E. R. Post

FEASIBILITY STUDY OF RETROFITTING CONCRETE MEDIAN BARRIERS

by
DR. EDWARD R. POST, P.E.
DR. PATRICK T. McCOY, P.E.

sponsored by
OFFICE OF UNIVERSITY RESEARCH
DEPARTMENT OF TRANSPORTATION

DOT-RC-92021
TASK 1 FINAL REPORT

in cooperation with
FEDERAL HIGHWAY ADMINISTRATION

CIVIL ENGINEERING DEPARTMENT
REASEARCH REPORT NO. TRP-03-006-80

UNIVERSITY OF NEBRASKA

RESEARCH SERVICE ENGINEERING TECHNOLOGY TEACHING

Engineering Research Center
College of Engineering and Technology
University of Nebraska
Lincoln, Nebraska 68588

FEASIBILITY STUDY

OF

RETROFITTING CONCRETE MEDIAN BARRIERS

by

Dr. Edward R. Post, P.E.
Associate Professor of Civil Engineering
University of Nebraska-Lincoln

Dr. Patrick T. McCoy, P.E.
Associate Professor of Civil Engineering
University of Nebraska-Lincoln

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May 30, 1980

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ABSTRACT

KEY WORDS: Concrete Median Barriers, Roadside Safety Appurtenances

Since the imposition of the 55 mph speed limit in 1974, accident data on the concrete median barriers (CMB) in California showed that the fatal + injury accident rates are increasing. Also, the California data showed that 7.7% of the 1,515 reported accidents in 1978 and 9.9% of the 1,796 reported accidents in 1979 resulted in vehicle rollover. In comparison, accident data summarized by SwRI showed that 3.9% of the 180 reported accidents prior to 1974 resulted in rollovers and mountings. Little or no information on the number by type of vehicle involved in rollovers was reported. However, the findings in this study indicate that this significant increase in rollovers since 1974 is undoubtedly due to (1) an increase in travel speeds, and (2) an increase in the number of small automobiles in the traffic stream. It is predicted that the rollover rate will continue to increase in the future and by 1985 it could be as high as 15%. Small automobiles seem to have a greater tendency to rollover on the CMB than the earlier standard size automobiles, for which the CMB was designed, because of their shorter wheel track widths and much lower roll-moment-of-inertia.

The proposed retrofit unit concept for improving the rollover performance characteristics of the standard New Jersey CMB was investigated in this feasibility study. Basically, the retrofit unit consists of reverse sloped surfaces to suppress vehicle uplift and rollover under impact angles greater than 10 deg. The retrofit unit would be of precast concrete construction and anchored to the CMB by rebar dowels and epoxy.

The findings in this feasibility study indicate that the retrofit unit has the potential of being a cost-effective improvement alternative on (1) rural interstate highways with 30 ft medians and carrying an ADT greater than 66,000 vpd, and (2) urban interstate highways with 16 ft medians and carrying an ADT greater than 117,000 vpd. These findings were based on an assumed retrofit unit cost of $10/ft, a compact automobile split of 50%, and accident societal costs published by the National Safety Council. As the compact automobile splits increase above 50% in the near future, the above breakeven ADT volumes would decrease.

Based on the findings in this study, it is recommended that the potential effectiveness of the retrofit unit in suppressing vehicle uplift and rollover be confirmed by conducting full-scale vehicle crash tests. To aid in the selection of the test vehicles and impact conditions, it is recommended that the California accident records for 1978 and 1979, in which 8.8% of the 3,311 reported accidents resulted in rollovers, be examined manually.

ACKNOWLEDGEMENTS

The cooperation of the Nebraska Department of Roads and the California Department of Transportation in providing accident data for this study was greatly appreciated.

Also, special recognition is given to the following individuals for their consultation, suggestions, and assistance during the conduct of the study:

Mr. Walter Witt, P.E.	... Special Projects Engineer Nebraska Department of Roads
Mr. Richard Ruby, P.E.	... Assistant Roadway Design Engineer Nebraska Department of Roads
Mr. Larry Brown	... Assistant Planning Engineer Nebraska Department of Roads
Mr. Kenneth Sieckmeyer	... Accident Records Bureau Manager Nebraska Department of Roads
Mr. E.J. Tye	... Assistant Traffic Engineer CALTRANS

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INTRODUCTION

PROBLEM STATEMENT

Observations of full-scale vehicle crash tests show that under low angles of impact of 7 to 10 deg. that the New Jersey CMB is very effective in redirecting compact (2,250 lb) and standard (4,500 lb) automobiles with little roll as the result of mostly tire interaction on the lower 55 deg. inclined barrier surface. Under impact angles of 15 deg. and higher, however, compact and standard automobiles have enough momentum to plow straight ahead, ramp in the lower inclined barrier surface and subsequently undergo large angles of roll after being redirected by the upper steep barrier surface.

A summary of accident data presented by the Southwest Research Institute (SwRI) on the concrete median barriers (CMB) prior to 1974 shows that 7 (4%) of the 180 reported accidents on the standard New Jersey CMB resulted in rollovers and mountings. More recent accident data compiled by CALTRANS on the CMB in California shows that 116 (7.7%) of the 1,515 reported accidents in 1978 and 177 (9.9%) of the 1,796 reported accidents in 1979 resulted in vehicle rollovers. About 50% of the rollovers reported by the SwRI were small size automobiles, whereas, the number of small automobile rollovers in California were not reported. This increase in rollovers is mostlikely due to (a) increases in travel speeds since the imposition of the 55 mph speed limit in 1974, and (b) increases in the number of small automobiles in the traffic stream because of the higher costs of fuel.

It is, however, certainly reasonable to expect in the near future that the number of small automobiles in the traffic stream will continue to increase. As a result, the number and severity of rollover accidents on the New Jersey and similar CMB designs involving small automobiles will undoubtedly continue to increase, because small automobiles have shorter wheel track widths and much lower roll-movments-of-inertia than standard automobiles.

OBJECTIVES OF FEASIBILITY STUDY

The proposed design concept for improving the rollover performance characteristics of the New Jersey CMB is shown in Figure 1. The retrofit unit with reversed sloped surfaces would be of precast concrete construction and anchored to the CMB by rebar dowels and epoxy.

The objective of this feasibility study was to determine the effectiveness of the retrofit unit in reducing accident costs by suppressing the uplift and rollover of errant automobiles under impact angles greater than 10 deg. The retrofit unit in Figure 1 would be designed in such a manner that it would not alter the performance characteristics of the original design for angles of impact of 10 deg. and less.

METHODOLOGY

In order for the retrofit unit to be considered as a feasible improvement alternative, the construction costs of retrofitting must not exceed the benefits to be derived from retrofitting. The benefits in this study were taken as the difference in accident costs before and after retrofitting. Based on this methodology, a cost-effectiveness computer simulation model was developed and used to compute "cost limits" for retrofitting. The cost limits computed were expressed as a function of the following variables:

- Rural interstate highway with 30 ft. median
- Urban interstate highway with 16 ft. median
- Compact automobile distributions of 50 and 75%
- Traffic volume ADT's in both directions

In the development of the cost-effectiveness computer simulation model, it was assummed that the retrofit unit would be effective in suppress-

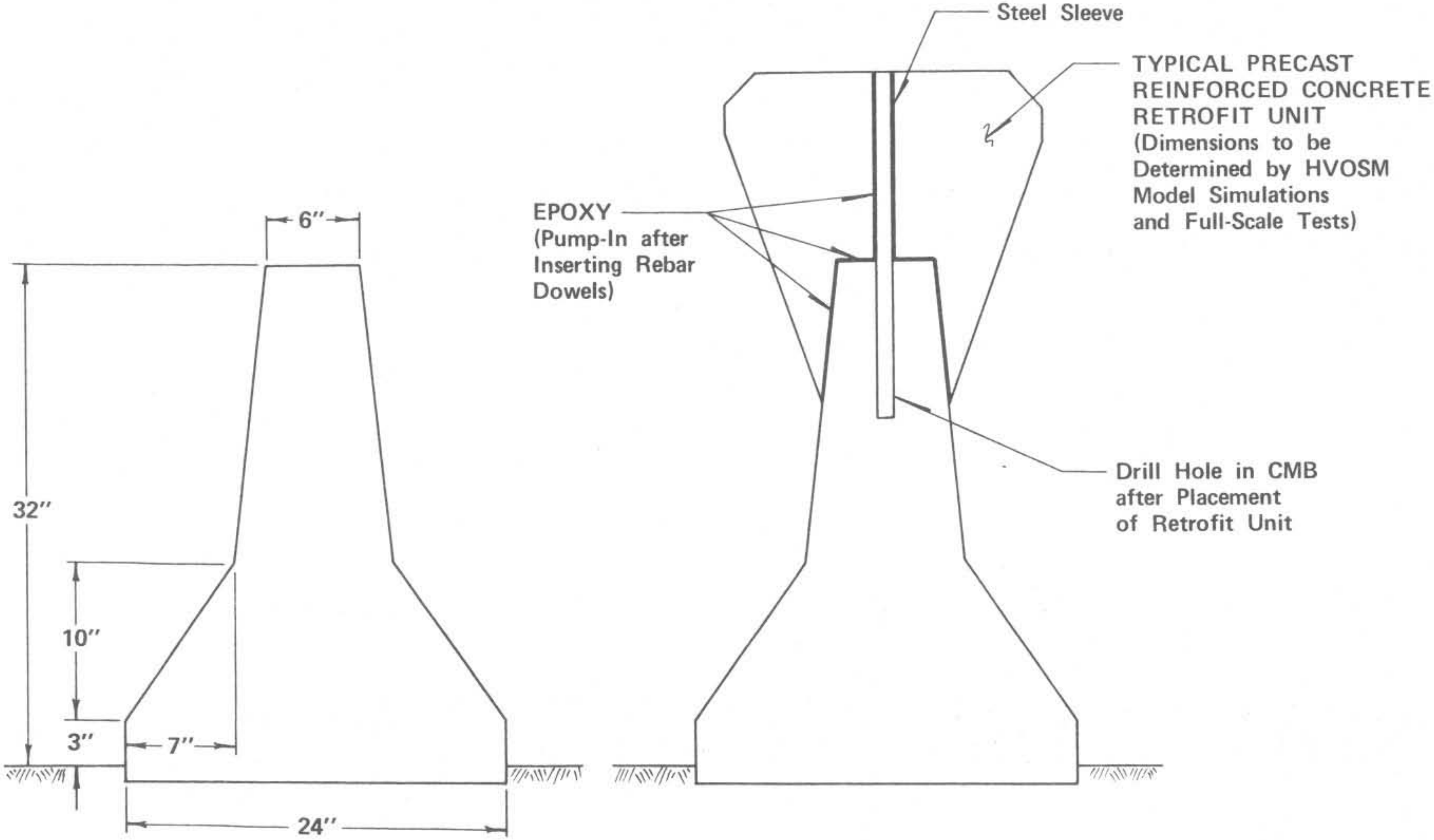


FIGURE 1.
RETROFIT OF NEW JERSEY (MB5) CONCRETE MEDIAN BARRIER

ing vehicle uplift and rollover. To accomplish this task, the vertical vehicle acceleration components computed by the use of the HVOSM model were adjusted accordingly to the magnitude of the impact angle. The results of this simulation study (Section 2) compared favorably with the results of a cost-effectiveness accident analysis study (Section 4).

The cost-effectiveness computer simulation model developed in this study was general in scope and it has the capability to (1) rapidily investigate the effects of variables such as median widths, encroachment frequency rates, lateral offset impact probabilities, and impact speed-angle probabilities (2) account for both non-rollover and rollover accidents, (3) account for the influence of higher impact speeds on rural highways and lower impact speeds on urban highways, (4) account for the influence of all possible combinations of impact speeds and impact angles, and (5) take into consideration the effects of using injury accident societal costs published by different private and public agencies.

BREAKEVEN
BENEFIT-COST ACCIDENT ANALYSIS
TO
RETROFIT CONCRETE MEDIAN BARRIERS
IN
CALIFORNIA

(SECTION 1)

In order for the CMB retrofit unit to be considered as a feasible improvement alternative, the construction costs of retrofitting must not exceed the benefits to be derived from retrofitting. The benefits in this study were computed as the difference in total accident costs before and after retrofitting. Total accident costs refers to the summation of all costs incurred in fatal, injury, and PDO accidents. The breakeven benefit-cost relationship described can be expressed mathematically as follows:

$$\frac{\text{Benefits of Retrofitting}}{\text{Costs to Retrofit}} = 1$$

$$\frac{AC_B - AC_A}{C_R} = 1 \qquad \text{---Eq. 1}$$

where:

AC_B = total CMB accident costs before retrofitting ($/yr/mi)

AC_A = total CMB accident costs after retrofitting ($/yr/mi)

C_R = CMB retrofit construction costs ($/yr/mi)

Assumming that the retrofit unit will be effective in reducing accident costs, one can express the accident costs after retrofitting as a percentage reduction of the accident costs before retrofitting as follows:

$$AC_A = (1-E)AC_B \qquad \text{---Eq. 2}$$

where:

AC_A = defined in Eq. 1

AC_B = defined in Eq. 1

E = effectiveness of retrofit unit required to reduce total accident costs

Upon the substitution of Eq. 2 into Eq. 1, the effectiveness of the retrofit unit required to reduce accident costs (E) can be expressed in terms of the retrofit unit construction costs (C_R) and the total accident costs before retrofitting (AC_B) as follows:

$$E = \frac{C_R}{AC_B} \qquad \text{---Eq. 3}$$

A discussion of the terms in Eq. 3 and a hypothetical example problem illustrating the use of Eq. 3 will be presented in the work to follow.

COSTS TO RETROFIT CMB

The CMB retrofit units would initially be of precast concrete construction and shipped by truck to the job site for installation. Design and maintenance engineers of the Nebraska Department of Roads, with many years of field experience, estimate that the retrofit units can be precast, shipped, installed and doweled in-place for $10 plf or less. Drilling the dowel rebar holes in the CMB, which may contain steel reinforcement, can be quickly done using a diamond core bit apparatus mounted on a truck. The holes in the retrofit units would be preformed.

If the retrofit concept should prove to be effective in later studies under full-scale vehicle crash test conditions, then other lighter, stronger, and cheaper materials such as rotational molded polyethylene plastics would be worthy of consideration. Snyder Industries in Lincoln, Nebraska have developed and marketed many commercial products using plastics with physical properties superior to steel. Design engineers from Snyder Industries believe that the CMB retrofit units could be fabricated from plastic materials.

For the purposes of this study, a retrofit unit cost of \$10 plf was used. More insight into the actual costs of the CMB retrofit unit can only be gained from field experience. The annualized cost to retrofit 1-mile of CMB would therefore be equal to a value of \$6,205. The equation used to compute the annualized cost was as follows:

$$C_R = 5{,}280\ (P_R)(CRF) \qquad \text{---Eq. 4}$$

$$= \$6{,}205 \text{ per yr. per mi.}$$

where:

C_R = annualized retrofit costs (\$/mi/yr)

P_R = retrofit construction costs (\$10 plf)

CRF = capital recovery factor for project improvement life of 20 yrs. at compounded interest rate of 10% = 0.1175

ACCIDENT COSTS BEFORE RETROFITTING

Accident data obtained from CALTRANS (1) on CMB accidents was analyzed to assess the severity of CMB collisions and to provide a basis for estimating the potential effectiveness of the retrofit unit in reducing accident costs (see Eq. 3).

Accident Data

The accident data obtained from CALTRANS on the CMB in California is summarized in Table 1 for the years from 1970 through 1979, excluding the year 1972 because no data was reported. In 1970, California had 6 mi. of CMB and 50 reported accidents; whereas, in 1978, it had 382 mi. of CMB

TABLE 1

CONCRETE MEDIAN BARRIER ACCIDENTS IN CALIFORNIA

YEAR	Number of Reported Accidents[a]			Total	Miles of CMB	Travel (MVM)	Accident Rates per MVM[b]		
	Fatal	Injury	PDO				Fatal	Fat. & Inj.	Total
1970	1 (2.0)	26 (52.0)	23 (46.0)	50	6	225	0.0044	0.120	0.222
1971	0 (0.0)	24 (48.0)	26 (52.0)	50	7	249	0.0000	0.096	0.201
1972	NR[c]	NR	NR	NR	NR	NR	NR	NR	NR
1973	3 (0.5)	216 (33.2)	431 (66.3)	650	139	3,560	0.0008	0.062	0.183
1974	4 (0.9)	211 (46.4)	240 (52.7)	455	182	4,658	0.0009	0.046	0.098
1975	4 (0.7)	287 (50.3)	280 (49.0)	571	262	6,145	0.0007	0.047	0.093
1976	12 (1.6)	396 (51.1)	366 (47.3)	774	274	8,100	0.0015	0.050	0.096
1977	10 (1.0)	536 (51.9)	487 (47.1)	1,033	309	9,626	0.0010	0.057	0.107
1978[d]	17 (1.1)	809 (53.4)	689 (45.5)	1,515	382	13,531	0.0013	0.061	0.112
1979[e]	22 (1.2)	1022 (56.9)	752 (41.9)	1,796	NR	17,454	0.0013	0.060	0.103

a. Number in ( ) represents the percentage of accidents by type
b. MVM = Million Vehicle Miles
c. NR = Not Reported
d. Number of rollovers in 1978 = 116 (7.7%)
e. Number of rollovers in 1979 = 177 (9.9%)

and 1,515 reported accidents. The miles of CMB was not reported for the year of 1979. Based on the data shown in Table 1, the following observations were evident:

1. The fatal + injury accident rates per MVM and the total accident rates dropped sharply in 1974. CALTRANS attributes this drop in accident rates to the imposition of the 55 mph speed limit.
2. Since 1974, the accident rates per MVM have been increasing. The fatal + injury accident rates, in particular, exhibit the greater increase. This increase in accident rates is most-likely due to (a) an increase in travel speeds, and (b) an increase in the number of small automobiles in the traffic stream.
3. The number of rollovers increased from 116 (7.7%) in 1978 to 177 (9.9%) in 1979. No data was reported on rollovers prior to 1978. However, accident data summarized by the SwRI (see Table 35) shows that rollovers and mountings on the New Jersey CMB constituted 4% of the reported accidents prior to 1974. For the same reasons given above, this increase in rollovers is most-likely due to (a) an increase in travel speeds, and (b) an increase in the number of small automobiles in the traffic stream.

The California accident data in Table 1 was somewhat limited, in that, the data was not broken down by vehicle weight distributions, impact conditions

Single Accident Costs

In order to compute accident costs of collisions with the CMB before retrofitting, it was necessary to consider the societal costs of an accident. The societal costs of a fatal accident, injury accident, and PDO accident vary widely among the different agencies reporting this information. Societal costs published by the National Safety Council (2) and the National Highway Traffic Safety Administration (3) are shown in Table 2. The societal costs of the NSC were used in this study because these costs provided the most conservative estimate of the potential effectiveness of the retrofit unit in reducing accident costs.

TABLE 2

Type Accident	NSC	NHTSA
PDO	850	900
Injury	5,800	4,900
Fatal	150,000	336,000

The average cost of a single accident with the CMB was obtained by considering the number of PDO, injury and fatal accidents in Table 1 and the accident societal costs in Table 2. The equation to compute this cost was as follows:

$$C_{acc.} = F(C_{fat}) + I(C_{inj}) + PDO(C_{PDO}) \quad \text{---Eq. 5}$$

where:

C_{acc} = average cost ($) per single accident

C_{fat} = $150,000 per fatal accident

C_{inj} = 5,800 per injury accident

C_{PDO} = 850 per PDO accident

F = total number of fatal accidents (%)

I = total number of injury accidents (%)

PDO = total number of PDO accidents (%)

The computed average costs of a single CMB accident for the years of 1973 and 1978 are shown in Table 3. The higher cost in 1978 of $5,167 compared to $3,181 in 1973 was a reflection of the increase in the number of injury and fatal type accidents.

Accidents per Mile of CMB

The total number of accidents in California that occurred annually for each 1-mile length of CMB was computed for different volumes of traffic by taking into consideration the total accident rate. The number of accidents, shown in Table 3, was computed by use of the following equation:

TABLE 3

ACCIDENT ANALYSIS OF
CONCRETE MEDIAN BARRIERS IN CALIFORNIA

ADT (1,000)	Cost of Single Accident ($/Acc)		Total Accident Rate[a] (Acc/MVM)		Total Accidents per year per mile		Total Accident Costs($) per year per mile		Breakeven Cost Reduction Factors (%)	
	1973	1978	1973	1978	1973	1978	1973	1978	1973	1978
20	3,181	5,167	0.183	0.122	1.34	0.82	4,263	4,237	145	146
40					2.67	1.64	8,493	8,474	73	73
60					4.01	2.45	12,756	12,659	49	49
80					5.34	3.27	16,987	16,896	37	37
100					6.68	4.09	21,249	21,133	29	29
120					8.02	4.91	25,512	25,370	24	24
140					9.35	5.72	29,742	29,555	21	21
160					10.69	6.54	34,005	33,792	18	18
180					12.02	7.36	38,236	38,029	16	16
200					13.36	8.18	42,498	42,266	15	15

a. Accident rates assummed to be the same for all traffic volumes

$$A_{tot} = ADT\ (A_{rate})(D_{yr}) \qquad \text{---Eq. 6}$$

where:

A_{tot} = total number of CMB accidents per mi. per yr.

A_{rate} = total accident rate per MVM

D_{yr} = 365 days per year

Referring to Table 3, it can be predicted that about 4.1 accidents would occur in 1978 for each mile of CMB located on a highway carrying a traffic volume of 100,000 vpd, whereas, the number of accidents would double on a highway carrying a higher traffic volume of 200,000 vpd.

Total Accident Costs per Mile of CMB

Once having computed the costs of a single accident (Eq. 5) and the number of accidents for each mile of CMB (Eq. 6), it was possible to then compute the total annual accident costs before retrofitting. The equation used to compute these costs was as follows:

$$AC_B = C_{acc}\ (A_{tot}) \qquad \text{---Eq. 7}$$

where:

AC_B = total CMB accident costs before retrofitting ($/yr/mi)

C_{acc} = average cost ($) per single accident

A_{tot} = total number of accidents per mi. per yr.

The computed total annual accident costs are shown in Table 3 for the years of 1973 and 1978. As evident, there was no significant difference in accident costs between these two years because the higher single accident costs in 1978 were offset by the lower number of accidents.

EFFECTIVENESS OF RETROFIT UNIT

In the preceding work, values were computed for the construction costs of retrofitting (Eq. 4), and the total annual accident costs before retrofitting for different levels of traffic volumes (Eq. 7). Upon the substitution of this work into Eq. 3, values were then computed for the effectiveness of the retrofit unit required to reduce accident costs. The effectiveness values computed are shown in Table 3 for the years of 1973 and 1978. As evident, no significant difference exists between these two years because the total accident costs were nearly the same. Also, it is evident that as the traffic volumes increase the effectiveness of the retrofit unit required to reduce accident costs decreases. For example, in 1978 the retrofit unit would need to be at least 29% effective on a highway carrying a traffic volume of 100,000 vpd; whereas, it would only need to be 21% effective on a highway carrying a higher traffic volume of 140,000 vpd.

In order to more clearly illustrate the application of the results presented in a Table 3, a hypothetical example problem was worked. The problem statement and its solution follows:

Example Problem No. 1
(hypothetical)

Based upon the results of full-scale vehicle crash tests, it is estimated that the CMB retrofit unit concept design will be 25% effective in reducing total accident costs. Determine the traffic volumes under which the retrofit unit could be considered as a feasible alternative.

Solution to Example Problem No. 1

(hypothetical)

A graph of "Traffic Volume (ADT)" versus "Effectiveness of Retrofit Unit Required to Reduce Total Accident Costs" is presented in Figure 2. Values of the variables in the graph were obtained from Table 3.

Since the "Actual effectiveness" of the CMB retrofit unit was estimated to be 25% from the results of full-scale vehicle crash tests, it can be seen in Figure 2 that the retrofit unit would be feasible on highways carrying traffic volumes of about 115,000 vpd and higher.

In the work to follow, analytical attempts will be made to determine the "potential effectiveness" of the CMB retrofit unit concept.

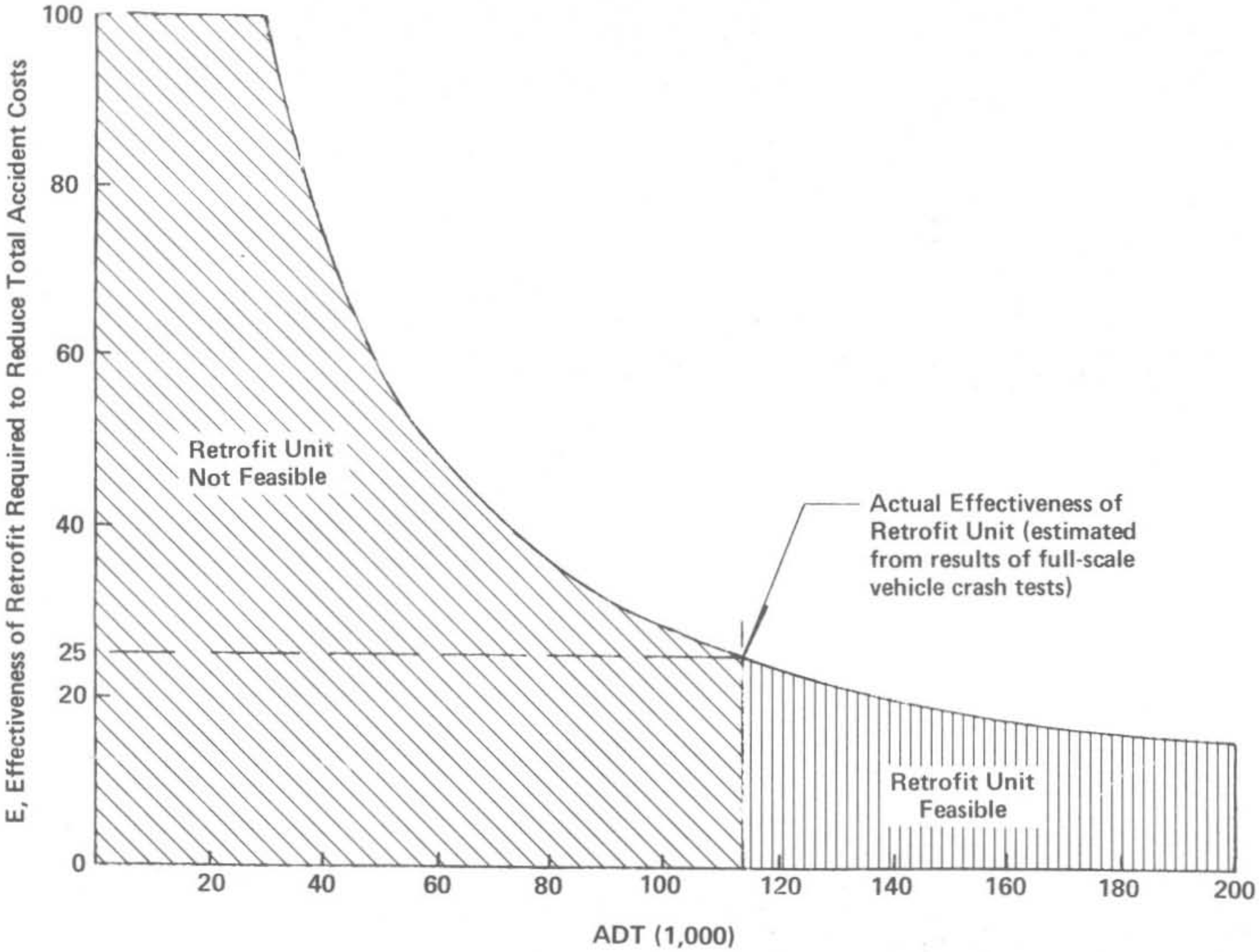


FIGURE 2.: EXAMPLE PROBLEM TO ILLUSTRATE THE FEASIBILITY OF THE CMB RETROFIT UNIT (Hypothetical)

COST LIMITS
TO
RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIERS
BASED ON
HVOSM COMPUTER SIMULATIONS

(SECTION 2)

The computer model simulations were made for two size automobiles impacting the New Jersey CMB under a wide range of speed-angle combinations. The automobiles weighed 2,250 and 4,500 lbs. The impact speeds were 30, 40, 50, 60 and 70 mph, whereas, the impact angles were 5, 10, 15, 20 and 25 deg.

HVOSM

The University of Nebraska-Lincoln (UNL) has successfully and extensively used the Texas Transportation Institute (TTI) version of HVOSM (4) for embankment and ditch transversals, however, attempts to use the model for vehicle-barrier impacts were unsuccessful in this study. The program was taking a standard fixup which produced results that appeared very questionable. No serious attempts were made to correct the program errors.

The FHWA version of HVOSM (5, 6, 7, 8) was then installed and made operational on the UNL IBM 360/65 and two IBM 370/158 computers.

Validation

The validation of the FHWA version of HVOSM was accomplished using the imput vehicle properties and the full-scale test results published by Bronstad (9, 10) on the New Jersey CMB. Good correlations were obtained for both the standard and subcompact vehicles under the impact conditions of approximately 60 mph and 7 and 15 deg. An example computer run of the input and output results for a subcompact vehicle (Vega) is presented in Appendix A. In validating the model, three idealizations of the CMB were considered as shown in Figure 3. The curb portion was used to simulate the interaction between the vehicle tires and barrier, whereas, the barrier portion was used to simulate the interaction between the vehicle body and the barrier. Case 3 in Figure 3 consisting of full curb and barrier provided the best correlations and therefore it was used for all subsequent work.

Simulation Results

The HVOSM simulation results for two size automobiles impacting the New Jersey CMB over a wide range of speed-angle combinations are presented in Tables 4 and 5. The vehicle acceleration components were averaged over the same 50 msec time interval during the primary impact stage. The maximum roll angle reported usually occurred after the secondary impact in which the rear of the vehicle impacts the CMB. Linear regression and the TTI results in HRR 460 (11) were used to obtain accelerations whenever the HVOSM output results were questionable or singularity occurred in the subroutine SIMSOL. No serious attempts were made to correct these errors. The rollover cases were based on the TTI results in HRR 460 for the standard size vehicle, whereas, engineering judgement was used to predict rollovers of the subcompact size vehicle.

