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CAPACITY OF SIGNALIZED INTERSECTIONS

FINAL REPORT

by

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16. Abstract

The use of standardized methods of estimating capacity at signalized intersections has been sought for at least 25 years. The publication of the 1950 Highway Capacity Manual was the first extensive effort made toward this objective. In 1960, Wes Bellis of the New Jersey Department of Transportation developed a more simplified technique.

The results of this research effort indicate that the Highway Capacity Manual technique yields greater than 20 percent error in estimating the through capacity of the approach to a signalized intersection for at least half the locations studied. Less than 20 percent of the locations studied showed this error using Wes Bellis' technique.

Revisions were made to the Highway Capacity Manual technique and the twenty percent error was found in only 25 percent of the locations studied.

The authors concluded that an estimate for capacity should not be made for existing intersection approaches; the capacity of an intersection should be measured directly in the field. A method of determining capacity from field measurements is briefly described in the report.

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I. SUMMARY AND CONCLUSIONS

The Highway Capacity Manual's accuracy in estimating capacity of approaches at two-way signalized intersections was tested. In addition, revisions were made to four of the factors used in the Manual and the accuracy of the Manual's method using the revised factors was tested. As a result, the following revisions to the HCM factors are suggested:

a) A reduction in turn corrections for narrow streets (less than 15 feet for "no parking" and less than 20 feet for "parking"), up to 10 percent turns.

b) For estimating the population, use the population of the municipality plus the population of the surrounding municipalities, in dense suburban areas.

c) Use factors for the "location in the metropolitan area" for two-way streets that are consistent with the factors for one-way streets.

d) Use a maximum correction factor for "near side bus stops" of 1.0.

Using 20 percent as an acceptable error range, results indicate that the Manual (unrevised) has errors in excess of ±20 percent for half of the study samples, while the Manual (with revisions) has errors in excess of ±20 percent for one-quarter of the samples.

The large variation that was found to exist in the capacity of signalized intersections could not be satisfactorily explained, even though certain parameter adjustments to the HCM resulted in dramatically reducing the percent error of the estimates. The authors can only conclude that no estimate for capacity should be made for existing intersections; the capacity of an intersection should be measured directly in the field.

The sample data were also used to test the accuracy of the modified Bellis' method of data collection and it was found that an error in excess of ±20 percent existed for 15 percent of the sites.

Three separate staffs (New Jersey Department of Transportation and two consultants) combined their efforts to supply input for this study. Data at one hundred and fifty sites were collected, but less than 60 percent of the sites had data that were considered useful. It is evident that continued efforts to extend this program using the current methods of data collection would be extremely time consuming.

II. INTRODUCTION

A. Background

The use of standardized methods of estimating capacity at signalized intersections has been sought for at least 25 years. The publication of the 1950 Highway Capacity Manual[1] (HCM) was the first extensive effort made toward this objective. The 1965 HCM added parameters not previously covered in the 1950 publication. Meanwhile, many engineers were continuing to use their own techniques for capacity estimation, because of a lack of accuracy in the use of the HCM, a complexity in using the Manual they did not deem necessary, the use of parameters which were too subjective, and several other reasons.

The current HCM has been the subject of several studies[2,5,6,7] into the applicability of the parameters, the accuracy of results and the modification of the approach used to determine capacity.

A study by the New Jersey Department of Transportation[2] was conducted to simply determine the accuracy of capacity estimation of the HCM. Generally, the results of this study indicated that the HCM capacity estimates were inaccurate by at least 20 percent for half of the approaches studied. Within the scope of a limited study sample, the results indicated an inaccurate quantification of some of the parameters in the HCM.

B. Objectives

As a result of the previous New Jersey Department of Transportation study[2], an expanded work plan was developed to study and revise the parameters of the HCM in an effort to improve its reliability as a Manual for estimating capacity.

In addition, more intensive analysis was performed on the Bellis method[3] of capacity estimation, that was developed using data collected in New Jersey.

III. STUDY METHODOLOGY

For a detailed explanation of the two methods of capacity estimation that are examined in this study, we refer the reader to References 1, 2, and 3. Both the Highway Capacity Manual and Bellis techniques are compared to a field measurement of capacity (ALE). ALE is considered to be the most accurate method of determining the capacity of a signalized approach, and represents an expansion of the average number of vehicles per loaded cycle. For example, if there were an average of 20 vehicles per loaded cycle and 60 cycles per hour, ALE would be 20 x 60 or 1,200 vehicles per hour.

Briefly, the HCM method of capacity estimation combines factors for several environmental and traffic conditions, which are applied to a basic volume; the basic volume is determined by the width of approach and parking condition at the site.

The Bellis method of capacity estimation uses a more simplified technique. The method, as presented in Reference 3, has been modified in this study to include a factor for right and left turns. Basically, a lane capacity volume is given for each of the four types of street for a specific green period. This volume is adjusted by the number of lanes, the number of cycles, and the percentage of trucks and turns.

A. Data Collection

With the primary object of this study aimed at improving the reliability of the HCM parameters, it is evident that the interaction of so many variables would require an extremely large sample size. The estimate of "Approach Volume" is dependent on ten separate variables; many of these variables have a wide range of application. From the initial planning, it was decided to try to incorporate the consultant's data collection under the TOPICS Program, since it would be impossible to amass the information with our own forces.

One consultant's field crews were trained. After direct supervision at a few intersections, the consultant's field crews were left on their own. The data collected (21 samples) in this manner were found to have a variety of inaccuracies, thus resulting in our using only 38 percent of the data collected.

A second consultant volunteered his input (24 samples). His field crews were not trained by the New Jersey Department of Transportation, but he collected saturation flow information in addition to the HCM parameters. However, only 50 percent of these data were useful in the analysis.

New Jersey Department of Transportation field crews tabulated 106 sample sites. Some of these samples were reruns because of inaccuracies in the original data. Sixty percent of these data were finally used in the analysis.

Tables 2 and 3 in the Appendix list the characteristics of 122 sites; 85 of these sites were finally used in the analysis. Although 151 sites were originally studied, some have not been tabulated in Tables 2 and 3. Typical reasons for this are:

a) The load factor (L.F.) was zero, or

b) The data were inaccurately collected in the field.

With the variety and enormity of unusable data, the original plan for the study had to be modified to accommodate the limited input that was available for the modification of so many parameters in the HCM. The revised method of analysis is explained below.

Because of the lack of available one-way streets, only two-way approaches were used. The method of collection was similar to the original New Jersey Department of Transportation study[2].

B. Data Analysis - "Highway Capacity" Method

The major steps in the analysis are as indicated below.

First, the HCM capacity is estimated using the adjustment factors in the Manual. This includes use of the "PHF - Metropolitan Area Population" factor. The population used for this factor is the population of the municipality in which the intersection is located plus the population of the adjacent municipalities.

Second, the HCM estimate of capacity is again computed, but no adjustment is made for the peak hour factor (PHF). The reason for using no adjustment is that the PHF correction accounts for delays due to peaking traffic and not for reductions in capacity. Since ALE does not make subjective judgments concerning delays, the HCM estimate for capacity is computed without a PHF adjustment, thereby putting the HCM estimate on the same basis as ALE.

Third, the parameters of the HCM are studied for their rationale and accurateness (as determined from prior studies) and changes made accordingly. Estimates of capacity are again made, using the revised factors, but again without applying a correction factor for the PHF.

The estimates of HCM capacity derived from these three steps are then compared to the ALE values for statistical differences.

The last step in the analysis would be to adjust the ALE capacities as determined from the field conditions by those basic conditions defined in the HCM charts (HCM Figures 6.8 and 6.9), as revised in the third step above. With the adjusted ALE values, a new curve should be computed for the 1.0 load factor condition. The resulting set of curves and adjustment factors could only be accurately checked with an entirely new set of field data. However, the utility of the HCM method of capacity estimation is currently under question and may be soon subject to complete revisions. Hence, this program will not be continued until the outcome of the current thinking is resolved.

Although data collected at sites included load factor, no examination of the HCM estimate at various levels of service was attempted. There were two reasons for this. The first was that it was not possible to adequately define a loaded cycle such that two individuals would each have equal assurance of its loaded condition. The resulting situation would reflect a wide variation in the load factor for equal service volumes. Although the level of service variation would be large, the average number of vehicles per loaded cycle would not be, thus maintaining reliable capacity estimates.

The second reason is the variability encountered in unloaded cycles. Assuming the loaded cycles were accurately defined, the unloaded cycles could contain any number of vehicles up to the number needed to load a cycle.

This variability results from an inability to measure the volume to capacity ratio of individual unloaded cycles. For a given period of time at a given intersection, this ratio will not vary significantly. However, when many intersections studied at different periods are considered, this ratio can range from near zero to one. Because of this, it would be possible for two intersections with similar physical and environmental characteristics to have great differences in volumes at equal load factors.

C. Data Analysis - "Bellis" Method

The revisions that have been made to the HCM parameters that apply to the Bellis method are also made here. The most prominent correction is for turns. Otherwise, the procedure for estimating capacity by this method is similar to that outlined in Reference 2.

D. Revisions to HCM Parameters

1. Turning Movements - The quantified adjustments for turns (found in Tables 6.4 and 6.5 of the HCM) reflect basic approach volume decreases for increases in the width of approach (0% turns), at two points of each curve. Refer to Figures 1 and 2 for the actual differences in service volume at the smaller widths. To overcome this apparent disparity for turns less than 10 percent, the turn factors of the HCM will be discarded for the lower approach widths, up to 10 percent turns. For example, for a 14-foot approach (with no

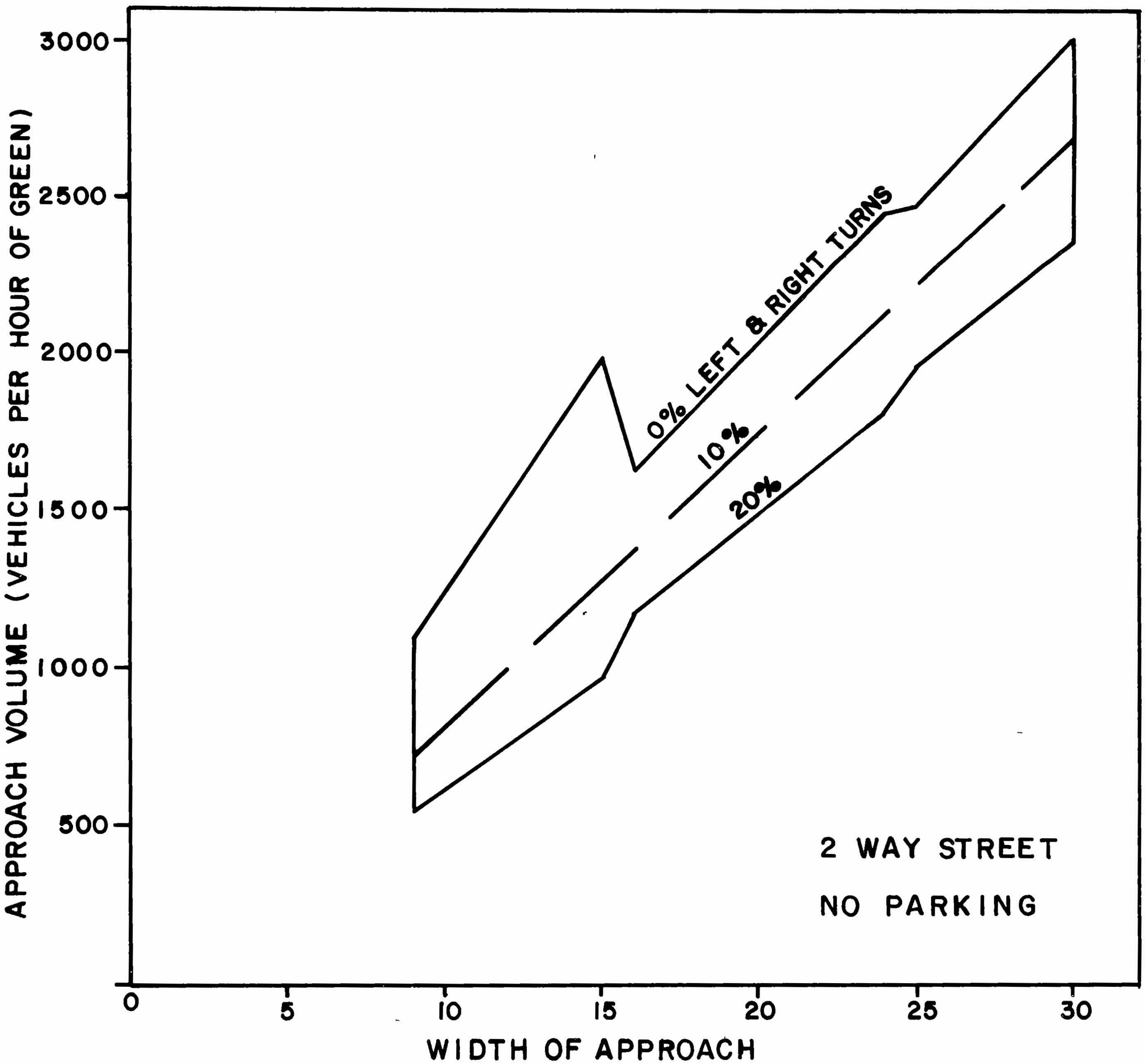

FIGURE 1 - HCM TURN FACTORS
(2WNP)

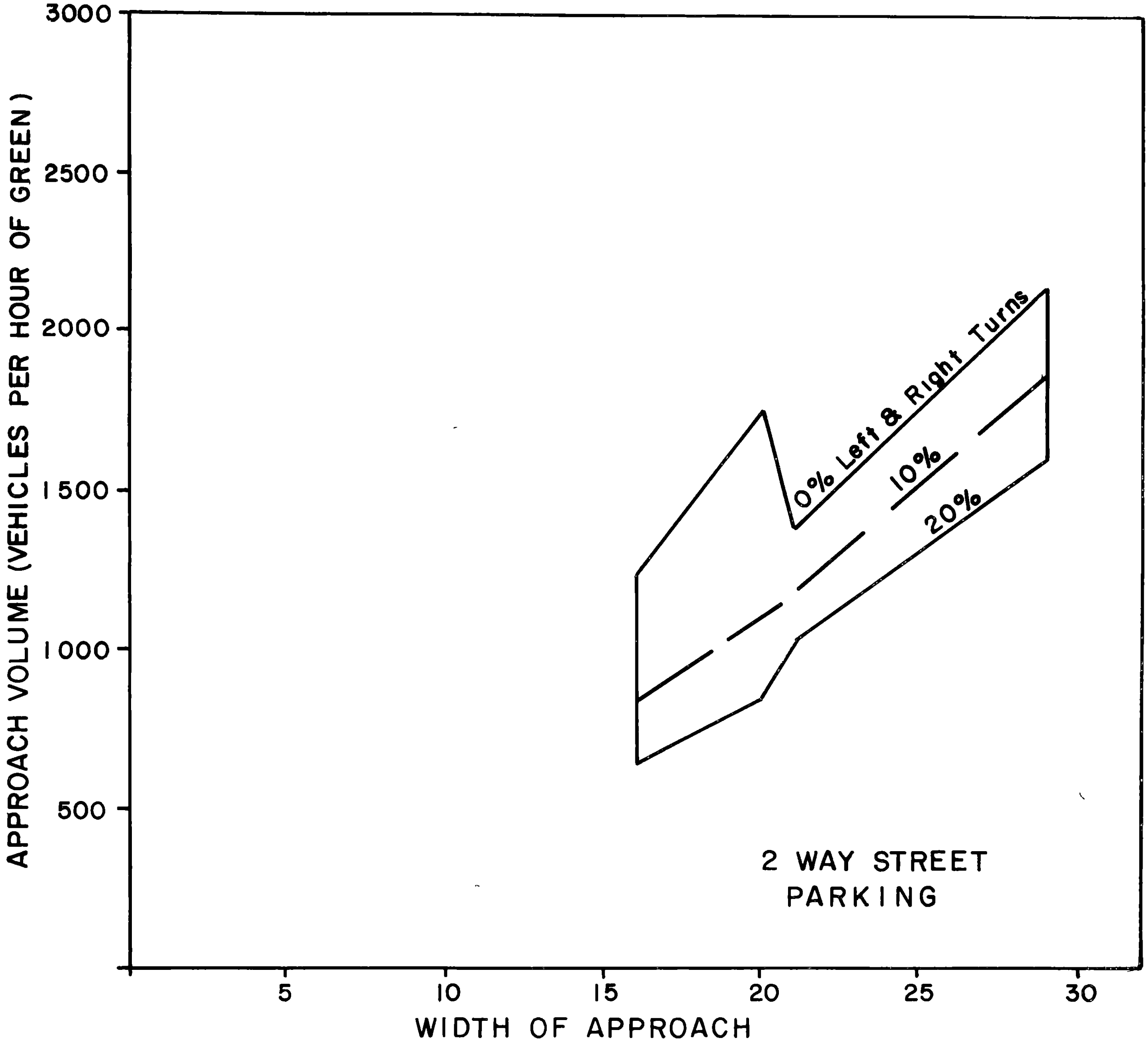

FIGURE 2 - HCM TURN FACTORS
(2WP)

parking) the factors for 16 to 24 feet (0% to 10%) will be used and the factors for $\leq$ 15 feet will be used for turns in excess of 10 percent.

2. <u>Metropolitan Area Size</u> - The choice of metro size was always a matter of concern. Three choices exist for the engineer:

a) The population of the municipality itself,

b) The population of the municipality and the surrounding municipalities, or

c) The population of the region in which the municipality exists.

