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16. Abstract

Available accident files are used to generate a 412-accident data base of guardrail impacts. This base is analyzed to develop a statistical model for predicting accident severity index (ASI) as a function of vehicle type or weight, impact speed, and impact angle.

Reported full-scale test results are used to generate a 91-test data base of guardrail full-scale crash tests. Mathematical severity index (MSI) is calculated for each test as the resultant of the reported maximum 50-ms vehicle lateral and longitudinal accelerations. The statistical model is applied to each test to predict the corresponding ASI. These pairs of MSI/ASI values are used to determine the relationship between the two indexes.

It is shown that only a moderate MSI/ASI relationship appears to exist and that the MSI is probably not a severity-discerning characteristic of full-scale tests. Low, constant ASI values over the range of MSI values indicate that guardrails are performing their intended purposes.

This volume includes technical documentation of work done in the study. Volume II contains related appendices.

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1. Introduction

Over the past two decades, hundreds of full-scale vehicle crash tests with longitudinal highway barrier configurations (bridge rails, guardrails, and median barriers) have been performed by various research organizations. As a measure of acceptance of the tested barriers, the following two tests have been recommended:[1]

(1) Structural Adequacy - Containment and redirection of a 4500-lb vehicle impacting at 60 mph and 25°.

(2) Impact Severity - Maximum 50-ms vehicle lateral and longitudinal accelerations less than specified values for an impact of a 2250-lb vehicle at 60 mph and 15°.

Lateral and longitudinal accelerations of the impacting vehicle are thus measured and reported in full-scale crash tests. They are also calculated in computer simulations of vehicle/barrier impacts. However, the relationship between these accelerations and real world accident severities has never been established. Thus, despite the fact that a barrier configuration satisfies the test evaluation criteria, no conclusions can be made concerning its in-service performance. Without a measure of its effectiveness in reducing accident severity, nothing is available to determine if its installation at a particular highway site will be cost effective. Yet in these times of economic crunch, cost-effectiveness warranting and evaluation procedures for highway safety appurtenances are becoming of ever-increasing importance.

As an example, a new self-restoring barrier concept (SERB) was recently designed and developed at SwRI.[2] The barrier satisfactorily passed its full-scale crash tests and is ready for field implementation. Vehicle accelerations are known for the test conditions. Computer simulations can be tuned to correlate with the test conditions and can then be used to extrapolate for other category impact conditions. Thus, for the range of expected in-service hits on the barrier, the vehicle accelerations are known. Despite this, an acceptable procedure is not currently available to estimate the expected yearly accident severity in terms of property damage only (PDO), injury (I), and fatal (F) accidents. The relationship between vehicle accelerations and real world accident severity is obviously needed. This constitutes the problem that was undertaken in this study. Taken from the RFP, the Prospectus for the study is included in Appendix A.

2. Objective

As indicated in Appendix A, the objective of the study was to develop and quantify a relationship between vehicle accelerations and real world accident severity. Details of the research approach taken to achieve this objective follow.

3. Mathematical Accident Severity (MSI)

The severity index SI, based on vehicle accelerations from full-scale tests or computer simulations, is usually defined as

$$SI = \sqrt{\left(\frac{G_{long.}}{G_{XL}}\right)^2 + \left(\frac{G_{lat.}}{G_{YL}}\right)^2 + \left(\frac{G_{vert.}}{G_{ZL}}\right)^2} \qquad (1)$$

where

$G_{long.}$ = average vehicle longitudinal acceleration
$G_{lat.}$ = average vehicle lateral acceleration
$G_{vert.}$ = average vehicle vertical acceleration
G_{XL} = tolerable average longitudinal acceleration
G_{YL} = tolerable average lateral acceleration
G_{ZL} = tolerable average vertical acceleration

The tolerable acceleration values used in this equation are usually

G_{XL} = 7 g's
G_{YL} = 5 g's
G_{ZL} = 6 g's

The customary procedure is to compute average accelerations and the SI for all 50-millisecond periods of the test or simulation and select the maximum. This means that individual maximum longitudinal, lateral, or vertical accelerations may not occur during the same 50-ms time period as that of the maximum combined SI.

It has usually been assumed that a SI from equation (1) of greater than one indicates that an occupant would sustain serious or fatal injuries. Figure 1 shows the two-dimensional version of the equation in which the vertical accelerations are excluded. In a recent SwRI study to develop a cost-effectiveness model for guardrail selection,[3] Graham's allowable limits (5 and 3 g's) were assumed as a reasonable interface between PDO and injury accidents, and a SI = 1.4 based on Weaver's limits (7 and 5 g's) was assumed as the injury/fatality interface. Despite the rather wide bands selected for PDO, I, and F severity categories, the indicator was a source of criticism in the FHWA review process, again indicating the need to substantiate these predictions by real-world accident experience.

To obtain a concrete measurement of full-scale crash test or simulation results, the SI of equation (1) was changed to a mathematical severity index (MSI) as follows:

$$MSI = \sqrt{(G_{long.})^2 + (G_{lat.})^2} \qquad (2)$$

Note that only the tolerable acceleration values have been omitted. Thus, the MSI is computed in the same manner as the SI. $G_{long.}$ and $G_{lat.}$ are 50-ms accelerations as obtained from the full-scale test results or the computer simulations.

Available full-scale test results were collected and screened to establish MSI values. Reporting requirements had not been standardized when many of the tests were conducted. Thus, only those test results for guardrail impacts that included the maximum 50-ms vehicle accelerations were selected. Ninety-one tests conducted by SwRI, TTI, and the States of California and New York were finally selected. Brief descriptions of the tests are included in Appendix B. The reported 50-ms lateral and longitudinal vehicle accelerations were assumed to occur simultaneously and were used in equation (2) to calculate the MSI values.

4. Accident Severity Index (ASI)

During the same period that full-scale crash tests were being conducted, numerous accident investigation studies were undertaken. For

