B E N T O N   C O U N T Y

W A S H I N G T O N

EXCERPTS FROM THE
SIDE HILL DEVELOPMENT STANDARDS
REPORT

Project No. E-78022

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PREFACE

The following are excerpts from the larger document prepared by Advanced Engineering Consultants discussing the Side Hill Development Standards. This document was prepared so that individuals will have the major points of concern, formulas, conclusions, recommendations and charts rather than the background information, technical data and explanations of the numerous methods used in deriving the Side Hill Standards that are recommended.

This summary document includes the information needed to design a subdivision or short plat to satisfy the requirements for a side hill development if the County were to adopt those standards.

TERRY A. MARDEN
Planning Director

INTRODUCTION

The purpose of this "Side Hill Development Standards" report is to tabulate side hill development problems and identify potential solution alternatives.

The primary cause of improper development along sloping hillsides stems from the fact that plat lot sizes and configurations are being determined using flat land design procedures. Also, the design of houses being built on side hill lots rarely incorporates the topography of the individual lot at the beginning of the design process for the house. Therefore, a method of sizing side hill lots to accommodate a variety of house designs, while adequately addressing:

- proper county road placement and gradients;
- proper site grading cut and fill slopes;
- proper driveway placement and gradients;
- proper sidewalk placement and gradients;
- adequate benching for the proper placement of the houses, parking pads, and on-site sanitary waste and disposal systems when necessary; and
- proper sizing, placement and maintenance of surface water drainage facilities,

must be identified, adopted and followed to reduce the side hill development problems being experienced.

SIDE HILL DEVELOPMENT PROBLEMS

A tabulation of problems found during visits to side hill developments and during discussions with local officials follows:

- County road gradients and switchback designs need further definition.
- Final site grading cut and fill slopes need regulating.
- Driveways and sidewalks have excessive gradients and, in some cases, are too narrow.
- Improper transitions between driveways and the county roads and between driveways and garages were found to commonly exist.
- Benching of the site to provide the necessary flat area for placing the house, yard, and on-site sanitary waste disposal system (when necessary) was found to normally be too small to accommodate all requirements.
- The on-site sanitary waste disposal drainfields were in fill areas and/or too close to slopes. Also, backup drainfields were found to be marginally available.
- Drainage problems both during and after construction were found too numerous to tabulate here. They should be addressed under the separate category of County Drainage.
- Setback and building height regulations need further definition.

SUMMARY

General

During the data collection portion of this study an extensive effort was expended identifying and tabulating the problems associated with development along hillsides being experienced in Benton County.

Simultaneously, the cities of Seattle, Portland, San Francisco and Los Angeles were contacted to obtain copies of their ordinances and controls for developing along hillsides. Since they have been experiencing this kind of development for many years, it was assumed that a simple compilation of their solutions and controls would adequately address the problems being experienced in Benton County. This was not the case.

However, the concept of Slope-Density did emerge, after reviewing the collected references, as one popular method of dealing with the experienced side hill development problems. Therefore, this study focusses on the use of this Slope-Density method, deriving and presenting a useable procedure for calculating recommended lot sizes and dimensions for individual lots within a side hill development.

The procedure derived in this report for calculating lot widths and depths addresses and integrates:

- Slope-Density concepts;
- proper County road gradients;
- proper cut and fill slopes;
- proper driveway placement and gradients;
- adequate benching for placement of houses, parking pads, and on-site sanitary waste disposal systems (when necessary); and
- proper control of drainage

in an attempt to develop a standard that the County can use when evaluating proposed side hill developments.

Since numerous variations of criteria assumptions, architectural designs, and actual site conditions exist, refinements to the use of this derived procedure will undoubtedly become apparent with experience. Until then, however, this procedure as presented provides a better basis for evaluation than previous ones.

Average Ground Slope

Average Ground Slope (X) used in the Slope-Density method is defined as the average slope of the subject area parcel or lot. It is not to be confused with ground cross section slope (S) or a street gradient slope (S).

$X = \frac{0.0023 \times I \times L}{A}$, where:

X = Average Ground Slope in %,

L = the total accumulated length of all constant contour interval contour lines within the subject parcel or lot in feet,

I = the constant vertical contour interval in feet,

A = the total area of the subject parcel or lot in acres, and

0.0023 is a conversion factor converting acres to square feet and the decimal slope to a percent slope.

Slope-Density

In general, the Slope-Density method equates the necessity of larger sized parcels or lots with increasing ground slope conditions, using the calculated average ground slope (X). This report further refines the method, providing the ability to calculate the lot dimensions associated with the described larger sized parcel requirement. The assumptions used in deriving this refinement confirm the validity of the larger sized parcel values required by several of the authorities interviewed during the data gathering effort. Pages A-10, A-11, and A-12 present the calculated refinements to the Slope-Density method, derived in this report. Figures shown on pages A-7, A-8 and A-9 define the calculation parameters.

Proper County Road Gradients

The proper maximum road centerline gradient is twelve percent (12%). However, under extreme circumstances, the gradient can be increased for short distances if, and only if, the gradient returns to twelve percent (12%) or less at the end of the allowed distance. These increases must not be applied consecutively.

The allowable increased gradients and their allowed horizontal distances measured between the two curve Vertical Points of Intersection (VPI) are:

Gradient (%)	Allowed Distance (feet)
13	200
14	175
15	150
16	125
17	100

Pages A-14 and A-15 present the basis for these stated values.

Proper Cut and Fill Slopes

In addition to gradient considerations, cut and fill slopes must be properly integrated. Pages A-16 and A-17 compare the relationships of cut and fill slopes, average ground slopes, roadway widths, and minimum right of way requirements.

Proper Driveway Placement and Gradients

The driveway placement alternatives considered in this report are shown on pages A-4, A-5 and A-5A. The driveway parking pad should be included, as shown, with a maximum slope of two percent (2%). Proper attention to drainage must be incorporated at the garage.

The maximum centerline gradient is taken to be fourteen percent (14%). When the driveway gradient changes (i.e., at the transition to the County road; at the parking pad; or, when applicable, at the switchback point shown on page A-5A) and the algebraic difference between the gradients is greater than nine (9%), vertical curves should be used. The minimum vertical curve length should be one foot (1') for each percentage point difference of the calculated algebraic difference.

The driveway transition curb return design used is shown on page A-17.

Adequate Benching

Adequate benching widths to accommodate on-site sanitary waste disposal systems are defined on apge A-3. Again, pages A-4, A-5 and A-5A illustrate additional benching considerations.

Proper Control of Drainage

Consideration of drainage patterns on the parcels or lots as finally graded is a must. Particular attention to erosion control where lots drain to the roads and where runoff becomes channeled along driveways is essential.

The County road must have an approved drainage plan.

Soils

The scope of this report did not include the necessary and important evaluation of soils related concerns. Foundation design; erosion prevention considering wind, precipitation runoff, and dust control watering runoff; on-site sanitary waste disposal system design; and drainage system design - all involve due consideration of site soils conditions.

Sidewalks

Sidewalk centerline gradients should not exceed twelve percent (12%). The use of stairs or winding ramps should be considered.

Sidewalks must be designed to drain properly, but the transverse slope should not exceed five percent (5%).

Design should consider the impact of surface water runoff overtopping or undermining installed sidewalks, as in the case of driveway design.

Intersection Angle

A valid concern about some of the tight driveway angles has been expressed demanding a brief investigation. An illustration as well as calculated values can be seen on page A-13.

The values of "T" and "L" on page A-13 were calculated with a radius of six feet and a range of driveway angles from fifteen degrees to ninety degrees using a five degree interval.

At the smaller driveway angles the chart indicates rather lengthy curb returns are required. However, these driveway connections are acceptable.

Gradient Transition

The maximum driveway centerline gradient is taken to be fourteen percent (14%). When the driveway gradient changes (i.e., at the transition to the County road; at the parking pad; or, when applicable, at the switchback point shown on page A-5A) and the algebraic difference between the gradients is greater than nine percent (9%), vertical curves should be used. The minimum vertical curve length should be one foot (1') for each percentage point difference of the calculated algebraic difference.

SLOPE-DENSITY CONCEPT

For various reasons, as the ground slope increases, the size or area of a building lot must also increase to facilitate proper development. Therefore, a correlation has been made between the "Average Ground Slope (X)" and the necessary building lot size in acres for each slope. This correlation is called "Slope-Density."

Average Ground Slope (X) used in the Slope-Density method is defined as the average slope of the subject areas parcel or lot. It is not to be confused with ground cross section slope (S) or a street gradient slope (S).

$X = \frac{0.0023 \times I \times L}{A}$, where:

X = Average Ground Slope in %,

L = the total accumulated length of all constant contour interval contour lines within the subject parcel or lot in feet,

I = the constant vertical contour interval in feet,

A = the total area of the subject parcel or lot in acres, and

0.0023 is a conversion factor converting acres to square feet and the decimal slope to a percent slope.

To achieve accuracy to within one percent, the constant vertical contour interval must be ten feet or less. Also, it is recommended that any ground with an actual cross section slope (S) equal to thirty-five percent or greater be excluded from side hill development.

Many cities and counties have the appropriate contour maps. Consequently, obtaining information for slope-density provisions is not expensive. Further, the task of determining average ground slope is relatively simple and easily within the capabilities of most planning agencies.

Although this slope-density concept provides an excellent guide to defining the necessary area of a building lot, it does not address the lot depth to width relationship. Without defining this relationship, it would be possible to assign the proper area to a lot and still not be able to build on it because it is either too long or too wide. Therefore, this report specifically develops a depth to width relationship intended to solve the problems associated with side hill development in Benton County.

COUNTY ROAD GRADIENTS

By their very locations, developments on hillsides demand roadway gradients that may approach difficult or even impossible grades for large vehicles to reasonably negotiate. The large vehicles of most immediate concern are of course fire fighting equipment.

Again, reasonable enforceable criteria must be developed. Many state highway departments have developed highway gradient controls and after an investigation of their various methods it was decided the California State Highway Department's critical grade criteria is most applicable.