The two former choices are straightforward. However, judgment again enters the decision in the latter choice. For the current study, all three choices are tried and the "regional" approach makes use of three main areas: New York City (1 million plus), Trenton (1 million), and Philadelphia (1 million plus). The HCM estimate of capacity for all samples is tabulated, using each of the three choices, but without the adjustment for the PHF. The mean and standard deviation is then compared for each choice.

Because of the 75,000 lower limit to population found in the HCM charts, this is the smallest factor used in this study.

One last difference that should be noted with the HCM adjustments for the "PHF - Metro Size" is the adjustments for two-way streets with no parking. These adjustments are three percent to four percent lower than all the other charts. No tests will be made of the data to check this difference, since it is too small in relation to the magnitude of adjustments for all other parameters.

3. Location within Metropolitan Area - Two primary reasons exist for adjusting the HCM factors for metropolitan location. As indicated in Reference 6, the disparity in the basic approach volume curves between one-way and two-way streets is made even greater with the application of the "fringe" area adjustments (Figure 3). In addition, the HCM description of the various areas defines levels of pedestrian and commercial vehicle activity in the different areas. Hence, for this study the following factors are used with the basic HCM curves, for the two-way streets:

CBD	FRINGE	OBD	RESIDENTIAL
1.00	1.10	1.15	1.25

These factors do not consider the "pressure" of traffic in the busier areas, but they are an attempt to equalize the disparity between one-way and two-way streets, considering the HCM description of these areas.

4. Local Transit Buses - The prior New Jersey Department of Transportation study (Reference 2) had indicated that large HCM capacity estimate errors were resulting with the use of the bus adjustment factors for "near side bus stops on streets with parking." For this study, the adjustment factors for "near side with parking" will cut off at 1.0.

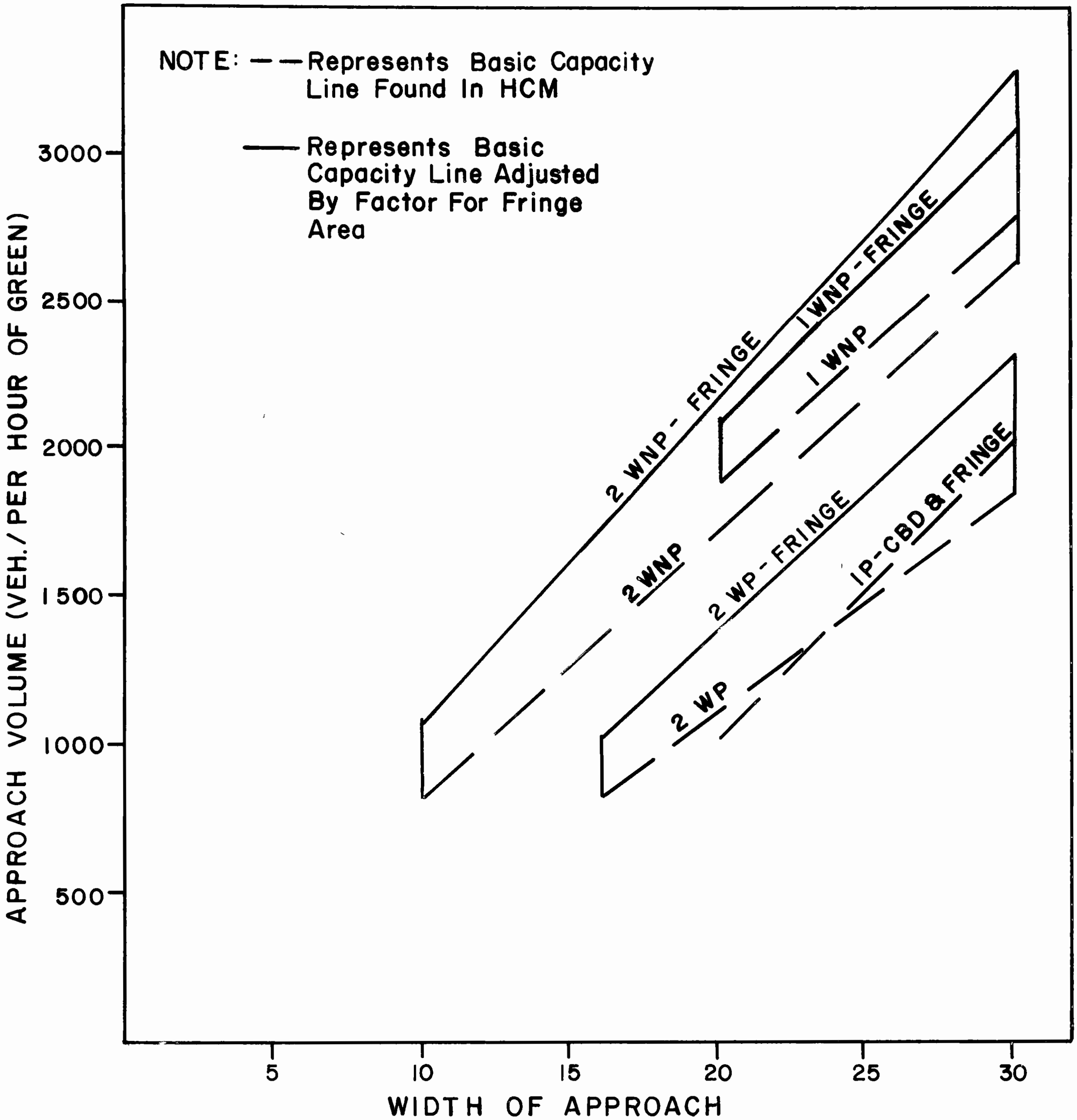

FIGURE 3 - HCM FACTOR FOR LOCATION IN METRO AREA

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5. Parking Conditions - An attempt is made to overcome some of the judgment that exists in determining whether or not an approach has parking and to what extent parking affects the capacity. The sites with parking are plotted, by width, against the ALE capacity (Figure 4). A visual inspection of the distance of parking from the stop line would be incomplete without the associated percent of left and right turns and the indication of a bus stop.

The impedance to the movement of traffic that is offered by parked vehicles is similar to that of a narrow street. But the parked vehicle would appear to have less affect at 200 feet than at 100 feet.

A multiple linear regression analysis will be made of the aforementioned variables to determine the effect of the distance of parking from the intersection.

IV. RESULTS

A. Highway Capacity Manual

1. Error of Estimate

Mean and standard deviation percentage differences of the HCM estimates and ALE (refer to "Data Analysis - HCM") are as shown in Table 1.

TABLE 1

AVERAGE ERROR OF HCM CAPACITY ESTIMATES

Method of Estimate	2 WNP % Error	2 WNP Std. Dev.	2 WP % Error	2 WP Std. Dev.
HCM (Unrevised)	+10	27	+7	24
HCM (Without PHF)	+23	30	+22	25
HCM (Revised)	+4	24	+5	17

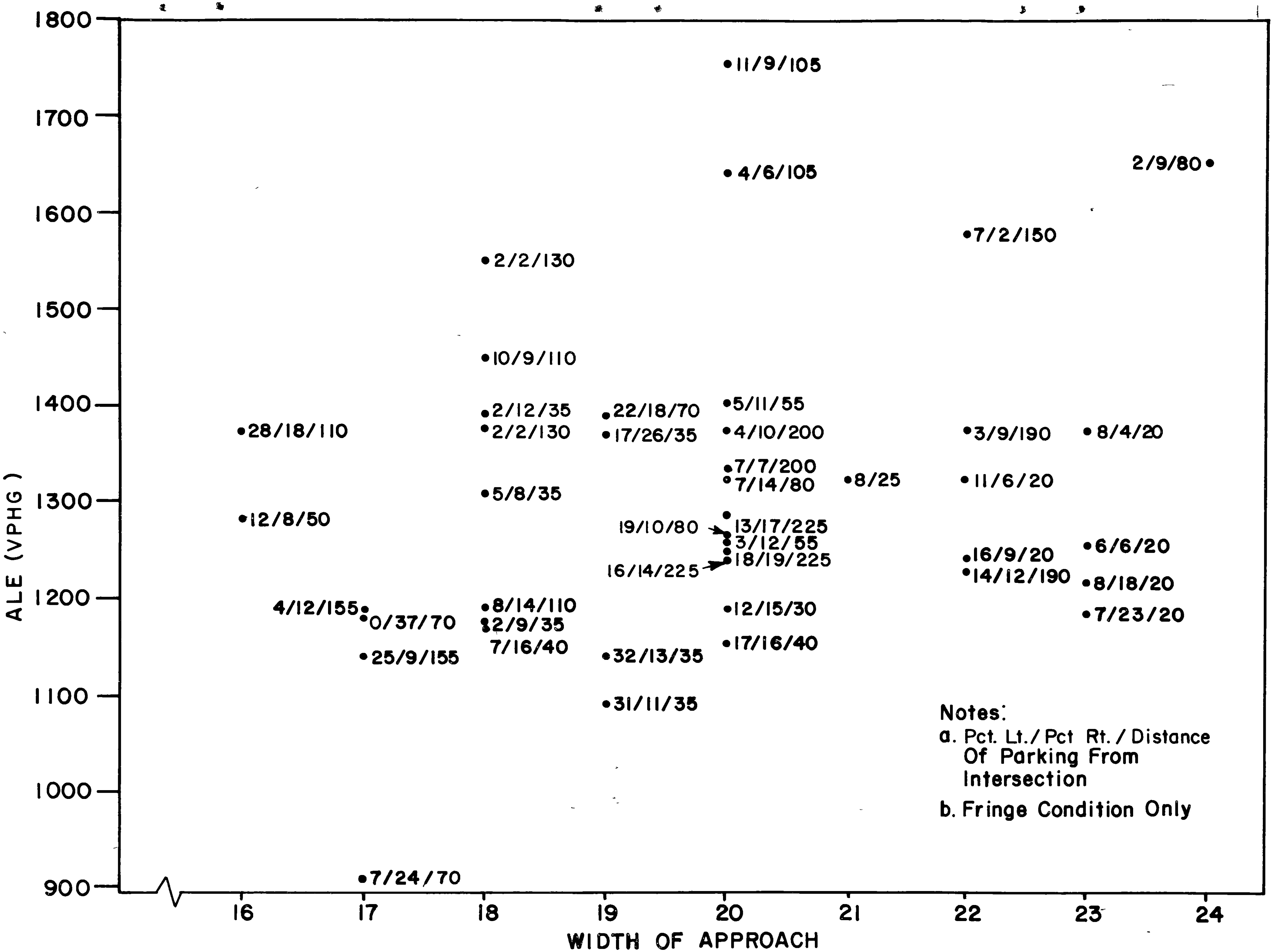

FIGURE 4 - PARKING CONDITIONS

An individual listing of the error by site is shown in the Appendix in Tables 4 and 5. The error of the "unrevised HCM" was expected to be negative, assuming the correction factors in the Manual are accurate. The reason to expect a negative error is that the Manual uses an adjustment for the peak-hour factor that is similar to the PHF itself; hence, an adjustment is made to the "approach volume" that is less than 1.0. The comparable volume for ALE has no adjustment for the "peaking" effect of traffic at the intersection approach.

The second set of errors listed in this Table is for the HCM estimate without an adjustment for the PHF. Hence, it should have a zero error with ALE, assuming the correction factors of the HCM are accurate. Because the data used to develop the HCM (unrevised) estimate had a PHF average of approximately .85, the error for the HCM (without PHF) can be expected to be approximately 15 percentage points higher than the HCM (unrevised). However, the percentage error shown indicates that the HCM (without PHF) capacity estimate is from 20 to 25 percent higher than actual field conditions indicated. Moreover, the error as shown, gives no indication of which parameter and to what extent a parameter's adjustments are inaccurate.

The third error is with modifications to all the existing HCM parameters (as outlined under "Study Methodology"), and without an adjustment for the PHF. Adjustments can be made for the PHF at the discretion of the user with the understanding that they represent a subjective reduction in the intersection's ability to handle traffic on an hourly basis. In effect, no peak hour adjustment would be made if we were willing to let drivers wait on the approach. The effectiveness of the adjustments to the HCM factors is evident in the comparison in Table 1 of the "Without PHF" and "Revised" estimate errors. Further comparison can be made in Figure 5.

There is no conclusive evidence that the choice of adjustments by the authors is the best one to make. To more accurately test the effect and subsequent adjustments for some of the factors in the HCM, the variation of a parameter would have to be controlled at a single intersection approach. The ability to exert this control may never be within the power of a researcher, since there are ten distinct parameters that are used to vary the estimate of capacity in the HCM. Only two parameters could be tested in this study. They are parking and the metropolitan area size.

2. Distance of Parking to Intersection

As a result, the authors have defined as closely as possible those features common to an intersection in an attempt to determine the effect of parking on an intersection's approach. A multiple linear regression analysis of the data shown in Figure 4 showed that the use of the distance to parking from the stop line had no significant affect in a regression equation defining ALE. However, the previous reasoning that implied an improved ability of an approach to handle demand, with parking

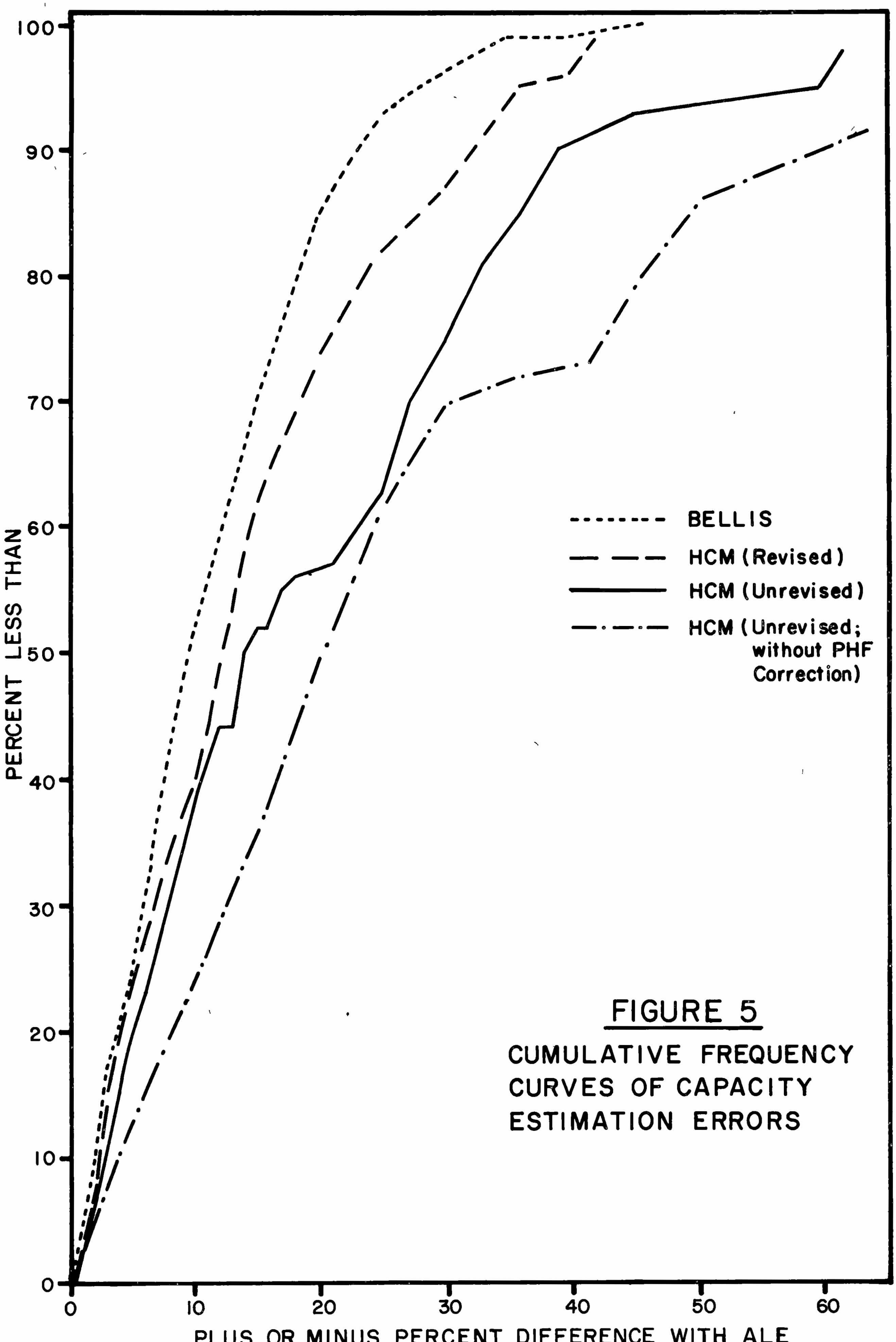

FIGURE 5

CUMULATIVE FREQUENCY CURVES OF CAPACITY ESTIMATION ERRORS

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removed to 200 feet (as opposed to 20 feet) is more logical than the statistical results indicate. Hence, the results of the regression analysis highlight the need for a more controlled testing of this parameter.

3. Metropolitan Area Size Factor

Another comparison was made on the choice of any of three values for the "Metropolitan Area Size." The percentage error of HCM (vs. ALE) using these values is as follows:

	Two-Way No Parking	Two-Way Parking
Municipality	17%	17%
Municipality + Surrounding Area	23	22
Region	40	40

As might be expected, the difference in percentage error of the first two values is approximately equal to the difference in factors. However, the third value's error far exceeds the proportional difference of the factors. Essentially, the logic for using a "Metropolitan Area Size" factor equivalent to the municipality plus the surrounding area's population appears to be reason enough to overlook the small difference in percent error.