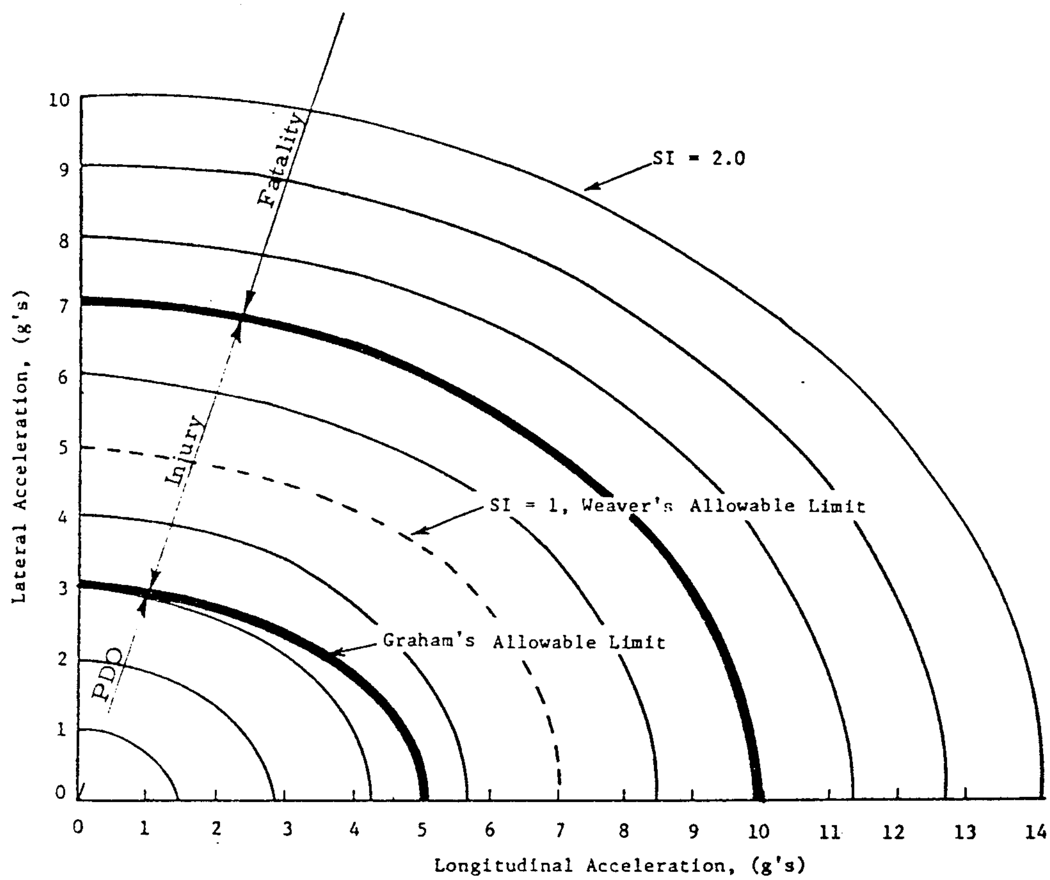

Figure 1. Guardrail severity level indicator

the most part, these studies were concerned with the vehicle and occupant and did not include data on the highway environment. As it became apparent that such data was needed for accident countermeasure evaluation and warrant development, these environmental data elements were added to the lists of elements collected by accident investigation teams.

The results of one of these more comprehensive studies, involving 7,972 single vehicle accidents investigated by Calspan,(4) were used to generate the accident data base. Other available accident files used were those generated in the SwRI encroachment study(5) and the SwRI narrow bridge study.(6) The Interstate System Accident Research Data Base(7) was investigated but was excluded because of lack of impact angle, questionable speeds, and coarse categories of vehicle type.

When guardrail accidents were extracted from the three applicable accident files, the following resulted for the final ASI data base:

Calspan (7,972 accidents)	355 used
SwRI encroachment (203 accidents)	35
SwRI narrow bridge (124 accidents)	22
Total accidents used	412

No attempt was made to screen these accidents further. Some inconsistencies obviously exist in the final file. For example, accidents in the two SwRI studies were reconstructed to establish speeds, while police data was used in the Calspan study.

It was desired to establish accident severity for a given impact condition (vehicle type, impact speed, impact angle) as the average fractions (or percentages) of property damage only (PDO), injury (I), and fatal (F) accidents that could be expected. This would account for the expected variance in accident severities caused by restraint usage, health and condition of the occupants, etc. The sum of the three PDO/I/F fractions would be unity.

The problem now was to convert the severities as PDO/I/F fractions or percentages to a single accident severity index (ASI). Table 1 shows the severity index included in the AASHTO guide,(8) where the SI is related to percentages of PDO, injury, and fatal accidents. A set of indices for

Table 1. Severity index and accident cost (reference 8)

Severity Index	% PDO Accidents*	% Injury Accidents	% Fatal Accidents	Total Accident Cost **
0	100	0	0	$ 700
1	85	15	0	2,095
2	70	30	0	3,490
3	55	45	0	4,885
4	40	59	1	8,180
5	30	65	5	16,710
6	20	68	12	30,940
7	10	60	30	66,070
8	0	40	60	124,000
9	0	21	79	160,100
10	0	5	95	190,500

*PDO refers to those accidents where property damage only is involved.

**Based on
PDO Accident = $700
Injury Accident = $10,000
Fatal Accident = $200,000

a number of roadside obstacles is included in Appendix E of the guide for use as guidelines in the absence of more definitive data. To a large extent, these indices were determined subjectively from questionnaires sent to State highway safety employees, who were requested to numerically rate the potential hazard of 52 roadside hazards and conditions.[9] Nevertheless, the table does provide a single numerical index that corresponds to the predicted values from a statistical analysis of the 412 included accidents. The resulting ASI values could then be used for comparison with the MSI values.

5. Statistical Analysis

The accident data consisted of 412 observations on guardrail accidents. Variables of interest included injury severity, vehicle type, impact speed, and impact angle. Selected categories for these variables are shown in Table 2. The distribution of the accidents into the 144 category combinations formed from the four variables is shown in Table 3.

Initially, the data in Table 3 were fit using a (hierarchical) log-linear model with injury severity type as the response variable. The logarithms of the expected cell frequencies were written as an additive function of the above variables and their interactions. This was accomplished using the BMDP4F computer program entitled "Two-Way and Multiway Frequency Tables." The full model had the form

$$\ell n\, F_{ijk\ell} = \theta + \lambda_i^{I} + \lambda_j^{V} + \lambda_k^{S} + \lambda_\ell^{A} + \lambda_{ij}^{IV} + \lambda_{ik}^{IS} + \lambda_{i\ell}^{IA} + \lambda_{jk}^{VS} + \lambda_{j\ell}^{VA} + \lambda_{k\ell}^{SA} + \lambda_{ijk}^{IVS} + \lambda_{ij\ell}^{IVA} + \lambda_{ik\ell}^{ISA} + \lambda_{jk\ell}^{VSA} + \lambda_{ijk\ell}^{IVSA} \quad (3)$$

where $F_{ijk\ell}$ is the expected value of the observed cell frequencies and the λ's are the parameter effects due to each variable combination.