The California Highway Department determines the critical lengths of uphill gradients for a selected truck as that which will cause a fifteen mile per hour maximum reduction in speed below the average running speed of the roadway on the approach to the upgrade.

By equating the change of momentum with the deceleration induced by gravity as the roadway gradient increases, we can derive the distance of travel on the increased gradient that will cause a decrease in speed of fifteen miles per hour.

To derive these critical grade lengths, the change in momentum of the truck is equated to the deceleration of the truck induced by gravity as the truck climbs an increased roadway gradient.

The method and equations used are summarized on page A-14. The results are tabulated on page A-15. County road gradients or slopes in excess of 17% are not recommended because average commercial vehicles cannot normally continuously ascend these grades.

COUNTY ROAD CUTS AND FILLS

The assumed sixty (60) feet wide roadway right of way must be reviewed in more detail. To accomplish this review, roadway cross sections with roadway widths of twenty, thirty, and forty feet were considered as shown on page A-16. Both 2:1 and 1.5:1 cut-and-fill slopes were considered.

The resulting right of way width values calculated for the three roadway widths and the two cut-and-fill slopes indicated above are tabulated on page A-17.

All required right of way values below the dark horizontal lines are in excess of the assumed sixty foot wide right of way. Therefore, if the forty foot wide roadway width is desired, cut and fill easements must be obtained when the average ground slope exceeds 14% for a 2:1 cut-or-fill slope. If a 1.5:1 slope is used with the forty foot wide roadway, then average ground slopes in excess of 18% will require cut and fill easements.

CONCLUSIONS

1. A review of ordinances and literature addressing side hill development problems revealed the concept of Slope-Density control. However, no procedures for explicit use were found.
2. The Slope-Density concept prescribing individual lot areas as a function of a calculated average ground slope (X) has merit.
3. Defining the depth to width relationship for a given Slope-Density has not been accomplished before this report.
4. Unless: proper County road gradients; proper cut and fill slopes; proper driveway gradients; adequate benches for placement of houses, parking pads, and on-site sanitary waste disposal systems (where necessary); and proper control of drainage are all simultaneously integrated, side hill developments cannot provide proper residential areas.
5. Because the developer and the builder are not necessarily the same, developer-determined hill side lot sizes have not allowed adequate spacial configurations for the construction of standard single family dwellings by the builders who purchase the lots.
6. Side hill residential developments provide view lots and reduce the depletion of farmable flat lands.

RECOMMENDATIONS

General

1. Public hearings presenting the concept of Slope-Density control for side hill developments should be held as soon as possible.
2. County codes controlling development standards along side hills should be developed and adopted incorporating the elements of this report as presented, or as refined during the public hearings.
3. Criteria other than those assumed in the development of the presented Slope-Density method should be allowed if the submittal requesting the alternate lot size(s) include(s) the residence design and lot layout for each lot of the total development, showing:
    1. County road gradients;
    2. cut and fill slopes;
    3. driveway gradients;
    4. sanitary waste disposal system locations (when necessary);
    5. sidewalk locations and gradients;
    6. house site locations; and
    7. surface water runoff control considerations;

    and all shown meet desired County standards.
4. As soon as possible, building heights should be evaluated against calculated average ground slope (X) values and controls should be implemented to maintain views for each lot.

Technical

1. The Average Ground Slope value calculated for a proposed lot should be used to determine the Lot Area, the Lot Depth, the Lot Width, the house setback and the driveway to county road intersection angle as given on page A-10 for Upper Side Lots and on page A-11 for Lower Side Lots <u>WITH</u> switchbacks.

2. Development on lots with calculated Average Ground Slopes in excess of thirty-five percent (35%) should be avoided.

3. The County road centerline gradients should not exceed twelve percent (12%) except for short distances as outlined on page A-15.

4. The County road paved section should be forty feet (40') wide with a right of way at least sixty feet (60') wide.

5. The County road cut and fill slopes should be a two foot horizontal run for each one foot of vertical rise (2:1).

6. Easements for accomplishing County road cuts and fills should be obtained when the required right of way width shown on page A-17 exceeds sixty feet (60').

7. All streets should have curbs and gutters on each side and should be paved curb to curb for surface runoff control.

8. The driveway gradients should not exceed fourteen percent (14%).

9. Driveway gradient transition vertical curves and tight driveway angle curb returns should be used as discussed in Section 3.

10. Parking pads should be provided next to the garage as shown on pages A-7, A-8 and A-9.

11. The sidewalk gradients should not exceed twelve percent (12%) with transverse slopes between five percent (5%) and two percent (2%).

12. Proper control of surface water runoff both during and after construction should be demonstrated.

13. The final plat should include a map showing:

    (i) Contour lines defining the approximate final grading plan for the lot or development;

    (ii) The calculated Average Ground Slope for each lot; and

    (iii) Information describing the soils within the development boundaries.

APPLICATION

The real test of any study report is the ability of the results to be applied in the field on a practical basis. The intent of this section is to present a procedure for using the results of this study when laying out a plat situated on a hillside.

Most developments include property of varying terrain conditions. When the terrain ground slopes exceed ten percent (10%), the side hill development criteria apply.

In most cases the sloping portion of the property is never consistantly sloped. The ground slopes always vary from a steep portion to a lesser sloped or even flat terrain. The first priority of the plat development procedure is to survey the property to develop and draw a contour map describing the terrain. This contour map provides all the data required to properly apply the side hill development criteria.

Application of the side hill development criteria must begin at the steepest portion of the property being developed. Using the contour map, a preliminary average ground slope can be calculated and preliminary lot sizes and dimensions can be determined using the data tabulated on Appendix pages A-10 and A-11 as recommended. Once the preliminary upper and lower lot sizes are determined, the lots can be situated in relation to the proposed roadway. Now the actual average ground slope can be calculated for each lot and compared with the preliminary values. If the values do not match, this procedure must be repeated until a match is accomplished.

Once the lots are designed on the steepest slopes, the design process continues down slope until the entire plat is designed.

As this procedure continues, the street gradients must be kept within the proposed limits discussed in Section 5 of this report.

The contour lines, the street gradients and the average ground slope for each lot should be drafted on a map accompanying the final plat map.

APPENDIX

SLOPE DENSITY TABLE (Acres)*

NR = No Requirement
ND = No Development

Ground Slope %	Santa Fe NM	Phoenix AZ	Orange Co. CA	Walnut Creek, CA	Thousand Oaks, CA	Pima Co. AZ	Recommended Area	
							W/O Sewer	With Sewer
5	0.25	NR	NR	NR	NR	NR	NR	NR
10	0.50	0.55	NR	0.29	0.50	NR	0.45	0.29
15	1.00	0.90	NR	0.33	0.63	1.00	0.62	0.32
20	2.00	1.30	0.16	0.40	0.83	2.00	1.10	1.10
25	5.00	2.00	0.22	0.50	1.25	6.00	2.40	2.40
30	ND	3.33	0.44	0.67	2.50	16.00	3.70	3.70
35	ND	5.00	1.00	1.00	10.00	36.00	5.00	5.00
40	ND	5.00	5.00	2.00	10.00	36.00	6.67	6.67
50	ND	5.00	10.00	ND	ND	36.00	10.00	10.00

* Values Listed as Acres Per Lot.

CALCULATION GUIDELINES

LOT SIZE

1. County and Municipal

Agency	Min. Lot Width (ft)	Min. Lot Area (ft^2)	Setback Front	Setback Rear
Benton Co., WA				
Single	75	7500	25/55	25
Multiple	90	10000	25/55	25
Thurston Co., WA	80	9600	25/55	25
Kennewick, WA	60	10000	25/55	25
Prosser, WA	-	10000	25/ -	20

