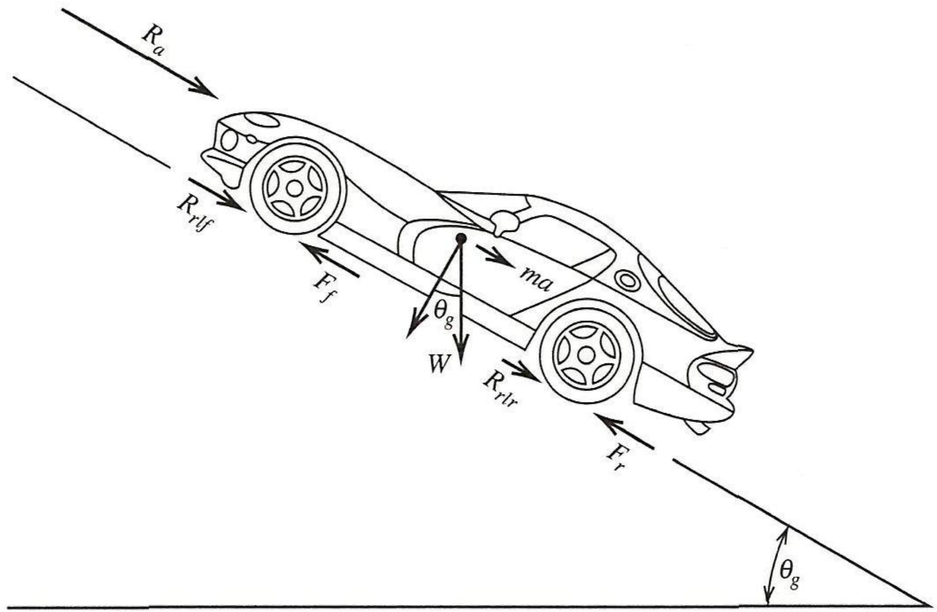

Figure 2.1 Forces acting on a road vehicle

Tractive Effort and Resistance

- The equation of the motion along the vehicle's longitudinal axis:

$$F_{net} = F - \sum R = ma \tag{2.1}$$

where,

F = available tractive force, ($F_{\mathrm{f}} + F_r$)

ΣR = resisting forces (N)

F_{net} = net force (N)

m = vehicle mass (kg)

a = acceleration (m/s^2)

Tractive Effort and Resistance

$$F_f + F_r = ma + R_a + R_{rlf} + R_{rlr} + R_g \qquad (2.2)$$

Where

F_f = available tractive force of the front tires (N)

F_r = available tractive force of the rear tires (N)

a = acceleration (m/s^2)

R_a = aerodynamic resistance (N)

R_{rlf} = rolling resistance of the front tires (N)

R_{rlr} = rolling resistance of the rear tires (N)

R_g = the grade resistance, ($W Sin\theta_g$) (N)

Aerodynamic Resistance

- The resisting force generated by the impact of air on the surface of vehicle. It is significant only at very high speeds. It is normally considered in the aerodynamic design of vehicles

$$R_a = \frac{\rho}{2} C_D A_f V^2 \tag{2.3}$$

where,

R_a = aerodynamic resistance (N)

ρ = air density (kg/m3)

C_D = coefficient of drag

A_f = frontal area of the vehicle (m2)

V = speed of the vehicle (m/s)

Rolling Resistance

- The resisting force generated from a vehicle's internal mechanical friction and from pneumatic tires and their interaction with the roadway surface.

- The primary source:

  The deformation of tire as it passes over the roadway

- Factors:

  - vehicle weight,
  - road surface type and condition,
  - tire pressure and condition,
  - vehicle speed

Rolling Resistance

- Due to wide range of factors and variation of them, the overall rolling resistance is simply approximated as the product of a friction term (coefficient of rolling resistance) and the weight component of the vehicle acting normal to the roadway surface.

$$f_{rl} = 0.01\left(1 + \frac{V}{44.73}\right) \tag{2.4}$$

where,

f_{rl} = coefficient of rolling resistance

V = vehicle speed (m/s)

Referring Fig. 2.1, taking $Cos\theta_g = 1$ for very small angle θ_g

$$R_{rl} = f_{rl}W \tag{2.5}$$

Grade Resistance

- The gravitational force component acting on the vehicle parallel to the roadway.

$$R_g = WSin\theta_g \tag{2.6}$$

- Since θ_g is very small, $Sin\theta_g = Tan\theta_g = G$

$$R_g = WG \tag{2.7}$$

Where, G is the grade, defined as the vertical rise for unit horizontal distance.

