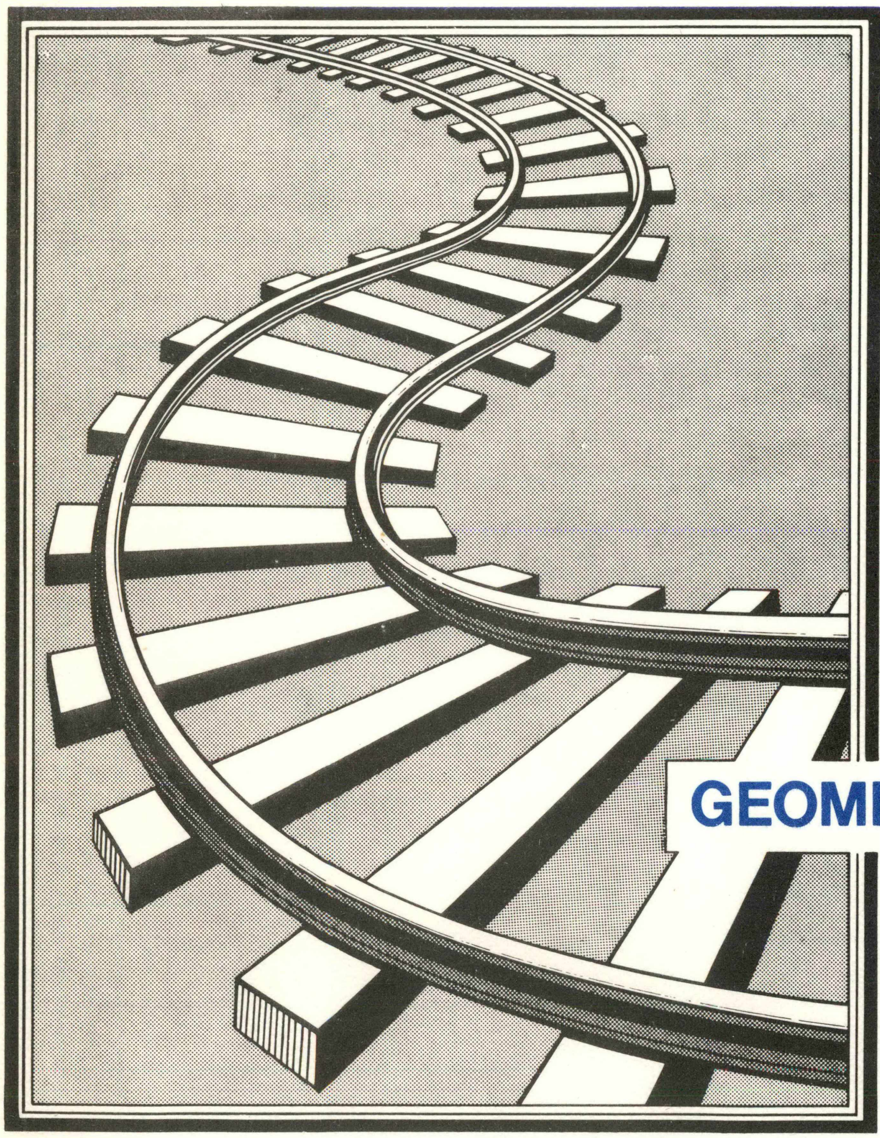
TRACK TRAIN DYNAMICS

TRACK STRUCTURES

VOLUME III

STUDY OF EFFECTS OF SPIRAL LENGTH ON LATERAL STABILITY IN SIMPLE CURVE NEGOTIATION



GEOMETRIC STUDY

AAR RPI·TDA

AN INTERNATIONAL GOVERNMENT - INDUSTRY RESEARCH PROGRAM ON TRACK - TRAIN DYNAMICS

·355

1. REPORT NO. R-355	**2. REPORT DATE** Jan.1979	**3. PERIOD COVERED**

4. TITLE AND SUBTITLE

Study of Effects of Spiral Length on Simple Curve Negotiation.

5. AUTHOR(S)

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6. PERFORMING ORGANIZATION NAME AND ADDRESS Association of American Railroads Track-Train Dynamics Phase II 3140 So, Federal Street Chicago, Illinois 60616	**7. TYPE OF REPORT** Technical **8. CONTRACT OR GRANT NO.** DOT-FR-64228
9. SPONSORING AGENCY NAME AND ADDRESS Federal Railroad Administration Department of Transportation 2100 Second Street S. W., Washington, D. C. 20590	**10. NO. OF PAGES** 61 **11. NO. OF REFERENCES** 4

12. SUPPLEMENTARY NOTES

TTD Task I - SUBTASK 1.1.1

13. ABSTRACT

Simple curve entries with/or without spiral for different curves are analyzed using the Quasi-Static Lateral Train Stability Model. The effect of spirals on maximum L/V ratios and coupler lateral angles in simple curve entries is investigated. The effect of buff force on lateral train stability in curve entries with spirals is studied for 2 to 16 degree simple curves. The United States Government assumes no liability for the contents of this report or the use thereof.

14. SUBJECT TERMS	**15. AVAILABILITY STATEMENT**
Simple Curve, Coupler Lateral Angle, L/V ratio, Spiral Length, Superelevation, Buff Force.	Director, Technical Center Association of American Railroads 3140 S. Federal Street Chicago, Illinois 60616

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BACKGROUND INFORMATION

ON THE

TRACK-TRAIN DYNAMICS PROGRAM

The Track-Train Dynamics Program encompasses studies of the dynamic interaction of a train consist with track as affected by operating practices, terrain, and climatic conditions.

Trains cannot move without these dynamic interactions. Such interactions, however, frequently manifest themselves in ways climaxing in undesirable and costly results. While often differing and sometimes necessarily so, previous efforts to reasonably control these dynamic interactions have been reflected in the operating practices of each railroad and in the design and maintenance specifications for track and equipment.

Although the matter of track-train dynamics is by no means a new phenomenon, the increase in train lengths, car sizes, and loadings has emphasized the need to reduce wherever possible excessive dynamic train action. This, in turn, requires a greater effort to achieve more control over the stability of the train as speeds have increased and railroad operations become more systematized.

The Track-Train Dynamics Program is representative of many new programs in which the railroad industry is pooling its resources for joint study and action.

A major planning effort on track-train dynamics was initiated in July 1971 by the Southern Pacific Transportation Company under contract to the AAR and carried out with AAR staff support. Completed in early 1972, this plan clearly indicated that no individual railroad had both the resources and the incentive to undertake the entire program. Therefore, AAR was authorized by its Board to proceed with the Track-Train Dynamics Program.

In the same general period, the FRA signaled its interest in vehicle dynamics by development of plans for a major test facility. The design of a track loop for train dynamic testing and the support of related research programs were also pursued by FRA.

In organizing the effort, it was recognized that a substantial body of information and competence on this program resided in the railroad supply industry and that significant technical and financial resources were available in government.

Through the Railroad Progress Institute, the supply industry coordinated its support for this program and has made available men, equipment, data from earlier proprietary studies, and monetary contributions.

Through the FRA, contractor personnel and direct financial resources have been made available.

Through the Transport Canada Research and Development Centre (TDC), the Canadian Government has made a major commitment to work on this problem and to coordinate that work with the United States' effort.

Through the Office de Recherces et D'Essais, the research arm of the Union Internationale des Chemins de Fer, the basis for a full exchange of information with European groups active in this field has been arranged.

The Track-Train Dynamics Program is managed by the Research and Test Department of the Association of American Railroads under the direction of an industry-government steering committee. Railroad members are designated by elected members of the AAR's Operation-Transportation General Committee, supply industry members by the Federal Railroad Administration, and Canadian Government members by the Transport Development Centre. Appropriate task forces and advisory groups are established by the Steering Committee on an ad hoc basis as necessary to pursue and resolve elements of the program.

The staff of the program comprises AAR employees, personnel contributed on a full- or part-time basis by railroads or members of the supply industry, and personnel under contract to the Federal Railroad Administration or the Transportation Development Agency.

The program plan as presented in 1972 comprises:

1) Phase I -- 1972-1974

   Analysis of an interim action regarding the present dynamic aspects of track, equipment, and operations to reduce excessive train action.

2) Phase II -- 1974-1977

   Development of improved track and equipment specifications and operating practices to increase dynamic stability.

3) Phase III -- 1977-1982

   Application of more advanced scientific principles to railroad track, equipment, and operations to improve dynamic stability.

Phase I officially ended in December of 1974. The major technical elements of Phase I included:

a) The establishment of the dynamic characteristics of track and equipment.

b) The development and validation of mathematical models to permit the rapid analysis of the effects on dynamic stability of modifications in design, maintenance, and use of equipment and track structures.

c) The development of interim guidelines for train handling, makeup, track structures, and engineer training to reduce excessive train action.

Reports on all elements of Phase I activities have been completed and are available through the AAR. A list of the Track Train Dynamics publications is available upon request.

The major technical elements of Phase II include:

a) The adaptation of Phase I analytical models to allow for conducting parameter investigations in the area of track, trucks, draft gear and cushion units, and vehicle behavior.

b) The development of fatigue analysis guidelines.

c) The development of a comprehensive program for identifying the loads to which track, vehicles, and vehicle components are subjected.

As research on this program proceeds, reports on other elements of Phase II will be issued, and existing reports updated at appropriate intervals.

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EXECUTIVE SUMMARY

The QLTS (Quasi-Static Lateral Train Stability) model has been used to analyze the effect of spiral lengths on simple curve negotiation. Curve entries without spiral for curves of 8 to 10 degrees were studied to evaluate the ride quality of cars. The coupler lateral angle, L/V ratios for wheel climb and rail roll-over were used as performance parameters for curves of 2 to 16 degrees. Two criterions have been proposed to compute necessary length of spiral for a given curve:

(a) spiral length based on coupler angle

(b) spiral length based on rail roll-over with L/V ratio of 0.64 or below.

A scheme is proposed to estimate the drawbar force once a spiral length has been chosen.

A comparison of spiral lengths obtained from QLTS study is made with AREA and FRA specifications (Table 4.8). The study shows that an uniform approach can be used to compute spiral lengths for the given curves once the critical train consist is defined and amount of drawbar forces is estimated. The upper and lower bounds on spiral length can be determined using the criteria (a) and (b) discussed in the chapters 4 and 5 and a compromised length can be used for track layout.

ACKNOWLEDGEMENT

The present study is part of the Research Project of the Track-Train Dynamics Program, which represents a joint effort of the Association of American Railroads, The Railway Progress Institute, The Federal Railroad Administration, and the Transport Canada Research and Development Centre. The Federal Railroad Administration is acknowledged for partly funding this study. The Association of American Railroads furnished the required manpower and computer facilities for the study.

The report is the third of the four volumes in fulfillment of the FRA Research contract on Task I - Track Structure Research. In particular, this study is classified under Subtask 1.1.1 which requires the utilization of a mathematical model to evaluate track geometries compatible with the operation of typical rail vehicle combinations under various operating conditions.

The authors wish to acknowledge the efforts contributed by Dr. D. R. Sutliff, TTD Phase II Director, and Mr. C. L. Gatton, a former TTD Task Manager, for their guidance in conducting this study. Dr. V. K. Garg and Messrs K. W. Bradley, J. R. Lundgren, K. L. Hawthorne and R.A. Abbott are acknowledged for their efforts in discussing and reviewing the results of this study.

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1. INTRODUCTION

The spiral length required in simple curves has been a subject of interest to the railroad industry for many years. The interest may be motivated by the desire to provide smooth transition from tangent to curved track during curve negotiation, to increase operating speed through curves, to improve track layouts and train handling procedures, and to ensure the safe operation of trains.

Many standards and formulae are used to calculate the required spiral length for a given curve. The application of these standards and formulae depends very much on individual railroads. Many times these standards and formulae have been modified to suit an individual railroad's need.

In this study, the effect of spiral length on the lateral train stability in simple curve entry is investigated. The Quasi-Static Lateral Train Stability model is used to simulate curve entries. Five consists, classified in terms of the gross length of the following vehicles, are chosen in the study.

(A) Long Car - Long Car

(B) Long Car - Medium Long Car

(C) Long Car - Medium Short Car

(D) Long Car - Short Car

The curve entries studied are:

(A) Simple Curve Entry without Spiral and Superelevation

(B) Simple Curve Entry with Spirals and Superelevation.

Each curve entry is simulated with the five consists in buff and at speeds equivalent to 3 inch under-balance operating conditions. Spiral lengths are varied in (B) to study the effects on maximum coupler lateral angles and L/V ratios for wheel climb and rail rollover conditions.

2. SELECTION OF CRITICAL CAR CONSISTS

Computer simulations were made from cars listed in [1] to determine the types of car combinations which are potentially more unstable in simple curve entries. Cars from the following groups were coupled to each other to establish the critical combinations:

(A) Long Cars (about 90 ft.)

(B) Medium Long Cars (about 70 ft.)

(C) Medium Short Cars (about 45 ft.), and

(D) Short Cars (under 40 ft.)

A total of six cars from the above groups were chosen based on relative stabilities and factors such as weight, center of gravity height, truck center distance, maximum coupler lateral angles and population of the cars:

(1) 95-ft. Auto Parts

(2) 89-ft. Pig/Container

(3) 70-ft. Gondola

(4) 68-ft.Insulated Box

(5) 44-ft. Box

(6) 32-ft. Gondola

CRITICAL CONSIST

With the six cars selected, each of the cars from (2) to (6) was coupled to the 95 ft. car. Two configurations were compared to select the critical consist arrangement to be used in the study. One arrangement was to have an alternating configuration of long car (95 ft) coupled to a shorter car. Another arrangement was to have the front half of the consist made up of the long cars (95 ft.) coupled to the rear half made up of the short cars only, Figure 2.1(a). It was found that the latter consist arrangement produced higher coupler angles and higher L/V ratios in all the cases studied. This arrangement, which represents the more critical situation in simple curve negotiations, was chosen for the study.

A total of five consists were used in the simulations to evaluate the effects of lengths on simple curves; they were the following:

(I) Long Cars Coupled to Long Cars

95'-95'-95'-89'-89'-89'-D

(II) Long Cars Coupled to Medium Long Cars

95'-95'-95'-70'-70'-70'-D

(III) Long Cars coupled to Medium Long Cars

95'-95'-95'-68'-68'-68'-D

(IV) Long Cars Coupled to Medium Short Cars

95'-95'-95'-44'-44'-44'-D

Note : Numbers in bracket designate the references at end of report.

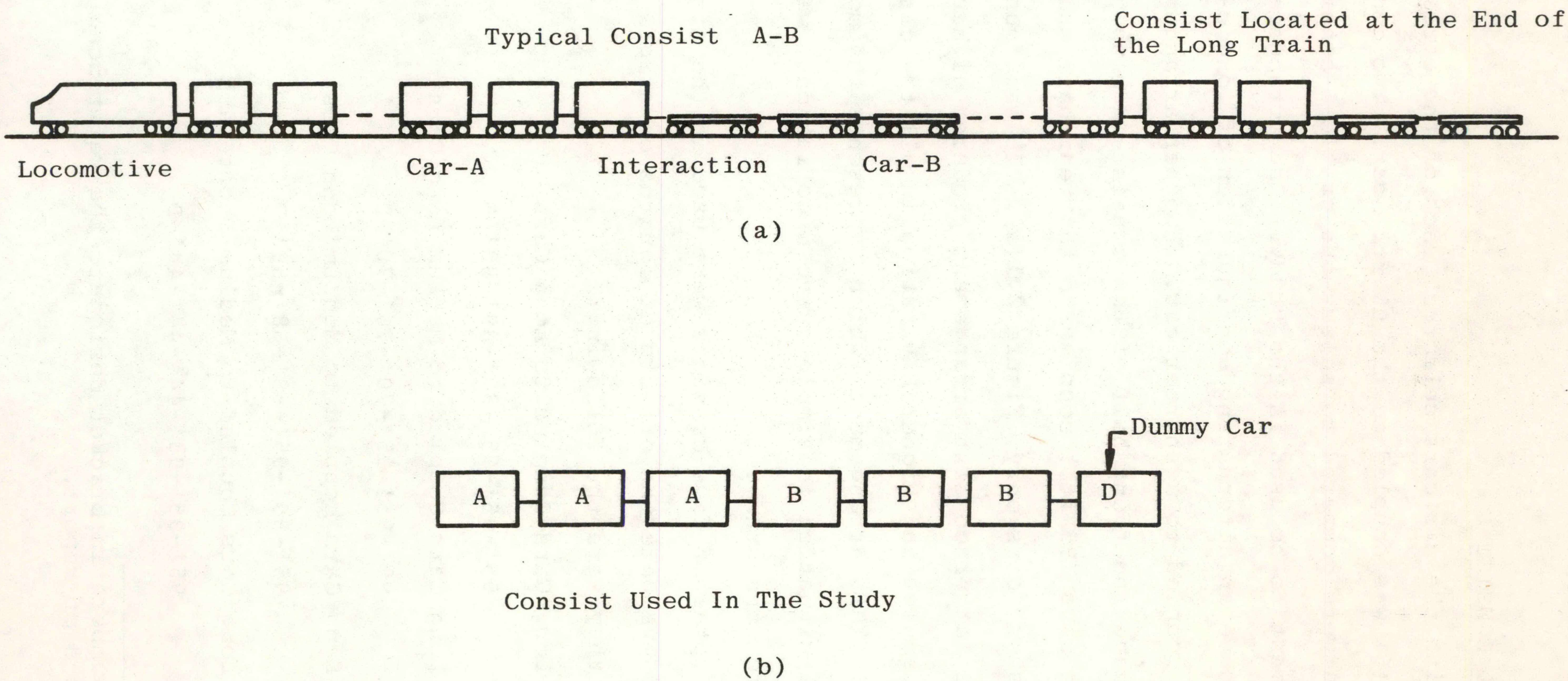


Fig. 2-1 Typical Car-Consist In Long Train Operation

(V) Long Cars Coupled to Short Cars

95'-95'-95'-32'-32'-32'-D

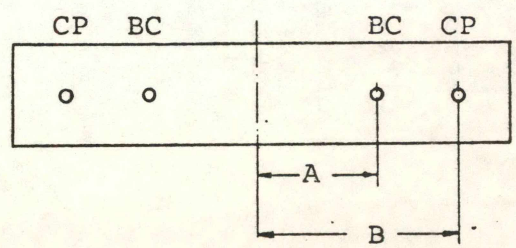
In the simulation of curve negotiations, a seventh car (D) was added to the rear of each consist as a dummy car so that all variables can be calculated for the sixth car. It was found that as far as quasi-static lateral stability of the train-consist during curve negotiation is concerned, the critical location usually occurs at the interface between groups of cars of different types. A consist of six or seven cars made up of the two different types of vehicles is sufficient for simulation to locate the critical coupler lateral angles and L/V ratios. It is unnecessary to include every car in a long train as shown in Figure 2.1(a) in the simulation for the purpose of this study.

The geometric and weight data for each car can be found in Table 2.1. Table 2.2 has been reproduced from [2] showing the maximum coupler lateral angles attainable for the arrangements of couplers, coupler yokes and strikers.

