ANALYSIS OF TRUCK SAFETY ON CREST VERTICAL CURVES

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

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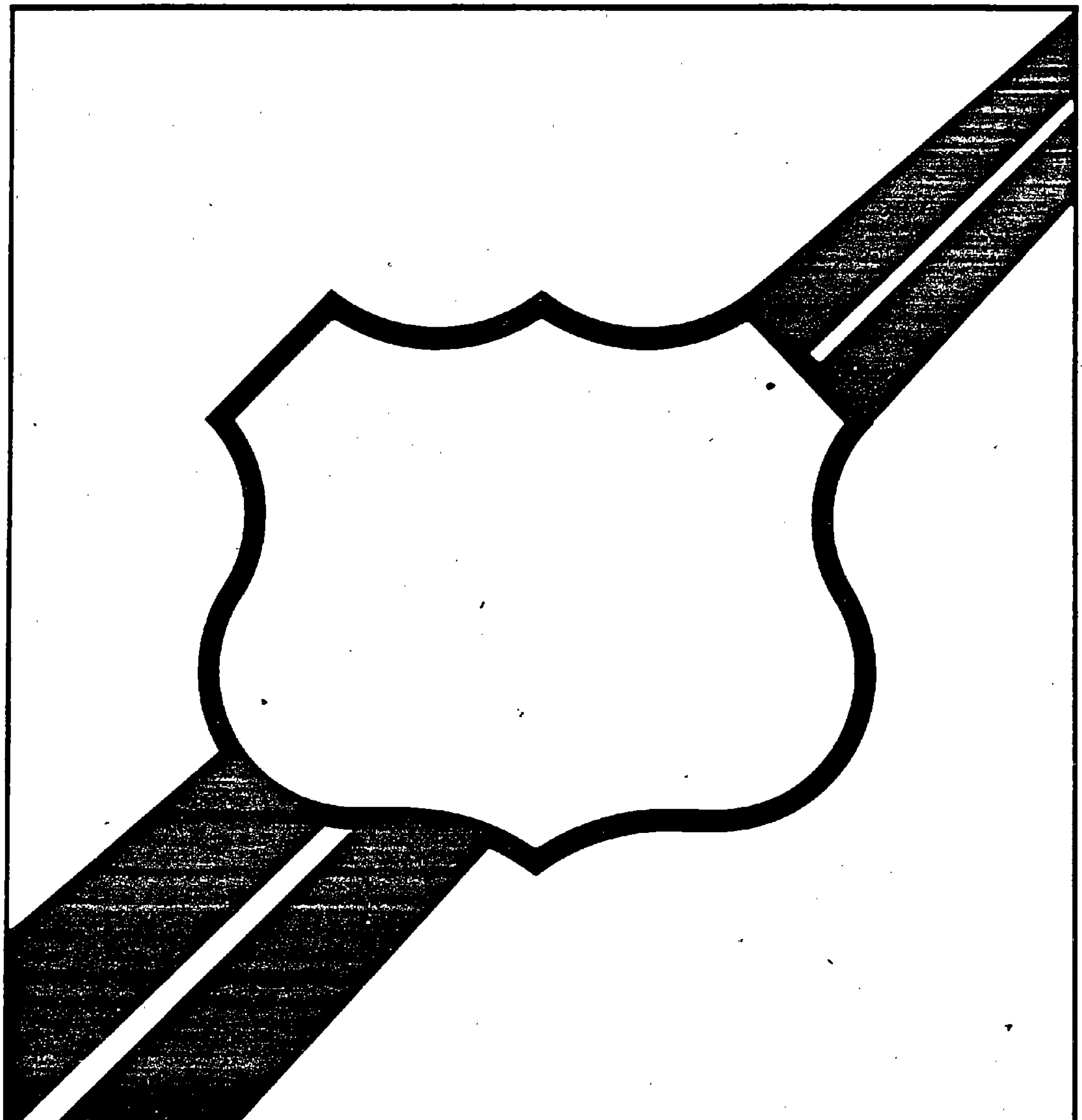

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16. Abstract

The objective of this project was to evaluate the potential for hazard to trucks operating on crest vertical curves designed to AASHTO standards.

A truck performance simulation model (TPSIM) was developed to permit the calculation of sight distance and stopping distance associated with each point along the path of a vehicle traversing a specified crest vertical curve. The total stopping distance is compared to the sight distance at each of a sequence of truck positions along the curve to determine if a hazardous situation exists.

The analysis was performed for a range of truck braking characteristics and cab types operating over a complete range of crest vertical curves. The analysis indicates that, for selected curve and truck combinations, there are potential hazards for trucks. A series of conclusions and recommendations are presented.

17. Key Words	18. Distribution Statement
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NOTICE

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

I. INTRODUCTION

This report presents the results of a project designed to evaluate the potential for hazard to trucks operating on crest vertical curves designed to AASHTO standards.

Section II describes the objectives of the project. Section III contains background information on crest vertical curve characteristics and AASHTO design values relating to crest vertical curve design. Section IV describes the technical approach used in evaluating potential hazards. It includes a description of the Truck Performance Simulation Model (TPSIM) which was used to calculate potential hazards for a complete range of crest vertical curves.

Section V describes the results of the analysis and presents a series of recommendations. Detailed descriptions of computational techniques and data sources are included in Appendices I, II, and III. Appendix IV contains detailed results from the simulation of a range of truck over a complete range of crest vertical curves.

II. PROJECT OBJECTIVES

The AASHTO highway design standards evolved over a period of years, beginning in 1937 with the establishment of a committee whose purpose was to formulate "administrative policies looking toward the incorporation in practice of highway design features which will result in maximum safety and utility." [1]

Over the next seven years, the Committee on Planning and Design Policies identified seven policies for adoption by AASHTO entitled, "Policies on Geometric Highway Design." These policies became known as the "Blue Book" and were published as a single volume in 1954. The latest edition was published in 1965.

The standards, known as the AASHTO standards, incorporate the issue of allowing sufficient sight distance when designing crest vertical curves. Several other design issues are treated as well; however, the standards, which focus on maximizing safety and utility in highway design, are derived from observation of the physical and operational characteristics of automobiles.

At the time the standards were being developed, automobiles represented most of the total traffic on highways. Truck use has increased considerably since then, with 23 states reporting more than 500,000 registered trucks in 1977 as compared to six reporting that number in 1967.[2]

Although an update to the AASHTO standards published in 1971 introduced minor modifications in design criteria for crest vertical curves, the automobile is still used as the standard

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[1] American Association of State Highway Officials, A Policy on Geometric Design of Rural Highways, 1965.

[2] U.S. Department of Commerce, Bureau of the Census, 1977 Census of Transportation, Truck Inventory and Use Survey, May 1980.

for determining safety and utility. An analysis of truck safety on vertical curves--particularly safe stopping sight distances--has not been pursued in depth.

In recognition of the increasing volume of truck travel and the lack of detailed safety design investigations involving trucks, the Federal Highway Administration has embarked on a program of analyzing truck safety to determine if design changes are needed. There are a number of safety issues to be examined; however, this analysis has focused on truck safety on vertical curves--specifically crest vertical curves.

The objective of this project is to evaluate the potential for hazard to trucks operating on crest vertical curves designed to AASHTO standards.

III. BACKGROUND

CREST VERTICAL CURVE CHARACTERISTICS

Vertical curves are designed as arcs of parabolas connecting two lines of constant grade. Vertical curves are further characterized as being either crest vertical curves (hills) or sag vertical curves (valleys) depending upon whether the parabola is concave (i.e., opening downward) or convex (opening upward). Crest vertical curves are constructed as concave parabolic arcs and are of three basic types as shown in Figure 1. The definitions of the three crest vertical curve types are based on the relationship between and the scope of grade lines g_1 and g_2, as shown below:

- o Type 1: g_1 positive and g_2 negative
- o Type 2: g_1 and g_2 both positive, $g_1 > g_2$
- o Type 3: g_1 and g_2 both negative, $g_1 < g_2$

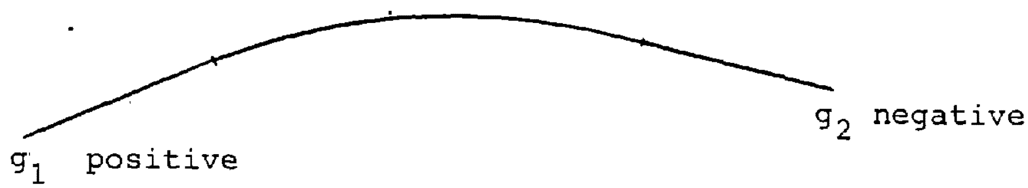
The profile of a highway may, therefore, be visualized as a series of straight line segments connected with parabolic arcs. The vertical curve begins at the point of tangency between the parabola and the beginning grade (g_1), and ends at its point of tangency with the ending grade (g_2).

As the driver approaches a crest vertical curve, his vision of the roadway may be obstructed by the roadway itself due to the curvature of the parabolic arc.

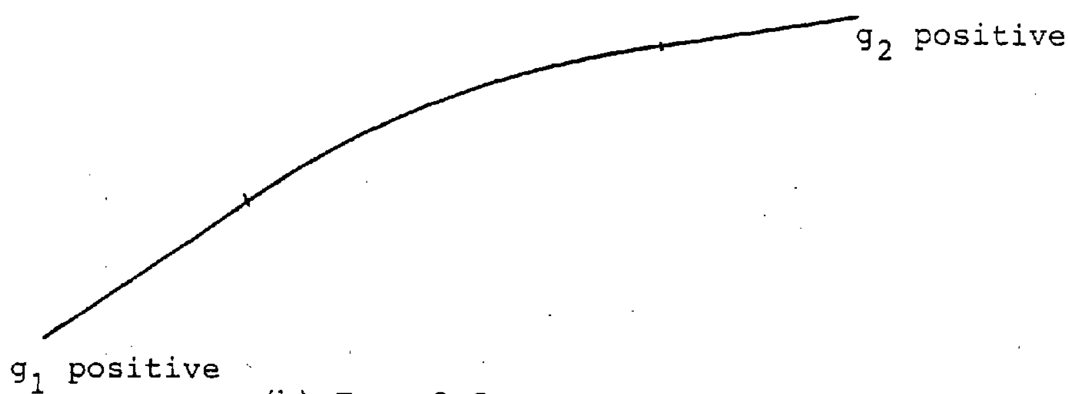
CHARACTERISTICS OF AASHTO DESIGN VALUES FOR CREST VERTICAL CURVES

AASHTO design values for crest vertical curves have safety as their basic tenet, such that:

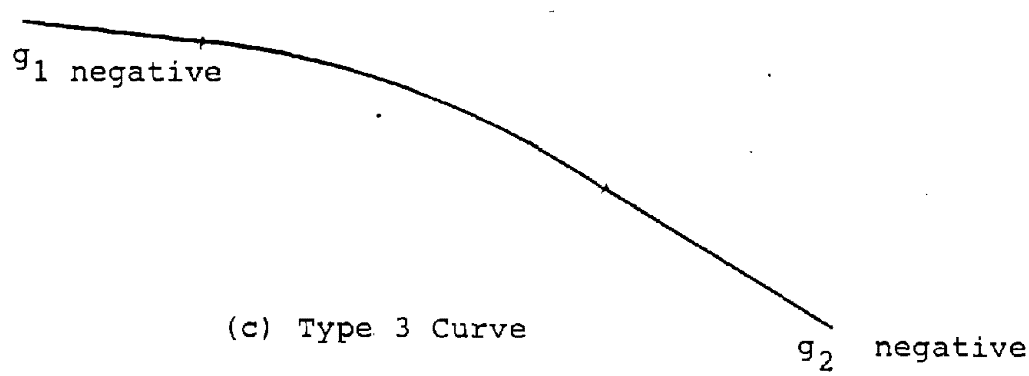
- o "sight distances be of sufficient length in which drivers can control the speed of their vehicles so as to avoid striking an unexpected obstacle in the traveled way;" and



(a) Type 1 Curve



(b) Type 2 Curve



(c) Type 3 Curve

FIGURE 1: CREST VERTICAL CURVE TYPES

- "sight distances be sufficiently long to enable a vehicle (automobile) traveling at or near the likely top speed to stop before reaching an object in its path."

In developing the design values, AASHTO evaluated three fundamental distances: sight distances, stopping distance, and stopping sight distance.

- Sight distance is the distance ahead that a driver can see an object in the roadway (a six-inch object is used by AASHTO to develop design standards).

- Stopping distance is the distance required for stopping from the instant the object is first sighted. This distance comprises three components: perception, reaction, and braking.

- Stopping sight distance is the minimum stopping distance and, therefore, also the minimum sight distance to provide for safe vehicle operation.

Based on the performance characteristics of automobiles and the geometry of the roadway, AASHTO recommended that vertical curves be designed with sufficient length to provide enough distance for drivers to brake should they encounter a six-inch obstacle while traversing the curve. Therefore, a crest vertical curve is deemed "safe" if the sight distance is equal to or longer than the stopping distance over the entire curve.

Braking distances, in the AASHTO design values are calculated conservatively, using the theoretical physical properties of braking together with the coefficient of friction between tire and pavement. The braking calculations represent the case where all four wheels are locked, or the situation that would occur in a "panic" stop. This is a conservative assumption since braking distances are less if the driver does not stop with the wheels "locked."

Other assumptions prevailing in the AASHTO design values are that vehicle operating conditions be "worse than average", i.e., the stop occurs on a wet pavement and that the driver is inexperienced.