4. Adjustment to Approach Volume Curves

The final step in the HCM analysis was the attempted derivation of a revised "Approach Volume" curve, using the values for ALE, but modified by the adjusted HCM parameters, thus allowing a direct comparison with the HCM curves. A careful review of both Tables 4 and 5 (Appendix) indicates the need for repositioning the basic curves relative to the width of approach.

Table 4 has one and two lane data combined. As an example, the "fringe" location sites extend from PH-1W through RS-21. Of these, the first 7 sites and the ninth site are used as a single lane approach and the eighth and the tenth through thirteenth sites are used as two lane approaches. Within each of these groupings, the width of approach increases from 14 feet through 19 feet (for the single lane) and from 19 feet through 26 feet (for the two lane approaches). The regression analyses grouped the data accordingly and was performed for each of the following groupings:

a) Two-Way Parking - Fringe only (40 samples)

b) Two-Way Parking - All sites combined (56 samples)

c) Two-Way No Parking - Single lane approaches (12 samples)

d) Two-Way No Parking - Two lane approaches (8 samples)

e) Two-Way No Parking - All sites combined (20 samples)

The percent error of the HCM (revised) varies from a negative error for the lower width streets to a positive error for the higher width streets. In effect, this would indicate a "flattening" of the basic approach volume curve. Figure 6 gives the results of this analysis against the background of the curves currently shown in the HCM.

The adjusted ALE curves for one and two lane two way no parking yield reasonably high correlation coefficients. However, the one lane curve shows a decrease in capacity for an increase in width. The two lane curve is also questionable.

Extremes in the values for ALE for the higher and lower width streets account for the shape of the computed curves.

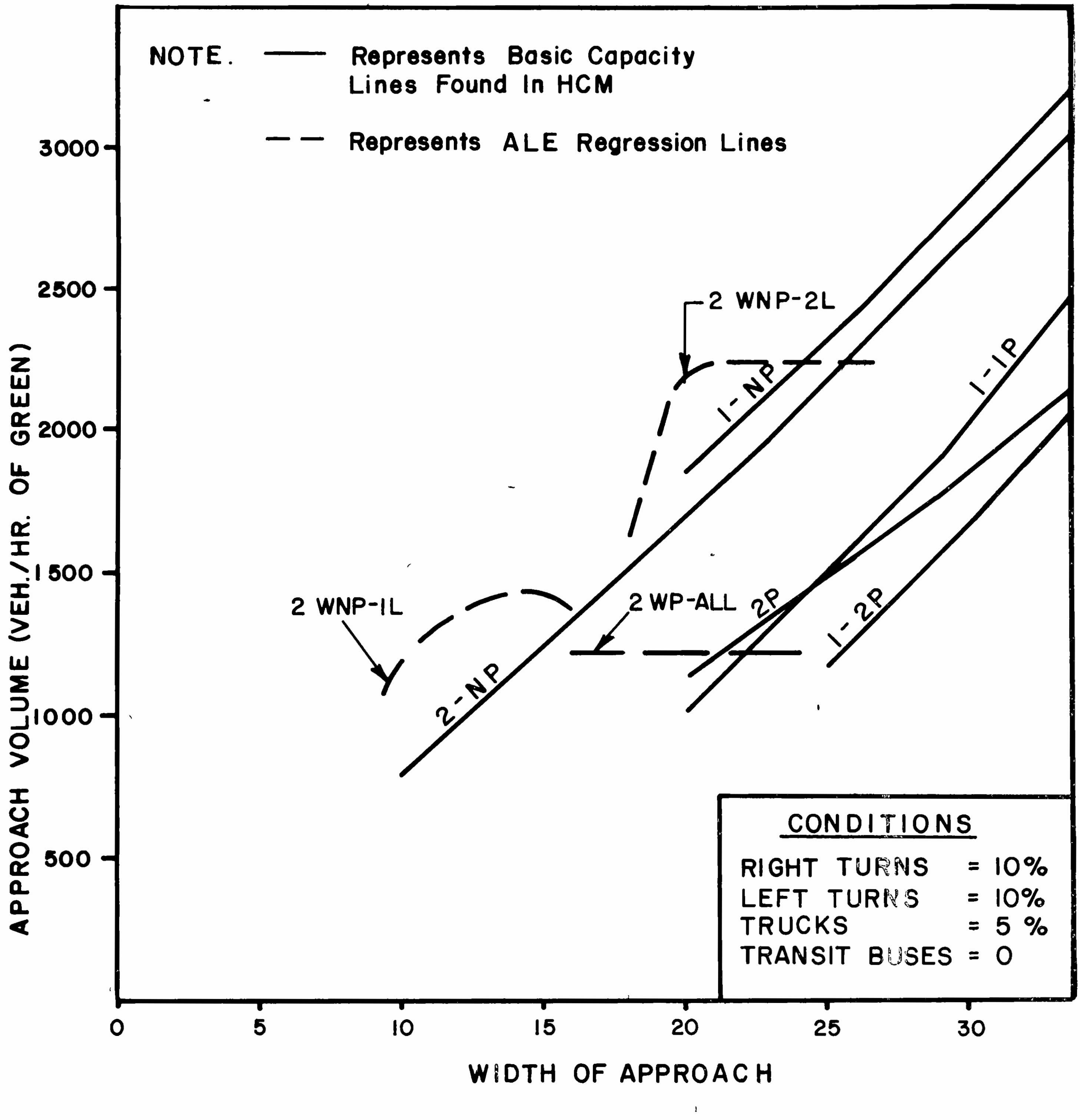

FIGURE 6 - CAPACITY CURVES

Inspection of ALE capacities as collected under field conditions (Tables 2 and 3) shows why the adjusted curves are questionable. Under constant physical and environmental conditions, there is great variability in the actual capacity (as measured by ALE) for similar types of intersection approaches. There are several cases where increased percentages of turns yield increased capacities. This appears contrary to the rationale behind the HCM turn correction factors in which turns have a decreasing effect on capacity.

The variability found for the actual capacity of similar intersection approaches leads to the conclusion that capacity estimation, in its present state, can be subject to large inaccuracies. It is the opinion of the authors that these inaccuracies render the Highway Capacity Manual useful only for gross estimates.

The capacity of specific locations should be determined using the intersection data and not generalized information from the HCM.

B. Bellis Method

As defined in References 2 and 3, the Bellis method for estimating capacity does not consider width of street and parking; only the type of street and number of lanes are taken into account. Although there are four types of streets for the Bellis curves, only the CBD (Type I) and those streets outside the CBD that allow both right and left turns (Type II) had sufficient sample sizes to consider in this study. The percent errors of capacity estimate are summarized as follows:

Type	No. of Samples	% Error	Standard Deviation
I	10	-19	8
II	72	2	13

These errors are almost identical to those found in the previous study (Reference 2). The resulting upward adjustment to the Type I capacity curve would be sufficient to satisfy the discrepancy.

Although the standard deviation of the percent error for Type II approaches is high (indicating the need for further refinement to the technique), the standard deviation is far less than that experienced with the HCM capacity estimates.

C. Data Collection

A very low proportion of intersections was used, compared to those that were studied. Hence, an extremely costly and time consuming effort would be required in extending the data collection effort in this study. With only 56 percent of all sites sampled being used, there would have to be substantial reasons to continue this study using the initial data collection format. A more productive approach may be found by varying parameters at individual sites.

In summary, the major percentage distribution of the use of the data is as follows:

Useful data - 56%

Non-useful data - 44%

[Reasons for non-useful data]

Zero load factor	-	13%
Inaccurate	-	8
Lane use variation	-	5
High turn or truck percent	-	5
Large green phase variation	-	4
Miscellaneous	-	9

Only eight percent of all data collected was rejected because of inaccuracies on the part of the data collectors.

The variation of the number of vehicles per loaded cycle for any <u>one</u> intersection approach can be defined by the standard deviation of the number of vehicles per loaded cycle, for that approach. Figure 7 is the frequency distribution of the standard deviations for the intersections in the two way parking, fringe category. As expected, a skewed distribution to the right results. There was absolutely no correlation of the standard deviation with the average number of vehicles per loaded cycle. Hence, the distribution of the standard deviation, as shown in Figure 7, could result for most of the range of average loaded cycle data (6.5 to 17.5 vehicles per loaded cycle). Inspection of the distribution only substantiates the variability of cycle to cycle activity that could result at an intersection.

An indication of the repetitiveness of the field measurement of the actual capacity of an intersection approach (which is expressed as ALE) is shown in Figure 8. Eighteen intersections

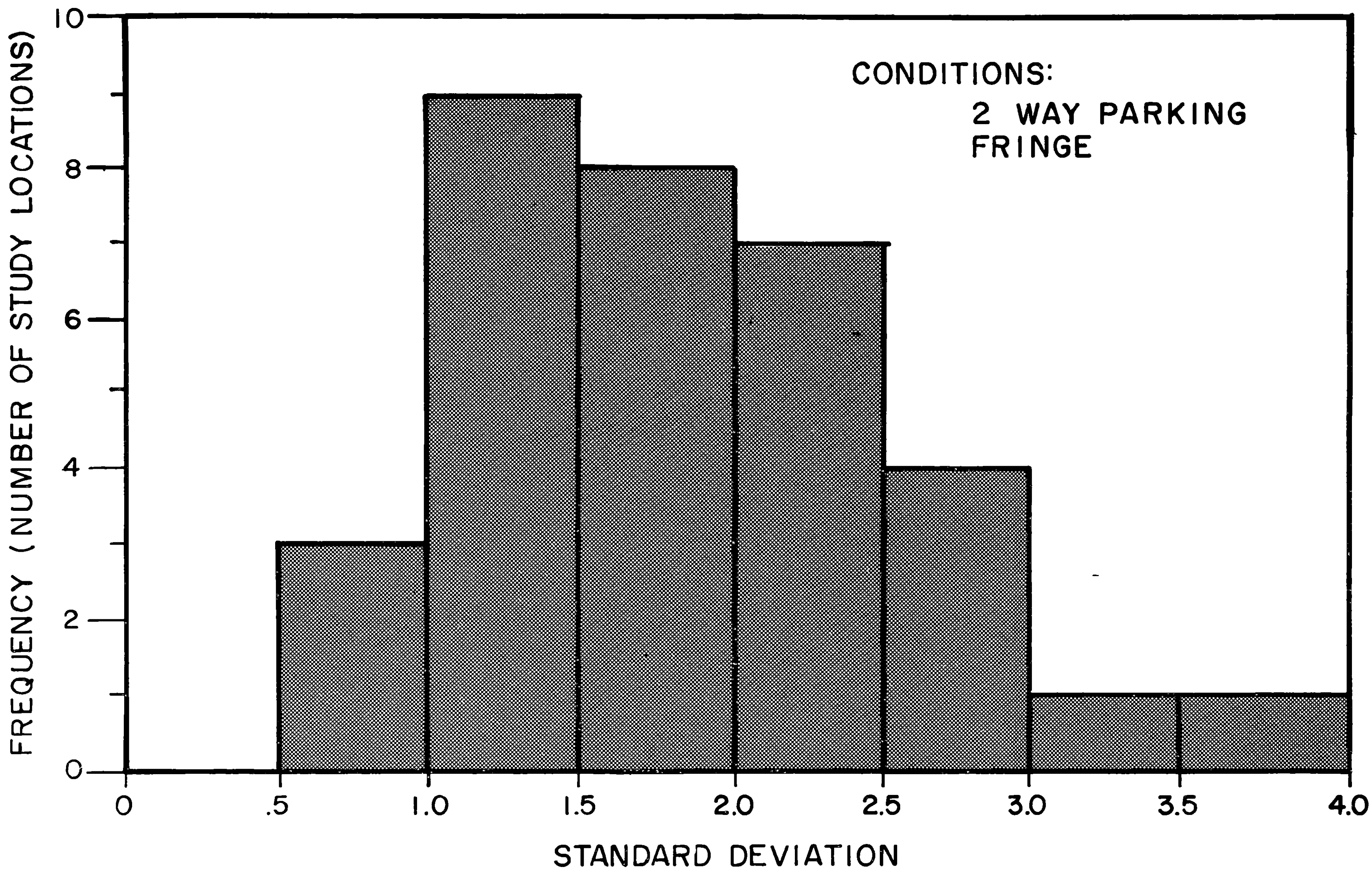

FIGURE 7 — Standard Deviation of Vehicles Per Loaded Cycle

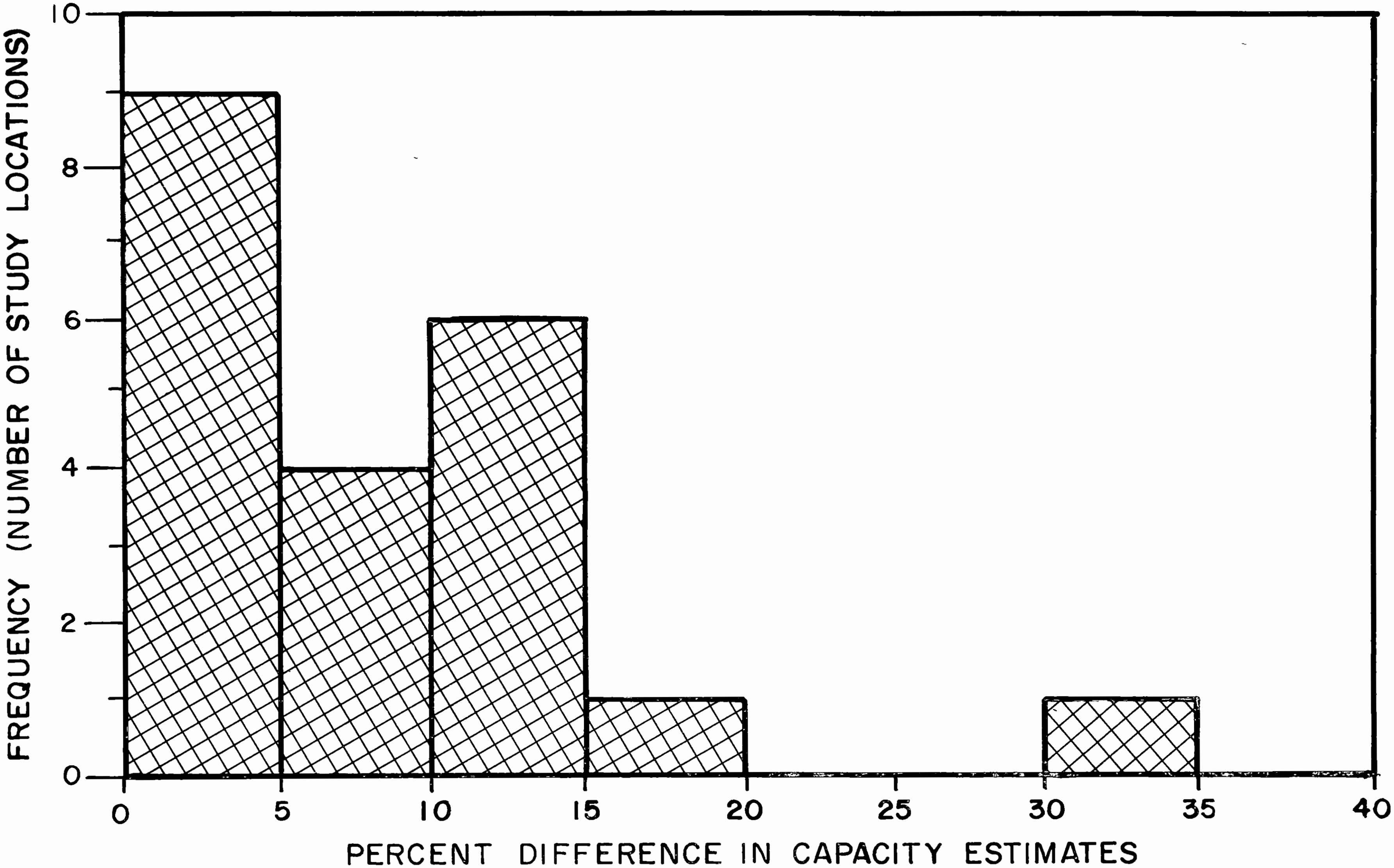

FIGURE 8 — Distribution of Difference In Capacity Estimate

were sampled a second and third time. The percent difference between repeat samples, as indicated by the frequency distribution of Figure 8, averages ten percent. Expressed in other terms, 90 percent of the repeat estimates of capacity (made from field measurements) were within ten percent of the original estimate. The variation of field measurement of capacity for any one site can only be hypothesized, but the reasons can vary from differences in drivers through the environmental and traffic changes.