TABLE 2.1 CAR DATA USED IN THE QLTS STUDY

(1) CAR SPECIFICATION NAME	(2) BOLSTER CENTER DISTANCE (INCHES)	(3) DISTANCE BETWEEN BOLSTER CENTER & COUPLER PIN (INCHES)	(4) LENGTH OF COUPLER (INCHES) (COUPLER TYPE)	(5) MAXIMUM ATTAINABLE COUPLER ANGLE (DEG.)	(6) CAR LIGHT WEIGHT (TON)	(7) OVERHANG (A/B) RATIO	(8) ESTIMATE C.G. HEIGHT
AUTO PARTS LA9 95'	792.0	114.0	60.0 (8) or (9)	15° +	65.0	0.776	70.0
PIGGYBACK/ CONTAINER LFC2 89'	780.0	101.0	43.0 (4) or (7)	13°	34.0	0.794	34.5
GONDOLA EG-6 70'	660.0	61.0	29.0 (6)	13°	30.0	0.884	50.0
INSULATED BOX LRB-6 68'	492.0	119.0	43.0 (4) or (7)	13°	43.0	0.674	50.0
BOX CAR EBH1 44'	348.0	57.0	33.0 (3)	8°	22.0	0.753	46.0
GONDOLA LG-3 32'	228.0	49.0	29.0 (1)	7°	23.0	0.699	40.0

+ Refer to Table 3 coupler Type No.



BC = Bolster center

CP = Coupler Pin

TABLE 2.2

HORIZONTAL CURVE DATA FOR STANDARD COUPLER APPLICATIONS

No.	Coupler Arrangement	Maximum Coupler Lateral Angle θ	Maximum Coupler Lateral Displacement at Coupling Line C	Effective Coupler Length L[1]	Length of Shank[2]
(1)	E60C-Design, Y40 A Yoke Design, AAR PL 532-C Striker	7°	3.47″	28.46″	21.5″
(2)	B-E61B-HT, B-Y30, AAR PL 530 Striker	9°	4.53″	28.94″	16.9375″
(3)	E67B, Y41 A Yoke Design, AAR PL 542 Striker	8°	4.63″	33.28″	25.00″
(4)	E68 B-Design Series Y45, Yoke Design 13° Design	13°	9.67″	43.00″	31.00″
(5)	F70C-Design, Y45 Yoke Design, S1C Striker AAR PL-538	10°	5.08″	29.25″	17.25″
(6)	F70C-Design, Y45, Yoke Design, S16B Striker AAR PL-538	13°	6.58″	29.25″	17.25″
(7)	F79C-Design Series, Y45, Yoke Design 13° Striker	13°	9.67″	43.00″	31.00″
(8)	E69AHTE Design Series, Y45, Yoke 15° Striker	15°	15.53″	60.00″	48.00″
(9)	F73A AHTE, Y45, Yoke Design 15° Striker	15°	15.53″	60.00″	48.00″

Notes:

1) Length from Coupling Line to intersection of Coupler Center Line with Car Center Line, for both vertical and horizontal angling.
2) Length from Coupler Horn to butt or pivot point of Coupler.
3) Lateral tabular values shown are maximum coupler displacements. Lateral values may be reduced providing cars can negotiate the required curves specified in Section 2.1.4.2.

3. THE QLTS MODEL AND ITS ASSUMPTIONS

The Quasi-Static Lateral Train Stability (QLTS) Model simulates a train operating on track made up of tangents, spirals and curves in a buff, draft or drifting mode. The model calculates the quasi-static L/V ratios for wheel-climb and rail rollover and the coupler lateral angles for equilibrium positions of each car. A detailed discussion of the model can be found in [3] and the usage of the model is given in [4].

3.1 ASSUMPTIONS

The QLTS Model is based on a number of assumptions. The following assumptions pertain to the present study:

(1) Couplers between vehicles are assumed to be a straight rigid link. The model does not include the coupler contouring effects in calculation of coupler lateral angles. For cars equipped with couplers that allow coupler knuckle contouring, the lateral coupler angle developed in operation is expected to be different from those calculated by the model.

(2) There is no coupler stop in the model to simulate the effect of coupler contacting the striker. In such a condition calculation of L/V ratios becomes much more complex and care must be taken when analyzing the L/V ratios, to check that no coupler lateral angles in the consist have exceeded the maximum attainable coupler angle limit. Table 2.2 gives the maximum attainable limits for various coupler arrangements. When

coupler angles exceed the maximum attainable, L/V ratios are not plotted in this report.

(3) All forces, displacements and coupler angles are calculated in a quasi-static manner. The equilibrium conditions are satisfied in a static sense. Inertial forces or accelerations of the car body or truck are not included in the calculations. When dynamic effects are included, forces and L/V ratios may change. With this in mind, it will be more appropriate to evaluate the trend of nominal L/V ratio variation with spiral lengths instead of considering the absolute magnitudes of the L/V ratios.

(4) A bolster lateral force of less than 2000 lb. is not included in equilibrium calculations, so that the truck can float between rails without constant flange contact.

(5) Any deviation of the cars is referenced from the track centerline.

(6) The last vehicle in the consist acts as a "DUMMY" and is not required to be in equilibrium, as it is far away from interface of cars under consideration.

(7) No grade or profile variations are considered in the model.

In this study, the relative performance of each consist in simple curves with varying spiral lengths has been evaluated; the assumptions are still valid.

3.2 MODEL INPUT PARAMETERS AND OUTPUT VARIABLES

3.2.1 Input Parameters:

(A) Distance between bolster centers

(B) Distance between bolster center and coupler pin

(C) Coupler lengths

(D) Maximum allowable lateral displacement of bolster centers measured from track centerline

(E) Initial bolster lateral displacements

3.2.2 Car Characteristics:

(A) Type of car

(B) Weight of car

(C) Type of coupler alignment control

(D) Net lateral load at leading outer wheel

(E) Buff or draft force on cars

(F) Train speed

3.2.3 Track Geometry Data:

(A) Degree, Length and Superelevation of curve

(B) Length of spiral

(C) Length of tangent

3.3 CALCULATION VARIABLES

3.3.1 Car Track Interaction:

(A) L/V ratio for wheel climb

(B) L/V ratio for rail rollover

3.3.2 Car Displacements and Forces:

(A) Coupler Lateral Angle

(B) Bolster Lateral Displacement and Reaction

(C) Centrifugal and Superelevation forces

(D) Alignment Moments

3.4 OPTIONAL OUTPUT

In addition to the above variables, the following variables may also be calculated by use of the modified version of the QLTS program.

- Resultant force acting on the front and rear half carbody.
- Angle subtended by the resultant force with respect to vertical axis perpendicular to gauge center.
- Distance from center of gauge acting by the resultant force.

Based on given operating conditions and track geometry, the speeds at which the resultant force is acting through points of distances for one-half gauge and one-sixth gauge, can be evaluated by varying the train speed (Figure 3.1). The speed that corresponds to one-half gauge criterion may be interpreted as the overturning speed, and that of the one-sixth gauge criterion as the comfort limiting speed.

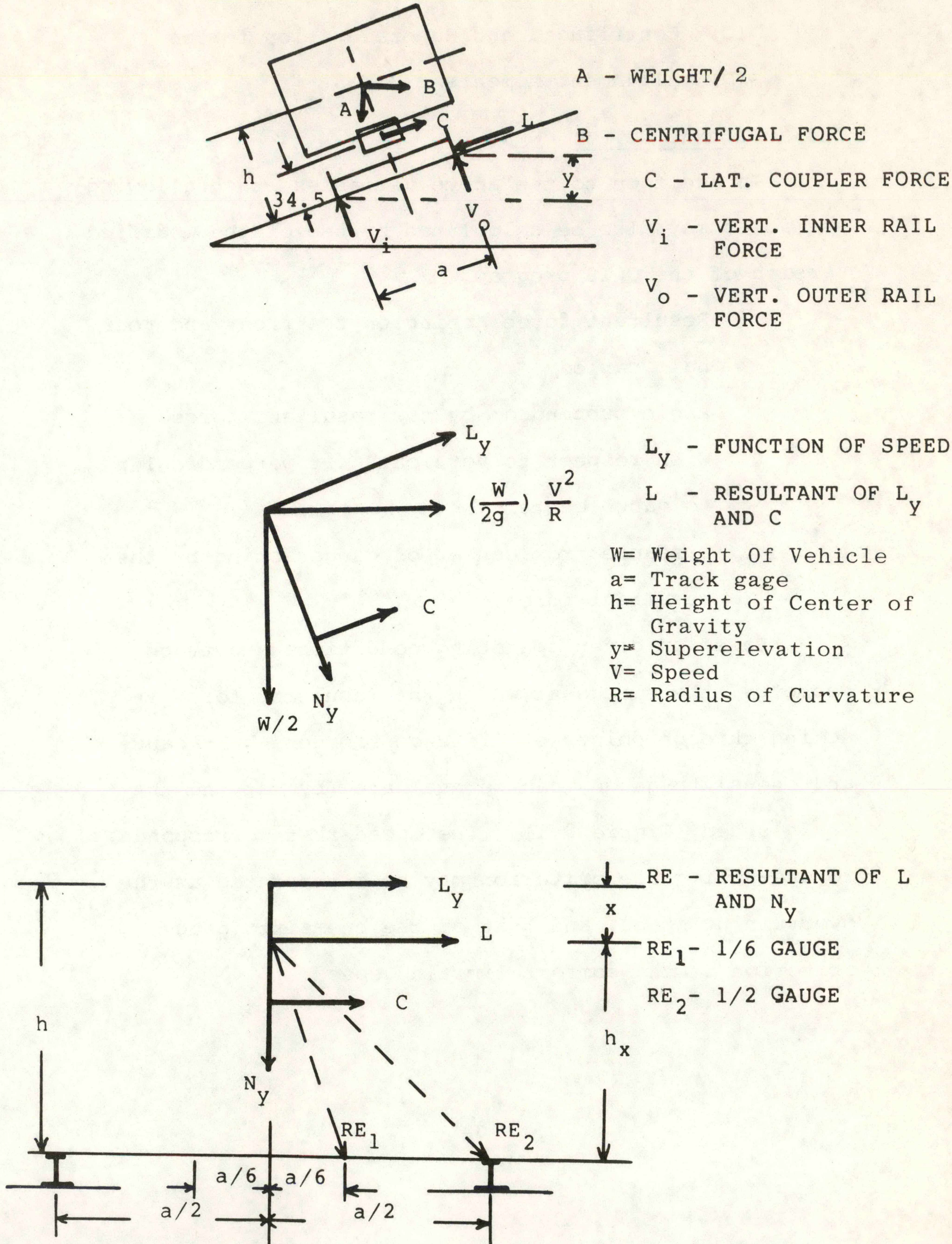


FIGURE 3.1 ONE-SIXTH AND ONE-HALF GAUGE CRITERIA ANALYSIS

4. RESULTS

4.1 SIMPLE CURVE ENTRY WITHOUT SPIRAL AND SUPERELEVATION

In this study five simple curve entries without spirals and super-elevation are analyzed. The curves are 8,10,12,14 and 16 degrees. The five consists discussed in section 3 are used for analyzing the quasi-static lateral train stability in curve entry. Constant buff force of 40 kips is applied to the consist in curve negotiations.

4.1.1 Coupler Lateral Angles In Simple Curve Entry Without Spirals

The maximum coupler lateral angles for the most critical cars of the consists, in simple curve entry without spiral and super-elevation, are plotted in figure 4.1. Under constant buff force, the maximum coupler lateral angles increase with higher curvatures. Each of five consists studied encountered situations in which couplers contact the strikers in one or more curve entries without spiral. Table 4.1 lists the highest degrees of simple curve entry, without spiral and super-elevation, which each consist can negotiate without exceeding the maximum coupler swing limits.

Of the five consists studied with respect to maximum coupler lateral angles, only the 95'-68' consist could marginally negotiate the 16-degree simple curve entry from a tangent into the curve at 40 kip buff. The 95'-89' consist arrangement can negotiate up to 13-degrees only. For the long and short car arrangement

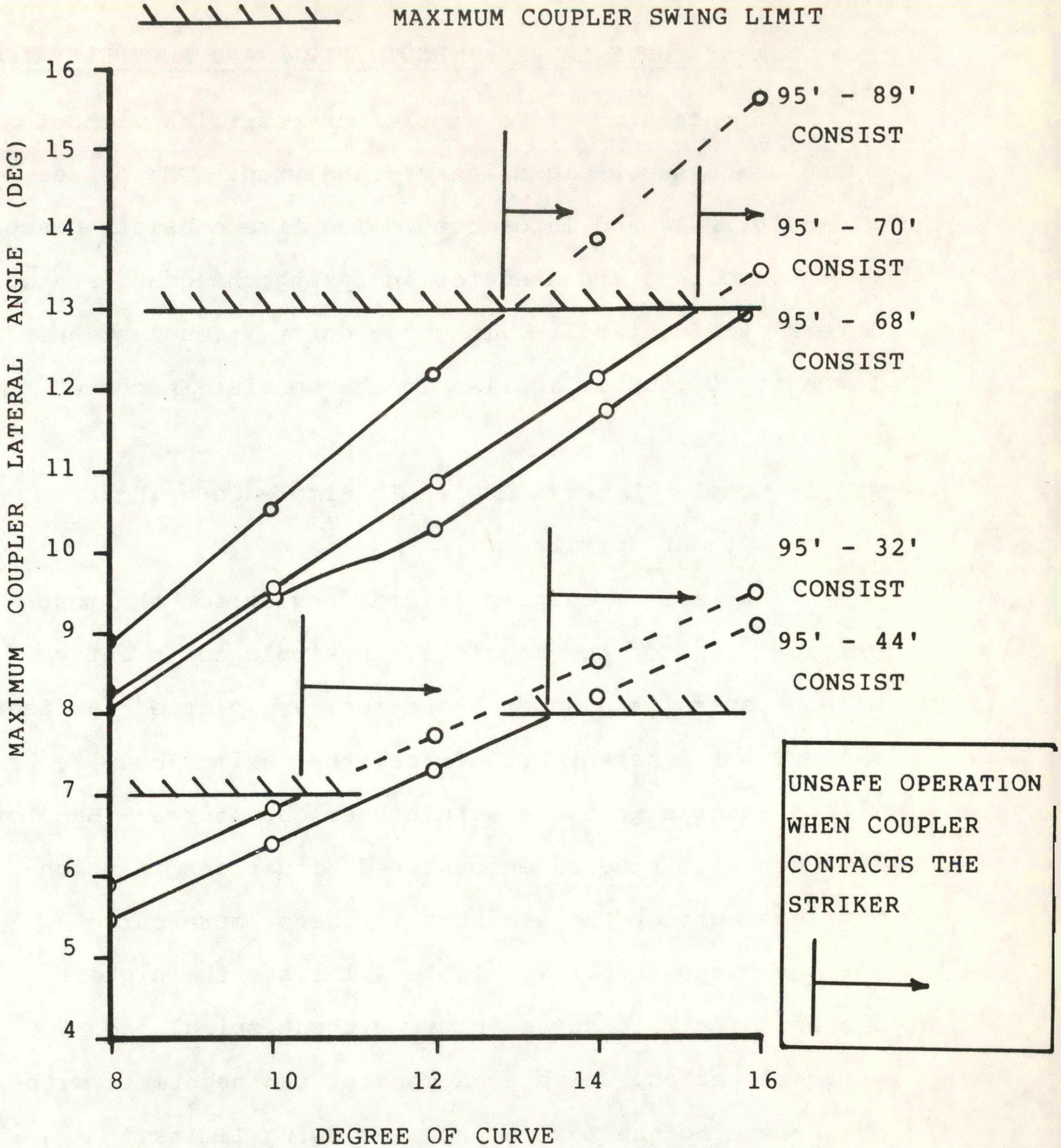


FIGURE 4.1 MAXIMUM COUPLER LATERAL ANGLES DEVELOPED ON THE SHORTER CAR OF THE CONSIST IN SIMPLE CURVE ENTRY WITHOUT SPIRAL AND SUPERELEVATION

TABLE 4.1 HIGHEST DEGREE OF CURVE (NEGOTIABLE WITHOUT SPIRAL AND SUPERELEVATION) FOR COUPLER ANGLE TO BE WITHIN SWING LIMIT

CONSIST	COUPLER SWING LIMIT	HIGHEST DEGREE OF CURVE NEGOTIABLE
95'-89'	13^o	13^o
95'-70'	13^o	15^o
95'-68'	13^o	16^o
95'-44'	8^o	13^o
45'-32'	7^o	10^o

of 95'-32', it may be advisable to operate up to 10 degrees only at a 40 kip buff condition.

4.1.2 Comfort Limiting Speed and Overturning Speeds In Simple Curves

In this study the QLTS program has been modified to establish the comfort limiting speeds based on the 1/6 gauge criterion and the overturning speed based on the 1/2 gauge criterion. An iterative process has been adopted in the modification to evaluate the speeds at which the carbody resultant force passes through distances equal to 1/6 gauge and 1/2 gauge on either side from the track centerline. It has been assumed in this study that the ride quality becomes quite poor when the operating conditions cause the carbody resultant force to act through distances of 1/6 gauge or more. As the train speed continues to increase, the resultant force progressively shifts towards the outer rail to the point of overturning.

The conditions used for evaluation of comfort limiting speeds and overturning speeds are at 40 kip buff drawbar force and at 3 inch underbalance operation. The same five consists are used to establish these speeds.

Figure 4.2 shows the comfort limiting speed based on 1/6 gauge criterion for simple curves of 8 to 16 degrees. It is observed that the comfort limiting speed decreases with increasing curvatures; it may also be noted that the comfort limiting speed for the 95' car is independent of the types of cars to which it is coupled.

The comfort limiting speed for a train consist is determined by those cars in the consist which do not satisfy the 1/6 gauge criterion. When coupled to the 95' long car and simulated under the conditions described earlier, the highest degree of curve in which 89' and 70' cars can pass the 1/6 gauge criterion is 12 degrees. These two cars can have poor ride quality when operating under similar conditions in curves equal to or higher than 12 degrees.

The maximum allowable operating speeds suggested by the FRA are also plotted in Figure 4.2. For the 8-degree curve, the maximum operating speed according to the FRA is lower than the comfort limiting speeds evaluated on all the cars in this study. On the other hand, FRA's maximum operating speed for the 16-degree curve is higher than those evaluated based on the 1/6 gauge criterion. However, the comfort limiting speed for the 95' car on a 16 degree curve agrees well with the FRA suggested maximum operating speed. The comfort limiting speeds in proximity of zero (89' car and 70' car) indicate that even in static condition the presence of buff forces would result in failure of 1/6 gage criterion. The mismatch between QLTS and FRA values can be attributed to the fact that 1/6 gauge criterion and FRA values do not have an established correlation.

Table 4.2 shows the comparison between FRA recommended maximum operating speeds and the comfort limiting speed based on 1/6 gauge criterion.