Tests of marginal and partial association based on chi-square statistics were used to screen the above variable combinations. Stepwise model building was then employed on the remaining terms in order to arrive at an appropriate model. The fitting algorithm indicated that the best model included the interactions VSA, IV, IS and IA and all their hierarchical components (i.e., see Appendix C for the estimated values of the θ and

Table 2. Accident categories

1. Injury Severity:

   1 = Property Damage Only PDO

   2 = Injury I

   3 = Fatal F

2. Vehicle Type:

   1 = subcompact/compact (< 2700 lb)

   2 = intermediate (2700-4000 lb)

   3 = full-size, light truck (4000-5000 lb)

   4 = heavy truck (> 5000 lb)

3. Impact Speed:

   1 = 0-20 mph

   2 = 21-40 mph

   3 = 41-60 mph

   4 = > 60 mph

4. Impact Angle:

   1 = 0-10°

   2 = 11-20°

   3 = > 20°

Combinations = 3 x 4 x 4 x 3 = 144

Table 3. Observed frequencies

INJURY	VEH	SPEED	ANGLE SMALL	MED	LARGE	TOTAL
PDO	SUB	S1	1	4	9	14
		S2	16	6	5	27
		S3	7	4	4	15
		S4	0	0	0	0
		TOTAL	24	14	18	56
	MED	S1	5	0	5	10
		S2	2	11	6	19
		S3	4	3	3	10
		S4	3	0	5	8
		TOTAL	14	14	19	47
	FULL	S1	5	5	6	16
		S2	12	8	9	29
		S3	16	8	6	30
		S4	4	0	3	7
		TOTAL	37	21	24	82
	TRUCK	S1	1	2	0	3
		S2	4	5	2	11
		S3	3	2	1	6
		S4	1	1	0	2
		TOTAL	9	10	3	22
INJ	SUB	S1	2	3	2	7
		S2	18	5	7	30
		S3	16	5	1	22
		S4	6	0	0	6
		TOTAL	42	13	10	65
	MED	S1	1	0	2	3
		S2	3	5	4	12
		S3	5	4	6	15
		S4	6	4	2	12
		TOTAL	15	13	14	42

Table 3. Observed frequencies (continued)

	FULL	S1	3	0	3	I	6
		S2	7	6	6	I	19
		S3	17	5	4	I	26
		S4	3	2	1	I	6
		TOTAL	30	13	14	I	57
	TRUCK	S1	1	1	0	I	2
		S2	4	2	2	I	8
		S3	9	5	1	I	15
		S4	5	1	0	I	6
		TOTAL	19	9	3	I	31
FATAL	SUB	S1	0	0	0	I	0
		S2	0	0	0	I	0
		S3	0	0	0	I	0
		S4	1	0	0	I	1
		TOTAL	1	0	0	I	1
	MED	S1	1	0	0	I	1
		S2	0	0	0	I	0
		S3	0	0	0	I	0
		S4	2	0	0	I	2
		TOTAL	3	0	0	I	3
	FULL	S1	0	0	0	I	0
		S2	0	1	1	I	2
		S3	1	0	1	I	2
		S4	0	0	0	I	0
		TOTAL	1	1	2	I	4
	TRUCK	S1	0	0	0	I	0
		S2	0	0	0	I	0
		S3	1	1	0	I	2
		S4	0	0	0	I	0
		TOTAL	1	1	0	I	2

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 412

λ's in the model). The likelihood-ratio chi-square statistic for this model had a value of 34.58 on 78 degrees of freedom and was nonsignificant ($p > .99$); hence, the fit was extremely good.

The above four variables each contributed significantly to the observed accident frequency. The resulting predicted distribution of accidents resulting from usage of the obtained model is given in Table 4. These expected frequency counts formed the basis for the calculation of the ASI values. The percentages of PDO, I, and F accidents for a given combination of vehicle type, impact speed, and impact angle were determined using the predicted frequencies from the table. For example, for guardrail accidents involving small cars at the lowest impact speed (i.e., 0-20 mph) and lowest impact angle (i.e., 0-10°), the percentages would be as follows:

$$\begin{aligned} PDO &= 100\% \times 2.3/(2.3 + 1.9 + 0.3) = 51.11\% \\ I &= 100\% \times 1.9/(2.3 + 1.9 + 0.3) = 42.22\% \\ F &= 100\% \times 0.3/(2.3 + 1.9 + 0.3) = 6.67\% \end{aligned} \quad (4)$$

From the PDO/I/F unit costs shown in Table 1, the corresponding cost of the accident would be

$$\begin{aligned} COST &= 700(0.5111) + 10{,}000(0.4222) + 200{,}000(0.0667) \\ &= \$17{,}920 \end{aligned} \quad (5)$$

Finally, this cost was used to interpolate the values of Table 1 for the ASI thus:

$$ASI = 5 + \frac{17920 - 16710}{30940 - 16710} = 5.09 \quad (6)$$

This procedure was applied to predict the ASI corresponding to the impact conditions for each of the 91 full-scale tests shown in Appendix B. A small computer program SEVER was written to make the calculations. The program listing and input are included in Appendix D. Program output is shown in Appendix B.

With the added value ASI = MSI = 0, 92 pairs of ASI/MSI were available for comparison purposes. Calculated ASI values were plotted against the corresponding MSI terms to determine if any relationship existed between them. The results are illustrated in Figure 2. Overall, it appears that the MSI values are scattered throughout their range; however, the

Table 4. Expected values

INJURY	VEH	SPEED	SMALL	MED	LARGE	TOTAL
PDO	SUB	S1	2.3	5.0	7.6	15.0
		S2	15.3	6.3	7.2	28.8
		S3	8.0	4.2	2.7	14.9
		S4	2.3	.5	.5	3.3
		TOTAL	28.0	15.9	18.1	62.0
	MED	S1	4.8	.9	5.5	11.3
		S2	3.2	9.8	6.7	19.7
		S3	4.0	3.8	5.0	12.8
		S4	3.9	2.0	3.3	9.3
		TOTAL	15.9	16.5	20.5	53.0
	FULL	S1	6.0	4.5	7.4	17.9
		S2	11.4	10.3	11.3	33.0
		S3	15.8	7.5	6.8	30.0
		S4	3.2	1.5	2.5	7.2
		TOTAL	36.3	23.7	28.0	88.0
	TRUCK	S1	1.7	2.4	.8	4.9
		S2	3.9	4.0	2.7	10.6
		S3	4.4	3.5	1.4	9.2
		S4	1.8	1.0	.5	3.3
		TOTAL	11.8	10.9	5.4	28.0
INJ	SUB	S1	1.9	2.9	3.9	8.6
		S2	19.1	5.7	5.8	30.6
		S3	15.4	5.8	3.4	24.6
		S4	5.5	.8	.8	7.1
		TOTAL	41.8	15.2	13.9	71.0
	MED	S1	2.9	.4	2.2	5.5
		S2	3.0	6.8	4.2	14.0
		S3	5.9	4.1	4.8	14.7
		S4	7.1	2.7	3.9	13.7
		TOTAL	19.0	14.0	15.0	48.0

Table 4. Expected values (continued)