Vehicle Acceleration

- An additional term is introduced to Eq. 2.1 to account for the inertia of the vehicle's rotating parts that must be overcome. The term is referred to as the mass factor (γ_m).

$$F_{net} = F - \sum R = \gamma_m ma \tag{2.8}$$

- The mass factor (γ_m) is approximated by

$$\gamma_m = 1.04 + 0.0025\varepsilon_o^2 \tag{2.9}$$

Where, ε_o is the overall gear reduction ratio. It refers to the relationship between the revolutions of the engine's crankshaft and the revolutions of the derive wheels.

Vehicle Acceleration

$$F_{net} = \gamma_m m \frac{dV}{dt} \qquad \text{or} \qquad dt = \frac{\gamma_m m dV}{F_{net}} \tag{2.10}$$

- Integration gives the time to accelerate as

$$t = \gamma_m m \int_{V_1}^{V_2} \frac{dV}{F_{net}} \tag{2.11}$$

Where, V_1 is the initial speed and V_2 is the final speed.

Vehicle Acceleration

- The distance to accelerate (d_a) can be calculated by

$$d_a = \gamma_m m \int_{V_1}^{V_2} \frac{VdV}{F_{net}} \tag{2.12}$$

- If F_{net} as a function of speed (V) is introduced into the above equation, there will be no closed-form solution of the integral in the equation.
- The integral can be solved by numerical integration by the aid of computer.

Braking

- The braking performance is used for:

  (1) determination of stopping sight distance,

  (2) road surface design, and

  (3) design of accident avoidance systems.

Braking

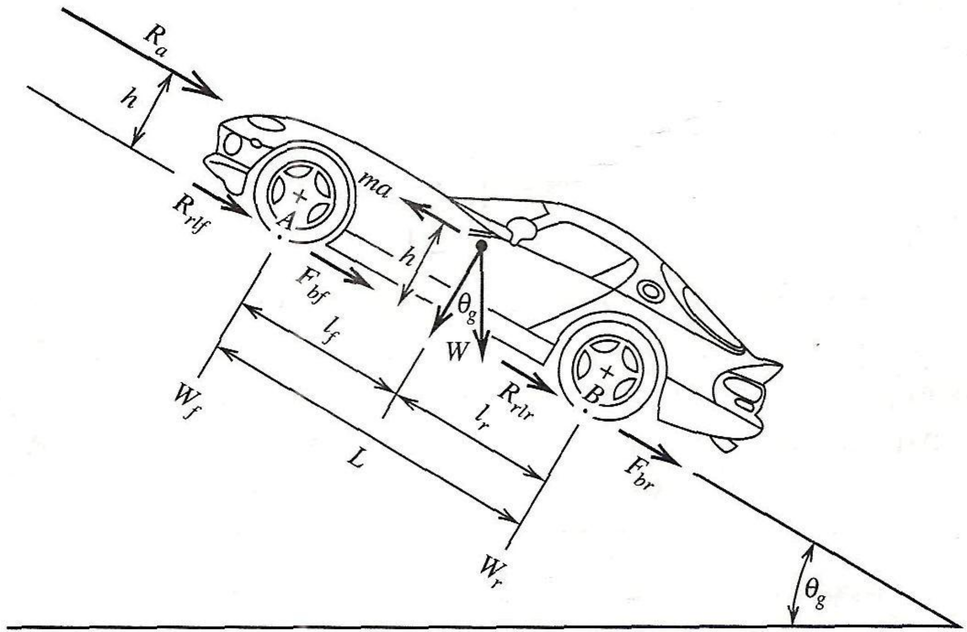

Figure 2.2 Forces acting on a vehicle during braking.