Sight Distance Invariant to Change in Position of Vehicle

The AASHTO design values for vertical curve lengths are derived by an analysis of the driver's eye height, the obstacle height, and the distance required for the vehicle to stop, as illustrated by the parameters describing the curve (g_1, g_2, and L), the height of the drivers eye (h_1), and the object (h_2) in the following two equations:

$$L = \frac{|g_2 - g_1| \; S^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2} \quad \text{when } S < L \qquad (1)^3$$

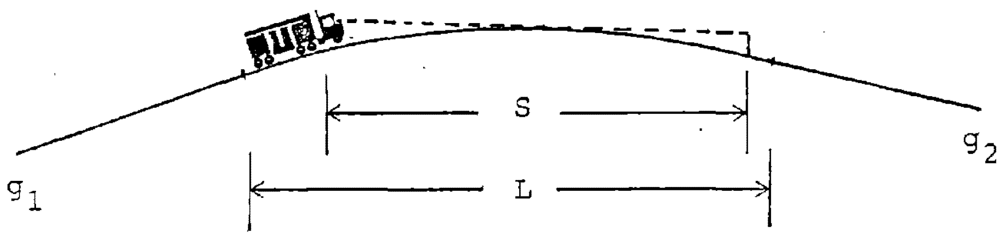
$$= 2S - \frac{200\;(\sqrt{h_1} + \sqrt{h_2})^2}{|g_2 - g_1|} \quad \text{when } S > L \qquad (2)^3$$

where

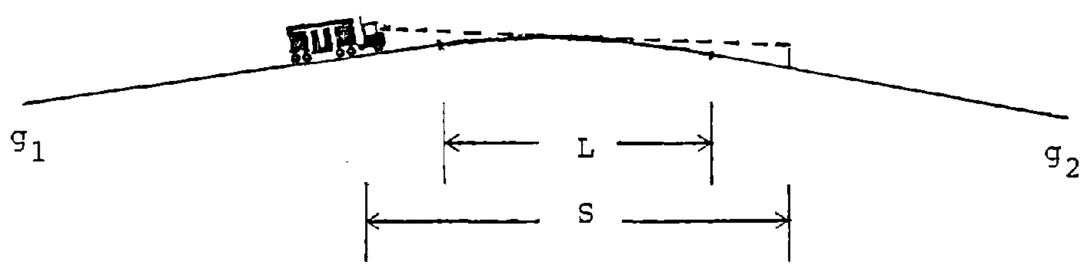
- L = length of vertical curve, feet
- S = sight distance, feet
- g_1 = beginning grade, percent
- g_2 = ending grade, percent
- h_1 = height of driver's eye above roadway surface, feet
- h_2 = height of object above roadway surface, feet

Figure 2 illustrates two possible situations: the case where the sight distance is less than the length of the vertical curve (S < L) and the case where the sight distance is greater than the length of the vertical curve (S > L). In Figure 2(a), where

[3] *Ibid*, p. 204.



2a: Geometry when S < L



2b: Geometry when S > L

FIGURE 2: CREST VERTICAL CURVE GEOMETRIES USED IN AASHTO DESIGN VALUES

(S < L), AASHTO assumes that both the vehicle and the object are located on the curve when the object first comes into view (see Equation 1). This represents the worst situation that could occur from the point of view of sight distance if S < L.[4] In Figure 2(b) (S > L), both the vehicle and the object are located off the curve, as represented by Equation 2.

Once the relationship of S and L is determined (S < L or S > L), the sight distance, measured horizontally, is a function of the grades being connected, the curve length, and the heights of the object and the driver's eye as described in Equations 1 and 2.

Horizontal sight distance is, then, invariant to changes in the vehicle's position and, for a given crest vertical curve, sight distance can assume one of two values depending upon whether (S < L) or (S > L).

<u>Stopping Distance Varies With the Position of the Vehicle</u>

Unlike sight distance, which can assume only one of two possible values, stopping distance will generally vary, depending upon the position of the vehicle when the object is first sighted. Since stopping distance will be less on upgrades and greater on downgrades, the total stopping distance will depend upon how much of the stopping distance takes place on the upgrade and downgrade portions of the curve.

Although AASHTO acknowledges the impact of grade on stopping distance[4], this effect is not incorporated in the calculation of design values for crest vertical curves. The recommended minimum values of curve length are based upon stopping distances that are achieved by a vehicle on level pavement.

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[4] American Association of State Highway Officials, <u>A Policy on Geometric Design of Rural Highways</u>, 1965.

A more complete analysis of vertical curve design considerations for trucks will include the following factors:

- truck braking characteristics;
- acceleration and deceleration effects due to grade; and
- effect of grade on braking.

Heavy trucks are expected to have significantly different braking distances than those of automobiles. In addition, the effect of grades on truck braking is expected to be greater because of the effect of grade on truck speed.

The focus of this project was to analyze the impacts of these factors in considering the performance of trucks on crest vertical curves. More specifically, the analysis of truck performance was performed to determine if hazardous situations result from trucks operating on crest vertical curves designed to AASHTO standards.

IV. TECHNICAL APPROACH

A simulation model was used to perform an analysis of the hazard potential for trucks on crest vertical curves. This chapter describes the simulation model, the inputs to the model, and sample outputs. Selected, more technical aspects of the model are described in a series of appendices:

- Appendix I: Computation of Sight Distance;
- Appendix II: Computation of Stopping Distance; and
- Appendix III: Driver Eye Height Data

THE TRUCK PERFORMANCE SIMULATION MODEL (TPSIM)

TPSIM was designed to permit the calculation of sight distance and stopping distance associated with each point along the path of a vehicle traversing a specified crest vertical curve. The model simulates the movement of the truck from its entry onto the vertical curve, followed by the driver's perception of and reaction to a roadway obstacle and his braking to a stop. The total stopping distance is compared to the sight distance at each of a sequence of truck positions along the curve. If the sight distance, at any of these positions, is less than the stopping distance, a hazard exists.

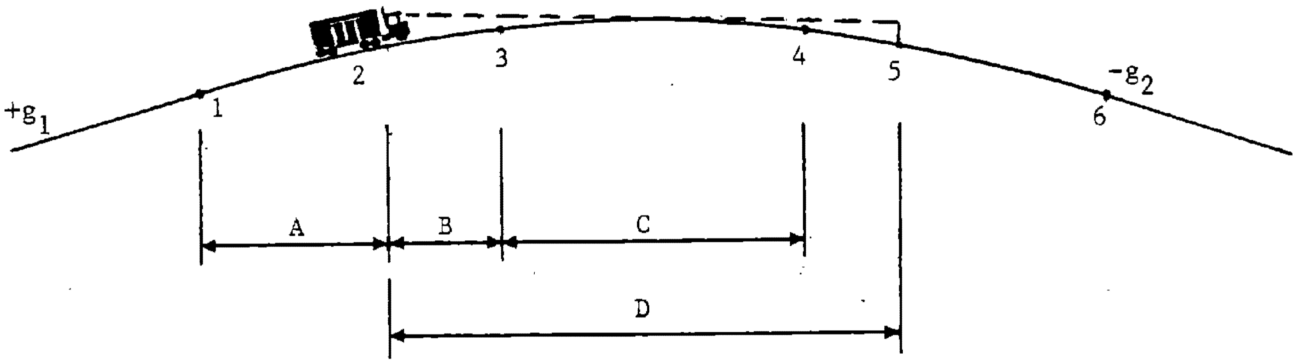
The simulation begins by placing the truck at the beginning of the crest vertical curve (i.e., the point of tangency between the beginning grade (g_1) and the vertical curve). The truck at this point is assumed to be traveling at a specified speed defined as the posted speed. The model then computes the perception and reaction distance traveled from the point of sighting the roadway object (sighting point) to the point where the brakes are applied (initial braking point). Next the model computes the braking distance to determine the stopping point. The sum of the perception and reaction distance and the braking distance is the stopping distance. The model also determines the maximum distance ahead that the driver could see an object located in the roadway. Measured horizontally, this distance is the sight distance. The procedure for computing sight distance is described in Appendix I. The stopping distance is then compared to the sight distance and, if it is greater, a hazardous situation exists (i.e., the sighting point is defined as a hazardous truck position). A graphical representation of the process is shown in Figure 3.

After the first sighting point has been evaluated, the model considers the next sighting point located at a fixed interval into the curve (20 feet was used in the analysis). Once again the model compares the stopping distance to the sight distance and, if it is greater, the sighting point is considered hazardous. This process is repeated for successive discrete points along the curve until the truck reaches the position where the driver's line of sight clears the crest of the curve and visibility is unobstructed.

The roadway grade (or point on the vertical curve) affects all of the travel distances involved in calculating stopping distance. Therefore, the model must be exercised for a sequence of sighting positions along the curve to evaluate the overall hazard associated with the curve.

The hazard index for a particular vertical curve and truck characteristic is computed as a ratio. The numerator is the length of the curve in which the sighting positions result in a hazardous situation. The denominator is the total length of the curve.

There are two optional speed profiles. The first assumes that the speed at the beginning of the curve is maintained until braking occurs. The second assumes that the vehicle accelerates or



Points

1. Beginning of vertical curve
2. Sighting point (point where truck driver sees roadway object)
3. Initial braking point (point where truck driver applies brakes)
4. Stopping point
5. Maximum point along curve that driver can see an object
6. End of vertical curve

Distances

A. Initial travel distance
B. Perception and reaction distance
C. Braking distance
D. Sight distance

Conditions

Hazard if $(B+C)>D$
for sighting point z.
Safe if $(B+C) \leq D$

FIGURE 3: DIAGRAM OF TRUCK PERFORMANCE SIMULATION COMPONENTS

decelerates depending on whether the grade is negative or positive, respectively. Under the second option, the maximum speed is equal to the posted speed.

If the truck is assumed to decelerate (accelerate) while ascending (descending) the curve, the stopping distance will also be affected since the speed of the truck when the brakes are applied may differ from the posted speed.

MODEL INPUT DATA

The input data to the TPSIM consists of four categories:

- o truck characteristics;
- o vertical curve characteristics;
- o object height data; and
- o speed profile data.

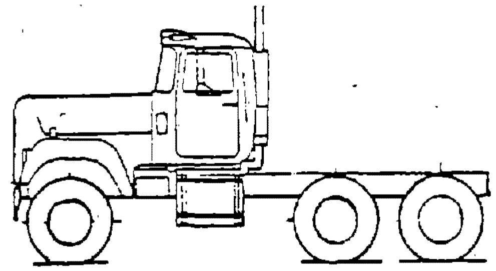
Truck Characteristics

The development of each of these types of data is described below.

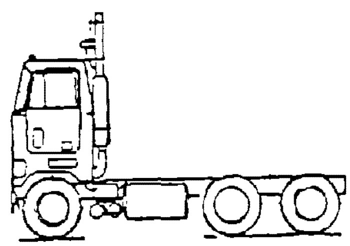
From the viewpoint of the TPSIM safety analysis, the characteristics of trucks required for input are eye height and braking distance. The eye height is related principally to the type of cab design for truck; the braking distance is related principally to the type of truck-trailer configurations.

There are three basic cab designs for trucks: cab behind engine (or conventional), cab over engine, and low cab over engine. A typical example of each type is shown in Figure 4.

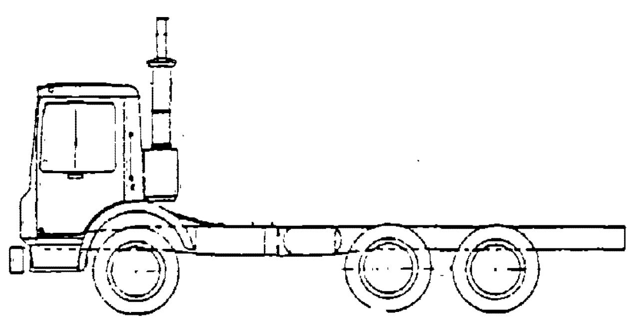
The variety of truck and trailer combinations is shown in the axle code classification structure in Figure 5. There are more than fifty combinations of cab type and truck-trailer combinations that currently operate on the highway system.



TYPICAL CAB BEHIND ENGINE
(OR CONVENTIONAL)

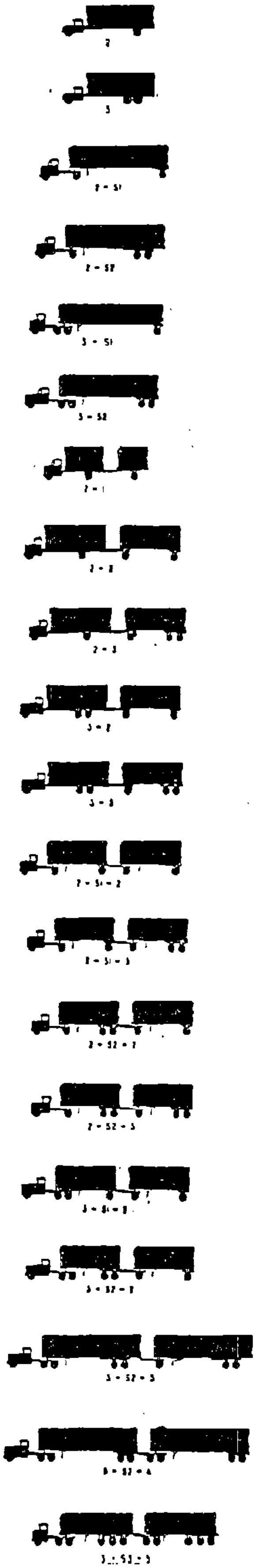


TYPICAL CAB OVER ENGINE



TYPICAL LOW CAB OVER ENGINE

FIGURE 4: TYPICAL TRUCK TYPES



- 2-axle single unit
- 3-axle single unit
- 2-axle truck tractor with 1-axle semitrailer
- 2-axle truck tractor with 2-axle semitrailer
- 3-axle truck tractor with 1-axle semitrailer
- 3-axle truck tractor with 2-axle semitrailer
- 2-axle truck with 1-axle trailer
- 2-axle truck with 2-axle trailer
- 2-axle truck with 3-axle trailer
- 3-axle truck with 2-axle trailer
- 3-axle truck with 3-axle trailer
- 2-axle truck tractor with 1-axle semitrailer and 2-axle trailer
- 2-axle truck tractor with 1-axle semitrailer and 3-axle trailer
- 2-axle truck tractor with 2-axle semitrailer and 2-axle trailer
- 2-axle truck tractor with 2-axle semitrailer and 2-axle trailer
- 3-axle truck tractor with 1-axle semitrailer and 2-axle trailer
- 3-axle truck tractor with 2-axle semitrailer and 2-axle trailer
- 3-axle truck tractor with 2-axle semitrailer and 3-axle trailer
- 3-axle truck tractor with 2-axle semitrailer and 4-axle trailer
- 3-axle truck tractor with 3-axle semitrailer and 5-axle trailer

FIGURE 5: AXLE CODE CLASSIFICATION FOR COMMERCIAL VEHICLES

Driver Eye Height

Two sources of data were used to define eye height by cab type. The first source was a study conducted for the National Highway Transportation Safety Administration (NHTSA) by Vector Enterprises (6). The second source was data collected by ASG directly from truck manufacturers.

A summary of the findings from these two sources is presented in Table 1. Column 2 indicates the average eye height for the manufacturers from the NHTSA study. The number of truck measurements used to compute each average is indicated in parentheses. The data provided to ASG by the manufacturers contacted during this project is summarized in Column 3. The eye height shown for Mack and International Harvester represents the midpoint of the range provided for the indicated cab type. Freightliner eye height was computed from data provided.