2. Benton-Franklin Sanitarian
   Minimum Width of 140 feet for drainfield
   Minimum Lot Area of 12500 square feet

3. Slope Density Area
   See SLOPE DENSITY TABLE (page A-6)

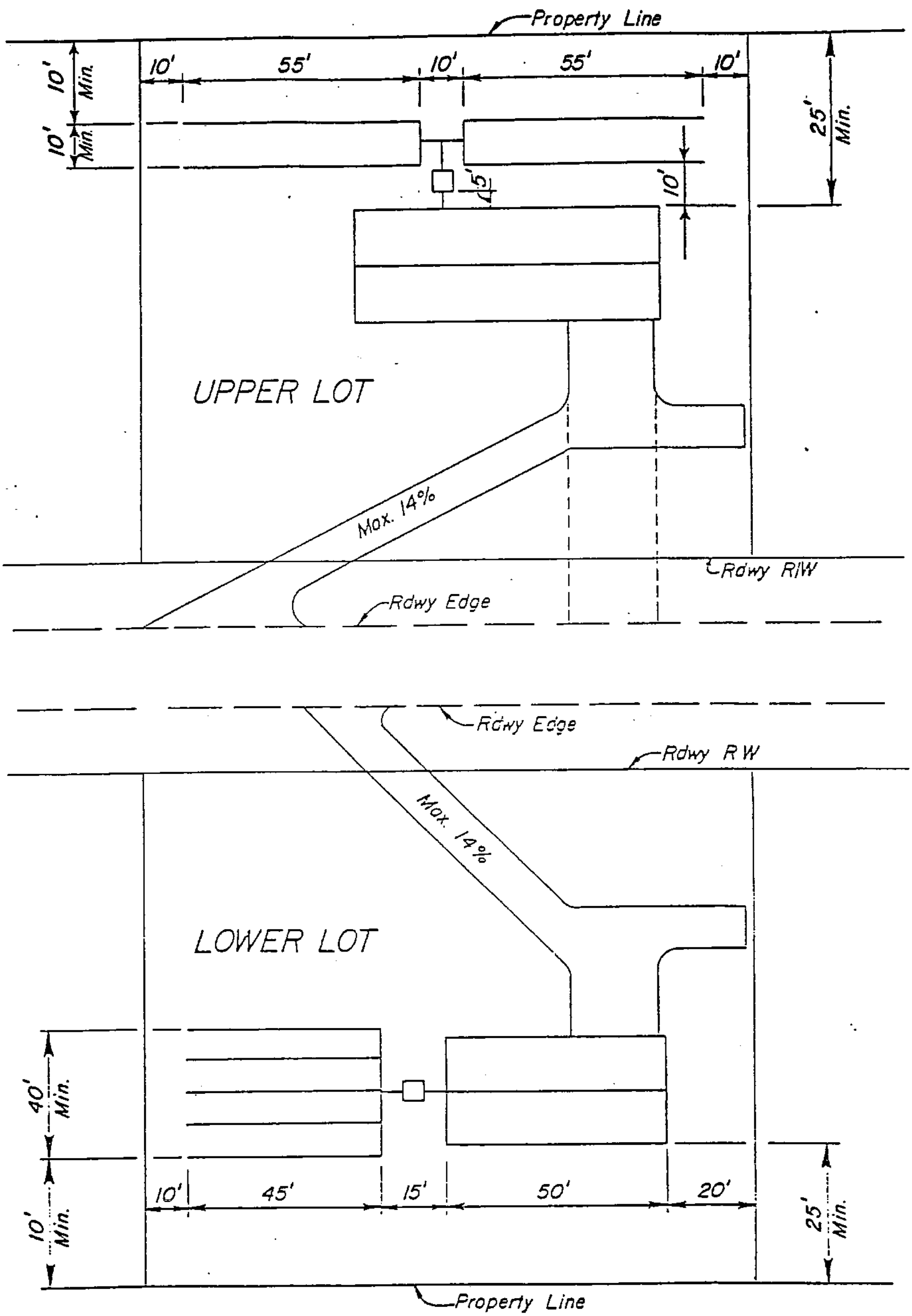
GRADING

1. U.B.C. Chapter 70 - Excavation and Grading
   Terrace lot for house
   15' front setback
   10' rear setback

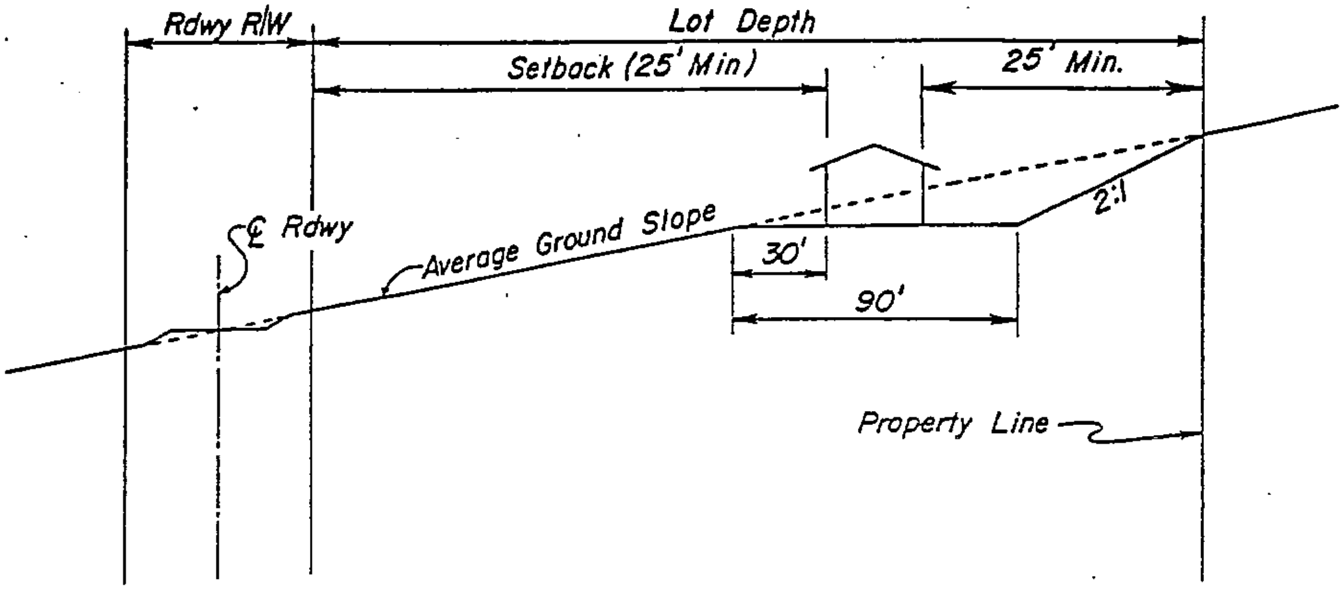
2. HUD Guidelines
   14% maximum driveway slope with
   0.5% parking pad

3. Benton County
   2:1 Cut and Fill Slopes (1-1/2:1 extreme maximum)

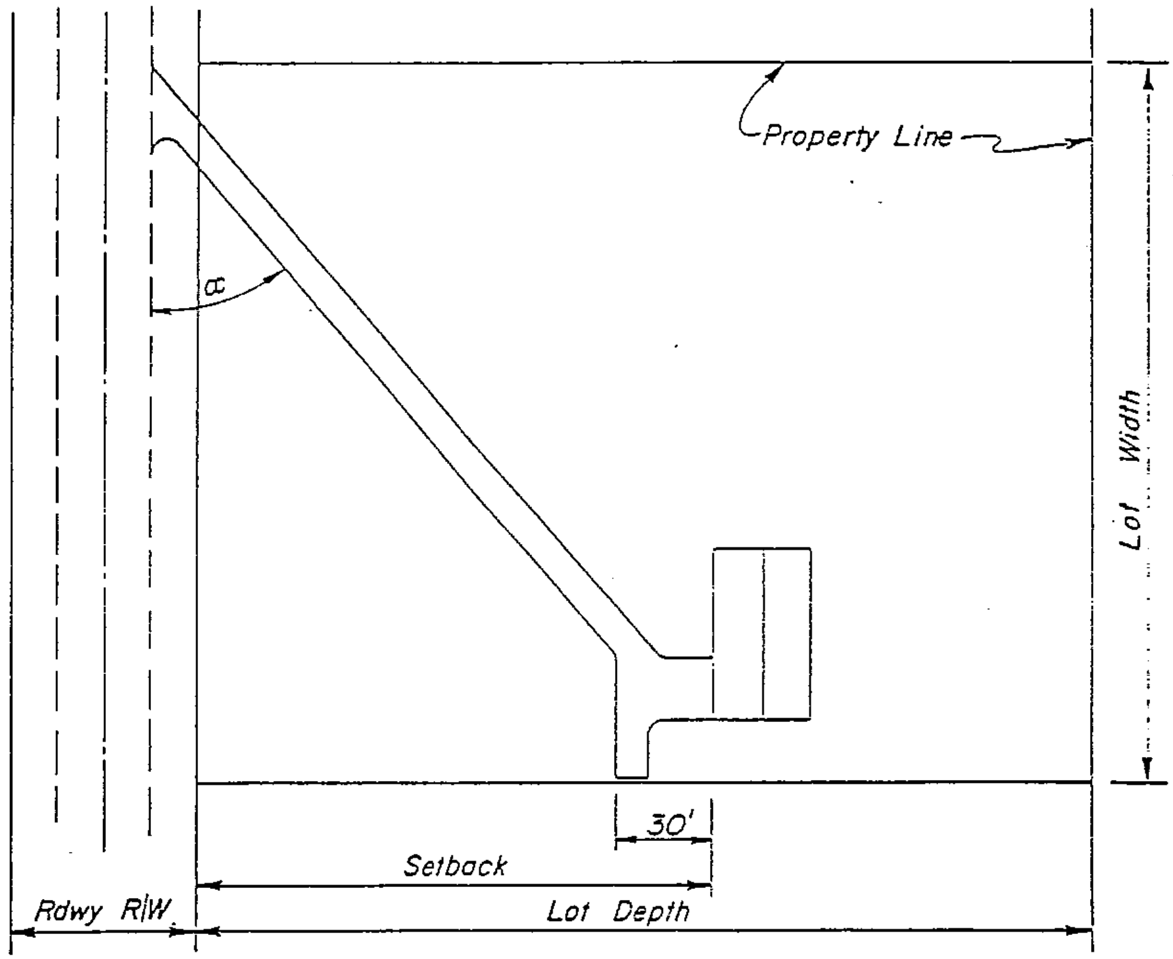
NOTE: Values underlined have been used in the development of this report.



Property Line
10' Min.
10' Min.
10'
55'
10'
55'
10'
25' Min.
5'
10'
UPPER LOT
Max. 14%
Rdwy R/W
Rdwy Edge
Rdwy Edge
Rdwy RW
Max. 14%
LOWER LOT
40' Min.
10' Min.
10'
45'
15'
50'
20'
25' Min.
Property Line



