Question 1

a) What are the different types of horizontal and vertical curves?

b) Explain using a neat sketch the main elements of spiral curves.

c) Derive an equation showing how to design horizontal curve super elevation to resist Centrifugal force

Question (2)

A building is located 6 m from the centerline of the inside lane of a curved section of highway whose radius is 125 m. The road is level and e = 0.10. Determine the posted Speed limit (to the nearest 10 km/h) considering the Sight Distance and curve radius.

Question (3)

A right turn horizontal curve on a two-lane highway has a lane width of 3.60 m, shoulder width of 2.5 m, super elevation of 4 %, crown slope of 2 %, shoulder 5%, design speed of 90 km/h, T.S. elevation of 23.75 m, T.S. station of 10+000, and longitudinal grade of +2.5 %.

a) Determine the minimum radius of the curve to satisfy good vehicle stability.

b) If the curve will be constructed with the minimum radius calculated above, draw the progress of the super elevation development from the normal crown section to the fully super elevated section if rotation is achieved around center line.

Question (4)

A vertical curve connects a +2.4% grade with -2.8% grade on a two-lane highway. If the criterion selected for design is the minimum stopping sight distance, and the design speed of the highway is 90km/h, compute and display in a tabular form the elevation of the curve at 50-m intervals if the grades intersect at station (22+000) at an elevation of 200 m. In the same table, show the station and elevation of BVC, EVC, and the highest point.

Question (5)

A sag vertical curve connects a -2 percent grade with a +2.5 percent grade on a rural arterial highway. If the criterion selected for design is the minimum stopping sight distance, and the design speed of the highway is 70 mph, compute the elevation of the curve at 100-ft stations if the grades intersect at the station (475+000) at an elevation of 300 ft. Also determine the elevation and station of the lowest point.

Question (6)

A vertical curve connects a (+g1) % grade with a (–g2) % grade on a two-lane highway. If the criterion selected for design is the minimum stopping sight distance, and the length of this curve is 300 m, the difference in elevation between the highest point and the beginning of curve is 1.35 m, stopping sight distance is 200 m.

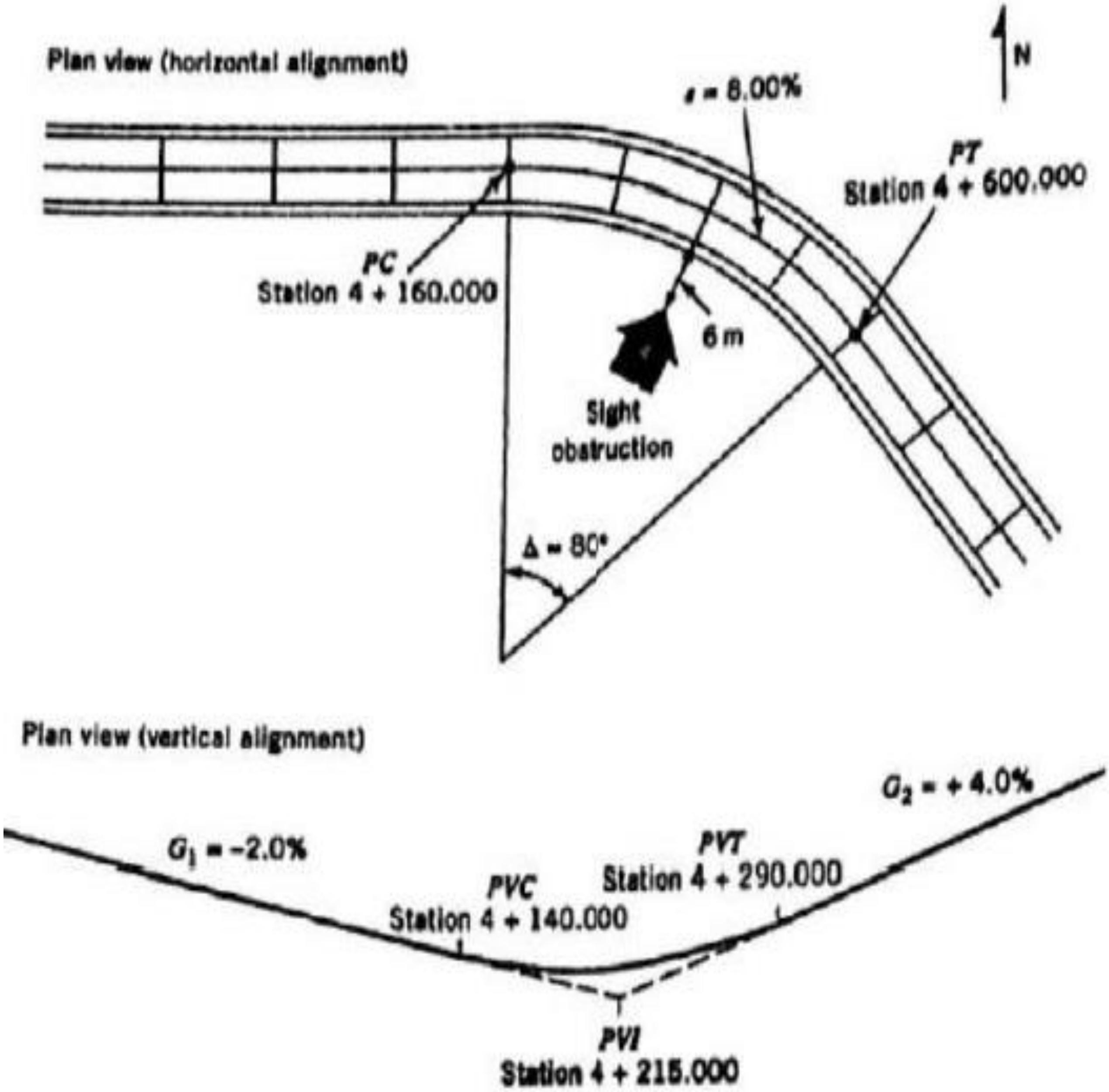
Determine the grades and safe speed of the vertical curve.