Based upon this data, the following values were used in the analysis to represent the eye height associated with each of the three cab types.

Conventional	93"
Cab Over Engine	107"
Low Cab Over Engine	91"

Braking Distances

Estimates for truck braking distance in the TPSIM analysis were developed by extrapolating from a set of empirical data on truck braking distances. A key requirement of the braking data is that braking distances represent those of trucks

CAB TYPE: CONVENTIONAL

MANUFACTURER [1]	NHTSA [2]	ASG [3]	AVERAGE [4]
GMC	87.2 (4)		
FORD	85.2 (1)		
MACK	95.4 (4)	95.1	
FLT		100.7	
IH		94.0	
	WEIGHTED AVG. 89.3 INCHES	WEIGHTED AVG. 96.6 INCHES	CAB-TYPE AVG. 93 INCHES

CAB TYPE: CAB OVER ENGINE

MANUFACTURER	NHTSA	ASG	AVERAGE
GMC	106.3 (4)		
FORD	110.0 (1)		
MACK	112.5 (1)	109.5	
FLT	98.7 (2)	105.9	
IH		103.5	
	WEIGHTED AVG. 106.9 INCHES	WEIGHTED AVG. 106.3 INCHES	CAB-TYPE AVG. 107 INCHES

CAB TYPE: LOW CAB OVER ENGINE

MANUFACTURER	NHTSA	ASG	AVERAGE
GMC			
FORD			
MACK	91.2 (2)	90.1	
FLT	98.7 (2)		
IH			
	WEIGHTED AVG. 91.2 INCHES	WEIGHTED AVG. 90.1 INCHES	CAB-TYPE AVG. 91 INCHES

[1] Manufacturer Codes: GMC - GMC Truck; FORD - Ford Truck; MACK - Mack Truck; FLT - Freightliner; IH - International Harvester

[2] Source: Vector Enterprises (6)
[3] Source: ASG data collected from manufacturers
[4] Average values rounded to the nearest inch

TABLE 1: SUMMARY OF DRIVER EYE HEIGHT DATA

currently in use on the nation's highways. The most complete source of data available was collected for the Federal Highway Administration in 1974.[5] Approximately 400 commercial vehicles were tested in each of three states to collect braking data at state weighing scales. The trucks of drivers who agreed to participate were weighed and equipped with a "fifth wheel" containing equipment for measuring distances and certain other variables. The actual measurements of braking distances were obtained by having each driver accelerate to a speed of 20 mph, at which point the brakes were applied. Drivers were instructed to maintain the vehicle's maximum braking capacity throughout the stop.

For this analysis, braking distance distribution information recorded during the FHWA 1974 tests was used to estimate the 85th percentile braking distances for nine different categories of trucks (Table 2). These distances formed the baseline from which braking distances were extrapolated for different positions along the crest vertical curve.

For purposes of the TPSIM, four braking distances were input: 28, 35, 42, and 48 feet. These are the computed 85th percentile stopping distances at 20 mph. Selecting these four stopping distances as a representative set implied that trucks could be grouped into four general categories with respect to braking ability:

- o Group 1: 2-axle light trucks (S = 28 feet);
- o Group 2: 2-axle medium trucks (S = 35 feet);
- o Group 3: 3-S2, 2-S1, 2-S2, 3-S3, 3-S4, 3-S5, 3-S6, 3-S7, 3-S8 (S = 42 feet); and
- o Group 4: Twin trailer combinations, 3-axle truck 2-1, 2-2, 2-3, 3-2 (S= 49 feet).

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[5] Paul A. Winter, Brake Performance Levels for Trucks and Passenger Cars, DOT, FHWA, BMCS, 1974.

CONFIGURATION		AVERAGE WEIGHT (LBS)	NUMBER TESTED	COMPUTED 85TH PERCENTILE BRAKING DISTANCES ON DRY PAVEMENT FROM 20 MPH (FT)
Light	2-axle	8,330	132	28
Medium	2-axle	16,050	279	35
Heavy	3-axle	31,590	45	47
	2-S1	27,100	62	41
	2-S2	32,510	146	41
	3-S2	44,260	427	42
	2-1, 2-2, 2-3, 3-2	34,800	29	48
Super Heavy	3-S3, 3-S4,...,3-S8	76,400	20	43
	Twin Combinations	67,800	51	49

TABLE 2: BASELINE BRAKING DISTANCES FROM 1974 TESTS

The extrapolation methodology described in Appendix II was used to develop braking distances for the four classes of trucks. The equation for this extrapolation is as follows:

$$d_1 = d_0 \left(\frac{\mu_0}{\mu_1 + g}\right) \left(\frac{V_1^2}{V_0^2}\right) \tag{3}$$

where

d_1 = braking distance from speed V_1 with coefficient of friction μ_1.

d_0 = observed braking distance from speed V_0 with coefficient of friction μ_0.

μ_0 = coefficient of friction for observed braking distances.

μ_1 = coefficient of friction for estimated braking distance d.

g = grade of roadway for braking activity (decimal form).

V_0 = initial velocity of truck in observed data.

V_1 = initial velocity of truck for estimated braking distance.

For example, the braking distance of the 3-S2 configuration from 55 mph on a +2 percent upgrade on wet pavement is calculated as follows. First, the coefficient of friction corresponding to the baseline data (i.e., stop from 20 mph on dry pavement) was determined to be .60. Next, the coefficient of friction corresponding to a stop from 55 mph on a wet pavement is determined (from data contained in the graphs on Page 137 of the AASHTO Blue Book) to be .30. Using the equation above, the extrapolated braking distance is computed as

$$d = \left(\frac{.6}{.3 + .02}\right) \left(\frac{55^2}{20^2}\right) 42 = 596 \text{ ft.}$$

Vertical Curve Characteristics

The TPSIM was used to analyze the three crest vertical curve types described in Chapter III. Each of these curve types was analyzed for a range of grade combinations from +9% to -9% for g_1 and g_2. The grade combinations analyzed included:

- Type 1 curve (81 combinations)
  - g_1: +1% to +9%
  - g_2: -1% to -9%
- Type 2 curve (36 combinations)
  - g_1: +2% to +9%
  - g_2: +1% to +8%, $g_2 < g_1$
- Type 3 curve (36 combinations)
  - g_1: -1% to -8%
  - g_2: -2% to -9%, $g_2 > g_1$

Object Height Data

The AASHTO design values for crest vertical curves assume a safe stopping distance for vehicles to accommodate the possibility of a driver sighting an object in the roadway. A six-inch high object was typically used in the AASHTO analysis. To determine the impact on truck safety, the TPSIM analysis was performed with both a six-inch and a fifteen-inch object height. Fifteen inches is the height of an automobile taillight and represents a larger object that a truck would have to stop to avoid, to avert damage, loss of control, or both.

Special Profile Assumptions

The stopping distance, including both perception and reaction distance and braking distance, is closely related to the speed of the truck at the point where the object is sighted. The posted speed of 55 miles per hour is the speed at which the truck enters the vertical curve for each TPSIM model simulation. The simulations were performed under two assumptions regarding the effect of grades on truck speed after the beginning of the vertical curves. The first assumption was that the posted speed was maintained regardless of grade. The second assumption was that the posted speed would be adjusted according to the grades that are encountered. This second assumption results in reduced truck speeds when ascending grades are encountered (type 1 and 2 vertical curves). For descending grades, the speeds are assumed to not exceed the posted limit. Thus, for type 3 vertical curves, the truck speed is equal to the posted speed until the braking point is reached. Trucks traveling on type 1 curves will decelerate on the ascending grade and begin accelerating on the descending grade until the braking point. In no case is the truck speed assumed to exceed the posted speed of 55 mph.

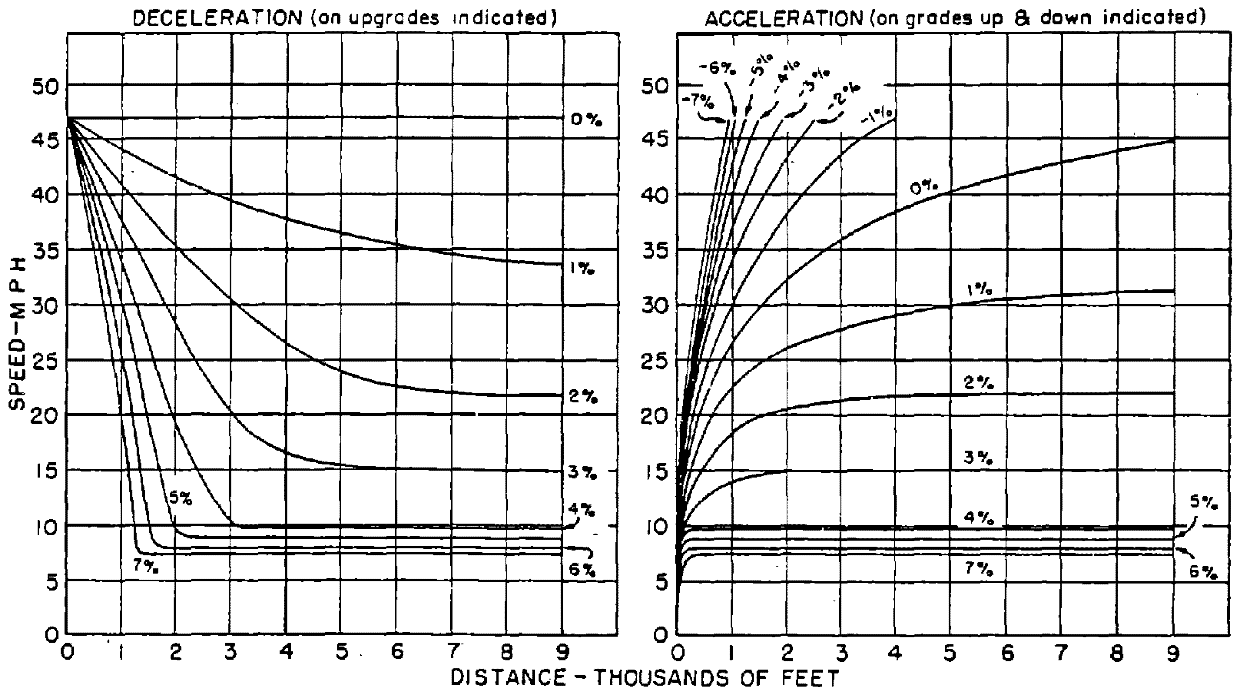
The deceleration and acceleration impacts of grades were taken from the AASHTO curves shown in Figure 6.

MODEL OUTPUT DATA

Output Description

The TPSIM computes the sight distance and the stopping distance for a truck at a sequence of sighting points along the vertical curve. For each sighting point, it determines if a hazard exists by comparing the stopping distance to the sight distance. When the stopping distance is greater than the sight distance, a hazard exists; otherwise it does not.

The TPSIM analysis indicates that, for some vertical curves and truck types, hazardous conditions exist along portions of the vertical curve. That is, the stopping distance may exceed the sight distance for the first four hundred feet (for example) of a vertical curve but may not for the remaining length of the curve.



SPEED-DISTANCE CURVES FROM ROAD TEST OF A TYPICAL HEAVY TRUCK OPERATING ON VARIOUS GRADES

Source: Huff & Scrivner, HRB Bul. 104, 1955

FIGURE 6: SPEED-DISTANCE CURVES FROM A ROAD TEST OF A TYPICAL HEAVY TRUCK OPERATING ON VARIOUS GRADES

Source: American Association of State Highway Officials, A Policy of Geometric Design of Rural Highways, 1965, p. 197.

As an illustration of the analysis, refer to Figure 7. This exhibit graphically portrays the results of the hazard analysis with the TPSIM for a type 1 crest vertical curve and a 3S-2 heavy truck using a low cab over engine cab type. The figure is divided into two parts. The upper part shows the crest vertical curve, and illustrates the calculation of hazard potential for a single sighting point a. Point b is the braking point and point d is the stopping point. The distance between points a and b is the perception and reaction distance; the distance between points b and d is the braking distance; and the distance between points a and d, total, is the stopping distance. Point c is the maximum sight point and the distance between points a and c is the sight distance. For this particular sighting point, a hazard exists since the stopping distance exceeds the sight distance.

The lower portion of Figure 7 is a graph of the stopping distance and sight distance for each sighting point along the vertical curve. The horizontal axis is the location of the sighting points; the vertical axis is the stopping and sight distances. As shown on the lower graph, the horizontal curve is hazardous for sighting points between points 0 and 100 feet and between 1,300 feet and 1,980 feet. For all other sighting positions along the vertical curve, the sight distance exceeds the stopping distance. The driver can see beyond the end of the vertical curve once he has reached 2,040 feet.

Table 3 displays the TPSIM output that was used for the illustration in Figure 7.