Braking

- **Braking force**

Considering in Fig. 2.2 and neglecting the air resistance (R_a),

$$W_f = \frac{1}{L}\left[Wl_r + h(ma \pm WSin\theta_g)\right] \tag{2.13}$$

$$W_r = \frac{1}{L}\left[Wl_f - h(ma \pm WSin\theta_g)\right] \tag{2.14}$$

Braking

- In Fig. 2.2 and in Eqs. 2.13 and 2.14

F_{bf} = braking force of the front tires (N)
F_{br} = braking force on the rear tires (N)
W = total weight of the vehicle (N)
W_f = weight of the vehicle on the front axle (N)
W_r = weight of the vehicle on the rear axle (N)
L = length of wheelbase (m)
h = height of the center of gravity above the road surface (m)
L_f = distance from the front axle to the center of gravity (m)
L_r = distance from the rear axle to the center of gravity (m)

Braking

- Neglecting air resistance, force equilibrium along the direction of movement from Fig. 2.2 is

$$F_b + R_{rl} = ma \pm WSin\theta_g \tag{2.15}$$

or

$$F_b + Wf_{rl} = ma \pm WSin\theta_g \tag{2.16}$$

- Substituting Eq. 2.16 into Eqs. 2.13 and 2.14

$$W_f = \frac{1}{L}\left[Wl_r + h(F_b + f_{rl}W)\right] \tag{2.17}$$

$$W_r = \frac{1}{L}\left[Wl_f - h(F_b + f_{rl}W)\right] \tag{2.18}$$

Braking

- The maximum braking force (F_{bmax}) is equal to the coefficient of road adhesion (μ) multiplied by the vehicle weight (W).
- So, in front and rear wheels maximum braking forces become

$$F_{bf\,\max} = \mu W_f = \frac{\mu W}{L}\left[l_r + h\left(\mu + f_{rl}\right)\right] \tag{2.19}$$

$$F_{br\,\max} = \mu W_r = \frac{\mu W}{L}\left[l_f - h\left(\mu + f_{rl}\right)\right] \tag{2.20}$$

- Maximum braking force would be developed when the tires are at a point of impending slide. If the tires begin to slide that means the wheels are locked and significant reduction in road adhesion will result.

Braking

- **Antilock brake system (ABS):** During braking keeps the wheels at the point of impending slide to increase the brake efficiency.

Table 2.1 Typical values of coefficients of road adhesion.

	Coefficient of road adhesion	
Pavement	Maximum	Slide
Good, dry	1.00*	0.80
Good, wet	0.90	0.60
Poor, dry	0.80	0.55
Poor, wet	0.60	0.30
Packed snow or ice	0.25	0.10

Braking

- **Braking force ratio and brake efficiency**

  The maximum braking force (F_{bmax}) is given by

$$F_{b\max} = F_{bf\max} + F_{br\max} \tag{2.21}$$

  Where, F_{bfmax} equal F_{brmax} are given by Eqs. 2.19 and 2.20.

- In order to obtain the maximum braking force (F_{bmax}), braking system must so distribute the braking force between the vehicle's front and rear brakes that the braking force at front wheels is exactly F_{bfmax} given by Eq. 2.19 and the braking force at rear wheels is exactly F_{brmax} given by Eq. 2.20.

Braking

- In such a case the ratio of F_{bfmax} to F_{brmax} is maximized and this ratio is called as maximum brake force ratio ($BFR_{fr\,max}$)

$$BFR_{fr\max} = \frac{F_{bf\max}}{F_{br\max}} = \frac{l_r + h(\mu + f_{rl})}{l_f - h(\mu + f_{rl})} \tag{2.22}$$

If this ratio is satisfied then maximum braking force will be developed. This is typically done by correct allocation of hydraulic pressure to front and rear brake mechanisms of the vehicle.

So called **electronic brake distribution (EBD)** systems of modern vehicles provides such brake application improving brake efficiency.