Question (7)

A two-lane highway (two 3.6 m lanes) has a posted speed limit of 80 km/h and, on one section, has both horizontal and vertical curves as shown in the figure. A number of accidents have been observed on the section as follows:

- Type I accidents: vehicles skidding off the horizontal curve.
- Type II accidents: vehicles hitting a stationary object at day time.
- Type III accidents: vehicles hitting a stationary object at night time.

You are asked to analyze the section to check if the 80 km/hr posted speed limit is an unsafe speed for the curves in question and a major cause of any of the two accident types. (Assume coefficient of longitudinal friction = 0.30, coefficient of side friction = 0.14, the perception-reaction time = 2.5 sec, and highway grade for SSD is the average of G1 and G2).



Metric

Design Speed (km/h)	Maximum e (%)	Limiting Values of f	Total (e/100 + f)	Calculated Radius (m)	Rounded Radius (m)
20	4.0	0.18	0.22	14.3	15
30	4.0	0.17	0.21	33.7	35
40	4.0	0.17	0.21	60.0	60
50	4.0	0.16	0.20	98.4	100
60	4.0	0.15	0.19	149.1	150
70	4.0	0.14	0.18	214.2	215
80	4.0	0.14	0.18	279.8	280
90	4.0	0.13	0.17	375.0	375
100	4.0	0.12	0.16	491.9	490
20	6.0	0.18	0.24	13.1	15
30	6.0	0.17	0.23	30.8	30
40	6.0	0.17	0.23	54.7	55
50	6.0	0.16	0.22	89.4	90
60	6.0	0.15	0.21	134.9	135
70	6.0	0.14	0.20	192.8	195
80	6.0	0.14	0.20	251.8	250
90	6.0	0.13	0.19	335.5	335
100	6.0	0.12	0.18	437.2	435
110	6.0	0.11	0.17	560.2	560
120	6.0	0.09	0.15	755.5	755
130	6.0	0.08	0.14	950.0	950
20	8.0	0.18	0.26	12.1	10
30	8.0	0.17	0.25	28.3	30
40	8.0	0.17	0.25	50.4	50
50	8.0	0.16	0.24	82.0	80
60	8.0	0.15	0.23	123.2	125
70	8.0	0.14	0.22	175.3	175
80	8.0	0.14	0.22	228.9	230
90	8.0	0.13	0.21	303.6	305
100	8.0	0.12	0.20	393.5	395
110	8.0	0.11	0.19	501.2	500
120	8.0	0.09	0.17	666.6	665
130	8.0	0.08	0.16	831.3	830
20	10.0	0.18	0.28	11.2	10
30	10.0	0.17	0.27	26.2	25
40	10.0	0.17	0.27	46.6	45
50	10.0	0.16	0.26	75.7	75
60	10.0	0.15	0.25	113.3	115
70	10.0	0.14	0.24	160.7	160
80	10.0	0.14	0.24	209.9	210
90	10.0	0.13	0.23	277.2	275
100	10.0	0.12	0.22	357.7	360
110	10.0	0.11	0.21	453.5	455
120	10.0	0.09	0.19	596.5	595
130	10.0	0.08	0.18	738.9	740
20	12.0	0.18	0.30	10.5	10
30	12.0	0.17	0.29	24.4	25
40	12.0	0.17	0.29	43.4	45
50	12.0	0.16	0.28	70.3	70
60	12.0	0.15	0.27	104.9	105
70	12.0	0.14	0.26	148.3	150
80	12.0	0.14	0.26	193.7	195
90	12.0	0.13	0.25	255.0	255
100	12.0	0.12	0.24	327.9	330
110	12.0	0.11	0.23	414.0	415
120	12.0	0.09	0.21	539.7	540
130	12.0	0.08	0.20	665.0	665