SEVERITY OF AUTOMOBILE COLLISIONS WITH RETROFIT CMB

The severity of an automobile impacting the retrofitted New Jersey CMB was expressed in terms of a Severity-Index. The severity-index is computed as the ratio of the measured or computed resultant automobile

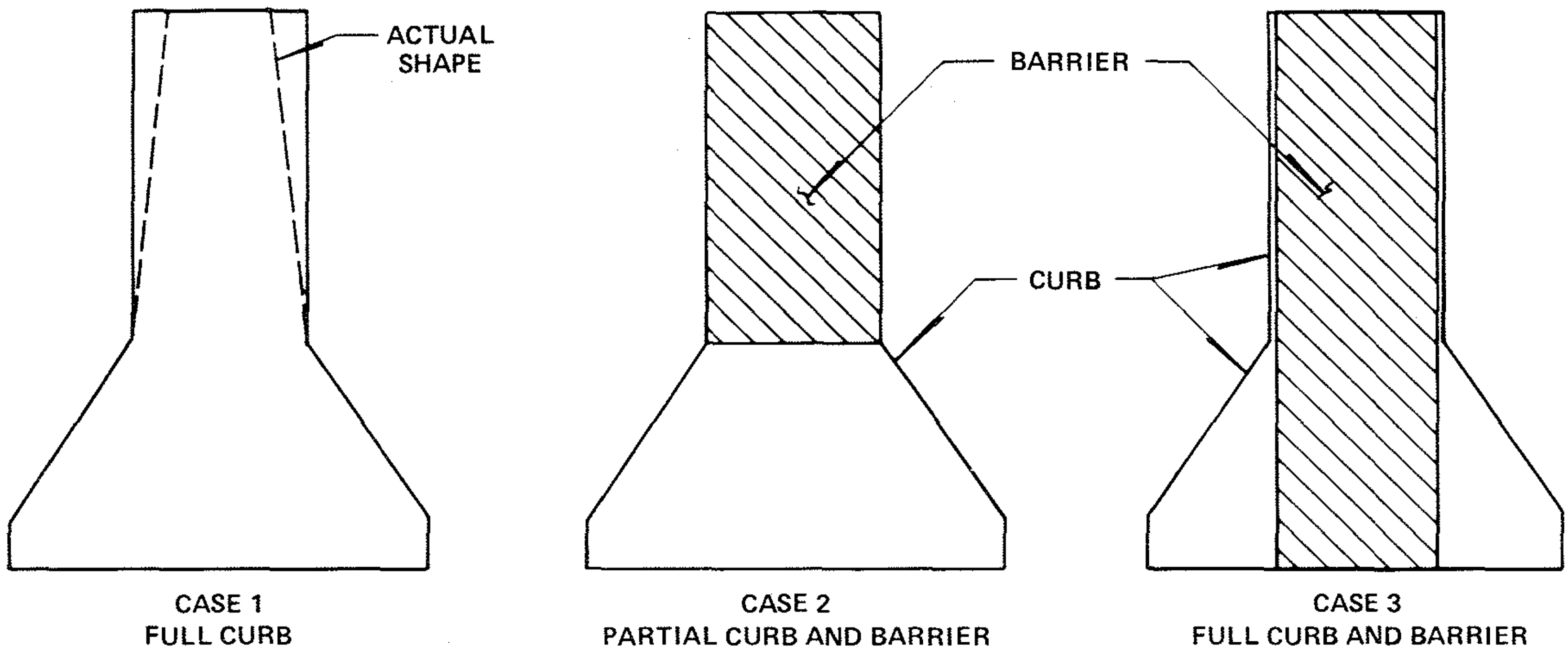


FIGURE 3. IDEALIZATIONS OF NEW JERSEY CONCRETE MEDIAN BARRIER FOR HVOSM COMPUTER MODEL SIMULATION

TABLE 4

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CMB

H V O S M S I M U L A T I O N S

AUTO WEIGHT = 2,250 lbs

Impact Conditions		Front Tire Climb	Max. Roll Angle	Avg. 50 ms Decelerations During Primary Impact			COMMENTS
Speed (mph)	Angle (deg)	(in)	(deg)	$G_{long.}$	$G_{lat.}$	$G_{vert.}$	
30	5	--	--	0.00[a]	1.78[a]	0.32[a]	Ran out of CPU time
	10	3	+28	0.90	2.98	0.58	
	15	7	+10	1.36	3.39	1.04	
	20	10	- 5	2.29	4.50	1.34	
	25	13	-10	3.62	5.62	1.45	
40	5	--	--	0.00[a]	0.47[a]	1.25[a]	Ran out of CPU time
	10	6	+31	0.95	3.19	1.57	
	15	10	- 9	1.83	4.59	1.59	
	20	15	-20	3.37	6.58	1.78	
	25	17	-16	5.21	9.68	2.10	
50	5	3	+16	0.41	2.74	0.25	
	10	9	+ 3	0.93	3.41	1.59	
	15	15	-29	2.54	6.36	1.98	
	20	17	-21	3.96	9.11	2.13	
	25	--	--	5.14[a]	11.23[a]	3.31[a]	Output results questionable
60	5	5	+20	0.55	2.82	1.37	
	10	11	-11	1.20	4.21	1.76	
	15	17	-26	3.10	9.32	2.20	
	20	--	--	4.37[a]	10.01[a]	3.52[a]	SIMSOL Matrix singular
	25	--	RO[c]	5.75[a]	11.07[d]	4.58[a]	Output results questionable
70	5	6	+20	0.46	2.75	1.36	
	10	14	-38	1.55	5.14	2.02	
	15	--	RO[c]	2.64[a]	7.53[a]	2.68[a]	
	20	--	RO[c]	3.73[a]	9.92[a]	3.34[a]	SIMSOL Matrix singular
	25	--	RO[c]	4.82[a]	12.31[a]	4.00[a]	SIMSOL Matrix singular

a. Decelerations determined by method of least squares Linear regression

c. Predicted rollover based on results in HRR460 (p 69) for standard size auto

d. Deceleration obtained by using same slope as standard auto in HRR460 (p 69) for 60 mph impacts

TABLE 5

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CMB

H V O S M S I M U L A T I O N S

AUTO WEIGHT = 4,500 lbs

Impact Conditions		Front Tire Climb	Max. Roll Angle	Avg. 50 ms Decelerations During Primary Impact			COMMENTS
Speed (mph)	Angle (deg)	(in)	(deg)	$G_{long.}$	$G_{lat.}$	$G_{vert.}$	
30	5	--	--	0.27[a]	1.32[a]	0.00	Ran out of CPU time
	10	4	+19	1.09	2.40	0.11	
	15	5	+ 8	1.91	3.48	0.67	
	20	--	--	2.73[a]	4.56[a]	1.23[a]	SIMSOL Matrix Singular
	25	--	--	3.55[a]	5.64[a]	1.79[a]	Output results questionable
40	5	--	--	0.34[a]	1.93[a]	0.32[a]	Ran out of CPU time
	10	6	+10	1.49	3.32	0.58	
	15	7	+ 4	2.54	4.12	1.20	
	20	10	+ 6	3.23	5.38	1.21	
	25	21	- 5	4.73	6.81	1.44	
50	5	3	+21	0.44	2.21	0.14	
	10	7	+20	1.31	3.48	1.27	
	15	10	- 6	2.43	5.11	1.55	
	20	14	- 8	4.72	9.38	2.16	
	25	--	--	5.91[a]	11.37[a]	2.97[a]	SIMSOL Matrix singular
60	5	5	+20	0.68	2.98	0.35	
	10	--	--	2.19[a]	5.65[a]	1.34[a]	SIMSOL Matrix singular
	15	17	-10	3.78	9.79	2.31	
	20	--	--	5.06[a]	10.35[a]	3.35[a]	SIMSOL Matrix singular
	25	--	-37[b]	6.41[b]	11.23[b]	4.38[b]	SIMSOL Matrix singular
70	5	3	+28	0.90	2.22	0.17	
	10	11[b]	-20[b]	0.16[b]	5.06[b]	2.03[b]	Output results questionable
	15	--	RO[b]	2.81[b]	6.44[b]	3.16[b]	Output results questionable
	20	--	RO[b]	5.21[a]	8.96[a]	4.84[a]	SIMSOL Matrix singular
	25	--	RO[b]	7.16[a]	11.16[a]	6.36[a]	SIMSOL Matrix singular

a. Decelerations determined by method of least squares Linear regression

b. HVOSM simulation results from HRR460, p 69 (TTI Version of HVOSM) acceleration to the resultant "tolerable" automobile acceleration that defines an ellipsoidal surface. This ratio can be expressed mathematically by Eq. 8. An in-depth discussion on the development of Eq. 8 was presented by Post (12, 13).

$$SI_{W,\Theta,v} = \sqrt{\left[\frac{G_{long}}{G_{XL}}\right]_W^2 + \left[\frac{G_{lat}}{G_{YL}}\right]_W^2 + \left[(RF)_{W,\Theta}\frac{G_{vert}}{G_{ZL}}\right]_W^2} \qquad \text{---Eq. 8}$$

where: $SI_{W,\Theta,v}$ = severity-index for a given vehicle size (W), encroachment angle (Θ) and speed (v)

$RF_{W,\Theta}$ = estimated reduction factor for CMB, retrofit as a function of vehicle size (W) and impact angle (Θ)

G_{long} = computed auto longitudinal accelerations along x-axis

G_{lat} = computed auto lateral accelerations along y-axis

G_{vert} = computed auto vertical accelerations along z-axis

G_{XL}, G_{YL}, G_{ZL} = tolerable auto accelerations along the x, y, and z-axes, respectively

The severity-index computations in the subsequent work based on automobile accelerations tolerable to an unrestrained occupant, and the automobile accelerations were averaged over a time duration of 50 msec as shown earlier in Tables 4 and 5. The relationship between severity-index and injury level will be discussed in a later section. Tolerable accelerations suggested by

Weaver (14) for use in the severity-index equation are shown in Table 6.

TABLE 6

TOLERABLE AUTOMOBILE ACCELERATIONS
(After Weaver 14)

Degree of Occupant Restraint	Accelerations		
	G_{YL}	G_{XL}	G_{ZL}
Unrestrained	5	7	6
Lap Belt Only	9	12	10
Lap Belt and Shoulder Harness	15	20	17

No computer models were available when this study started that could take into account the suppression of uplift and roll of an automobile by the reverse slope of the CMB retrofit unit shown in Figure 1. To accomplish this task, the HVOSM model was used in conjunction with engineering judgement. The average vertical acceleration component in Eq. 8 was reduced by a reduction factor, RF, which was a function of the vehicle size and impact angle. A listing of the "lower" and "upper" limit reduction factors used in this study are shown in Tables 7 and 8, respectively. CASE I applies to those impacts in which only rollovers occurred.

The severity-indicies computed for CASE III reduction factors are shown in Tables 10, 11, 13 and 14. In Tables 9 and 12, no adjustment factors were used and the severity-indicies were set equal to 5.00 for impacts involving rollovers (i.e. 70 mph and 15 deg).

TABLE 7

VERTICAL AUTOMOBILE REDUCTION FACTORS: LOWER LIMIT

Impact Angle (deg)	CASE I		CASE II		CASE III		CASE IV	
	2,250 lb Auto	4,500 lb Auto	2,250 lb Auto	4,500 lb Auto	2,250 lb Auto	4,500 lb Auto	2,250 lb Auto	4,500 lb Auto
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	1.00	1.00	0.97	0.98	0.95	0.97	0.80	0.80
20	1.00	1.00	0.94	0.95	0.90	0.92	0.60	0.60
25	1.00	1.00	0.90	0.91	0.85	0.87	0.40	0.40

TABLE 8

VERTICAL AUTOMOBILE REDUCTION FACTORS: UPPER LIMIT

Impact Angle (deg)	CASE I		CASE II		CASE III		CASE IV	
	2,250 lb Auto	4,500 lb Auto	2,250 lb Auto	4,500 lb Auto	2,250 lb Auto	4,500 lb Auto	2,250 lb Auto	4,500 lb Auto
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	1.00	1.00	0.95	0.97	0.90	0.92	0.70	0.70
20	1.00	1.00	0.86	0.88	0.80	0.82	0.40	0.40
25	1.00	1.00	0.80	0.82	0.70	0.72	0.20	0.20

TABLE = 9

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

S E V E R I T Y - I N D I C E S

ADJUSTMENT FACTOR: NONE

AUTOMOBILE SIZE = 2250.0 LBS

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.36	0.23	0.55	0.61	0.60
10.0	0.62	0.70	0.74	0.91	1.10
15.0	0.73	0.99	1.36	1.95	5.00
20.0	0.98	1.43	1.94	2.18	5.00
25.0	1.26	2.10	2.43	5.00	5.00

TABLE = 10

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

S E V E R I T Y - I N D I C E S

ADJUSTMENT FACTOR: LOWER LIMIT

CASE III

AUTOMOBILE SIZE = 2250.0 LBS

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.36	0.23	0.55	0.61	0.60
10.0	0.62	0.70	0.74	0.91	1.10
15.0	0.72	0.99	1.36	1.95	1.61
20.0	0.98	1.43	1.93	2.16	2.11
25.0	1.25	2.10	2.41	2.45	2.62

TABLE = 11

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

S E V E R I T Y - I N D I C E S

ADJUSTMENT FACTOR: UPPER LIMIT

CASE III

AUTOMOBILE SIZE = 2250.0 LBS

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.36	0.23	0.55	0.61	0.60
10.0	0.62	0.70	0.74	0.91	1.10
15.0	0.72	0.98	1.36	1.94	1.60
20.0	0.97	1.42	1.93	2.15	2.10
25.0	1.25	2.09	2.39	2.42	2.60

TABLE = 12

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

S E V E R I T Y - I N D I C E S

ADJUSTMENT FACTOR: NONE

AUTOMOBILE SIZE = 4500.0 LBS

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.27	0.39	0.45	0.61	0.46
10.0	0.50	0.70	0.75	1.19	1.07
15.0	0.76	0.92	1.11	2.07	5.00
20.0	1.01	1.19	2.03	2.26	5.00
25.0	1.27	1.54	2.48	2.53	5.00

TABLE = 13

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

S E V E R I T Y - I N D I C E S

ADJUSTMENT FACTOR: LOWER LIMIT

CASE III

AUTOMOBILE SIZE = 4500.0 LBS

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.27	0.39	0.45	0.61	0.46
10.0	0.50	0.70	0.75	1.19	1.07
15.0	0.76	0.92	1.11	2.07	1.44
20.0	1.01	1.19	2.02	2.25	2.08
25.0	1.26	1.53	2.46	2.51	2.62

TABLE =14

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

S E V E R I T Y - I N D I C E S

ADJUSTMENT FACTOR: UPPER LIMIT

CASE III

AUTOMOBILE SIZE = 4500.0 LBS

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.27	0.39	0.45	0.61	0.46
10.0	0.50	0.70	0.75	1.19	1.07
15.0	0.75	0.92	1.11	2.06	1.43
20.0	1.01	1.18	2.02	2.24	2.05
25.0	1.26	1.53	2.45	2.48	2.57

INJURY PROBABILITIES

An indepth discussion on a tentative relationship between Severity-Index and the probability of occurrence of injury type accidents was recently presented by Post (15) to the Transportation Research Board. The relationship established for injury probability is shown in Table 15. For simplicity purposes in this study, the histogram relationship was approximated by the two linear relationships as shown in Figure 4.

TABLE 15

RELATIONSHIP BETWEEN SEVERITY-INDEX AND PROBABILITY OF INJURY ACCIDENTS (AFTER POST 15)

Severity-Index (SI)	Probability of Injury Accident
$SI \le 0.5$	0.1
$0.5 < SI \le 1.0$	0.3
$1.0 < SI \le 1.5$	0.5
$1.5 < SI \le 2.0$	0.7
$2.0 < SI \le 2.5$	0.8
$2.5 < SI$	1.0

INJURY ACCIDENT COSTS

An approach similar to that used by Weaver and Post (16) was also used in this study to establish a relationship between severity-index and injury

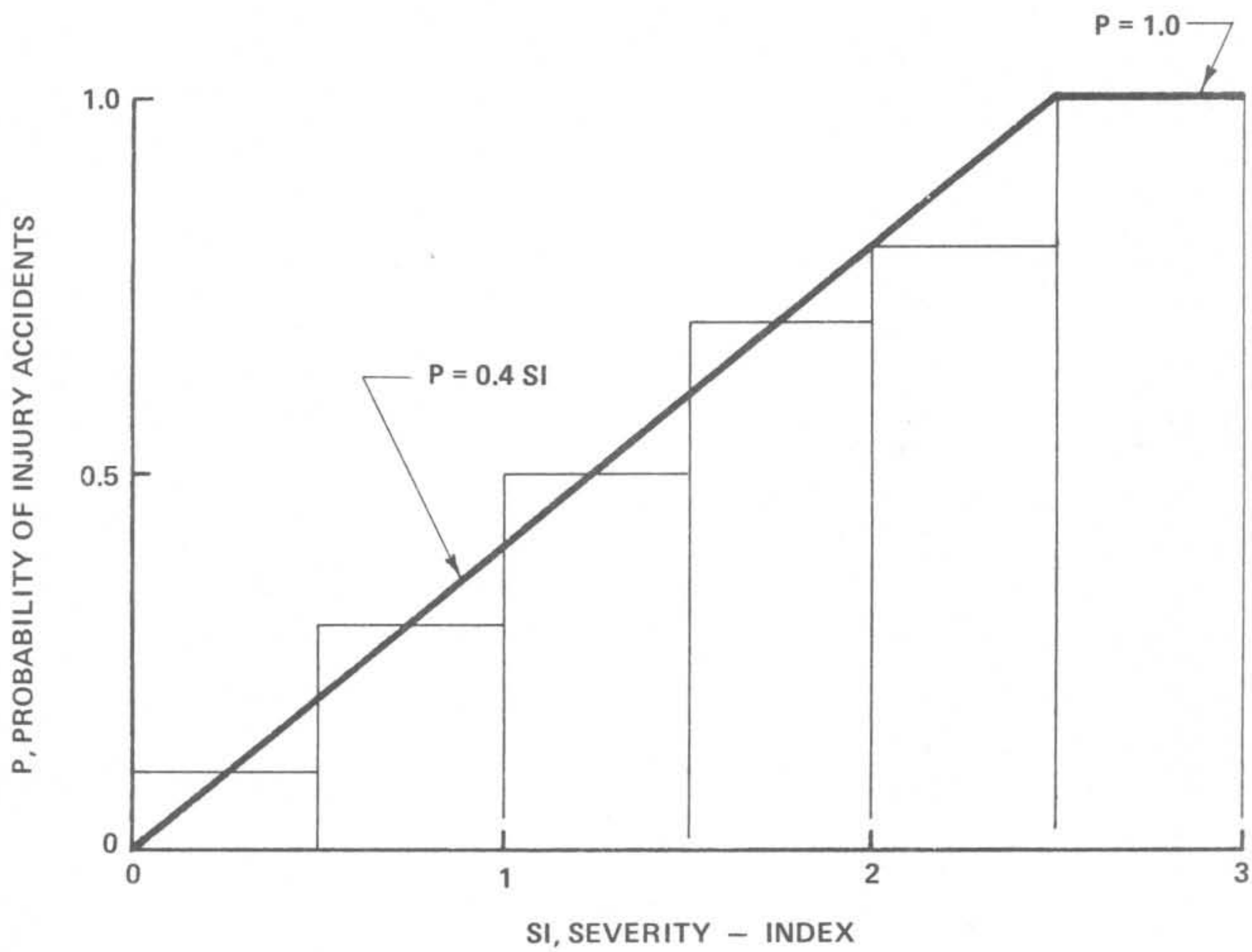


FIGURE 4. RELATIONSHIP BETWEEN SEVERITY – INDEX AND PROBABILITY OF INJURY ACCIDENTS

accident costs. Referring to Table 16, the severity-index and the probability of an injury accident were expressed by a percentage distribution in terms of three accident classifications: Property-Damage-Only-Accidents, Injury-Accidents, and Fatal-Accidents. The total accident costs in Table 16 were determined by using societal cost figures of the National Safety Council (2), Texas Transportation Institue (17), and the Nebraska Department of Roads (3). The histogram relationships in Table 16 were approximated by the linear equations shown in Figure 5, whereby, the upper limits of the accident costs were established for severity-indicies of 2.75 and greater.

COST-EFFECTIVENESS COMPUTER PROGRAM

The computations involved in determining the cost limits to retrofit the New Jersey CMB over the sensitivity range of the many variables would have been a very laborious and tedious task without the aid of a computer. The Fortran IV program written for this study is presented in Appendix B. Using the IBM 370 required approximately 75 sec of CPU time and cost $6.50 to generate and print 188 tables of output, whereas, it would have taken several man-months of effort to accomplish the same task.

EFFECTIVENESS OF RETROFIT CMB

The effectiveness of retrofitting the New Jersey CMB was expressed in terms of the reduction in the Hazard-Index before and after retrofitting. The methodology to compute effectiveness was formulated by Glennon (18) and implemented in Texas by Weaver and Post (19) for managing roadside improvement programs on both non-controlled access highways and freeways. The equation used to compute the effectiveness was:

TABLE 16

RELATIONSHIP BETWEEN SEVERITY-INDEX AND INJURY ACCIDENT PROBABILITIES, ACCIDENT CLASSIFICATION, AND TOTAL ACCIDENT COSTS

Severity-Index[a]	Probability of Injury Accident	Accident Classification[b]			Total Accident Costs ($)		
		PDO Accidents (%)	Injury Accidents (%)	Fatal Accidents (%)	NSC[c]	TTI[d]	NDR[e]
SI ≤ 0.5	0.1	90	10	0	1,400	1,600	1,300
0.5 < SI ≤ 1.0	0.3	60	40	0	2,300	4,400	2,500
1.0 < SI ≤ 1.5	0.5	40	60	0	3,820	6,280	3,300
1.5 < SI ≤ 2.0	0.7	10	88	2	8,190	12,870	11,120
2.0 < SI ≤ 2.5	0.8	0	96	4	11,570	17,600	18,140
2.5 < SI	1.0	0	94	6	14,450	21,400	24,770

a. Computed by HVOSM Simulations

b. Assumed in similar manner as done in TTI Report (Ref. 16)

c. National Safety Council (Ref. 2) - - - - - - - $150,000 per fatal accident
5,800 per injury accident
350 per PDO accident

d. Texas Transportation Institute (Ref. 17) - - - $200,000 per fatal accident
10,000 per injury accident
700 per PDO accident

e. Nebraska Department of Roads (Ref. 3) - - - - $336,000 per fatal accident
4,900 per injury accident
900 per PDO accident

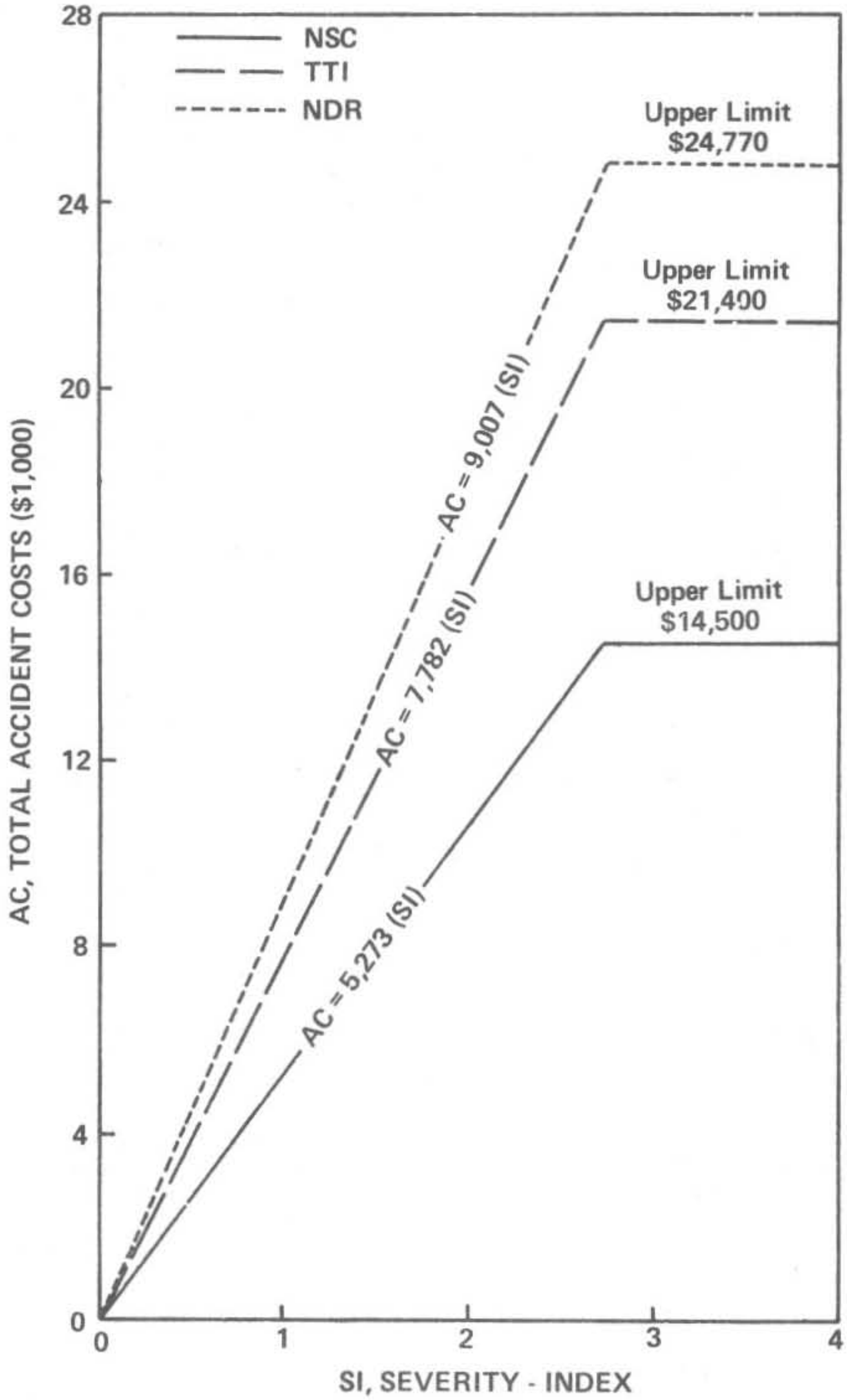


FIGURE 5.: RELATIONSHIPS BETWEEN SEVERITY - INDEX AND TOTAL ACCIDENT COSTS

$$E = HI_{CMB} - HI_{\substack{CMB \\ Retrofit}} \qquad \text{---Eq. 9}$$

where: E = effectiveness to retrofit (injury accident eliminated per mile per year)

HI = hazard-index (expected number of injury type accidents per mile per year)

The generalized equation used to compute the weighted Hazard-Index of the retrofit was:

$$HI = E_f D \sum_{W} S \sum_{\theta} P_\theta \sum_{V} (IP)_{\theta,v} \, (PI)_{\theta,v} \qquad \text{---Eq. 10}$$

where: HI = hazard-index (expected number of injury accidents per mile per year)

E_f = total vehicle encroachment rate = 0.0009 (ADT) for both rural and urban interstate highways (encroach/mi/yr)

D = portion of ADT involved in median encroachments = 0.5 (assumed)

W = weight of automobiles (2,250 and 4,500 lbs)

S = automobile split by weight

P_θ = probability that the CMB will be impacted given that an encroachment of an angle (θ) has occurred

$IP_{\theta,v}$ = impact condition probability for a given encroachment angle (θ) and speed (v)

$PI_{\theta,v}$ = probability of an injury accident for a computed severity-index (see Figure 4)

$PI_{\theta,v} = 0.4(SI_{\theta,v})$ if, $SI_{\theta,v} \leq 2.5$

$PI_{\theta,v} = 1.0$ if, $SI_{\theta,v} > 2.5$

$SI_{\theta,v} \overset{set}{=} 5.0$ if, Rollover Occurs

Encroachment Frequencies

Knowledge of the frequency at which vehicles encroach on the roadside is very limited. Therefore, the encroachment frequencies used by Glennon (20) were assumed to be applicable for the purposes of this study. These relationships were:

Urban Freeway

$$E_f = 0.00090\ (ADT)$$

Rural Freeway

$$E_f = 0.00090\ (ADT)$$

The encroachment frequency rate of $E_f = 0.0009$ (ADT) used in this study for both rural and urban interstate highways means that the total number of vehicle encroachments for the "left side" of each roadway (2 or more lanes in the same direction) into the median and from the "right side" of each roadway is equal to 9 vehicle encroachments per mile per year for ADT increments of 10,000. It was assumed in this study that 50% (D = 0.5) of these encroachments, or 4.5, would occur in the median.

The number of vehicle CMB impacts that can be expected to occur over a range of encroachment angles can be computed by the following equations:

$$CMB_I = E_f(D) \sum (P_{C/E}) \qquad \text{---Eq. 11}$$

and,

$$P_{C/E} = \theta_D(P_\theta) \qquad \text{---Eq. 12}$$

where: CMB_I = number of CMB impacts per mile of barrier per year for given encroachment angles (θ) and ADT

$P_{C/E}$ = probability of a CMB collision given that an encroachment has occurred

E_f = total vehicle encroachment rate = 0.0009 (ADT) for both rural and urban interstate highway (encroach/mi/yr)

D = portion of ADT involved in median encroachments = 0.5 (assumed)

θ_D = distribution of encroachment angles independent of of speed (see Tables 20 and 21)

P_θ = lateral offset encroachment probabilities (see Figure 6)

The results computed from Eqs. 11 and 12 are presented in Table 17. It can be seen that for a given encroachment angle of 5 deg that one could expect 1.30 and 1.75 CMB impacts per mile of barrier per year per ADT of 10,000 to occur on a rural (30 ft. median) and urban (16 ft. median) interstate highway, respectively; whereby, upon considering all encroachment angles, one could expect the number of CMB impacts to increase to 3.31 and 4.01.

The weighted averages of the CMB impact probabilities in Table 17 of 0.735 (rural interstate) and 0.890 (urban interstate) were used later in Eq. 18.

Lateral Impact Probabilities

The probability that an encroaching vehicle on an intersecting path will impact the CMB is a function of the lateral distance between the inside edge of the traveled roadway and the location of the CMB. The greater this distance,

TABLE 17

CMB IMPACTS

Urban Freeway: Median Width = 16 ft.

