ANALYTICAL EVALUATION OF STATE CURB DESIGNS

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16. Abstract

MGA Research Corporation has conducted a limited study on three curb types that have been designed by the State Highway Departments of the States of Arizona and New Hampshire using the Highway-Vehicle-Object-Simulation Model (HVOSM). The purpose of this study was to evaluate what effect, if any, these curb designs would have on the guidelines governing the placement of longitudinal barriers. In order to make any determination, the HVOSM results were used to create bumper trajectory plots which showed that all three curb types cause responses which are within the same range or even less extreme than those caused by curbs presently in use. This led to the conclusion that the longitudinal barrier placement guidelines should not have to be modified when considering the Arizona and New Hampshire curbs.

17. Key Words
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1. INTRODUCTION

The purpose of this study conducted at MGA Research Corporation was to evaluate the effect of curb designs upon vehicle responses to interraction with the curbs through the use of computer simulation. The conditions of simulation included two vehicles (one full-size vehicle and one compact size vehicle) encroaching upon the curbs at a 15° angle and at velocities of 20, 40 and 60 mph (32.2, 64.4, and 96.6 km/h). The results of this limited study were then be used for the evaluation of the effects of curb designs on longitudinal barrier placement guidelines.

In conducting this study, MGA made use of the Highway-Vehicle-Object Simulation Model (HVOSM) (Ref. 1). The HVOSM is a general three dimensional vehicle dynamics model which allows the user to simulate the response of a vehicle due to such occurrances as contact with physical objects within the vehicle's path, changes in trajectory due to driver interraction and changes in terrain. (For a full discussion on the HVOSM, the reader is directed to Ref. 1). The study involved the simulation of two vehicles as they impacted three different curb designs. Each curb design also called for two variations in curb face height. The final variable in this study was the encroachment conditions. Each simulation used the same encroachment angle while the encroachment velocities varied between the three selected velocities.

The curb designs simulated have been developed by the State Highway Departments of the States of Arizona (one curb design) and New Hampshire (two curb designs - one for two lane roads and the other for parkways). The actual conditions and variables of each simulation are presented later in this report.

For this study, MGA made use of the HVOSM's terrain option. This option allows the terrain over which the simulation vehicle travels to be specified by a series of user defined locations and the terrain elevations at those locations. This, therefore, allows the terrain to be defined in all three physical dimensions.

Analysis of the simulation led to the development of bumper height plots which can be used to evaluate the effects of these curbs on recommendations for longitudinal barrier placement.

2. CONCLUSIONS

This section contains a summary of the conclusions resulting from the curb design study.

In this study, two vehicles (one full size - 1977 Plymouth Fury, one compact - Volkswagen Rabbit) were simulated impacting the curbs designed by the States of Arizona and New Hampshire. The conditions of impact involved an encroachment angle of 15° (for all simulations) and encroachment velocities of 20, 40 and 60 mph (32.2, 64.4, and 96.6 km/h). In this limited number of simulation runs of the Arizona curb caused a range of maximum bumper rise from 2.4 to 8.3 inches (61.0 to 210.8 mm) above the normal vehicle bumper heights. The ranges for maximum bumper rise for the two New Hampshire curbs were 1.8 to 18.5 inches (45.7 to 469.9 mm) above normal for the 2 lane curb and 2.0 to 20.9 inches (50.8 to 530.9 mm) above normal for the parkway curb. These ranges of maximum bumper rise are well within the range of bumper rises caused by curbs in use today. (For example, a Type A curb causes a range of bumper rise from 5.5 to 47.0 inches (139.7 to 1193.8 mm) above normal bumper height).

Upon complete evaluation of the results available from this limited study, it is seen that the Arizona and New Hampshire curbs do not cause vehicle response much different than those caused by curbs presently in use on highways today. This indicates that present guidelines on the placement of longitudinal barriers should be sufficient for these three curb types.

3. SIMULATION STUDY

This section contains a discussion of the simulation input data and the results obtained from the study.

3.1 Simulation Data

For the study, two vehicles were simulated. These vehicles were chosen because they are representative of the two extremes in vehicle size classification. For the full-size class, a 1977 Plymouth Fury was chosen. The necessary data for this vehicle was obtained from a report prepared for the National Highway Traffic Safety Administration by MGA entitled "Analytical Study in Support of the 400 Series Rollover Standard" (Ref. 2) and a report prepared for the Federal Highway Administration by the Texas Transportation Institute entitled "Guidelines for Placement of Longitudinal Barriers on Slopes - Volume III - Guidelines" (Ref. 3). The compact sized class is represented by the Volkswagen Rabbit. The necessary data for this vehicle comes from a report prepared for the Federal Highway Administration by ENSCO, Incorporated - Transportation Technology Engineering Division entitled "Laboratory Procedures to Determine the Breakaway Behavior of Luminaire Support in Mini-Sized Vehicle Collisions" (Ref. 4). Listings of the vehicle data used in the simulations are found in Tables 1 through 5.

The curb profiles used were supplied by the Federal Highway Administration. The two curb height variations that were specified for each curb design were heights of 3.0 in. and 6.0 in. (76.2 mm and 152.4 mm). Figures 1, 2 and 3 show the profiles of the Arizona, New Hampshire 2 lane and New Hampshire Parkway curbs and backslopes respectively.

In total, 36 simulation runs were made. Table 6 shows the conditions and physical factors involved in each run.

Table 1

INERTIA AND DIMENSIONAL DATA

Variable	Description	Values: 1977 Plymouth Fury	Values: Volkswagen Rabbit	Units
M_s	sprung mass	9.69	3.9441	$lb{-}s^2/in$
M_{uf}	front unsprung mass	0.544	0.3882	$lb{-}s^2/in$
M_{ur}	rear unsprung mass	0.907	0.3261	$lb{-}s^2/in$
I_x	X moment of inertia	4390.0	1932.0	$lb{-}s^2{-}in$
I_y	Y moment of inertia	27100.0	7231.0	$lb{-}s^2{-}in$
I_z	Z moment of inertia	31500.0	7976.0	$lb{-}s^2{-}in$
I_{xz}	XZ product of inertia	0.0	0.0	$lb{-}s^2{-}in$
I_r	rear axle moment of inertia	460.0	N/A	$lb{-}s^2{-}in$
a	front wheel X location (relative to vehicle C.G.)	51.79	32.7	in
b	rear wheel X location (relative to vehicle C.G.)	65.61	61.8	in
T_f	front wheel track	61.9	54.5	in
T_r	rear wheel track	62.0	53.5	in
	rear axle roll axis	-2.0	N/A	in
T_s	rear spring track	47.3	N/A	in
Z'_{co}	sprung mass C.G. height	21.195	21.1	in

SI Conversion

1 $lb{-}S^2/in$ = 17.8580 $kg{\cdot}S^2/m$
1 $lb{-}S^2{-}in$ = .01152 $kg{\cdot}S^2{\cdot}in$
1 in = 0.0254m

Table 2
SUSPENSION RATE DATA

Variable	Description	Values: 1977 Plymouth Fury	Values: Volkswagen Rabbit	Units
K_f	linear front suspension rate	138.0	75.0	lb/in
K_{fc}	linear coeff. of front suspension compression	162.0	303.6	lb/in
K'_{fc}	cubic coeff. of front suspension compression	283.0	902.1	lb/in^3
K_{fe}	linear coeff. of front suspension extension	162.0	2916.1	lb/in
K'_{fe}	cubic coeff. of front suspension extension	313.4	134265.0	lb/in^3
λf	front suspension stop energy dissipation ratio	0.5	0.65	
Ωfc	front suspension compression stop location	-3.88	-2.0	in
Ωfe	front suspension extension stop location	3.83	2.5	in
K_r	linear rear suspension rate	115.0	77.25	lb/in
K_{rc}	linear coeff. of rear suspension compression	185.0	150.6	lb/in
K'_{rc}	cubic coeff of rear suspension compression	283.0	37.3	lb/in^3
K_{re}	linear coeff. of rear suspension extension	313.4	1029.3	lb/in
λr	rear suspension stop energy dissipation ratio	0.5	0.65	
Ωrc	rear suspension compression stop location	-3.82	-2.25	in
Ωre	rear suspension extension stop location	4.5	4.25	in

SI Conversion

1 lb/in = 17.8580 kg/m
1 lb/in^3 = 2.7675×10^4 kg/m^3
1 in = 0.0254m

Table 3

SUSPENSION AND STEERING DATA

Variable	Description	Values: 1977 Plymouth Fury	Values: Volkswagen Rabbit	Units
C_f	front viscous damping coefficient	2.0	6.08	lb-s/in
C'_f	front suspension coulomb friction	36.0	15.0	lb
E_f	front suspension friction null band	0.05	0.1	in/sec
C_r	rear viscous damping coefficient	1.5	3.58	lb-s/in
C'_r	rear suspension coulomb friction	50.0	15.0	lb
E_r	rear suspension friction null band	0.05	0.1	in/sec
R_f	front suspension auxiliary roll stiffness	250000.0	0.0	lb-in/rad
R_r	rear suspension auxiliary roll stiffness	60000.0	84750.0	lb-in/rad
K_{rs}	rear axle roll-steer coefficient	0.05	N/A	deg/deg
$K_{\delta s}$	coefficient for cubic representation	N/A	0.0	rad
$K_{\delta s1}$	of rear wheel steer angle as a function	N/A	0.0	rad/in
$K_{\delta s2}$	of displacement	N/A	0.0	rad/in^2
$K_{\delta s3}$		N/A	0.0	rad/in^3
I_ψ	steering system steer moment of inertia	300.0	16.0	$lb\text{-}s^2\text{-}in$
C'_ψ	steering system coulomb friction torque	1000.0	270.0	lb-in
Ω_ψ	front wheel steer angle when steering limit stops are engaged	0.523	0.676	rad
K_ψ	stiffness of steering limits	50000.0	32396.0	lb-in/rad
E_ψ	steering system friction lag	0.01	0.1	rad/sec
PT	front wheel pneumatic trail	1.5	1.58	in