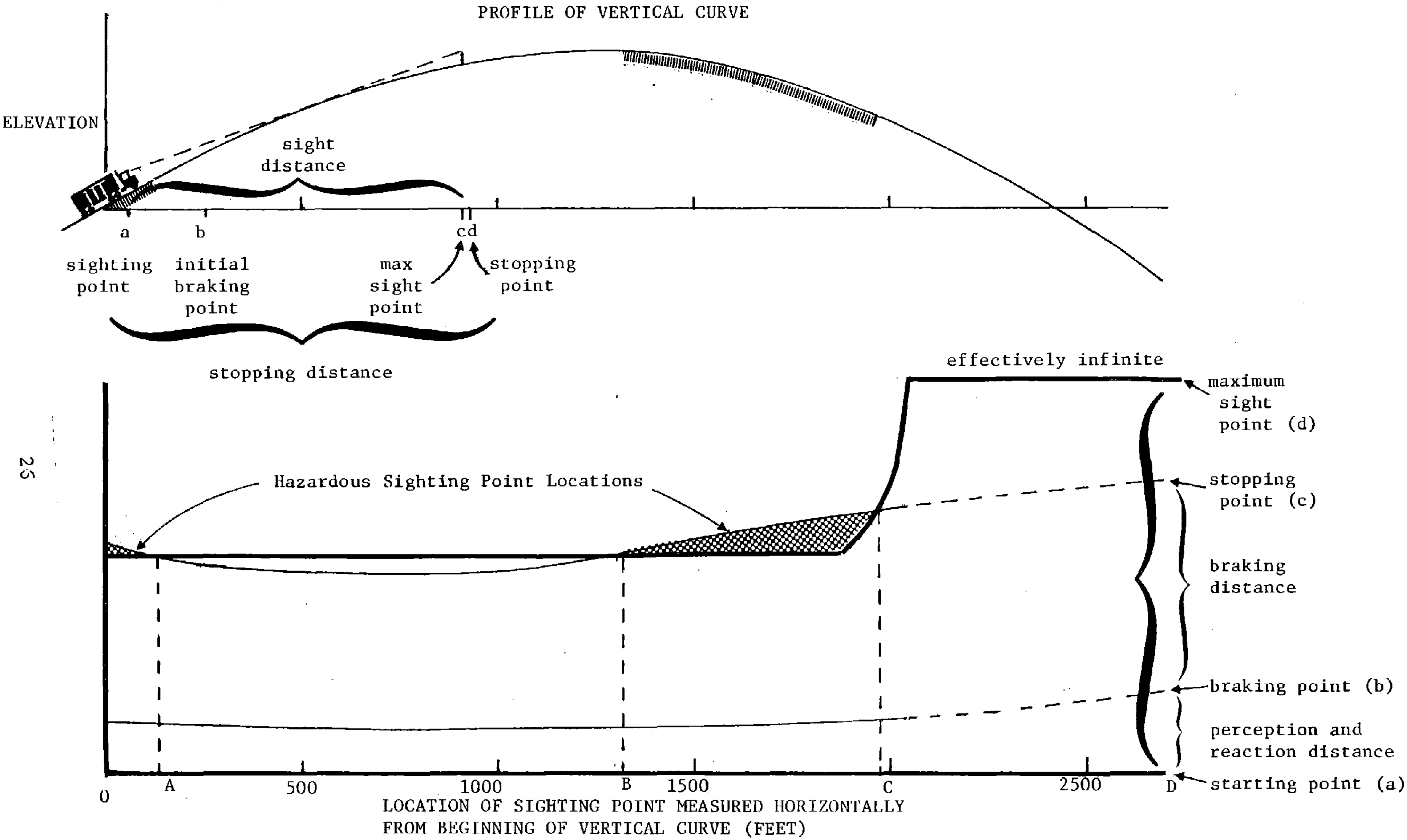


FIGURE 7: ILLUSTRATION OF HAZARDOUS LOCATIONS ON A TYPE 1 CREST VERTICAL CURVE FOR A TWIN TRAILER WITH A CAB OVER ENGINE

DESIGN SPEED = 60.0 MPH POSTED SPEED = 55.0 MPH
K = 300. LENGTH OF V.C. = 2700.00 FT
COEFF. OF FRICTION = 0.30 P&BR TIME = 2.50 SEC
G1 = 0.040 ACCELERATION RATE =-0.00600 MPH/FT
G2 =-0.050 ACCELERATION RATE = 0.00775 MPH/FT
BRAKING DISTANCE (FOR V0=20 MPH, F=.6) = 49.0 FT
LOCATION INCREMENT = 20.0 FT
SPEED CHANGES WITH GRADES, BUT NOT TO EXCEED 55.0 MPH

LOCATION FT	BRAKING-DIST FT	STOPPING-DIST FT	SIGHT-DISTANCES (FT.) (1)	(2)	(3)	(4)	(5)
0.	665.	864.	905.	855.	848.		
20.	662.	861.	905.	855.	848.		
40.	659.	858.	905.	855.	848.		
60.	656.	854.	905.	855.	848.		
80.	653.	851.	905.	855.	848.		
100.	650.	848.	905.	855.	848.		
120.	648.	844.	905.	855.	848.		
140.	645.	841.	905.	855.	848.		
160.	642.	838.	905.	855.	848.		
180.	639.	835.	905.	855.	848.		
200.	636.	831.	905.	855.	848.		
220.	633.	828.	905.	855.	848.		
240.	631.	825.	905.	855.	848.		
260.	628.	822.	905.	855.	848.		
280.	625.	818.	905.	855.	848.		
300.	622.	815.	905.	855.	848.		
320.	619.	812.	905.	855.	848.		
340.	616.	809.	905.	855.	848.		
360.	614.	805.	905.	855.	848.		
380.	611.	802.	905.	855.	848.		
400.	608.	799.	905.	855.	848.		
420.	608.	798.	905.	855.	848.		
440.	608.	798.	905.	855.	848.		
460.	608.	797.	905.	855.	848.		
480.	608.	797.	905.	855.	848.		
500.	608.	796.	905.	855.	848.		
520.	608.	796.	905.	855.	848.		
540.	608.	796.	905.	855.	848.		
560.	608.	795.	905.	855.	848.		
580.	608.	795.	905.	855.	848.		
600.	608.	794.	905.	855.	848.		
620.	608.	794.	905.	855.	848.		
640.	608.	794.	905.	855.	848.		
660.	608.	793.	905.	855.	848.		
680.	608.	793.	905.	855.	848.		
700.	608.	793.	905.	855.	848.		
720.	608.	792.	905.	855.	848.		
740.	609.	792.	905.	855.	848.		
760.	609.	792.	905.	855.	848.		
780.	609.	791.	905.	855.	848.		
800.	609.	791.	905.	855.	848.		
820.	609.	791.	905.	855.	848.		
840.	609.	790.	905.	855.	848.		
860.	609.	790.	905.	855.	848.		
880.	609.	790.	905.	855.	848.		
900.	610.	789.	905.	855.	848.		
920.	610.	789.	905.	855.	848.		
940.	610.	789.	905.	855.	848.		
960.	610.	789.	905.	855.	848.		
980.	610.	788.	905.	855.	848.		
1000.	610.	788.	905.	855.	848.		
1020.	611.	788.	905.	855.	848.		
1040.	614.	791.	905.	855.	848.		
1060.	618.	795.	905.	855.	848.		
1080.	622.	798.	905.	855.	848.		
1100.	626.	802.	905.	855.	848.		
1120.	630.	806.	905.	855.	848.		
1140.	634.	811.	905.	855.	848.		
1160.	638.	815.	905.	855.	848.		
1180.	642.	819.	905.	855.	848.		
1200.	646.	824.	905.	855.	848.		
1220.	651.	829.	905.	855.	848.		
1240.	656.	834.	905.	855.	848.		
1260.	661.	839.	905.	855.	848.		
1280.	666.	843.	905.	855.	848.		
1300.	670.	848.	905.	855.	848.		
1320.	675.	853.	905.	855.	848.		
1340.	680.	858.	905.	855.	848.		
1360.	685.	863.	905.	855.	848.		
1380.	690.	868.	905.	855.	848.		
1400.	695.	873.	905.	855.	848.		
1420.	700.	877.	905.	855.	848.		
1440.	705.	882.	905.	855.	848.		
1460.	710.	887.	905.	855.	848.		
1480.	714.	892.	905.	855.	848.		
1500.	719.	897.	905.	855.	848.		
1520.	724.	902.	905.	855.	848.		
1540.	729.	907.	905.	855.	848.		
1560.	734.	912.	905.	855.	848.		
1580.	739.	917.	905.	855.	848.		
1600.	744.	922.	905.	855.	848.		
1620.	750.	927.	905.	855.	848.		
1640.	755.	932.	905.	855.	848.		
1660.	760.	937.	905.	855.	848.		
1680.	765.	943.	905.	855.	848.		
1700.	770.	948.	905.	855.	848.		
1720.	775.	953.	905.	855.	848.		
1740.	780.	958.	905.	855.	848.		
1760.	785.	963.	905.	855.	848.		
1780.	790.	968.	905.	855.	848.		
1800.	796.	973.	905.	855.	848.		
1820.	801.	979.	907.	855.	848.		
1840.	806.	984.	912.	855.	848.		
1860.	811.	989.	924.	856.	848.		
1880.	816.	994.	945.	860.	850.		
1900.	822.	999.	984.	868.	857.		
1920.	827.	1005.	1065.	884.	869.		
1940.	808.	1008.	1271.	913.	893.		
1960.	809.	1008.	2487.	969.	936.		
1980.	809.	1009.	99999.	1095.	1027.		
2000.	809.	1009.	99999.	1520.	1276.		
2020.	808.	1009.	99999.	99999.	3423.		
2040.	808.	1010.	99999.	99999.	99999.		

HAZARD INDEX = 0.1397 FOR (1) EYE HT. = 107.00 IN. OBJECT HT. = 6.00 IN.

HAZARD INDEX = 0.2574 FOR (2) EYE HT. = 93.00 IN. OBJECT HT. = 6.00 IN.

HAZARD INDEX = 0.2941 FOR (3) EYE HT. = 91.00 IN. OBJECT HT. = 6.00 IN.

TABLE 3: DETAILED TPSIM CALCULATIONS

SIMULATION CASES

A number of geometrical conditions, truck behavior assumptions, truck characteristics, and safety conditions were tested using TPSIM. The conditions included:

- Vertical curve type
  - type 1 curve (positive g_1, negative g_2) or "summit" curve
  - type 2 curve (positive g_1, positive g_2) or ascending curve
  - type 3 curve (negative g_1, negative g_2) or descending curve
- Truck type
  - type, size, weight and braking characteristics
    - -- Group 1: 2-axle light trucks;
    - -- Group 2: 2-axle medium trucks;
    - -- Group 3: 3-S2, 2-S1, 2-S2, 3-S3, 3-S4, 3-S5, 3-S6, 3-S7, 3-S8
    - -- Group 4: Twin trailer combinations, 3-axle truck 2-1, 2-2, 2-3, 3-2
  - cab type
    - -- cab over engine
    - -- conventional (cab behind engine)
    - -- low cab over engine
- Object height
  - 6 inches
  - 15 inches
- Truck speed profile
  - posted speed maintained
  - accelerate/decelerate with grade

A total of 144 simulations were performed and for each of these simulations, the hazard potential for each point along the curve was defined using all of the relevant input grade combinations for the curve type. For type 1 curves, for example, 81 different curves were analyzed using 9 starting grades (+1% to +9%) and 9 ending grades (-1 to -9%).

V. RESULTS OF ANALYSIS AND RECOMMENDATIONS

The results of the analysis of potential hazards to different cab-trailer configurations are summarized in Table 4. The trailer types indicated in the first column were grouped on the basis of similar braking performance as reflected in the 1974 tests [6]. Light, two-axle trucks had an average weight of 8,330 pounds and an 85th percentile braking distance of 28 feet from 20 mph. Medium, two-axle trucks had an average weight of 16,050 pounds and an 85th percentile braking distance of 35 feet from 20 mph. The third group of trailer types includes those having 85th percentile braking distances (from 20 mph) ranging from 41 feet to 43 feet. Average weights for trucks in this group ranged from 27,100 pounds for the 2-S1 up to 75,400 pounds for the 3-S3, ..., 3-S8 combinations. The fourth group of trailer types includes those with 85th percentile braking distances ranging from 47 feet to 49 feet. Average weights ranged from 31,590 pounds for the three-axle trucks to 67,800 pounds for the twin trailer combinations.

The second column in the table indicates which of the three possible cab types is used with the trailer indicated in Column 1. The three possible types are:

Cab Type	Driver Eye Height (in.)
Cab Over Engine (COE)	107
Conventional (CONV)	93
Low Cab Over Engine (LCOE)	91

The next column indicates the height of the roadway object. A six-inch object corresponds to the height assumed by AASHTO in developing design standards. A fifteen-inch object was analyzed

[6] Winter, Paul A., Brake Performance Levels for Trucks and Passenger Cars, DOT, FHWA, BMCS, 1974.

TRAILER TYPE	CAB TYPE	OBJECT HEIGHT	TYPE 1 CURVE		TYPE 2 CURVE		TYPE 3 CURVE	
			POSTED SPEED MAINTAINED	ACCELERATE/ DECELERATE WITH GRADE	POSTED SPEED MAINTAINED	ACCELERATE/ DECELERATE WITH GRADE	POSTED SPEED MAINTAINED	ACCELERATE/ DECELERATE WITH GRADE
GROUP 1	COE	6 in.	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
	CONV		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
2-AXLE	LCOE		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
LIGHT	COE	15 in.	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
TRUCKS	CONV		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
	LCOE		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
GROUP 2	COE	6 in.	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	POTENTIAL HAZARD	NOT CONSIDERED
	CONV		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	POTENTIAL HAZARD	NOT CONSIDERED
2-AXLE	LCOE		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	POTENTIAL HAZARD	NOT CONSIDERED
MEDIUM	COE	15 in.	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
TRUCKS	CONV		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
	LCOE		NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED	NO HAZARD	NOT CONSIDERED
GROUP 3	COE	6 in.	POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
3-S2, 2-S1,	CONV		POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
2-S2, 3-S3,	LCOE		POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
3-S4, 3-S5,	COE	15 in.	NO HAZARD	NO HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
3-S6, 3-S7,	CONV		NO HAZARD	NO HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
3-S8,	LCOE		POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
GROUP 4	COE	6 in.	POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
TWIN TRAILER	CONV		POTENTIAL HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
COMBINATIONS	LCOE		POTENTIAL HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
3-AXLE TRUCKS	COE	15 in.	POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
2-1, 2-2, 2-3,	CONV		POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD
3-2	LCOE		POTENTIAL HAZARD	POTENTIAL HAZARD	NO HAZARD	NO HAZARD	POTENTIAL HAZARD	POTENTIAL HAZARD

TABLE 4: SUMMARY OF POTENTIAL HAZARDS TO DIFFERENT CAB-TRAILER TYPES

Legend

vertical bars	POTENTIAL HAZARD
blank	NO HAZARD
cross-hatch	NOT CONSIDERED

in order to assess the sensitivity of the results to object height. The fifteen-inch standard was chosen because it represents the height of an automobile taillight and would pose a more significant potential hazard to the truck.

The analysis was conducted for each of the three curve types. A total of 81 individual type 1 curves were evaluated, representing initial grades (g_1) from 1% to 9% and ending grades (g_2) from -1% to -9%. For type 2 curves the conditions that grade g_2 is less than g_1 led to 36 individual curves which were analyzed. Similarly, 36 individual curves were evaluated in the analysis of type 3 curves for ($g_1 < g_2$). For the heavier trucks (groups 3 and 4), the results were analyzed for both the case where the posted speed was maintained until braking as well as the case where the truck's speed prior to braking was influenced by grade.

The basic measure of the safety of a particular curve, as determined by the TPSIM model, is the hazard index. This index is calculated as the fraction of the total curve length representing points from which the truck would be unable to stop in time should the object come into view (hazardous sighting positions). A small hazard index indicates that there are a relatively small number of hazardous sighting positions along the curve, while a hazard index near 1.0 indicates that hazrdous sighting positions exist along most of the curve. Hazard indices for each curve analyzed are contained in Appendix IV.