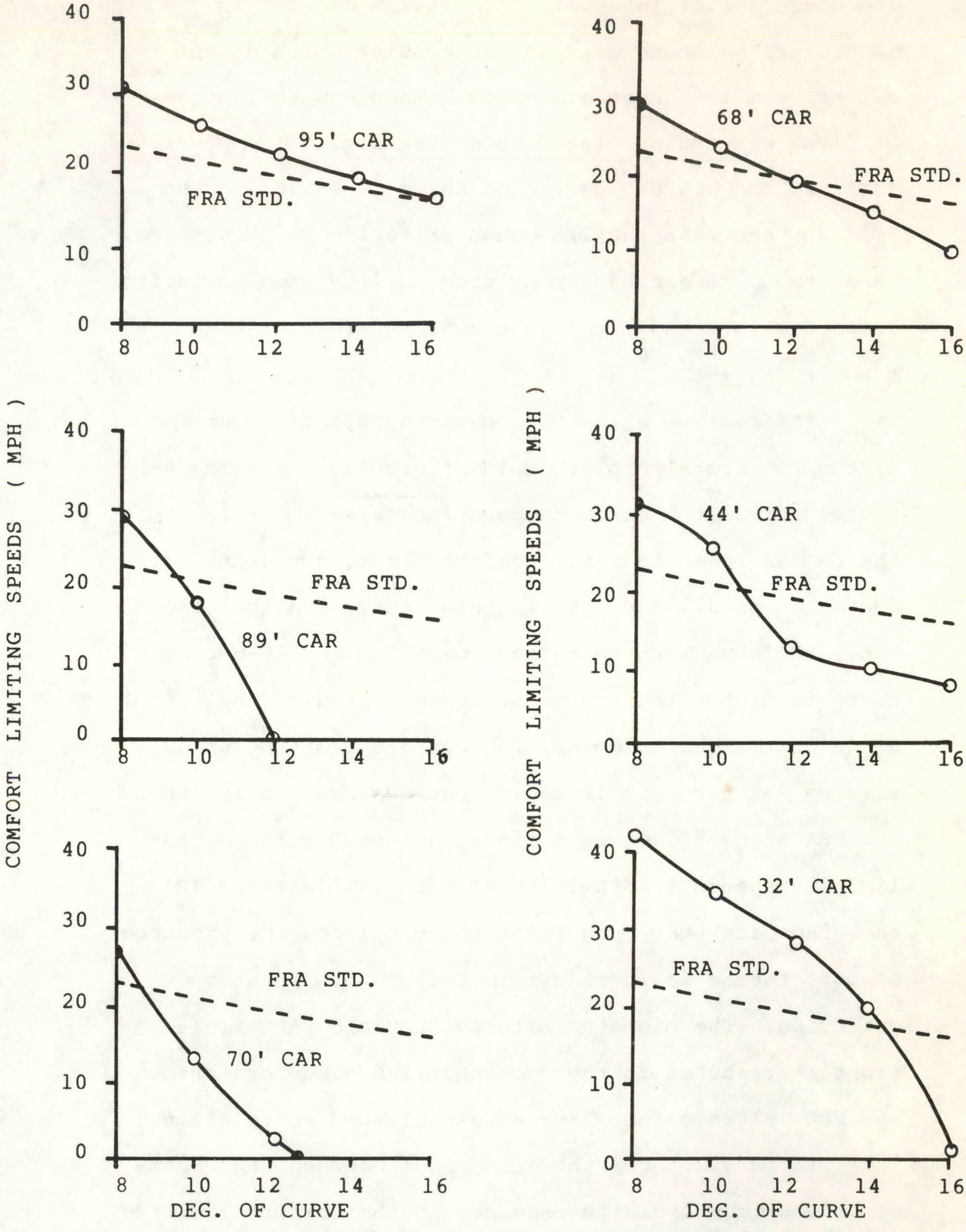


FIGURE 4.2 COMPARISON OF COMFORT LIMITING SPEEDS BASED ON 1/6 GAUGE CRITERION WITH MAXIMUM ALLOWABLE OPERATING SPEEDS BASED ON FRA TRACK SAFETY STANDARD IN CURVES

Degree of Curve	Comfort Limiting speed (MPH) Based on 1/6 gage Criterion						Maximum Operating Speed (MPH) based on FRA Standard
	95'Car	89'Car	70'Car	68'Car	44'Car	32'Car	
8	30	29	26	29	31	42	23
10	25	18	13	23	25	35	21
12	22	0	2	19	13	28	19
14	19	0	0	15	10	20	17
16	16	0	0	9	7	2	16

TABLE 4.2

COMPARISON OF MAXIMUM OPERATING SPEED BASED ON FRA STANDARD AND COMFORT LIMITING SPEED BASED ON 1/6 GAUGE CRITERION FOR SIMPLE CURVE ENTRIES

A similar analysis is performed to evaluate the overturning speeds based on 1/2 gauge criterion under the same operating conditions. Two formulae that generally have been used for calculations of overturning speeds are included here for comparison purposes. These formulae are:

(1) For 6-Foot C.G. Height - $185.1\sqrt{D}$

(2) For 7-Foot C.G. Height - $170.0\sqrt{D}$

When D is the degree of curve in radians.

Figure 4.3 shows the overturning speeds of the various cars used in this study as compared to the above two formulae. All overturning speeds decrease with higher degrees of curve. The overturning speed for the 95' car as based on 1/2 gauge criterion follows closely with the speeds calculated using formulae (2). Comparing with the overturning speeds based on the formulae, it is found that the 89' and 32' cars have higher overturning speeds based on 1/2 gauge criterion. The emperical formulae do not account for the car geometry effect which can be reason for the scatter between QLTS and emperical values for these cars. They are about 20 MPH higher in the 8-degree curve and 5 to 10 MPH higher in the 16-degree curve. The 70' and 68' cars have overturning speeds based on 1/2 gauge criterion about the same as those calculated by the above two formulae.

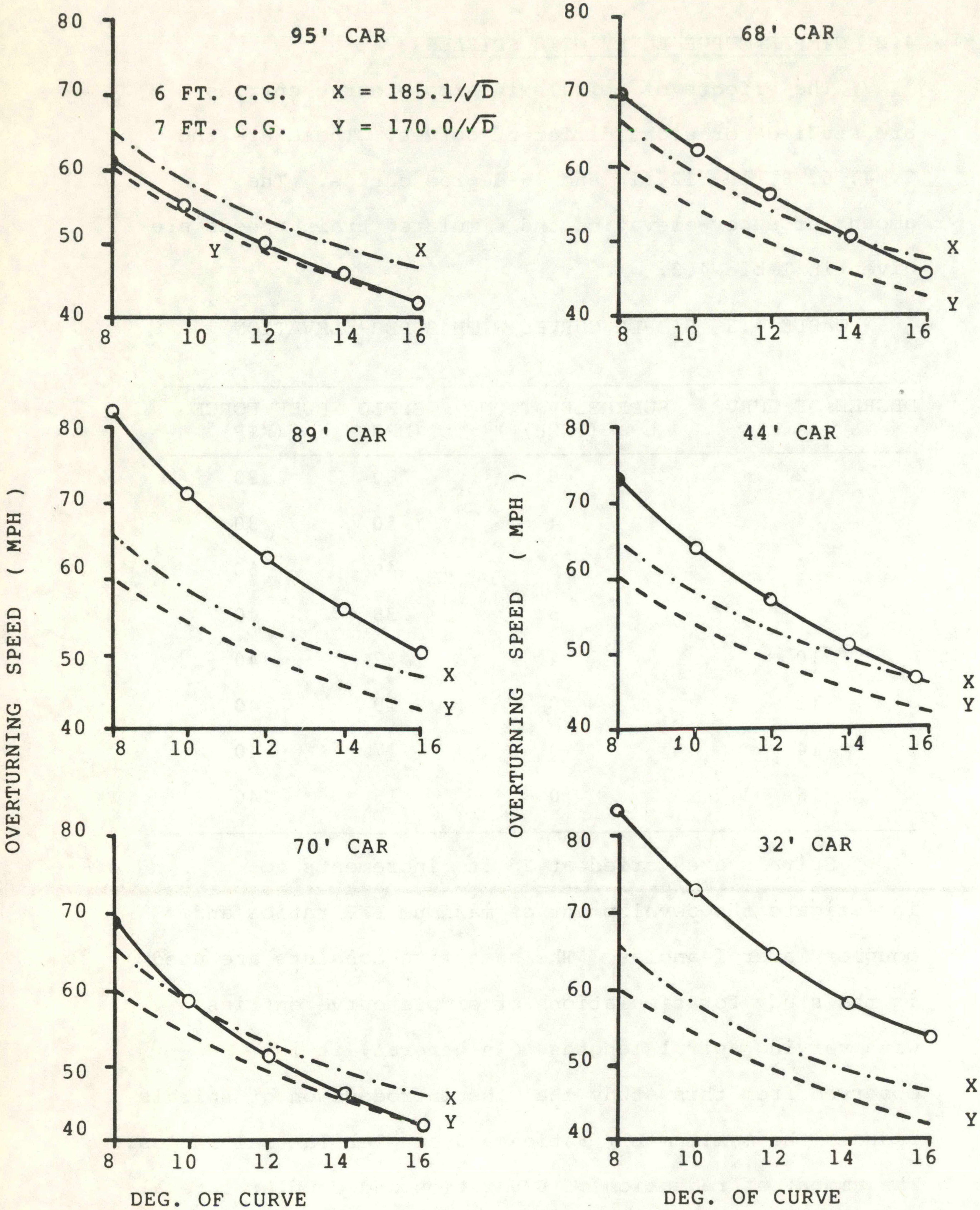


FIGURE 4.3 COMPARISON OF OVERTURNING SPEEDS BASED ON 1/2 GAUGE CRITERION WITH THOSE BASED ON FORMULAE

4.2 SIMPLE CURVE ENTRY WITH SPIRALS

The effects of spirals in simple curve entries are studied for eight different curves. These are the 2, 4, 6, 8, 10, 12, 14 and 16-degree curves. The amount of super-elevation and simulated train speeds are given in Table 4.3.

TABLE 4.3 SIMPLE CURVES WITH SUPER-ELEVATION

DEGREE OF CURVE	SUPERELEVATION (INCH)	SPEED (MPH)	BUFF FORCE (KIP)
2	6	80	80
4	4	50	80
6	6	46	60
8	5	38	40
10	4	32	40
12	0	19	40
14	0	17	40
16	0	16	40

Spirals are varied at 25 ft. increments to investigate the development of maximum L/V ratios and coupler lateral angles. The same five consists are used in the study for simulations of simple curve entries with varying spiral lengths. In general, it is observed from this study that the introduction of spirals reduces the maximum L/V ratios and coupler lateral angles. The amount of reduction of L/V ratios and coupler lateral angles is greater on higher degree curves.

4.2.1 Effects of Spirals on Maximum Coupler Lateral Angles

The results of the analysis of varying spiral length with the QLTS program indicate that for each simple curve entry, increase in spiral length reduced the maximum coupler lateral angle. Some of the consists failed to negotiate safely the simple curves 12 to 16 degrees without spirals. The provision of spirals results in smaller coupler lateral angles during the curve entry making curve negotiation possible.

For the 16-degree simple curve entry (without any spiral), all consists except the 95'-68' show coupler contact with the striker (Figure 4.4). Some consists require longer spiral lengths to maintain the coupler angles within the swing limits whereas others require shorter spirals. The dotted lines in the Figure 4.4 indicate maximum coupler swing limits on the shorter cars of the consists. Shorter cars equipped with couplers of smaller swing limits are more critical with respect to coupler lateral angles. In this case, a 150-foot spiral provided between the tangents and the curves brings the coupler lateral angles well within the coupler swing limits for consists 95'-89', 95'-70', 95'-44'. For the 95'-32' consist, the same spiral length reduces the coupler angle on the 32' car to the marginal 7 degree limit. It can be observed from this study that a consist of long cars coupled to short cars, may be marginally unsafe in entries of curves as high as 16 degrees even when spiral of 150 ft. is provided.

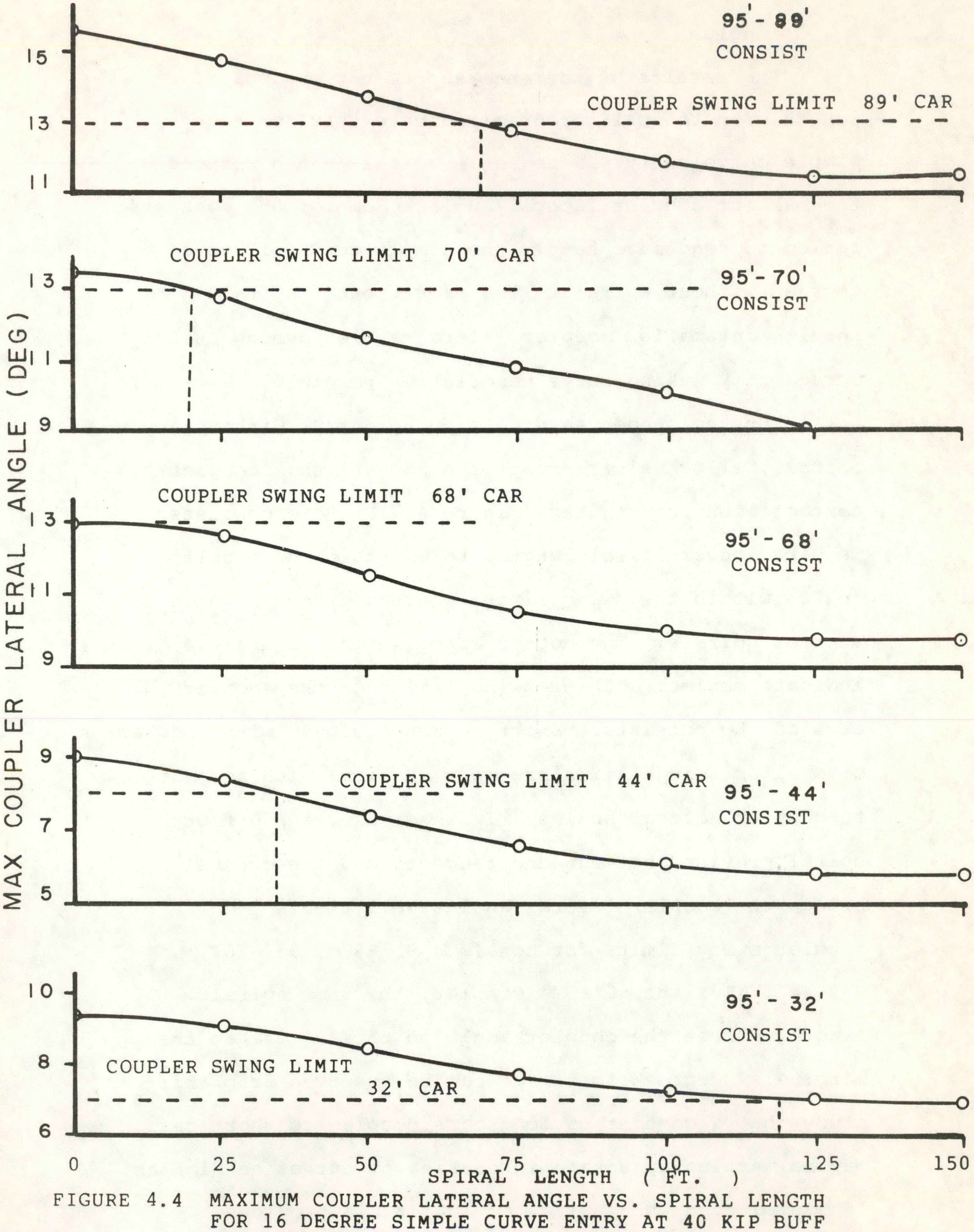


FIGURE 4.4 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 16 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

For the 14-degree simple curve, coupler angles are reduced as spiral length is increased, up to about 125 feet. Further addition of spiral lengths does not appear to reduce the coupler lateral angles (Figure 4.5). The 89' car when coupled to the 95' long car can have the coupler angles within swing limit of 13-degrees with a 33-ft. spiral. On the other hand, for a 14-degree simple curve entry, the 32' car, when coupled to the 95' car, would require about 80' of spiral to have the coupler lateral angle within swing limits.

Figure 4.6 shows a similar trend toward reduction in coupler lateral angles for the 12-degree simple curve entry when spiral lengths are increased. Among the five consists chosen for this study, the 95'-32' consist is the only one on which the coupler lateral angle exceeds the swing limit when there is no spiral. By introducing the 40 ft. spiral, the coupler angle can be maintained within its swing limit.

For the 10-degree simple curve entry (Figure 4.7) all consists can negotiate the curve without any spirals. The 100 ft. spiral appears to be reasonable from a coupler lateral angle consideration for all consists as longer spirals do not further reduce the coupler angles.

Figures 4.8 and 4.9 show the corresponding coupler angles for simple curve entries of 8 and 6 degrees. Reduction in coupler angles appears to level off beyond 100 to 125 feet of spirals. For simple curve of 4 degree (Figure 4.10) spiral lengths have been increased beyond 100 feet. However, the effects of spiral lengths, in

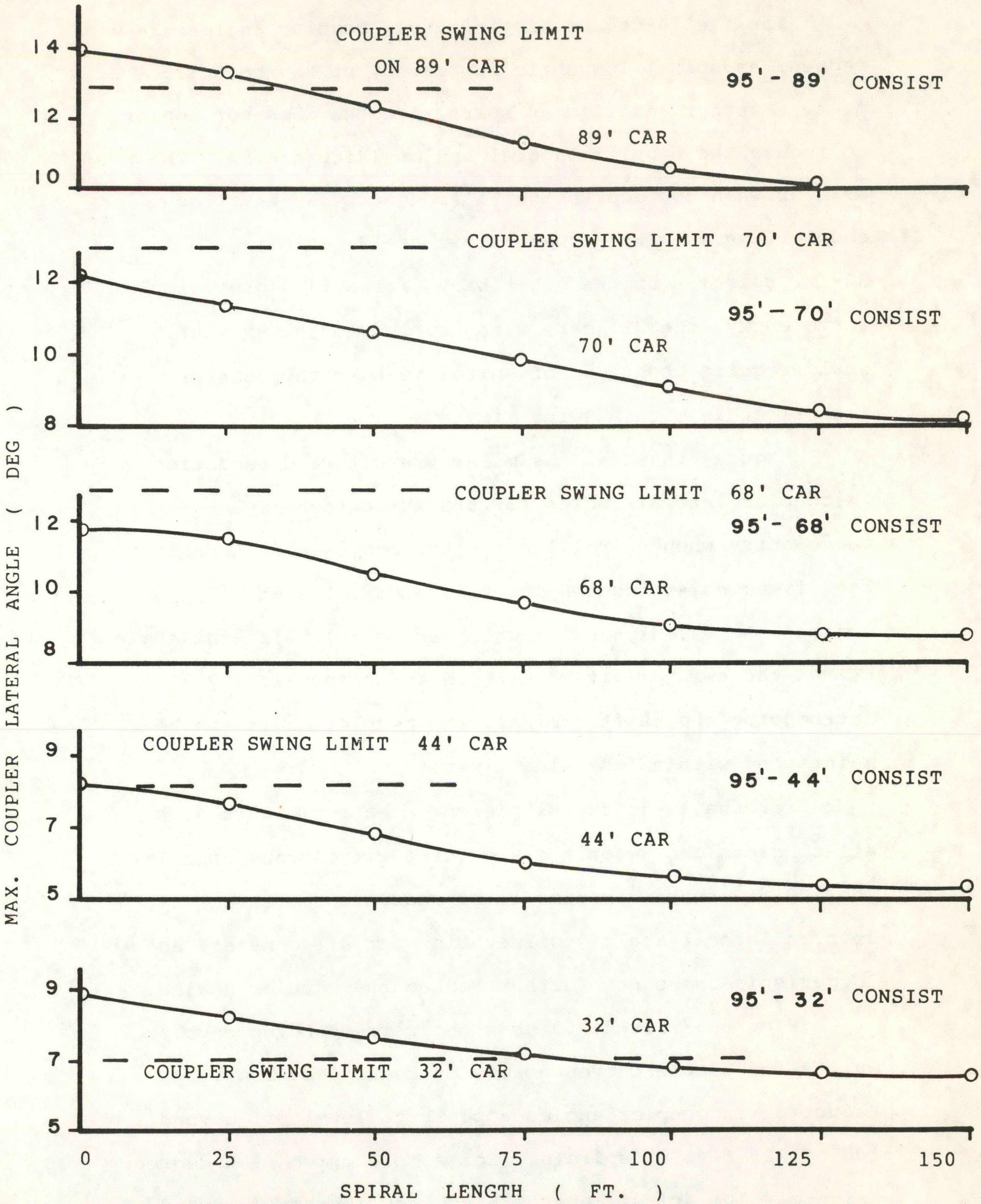


FIGURE 4.5 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 14 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