SI Conversion

1 lb-s/in = 17.8580 kg-s/m
1 in = 0.0254 m
1 in/sec = 0.0254 m/s
1 lb-in/rad = 0.1130 N-m/rad
1 rad/in = 39.37 rad/m
1 $rad/in^2 = 1.5500 \times 10^3\ rad/m^2$
1 $rad/in^3 = 6.1013 \times 10^4\ rad/m^3$
1 lb-s-in = 0.1130 N-s-m
1 lb-in = 0.1130 N-m

Table 4

TIRE DATA

Variable	Description	Values: 1977 Plymouth Fury	Values: Volkswagen Rabbit	Units
RWHJE	final deflection of force vs deflection for radial spring tire model	6.0	6.0	in
DRWHJ	increment of deflection for radial spring tire model	0.25	0.25	in
K_t	tire load-deflection rate	1285.0	865.0	lb/in
σ_t	tire deflection at which the load rate increases	6.0	3.0	in
λ_t	multiplier of K_t used to obtain tire stiffness at larger deflections	10.0	10.0	
A_0	constant for tire side force characteristics due to slip angle	4000.0	2100.0	
A_1		8.4	3.8	
A_2		3000.0	1800.0	
A_3	constants for tire side force characteristics due to camber angle	1.17	1.9	
A_4		4200.0	3400.0	
Ω_t	multipler of A_2 at which side force characteristics stop	0.75	0.85	
μ	tire/ground friction coefficient	0.7	0.7	
R_w	undeformed tire radius	13.75	11.285	in

SI Conversion

1 in = 0.0254 m
1 lb/in = 17.8580 kg/m

Table 5

CAMBER AND TRACK CHANGE DATA FOR 1977 PLYMOUTH FURY

Suspension deflection (in)	Camber (deg) front	Camber (deg) rear	Half-track change (in) front	Half-track change (in) rear
-4.0	-2.02		0.0	
-3.0	-2.02		0.0	
-2.0	-0.91		0.0	
-1.0	-0.32		0.0	
0.0	0.25	N/A	0.0	N/A
1.0	0.12		0.0	
2.0	0.06		0.0	
3.0	0.32		0.0	
4.0	0.32		0.0	

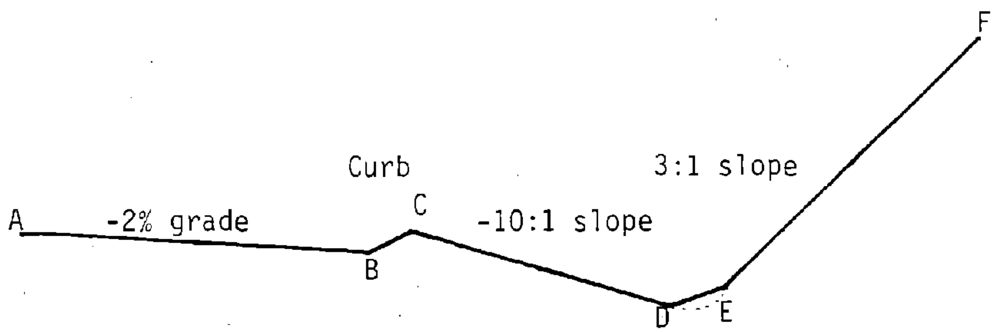
Table 5 (Condt.)

CAMBER AND TRACK CHANGE DATA FOR VOLKSWAGEN RABBIT

Suspension deflection (in)	Camber (deg) front	Camber (deg) rear	Half-track change (in) front	Half-track change (in) rear
-8.0	3.66	0.0	-2.65	0.0
-7.0	1.66	0.0	-1.85	0.0
-6.0	0.66	0.0	-1.20	0.0
-5.0	-0.08	0.0	-0.65	0.0
-4.0	-0.33	0.0	-0.30	0.0
-3.0	-0.50	0.0	-0.10	0.0
-2.0	-0.50	0.0	0.50	0.0
-1.0	-0.17	0.0	0.50	0.0
0.0	0.33	0.0	0.0	0.0
1.0	0.83	0.0	-0.20	0.0
2.0	1.83	0.0	-0.45	0.0
3.0	2.58	0.0	-0.80	0.0
4.0	3.50	0.0	-1.25	0.0
5.0	5.0	0.0	-1.85	0.0

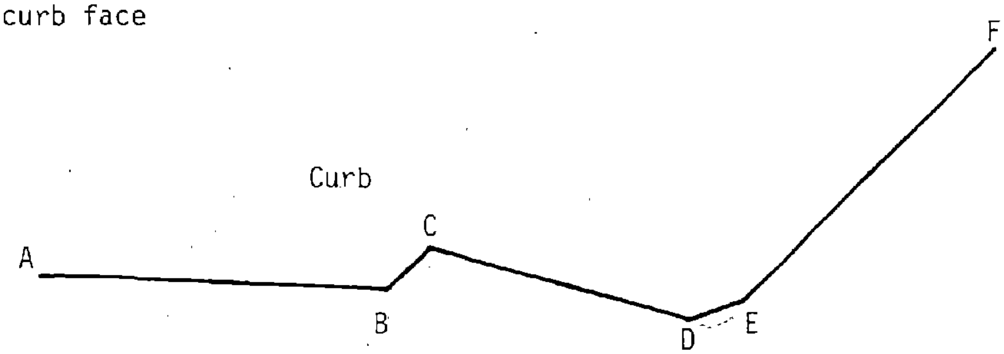
SI Conversion

in = 25.4 mm



Point	Physical Representation	Distance from edge of payment	Elevation (Pos. down)
A	beginning of section	-10.0 ft	0.0 in
B	bottom of gutter	2.0 ft	2.88 in
C	top of curb	3.5 ft	-0.12 in
*D	beginning of rounding section	12.5 ft	10.68 in
*E	end of rounding section	14.5 ft	7.92 in
F	end of section	23.5 ft	-28.08 in

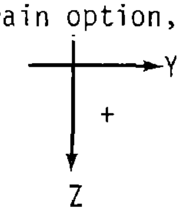
a) 3 inch curb face



Point	Physcial Representation	Distance from edge of payment	Elevation (Pos. down)
A	beginning of section	-10.0 ft	0.0 in
B	bottom of gutter	2.0 ft	2.88 in
C	top of curb	3.5 ft	-3.12 in
*D	beginning of rounding section	12.5 ft	7.68 in
*E	end of rounding section	14.5 ft	4.92 in
F	end of section	23.5 ft	-31.08 in

b) 6 inch curb face

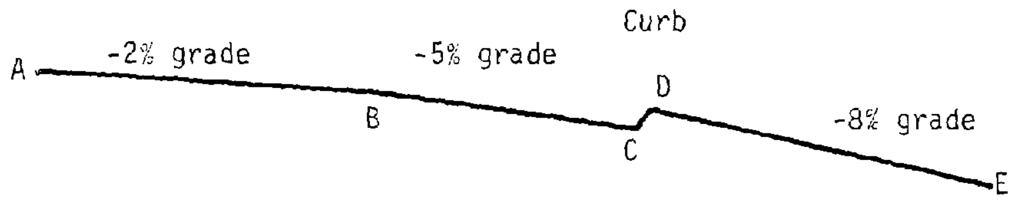
*NOTE: Due to the nature of the interpolation routine in the HVOSM terrain option, the section between points D and E is rounded (as desired)



SI Conversion

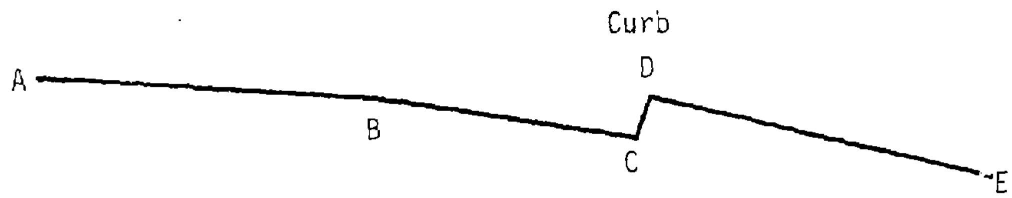
1 ft = 0.3048 m
1 in = 25.4 mm

Figure 1 ARIZONA CURB AND BACKSLOPE PROFILES



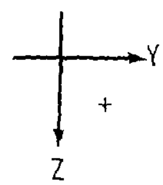
Point	Physical Representation	Distance from edge of payment	Elevation (Pos. down)
A	beginning of section	-12.0 ft	0.0 in
B	edge of payment	0.0 ft	2.83 in
C	bottom of gutter	9.0 ft	8.28 in
D	top of curb	9.5 ft	5.28 in
E	end of section	21.5 ft	16.8 in

a) 3 inch curb face



Point	Physical Representation	Distance from edge of payment	Elevation (Pos. down)
A	beginning of section	-12.0 ft	0.0 in
B	edge of pavement	0.0 ft	2.38 in
C	bottom of gutter	9.0 ft	8.28 in
D	top of curb	9.5 ft	2.28 in
E	end of section	21.5 ft	13.8 in