Braking

- When maximum braking force applied the vehicle will decelerate at the maximum rate. This condition can be expressed by

$$F_{b\max} = \mu W = m.a_{\max} \tag{2.23}$$

Where, a_{max} = the maximum deceleration rate.

Eq.2.23 can be rewritten as

$$\mu.m.g = m.a_{\max} \tag{2.24}$$

or

$$\mu = \frac{a_{\max}}{g} \tag{2.25}$$

Braking

- The road adhesion which is equivalent to the ratio of a_{max} to g can be defined as the maximum attainable deceleration in g units (g_{max}).
- The maximum deceleration rate a_{max} and hence g_{max} are achievable if and only if the maximum braking force is produced by the braking system of the vehicle.

Braking

- **Example 2.1:** A car has a wheelbase of 2.50 m and a center of gravity that is 1.0 m behind the front axle at a height of 0.60. If the car is travelling at 130 km/h on a road with poor and wet pavement, determine the percentage of braking force that should be allocated to the front and rear brake by the vehicle's brake system to ensure the maximum braking force is developed.

$$f_{rl} = 0.01\left(1 + \frac{130/3.6}{44.73}\right) = 0.18$$

μ = 0.6 (from table 2.1). Applying Eq. 2.22

$$BFR_{fr\max} = \frac{150 + 60(0.6 + 0.18)}{100 - 60(0.6 + 0.18)} = 2.97$$

Since $BFR_{fr\ max} = F_{bfmax}/F_{brmax}$, about 75% of the braking fore is allocated to front wheels and 25 % is allocated to rear wheels.

Braking

- The above example problem that it is not an easy task to design vehicle braking system to provide appropriate brake force proportioning and thus maximum braking force.

- A brake efficiency term is defined since true optimal brake force distribution is seldom achieved by standard brake systems. The brake efficiency is defined as the ratio of the maximum rate of deceleration expressed in g's (g_{max}) achievable prior to any wheel lock up to the coefficient of road adhesion (μ).

$$\eta_b = \frac{g_{\max}}{\mu} \tag{2.26}$$

Braking

where,

η_b = braking efficiency

g_{max} = a/g : maximum deceleration in g units (maximum = μ)

μ = road adhesion

- Note once more that g_{max} in Eqs. 2.26 is not the absolute maximum value defined for maximum brake efficiency. For maximum brake efficiency (i.e. η_b =1), a will attain its absolute maximum value (a_{max}) and g_{max} will be equal μ.

- Then, the braking force for a given road efficiency (η_b) can be written as

$$F_b = \eta_b.\mu.W = m.a \qquad (2.27)$$

Theoretical Braking Distance

- In the case of braking a factor to account for the moments of inertia is introduced to the equation of motion. Referring to Fig 2.2 the equation of motion for braking can be written as

$$F_{net} = F_b + \sum R = \gamma_b ma \qquad (2.28)$$

Where, γ_b = mass factor accounting for moments of inertia during braking which has the value of 1.04 for automobiles.

- The last equation can be rewritten as

$$F_{net} = \gamma_b m \frac{dV}{dt} \quad \text{or} \quad dt = \frac{\gamma_b m dV}{F_{net}} \qquad (2.29)$$

Theoretical Braking Distance

- Integration gives the time for braking as

$$t = \gamma_b m \int_{V_1}^{V_2} \frac{dV}{F_{net}} = \gamma_b m \int_{V_1}^{V_2} \frac{dV}{F_b + \sum R} \tag{2.30}$$

where, V_1 is the initial speed and V_2 is the final speed.

- Braking distance (d_b) then can be calculated by

$$d_b = \gamma_b m \int_{V_1}^{V_2} \frac{V dV}{F_b + \sum R} \tag{2.31}$$

Theoretical Braking Distance

- Substituting the expression for resisting forces (aerodynamic resistance is neglected)

$$d_b = \gamma_b m \int_{V_1}^{V_2} \frac{V dV}{F_b + f_{rl} W \pm WG} \tag{2.32}$$

- Letting $m = W/g$ and $F_b = \eta_b \mu W$, expression can be written as

$$d_b = \gamma_b \frac{1}{g} \int_{V_1}^{V_2} \frac{V dV}{\eta_b \mu + f_{rl} \pm G} \tag{2.33}$$

where, g is the gravitational constant (9.807 m/s^2).

