Solutions Manual

TRANSPORTATION ENGINEERING AND PLANNING

THIRD EDITION

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NOTE TO THE INSTRUCTOR

This booklet supplements the 3rd edition of TRANSPORTATION ENGINEERING AND PLANNING. It contains solutions to exercises which require numerical calculations as well as selected answers to questions which elicit qualitative treatment. Solutions are not given for the computer programming of exercises because they can be programmed in Basic, Fortran, Pascal, C, C++, etc. or with commands in Excel or Lotus spreadsheet software.

Chapters 1 and 15 do not contain exercises. All exercises in Chapter 7 are essay type, thus, no essays are provided in this solutions manual. The open ended questions of Chapter 7 (and of other Chapters) intend to help the students appreciate the wide context of transportation engineering and planning, to develop tolerance to ambiguity, and to hone the ability to think critically. We consider these important elements which need to be cultivated and we are convinced that introductory transportation course(s) based on this textbook are effective means for accomplishing the task for developing and cultivating such skills to our students.

Requiring students to conduct research and to report on cases and issues pertinent to the students' locale is an excellent way to achieve an understanding of the more elusive concepts covered in the textbook. In line with this thesis, the students should be encouraged to interpret the results of quantitative exercises.

The use of computers by engineering and planning students has become essential. A good sense of proportion dictates (a) some computer programming in a basic computer language such as Fortran or C++, (b) hands-on experience with existing traffic and transportation software, (c) use of spreadsheets for analysis –including basic statistical modeling– and chart-making, and (d) use of presentation and word-processing software for the delivery of homework and class presentations.

Your comments on both the textbook and the exercises are always welcome and much appreciated. Although it is said that a perfect manuscript tends to develop defects in the publication process, in actuality, any errors and omissions are the sole responsibility of the authors.

Thank you for selecting our textbook for your course.

Constantinos S. Papacostas
Panos D. Prevedouros
(Honolulu, June 1999)

2/1 $v_o = 12$ mi/h $= 17.6$ ft/s and $x_o = 0.0$ ft.

Interval $0 \leq t \leq 5$ s.

$\frac{dv}{dt} = a = t$ ft/s^2. By integration, $v = \frac{t^2}{2} + 17.6$ ft/s.

$\frac{dx}{dt} = v$ and $x = \frac{t^3}{6} + 17.6\,t + 0.0$ ft.

When $t = 5$ s, $v(5) = 30.1$ ft/s and $x(5) = 108.8$ ft.

Interval $5 \leq t \leq 15$ s or $0 \leq (t - 5) \leq 10$

$\frac{dv}{dt} = a = 5$ ft/s^2 and $v = 5(t - 5) + 30.1$ ft/s.

$\frac{dx}{dt} = v$. Therefore, $x = 5\,\frac{(t - 5)^2}{2} + 30.1(t - 5) + 108.8$ ft.

When $t = 15$ s, $v(15) = 80.1$ ft/s and $x(15) = 659.8$ ft.

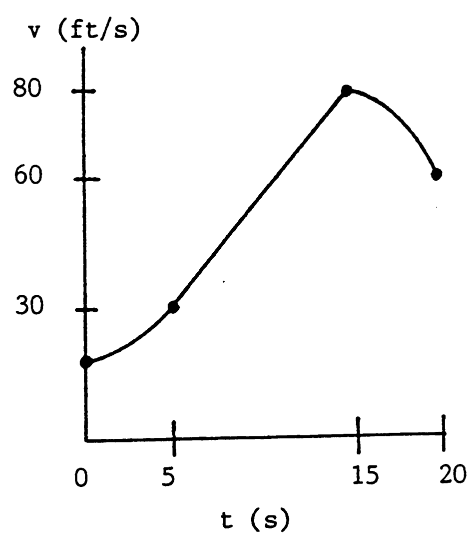
Interval $15 \leq t \leq 20$ s or $0 \leq (t - 15) \leq 5$

$\frac{dv}{dt} = a = -\frac{8}{5}(t - 15)$ ft/s^2 and $v = -\frac{8}{5}\,\frac{(t - 15)^2}{2} + 80.1$ ft/s.

$\frac{dx}{dt} = v$. Consequently, $x = -\frac{8}{5}\,\frac{(t - 15)^3}{6} + 80.1(t - 15) + 659.8$ ft.

