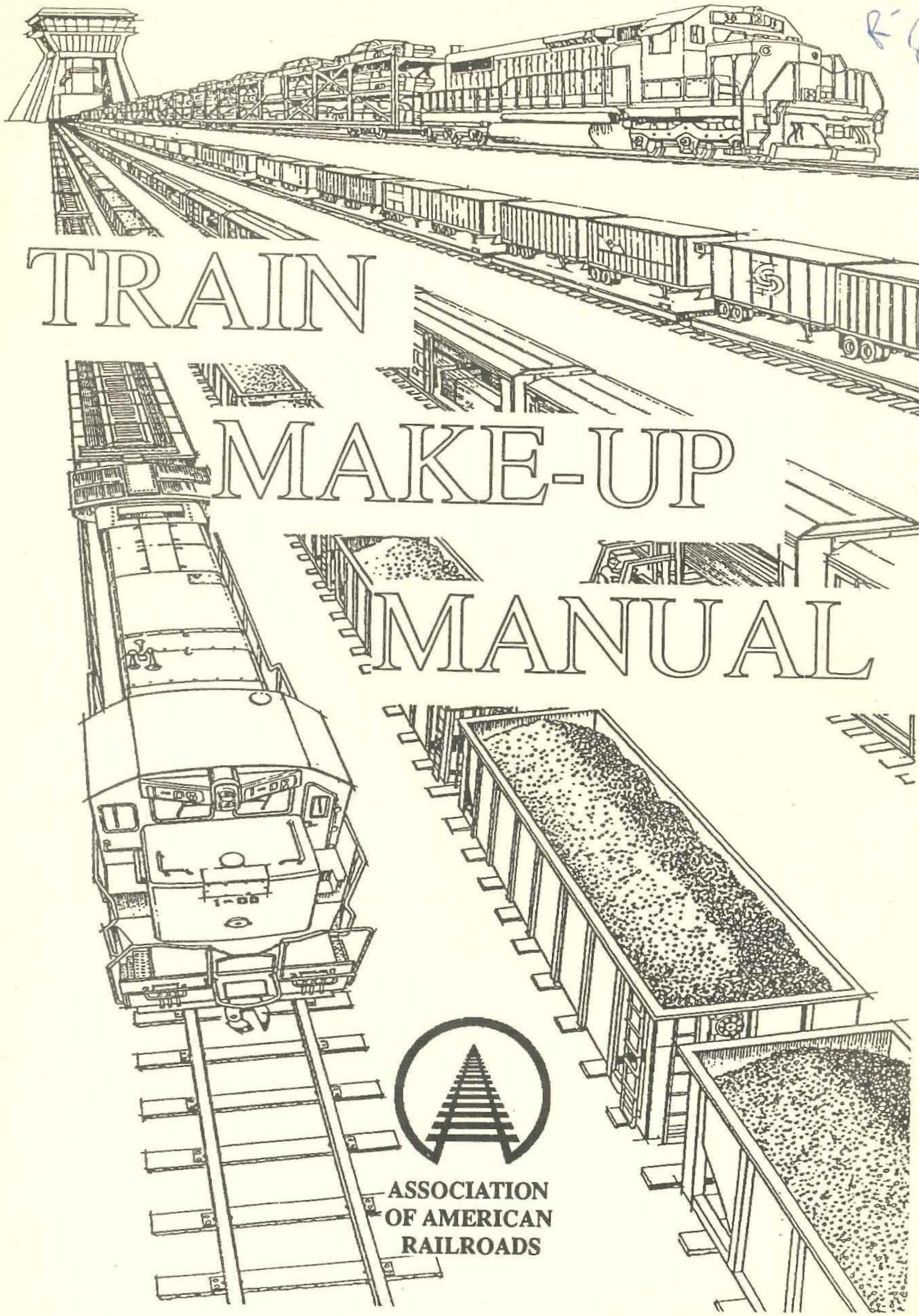
TRAIN MAKE-UP MANUAL



ASSOCIATION OF AMERICAN RAILROADS

R-802

K. L. Hawthorne, P.E.
Assistant Vice President

ASSOCIATION
OF AMERICAN
RAILROADS

March 4, 1992

VEHICLE TRACK SYSTEMS EXECUTIVE COMMITTEE

Gentlemen:

Enclosed is a copy of Report R-802, *Train Make-up Manual*. This manual was developed under the Vehicle Track Systems Program by a special task force of the VTS Implementation Officers Group.

This manual represents an update of Section 3 - Train Make-up Section of Report R-185, *Track Train Dynamics-To Improve Freight Train Performance - Second Addition*, published in 1979. It is intended as a source of information for considerations, such as train size and car placement, that relate to the make-up of trains.

Sincerely,

Keith L. Hawthorne

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Mechanical Management Committee
Operating General Committee
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ASSOCIATION OF AMERICAN RAILROADS | RESEARCH AND TEST DEPARTMENT | REPORT BRIEF

TRAIN MAKE-UP MANUAL

R-802

January 1992

The Train Make-up Manual is a self contained, updated version of the train make-up guidelines contained in AAR Report R-185, *Track Train Dynamics - To Improve Freight Train Performance - 2nd Edition* published under the Track Train Dynamics (TTD) Program in 1979. It is intended to serve as a source of information for considerations such as train size and car placement, that relate to the make-up of trains.

Prior to the introduction of TTD guidelines, most train make-up practices were based on individual railroad experiences and operational considerations, including safety of operation, motive power assignment, train schedules, and customer service requirements. Extensive research under the TTD Program was translated into actual train make-up guidelines. **These guidelines provide recommendations for maximum trailing tonnage, use of head end and helper power, and the placement of critical car combinations in the train according to TTD principles.** They take into account all train forces including locomotive tractive effort, trailing tonnage, drawbar force, grade and curvature resistance, and dynamic braking.

Since 1979, the industry has undergone vast changes in motive power handling, types of equipment, and increased train weight. This manual is designed for ease of use by those involved in the train make-up decision process. It is intended for use by a railroader's operations "rule maker." The guidelines were developed by the Implementation Officers Group of the Vehicle Track Systems Program. A special task force of experienced research and operations personnel was responsible for this document.

For trains under 4000 tons total train weight, this manual suggests that no special consideration is required. For trains of mixed cars over the 4000 ton size, the manual suggests the placement of long car/ short car combinations be restricted within the consist, so as not to exceed a suggested maximum trailing tonnage for the ruling grade and curve combination for the particular route. The suggested values are obtained from either tables or curves presented in the manual. For special cars or car combinations, the best current practice for estimating the maximum trailing tonnage is included.

The manual also provides an understanding of train forces, their nature and a means for estimating them.

Copies of the AAR Report: "Train Make-up Manual," are available from the Document Distribution Center, Chicago Technical Center, 3140 South Federal Street, Chicago, Illinois 60616. The AAR report number is R-802; the price is $10.00 for member railroads and $100.00 for nonmembers. Illinois residents please add 8% sales tax. The cost includes surface mail postage if mailed within North America. There will be a surcharge for any overseas mail. Checks should be made payable to the Association of American Railroads. This report was issued in January, 1992. A report list is available upon request.

ASSOCIATION OF AMERICAN RAILROADS
Research and Test Department

TRAIN MAKE-UP MANUAL

Report No. R-802

Vehicle Track Systems TTD
Implementation Officers

January 1992

AAR Technical Center
Chicago, Illinois

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13. ABSTRACT

This self contained manual represents an updated version of the Train Make-up guidelines contained in Chapter 3 of AAR Report R-185, "Track Train Dynamics-To Improve Freight Train Performance - 2nd Edition" published under the Track Train Dynamics Program in 1979. It is intended to serve as a source of information for considerations such as train size and car placement, that relate to the make-up of trains.

This manual suggests that for trains under 4000 tons total train weight (TTW), no special consideration is required. However, for trains of mixed cars over 4000 tons TTW, the manual suggests that the placement of long car/short car combinations be restricted within the consist, so as not to exceed a suggested maximum trailing tonnage for the ruling grade and curve combination for a particular route. The suggested values are obtained from either tables or curves presented in this manual. For special cars or car combinations the best current practice is described. The detailed calculation procedure for estimating the maximum trailing tonnage is included in Section 10.

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Train Make-up, Train Forces, Stringlining, Jackknifing, Harmonic Motion, Trailing Tonnage, Train Handling, Curves.

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The publication of this manual would not have been possible without the dedication and perseverance of Mike Lovette, Conrail and Jacques Thivierge, Canadian National. In addition several other individuals contributed through their attendance at the working manual meetings and contributions of written material contained in this publication. Included are Warren Egan, Union Pacific, Keith Kieres, Burlington Northern, Don Manconi, Canadian Pacific, Jon Robertson, Norfolk Southern, Terry Bagaus, Soo Line, Mike Volkmar and Dwight Anderson, Chicago & NorthWestern, and John Punwani and Ralph Groskopf, AAR. Thanks also to the Vehicle Track Systems TTD Implementation Officers for their diligent review and guidance in the preparation of this manual.

EXECUTIVE SUMMARY

AAR Report No. R-185, Track Train Dynamics - To Improve Freight Train Performance, was issued in November, 1979. Section 3 of this report, entitled Train Make-up, attempted to bring train action considerations into the train make-up decision process.

Prior to the introduction of TTD, most train make-up practices were based solely on individual railroad experiences and operational considerations. These considerations included safety of operation, motive power assignment, train schedules and customer service requirements. The results of extensive research as part of the TTD Program were translated into actual train make-up guidelines. These encompassed the regulation of trailing tonnage, use of head end and helper power, and the placement of critical car combinations in the train according to TTD principles.

These TTD principles take into account all train forces including the locomotive tractive effort, trailing tonnage, drawbar force, grade and curvature resistance, and dynamic braking.

Since 1979, the industry has undergone vast changes in motive power handling, types of equipment, and increased train weight. This manual is a self contained separate publication designed for ease of use by those involved in the train make-up decision process. It is intended for use by the railroad's operations "rule makers." The guidelines contained herein were developed by the Implementation Officers Group of the Vehicle Track Systems Program. A special task force of experienced research, operations and others was responsible for this document.

For trains under 4000 tons total train weight, this manual suggests that no special consideration is required. For trains of mixed cars over the 4000 ton size, the manual suggests the placement of long car/short car combinations be restricted within the consist, so as not to exceed a suggested maximum trailing tonnage for the ruling grade and curve combination for the particular route. The suggested values are obtained from either tables or curves presented in this manual. For special cars or car combinations, the best current practice for estimating the maximum trailing tonnage is included.

This manual also provides an understanding of train forces, their nature and a means for estimating them.

TABLE OF CONTENTS

LIST OF EXHIBITS

1.0 PREFACE

The Vehicle Track Systems (VTS) Program, like its predecessor the Track Train Dynamics Program is a cooperative industry program, drawing support from AAR Member Railroads, the Association of American Railroads, Rail Advisory Committee of Transport Canada, and the U. S. Department of Transportation's Federal Railroad Administration. One important function of the VTS Program is to transfer research, conducted under the auspices of the program, into railroad operating practices which enhance safety and also improve productivity. This important function is provided by the Program through its Implementation Officers Group, which is comprised of railroad officers whose expertise and job functions encompass mechanical, track, and operations related activities. This group also serves to provide a forum for exchange of technical information which enhances safety and productivity. This manual is one of the vehicles for disseminating train make-up guidelines which represent the embodiment of research and practical operating experience. The manual was developed by the Implementation Officers Group, in particular by a committee assigned to the task.

This manual is intended to provide a basic understanding of the parameters that affect train safety due to train make-up. Obviously, it is not possible to prevent derailments solely on the basis of train make-up; therefore, the manual assumes that reasonable train handling practices will be followed when operating trains. By following the guidelines and observing the cautions outlined in this manual, the chance of derailments due to train make-up practices should be reduced to a minimum.

The manual presents the most basic information first and the information increases in complexity throughout the manual. This should allow the user to read no more than is necessary to solve a particular train make-up problem. It also presents the information in a logical fashion which should make it useful as a general reference work on train make-up.

2.0 GENERAL TRAIN MAKE-UP GUIDELINES

The Train Make-Up Manual is intended to provide guidelines for train make-up, covering as many situations as possible that a railroad may encounter. The focus of this manual is on general service mixed consist trains that can be made up. Unit trains are trains that have already been made up - that is, there are no choices remaining with respect to train make-up. The principal problem of train make-up pertains to long cars and short cars, especially when they are coupled to each other and operated in a train of some size on territory where the curves and grades are significant with respect to train action. A threshold value of car, train, and route parameters has been suggested below which train make-up presents no particular problem. Simply stated, and representing the combined best judgement of experienced railroad operations officers; If the total train weight and operating territory conditions meet the following guidelines, no consideration for train make-up need be given for general merchandise trains composed of cars not listed in Section 6.0, that are unrestricted in interchange service.

- TOTAL TRAIN WEIGHT IS LESS THAN 4000 TONS, <u>and</u>
- MAXIMUM GRADIENT IS LESS THAN 2.0%, <u>and</u>
- MAXIMUM CURVATURE IS LESS THAN 8°

Trains that are operated under conditions other than these, should be evaluated by using the techniques in Section 5.

3.0 TRAIN FORCE DEVELOPMENT

Train forces can be developed by either the action of operating a locomotive or the natural movement of a group of coupled cars over the track. The convention in this manual will assume that forces are negative in buff (compression) and positive in draft (tension).

3.1 Train Resistance

Train resistance is composed of four different components which are described below. To obtain the total train resistance, one simply adds the four components; grade, curve, acceleration, and rolling resistance, paying careful attention to the appropriate signs. This manual makes several simplifying assumptions about curve and rolling resistance. One major assumption is a uniformly distributed train weight. These assumptions are sufficient for the calculations presented herein. These assumptions and values are listed in Section 10. Computer models are available to perform a more exact analysis when necessary.

3.1.1 Grade Resistance

Grade resistance is the force exerted on a train by gravity. This force is negative on descending grade and positive on ascending grade.

R_g = TTW x (% Grade) x 20 lb/ton/% Grade

where:

TTW = total train weight (tons)

% Grade = (1% = 1) (.5% = .5)(0% = 0) etc.

EXAMPLE: 5000 ton train going up 1.5 percent grade.

R_g = 5000 x 1.5 x 20

= 150,000 lbs.

3.1.2 Curve Resistance

Curve resistance is the train force generated when a vehicle negotiates a curve [1].

R_c = C_{avg} x TTW x 0.8 lb/ton/degree where:

TTW = total train weight (tons)

C_{avg} = curve or series of curves under train

$$C_{avg} = \frac{[(D_{c1}) \times (L_{c1})] + [(D_{c2}) \times (L_{c2})] + \ldots + [(D_{cn}) \times (L_{cn})]}{\text{Total Length of Train}}$$

D_{cn} = Degree of Curvature

L_{cn} = Length of Curve (ft)

The grade equivalent of curve resistance is calculated as follows:

$$G_c = R_c / (TTW \times 20)$$

Where:

G_c = Grade Equivalent (% grade)

R_c = Curve Resistance (lbs.)

TTW = Total Train Weight (tons)

20 = Grade Resistance Constant (lb/ton/%grade)

EXAMPLE: 5000 ton train that is 4000 feet long going through two curves. One curve is 5 degrees and 500 feet long; the other is 3 degrees and 400 feet long.

$$R_c = \frac{[5 \times 500] + [3 \times 400]}{4000} \times 5000 \times 0.8$$

$$= \frac{3700}{4000} \times 5000 \times 0.8 = 3700 \text{ lbs.}$$

$$G_c = 3700 / (5000 \times 20) = 0.037\% \text{ grade}$$

3.1.3 Rolling Resistance

Rolling resistance is the resistance to the train movement as it rolls along the track, by such factors as weight, speed, size, wheel flange to rail, journal type, wind, etc. [1]. The Davis Formula [2] is the most widely used for calculating rolling resistance but a close approximation can be obtained by the following:

R_r = TTW x (K)

where:

K = constant (8 lbs./ton) if starting train;

4.5 lbs./ton if train in motion

TTW = total train weight (tons)

EXAMPLE 1: 5000 ton train starting

R_r = 5000 x 8 = 40,000 lbs.