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A P P E N D I X

TABLE 2

PHYSICAL, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS OF STUDY LOCATIONS

TWO-WAY NO PARKING

Site	Appr.[1] Width	Metro[2] Loc.	Metro[2] Pop. (1000's)	PHF[2]	L.F.[2]	% LT.[3]	% RT.[3]	Trucks[3] %	Buses[3] #/Side	Cycle	Green Time	Serv. Vol. (vphg)	Capacity[4] (ALE) (vphg)	Comments
SS-2E	10/1	FRNG	75	.72	.33	0/0	29/40	4/5	---	70	25	1300	1882	See Note 6.
SS-2N	10/1	FRNG	75	.56	.33	0/0	33/35	4/5	---	70	32	1488	1674	See Note 6.
EBL-1S	10/1	FRNG	250	.85	.49	62/56	11/11	11/7	0/0/N	80	31	809	966	73% turns - See Note 7.
RS-15[5]	13/1	FRNG	250	.86	.23	0	10	1	---	70	36	895	1167	See Note 10.
PH-1W	14/1	FRNG	100	.89	.82	6/7	37/37	5/5	---	80	30	1379	1466	
PH-1WPE	14/1	FRNG	100	.93	.76	7/7	47/46	5/4	---	80	30	1544	1624	
EI-5N	14/1	FRNG	250	.84	.82	42/41	15/14	3/3	4/4/N	90	29	1161	1249	
PC-2SRE	15/1	FRNG	100	.77	.47	29/31	9/10	3/3	---	90	41	1013	1285	
PC-2S	15/1	FRNG	100	.79	.32	31/27	11/12	5/5	---	90	41	859	1168	
EI-3N	16/1	FRNG	250	.86	.90	15/15	9/8	5/4	---	90	31	1099	1094	Reclassified as CBD.
EI-3E	19/1	FRNG	250	.88	.57	11/11	7/9	4/4	1/3/N	90	51	1264	1399	Reclassified as CBD.
EI-2S	19/2	FRNG	250	.91	.75	14/14	10/9	1/1	---	90	34	1828	1976	See Note 9.
EI-2SRE	19/2	FRNG	250	.86	.42	14/14	13/12	0/0	---	90	34	1878	2111	Reclassified as CBD.
EI-2NRE	19/1	FRNG	250	.83	.47	16/15	31/29	1/1	---	90	34	950	1176	Reclassified as CBD.
MEP-3N	20/2	FRNG	75	.86	.14	27/22	14/17	0/1	---	70	32	1272	1785	
EBL-2WRE	20/2	FRNG	250	.86	.31	30/30	4/4	0/1	---	70	29	1927	2348	
RS-19[5]	22/1-2	FRNG	250	.86	.19	6	6	1	---	70	27	1308	2179	See Note 8.
EI-1E	25/2	FRNG	250	.81	.02	18/13	3/4	6/4	0/7/N	90	45	2092	2640	See Note 11.
EI-1W	25/2	FRNG	250	.81	.07	2/2	8/7	4/4	0/0/N	90	47	2029	3013	See Note 11.
PS-18[5]	26/2	FRNG	250	.87	.12	8	2	1	---	70	31	1445	2280	
RS-21[5]	26/2	FRNG	250	.87	.10	17	15	6	---	70	31	1600	2267	
EG-1W	30/2	FRNG	250	.87	.27	2/2	1/1	6/5	4/8/N	90	54	2200	2636	See Note 9.

TABLE 2

PHYSICAL, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS OF STUDY LOCATIONS

TWO-WAY NO PARKING (CONTINUED)

Site	Appr. Width[1]	Metro Loc.[2]	Metro Pop. (1000's)[2]	PHF[2]	L.F.[2]	% LT.[3]	% RT.[3]	Trucks %[3]	Buses #/Side[3]	Cycle	Green Time	Serv. Vol. (vphg)	Capacity[4] (ALE) (vphg)	Comments
RS-16[5]	9/1	RES	250	.89	.35	0	7	0	---	90	63	1291	1486	
RS-22[5]	9.5/1	RES	250	.84	.90	31	3	2	---	70	26	1402	1455	
MEP-1W	10/1	RES	75	.89	.63	0/0	19/23	1/2	---	70	27	1129	1173	
SB-2S	14/1	RES	75	.78	.51	25/27	12/10	2/1	---	70	26	1035	1246	See Note 6.
EN-1S	14/1	RES	250	.79	.27	8/9	21/23	2/3	---	60	26	954	1385	
MET-1E	15/1	RES	250	.57	.20	5/9	17/18	2/1	1/1/N	70	28	877	1683	
MET-1N	15/1	RES	250	.93	.67	2/3	67/65	0/0	---	70	33	1359	1454	68% turns - See Note 7.
RS-17[5]	18/1	RES	250	.79	.46	10	11	6	---	70	31	1022	1156	
SB-1E	18/2	RES	75	.85	.31	27/27	8/8	1/2	---	70	36	1370	1605	See Note 6.
EM-1E	18/1-2	RES	250	.85	.78	6/5	22/23	0/0	---	60	24	1852	2014	See Note 8.
SB-1S	20/2	RES	75	.81	.59	11/11	25/27	1/1	---	70	25	2308	2570	See Note 6.
RS-14(A)[5]	20/2	RES	250	.80	.12	0	0	3	5/N	90	31	2520	3314	
RS-14(B)[5]	20/2	RES	250	.91	.40	0	8	4	0/N	90	31	2616	3227	
RS-20[5]	20/2	RES	250	.89	.78	4	7	2	0/N	90	55	1751	1833	Two-lane approach narrows to one lane downstream - Data were not used.
RS-12[5]	10/1	CBD	250	.87	.21	0	2	3	15/N	70	39	839	1107	
RS-23[5]	10/1	CBD	250	.81	.27	16	0	3	11/F	70	32	783	978	Left-turn lane also used for thru movement - data were not used.
MEP-2E	11/1	CBD	75	.87	.41	62/59	15/17	6/6	---	70	29	1077	1260	77% turns - See Note 7.
MEP-2EII	11/1	CBD	75	.84	.18	70/60	15/18	14/7	---	70	29	911	1204	85% turns - See Note 7.
EB-1S	30/3	CBD	250	.81	.07	41/39	3/3	8/5	3/12/N	80	48	1792	2200	See Note 11.

TABLE 2

PHYSICAL, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS OF STUDY LOCATIONS

TWO-WAY NO PARKING (CONTINUED)

Site	Appr. Width[1]	Metro Loc.[2]	Metro Pop. (1000's)[2]	PHF[2]	L.F.[2]	% LT.[3]	% RT.[3]	Trucks %[3]	Buses #/Side[3]	Cycle	Green Time	Serv. Vol. (vphg)	Capacity[4] (ALE) (vphg)	Comments
EO-4E	14/1	OBD	250	.90	.23	23/18	18/20	8/6	---	60	21	577	808	Excessive delays during loaded cycles - data were not used.
EO-4S	16/1	OBD	250	.76	.27	3/2	5/8	11/8	---	60	31	862	1191	Reclassified as CBD.
MNB-1N	18/2	OBD	100	.90	.12	28/34	2/3	0/1	---	70	31	1330	1708	
RS-13	21/2	OBD	250	.75	.02	0	11	0	0/N	70	42	1150	2317	See Note 11.
MET-2W	22/2	OBD	250	.87	.39	17/15	53/52	6/6	---	70	21	1420	1827	70% turns - See Note 7.
MET-2N	26/2	OBD	250	.83	.31	20/18	1/2	6/6	---	70	39	1977	2294	Reclassified as CBD.

[1] Approach width/Number of lanes

[2] See definitions in Highway Capacity Manual, Chapter 6 (HRB-SR 87, Pgs. 115-121)

Metro Loc - Location in Metropolitan Area
Metro Pop - Metropolitan Area Population
PHF - Peak Hour Factor
L.F. - Load Factor

[3] Expanded loaded cycle data/peak hour data - In Buses column, F or N following second slash indicates near or far-side bus stop.

[4] ALE - Average loaded cycle volume expanded to full volume

[5] Peak hour data unavailable

[6] Large variation in green phase - data were not used.

[7] Few samples available having 60%+ turns - data were not used.

[8] Combined one and two-lane operation - data were not used.

[9] Loaded cycle data were inaccurately tabulated - data were not used.

[10] Traffic back-up due to downstream signal - data were not used.

[11] Load factor too low to allow accurate expansion of loaded cycle volume - data were not used.

TABLE 3

PHYSICAL, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS OF STUDY LOCATIONS

TWO-WAY PARKING

Site	Appr. Width[1]	Metro Loc.[2]	Metro Pop. (1000's)[2]	PHF[2]	L.F.[2]	% LT.[3]	% RT.[3]	Trucks % [3]	Buses #/Side[3]	Cycle	Green Time	Serv. Vol. (vphg)	Capacity (ALE) (vphg)[4]	Comments
PC-3E	16/1	FRNG	250	.85	.13	23/20	36/33	5/5	---	90	33	669	851	See Note 9.
PC-3ERE	16/1	FRNG	250	.83	.13	12/15	8/20	8/5	---	90	33	885	1287	
PC-3WRE	16/1	FRNG	250	.84	.35	28/28	18/18	5/5	1/2/N	90	33	1148	1379	
RS-27[5]	17/1	FRNG	250	.85	.52	0	37	6	---	70	28	1000	1184	
RS-29[5]	17/1	FRNG	250	.83	.41	4	12	3	---	70	28	934	1184	
MNB-2W	17/1	FRNG	100	.71	.12	13/12	10/9	3/3	---	70	30	697	1249	Reclassified as residential.
RS-27II	17/1	FRNG	250	.84	.24	7/4	24/26	9/8	0/2/F	70	25	675	904	
RS-29II	17/1	FRNG	250	.78	.16	25/25	9/13	8/6	0/0/F	70	25	888	1142	
MNB-4WII	18/1	FRNG	100	.84	.59	5/5	8/8	1/1	---	70	28	1185	1313	
MNB-4WIII	18/1	FRNG	100	.82	.45	2/2	12/12	0/1	---	70	28	1117	1392	
MNB-4W	18/1	FRNG	100	.88	.33	2/3	9/10	4/3	---	70	35	998	1176	
SS-1N	18/1	FRNG	75	.90	.18	7/11	16/13	4/4	---	80	36	813	1175	
PC-2E	18/1	FRNG	250	.85	.38	8/8	14/12	5/5	---	90	43	1146	1194	
PH-1N	18/1	FRNG	100	.96	.40	2/3	2/4	5/5	---	80	40	1328	1386	
PH-1NRE	18/1	FRNG	100	.94	.69	2/2	2/2	2/3	---	80	40	1428	1553	
PC-2ERE	18/1	FRNG	250	.75	.52	10/10	9/9	2/2	2/2/F	90	43	1218	1451	
MNB-4SII	19/1	FRNG	100	.86	.43	31/30	11/11	1/1	---	70	31	850	1094	
MNB-4SIII	19/1	FRNG	100	.80	.41	32/33	13/11	1/1	---	70	31	866	1143	
MNB-4S	19/1	FRNG	100	.83	.45	17/16	26/21	0/0	---	70	25	1157	1372	
EI-1SRE	19/1	FRNG	250	.87	.25	27/17	26/37	47/22	---	90	33	760	851	High percentage of trucks - data were not used.

TABLE 3

PHYSICAL, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS OF STUDY LOCATIONS

TWO-WAY PARKING

Site	Appr.[1] Width	Metro[2] Loc.	Metro[2] Pop. (1000's)	PHF[2]	L.F.[2]	% LT.[3]	% RT.[3]	Trucks[3] %	Buses[3] #/Side	Cycle	Green Time	Serv. Vol. (vphg)	Capacity[4] (ALE) (vphg)	Comments
EI-1S	19/1	FRNG	250	.84	.45	22/25	18/15	1/2	---	90	33	1145	1394	
UP-1SII	20/1	FRNG	75	.91	.13	3/3	12/10	5/4	---	80	36	933	1250	
UP-1WII	20/1	FRNG	75	.87	.07	4/10	6/8	2/4	---	80	36	1147	1633	
EI-4W	20/1	FRNG	250	.90	.55	10/9	7/8	4/3	---	70	28	1348	1557	Reclassified as residential.
CC-1W	20/1	FRNG	100	.88	.24	7/5	14/13	3/5	---	70	31	962	1324	
SP-1E	20/1	FRNG	75	.82	.22	12/11	15/13	5/3	---	60	30	852	1182	
SP-1S	20/1	FRNG	75	.89	.28	17/18	16/20	2/1	---	60	23	929	1160	
RS-30-a[5]	20/1	FRNG	250	.81	.41	13	17	4	---	70	32	1022	1267	
RS-30-b[5]	20/1	FRNG	250	.83	.58	16	14	3	---	70	32	1044	1244	
RS-31[5]	20/1	FRNG	250	.82	.41	4	10	4	0/F	70	36	1118	1372	
RS-36[5]	20/1	FRNG	250	.81	.18	7	7	1	6/N	70	36	1104	1333	
RS-30II	20/1	FRNG	250	.87	.39	18/17	19/18	6/5	---	70	31	1007	1244	
PC-3SRE	20/1	FRNG	250	.92	.15	19/15	10/7	9/11	0/0/F	90	51	954	1259	
RS-34[5]	21/1	FRNG	500	.86	.75	8	25	1	0/N	90	29	1247	1327	
PP-1WRE	22/1	FRNG	250	.88	.68	11/12	6/6	1/1	---	60	24	1162	1324	
PP-1W	22/1	FRNG	250	.86	.70	16/16	9/9	5/5	---	60	24	1105	1246	
RS-38[5]	22/1	FRNG	250	.85	.88	3	9	5	6/N	70	28	1350	1375	
RS-37[5]	22/1	FRNG	250	.94	.35	7	2	1	3/N	70	42	1467	1583	
RS-37II	22/1	FRNG	250	.83	.06	12/8	10/6	6/6	---	70	42	840	1388	See Note 10.
RS-38II	22/1	FRNG	250	.94	.63	14/12	12/13	7/7	---	70	28	1140	1235	

TABLE 3

PHYSICAL, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS OF STUDY LOCATIONS

TWO-WAY PARKING

Site	Appr. Width[1]	Metro Loc.[2]	Metro Pop. (1000's)[2]	PHF[2]	L.F.[2]	% LT.[3]	% RT.[3]	Trucks %[3]	Buses #/Side[3]	Cycle	Green Time	Serv. Vol. (vphg)	Capacity[4] (ALE) (vphg)	Comments
PP-1S	23/1	FRNG	250	.85	.10	6/10	6/8	5/5	---	60	30	900	1260	
PP-1N	23/1	FRNG	250	.83	.65	7/8	23/22	5/5	---	60	30	1058	1185	
PP-1NRE	23/1	FRNG	250	.88	.83	8/8	18/18	2/3	---	60	30	1158	1217	
PP-1E	23/1	FRNG	250	.87	.58	8/7	4/4	5/5	---	60	24	1172	1371	
CC-1N	24/1	FRNG	100	.87	.33	2/3	9/6	3/3	1/5/N	70	31	1406	1666	
MNB-5E	24/1-2	FRNG	100	.84	.47	9/8	11/12	1/2	---	70	25	1381	1618	See Note 8.
RS-32[5]	25/1-2	FRNG	250	.87	.18	26	15	1	---	70	31	1512	2032	See Note 8.
EN-1W	18/1	RES	250	.88	.15	17/14	19/16	3/3	---	60	28	1004	1400	
MNB-3W	18/1	RES	100	.85	.61	35/32	6/8	2/1	---	70	38	1050	1127	
SB-2E	18/1	RES	100	.85	.24	10/8	8/8	3/2	---	70	37	1159	1496	See Note 6.
MNB-3N	20/1	RES	100	.86	.55	14/13	3/2	1/1	---	70	25	1179	1382	
PP-6NRE	20/1	RES	250	.83	.05	12/12	0/2	0/1	---	60	33	727	1491	See Note 10.
PP-5E	20/1	RES	250	.82	.15	24/30	26/25	5/5	---	60	19	611	1137	
PP-4W	20/1	RES	250	.81	.20	12/13	17/19	5/5	---	60	20	697	1035	See Note 9.
PP-5W	20/1	RES	250	.82	.22	22/17	10/14	5/5	---	60	19	778	1253	
PP-4WRE	20/1	RES	250	.84	.18	14/15	19/20	5/2	---	60	20	946	1358	
PP-5WRE	20/1	RES	250	.84	.27	8/8	14/12	4/4	---	60	19	1063	1397	
PP-4E	20/1	RES	250	.79	.17	38/39	13/15	5/5	---	60	20	586	1152	
PP-6N	20/1	RES	250	.72	.17	9/6	13/11	5/5	---	60	33	624	993	See Note 9.
MNB-2S	22/1	RES	100	.84	.22	10/7	21/24	5/3	---	70	30	1296	1634	
PP-6W	22/1	RES	250	.87	.27	27/20	14/13	5/5	---	60	21	1131	1402	

TABLE 3

PHYSICAL, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS OF STUDY LOCATIONS

TWO-WAY PARKING

Site	Appr. Width[1]	Metro Loc.[2]	Metro Pop. (1000's)[2]	PHF[2]	L.F.[2]	% LT.[3]	% RT.[3]	Trucks % [3]	Buses #/Side[3]	Cycle	Green Time	Serv. Vol. (vphg)	Capacity (ALE) (vphg)[4]	Comments
PP-6WRE	22/1	RES	250	.92	.30	19/19	12/14	3/3	---	60	21	1214	1467	
PP-2E	17/1	CBD	250	.85	.52	0/0	10/9	5/5	---	90	33	740	873	See Note 7.
MNB-1W	19.5/1	CBD	100	.87	.20	12/11	16/19	6/2	---	70	29	978	1145	
UP-1S	20/1	CBD	75	.83	.18	5/12	11/13	4/4	---	80	36	1067	1400	Reclassified as fringe.
UP-1W	20/1	CBD	75	.83	.18	11/9	9/10	2/5	0/3/N	80	36	1147	1762	Reclassified as fringe.
RS-33[5]	20/1	CBD	250	.86	.58	0	18	5	18/N	70	32	1152	1239	
MEP-4S	21/1	CBD	75	.90	.29	0/0	0/0	6/8	5/19/N	70	42	927	1139	
MEP-4SII	21/1	CBD	75	.88	.10	0/0	0/0	7/5	0/0/N	70	42	783	1190	
PP-3N	22/1	CBD	250	.90	.20	0/0	0/0	5/5	0/0/N	90	53	1292	1622	See Note 7.
RS-26[5]	25/1	CBD	250	.91	.10	0	12	5	4/F	120	47	1200	1436	
MEP-4N	26/1-2	CBD	75	.92	.37	0/0	28/25	2/2	---	70	42	1275	1445	See Note 8.
MEP-4NII	26/1-2	CBD	75	.88	.12	0/0	27/28	8/6	---	70	42	1102	1346	See Note 8.
MEP-2S	28/1-2	CBD	75	.86	.24	3/4	42/38	8/6	---	70	36	1307	1702	See Note 8.