Theoretical Braking Distance

- Since the coefficient of rolling resistance (f_{rl}) is function of speed (V), there is no closed form solution of the integral in Eq. 2.33.
- In order to have a closed form solution, the coefficient of rolling resistance is assumed to be constant and approximated by assigning the speed V in Eq. 2.4 the value of average of initial and final speeds (i.e. $V=(V_1+V_2)/2$). Then,

$$d_b = \frac{\gamma_b (V_1^2 - V_2^2)}{2g(\eta_b \mu + f_{rl} \pm G)} \tag{2.34}$$

- By taking $V_2 = 0$ the expression for theoretical stopping distance (S) will be obtained as

$$d_s = \frac{\gamma_b V_1^2}{2g(\eta_b \mu + f_{rl} \pm G)} \tag{2.35}$$

Theoretical Braking Distance

- **Example 2. :** A new experimental car is travelling at 145 km/h down a 10% grade. The coefficient of road adhesion is 0.7. The car has an advanced antilock braking system that gives it a braking efficiency of 100%. Determine the theoretical minimum stopping distance.

  <u>Solution:</u>

$$f_{rl} = 0.01\left[1 + \frac{\frac{145/3.6 + 0}{2}}{44.73}\right] = 0.0145$$

$$d_b = \frac{1.04 * (145/3.6)^2}{2(9.807)(1.0 * 0.7 + 0.0145 - 0.1)}$$

$$d_b = 139.87\ m$$

Theoretical Braking Distance

- **Example 2.3:** A car with braking efficiency of 80% is travelling at 120 km/h on a road surface where the coefficient of road adhesion is 0.85. The brakes are applied to miss an object that is 45 m from the point of brake application. Ignoring aerodynamic resistance and assuming theoretical minimum stopping distance, estimate how fast the car will be going when it strikes the object if (a) the surface is level, (b) the surface is on 5% upgrade.

  Solution:

  V_1 = 120 km/hr (120/3.6 m/s)

  V_{av} = (120/3.6 + V_2)/2

Theoretical Braking Distance

- **Example 2.3 (continued)**

In both cases rolling resistance will be approximated by

$$f_{rl} = 0.01\left[1 + \frac{\left(\frac{120/3.6 + V_2}{2}\right)}{44.730}\right] = 0.014 + 0.000112\,V_2$$

a) Applying Eq. 2.33 for G=0 and γ_b=1.04,

$$45 = \frac{1.04\left[\left(\frac{120}{3.6}\right)^2 - V_2^2\right]}{2(9.807)[0.8(0.85) + (0.014 + 0.000112V_2) \pm 0]}$$

V_2 = 21.32 m/s (76.0 km/h)

Theoretical Braking Distance

- **Example 2.3 (continued)**

b) Applying Eq. 2.33 for G= 0.05 and γ_b=1.04,

$$45 = \frac{1.04\left[\left(\frac{120}{3.6}\right)^2 - V_2^2\right]}{2(9.807)[0.8(0.85) + (0.014 + 0.0001118V_2) + 0.05]}$$

V_2 = 20.18 m/s (72.7 km/h)

Practical Braking Distance

- For practical expression for braking distance the basic physics equation on rectilinear motion is taken as the basis by assuming constant deceleration:

$$d_b = \frac{V_2^2 - V_1^2}{2a} \qquad (2.36)$$

Where,

V_1 = initial vehicle speed (m/s),
V_2 = final vehicle speed (m/s),
d_b = deceleration distance (braking distance) (m).