	FULL	S1	2.8	1.5	2.2 I	6.6
		S2	8.4	5.5	5.4 I	19.3
		S3	17.9	6.1	4.9 I	29.0
		S4	4.4	1.5	2.3 I	8.2
		TOTAL	33.5	14.7	14.8 I	63.0
	TRUCK	S1	1.4	1.4	.4 I	3.3
		S2	5.0	3.8	2.3 I	11.1
		S3	8.9	5.0	1.8 I	15.7
		S4	4.5	1.8	.7 I	7.0
		TOTAL	19.7	12.1	5.2 I	37.0
FATAL	SUB	S1	.3	.6	1.0 I	1.9
		S2	1.1	.5	.5 I	2.2
		S3	1.0	.5	.3 I	1.9
		S4	.7	.2	.2 I	1.1
		TOTAL	3.2	1.8	2.0 I	7.0
	MED	S1	.7	.1	.8 I	1.7
		S2	.3	.9	.6 I	1.8
		S3	.6	.6	.8 I	2.0
		S4	1.5	.8	1.3 I	3.5
		TOTAL	3.1	2.5	3.5 I	9.0
	FULL	S1	.7	.5	.9 I	2.1
		S2	.8	.7	.8 I	2.3
		S3	1.8	.9	.8 I	3.5
		S4	.9	.5	.7 I	2.1
		TOTAL	4.2	2.6	3.2 I	10.0
	TRUCK	S1	.5	.7	.2 I	1.4
		S2	.6	.7	.5 I	1.8
		S3	1.2	1.0	.4 I	2.6
		S4	1.2	.7	.3 I	2.3
		TOTAL	3.5	3.1	1.4 I	8.0

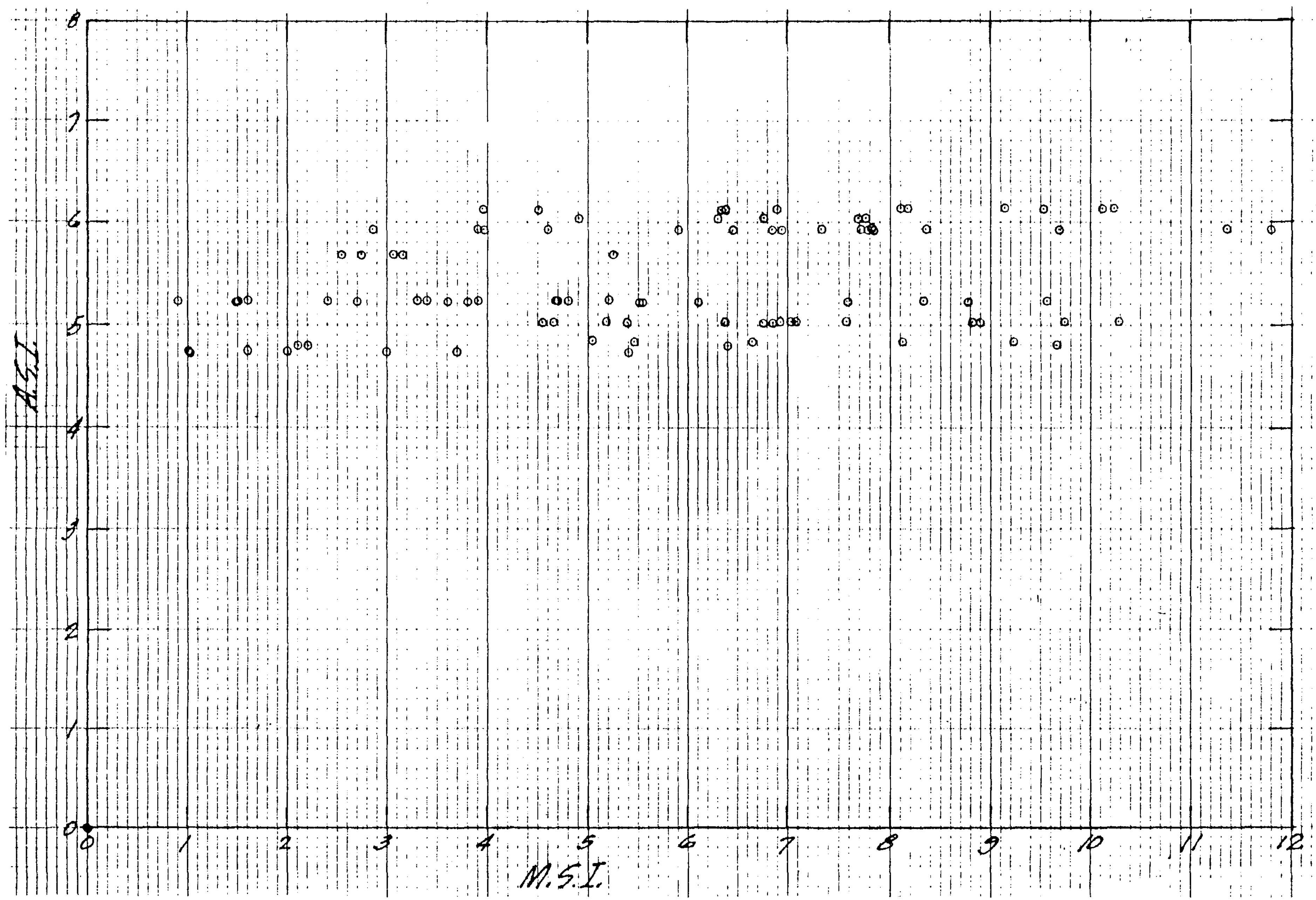

Figure 2. MSI/ASI plot with mathematical model

ASI values are clustered narrowly between 4.7 and 6.2.

The lack of a strong trend in the plot given in Figure 2 may be attributed to several factors. These include:

1. The low frequency of occurrence of fatalities in the study sample. Only 10 of the 412 accidents involved a fatality; this represents less than 2.5 percent of the accidents. With such a low frequency of occurrence, the impact of higher fatality costs in equation (5) was not realized. With lower costs, the severity indices in Table 1 were limited in their upper range.

2. Too many categories for the frequency counts in Table 3. With 144 categories and 412 observations, there was an average of less than four observations per cell if the variable combinations occurred randomly. Since the data were spread thinly about the table, it was possible for the accident severity index to remain relatively constant as illustrated in Figure 2.

3. An incorrect relationship between accident cost and severity. The calculation of ASI depends heavily on the relationship established in Table 1. If this were incorrect, it could result in ASI values that were not reflective of the actual accident severity.

4. Insensitive statistical model. The log-linear model in equation (3) may not have been sensitive enough to the changes occurring in the data.

Several approaches were taken to adjust for the factors listed above. To compensate for the lack of fatal accidents, the data were re-categorized using only two injury severity type variable values: PDO and injury-producing. Also, the speed variables were collapsed to $<$ 30, 31-50, and $>$ 50 mph in order to compensate for the problem of too many cell categories. This reduced the cell combinations from 144 to 72.