[1-6] See notes on previous table.

[7] Unusual layout - data were not used.

[8] Combined one and two-lane operation - data were not used.

[9] Loaded cycle data were inaccurately tabulated - data were not used.

[10] Load factor too low to allow accurate expansion of loaded cycle volume - data were not used.

TABLE 4

HCM AND BELLIS CAPACITY ESTIMATES

TWO-WAY NO PARKING

	Estimates			Percent Error		
Site	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis
PH-1W	1280	1235	1320	-13	-16	-10
PH-1WRE	1360	1223	1254	-16	-25	-23
EI-5N	1110	1135	1325	-11	- 9	6
PC-2SRE	1275	1300	1279	- 1	1	0
PC-2S	1200	1246	1319	2	7	13
EI-3N	1650	1451	994	51	33	- 9
EI-3E	1760	1541	1016	26	10	-27
EI-2SRE	2060	1813	1578	- 2	-14	-25
EI-2NRE	1790	1594	1050	52	35	-11
MEP-3N	1810	1755	1800	1	- 2	1
EBL-2WRE	2080	1930	1883	-11	-18	-20
RS-18	3120	2992	2310	37	31	1
RS-21	2920	2450	1890	29	8	-17
RS-16	1380	1224	1657	- 7	-18	11
RS-22	1530	963	1333	6	-34	- 8
MEP-1W	1200	1125	1201	2	- 4	2
EN-1S	1390	1561	1358	0	13	- 2
MET-1E	1300	1794	1385	-23	7	-18
RS-17	1820	2119	1382	57	83	14
RS-14 (A)	2270	2835	3081	-32	-14	- 7
RS-14 (B)	2350	2693	2936	-27	-16	- 9
RS-12	1770	1090	979	60	- 1	-11

TABLE 4

HCM AND BELLIS CAPACITY ESTIMATES

TWO-WAY NO PARKING

Site	Estimates: HCM (Unrevised Factors)	Estimates: HCM (Revised Factors)	Estimates: Bellis	Percent Error: HCM (Unrevised Factors)	Percent Error: HCM (Revised Factors)	Percent Error: Bellis
EO-4S	1770	1576	971	49	32	-18
MNB-1N	1780	1774	1962	4	4	15
MET-2N	2430	2295	1803	6	0	-21

TABLE 5

HCM AND BELLIS CAPACITY ESTIMATES

TWO-WAY PARKING

	Estimates			Percent Error		
Site	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis
PC-3ERE	948	1014	1207	-26	-21	- 6
PC-3WRE	1020	813	1246	-26	-41	-10
RS-27	1240	1091	1271	4	- 8	7
RS-29	1289	1258	1312	9	6	11
MNB-2W	870	1080	1278	-30	-13	2
RS-27II	1060	1026	1310	18	13	45
RS-29II	801	947	1325	-29	-17	16
MNB-4WII	1440	1335	1352	9	2	3
MNB-4WIII	1450	1336	1366	4	- 4	- 2
MNB-4W	1550	1326	1330	32	13	13
SS-1N	1240	1151	1248	5	- 2	6
PC-2E	1260	1241	1272	6	4	7
PH-1N	1900	1355	1282	37	- 2	- 7
PH-1NRE	1890	1397	1323	22	-10	-15
PC-2ERE	1260	1301	1315	-13	-10	- 9
MNB-4SII	1020	1066	1382	- 6	- 3	26
MNB-4SIII	940	1045	1388	-13	- 8	21
MNB-4S	940	1041	1580	-33	-24	15

TABLE 5

HCM AND BELLIS CAPACITY ESTIMATES

TWO-WAY PARKING

	Estimates			Percent Error		
Site	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis
EI-1S	1040	1088	1298	-25	-22	- 7
UP-1SII	1650	1413	1420	32	13	17
UP-1WII	1490	1504	1401	- 9	- 8	-14
EI-4W	1600	1477	1357	2	- 5	-13
CC-1W	1452	1454	1354	9	10	2
SP-1E	1130	1222	1254	- 4	3	6
SP-1S	1150	1142	1382	- 1	- 2	19
RS-30-a	1220	1271	1316	- 4	0	4
RS-30-b	1220	1257	1330	- 2	1	7
RS-31	1680	1551	1434	23	13	4
RS-36	1900	1568	1479	43	18	11
RS-30II	1131	1130	1340	- 9	- 9	8
PC-3SRE	1254	1190	1222	0	- 6	- 3
RS-34	2130	1575	1344	61	19	1
PP-1WRE	1750	1700	1337	32	28	1
PP-1W	1545	1527	1350	24	22	8
RS-38	1870	1739	1504	36	26	9
RS-37	2130	1800	1479	35	14	- 6
RS-38II	2210	1509	1656	80	22	34
PP-1S	1820	1807	1254	44	43	0
PP-1N	1510	1618	1320	28	37	11
PP-1NRE	1660	1720	1294	37	41	6

TABLE 5

HCM AND BELLIS CAPACITY ESTIMATES

TWO-WAY PARKING

	Estimates			Percent Error		
Site	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis	HCM (Unrevised Factors)	HCM (Revised Factors)	Bellis
PP-1E	1840	1792	1283	34	31	- 6
CC-1N	2080	1903	1354	25	14	-21
EN-1W	1101	1176	1374	-21	-16	- 2
MNB-3W	1030	1154	1306	- 9	2	16
MNB-3N	1460	1551	1425	3	12	3
PP-5E	990	1182	1263	-13	4	11
PP-5W	1160	1376	1263	- 7	10	2
PP-4WRE	1170	1372	1369	-14	1	1
PP-5WRE	1430	1620	1276	2	16	- 9
PP-4E	1040	1272	1369	-10	10	19
MNB-2S	1400	1610	1252	-14	- 1	-23
PP-6W	1590	1561	1369	13	11	- 5
PP-6WRE	1330	1696	1330	- 9	16	- 9
MNB-1W	1160	1086	1284	1	- 5	12
UP-1S	1180	1280	1448	-16	- 9	3
UP-1W	1320	1235	1529	-25	-30	-13
RS-33	1720	1325	956	39	7	-23
MEP-4S	1250	1366	966	10	20	-15
MEP-4SII	1300	1464	956	9	23	-20
RS-26	1720	1816	950	20	26	-34