Practical Braking Distance

- Assuming a is negative for deceleration and replacing the acceleration term (a) by force (F_{net}) to mass (m) ratio gives the expression for braking distance as

$$d_b = m\frac{V_1^2 - V_2^2}{F_{net}} \tag{2.37}$$

- For practical braking distance, constant force acting on the vehicle is assumed to be composed of braking force and grade resistance only by neglecting aerodynamic resistance and rolling resistance.

$$d_b = \frac{V_1^2 - V_2^2}{2g(\eta_b \mu \pm G)} \tag{2.38}$$

Practical Braking Distance

- And the practical stopping distance (d_s) will be

$$d_s = \frac{V_1^2}{2g(\eta_b \mu \pm G)} \tag{2.39}$$

- Note that, Eq. 2.38 for practical braking distance is consistent with Eq. 2.34 given for theoretical braking distance.

Practical Braking Distance

- For the practical braking distance again coefficient of road adhesion (μ) and brake efficiency (η_b) or alternatively their product $\eta_b\mu = g_{max}$ (from Eq. 2.26) should be determined. However, for practical purposes, instead of determining the maximum deceleration rate in g's ($g_{max} = a_{max}/g$) for a specific vehicle efficiency and specific road adhesion, AASHTO recommends a maximum deceleration rate of 0.35 g's (or a_{max} = 3.4 m/s^2). Then

$$d_b = \frac{V_1^2 - V_2^2}{2g(0.35 \pm G)} \tag{2.40}$$

- And braking distance to stop is given by

$$d_s = \frac{V_1^2}{2g(0.35 \pm G)} \tag{2.41}$$

Stopping Sight Distance

- In order to provide sufficient sight distance for a driver to stop safely it is necessary to consider the distance travelled by the vehicle during perception and reaction time of the driver.

$$d_r = V_1 \ x \ t_r \tag{2.42}$$

where,

(d_r) = distance travelled during perception/reaction time (m)
V_1 = initial vehicle speed (m/s)
t_r = perception/reaction time (s)

- The perception/reaction time varies from person to person.

Stopping Sight Distance

- It is a function of a number of human factors such as
  - the driver's age,
  - physical condition and emotional state,
  - and environmental factors such as visibility, time of day, weather conditions, as well as the complexity of the situation and the strength of the stimuli requiring a stopping action.

- The perception/reaction time varies from person to person and the range is about 1.0 to 1.5 s,

- AASHTO recommends a highly conservative perception reaction time, 2.5 s, for design purpose.

Stopping Sight Distance

- With considering the perception and reaction time of the deriver total required stopping distance (d_s) is the summation of the braking distance either theoretical (Eq. 2.35) or practical and the distance travelled during perception/reaction time (Eq. 2.41)

$$S_s = d_s + d_r \tag{2.43}$$

Where,

S_s = total stopping distance (Stopping Sight Distance (m)
d_s = distance travelled during braking to stop (m)
d_r = distance travelled during perception/reaction time (m)

- Total stopping distance (stopping sight distance) is one of outmost importance in designing horizontal and vertical highway curves and its use will be discussed later in this chapter. Table 2.2 gives the design values recommended by AASHTO.

Stopping Sight Distance

Table 2.2 Stopping sight distance on level and on grades (AASHTO 2004)

Design Speed (km/h)	Brake reaction distance (m)	Braking distance on level (m)	Stopping sight distance On Level		Stopping sight distance (m) Downgrades			Stopping sight distance (m) Upgrades		
			Calculated (m)	Design (m)	3%	6%	9%	3%	6%	9%
20	13.9	4.6	18.5	20	20	20	20	19	18	18
30	20.9	10.3	31.2	35	32	35	35	31	30	29
40	27.8	18.4	46.2	50	50	50	53	45	44	43
50	34.8	28.7	63.5	65	66	70	74	61	59	58
60	41.7	41.3	83.0	85	87	92	97	80	77	75
70	48.7	56.2	140.9	105	110	116	124	100	97	93
80	55.6	73.4	129.0	130	136	144	154	123	118	114
90	62.6	92.9	155.5	160	164	174	187	148	141	136
100	69.5	114.7	184.2	185	194	207	223	174	167	160
110	76.5	138.8	215.3	220	227	243	262	203	194	186
120	83.4	165.2	248.6	250	263	281	304	234	223	214
130	90.4	193.8	284.2	285	302	323	350	267	254	243

Note: Perception reaction distance predicated on a time of 2.5 s; deceleration rate of 3.4 m/s^2 used to determine braking distance.