Rural Freeway: Median Width = 30 ft.

Total Encroachment Rate: 0.00090 (ADT)

Median Encroachment Rate: 0.00045 (ADT)

Encroachment Conditions		Lateral Offset Probabilities[b.] P_{Θ}		CMB Impact Probabilities $P_{C/E}$		CMB Impacts per mile per year per ADT of 10,000	
Angle (deg)	Angle Distributions[a.] Θ_D	Rural	Urban	Rural	Urban	Rural	Urban
5	0.48	0.60	0.81	0.288	0.389	1.30	1.75
10	0.20	0.82	0.94	0.164	0.188	0.74	0.85
15	0.12	0.86	0.97	0.103	0.116	0.46	0.52
20	0.08	0.86	0.97	0.069	0.078	0.31	0.35
25	0.12	0.93	0.99	0.112	0.119	0.50	0.54
				0.736	0.890	3.31	4.01

a. Angle Distributions Independent of Speed --- see Tables 20 and 21.

b. See Figure 6 and Table 18.

the further the vehicle must travel along the path to reach the CMB and the less likely it is that the vehicle will impact the CMB. Therefore, the encroachment data of Hutchinson and Kennedy (21) were analyzed to determine the relationship between encroachment angle and the probability distribution of the lateral extent of encroachment. The four distributions shown in Figure 6 were found to be significantly different. These distributions were used to determine the probability of impacting the CMB given that the encroaching vehicle was on an intersecting path for a given angle of encroachment: because, this probability is equal to the probability that the lateral extent of the encroachment is greater than the lateral distance between the inside edge of the traveled roadway and the location of the CMB.

The lateral impact probabilities used in this study for a CMB located in the median of an urban and rural freeway are shown in Table 18.

TABLE 18

LATERAL IMPACT PROBABILITIES

Urban Freeway: Median Width = 16 ft
Rural Freeway: Median Width = 30 ft

Encroachment Angle (deg)	Lateral Impact Probabilities	
	Rural Freeway	Urban Freeway
5	0.60	0.81
10	0.82	0.94
15	0.86	0.97
20	0.86	0.97
25	0.93	0.99

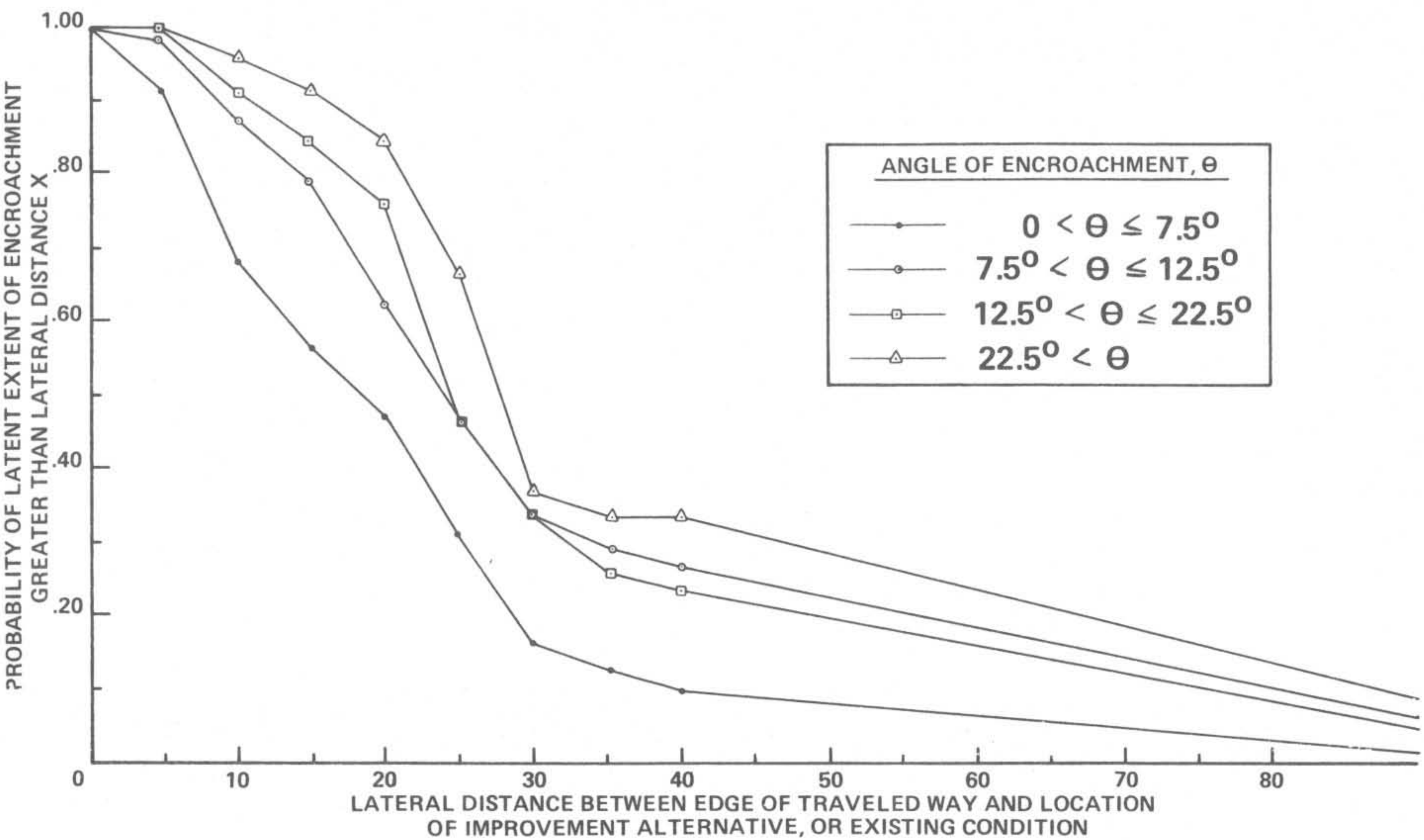


FIGURE 6. DISTRIBUTIONS OF LATERAL EXTENT OF ENCROACHMENTS

Impact Condition Probabilities

The impact condition probabilities were computed by combining the distributions of vehicle speeds and encroachment angles. The vehicle speed distributions were determined from an analysis of spot speed data contained in the 1978 annual speed monitoring certification report prepared by the Nebraska Department of Roads. It was assumed that vehicle speeds were normally distributed with the mean and standard deviation values computed from the spot speed data. These values are shown in Table 19. The encroachment angle distribution used was that reported by Hutchinson and Kennedy (21).

TABLE 19

MEAN SPEEDS AND STANDARD DEVIATIONS

Type Freeway	Mean Speed (mph)	Standard Deviation (mph)
Rural	59.2	±4.8
Urban	55.5	±5.2

The vehicle speed distribution for each type highway was combined with the encroachment angle distribution, assuming that the speed and angle distributions were independent. The combined distributions were then used to compute the encroachment impact condition probabilities that are shown in Tables 20 and 21 for rural and urban freeways.

Using the point mass model presented by Ross (22), it was determined that some high-speed, high-angle impacts were not possible. However, because of

TABLE = 20

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

I M P A C T   C O N D I T I O N   P R O B A B I L I T I E S

RURAL INTERSTATE HIGHWAY

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.000	0.001	0.090	0.335	0.054
10.0	0.000	0.000	0.038	0.139	0.023
15.0	0.000	0.000	0.022	0.084	0.014
20.0	0.000	0.000	0.015	0.056	0.009
25.0	0.000	0.000	0.022	0.084	0.014

TABLE = 21

COST-EFFECTIVENESS OF RETROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER

I M P A C T   C O N D I T I O N   P R O B A B I L I T I E S

URBAN INTERSTATE HIGHWAY

IMPACT ANGLE (DEG)	IMPACT SPEED (MPH) 30	40	50	60	70
5.0	0.002	0.008	0.210	0.243	0.016
10.0	0.001	0.003	0.088	0.101	0.007
15.0	0.001	0.002	0.053	0.061	0.004
20.0	0.000	0.002	0.035	0.040	0.003
25.0	0.000	0.003	0.053	0.060	0.004

the lack of encroachment data on speed-angle combinations to support this conclusion, it was decided that adjustment of the impact condition probabilities to account for the apparent impossibility of high-speed, high-angle impacts was not warranted.

Effectiveness Performance Levels

Effectiveness performance levels for retrofitting the New Jersey CMB as a function of automobile weight splits, ADT, and vertical acceleration adjustment limits (CASE III) are shown in Tables 22 and 23 for rural freeways and Tables 24 and 25 for urban freeways. The vertical acceleration adjustment factors were defined earlier in Tables 7 and 8. The accident cost reduction values shown in these tables will be discussed later.

For illustration purposes, the results in Tables 22 thru 25 are presented graphically in Figure 7 for an assumed project improvement life of 20 years. Referring to Figure 7, one can reach the following conclusions in regard to the effectiveness of the CMB retrofit:

(1) The number of injury type accidents reduced per mile is significant and increases in direct proportion to the ADT.

(2) The CMB retrofit is more effective on the rural type freeway even though the median width was nearly double the width of the urban freeway. This can be explained by referring to Tables 20 and 21 which show that the impact condition probabilities assign greater weight to high-speed, high-angle impacts that have higher injury producing accident potential.

(3) The higher the compact automobile split in the traffic stream, the more effective the CMB retrofit.

TABLE = 22

NEW JERSEY CMB RETROFIT PERFORMANCE LEVELS BASED ON HVOSM SIMULATIONS

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO	= $ 850	/ACCIDENT
INJURY	= $ 5800	/ACCIDENT
FATAL	= $150000	/ACCIDENT
UPPER LIMIT	= $ 14500	/ACCIDENT

CASE III

2,250 LB AUTO DISTRIBUTION = 0.50
4,500 LB AUTO DISTRIBUTION = 0.50

RURAL INTERSTATE HIGHWAY

ADT	VERTICAL AUTOMOBILE ACCELERATION ADJUSTMENT FACTORS (RF)			
TRAFFIC	LOWER	LIMIT	UPPER	LIMIT
VOLUMES (VPD)	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)
10000.	0.032561	841.83	0.038507	938.00
20000.	0.065123	1683.67	0.077014	1876.01
30000.	0.097684	2525.50	0.115521	2814.00
40000.	0.130245	3367.31	0.154029	3752.00
50000.	0.162807	4209.19	0.192536	4690.00
60000.	0.195369	5051.00	0.231044	5628.00
70000.	0.227930	5892.88	0.269551	6566.06
80000.	0.260491	6734.63	0.308059	7504.00
90000.	0.293054	7576.50	0.346566	8442.06
100000.	0.325607	8418.31	0.385071	9380.00

TABLE = 23

NEW JERSEY CMB RETROFIT PERFORMANCE LEVELS BASED ON HVOSM SIMULATIONS

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO	= $ 850 /ACCIDENT
INJURY	= $ 5800 /ACCIDENT
FATAL	= $150000 /ACCIDENT
UPPER LIMIT	= $ 14500 /ACCIDENT

CASE III

2,250 LB AUTO DISTRIBUTION = 0.75
4,500 LB AUTO DISTRIBUTION = 0.25

RURAL INTERSTATE HIGHWAY

ADT TRAFFIC VOLUMES (VPD)	VERTICAL AUTOMOBILE ACCELERATION ADJUSTMENT FACTORS (RF)			
	L O W E R	L I M I T	U P P E R	L I M I T
	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)
10000.	0.033535	958.85	0.039807	1053.53
20000.	0.067069	1917.70	0.079615	2107.05
30000.	0.100604	2876.56	0.119422	3160.63
40000.	0.134138	3835.38	0.159229	4214.06
50000.	0.167672	4794.25	0.199037	5267.63
60000.	0.201208	5753.13	0.238845	6321.19
70000.	0.234742	6711.94	0.278652	7374.69
80000.	0.268276	7670.81	0.318460	8428.19
90000.	0.301811	8629.69	0.358267	9481.75
100000.	0.335342	9588.50	0.398071	10535.25

TABLE 24

NEW JERSEY CMB RETROFIT PERFORMANCE LEVELS BASED ON HVOSM SIMULATIONS

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO	= $ 850 /ACCIDENT
INJURY	= $ 5800 /ACCIDENT
FATAL	= $150000 /ACCIDENT
UPPER LIMIT	= $ 14500 /ACCIDENT

CASE III

2,250 LB AUTO DISTRIBUTION = 0.50
4,500 LB AUTO DISTRIBUTION = 0.50

URBAN INTERSTATE HIGHWAY

ADT	VERTICAL AUTOMOBILE ACCELERATION ADJUSTMENT FACTORS (RF)			
TRAFFIC	L O W E R	L I M I T	U P P E R	L I M I T
VOLUMES (VPD)	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)
10000.	0.014889	442.90	0.020709	528.10
20000.	0.029778	885.80	0.041419	1056.20
30000.	0.044667	1328.69	0.062129	1584.31
40000.	0.059557	1771.56	0.082838	2112.38
50000.	0.074446	2214.50	0.103548	2640.50
60000.	0.089335	2657.38	0.124258	3168.63
70000.	0.104224	3100.31	0.144967	3696.69
80000.	0.119114	3543.19	0.165677	4224.75
90000.	0.134003	3986.06	0.186386	4752.88
100000.	0.148895	4429.00	0.207108	5281.00

TABLE = 25

NEW JERSEY CMB RETROFIT PERFORMANCE LEVELS BASED ON HVOSM SIMULATIONS

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO	= $ 850 /ACCIDENT
INJURY	= $ 5800 /ACCIDENT
FATAL	= $150000 /ACCIDENT
UPPER LIMIT	= $ 14500 /ACCIDENT

CASE III

2,250 LB AUTO DISTRIBUTION = 0.75
4,500 LB AUTO DISTRIBUTION = 0.25

URBAN INTERSTATE HIGHWAY

ADT	VERTICAL AUTOMOBILE ACCELERATION ADJUSTMENT FACTORS (RF)			
TRAFFIC	L O W E R	L I M I T	U P P E R	L I M I T
VOLUMES (VPD)	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)	HAZARD-INDEX REDUCTION (INJ/MI-YR)	ACCIDENT COST REDUCTION ($/MI-YR)
10000.	0.016231	539.65	0.022396	626.10
20000.	0.032460	1079.30	0.044791	1252.20
30000.	0.048691	1618.94	0.067188	1878.31
40000.	0.064920	2158.56	0.089583	2504.38
50000.	0.081151	2698.25	0.111980	3130.50
60000.	0.097381	3237.88	0.134376	3756.56
70000.	0.113610	3777.56	0.156771	4382.69
80000.	0.129841	4317.19	0.179168	5008.75
90000.	0.146072	4856.81	0.201569	5634.88
100000.	0.162308	5396.50	0.223969	6261.00

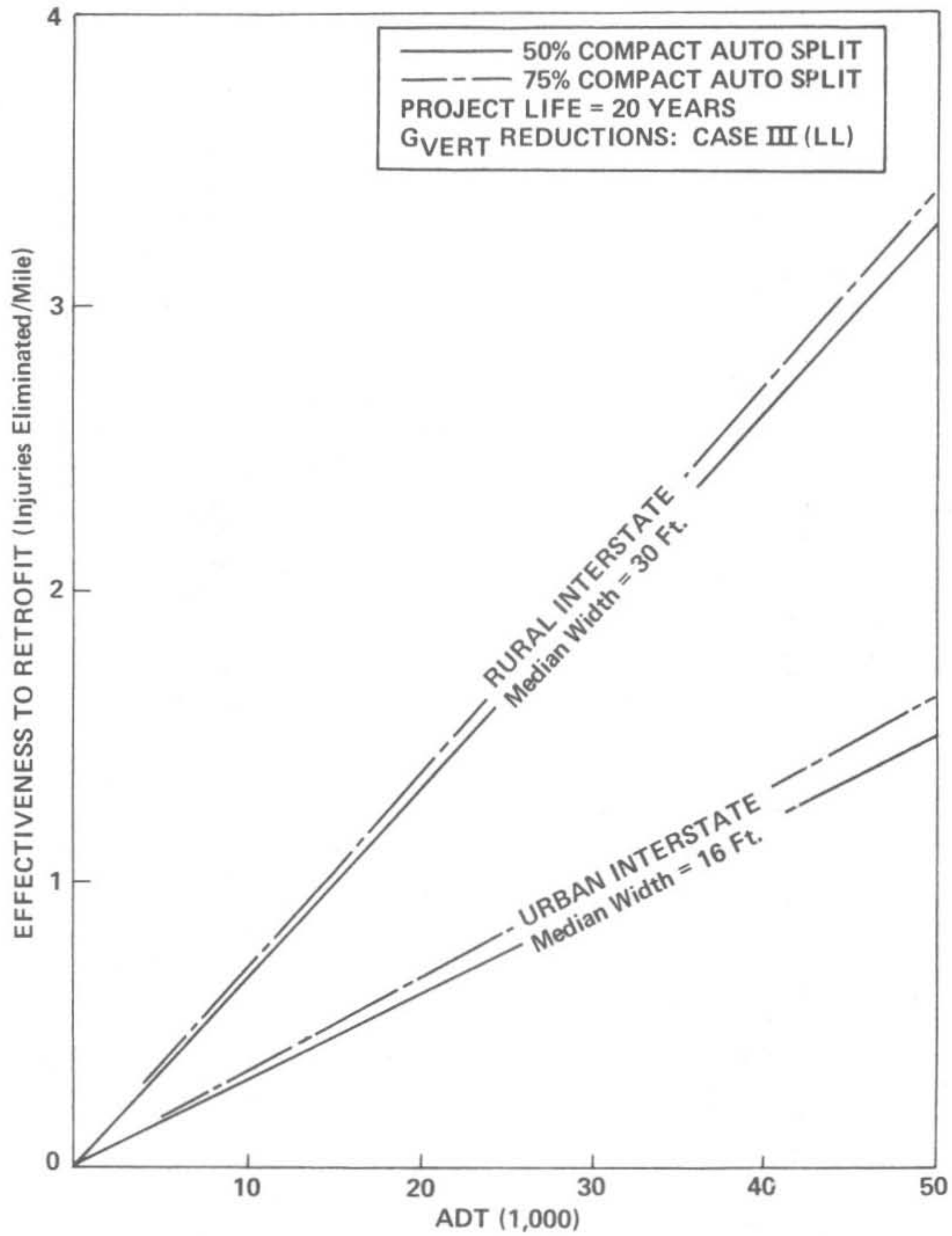


FIGURE 7.
HVOSM SIMULATIONS: COST LIMITS TO RETROFIT NEW JERSEY CMB AS FUNCTION OF AUTO SPLIT, HIGHWAY CLASSIFICATION, AND PROJECT LIFE

BENEFIT OF CMB RETROFIT UNIT

The benefit of retrofitting the New Jersey CMB was expressed in terms of the reduction in the injury accident costs before and after retrofitting. The methodology to compute a benefit value is similar to that used to compute on effectiveness value. The difference between the two methods is that the benefit method takes into consideration the societal costs of an injury accident, whereas, the effectiveness method does not take into consideration societal costs. The equation used to compute a benefit value was:

$$B = IC_{CMB} - IC_{\substack{CMB \\ Retrofit}} \qquad \text{---Eq. 13}$$

where: B = benefits of retrofitting (expected reduction in injury accident costs per mile per year)

IC = weighted injury accident cost (injury accident costs per mile per year)

The generalized equation used to compute the weighted injury accident costs of retrofitting was:

$$IC = E_f D \sum_{W} S \sum_{\theta} P_{\theta} \sum_{V} (IP)_{\theta,v} \, (AC)_{\theta,v} \qquad \text{---Eq. 14}$$

where: IC = weighted injury accident cost (injury accident costs per mile per year)

E_f = total vehicle encroachment rate = 0.009 (ADT) for both rural and urban interstate highways (encroach/mi/yr)

D = portion of ADT involved in median encroachments = 0.5 (assumed)

W = weight of automobiles

S = automobile split by weight

P_θ = probability that the CMB will be impacted given that an encroachment at an angle (θ) has occurred (see Table 18).

$IP_{\theta,v}$ = impact condition probability for a given encroachment angle (θ) and speed (v) (see Tables 20 and 21)

$AC_{\theta,v}$ = injury accident cost for a given impact angle (θ) and speed (v) for a computed severity-index and societal costs (see Figure 5)

Benefit Performance Levels

Benefit performance levels for retrofitting the New Jersey CMB as a function of aubomobile weight splits, ADT, vertical acceleration adjustment limits (CASE III), and injury accident societal costs of the National Safety Council were shown earlier in Tables 22 and 23 for rural freeways and Tables 24 and 25 for urban freeways. Conclusions in regard to the benefits of retrofitting are discussed in the next section to follow.

COST LIMIT SENSITIVITY ANALYSES

The cost limits to retrofit the New Jersey CMB were determined by setting the ratio of the benefits derived to the costs of construction equal to unity. Using the Capital Recovery Method, the equation to determine cost limits was:

$$P = \frac{B}{5280\ (CRF)} \qquad \text{---Eq. 15}$$

where: P = construction costs to retrofit CMB (\$/ft)

B = benefits of retrofitting (expected reduction in injury accident costs per mile per year)

$$CRF = \text{capital recovery factor} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i = compound interest rate

n = project improvement life

Assuming an interest rate of 10% and a project life of 20 yrs, Eq. 15 becomes:

$$P = 0.0016214\ (B) \qquad \text{---Eq. 16}$$

Cost limits to retrofit the New Jersey CMB are shown in Tables 26 thru 29. These cost limits are a function of (a) freeway classification; rural and urban, (b) ADT, (c) compact automobile splits of 50 and 75% in the traffic stream, and (d) two sets of injury accident societal costs. The lower societal costs are figures obtained from the National Safety Council (2), whereas, the higher societal costs are figures obtained from the Nebraska Department of Roads (3). These tables were based on CASE III vertical acceleration reduction factors listed in Tables 7 and 8. The cost limits in Tables 26 thru 29 were obtained by substituting the accident cost reduction values in Tables 22 thru 25 into Eq. 16.

For purposes of illustration, the cost limits in Tables 26 thru 29 are shown graphically in Figures 8, 9, and 10 as a function of ADT. The vertical acceleration reduction plots for CASES I, II, and III in Figure 10 were obtained from Tables 30 thru 32.

The sensitivity of the cost limits to the magnitude of the vertical acceleration reduction factors is shown in Figure 8. It is evident that the more effective the retrofit unit is in suppressing vehicle uplift and roll the

TABLE = 26

COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO	= $ 850	/ACCIDENT
INJURY	= $ 5800	/ACCIDENT
FATAL	= $150000	/ACCIDENT
UPPER LIMIT	= $ 14500	/ACCIDENT

CASE III

2,250 LB AUTO DISTRIBUTION = 0.50
4,500 LB AUTO DISTRIBUTION = 0.50

ADT TRAFFIC VOLUMES VPD	LOWER COST LIMIT ($/FT) RURAL HIGHWAY	LOWER COST LIMIT ($/FT) URBAN HIGHWAY	UPPER COST LIMIT ($/FT) RURAL HIGHWAY	UPPER COST LIMIT ($/FT) URBAN HIGHWAY
10000.	1.36	0.71	1.51	0.85
20000.	2.71	1.43	3.02	1.70
30000.	4.07	2.14	4.54	2.55
40000.	5.43	2.86	6.05	3.41
50000.	6.79	3.57	7.56	4.26
60000.	8.14	4.28	9.07	5.11
70000.	9.50	5.00	10.59	5.96
80000.	10.86	5.71	12.10	6.81
90000.	12.22	6.43	13.61	7.66
100000.	13.57	7.14	15.12	8.52

TABLE = 27

COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER

2 SIZE AUTOMOBILES 2,250 AND 4,500 LBS
5 IMPACT SPEEDS 30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES 5, 10, 15, 20 AND 25 DEG

PDO = $ 850 /ACCIDENT
INJURY = $ 5800 /ACCIDENT
FATAL = $150000 /ACCIDENT
UPPER LIMIT = $ 14500 /ACCIDENT

CASE III
2,250 LB AUTO DISTRIBUTION = 0.75
4,500 LB AUTO DISTRIBUTION = 0.25

ADT TRAFFIC VOLUMES VPD	LOWER COST LIMIT ($/FT)		UPPER COST LIMIT ($/FT)	
	RURAL HIGHWAY	URBAN HIGHWAY	RURAL HIGHWAY	URBAN HIGHWAY
10000.	1.55	0.87	1.70	1.01
20000.	3.09	1.74	3.40	2.02
30000.	4.64	2.61	5.10	3.03
40000.	6.18	3.48	6.79	4.04
50000.	7.73	4.35	8.49	5.05
60000.	9.28	5.22	10.19	6.06
70000.	10.82	6.09	11.89	7.07
80000.	12.37	6.96	13.59	8.08
90000.	13.91	7.83	15.29	9.09
100000.	15.46	8.70	16.99	10.10

TABLE = 28

COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER

2 SIZE AUTOMOBILES 2,250 AND 4,500 LBS
5 IMPACT SPEEDS 30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES 5, 10, 15, 20 AND 25 DEG

PDO = $ 900 /ACCIDENT
INJURY = $ 4900 /ACCIDENT
FATAL = $336000 /ACCIDENT
UPPER LIMIT = $ 24770 /ACCIDENT

CASE III
2,250 LB AUTO DISTRIBUTION = 0.50
4,500 LB AUTO DISTRIBUTION = 0.50

ADT TRAFFIC VOLUMES VPD	LOWER COST LIMIT ($/FT)		UPPER COST LIMIT ($/FT)	
	RURAL HIGHWAY	URBAN HIGHWAY	RURAL HIGHWAY	URBAN HIGHWAY
10000.	2.32	1.22	2.58	1.46
20000.	4.64	2.44	5.17	2.91
30000.	6.96	3.66	7.75	4.37
40000.	9.28	4.88	10.34	5.82
50000.	11.60	6.10	12.92	7.28
60000.	13.92	7.32	15.51	8.73
70000.	16.24	8.54	18.09	10.19
80000.	18.56	9.76	20.68	11.64
90000.	20.88	10.98	23.26	13.10
100000.	23.20	12.20	25.85	14.55

TABLE = 29

COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO	= $ 900 /ACCIDENT
INJURY	= $ 4900 /ACCIDENT
FATAL	= $336000 /ACCIDENT
UPPER LIMIT	= $ 24770 /ACCIDENT

CASE III

2,250 LB AUTO DISTRIBUTION = 0.75
4,500 LB AUTO DISTRIBUTION = 0.25

ADT TRAFFIC VOLUMES VPD	LOWER COST LIMIT ($/FT) RURAL HIGHWAY	LOWER COST LIMIT ($/FT) URBAN HIGHWAY	UPPER COST LIMIT ($/FT) RURAL HIGHWAY	UPPER COST LIMIT ($/FT) URBAN HIGHWAY
10000.	2.64	1.49	2.90	1.73
20000.	5.28	2.97	5.81	3.45
30000.	7.93	4.46	8.71	5.19
40000.	10.57	5.95	11.61	6.90
50000.	13.21	7.44	14.51	8.63
60000.	15.85	8.92	17.42	10.35
70000.	18.50	10.41	20.32	12.08
80000.	21.14	11.90	23.22	13.80
90000.	23.78	13.38	26.13	15.53
100000.	26.42	14.87	29.03	17.25

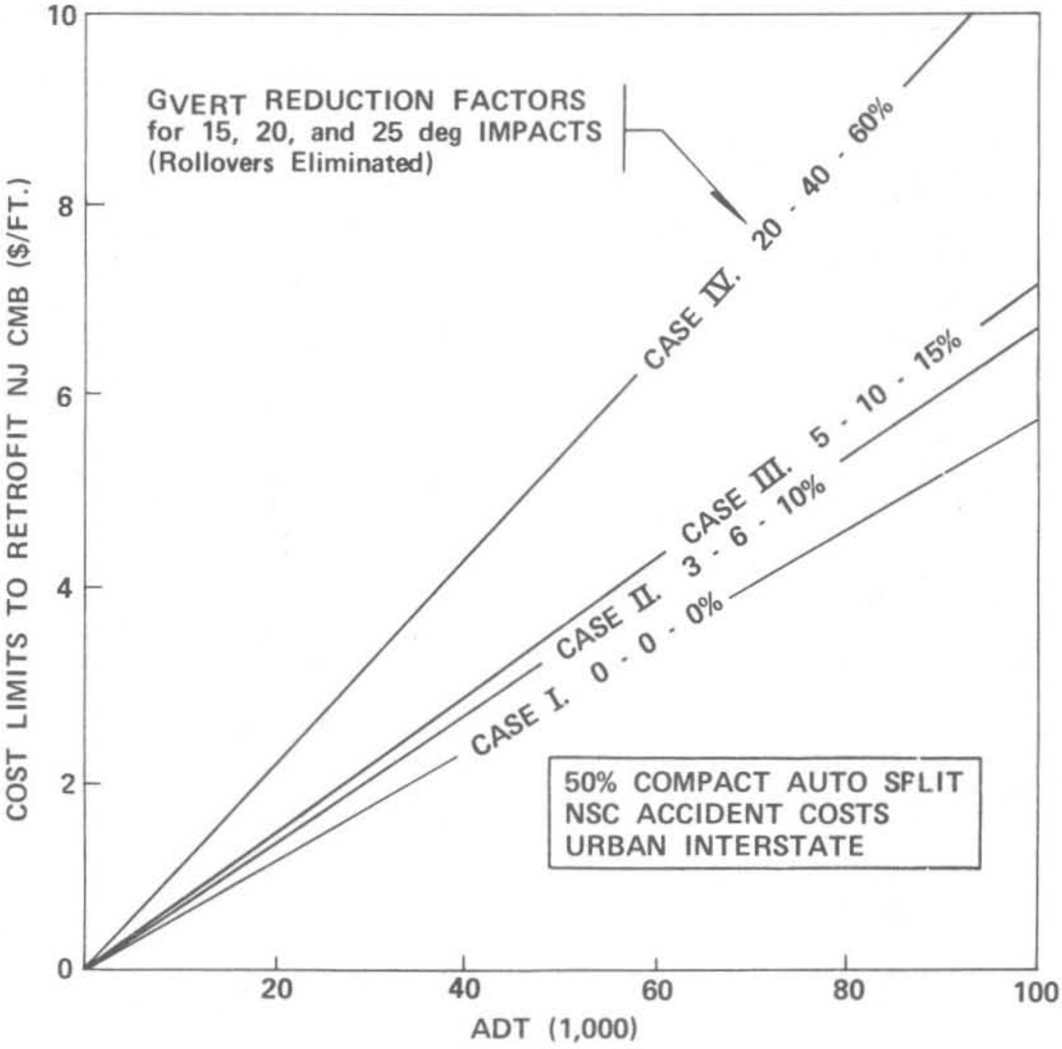


FIGURE 8.