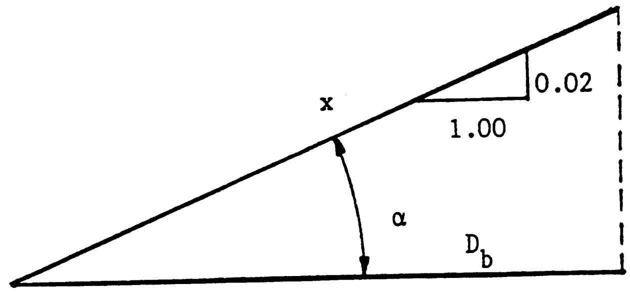
When $t = 20$ s, $v(20) = 60.1$ ft/s and $\underline{x(20) = 1027.0 \text{ ft.}}$ Answer

The relationship between speed and time is plotted below.



Note that the shape of the v–t curve can be inferred directly from the shape of the a–t diagram. At $t = 0$, the slope of the v–t diagram is zero since $a = 0$. The slope increases in a linear fashion until $t = 5$ s. Between $t = 5$ s and $t = 15$ s, the slope remains constant. At $t = 15$ s, it abruptly changes to zero, and then it decreases linearly.

2/2



From the above diagram $\tan\alpha = 0.02$ and $\alpha = 1.15°$.

Also $D_b = x \cos\alpha \simeq x$.

Eq. 2.2.6 gives $x = \frac{v^2 - v_0^2}{(2)(8)}$ and Eq. 2.2.13 yields $D_b = x = -\frac{v^2 - v_0^2}{2g(f + 0.02)}$

Therefore $16 = 2g(f + 0.02) = 64.4\ (f + 0.02)$.

Solving for the coefficient of friction, $f = 0.23$.

This value suggests a wet pavement.

2/3

Assuming the case of constant acceleration,

$$v = at + v_0 \quad \text{and} \quad (v^2 - v_0^2) = 2a(x - x_0) \qquad \text{[Eqs. 2.2.4 \& 2.2.6]}$$

The movement from the ground floor to the restaurant level involved:

Total distance = 140 ft.

Time to reach cruising velocity when $a = 5\ \text{ft/s}^2 = \frac{20}{5} = 4$ s.

Time to stop from cruising velocity when $d = 4\ \text{ft/s}^2 = \frac{20}{4} = 5$ s.

Acceleration distance = $20^2/[2(5)] = 40$ ft.

Deceleration distance = $20^2/[2(4)] = 50$ ft.

Cruising distance = $140 - 40 - 50 = 50$ ft.

Cruising time at maximum cruising speed = $50/20 = 2.5$ s.

During the movement from the restaurant level to the observation deck the elevator did not reach cruising velocity. The total distance of 20 ft consisted of accelerating (x_a) and decelerating (x_d) distances, i.e.,

$$x_a + x_d = 20 \text{ ft.}$$

2/3 (cont.)

Hence, $\frac{v^2}{2(5)} + \frac{v^2}{2(4)} = 20$ ft.