UPPER LOT



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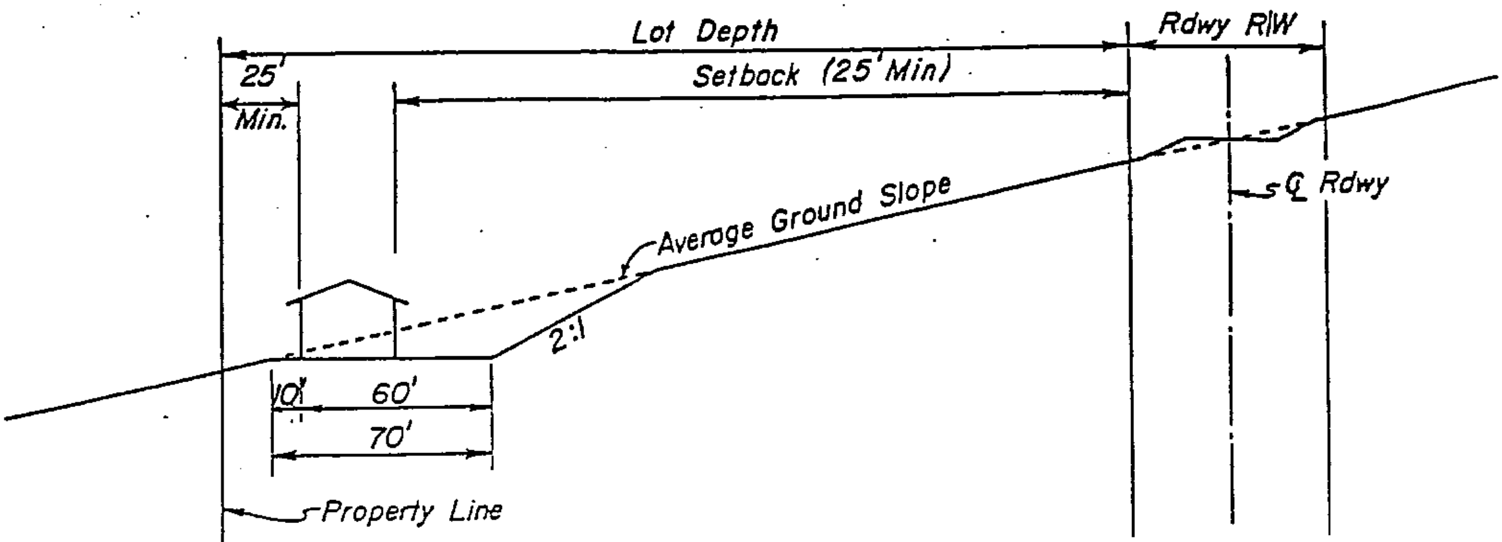
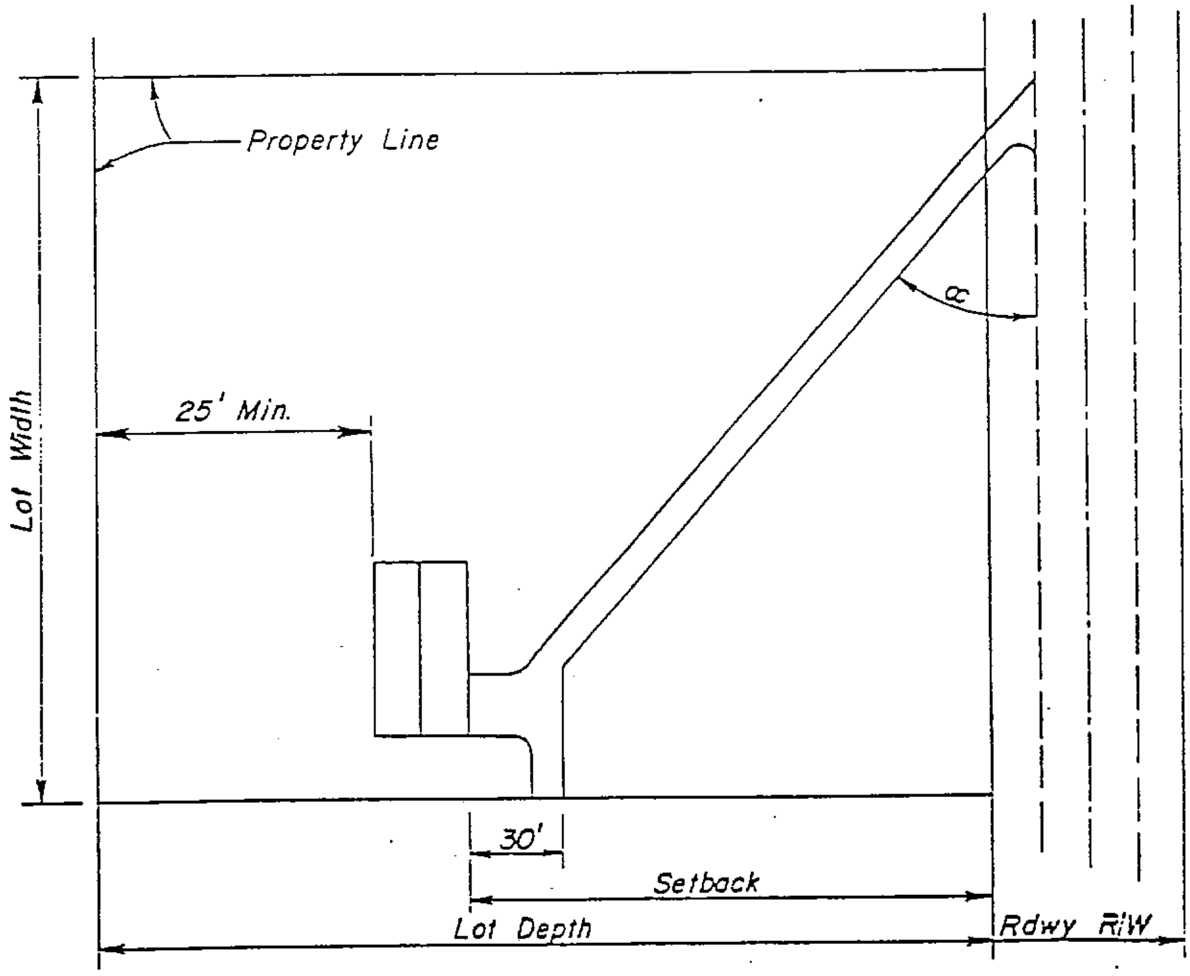


LOWER LOT



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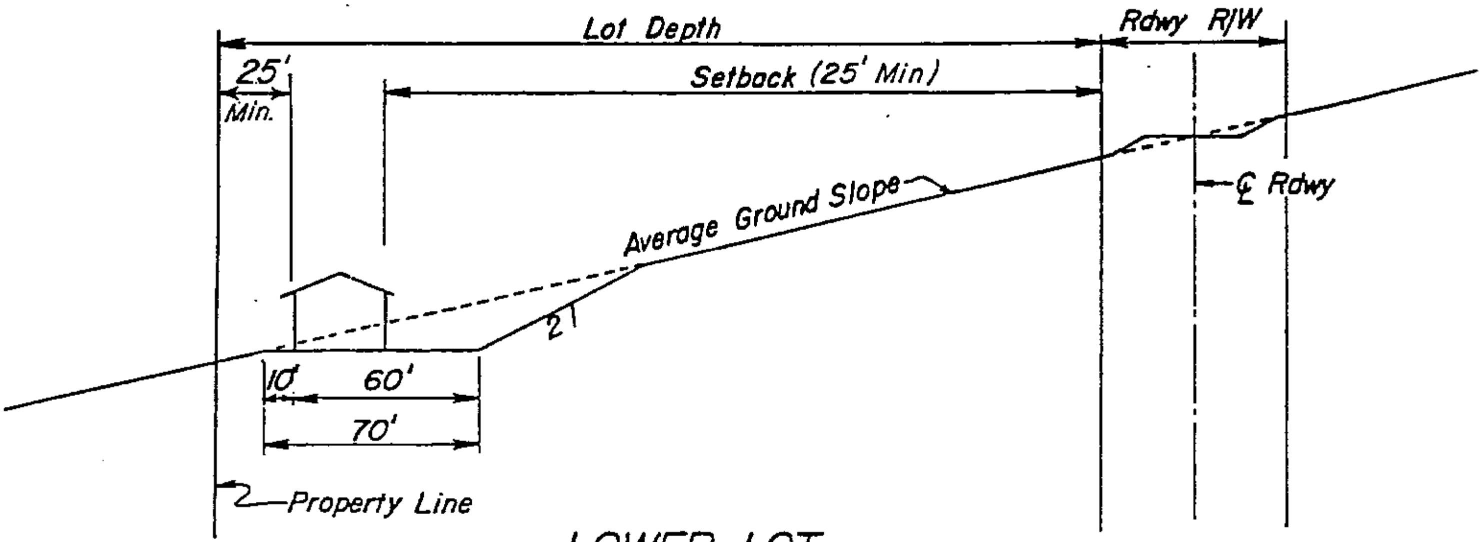
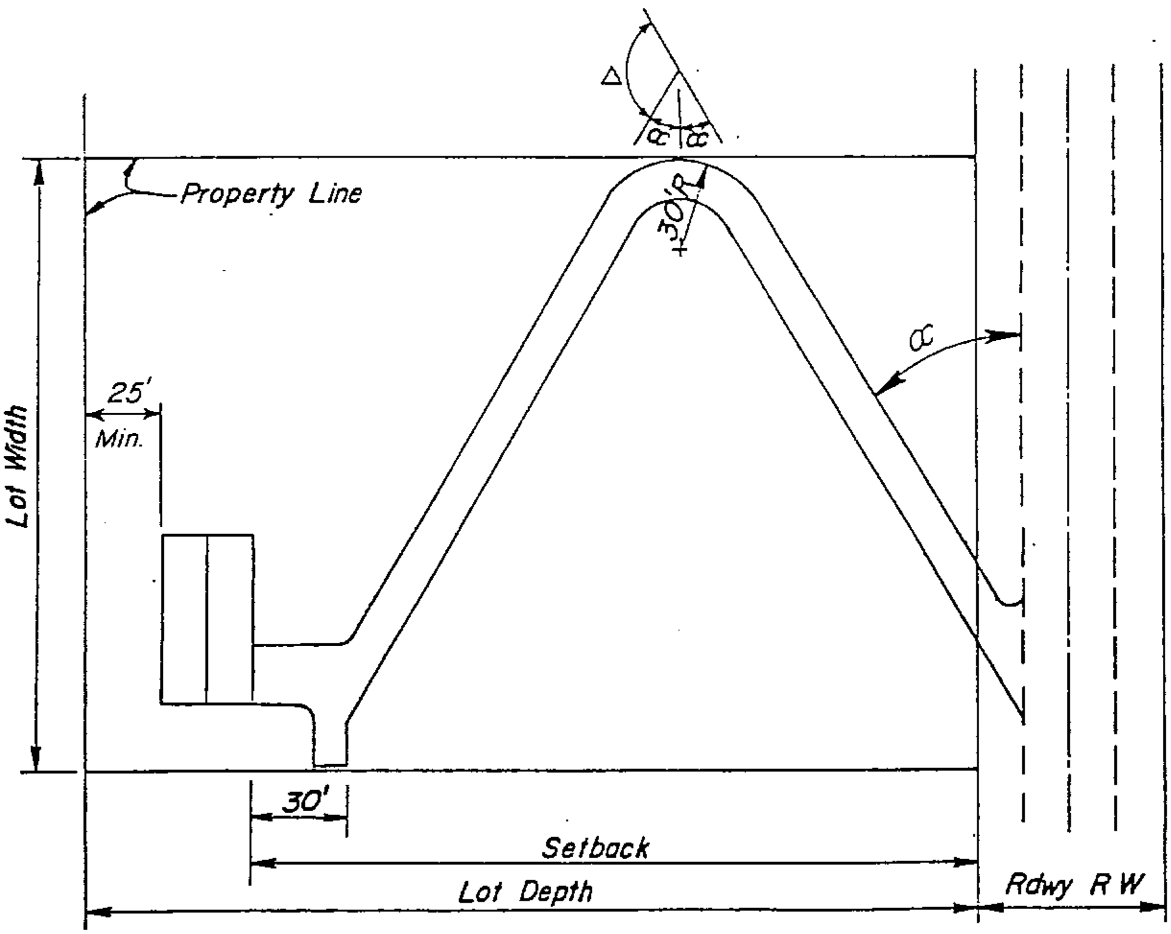