HVOSM SIMULATIONS: COST LIMITS TO RETROFIT NEW JERSEY CMB AS FUNCTION OF VERTICAL DECELERATION REDUCTION FACTORS

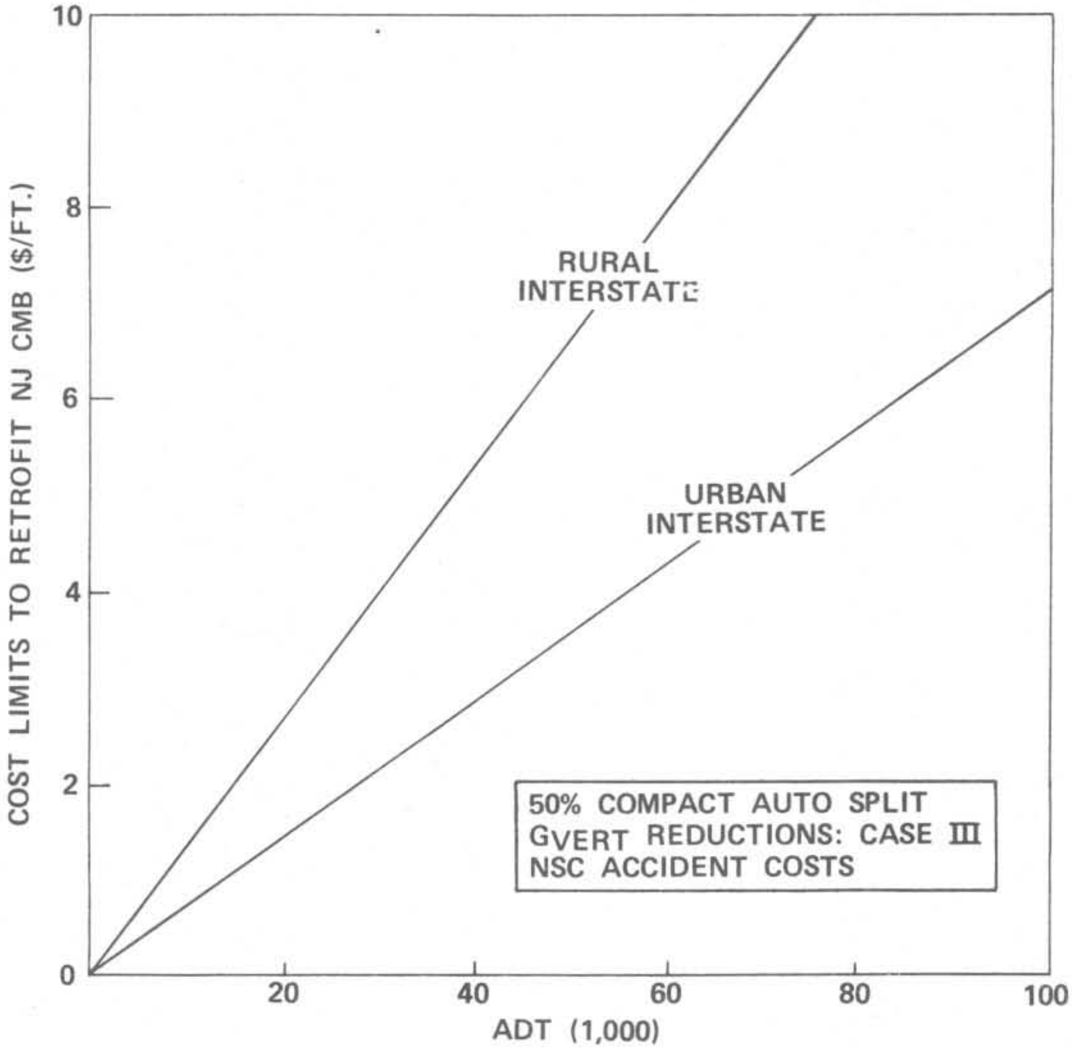


FIGURE 9.

HVOSM SIMULATIONS: COST LIMITS TO RETROFIT NEW JERSEY CMB AS FUNCTION OF INTERSTATE HIGHWAY CLASSIFICATION

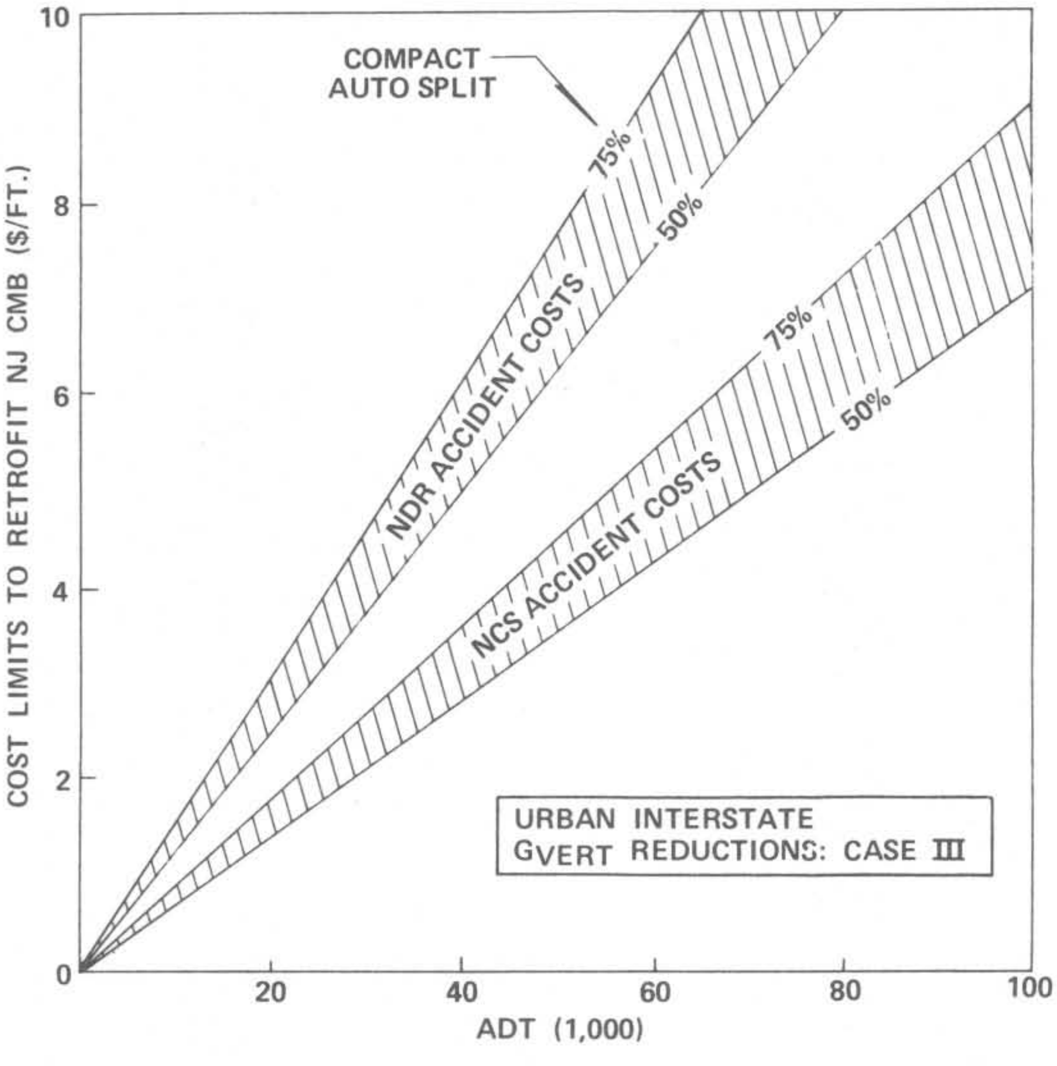


FIGURE 10.
HVOSM SIMULATIONS: COST LIMITS TO RETROFIT NEW JERSEY CMB AS FUNCTION OF ACCIDENT COSTS AND AUTO SPLIT FOR URBAN INTERSTATE HIGHWAY

TABLE = 30

COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO = $ 850 /ACCIDENT
INJURY = $ 5800 /ACCIDENT
FATAL = $150000 /ACCIDENT
UPPER LIMIT = $ 14500 /ACCIDENT

CASE I

2,250 LB AUTO DISTRIBUTION = 0.50
4,500 LB AUTO DISTRIBUTION = 0.50

ADT TRAFFIC VOLUMES VPD	LOWER COST LIMIT ($/FT)		UPPER COST LIMIT ($/FT)	
	RURAL HIGHWAY	URBAN HIGHWAY	RURAL HIGHWAY	URBAN HIGHWAY
10000.	1.20	0.57	1.20	0.57
20000.	2.39	1.14	2.39	1.14
30000.	3.59	1.71	3.59	1.71
40000.	4.78	2.28	4.78	2.28
50000.	5.98	2.85	5.98	2.85
60000.	7.17	3.42	7.17	3.42
70000.	8.37	3.99	8.37	3.99
80000.	9.56	4.56	9.56	4.56
90000.	10.76	5.13	10.76	5.13
100000.	11.95	5.70	11.95	5.70

TABLE = 31

COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER

2 SIZE AUTOMOBILES	2,250 AND 4,500 LBS
5 IMPACT SPEEDS	30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES	5, 10, 15, 20 AND 25 DEG

PDO	= $ 850 /ACCIDENT
INJURY	= $ 5800 /ACCIDENT
FATAL	= $150000 /ACCIDENT
UPPER LIMIT	= $ 14500 /ACCIDENT

CASE II

2,250 LB AUTO DISTRIBUTION = 0.50
4,500 LB AUTO DISTRIBUTION = 0.50

ADT TRAFFIC VOLUMES VPD	LOWER COST LIMIT ($/FT)		UPPER COST LIMIT ($/FT)	
	RURAL HIGHWAY	URBAN HIGHWAY	RURAL HIGHWAY	URBAN HIGHWAY
10000.	1.30	0.67	1.41	0.76
20000.	2.61	1.33	2.82	1.52
30000.	3.91	2.00	4.23	2.28
40000.	5.22	2.67	5.64	3.04
50000.	6.52	3.34	7.04	3.80
60000.	7.83	4.00	8.45	4.55
70000.	9.13	4.67	9.86	5.31
80000.	10.44	5.34	11.27	6.07
90000.	11.74	6.00	12.68	6.83
100000.	13.05	6.67	14.09	7.59

TABLE 32

COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER

2 SIZE AUTOMOBILES 2,250 AND 4,500 LBS
5 IMPACT SPEEDS 30, 40, 50, 60 AND 70 MPH
5 IMPACT ANGLES 5, 10, 15, 20 AND 25 DEG

PDO = $ 850 /ACCIDENT
INJURY = $ 5800 /ACCIDENT
FATAL = $150000 /ACCIDENT
UPPER LIMIT = $ 14500 /ACCIDENT

CASE IV
2,250 LB AUTO DISTRIBUTION = 0.50
4,500 LB AUTO DISTRIBUTION = 0.50

ADT TRAFFIC VOLUMES VPD	LOWER COST LIMIT ($/FT)		UPPER COST LIMIT ($/FT)	
	RURAL HIGHWAY	URBAN HIGHWAY	RURAL HIGHWAY	URBAN HIGHWAY
10000.	1.76	1.07	1.88	1.18
20000.	3.52	2.14	3.76	2.35
30000.	5.28	3.21	5.63	3.53
40000.	7.03	4.28	7.51	4.71
50000.	8.79	5.35	9.39	5.89
60000.	10.55	6.42	11.27	7.06
70000.	12.31	7.49	13.14	8.24
80000.	14.07	8.56	15.02	9.42
90000.	15.83	9.63	16.90	10.60
100000.	17.59	10.70	18.78	11.77

higher the cost limits. A good compromise would be CASE III, whereby, in addition to eliminating rollovers the vertical accelerations during the primary stage of impact would be reduced 5, 10, and 15% for the corresponding impact angles at 15, 20, and 25 deg. For example, one could spend up to $37/ft to retrofit the New Jersey CMB on an urban freeway carrying an ADT of 100,000 vpd.

The sensitivity of the cost limits to the classification of highway is shown in Figure 9. It is evident that the retrofit unit is more effective on the rural type freeway even though the probability of an errant vehicle impacting the CMB is less on the rural freeway with a median width nearly double that on the urban freeway. This can be explained by referring to Tables 20 and 21 which show that the impact condition probabilities assign greater weight to the high-speed, high-angle impacts having higher injury accident potential.

The sensitivity of the cost limits to the split of compact automobiles in the traffic stream and the injury accident societal costs is shown in Figure 10 for an urban freeway. Of the two variables, it is evident that the cost limits are more sensitive to the injury accident societal costs. The societal costs of the National Safety Council would most likely be a lower bound on the cost limits, whereas, the societal costs of the Nebraska Department of Roads would most likely to an upper bound on the cost limits. It is also evident in Figure 10 that the higher the split of compact automobiles in the traffic stream the higher the cost limits for retrofitting. For a given impact speed and angle, a compact automobile would experience higher uplift vertical accelerations and a greater tendency to rollover on the CMB than a standard size automobile because of its shorter wheel track and lower roll moment of inertia.

ACCIDENT ANALYSIS:

COST LIMITS TO RETROFIT NEW JERSEY CMB
BASED ON
ASSUMED INJURY ACCIDENT COST REDUCTIONS

(SECTION 3)

In order for the New Jersey CMB retrofit concept to be cost-effective, the cost of retrofitting must not exceed the potential reduction in accident costs that it can be expected to provide. Therefore, accident data were analyzed to assess the severity of New Jersey CMB impacts and provide a basis for estimating the potential accident cost reduction that would result from retrofitting the CMB.

ACCIDENT DATA

Accident data pertinent to the New Jersey CMB were requested from the following agencies:

* FHWA
* NHTSA
* CALTRANS
* New York State DOT
* Texas Transportation Institute (TTI)
* Southwest Research Institute (SwRI)
* Nebraska Department of Roads (NDR)

In addition, an HRIS literature search was conducted to identify sources of information concerning the safety-related performance of the New Jersey CMB. As a result of this effort only two readily-available sources of accident data were found: (a) the results of a CMB study conducted by the Southwest Research Institute (10) and, (b) the accident records system of the Nebraska Department of Roads. Later in the study, accident data was requested and obtained from CALTRANS (1). The CALTRANS data reported vehicle exposure mileage which was not reported in the SwRI or the NDR data. Analysis of the CALTRANS data was presented earlier in Section 1.

Southwest Research Institute Data

The SwRI data were the result of a questionaire sent by the Southwest Research Institute to the states requesting data on accidents involving CMB's. The accident report form included in the questionaire asked for detailed information describing the type of barrier involved, accident site, impact conditions, type of vehicle, and accident severity. Of the 575 cases reported, 180 of them involved the New Jersey CMB.

Omaha Data

The only New Jersey CMB installed in Nebraska is located on the interstate system in Omaha. The accident records of the Nebraska Department of Roads for the past three years were reviewed to identify and CMB accidents at these locations. Accident reports for 42 such accidents were found.

ANALYSIS OF ACCIDENT DATA

The two accident data sets described above were analyzed to determine the severity of CMB accidents with respect to vehicle weight, impact speed, and impact angle. However, in the case of the SW data, vehicle weight was given in only 72 of the 180 cases, and the speed and angle of impact was provided in only 39 cases. The results of a cross-tabulation analysis of these data did not indicate that there were any significant correlations between accident severity and these three factors.

In the case of the Omaha data, vehicle weight was determined from the vehicle description provided in the accident report. However, the speed and angle of impact could not be determined from the information given in the accident report. Thus, for the purposes of this study, the only one of these factors accounted for in the analysis of these data was vehicle weight.

In the case of each data set, the vehicles were classified into two categories: (1) those weighing not more than 3,500 lbs (compact autos) and (2) those weighing more than 3,500 lbs. The accident severity was then determined for each vehicle class. The results of this analysis are presented in Table 33. Although in neither case was the difference in accident severity between smaller and larger vehicles found to be statistically significant, this difference was nevertheless accounted for in the subsequent calculation of accident costs.

Also, it should be noted that there is a considerable difference in accident severity between the two data sets. Therefore, both sets of accident severities were used separately in computing the cost limits of retrofitting, thus providing a range of potential accident cost savings.

TABLE 33. SEVERITY OF NEW JERSEY CMB ACCIDENTS

VERSUS VEHICLE WEIGHT

Vehicle Weight (lbs)	Accident Severity		
	Fatal (%)	Personal Injury (%)	Property Damage Only (%)
Omaha Accident Data			
≤ 3,500	0	70	30
> 3,500	0	55	45
SW Accident Data			
≤ 3,500	0	25	75
> 3,500	0	30	70

COST LIMIT SENSITIVITY ANALYSES

The cost limit to retrofit the New Jersey CMB is equal to the accident cost savings that would be expected to result from such retrofitting. In this analysis, it was assumed that the retrofitting would only be effective in reducing the injury accident costs associated with CMB accidents having impact angles of more than 10 degrees. According to the impact condition probabilities presented in Tables 20 and 21, about 32 percent of the CMB accidents would have impact angles greater than 10 degrees. Thus the potential accident cost savings resulting from the retrofitting was limited to the injury accident costs of 32 percent of the CMB accidents.

Injury Accident Costs

Therefore, to determine the cost limits to retrofit, the injury accident costs for New Jersey CMB accidents with impact angles greater than 10 degrees were first computed for the same rural and urban interstate highway conditions that were used in the HVOSM simulation cost limits analysis, which was presented in a previous section of this report. The following equation was used for this computation:

$$PAC = \frac{E \cdot D \cdot P(Q>10°/E) \cdot P(C/E) \cdot [\sum_{W} P(w) \cdot P_{w}(I/C)] \cdot AC \cdot PWF(i = 10\%, n = 20 \text{ yrs})}{5{,}280} \quad \text{--Eq. 17}$$

where: PAC = present worth of injury accident costs over a 20-year retrofit life at a 10% interest rate for those CMB accidents with an impact angle greater tha 10° ($/ft);

E = encroachment rate (no./mi/yr) = 0.0009 ADT for both rural and urban interstate highways; (20)

D = directional traffic split = 0.5 (assumed);

$P(Q>10°/E)$ = probability that encroachment angle will be greater than 10° given that an encroachment has occurred = 0.32;

$P(C/E)$ = probability that CMB will be struck given that an encroachment has occurred = 0.89 for the rural interstate highway and 0.98 for the urban interstate highway considered in this analysis (weighted average of lateral impact probabilities presented in Table 18 for 15°, 20°, and 25° encroachment angles);

$P(w)$ = portion of vehicles of weight class "w" in traffic stream (w = 1 for vehicles weighing not more than 3,500 lbs and w = 2 for vehicles weighing more than 3,500 lbs)

$P_w(I/C)$ = probability of an injury accident given that CMB has been struck by vehicle in weight class w = portion of personal injury accidents given in Table 33;

AC = unit injury-accident cost ($/injury accident:

PWF = present worth factor for an interest rate of 10% and a retrofit life of 20 years = 8.514.

This equation was used to compute the present worth injury accident costs of New Jersey CMB accidents, that have impact angles greater than 10 degrees, for each of the 16 possible combinations of the following for variables for ADT's up to 100,000 vehicles per day:

(a) Two sets of injury accident probabilities, $P_w(I/C)$: (1) computed from the SW accident data and (2) computed from the Omaha accident data (Refer to Table 33);

(b) Two unit injury-accident costs, AC: (1) $4,900 determined by the Nebraska Department of Roads (3) and (2) $5,800 determined by the National Safety Council (2);

(c) Two compact auto percentages, P(w); (1) 50% compact autos and (2) 75% compact autos;

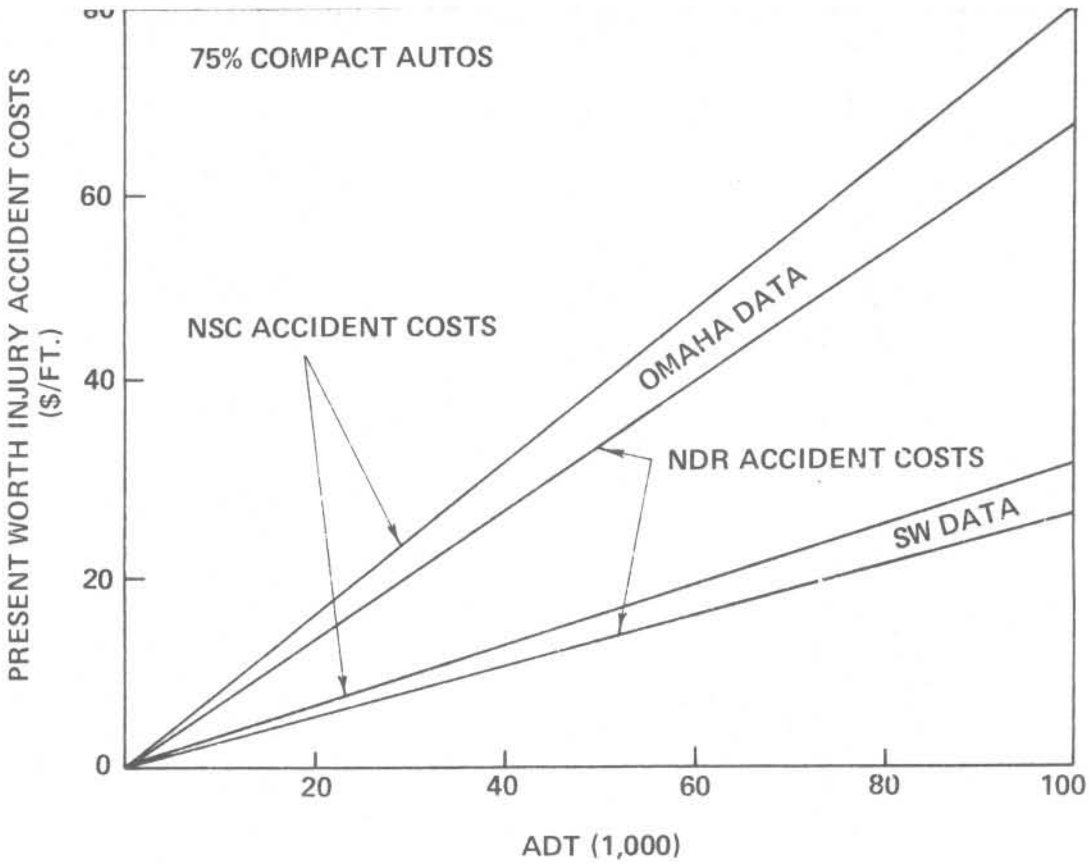
(d) Two classes of interstate highway: (1) rural and (2) urban.

The results of these computations are shown in Figures 11 and 12.

Obviously the injury accident costs computed using the National Safety Council's unit injury-accident cost were higher because this unit cost is higher than that of the Nebraska Department of Roads ($5,800 vs $4,900 per injury accident). Also, the injury accident costs computed based on the Omaha data were higher than those based on the SW data because of the higher percentage of injury accidents contained in the Omaha data (Refer to Table 33).

The injury accident costs based on the Omaha data were directly proportional to the percentage of compact autos because of the higher percentage of injury accidents for compact autos. However, the opposite was true for the results based on the SW data in which the compact autos had the lower percentage of injury accidents, as shown in Table 33.

Finally, it should be noted that the injury accident costs computed for the urban interstate highway were higher than those computed for the rural interstate highway. This was because the narrower median on the urban interstate highway resulted in a higher probability of the CMB being struck by an encroaching vehicle. This result was contrary to that obtained in the HVOSM simulation cost limits analysis, because the effect of increased accident severity due to higher speeds on the rural interstate highway could not be accounted for in the accident data analysis.



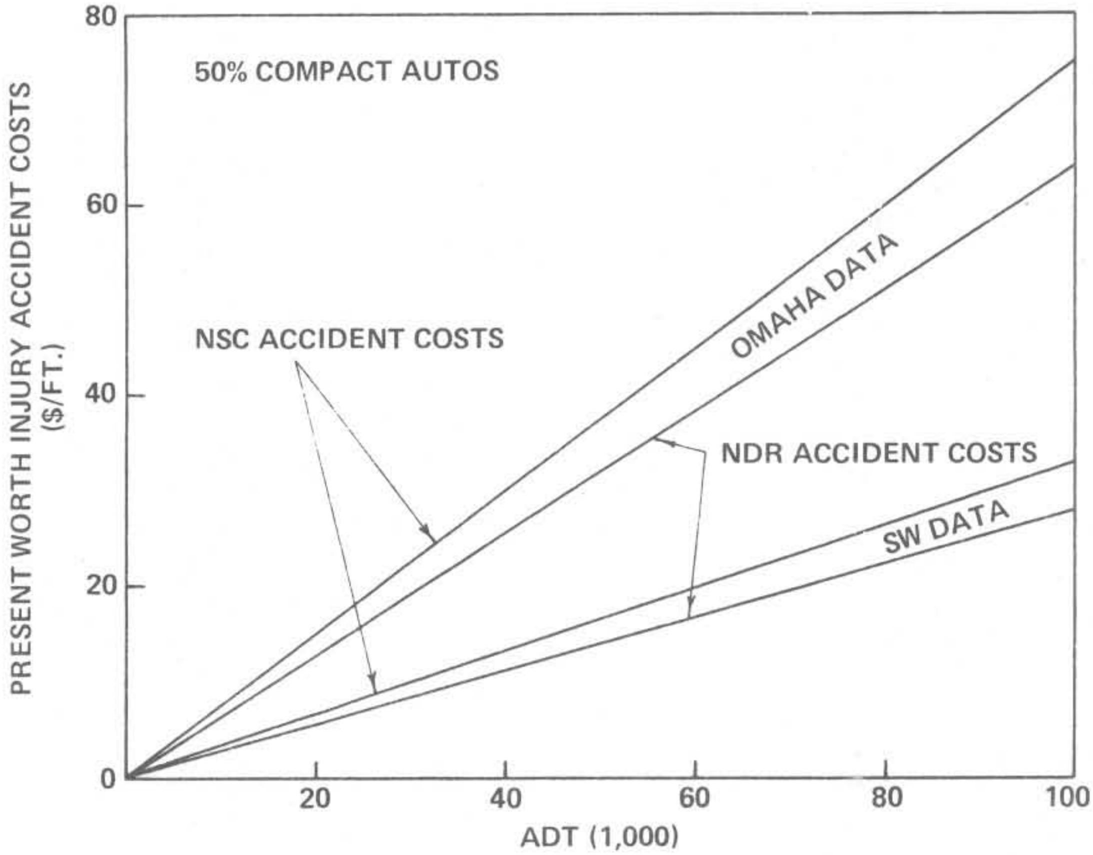
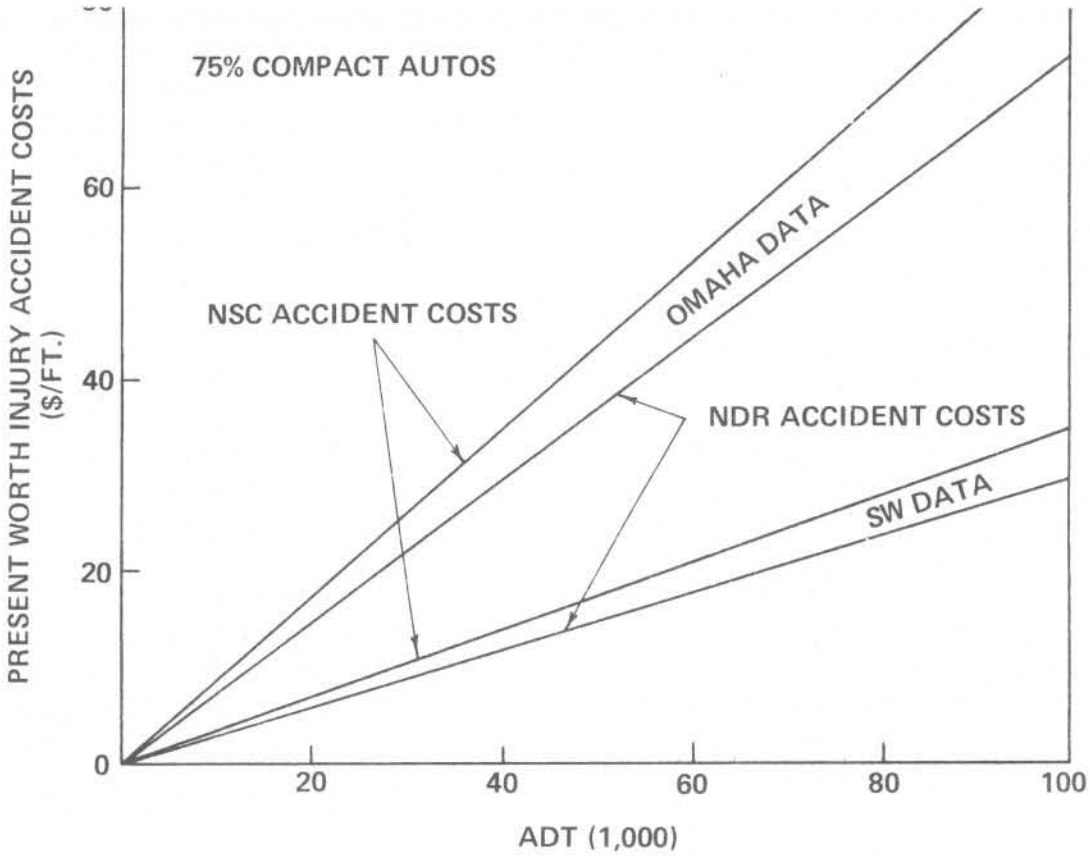


FIGURE 11. ACCIDENT ANALYSIS: PRESENT WORTH INJURY ACCIDENT COSTS FOR NEW JERSEY CMB ON RURAL INTERSTATE HIGHWAY.