The results were similar to the above and are illustrated in Figure 3. The lack of spread in ASI values is even more pronounced than that given in Figure 2 with the full statistical model. Hence, this approach was not selected for further study.

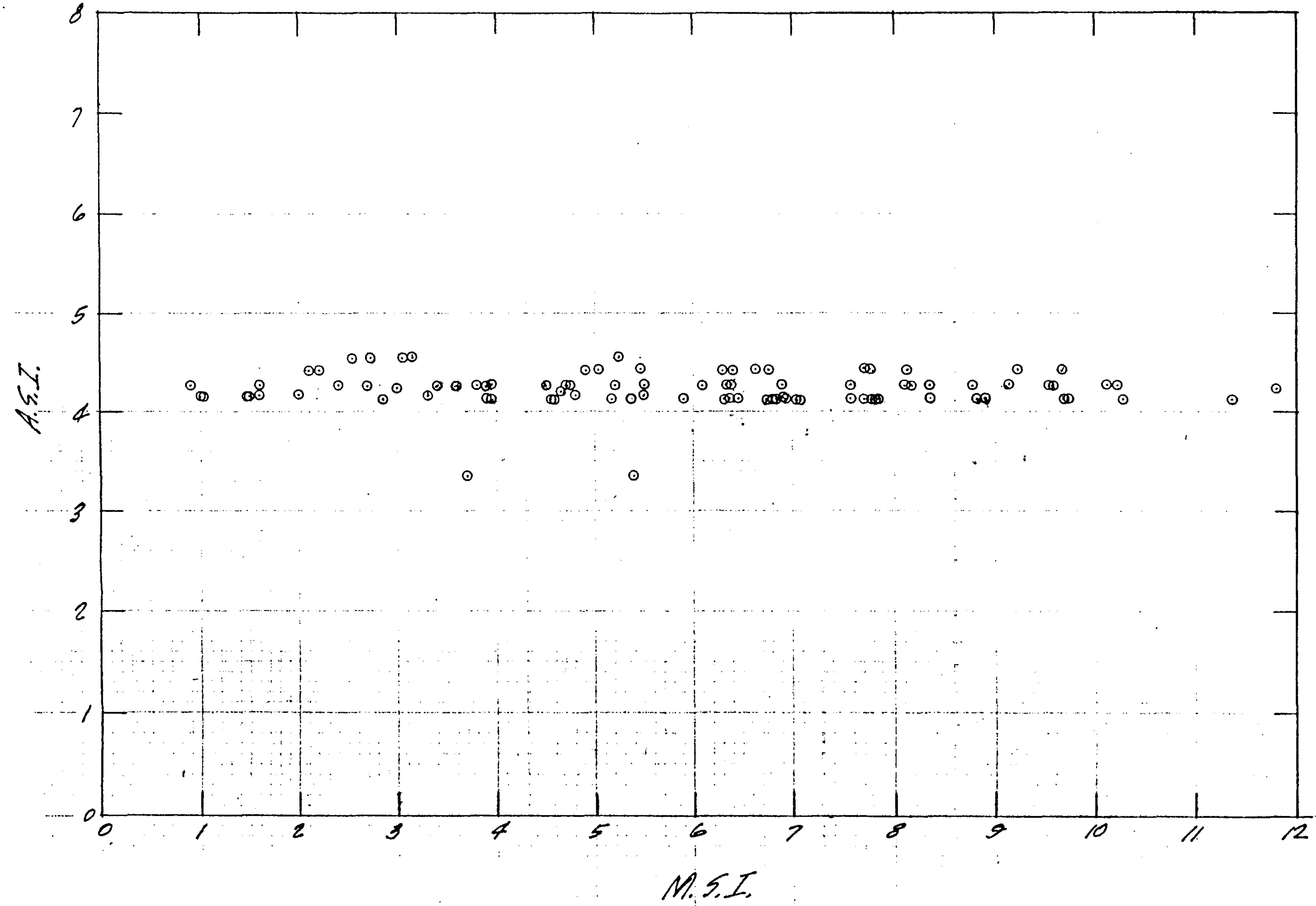

Figure 3. MSI/ASI plot with collapsed cells

A straight line of fit of the ASI versus cost relationship was utilized as an alternative to the exponential growth curve of Table 1 in order to determine the validity of the relationship. However, no improvement was noted in the MSI versus ASI curve, as shown in Figure 4. Hence, this approach also was abandoned.

With the relatively good correlation of ASI and impact speed (R^2 = 0.455), it was decided to try ΔV as the MSI rather than that of equation (2). The 91 full-scale test results were screened for those with sufficient information to determine ΔV, and the results are shown in Figure 5. It can be seen that the relationship is again poor; thus, this approach was also abandoned.

Finally, a check was made on the sensitivity of the statistical model. This was done by calculating the percentages of PDO, I, and F accidents in equation (4) using the actual observed values in Table 3 rather than the predicted values in Table 4. Also, the data points in the resultant plot were identified by vehicle weight to see if this factor indirectly influenced the relationship. The results are illustrated in Figure 6.

The spread in ASI was increased using the raw data, but no effect of vehicle weight was apparent. This spread effect is not unexpected since statistical modelling tends to reduce the apparent variation in data. Given the desire to see more variation in the ASI values rather than to obtain an ASI prediction model, it was decided to use these raw data results to establish the best fit of the ASI to the MSI. However, the largest R^2 value for any given fit did not exceed 0.10. Since better fits were obtained using the original fitted data of Table 4, the predicted rather than raw ASI values were fitted to the calculated MSI values (i.e., see Figure 2).

A polynomial fit to the data indicated that a fourth-degree fit was best. The R^2 value was 0.45 and the prediction equation was

$$\text{ASI} = 1.8706 + 2.7856(\text{MSI}) - 0.7232(\text{MSI})^2 + 0.07589(\text{MSI})^3 - 0.00275(\text{MSI})^4 \quad (7)$$

The point (0,0) was added to the data in this calculation, but the curve-fitting routine did not force the curve to pass through this point. A plot of the data is given in Figure 7.