Stopping Sight Distance

- **Turkish Practice for stopping sight distance**

Turkish General Directorate of Highways adopted exactly the practical braking distance given by Eq. 2.41 suggested by AASHTO to calculate the braking distance by replacing the speed term V_1 by the design speed (V_d).

$$S_s = V_d t_r + \frac{V_d^2}{2g(0.35 \pm G)} \qquad (2.44)$$

Where, V_d = design speed (m/s), and all others are as defined before.

Stopping Sight Distance

- **Turkish Practice for stopping sight distance (continued)**

  The equation can be rewritten in the following form by using accustomed speed unit, km/hr, and replacing *g* by its numeric value

$$S_s = 0.278V_d + \frac{V_d^2}{254(0.35 \pm G)} \qquad (2.45)$$

  On the other hand, the perception reaction time (t_r) for calculating the distance travelled during perception/reaction is taken as 2.0 seconds. Minimum stopping sight distances for design purpose are given on Table 2.3.

Stopping Sight Distance

- **Turkish Practice for stopping sight distance (continued)**

Table 2.3 Minimum Stopping sight distances (Turkish Practice, AASHTO 2001)

Design Speed (km/h)	Stopping sight distance		Stopping sight distance (m)					
	On Level		Downgrades			Upgrades		
	Calculated (m)	Design (m)	3%	6%	9%	3%	6%	9%
20	15.7	20	17	17	18	16	15	15
30	27.0	30	28	30	31	27	26	25
40	40.6	45	42	45	47	39	38	37
50	56.5	60	59	63	67	54	52	51
60	74.7	75	79	83	89	71	69	66
70	95.1	100	100	107	115	91	87	84
80	117.9	120	125	133	143	112	107	103
90	143.0	145	151	162	175	135	129	124
100	170.3	175	180	193	210	161	153	146
110	200.0	200	212	228	247	188	179	171
120	231.3	235	246	265	288	218	207	197
130	266.1	270	283	305	332	249	236	225

Passing Sight Distance

- Passing operation is mainly critical on two-lane, two way highways.

