GEOMETRIC DESIGN (Ch. 2)

Rectilinear Motion

$v = at + v_0$

$\frac{1}{2}(v^2 - v_0^2) = a(x - x_0)$

$x = \frac{1}{2}at^2 + v_0 t + x_0$

Breaking Distance

$\left(\frac{W}{g}\right)a + Wf\cos\alpha + W\sin\alpha = 0$

$a = (v^2 - v_0^2)\frac{\cos\alpha}{2D_b}$ $G = \tan\alpha$

$D_b = x\cos\alpha$ $D_b = \frac{v_0^2 - v^2}{2g(f \pm G)}$

$f = 0.6$ DRY

$f = 0.3$ WET

Curvilinear Motion

$a_n = \frac{v^2}{\rho}$ $\Sigma F_n = \frac{mv^2}{\rho}$

$e + f_s = \frac{v^2}{gR}(1 - f_s e)$

$e = \tan\beta$ → minimum angle

$ef_s = 0$ for typical highway

Lateral Displacement

$l = a\cot\theta$ $\frac{dl}{dt} = -v$

$\frac{dl}{dt} = -a\csc^2\theta\frac{d\theta}{dt}$

$\csc^2\theta = \frac{a^2 + l^2}{a^2}$ a is lateral separation

$\frac{d\theta}{dt} = \frac{va}{a^2 + l^2}$

Dilemma Zone

distance to clear intersection

$X + W + L$ (to sect. / width xsect. / length car)

For successful stopping

$\underbrace{X - v_0\delta_2}_{\text{max } D_b} \geq \underbrace{\frac{v_0^2}{2a_2}}_{D_b @ a_2}$ $X_c = v_0\delta_2 + \frac{v_0^2}{2a_2}$ ← min dist. to stop comfortably

$a_1 = \frac{2x}{(\tau - \delta_1)^2} + \frac{2(W + L - v_0\tau)}{(\tau - \delta_1)^2}$ ← a to clear intersection

$X_0 = v_0\tau - (W + L)$ ← max x to clear w/o accel.

$\tau_{min} = \delta_2 + \frac{v_0}{2a_2} + \frac{W + L}{v_0}$ ← min amber for $x_0 = x_c$

$L_D = X_c - X_0$ ← length dilemma zone

Design Radius $e + f_s = \frac{V^2}{gR}$ $R_{min} = \frac{V^2}{g(e_{max} + f_{smax})}$

$\frac{mi}{hr}$ & ft; imperial: $g = 15$

$\frac{km}{hr}$ & m; metric: $g = 127$

$e_{des} = \frac{V^2}{gR} - f_s$ $R > R_{min}$

Horizontal Alignment

$D = \frac{180A}{\pi R}$ (highway) $\sin\left(\frac{D}{2}\right) = \frac{A}{2R}$ (railway)

D – degree of curve $L = 2\pi R\left(\frac{\Delta}{360}\right)$

Δ – intersecting angle $L = \frac{A\Delta}{D}$

E – external distance $T = R\tan\left(\frac{\Delta}{2}\right)$

M – middle ordinate $E = R\left(\sec\left(\frac{\Delta}{2}\right) - 1\right)$

T – tangent length $M = R\left(1 - \cos\left(\frac{\Delta}{2}\right)\right)$

L – curve length $LC = 2R\sin\left(\frac{\Delta}{2}\right)$

LC – long chord $PC = PI - T$

$PT = PC + L$

Vertical Alignment

$A = G_2 - G_1$ (%)

$K = \frac{L}{|A|}$

$E = \frac{AL}{800}$

$x = \frac{LG_1}{G_1 - G_2}$ $(x \geq 0)$

$y = 4E\left(\frac{x}{L}\right)^2$ (+) – sag, (–) – crest

$P_{elev} = \left[VPC_{elev} + \left(\frac{G_1}{100}\right)x\right] + y$

Stopping Sight Distance

horiz: $\theta = \frac{90 SSD}{\pi R}$ $C = R(1 - \cos\theta)$ $SSD = v_0\delta + D_b$

crest:

$L = \frac{|A| SSD^2}{200(\sqrt{h_1} + \sqrt{h_2})^2}$ $(SSD \leq L)$ $h_1 = 1.05$m (3.5 ft), $h_2 = 0.6$m (2 ft)

$L = 2SSD - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{|A|}$ $(SSD \geq L)$

sag:

$L = \frac{|A| SSD^2}{200(h + S\tan\beta)}$ $(SSD \leq L)$ $h = 0.6$m (2 ft), $\beta = 1°$

$L = 2SSD - \frac{200(h + SSD\tan\beta)}{|A|}$ $(SSD \geq L)$

$S > L$ impractical

Passing Sight Distance

d_1 – percep.-rxn dist $d_1 = 1.47t_1\left[v_{avg} - m + \frac{at_1}{2}\right]$ ← Δv vehicles

d_2 – dist. while in left lane $d_2 = 1.47vt_2$

d_3 – dist. b/w pass & opposing after pass $d_3 = 100 - 300$ ft

d_4 – dist. opp. travels $d_4 = \frac{2}{3}d_2$

Vertical Curves

1) Find L_{min}
2) Find VPI sta & VPI elev
3) Find VPC sta & VPT sta
4) Compute offsets (y) [1st whole sta then +1 sta]
5) Compute elevations
6) Location & elev of high/low point