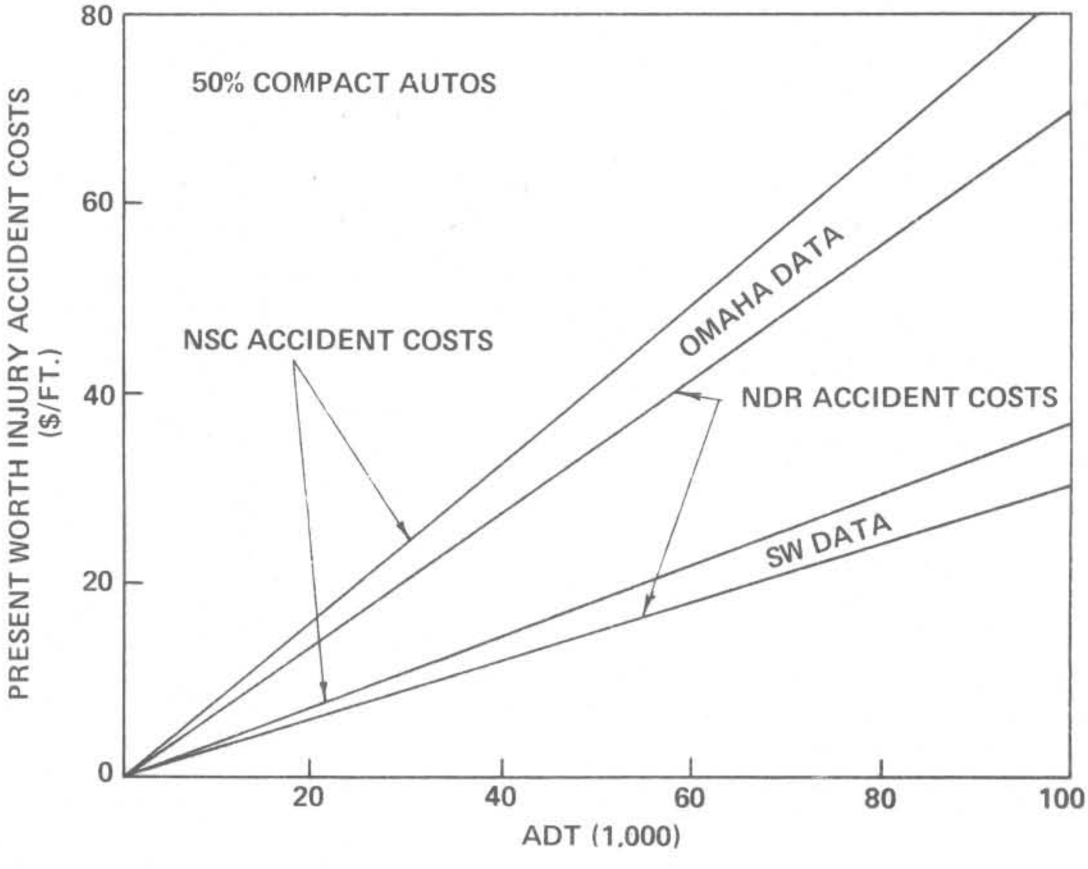


FIGURE 12. ACCIDENT ANALYSIS: PRESENT WORTH INJURY ACCIDENT COSTS FOR NEW JERSEY CMB ON URBAN INTERSTATE HIGHWAY.

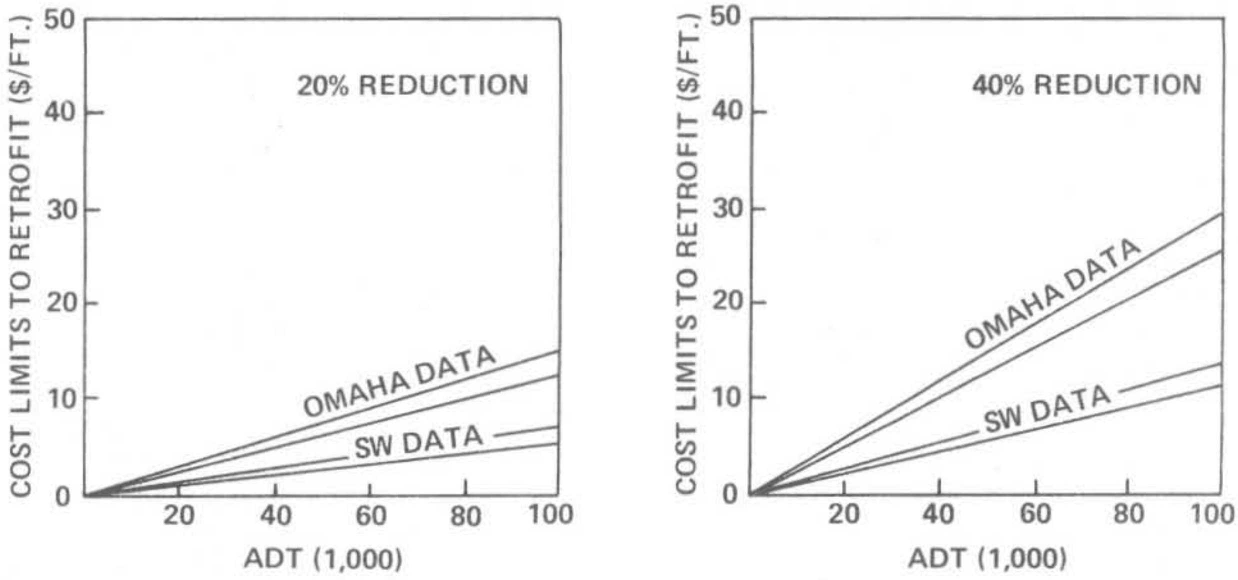
Cost Limits

Cost limits to retrofit New Jersey CMB's were computed by applying a percentage reduction factor to the injury accident costs for New Jersey CMB accidents with impact angles greater than 10 degrees, which are shown in Figures 11 and 12. Based on the experience and engineering judgment of the researchers, 20-percent and 40-percent injury-accident cost reductions were selected as the expected lower and upper limits of retrofit effectiveness. The cost limits to retrofit computed for these limits of effectiveness are shown in Figures 13 and 14.

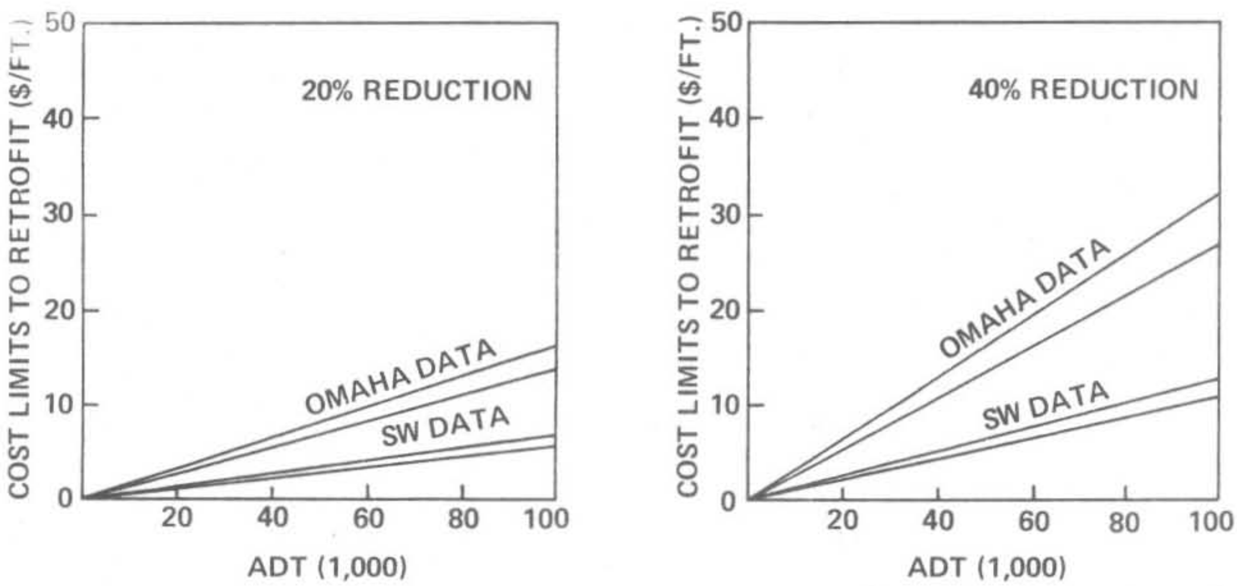
Of course, as injury accident costs increase as a function of ADT, percent compact autos, unit injury accident costs, and type of highway, so do the cost limits to retrofit. And, as these cost limits increase, retrofitting becomes more cost-effective.

The difference between the cost limits based on the SW accident data and those based on the Omaha accident data establishes a range of retrofit costs within which the cost-effectiveness of retrofitting is likely, but uncertain, depending on which data best represent the severity of accidents with New Jersey CMB's. However, if the cost to retrofit were below the SW data cost limit, it would indicate that retrofitting would be almost definitely cost-effective. But, on the other hand, if the cost to retrofit were higher than the Omaha data cost limit, it would be very unlikely that retrofitting would be cost-effective.

From discussions with engineers at the Nebraska Department of Roads, a cost to retrofit of $10 per linear foot seems to be a reasonable estimate.



(A) 50% COMPACT AUTOS



(B) 75% COMPACT AUTOS

FIGURE 13. ACCIDENT ANALYSIS: COST LIMITS TO RETROFIT NEW JERSEY CMB ON RURAL INTERSTATE HIGHWAY.

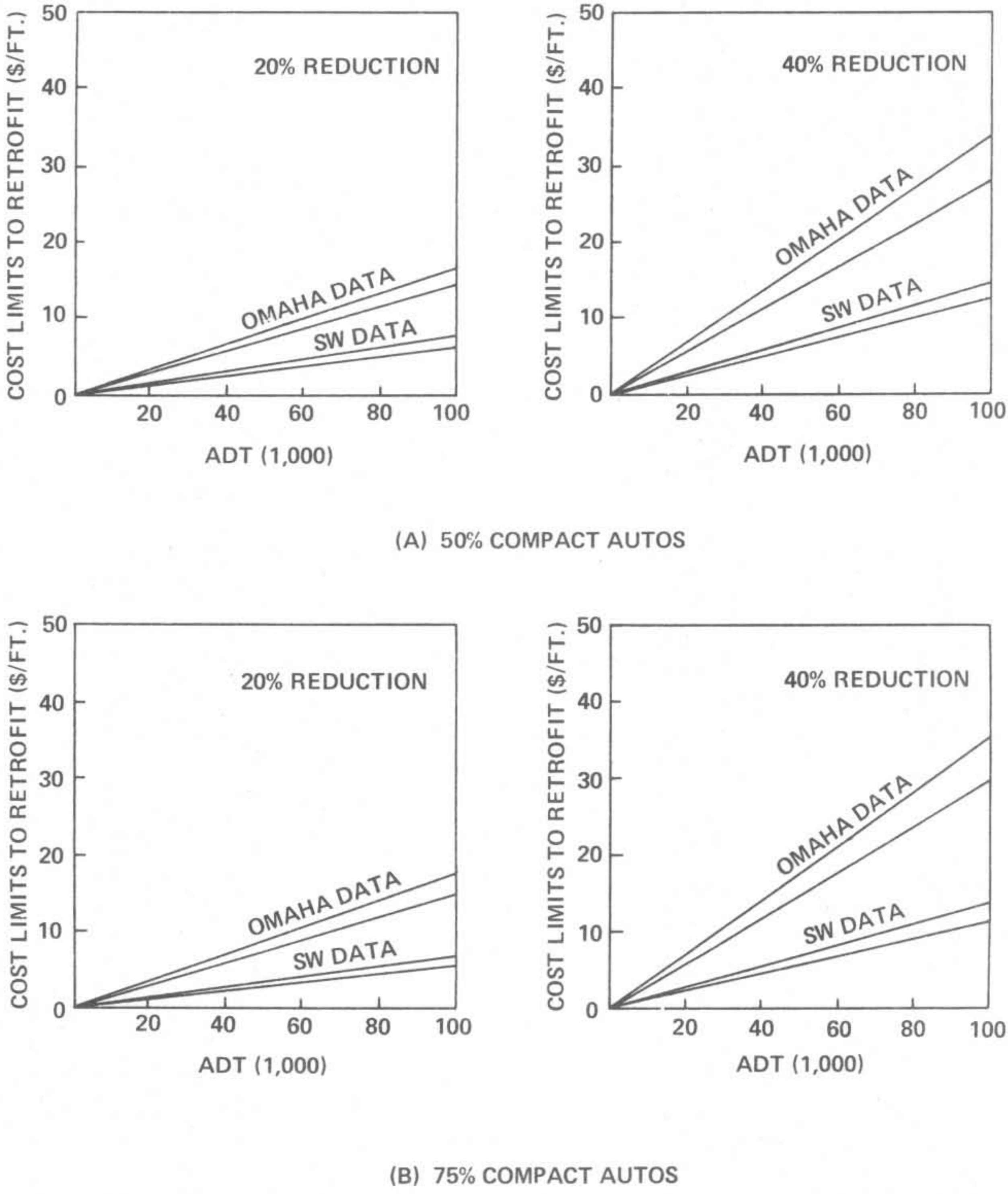


FIGURE 14. ACCIDENT ANALYSIS: COST LIMITS TO RETROFIT NEW JERSEY CMB ON URBAN INTERSTATE HIGHWAY.

Therefore, using $10 per foot as the cost limit, breakeven ADT's were determined from Figures 13 and 14, and are presented in Table 34.

If the ADT on a highway is greater than the breakeven ADT shown in Table 34 for the appropriate highway type, then retrofitting would be cost-effective on that highway; otherwise, it would not be cost-effective. The breakeven ADT's shown in Table 34 are lower than those on freeways in many areas on which New Jersey CMB's are located. Therefore, it is concluded that retrofitting is cost-effective, and that its cost-effectiveness will be enhanced as the percentage of smaller cars in the traffic stream increases in the future.

TABLE 34. BREAKEVEN ADT'S FOR RETROFIT COST OF $10/FT. AND NATIONAL SAFETY COUNCIL INJURY ACCIDENT COSTS

Compact Auto Split (%)	Based on Omaha Accident Data		Based on SWRI Accident Data	
	20% Reduction	40% Reduction	20% Reduction	40% Reduction
Rural Interstate Highway				
50	68,000	34,000	148,000	74,000
75	64,000	32,000	120,000	80,000
Urban Interstate Highway				
50	60,000	30,000	140,000	70,000
75	56,000	28,000	144,000	72,000

ACCIDENT ANALYSIS:
COST LIMITS TO RETROFIT NEW JERSEY CMB
BASED ON
ELIMINATING ROLLOVER INJURY ACCIDENT COSTS

(SECTION 4)

In the previous accident study (Section 3), the cost limits to retrofit the CMB were based on the assumption that the retrofit would be effective in reducing both non-rollover and rollover injury accident costs somewhere within the range of 20 to 40% for those accidents occurring at impact angles greater than 10 deg.

In the work to follow, the cost limits were computed on the assumption that the retrofit unit will be effective in eliminating only the injury accident costs associated with rollovers. The effect of neglecting the injury accident costs associated with non-rollover accidents as shown later in Figure 15 will produce a conservative estimate of the cost limits to retrofit. It is the opinion of the authors that this assumption is more direct and realistic than that used in the previous accident study (Section 3). Also, the assumption of eliminating rollover accidents is more consistent with the approach used in the HVOSM simulation study (Section 2).

EFFECTIVENESS OF RETROFIT UNIT

The CMB retrofit unit will be effective in reducing the severity of both non-rollover and rollover injury accidents for automobile impacts greater than 10 deg. Based on the results of the HVOSM simulation study (Section 2), it can be predicted that about 75% of the retrofit unit's effectivness would be in eliminating rollover type accidents. A specific example illustrating the effectiveness of the retrofit unit is shown in Figure 15.

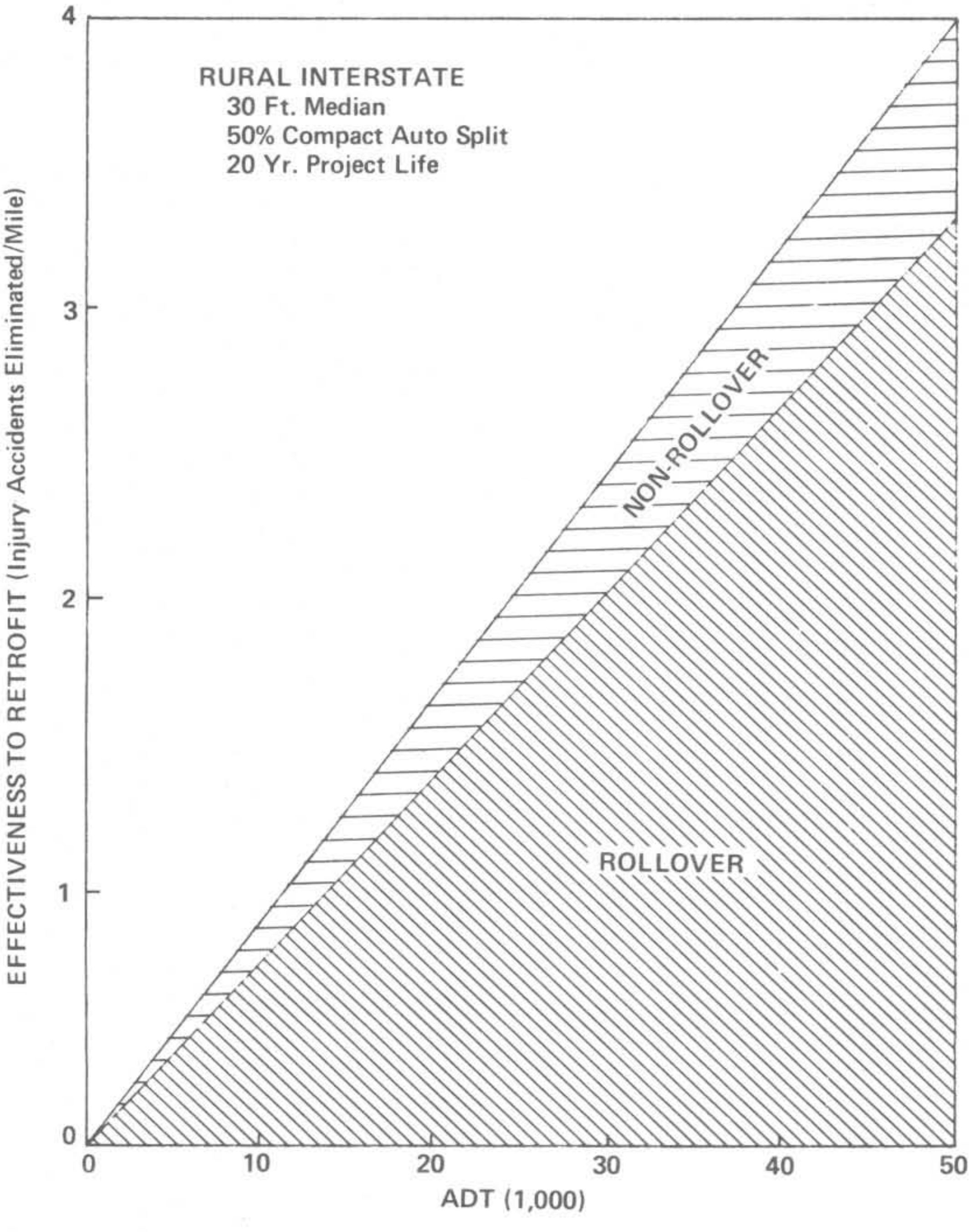


FIGURE 15: SIMULATION STUDY: EFFECTIVENESS TO RETROFIT NEW JERSEY CMB IN TERMS OF NON-ROLLOVER AND ROLLOVER ACCIDENTS ELIMINATED

TABLE 35

SwRI ACCIDENT DATA SUMMARY

(Ref. 9 and 10)

Barrier Type	Number of Accident Cases[a]	Accident Severity[b]			Vehicle[c] Rollovers	Mounting
		PDO	Hosp. Inj.	Fatal		
1. New Jersey	180	133	35	0	6	1
	(33)	(79)	(21)	(0)	(3)	(1)
2. New Jersey (Mod)[d]	73	58	15	1	9	0
	(13)	(77)	(20)	(1)	(12)	(0)
3. General Motors	299	225	74	0	19	4
	(54)	(75)	(25)	(0)	(6)	(1)
Total	552	416	124	1	34	5

(a) Numbers in parentheses are percentages of total accident cases with specified barrier profile.

(b) Numbers are number of cases for each category; numbers in parentheses are percentage for that barrier profile.

(c) Numbers are number of vehicle rollovers for each barrier profile; numbers in parentheses represent percentage of total number of accidents for each barrier profile.

(d) New Jersey (Mod) Initial Step 4-5 in. instead of New Jersey Standard 3 in.

NUMBER OF CMB ROLLOVER ACCIDENTS

Insight into the number of rollover accidents can be provided from both the HVOSM simulation study (Section 2) and accident data. Accident data presented by the SwRI (9, 10) and NDR were analyzed earlier in this study (Section 3). The accident data summary in the SwRI report prior to 1974 is shown in Table 35. It is evident that rollovers and mountings on the standard New Jersey CMB constituted 3.9% of the reported accidents. More recent accident data was obtained from CALTRANS (1) on the California CMB. Referring back to Table 1 (Section 1), the California data showed that 116 (7.7%) of the 1,515 reported accidents in 1978 and 177 (9.9%) of the 1,796 reported accidents in 1979 resulted in vehicle rollovers.

Accident data from the above sources contained little or no information on the relationships between rollovers and the type of vehicle; vehicle distribution; impact speed; and impact angle. However, insight into these relationships was provided by the HVOSM model. The HVOSM rollover predictions on the New Jersey CMB are shown in Table 36. It is clearly evident that rollovers occur only at the higher impact speeds of 60 and 70 mph.

TABLE 36

HVOSM ROLLOVER PREDICTIONS[a]

Size Automobile	Impact Speed (mph)	Impact Angles (deg)
Standard	70	15,20,25
Compact	60	25
	70	15,20,25

a. See Tables 4 and 5.

The rural and urban impact condition probabilities that correspond to the HVOSM rollover predictions are shown in Table 37 for various compact automobile distributions in the traffic stream. The SwRI data in Table 35 for the standard New Jersey CMB, which includes accidents prior to 1974, compares well with the HVOSM predictions in Table 37 for either a rural or urban highway and an assumed compact automobile split of 25%. Also, the CALTRANS accident data for 1978 and 1979, in which 293 (8.8%) rollovers occurred out of 3,311 reported accidents, compares well with the HVOSM predictions in Table 37 for a rural highway and an assummed compact automobile split of 50%.

It is certainly reasonable to expect that by 1990 that this split could be as high as 75%, and as a result, compact automobile rollover accidents could increase significantly because of their shorter wheel track widths and lower roll moment-of-inertia resistance.

CMB ROLLOVERS AS FUNCTION OF HIGHWAY CONDITIONS

The number of CMB rollover accidents per mile of CMB length per year that can be expected on roads of various design, ADT, and traffic mix are shown in Figure 16. This graph was based on the results of the HVOSM simulation study (Section 2) for two selected rural and urban sites. The rollover

TABLE 37

ROLLOVER ACCIDENTS (%)[a]

Type Interstate Highway	Size Automobile	Compact/Standard Split		
		25/75 (1974)[b]	50/50 (1980)[b]	75/25 (1990)[b]
Rural	Standard	2.8	1.9	0.9
	Compact	3.0	6.1	9.1
		5.8	8.0	10.0
Urban	Standard	0.8	0.5	0.3
	Compact	1.8	3.6	5.3
		2.6	4.1	5.6

a. Based on Impact Condition Probabilities in Section 2.

Rural Interstate --- see Table 20

Urban Interstate --- see Table 21

b. Predictions of authors

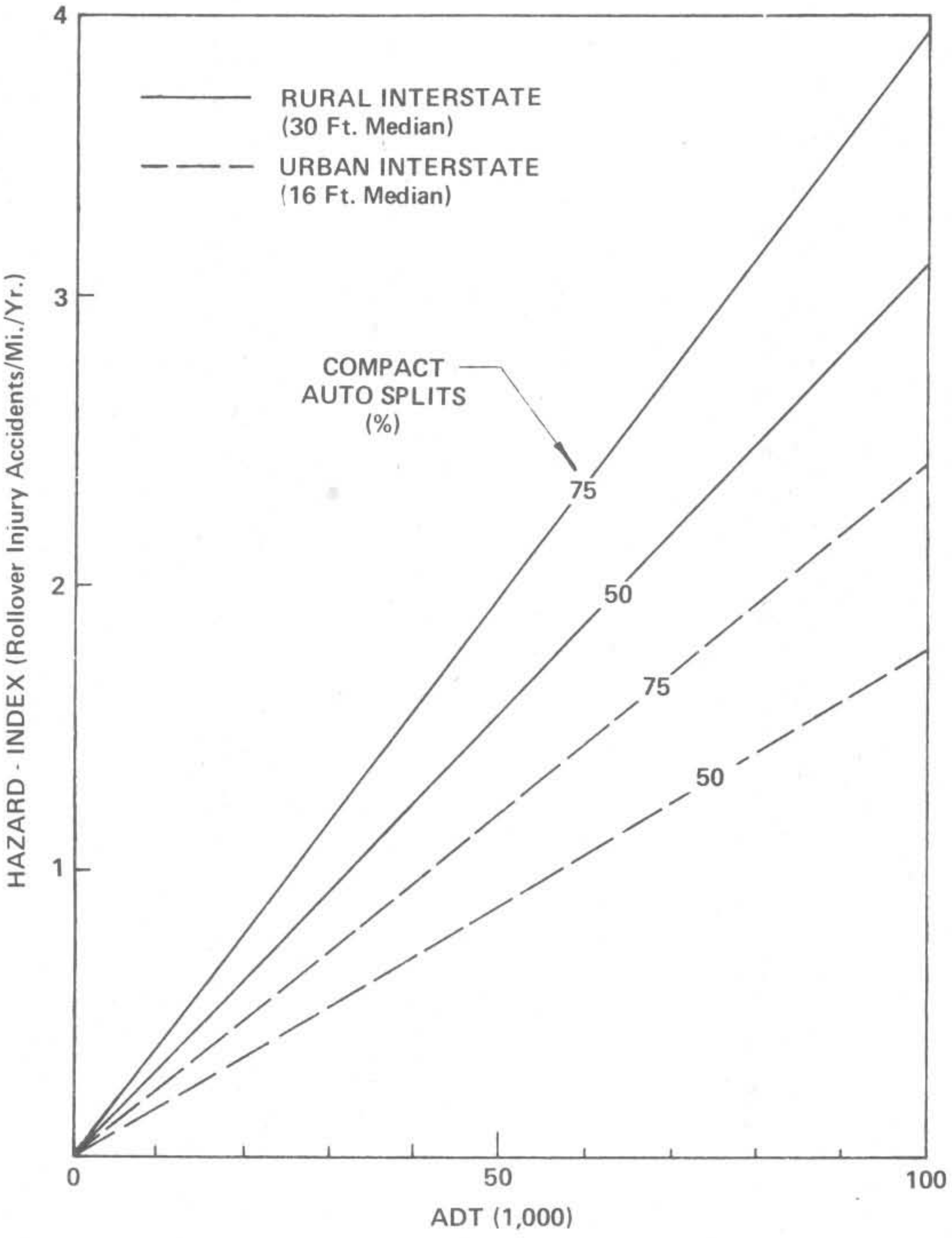


FIGURE 16: SIMULATION STUDY: RELATIONSHIP BETWEEN ROLLOVER INJURY TYPE ACCIDENTS ON NEW JERSEY CMB AND TRAFFIC CONDITIONS

accidents are higher on the rural interstate highway in lieu of the wider median width because of the higher impact speeds. As an example, for an ADT of 50,000, a compact automobile split of 50%, and a 1 mile length of CMB, one can expect that about 0.8 and 1.5 rollover accidents per year will occur on the rural and urban interstate highway sites defined, respectively. The CALTRANS, SwRI, and NDR accident data analyzed earlier in this study (Sections 1, 2 & 3) did not enable the determination of the frequency of CMB rollover accidents on highways of various design, ADT, and traffic mix.

COST LIMITS TO RETROFIT

Using the same probabilitic method as used in the previous accident study (Section 3), the equation used to compute the cost limits to retrofit was as follows:

$$CL = \frac{E_f(D)(PWF)\ P_{C/E}}{5280}\left\{\sum_{W} (P_W)(P_{RO/C})\ [P_{I/BR}(AC_{BR}) - P_{I/AR}(AC_{AR})]\right\} \text{---Eq. 18}$$

where:

CL = cost limits to retrofit New Jersey CMB over a 20 yr. retrofit life at a 10% interest rate for those impacts that result in rollovers ($/ft);

E_f = total encroachment rate = 0.0009 ADT for both rural and urban interstate highways (encroach/mi/yr);

D = portion of ADT involved in median encroachments = 0.5 (assumed)

PWF = compound present worth factor for 20 yrs at 10% interest = 8.514

$P_{C/E}$ = probability of a CMB collision given that an encroachment has occurred; (weighted average --- see Table 17)

Rural Interstate (30 ft. Median) = 0.736

Urban Interstate (16 ft. Median = 0.890

P_W = portion of automobiles of weight class "w" in the traffic stream (W=1 for compact automobiles and W=2 for standard automobiles);

$P_{RO/C}$ = probability of a rollover (includes mountings) given that a collision has occurred. The values used were presented in Table 37;

$P_{I/BR}$ = probability of an injury accident given that a rollover has occurred before retrofitting (see Table 38);

$P_{I/AR}$ = probability of an injury accident assuming that a rollover has been eliminated after retrofitting (see Table 38);

AC_{BR} = total accident costs before retrofitting (see Table 38);

A_{AR} = total accident costs after retrofitting (see Table 38).

The assumed relationships between rollover accidents, accident severity classification, and total accident costs are shown in Table 38. The SwRI accident data shown earlier in Table 35 and the recent accident data presented by CALTRANS (1) and shown in Table 1 (Section 1) indicate that a low percentage of CMB accidents involve fatals. In Table 38, it was assumed that fatal accidents could range from 0 to 4% before retrofitting, and after retrofitting the fatal accidents were completely eliminated; in other words, all fatal accidents were assumed to be directly related to rollovers. Property-damage-only accidents were assumed as 10% before retrofitting and 80% after retrofitting.