Entries in the summary table indicate whether the analysis revealed a nonzero hazard index for any of the individual curves comprising the curve type. Since the hazard index represents the fraction of total curve length that would be a hazardous sighting position for the truck, the designation "potential hazard" for a set of conditions indicates that at least one curve of that type contained hazardous sighting positions.

Table 5 provides slightly more detailed results for those cases where potential hazards were indicated by the analysis. Each entry in the table indicates the number of the individual curves

TRAILER TYPE	CAB TYPE	OBJECT HEIGHT	TYPE 1 CURVE		TYPE 2 CURVE		TYPE 3 CURVE	
			POSTED SPEED MAINTAINED	ACCELERATE/ DECELERATE WITH GRADE	POSTED SPEED MAINTAINED	ACCELERATE/ DECELERATE WITH GRADE	POSTED SPEED MAINTAINED	ACCELERATE/ DECELERATE WITH GRADE
GROUP 1	COE	6 in.						
	CONV							
2-AXLE	LCOE							
LIGHT	COE	15 in.						
TRUCKS	CONV							
	LCOE							
GROUP 2	COE	6 in.					6 (17%)	
	CONV						15 (42%)	
2-AXLE	LCOE						15 (42%) [1]	
MEDIUM	COE	15 in.						
TRUCKS	CONV							
	LCOE							
GROUP 3	COE	6 in.	36 (44%)	23 (28%)			20 (56%)	20 (56%)
3-S2, 2-S1,	CONV		65 (80%)	35 (43%)			21 (58%)	21 (58%)
2-S2, 3-S3,	LCOE		72 (89%) [2]	36 (44%) [3]			21 (58%) [4]	21 (58%) [5]
3-S4, 3-S5,	COE	15 in.	0	0			10 (28%)	10 (28%)
3-S6, 3-S7,	CONV		0	0			17 (47%)	17 (47%)
3-S8,	LCOE		9 (11%) [6]	7 (9%) [7]			18 (50%) [8]	18 (50%) [9]
GROUP 4	COE	6 in.	77 (95%)	38 (47%)	0		21 (58%)	21 (58%)
TWIN TRAILER	CONV		80 (99%)	45 (56%)	13 (36%)		21 (58%)	21 (58%)
COMBINATIONS	LCOE		80 (99%) [10]	45 (56%) [11]	15 (42%) [12]		21 (58%) [13]	21 (58%) [14]
3-AXLE TRUCKS	COE	15 in.	45 (56%)	26 (32%)			20 (56%)	20 (56%)
2-1, 2-2, 2-3,	CONV		65 (80%)	34 (42%)			21 (58%)	21 (58%)
3-2	LCOE		69 (85%) [15]	36 (44%) [16]			21 (58%) [17]	21 (58%) [18]

* The first entry in each cell indicates the number of hazardous curves.
The percent of total curves is indicated in parentheses.

TABLE 5: DETAILED SUMMARY OF POTENTIAL HAZARDS TO DIFFERENT CAB-TRAILER TYPES

considered having a nonzero hazard index and, the percentage of all curves of the indicated type represented by these hazardous curves. For example, for trucks in group 3 using a cab-over-engine cab, 36 of the type 1 curves were found to be potentially hazardous. This represents 44 percent of the total of 81 possible Type 1 curves considered.

TYPE 1 CURVES

The analysis revealed that Type 1 curves can pose potentially hazardous situations for trucks in Groups 3 and 4. This is true whether the object is six-inches or fifteen-inches. For trucks in Group 3, the six-inch object poses a potential hazard to all cab types. If a fifteen inch object is assumed, the only hazard to Group 3 trucks is when the low cab over engine is used. The greatest potential hazard from Type 1 curves was to trucks in Group 4. Because of the relatively poor braking ability of these trucks, some hazard is present regardless of the cab type used. The hazard is not significantly reduced if a fifteen-inch object is used.

TYPE 2 CURVES

The only hazardous situations indicated for Type 2 curves are to trucks in Group 4 using the conventional cab or the low cab over engine. Fifteen of the 36 Type 2 curves analyzed contained hazardous sighting positions for the low cab over engine and thirteen were potentially hazardous to the conventional cab. The hazard is eliminated if the cab-over-engine cab is used. The analysis revealed no hazard from Type 2 curves to any truck group when a fifteen inch object is assumed.

TYPE 3 CURVES

The analysis revealed potential hazards from Type 3 curves to trucks in Groups 2, 3 and 4. For trucks in Group 3, 15 of the

36 Type 3 curves contain hazardous sighting positions for the low-cab-over-engine and conventional cabs. For the cab over engine six of the curves present a potential hazard. If a fifteen-inch object is assumed, type 3 curves present no hazard to trucks in Group 2 regardless of cab type.

Type 3 curves were found to present a significant potential hazard to trucks in Group 3. This is true regardless of the cab type used.

DESCRIPTION OF DETAILED RESULTS

The detailed results for each case indicating a potential hazard are provided in Appendix IV. Eighteen exhibits are included which correspond to each of the eighteen cells shown in Tables 4 or 5. The numbering of exhibits in the Appendix corresponds to the numbering in the lower right-hand corner of each cell in Table 5. For example, the detailed results corresponding to the cell number 11 in Table 5 is Exhibit IV.11 of Appendix IV. This table is reproduced here as Table 6 for purposes of illustration. The Table contains the hazard indices for Group 4 trucks operating on Type 1 curves. A six-inch object is assumed and it is assumed that the truck accelerates/decelerates prior to braking as a function of grade. Each cell in the table contains the hazard index for an individual curve having the indicated value of g_1 and g_2. The results are typical of those when the truck is assumed to decelerate or accelerate prior to braking. The greatest hazard is seen to exist on those curves with relatively small positive entering grades (g_1) and large negative following grades (g_2). In these cases the truck's sight distance is relatively small due to the large difference in grades. However, because the entering grade is small, the truck is traveling at near the posted speed when braking begins so that the distance required to stop is still relatively large.

As the entering grades become larger, the sight distance shortens; but the truck's speed when the brakes are applied is also lessened. The resulting stopping distances are small enough that the truck would be able to brake to a halt before hitting the object. For the cab-over-engine cab types, the data in Table 6 indicate that entering grades of about 2 percent pose the greatest hazard to trucks in Group 4 operating on type 1 curves. As entering grades reach 3 percent and above, the decreased speed when the brakes are applied begins to dominate the effects of the shorter sight distance and the hazard index begins to decrease. For conventional, as with the low-cab-over-engine cab types, the entering grade of greatest hazard is about 3 percent with stopping distances beginning to dominate at entering grades of 4 percent or greater.

RECOMMENDATIONS

The analysis conducted during this project indicates that certain truck types are exposed to potentially hazardous situations on certain crest vertical curves. Although the results were generally pronounced enough to support this general conclusion, some of the data on which they are based is relatively old and may not be totally representative of today's truck population. Consequently, some of the more specific results must be considered somewhat preliminary at this time. Several recommendations are presented in this section which, if implemented, will permit more specific conclusions to be validated and identify those actions which should be taken to address those safety problems which are confirmed.

Develop Empirical Data on Characteristics of Current Truck Population

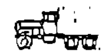
The necessary research should be conducted to collect empirical data in two major areas:

- truck braking distance; and
- the effect of different grades on truck speeds.

The results of this project were based upon truck braking distances measured during tests conducted in 1974 by the Bureau of Motor Carrier Safety.

EYE HEIGHT =107.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.11	0.33	0.47	0.56	0.62	0.67	0.71	0.74
2%	0.07	0.30	0.46	0.56	0.62	0.67	0.71	0.74	0.77
3%	0.00	0.00	0.00	0.20	0.34	0.43	0.57	0.65	0.71
4%	0.00	0.00	0.00	0.00	0.14	0.27	0.37	0.44	0.50
5%	0.00	0.00	0.00	0.00	0.00	0.10	0.23	0.32	0.40
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.20	0.30
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.19
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.17	0.39	0.51	0.59	0.65	0.69	0.73	0.75
2%	0.17	0.38	0.51	0.59	0.65	0.69	0.73	0.75	0.78
3%	0.33	0.43	0.57	0.65	0.69	0.73	0.75	0.78	0.80
4%	0.04	0.03	0.03	0.07	0.26	0.36	0.44	0.50	0.55
5%	0.00	0.00	0.00	0.00	0.00	0.17	0.28	0.36	0.43
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.24	0.33
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.22
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.20	0.39	0.51	0.59	0.65	0.70	0.74	0.76
2%	0.17	0.38	0.51	0.59	0.65	0.69	0.74	0.76	0.78
3%	0.34	0.46	0.58	0.65	0.69	0.73	0.76	0.78	0.80
4%	0.08	0.07	0.06	0.12	0.29	0.39	0.47	0.53	0.58
5%	0.00	0.00	0.00	0.00	0.00	0.18	0.29	0.37	0.44
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.25	0.33
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.22
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 6: DETAILED HAZARD CALCULATIONS

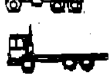
Group 4 Trucks
Type 1 Curves

Six-inch Object
Acceleration/Deceleration
Due to Grade

LEGEND:

 Cab Over Engine (COE)

 Conventional (CONV)

 Low Cab Over Engine (LCOE)

Similar testing should be repeated to provide better estimates of the braking performance of today's truck population. This testing should attempt to determine braking distances from the highest speeds possible.

The analysis conducted during this project indicates that the hazard associated with certain vertical curves is partially dependent on the extent to which the truck decelerates or accelerates while ascending or descending the curve. This factor was incorporated in the analysis by adjusting the truck's speed on the basis of data from a 1953 study. Since that time, changes in truck weight to horsepower ratios may have introduced changes in the amount by which truck speed is affected by grade. More recent data is therefore necessary to realistically represent the current truck population.

Evaluate Sensitivity of Results to Highway Design Speeds and Truck Braking Profiles

The results of this study apply to crest vertical curves designed according to AASHTO standards for a design speed of 60 mph. The truck speed upon entering the curve was assumed to be the posted speed of 55 mph (chosen based on the current speed limit). Vertical curves constructed for different design speeds will lead to differences in both sight and stopping distances stemming from differences in the length of the curve. Work should be initiated to extend the analysis of truck safety on vertical curves to include an evaluation of the sensitivity of the results to differences in highway design speeds, posted speed limits and differences in truck braking profiles.

The braking ability of the truck is a large factor in the hazard presented from crest vertical curves. Since trucks experience wide variation in braking performance, it is important to understand the impact of differences in this ability on the potential hazard. Although the best available estimates of truck braking distances were used in the analysis, the data is relatively old. While the results obtained were significant enough to indicate a clear potential for hazard to some truck groups, the impact of differences in braking distances should be investigated to allow the magnitude of the impact on potential hazard to be more precisely determined.

Reevaluate Perception and Reaction Times for the Population of Truck Drivers

Research should be conducted to determine the perception and reaction times which can be achieved by the existing population of truck drivers. A time of 2.5 seconds was used in the present project and has been generally accepted as that required for drivers of automobiles to perceive and react to a roadway object from the instant it comes into view. However, truck drivers represent a more experienced segment of the driving population and, therefore, may react differently in a potentially hazardous situation. The analysis during this project indicates that the impact of perception and reaction is not negligible since the distance traveled by the truck during this period typically represents from 20 to 25 percent of the total stopping distance. Differences in perception and reaction could impact the magnitude of the potential hazard to certain truck groups. A careful investigation should be conducted to determine if differences in driver experience and other factors lead to a different perception and reaction time for truck drivers.

Investigate the Need for Changes in Crest Vertical Curve Design Criteria

After further analysis using more current data (as discussed in the recommendations above), it should be determined if any changes are warranted in crest vertical curve design criteria.

Extend the Capability of the TPSIM to Include Hazard Analysis for Horizontal Curves and Tangent Sections

The TPSIM was developed to analyze the hazardous situations arising from trucks traversing crest vertical curves. Other situations that may be as hazardous to a truck include: horizontal curves, tangent sections (particularly downgrades), transition sections between vertical curves and transition sections between horizontal curves. The features of the TPSIM need to be expanded to treat these conditions with the objective of developing a TPSIM that is capable of assessing the hazardous location position for a segment of roadway representing a variety of horizontal and vertical geometric characteristics.

Investigate the Feasibility of Including Geometric Data in the Highway Performance Monitoring System

The potential hazard posed by crest vertical curves was evaluated separately for each possible combination of beginning and ending grades and the length of curve as specified using AASHTO design standards.

Assuming that the TPSIM was extended in its analysis capabilities to include horizontal curves, tangent sections and curve transitions as suggested in the previous recommendation, it would be possible to analyze the entrie roadway segment for hazardous locations given truck characteristics and posted speeds. Entire roadway networks could then be evaluated using "as built" highway plans for input data.

It is recommended that a feasibility study be conducted to determine if the data can be obtained from existing data bases. In particular this study should investigate the Highway Performance Monitoring System (HPMS) which already contains data on the vertical curves which exist on a number of representative sample sections of highway. The feasibility study should determine whether it is possible to extract sufficient data from the existing HPMS data base and, if not, the requirements for including the necessary data should be determined.

APPENDIX I: COMPUTATION OF SIGHT DISTANCE

In computing the sight distance, the TPSIM calculates the distance between the sighting point and the maximum sight point. The sighting point is that point along the roadway from which the driver first sees an object in the roadway. The maximum sighting point is the location of the sighted object when it is at the most distant point where it can still be seen.

For each successive sighting point along the curve, the TPSIM computes the sight distance (measured horizontally) to the maximum sight point. The resulting sight distance at each point will assume one of three possible values depending upon the following conditions on the geometry corresponding to the particular truck position (Figure A1).

Case 1: The farthest point ahead that the object can be seen is a point on the curve.

Case 2: The farthest ahead that the object can be seen is a point on the constant grade line (g_2) following the curve.

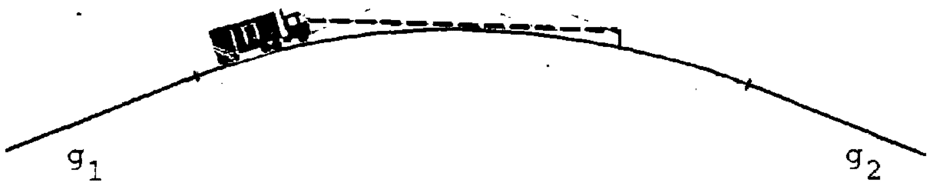
Case 3: The truck has reached a point on the curve where all points are visible until the constant grade (g_2) following the curve changes. The sight distance in this case is assumed to be effectively infinite and will, by definition, exceed stopping distance.