LOWER LOT

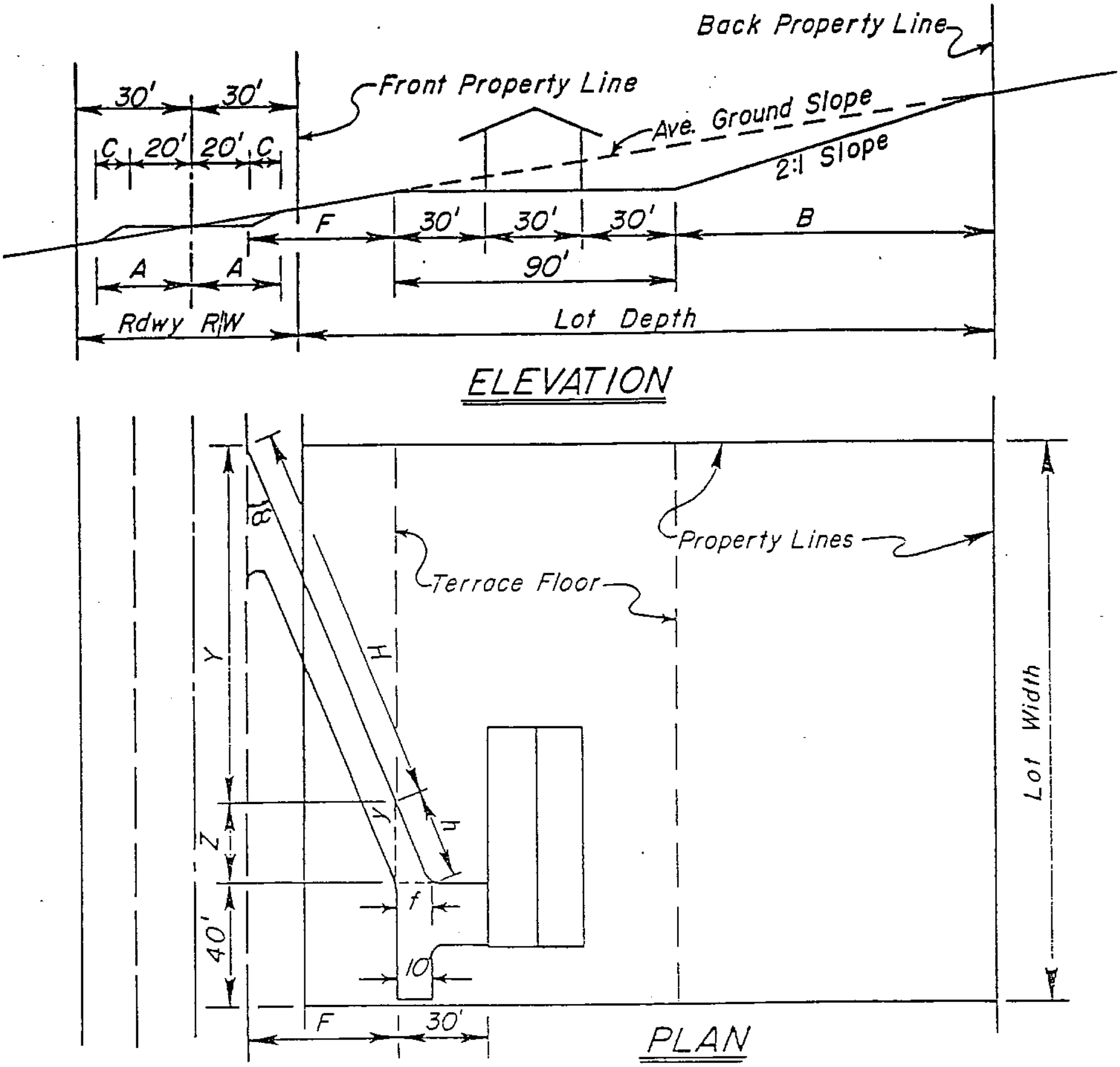


LOWER LOT

SIDE HILL LOT AREAS*

Avg. Ground Slope Per Cent	Area ft^2	Avg. Ground Slope Per Cent	Area ft^2
10	16520 to 16800	31	171336
11	18480 to 19460	32	182952
12	22120	33	194568
13	24800	34	206184
14	27480	35	217800
15	30160	36	232320
16	32840	37	246840
17	35520	38	261360
18	38200	39	275880
19	40880	40	290400
20	43560	41	304920
21	55176	42	319440
22	66792	43	333960
23	78408	44	348480
24	90024	45	363000
25	101640	46	377520
26	113256	47	392040
27	124872	48	406560
28	136488	49	421080
29	148104	50	435600
30	159720		

* Derived by Slope Density Table



UPPER LOT CALCULATIONS

X is Average Ground Slope (ft./ft.)

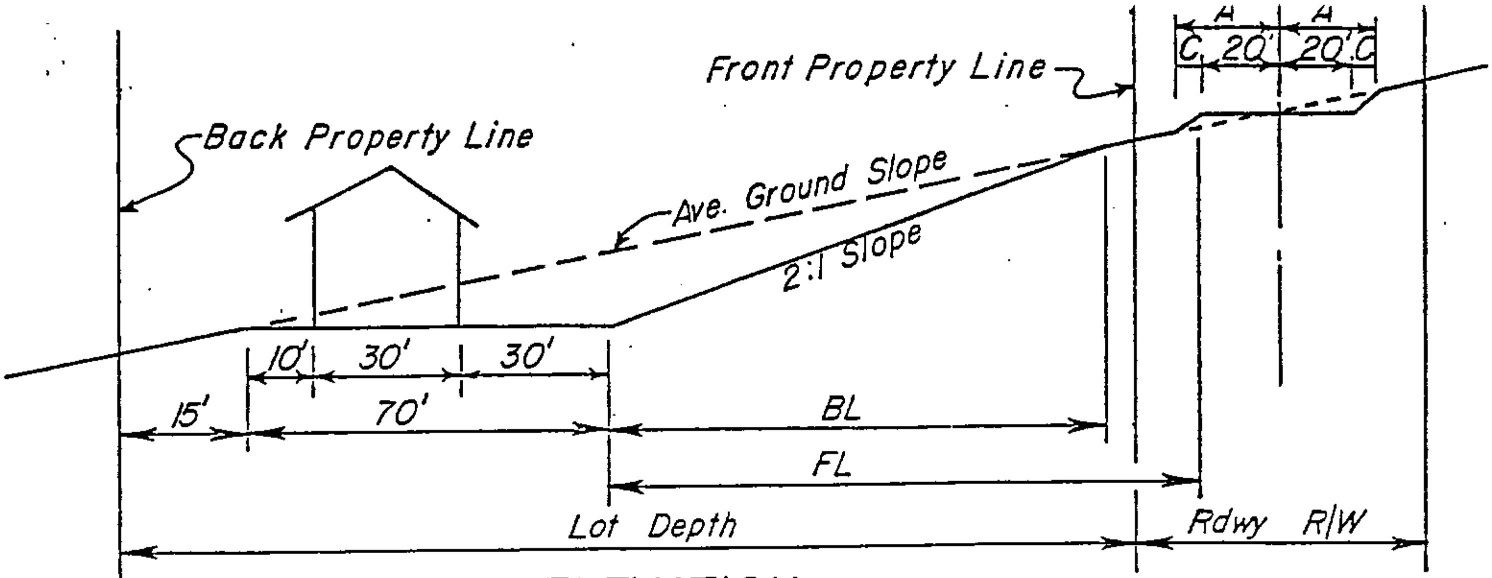
$$C = \frac{20'X}{(.5-X)} \qquad A = 20' + C \qquad B = \frac{90'X}{(.5-X)}$$

$$H = \frac{X(F+20')}{0.14} \qquad Y = \sqrt{H^2 - F^2} \qquad Z = \frac{10'Y}{F}$$