TABLE 38

RELATIONSHIP BETWEEN ROLLOVER ACCIDENTS, ACCIDENT CLASSIFICATION, AND TOTAL ACCIDENT COSTS

Type Collision	Accident Classification[a.]			Total Accident Costs[b.] ($)
	PDO Accidents (%)	Injury Accidents (%)	Fatal Accidents (%)	
Rollovers	10	90	0	5,310
(Before Retrofit)	10	88	2	8,190
	10	86	4	11,080
Rollovers Eliminated (After Retrofit)	80	20	0	1,840

a. Assumed in manner similar to that done in Simulation Study (see Table

b. National Safety Council (provided by Mr. Jim Boos, former FHWA contract manager) --- $150,000 per fatal accident; 5,800 per injury accident; 850 per PDO accident

Using the NSC accident costs provided by Mr. Jim Boos (former FHWA contract manager), the total accident costs for the assumed accident severity classifications are shown in Table 38.

The cost limits to retrofit the New Jersey CMB as computed by use of Eq. 18 are presented in Table 39 for two selected rural and urban interstate highway sites carrying an ADT of 100,000 at various traffic mixes. It is clearly evident that the compact automobile split and fatal accident rate have a significant influence on the cost limits to retrofit for a given ADT. Referring to Eq. 18, it can be seen that the cost limits are a linear function of the ADT. For example, the cost limits in Table 39 would be reduced by a factor of one-half for an ADT of 50,000.

TABLE 39

COST LIMITS TO RETROFIT CMB[a] ($/ft.)

ADT = 100,000

Project Life = 20 yrs.

Interest Rate = 10 %

Type Interstate Highway	Median Width (ft)	Compact Auto Split (%)	Cost Limits ($/ft) Fatal Accidents (%)		
			0	2	4
Rural	30	50	9.42	14.96	20.52
		75	16.61	26.37	36.16
Urban	16	50	5.84	9.27	12.71
		75	11.54	18.32	25.12

a. Accident study analysis assuming retrofit will eliminate all rollovers. Cost limits are linear function of ADT.

COMPARISON
OF
COST-EFFECTIVENESS STRATEGIES

(SECTION 5)

In the previous work, three cost-effectiveness analytical methods were used to compute the cost limits and breakeven traffic volumes for retrofitting the New Jersey CMB. These methods were:

Section 2 --- Cost Limits to Retrofit New Jersey CMB Based on HVOSM Computer Simulations

Section 3 --- Cost Limits to Retrofit New Jersey CMB Based on Assumed Injury Accident Cost Reductions

Section 4 --- Cost Limits to Retrofit New Jersey CMB Based on Eliminating Rollover Injury Accident Costs

The work done in Sections 3 and 4 were based on an analysis of accident data compiled by the NDR (3) and the SwRI (9, 10); whereas, the work done in Section 2 was based on HVOSM computer simulations in which the vertical vehicle accelerations were adjusted (see Eq. 8) to take into consideration the effectiveness of the retrofit unit in suppressing uplift and rollover.

The validation of the computer simulation study in Section 2 was based on a comparison with the results of the accident analysis study in Section 4 assuming a 50% compact automobile split and a fatal accident occurrence of 2%. A comparison of the two studies is shown in Table 40 in terms of "Break-even traffic volumes" for retrofitting the New Jersey CMB. Referring to Table 40, it can be predicted that the retrofit unit would be feasible on (a) an urban highway with a 16 ft. median and carrying a traffic volume greater than 117,000 vpd, and (b) a rural highway with a 30 ft. median and carrying a traffic volume greater than 66,000 vpd.

TABLE 40

COMPARATIVE STUDY OF BREAKEVEN ADT's (1,000 vpd)
FOR RETROFITTING NEW JERSEY CMB

Retrofit Construction Cost = $10 plf
Improvement Project Life = 20 yrs
Compounded Interest Rate = 10 %
Accident Societal Costs = NSC (1979)[a]

Type Interstate Highway	Median Width (ft)	Compact Auto Split (%)	COST - EFFECTIVENESS STUDIES							
			HVOSM Simulations (Section 2)	Accident Analysis (Section 3)				Accident Analysis (Section 4)		
				Based on NDR Accident Data		Based on SwRI Accident Data		Fatal Accidents (%)		
				20% Reduction	40% Reduction	20% Reduction	40% Reduction	0	2	4
Rural	30	50	66	68	34	148	74	106	67	49
		75	59	64	32	120	80	60	38	28
Urban	16	50	117	60	30	140	70	171	108	79
		75	100	56	28	144	72	87	55	40

a. NSC Accident Societal Costs ... PDO = $ 850
Injury = $ 5,800
Fatal = $150,000

The results of the accident analysis study in Section 3 are also shown in Table 40 for comparative purposes. It can be seen that the accident cost reduction factors of 20% and 40% used in that study fairly well bracket the computer simulation study results in Section 2 and the accident analysis study results in Section 4. These findings tend to indicate that effectiveness of the retrofit required to reduce total accident costs will need to be somewhat within the 20% to 40% range. Better insight into the required retrofit unit effectiveness will be provided later in the report by combining the simulation results in Section 2 with the CALTRANS accident analysis study results in Section 1.

CONCLUSIONS

(SECTION 6)

The findings in this feasibility study indicate the proposed design concept for retrofitting the New Jersey CMB (see Figure 1) has the potential of being a cost-effective improvement alternative on divided highways carrying high traffic volumes.

ACCIDENT DATA

Since the imposition of the 55 mph speed limit in 1974, accident data on the CMB in California shows that the fatal + injury accident rates were increasing. Also, the California data showed that 116 (7.7%) of the 1,515 reported accidents in 1978 and 177 (9.9%) of the 1,796 reported accidents in 1979 resulted in vehicle rollovers. In comparison, a summary of accident data presented by the SwRI on the standard New Jersey CMB showed that 7 (4%) of the 180 accidents prior to 1974 resulted in vehicle rollovers and mountings.

Although the number of CMB rollovers by type of vehicle was not reported in the California data, the findings in this study indicate that the increase in rollovers since 1974 is most-likely due to (1) an increase in travel speeds, and (2) an increase in the number of small automobiles in the traffic stream. However, it is certainly reasonable to expect in the near future that the number of small automobilies in the traffic stream will continue to increase. As a result, the number of rollover accidents involving small automobiles will undoubtedly continue to increase because small automobiles have shorter wheel track widths and much lower roll-moments-of-inertia than the larger size standard automobiles. It is predicted that by 1985 the number of rollovers could be as high as 15%.

COST LIMITS TO RETROFIT CMB

Cost limits to retrofit the CMB are shown in Figure 17. The cost limits in this study were expressed as a function of the following variables:

* Rural Interstate Highways
  (Selected Median Width = 30 ft)
* Urban Interstate Highways
  (Selected Median Width = 16 ft)
* Traffic Volumes (ADT in both directions)
* Automobile Weight Distributions in Traffic Stream
  Selected Automobiles---Compact Wt = 2,250 lbs
  ---Standard Wt = 4,500 lbs

For pruposes of illustration, assume that a rural interstate highway with a 30 ft. median is carrying an ADT of 120,000 and that the traffic is comprised of 50% compact automobiles. Referring to Figure 17, it can seen that the CMB retrofit unit has the potential of being cost-effective on the condition that the construction costs of retrofitting do not exceed the cost limit of $18 plf.

BREAKEVEN ADT TRAFFIC VOLUMES

The CMB retrofit unit will be of precast concrete construction and shipped by truck to the job site. It is, therefore, reasonable to assume that the construction costs will remain relatively fixed from job site to job site. For this reason, it is possible to determine the cost-effectiveness of retrofitting in terms of a "breakeven ADT traffic volumes" for a fixed retrofit construction cost.

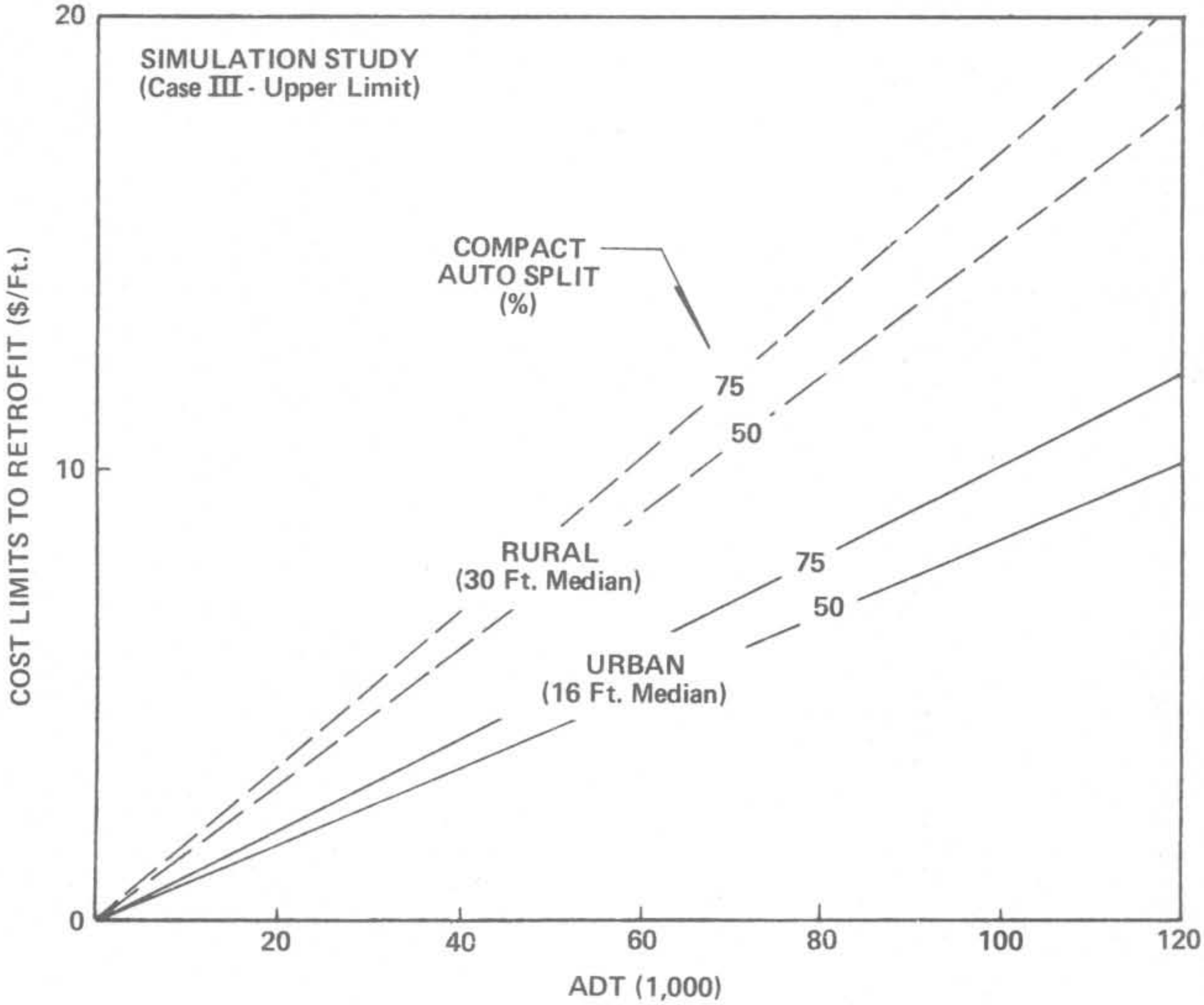


FIGURE 17: COST LIMITS TO RETROFIT NEW JERSEY CMB USING NSC ACCIDENT INJURY COSTS

Design and maintenance engineers from the Nebraska Department of Roads estimate that the CMB retrofit unit can be precast, shipped, and installed in-place for a cost of $10 plf. The breakeven ADT traffic volumes obtained from Figure 17 for a fixed retrofit unit cost of $10 plf are shown in Table 41.

TABLE 41

BREAKEVEN ADT TRAFFIC VOLUMES
Retrofit Unit Cost = $10 plf
Accident Societal Costs = NSC

Type Interstate	Median Width (ft)	Compact Auto Split	
		50%	75%
Urban	16	117,000	100,000
Rural	30	66,000	59,000

Referring to Table 41 and assuming that the traffic stream is comprised of 50% compact automobiles, it can be seen that the CMB retrofit unit has the potential of being cost-effective on (1) urban highway with a 16 ft. median and carrying an ADT of 117,000 and higher, and (2) a rural highway with a 30 ft. median and carrying an ADT of 66,000 vpd and higher.

The lower breakeven ADT's on a rural highway than an urban highway in Table 41 are a reflection of the increased probability of vehicle rollover because of the higher travel speeds on a rural highway.

POTENTIAL EFFECTIVENESS OF CMB RETROFIT UNIT

The effectiveness of the CMB retrofit unit required to reduce total accident costs was determined from an analysis of the accident data provided by CALTRANS (refer to Section 1). The graph of retrofit effectiveness in terms of ADT presented earlier in Figure 2 is presented again in Figure 18. Insight into the actual or potential effectiveness of the retrofit unit was provided by superimposing the breakeven ADT traffic volumes in Table 41 on the curve in Figure 18.

Referring to Figure 18 and assuming that the traffic stream is comprised of 50% compact automobiles, it can be seen that the retrofit unit will be at least (1) 45% effective on a rural highway with a 30 ft. median and carrying an ADT of 66,000 and higher, and (2) 25% effective on an urban highway with a 16 ft. median and carrying an ADT of 117,000 and higher.

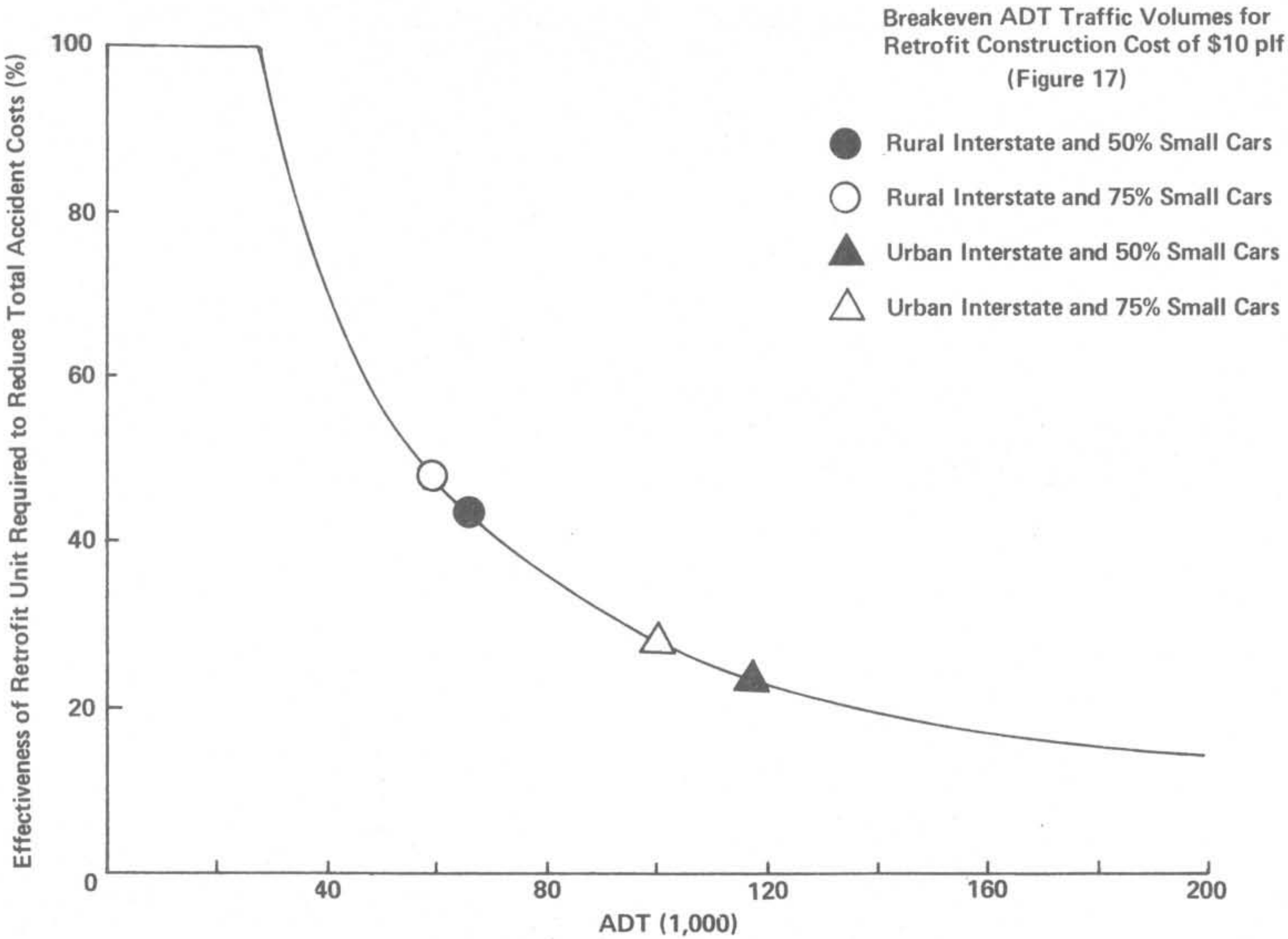


FIGURE 18: POTENTIAL EFFECTIVENESS OF CMB RETROFIT UNIT

RECOMMENDATIONS

(SECTION 7)

The findings in this feasibility study have been based on the assumption that the reverse sloped surfaces of the CMB retrofit unit would be effective in suppressing vehicle uplift and rollover under impact angles greater than 10 deg.

It is recommended that the effectiveness of the retrofit unit be confirmed by conducting a limited number of full-scale vehicle crash tests. Also, it is recommended that the California accident records for the years of 1978 and 1979, in which 293 (8.8%) rollovers occurred out of a total of 3,311 reported accidents on the CMB, be reviewed manually to aid in the selection of the test vehicles and the impact speed-angle conditions.

A detailed work plan and schedule was submitted on May 19, 1980 for review and approval for the continuation of this study to conduct full-scale vehicle crash tests. A copy of the work plan and schedule is presented in Appendix C.

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APPENDIX A

HVOSM SIMULATION OF IMPACT ON NEW JERSEY CMB

1971 Chevrolet Vega

60 mph

15 deg

```
  UNL-FHWA NEW JERSEY CMB STUDY.  60 MPH / 15.0 DEG  (RUN NO. 18)            0 100
0.0     1.00    .005    .01     70.     0.0     0.0                          0 101
0.0     1.0     5.0     .001    1.0     0.001                                0 102
1.0                                                                          0 103
        1.0     1.0     1.0                                                  0 104
  1971 CHEVROLET VEGA (2450 LB)                                              0 200
5.3370  0.4240  0.5760  2640.0  14400.0 14400.0 -100.0  250.0                0 201
43.87   53.13   55.10   54.10   1.31    38.00                                0 202
0.0     9.0     8.0     0.0     -9.0    8.0     6.56    7.21                 0 203
96.00   300.0   2.0     300.0   2.0     0.50    -2.2    3.84                 0 204
121.0   300.0   2.0     300.0   2.0     0.50    -2.2    4.85                 0 205
2.0     37.0    0.001   2.0     58.0    0.001                                0 206
0.0     11690.0 -0.01                                                        0 207
300.0   1000.0  0.614   5000.0  0.010   1.5                                  0 208
-5.0    5.0     1.0                                                          0 209
-6.8    -4.75   -3.08   -1.75   -0.73   0.0     0.48    0.65    0.78         1 209
0.83    0.85                                                                 2 209
-5.0    5.0     0.5                                                          0 210
                                                                             1 210
                                                                             2 210
                                                                             3 210
-5.0    5.0     5.0                                                          0 211
                                                                             1 211
73.87   -96.13  32.70   -12.50  8.50    4.0                                  0 212
47.40   -47.50  65.20   28.0    28.0    21.0                                 0 213
14.45   17.00   0.00    2500.0  2500.0  2500.0                               0 214
  TIRE  INPUT  DATA                                                          0 300
1.0     1.0     1.0     1.0     6.0     .25                                  0 301
1240.0  6.0     10.0    3625.0  7.711   2344.0  1.55    5500.0  0.750        1 301
0.70                            11.83                                        0 302
  NJ CMB (FULL CURB + BARRIER)                                               0 500
590.0   600.00  600.052 607.054 609.054         0.50                         0 507
0.00    -3.0    -13.0   -32.00                                               0 508
0.0     -89.00  -55.00  -83.66  0.0                                          0 509
609.054 -32.00  0.0     0.50    0.30    1.0     500.0   0.001   1.0          0 510
0.0     50000.0                                                              0 511
  IMPACT CONDITIONS  60.0 MPH / 15.0 DEG                                     0 600
0.0     0.0     15.0    0.0     0.0     0.0     0.0     0.0                  0 601
160.0   500.0   -20.42  1056.0                                               0 602
                                                                             09999
```

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   UNL-FHWA NEW JERSEY CMB STUDY.  60 MPH / 15.0 DEG  (RUN NO. 18)                              APRIL
1971 CHEVROLET VEGA (2450 LB)             TIRE  INPUT  DATA
NJ CMB (FULL CURB + BARRIER)              IMPACT CONDITIONS  60.0 MPH / 15.0 DEG


                  P R O G R A M   C O N T R O L   D A T A
   START TIME                       T0      =    0.0     SEC
   END TIME                         T1      =    1.0000  SEC
   INTEGRATION INCREMENT            DTCOMP  =    0.0050  SEC
                                                          (0=VARIABLE STEP ADAMS-MOULTON
   INTEGRATION MODE                 MODE    =    1       -) 1= RUNGA-KUTTA
                                                          (2= FIXED STEP ADAMS-MOULTON
   PRINT INTERVAL                   DTPRNT  =    0.0100  SEC
                                                          (0= INDEPENDENT FRONT SUSPENSION, SOLID REAR AXLE
   SUSPENSION OPTION                ISUS    =    0       -) 1= INDEPENDENT FRONT AND REAR SUSPENSION
                                                          (2= SOLID FRONT AND REAR AXLES
                                                          (0= NO CURB, NO STEER DEGREE OF FREEDOM
   CURB/STEER OPTION                INDCRB  =    1       -) 1= CURB
                                                          (-1=STEER DEGREE OF FREEDOM, NO CURB
   CURB INTEGRATION INCR.           DELTC   =   0.00100  SEC
                                                          (0= NO BARRIER
                                                          | 1= RIGID BARRIER , FINITE VERT. DIM.
   BARRIER OPTION                   INDB    =    1       -) 2=  ''     ''   ,INFINITE  ''    ''
                                                          | 3= DEFORM. ''    , FINITE  ''    ''
                                                          (4=   ''     ''   ,INFINITE  ''    ''
   BARRIER INTEGRATION INCR.        DELTB   =   0.00100  SEC


                                           I N I T I A L   C O N D I T I O N S

                                    XCOP    =   160.00   INCHES                                          U0     = 1056.00  IN/SEC
   SPRUNG MASS C.G. POSITION        YCOP    =   500.00   INCHES       SPRUNG MASS LINEAR VELOCITY        V0     =    0.0   IN/SEC
                                    ZCOP    =   -20.42   INCHES                                          W0     =    0.0   IN/SEC
                                    PHI0    =    0.0     DEGREES                                         P0     =    0.0   DEG/SEC
   SPRUNG MASS ORIENTATION          THETA0  =    0.0     DEGREES      SPRUNG MASS ANGULAR VELOCITY       Q0     =    0.0   DEG/SEC
                                    PSI0    =   15.00    DEGREES                                         R0     =    0.0   DEG/SEC

                                    DEL10   =    0.0     INCHES                                          DEL10D =    0.0   IN/SEC
   UNSPRUNG MASS POSITIONS          DEL20   =    0.0     INCHES       UNSPRUNG MASS VELOCITIES           DEL20D =    0.0   IN/SEC
                                    DEL30   =    0.0     INCHES                                          DEL30D =    0.0   IN/SEC
                                    PHIR0   =    0.0     DEGREES                                         PHIR0D =    0.0   DEG/SEC
   STEER ANGLE                      PSIFI0  =    0.0     DEGREES      STEER VELOCITY                     PSIFD0 =    0.0   DEG/SEC
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UNL-FHWA NEW JERSEY CMB STUDY. 60 MPH / 15.0 DEG (RUN NO. 18) APRIL
1971 CHEVROLET VEGA (2450 LB) TIRE INPUT DATA
NJ CMB (FULL CURB + BARRIER) IMPACT CONDITIONS 60.0 MPH / 15.0 DEG

SPRUNG MASS	XMS	=	5.337	LB-SEC**2/IN	FRONT WHEEL X LOCATION	A	=	43.870	INCHES
FRONT UNSPRUNG MASS	XMUF	=	0.424	LB-SEC**2/IN	REAR WHEEL X LOCATION	B	=	53.130	INCHES
REAR UNSPRUNG MASS	XMUR	=	0.576	LB-SEC**2/IN	FRONT WHEEL Z LOCATION	ZF	=	8.580	INCHES
X MOMENT OF INERTIA	XIX	=	2640.000	LB-SEC**2-IN	REAR WHEEL Z LOCATION	ZR	=	7.210	INCHES
Y MOMENT OF INERTIA	XIY	=	14400.000	LB-SEC**2-IN	FRONT WHEEL TRACK	TF	=	55.100	INCHES
Z MOMENT OF INERTIA	XIZ	=	14400.000	LB-SEC**2-IN	REAR WHEEL TRACK	TR	=	54.100	INCHES
XZ PRODUCT OF INERTIA	XIXZ	=	-100.000	LB-SEC**2-IN	FRONT ROLL AXIS	RHOF	=	0.0	NOT USED
FRONT AXLE MOMENT OF INERTIA	XIF	=	0.0	NOT USED	REAR ROLL AXIS	RHO	=	1.310	INCHES
REAR AXLE MOMENT OF INERTIA	XIR	=	250.000	LB-SEC**2-IN	FRONT SPRING TRACK	TSF	=	0.0	NOT USED
GRAVITY	G	=	386.400	IN/SEC**2	REAR SPRING TRACK	TS	=	38.000	INCHES
	X1	=	0.0	INCHES	FRONT AUX ROLL STIFFNESS	RF	=	0.0	LB-IN/RAD
ACCELEROMETER 1 POSITION	Y1	=	9.00	INCHES	REAR AUX ROLL STIFFNESS	RR	=	11690.00	LB-IN/RAD
	Z1	=	8.00	INCHES	REAR ROLL-STEER COEF.	AKRS	=	-0.0100	RAD/RAD
	X2	=	0.0	INCHES		AKDS	=	0.0	NOT USED
ACCELEROMETER 2 POSITION	Y2	=	-9.00	INCHES	REAR DEFL-STEER COEFS.	AKDS1	=	0.0	NOT USED
	Z2	=	8.00	INCHES		AKDS2	=	0.0	NOT USED
						AKDS3	=	0.0	NOT USED

S T E E R I N G   S Y S T E M

MOMENT OF INERTIA	XIPS	=	300.000	LB-SEC**2-IN
COULOMB FRICTION TORQUE	CPSP	=	1000.000	LB-IN
FRICTION LAG	EPSP	=	0.010	RAD/SEC
ANGULAR STOP RATE	AKPS	=	5000.000	LB-IN/RAD
ANGULAR STOP POSITION	OMGPS	=	0.614	RADIANS
PNEUMATIC TRAIL	XPS	=	1.500	INCHES

	FRONT SUSPENSION				REAR SUSPENSION			
SUSPENSION RATE	AKF	=	96.000	LB/IN	AKR	=	121.000	LB/IN
COMPRESSION STOP COEFS.	AKFC	=	300.000	LB/IN	AKRC	=	300.000	LB/IN
	AKFCP	=	2.000	LB/IN**3	AKRCP	=	2.000	LB/IN**3
EXTENSION STOP COEFS.	AKFE	=	300.000	LB/IN	AKRE	=	300.000	LB/IN
	AKFEP	=	2.000	LB/IN**3	AKREP	=	2.000	LB/IN**3
COMPRESSION STOP LOCATION	OMEGFC	=	-2.200	INCHES	OMEGRC	=	-2.200	INCHES
EXTENSION STOP LOCATION	OMEGFE	=	3.840	INCHES	OMEGRE	=	4.850	INCHES
STOP ENERGY DISSIPATION FACTOR	XLAMF	=	0.500		XLAMR	=	0.500	
VISCOUS DAMPING COEF.	CF	=	2.000	LB-SEC/IN	CR	=	2.000	LB-SEC/IN
COULOMB FRICTION	CFP	=	37.000	LB	CRP	=	58.000	LB
FRICTION LAG	EPSF	=	0.001	IN/SEC	EPSR	=	0.001	IN/SEC

C U R B   D A T A

CURB SLOPE CHANGE LATERAL POSITION INCHES		ELEVATION AT SLOPE CHANGE INCHES		CURB FACE ANGLE DEGREES	
YC1P =	590.00			PHIC1 =	0.0
YC2P =	600.00	ZC2P =	0.0	PHIC2 =	-89.00
YC3P =	600.05	ZC3P =	-3.00	PHIC3 =	-55.00
YC4P =	607.05	ZC4P =	-13.00	PHIC4 =	-83.66
YC5P =	609.05	ZC5P =	-32.00	PHIC5 =	0.0
YC6P =	0.0	ZC6P =	0.0	PHIC6 =	0.0

NCRBSL = 5
CURB FRICTION COEFFICIENT FACTOR AMUC = 0.500

WHEEL RADIUS-RADIAL SPRING FOR TABLE
RWHJB(BEGIN) = 0.0 INCHES
RWHJE(END) = 6.000 ''
DRWHJ(INCRE.) = 0.250 ''

RW-HJ IN.	FJP. LBS. RF	FJP. LBS. LF	FJP. LBS. RR	FJP. LBS. LR
0.0	0.0	0.0	0.0	0.0
0.250	80.5	80.5	80.5	80.5
0.500	90.0	90.0	90.0	90.0
0.750	122.	122.	122.	122.
1.00	135.	135.	135.	135.
1.25	145.	145.	145.	145.
1.50	171.	171.	171.	171.
1.75	182.	182.	182.	182.
2.00	182.	182.	182.	182.
2.25	221.	221.	221.	221.
2.50	201.	201.	201.	201.
2.75	241.	241.	241.	241.
3.00	223.	223.	223.	223.
3.25	261.	261.	261.	261.
3.50	244.	244.	244.	244.
3.75	27[illegible].	274.	274.	274.
4.00	274.	274.	274.	274.
4.25	290.	290.	290.	290.
4.50	287.	287.	287.	287.
4.75	312.	312.	312.	312.
5.00	303.	303.	303.	303.
5.25	325.	325.	325.	325.
5.50	328.	328.	328.	328.
5.75	334.	334.	334.	334.
6.00	341.	341.	341.	341.