EXAMPLE 2: 5000 ton train already moving

R_r = 5000 x 4.5 = 22,500 lbs.

3.1.4 Acceleration

Acceleration (or deceleration) forces are created any time a train increases or decreases speed. When using only the dynamic brake to decelerate a train, this force is largest directly behind the locomotives and can be significant. The forces of acceleration or deceleration can be computed by:

Force = Mass x Acceleration

which can be rewritten for train operations as:

R_a = 1.52 x A x TTW

where:

R_a = Resistance due to acceleration (lbs.)

TTW = Total Train Weight (tons)

A = Train acceleration (mph/min)
- Positive if speed is increasing
- Zero if speed is constant
- Negative if speed is decreasing

1.52 = Conversion Constant (lb x min)/(ton x mph)

Example: A 4000 ton train decelerating at a rate of 10 mph/min produces an acceleration force of:

$R_a = 1.52 \times (-10) \times 4000$ lbs.

$R_a = -60{,}800$ lbs.

NOTE: This creates a buff force and is only a portion of the total drawbar force.

3.1.5 Total Train Resistance

Total train resistance is simply the sum of the above terms:

$$R_{tot} = R_g + R_c + R_r + R_a$$

paying close attention to the signs of each of the terms.

3.2 Tractive Effort

Tractive effort is the force generated by the locomotive at the drawbar to overcome train resistance.

$$TE = \frac{\text{HORSEPOWER} \times 308}{\text{Speed}} \times \text{(Number of locomotives)}$$

Horsepower = horsepower of locomotive

Speed = speed of locomotive (mph)

308 = constant derived from 375 pound-miles per hour (1 horsepower) x 82% transmission efficiency

EXAMPLE: Three - 3000 horsepower locomotives pulling a 5000 ton train at 20 mph can generate a force of:

$$TE = \frac{3000 \times 308}{20} \times 3$$

$$= \frac{924000}{20} \times 3 = 138{,}600 \text{ lbs.}$$

These forces are valid only in throttle position RUN 8 and at no time will exceed the adhesion limit of the locomotive. The adhesion limit may be calculated as a percentage of the locomotive weight:

$$TE = \text{\% ADHESION} \times WT_{max}$$

% ADHESION = Adhesion obtainable by the particular locomotive. Values range from 8% (0.08) to 33% (0.33). A value of 25% (0.25) is typical.

WT_{max} = Weight of the locomotive in pounds.

Example: A 392,000 lb. locomotive can generate a maximum tractive effort of approximately:

TE_{max} = 0.25 x 392,000 lbs.

TE_{max} = 98,000 lbs.

This value will be a good approximation of maximum drawbar force on tangent track and at speeds above 10 mph. Consult the appropriate locomotive manual to determine the actual value of adhesion and drawbar force that can be expected for a particular operating regime.

3.3 Braking

3.3.1 Dynamic Brake

Dynamic braking is a process by which the traction motors are electrically converted to generators, creating a current that is dissipated through resistor grids. There are two types that create forces as follows:

Standard = 10,000 lbs. per axle maximum
High Capacity = 13,500 lbs. per axle maximum

These maximum forces normally occur at between 17 and 25 MPH unless extended range dynamic braking is used. Extended range increases the speed range for maximum forces to between 6 and 25 MPH. Because of this braking force being concentrated on the head end, care should be taken on the number of dynamic brake axles in lead. Industry practice today is to use not more than 250,000 lbs. of dynamic brake on the head end of general merchandise trains.

EXAMPLE: Two standard dynamic brake SD-40-2 (six axle) locomotives in full dynamic brake.

R_{db} = 10,000 x 12 = 120,000 lbs.

3.3.2 Automatic Brake

Automatic brake controls the application or release of brake shoes against the wheels initiated from a brake valve located in a locomotive. Since the retardation force is applied to every car, there is no steady state concentration of braking force in the train. For an approximation of automatic brake retarding force per car on a conventional four axle car, the following equation can be used:

$$R_{ab} = [270 \times (\text{BP reduction} - 6)] + 1400 \text{ lbs.}$$

NOTE: This can be used up through full service (Maximum of 26 lb. brake pipe reduction for 90 lb. trainline). For emergency application use 7800 lb/car for retarding force.

EXAMPLE: An automatic brake pipe reduction has been made totalling 12 lbs. Each car therefore has a retarding force of:

$$R_{ab} = [270 \times (12-6)] + 1400 \text{ lbs.}$$

$$= 1620 + 1400$$

$$= 3020 \text{ lbs.}$$

It should be noted that the automatic brake force is dependent upon train speed and brake cylinder pressure buildup. A computer model should be used for a more exact analysis [3][4].

3.3.3 Independent Brake

Independent brake controls the application or release of brake shoes against the wheels of a locomotive only, initiated from a brake valve located in the locomotive. Because all retarding force is concentrated at the head end, high drawbar forces can develop creating unnecessary train shock by improper use of independent brake. The total independent brake retarding force can be approximated by use of the following equation:

$$R_{tib} = \left[\frac{BCP_{ib}}{72} \right] \times \left[(R_{ib})^* \right] \times \left[\text{\# of Axles} \right]$$

*See Exhibit 3.1

R_{tib} = total independent brake retarding force (lbs.)

R_{ib} = independent brake retarding force (lbs.)

BCP_{ib} = independent brake cylinder pressure

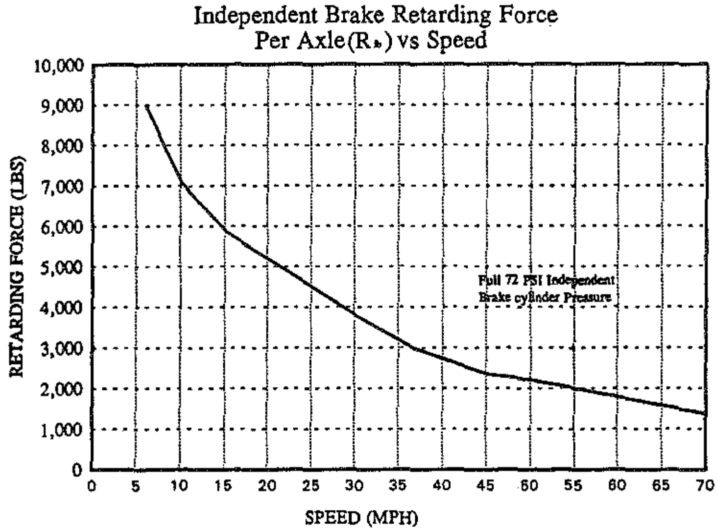


Exhibit 3.1

It should be noted that the independent brake force is highly dependent upon train speed. Train simulation models use more exact analysis.

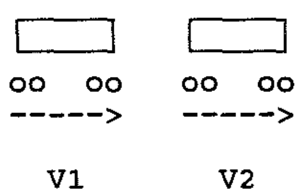
EXAMPLE: A locomotive consist with 16 axles (2 6-axle and 1 4-axle) moving 15 mph with a brake cylinder pressure of 18 psi will produce a retarding force of:

$$R_{tib} = (18/72) \times (6000) \times (16)$$

$$= 24,000 \text{ lbs.}$$

3.4 Slack

Slack (clearances) between cars can result in slack action forces being created by changing the relative velocity between two adjacent groups of cars.



V2 = V1 no slack action
V2 > V1 slack runs out
V2 < V1 slack runs in

If the difference between V1 and V2 becomes large enough, high in-train forces can develop causing severe run-in and run-out. A detailed description is contained in R-185 [5]. Further discussion of slack effects can be found in Sections 6.6 and 6.7.

4.0 EXCESSIVE TRAIN FORCES

4.1 Steady State Forces

Steady state forces are the basis for an initial computation of acceptable train make-up. Steady state forces are those that are applied for a relatively long period of time, such as steady pull up an ascending grade or retardation under dynamic brakes. Train longitudinal forces result in lateral track loading that may be significant depending on such factors as degree of curve and length of coupled cars. These forces, when large, can create three distinct problems:

4.1.1 Train Separation

Excessively high draft forces may exceed the strength of the materials used in the draft system resulting in mechanical failure and subsequent train separation. The knuckle is designed as the weak link, a mechanical "fuse", in this system. When draft forces approach levels that might damage a car, the knuckle fails instead of the car.

Currently, two different coupler system materials are used in North America, Grade C and Grade E steel. Grade C material, the weaker of the two, is normally used in unrestricted interchange equipment. It has an accepted working limit of 250,000 pounds in draft (ultimate design load limit is 300,000 lbs.[6]). When calculating general merchandise train make-up, this value is generally used to develop guidelines for train make-up and train handling.

Grade E equipment, sometimes known as "high tensile" or marked "HTE" equipment, has an accepted working limit of 350,000 pounds in draft (ultimate design load limit is 400,000 lbs.[6]). This type of equipment is generally restricted to unit train and special service operations. This value may be used to develop guidelines for train make-up and train handling where it is positively known that no Grade C equipment will be entrained.

The values for working limits were selected after reviewing coupler specifications and the coupler load environment data found in the AAR Mechanical Division "Manual of Standards and Recommended Practices" [7].

4.1.2 Stringlining

Even if draft forces are kept below the ultimate levels described in Section 4.1.1, difficulties can still arise in curves. Draft forces tend to stretch the train into a straight line, much like pulling on the ends of a looped string will force the string into a straight line; hence the term "stringlining". Large lateral loads are transmitted to the track under these conditions.

The track is designed to resist these forces under normal circumstances. Even though the track does withstand this force, cars with a high center of gravity that are empty or lightly loaded may turn over. This condition is made worse on track that is highly superelevated when the train is running at a low speed. See R-185, Section 2.5.2 [5]. On some track, the inside rail may turn over or the entire track structure may be pulled from the ballast to the inside of the curve. On stronger track, the wheels on the high side of the curve may lift and derail.

4.1.3 Jackknifing

The opposite situation from Section 4.1.2 occurs when the forces acting on a car are in the buff direction. Adjacent car bodies attempt to fold up similar to a jackknife when they are in this condition. Coupler angles create a lateral force similar to, but opposite in direction, from the stringlining case. The vehicle usually does not turn over but instead a wheel is induced to climb the rail or one rail will turn over.

A jackknifing derailment is usually accompanied by couplers which are angled within the car striker to their coupler angling limit.

4.2 Transient Forces

In addition to the steady state forces, transient forces also play an important role in train make-up. Transient forces are, by definition, of short duration. These transient forces are the result of train operations in areas of changing grades or from acceleration/deceleration of a train. Acceleration or deceleration usually only has the effect of a static increase in the steady state forces already present in a train. Effects of terrain are much more unpredictable and severe.

Proper train make-up is essential to avoid excessive transient forces in these situations. Evenly distributing tonnage throughout the train is the most desirable train make-up followed by concentrating tonnage on the head end. The worst case situation occurs when tonnage is concentrated on the rear end of the train behind empty or lightly loaded cars.

4.2.1 Crests

A crest refers to a change in gradient from uphill to downhill. The free play in the train adjusts from a slack-out condition to a slack-in condition. This creates a transient force as the slack runs in. This force can become sufficiently high to derail a car by jackknifing. The magnitude of this force increase is influenced by the following:

- Greater difference in gradient
- Higher speed of the train
- Faster rate of application of the air or dynamic brake at the top of the hill
- Tonnage distribution concentrated toward the rear of the train

4.2.2 Sags

A sag refers to change in gradient from downhill to uphill. The free play in the train adjusts from a slack-in condition to a slack-out condition. This creates a transient force as the slack runs out. This force can become sufficiently high to break a knuckle or other draft component or, if the train is in a curve, derail a car by stringlining. The magnitude of this force increase is influenced by the following:

- Greater difference in gradient
- Higher speed of the train
- Faster rate of application of power or release of air brakes at the bottom of the grade
- Tonnage distribution concentrated toward the rear of the train

4.2.3 Undulating Terrain

An undulating terrain combines the worst of the above two conditions; locations exist in the train where a crest and sag situation occurs at the same time but in two or more places in the train. Only good train make-up practices, coupled with good train handling techniques, will allow safe negotiation of such terrain. Tonnage should never be concentrated on the rear of a train that will encounter this type of terrain. Power and braking adjustments must be small and gradual.

5.0 DETAILED MAKE-UP GUIDELINES FOR NON-STANDARD CONDITIONS

Two methods are presented for arriving at acceptable trailing tonnages for long car/short car combinations. Included are several sample cases using both methods. The data is presented in both tabular and graphical form. Method 1 (Section 5.1) is used when train acceleration need not be considered, such as steady state operation up or down grades. Method 2 (Section 5.2) is used when consideration must be given to starting, accelerating, decelerating, or stopping trains.

Exhibit 5.1 below describes the car dimensions used to generate Exhibits 5.2 through 5.19 in this section. They are in all respects, conventional freight cars. For car lengths significantly different from those shown in Section 5.1 refer to Section 5.3.

	92'	58'	44'	38'
TRUCK CENTERS (Ft.)	64.00	43.75	31.00	25.25
LOPF[1] (Ft.)	92.00	57.75	44.00	37.75
COUPLER LENGTH (In.)	60.00	28.50	28.50	28.50
OVERHANG (Ft.)	14.00	7.00	6.50	6.25

Exhibit 5.1

5.1 Method 1 - No Acceleration

For the first method, it is assumed that the train is not accelerating or decelerating. On ascending grades, the train is assumed to be at balance speed. On descending grades the train is using dynamic brake to maintain a constant speed and will use air braking if the train is required to slow or stop. If dynamic brake is to be used to slow or stop, use Method 2.

The assumptions used for these guidelines are listed at the bottom of the tables. One-half of the trailing cars are assumed to occupy the degree of curve listed, thus, one-half of the value for curve resistance is used in the calculations. The limiting operating condition is listed directly under the tonnage for each situation. The other operating condition would be no less than what the exhibit shows.

[1]LOPF is the Length Over (Coupler) Pulling Face

Note that the tonnages are given as tons per ton of long car weight. This is a very important consideration since the car weights greatly affect the L/V ratio. More total trailing tonnage can be carried behind a loaded car than behind a light car.