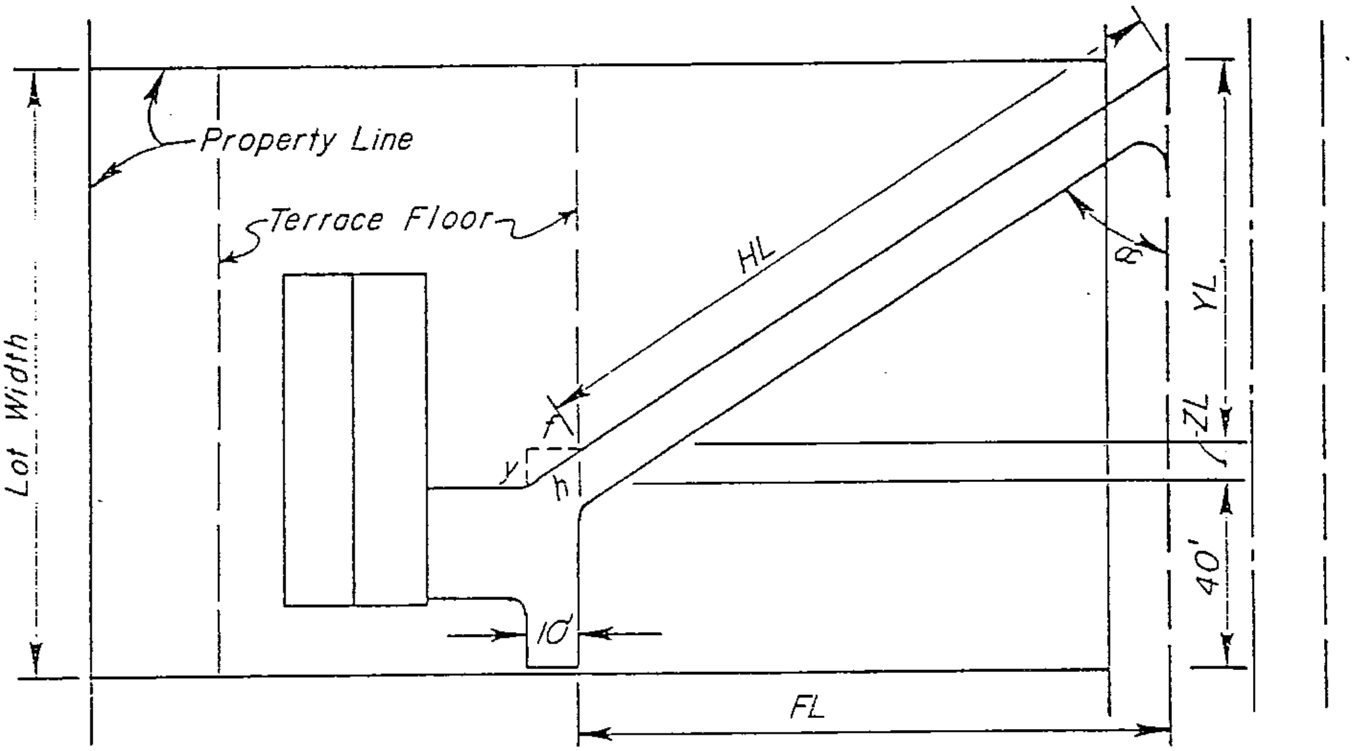
$$\alpha = \text{Arc. Tan. } F/Y$$

$$\text{Lot Depth} = (F-10') + 90' + B = F + B + 80'$$

$$\text{Lot Width} = Y + Z + 40'$$



ELEVATION



PLAN (STRAIGHT)

LOWER LOT CALCULATIONS

X is Average Ground Slope (ft./ft)

$C = \frac{20'X}{(0.5-X)}$ $A = 20' + C$ $BL = \frac{70'X}{(0.5-X)}$

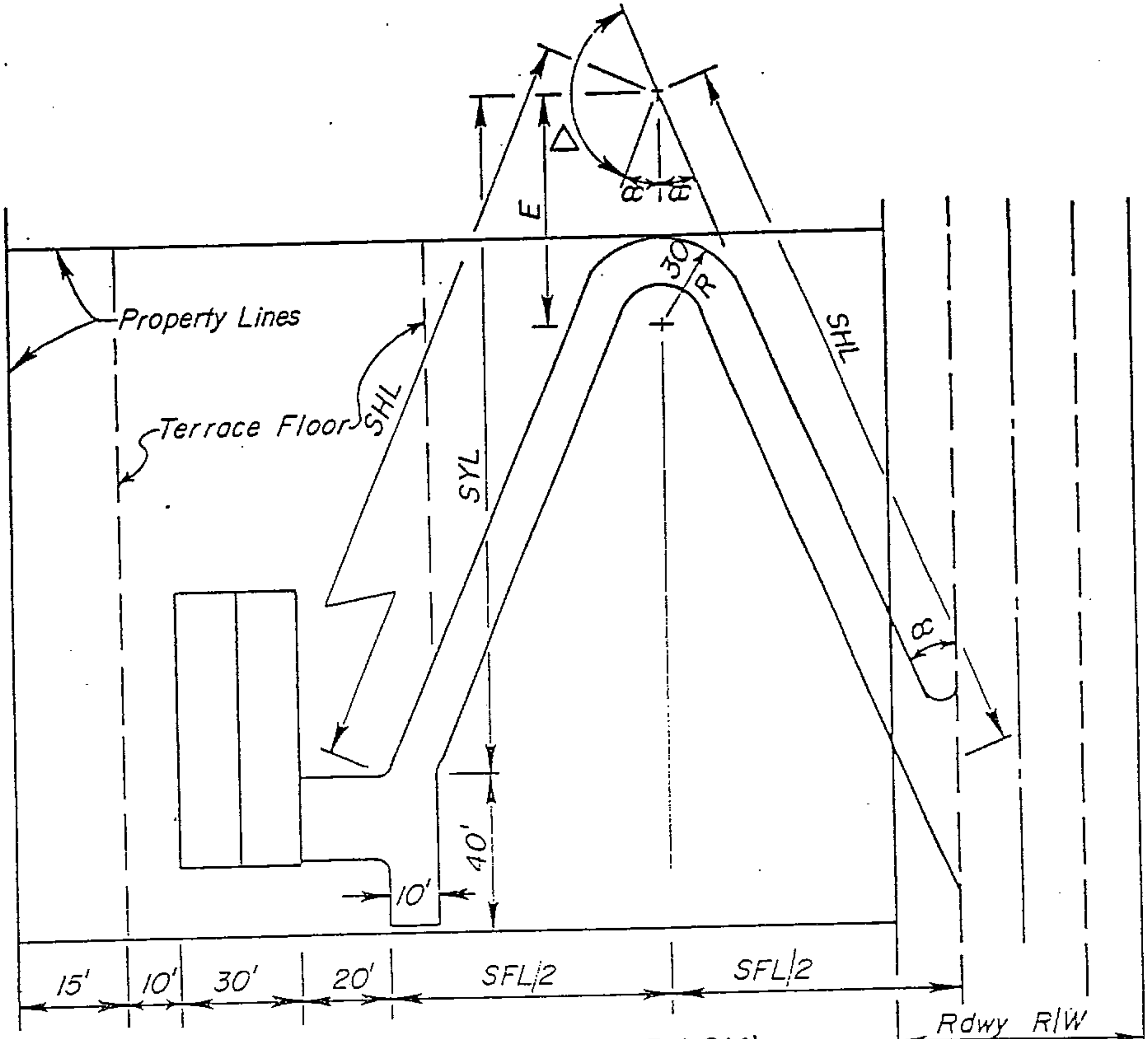
when: (i) $A - 20' \leq 10.0'$; then, $FL = 10' + BL$ at a minimum

(ii) $A - 20' > 10.0'$; then, $FL = (A - 20') + BL$ at a minimum

$HL = \frac{X(FL + 90')}{0.14}$ $YL = \sqrt{HL^2 - FL^2}$ $ZL = \frac{10'YL}{FL}$

$\alpha = \text{Arc. Tan } FL/YL$

Lot Depth = (FL – 10') + 70' + 15' = FL + 75' Lot Width = YL + ZL + 40'



PLAN (SWITCHBACK)

LOWER LOT CALCULATIONS

X is Average Ground Slope (ft/ft)

$C = \dfrac{20'X}{(0.5-X)}$ $\qquad A = 20' + C \qquad$ $SBL = \dfrac{70'X}{(0.5-X)}$

when: (i) $A - 20' \leq 10.0'$; then, $SFL = 10' + SBL$ at a minimum

(ii) $A - 20' > 10.0'$; then, $SFL = (A - 20') + SBL$ at a minimum

$SHL = \dfrac{X(SFL + 80')}{0.28}$ $\qquad SYL = \sqrt{SHL^2 - SFL^2} \qquad$ $\alpha = \text{Arc. Tan.} \dfrac{SFL}{2SYL}$

$\Delta = 180 - 2\alpha$ $\qquad E = 30' \left[\text{Tan} \dfrac{\Delta}{2}\right] \left[\text{Tan} \dfrac{\Delta}{4}\right]$

Lot Depth $= (SFL - 10') + 20' + 30' + 10' + 15' = SFL + 65'$

Lot Width $= 40' + SYL - E + 30' = SYL - E + 70'$

LOT DEMENSIONS
WITH ON-SITE SANITARY DISPOSAL SYSTEM

UPPER SIDE LOTS					
Ave. Ground Slope	α Angle	Minimum Lot Dimensions No Sewer Collection System			
		Setback	Depth	Width	Area
Per Cent	Degrees	ft.	ft.	ft.	$ft.^2$
10	90	35	118	140	16520
11	90	47	132	140	18480
12	90	70	158	140	22120
13	55.7	86	177	140	24780
14	59.7	101	196	140	27440
15	50.7	117	216	140	30240
16	47.9	132	233	141	32853
17	44.0	128	234	152	35568
18	40.8	125	236	162	38232
19	38.1	123	238	171	40698
20	35.8	121	241	181	43621
21	34.8	138	263	210	55230
22	33.5	150	281	237	66597
23	32.2	161	298	264	78672
24	31.0	169	312	288	89856
25	29.8	176	326	313	102038
26	28.6	181	339	335	113565
27	27.8	185	351	356	124956
28	26.5	188	363	376	136488
29	25.6	190	374	395	147730
30	24.7	192	387	413	159831
31	23.9	192	399	429	171171
32	23.1	192	412	444	182928
33	22.3	191	426	457	194682
34	21.6	189	441	467	205947
35	20.9	187	457	477	217989
36	20.3	185	476	487	231812
37	19.7	183	499	495	247005
38	19.1	179	524	499	261476
39	18.5	174	553	499	275947
40	INDIVIDUAL DESIGN		561	518	290598
41			568	537	305016
42			576	555	319680
43			583	573	334059
44			591	591	349281
45			603	603	363609
46			615	615	378225
47			626	626	391676
48			638	638	407044
49			649	649	421201
50			660	660	435600