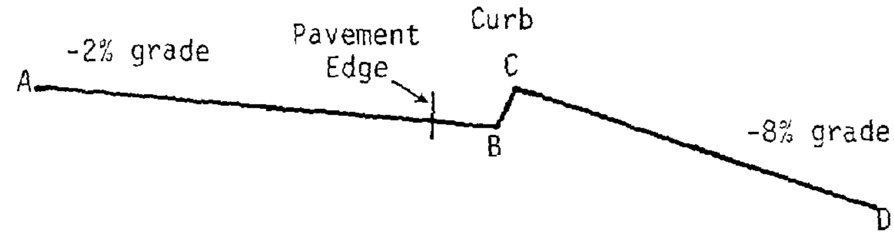
b) 6 inch curb face



SI Conversion

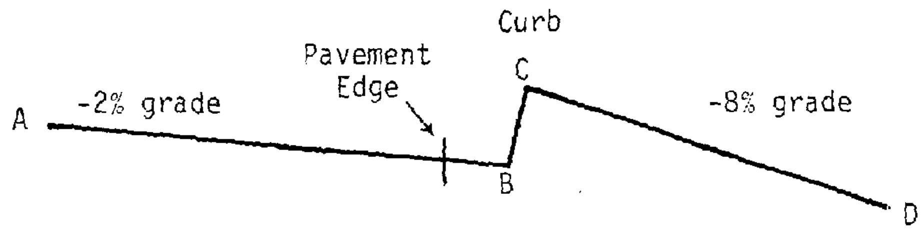
1 ft = 0.3048 m
1 in = 25.4 mm

Figure 2 NEW HAMPSHIRE 2 LANE CURB AND BACKSLOPE PROFILES



Point	Physical Representation	Distance from edge of payment	Elevat (Pos. c
A	beginning of section	-10.0 ft	0.0
B	bottom of gutter	2.0 ft	2.88
C	top of curb	2.5 ft	-0.12
D	end of section	12.0 ft	9.0

a) 3 inch curb face



Point	Physical Representation	Distance from edge of payment	Elevat (Pos. d
A	beginning of section	-10.0 ft	0.0
B	bottom of gutter	2.0 ft	2.88
C	top of curb	2.5 ft	-3.12
D	end of section	12.0 ft	6.0

b) 6 inch curb face

SI Conversion

1 ft = 0.3048 m
1 in = 25.4 mm

Figure 3 NEW HAMPSHIRE PARKWAY CURB AND BACKSLOPE PROFILES

Table 6

SIMULATION RUN MATRIX

Vehicle simulated	Impact velocity	General curb design simulated	Height of curb face simulated
1977 Plymouth Fury	20 mph	Arizona	3"
1977 Plymouth Fury	40 mph	Arizona	3"
1977 Plymouth Fury	60 mph	Arizona	3"
1977 Plymouth Fury	20 mph	Arizona	6"
1977 Plymouth Fury	40 mph	Arizona	6"
1977 Plymouth Fury	60 mph	Arizona	6"
1977 Plymouth Fury	20 mph	New Hampshire 2 lane	3"
1977 Plymouth Fury	40 mph	New Hampshire 2 lane	3"
1977 Plymouth Fury	60 mph	New Hampshire 2 lane	3"
1977 Plymouth Fury	20 mph	New Hampshire 2 lane	6"
1977 Plymouth Fury	40 mph	New Hampshire 2 lane	6"
1977 Plymouth Fury	60 mph	New Hampshire 2 lane	6"
1977 Plymouth Fury	20 mph	New Hampshire Parkway	3"
1977 Plymouth Fury	40 mph	New Hampshire Parkway	3"
1977 Plymouth Fury	60 mph	New Hampshire Parkway	3"
1977 Plymouth Fury	20 mph	New Hampshire Parkway	6"
1977 Plymouth Fury	40 mph	New Hampshire Parkway	6"
1977 Plymouth Fury	60 mph	New Hampshire Parkway	6"
Volkswagen Rabbit	20 mph	Arizona	3"
Volkswagen Rabbit	40 mph	Arizona	3"
Volkswagen Rabbit	60 mph	Arizona	3"
Volkswagen Rabbit	20 mph	Arizona	6"
Volkswagen Rabbit	40 mph	Arizona	6"
Volkswagen Rabbit	60 mph	Arizona	6"
Volkswagen Rabbit	20 mph	New Hampshire 2 lane	3"
Volkswagen Rabbit	40 mph	New Hampshire 2 lane	3"
Volkswagen Rabbit	60 mph	New Hampshire 2 lane	3"
Volkswagen Rabbit	20 mph	New Hampshire 2 lane	6"
Volkswagen Rabbit	40 mph	New Hampshire 2 lane	6"
Volkswagen Rabbit	60 mph	New Hampshire 2 lane	6"
Volkswagen Rabbit	20 mph	New Hampshire Parkway	3"
Volkswagen Rabbit	40 mph	New Hampshire Parkway	3"
Volkswagen Rabbit	60 mph	New Hampshire Parkway	3"
Volkswagen Rabbit	20 mph	New Hampshire Parkway	6"
Volkswagen Rabbit	40 mph	New Hampshire Parkway	6"
Volkswagen Rabbit	60 mph	New Hampshire Parkway	6"

SI Conversion

1 mph = 1.609 km/h
1 in = 25.4 mm

3.2 Simulation Results

A vehicle's response and handling capabilities can be judged and scrutinized through many different avenues. In the case of impacting an object, such as a curb, what happens to the vehicle as far as orientation, positioning and forces of impact become important. Table 7 shows the resulting extremes of three such response factors for each simulation. These three factors are the vehicle's roll and pitch angles and the acceleration (expressed in G's) experienced at the vehicle's center of gravity.

A second and most often used area in evaluating curb designs is the vehicles response in the form of bumper trajectory. Figures 5, 6, and 7 show the results of the simulations made. In each of these figures, the initial dip in the bumper height is due to the traversing of the curb face. One point should be noted from Figures 6 and 7. That is, both New Hampshire curbs show redirective qualities for the smaller vehicle at lower speeds.

Table 7
VEHICLE RESPONSE EXTREMES

Vehicle	Curb	Curb face height (in)	Encroachment speed (mph)	Roll Angle* (deg) min	Roll Angle* (deg) max	Pitch Angle* (deg) min	Pitch Angle* (deg) max	Vert. Accel.* G forces min	Vert. Accel.* G forces max
Plymouth Fury	Arizona	3	20	-20.30	6.29	-2.02	5.65	-0.24	0.15
Plymouth Fury	Arizona		40	-20.01	8.54	-1.64	4.11	-1.03	0.16
Plymouth Fury	Arizona		60	-28.93	9.62	-1.58	4.77	-2.19	0.38
Plymouth Fury	Arizona	6	20	-20.47	6.91	-3.58	4.47	-0.43	0.23
Plymouth Fury	Arizona		40	-19.70	10.57	-1.72	4.05	-0.99	0.31
Plymouth Fury	Arizona		60	-30.35	12.68	-1.38	4.97	-2.46	0.84
VW Rabbit	Arizona	3	20	-18.88	6.69	-1.98	7.66	-0.49	0.15
VW Rabbit	Arizona		40	-20.15	7.41	-1.45	6.54	-1.23	0.27
VW Rabbit	Arizona		60	-25.51	8.59	-1.70	6.77	-4.09	0.67
VW Rabbit	Arizona	6	20	-18.93	6.83	-2.28	7.55	-0.42	0.35
VW Rabbit	Arizona		40	-19.82	8.46	-1.86	6.04	-1.25	0.51
VW Rabbit	Arizona		60	-29.97	12.40	-2.26	6.57	-4.22	0.82
Plymouth Fury	NH 2 Lane	3	20	-0.42	4.98	-1.98	0.47	-0.23	0.11
Plymouth Fury	NH 2 Lane		40	-0.85	7.13	-1.57	0.11	-0.25	0.24
Plymouth Fury	NH 2 Lane		60	-0.59	7.82	-1.04	0.03	-0.25	0.30
Plymouth Fury	NH 2 Lane	6	20	-2.58	5.14	-2.86	2.52	-0.20	0.33
Plymouth Fury	NH 2 Lane		40	-5.38	11.58	-0.71	1.73	-1.85	0.54
Plymouth Fury	NH 2 Lane		60	-6.61	15.74	-1.29	1.13	-0.72	1.03
VW Rabbit	NH 2 Lane	3	20	-0.22	5.32	-1.76	0.57	-0.73	0.18
VW Rabbit	NH 2 Lane		40	-1.07	6.26	-1.35	0.35	-0.77	0.43
VW Rabbit	NH 2 Lane		60	-1.30	6.93	-1.34	0.12	-0.61	0.46
VW Rabbit	NH 2 Lane	6	20	-6.18	2.79	-2.87	3.32	-0.41	0.65
VW Rabbit	NH 2 Lane		40	-8.61	8.44	-1.54	4.66	-3.19	0.99
VW Rabbit	NH 2 Lane		60	-14.58	11.67	-5.82	4.17	-8.24	1.13
Plymouth Fury	NH Parkway	3	20	-1.16	5.28	-1.60	0.84	-0.22	0.09
Plymouth Fury	NH Parkway		40	-1.27	7.43	-1.31	0.37	-0.25	0.26
Plymouth Fury	NH Parkway		60	-1.24	7.04	-0.52	0.03	-0.38	0.20
Plymouth Fury	NH Parkway	6	20	-4.09	3.39	-2.43	2.61	-0.18	0.21
Plymouth Fury	NH Parkway		40	-5.59	10.70	-2.09	2.09	-2.25	0.51
Plymouth Fury	NH Parkway		60	-7.40	15.06	-0.82	1.17	-1.77	0.68
VW Rabbit	NH Parkway	3	20	-1.07	5.34	-1.54	0.91	-0.42	0.19
VW Rabbit	NH Parkway		40	-1.78	6.64	-1.21	0.63	-0.52	0.38
VW Rabbit	NH Parkway		60	-2.04	7.96	-1.55	0.38	-0.85	0.65
VW Rabbit	NH Parkway	6	20	-5.88	1.14	-2.13	3.34	-0.61	0.51
VW Rabbit	NH Parkway		40	-9.28	10.90	-1.87	4.45	-7.52	1.00
VW Rabbit	NH Parkway		60	-16.31	7.03	-6.32	4.70	-0.33	2.64