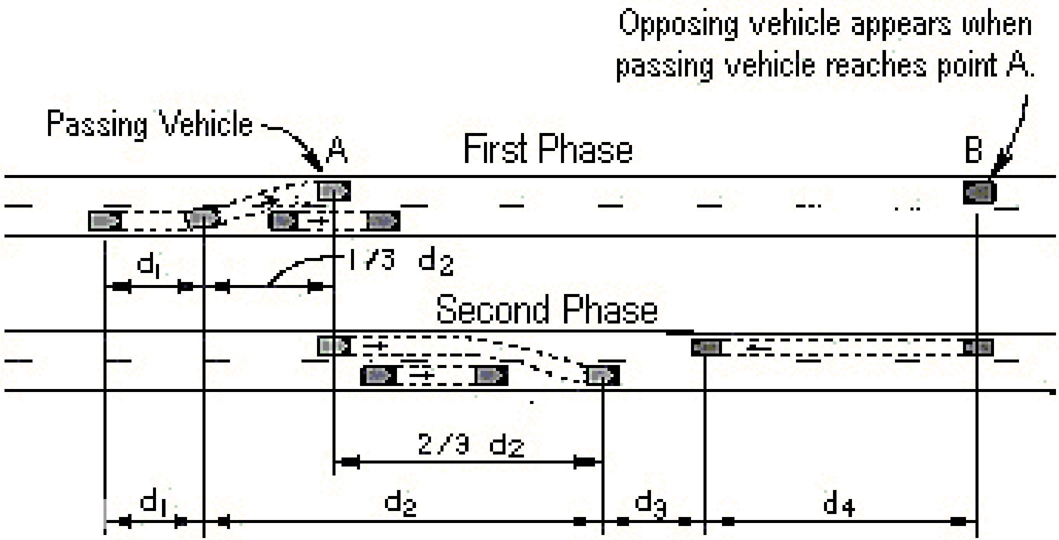

Figure 2.3 Components of passing sight distance

Passing Sight Distance

- The following assumptions are made concerning driver behavior in passing (AAHTO, 2001)
  1. The overtaken vehicle travels at uniform speed.
  2. The passing vehicle has reduced speed and trails the overtaken vehicle as it enters a passing section.
  3. When passing section is reached, the passing driver needs a short period of time to perceive the clear passing section and react to start his or her maneuver.
  4. Passing is accomplished under that way may be termed a delayed start and hurried return in the face of opposing traffic. The passing vehicle accelerates during the maneuver, and its average speed during the occupancy of the left lane is 15km/h higher than that of the overtaken vehicle.
  5. When the passing vehicle returns to its lane, there is a suitable clearance between it and an oncoming vehicle in the other lane.

Passing Sight Distance

- With these assumptions AASHTO defines four distances shown in Fig. 2.3 as follows

d_1 = **Initial maneuver distance (m):** distance travelled during perception and reaction time and during the initial acceleration to the point of encroachment on the left lane. It is calculated by

$$d_1 = 0.278 t_1 \left(V - m + \frac{a t_1}{2} \right) \tag{2.46}$$

d_2 = **Distance while passing vehicle occupies left lane (m):** distance travelled while the passing vehicle occupies left lane and given by

$$d_2 = 0.278 V t_2 \tag{2.47}$$

Passing Sight Distance

d_3 = **Clearance length (m)**: distance between the passing vehicle at the end of its maneuver and the opposing vehicle. The design values are given in tabular form.

d_4 = **distance traversed by an opposing vehicle (m):** for two-thirds of the time the passing vehicle occupies the left lane or $2/3d_2$.

Where,

t_1 = time of initial maneuver (s),

a = average acceleration (km/h/s),

V = average speed of passing vehicle (km/h),

m = difference in speed of passed and passing vehicle (km/h),

t_2 = time passing vehicle occupies the left lane (s).

Passing Sight Distance

- Hence the passing sight distance (S_p) will be the summation of these four distances:

$$S_p = d_1 + d_2 + d_3 + d_4 \qquad (2.48)$$

  Values d_1 through d_4 determined through studies of actual passing behavior form the basis for the AASHTO recommendations for passing sight distances on two-lane highways.

  Table 2.4 is prepared by using durations recommended by AASHTO.

- Turkish highway authority, General Directorate of Highways adopts AASHTO recommendations.

Passing Sight Distance

Table 2.4 Passing sight distance for two lane highways

Design Speed, km/hr	Accepted speed (km/h)		Passing Sight Distance (m)	
	Vehicle being passed	Passing Vehicle	Calculated Value	Rounded Value
30	29	44	200	200
40	36	51	266	270
50	44	59	341	345
60	51	66	407	410
70	59	74	482	485
80	65	80	538	540
90	73	88	613	615
100	79	94	670	670
110	85	100	727	730
120	90	105	774	775
130	94	109	812	815

Passing Sight Distance

- **Example 2.4**

  For the design speed of 70 km/hr, AASHTO suggests the following values for the parameters to calculate passing sight distance

  $t_1 = 4.10$ s,
  $a = 2.32$ km/h/s,
  $t_2 = 10.40$ s,
  $d_3 = 53.0$ m

  Calculate the necessary passing sight distance.

Passing Sight Distance

<u>Solution</u>:

From Table 2.4; V = 74.0 km/h and (V-m) = 59.0 km/h.

Then, using Eqs 2.46 and 2.47;

$$d_1 = 0.278 * 4.10 * (59.0 + 4.10 * 2.32/2) = 72.67 \text{ m}$$
$$d_2 = 0.278 * 74.0 * 10.4 = 213.95 \text{ m}$$
$$d_4 = 2/3 * (213.95) = 142.63 \text{ m}$$

And it follows

$$S_p = d_1 + d_2 + d_3 + d_4$$
$$S_p = 72.67 + 213.95 + 53.0 + 142.63 = 482.25 \text{ m}$$

Note that, for design purpose ASSHTO rounds up this value and takes S_p = 485 m.