5.1.1 Example

EXAMPLE: A 92'-44' combination is traversing a 1.5% grade in a 10° curve. The long car empty weight is 35 tons. From the table or the graph, a value of 147 tons/ton is extracted (Exhibit 5.4). The most critical situation will be in draft. The allowable trailing tonnage is:

$$TT = 147 \times 35 = 5{,}145 \text{ tons}$$

TRAILING TONNAGE PER TON OF LONG CAR
WEIGHT FOR A 92'-38' COMBINATION

DEGREE CURVE	TRAILING TONNAGE/TON OF LONG CAR WEIGHT					
	***************** GRADE ******************					
	0.0	0.5	1.0	1.5	2.0	2.5
2	5257 DRAFT	1821 DRAFT	892 BUFF	531 BUFF	378 BUFF	293 BUFF
4	2269 DRAFT	860 DRAFT	530 DRAFT	372 BUFF	262 BUFF	202 BUFF
6	1335 DRAFT	545 DRAFT	342 DRAFT	250 DRAFT	196 DRAFT	156 BUFF
8	897 DRAFT	390 DRAFT	249 DRAFT	183 DRAFT	145 DRAFT	120 DRAFT
10	650 DRAFT	299 DRAFT	194 DRAFT	144 DRAFT	114 DRAFT	95 DRAFT
12	496 DRAFT	239 DRAFT	157 DRAFT	117 DRAFT	94 DRAFT	78 DRAFT
14	392 DRAFT	197 DRAFT	132 DRAFT	99 DRAFT	79 DRAFT	66 DRAFT
16	318 DRAFT	166 DRAFT	112 DRAFT	85 DRAFT	68 DRAFT	57 DRAFT
18	264 DRAFT	142 DRAFT	98 DRAFT	74 DRAFT	60 DRAFT	50 DRAFT
20	223 DRAFT	124 DRAFT	86 DRAFT	66 DRAFT	53 DRAFT	45 DRAFT

NOTES:		
	MAXIMUM DBF	(DRAFT) 250 KIP (BUFF) 250 KIP
	DAVIS RESISTANCE	4.5 LBS/TON
	CURVE RESISTANCE	0.4 LBS/TON/° CURVE
	ASSUMED TRUCKSIDE L/V RATIO	0.82
	MAXIMUM ACCELERATION RATE	0 MI/HR/MIN
	MAXIMUM DECELERATION RATE	0 MI/HR/MIN

Exhibit 5.2

TRAILING TONNAGE PER TON OF LONG CAR WEIGHT FOR A 92'-38' COMBINATION

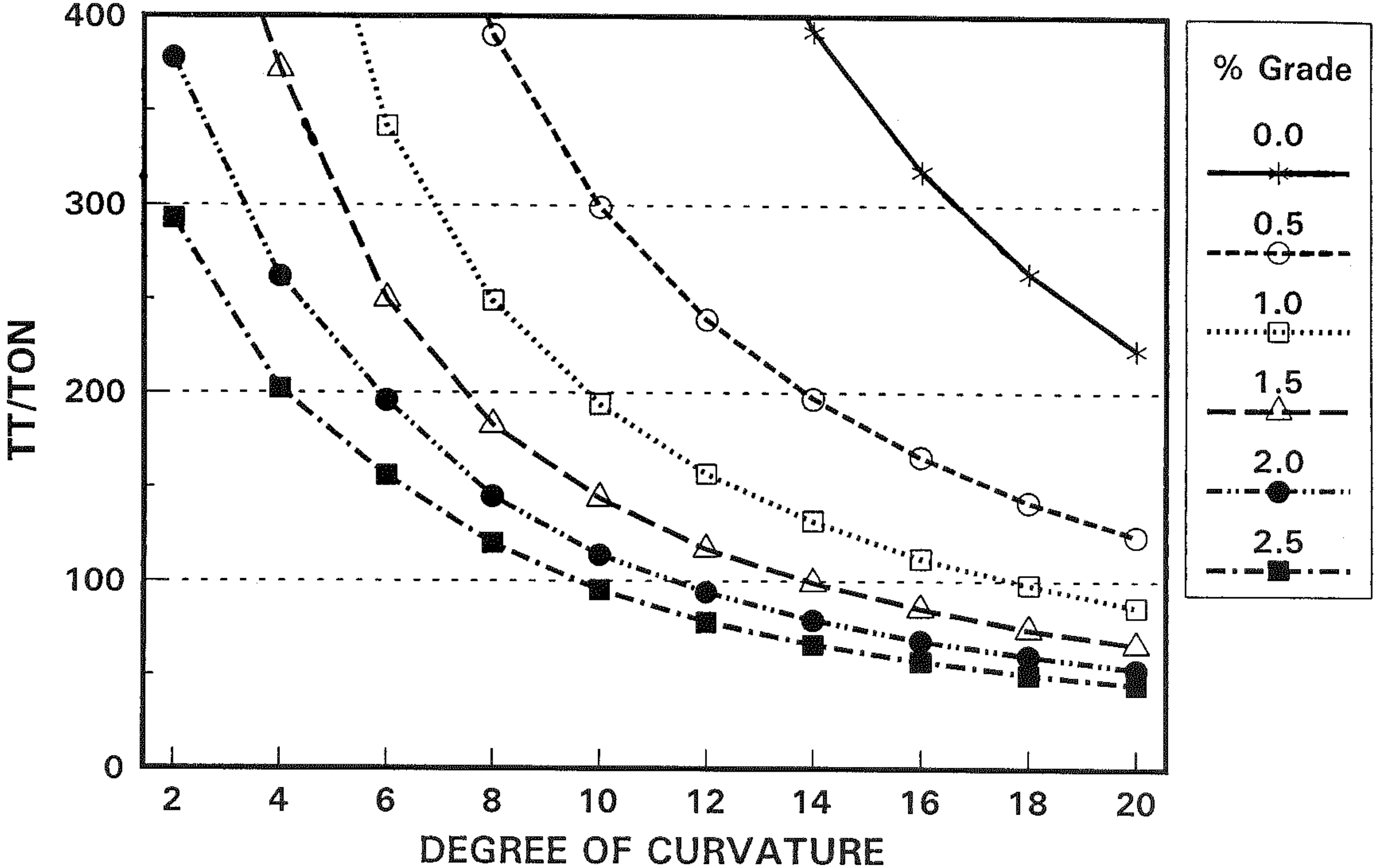


Exhibit 5.3

TRAILING TONNAGE PER TON OF LONG CAR WEIGHT FOR A 92'-44' COMBINATION

DEGREE CURVE	TRAILING TONNAGE/TON OF LONG CAR WEIGHT *************** GRADE *****************					
	0.0	0.5	1.0	1.5	2.0	2.5
2	5257 DRAFT	1821 DRAFT	919 BUFF	547 BUFF	389 BUFF	302 BUFF
4	2301 DRAFT	872 DRAFT	538 DRAFT	383 BUFF	270 BUFF	208 BUFF
6	1360 DRAFT	555 DRAFT	349 DRAFT	254 DRAFT	200 DRAFT	161 BUFF
8	916 DRAFT	398 DRAFT	255 DRAFT	187 DRAFT	148 DRAFT	122 DRAFT
10	665 DRAFT	306 DRAFT	198 DRAFT	147 DRAFT	117 DRAFT	97 DRAFT
12	507 DRAFT	245 DRAFT	161 DRAFT	120 DRAFT	96 DRAFT	80 DRAFT
14	401 DRAFT	202 DRAFT	135 DRAFT	101 DRAFT	81 DRAFT	67 DRAFT
16	326 DRAFT	170 DRAFT	115 DRAFT	87 DRAFT	70 DRAFT	58 DRAFT
18	271 DRAFT	146 DRAFT	100 DRAFT	76 DRAFT	61 DRAFT	51 DRAFT
20	229 DRAFT	127 DRAFT	88 DRAFT	67 DRAFT	54 DRAFT	46 DRAFT

NOTES:

MAXIMUM DBF	(DRAFT) 250 KIP (BUFF) 250 KIP
DAVIS RESISTANCE	4.5 LBS/TON
CURVE RESISTANCE	0.4 LBS/TON/° CURVE
ASSUMED TRUCK SIDE L/V RATIO	0.82
MAXIMUM ACCELERATION RATE	0 MI/HR/MIN
MAXIMUM DECELERATION RATE	0 MI/HR/MIN

Exhibit 5.4

TRAILING TONNAGE PER TON OF LONG CAR WEIGHT FOR A 92'-44' COMBINATION

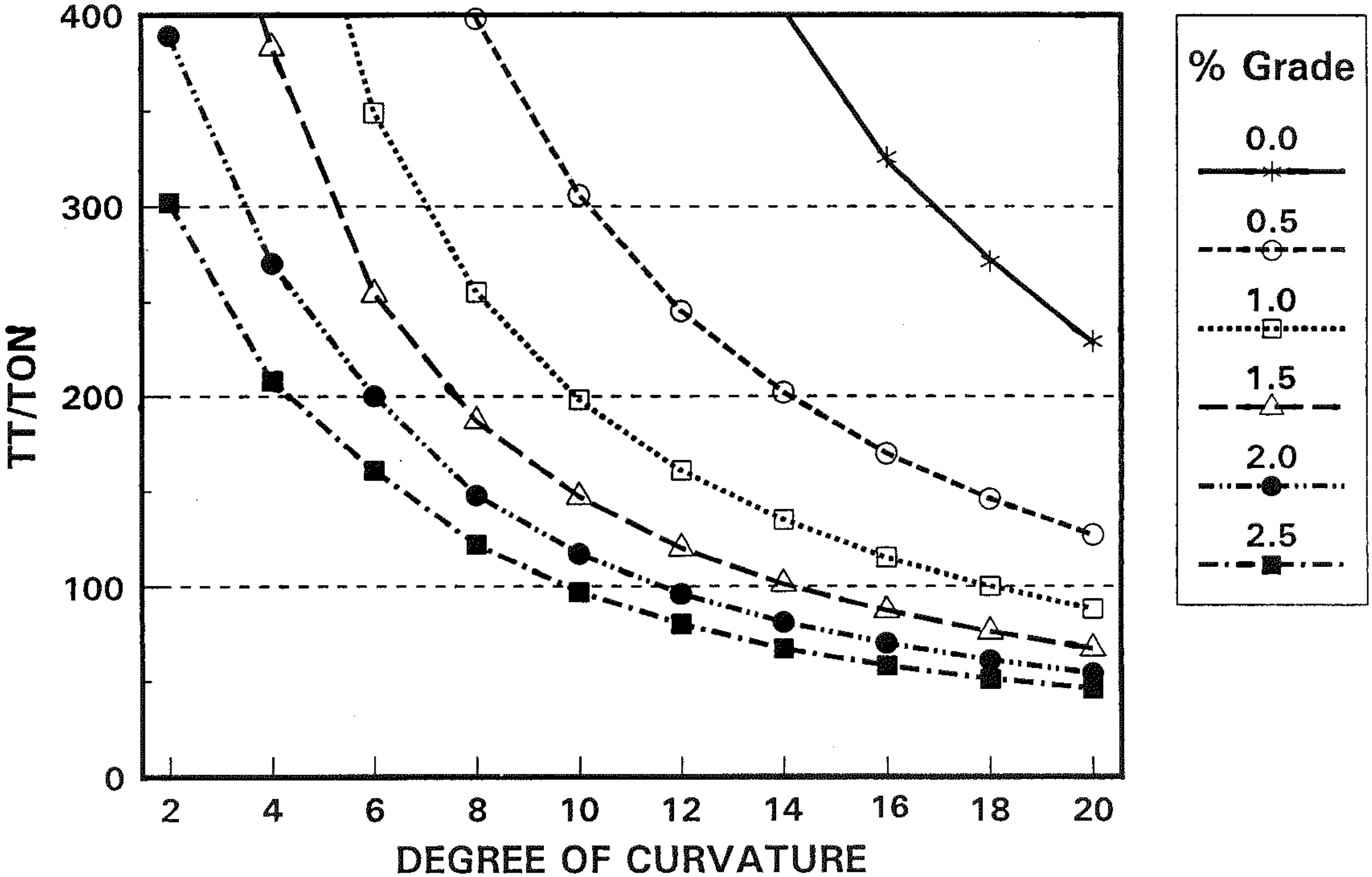


Exhibit 5.5

TRAILING TONNAGE PER TON OF LONG CAR WEIGHT FOR A 92'-58' COMBINATION

DEGREE CURVE	TRAILING TONNAGE/TON OF LONG CAR WEIGHT					
	*************** GRADE	*****************				
	0.0	0.5	1.0	1.5	2.0	2.5
2	5608 DRAFT	1943 DRAFT	948 BUFF	564 BUFF	402 BUFF	312 BUFF
4	2464 DRAFT	934 DRAFT	576 DRAFT	400 BUFF	282 BUFF	218 BUFF
6	1459 DRAFT	596 DRAFT	374 DRAFT	273 DRAFT	215 DRAFT	169 BUFF
8	983 DRAFT	428 DRAFT	273 DRAFT	201 DRAFT	159 DRAFT	131 DRAFT
10	714 DRAFT	328 DRAFT	213 DRAFT	158 DRAFT	125 DRAFT	104 DRAFT
12	545 DRAFT	263 DRAFT	173 DRAFT	129 DRAFT	103 DRAFT	85 DRAFT
14	431 DRAFT	216 DRAFT	145 DRAFT	109 DRAFT	87 DRAFT	72 DRAFT
16	350 DRAFT	183 DRAFT	123 DRAFT	93 DRAFT	75 DRAFT	63 DRAFT
18	290 DRAFT	157 DRAFT	107 DRAFT	82 DRAFT	66 DRAFT	55 DRAFT
20	245 DRAFT	136 DRAFT	94 DRAFT	72 DRAFT	58 DRAFT	49 DRAFT

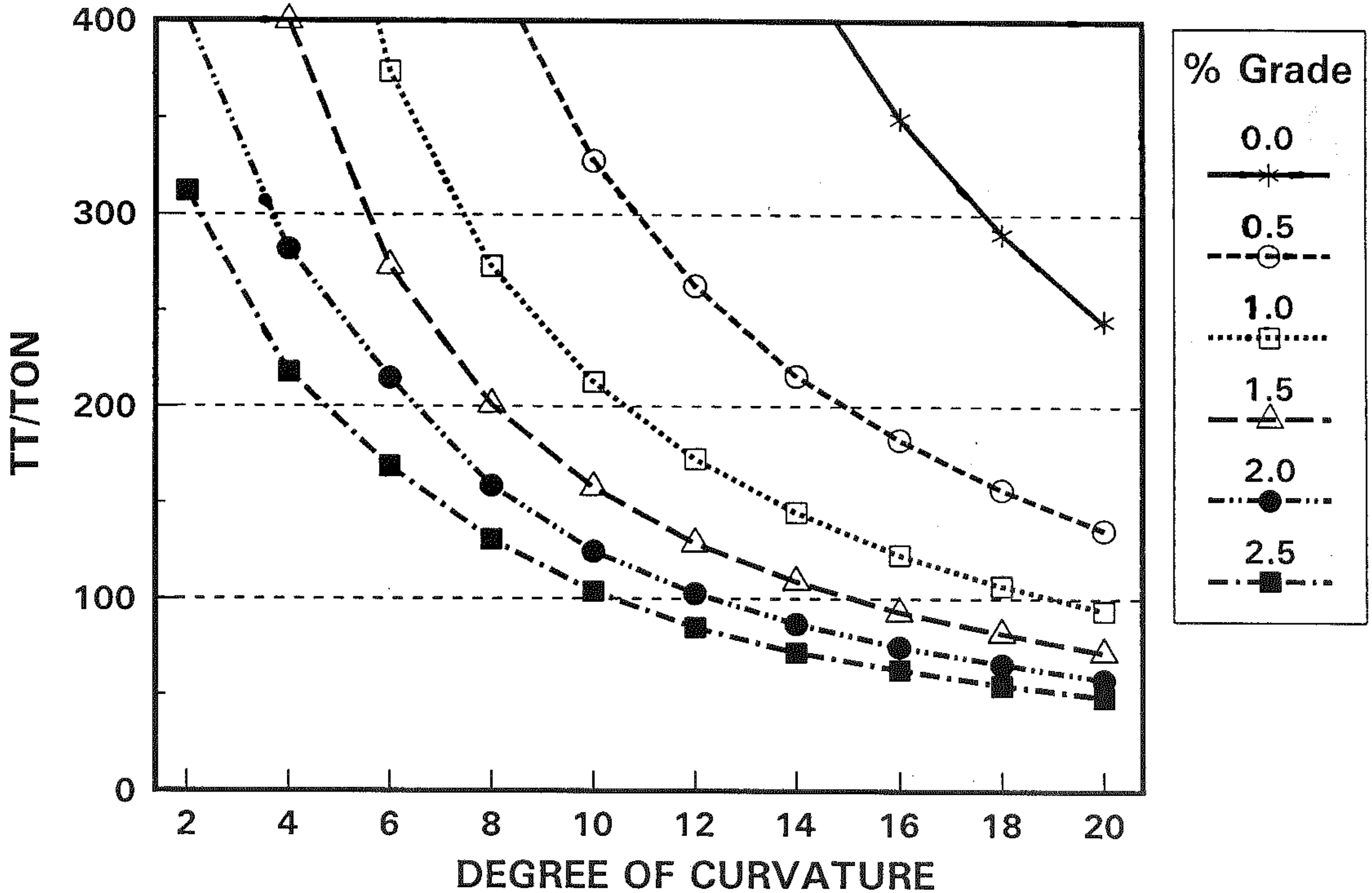
NOTES:

MAXIMUM DBF	(DRAFT) 250 KIP (BUFF) 250 KIP
DAVIS RESISTANCE	4.5 LBS/TON
CURVE RESISTANCE	0.4 LBS/TON/° CURVE
ASSUMED TRUCK SIDE L/V RATIO	0.82
MAXIMUM ACCELERATION RATE	0 MI/HR/MIN
MAXIMUM DECELERATION RATE	0 MI/HR/MIN

Exhibit 5.6

Exhibit 5.7

TRAILING TONNAGE PER TON OF LONG CAR WEIGHT FOR A 92'-58' COMBINATION



5.2 Method 2 - Limited Maximum Drawbar Force

This method takes a slightly different approach for calculating trailing tonnage. It assumes that the engineer will control his maximum drawbar force to ± 250 KIP when starting, accelerating, decelerating, or stopping his train. This method will allow for the forces required to accelerate and decelerate a train.