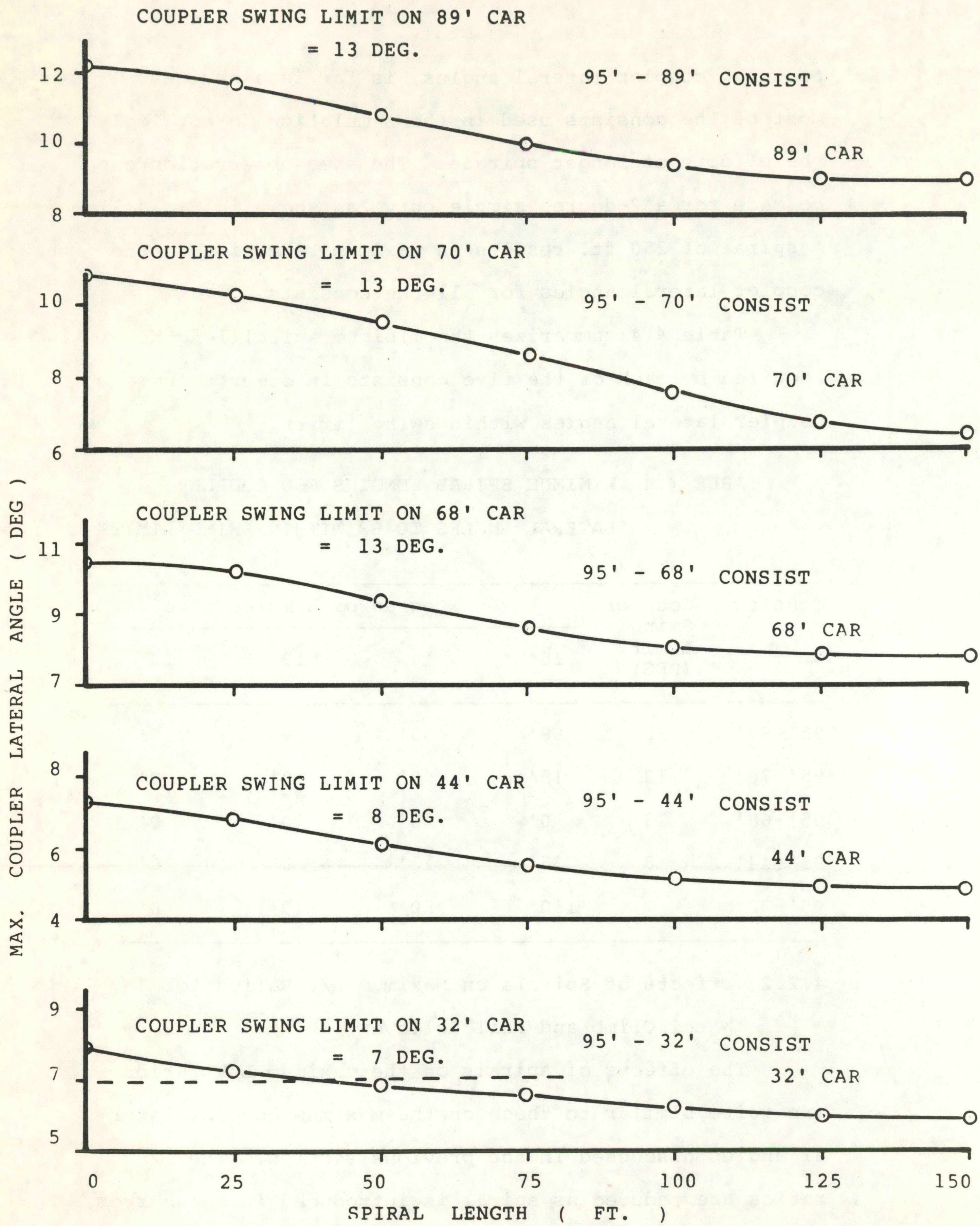


FIGURE 4.6 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 12-DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

reducing coupler lateral angles, is far less obvious. Most of the consists used in the simulation do not feel the effects of longer spirals. The same observation can be made for a 2-degree simple curve as shown in Fig.4.11. A spiral of 250 ft. results in maximum reduction in the coupler lateral angles for all the consists.

Table 4.4 summarizes the minimum spiral lengths required by each of the five consists in order to have coupler lateral angles within swing limits.

TABLE 4.4 MINIMUM SPIRAL LENGTHS FOR COUPLER LATERAL ANGLES TO BE WITHIN SWING LIMITS

Consist	Coupler Swing Limit (DEG)	Degree of Simple Curve			
		16	14	12	10 and under
95'-89'	13	68'	33'	0'	0'
95'-70'	13	15'	0'	0'	0'
95'-68'	13	0'	0'	0'	0'
95'-44'	8	35'	13'	0'	0'
95'-32'	7	150'	80'	40'	0'

4.2.2 Effects of Spirals on Maximum L/V Ratios for Wheel Climb and Rail Rollover

The effects of spirals on the maximum L/V ratios are quite similar to those on the maximum coupler lateral angles discussed in the previous section. The L/V ratios are reduced as spiral is introduced in the curves. Based on the degree of curve and the consists used in

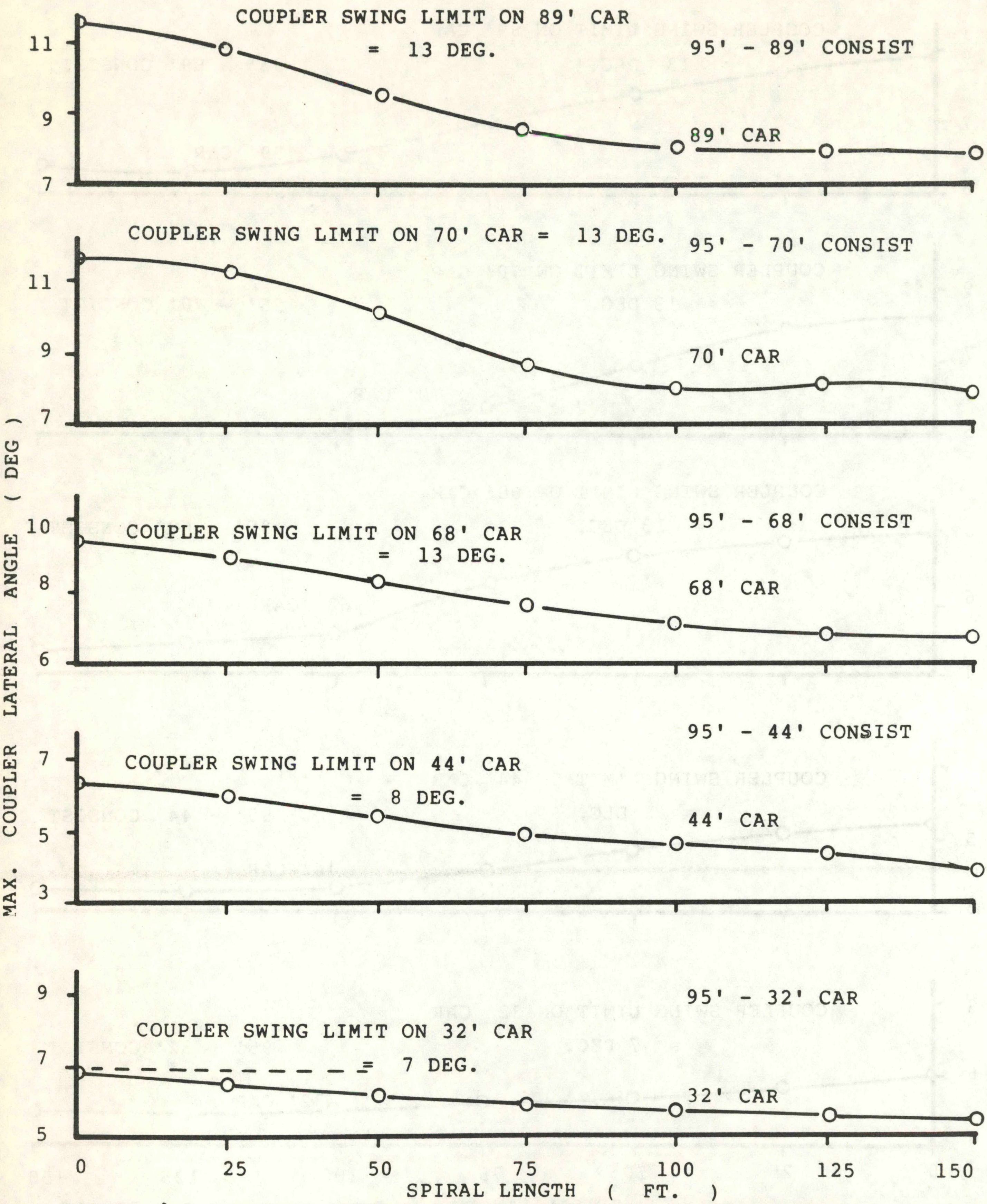


FIGURE 4.7 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 10 DEGREE SIMPLE CURVE ENTRY WITH 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

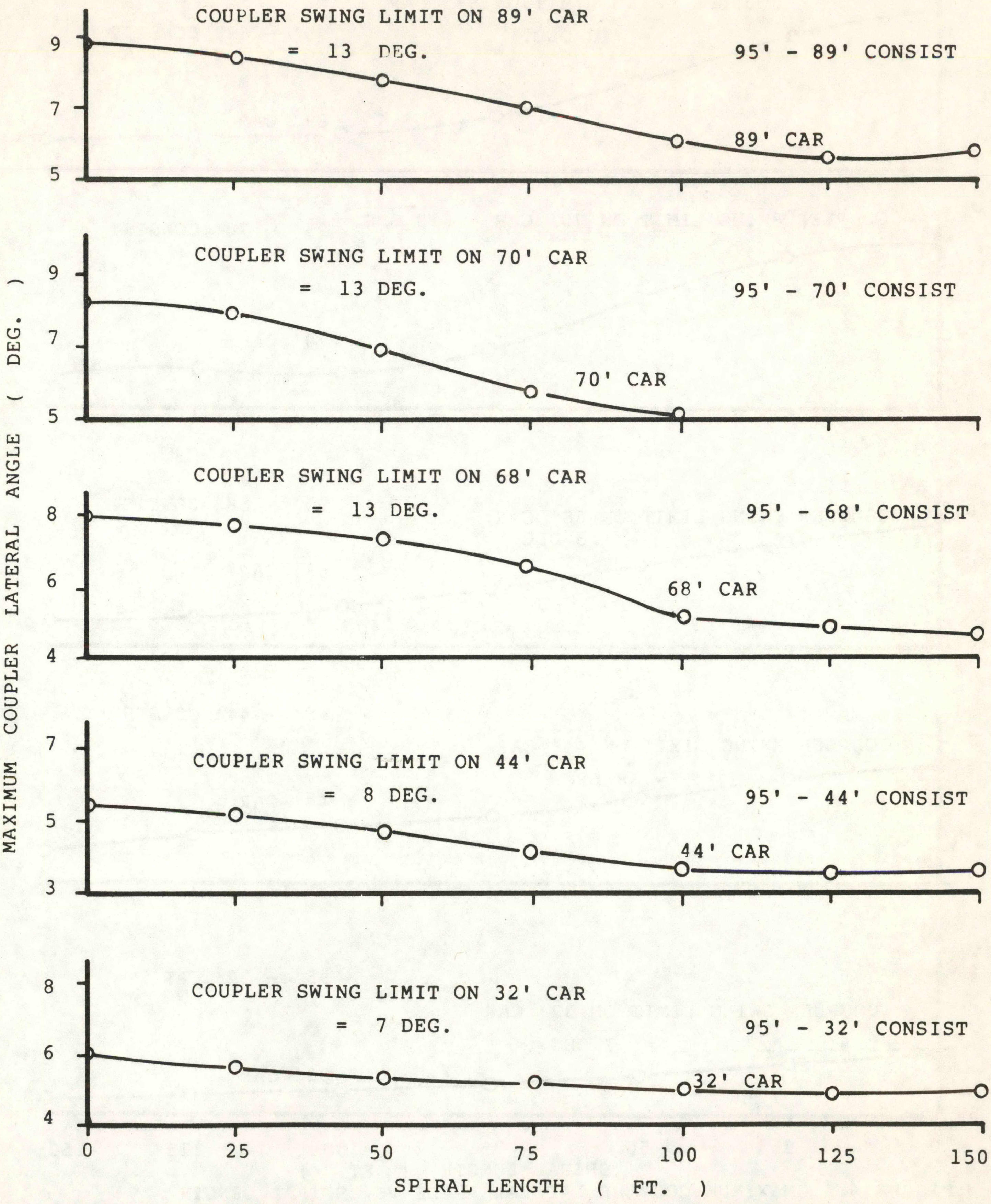


FIGURE 4.8 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 8 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

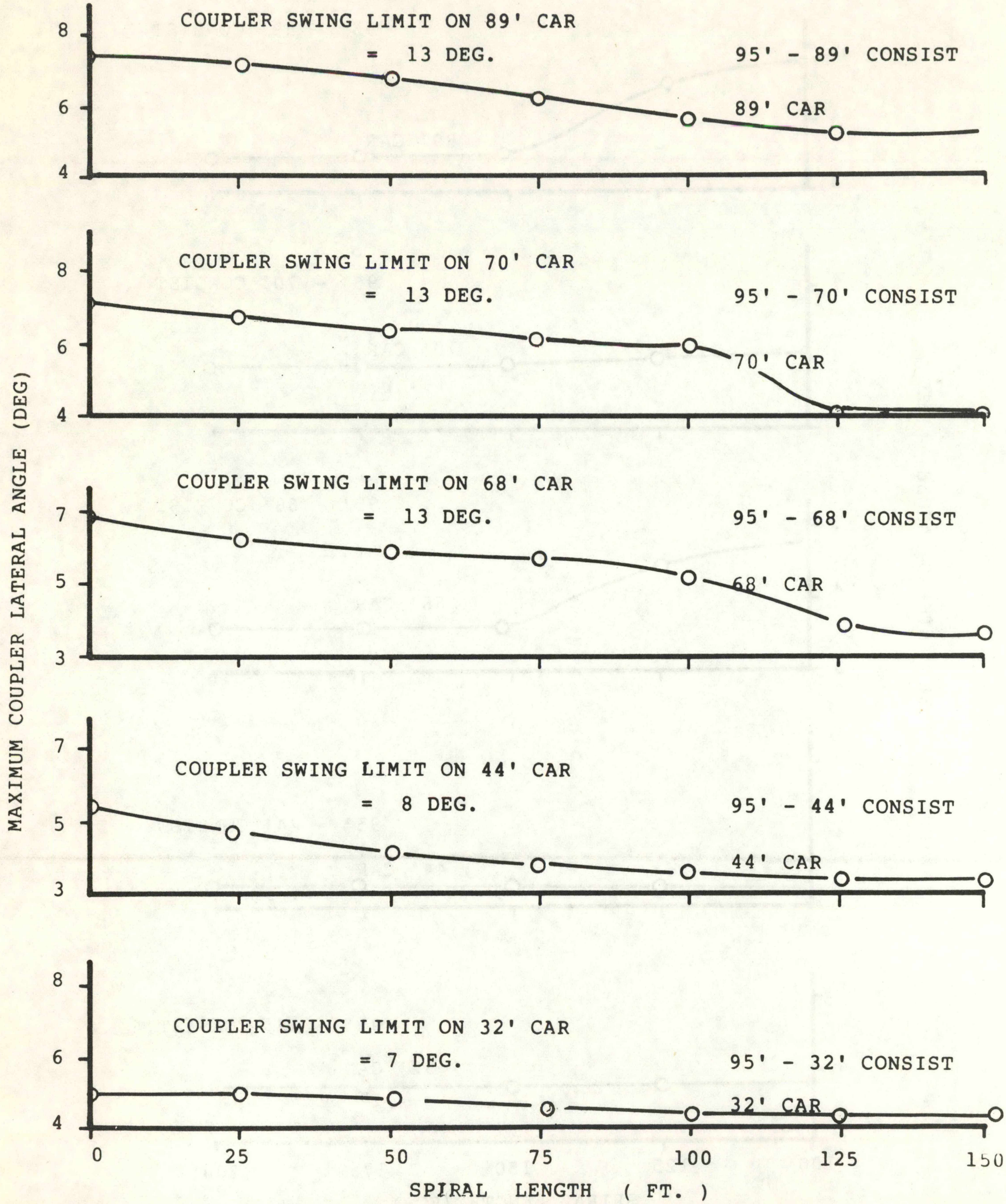


FIGURE 4.9 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 6 DEGREE SIMPLE CURVE ENTRY AT 60 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

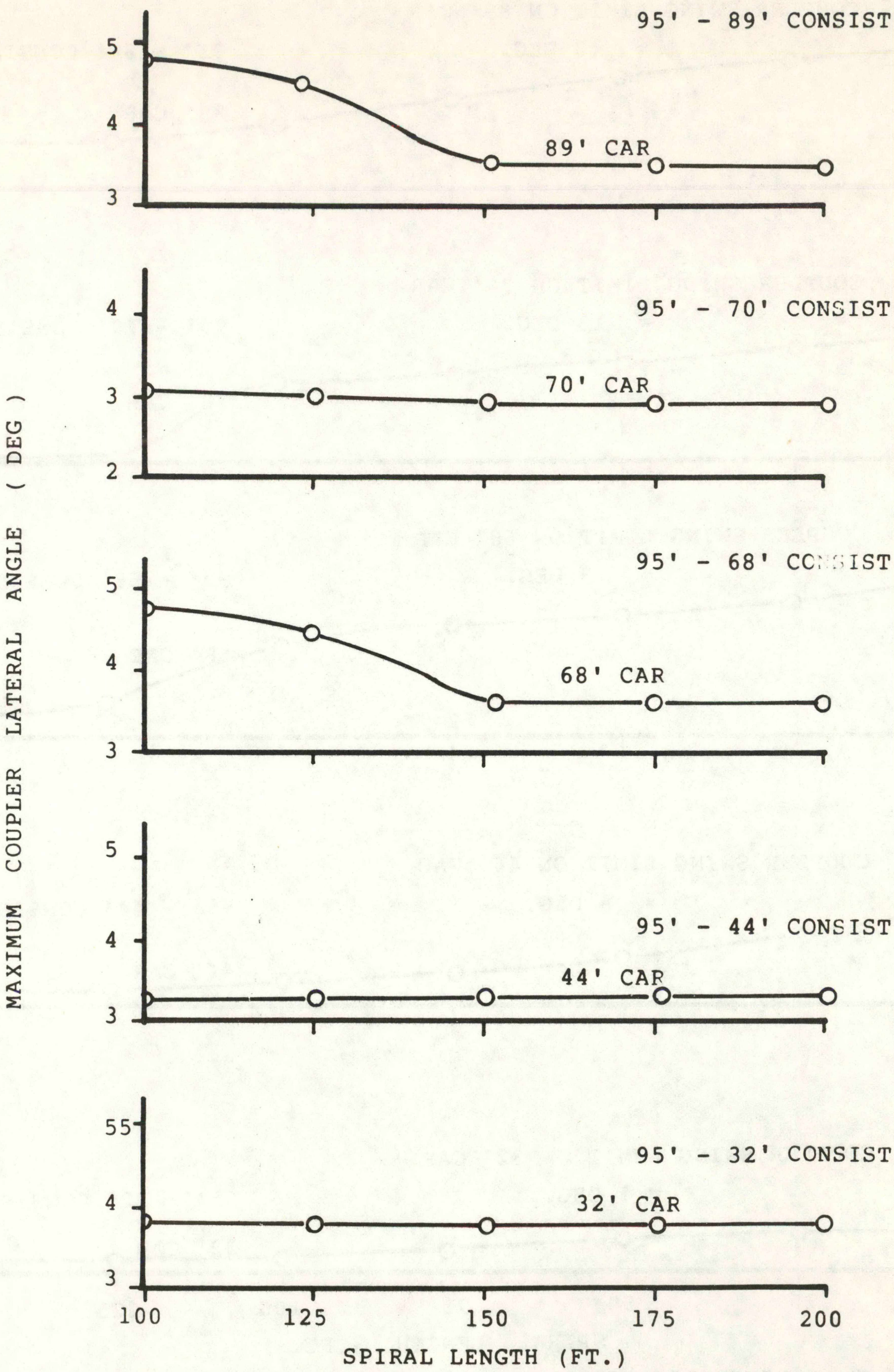


FIGURE 4.10 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 4 DEGREE SIMPLE CURVE ENTRY AT 80 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