(YB')0 =	609.054 INCHES	KV	=	4.000 LB/IN**3	SIGMAR 0	=	0.0
DELYB' =	0.500 ''	SET	=	0.001 DEFL. RATIO	SIGMAR 1	=	50000.0000
ZBT' =	-32.000 ''	CONS	=	1.000 ENERGY RATIO	SIGMAR 2	=	0.0
ZBB' =	0.0 ''	MUB	=	0.300	SIGMAR 3	=	0.0
VEHICLE DIMENSIONS		EPSILON V =		1.000 IN/SEC	SIGMAR 4	=	0.0

1971 CHEVROLET VEGA (2450 LB) TIRE INPUT DATA
NJ CMB (FULL CURB + BARRIER) IMPACT CONDITIONS 60.0 MPH / 15.0 DEG

T I R E D A T A

			RF	LF	RR	LR	
TIRE LINEAR SPRING RATE	AKT	=	1240.000	1240.000	1240.000	1240.000	LB/IN
DEFL. FOR INCREASED RATE	SIGT	=	6.000	6.000	6.000	6.000	INCHES
SPRING RATE INCREASING FACTOR	XLAMT	=	10.000	10.000	10.000	10.000	
	A0	=	3625.000	3625.000	3625.000	3625.000	
	A1	=	7.711	7.711	7.711	7.711	
SIDE FORCE COEFFICIENTS	A2	=	2344.000	2344.000	2344.000	2344.000	
	A3	=	1.550	1.550	1.550	1.550	
	A4	=	5500.000	5500.000	5500.000	5500.000	
TIRE OVERLOAD FACTOR	OMEGT	=	0.750	0.750	0.750	0.750	
TIRE UNDEFLECTED RADIUS	RW	=	11.830	11.830	11.830	11.830	INCHES
TIRE / GROUND FRICTION COEF.	AMU	=	0.700	0.700	0.700	0.700	

ANTI-PITCH TABLES FOR CIRCUMFERENTIAL TIRE FORCE

FRONT WHEEL DEFL. - IN.	APF LB/LB-FT	REAR WHEEL DEFL. - IN.	APR LB/LB-FT
-5.0000	0.0	-5.0000	0.0
-4.5000	0.0	0.0	0.0
-4.0000	0.0	5.0000	0.0
-3.5000	0.0		
-3.0000	0.0		
-2.5000	0.0		
-2.0000	0.0		
-1.5000	0.0		
-1.0000	0.0		
-0.5000	0.0		
0.0	0.0		
0.5000	0.0		
1.0000	0.0		
1.5000	0.0		
2.0000	0.0		
2.5000	0.0		
3.0000	0.0		
3.5000	0.0		
4.0000	0.0		
4.5000	0.0		
5.0000	0.0		

XVF	=	73.870 INCHES	EPSILON B =	500.000 LB	SIGMAR 5 = 0.0
XVR	=	-96.130 ''			SIGMAR 6 = 0.0
YV	=	32.700 ''			SIGMAR 7 = 0.0
ZVT	=	-12.500 ''			SIGMAR 8 = 0.0
ZVB	=	8.500 ''			SIGMAR 9 = 0.0
					SIGMAR10 = 0.0

SPRUNG MASS HARD POINT DATA

	LOCATION IN VEH. COORDS.			STIFFNESS
POINT NO.	XSTIO IN.	YSTIO IN.	ZSTIO IN.	AKST LB/IN
1	47.40	28.00	14.45	2500.00
2	-47.50	28.00	17.00	2500.00
3	65.20	21.00	0.0	2500.00

UNL-FHWA NEW JERSEY CMB STUDY. 60 MPH / 15.0 DEG (RUN NO. 18) APRIL
1971 CHEVROLET VEGA (2450 LB) TIRE INPUT DATA
NJ CMB (FULL CURB + BARRIER) IMPACT CONDITIONS 60.0 MPH / 15.0 DEG

FRONT WHEEL CAMBER VS SUSPENSION DEFLECTION		REAR WHEEL CAMBER VS SUSPENSION DEFLECTION		FRONT HALF-TRACK CHANGE VS SUSPENSION DEFLECTION		REAR HALF-TRACK CHANGE VS SUSPENSION DEFLECTION	
DELTAF INCHES	PHIC DEGREES	DELTAR NOT USED	PHIRC NOT USED	DELTAF INCHES	DTHF INCHES	DELTAR NOT USED	DTHR NOT USED
-5.00	-6.80	-5.00	0.0	-5.00	0.0	-5.00	0.0
-4.00	-4.75	-4.00	0.0	-4.00	0.0	-4.00	0.0
-3.00	-3.08	-3.00	0.0	-3.00	0.0	-3.00	0.0
-2.00	-1.75	-2.00	0.0	-2.00	0.0	-2.00	0.0
-1.00	-0.73	-1.00	0.0	-1.00	0.0	-1.00	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.48	1.00	0.0	1.00	0.0	1.00	0.0
2.00	0.65	2.00	0.0	2.00	0.0	2.00	0.0
3.00	0.78	3.00	0.0	3.00	0.0	3.00	0.0
4.00	0.83	4.00	0.0	4.00	0.0	4.00	0.0
5.00	0.85	5.00	0.0	5.00	0.0	5.00	0.0

UNL-FHWA NEW JERSEY CMB STUDY. 60 MPH / 15.0 DEG (RUN NO. 18)

971 CHEVROLET VEGA (2450 LB) TIRE INPUT DATA

J CMB (FULL CURB + BARRIER) IMPACT CONDITIONS 60.0 MPH / 15.0 DEG

TIME	POSITION (FEET)			SPRUNG MASS VELOCITY (FT/SEC)			ACCI
SEC	XC'	YC'	ZC'	FORWARD	LATERAL	VERTICAL	LONG.
0.0	13.33	41.67	-1.70	88.00	0.0	0.0	0.00
0.010	14.18	41.89	-1.70	88.00	-0.00	0.04	-0.00
0.020	15.03	42.12	-1.70	88.00	0.00	0.12	-0.00
0.030	15.88	42.35	-1.70	88.00	0.00	0.23	-0.00
0.040	16.73	42.58	-1.70	88.00	0.00	0.32	-0.00
0.050	17.58	42.81	-1.69	88.00	0.00	0.36	-0.00
0.060	18.43	43.03	-1.69	88.00	0.00	0.36	-0.00
0.070	19.28	43.26	-1.69	88.00	0.00	0.35	0.00
0.080	20.13	43.49	-1.68	88.00	0.00	0.33	0.00
0.090	20.98	43.72	-1.68	88.00	0.00	0.33	0.00
0.100	21.83	43.94	-1.68	88.00	0.00	0.36	-0.00
0.110	22.68	44.17	-1.68	88.00	0.00	0.41	-0.00
0.120	23.53	44.40	-1.67	88.00	0.00	0.45	-0.00
0.130	24.38	44.63	-1.67	88.00	0.00	0.48	-0.00
0.140	25.23	44.86	-1.66	88.00	0.00	0.46	0.00
0.150	26.08	45.08	-1.66	88.00	0.00	0.44	0.00
0.160	26.93	45.31	-1.66	88.00	-0.00	0.42	0.00
0.170	27.78	45.54	-1.66	88.00	-0.00	0.40	0.00
0.180	28.63	45.77	-1.65	88.00	-0.00	0.38	0.00
0.190	29.48	45.99	-1.65	88.00	-0.00	0.35	0.02
0.200	30.33	46.22	-1.65	88.00	0.00	0.33	0.00
0.210	31.18	46.45	-1.65	88.00	0.00	0.32	0.00
0.220	32.03	46.68	-1.64	88.00	-0.00	0.32	-0.25
0.230	32.88	46.90	-1.64	87.60	-0.64	0.29	-2.09
0.240	33.73	47.11	-1.64	86.79	-2.47	0.11	-3.00
0.250	34.57	47.29	-1.64	85.70	-4.65	-0.38	-4.11
0.260	35.41	47.44	-1.65	84.18	-7.94	-1.40	-5.83
0.270	36.25	47.53	-1.68	82.95	-11.04	-2.53	-5.06
0.280	37.08	47.58	-1.71	82.94	-9.73	-2.81	-0.33
0.290	37.92	47.63	-1.75	83.16	-7.27	-2.57	-0.24
0.300	38.75	47.67	-1.80	83.32	-4.77	-2.15	-0.18
0.300	39.58	47.71	-1.84	83.40	-2.16	-1.52	-0.14
0.300	40.41	47.74	-1.88	83.39	0.63	-0.70	-0.19
0.300	41.25	47.77	-1.93	83.27	3.13	0.29	0.02
0.300	42.08	47.79	-1.97	83.20	4.13	1.24	0.25
0.300	42.91	47.79	-2.01	83.09	4.23	2.03	-0.12
0.300	43.74	47.77	-2.05	82.86	3.60	2.47	-0.66
0.300	44.57	47.72	-2.09	82.68	2.13	2.41	-0.24
0.300	45.39	47.66	-2.13	82.68	1.62	1.98	0.10
0.300	46.21	47.59	-2.18	82.67	1.97	1.81	-0.03
0.400	47.03	47.52	-2.24	82.65	2.36	1.70	-0.03
0.400	47.86	47.44	-2.29	82.64	2.72	1.59	-0.01
0.400	48.68	47.37	-2.34	82.62	3.05	1.59	-0.01
0.400	49.50	47.30	-2.39	82.60	3.38	1.69	-0.01
0.400	50.32	47.23	-2.43	82.61	3.62	1.84	0.13
0.400	51.15	47.15	-2.47	82.66	3.72	2.03	0.20
0.400	51.97	47.07	-2.51	82.71	3.70	2.30	0.14
0.400	52.79	46.99	-2.54	82.72	3.69	2.54	-0.01
0.400	53.62	46.91	-2.57	82.70	3.84	2.76	-0.07
0.400	54.44	46.83	-2.59	82.67	4.00	2.96	-0.06

TIME	SPRUNG MASS ANGULAR VELOCITIES (DEG/SEC)			SPRUNG MASS ORIENTATION (DEGREES)			SIDESLIP ANGLE	COURSE ANGLE	FRONT STEER ANGLE	REAR STEER ANGLE
SEC	P	Q	R	ROLL	PITCH	YAW	DEG	DEG	DEG	DEG
0.0	0.0	0.0	0.0	0.0	0.0	15.00	-0.00	15.00	0.0	0.0
0.0100	-0.00	0.08	0.00	-0.00	0.00	15.00	-0.00	15.00	0.0	-0.00
0.0200	-0.00	0.18	-0.00	-0.00	0.00	15.00	-0.00	15.00	0.0	-0.00
0.0300	-0.00	0.33	-0.00	-0.00	0.00	15.00	-0.00	15.00	0.0	-0.00
0.0400	-0.00	0.61	-0.00	-0.00	0.01	15.00	-0.00	15.00	0.0	-0.00
0.0500	-0.00	0.91	-0.00	-0.00	0.02	15.00	-0.00	15.00	0.0	-0.00
0.0600	-0.00	1.00	-0.00	-0.00	0.03	15.00	-0.00	15.00	0.0	-0.00
0.0700	-0.00	1.01	-0.00	-0.00	0.04	15.00	-0.00	15.00	0.0	-0.00
0.0800	-0.00	0.89	-0.00	-0.00	0.05	15.00	-0.00	15.00	0.0	-0.00
0.0900	-0.00	0.40	-0.00	-0.00	0.05	15.00	-0.00	15.00	0.0	-0.00
0.1000	-0.00	0.08	-0.00	-0.00	0.05	15.00	-0.00	15.00	0.0	-0.00
0.1100	-0.00	0.09	-0.00	-0.00	0.06	15.00	-0.00	15.00	0.0	-0.00
0.1200	-0.00	0.28	-0.00	-0.00	0.06	15.00	-0.00	15.00	0.0	-0.00
0.1300	-0.00	0.69	-0.00	-0.00	0.06	15.00	-0.00	15.00	0.0	-0.00
0.1400	-0.00	0.69	-0.00	-0.00	0.07	15.00	-0.00	15.00	0.0	-0.00
0.1500	-0.00	0.65	-0.00	-0.00	0.08	15.00	-0.00	15.00	0.0	-0.00
0.1600	-0.01	0.56	-0.00	-0.00	0.08	15.00	-0.00	15.00	0.00	-0.00
0.1700	-0.23	0.32	-0.00	-0.00	0.09	15.00	-0.00	15.00	0.00	-0.00
0.1800	-0.25	-0.15	-0.00	-0.00	0.09	15.00	-0.00	15.00	0.00	-0.00
0.1900	-0.15	-0.50	-0.01	-0.01	0.08	15.00	-0.00	15.00	0.00	-0.00
0.2000	0.41	-0.84	-0.03	-0.00	0.08	15.00	0.00	15.00	0.00	-0.00
0.2100	1.33	-1.09	-0.04	0.00	0.07	15.00	0.00	15.00	0.00	-0.00
0.2200	2.64	-1.56	-0.23	0.02	0.05	15.00	-0.00	15.00	0.00	-0.00
0.2300	14.06	-2.88	-7.87	0.09	0.03	14.97	-0.42	14.55	-0.09	0.00
0.2400	37.12	-2.81	-33.10	0.35	0.00	14.78	-1.63	13.15	-0.41	0.00
0.2500	39.61	1.84	-67.75	0.76	-0.00	14.28	-3.10	11.18	-0.84	0.01
0.2600	7.47	14.41	-121.04	1.03	0.08	13.39	-5.37	8.02	-1.54	0.01
0.2700	-38.04	31.02	-181.33	0.85	0.34	11.86	-7.55	4.31	-3.66	0.01
0.2800	-56.95	39.92	-195.76	0.34	0.72	9.95	-6.69	3.26	-6.76	0.00
0.2900	-65.28	44.78	-198.36	-0.31	1.15	7.98	-5.01	2.97	-9.90	-0.00
0.3000	-68.49	48.99	-201.75	-1.03	1.59	5.97	-3.31	2.67	-12.93	-0.01
0.3100	-67.77	52.40	-204.54	-1.78	2.05	3.93	-1.52	2.41	-15.82	-0.02
0.3200	-65.67	54.80	-205.50	-2.53	2.51	1.86	0.41	2.26	-18.57	-0.04
0.3300	-59.19	56.39	-199.35	-3.27	2.96	-0.22	2.16	1.95	-21.25	-0.05
0.3400	-40.86	56.23	-174.56	-3.87	3.41	-2.13	2.90	0.77	-23.91	-0.04
0.3500	-30.78	52.33	-138.82	-4.32	3.84	-3.74	3.02	-0.73	-26.54	-0.00
0.3600	-39.92	42.95	-95.27	-4.74	4.23	-4.95	2.62	-2.33	-29.16	0.06
0.3700	-59.06	27.84	-49.21	-5.30	4.53	-5.71	1.62	-4.08	-31.76	0.11
0.3800	-75.90	10.59	-33.01	-6.01	4.68	-6.10	1.27	-4.83	-34.34	0.12
0.3900	-82.17	-1.69	-32.48	-6.83	4.68	-6.43	1.51	-4.92	-36.90	0.12
0.4000	-84.34	-11.07	-32.44	-7.69	4.58	-6.74	1.78	-4.96	-39.43	0.11
0.4100	-86.36	-16.30	-31.97	-8.57	4.39	-7.04	2.03	-5.01	-41.95	0.08
0.4200	-84.89	-18.60	-31.21	-9.45	4.17	-7.33	2.27	-5.06	-44.43	0.05
0.4300	-81.13	-18.63	-30.50	-10.30	3.93	-7.60	2.52	-5.08	-46.87	0.01
0.4400	-76.40	-17.39	-29.00	-11.10	3.70	-7.86	2.71	-5.15	-49.28	-0.03
0.4500	-70.40	-15.16	-26.17	-11.86	3.48	-8.10	2.81	-5.29	-51.65	-0.06
0.4600	-62.62	-11.84	-22.32	-12.53	3.30	-8.31	2.85	-5.46	-53.97	-0.08
0.4700	-57.84	-9.52	-19.30	-13.14	3.15	-8.49	2.89	-5.60	-56.23	-0.07
0.4800	-57.62	-8.36	-18.97	-13.72	3.02	-8.65	3.03	-5.62	-58.45	-0.07
0.4900	-58.71	-7.62	-19.02	-14.31	2.90	-8.82	3.19	-5.63	-60.60	-0.05

TIME SEC	TIRE CONTACT POINT ELEVATION (INCHES) RF	LF	RR	LR
0.5000	-8.74	0.0	-6.52	0.0
0.5100	-8.74	0.0	-6.52	0.0
0.5200	-8.74	0.0	-6.52	0.0
0.5300	-8.74	0.0	-6.52	0.0
0.5400	-8.74	0.0	-6.52	0.0
0.5500	-8.74	0.0	-6.52	0.0
0.5600	0.0	0.0	-6.52	0.0
0.5700	0.0	0.0	-6.52	0.0
0.5800	0.0	0.0	-6.52	0.0
0.5900	0.0	0.0	-6.52	0.0
0.6000	0.0	0.0	-6.52	0.0
0.6100	0.0	0.0	-6.52	0.0
0.6200	0.0	0.0	-6.52	0.0
0.6300	0.0	0.0	-6.52	0.0
0.6400	0.0	0.0	-6.52	0.0
0.6500	0.0	0.0	-6.52	0.0
0.6600	0.0	0.0	-6.52	0.0
0.6700	0.0	0.0	-6.52	0.0
0.6800	0.0	0.0	-6.52	0.0
0.6900	0.0	0.0	-6.52	0.0
0.7000	0.0	0.0	-6.52	0.0
0.7100	0.0	0.0	-6.52	0.0
0.7200	0.0	0.0	-6.52	0.0
0.7300	0.0	0.0	-6.52	0.0
0.7400	0.0	0.0	-6.52	0.0
0.7500	0.0	0.0	0.0	0.0
0.7600	0.0	0.0	0.0	0.0
0.7700	0.0	0.0	0.0	0.0
0.7800	0.0	0.0	0.0	0.0
0.7900	0.0	0.0	0.0	0.0
0.8000	0.0	0.0	0.0	0.0
0.8100	0.0	0.0	0.0	0.0
0.8200	0.0	0.0	0.0	0.0
0.8300	0.0	0.0	0.0	0.0
0.8400	0.0	0.0	0.0	0.0
0.8500	0.0	0.0	0.0	0.0
0.8600	0.0	0.0	0.0	0.0
0.8700	0.0	0.0	0.0	0.0
0.8800	0.0	0.0	0.0	0.0
0.8900	0.0	0.0	0.0	0.0
0.9000	0.0	0.0	0.0	0.0
0.9100	0.0	0.0	0.0	0.0
0.9200	0.0	0.0	0.0	0.0
0.9300	0.0	0.0	0.0	0.0
0.9400	0.0	0.0	0.0	0.0
0.9500	0.0	0.0	0.0	0.0
0.9600	0.0	0.0	0.0	0.0
0.9700	0.0	0.0	0.0	0.0
0.9800	0.0	0.0	0.0	0.0
0.9900	0.0	0.0	0.0	0.0

TIME SEC	INTERFACE AREA IN**2	VEHICLE DEFORMATION INCHES	NORMAL FORCE LBS	FRICTION FORCE LBS	BARRIER DEFLECTION INCHES	POSITION OF APPLIED LOAD XR INCHES	YR INCHES	ZR INCHES
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2200	147.35	1.78	534.20	160.26	0.0	71.48	31.50	-1.86
0.2300	371.34	4.47	3311.31	993.39	0.0	67.75	29.72	-1.92
0.2400	575.86	6.83	7807.96	2342.39	0.0	64.47	28.18	-2.05
0.2500	739.51	8.55	12455.00	3736.50	0.0	61.81	27.08	-2.09
0.2600	856.14	9.36	15729.43	4718.83	0.0	59.95	26.57	-2.09
0.2700	867.50	8.65	14760.44	4428.13	0.0	59.46	27.03	-1.82
0.2800	862.25	6.95	0.0	0.0	0.0	429420.50	196220.56	-12795.98
0.2900	862.25	5.18	0.0	0.0	0.0	429420.50	196220.56	-12795.98
0.3000	862.25	3.35	0.0	0.0	0.0	429420.50	196220.56	-12795.98
0.3100	862.25	1.36	0.0	0.0	0.0	429420.50	196220.56	-12795.98
0.3200	862.25	0.0	0.0	0.0	0.0	429420.50	196220.56	-12795.98
0.3300	862.25	0.0	0.0	0.0	0.0	429420.50	196220.56	-12795.98
0.3400	282.19	1.17	478.12	143.44	0.0	-88.87	32.07	4.37
0.3500	944.59	3.87	6210.59	1863.18	0.0	-79.63	30.50	0.07
0.3600	1069.96	5.59	10373.19	3111.96	0.0	-77.03	29.42	-0.51
0.3700	367.91	6.30	6631.50	1989.45	0.0	-84.49	28.21	0.34
0.3800	1013.08	6.20	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.3900	1013.08	5.95	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4000	1013.08	5.67	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4100	1013.08	5.35	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4200	1013.08	4.99	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4300	1013.08	4.59	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4400	1013.08	4.16	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4500	1013.08	3.67	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4600	1013.08	3.09	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4700	1013.08	2.43	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4800	1013.08	1.73	0.0	0.0	0.0	-449644.44	166697.31	-1041.95
0.4900	1013.08	1.02	0.0	0.0	0.0	-449644.44	166697.31	-1041.95