Consequently, the highest speedreached was v = 9.4 ft/s. In addition,

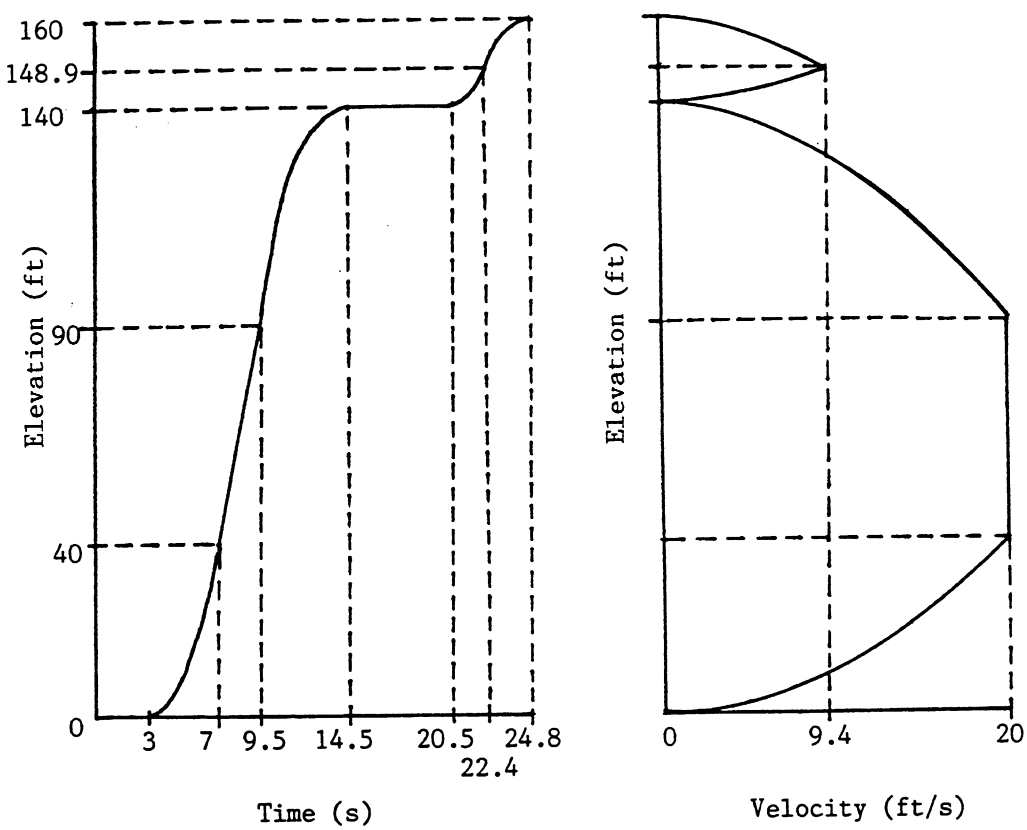
Acceleration distance ≃ 8.9 ft.

Deceleration distance ≃ 11.1 ft.

Acceleration time ≃ 1.9 s.

Deceleration time ≃ 2.4 s.

The required diagrams are drawn below.



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$A = 100$ ft^2 $\quad W = 40{,}000$ lb $\quad \alpha = 100$ lb/ft^2 $\quad \beta = 3.33$ lb/ft^2-s

a) $F = (\Delta P)A = (W/g)a$

Solve for acceleration in terms of pressure difference ΔP:

$$a = \frac{g}{W} A\ (\Delta P) = \frac{32.2}{40{,}000}(100)(\Delta P) = 0.0805(\Delta P)$$

Also, $v = \int a\ dt$ and $x = \int v\ dt$.

For simplicity, set $t_0 = 0$ and $x_0 = 0$.

2/4 (cont.)

<u>Acceleration phase</u> ($0 \leq t \leq t_1$):

$$a = 0.0805(100 - 3.33t) = 8.05 - 0.268t \quad ft/s^2$$

$$v = 8.05t - 0.268(t^2/2) + v_0 = 8.05t - 0.134t^2 \quad ft/s \qquad (Eq.1)$$

$$x = 8.05(t^2/2) - 0.134(t^3/3) + x_0 \quad ft.$$

According to the given a–t diagram, a = 0 when $t = t_1$. Consequently, $t_1 = (8.05)/(0.268) = 30$ s. At this instant, cruising velocity is attained:

$$v_{cruise} = 8.05(30) - 0.134(30)^2 = 120.9 \quad ft/s.$$

The distance traveled during the acceleration phase is $x_a = 2416.5$ ft.

<u>Deceleration phase</u> ($t_2 \leq t \leq t_3$):

$$a = 0.0805(-3.33)(t - t_2) \quad \text{where } t_2 \text{ depends on station spacing.}$$

$$v = -0.268\frac{(t - t_2)^2}{2} + v_{cruise} = 120.9 - 0.134(t - t_2)^2 \qquad (Eq.2)$$