US Customary

Design Speed (mph)	Maximum e (%)	Limiting Values of f	Total (e/100 + f)	Calculated Radius (ft)	Rounded Radius (ft)
15	4.0	0.175	0.215	70.0	70
20	4.0	0.170	0.210	127.4	125
25	4.0	0.165	0.205	203.9	205
30	4.0	0.160	0.200	301.0	300
35	4.0	0.155	0.195	420.2	420
40	4.0	0.150	0.190	563.3	565
45	4.0	0.145	0.185	732.2	730
50	4.0	0.140	0.180	929.0	930
55	4.0	0.130	0.170	1190.2	1190
60	4.0	0.120	0.160	1505.0	1505
15	6.0	0.175	0.235	64.0	65
20	6.0	0.170	0.230	116.3	115
25	6.0	0.165	0.225	185.3	185
30	6.0	0.160	0.220	273.6	275
35	6.0	0.155	0.215	381.1	380
40	6.0	0.150	0.210	509.6	510
45	6.0	0.145	0.205	660.7	660
50	6.0	0.140	0.200	836.1	835
55	6.0	0.130	0.190	1065.0	1065
60	6.0	0.120	0.180	1337.8	1340
65	6.0	0.110	0.170	1662.4	1660
70	6.0	0.100	0.160	2048.5	2050
75	6.0	0.090	0.150	2508.4	2510
80	6.0	0.080	0.140	3057.8	3060
15	8.0	0.175	0.255	59.0	60
20	8.0	0.170	0.250	107.0	105
25	8.0	0.165	0.245	170.8	170
30	8.0	0.160	0.240	250.8	250
35	8.0	0.155	0.235	348.7	350
40	8.0	0.150	0.230	465.3	465
45	8.0	0.145	0.225	602.0	600
50	8.0	0.140	0.220	760.1	760
55	8.0	0.130	0.210	963.5	965
60	8.0	0.120	0.200	1204.0	1205
65	8.0	0.110	0.190	1487.4	1485
70	8.0	0.100	0.180	1820.9	1820
75	8.0	0.090	0.170	2213.3	2215
80	8.0	0.080	0.160	2675.6	2675
15	10.0	0.175	0.275	54.7	55
20	10.0	0.170	0.270	99.1	100
25	10.0	0.165	0.265	157.8	160
30	10.0	0.160	0.260	231.5	230
35	10.0	0.155	0.255	321.3	320
40	10.0	0.150	0.250	428.1	430
45	10.0	0.145	0.245	552.9	555
50	10.0	0.140	0.240	696.8	695
55	10.0	0.130	0.230	876.7	880
60	10.0	0.120	0.220	1094.6	1095
65	10.0	0.110	0.210	1345.8	1345
70	10.0	0.100	0.200	1638.8	1640
75	10.0	0.090	0.190	1980.3	1980
80	10.0	0.080	0.180	2378.3	2380
15	12.0	0.175	0.295	51.0	50
20	12.0	0.170	0.290	92.3	90
25	12.0	0.165	0.285	146.7	145
30	12.0	0.160	0.280	215.0	215
35	12.0	0.155	0.275	298.0	300
40	12.0	0.150	0.270	396.4	395
45	12.0	0.145	0.265	511.1	510
50	12.0	0.140	0.260	643.2	645
55	12.0	0.130	0.250	809.4	810
60	12.0	0.120	0.240	1003.4	1005
65	12.0	0.110	0.230	1228.7	1230
70	12.0	0.100	0.220	1489.8	1490
75	12.0	0.090	0.210	1791.7	1790
80	12.0	0.080	0.200	2140.5	2140