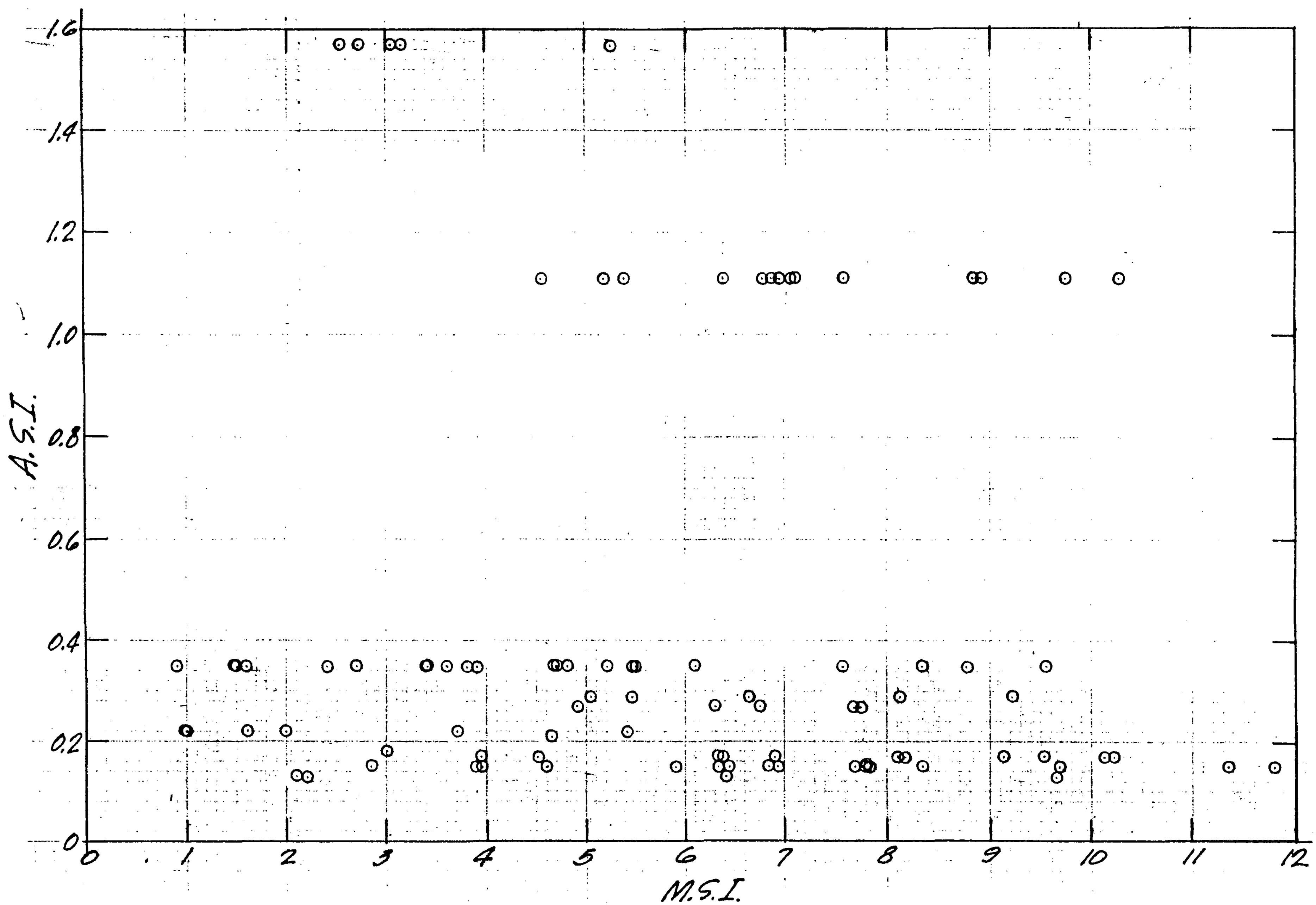

Figure 4. MSI/ASI plot with linear ASI/cost relationship

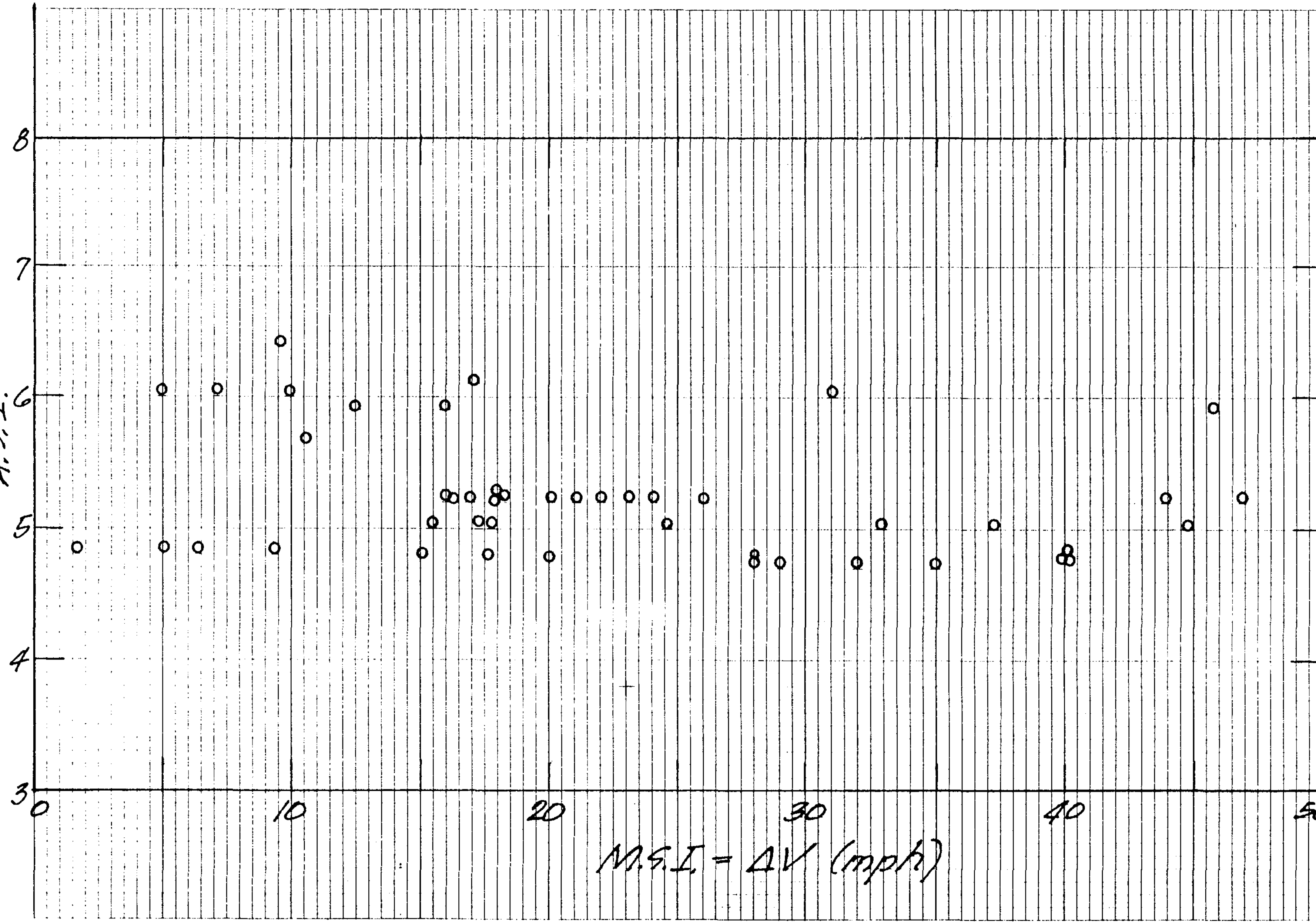

Figure 5. ASI versus MSI = ΔV

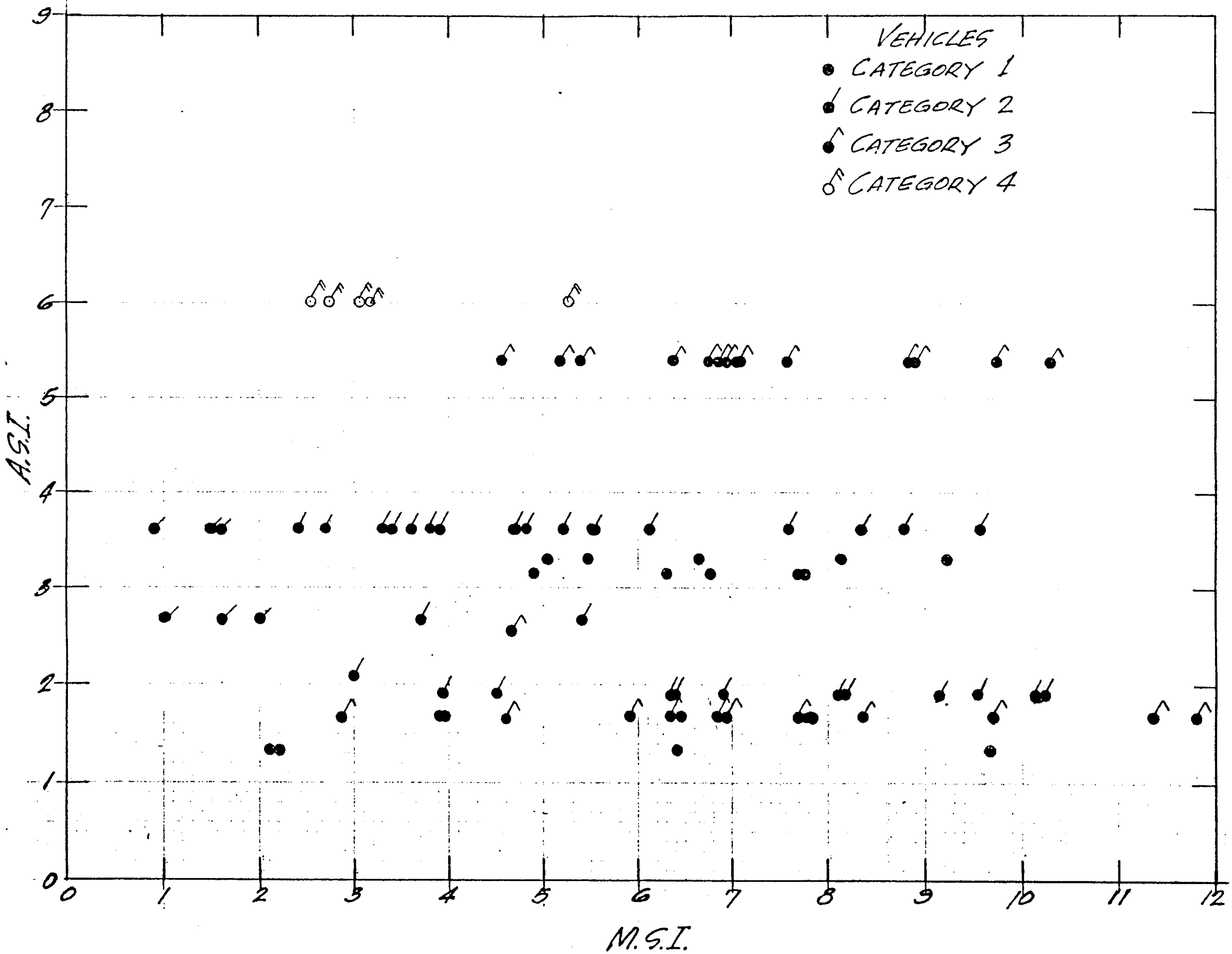

Figure 6. MSI/ASI relationship with raw data groupings and vehicle classes

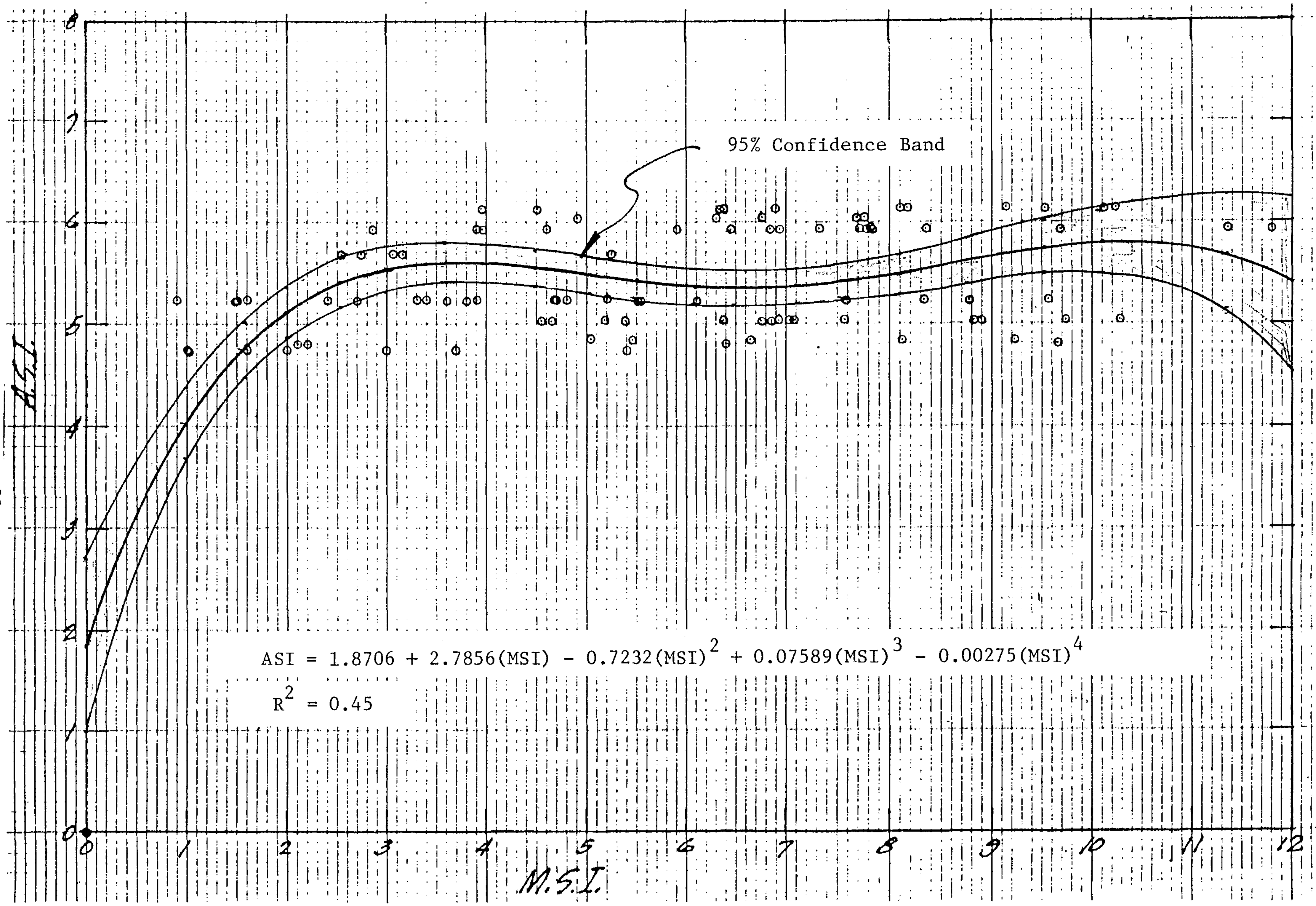

Figure 7. MSI/ASI relationship

6. Relative Mathematical Severities

The 412 accident cases used in this study are for all guardrail impacts (i.e., guardrail types were not specified as individual object types and the ASI values are average over all types). Until sufficient data is available to distinguish between guardrail types, some rationale is needed to modify these average values of ASI for a given guardrail under consideration. To do this, common BARRIER VII simulation runs on ten guardrail types were used from a previous SwRI study.(3) No customary 60 mph/25° impacts were simulated in the study, but common 50 mph/30° impacts were available. Results are shown in Table 5. The type C guardrail in the table is a W-beam system on blocked-out wood posts at 12'-6" spacing. The other types are those designations indicated in the AASHTO guide.(8)

The ratios of Table 5 look reasonable, both from the standpoints of approximately 1.00 for the commonly used "average" guardrail types G4(1S) and G4(2W) and from the expected increase/decrease in severity for the stiffer/softer guardrail types. A measured or simulated MSI value, as modified by its ratio to the corresponding MSI value of a known guardrail type, could be used to predict the corresponding ASI from the relationship of Figure 7. However, from the flatness of the curve, this refinement is probably not warranted.

7. Conclusions

Overall, specific conclusions to be drawn from this study are as follows:

1. The 412-accident data base was limited in its range of highly severe (i.e., fatal) accidents, but it had sufficient counts of PDO and injury accidents.