*See Figure 4 for definition of positive and negative senses

SI Conversion

1 in = 25.4 mm
1 mph = 1.609 km/h
1 g = 9.806 m/s^2

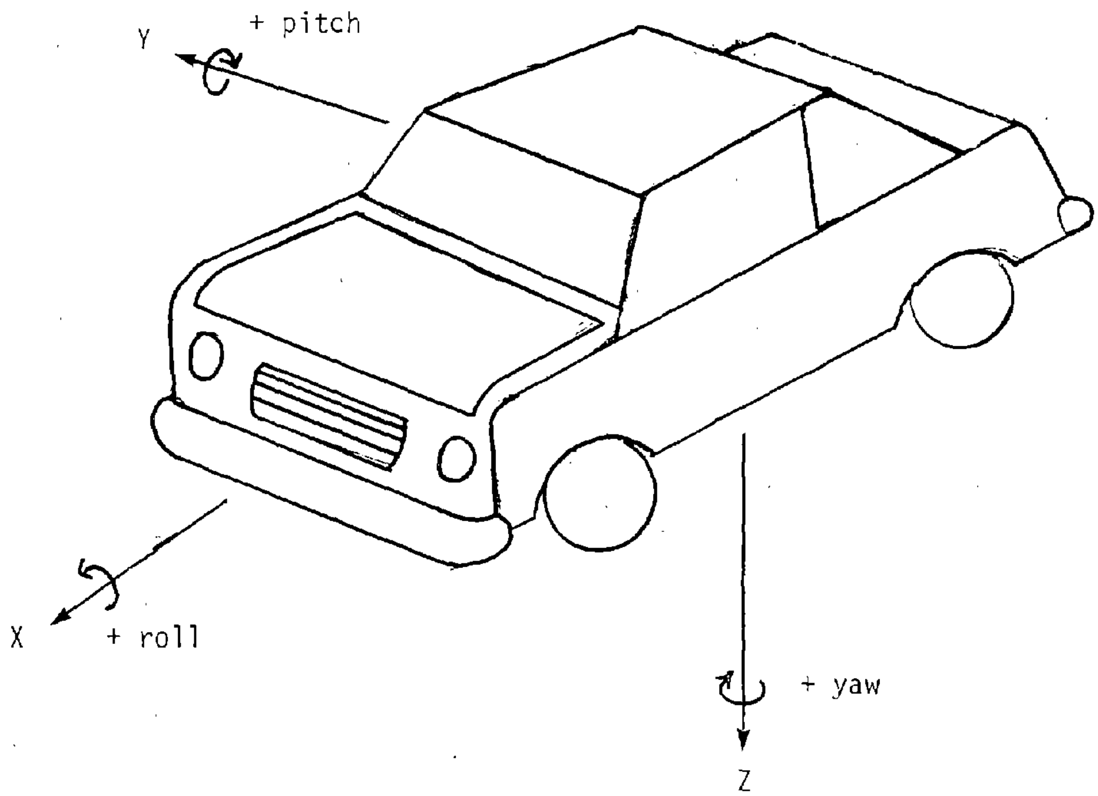
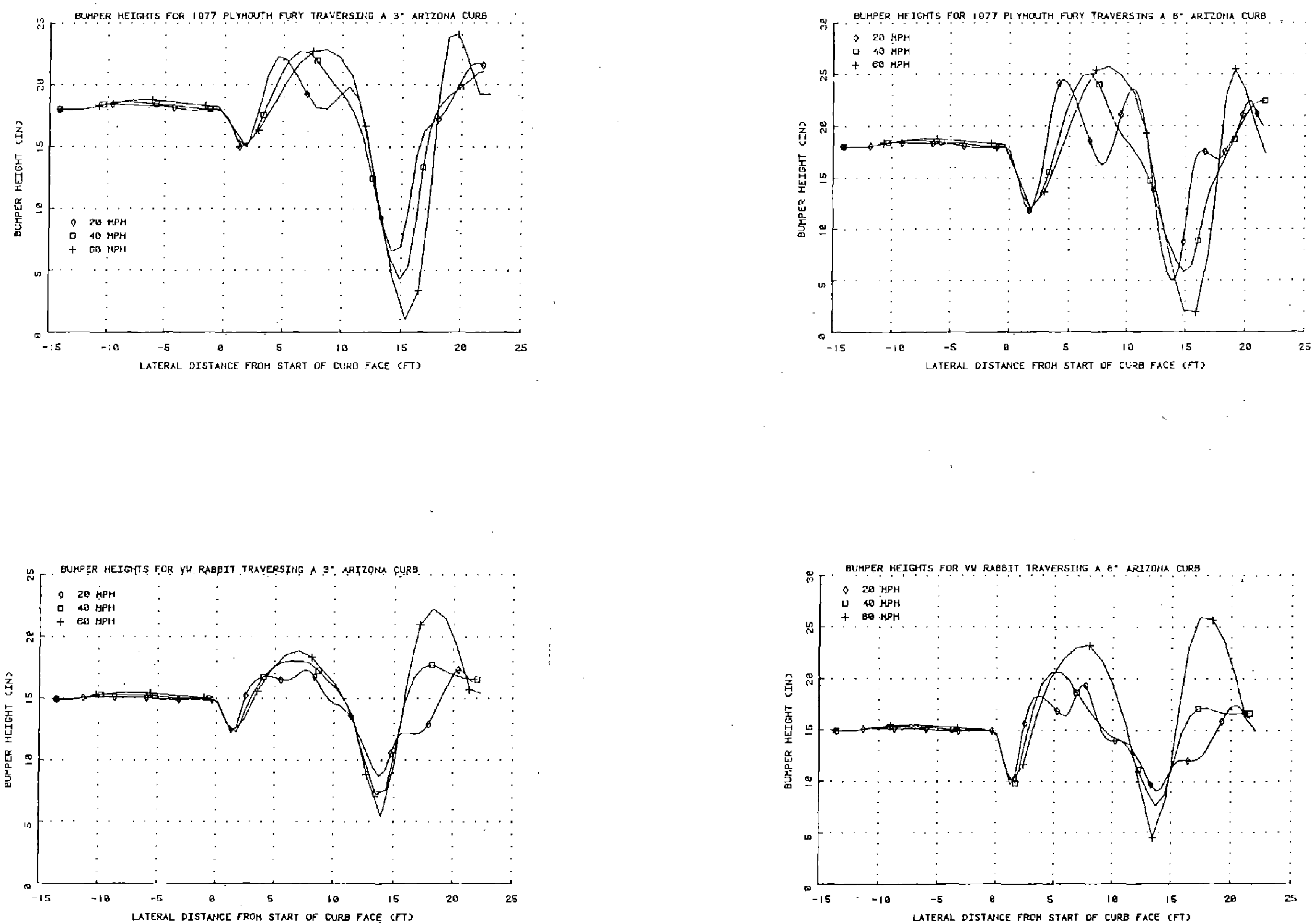