Note: In recognition of safety considerations, use of e_{max} = 4.0% should be limited to urban conditions.

Exhibit 3-14. Minimum Radius for Design of Rural Highways, Urban Freeways, and High-Speed Urban Streets Using Limiting Values of e and f

Metric			US Customary		
Design speed (km/h)	Maximum relative gradient (%)	Equivalent maximum relative slope	Design speed (mph)	Maximum relative gradient (%)	Equivalent maximum relative slope
20	0.80	1:125	15	0.78	1:128
30	0.75	1:133	20	0.74	1:135
40	0.70	1:143	25	0.70	1:143
50	0.65	1:150	30	0.66	1:152
60	0.60	1:167	35	0.62	1:161
70	0.55	1:182	40	0.58	1:172
80	0.50	1:200	45	0.54	1:185
90	0.47	1:213	50	0.50	1:200
100	0.44	1:227	55	0.47	1:213
110	0.41	1:244	60	0.45	1:222
120	0.38	1:263	65	0.43	1:233
130	0.35	1:286	70	0.40	1:250
			75	0.38	1:263
			80	0.35	1:286

Exhibit 3-27. Maximum Relative Gradients

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K[a] Calculated	Rate of vertical curvature, K[a] Design	Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a] Calculated	Rate of vertical curvature, K[a] Design
20	20	0.6	1	15	80	3.0	3
30	35	1.9	2	20	115	6.1	7
40	50	3.8	4	25	155	11.1	12
50	65	6.4	7	30	200	18.5	19
60	85	11.0	11	35	250	29.0	29
70	105	16.8	17	40	305	43.1	44
80	130	25.7	26	45	360	60.1	61
90	160	38.9	39	50	425	83.7	84
100	185	52.0	52	55	495	113.5	114
110	220	73.6	74	60	570	150.6	151
120	250	95.0	95	65	645	192.8	193
130	285	123.4	124	70	730	246.9	247
				75	820	311.6	312
				80	910	383.7	384

[a] Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A). K = L/A

Exhibit 3-76. Design Controls for Stopping Sight Distance and for Crest and Sag Vertical Curves

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K[a] Calculated	Rate of vertical curvature, K[a] Design	Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a] Calculated	Rate of vertical curvature, K[a] Design
20	20	2.1	3	15	80	9.4	10
30	35	5.1	6	20	115	16.5	17
40	50	8.5	9	25	155	25.5	26
50	65	12.2	13	30	200	36.4	37
60	85	17.3	18	35	250	49.0	49
70	105	22.6	23	40	305	63.4	64
80	130	29.4	30	45	360	78.1	79
90	160	37.6	38	50	425	95.7	96
100	185	44.6	45	55	495	114.9	115
110	220	54.4	55	60	570	135.7	136
120	250	62.8	63	65	645	156.5	157
130	285	72.7	73	70	730	180.3	181
				75	820	205.6	206
				80	910	231.0	231

[a] Rate of vertical curvature, K, is the length of curve (m) per percent algebraic difference intersecting grades (A). K = L/A

Exhibit 3-79. Design Controls for Sag Vertical Curves

Desirable Spiral Parameter (Metric)

Design speed (km/h)	Spiral parameter (m)
40	50
50	75
60	100
70	125
80	150
90	175
100	200
110	275
120	350
130	425
140	500