When calculated in this mode, one must compute the position of the long car/short car consist in the train in terms of total train tonnage. The data is presented in both tabular and graphical forms as a function of long car weight. Note that the percentages are the total train tonnages that can *trail* the long car/short car combination.

An example for Section 5.2 follows the graphs and tables.

5.2.1 Ascending Grades or Descending Grades Using Air Brake Only.

The tables and graphs in this section should be used for trains that do not use dynamic brake. These trains are most critical in the ascending direction because the air brakes tend to distribute the forces throughout the train in the descending direction.

5.2.2 Example

EXAMPLE: A 92'-44' combination is to be placed in a train of 8,500 tons that will rely on air brakes only. The 92 foot car weighs 50 tons and the maximum curvature is 14° which is located on an ascending grade. From Exhibit 5.10, a figure of 81% is extracted. Thus the allowable trailing tonnage is:

TT = .81 x 8500 = 6885 tons

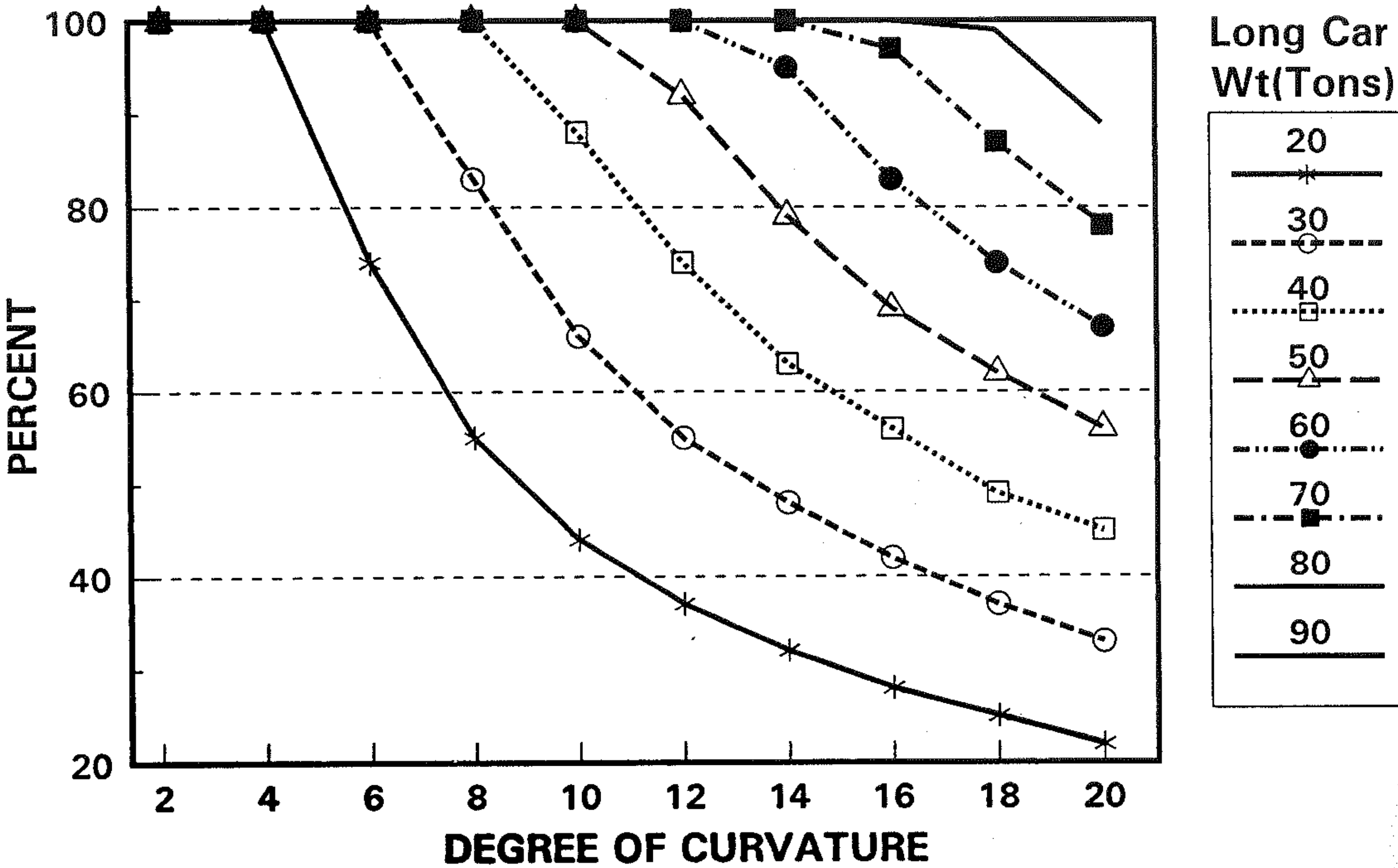
PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A
92'-38' COMBINATION
WITH 250 KIPS DBF (ASCENDING GRADES)

DEGREE CURVE	LONG CAR WEIGHT (TONS) 20	30	40	50	60	70	80	90	100
2	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
4	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
6	74%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
8	55%	83%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
10	44%	66%	88%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
12	37%	55%	74%	92%	**100%**	**100%**	**100%**	**100%**	**100%**
14	32%	48%	63%	79%	95%	**100%**	**100%**	**100%**	**100%**
16	28%	42%	56%	69%	83%	97%	**100%**	**100%**	**100%**
18	25%	37%	49%	62%	74%	87%	99%	**100%**	**100%**
20	22%	33%	45%	56%	67%	78%	89%	**100%**	**100%**

Exhibit 5.8

Exhibit 5.9

PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A 92' -38' COMBINATION WITH 250 KIPS DBF (ASCENDING GRADE)



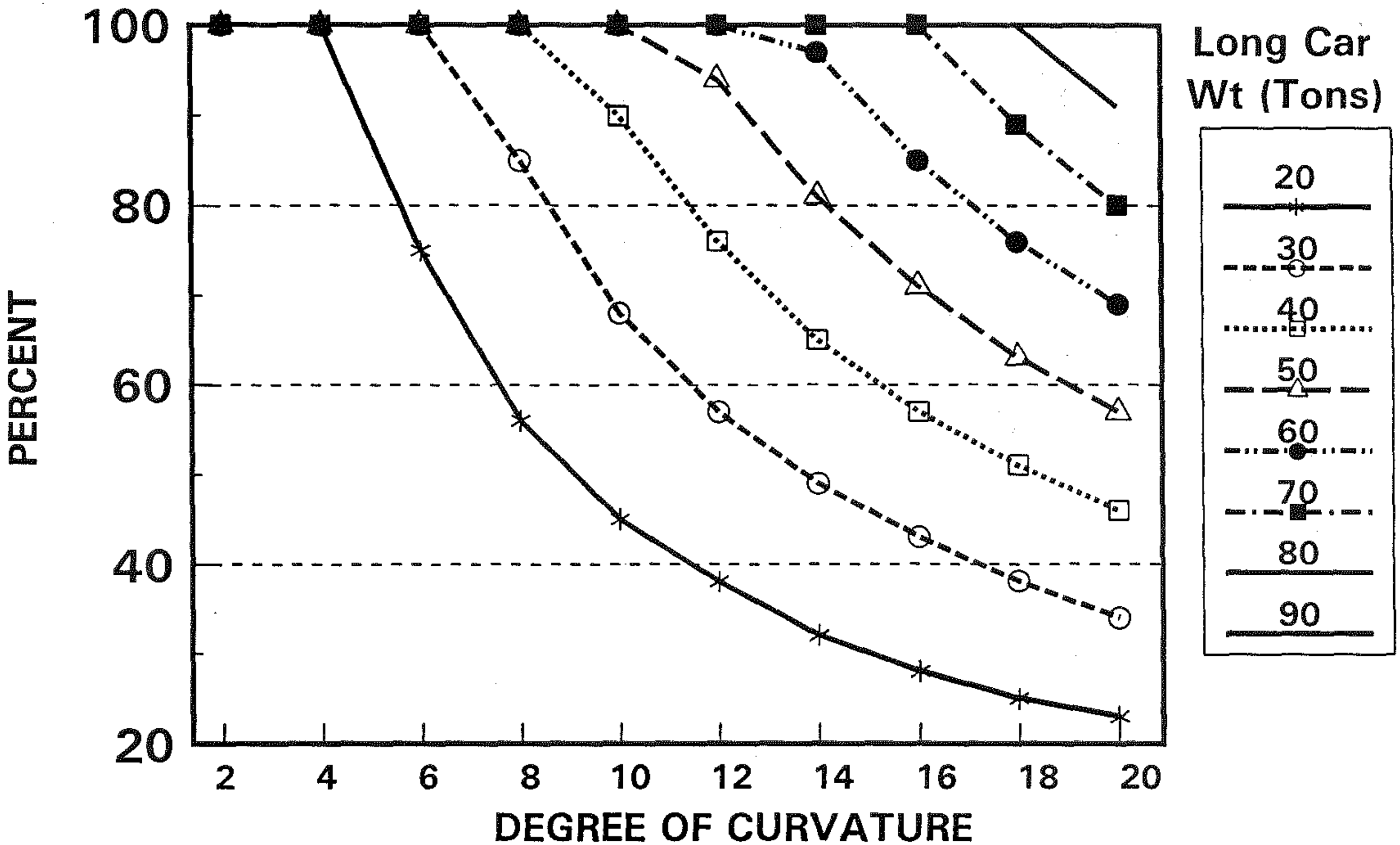
PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A
92'-44' COMBINATION
WITH 250 KIPS DBF (ASCENDING GRADE)

DEGREE CURVE	LONG CAR WEIGHT (TONS) 20	30	40	50	60	70	80	90	100
2	100%	100%	100%	100%	100%	100%	100%	100%	100%
4	100%	100%	100%	100%	100%	100%	100%	100%	100%
6	75%	100%	100%	100%	100%	100%	100%	100%	100%
8	56%	85%	100%	100%	100%	100%	100%	100%	100%
10	45%	68%	90%	100%	100%	100%	100%	100%	100%
12	38%	57%	76%	94%	100%	100%	100%	100%	100%
14	32%	49%	65%	81%	97%	100%	100%	100%	100%
16	28%	43%	57%	71%	85%	100%	100%	100%	100%
18	25%	38%	51%	63%	76%	89%	100%	100%	100%
20	23%	34%	46%	57%	69%	80%	91%	100%	100%

Exhibit 5.10

Exhibit 5.11

PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A 92' -44' COMBINATION WITH 250 KIPS DBF (ASCENDING GRADE)



PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A 92'-58' COMBINATION WITH 250 KIPS DBF (ASCENDING GRADE)

DEGREE CURVE	LONG CAR WEIGHT (TONS) 20	30	40	50	60	70	80	90	100
2	100%	100%	100%	100%	100%	100%	100%	100%	100%
4	100%	100%	100%	100%	100%	100%	100%	100%	100%
6	81%	100%	100%	100%	100%	100%	100%	100%	100%
8	61%	91%	100%	100%	100%	100%	100%	100%	100%
10	49%	73%	97%	100%	100%	100%	100%	100%	100%
12	41%	61%	81%	100%	100%	100%	100%	100%	100%
14	35%	52%	70%	87%	100%	100%	100%	100%	100%
16	31%	46%	61%	76%	92%	100%	100%	100%	100%
18	27%	41%	54%	68%	82%	95%	100%	100%	100%
20	25%	37%	49%	61%	74%	86%	98%	100%	100%

Exhibit 5.12

PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A 92' -58' COMBINATION WITH 250 KIPS DBF (ASCENDING GRADE)

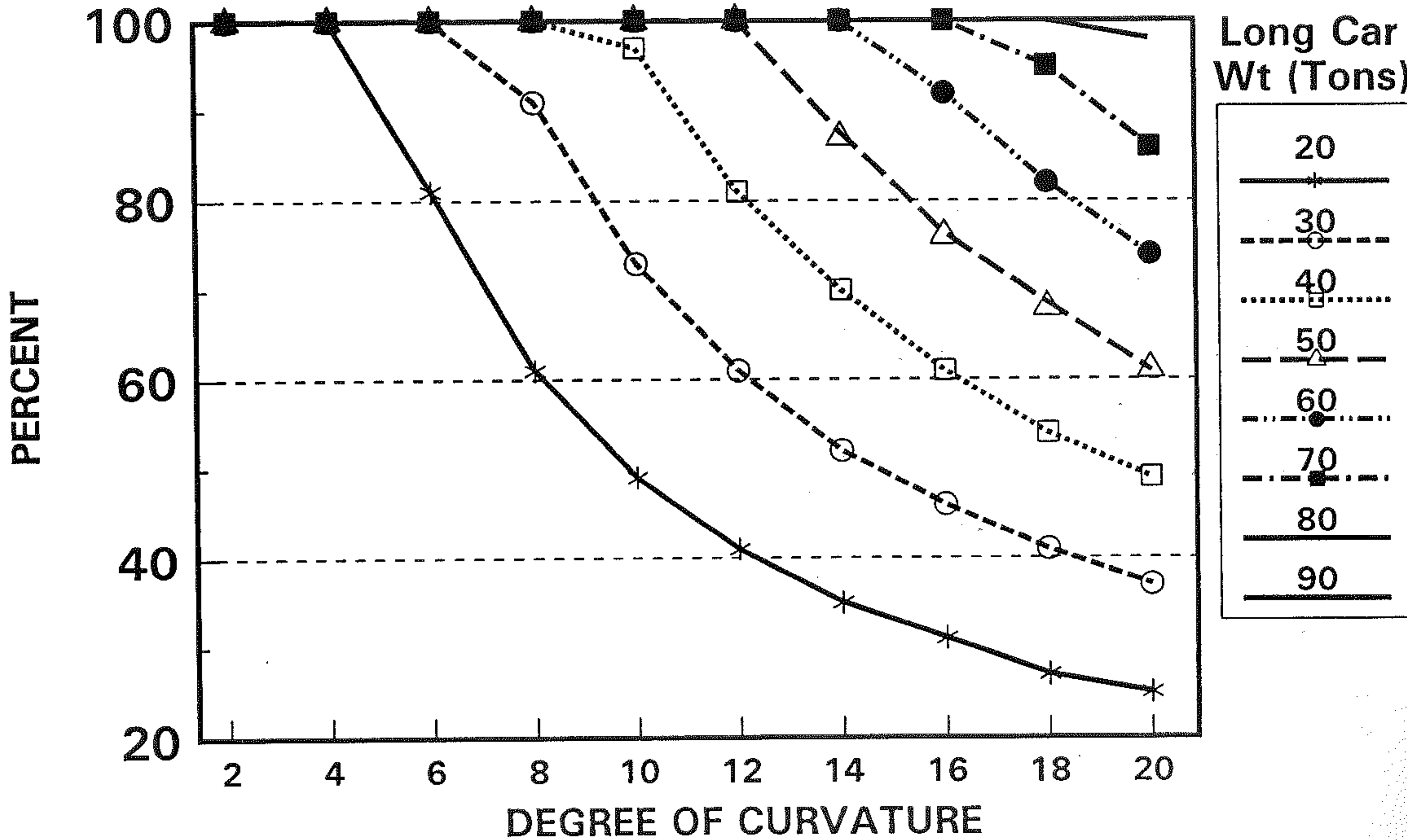


Exhibit 5.13

5.2.3 Descending Grades Using Only Dynamic Brake

The tables and graphs in this section should be used for trains that use only dynamic braking in the descending direction. The train forces are concentrated at the head end in this situation and it becomes the governing condition.