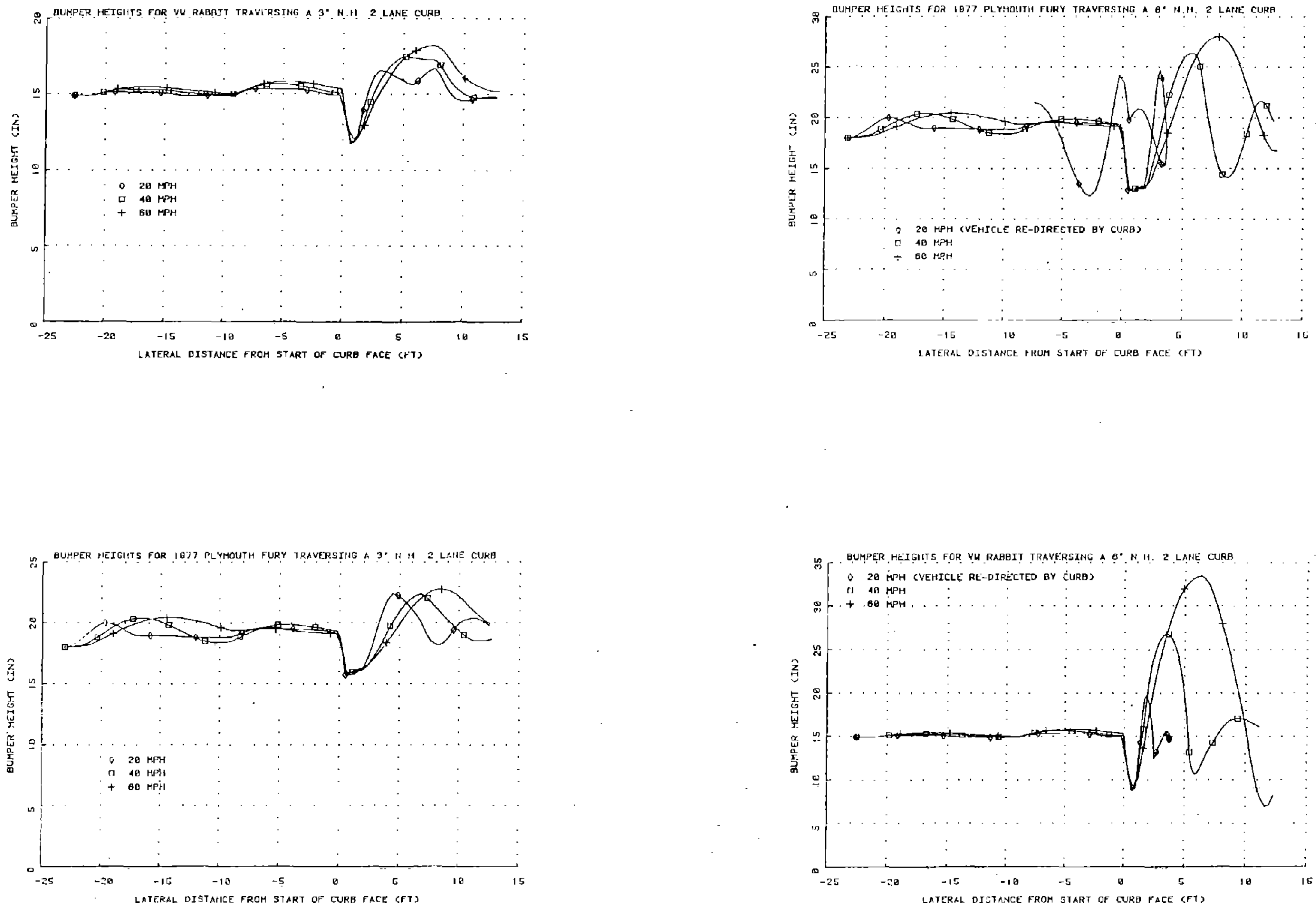
Figure 4 HVOSM VEHICLE REFERENCE SYSTEM



SI Conversion

1 in = 25.4 mm
1 ft = 0.3048 m

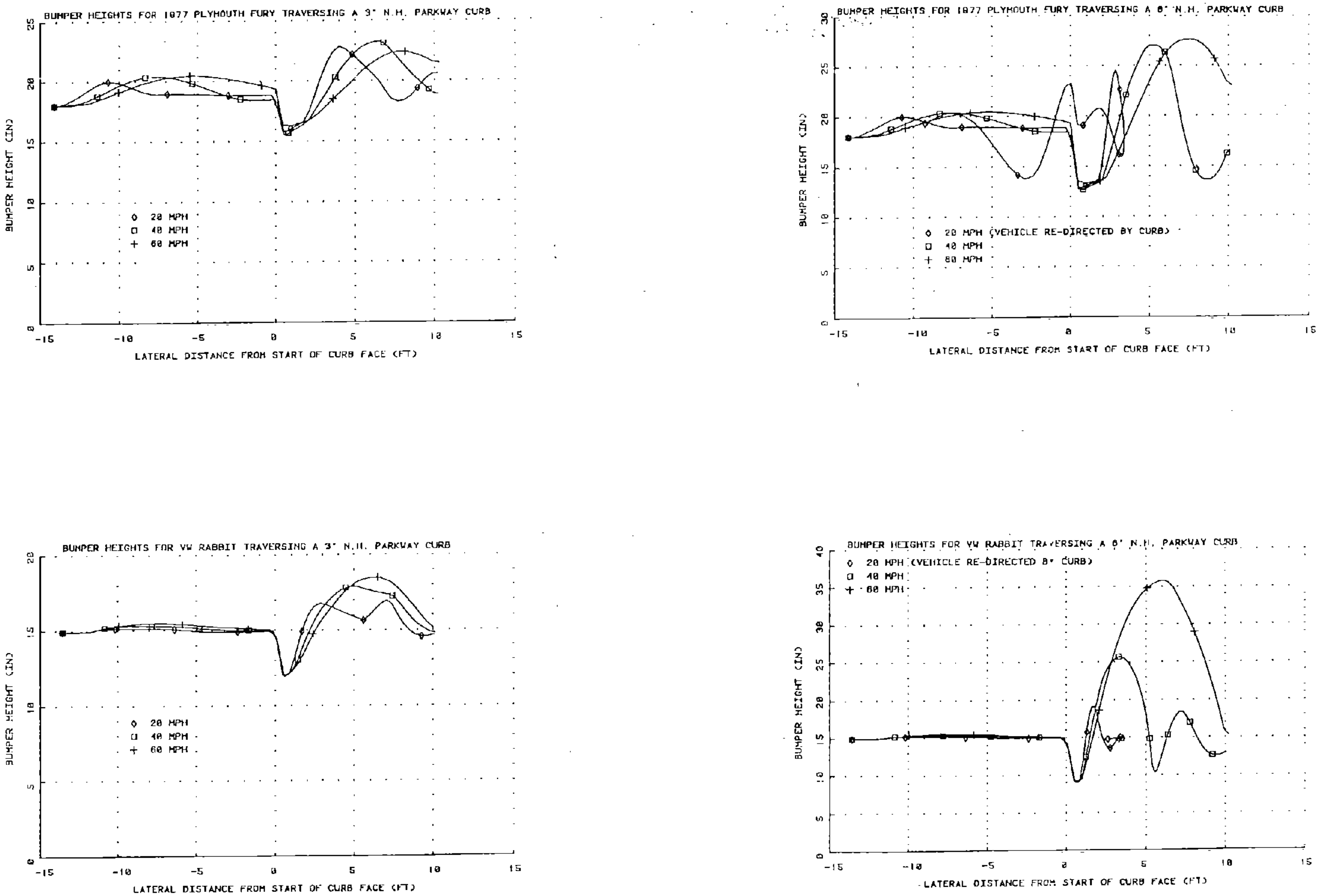
Figure 5 BUMPER TRAJECTORIES FOR ARIZONA CURB IMPACTS SIMULATED



SI Conversion

1 in = 25.4 mm
1 ft = 0.3048 m

Figure 6 BUMPER TRAJECTORIES FOR NEW HAMPSHIRE 2 LANE CURB IMPACTS SIMULATED



SI Conversion

1 in = 25.4 mm
1 ft = 0.3048 m

Figure 7 BUMPER TRAJECTORIES FOR NEW HAMPSHIRE PARKWAY CURB IMPACTS SIMULATED

4. DISCUSSION

From this limited study of the Arizona and New Hampshire curbs, nothing has emerged to show that the responses they cause are different from the curbs presently in use. As an example, each curve shows the general sinusoidal pattern of bumper trajectory (see Figures 5 through 7) caused by curb impacts as shown in Figure 8. Figure 8 shows the design parameters for vehicle encroachments on curbs as defined by the American Association of State Highway and Transportation Officials (AASHTO) (Ref. 5). These parameters represent distances and vertical bumper displacements at key positions in the bumper trajectory. They include: 1) ΔH_{min} - the greatest vertical bumper displacement when the bumper is below its normal height;[1] 2) ΔH_{max} - the greatest vertical bumper displacement when the bumper is above its normal height; 3) L_{min} - the lateral distance where ΔH_{min} occurs; 4) L_o - the lateral distance where the bumper first returns to its normal height; 5) L_{max} - the lateral distance where ΔH_{max} occurs; and 6) L - the lateral distance where the bumper returns to its normal height for the second time. For L_{min}, L_o, L_{max} and L, the distance is taken from the top of the curb. These design parameters can be used to compare the curbs studied with those in use of highways today. Such comparisons have been made and are included as Figures 9 through 14. The information used for these comparisons comes from the 1977 AASHTO guide (Ref. 5) and are for the range of encroachment speeds covered by this study and a range of enchroachment angles from 12.5° to 25°. (See Figure 15 for the curb geometries used in the comparisons). These comparisons also include both vehicle class sizes covered in this study. Although the encroachment conditions documented in the AASHTO reported tests do not correspond directly to the simulations made, Figures 9 through 14 show that the design parameters for the Arizona and New Hampshire curbs fall within the ranges or are lower than those for the curbs presently in use.

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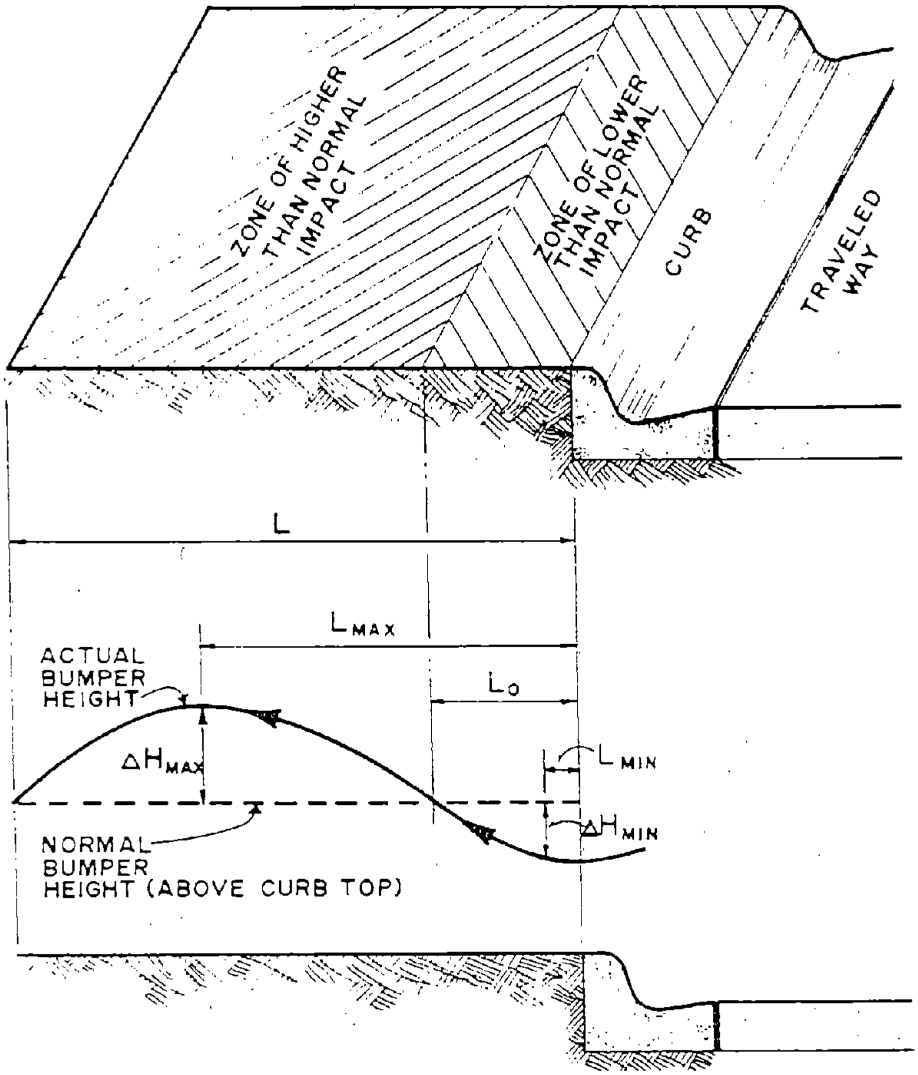
[1]Normal bumper height is the distance from the ground to the bumper when the vehicle is at rest on level (flat) ground.