Based upon the properties of the parabola and the heights of the driver's eye and the object, the horizontal offset along the curve leading to each case can be determined and the calculations carried out as follows:

Let

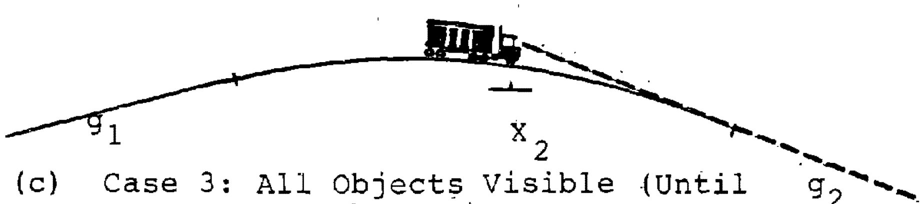
x = the horizontal offset from the beginning of the curve corresponding to the truck's position.

x_1 = the sighting point on the vertical curve where the farthest ahead that an object can be seen is no longer on the vertical curve, but is on the constant ending grade g_2.



(a) Case 1: Truck and Object Both on Curve

(b) Case 2: Truck on Curve - Object on Constant Ending Grade g_2



(c) Case 3: All Objects Visible (Until g_2 Changes)

FIGURE A1.1: THREE CASES FOR COMPUTING SIGHT DISTANCE

x_2 = the sighting point on the vertical curve where the driver's eye intersects the grade line g_2 and sight distance becomes effectively infinite.

The location of x_1 and x_2 are given by the following equations.

$$x_1 = L - 10\sqrt{K}\left(\sqrt{2h_1} + \sqrt{2h_2}\right) \quad \text{(A1)}$$

and

$$x_2 = L - \sqrt{200Kh_1} \quad \text{(A2)}$$

where

K is the ratio of the curve length (L) to the algebraic difference in grades.

h_1 is the height of the driver's eye (feet).

h_2 is the height of the roadway obstacle (feet).

L is the length of the vertical curve (feet).

The sight distance, S, is then given by the following equations:

$$S = \begin{cases} 10\sqrt{K}\left(\sqrt{2h_1} + \sqrt{2h_2}\right) & \text{when } 0 \le x \le x_1 \text{ (Case 1)} \quad \text{(A3)} \\ 1/2 \; \dfrac{(x - L)^2 + 200K(h_2 - h_1)}{(L - x) - \sqrt{200Kh_1}} & \text{when } x_1 < x < x_2 \text{ (Case 2)} \quad \text{(A4)} \\ \infty \text{ (i.e., unobstructed)} & \text{when } x \ge x_2 \text{ (Case 3)} \quad \text{(A5)} \end{cases}$$

APPENDIX II:

COMPUTATION OF STOPPING DISTANCE ON CREST VERTICAL CURVES

The stopping distance for any vehicle on a roadway consists of two components: distance traveled during perception and reaction and distance traveled during braking. Existing literature and data regarding truck characteristics suggest that stopping distance will differ as a function of the truck's specific location on the curve.

Two primary factors contribute to this difference. First, assuming the truck enters the curve at a posted speed, some trucks are likely to decelerate as they ascend the curve depending upon their weight-to-horsepower ratio. For these trucks, the velocity at each successive point along the curve will change, thereby changing the distance required to stop. Secondly, braking distances on uphill grades are less than those on downhill grades.

<u>Perception and Reaction Stopping Distance</u>

Total stopping distance is measured from the point at which the driver first sights the roadway object (the sighting point). The time required to perceive and react before actually applying the brakes is taken as 2.5 seconds.

Two options are available for computing the perception and reaction distance. In the first, the speed of the truck prior to applying the brakes is assumed to be unaffected by the grade of the roadway. The truck enters the curve at posted speed and continues at that speed until the point at which the brakes are applied. In the second option, the truck decelerates while ascending the curve (approximated as constant grade $g_{1/2}$) even prior to applying the brakes. It is also assumed in this option that, if the brakes are not applied prior to beginning the descent of the curve, the truck will begin to accelerate (up to a maximum of the posted speed) until braking begins.

Braking Distance

Although, empirical data on braking distances on crest vertical curves are not available, a large number of braking distance measurements on a level roadway are available.[1] A technique was developed for extrapolating from this data to determine braking distances which could be achieved from different positions on a crest vertical curve, under wet pavement conditions at varying speeds.

This extrapolation was accomplished by representing each curve by two straight line segments. The first segment connects the beginning of the curve (i.e., the point of tangency with the beginning grade g_1) to the crest of the curve (i.e., the point of maximum elevation on the curve). The second line segment connects the crest of the curve to its point of tangency with the grade following the curve. Using the properties of the parabola, it is seen that the two line segments are at grades $\frac{1}{2}g_1$ and $\frac{1}{2}g_2$, respectively. Stopping distances were calculated assuming that the performance on the uphill portion of the curve is approximately equal to that achieved if the braking took place on the constant grade represented by $\frac{1}{2}g_1$. Braking performance on the downhill was assumed approximately equivalent to stopping on a segment having grade $\frac{1}{2}g_2$.

The physical relationship describing the effect of a constant grade on braking distance is shown in Equation 1.

$$d = \frac{v^2}{30\ (\mu \pm g)} \qquad (1)$$

where

d = distance in feet

v = velocity when brakes are applied (mph)

μ = coefficient of friction

g = grade (expressed in decimal form)

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[1] Paul A. Winter, Brake Performance Levels for Trucks and Passenger Cars, DOT, FHWA, BMCS, 1974.

The relationship between stopping distance, on a grade (d_g) to that on a level surface d_0 is shown in Equation 2.

$$d_g = \frac{\mu}{\mu+g} \; d_0 \tag{2}$$

where

d_0 is the braking distance on a level roadway (feet),
μ is the coefficient of friction, and
g is the grade (expressed in decimal form).

The empirical braking distances had to be adjusted to account for the fact that they represented stops from initial speeds of 20 mph on dry pavement. The translation of empirical distance to extrapolated distances is accomplished by Equation 3.

$$d_1 = d_0 \left(\frac{\mu_0}{\mu_1 + g} \right) \left(\frac{V_1^2}{V_0^2} \right) \tag{3}$$

where

d_1 = braking distance at speed V_1 with coefficient of friction μ_1.

d_0 = observed braking distance at speed V_0 with coefficient of friction μ_0.

μ_0 = coefficient of friction for observed braking distances.

μ_1 = coefficient of friction for estimated braking distance d.

g = grade of roadway for braking activity (decimal form).

V_0 = initial velocity of truck in observed data.

V_1 = initial velocity of truck for estimated braking distance.

The assumption in this approach is that the coefficient of friction equation may be used to produce relative values of the braking distance under varying conditions and that the ratio of actual braking distances between one set of conditions and another is equal to the ratio between theoretical braking distances between the same set of conditions.

Once braking begins, the TPSIM determines the point at which the truck will come to a halt. If braking begins on the uphill portion of the curve, the braking distance for the grade $\frac{1}{2}g_1$ is used to determine the deceleration rate. This rate is used to determine the velocity of the truck when it reaches the crest of the curve. This new velocity is used to determine the distance traveled along $\frac{1}{2}g_2$ before the truck comes to a halt. Total braking distance is taken as the sum of the two components (i.e., distance traveled on uphill grade, and the distance traveled on the downhill grade).

The total stopping distance is the sum of the perception and reaction distance and the braking distance.

APPENDIX III: DRIVER EYE HEIGHT

Two sources of data were used to define eye height for each cab type. The first set of data was obtained from a 1982 study for the National Highway Traffic Safety Administration (NHTSA) conducted by Vector Enterprise.[2] The study was conducted to analyze the relationships among cab dimensions and other characteristics of a sample of trucks to the size of mirrors needed to view proposed ground and vertical FMVSS III indirect field of view targets. As a part of this study, truck eye heights above ground were obtained from Ford, General Motors, Mack and Freightliner. The resulting data from sixteen trucks is shown in Table A-1.

The second set of eye height data was provided by three major manufacturers for use in the present project. Mack Truck, Freightliner, and International Harvester were each asked to provide driver eye heights for their most common cab types. Mack and Freightliner both provided eye height data as ranges to account for the effect of other variables which will likely impact the eye heights experienced in practice. The Mack Truck data (Table A-2), consist of driver eye heights for seven representative cab types with the driver's seats in their "mid-ride/mid-height" adjustments. Ranges were provided to account for the effect of differences in the tire/axle/suspension combination. International Harvester provided driver eye heights for three of their basic models (Table A-3). The range of eye heights for each cab type was derived using the 5 percentile female driver for the lowest height and a 95 percentile make for the upper limit. The range also accounts for vehicle height variables such as tire size, suspensions, cab mounting, seat configurations, seat adjustment, etc.

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[2] Burger, W. J. and Mulholland, M. U., Plane and Convex Mirror Sizes for Small to Large Trucks: Predictions from Truck Characteristics, Vector Enterprises, Inc., Contract DOT-HS-7-01721, 1982.

MAKE	MODEL	GVWR (x1000)	EYE HEIGHT (inches)
GMC	CJ0064 Con.	50.0	80.9
GMC	J8C064 Con.	54.0	85.4
Ford	LN-600 Con.	50.0	85.2
GMC	J9C0G4 Con.	50.0	88.2
Mack	MC600S LCF	56.0	89.2
Mack	R400P Con.	47.0	92.5
Mack	U600T Con.	41.0	92.7
Mack	MR600S LCF	78.0	93.2
GMC	N9F064 Con.	50.0	94.1
FLT	FLC12064T	40.0	96.5
Mack	RWS70LS Con.	68.0	99.5
FLT	FLT8664T COE	40.0	100.8
Mack	DM800SX Con.	103.0	103.6
GMC	D9L064 COE	46.0	106.3
Ford	CLT9000 COE	55.0	110.0
Mack	WS700LS COE	68.0	112.5

GVWR: Gross Vehicle Weight Rating

TABLE A-1: DRIVER EYE HEIGHTS FROM 1982 STUDY BY VECTOR ENTERPRISES

MACK MODEL	DRIVER'S EYE POINT TO GROUND (INCHES)	
	RANGE	MIDPOINT
RW700LS	95.71 - 99.51	97.6
R400P	90.42 - 92.48	91.5
U600T	90.81 - 92.74	91.8
MC600S	87.63 - 89.21	88.4
M600S	90.34 - 93.24	91.79
W700LS	106.50 - 112.51	109.5
DM800SX	95.19 - 103.65	99.4

TABLE A-2: DRIVER EYE HEIGHT DATA PROVIDED BY MACK TRUCK

	IH TRUCK MODEL		
	S-Series Conventional	42/4300 Conventional	CO-9670 Cab Over
Driver Eye Height (in inches)			
Minimum	71.50"	87"	94.50"
Maximum	100.00"	101"	112.50"

TABLE A-3: DRIVER EYE HEIGHT DATA PROVIDED BY INTERNATIONAL HARVESTER

The data provided by Freightliner (Table A-4) consists of measurements from the ground to the driver's H-point for their cab over engine and conventional cabs. The data is based upon their highest use seat (National levelair II Seat), in its rear most adjustment. The seat was in its lowest ride position which would correspond to where a fifth percentile person would adjust the seat in order to reach the pedals. Driver eye heights were estimated by adding to the H-point measurements provided, measurements from the H-point to the driver eye point.[3]

Summary data is provided in Table A-5.

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[3] Sanders, M., U.S. Truck Driver Anthropometric and Truck Work Space Data Survey, Canyon Research Group, Inc., under contract to the Society of Automotive Engineers, 1983.

H-Point Location (inches)

	COE	CONVENTIONAL
Horizontal Distance from Bumper	40.37	104.37
Elevation above Road	73.92	68.67
Lateral distance from Vehicle Center line	33.07	22.57
Estimated Eye Height	105.92	100.67

TABLE A-4: DRIVER EYE HEIGHT DATA PROVIDED BY FREIGHTLINER

CAB TYPE: CONVENTIONAL

MANUFACTURER [1]	NHTSA [2]	ASG [3]	AVERAGE [4]
GMC	87.2 (4)		
FORD	85.2 (1)		
MACK	95.4 (4)	95.1	
FLT		100.7	
IH		94.0	
	WEIGHTED AVG. 89.3 INCHES	WEIGHTED AVG. 96.6 INCHES	CAB-TYPE AVG. 93 INCHES

CAB TYPE: CAB OVER ENGINE

MANUFACTURER	NHTSA	ASG	AVERAGE
GMC	106.3 (4)		
FORD	110.0 (1)		
MACK	112.5 (1)	109.5	
FLT	98.7 (2)	105.9	
IH		103.5	
	WEIGHTED AVG. 106.9 INCHES	WEIGHTED AVG. 106.3 INCHES	CAB-TYPE AVG. 107 INCHES

CAB TYPE: LOW CAB OVER ENGINE

MANUFACTURER	NHTSA	ASG	AVERAGE
GMC			
FORD			
MACK	91.2 (2)	90.1	
FLT	98.7 (2)		
IH			
	WEIGHTED AVG. 91.2 INCHES	WEIGHTED AVG. 90.1 INCHES	CAB-TYPE AVG. 91 INCHES

[1] Manufacturer Codes: GMC - GMC Truck; FORD - Ford Truck; MACK - Mack Truck; FLT - Freightliner; IH - International Harvester

[2] Source: Vector Enterprises (6)
[3] Source: ASG data collected from manufacturers
[4] Average values rounded to the nearest inch

TABLE A-5: SUMMARY OF DRIVER EYE HEIGHT DATA

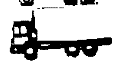
APPENDIX IV: SIMULATION RESULTS

This appendix presents tables containing the hazard indices computed by the TPSIM for each of the eighteen truck/curve combinations where a potential hazard was indicated. Tables are numbered Exhibits 1 through 18 corresponding to the cell numbers in Table IV.1 or Table IV.2. Each exhibit consists of three matrices corresponding, to the cab-over-engine, conventional, and low cab-over-engine cab types. Each entry indicates the function of the indicated curve that represents a hazardous sighting position for the truck (i.e., the hazard index). The legend for the three cab types is illustrated below:

LEGEND

 Cab Over Engine (COE)

 Conventional (CONV)

 Low Cab Over Engine (LCOE)

EYE HEIGHT =107.00 IN. OBJECT HEIGHT = 6.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
-2%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
-3%			0.00	0.00	0.00	0.00	0.00	0.00	0.19
-4%				0.00	0.00	0.00	0.00	0.00	0.18
-5%					0.00	0.00	0.00	0.00	0.20
-6%						0.00	0.00	0.00	0.07
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT = 6.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.29	0.37
-2%		0.00	0.00	0.00	0.00	0.00	0.14	0.31	0.40
-3%			0.00	0.00	0.00	0.00	0.15	0.33	0.43
-4%				0.00	0.00	0.00	0.11	0.36	0.50
-5%					0.00	0.00	0.00	0.15	0.38
-6%						0.00	0.00	0.00	0.17
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT = 6.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.32	0.40
-2%		0.00	0.00	0.00	0.00	0.00	0.20	0.34	0.42
-3%			0.00	0.00	0.00	0.00	0.23	0.38	0.45
-4%				0.00	0.00	0.00	0.13	0.38	0.50
-5%					0.00	0.00	0.00	0.17	0.38
-6%						0.00	0.00	0.00	0.17
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.1: DETAILED HAZARD CALCULATIONS

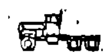
Group 2 Trucks
Type 3 Curves

Six-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT = 6.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.55	0.64	0.69	0.73
2%	0.00	0.00	0.00	0.00	0.00	0.48	0.57	0.64	0.69
3%	0.00	0.00	0.00	0.00	0.00	0.42	0.51	0.58	0.63
4%	0.00	0.00	0.00	0.00	0.00	0.38	0.46	0.52	0.58
5%	0.00	0.00	0.00	0.00	0.00	0.34	0.42	0.48	0.54
6%	0.00	0.00	0.00	0.00	0.00	0.31	0.39	0.45	0.50
7%	0.00	0.00	0.00	0.00	0.00	0.29	0.36	0.42	0.46
8%	0.00	0.00	0.00	0.00	0.00	0.27	0.33	0.39	0.43
9%	0.00	0.00	0.00	0.00	0.00	0.25	0.31	0.36	0.41

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT = 6.00 IN.



\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.04	0.34	0.47	0.57	0.63	0.69	0.72	0.75
2%	0.00	0.02	0.32	0.47	0.58	0.65	0.71	0.75	0.77
3%	0.00	0.00	0.25	0.39	0.50	0.57	0.63	0.67	0.71
4%	0.00	0.00	0.21	0.33	0.43	0.50	0.56	0.61	0.64
5%	0.00	0.00	0.17	0.29	0.38	0.45	0.51	0.55	0.59
6%	0.00	0.00	0.15	0.25	0.34	0.40	0.46	0.51	0.55
7%	0.00	0.00	0.13	0.23	0.31	0.37	0.43	0.47	0.51
8%	0.00	0.00	0.12	0.20	0.28	0.34	0.39	0.44	0.48
9%	0.00	0.00	0.10	0.18	0.26	0.31	0.37	0.41	0.45

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT = 6.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.13	0.36	0.49	0.58	0.64	0.69	0.72	0.75
2%	0.00	0.15	0.38	0.53	0.62	0.69	0.72	0.75	0.78
3%	0.00	0.09	0.30	0.42	0.53	0.60	0.64	0.68	0.72
4%	0.00	0.07	0.25	0.36	0.46	0.52	0.57	0.61	0.65
5%	0.00	0.05	0.21	0.31	0.40	0.46	0.52	0.56	0.60
6%	0.00	0.04	0.18	0.27	0.36	0.42	0.47	0.52	0.56
7%	0.00	0.03	0.15	0.24	0.32	0.38	0.43	0.48	0.52
8%	0.00	0.03	0.13	0.22	0.30	0.35	0.40	0.44	0.48
9%	0.00	0.02	0.12	0.20	0.27	0.32	0.37	0.41	0.45

EXHIBIT IV.2: DETAILED HAZARD CALCULATIONS

Group 3 Trucks
Type 1 Curves

Six-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN.   OBJECT HEIGHT = 6.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.52	0.62	0.69	0.73
2%	0.00	0.00	0.00	0.00	0.00	0.40	0.50	0.57	0.63
3%	0.00	0.00	0.00	0.00	0.00	0.26	0.38	0.46	0.53
4%	0.00	0.00	0.00	0.00	0.00	0.12	0.26	0.36	0.44
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.24	0.34
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.24
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 93.00 IN.   OBJECT HEIGHT = 6.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.34	0.47	0.57	0.63	0.69	0.72	0.75
2%	0.00	0.00	0.04	0.27	0.43	0.56	0.65	0.72	0.75
3%	0.00	0.00	0.00	0.06	0.25	0.37	0.46	0.52	0.58
4%	0.00	0.00	0.00	0.00	0.06	0.21	0.33	0.41	0.47
5%	0.00	0.00	0.00	0.00	0.00	0.05	0.20	0.30	0.38
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.18	0.28
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.17
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 91.00 IN.   OBJECT HEIGHT = 6.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.04	0.36	0.49	0.58	0.64	0.69	0.72	0.75
2%	0.00	0.00	0.09	0.32	0.49	0.61	0.68	0.74	0.78
3%	0.00	0.00	0.00	0.08	0.26	0.38	0.47	0.53	0.59
4%	0.00	0.00	0.00	0.00	0.07	0.23	0.34	0.41	0.48
5%	0.00	0.00	0.00	0.00	0.00	0.07	0.20	0.30	0.38
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.18	0.28
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.17
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXHIBIT IV.3: DETAILED HAZARD CALCULATIONS

Group 3 Trucks
Type 1 Curves

Six-inch Object
Acceleration/Deceleration
Due to Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2 G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.31	0.45	0.52	0.54	0.67
-2%		0.00	0.00	0.00	0.09	0.33	0.47	0.56	0.62
-3%			0.00	0.00	0.00	0.11	0.34	0.47	0.56
-4%				0.00	0.00	0.00	0.13	0.34	0.49
-5%					0.00	0.00	0.00	0.13	0.36
-6%						0.00	0.00	0.00	0.15
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2 G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.15	0.38	0.50	0.59	0.65	0.69
-2%		0.00	0.00	0.00	0.17	0.39	0.51	0.59	0.65
-3%			0.00	0.00	0.00	0.20	0.39	0.51	0.59
-4%				0.00	0.00	0.00	0.20	0.39	0.51
-5%					0.00	0.00	0.00	0.20	0.39
-6%						0.00	0.00	0.00	0.20
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2 G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.17	0.39	0.51	0.59	0.65	0.70
-2%		0.00	0.00	0.00	0.20	0.39	0.51	0.59	0.66
-3%			0.00	0.00	0.00	0.20	0.39	0.53	0.60
-4%				0.00	0.00	0.00	0.20	0.41	0.53
-5%					0.00	0.00	0.00	0.22	0.41
-6%						0.00	0.00	0.00	0.22
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.4: DETAILED HAZARD CALCULATIONS

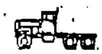
Group 3 Trucks
Type 3 Curves

Six-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN.   OBJECT HEIGHT = 6.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.31	0.45	0.52	0.54	0.67
-2%		0.00	0.00	0.00	0.09	0.33	0.47	0.56	0.62
-3%			0.00	0.00	0.00	0.11	0.34	0.47	0.56
-4%				0.00	0.00	0.00	0.13	0.34	0.49
-5%					0.00	0.00	0.00	0.13	0.36
-6%						0.00	0.00	0.00	0.15
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN.   OBJECT HEIGHT = 6.00 IN.



G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.15	0.38	0.50	0.59	0.65	0.69
-2%		0.00	0.00	0.00	0.17	0.39	0.51	0.59	0.65
-3%			0.00	0.00	0.00	0.20	0.39	0.51	0.59
-4%				0.00	0.00	0.00	0.20	0.39	0.51
-5%					0.00	0.00	0.00	0.20	0.39
-6%						0.00	0.00	0.00	0.20
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN.   OBJECT HEIGHT = 6.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.17	0.39	0.51	0.59	0.65	0.70
-2%		0.00	0.00	0.00	0.20	0.39	0.51	0.59	0.66
-3%			0.00	0.00	0.00	0.20	0.39	0.53	0.60
-4%				0.00	0.00	0.00	0.20	0.41	0.53
-5%					0.00	0.00	0.00	0.22	0.41
-6%						0.00	0.00	0.00	0.22
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

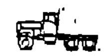
EXHIBIT IV.5: DETAILED HAZARD CALCULATIONS

Group 3 Trucks
Type 3 Curves

Six-inch Object
Acceleration/Deceleration
Due to Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



EYE HEIGHT = 93.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66
2%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
3%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55
4%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37

EXHIBIT IV.6: DETAILED HAZARD CALCULATIONS

Group 3 Trucks
Type 1 Curves

Fifteen-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT =15.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT =15.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT =15.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62
2%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52
3%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44
4%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXHIBIT IV.7: DETAILED HAZARD CALCULATIONS

Group 3 Trucks
Type 1 Curves

Fifteen-inch Object
Acceleration/Deceleration
Due to Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT =15.00 IN. 

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.30
-2%		0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.30
-3%			0.00	0.00	0.00	0.00	0.00	0.17	0.34
-4%				0.00	0.00	0.00	0.00	0.20	0.38
-5%					0.00	0.00	0.00	0.00	0.28
-6%						0.00	0.00	0.00	0.04
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT =15.00 IN. 

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.11	0.27	0.38	0.44
-2%		0.00	0.00	0.00	0.00	0.05	0.30	0.43	0.47
-3%			0.00	0.00	0.00	0.00	0.31	0.46	0.56
-4%				0.00	0.00	0.00	0.07	0.33	0.47
-5%					0.00	0.00	0.00	0.11	0.34
-6%						0.00	0.00	0.00	0.13
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT =15.00 IN. 

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.16	0.32	0.41	0.46
-2%		0.00	0.00	0.00	0.00	0.15	0.36	0.45	0.51
-3%			0.00	0.00	0.00	0.04	0.31	0.46	0.56
-4%				0.00	0.00	0.00	0.09	0.34	0.47
-5%					0.00	0.00	0.00	0.11	0.34
-6%						0.00	0.00	0.00	0.13
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.8: DETAILED HAZARD CALCULATIONS

Group 3 Trucks
Type 3 Curves

Fifteen-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN.   OBJECT HEIGHT =15.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.30
-2%		0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.30
-3%			0.00	0.00	0.00	0.00	0.00	0.17	0.34
-4%				0.00	0.00	0.00	0.00	0.20	0.38
-5%					0.00	0.00	0.00	0.00	0.28
-6%						0.00	0.00	0.00	0.04
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN.   OBJECT HEIGHT =15.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.11	0.27	0.38	0.44
-2%		0.00	0.00	0.00	0.00	0.05	0.30	0.43	0.47
-3%			0.00	0.00	0.00	0.00	0.31	0.46	0.56
-4%				0.00	0.00	0.00	0.07	0.33	0.47
-5%					0.00	0.00	0.00	0.11	0.34
-6%						0.00	0.00	0.00	0.13
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN.   OBJECT HEIGHT =15.00 IN.

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.00	0.16	0.32	0.41	0.46
-2%		0.00	0.00	0.00	0.00	0.15	0.36	0.45	0.51
-3%			0.00	0.00	0.00	0.04	0.31	0.46	0.56
-4%				0.00	0.00	0.00	0.09	0.34	0.47
-5%					0.00	0.00	0.00	0.11	0.34
-6%						0.00	0.00	0.00	0.13
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.9: DETAILED HAZARD CALCULATIONS

Group 3 Trucks
Type 3 Curves

Fifteen-inch Object
Acceleration/Deceleration
Due to Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.11	0.33	0.47	0.56	0.62	0.67	0.71	0.74
2%	0.09	0.33	0.46	0.56	0.62	0.67	0.71	0.74	0.77
3%	0.31	0.46	0.55	0.62	0.67	0.71	0.74	0.76	0.78
4%	0.18	0.33	0.43	0.51	0.57	0.62	0.65	0.69	0.71
5%	0.09	0.25	0.35	0.43	0.50	0.54	0.59	0.62	0.65
6%	0.04	0.19	0.29	0.37	0.43	0.49	0.53	0.56	0.60
7%	0.00	0.15	0.25	0.33	0.39	0.44	0.48	0.52	0.56
8%	0.00	0.12	0.21	0.29	0.35	0.40	0.44	0.48	0.52
9%	0.00	0.10	0.18	0.26	0.31	0.36	0.41	0.45	0.48

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.17	0.39	0.51	0.59	0.65	0.69	0.73	0.75
2%	0.17	0.38	0.51	0.59	0.65	0.69	0.73	0.75	0.78
3%	0.38	0.50	0.59	0.65	0.69	0.73	0.75	0.78	0.80
4%	0.50	0.58	0.65	0.69	0.73	0.75	0.78	0.80	0.81
5%	0.58	0.64	0.69	0.73	0.75	0.78	0.80	0.81	0.82
6%	0.64	0.69	0.73	0.75	0.78	0.80	0.81	0.82	0.84
7%	0.69	0.72	0.75	0.78	0.80	0.81	0.82	0.84	0.85
8%	0.72	0.75	0.78	0.80	0.81	0.82	0.84	0.85	0.86
9%	0.11	0.19	0.27	0.33	0.37	0.42	0.45	0.48	0.52

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT = 6.00 IN. 

\G2: / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.20	0.39	0.51	0.59	0.65	0.70	0.74	0.76
2%	0.20	0.39	0.51	0.59	0.65	0.69	0.74	0.76	0.78
3%	0.39	0.51	0.59	0.65	0.69	0.73	0.76	0.78	0.80
4%	0.50	0.59	0.65	0.69	0.73	0.75	0.78	0.80	0.82
5%	0.58	0.65	0.69	0.73	0.75	0.78	0.80	0.82	0.83
6%	0.64	0.69	0.73	0.75	0.78	0.80	0.82	0.83	0.84
7%	0.69	0.73	0.75	0.78	0.80	0.81	0.83	0.84	0.85
8%	0.72	0.75	0.78	0.80	0.81	0.82	0.84	0.85	0.86
9%	0.13	0.21	0.28	0.33	0.38	0.42	0.46	0.50	0.52

EXHIBIT IV.10: DETAILED HAZARD CALCULATIONS

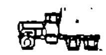
Group 4 Trucks
Type 1 Curves

Six-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT = 6.00 IN.