Superelevation runoff is from when adverse crown is removed to full superelevation

Tangent runout is from the normal crown to when adverse crown is removed

1 mi = 1.60934 km

1 m = 3.28084 ft

$1\frac{m}{s} = 3.6\frac{km}{hr}$

$1\frac{mi}{hr} = 0.44704\frac{m}{s}$

1 mi = 5280 ft

TRAFFIC STREAM FLOW MODELS (Ch. 5)

Spacing

$x_L = \frac{v^2}{2d_L}$

$x_f = v\delta + \frac{v^2}{2d_f}$

d - deceleration
x_0 - safety margin
L - car length
N - # vehicles in train

$x_f = S + x_L - NL - x_0$

$S = v\delta + \frac{v^2}{2d_f} - \frac{v^2}{2d_L} + NL + x_0$

$S = \frac{1}{K}$

$h = \frac{\text{constant } S}{\text{constant } v}$

time headway

$h = \frac{1}{q}$

$u_t = \frac{1}{N}\sum_1^N v_i$ → time mean speed (spot speeds)

$t_i = \frac{D}{v_i}$ $u_s = \frac{D}{t_{ave}} = \frac{1}{\frac{1}{N}\sum_1^N \frac{1}{v_i}}$

space mean speed (avg time)

when $\frac{dq}{dK} = 0$, it's q_{max} when $u = 0$, it's K_j

Fundamental Eqn

$h = \frac{S}{u} = t$ $h = \frac{1}{q}$

$S = \frac{1}{K} = hu$ $\frac{1}{q}u = \frac{1}{K}$

$q = uK$

q = flow (veh/h)
u = speed (dist./s)
K = concentration (veh/dist.)

Moving Observer

$q = \frac{N_0}{T}$ → stationary obs. moving vehicle

$N_p = KVT$ (stationary traffic, moving observer)

observer speed

$M = M_0 - M_p = qT - KVT$
moving observer in traffic

From two tests (w-with; a-against)

$\frac{M_w}{T_w} = q - KV_w$ $\frac{M_a}{T_a} = q + KV_a$ $V_w T_w = V_a T_a = l$

$q = \frac{M_w + M_a}{T_w + T_a}$ $u = \frac{L}{T_w - \frac{M_w}{q}}$ space mean speed

$T_{ave} = T_w - \frac{M_w}{q} = \frac{L}{u}$

$K = \frac{q}{u}$

$-M_w$: $T_{ave} > T_w$
$+M_w$: $T_{ave} < T_w$
ϕ M_w: $T_{ave} = T_w$

Shockwave

$u_{sw} = \frac{q_b - q_a}{k_b - k_a}$

(+) - direction of flow
(-) - opposite of flow
ϕ - stationary

rate of growth of platoon $= u_{sw_1} - u_{sw_2}$

platoon = (rate)(time)

Fundamental Graphs (y-x)

u-K : inversely proportional
u-q : sideways parabola
q-K : parabola?

K_j is when $u = \phi$

q_{max} is at u_{max} & $\frac{dq}{dK} = \phi$

CAPACITY & LEVEL OF SERVICE (Ch. 7)

Freeway is N = 2
Two-lane highway is N = 1

Capacity & LOS Analysis

1) FFS, S, D, LOS
2) v_p, S, D, LOS

Determining FFS

not adjusted if field

$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$

- BFFS: 110 (urban), 120 (rural)
- f_{LW}: lane width
- f_{LC}: lat. clear.
- f_N: # lanes (∅ rural)
- f_{ID}: interchange density

$$\text{interchange density} = \frac{1}{\text{interchange spacing}}$$

f_{LW}	TABLE 2
f_{LC}	TABLE 3
f_N	TABLE 4
f_{ID}	TABLE 5
ext. seg. f_{HV}	TABLE 6
upgrade f_{HV}	TABLE 7
upgrade f_{HV}	TABLE 8
downgrade f_{HV}	TABLE 9

Determining Flow Rate

$$v_p = \frac{V}{PHF\, N\, f_{HV}\, f_p}$$

V ← volume; PHF: peak hour factor; f_{HV}: heavy veh.; f_p: driver pop.

$$PHF = \frac{V}{V_{15}(4)}$$ ↑ urban ↓ rural

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

* RVs treated as if level *
* on downgrade *

Determining LOS

1) Given v_p & FFS: Find S FIGURE 1

↳ For $90 < FFS \le 120$ & $(3100 - 15FFS) < v_p \le (1800 + 5FFS)$

$$S = FFS - \left[\frac{1}{28}(23FFS - 1800)\left(\frac{v_p + 15FFS - 3100}{20FFS - 1300}\right)^{2.6}\right]$$

↳ For $90 < FFS \le 120$ & $v_p \le (3100 - 15FFS)$

$$S = FFS$$

2) Calculate density

$$D = \frac{v_p}{S}$$ pc/km/ln = (pc/hr/ln) / (km/hr)

3) Determine LOS TABLE 1

TWO-LANE HIGHWAYS

- Class I: long ATS & PTSF
- Class II: local PTSF

Capacity

1700 pc/hr/direction
(3200 for both direct.)