LOT DEMENSIONS
WITH ON-SITE SANITARY DISPOSAL SYSTEM

LOWER SIDE LOTS

Ave. Ground Slope	STRAIGHT ANGLE DRIVEWAYS					SWITCHBACK DRIVEWAYS					
	α Angle	Minimum Lot Dimensions No Sewer Collection System				Minimum Lot Dimensions No Sewer Collection System					
		Setback	Depth	Width	Area	α	Δ	Setback	Depth	Width	Area
Per Cent	Degrees	ft.	ft.	ft.	ft.²	Degrees	Degrees	ft.	ft.	ft.	ft.²
10	34.8	65	120	140	16800	34.8	110.5	65	120	140	16800
11	37.7	84	139	140	19460	37.7	104.6	84	139	140	19460
12	35.9	91	146	152	22192	38.8	102.3	103	158	140	22120
13	33.5	94	149	167	24883	38.9	102.2	122	177	140	24780
14	31.2	96	151	182	27482	38.4	103.2	141	196	140	27440
15	29.3	98	153	197	30141	37.0	106.1	155	210	146	30660
16	27.6	100	155	212	32860	34.6	110.8	158	213	154	32802
17	26.0	101	156	227	35412	32.7	114.7	162	217	163	35371
18	24.7	103	158	242	38236	31.0	118.0	167	222	172	38184
19	23.5	104	159	257	40863	29.3	121.0	171	226	181	40906
20	22.3	105	160	272	43520	28.1	123.9	174	229	190	43510
21	23.1	124	179	308	55132	28.0	124.0	201	256	215	55040
22	23.2	140	195	343	66885	27.6	124.9	223	278	240	66720
23	23.0	153	208	377	78416	26.9	126.1	243	298	263	78374
24	22.6	164	219	411	90009	26.2	127.6	260	315	286	90090
25	22.1	174	229	444	101676	25.5	129.1	275	330	308	101640
26	21.6	183	238	476	113288	24.7	130.6	288	343	330	113190
27	21.0	190	245	509	124705	24.0	132.0	300	355	352	124960
28	20.5	197	252	541	136332	23.3	133.5	310	365	374	136510
29	20.0	204	259	573	148407	22.6	134.9	320	375	395	148125
30	19.4	209	264	604	159456	21.9	136.2	329	384	416	159744
31	18.9	214	269	635	170815	21.3	137.5	337	392	437	171304
32	18.4	219	274	667	182758	20.7	138.7	344	399	458	182742
33	18.0	224	279	699	195021	20.1	139.8	351	406	479	194474
34	17.5	228	283	730	206590	19.6	140.9	358	413	500	206500
35	17.1	231	286	760	217360	19.0	141.9	364	419	520	217880
36						18.6	142.9	372	427	544	232288
37						18.1	143.8	380	434	568	246512
38						17.7	144.6	387	442	592	261664
39						17.3	145.5	393	448	615	275520
40						INDIVIDUAL DESIGN			472	615	290280
41									496	615	305040
42									520	615	319800
43									543	615	333945
44									567	615	348705
45									590	615	362850
46									615	615	378225
47									626	626	391876
48									638	638	407044
49									649	649	421201
50									660	660	435600

LOT DEMENSIONS

SERVED BY SANITARY SYSTEM*

	UPPER SIDE LOTS					LOWER SIDE LOTS										
	STRAIGHT ANGLE DRIVEWAYS					STRAIGHT ANGLE DRIVEWAYS					SWITCHBACK DRIVEWAYS					
Ave. Ground Slope	Minimum Lot Dimensions With Sewer Collection System					Minimum Lot Dimensions With Sewer Collection System					Minimum Lot Dimensions With Sewer Collection System					
	α	Setback	Depth	Width	Area	α	Setback	Depth	Width	Area	α	Δ	Setback	Depth	Width	Area
Per Cent	Degrees	ft	ft.	ft.	$ft.^2$	Degrees	ft.	ft.	ft.	$ft.^2$	Degrees	Degrees	ft.	ft.	ft.	$ft.^2$
10	90	35	118	90	10620	34.8	65	120	119	14280	34.8	110.5	65	120	90	10800
11	90	47	132	90	11880	37.7	84	139	136	18904	37.7	104.6	84	139	99	13761
12	90	70	158	90	14220	SAME AS WITHOUT SEWER					38.8	102.3	103	158	110	17380
13	55.7	86	177	90	15930						38.9	102.2	122	177	122	21594
14	59.7	101	196	90	17640						38.4	103.2	141	196	134	26264
15	50.7	117	216	119	25704							SAME AS WITHOUT SEWER				
16	SAME AS WITHOUT SEWER															
17																
18																
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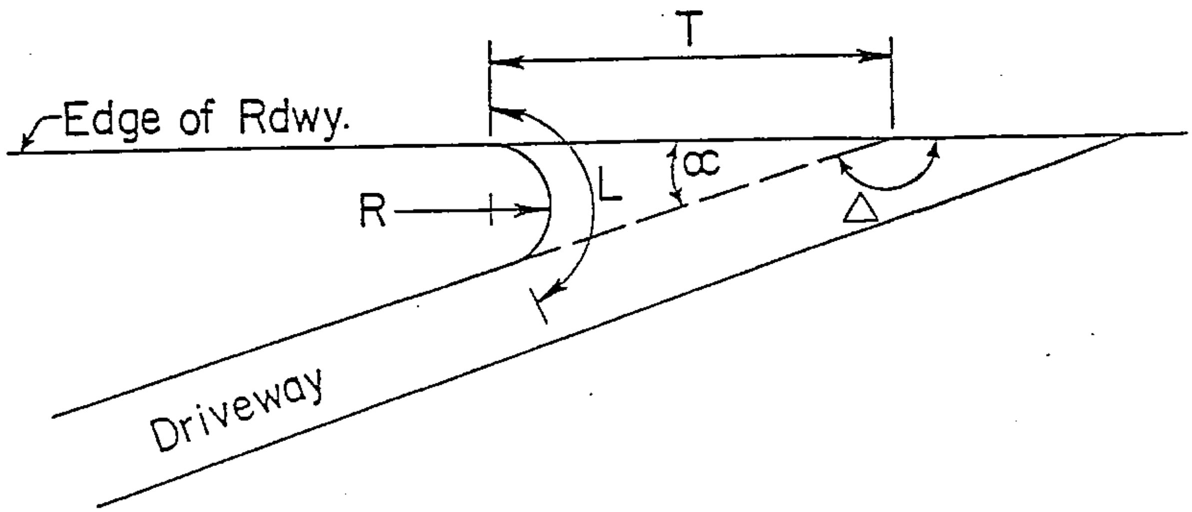
... lot dimensions should actually be used in practice

DRIVEWAY TRANSITION



$\Delta = 180 - \alpha$

$L = R\Delta(.017453293)$

$T = R \tan \Delta/2$

RADIUS R=6'					
∝	T	L	∝	T	L
Degrees	Feet	Feet	Degrees	Feet	Feet
15	45.57	17.28	55	11.53	13.09
20	34.03	16.76	60	10.39	12.57
25	27.06	16.23	65	9.42	12.04
30	22.39	15.71	70	8.57	11.52
35	19.03	15.18	75	7.82	11.00
40	16.48	14.66	80	7.15	10.47
45	14.49	14.13	85	6.55	9.95
50	12.87	13.61	90	6.00	9.43

CRITICAL LENGTH OF GRADES

CALIFORNIA HIGHWAY DEPARTMENT:

THE CRITICAL GRADE LENGTH IS DETERMINED FOR A SELECTED TRUCK AS THAT WHICH WILL CAUSE A 15 M.P.H. REDUCTION IN SPEED BELOW THE AVERAGE RUNNING SPEED ON THE APPROACH TO THE UPGRADE.

TO DERIVE THESE CRITICAL GRADE LENGTHS, THE CHANGE IN MOMENTUM OF THE TRUCK IS EQUATED TO THE DECELERATION OF THE TRUCK INDUCED BY GRAVITY AS THE TRUCK CLIMBS AN INCREASED ROADWAY GRADIENT.

CRITICAL GRADE LENGTH CALCULATIONS:

ASSUMPTIONS:

Weight of Truck = W = 40,000 lbs

Loss of Velocity = 15 miles per hour = 22 feet per second

CHANGE IN MOMENTUM: $F_M = -M\frac{(22\ fps)}{T}$

DECELERATION: $F_D = MA\ (\sin \emptyset)$

EQUATING F_M WITH F_D: $T = \frac{0.68}{\sin \emptyset}$

REQUIRED DISTANCE: $D = \frac{0.68\ (\text{Initial Velocity} - 11\ fps)}{\sin \emptyset}$

CRITICAL LENGTH OF GRADES (cont.)

CALCULATION TABLE

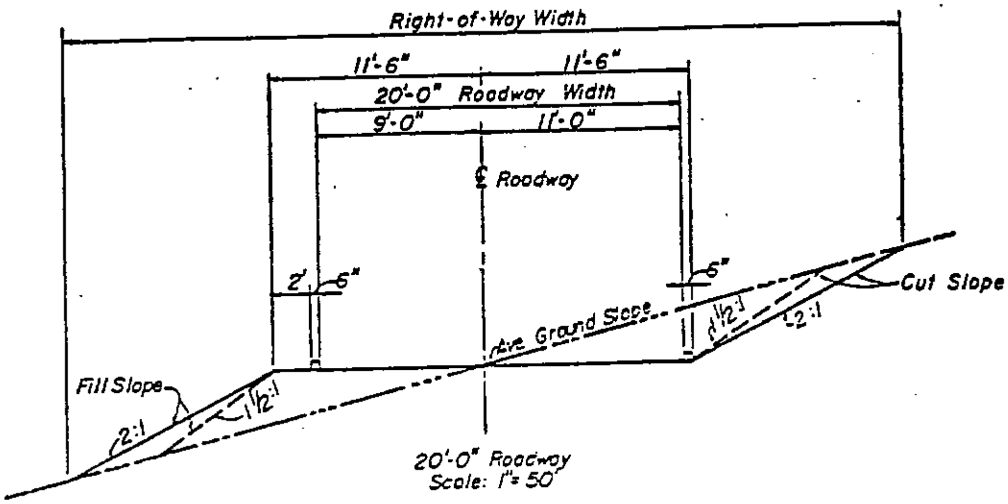
Upgrade Slope %	Upgrade Angle Ø	Time (Sec) T	Distance D (feet)		
			30 MPH Initial Vel.	40 MPH Initial Vel.	50 MPH Initial Vel.
3	1.718	22.79	752	1086	1420
6	3.434	11.41	377	544	711
8	4.574	8.57	283	408	534
10	5.711	6.87	227	327	428
11	6.277	6.25	206	298	390
12	6.843	5.73	189	273	357
13	7.407	5.30	175	253	330
14	7.970	4.93	163	235	307
15	8.531	4.61	152	220	287
16	9.090	4.33	143	206	270
17	9.648	4.08	135	194	254
18	10.204	3.86	127	184	240
19	10.758	3.660	121	175	228
20	11.310	3.484	115	166	217