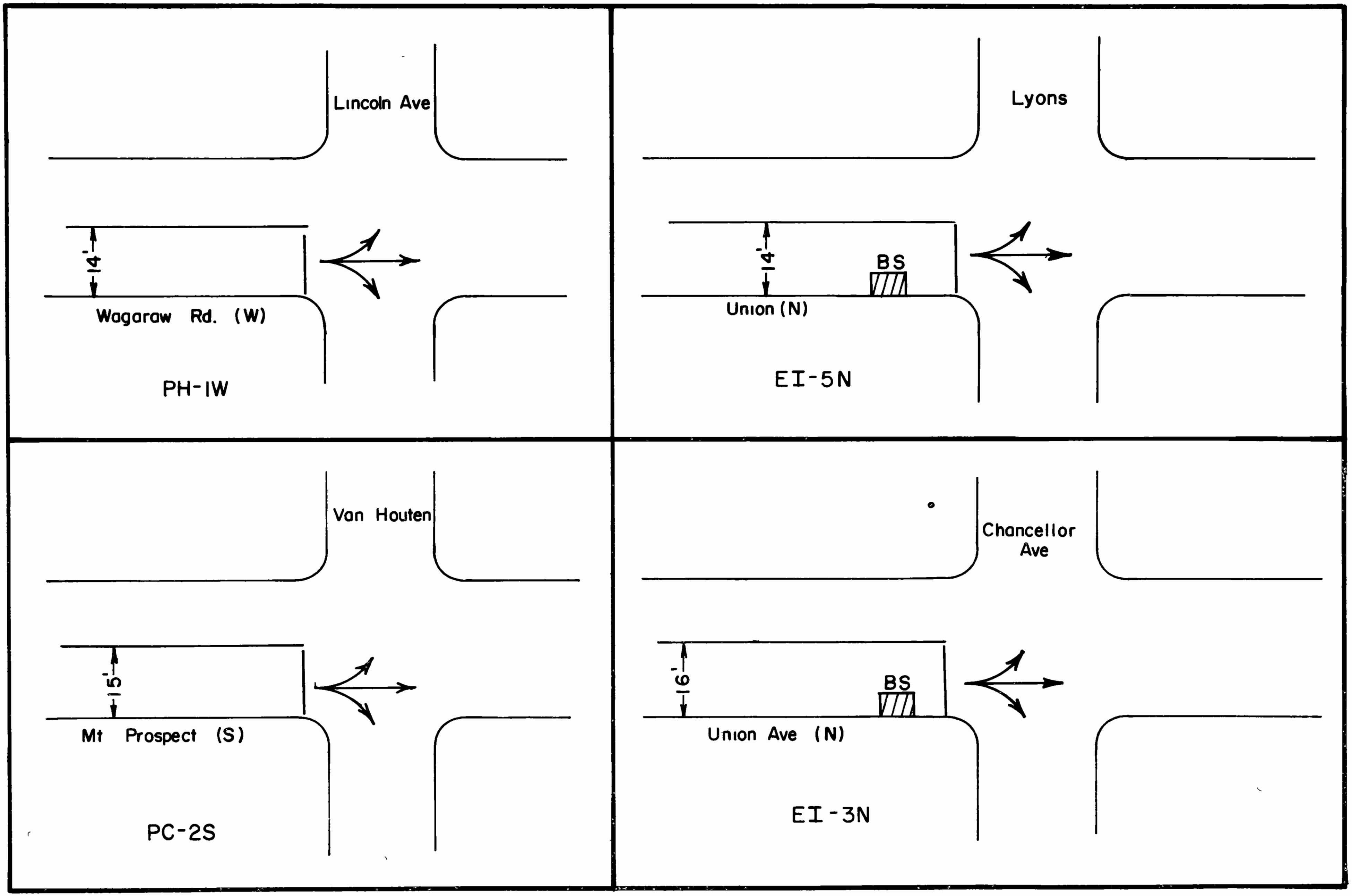

FIGURE 9 — 2 WAY, NO PARKING

A-212-4

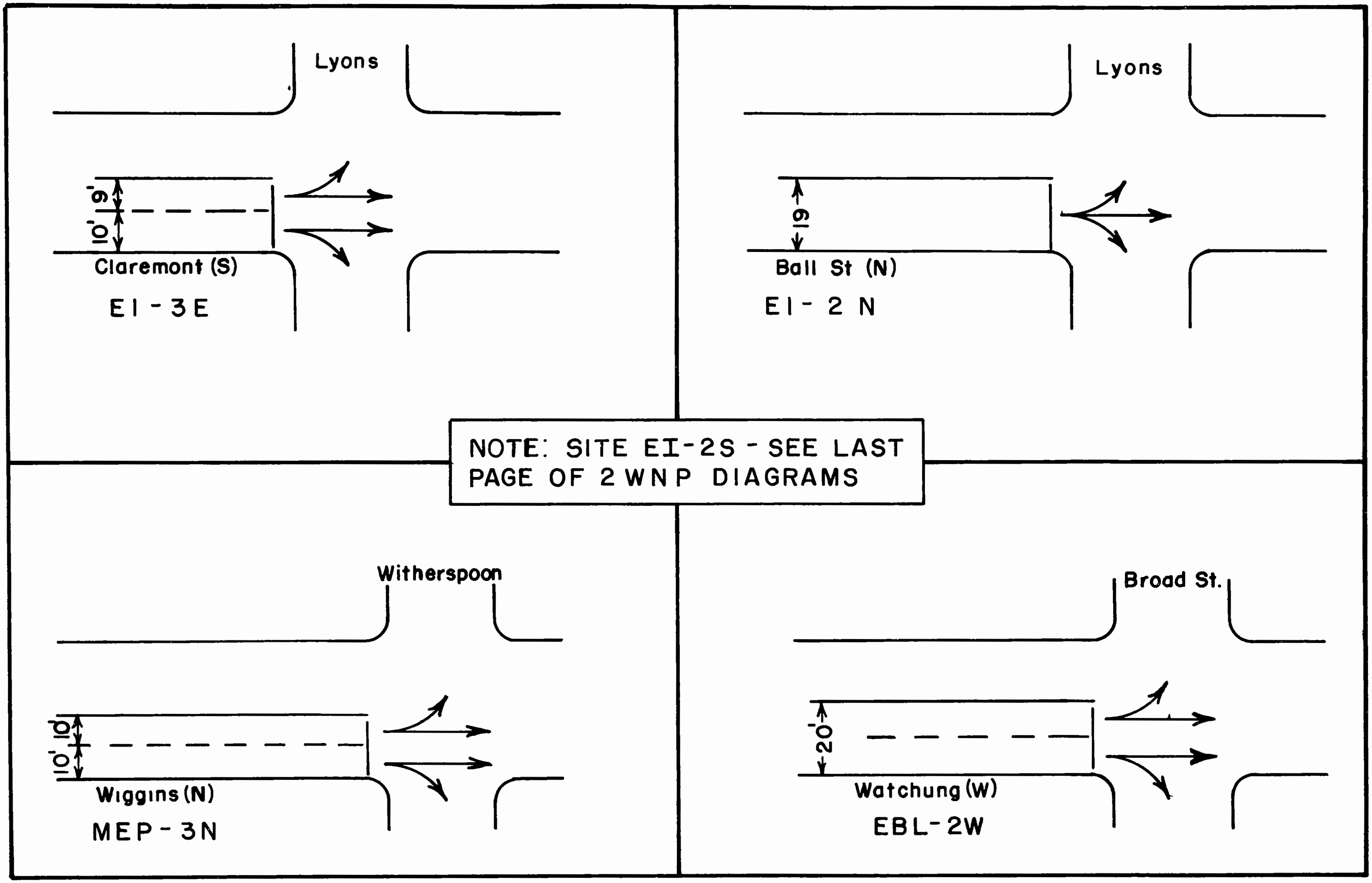

FIGURE 9 — 2 WAY, NO PARKING

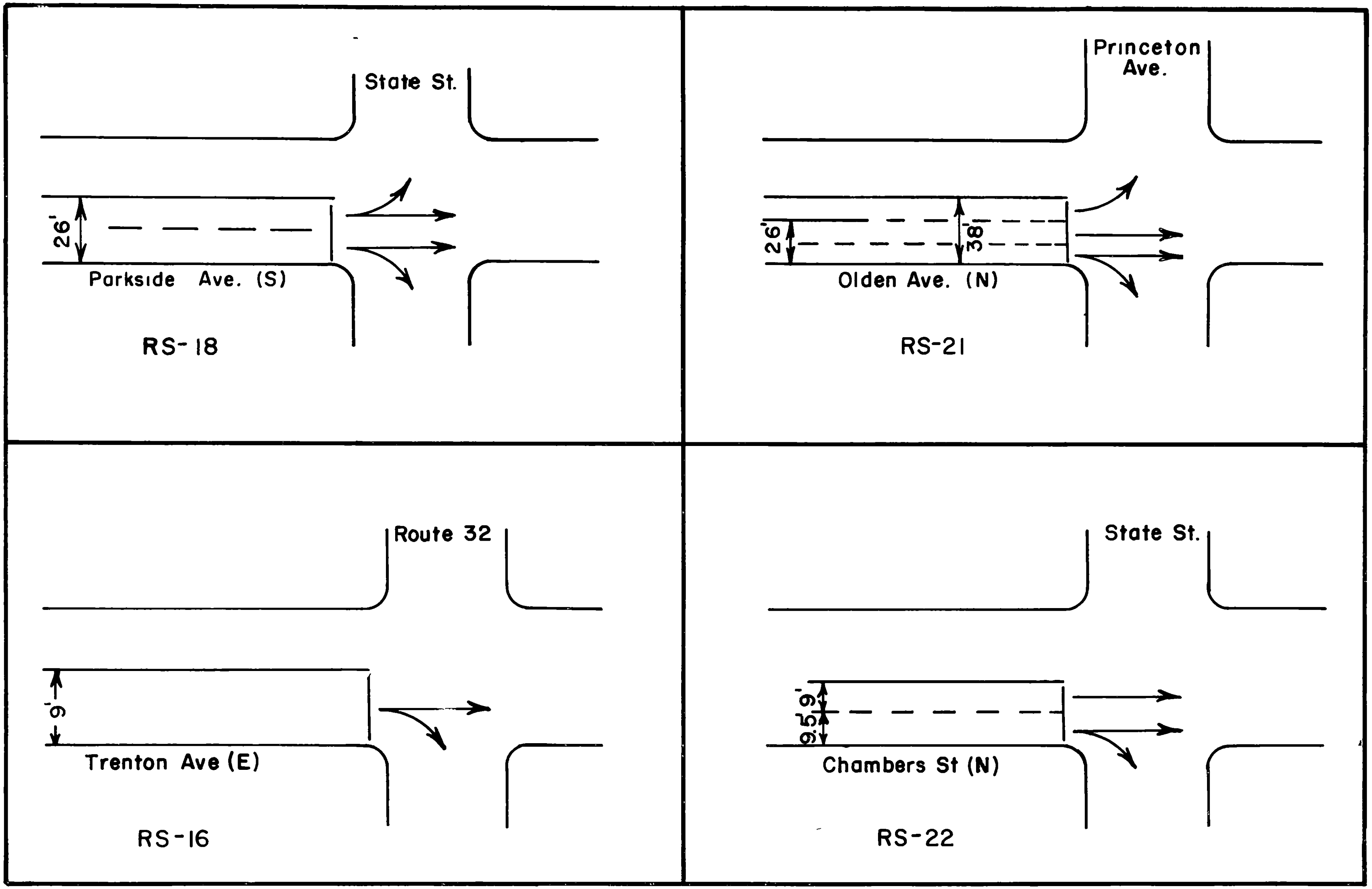

FIGURE 9 — 2 WAY, NO PARKING

A-212-6

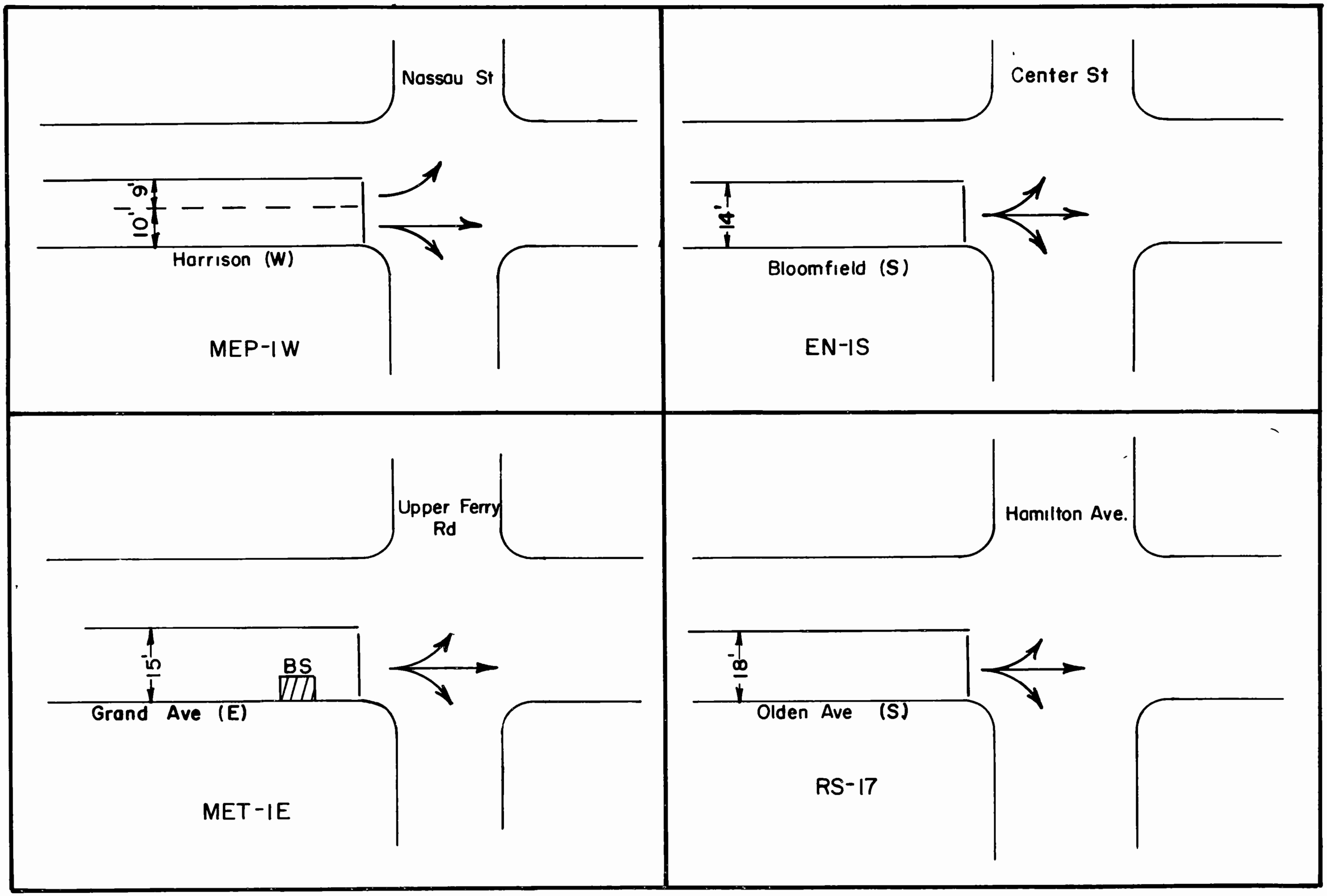

FIGURE 9 — 2 WAY, NO PARKING

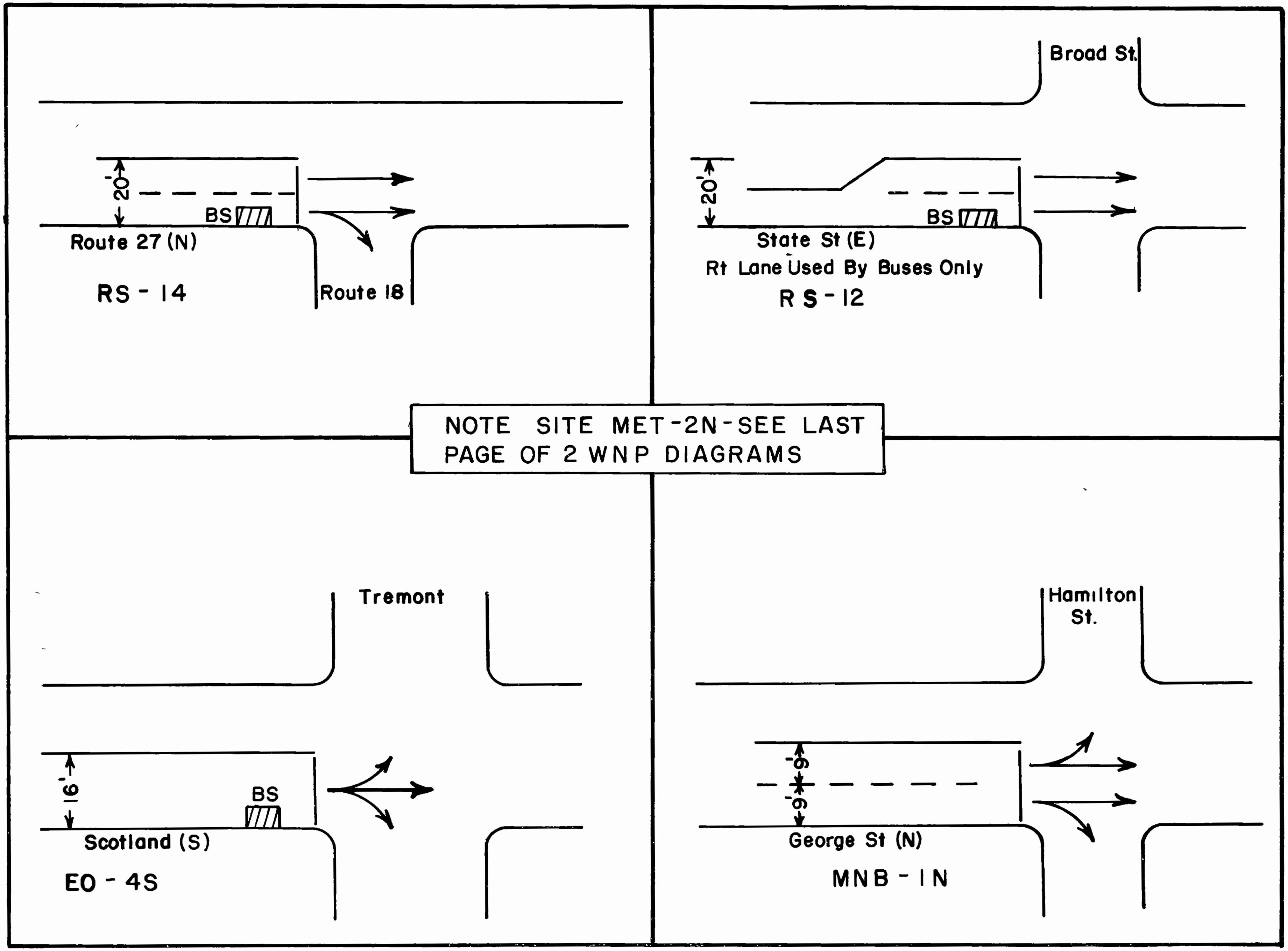

FIGURE 9 — 2 WAY, NO PARKING

A-212-8

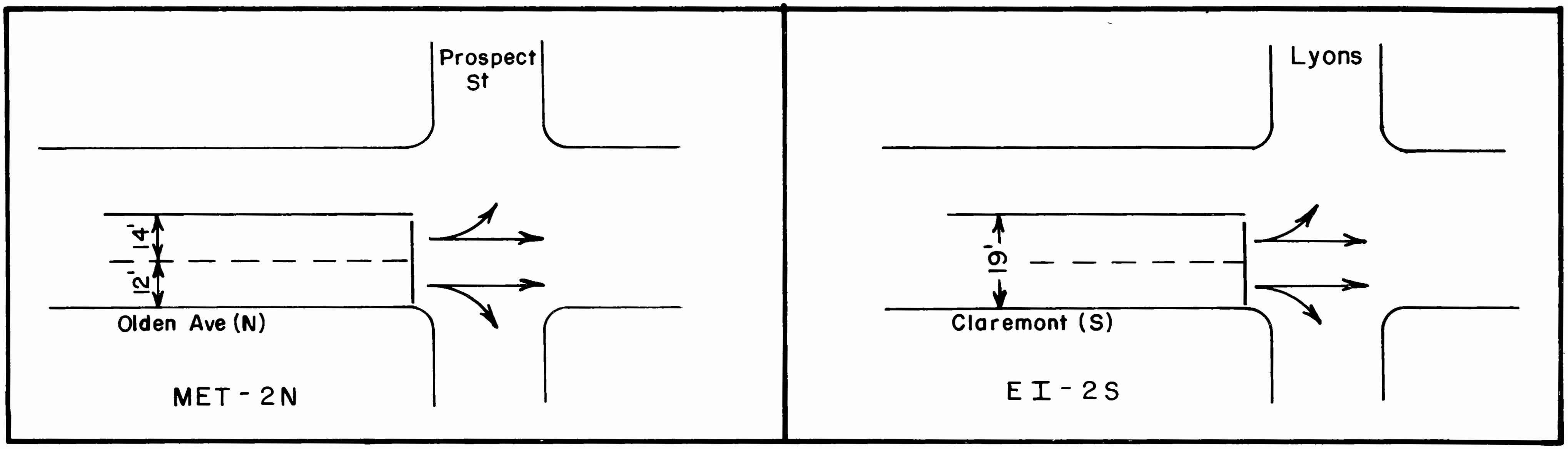