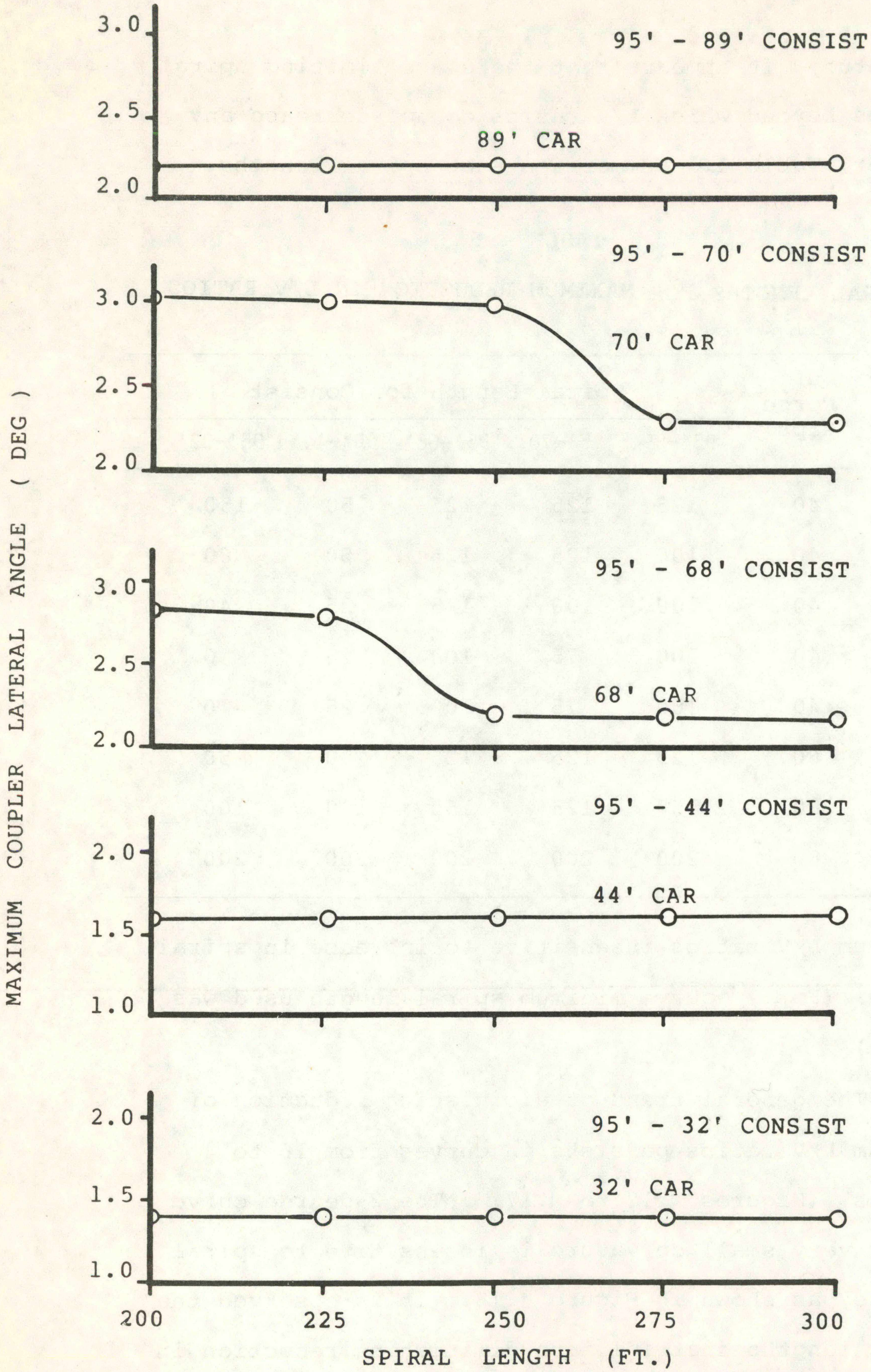


FIGURE 4.11 MAXIMUM COUPLER LATERAL ANGLE VS. SPIRAL LENGTH FOR 2 DEGREE SIMPLE CURVE ENTRY AT 80 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

this study, it appears that there are limiting spiral lengths beyond which L/V ratios do not decrease any further; Table 4.5 summarizes such spiral lengths.

TABLE 4.5

SPIRAL LENGTHS FOR MAXIMUM REDUCTION IN L/V RATIOS

Degree of Curve	Buff Force Kips	Spiral Length for Consist				
		95'-89'	95'-70'	95'-68'	95'-44'	95'-32'
16°	40	125	125	125	50	150
14°	40	100	125	125	50	80
12°	40	100	100	125	25	40
10°	40	100	75	100	25	0
8°	40	100	75	100	25	0
6°	60	125	125	125	50	50
4°	80	150	125	150	100	100
2°	80	200*	200	200	200	200

*Maximum L/V ratios insensitive to increase in spiral length. (For 2° curve minimum spiral length used was 200 ft)

The general trend of diminishing reduction of maximum L/V ratios persists in curves from 16 to 4 degrees, (Figures 4.12 to 4.17). The 2-degree curve having very small curvature is insensitive to spiral lengths, as shown in Figure 4.18. It is observed the spiral lengths that initiate diminishing reduction in L/V ratios vary with consists, degree of curve, and amount of buff. Given a consist under the action of a constant buff force, the required spiral length decreases with decreased curvature. At higher buff forces however, longer spiral lengths are required to reduce L/V ratios.

The spiral lengths that are long enough to result in safe negotiation for some consists may not be long enough for severy consist. For the 16 degree curve (Figure 4.12), it can be seen that about 70' of spiral length is acceptable for all the consists except the 95-32' combination. For the safe negotiation of a 16-degree simple curve by the 95'-32' consist, it requires a spiral of at least 150 feet or more. Based on the type of consist and the amount of buff used in this study, one may select a spiral length that is safer for a particular simple curve entry. Such selected spiral lengths may only assure the lateral train stability in curve entries under a steady state situation. The following table gives an example of such spiral lengths.

TABLE 4.6

POSSIBLE SPIRAL LENGTH FOR SIMPLE CURVE ENTRY AT THE SPECIFIED BUFF LEVEL

Degree of Curve	Buff Force (Kip)	Possible Spiral Length* (Ft.)
16	40	150
14	40	125
12	40	125
10	40	100
8	40	100
6	60	125
4	80	150
2	80	200

These spiral lengths have been chosen on the basis of the following two criteria:*

(1) The coupler lateral angle is within the swing limits

(2) The Rail Rollover L/V ratio is below 0.64

Any spiral length meeting these two requirements may be considered safe for operation, but further increase in spiral length up to a point where L/V ratios do not reduce any further, will result in improved safety.

4.2.3 Effect of Buff Force on Maximum Coupler Lateral Angles and L/V Ratios

For each of the simple curves two consists are chosen to illustrate the effect of increased buff forces on maximum L/V ratio and coupler lateral angles. The consists are of 95'-89' and 95'-68' arrangement.

For a given track configuration and consist, higher buff forces result in higher maximum L/V ratios. Higher buff forces also increase the coupler lateral angles up to a certain limit. Some of these limiting coupler angles may exceed the maximum attainable limit defined by the arrangement of coupler and striker types and under such condition curve negotiation may become unsafe.

Figure 4.19 shows the rise in maximum L/V ratios with increased buff for the two selected consists. It also shows the variation of maximum coupler lateral angles on a 16-degree simple curve entry with 150 feet of spiral. It may be noted that the maximum safe drawbar force for

*Note: These spiral lengths are for buff levels used in the study.

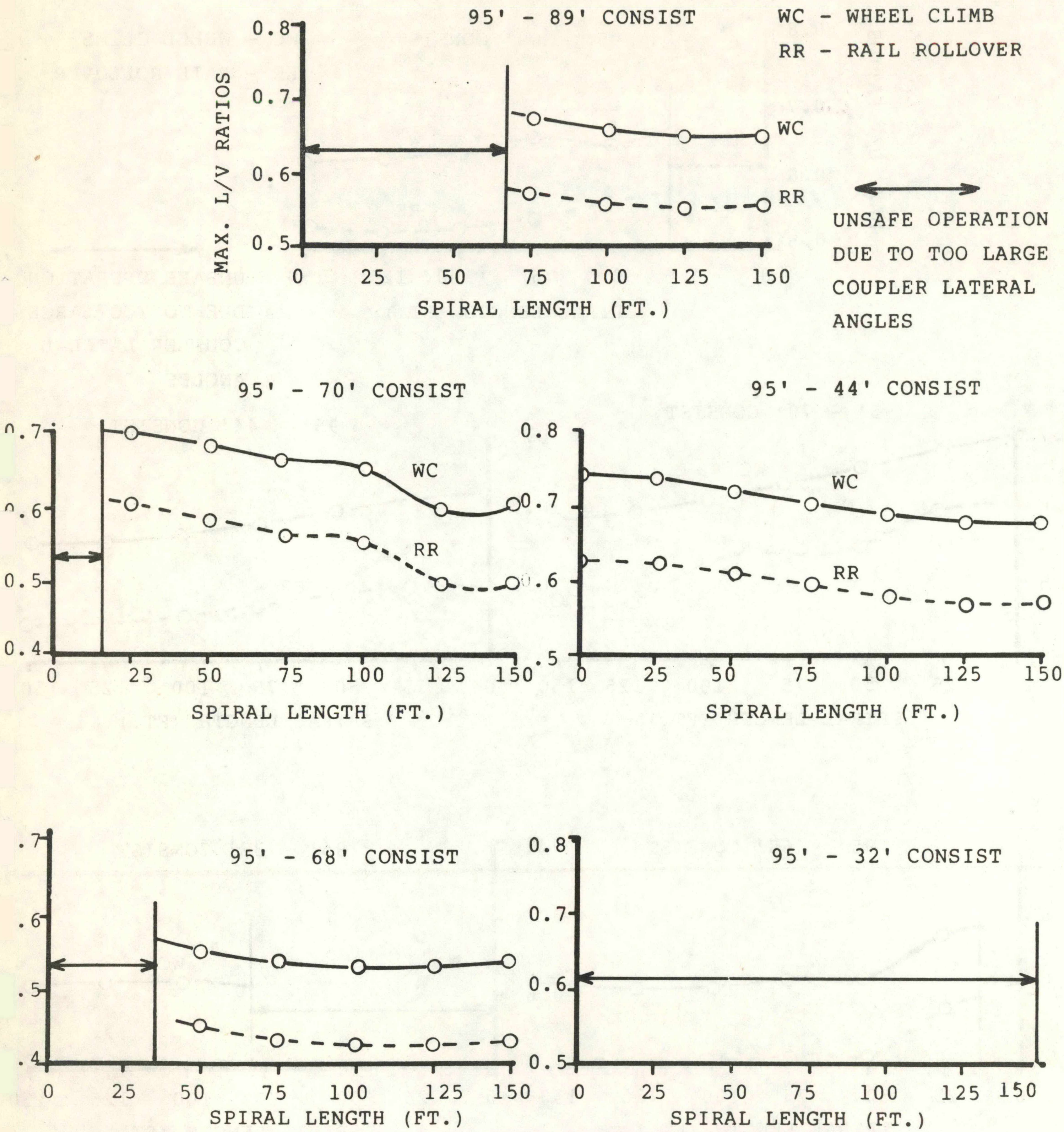


FIGURE 4.12 MAXIMUM L/V RATIOS ON THE SHORTER CARS IN THE CONSIST FOR 16 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

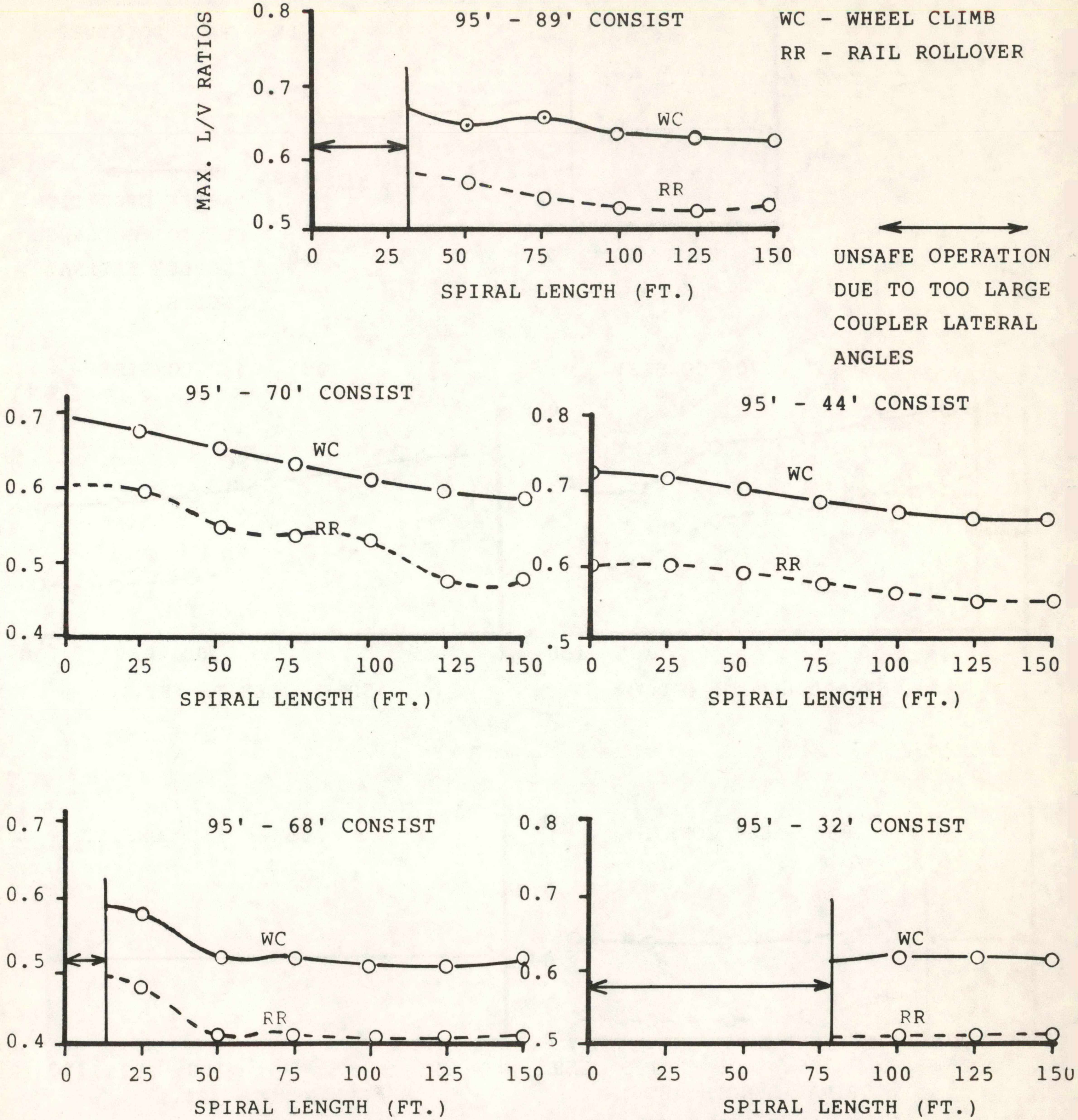


FIGURE 4.13 MAXIMUM L/V RATIOS FOR WHEEL CLIMB AND RAIL ROLLOVER ON THE SHORTER CAR IN THE CONSIST FOR 14 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF AND SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

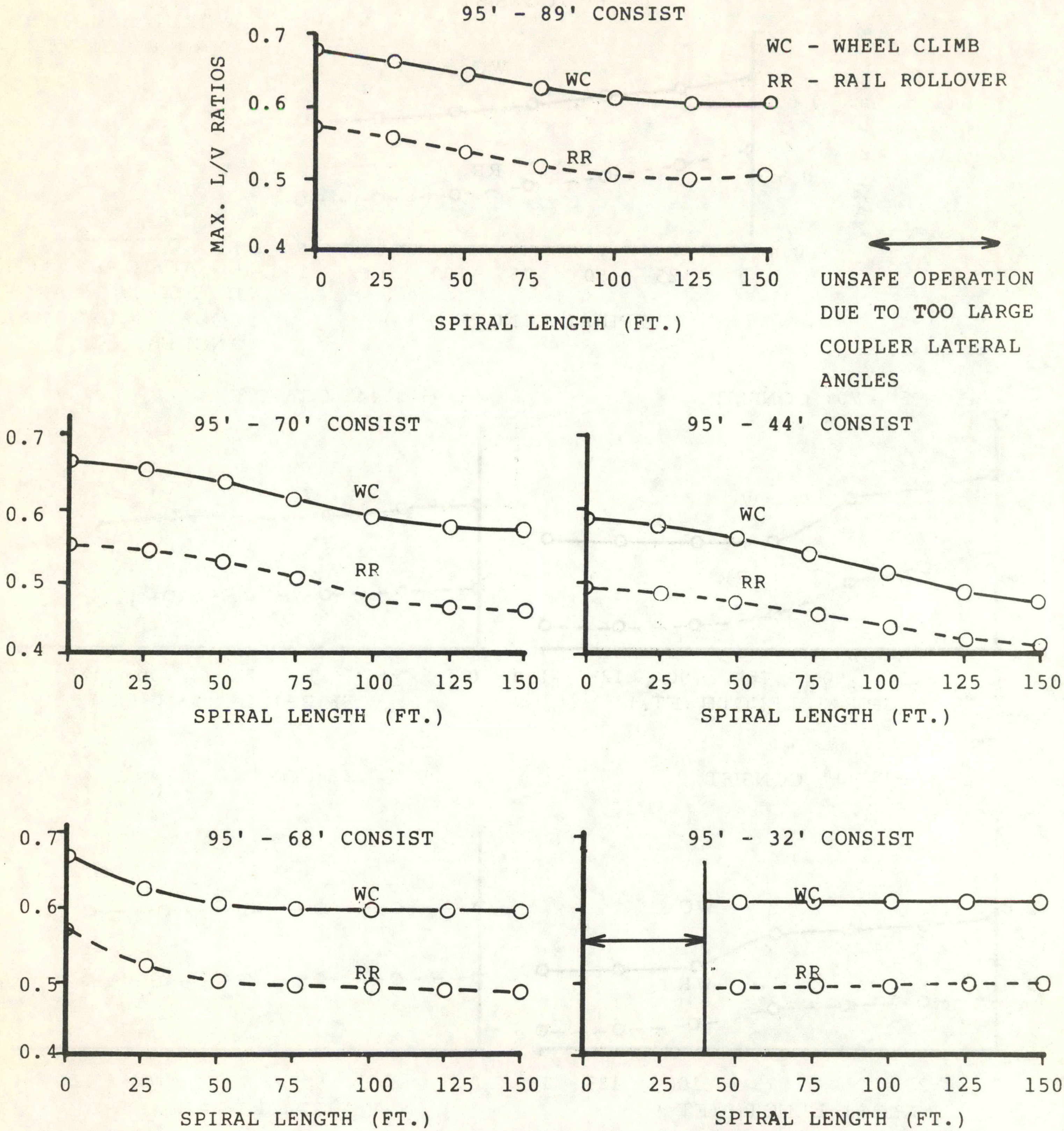


FIGURE 4.14(A) MAXIMUM L/V RATIOS FOR WHEEL CLIMB AND RAIL ROLLOVER ON THE SHORTER CAR IN THE CONSIST FOR 12 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