L = DISTANCE FROM TOP OF CURB TO SECOND RETURN TO NORMAL BUMPER HEIGHT

L_{max} = DISTANCE FROM TOP OF CURB TO OCCURRANCE OF HIGHEST BUMPER HEIGHT

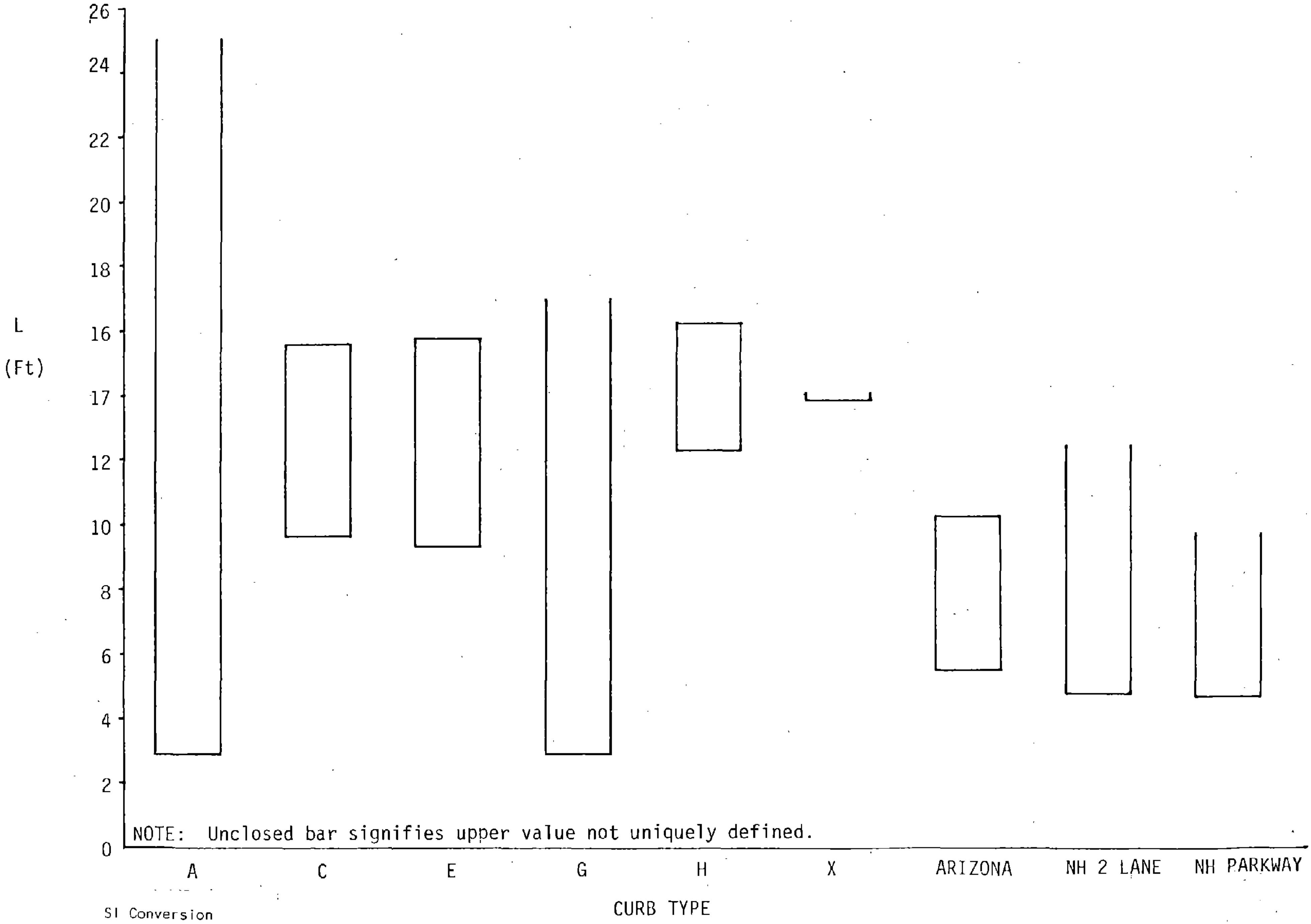
L_o = DISTANCE FROM TOP OF CURB TO FIRST RETURN TO NORMAL BUMPER HEIGHT

L_{min} = DISTANCE FROM TOP OF CURB TO OCCURRANCE OF LOWEST BUMPER HEIGHT

ΔH_{min} = MAXIMUM HEIGHT BUMPER BELOW NORMAL HEIGHT

ΔH_{max} = MAXIMUM HEIGHT BUMPER ABOVE NORMAL HEIGHT

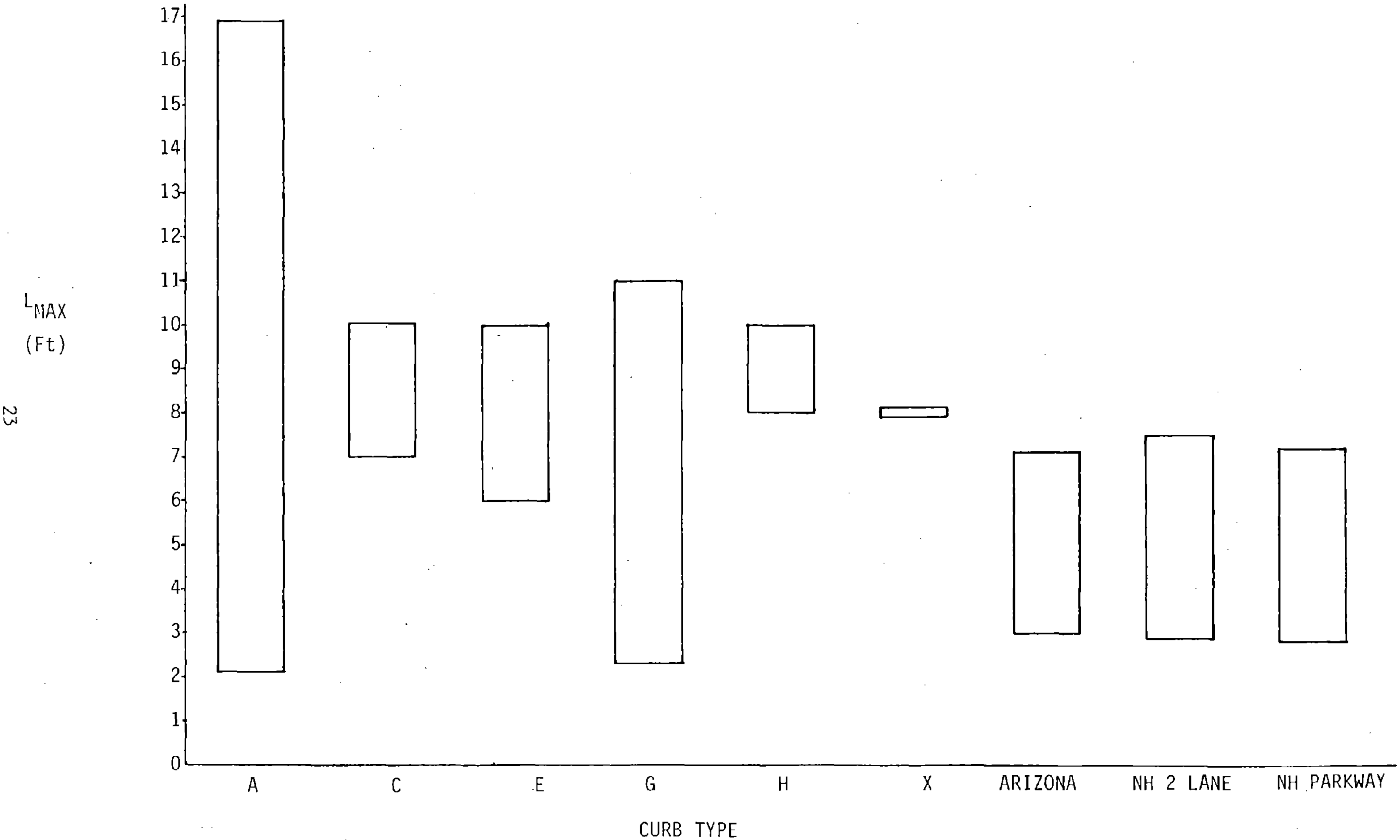
Figure 8 DESIGN PARAMETERS FOR VEHICLE ENCROACHMENTS ON CURBS