FIGURE 9 — 2 WAY, NO PARKING

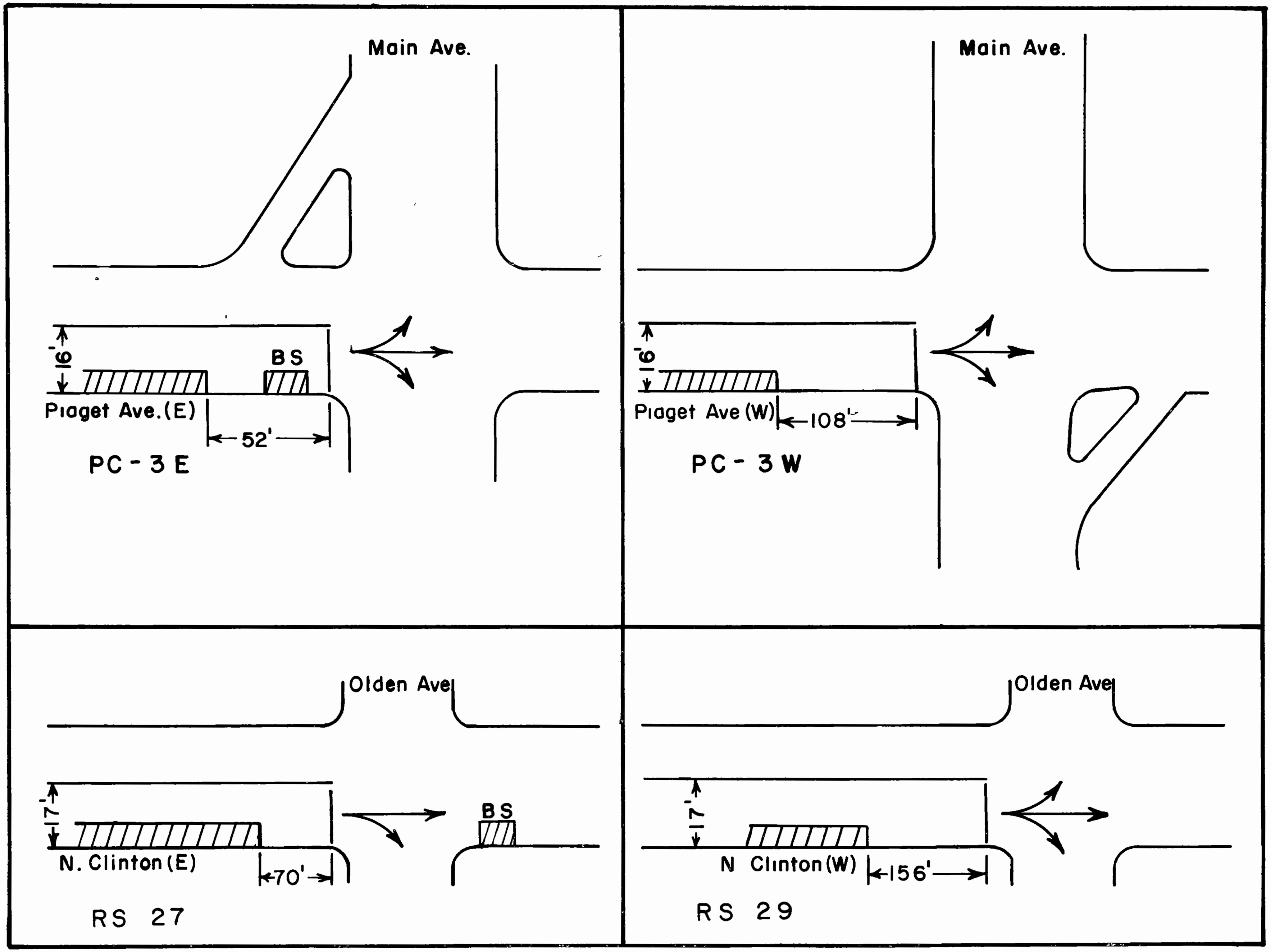

FIGURE 10 — 2 WAY PARKING

A-212-11

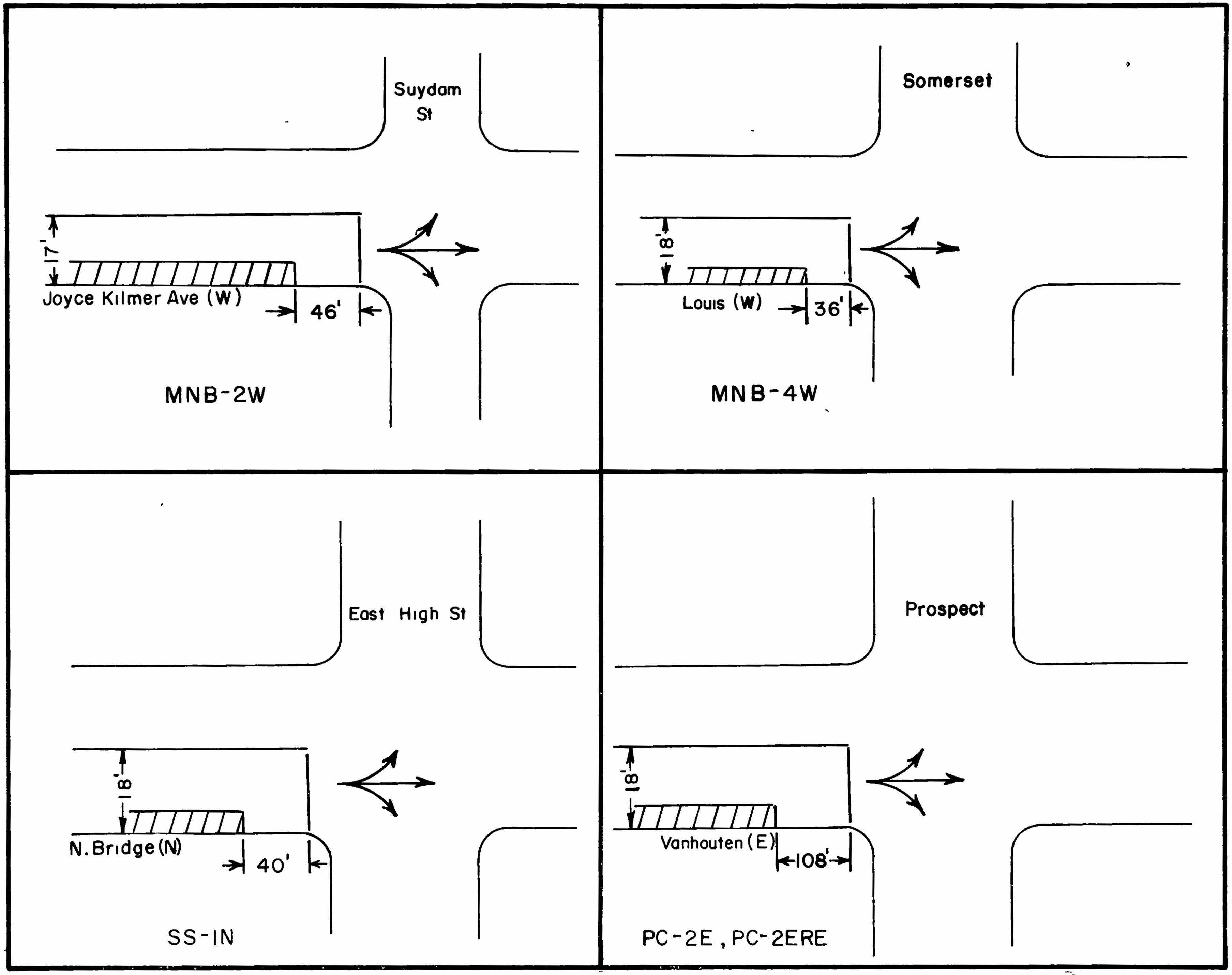

FIGURE 10 – 2 WAY PARKING

A-212-1

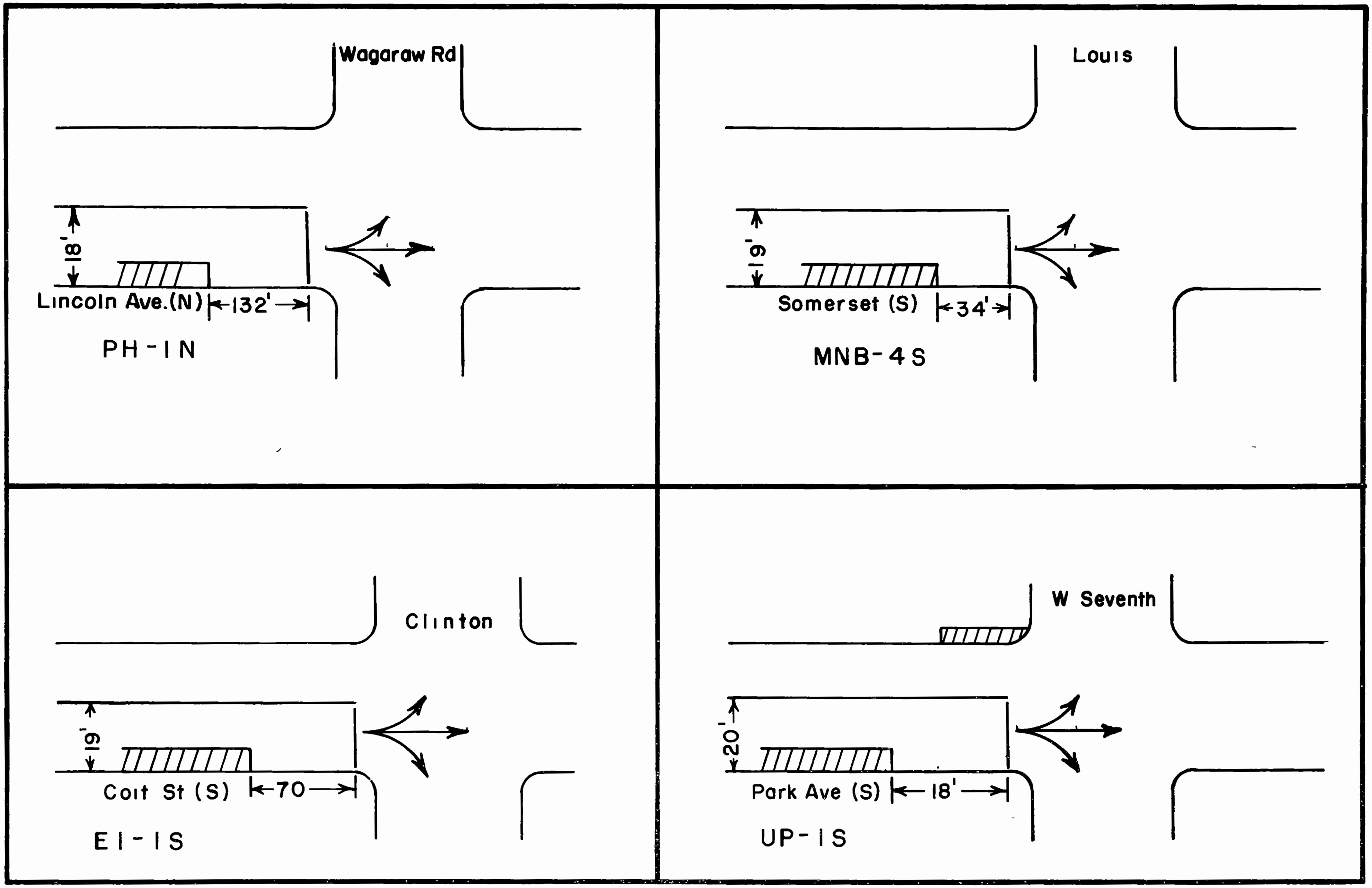

FIGURE 10 — 2 WAY PARKING

A-212-12

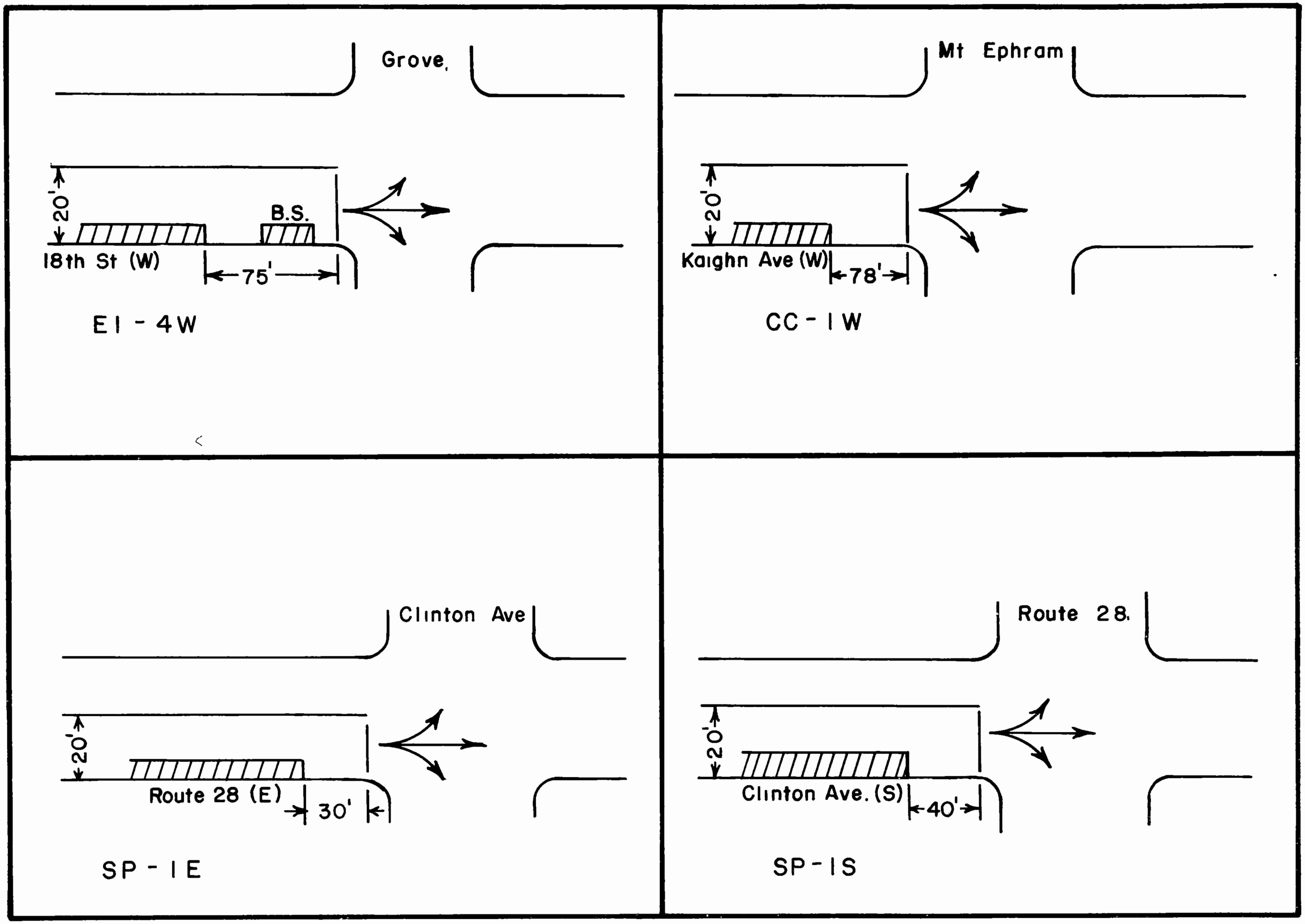

FIGURE 10 - 2 WAY PARKING

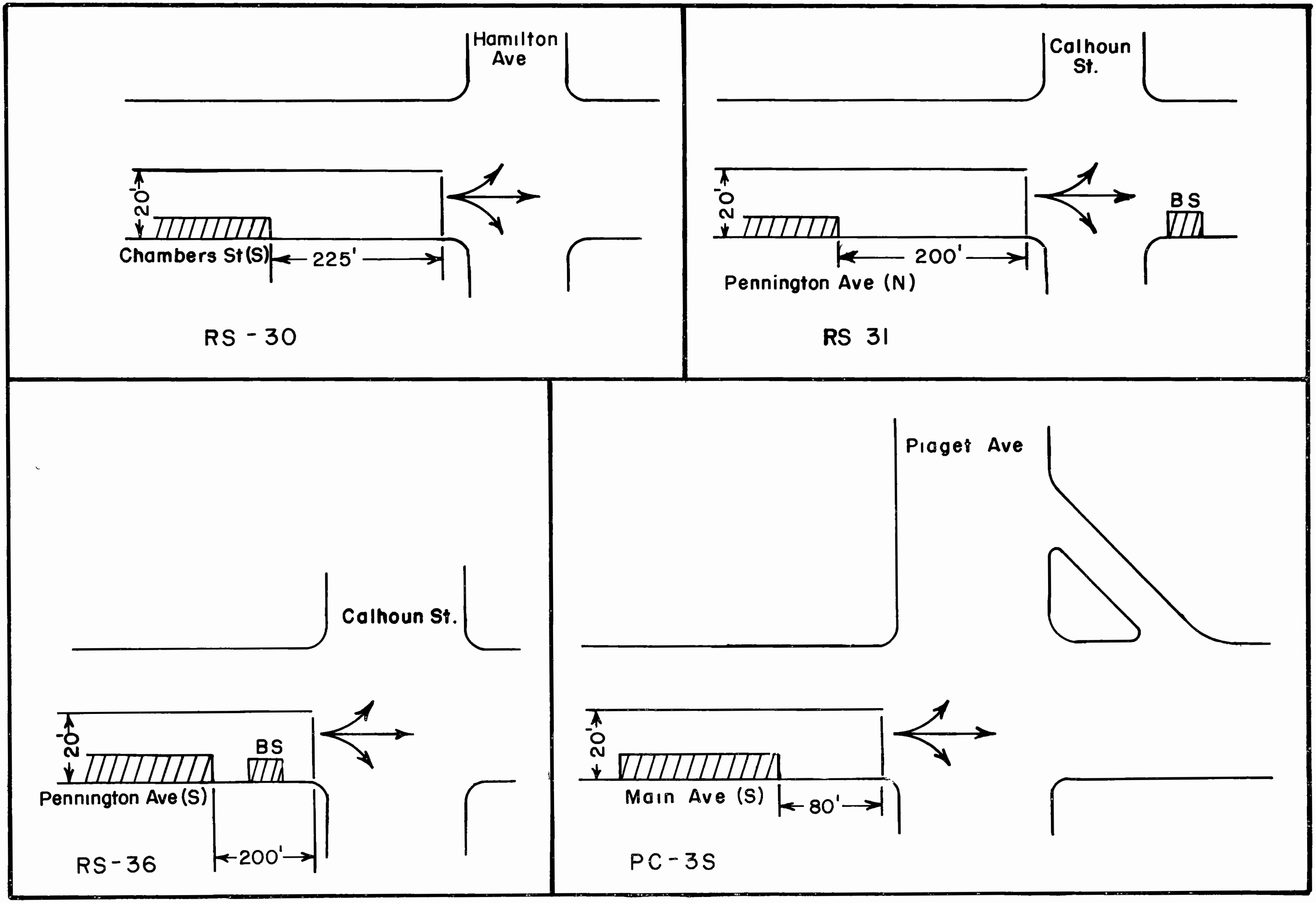

FIGURE 10 – 2 WAY PARKING

A-212-14

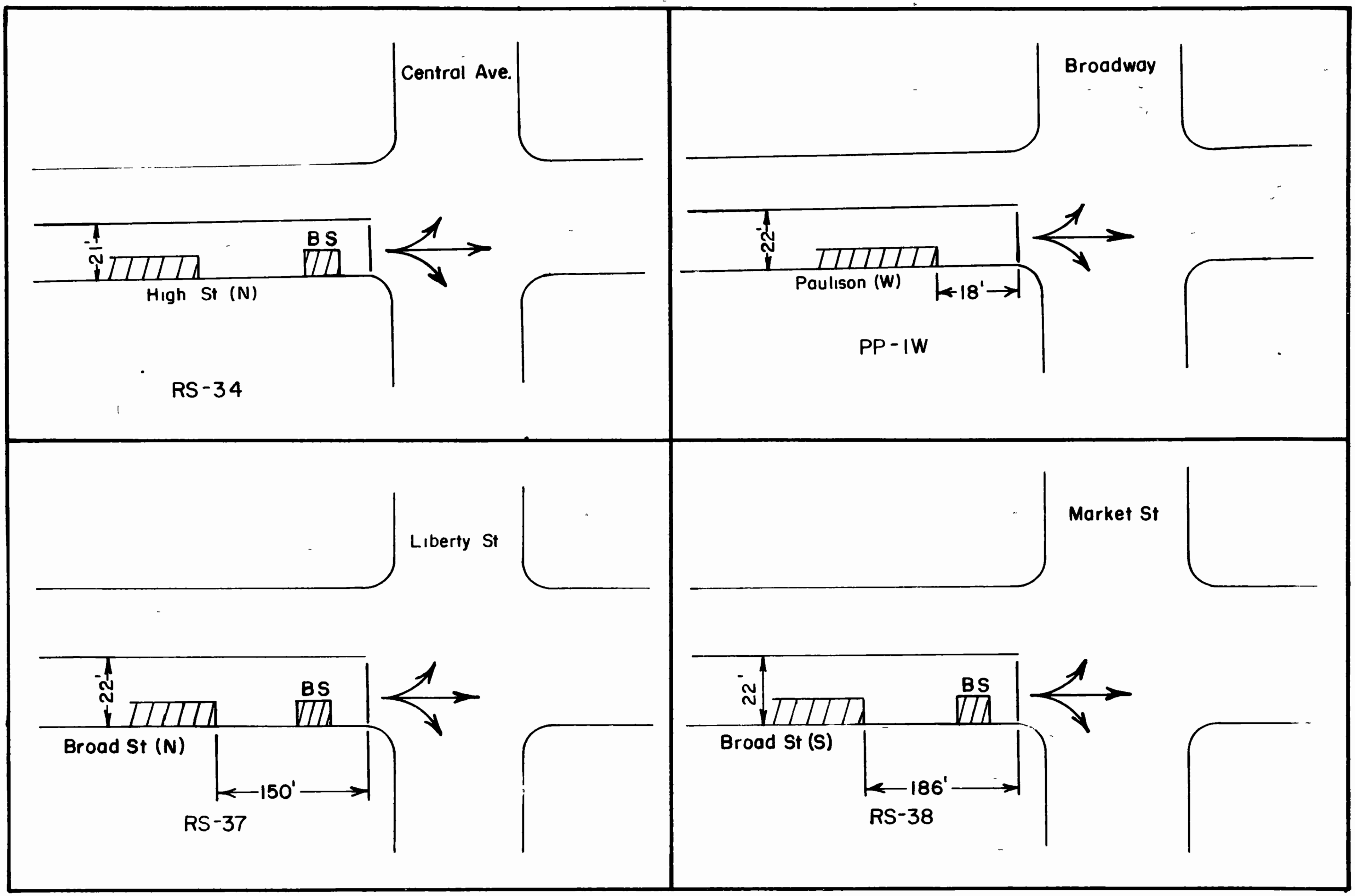