The combined use of air and dynamic brake will result in a less critical situation than shown in this Section.

5.2.4 Example

EXAMPLE: A 92'-44' combination is to be placed in a train of 8,500 tons that will use only dynamic brake. The 92' car weighs 50 tons, and the maximum curvature is 14° which will be traversed on a descending grade. From the table or the graph, a figure of 70% is extracted. Thus the allowable trailing tonnage is:

TT = .70 x 8,500 = 5,950 tons

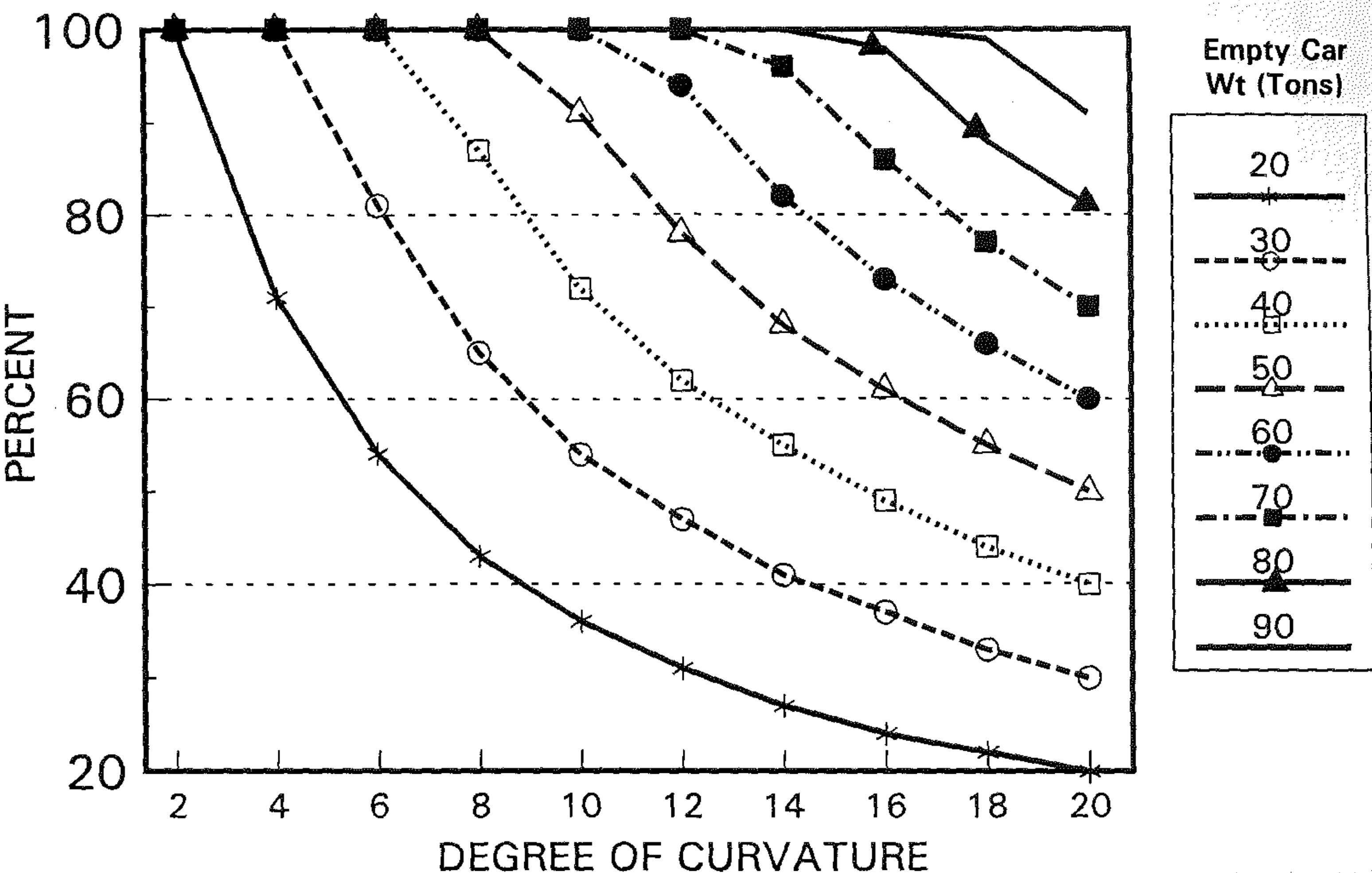
PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A
92'-38' COMBINATION
WITH 250 KIPS DBF (DESCENDING GRADE)

DEGREE CURVE	LONG CAR WEIGHT (TONS) 20	30	40	50	60	70	80	90	100
2	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
4	71%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
6	54%	81%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
8	43%	65%	87%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
10	36%	54%	72%	91%	**100%**	**100%**	**100%**	**100%**	**100%**
12	31%	47%	62%	78%	94%	**100%**	**100%**	**100%**	**100%**
14	27%	41%	55%	68%	82%	96%	**100%**	**100%**	**100%**
16	24%	37%	49%	61%	73%	86%	98%	**100%**	**100%**
18	22%	33%	44%	55%	66%	77%	88%	99%	**100%**
20	20%	30%	40%	50%	60%	70%	81%	91%	**100%**

Exhibit 5.14

Exhibit 5.15

PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A 92' -38' COMBINATION WITH 250 KIPS DBF (DESCENDING GRADE)



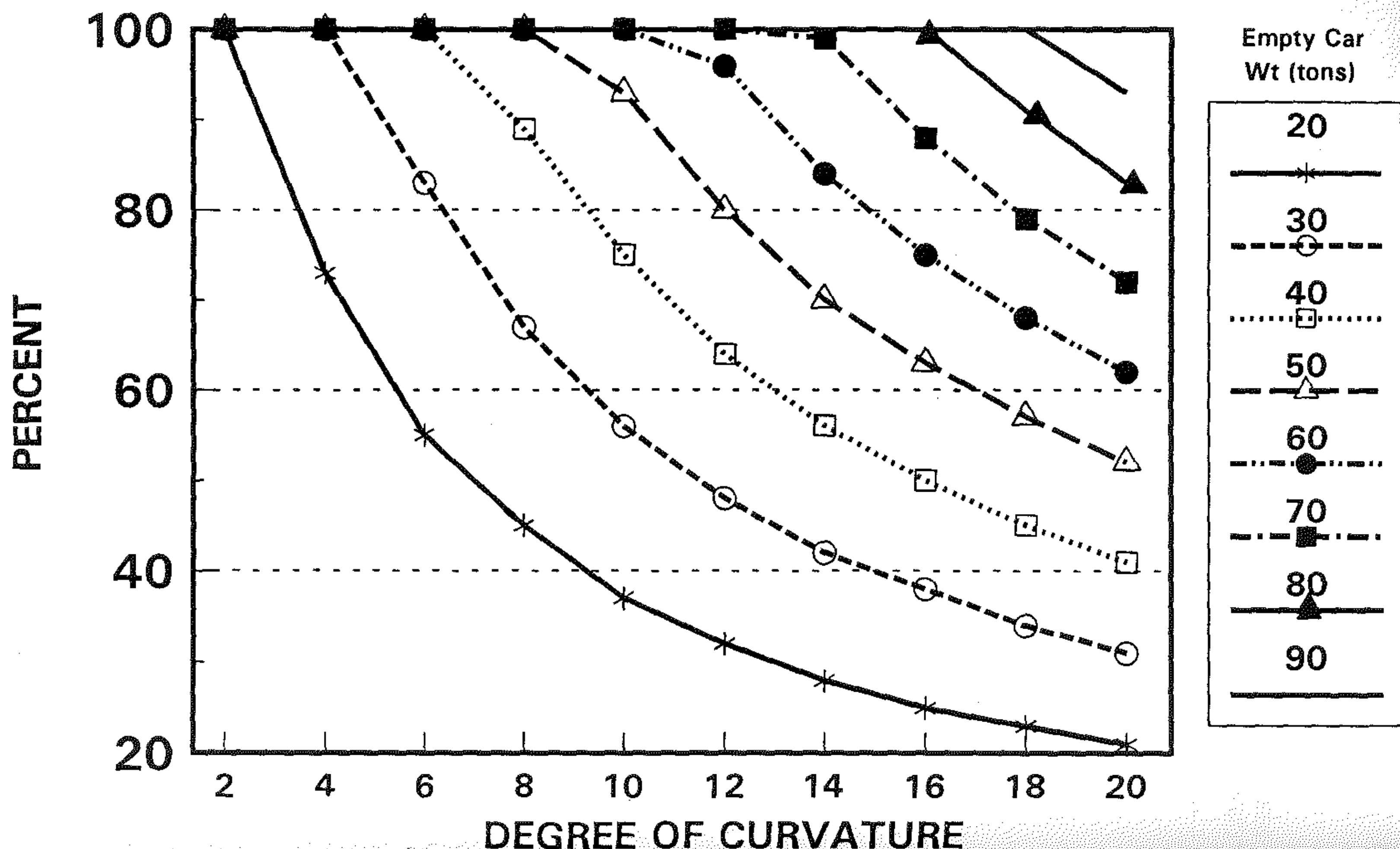
PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A
92'-44' COMBINATION
WITH 250 KIPS DBF (DESCENDING GRADE)

	LONG CAR WEIGHT (TONS)								
DEGREE CURVE	20	30	40	50	60	70	80	90	100
2	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
4	73%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
6	55%	83%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
8	45%	67%	89%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
10	37%	56%	75%	93%	**100%**	**100%**	**100%**	**100%**	**100%**
12	32%	48%	64%	80%	96%	**100%**	**100%**	**100%**	**100%**
14	28%	42%	56%	70%	84%	99%	**100%**	**100%**	**100%**
16	25%	38%	50%	63%	75%	88%	**100%**	**100%**	**100%**
18	23%	34%	45%	57%	68%	79%	91%	**100%**	**100%**
20	21%	31%	41%	52%	62%	72%	83%	93%	**100%**

Exhibit 5.16

Exhibit 5.17

PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL
A 92' -44' COMBINATION
WITH 250 KIPS DBF (DESCENDING GRADE)



PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL A
92'-58' COMBINATION
WITH 250 KIPS DBF (DESCENDING GRADE)

DEGREE CURVE	LONG CAR WEIGHT (TONS) 20	30	40	50	60	70	80	90	100
2	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
4	77%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
6	58%	87%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
8	47%	71%	94%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
10	40%	59%	79%	99%	**100%**	**100%**	**100%**	**100%**	**100%**
12	34%	51%	68%	85%	**100%**	**100%**	**100%**	**100%**	**100%**
14	30%	45%	60%	75%	90%	**100%**	**100%**	**100%**	**100%**
16	27%	40%	53%	67%	80%	94%	**100%**	**100%**	**100%**
18	24%	36%	48%	60%	72%	85%	97%	**100%**	**100%**
20	22%	33%	44%	55%	66%	77%	88%	99%	**100%**

Exhibit 5.18

PERCENT OF TOTAL TRAIN TONNAGE TO TRAIL
A 92' -58' COMBINATION
WITH 250 KIPS DBF (DESCENDING GRADE)

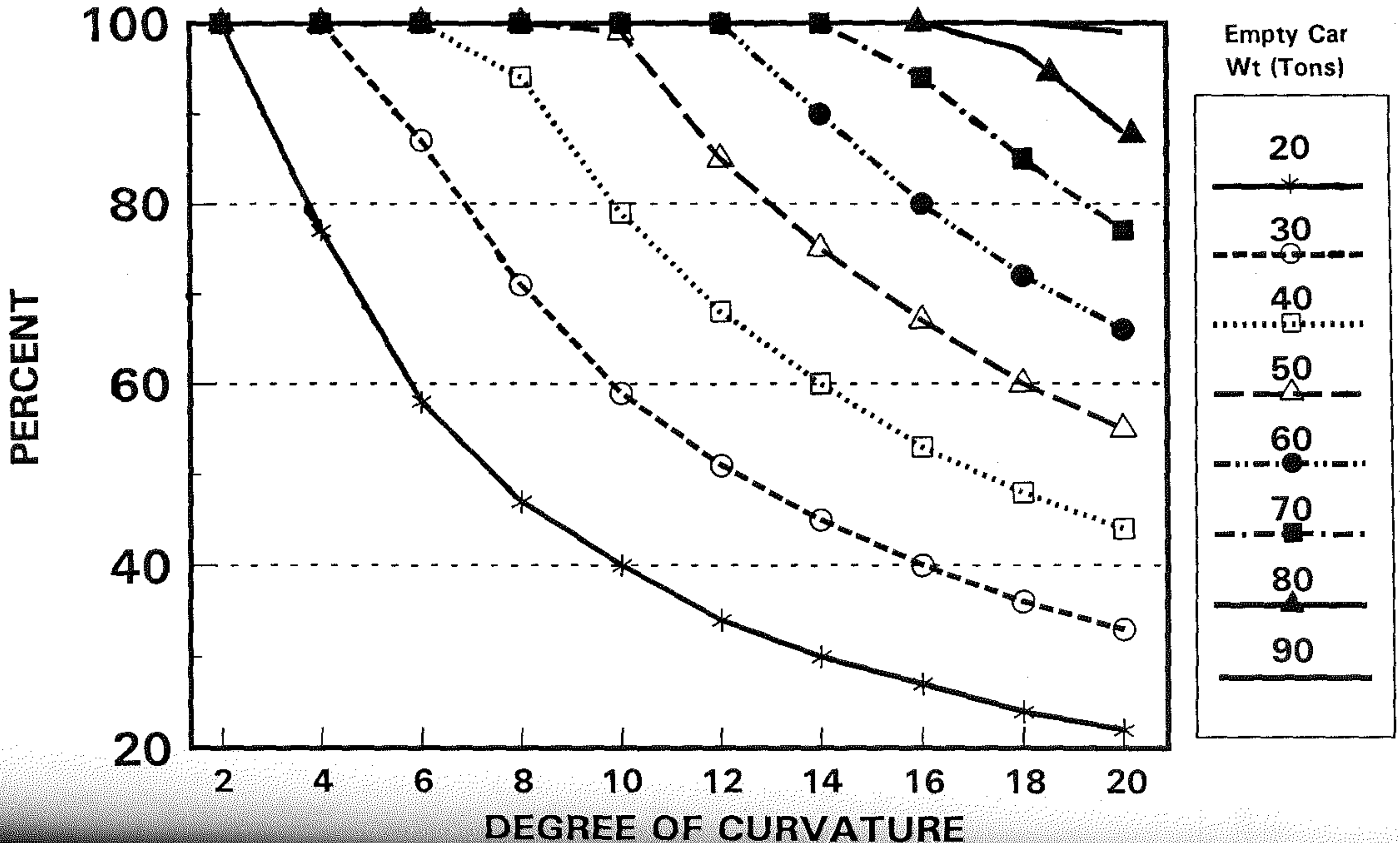


Exhibit 5.19

5.3 Non-standard Conversions

Should the actual car lengths differ from those in the examples given in Sections 5.1 and 5.2, use Exhibits 5.20 and 5.21 to convert for these differences. Simply multiply the number found for the 92'-44' combination by the appropriate factors found in the graphs.