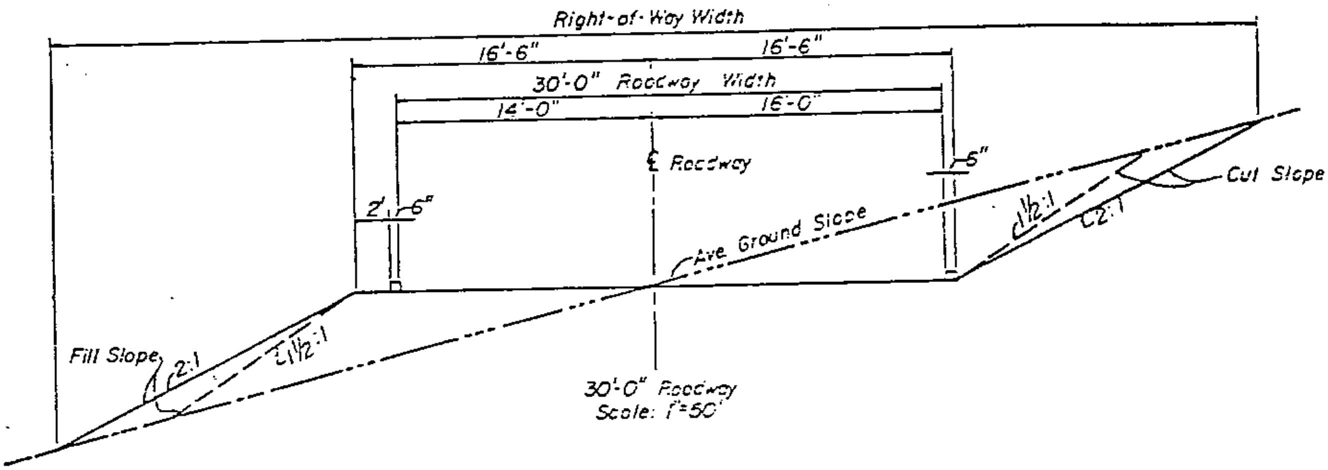
RECOMMENDED GRADE SPECIFICATION

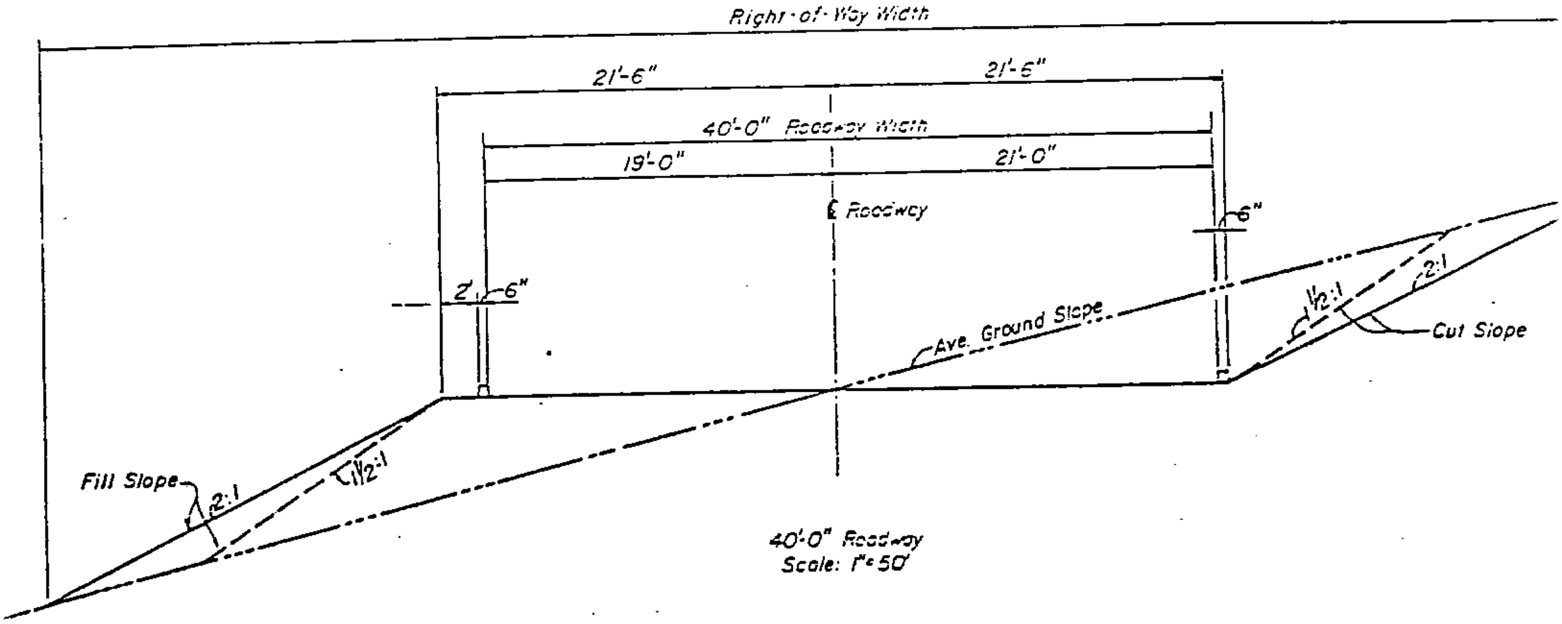
THE MAXIMUM ALLOWABLE CENTERLINE GRADE SHALL BE THE 12% AS SHOWN IN TABLE, BUT UNDER EXTREME CIRCUMSTANCES THE CENTERLINE GRADE MAY BE INCREASED TO AN EXTREME MAXIMUM OF 17%. BUT GRADIENTS LARGER THAN THE 12% SHALL BE HELD TO A MAXIMUM LENGTH. THE INCREASED GRADIENT, ABOVE THE 12%, MAY ONLY BE APPLIED ONCE INDIVIDUALLY AND THEN THE GRADIENT MUST BE RETURNED TO THE 12% OR LESS FOR A DISTANCE OF AT LEAST 500 FEET. THE DISTANCES FOR GRADIENTS LARGER THAN 12% CANNOT BE APPLIED CONSECUTIVELY. THE ALLOWABLE INCREASED GRADIENTS AND CORRESPONDING DISTANCES ARE:

Grade (%)	Max. Distance (ft)
13	200
14	175
15	150
16	125
17	100

TYPICAL ROADWAY SECTIONS







NOTE: See "Minimum Right of Way Required" Table on Page A-17

MINIMUM RIGHT OF WAY REQUIRED

AVERAGE GROUND SLOPE (%)	40'-0" ROADWAY WIDTH CUT and FILL SLOPE		30'-0" ROADWAY WIDTH CUT and FILL SLOPE		20'-0" ROADWAY WIDTH CUT and FILL SLOPE	
	2:1	1½:1	2:1	1½:1	2:1	1½:1
10	53.75	50.59	41.25	38.82	28.75	27.06
11	55.13	51.50	42.31	39.52	29.49	27.55
12	56.58	52.44	43.42	40.24	30.26	28.05
13	58.11	53.42	44.59	40.99	31.08	28.57
14	59.72	54.43	45.83	41.77	31.94	29.11
15	61.43	55.48	47.14	42.58	32.86	29.68
16	63.24	56.58	48.53	43.42	33.82	30.26
17	65.15	57.72	50.00	44.30	34.85	30.87
18	67.19	58.90	51.56	45.21	35.94	31.51
19	69.36	60.14	53.23	46.15	37.10	32.17
20	71.67	61.43	55.00	47.14	38.33	32.86
21	74.14	62.77	56.90	48.18	39.66	33.58
22	76.79	64.18	58.93	49.25	41.07	34.33
23	79.63	65.65	61.10	50.38	42.59	35.12
24	82.69	67.19	63.46	51.56	44.23	35.94
25	86.00	68.80	66.00	52.80	46.00	36.80
26	89.58	70.49	68.75	54.10	47.92	37.70
27	93.48	72.27	71.74	55.46	50.00	38.65
28	97.73	74.14	75.00	56.90	52.27	39.65
29	102.38	76.11	78.57	58.41	54.76	40.71
30	107.50	78.18	82.50	60.00	57.50	41.82
31	113.16	80.37	86.84	61.68	60.53	42.99
32	119.44	82.69	91.67	63.46	63.89	44.23
33	126.47	85.15	97.06	65.35	67.65	45.54
34	134.38	87.76	103.13	67.35	71.88	46.94
35	143.33	90.53	110.00	69.47	76.67	48.42
36	153.57	93.48	117.86	71.74	82.14	50.00
37	165.39	96.63	126.92	74.16	89.46	51.68
38	179.17	100.00	137.50	76.74	95.83	53.49
39	195.46	103.62	150.00	79.52	104.55	55.42
40	215.00	107.50	165.00	82.50	115.00	57.50
41	238.89	111.69	183.33	85.71	127.78	59.74
42	268.75	116.22	206.25	89.19	143.75	62.16
43	307.14	121.13	235.71	92.96	164.29	64.78
44	358.33	126.47	275.00	97.06	191.67	67.64
45	430.00	132.31	330.00	101.54	230.00	70.76
46	537.50	138.71	412.50	106.45	287.50	74.19
47	716.67	145.76	550.00	111.86	383.33	77.96
48	1075.00	153.57	825.00	117.86	575.00	82.13
49	2150.00	162.26	1650.00	124.53	1150.00	86.78
50	INFINITE	172.00	INFINITE	132.00	INFINITE	91.99