$$(x - x_2) = 120.9(t - t_2) - 0.134\frac{(t - t_2)^2}{3}$$

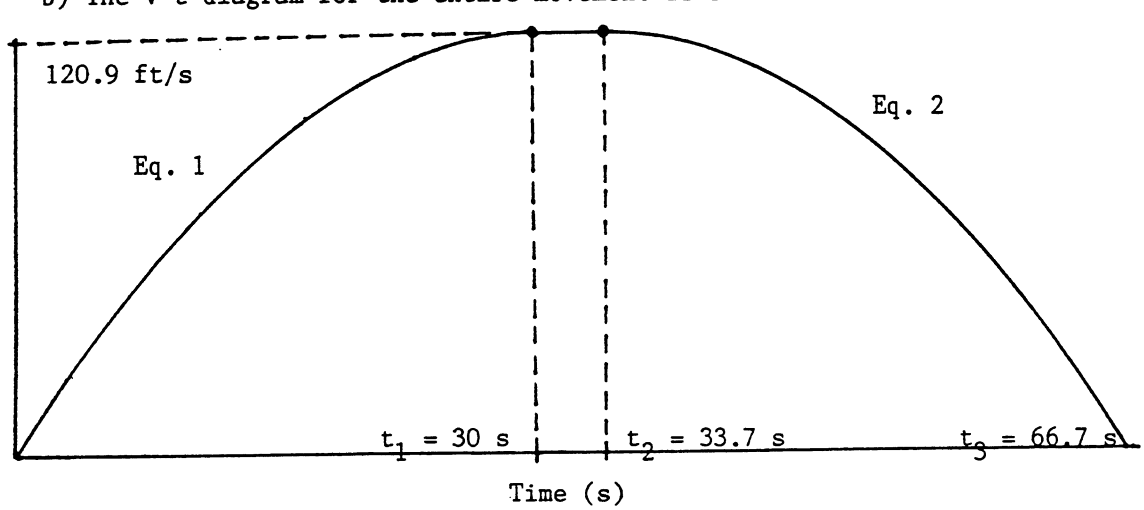
The deceleration time may be computed via Eq. 2 or by symmetry with the acceleration phase to be $(t_3 - t_2) = 30$ s. By similar reasoning, the deceleration distance x_d equals the acceleration distance x_a , that is 2416.5 ft.

<u>Cruising phase</u> ($t_1 \leq t \leq t_2$):

The total cruising distance equals the station spacing (1 mi = 5280 ft) minus $(x_a + x_b)$, or $x_{cruise} = 447$ ft. The required equations for the cruising phase are:

$$a = 0 \ ft/s^2 \qquad v = 120.9 \ ft/s \quad \text{and} \quad x = 120.9(t - 30) + 2416.5 \quad ft.$$

b) The v–t diagram for the entire movement is shown below:



2/5

The estimated speed at impact was 15 mi/h or 22 ft/s.

α = arctan 0.03 = 1.72°.

D_b = x cos 1.72° = 20 cos 1.72° = 19.99 ft ≈ 20 ft.

In the absence of a measured value for f, use 0.6 as an approximation since the pavement was dry. Using v = 22 ft/s and G = +0.03, apply Eq. 2.2.13 to find v_0 = 36 ft/s ≈ 24.5 mi/h. Answer

2/6

The total stopping distance equals the distance traveled during δ, i.e., perception reaction time, plus the braking distance:

$$x_s = v_0\,\delta + \frac{v_0^2}{2g(f + G)}$$

For v_0 = 42 mi/h = 61.6 ft/s; δ = 0.8 s; f = 0.5 s; and G = 0

$$x_s = 49.28 + 117.84 = 167.12 \text{ ft.}$$

Since 167.12 < 175, there was no impact. Answer

2/7

According to Fig. 2.3.5 the length of the dilemma zone, L_D, equals $(x_c - x_o)$. Substitution of the given data into Eqs. 2.3.3 and 2.3.6 yields:

$$x_c = 1.0\,v_o + \frac{v_o^2}{32.2}$$

$$x_o = 4.5\,v_o - 80$$

and $$L_D = 0.03\,v_o^2 - 3.5\,v_o + 80$$

This is a quadratic equation with roots v_o ≈ 32 and v_o ≈ 85 ft/s. By setting the first derivative of L_D with respect to v_o equal to zero,

$$0.06\,v_o - 3.5 = 0$$

the critical point is found to occur at v_o ≈ 58 ft/s. Since the second derivative at this point is +0.06, the curve is concave upward and the critical point is a minimum. At this point the value of L_D is -22 ft. The relationship between approach speed and the length of the dilemma zone is plotted on the following page. Note that negative values of v_o are meaningless in this case; they may describe the situation in which the vehicle backs up to clear the intersection behind it! Also, negative values of L_D represent the situation illustrated by Fig. 2.3.5 in the textbook, a situation that does not present a dilemma zone problem. Thus for the data given the dilemma zone problem arises for the range of speeds