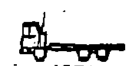
G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.11	0.33	0.47	0.56	0.62	0.67	0.71	0.74
2%	0.07	0.30	0.46	0.56	0.62	0.67	0.71	0.74	0.77
3%	0.00	0.00	0.00	0.20	0.34	0.43	0.57	0.65	0.71
4%	0.00	0.00	0.00	0.00	0.14	0.27	0.37	0.44	0.50
5%	0.00	0.00	0.00	0.00	0.00	0.10	0.23	0.32	0.40
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.20	0.30
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.19
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT = 6.00 IN.



G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.17	0.39	0.51	0.59	0.65	0.69	0.73	0.75
2%	0.17	0.38	0.51	0.59	0.65	0.69	0.73	0.75	0.78
3%	0.33	0.43	0.57	0.65	0.69	0.73	0.75	0.78	0.80
4%	0.04	0.03	0.03	0.07	0.26	0.36	0.44	0.50	0.55
5%	0.00	0.00	0.00	0.00	0.00	0.17	0.28	0.36	0.43
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.24	0.33
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.22
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT = 6.00 IN.



G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.20	0.39	0.51	0.59	0.65	0.70	0.74	0.76
2%	0.17	0.38	0.51	0.59	0.65	0.69	0.74	0.76	0.78
3%	0.34	0.46	0.58	0.65	0.69	0.73	0.76	0.78	0.80
4%	0.08	0.07	0.06	0.12	0.29	0.39	0.47	0.53	0.58
5%	0.00	0.00	0.00	0.00	0.00	0.18	0.29	0.37	0.44
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.25	0.33
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.22
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXHIBIT IV.11: DETAILED HAZARD CALCULATIONS

Group 4 Trucks
Type 1 Curves

Six-inch Object
Acceleration/Deceleration
Due to Grade

EYE HEIGHT =107.00 IN.   OBJECT HEIGHT = 6.00 IN. 

\G2: G1\	1%	2%	3%	4%	5%	6%	7%	8%	9%
1%	0.00								
2%	0.00	0.00							
3%	0.00	0.00	0.00						
4%	0.00	0.00	0.00	0.00					
5%	0.00	0.00	0.00	0.00	0.00				
6%	0.00	0.00	0.00	0.00	0.00	0.00			
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 93.00 IN.   OBJECT HEIGHT = 6.00 IN. 

\G2: G1\	1%	2%	3%	4%	5%	6%	7%	8%	9%
1%	0.00								
2%	0.00	0.00							
3%	0.00	0.00	0.00						
4%	0.15	0.00	0.00	0.00					
5%	0.36	0.13	0.00	0.00	0.00				
6%	0.43	0.31	0.00	0.00	0.00	0.00			
7%	0.38	0.28	0.05	0.00	0.00	0.00	0.00		
8%	0.36	0.26	0.09	0.00	0.00	0.00	0.00	0.00	
9%	0.36	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 91.00 IN.   OBJECT HEIGHT = 6.00 IN. 

\G2: G1\	1%	2%	3%	4%	5%	6%	7%	8%	9%
1%	0.00								
2%	0.00	0.00							
3%	0.00	0.00	0.00						
4%	0.17	0.00	0.00	0.00					
5%	0.38	0.15	0.00	0.00	0.00				
6%	0.50	0.36	0.11	0.00	0.00	0.00			
7%	0.43	0.34	0.16	0.00	0.00	0.00	0.00		
8%	0.39	0.32	0.17	0.00	0.00	0.00	0.00	0.00	
9%	0.37	0.30	0.19	0.00	0.00	0.00	0.00	0.00	0.00

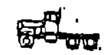
EXHIBIT IV.12: DETAILED HAZARD CALCULATIONS

Group 4 Trucks
Type 2 Curves

Six-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT = 6.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.13	0.36	0.49	0.57	0.63	0.68
-2%		0.00	0.00	0.00	0.13	0.36	0.49	0.57	0.63
-3%			0.00	0.00	0.00	0.15	0.36	0.49	0.57
-4%				0.00	0.00	0.00	0.15	0.36	0.49
-5%					0.00	0.00	0.00	0.15	0.36
-6%						0.00	0.00	0.00	0.15
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00



EYE HEIGHT = 93.00 IN. OBJECT HEIGHT = 6.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.20	0.39	0.51	0.60	0.66	0.70
-2%		0.00	0.00	0.00	0.20	0.41	0.53	0.60	0.66
-3%			0.00	0.00	0.00	0.22	0.41	0.53	0.60
-4%				0.00	0.00	0.00	0.22	0.41	0.53
-5%					0.00	0.00	0.00	0.22	0.41
-6%						0.00	0.00	0.00	0.22
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT = 6.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.22	0.41	0.53	0.60	0.66	0.70
-2%		0.00	0.00	0.00	0.22	0.41	0.53	0.60	0.66
-3%			0.00	0.00	0.00	0.22	0.41	0.53	0.60
-4%				0.00	0.00	0.00	0.22	0.41	0.53
-5%					0.00	0.00	0.00	0.22	0.41
-6%						0.00	0.00	0.00	0.22
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.13: DETAILED HAZARD CALCULATIONS

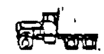
Group 4 Trucks
Type 3 Curves

Six-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN.   OBJECT HEIGHT = 6.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.13	0.36	0.49	0.57	0.63	0.68
-2%		0.00	0.00	0.00	0.13	0.36	0.49	0.57	0.63
-3%			0.00	0.00	0.00	0.15	0.36	0.49	0.57
-4%				0.00	0.00	0.00	0.15	0.36	0.49
-5%					0.00	0.00	0.00	0.15	0.36
-6%						0.00	0.00	0.00	0.15
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN.   OBJECT HEIGHT = 6.00 IN.



\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.20	0.39	0.51	0.60	0.66	0.70
-2%		0.00	0.00	0.00	0.20	0.41	0.53	0.60	0.66
-3%			0.00	0.00	0.00	0.22	0.41	0.53	0.60
-4%				0.00	0.00	0.00	0.22	0.41	0.53
-5%					0.00	0.00	0.00	0.22	0.41
-6%						0.00	0.00	0.00	0.22
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN.   OBJECT HEIGHT = 6.00 IN.

\G2 / G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.22	0.41	0.53	0.60	0.66	0.70
-2%		0.00	0.00	0.00	0.22	0.41	0.53	0.60	0.66
-3%			0.00	0.00	0.00	0.22	0.41	0.53	0.60
-4%				0.00	0.00	0.00	0.22	0.41	0.53
-5%					0.00	0.00	0.00	0.22	0.41
-6%						0.00	0.00	0.00	0.22
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.14: DETAILED HAZARD CALCULATIONS

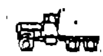
Group 4 Trucks
Type 3 Curves

Six-inch Object
Acceleration/Deceleration
Due to Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.44	0.57	0.63	0.67	0.71
2%	0.00	0.00	0.00	0.00	0.37	0.50	0.60	0.66	0.70
3%	0.00	0.00	0.00	0.00	0.32	0.45	0.53	0.59	0.64
4%	0.00	0.00	0.00	0.00	0.29	0.40	0.48	0.54	0.59
5%	0.00	0.00	0.00	0.00	0.26	0.36	0.43	0.49	0.54
6%	0.00	0.00	0.00	0.00	0.23	0.33	0.40	0.45	0.50
7%	0.00	0.00	0.00	0.00	0.22	0.30	0.36	0.42	0.46
8%	0.00	0.00	0.00	0.00	0.20	0.27	0.34	0.39	0.44
9%	0.00	0.00	0.00	0.00	0.18	0.26	0.32	0.36	0.41

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT =15.00 IN.



\G2: G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.02	0.30	0.43	0.54	0.61	0.66	0.70	0.74
2%	0.00	0.07	0.36	0.51	0.60	0.66	0.70	0.73	0.76
3%	0.00	0.01	0.27	0.42	0.51	0.59	0.64	0.68	0.72
4%	0.00	0.00	0.22	0.35	0.44	0.52	0.57	0.61	0.66
5%	0.00	0.00	0.18	0.29	0.39	0.46	0.51	0.56	0.60
6%	0.00	0.00	0.15	0.26	0.34	0.41	0.47	0.51	0.56
7%	0.00	0.00	0.13	0.23	0.31	0.38	0.43	0.47	0.51
8%	0.00	0.00	0.11	0.20	0.28	0.35	0.40	0.44	0.48
9%	0.00	0.00	0.10	0.18	0.26	0.32	0.37	0.41	0.45

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.04	0.30	0.45	0.55	0.61	0.67	0.71	0.74
2%	0.00	0.18	0.42	0.54	0.61	0.66	0.71	0.74	0.76
3%	0.00	0.11	0.31	0.45	0.55	0.61	0.66	0.70	0.73
4%	0.00	0.07	0.25	0.37	0.46	0.53	0.59	0.63	0.66
5%	0.00	0.04	0.20	0.32	0.41	0.47	0.53	0.57	0.61
6%	0.00	0.02	0.17	0.28	0.36	0.43	0.48	0.53	0.56
7%	0.00	0.00	0.15	0.25	0.33	0.39	0.44	0.48	0.52
8%	0.00	0.00	0.13	0.22	0.30	0.35	0.41	0.45	0.48
9%	0.00	0.00	0.12	0.20	0.27	0.32	0.38	0.42	0.45

EXHIBIT IV.15: DETAILED HAZARD CALCULATIONS

Group 4 Trucks
Type 1 Curves

Fifteen-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.00	0.00	0.40	0.56	0.63	0.67	0.71
2%	0.00	0.00	0.00	0.00	0.26	0.40	0.50	0.57	0.65
3%	0.00	0.00	0.00	0.00	0.11	0.27	0.38	0.46	0.52
4%	0.00	0.00	0.00	0.00	0.00	0.13	0.26	0.35	0.43
5%	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.24	0.33
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.23
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.00	0.30	0.43	0.54	0.61	0.66	0.70	0.74
2%	0.00	0.00	0.00	0.27	0.47	0.62	0.70	0.73	0.76
3%	0.00	0.00	0.00	0.03	0.24	0.36	0.45	0.52	0.57
4%	0.00	0.00	0.00	0.00	0.04	0.21	0.32	0.40	0.47
5%	0.00	0.00	0.00	0.00	0.00	0.04	0.19	0.29	0.37
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.17	0.27
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.16
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT =15.00 IN.

\G2: G1\	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
1%	0.00	0.02	0.30	0.45	0.55	0.61	0.67	0.71	0.74
2%	0.00	0.00	0.08	0.31	0.56	0.66	0.71	0.74	0.76
3%	0.00	0.00	0.00	0.07	0.26	0.37	0.46	0.52	0.57
4%	0.00	0.00	0.00	0.00	0.06	0.22	0.33	0.41	0.47
5%	0.00	0.00	0.00	0.00	0.00	0.06	0.20	0.30	0.37
6%	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.18	0.27
7%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.17
8%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
9%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXHIBIT IV.16: DETAILED HAZARD CALCULATIONS

Group 4 Trucks
Type 1 Curves

Fifteen-inch Object
Acceleration/Deceleration
Due to Grade

EYE HEIGHT =107.00 IN.   OBJECT HEIGHT =15.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.28	0.43	0.53	0.60	0.65
-2%		0.00	0.00	0.00	0.02	0.30	0.43	0.54	0.60
-3%			0.00	0.00	0.00	0.07	0.31	0.45	0.55
-4%				0.00	0.00	0.00	0.09	0.31	0.46
-5%					0.00	0.00	0.00	0.09	0.33
-6%						0.00	0.00	0.00	0.11
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN.   OBJECT HEIGHT =15.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.11	0.34	0.47	0.57	0.63	0.68
-2%		0.00	0.00	0.00	0.13	0.34	0.49	0.57	0.63
-3%			0.00	0.00	0.00	0.13	0.36	0.49	0.58
-4%				0.00	0.00	0.00	0.15	0.36	0.50
-5%					0.00	0.00	0.00	0.15	0.38
-6%						0.00	0.00	0.00	0.17
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN.   OBJECT HEIGHT =15.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.11	0.34	0.49	0.57	0.63	0.69
-2%		0.00	0.00	0.00	0.13	0.36	0.49	0.58	0.64
-3%			0.00	0.00	0.00	0.15	0.36	0.50	0.58
-4%				0.00	0.00	0.00	0.15	0.38	0.50
-5%					0.00	0.00	0.00	0.17	0.38
-6%						0.00	0.00	0.00	0.17
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.17: DETAILED HAZARD CALCULATIONS

Group 4 Trucks
Type 3 Curves

Fifteen-inch Object
Speed Unaffected by Grade

EYE HEIGHT =107.00 IN. OBJECT HEIGHT =15.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.00	0.28	0.43	0.53	0.60	0.65
-2%		0.00	0.00	0.00	0.02	0.30	0.43	0.54	0.60
-3%			0.00	0.00	0.00	0.07	0.31	0.45	0.55
-4%				0.00	0.00	0.00	0.09	0.31	0.46
-5%					0.00	0.00	0.00	0.09	0.33
-6%						0.00	0.00	0.00	0.11
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 93.00 IN. OBJECT HEIGHT =15.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.11	0.34	0.47	0.57	0.63	0.68
-2%		0.00	0.00	0.00	0.13	0.34	0.49	0.57	0.63
-3%			0.00	0.00	0.00	0.13	0.36	0.49	0.58
-4%				0.00	0.00	0.00	0.15	0.36	0.50
-5%					0.00	0.00	0.00	0.15	0.38
-6%						0.00	0.00	0.00	0.17
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EYE HEIGHT = 91.00 IN. OBJECT HEIGHT =15.00 IN.

G1 \ G2	-1%	-2%	-3%	-4%	-5%	-6%	-7%	-8%	-9%
-1%	0.00	0.00	0.00	0.11	0.34	0.49	0.57	0.63	0.69
-2%		0.00	0.00	0.00	0.13	0.36	0.49	0.58	0.64
-3%			0.00	0.00	0.00	0.15	0.36	0.50	0.58
-4%				0.00	0.00	0.00	0.15	0.38	0.50
-5%					0.00	0.00	0.00	0.17	0.38
-6%						0.00	0.00	0.00	0.17
-7%							0.00	0.00	0.00
-8%								0.00	0.00
-9%									0.00

EXHIBIT IV.18: DETAILED HAZARD CALCULATIONS

Group 4 Trucks
Type 3 Curves

Fifteen-inch Object
Acceleration/Deceleration
Due to Grade