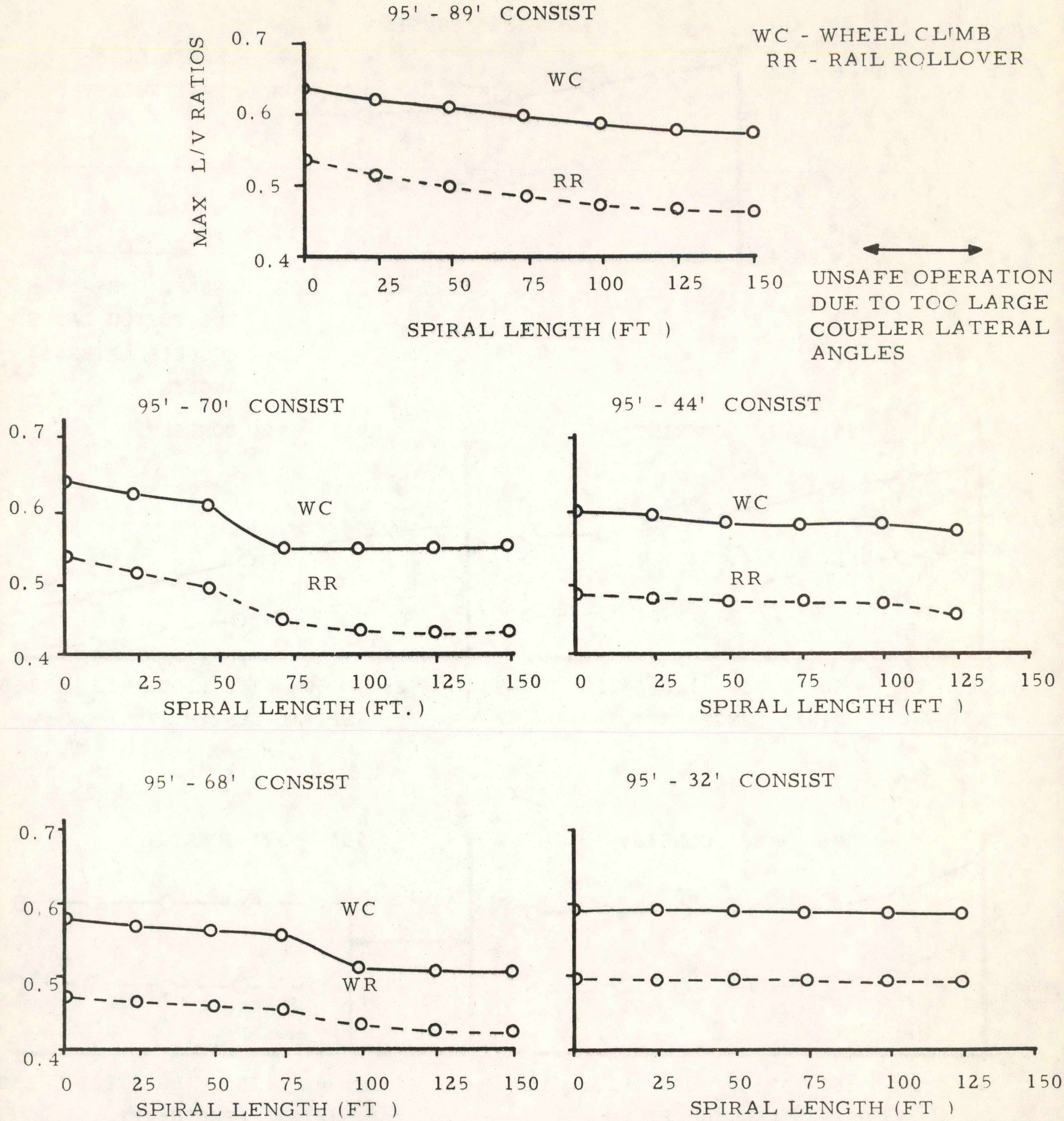


FIGURE 4.14(B) MAXIMUM L/V RATIOS FOR WHEEL CLIMB AND RAIL ROLLOVER ON THE SHORTER CAR IN THE CONSIST FOR 10 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

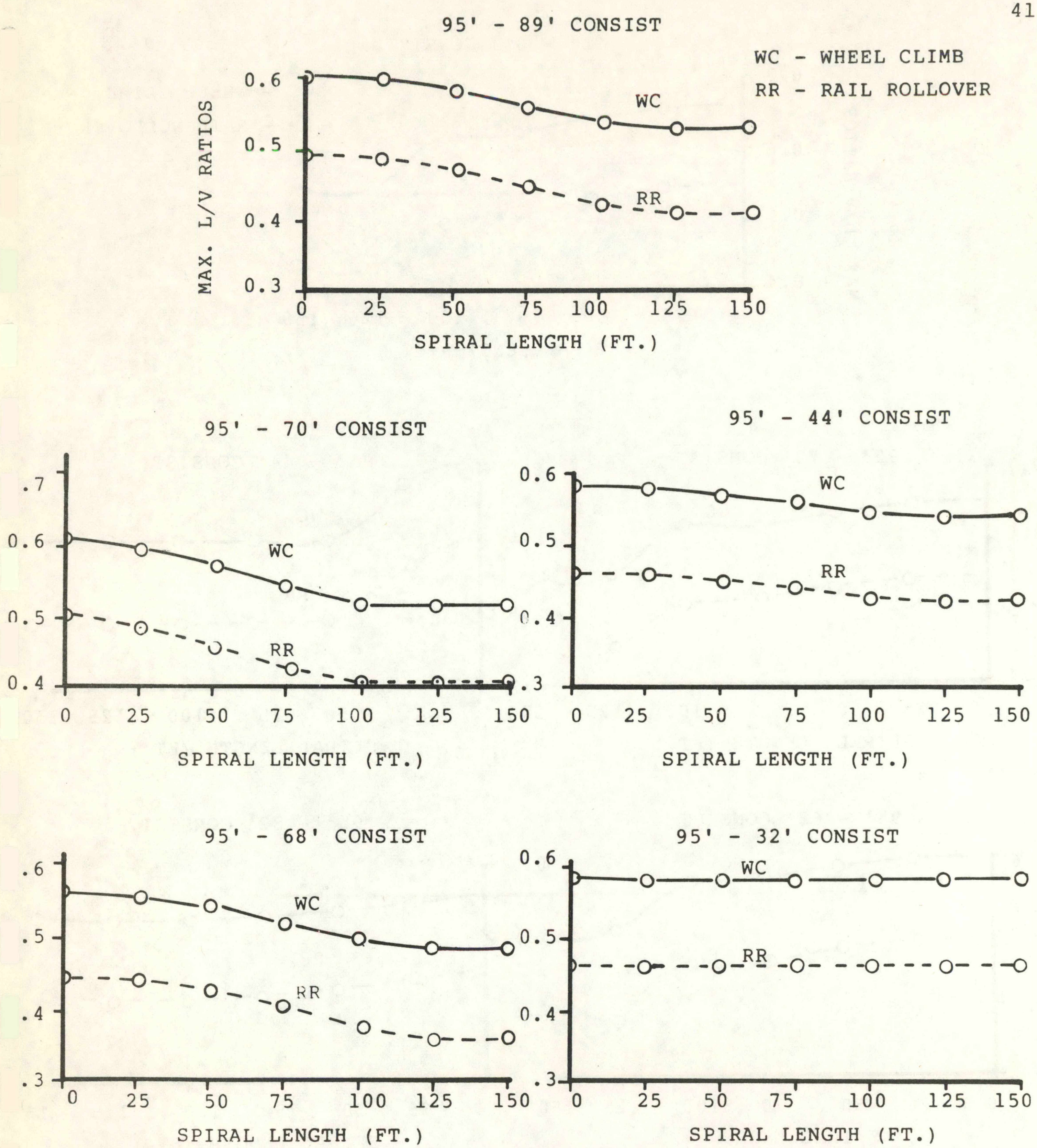


FIGURE 4.15 MAXIMUM L/V RATIOS FOR WHEEL CLIMB AND RAIL ROLLOVER ON THE SHORTER CAR IN THE CONSIST FOR 8 DEGREE SIMPLE CURVE ENTRY AT 40 KIP BUFF WITH SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

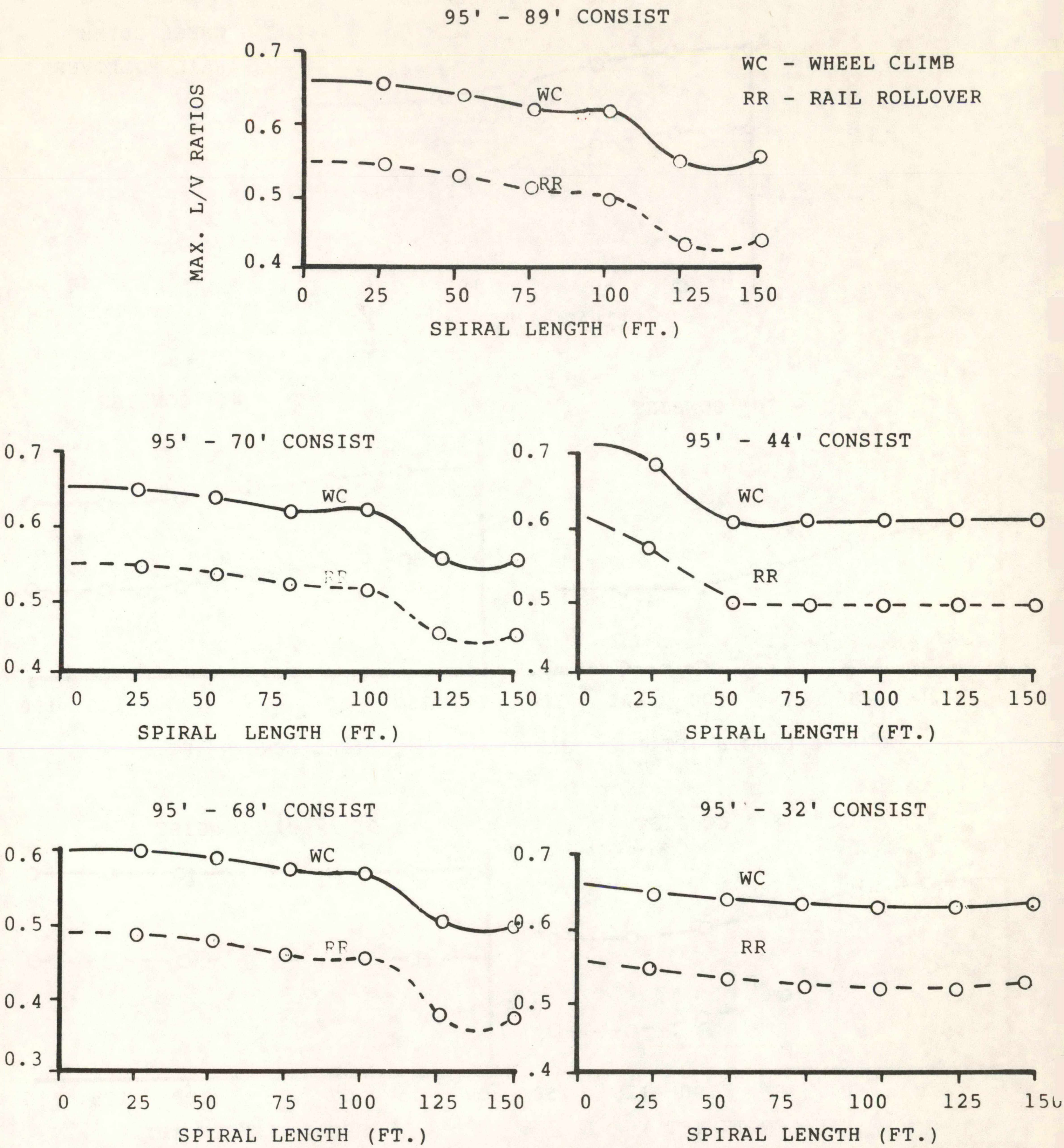


FIGURE 4.16 MAXIMUM L/V RATIOS FOR WHEEL CLIMB AND RAIL ROLLOVER ON THE SHORTER CAR OF THE CONSIST AT 60 KIP BUFF IN 6 DEGREE SIMPLE CURVE ENTRY AT SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

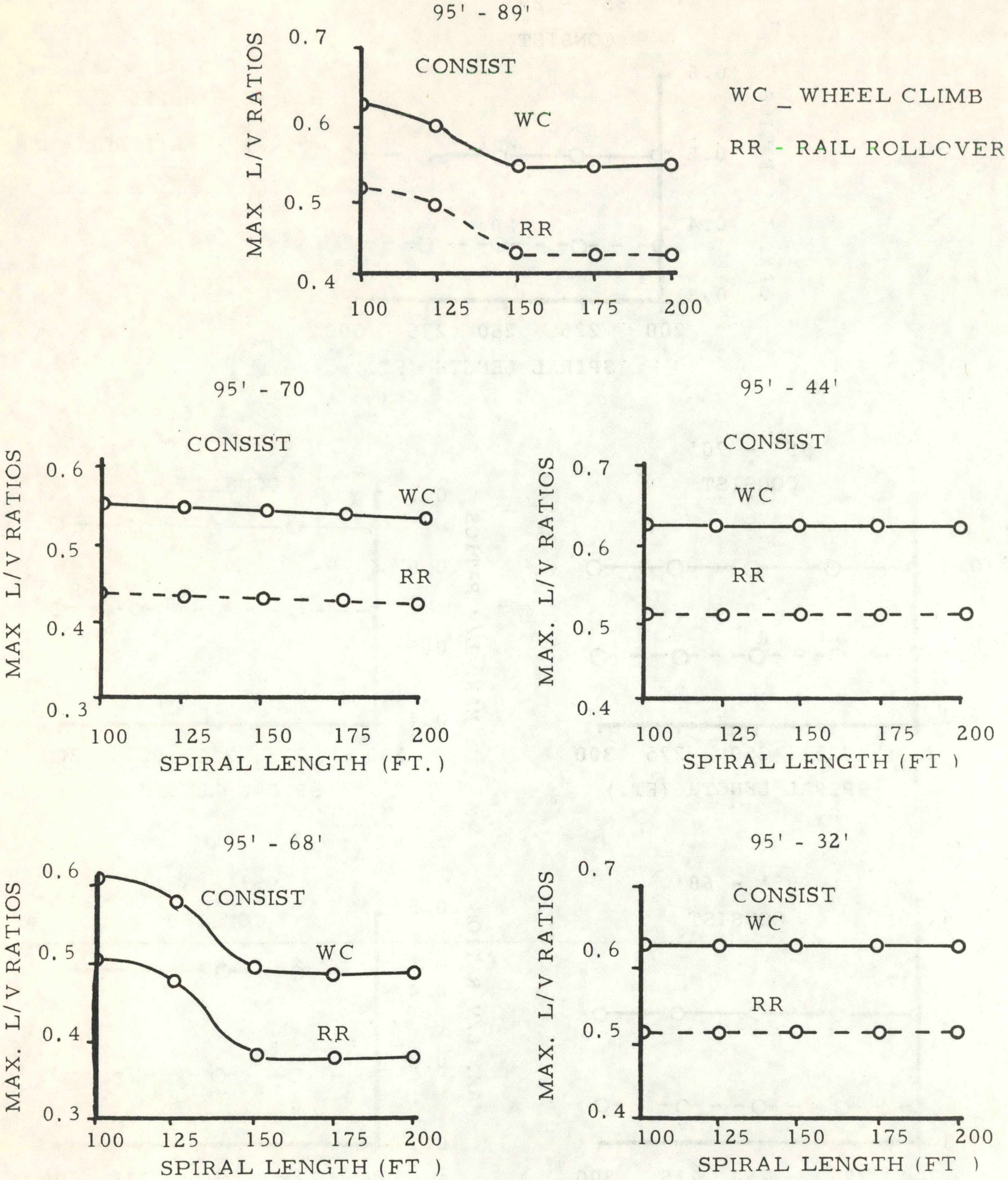


FIGURE 4.17 MAXIMUM L/V RATIOS FOR WHEEL CLIMB AND RAIL ROLLOVER ON THE SHORTER CAR OF THE CONSIST AT 80 KIP BUFF IN 4 DEGREE SIMPLE CURVE ENTRY AT SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

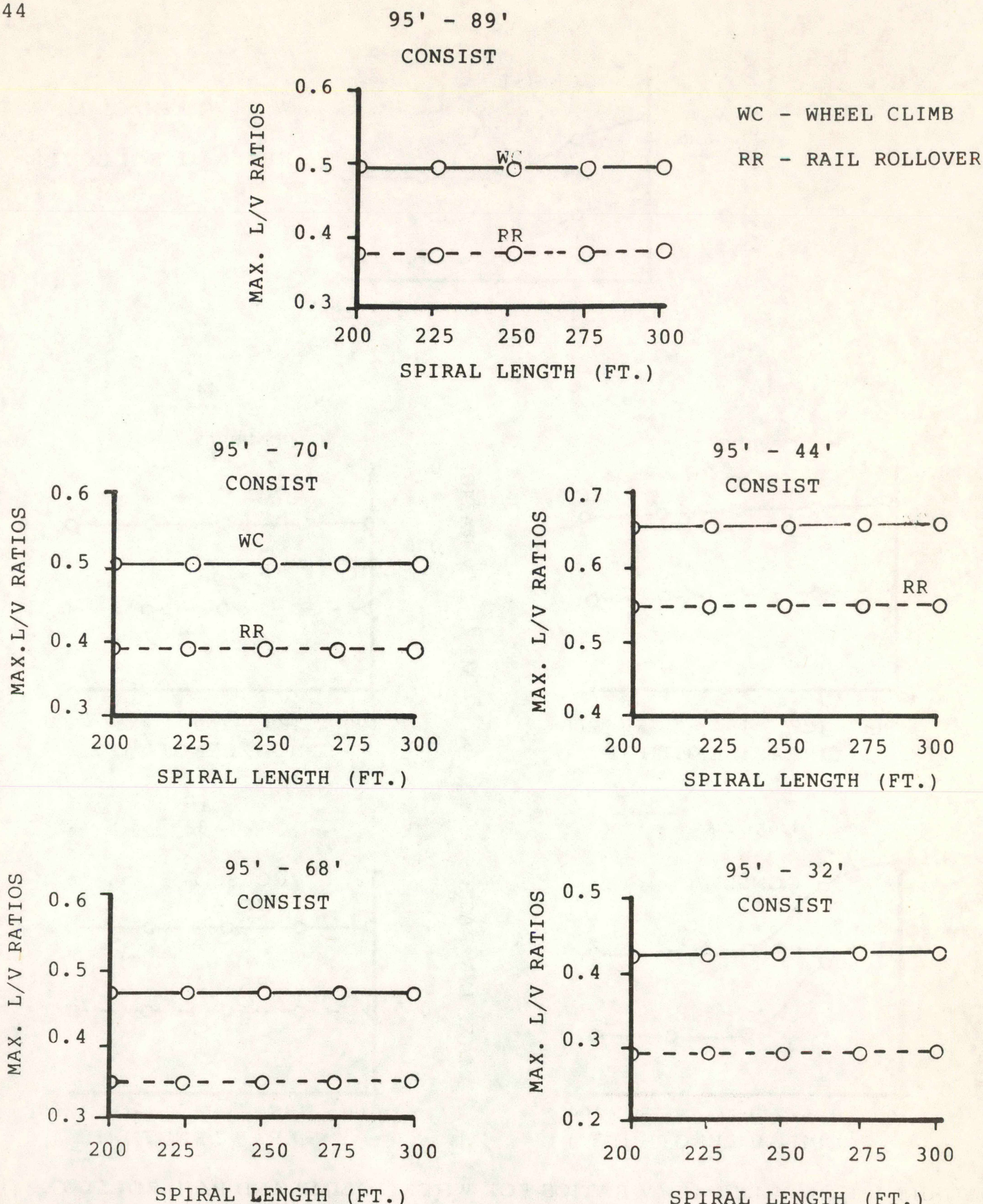


FIGURE 4.18 MAXIMUM L/V RATIOS FOR WHEEL CLIMB AND RAIL ROLLOVER ON THE SHORTER CAR OF THE CONSIST AT 80 KIP BUFF IN 2 DEGREE SIMPLE CURVE ENTRY AT SPEED EQUIVALENT TO 3 INCH UNDERBALANCE OPERATION

the 95'-89' consist is about 56 kips for the rail-rollover condition as defined with L/V ratio of 0.64. When a coupler swing limit is used, the safe drawbar force is about 50 kips. For the 95'-68' consist, the maximum safe drawbar force is about 70 kips using the L/V ratio for the rail rollover criterion, although the coupler angle criterion alone will predict the drawbar forces of 200 kips or more.