5.3.1 Adjustments For Non-Standard Car Lengths

EXAMPLE: To adjust the example given in Section 5.1.1 for an 85'-48' combination, extract a value for the 85' car of 1.38 and a value of 1.015 for the 48' car from the tables.

TT = 8,820 x 1.38 x 1.015 = 12,354 tons

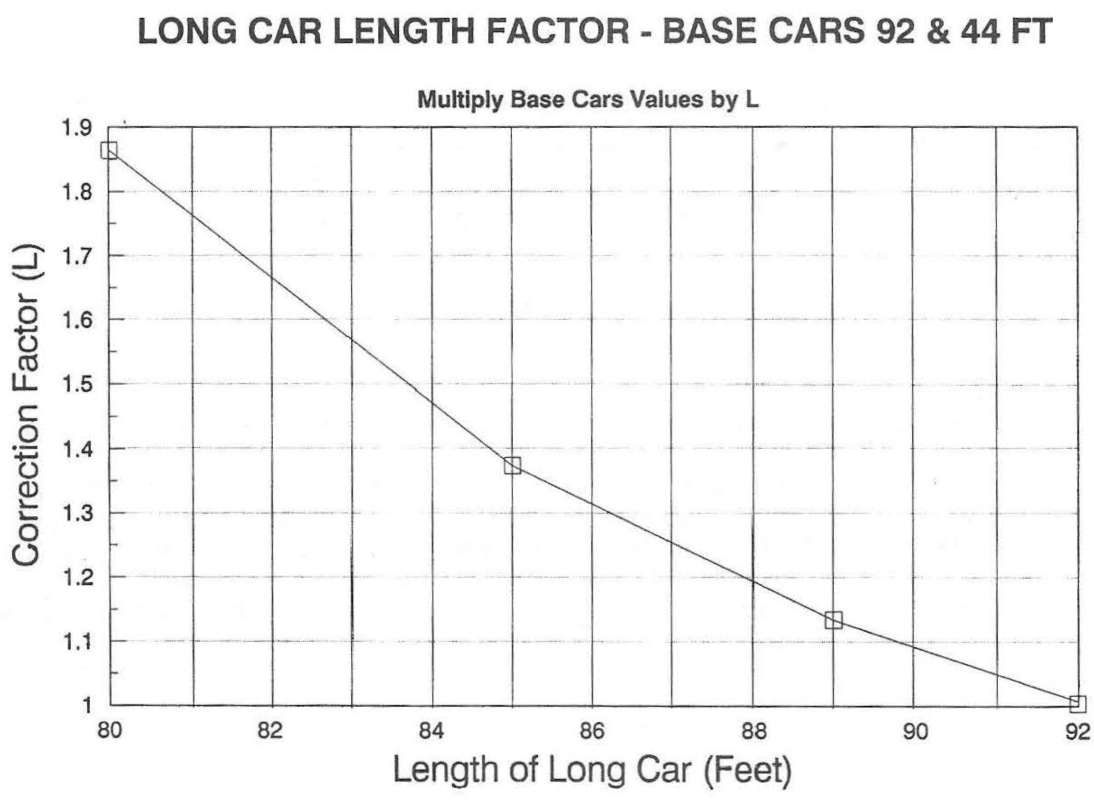


Exhibit 5.20

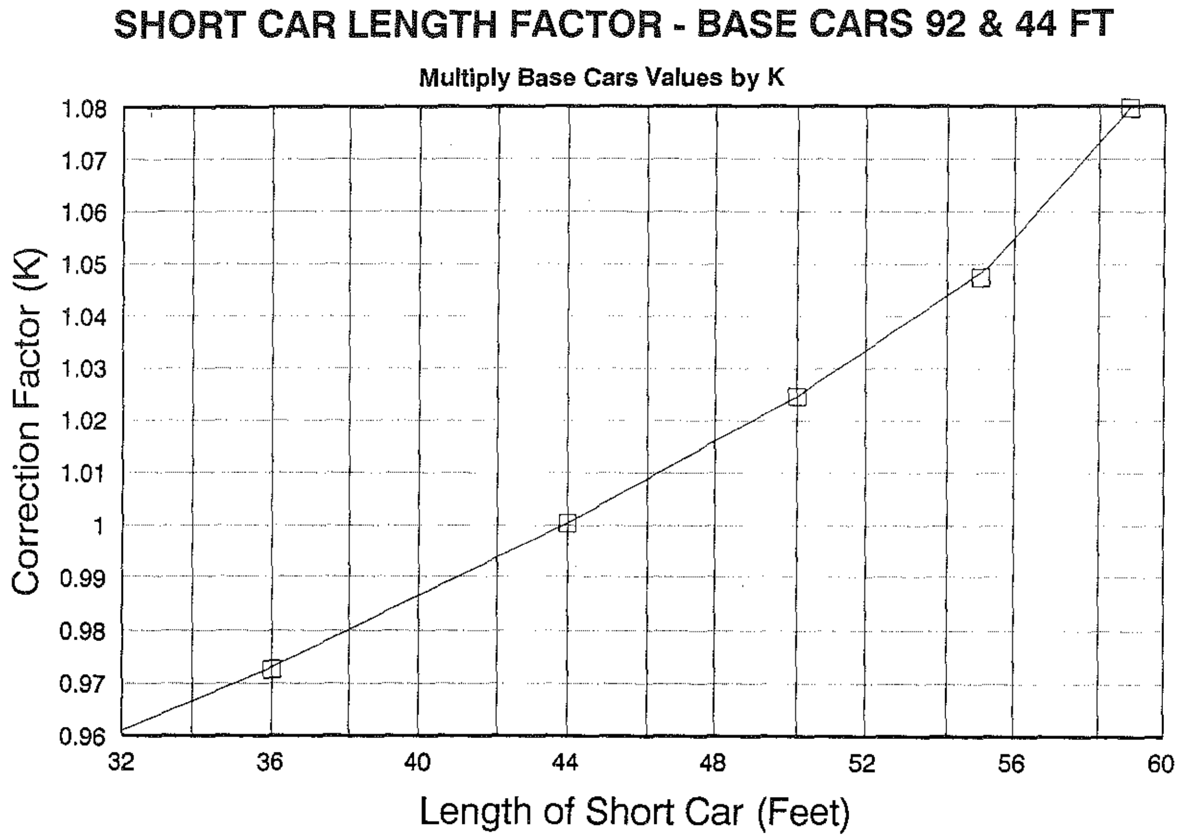


Exhibit 5.21

5.3.2 Adjustment For A Lightweight Short Car

If the short car weight is less than 50% of the long car weight, the short car weight (instead of the long car weight) should be used for calculations in Sections 5.1 and 5.2. This is because the short car coupler angle is almost always less than half of the long car coupler angle.

6.0 SPECIAL CAR CASES

This section describes certain types of cars that are physically different from conventional cars and some of which are known to create operational problems. Most of these cars are of new designs which have been introduced into service in recent years. Some of these may in fact not be approved for full interchange, but are operated by agreement between railroads. As information, the AAR Manual of Standards and Recommended Practices [7] defines a requirement to test new car designs on a 10 degree curve (or greater) under a steady buff/draft load of 200,000 lbs. without wheel lift or truck/carbody separation. This should not be construed to mean that cars can be operated regularly at this load level on 10 degree curves. It is not intended to minutely describe these conditions in this section, but to provide general information and sufficient warning to those who are responsible for train make-up.

6.1 Multiple Platform Cars

These cars can be classified into two categories: those with stand-alone two-truck platforms interconnected with either solid drawbars or non-operable conventional couplers, and those with articulated platforms sharing a common truck. Both multiple platform car types have conventional couplers at each end of each platform.

The first category can be evaluated like a conventional freight car. The second category can be evaluated by considering the tonnage trailing each of three types of "coupler" connections on a multi-unit car, namely, the connection (articulated) between two intermediate platforms (units), the connection between the end units of two multi-unit cars, and the coupler connection between the end unit of a multi-unit freight car and a conventional freight car. To estimate the allowable trailing tonnage, the procedure in Section 10 can be used, including the use of the coupler angle formulas in Exhibit 10.1. However, it should be noted that the make-up problems caused by multi-platform articulated shared truck cars are not the result of the articulated shared truck but are the result of a lighter tare weight. The truck and car geometry of articulated shared truck cars are an improvement over the conventional freight car. However, in these cars, the increased L/V ratio due to reduced vertical load must be considered and may be the limiting condition. While no definitive minimum content weight (below which this becomes a limiting condition) has been established, some railroads consider content weights below 13 tons per platform to be worth a "second" look. It is recommended that each railroad establish their own criteria in this regard, based on tare weight, geometry, and dynamic slack action.

6.2 Single Axle Cars

These cars can be considered as normal freight cars when using the formulas in this manual. The formulas assume a truck side L/V ratio which, in the case of single axle cars, is the same as the wheel L/V. Even more critical in these cars is the tare weight. Because of extremely low tare weights (26,000 lb.), L/V ratio can become critical if these cars are entrained ahead of heavier cars. Sharp vertical curves at crests, such as in yards and at crossovers, can significantly contribute to wheel unloading.

6.3 Cars With Increased Lateral Truck Clearances

Some cars are equipped with special trucks that allow larger lateral displacements of the truck bolster than are normally found in a standard three piece truck. These cars include some cabooses and single axle cars. This design improves the ride quality of the vehicle. These trucks can allow much larger coupler angles to develop in buff due to the increased car body angles allowed by these trucks. This makes the jackknifing situation much worse than the typical long car-short car case.

It is recommended that cars equipped with this type of truck be entrained towards the rear. Also, cars so equipped should not be shoved against. If they are entrained in these locations, a larger than normal value for lateral displacement should be substituted in the formulas in Section 10, to calculate an acceptable train make-up.

6.4 Long Car Equipped With 43" Couplers

While the majority of these cars have been retired from service or fitted with the longer 60" couplers, some still remain in service. Because of the long overhang of these long cars, the drawbar length becomes extremely critical. When coupled to a car shorter than 45 feet, this combination becomes the most critical train make-up problem in existence. It should be noted that the analyses in Section 5 assume a 60" coupler for long cars.

6.5 Long Car/Long Car In Crossover

This situation can become critical where there is less than one car length of track in between the lead curves of the switches in a crossover. It becomes more severe for the sharper turnouts (#10 and less). The problem is caused by the long overhang on these long cars. Consideration should be given in yards for this train make-up by limiting the routes traversed to areas where the above mentioned problem is minimized.

6.6 End-of-Car Cushioning (EOC)

EOC devices were designed to eliminate shocks and subsequent lading damage in yard impacts. Unfortunately, they also contribute to the amount of slack in a train. Operation of trains containing a large amount of such devices can greatly increase the dynamic forces in the train. For further information, see AAR Report R-718 [8]. No firm guidelines exist for operation of cars with EOC cushioning; however, at the time of publication, several North American roads operate no more than 40 cars equipped with these devices entrained in a block. Also, large blocks of EOC equipped cars should not be entrained ahead of large blocks of loaded cars with conventional draft gears (see Section 6.7). Adequate simulation of EOC equipped cars can be performed with the TOES model [3][4].

6.7 Slack Considerations In Train Make-Up

The free play between freight cars is directly proportional to the magnitude of slack action in a train. The greater the free play, the higher the slack forces. A good rule of thumb for entraining cars with various amounts of slack is to place the cars with the least amount of slack on the head end and the most amount of slack on the rear. Thus, slackless cars such as articulated cars should be entrained ahead of cars with conventional draft gears, which in turn should be entrained ahead of cars with EOC units.

7.0 HARMONIC MOTION

The purpose of this section is to provide an awareness of freight car dynamics particularly harmonic motion, which is commonly encountered in revenue service. Certain car types are known to be more prone to truck hunting while others are well known as "rockers."

Three different types of harmonic motion should be considered when evaluating train make-up. These conditions are very sensitive to train speed, but are usually insensitive to train length and tonnage. Their affect on train make-up is strictly in the area of projected train speeds. A detailed description of harmonic freight car motion can be found in R-185 [5].

7.1 Truck Hunting

This instability occurs at speeds in excess of 45 mph in cars that are empty or lightly loaded. It consists of a yawing and twisting motion of the car body around the center of the car. Sufficiently large excursions can be developed in the car body to cause high lateral and low vertical forces that result in wheel climb. If the mechanical wear in the truck components is excessive, truck hunting may occur at speeds as low as 35 mph.

Tangent track with welded rail is the location where truck hunting may be expected to occur. Curvature of greater than about 1.0 degree is sufficient to suppress the truck hunting phenomenon. Poor track alignment and surface decreases the likelihood of truck hunting, but increases the possibility of derailment should a hunting car be present in the consist. Cars with relatively heavy ends, such as bulkhead flat cars, tend to be the worst offenders. Most North American roads maintain speed restrictions on certain car series that are known to exhibit these characteristics. Consideration should be given to expected train speeds and operating location before such cars are entrained.

7.2 Pitch And Bounce

Another high speed (>45 mph) harmonic motion is pitch and bounce. It is manifested by extreme vertical displacements at the ends of the car, with the ends either in-phase or out-of-phase, depending on whether the car is in the bounce or pitch mode. This condition occurs most often in loaded cars that have insufficient suspension damping. Short cars (ore jennys and short tank cars), tend to be more prone to this condition than longer cars. Again, a list identifying such cars should be consulted before high speed operation.

7.3 Harmonic Roll

This is a low speed harmonic motion (10-25 mph) exhibited by heavily loaded, high center-of-gravity cars on secondary track. The condition occurs most often on half-point staggered jointed rail where the truck centers of the cars are close to the joint spacing. When operating on secondary track with half-point staggered jointed rail, speed should not remain in the above range. A more detailed description is contained in R-185 [5].

8.0 LOCOMOTIVES

8.1 Remote Unit Placement/Helper Operations

No manual on Train Make-up would be complete without a discussion on Remote Motive Power Placement in trains, operating in heavy grade territory or in undulating territory. The purpose of this section is to provide the background information relative to remote unit use and to discuss the options available to the railroad industry.

The specific choice for placement of remote locomotives will depend on the nature of the territory and the limitations placed by track and other considerations. The use of remote locomotives is an attempt to limit the maximum drawbar force in train operations. This drawbar force limit pertains to a steady drawbar pull, that is, the force occurs consistently, and acts over a time duration sufficient to cause coupler failure. Improper placement can result in train action forces which can further exceed the coupler force limit. Several different approaches to remote unit placement are practiced and are successful. These are described below after some basic considerations are discussed.

Helper locomotives are required to assist heavy trains in territories with severe grades and may be manned by an engineer or operated as radio controlled units.