APPENDIX B

COST-EFFECTIVENESS COMPUTER PROGRAM

```
$JOB            PAGES=400,TIME=40
C
C           ******************************************************************
C           *                                                                *
C           *          C O S T - E F F E C T I V E N E S S                   *
C           *                          O F                                   *
C           *                R E T R O F I T T I N G                         *
C           *                  N E W   J E R S E Y                           *
C           *     C O N C R E T E   M E D I A N   B A R R I E R              *
C           *                                                                *
C           *                          BY                                    *
C           *                                                                *
C           *                DR. EDWARD R. POST, P.E.                        *
C           *                (PRINCIPAL INVESTIGATOR)                        *
C           *                          AND                                   *
C           *                MR. PATRICK A. CHASTAIN                         *
C           *                  (RESEARCH ASSISTANT)                          *
C           *                                                                *
C           *              TASK 1 ... CONDUCT C/E STUDY                      *
C           *                                                                *
C           *                     DOT-RC-92021                               *
C           *                    UNL-87-140-222                              *
C           *                                                                *
C           *              CIVIL ENGINEERING DEPARTMENT                      *
C           *             UNIVERSITY OF NEBRASKA-LINCOLN                     *
C           *                                                                *
C           *                                                                *
C           ******************************************************************
C
      DIMENSION SI(2,3,5,5),PI(2,3,5,5),AC(2,3,5,5),IP(2,5,5),HI(3,10),
     *IC(3,10),EFFET1(10),EFFET2(10),BENEF1(10),BENEF2(10),ANG(5),E(10),
     *W(2),S(2),P(5),ADT(10),ROLL(2,3,5,5),GLONG(2,3,5,5),GLAT(2,3,5,5),
     *GVERT(2,3,5,5),B1(2,10),B2(2,10)
C
C
      REAL IP,IC,INT
C
C
C  OUTPUT TABLE NUMBER
C
      ITABLE = 1
C
      DO 1010 LOOP = 1,5
      DO 1005  INJ = 1,3
C
C  HIGHWAY CLASSIFICATION
C     IS = 1 ......RURAL INTERSTATE
C     IS = 2 ......URBAN INTERSTATE
C
      DO 1000 IS = 1,2
C
C
C  IMPACT ANGLES, ANG(K)
C
      ANG(1)  =  5.0
      ANG(2)  = 10.0
      ANG(3)  = 15.0
      ANG(4)  = 20.0
      ANG(5)  = 25.0
C
C  AUTOMOBILE WEIGHTS, W(I)
```

```
      C
            W(1) = 2250
            W(2) = 4500
      C
      C  AUTOMOBILE SIZE DISTRIBUTIONS, S(I)
      C     I = 1...........2,250 LB AUTO
      C     I = 2...........4,500 LB AUTO
      C
            GO TO (40,41,42,43,44), LOOP
      C
       40   S(1) = 1.00
            S(2) = 0.00
            GO TO 45
       41   S(1) = 0.75
            S(2) = 0.25
            GO TO 45
       42   S(1) = 0.50
            S(2) = 0.50
            GO TO 45
       43   S(1) = 0.25
            S(2) = 0.75
            GO TO 45
       44   S(1) = 0.00
            S(2) = 1.00
       45   CONTINUE
      C
      C
      C  AVERAGE DAILY TRAFFIC, ADT(M)
      C
            A = 1.0
            DO 100 M = 1,10
            ADT(M) = A * 10000.0
            A = A + 1.0
      100   CONTINUE
      C
      C  ENCROACHMENT FREQUENCY, E(M)
      C
            IF (IS .EQ. 1) CONST = 0.00090
            IF (IS .EQ. 2) CONST = 0.00090
            DO 102 M = 1,10
            E(M) = CONST * ADT(M)
      102   CONTINUE
      C
      C  TRAFFIC DIRECTIONAL SPLIT, D
      C
            D = 0.5
      C
            IF(ITABLE .GT. 1) GO TO 80
      C
      C   INTEREST RATE, INT
      C   PROJECT LIFE, YR
      C
            INT = 0.10
            YR  = 20.0
      C
      C   CAPITAL RECOVERY FACTOR, CRF
      C
            D1 = (1.0 + INT)**YR
            CRF = (INT * D1)/(D1-1)
      C
       80   CONTINUE
```

```
C
          IF (IS .EQ. 1) GO TO 85
          IF (IS .EQ. 2) GO TO 86
   85     CONTINUE
C
C  LATERAL IMPACT PROBABILITIES, P(K), AT LATERAL OFFSET DISTANCE
C  OF 14 FT. ON RURAL INTERSTATE HIGHWAY (FUNCTION OF ENCROACHMENT
C  ANGLE(K)).  MEDIAN WIDTH = 30.0 FT.
C
          P(1) = 0.60
          P(2) = 0.82
          P(3) = 0.86
          P(4) = 0.86
          P(5) = 0.93
C
          GO TO 87
   86     CONTINUE
C  LATERAL IMPACT PROBABILITIES,P(K), AT LATERAL OFFSET DISTANCE
C  OF 7 FT. ON URBAN INTERSTATE HIGHWAY.  MEDIAN WIDTH = 16 FT.
C
          P(1) = 0.81
          P(2) = 0.94
          P(3) = 0.97
          P(4) = 0.97
          P(5) = 0.99
   87     CONTINUE
C
          IF(IS .EQ. 2 .OR. INJ .GE. 2 .OR. LOOP .GT. 1)GO TO 301
C
C  READ IMPACT CONDITION PROBILITIES, IP(K,L), AS FUNCTION
C  OF IMPACT ANGLE(K) AND SPEED(L)).
C
          DO 104 IT = 1,2
          DO 104  K = 1,5
          READ(5,500)(IP(IT,K,L),L = 1,5)
  104     CONTINUE
C
C
C
C  READ HVOSM AUTOMOBILE ROLL AND DECELERATIONS
C
C         I = AUTOMOBILE SIZES
C         J = SEVERITY-INDEX ADJUSTMENT FACTORS
C         K = IMPACT ANGLES
C         L = IMPACT SPEEDS
C
          J = 1
          DO 300 I = 1,2
          DO 300 L = 1,5
          DO 300 K = 1,5
          READ(5,502) ROLL(I,J,K,L), GLONG(I,J,K,L), GLAT(I,J,K,L),
         *              GVERT(I,J,K,L)
  300     CONTINUE
  301     CONTINUE
C
C  CALCULATE SEVERITY-INDICES, SI(I,J,K,L)
C     SI(I,1,K,L) SET EQUAL TO 5.00 IF ROLL(I,1,J,K) IS GREATER TH
C
          DO 380 I = 1,2
          DO 380 J = 1,3
          DO 380 K = 1,5
```

```
            DO 380 L = 1,5
      C
            GO TO (350,352,354), J
       352  GO TO (360,360,361,362,363), K
       354  GO TO (360,360,371,372,373), K
      C
       360  GVERT(I,J,K,L) = 1.00 * GVERT(I,1,K,L)
            GO TO 350
       361  GO TO (385,386),I
       385  GVERT(I,J,K,L) = 0.95 * GVERT(I,1,K,L)
            GO TO 350
       386  GVERT(I,J,K,L) = 0.97 * GVERT(I,1,K,L)
            GO TO 350
       362  GO TO (387,388),I
       387  GVERT(I,J,K,L) = 0.90 * GVERT(I,1,K,L)
            GO TO 350
       388  GVERT(I,J,K,L) = 0.92 * GVERT(I,1,K,L)
            GO TO 350
       363  GO TO (389,390),I
       389  GVERT(I,J,K,L) = 0.85 * GVERT(I,1,K,L)      — CASE III
            GO TO 350
       390  GVERT(I,J,K,L) = 0.87 * GVERT(I,1,K,L)
            GO TO 350
       371  GO TO (391,392),I
       391  GVERT(I,J,K,L) = 0.90 * GVERT(I,1,K,L)
            GO TO 350
       392  GVERT(I,J,K,L) = 0.92 * GVERT(I,1,K,L)
            GO TO 350
       372  GO TO (393,394),I
       393  GVERT(I,J,K,L) = 0.80 * GVERT(I,1,K,L)
            GO TO 350
       394  GVERT(I,J,K,L) = 0.82 * GVERT(I,1,K,L)
            GO TO 350
       373  GO TO (395,396),I
       395  GVERT(I,J,K,L) = 0.70 * GVERT(I,1,K,L)
            GO TO 350
       396  GVERT(I,J,K,L) = 0.72 * GVERT(I,1,K,L)
       350  CONTINUE
            G1 = (GLONG(I,1,K,L)/7.0)**2
            G2 = ( GLAT(I,1,K,L)/5.0)**2
            G3 = (GVERT(I,J,K,L)/6.0)**2
      C
            SI(I,J,K,L) = (G1 + G2 + G3)**0.5
      C
            IF(ABS(ROLL(I,1,K,L)).LT.90.0) GO TO 375
            IF(J .EQ. 2 .OR. J .EQ. 3) GO TO 375
            SI(I,J,K,L) = 5.00
       375  CONTINUE
       380  CONTINUE
      C
      C  WRITE IMPACT CONDITION PROBABILITIES, IP(K,L)
      C
            IF(IS .EQ. 2 .OR. INJ .GE. 2 .OR. LOOP .GT. 1) GO TO 51
            DO 50 IK = 1,2
      C
            WRITE(6,598) ITABLE
            IF(IK .EQ. 1) WRITE(6,599)
            IF(IK .EQ. 2) WRITE(6,600)
            WRITE(6,601)
      C
            L = 1
```

```
          DO 108 K = 1,5
          WRITE(6,602) ANG(K), IP(IK,K,L), IP(IK,K,L+1), IP(IK,K,L+2),
     *                 IP(IK,K,L+3), IP(IK,K,L+4)
  108     CONTINUE
C
          ITABLE = ITABLE + 1
   50     CONTINUE
   51     CONTINUE
C
C  WRITE SEVERITY-INDICES, SI(I,J,K,L)
C
          IF(IS .EQ. 2 .OR. INJ .GE. 2 .OR. LOOP .GT. 1) GO TO 109
C
C
          DO 110 I = 1,2
          DO 110 J = 1,3
          WRITE(6,604) ITABLE
          GO TO (112, 114, 116), J
  112     WRITE(6,606)
          GO TO 118
  114     WRITE(6,608)
          GO TO 118
  116     WRITE(6,610)
  118     CONTINUE
          WRITE(6,612) W(I)
          L = 1
          DO 120 K = 1,5
          WRITE(6,614) ANG(K), SI(I,J,K,L), SI(I,J,K,L+1), SI(I,J,K,L+
         *SI(I,J,K,L+3), SI(I,J,K,L+4)
  120     CONTINUE
          ITABLE = ITABLE + 1
  110     CONTINUE
  109     CONTINUE
C
C  INJURY PROBABILITIES, PI(I,J,K,L)
C
          DO 122 I = 1,2
          DO 122 J = 1,3
          DO 122 K = 1,5
          DO 122 L = 1,5
          PI(I,J,K,L) = 0.40 * SI(I,J,K,L)
          IF(PI(I,J,K,L) .LT. 1.00) GO TO 124
          PI(I,J,K,L) = 1.00
  124     CONTINUE
  122     CONTINUE
C
C  INJURY ACCIDENT COSTS, AC(I,J,K,L)
C
          GO TO(800,801,802), INJ
  800     CONTINUE
C
C  NSC ACCIDENT COSTS (PROVIDED BY MR. JIM BOOS, FHWA PROJECT MANA
C
C  PDC         = $     850/ACCIDENT
C  INJURY      = $   5,800/ACCIDENT
C  FATAL       = $ 150,000/ACCIDENT
C  UPPER LIMIT = $  14,500/ACCIDENT
C
          C1 =    5273.0
          C2 =       0.0
          C3 =       0.0
```

```
          C4 =  14500.0
          N1 =    850
          N2 =   5300
          N3 = 150000
          N4 =  14500
          GO TO 804
C
  801  CONTINUE
C
C  ITI ACCIDENT COSTS
C
C  PDC          = $    700/ACCIDENT
C  INJURY       = $ 10,000/ACCIDENT
C  FATAL        = $200,000/ACCIDENT
C  UPPER LIMIT = $ 21,400/ACCIDENT
C
          C1 =   7782.0
          C2 =      0.0
          C3 =      0.0
          C4 =  21400.0
          N1 =    700
          N2 =  10000
          N3 = 200000
          N4 =  21400
C
          GO TO 804
  802  CONTINUE
C
C  NDR ACCIDENT COSTS
C
C  PDC          = $    900/ACCIDENT
C  INJURY       = $  4,900/ACCIDENT
C  FATAL        = $336,000/ACCIDENT
C  UPPER LIMIT = $ 24,770/ACCIDENT
C
          C1 =   9007.0
          C2 =      0.0
          C3 =      0.0
          C4 =  24770.0
          N1 =    900
          N2 =   4900
          N3 = 336000
          N4 =  24770
C
  804  CONTINUE
C
          DO 806 I = 1,2
          DO 806 J = 1,3
          DO 806 K = 1,5
          DO 806 L = 1,5
C
          AC(I,J,K,L) = C1*SI(I,J,K,L) + C2*SI(I,J,K,L)**2 +
        *                    C3*SI(I,J,K,L)**3
          GO TO (810,807,808), INJ
  810  IF (AC(I,J,K,L) .LE. 14500.0) GO TO 809
          AC(I,J,K,L) = 14500.0
          GO TO 809
  807  IF(AC(I,J,K,L) .LE.  21400.0) GO TO 809
          AC(I,J,K,L) =  21400.0
          GO TO 809
  808  IF(AC(I,J,K,L) .LE.  24770.0) GO TO 809
```

```
      AC(I,J,K,L) =  24770.0
  809 CONTINUE
  806 CONTINUE
C
C
C  EFFECTIVENESS CALCULATIONS (REDUCTION IN
C     HAZARD-INDICES DUE TO RETROFITTING)
C                   AND
C  BENEFIT CALCULATIONS (REDUCTION IN
C     COSTS DUE TO RETROFITTING
C
      WRITE(6,615) ITABLE
      WRITE(6,633)
      WRITE(6,631) N1,N2,N3,N4,S(1),S(2)
      IF(IS .EQ. 1) WRITE(6,616)
      IF(IS .EQ. 2) WRITE(6,617)
      WRITE(6,618)
      ITABLE = ITABLE + 1
C
      DO 200 J = 1,3
C
      ESUM2 = 0.0
      BSUM2 = 0.0
C
      DO 204 I = 1,2
      DO 206 K = 1,5
C
      ESUM1 = 0.0
      BSUM1 = 0.0
C
      DO 208 L = 1,5
C
      ESUM1 = ESUM1 + IP(IS,K,L) * PI(I,J,K,L)
      BSUM1 = BSUM1 + IP(IS,K,L) * AC(I,J,K,L)
  208 CONTINUE
      ESUM2 = ESUM2 + ESUM1 * S(I)  * P(K)
      BSUM2 = BSUM2 + BSUM1 * S(I)  * P(K)
  206 CONTINUE
  204 CONTINUE
C
      DO 210 M = 1,10
C
      HI(J,M) = E(M) * D * ESUM2
      IC(J,M) = E(M) * D * BSUM2
  210 CONTINUE
  200 CONTINUE
C
      DO 212 M = 1,10
C
      EFFET1(M) = HI(1,M) - HI(2,M)
      EFFET2(M) = HI(1,M) - HI(3,M)
C
      BENEF1(M) = IC(1,M) - IC(2,M)
      BENEF2(M) = IC(1,M) - IC(3,M)
  212 CONTINUE
C
      DO 250 M = 1,10
      B1(IS,M) = (BENEF1(M))/(5280.0 * CRF)
      B2(IS,M) = (BENEF2(M))/(5280.0 * CRF)
C
      WRITE(6,619) ADT(M), EFFET1(M), BENEF1(M), EFFET2(M), BENEF
```

```
  250 CONTINUE
C
  1000 CONTINUE
C
C
C   WRITE COST LIMITS TO RETROFIT
C
C
        WRITE(6,630) ITABLE
        WRITE(6,633)
        WRITE(6,631) N1,N2,N3,N4,S(1),S(2)
        WRITE(6,632)
        ITABLE = ITABLE + 1
C
        DO 82 M = 1,10
        WRITE(6,635) ADT(M),B1(1,M),B1(2,M),B2(1,M),B2(2,M)
  82    CONTINUE
C
  1005 CONTINUE
  1010 CONTINUE
C
        WRITE (6,620)
C
C                       ***** END OF TASK 1 PROGRAM *****
C
C   FORMAT STATEMENTS
C
  500  FORMAT (5 F10.3)
C
  502  FORMAT (4 F10.2)
C
  598  FORMAT (1H1,////,T45,'TABLE =',I2,//,T14,'COST-EFFECTIVENESS OF RE
     *TROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER',//,T20,'I M P A C T
     *   C O N D I T I O N   P R O B A B I L I T I E S',//)
C
  599  FORMAT(T37,'RURAL INTERSTATE HIGHWAY',///)
C
  600  FORMAT(T37,'URBAN INTERSTATE HIGHWAY',///)
C
  601  FORMAT(T25,'IMPACT',T41,'I M P A C T   S P E E D',
     */,T25,'ANGLE',T47,'(MPH)',/,T25,'(DEG)',T35,'30',T44,'40',T53,'50'
     *,T62,'60',T71,'70',//)
C
  602  FORMAT (T25,F4.1,T33,F5.3,T42,F5.3,T51,F5.3,T60,F5.3,T69,F5.3)
C
  604  FORMAT (1H1,////,T56,'TABLE =',I2,//,T25,'COST-EFFECTIVENESS OF RE
     *TROFITTING NEW JERSEY CONCRETE MEDIAN BARRIER',//,T45,'S E V E R I
     * T Y - I N D I C E S',//)
C
  606  FORMAT (T48,'ADJUSTMENT FACTOR: NONE',//)
C
  608  FORMAT (T45,'ADJUSTMENT FACTOR: LOWER LIMIT',//)
C
  610  FORMAT (T45,'ADJUSTMENT FACTOR: UPPER LIMIT',//)
C
  612  FORMAT (T47,'AUTOMOBILE SIZE = ',T65,F6.1,T72,'LBS',//,T37,'IMPACT
     *',T52,'I M P A C T   S P E E D',/,T37,'ANGLE',T58,'(MPH)',/,T37,
     *'(DEG)',T47,'30',T55,'40',T63,'50',T71,'60',T79,'70',//)
C
  614  FORMAT (T38,F4.1,T46,F4.2,T54,F4.2,T62,F4.2,T70,F4.2,T78,F4.2)
C
```

```
  615 FORMAT (1H1,//////,T57,'TABLE =',I2,//,
     *                                        T27,'NEW JERSEY CMB RETROFIT PERF
     *ORMANCE LEVELS BASED ON HVOSM SIMULATIONS',//)
C
  633 FORMAT (T39,'2 SIZE AUTOMOBILES',
     *T63,'2,250 AND 4,500 LBS',/,T39,'5 IMPACT SPEEDS',T63,'30, 40, 50,
     * 60 AND 70 MPH',/,T39,'5 IMPACT ANGLES',T63,'5, 10, 15, 20 AND 25
     *DEG',//)
C
C
  618 FORMAT(T26,'ADT',T40,'VERTICAL AUTOMOBILE ACCELERATION ADJUSTMENT
     *FACTORS (RF)',//,T24,'TRAFFIC',T38,'L O W E R',T54,'L I M I T',
     *        T77,'U P P E R',T92,'L I M I T',//,T24,'VOLUMES',T36,'HAZARD
     *-INDEX',T52,'ACCIDENT COST',T74,'HAZARD-INDEX',T90,'ACCIDENT COST'
     *,/,T38,'REDUCTION',T54,'REDUCTION',T76,'REDUCTION',T92,'REDUCTION'
     *,/,T25,'(VPD)',T37,'(INJ/MI-YR)',T54,'($/MI-YR)',T75,'(INJ/MI-YR)'
     *,T92,'($/MI-YR)',///)
C
  616 FORMAT(T51,'RURAL INTERSTATE HIGHWAY',//)
C
  617 FORMAT(T51,'URBAN INTERSTATE HIGHWAY',//)
C
  619 FORMAT (T24,F7.0,T36,F10.6,T51,F11.2,T74,F10.6,T89,F11.2)
C
  620 FORMAT (1H1)
C
  630 FORMAT(1H1,//////,T57,'TABLE =',I2,//,T31,
     *'COST LIMITS TO RETROFIT NEW JERSEY CONCRETE MEDIAN BARRIER',
     *///)
C
  631 FORMAT (T50,'PDO',T58,'= $',T64,I3,T68,'/ACCIDENT',/,T50,
     *'INJURY',T58,'= $',T62,I5,T68,'/ACCIDENT',/,T50,'FATAL',
     *T58,'= $',T61,I6,T68,'/ACCIDENT',/,T44,'UPPER LIMIT',T58,
     *'= $',T61,I6,T68,'/ACCIDENT',///,T46,
     *'2,250 LB AUTO DISTRIBUTION =',T76,F4.2,/,T46,
     *'4,500 LB AUTO DISTRIBUTION =',T76,F4.2,//)
C
  632 FORMAT (T22,'ADT',T33,'L O W E R   C O S T   L I M I T',
     *T71,'U P P E R   C O S T   L I M I T',/,T20,
     *'TRAFFIC',T45,'($/FT)',T83,'($/FT)',/,T20,'VOLUMES',T38,
     *'RURAL',T53,'URBAN',T76,'RURAL',T91,'URBAN',/,T21,'VPD',T37,
     *'HIGHWAY',T52,'HIGHWAY',T75,'HIGHWAY',T90,'HIGHWAY',///)
C
  635 FORMAT(T20,F7.0,T35,F8.2,T50,F8.2,T73,F8.2,T88,F8.2)
      STOP
      END

$ENTRY
```

APPENDIX C

REVISED WORK PLAN

TO CONDUCT

FULL-SCALE VEHICLE CRASH TESTS

DOT-RC-9201

May 19, 1980

UNL

The University of Nebraska–Lincoln

Department of
Civil Engineering
Lincoln, Nebraska 68588

May 19, 1980

Mr. Ted Higgs
Department of Transportation, RSPA
Procurement Branch, DPA-14
400 Seventh Street, S.W.
Washington, D.C. 20590

Re: DOT Contract RC-92021

Dear Mr. Higgs:

This letter is a request to redefine the scope of several of the work tasks in the research contract DOT-RC-92021, entitled "Cost-Effectiveness of Retrofitting Concrete Median Barriers". Mr. Michael Freitas, HRS-43, who is the project's second Contracting Officer's Technical Representative (COTR), is in agreement with this request.

Copies of the revised work plan are enclosed for your review and distribution to the COTR. The revised budget sheet is shown in Table 1A. The revised work plan will require no additional funding from DOT, but it will require an increase in the Universities cost sharing funds from $13,500 to $17,828. The revised budget sheet in Table 1A is in a format agreed upon in a telephone conversation (May 15, 1980) between yourself and Mr. Carl Mueller, who is the University's Fiscal Manager of Grants and Contracts.

There are three reasons for requesting a revision of the work plan. These reasons are as follows:

1. A new and second COTR, Mr. Michael Freitas, HRS-43, was assigned to the project. This change in COTR's delayed the review of the Task 1 Report by about two months.

2. Tasks 2, 3 and 4 in the original work plan were dependent upon the FHWA providing a computer model named GUARD for simulating the impact between a vehicle and the retrofitted concrete median barrier. Dr. Morton Oskard, HRS-12, of the FHWA made the decision that no attempt should be made to use the GUARD program because of the technical difficulties being encountered with the program on other research contracts.

Mr. Higgs
May 19, 1980
page 2

3. The scope of Task 1 was expanded by the second COTR in requiring a more indepth analysis of accident data involving rollovers on the concrete median barriers. It is the opinion of the contractor that the additional work was well justified because it provided a better understanding of the rollover problem and traffic conditions in which the retrofit unit would be potentially cost-effective.

Task 1 on the cost-effectiveness of retrofitting concrete median barriers has been completed to the satisfaction of the COTR, Mr. Michael Freitas. Because of the uncertain operational status of the FHWA's GUARD program, it is requested that (1) Tasks 2, 3 and 4 be deleted, and (2) the project proceed into the full-scale vehicle crash testing phase in Task 6. The original work plan required that two full-scale crash tests be conducted. In lieu of the simulation work that would have been done in Tasks 2, 3 and 4, the contractor and the COTR are in agreement that two additional full-scale crash tests should be conducted in order to determine the feasibility and effectiveness of retrofitting concrete median barriers. Conducting two additional full-scale crash tests will require that the completion date of the project be extended two months from August 31 to October 31, 1980 (see Table 1B in revised work plan).

Mr. Michael Freitas, HRS-43, has reached the decision that the project should be turned over to an engineer in FHWA's Protective Systems Group, Structures and Applied Mechanics Division for conducting the full-scale crash tests in Task 6. Dr. Morton S. Oskard, HRS-12, has agreed to serve, if approved, as the new and third COTR.

Conducting full-scale crash tests requires much lead time in planning and preparing the test site and vehicles. Therefore, your consideration of this request to modify the work plan at your earliest convenience will be greatly appreciated. Thank you.

Respectfully,

Edward R. Post

Dr. Edward R. Post, P.E.
Associate Professor of Civil Engineering

Francis L. Schmehl

Dr. Francis Schmehl
Research Administrator

Enclosures (3)

cc: Dr. E. N. Wilson, P.E. (C.E. Chairman)
Dean D. M. Edwards, P.E. (Dir. of Engr. Res. Center)
Mr. Michael Freitas, HRS-43
Dr. Morton Oskard, HRS-12

mlw

Table 1A

NEW BUDGET[c]: COST-EFFECTIVENESS OF RETROFITTING CONCRETE MEDIAN BARRIERS

(DOT-RC-92021)

I T E M	Original Budget ($)	Estimated Working Balance ($)	New Budget (Tasks 6&7) ($)
Personnel			
E. R. Post	16,400	5,778	2,889
P. T. McCoy	7,200	5,778	0
Graduate Assistants	8,500	0	0
Undergraduates	4,000	0	1,500
Draftsman/Clerical	1,200	1,200	0
Staff Benefits	3,348	795	390
Operating	1,800	800	800
Full-Scale Crash Tests	11,000	11,000	24,662
Travel	1,000	1,000	1,000
Indirect Costs	22,007	7,480	2,590
Total (DOT)	76,455	33,831	33,831
UNL Cost Share			
Computer	13,500	13,500	0
Personnel			
E. R. Post[a]	0	0	4,938
P. T. McCoy[a]	0	0	4,938
T. J. Wipf[a]	0	0	2,875
R. W. Bolton[a]	0	0	2,684
P. Chastain[b]	0	0	1,193
Clerical[a]	0	0	1,200
Total (UNL)	13,500	13,500	17,828

a. Includes Fringe Benefits and Indirect Costs

b. Includes Indirect Costs Only

c. New Budget (5-19-80)

FEASIBILITY STUDY
of
RETROFITTING CONCRETE MEDIAN BARRIERS

DOT-RC-92021

REVISED WORK PLAN

May 19, 1980

Principal Investigator

Dr. Edward Robert Post, P.E.
Associate Professor of Civil Engineering
226 Bancroft Hall
Civil Engineering Department
University of Nebraska-Lincoln
Lincoln, Nebraska 68588

WORK SCHEDULES

The revised work task schedule and personnel assignment schedule are shown in Tables 1B and 1C. The changes made are shown in a hand written format on the original schedules. A brief description of the revised schedules follows.

WORK TASKS

TASK 1. CONDUCT COST-EFFECTIVENESS STUDY

As of May 1, 1980, Task 1 was completed to the satisfaction of the project's second COTR*, Mr. Michael Freitas, HRS-43. Additional time was required to complete Task 1 because of (1) a change in contract managers in about December of 1979 which delayed the review of the Task 1 report by about two months, and (2) the new COTR increased the scope of the project by requiring a more indepth analysis of accident information related to vehicle rollovers on the CMB. However, it is the opinion of the contractor that the additional work was well justified because it provided a better understanding of the rollover problem and traffic conditions in which the retrofit unit would be potentially cost-effective.

TASK 2. OBTAIN AND INSTALL GUARD PROGRAM ON UNL COMPUTER SYSTEM

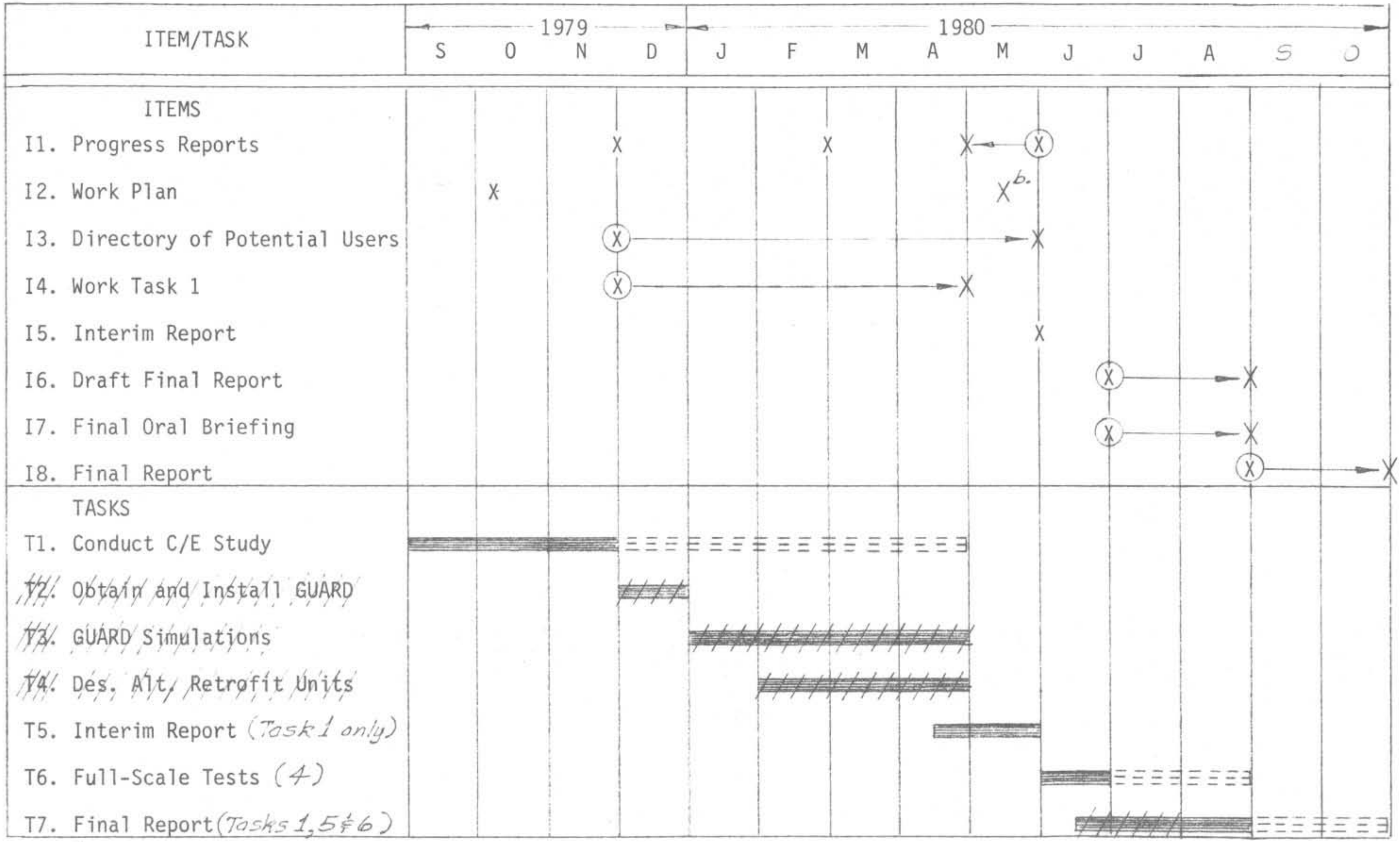
This task and the two following tasks (Tasks 3 and 4) are to be deleted. These tasks were designed to determine the feasibility of the concrete

---

* COTR - Contracting Officer's Technical Representative

Table 1 *B*

WORK SCHEDULE [a] *(REVISED)* [b]



a. Due to late processing of the contract, the deadlines for the contract Items and Tasks have been changed to the new dates shown in attached letter of September 11, 1979.

b. *Revised Work Plan (Revision No. 1, May 19, 1980)*

Table ~~2~~ 1C

PERSONNEL ASSIGNMENTS [a]

(man-months)

TASKS	Professionals: E.R. Post	Professionals: P.T. McCoy	Graduates Assistants: T.J. Wipf	Graduates Assistants: R.W. Bolton	Under-Graduates	Staff	Sub-Totals
1	~~1.3~~ 3.0	~~1.6~~ 0.5	~~0.5~~ 1.0	~~0.5~~ 0.7	~~1.7~~ 2.5	~~0.5~~ 0.8	~~6.1~~ 8.5
~~2~~	~~0.5~~	~~0.0~~	~~0.8~~	~~0.8~~	~~1.0~~	~~0.0~~	~~3.1~~
~~3~~	~~0.5~~	~~0.0~~	~~1.0~~	~~1.0~~	~~1.0~~	~~0.0~~	~~3.5~~
~~4~~	~~0.5~~	~~0.2~~	~~0.3~~	~~0.2~~	~~0.2~~	~~0.3~~	~~1.7~~
5	~~0.5~~ 0.7	~~0.5~~ 0.0	0.1	0.1	0.0	0.5	~~1.7~~ 1.4
6	1.0	~~0.2~~ 0.5	~~0.5~~ 2.7	~~0.5~~ 3.2	~~1.1~~ 5.3	0.2	~~3.5~~ 12.9
7	1.0	0.5	~~0.1~~ 0.5	~~0.1~~ 0.2	~~0.0~~ 0.2	0.5	~~2.2~~ 2.9
Sub-Totals [b]	~~5.3~~ 5.7	~~3.0~~ 1.5	← ~~6.5~~ 8.5 →		~~5.0~~ 8.0	2.0	~~21.8~~ 25.7

a. Revision No. 1 (5-19-90)

b. Includes UNL Cost Sharing Time

median barrier retrofit unit concept by mathematical model simulations using the GUARD program developed by FHWA. The decision was made by the contractor and the COTR to delete these tasks because of the uncertain operational status of the GUARD program. The FHWA has been encountering technical problems in attempting to use the GUARD program on other contracts.

TASK 3. SIMULATE GUARD PROGRAM

This task is to be deleted for reasons discussed in Task 2.

TASK 4. DESIGN ALTERNATIVE RETROFIT UNIT

This task is to be deleted for reasons discussed in Task 2.

TASK 5. INTERIM REPORT

The cost-effectiveness study in Task 1 has been completed to the satisfaction of the COTR, Mr. Michael Freitas, HRS-43. Three reports of Task 1 have been presented to the COTR. The second and third reports were prepared in response to constructive criticism made by the COTR. A single consolidated interim report of the findings, conclusions, and recommendations of Task 1 will be submitted by May 30, 1980

The COTR has stated verbally by telephone that he will sign the interim report as having been completed satisfactorily and will recommend that (a) Tasks 2, 3 and 4 be deleted because of the uncertain operational status of the FHWA computer simulation model, GUARD, (b) the study continue into the full-scale vehicle crash testing phase in Task 6, and (c) the remainder of the project be monitored by a new COTR in the

FHWA Protective Systems Group, Structures and Applied Mechanics Division. The following professional engineer has agreed, if appointed, to serve as the new and third project COTR.

Dr. Morton S. Oskard, HRS-12
Federal Highway Administration
U.S. Department of Transportation
400 Seventh Street, S.W.
Washington, D.C. 20590

TASK 6. CONDUCT FULL-SCALE TESTS

The original work plan dated October 3, 1980 required that two full-scale vehicle crash tests were to be conducted. Because the computer model simulation studies in Tasks 2, 3 and 4 were deleted, the contractor and the COTR, Dr. Morton Oskard, have made the decision to conduct two additional full-scale tests in lieu of the deleted tasks. It was decided that four tests, without the aid of the computer simulation results, was a minimum number of tests required to determine the effectiveness and feasibility of the CMB retrofit unit concept.

Wherever possible, the full-scale tests will be conducted in accordance with the guidelines presented in TRB Circular 191, entitled "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances". Deviations from TRB Circular 191 will be noted in the outline of the subtasks to follow.

Subtask 6.1. Construct New Jersey CMB

The CMB will be about 80 ft. in length and it will consist of pin-connected 10 ft. precast units. The CMB will be fixed at its base against rotations and horizontal displacements under impact. Heavy steel reinforcement will be used to minimize structural impact damage. Steel female bolt connection inserts will be cast in the CMB for anchoring the retrofit unit to the CMB.

Subtask 6.2. Vehicle Impact Test Conditions

The accident record reports in California for the years of 1978 and 1979, in which CMB rollovers occurred, will be reviewed by hand to define and select four test vehicles. An attempt will also be made to determine the impact speed-angle combinations in which rollovers occurred.

In the absence of reliable rollover speed-angle accident data, it is predicted from the findings in Task 1 that a minimum speed of 60 mph and a minimum angle of 15 deg. will provide a good measure of the effectiveness of the CMB retrofit unit concept in eliminating rollovers.

Subtask 6.3. Design and Construct CMB Retrofit Unit

No computer simulation model will be available to help design the shape of the retrofit unit because Tasks 2, 3, and 4 were deleted. Therefore, engineering judgment will be used to accomplish this task. Insight into the shape of the retrofit unit will be obtained by using prototype plywood mockups of retrofitted CMB's placed alongside automobiles of different sizes.

Subtask 6.4. Data Acquisition Methods

Vehicle Accelerations. A triaxial accelerometer unit will be used to measure the lateral, longitudinal, and vertical vehicle accelerations.

<u>Occupant Responses</u>. An onthropometric dummy in the driver's position will be used "on the condition" that the FHWA will furnish the dummy and the high-speed camera to be mounted in the rear of the test vehicle. The FHWA shall make the decision on whether the side door window shall be open or closed since no guidelines have yet been defined in TRB Circular 191.

The use of anthropometric dummies is considered optional for the evaluation of highway appurtences. However, in this study a dummy would be beneficial and would provide an indication of the degree-of-hazardousness associated with the retrofit unit, in that, the height of the retrofit unit will be at about the same height as the driver's head.

<u>High-Speed Cameras</u>. Three high-speed cameras operating at a minimum speed of 500 fps will be used in this study. One camera will be positioned perpendicular to the CMB; and the other two cameras mounted side by side will be positioned nearly parallel to the CMB on the downstream side of the impact location.

TASK 7. FINAL REPORT

The final report of the findings, conclusions, and recommendations of Tasks 1 and 6 will be submitted by October 31, 1980. The report section on Task 6 will be prepared in accordance with the guidelines of TRB

Circular 191. The report will contain no material on Tasks 2, 3 and 4 because these tasks have been deleted from this study.