The following table shows the maximum safe drawbar force that may be applied to a 95'-89' consist based on the L/V ratio criterion of 0.64 for rail rollover.

TABLE 4.7

MAXIMUM DRAWBAR FORCE (KIPS) IN SIMPLE CURVE ENTRY FOR 95'-89' CONSIST BASED ON L/V RATIO OF 0.64 FOR RAIL ROLLOVER

Degree of curve	16	14	12	10	8	6	4	2
Spiral length(ft)	150	125	100	100	100	125	150	200
Max.safe drawbar force (Kip)	56	60	68	76	84	80	136	175

Figures 4.20 to 4.26 show the effect of buff forces on the L/V ratios and coupler angles for the remaining simple curves. The results plotted in these figures clearly demonstrate that with higher buff load, longer spirals should be used because the rail rollover criterion may not be satisfied even though the coupler angle remains within the swing limits.

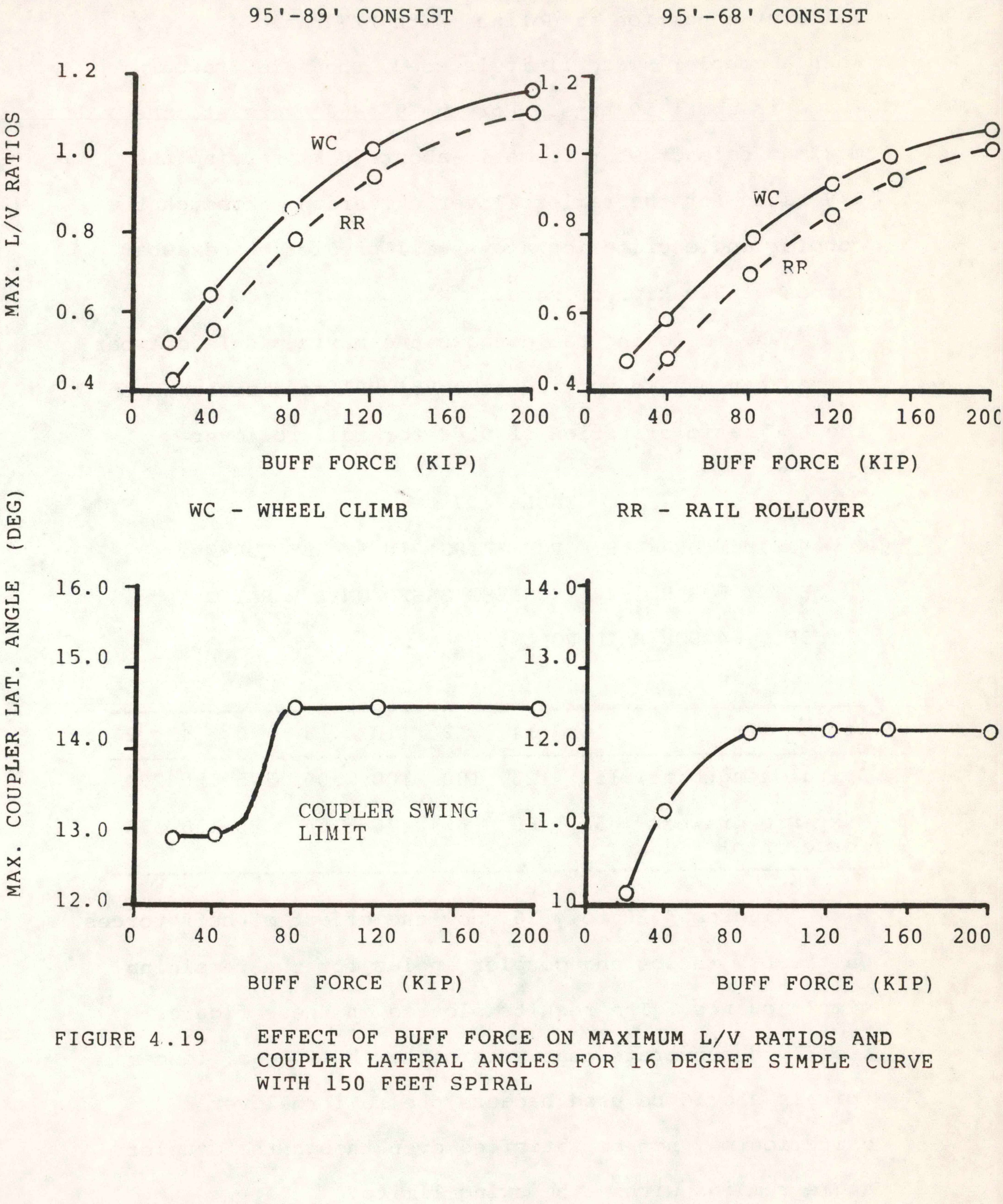


FIGURE 4.19 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND COUPLER LATERAL ANGLES FOR 16 DEGREE SIMPLE CURVE WITH 150 FEET SPIRAL

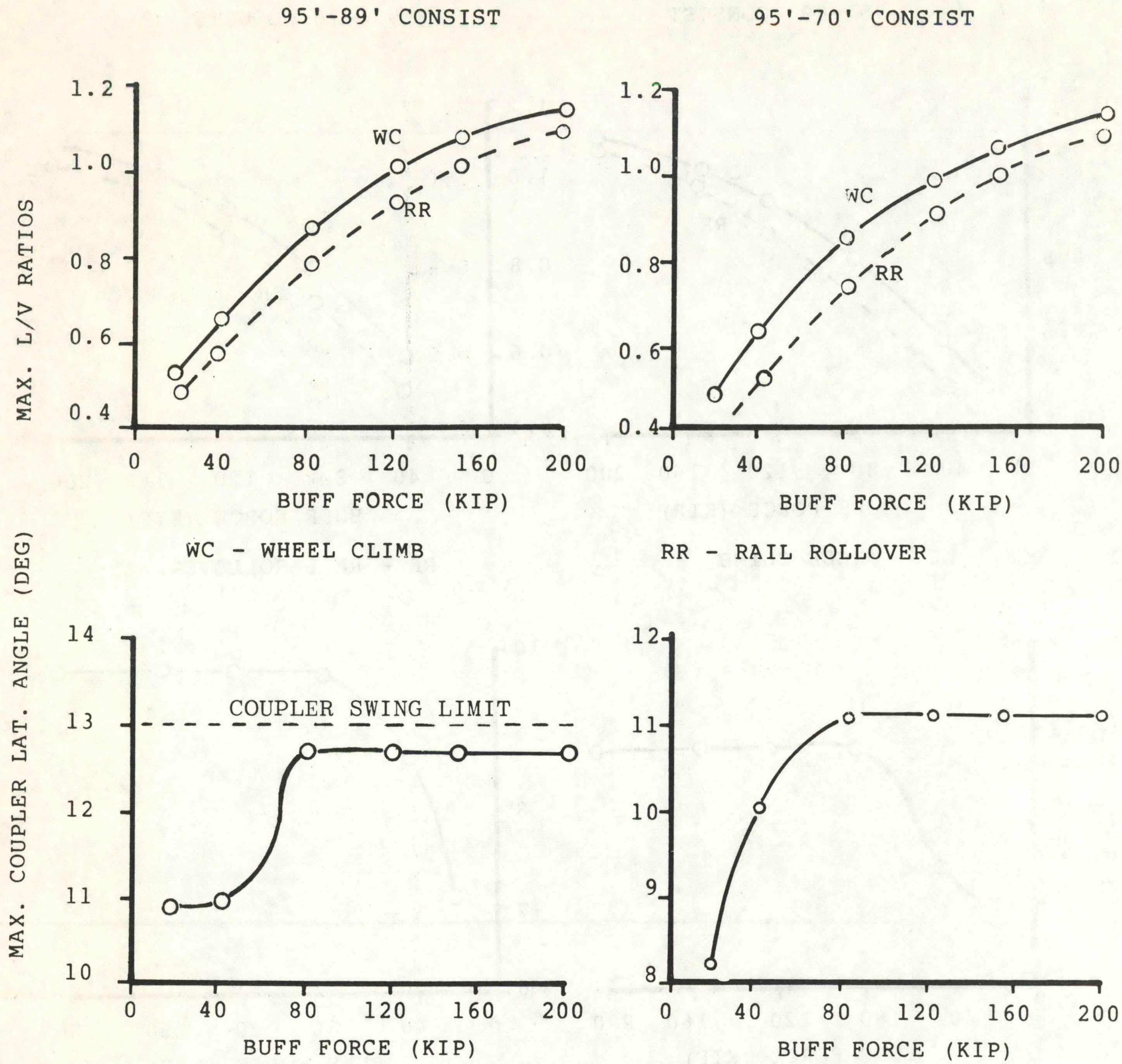


FIGURE 4. 20 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND COUPLER LATERAL ANGLES FOR 14 DEGREE SIMPLE CURVE WITH 125 FEET SPIRAL

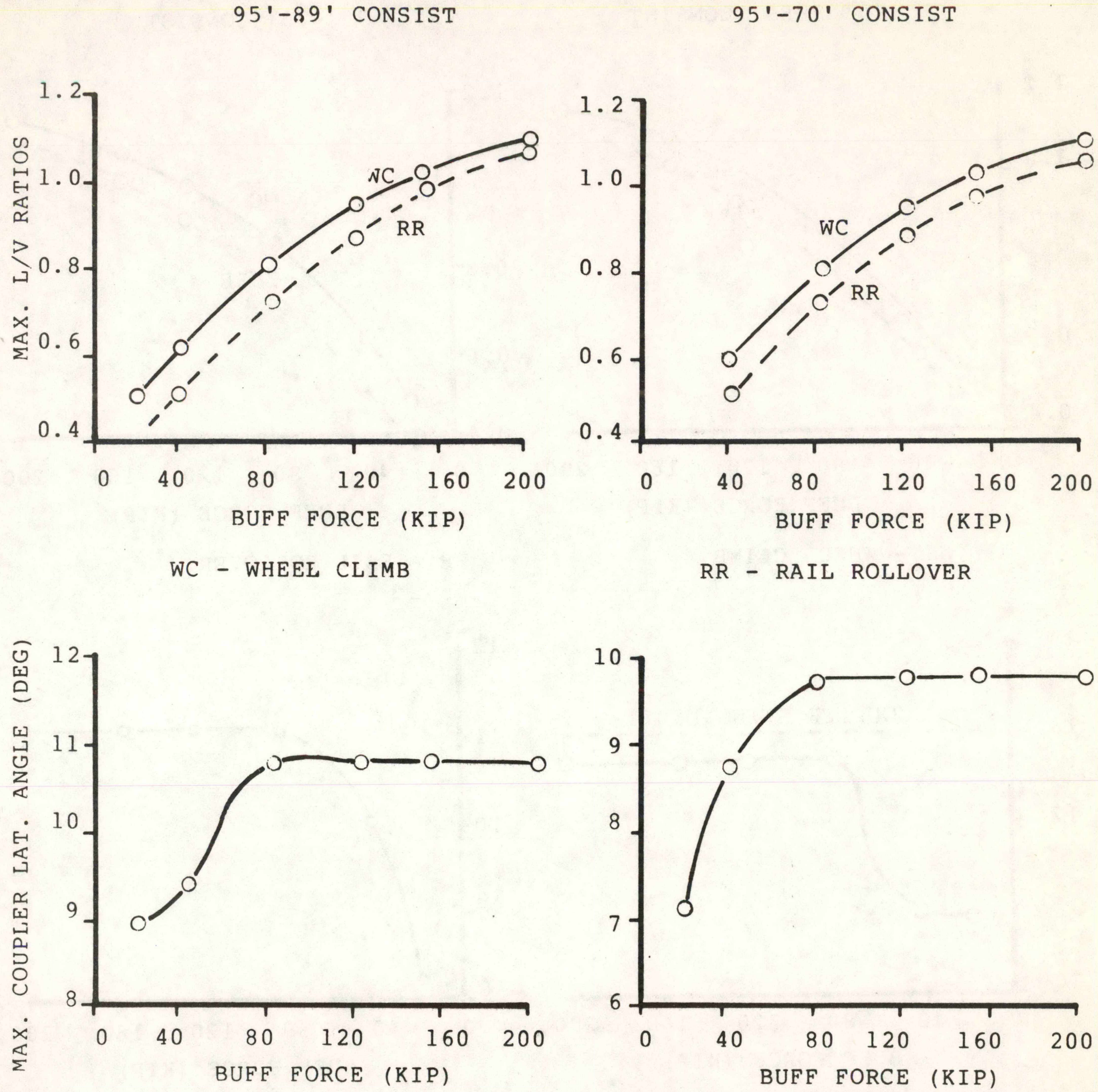


FIGURE 4.21 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND COUPLER LATERAL ANGLES FOR 12 DEGREE SIMPLE CURVE WITH 100 FEET SPIRAL

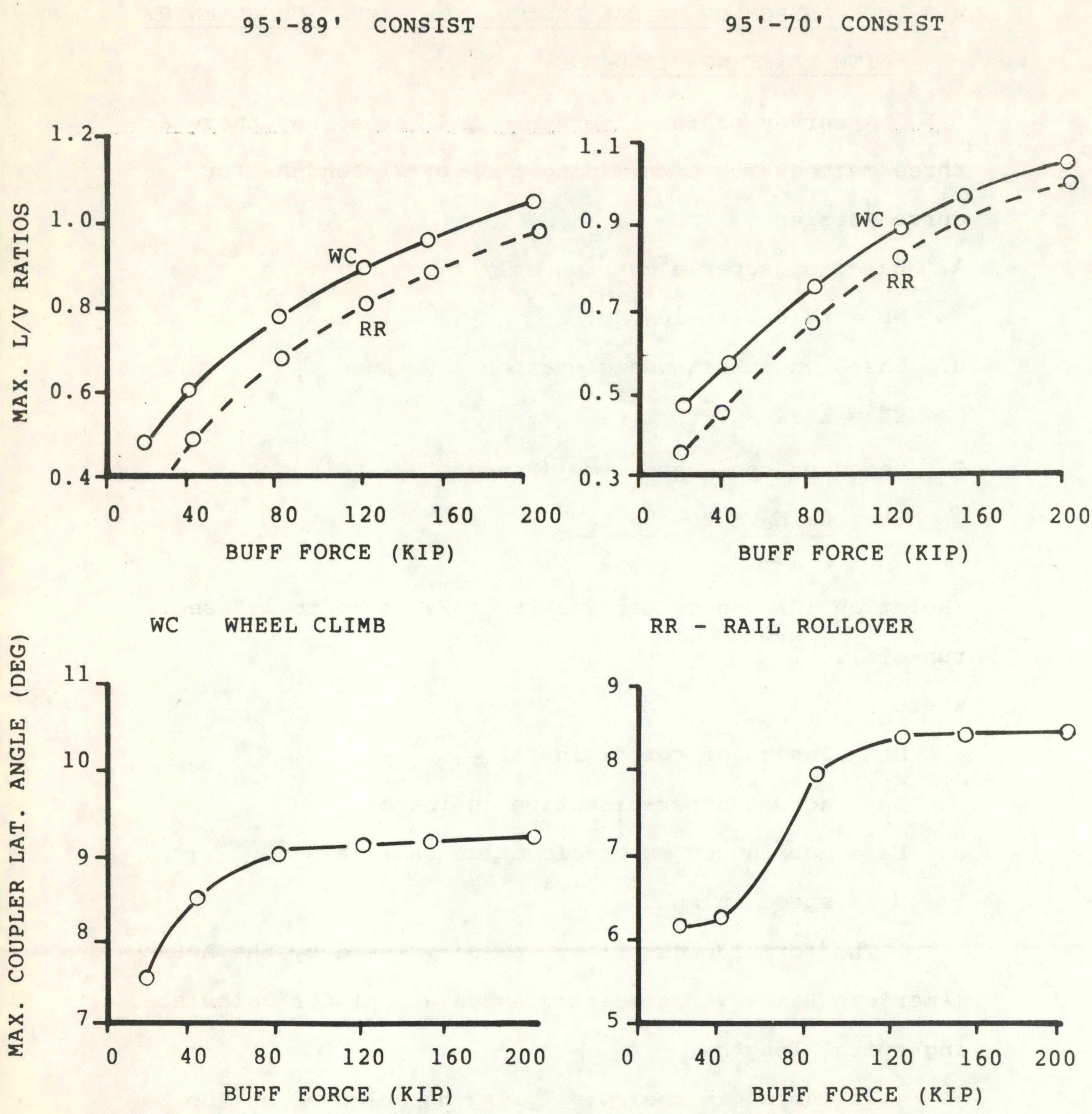


FIGURE 4.22 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND COUPLER LATERAL ANGLES FOR 10 DEGREE SIMPLE CURVE WITH 100 FEET SPIRAL

4.3 COMPARISON OF SPIRAL LENGTHS FOR SIMPLE CURVE ENTRY WITH EXISTING STANDARDS

A survey of the literature indicates that there are three methods for determining the spiral lengths for curve entries.

A. Based on super-elevation only

$SL = 62\ Ea.$ to $104\ Ea.$

B. Based on unbalanced elevation and speed

$SL = 1.22\ E_uV$ to $1.63\ E_uV$

C. Based on speed and time (Run-off)

$SL = \frac{88\ E_aV}{45}$ to $\frac{88\ E_aV}{45}$

(Relation (C) can be derived from 3/4" sec. to 1¼" sec. run-off).

where

SL = length of spiral in ft.

Eu = actual super-elevation in inches

Ea = unbalanced super-elevation in inches

V = speed in mph.

The formulae described in 'B' is used by the AREA (American Railway Engineering Association) for calculating spiral lengths.

In Table 4.8 the spiral lengths selected on the basis of QLTS study are compared with those calculated by using existing formulaes or standards. For the simple curves of 4,6,8 and 10 degrees it can be observed that the spiral lengths obtained from QLTS study are lower than the spiral length suggested by the AREA.