SI Conversion

1 ft = 0.3048 m

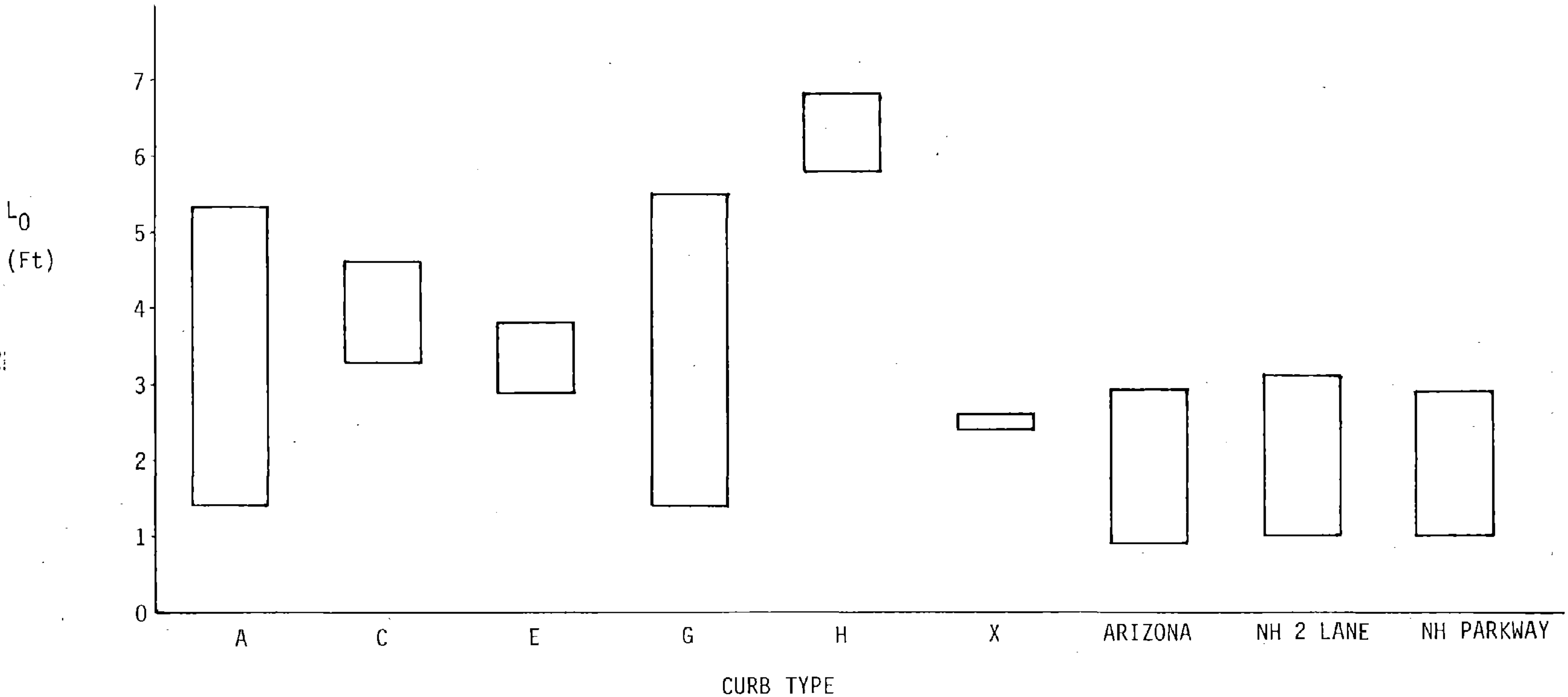
Figure 9 CURB BY CURB COMPARISON OF THE DESIGN PARAMETER L



SI Conversion

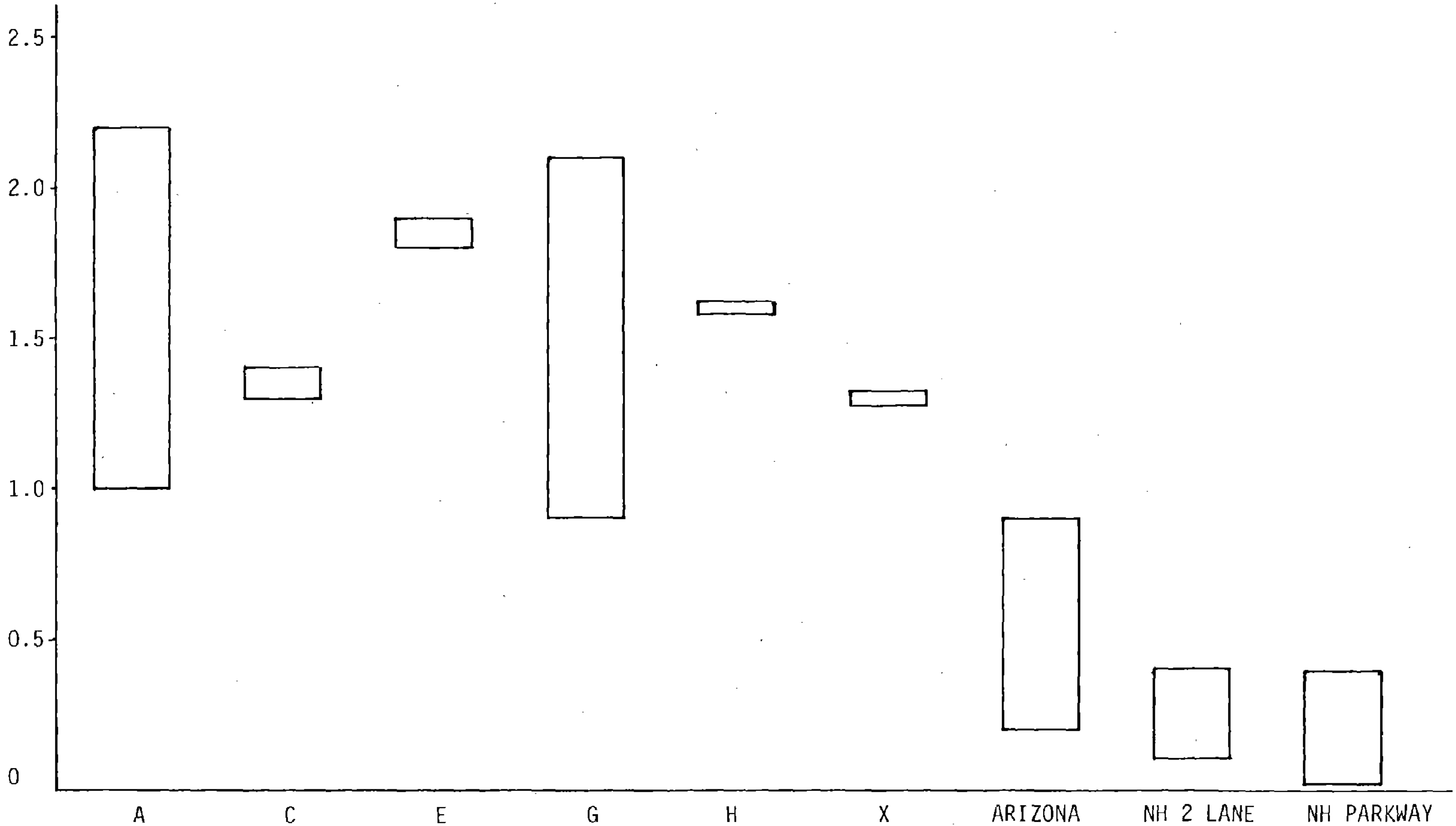
1 ft = 0.3048 m

Figure 10 CURB BY CURB COMPARISON OF THE DESIGN PARAMETER L_{MAX}



SI Conversion
1 ft = 0.3048 m

Figure 11 CURB BY CURB COMPARISON OF THE DESIGN PARAMETER L_0



L_{MIN} (Ft)