FIGURE 10 — 2 WAY PARKING

A-212-2

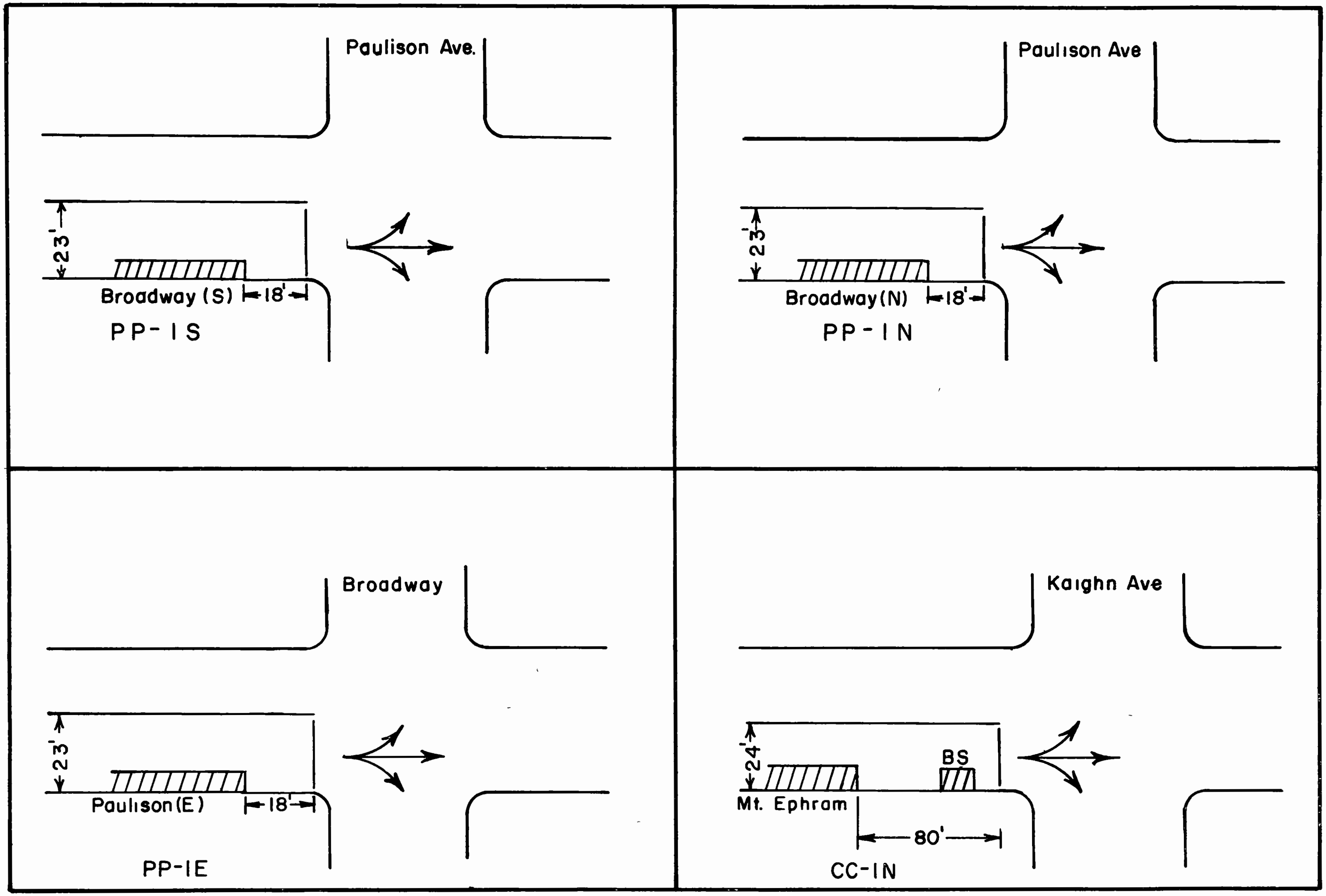

FIGURE 10 — 2 WAY PARKING

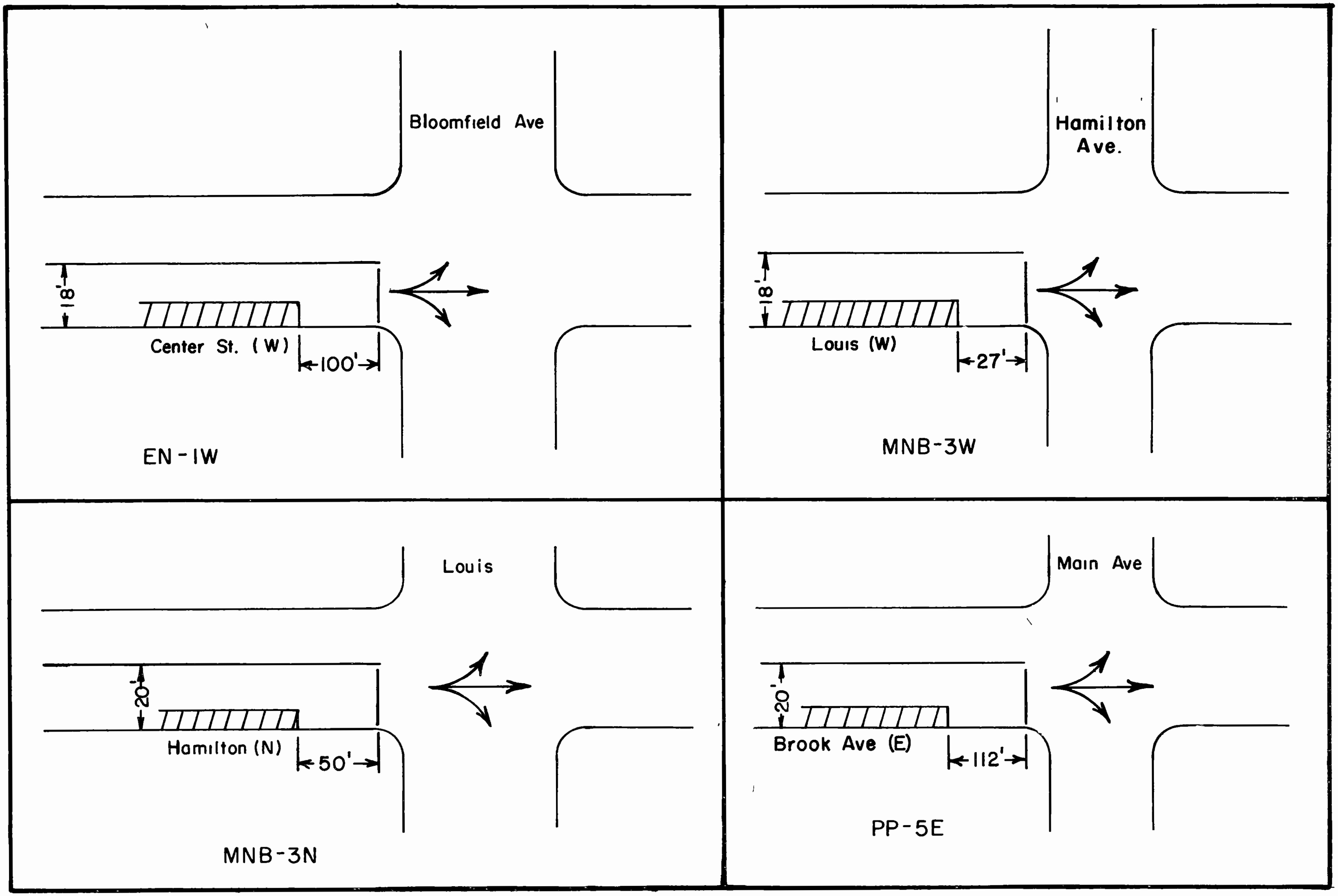

FIGURE 10— 2 WAY PARKING

A-212-3

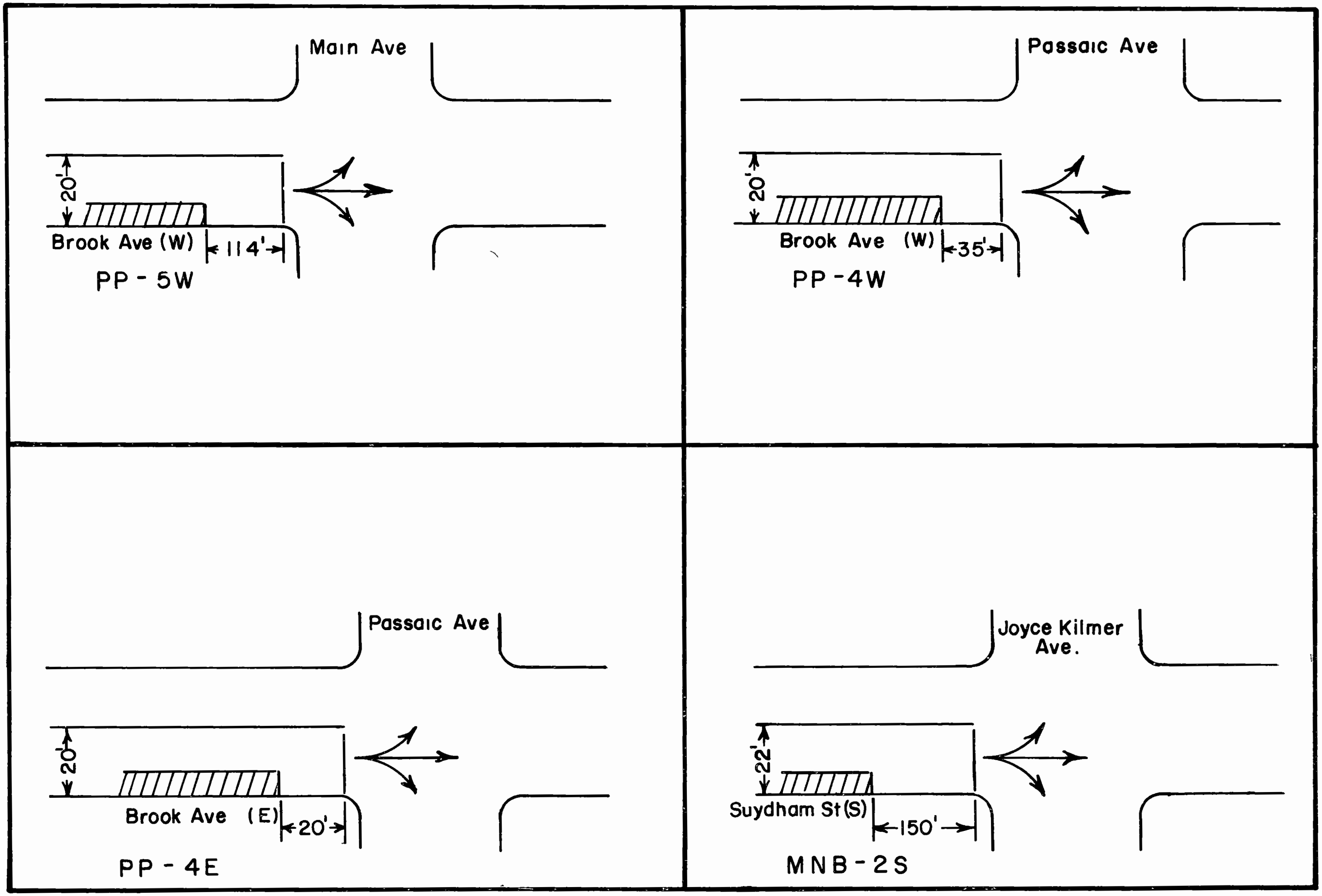

FIGURE 10 – 2 WAY PARKING

A-215-16

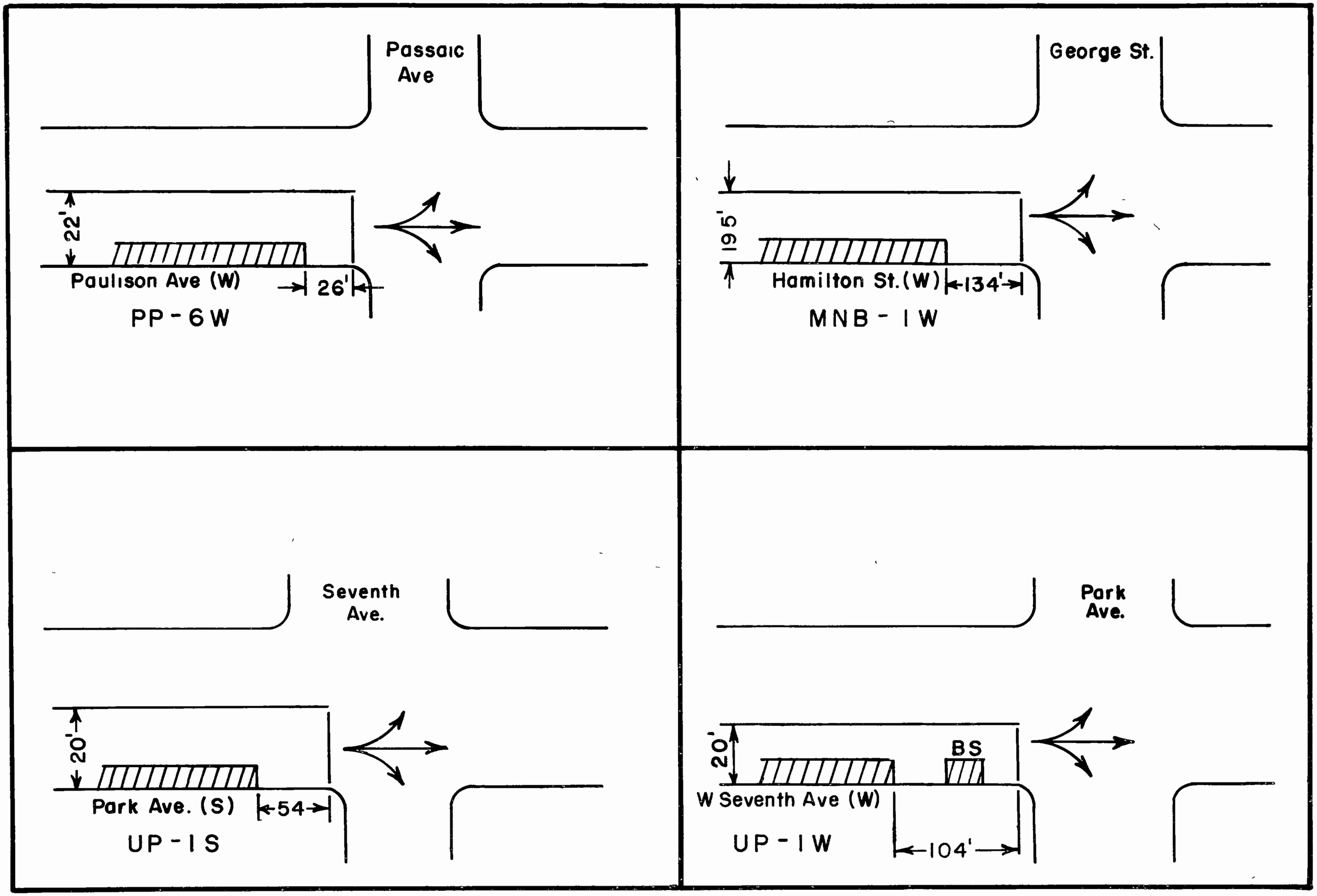

FIGURE 10 – 2 WAY PARKING

A-212-10

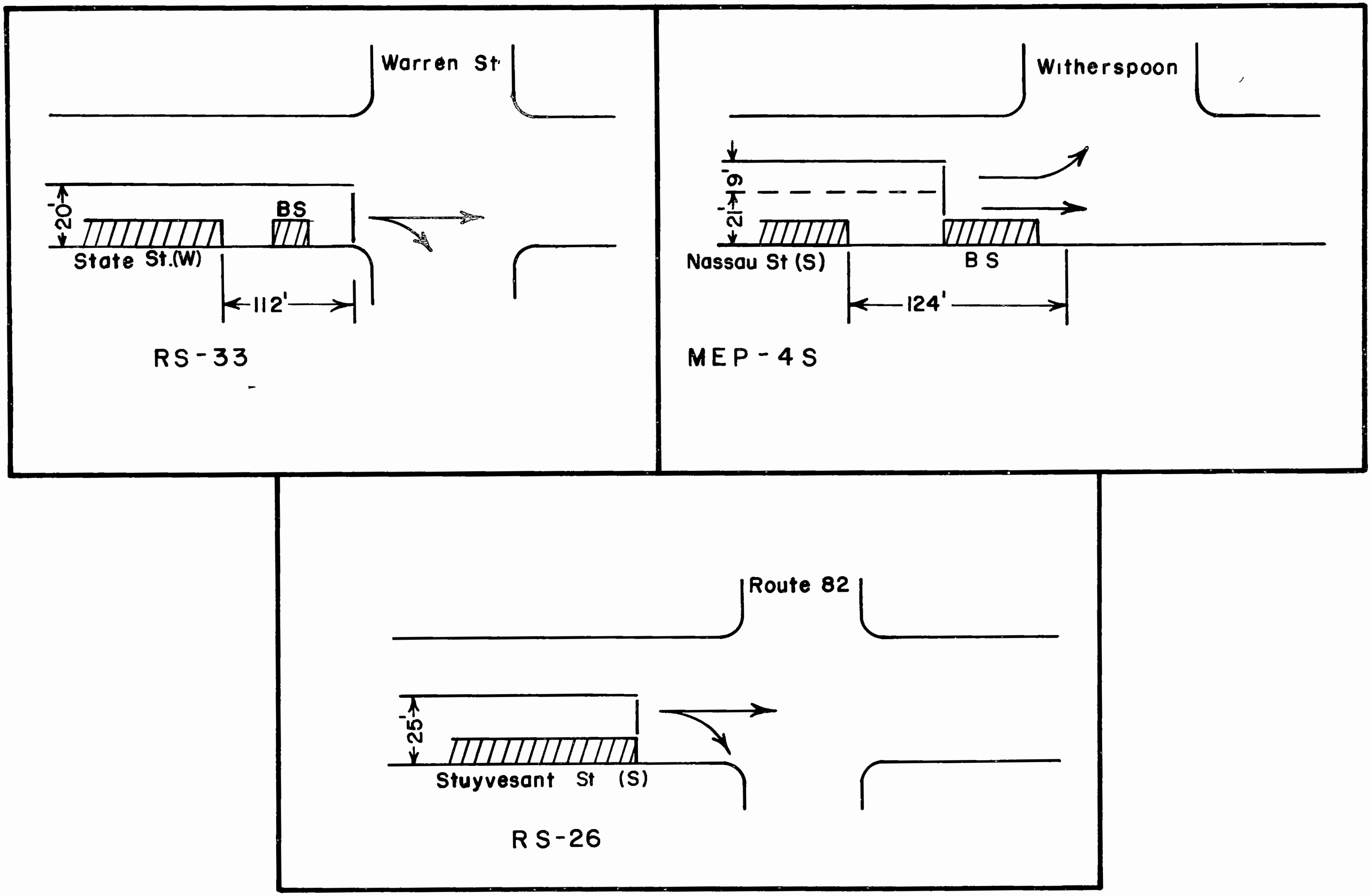

FIGURE 10 — 2 WAY PARKING

A-212-9