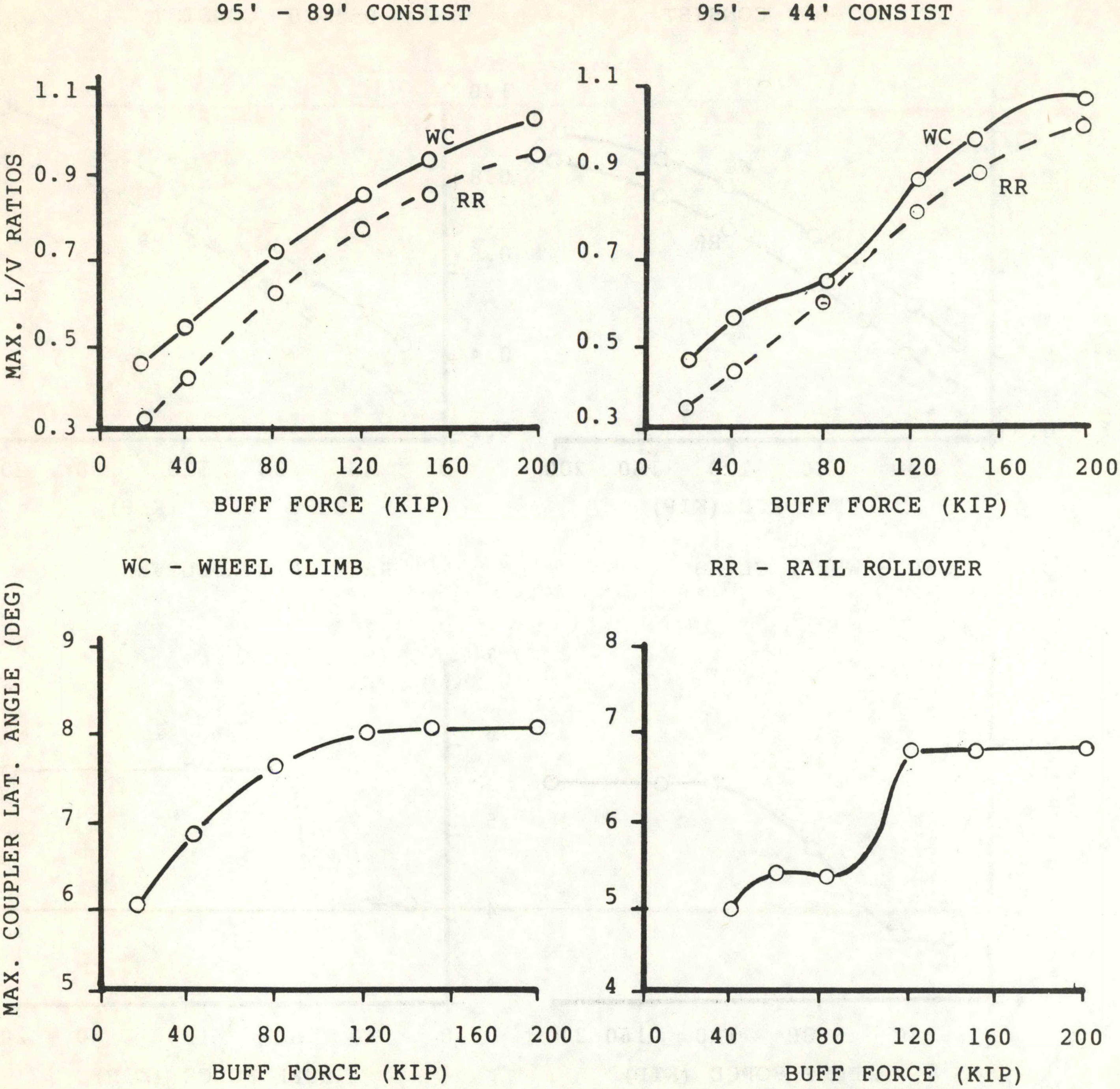


FIGURE 4.23 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND COUPLER LATERAL ANGLES FOR 8 DEGREE SIMPLE CURVE WITH 100 FEET SPIRAL

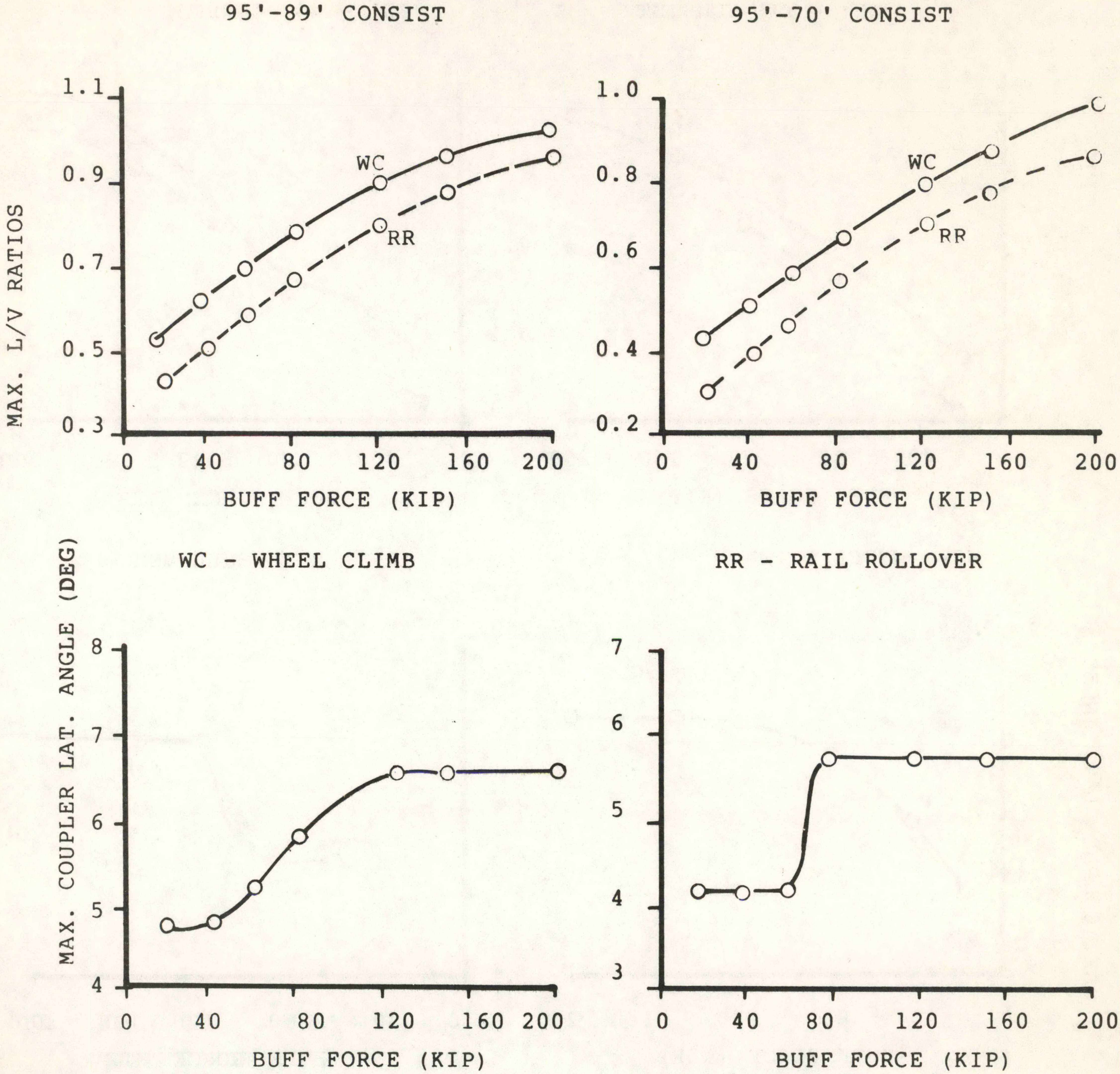


FIGURE 4.24 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND COUPLER LATERAL ANGLES FOR 6 DEGREE SIMPLE CURVE WITH 125 FEET SPIRAL

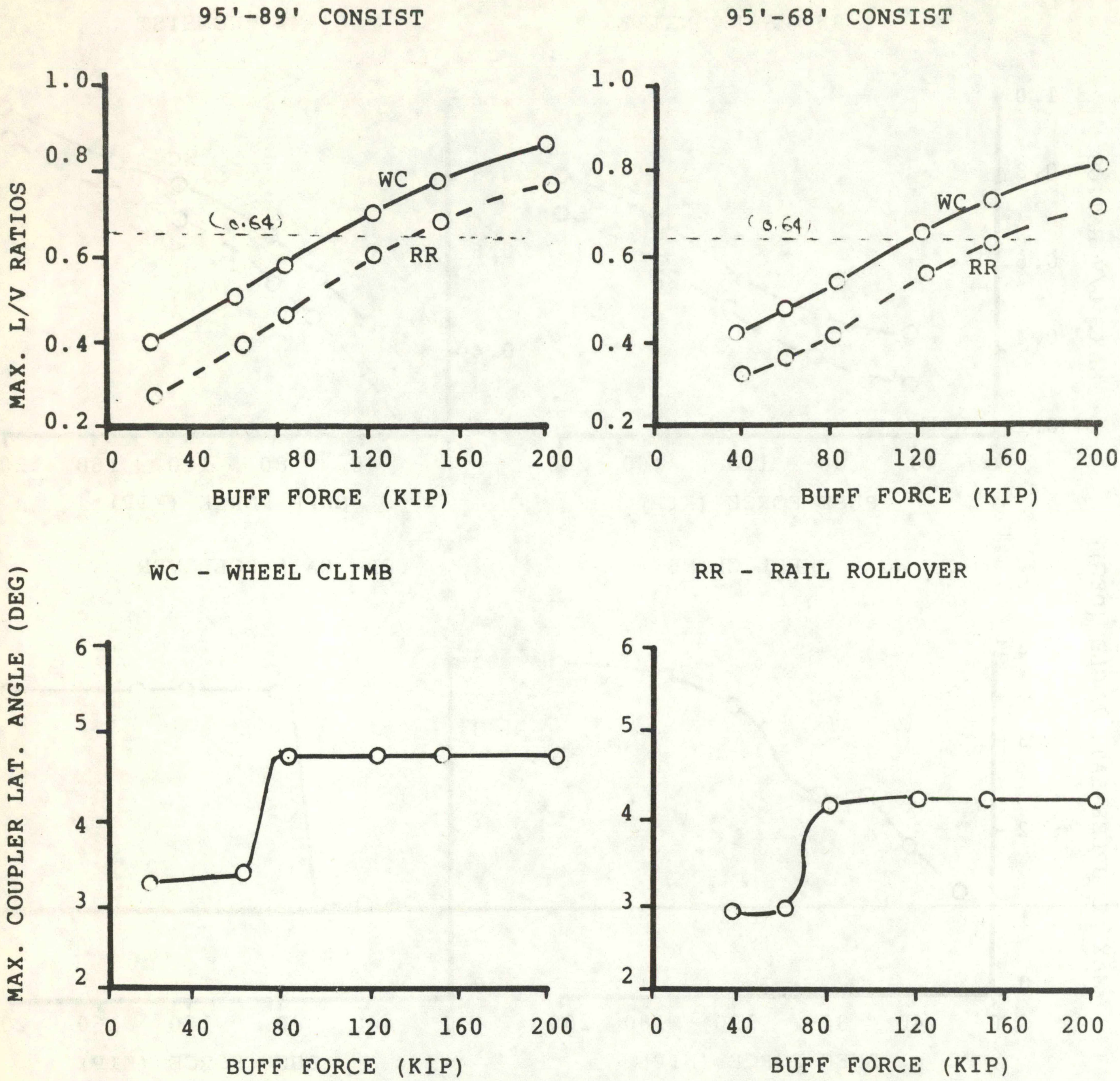


FIGURE 4.25 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND COUPLER LATERAL ANGLES FOR 4 DEGREE SIMPLE CURVE WITH 150 FEET SPIRAL

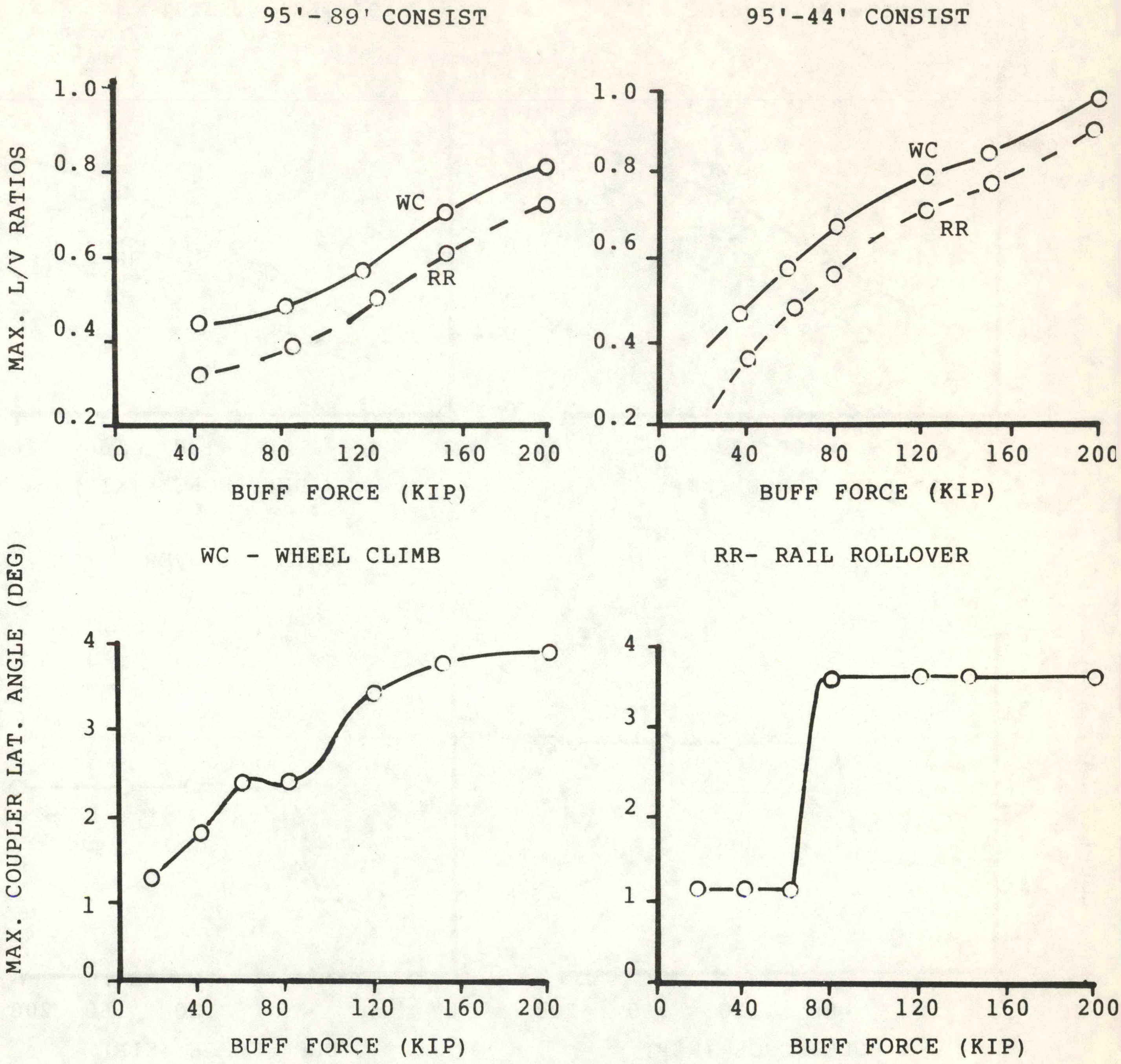


FIGURE 4.26 EFFECT OF BUFF FORCE ON MAXIMUM L/V RATIOS AND MAXIMUM COUPLER LATERAL ANGLES FOR 2 DEGREE SIMPLE CURVE WITH 260 FEET SPIRAL

TABLE 4.8 COMPARISON OF SPIRAL LENGTH WITH EXISTING STANDARDS

Curvature (DEG)		10	8	6	4	2
Superelevation (IN)		4	5	6	4	6
Buff Force (KIPS)		40	40	60	80	80
Velocity (MPH)		32	38	46	50	80
QLTS STUDY -Spiral Length		100	100	125	150	200
AREA	Min 1.22 E_u V	117	139	168	183	293
AREA	Max 1.63 E_u V	156	186	225	245	391
FRA	CLASS 3	62	78	93	62	93
FRA	CLASS 4	83+	103+	124+	83	124
FRA	CLASS 5	124	155	186	124	186
FRA	CLASS 6	248	310	372	248	372+
Based on Superelevation only	62 E_a	248	310	372	248	372
Based on Superelevation only	104 E_a	416	520	624	416	624
Based on runoff	3/4"/sec	250	372	540	391	939
Based on runoff	1"/sec	188	279	405	293	704
Based on runoff	1¼"/sec	150	223	324	235	563
Based on runoff	2"/sec	94	139	202	147+	352
Based on runoff	2½"/sec	75+	111+	162+	117	282+

Comparison for 10^o, 8^o, 6^o and 4^o curve with FRA standards indicates that spiral lengths obtained by QLTS are close to the values suggested by FRA for class 4 to 6 tracks.

Considering the quasi-static lateral stability of the train consist in simple curve entries alone it appears that selected spiral lengths on the basis of this study for 4^o to 10^o curves represent the lower limits.

5. SUMMARY AND CONCLUSIONS

The QLTS model has been used to analyze the effects of spiral lengths on simple curve negotiation. The coupler lateral angle, wheel climb and rail rollover L/V ratios have been used as performance evaluating parameters. The curves of 2 to 16 degrees have been analyzed with spirals. Curves of 8 to 16 degrees without spirals were used for studying the comfort limit speed and overturning speed.

Spiral lengths were determined for different curves, based on coupler lateral angles and L/V ratio for the consists used in study. The spiral lengths computed, using the QLTS model, have been reported in Table 4.8 along with spiral lengths based on existing standards for comparison purposes. The conclusions derived from the results discussed in the report are listed below:

A. Curve Entry without Spirals:

In absence of spirals the curve negotiability of a consist is dictated by the swing limits of coupler. Except on 95'-68' consist, none of the consists considered were able to negotiate the 16 degree curve without coupler contacting the striker, because the coupler angles exceeds or approaches the swing limit during curve negotiation. The magnitude of L/V ratios cannot be very reliable and should be used with caution when evaluating the lateral stability of the consist.

The 1/6 gage criterion used for 'comfort limit speed' predicts that ride quality of cars operated at low speed limits on curves of 10 degrees or higher, is poor. The QLTS model can be used to compute overturning speeds based on 1/2 gage criterion although a judicious use of results may be required because the model is quasi-static.

B. Curve Entry with Spirals

The provision of spirals into curves improves the lateral stability of train consists. Maximum values of coupler angle and L/V ratio are reduced with the introduction of spirals. A lower limit on spiral lengths can be estimated by using the coupler swing limit as the criterion for coupler lateral angles.

Two criterions can be used to evaluate the upper limit on spiral lengths.

(1) Spiral length based on coupler angle : This will be the length after which any increase in spiral will not result in any further reduction of coupler lateral spiral.

(2) Spiral length based on L/V ratio : A spiral length which will result in rail rollover L/V ratio of 0.64 or lower.

For safe operation both criteria should be used and a spiral length which results in no further reduction of L/V ratio or coupler angle should be selected. Tables 4.4 and 4.6 refer to the lower and upper limits on spiral lengths for different degree of curves.

The buff force level plays an important role in lateral train stability. The coupler angle and L/V ratio are greatly affected by variation in buff force. Actually once a spiral length based on 0.64 rail rollover and coupler angle has been chosen, a critical buff load can be obtained. If higher buff load is to be used, the spiral length should be increased.

6. REFERENCES

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