Helper locomotives may be placed at the rear of the train (behind the caboose or immediately ahead of the caboose), or cut into the train at specified distances ahead of the last car.

When using helpers on the rear end, consideration must be given to curvature, grade, number of powered axles in the locomotive consists, and location of long cars (80 feet and longer) coupled to short cars (50 feet or shorter). The excessive buff drawbar force could result in high lateral forces leading to rail rollover, flange climbing, or train jackknifing.

Normally, helpers placed at the rear of the train, should be restricted to the number of powered axles that will produce the maximum safe drawbar force at stall speed for the most restrictive grade/curve combination encountered and the most restrictive long car/short car combination. This will typically result in a restriction of 12 to 16 axles for rear helpers on trains of mixed long and short cars, depending on grade, curves, and tonnage buffer provided between rear helpers and the rear most empty car, 80 feet and longer. On the other hand, loaded unit trains can safely be allowed with helpers in excess of 24 powered axles where grade and curvature permit.

Where cars 80 feet and longer coupled to cars 50 feet and shorter are handled in helper trains, a tonnage buffer should be provided between helper unit and rear-most empty car (80 ft. or longer), sufficient to absorb drawbar force in excess of the maximum safe coupler force that can be tolerated in long-short car combination.

In helper assisted trains, it is important to recognize the effect of the location of the "node" on train operation. The "node" is defined as that point of zero force where the draft gear is in neither compression (buff), nor tension (draft). The location of the "node" is in the options discussed below:

1. The helper locomotive can be positioned so its share of the tonnage is entirely behind it, plus some of the leading locomotive's share. In that case, the entire train will normally be in draft condition while powering, or in buff condition during dynamic braking. (Exhibit 8.1a).

2. The helper locomotive can be positioned so its share is on both sides, some being pushed and some being pulled. In this case the "node" exists between the helper and the lead locomotive. When powering, the train is in draft ahead of the "node"; in buff, between the "node" and the helper, and in draft, behind the helper. In dynamic braking, each of these conditions reverses. (Exhibit 8.1b).

3. The helper locomotive can be positioned so that the "node" is normally at the front coupler of the helper. In this case, it is as if two separate trains were operating with very little interaction between the portion ahead of the helper and that behind. Variations of gradient or power output by the leading or helper locomotives relative to each other will move the "node" so that at any point in the trip, situation 1 or 2 above will exist to some degree (Exhibit 8.1d). Rear end helper operations are a variation of situation 2, except there is no portions of the train behind the helper. (Exhibit 8.1c).

All of these modes of operation have been successfully used. It is important to consider each segment of the train relative to the intended use of the power. Each segment should independently meet the train make-up trailing tonnage criteria for long car/short car combinations in buff and draft.

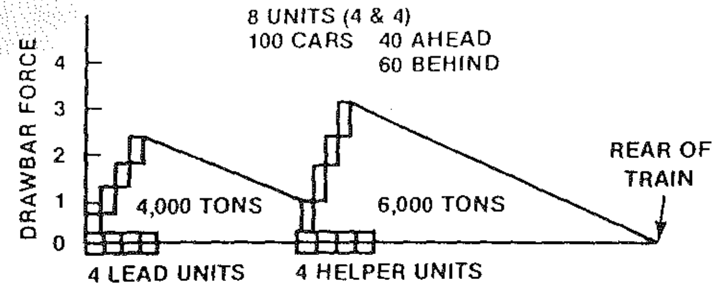


Exhibit 8.1a - Helper Placement, Situation One

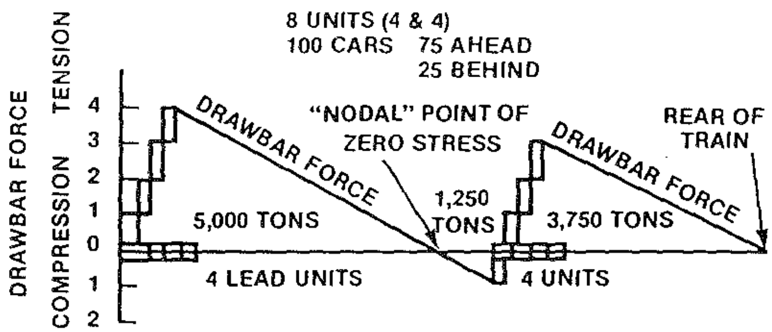


Exhibit 8.1b - Helper Placement, Situation Two

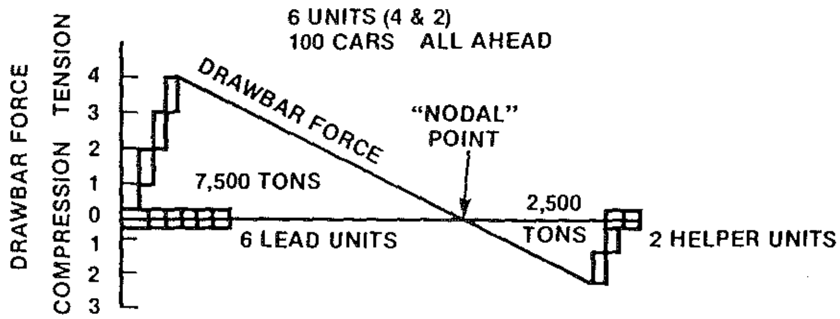


Exhibit 8.1c - Helper Placement, Situation Two (Rear)

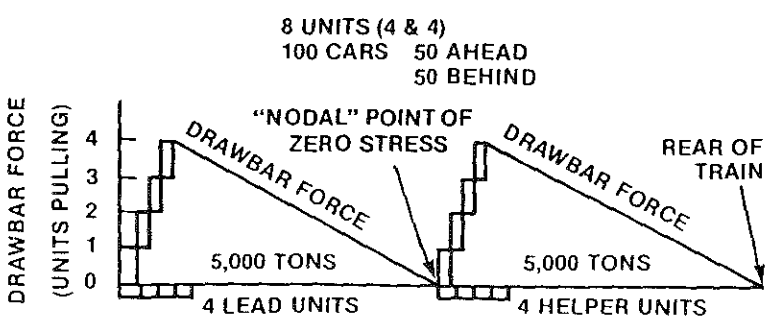


Exhibit 8.1d -,Helper Placement, Situation Three

Summary

Any time there is more than one location in a train where a powered unit is used, there will also be a node located in that train where the slack condition changes from buff to draft or vice-versa. The location of this node will not be fixed, but will move forward and backward in the train depending on such things as throttle and brake changes, grade changes, curvature changes, and any other phenomenon that alters train resistance. Under certain conditions, this slack change can be severe.

Detailed instructions for the location of a helper or radio controlled unit is site and operation specific, and is beyond the scope of this manual. It is sufficient to say that one should not locate problem cars or combinations of cars near the node, in order to prevent high buff or draft forces from affecting these cars. The considerations presented in this section along with the other long car/short car trailing tonnage limitation data will be useful in determining the approach to be used.

8.2 Locomotive Coupler Alignment Control Features

Alignment Control Couplers are normally installed on locomotives. The coupler butt is contoured so as to limit the coupler angle relative to the locomotive car body center line, thereby limiting the lateral load (and resulting truck side L/V ratio).

Some early model locomotives were not equipped with coupler alignment control. These locomotives can become a problem because of their tendency to jackknife if they are entrained behind other locomotives that can generate large dynamic brake forces. Most railroads maintain a list of affected locomotives and limit the number that may be used in the above situation to one or two locomotives without the alignment control feature.

9.0 GLOSSARY OF TERMS

Adhesion - The coefficient of friction between the wheel and the rail in the longitudinal direction, for acceleration and retardation. It is a direct indicator of the amount of turning force the wheel can impart on the rail before wheel slip occurs. Example: High adhesion (dry, sanded rail) would mean a higher tractive effort can be achieved before wheel slip occurs. Low adhesion (wet rails) would mean less tractive effort can be achieved before wheel slip occurs. A locomotive with good rail conditions can normally transfer between 20% and 25% of its weight into tractive effort.

Articulated Car - A car created by uniting two or more railcar segments or units to form a single unit whose joints are created by a drawbar or coupling included between the segments or units. Many articulated cars share a common truck under the articulated joints.

Ascending Grade - See definition for "Light Ascending Grade" and "Heavy Ascending Grade."

Automatic Air Brake - Pertaining to the air brake system used for retarding or stopping trains.

Balance Speed - The equilibrium speed at which the drawbar force exerted by the locomotive is equal to the train resistance, resulting in a constant speed. A change in drawbar force (i.e. raising or lowering the throttle or dynamic brake position), or a change in train resistance (i.e. variation in grade) will cause a corresponding change in speed until a new balance speed is reached.

Buff - A term used to describe compressive coupler forces.

Coupler - A device located at both ends of all cars and locomotives in a standard location to provide a means for connecting one rail vehicle to another. The standard AAR coupler uses a pivoting knuckle and an internal mechanism that automatically locks when the knuckle is pushed closed, either manually or by a mating coupler. A manual operation is necessary to uncouple two cars whose couplers are locked together.

Coupler Alignment Control - An arrangement for maintaining the coupler nominally in the center line of draft, but allowing it to move to either side when a car is rounding a curve while coupled to another car.

Crest - A long ascending grade which changes to a long descending grade, both grades being of sufficient magnitude to require a change in train handling procedures as the grade is topped.

Crossover - Two turnouts in which the track between the frogs is arranged to form a continuous passage between two nearby and generally parallel tracks.

Curvature - In the United States, it is customary to express track curvature in degrees noted by the deflection from the tangent measured at stations 100 feet apart. In other words, the number of degrees of central angle subtended by a chord of 100 feet represents the "degree curve." One degree of curvature is equal to a radius of 5,730 feet.

Curve Resistance - The train force generated when a vehicle negotiates a curve.

Davis Formula - A mathematical formula used for calculating resistance of a given train.

Descending Grade - See definition for "Light Descending Grade" and "Heavy Descending Grade."

Draft - A term used to describe tensile coupler forces.

Drawbar - A term formerly used synonymously with coupler. It has been used indiscriminately to designate both the old link and pin drawbar, and the modern automatic car coupler.

Drawbar Forces - Longitudinal forces at the couplers between cars and/or locomotives that may be either tensile (draft) or compressive (buff), depending on the operation of the train at the time.

Dynamic Brake - A term used to describe a method of train braking whereby the kinetic energy of a moving train is used to generate electric current at the locomotive traction motors, which is then dissipated through banks of resistor grids on the locomotive.

EOC - Acronym for end-of-car cushioning; a unit installed at the ends of a car that develops energy-absorbing capacity through a hydraulic piston arrangement supplemented by springs to assure positive repositioning of the unit, in order that the maximum designed longitudinal cushioning for that device can be realized in both directions.

Grade - A slope of the track (ascending or descending) in the longitudinal direction. Grade is usually expressed as a percentage figure, which is the number of feet the track rises, or falls, in a longitudinal distance of 100 feet. Thus, for example 1% ascending grade means that the track rises 1 foot in elevation for every 100 feet of distance traversed along the track. A 1% descending grade means that the track falls 1 foot in elevation for every 100 feet of distance traversed along the track. A 2.46% ascending grade means that the track rises in elevation 2.46 feet for every 100 feet of distance traversed along the track.

Grade Resistance - The force exerted on a train by gravity. It is negative on descending grade and positive on ascending grade.

Gradient - The rate of inclination of the grade-line from the horizontal.

Harmonic Roll - See "Rock and Roll."

Heavy Ascending Grade - An ascending grade greater than 1.0%. Train handing procedures for trains operating on heavy ascending grade assume the grade to be long enough so that the retarding influence of the grade will be balanced by the power of the locomotive.

Heavy Descending Grade - A descending grade of greater than 1.0%. Train handling procedures for trains operating on heavy descending grade assume the grade to be long enough so that a balance can be reached between forces due to the grade (which tend to increase the train speed), and forces of natural train resistance, automatic brakes and dynamic brakes (as required), which tend to slow the train.

Helper/Pusher - A manned locomotive, usually placed towards the rear of a train, to assist in the movement of the train. For instance, a helper may be used on a heavy ascending grade.

Independent Brake - The air brake control valve on a locomotive unit that controls the brakes on that locomotive (or multiple unit consist) independently from the train brakes.

Jackknifing - A condition involving two coupled rail vehicles in which there is excessive center sill misalignment and coupler angularity. Jackknifing is caused by high buff forces in the train.

L/V (Truck Side) - Defined as the ratio of the lateral force to the vertical force of a car or locomotive truck on a rail. It is an important indicator of rail turnover and/or derailments.

Light Ascending Grade - An ascending grade of 1.0% or less. Train handling procedures for trains operating on light ascending grade assume the grade to be long enough so that the retarding influence of the grade will be balanced by the power of the locomotive.

Light Descending Grade - A descending grade of 1.0% or less. Train handling procedures for trains operating on light descending grade assume the grade to be long enough so that a balance can be reached between forces due to the grade (which tend to increase the train speed), and forces of natural train resistance, automatic brakes, and dynamic brakes, which tend to slow the train.

Locomotive Adhesion Limit - A measure of the ability of locomotive driving wheels to accept rotational force without slipping on rails, usually expressed as a percent of the total weight on the drivers.

Locomotive Coupler Alignment Control - See "Coupler Alignment Control."

Node - The point of zero longitudinal stress (or coupler force) in a train using helper service. The node tends to fluctuate in any one train, due to changes in the terrain or in the control settings of the locomotive consists in the train.

Radio Controlled Unit - Unmanned unit entrained at a location other than the rear.

Resistance - In general, resistance denotes opposition to movement or flow. In mechanical systems, any force that opposes motion such as friction or action of a spring could be termed as resistance.

Retarding Force - The sum of external forces acting on a moving body tending to oppose continued motion. In train braking, the brake retarding force is the product of the actual brake shoe force and the instantaneous coefficient of friction at the braking contact surfaces.

Rock and Roll - A slang term for the excessive lateral rocking of cars and locomotives, usually at low speeds and associated with jointed rail. The speed range at which the cyclic phenomenon occurs is between 10 and 25 mph, with the exact speed determined by such factors as the wheel base, height of the center of gravity of each individual car or engine, the damping associated with each vehicle's suspension system and the relative difference in elevation between successive joints in jointed rail territory. In extreme cases, actual wheel lift can occur which can result in derailments.

Rolling Resistance - The resistance to the train movement, as it rolls along the track, due to such factors as weight, speed, wheel flange to rail contact, journal type, wind, etc.

Run-in - Describes the relative movement of the cars in the train to a state of compression.

Run-out - Describes the relative movement of the cars in the train to a state of tension.

Sag - A descending grade followed by an ascending, level, or nearly level grade, the combination of which is sufficient to result in significantly greater slack adjustment than in most other territories.

Slack - Unrestrained free movement between the cars in a train.

Steady State Forces - Forces applied for a relatively long period of time; i.e., steady pull up an ascending grade.

Stringlining - A term used to describe the tendency of cars to pull off the inside of curves, trying to approach a straight line when the train is in draft.

Swing Motion Truck - A design of freight car truck with a bolster and spring plank suspended on swing hangers so that they can swing laterally in relation to the truck frame.

Tare Weight - The weight of an empty car.

Total Train Weight - The total weight of a train including the locomotive; usually expressed in tons.

Tractive Effort - The force developed at all the locomotive driving wheels parallel to rail to move the locomotive and cars. This force is expressed in pounds and is directly proportional to the locomotive horsepower and inversely proportional to the locomotive speed.

Train Resistance - The combined effect of friction, grade, curves and wind that tend to resist the effort exerted by the locomotive to move a train.

Transient Forces - Forces applied for a relatively short period of time.

Truck Hunting - An instability at high speed of a wheel set (truck) causing it to weave down the track, usually with the flanges striking the rail.