2. The accident severity index, as calculated, appears to be unrelated to the mathematical index across the sample points. When the origin is added to the data, a moderate relationship appears to exist. A nonlinear fourth degree polynomial curve-fit produced an $R^2 = 0.45$.

3. The results indicate that guardrails are performing to their standards in that expected severe accidents are reduced to low-injury-producing accidents.

Table 5. Relative mathematical severities*

(Use BARRIER VII Runs for 50 mph/30°)

Guardrail Type	2250-lb Vehicle				4500-lb Vehicle			
	Long.	Lat.	MSI	Ratios**	Long.	Lat.	MSI	Ratios**
GR2	7.04	5.68	9.05	1.06	4.12	4.37	6.01	1.15
G4(1W)	7.76	6.80	10.32	1.21	4.70	3.62	5.93	1.13
C	7.60	6.13	9.76	1.14	4.54	4.02	6.06	1.16
G4(2W)	6.25	5.64	8.42	0.90	3.70	3.66	5.20	0.99
G4(2S)	7.34	6.51	9.81	1.15	4.11	3.76	5.57	1.06
G1	3.00	4.76	5.63	0.66	1.60	2.56	3.02	0.58
G2	3.47	3.86	5.19	0.61	2.27	3.14	3.87	0.74
G3	6.61	6.30	9.13	1.07	3.94	3.60	5.34	1.02
G4(1S)	6.72	6.15	9.11	1.07	3.83	3.58	5.24	1.00
G9	6.67	5.89	8.90	1.04	4.67	4.00	6.15	1.17
		Averages	8.53				5.24	

*See Reference 3.

**MSI/Average of MSI's.

An obvious limitation in this study was the all-inclusive single object guardrail in the accident data. That is, the various types of guardrails in use were not specified as individual object types. This indistinction has customarily been used for severity measures in past studies. Other inaccuracies were introduced in both the full-scale test results and in the accident files. For example, only peak lateral and longitudinal accelerations are usually reported for full-scale tests and seldom occur at the same time in the test sequence. Also, it is well known that repeatability of full-scale tests is practically impossible and that variations in reported acceleration results exist. The Calspan accident data was based on police-reported data for vehicle speeds and impact angles, which are also subject to error. As a result, the MSI/ASI plot was expected to contain considerable scatter. Unexpected was the recalcitrant problem of lack of spread in the ASI values. An important finding could be inferred from the low, constant ASI values over the range of MSI values that guardrails are performing their intended purpose.