FFS Class I

→ field: only adjust if > 200 pc/hr

$$FFS = S_{FM} + 0.0125\frac{V_f}{f_{HV}}$$

S_{FM}: mean traffic speed; V_f ← veh/hr

→ estimating

$$FFS = BFFS - f_{LS} - f_A$$

BFFS: may be posted limit; f_{LS}: lane & shoulder; f_A: access pts (BOTH SIDES)

Flow rate (I & II)

$$v_p = \frac{V}{PHF\, f_G\, f_{HV}}$$

iteration required

1) set $v_p = \frac{V}{PHF}$
2) Calc new v_p w/ adj.
3) Check if same adj.
4) Repeat until same

ATS Class I

$$ATS = FFS - 0.0125v_p - f_{np}$$

f_{np}: no passing zone

PTSF (I & II)

$$PTSF = BPTSF + f_{d/np}$$

$$BPTSF = 100\left[1 - e^{-0.000879v_p}\right]$$

LOS (I)	TABLE 1
LOS (II)	TABLE 2
FFS f_{LS}	TABLE 3
FFS f_A	TABLE 4
ATS f_G	TABLE 5a
PTSF f_G	TABLE 5b
ATS f_{HV}	TABLE 6a
PTSF f_{HV}	TABLE 6b
ATS f_{np}	TABLE 7a
PTSF $f_{d/np}$	TABLE 7b

METHOD FOR LOS

1) calculate FFS
2) Calculate v_p
3) Calculate PTSF
4) Calculate ATS (Class I)
5) Find LOS

* if 2-way v_p > 3200 pc/hr – LOS F
* if v_p * directional split > 1700 pc/hr – LOS F

PAVEMENT DESIGN (Ch. 5)

$M_r = \frac{\Delta(\sigma_1 - \sigma_3)}{\varepsilon_{1,r}}$

Standard Axle
→ 80 kN (18000 lb)

traffic load is determined in terms of # of repeated 80 kN single-axle loads applied to pavement on two sets of dual tires

ESAL

Traffic factor = $\frac{\sum ESAL}{\# \text{vehicles}}$

ESAL = (#axles)(load eq. factor)

$ESAL_i = f_d G_{jt} AADT_i (365) N_i FE_i$

$ESAL = \sum ESAL_i$

w/ truck factors

$ESAL_i = AADT_i (365) f_i G_{jt} f_d$

f_d - design lane factor
G_{jt} - growth factor
$AADT_i$ - 1st year annual avg daily traffic
N - # axles per vehicle
FE_i - load equivalency factor

FLEXIBLE PAVEMENT DESIGN

Surface - mineral agg. & asphalt - prevents water penetration
- distributes load, resists abrasion - varies 3-6 in

Granular base - crushed stone, gravel, sand & slag - distributes stress
- foundation to surface - protects surface against volume change

Subbase - granular material - can be excluded if subgrade is good - protects base against vol change
- reduces stress applied in subgrade - water drainage

Subgrade - natural materials - foundation of structure

- avoid overloading subgrade
- avoid overloading all layers
- maintain good serviceability along pavement design life
- usually 20 years

$PSI = 5.03 - \log(1+\underbrace{SV}_{\text{slope variance}}) - 1.38(\underbrace{RD}_{\text{rut depth}})^2 - 0.01(\underbrace{C}_{\text{cracking}}+\underbrace{P}_{\text{patching}})^{1/2}$

AASHTO design method

Structural number $SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$

m - drainage coefficient
a_1, a_2, a_3 - layer coefficients (surface, base, subbase)
D - thickness
SN can be converted to thickness

1) Determine total ESAL for period
2) Determine design serviceability loss $\Delta PSI = P_i - P_t$
3) Determine effective M_r (subgrade), M_r (subbase & base) and layer coefficients (a_1, a_2, a_3)
4) Determine drainage coefficients $(m_2 \& m_3)$
5) Select reliability (R) & overall standard deviation (S_o)
6) Read SN from FIGURE 1
7) Calculate D

HOW TO USE FIGURE 1

1) Draw line joining R & S_o, extend to first T_L
2) Draw line from T_L to ESAL, extend to second T_L
3) Draw line from T_{L_2} to M_r, extend to graph
4) Interpolate SN

S_o
Flexible (0.40 - 0.5)
Rigid (0.3 - 0.4)

Initial serviceability = 4.5
terminal serviceability = 2.5

At Step (2)
For subgrade

$M_r = 1500\,CBR$ (lb/in²)
$M_r = 220\,CBR$ (kN/m²)
} fine-grained soils w/ CBR ≤ 10

$M_r = 1000 + 555R$ (lb/in²)
$M_r = 145 + 80.4R$ (kN/m²)
} for R ≤ 20

At Step (7)
→ use M_r of base for SN_1
→ use M_r of subbase for SN_2
→ use M_r of subgrade for SN_3