CURB TYPE

SI Conversion

1 ft = 0.3048 m

Figure 12 CURB BY CURB COMPARISON OF THE DESIGN PARAMETER L_{MIN}

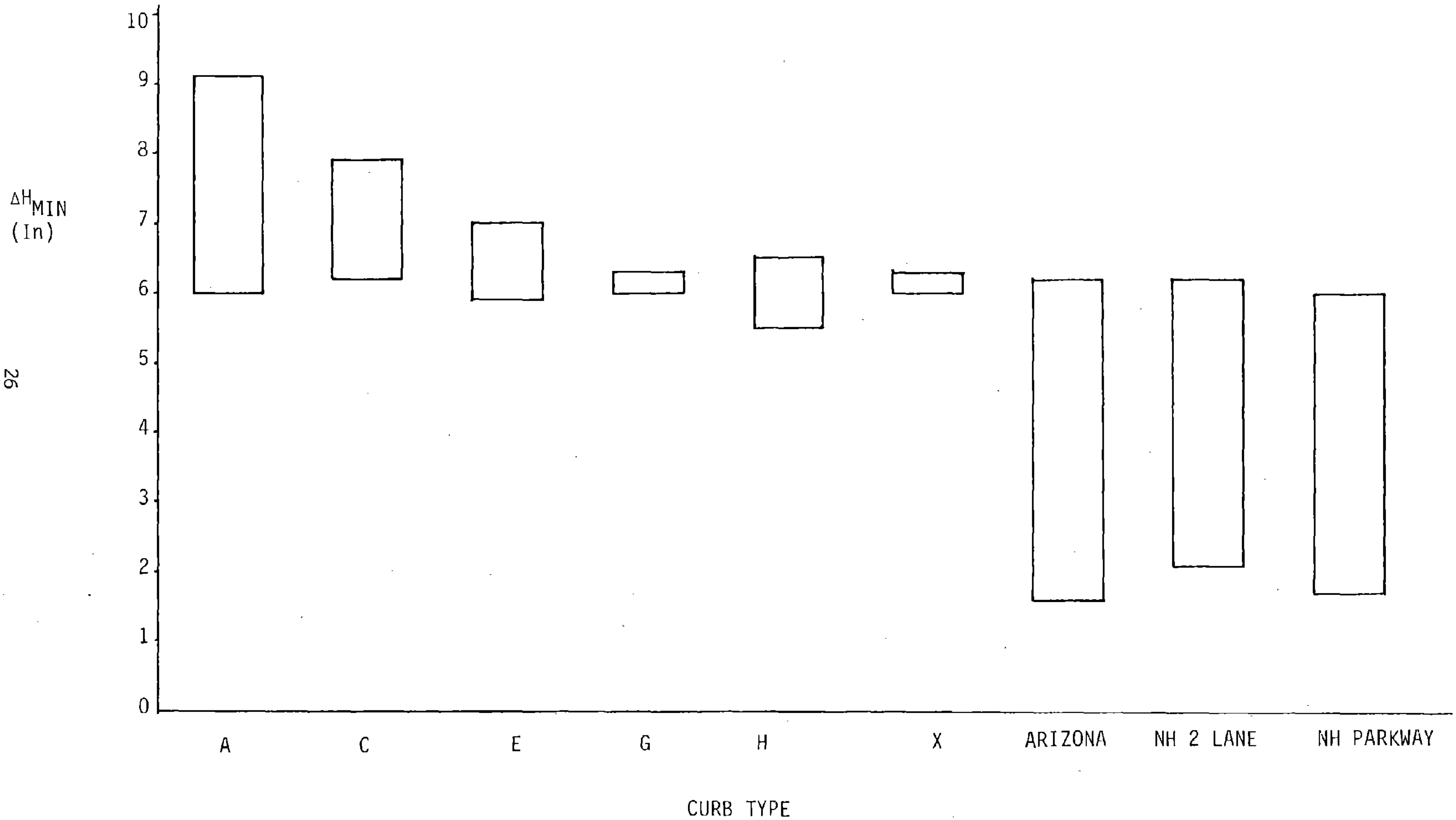
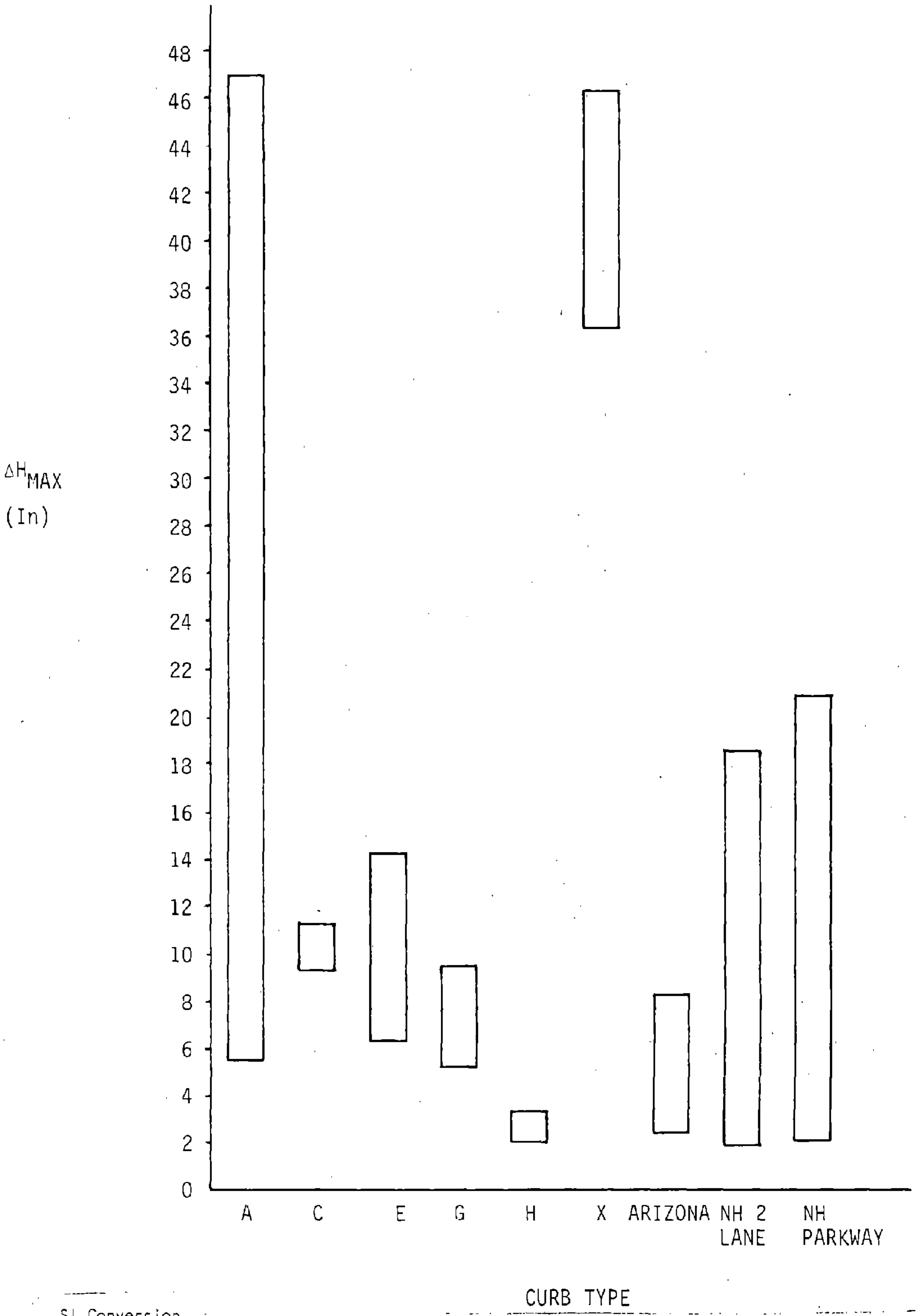


Figure 13 CURB BY CURB COMPARISON OF THE DESIGN PARAMETER ΔH_{MIN}

SI Conversion

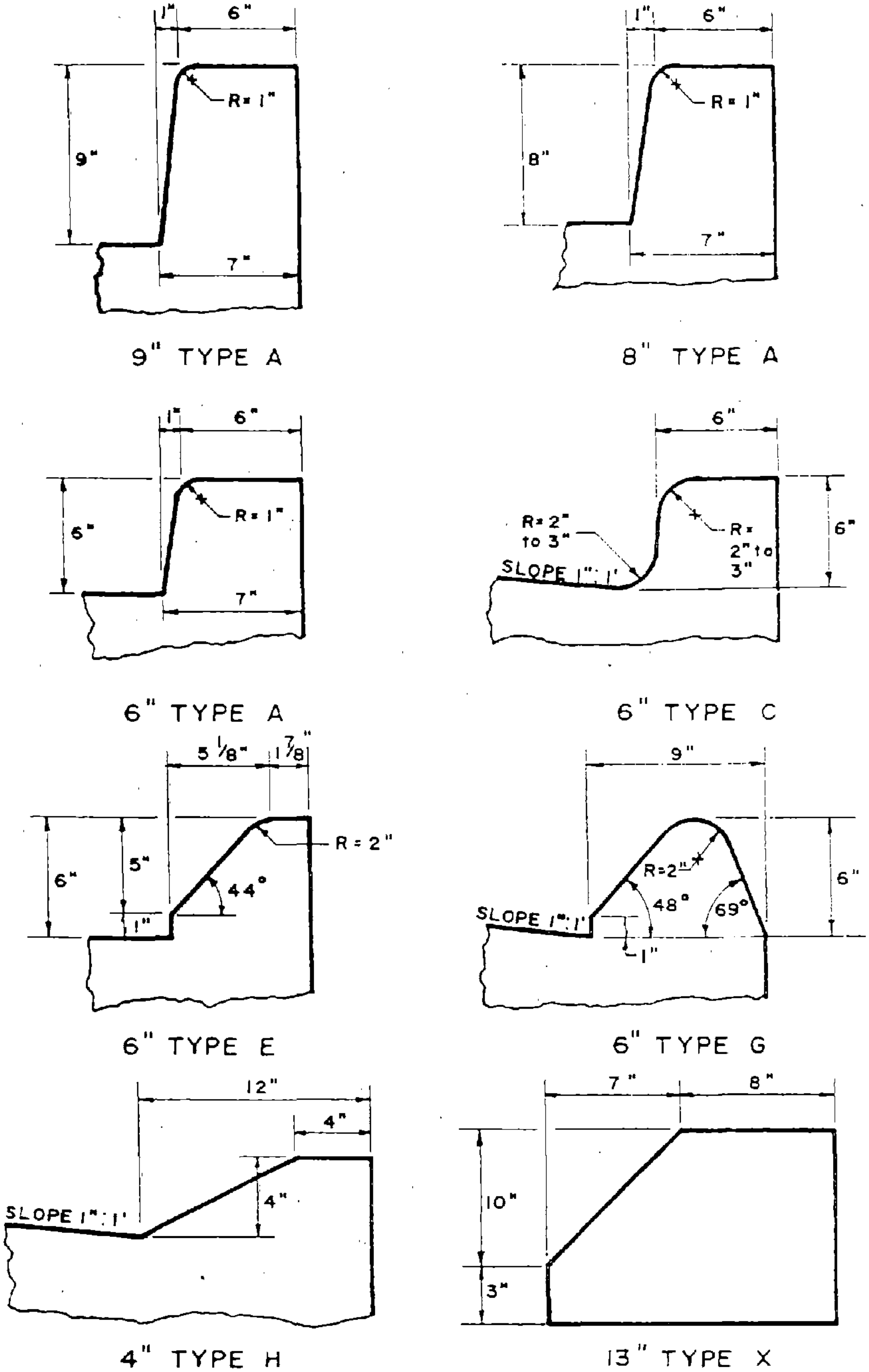
1 in = 25.4 mm



SI Conversion

1 in = 25.4 mm

Figure 14 CURB BY CURB COMPARISON OF THE DESIGN PARAMETER ΔH_{MAX}



SI Conversion

Figure 15 CURB GEOMETRY 1 in = 25.4 mm

The only area of concern would be the large bumper rise caused by both 6 inch New Hampshire curbs for the smaller vehicle. This, however, is still below the rise caused by a Type A curb (see Figure 14).

In light of this lack of deviation from normal curb response characteristics, the procedure for establishing guidelines for placement of longitudinal barriers for the curbs evaluated should not have to be modified from those procedures currently being used for the curbs which are in use today.

5. REFERENCES

1. Segal, D.J. "Highway-Vehicle-Object Simulation Model - Version II", Report No. FHWA-RD-76-162 (four volumes), February 1976.

2. Segal, D.J. and Miller, P.M., "Analytical Study In Support of the 400 Series Rollover Standard", Contract No. DOT-HS-8-01936, May 1979.

3. Ross, Hayes E. and Sicking, Dean L., "Guidelines for Placement of Longitudinal Barriers on Slopes - Volume III - Guidelines", Report No. FHWA/RD-83/055, Contract No. DOT-FH-11-9343, February 1984.

4. Howerter, E.D., Hinch, J.A., and Owings, R.P., "Laboratory Procedures to Determine the Breakway Behavior of Luminaire Supports in Mini-Sized Vehicle Collisions", Contract No. DTFH61-81-C-00036, April 1983.

5. American Association of State Highway and Transportation Officals, "Guide for Selecting, Locating, and Designing Traffic Barriers", 1977.