In accordance with impact severity procedures in NCHRP 153,(1) vehicle maximum 50-ms lateral and longitudinal accelerations have been measured in full-scale crash tests over the past decade. These values have been used in analytical formulations of severity (e.g., see equation (1)). Despite the known shortcomings of data mentioned above, the important consideration of this study was that a method would be developed by which these measured values could be used to estimate the probable in-service performance of the tested guardrail. As greater specificity of guardrail types was determined from the current National Accident Sampling System (NASS) investigation teams and corresponding ASI formulations are developed, refinements could be made in the technique.

This MSI/ASI relationship was predicated on the assumption that the MSI was a discerning characteristic of the full-scale tests. Though not completely definitive, Figure 6 indicates a trend that accident severity increases with vehicle weight. For a given impact condition, the opposite is true for the MSI. That is, vehicle accelerations decrease with increasing vehicle weight. Thus, this MSI is probably not a satisfactory measure. In NCHRP 230,(10) the update of NCHRP 153, impact severity has been replaced with occupant risk considerations, in which occupant impact velocity against vehicle interior and subsequent occupant maximum 10-ms ridedown accelerations are required. These quantities are more difficult to obtain than vehicle accelerations in that greater manipulation in the data reduction process is required. Determination of occupant risk factors from past tests would not be economically feasible. However, future measures, along with the more complete environmental data that is currently being taken in accident investigations, may provide a better relationship between full-scale test results and accident experience than that developed herein.

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