Undulating Terrain - A track profile with grade changes so often that an average train passing over the track has some cars on three or more alternating ascending or descending grades. The train slack is constantly adjusting as cars on descending grades tend to roll faster than those on ascending grades.

Unit Train - A train transporting a single commodity from one source (shipper) to one destination (consignee) in accordance with an applicable tariff and with assigned cars.

$<$ - Less than
$>$ - Greater than

10.0 TRAILING TONNAGE CALCULATIONS

The basic train force equation:

$$TT = DBF / R_t$$

Where:

TT = Trailing Tonnage (tons)

DBF = Drawbar Force (lbs.)

R_t = Resistance per ton of trailing cars (lb/ton)

In draft and ascending grade:

$$TT = DBF / (20 \times \%\ Grade + 4.5 + (0.8/2) \times Curve + 1.52 \times A)$$

where:

DBF = Allowable Draft Force (lbs.)

20 = Grade Resistance Constant (lb/ton/% grade)

% Grade = Grade (1% = 1.0, .5% = 0.5, 0% = 0.0 etc)

4.5 = Rolling Resistance Constant - Assumes train is in motion (lb/ton)

0.8/2 = Curve Resistance Constant - Assumes half of trailing cars are on curve (lb x min)/(ton x mph)

Curve = Degree of Curvature (deg)

1.52 = Conversion Constant (lb x min)/(ton x mph)

A = Acceleration (mph/min)
- Positive if speed is increasing
- Zero if speed is constant
- Negative if speed is decreasing

In buff and descending grade:

$$TT = -DBF / (-20 \times \%\ Grade + 4.5 - (0.8/2) \times Curve + 1.52 \times A)$$

where:

DBF = Allowable Buff Force (lbs.)

20 = Grade Resistance Constant (lb/ton/% grade)

% Grade = Grade (1% = 1.0, .5% = 0.5, 0% = 0.0 etc)

4.5 = Rolling Resistance Constant - Assumes train is in motion (lb/ton)

0.8/2 = Curve Resistance Constant - Assumes half of Trailing Cars are on Curve (lb x min)/(ton x mph)

Curve = Degree of Curvature (deg)

1.52 = Conversion Constant (lb x min)/(ton x mph)

A = Acceleration (mph/min)
- Positive if speed is increasing
- Zero if speed is constant
- Negative if speed is decreasing

Safe lateral wheel load:

For the purposes of this manual, if the L/V ratio exceeds 0.82[2] there is a possibility that the wheel may climb. In other words, the vertical load (mainly the car weight) may not be sufficient to prevent the wheel from climbing under the effect of the lateral load.

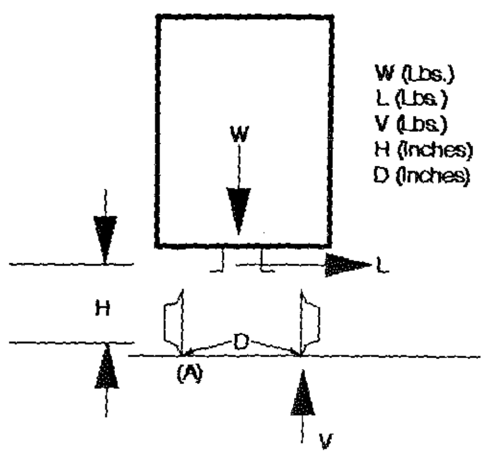
Therefore, if at the wheel,

$$L = 0.82 \times V \qquad (1)$$

there may exist a potential for derailment. The lateral wheel load of interest, in this analysis, originates at the coupler. The free body diagram below can represent all the forces involved.

Summing moments about point (A) (see diagram):

$$V \times D = \frac{W}{2} \times \frac{D}{2} + L \times H \qquad (2)$$



where:

W = Weight of Car (lbs.)

L = Lateral Load (lbs.)

D = Track Gage (inches)

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[2]A more conservative value of 0.75 may be used, if desired.

H = Coupler Height (inches)

V = Vertical Reaction (lbs.)

$$V = \frac{W}{4} + L \times \frac{H}{D} \qquad (3)$$

replacing V in equation (1) with (3):

$$L = 0.82 \left(\frac{W}{4} + L \times \frac{H}{D}\right) \qquad (4)$$

rearranging equation (4) and substituting their values:

$$L = \frac{0.82 \times W/4}{1 - 0.82 \times 34/59}$$

$$L = 0.389 \times W \qquad (5)$$

Therefore, the maximum lateral bolster load (lateral component of coupler load) for safety against wheel climb situations will be equal to 0.389 times the car weight in pounds.

<u>Maximum DBF and consequently trailing tonnage may be calculated by</u>:

DBF = 0.389 x Weight/Sin(Angle)

where:

DBF = Allowable Drawbar Force based on Truck Side L/V ratio of 0.82 (lbs.)

0.389 = Physical Ratio

Weight = Weight of Long Car (lbs.)

Angle = Coupler Angle of the Long Car (deg)

Coupler angles can be calculated from the formulas shown in Exhibit 10.1. If multi-unit cars are in the consist, special consideration must be given to the end and intermediate platforms; that is, to the coupler connection between intermediate units and the coupler connection between end units, or the connection of an end unit to a conventional freight car. These special considerations for estimating the coupler angle are discussed below.

Multi-Platform Cars - Two Trucks-Solid Connection (drawbar)

End Platforms - Use equations provided in Exhibit 10.1. Consider the outboard half of the end platform and use dimensions based on this as if it represented a fully symmetric car of these dimensions. This is the case whether coupled to a like end platform or a conventional car.

Intermediate Platforms - Evaluate like a conventional car having a coupler length equal to one-half of the drawbar length. Coupler contour angle must be set at zero.

Multi-Platform Cars - Shared Articulated Truck Type

End Platforms - Consider the half of the platform on the outboard end and use dimensions based on this as though it represented a fully symmetric car of these dimensions. Use equations in Exhibit 10.1 as with a conventional car of these dimensions. This is the case whether coupled to a like end platform or to a conventional car.

Intermediate Platforms - To obtain the angle formed between the inboard half of the end platform and the adjacent articulated platform or between two articulated intermediate platforms, the following relationship must be used:

$$\text{Angle} = 180 - \text{Arccos}(A1/(R+E)) - \text{Arccos}(A2/(R+E))$$

Where:

Angle = Small angle formed between platforms at articulated connection (deg)

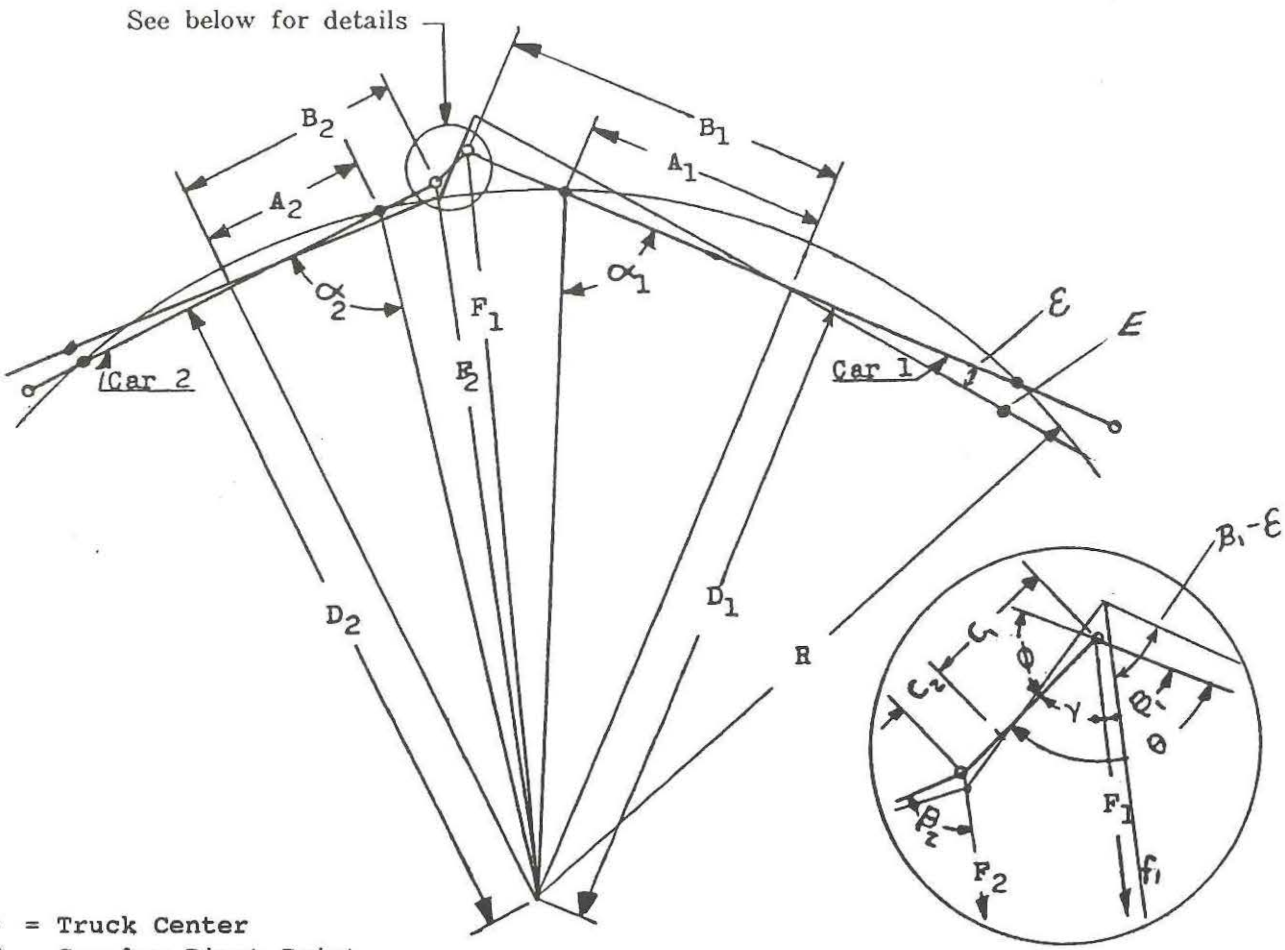
A1 = Half of Truck Center of Platform 1 (ft)

A2 = Half of Truck Center of Platform 2 (ft)

R = Radius of Curve (ft)

E = Lateral Bolster/Track Play (ft)

As can be seen from the above, these cases are not likely to be the limiting condition based on geometry. However, multi-platform cars with very light tare weight may represent the limiting condition based on the lower vertical loads.



• = Truck Center
° = Coupler Pivot Point
C = Coupler Length
A = Truck Center Distance /2
B = [Length Over Pulling Faces of Couplers -2 (Coupler Length)]/2
E = Lateral Bolster/Track Play
R = Radius of Curve = 50 / sin(track curvature in degrees /2)
α = Arc cos(A/R)
ϵ = Arc sin(E/A)
D = R sin(α)

$F = (B^2 + D^2)^{1/2}$ or $F = B/\cos(\beta)$
β = Arc cot (B/D)

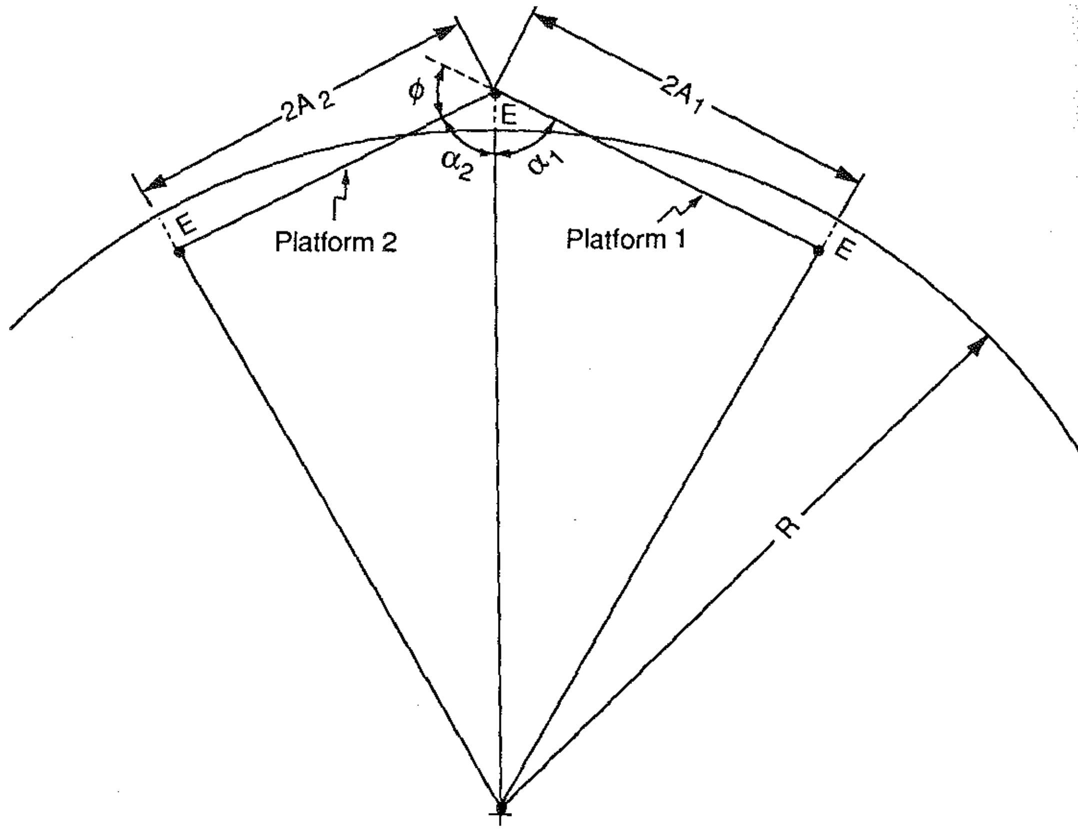
$$Y = \text{Arc Cos} \frac{(C_1 + C_2)^2 + F_1^2 - F_2^2}{2\,(C_1 + C_2)\,F_1}$$

Introducing Bolster/Track Plan
$f_1 = F_1 - E_1 \times B_1/A_1$ and $f_2 = F_2 + E_2 \times B_2/A_2$

$$\gamma = \text{Arc Cos} \frac{(C_1 + C_2)^2 + f_1^2 - f_2^2}{2\,(C_1 + C_2)\,f_1}$$

$\Theta = \beta_1 - \epsilon + \gamma$
Φ = Coupler Angle = 180 - Θ
P = Coupler Force
L = Lateral Component of Coupler Force = P sin(Φ)

Exhibit 10.1



A = Truck Center Distance/2
E = Lateral Bolster/Track Play
R = Radius of Curve = 50/sin (Track Curvature in Degrees/2)

$$\alpha_1 = \text{ARCCOS}\left[\frac{(2A_1)^2+(R+E)^2-(R-E)^2}{2(2A_1)\ (R+E)}\right]$$

$$= \text{ARCCOS}\left[\frac{A_1^2+\ ER}{A_1\ (R+E)}\right] \approx \text{ARCCOS}\left[\frac{A_1}{R}+\frac{E}{A_1}\right]$$

$$\alpha_2 = \text{ARCCOS}\left[\frac{(2A_2)^2+(R+E)^2-(R-E)^2}{2(2A_2)\ (R+E)}\right]$$

$$= \text{ARCCOS}\left[\frac{A_2^2+\ ER}{A_2\ (R+E)}\right] \approx \text{ARCCOS}\left[\frac{A_2}{R}+\frac{E}{A_2}\right]$$

$$\phi = \text{PLATFORM ANGLE} = 180 - \alpha_1 - \alpha_2$$

EXHIBIT 10.2

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