Accidents versus Width of Paved Shoulders on California Two-Lane Tangents - 1951 and 1952

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Two-lane rural tangents with paved shoulders were examined for the relation between shoulder width and injury accident rate. It was found that the accident rate tended to increase with shoulder width, except at traffic volumes below about 2000 vehicles per day, where the trend may be reversed. The effect appears to be controlled directly by shoulder width, rather than by other, associated, road factors.

● THIS report examines one-mile road sections of the California State Highway system satisfying the following conditions in 1951 and 1952: The roads were in rural areas, with 55-mph. nominal speed limits, and with no substantial roadside development. They were essentially straight and level; there were no curves which significantly restricted speed or visibility. The traveled way had two lanes, each 10 to 12 feet wide, of bituminous or concrete pavement.

The roads had paved or treated shoulders (some concrete but the large majority bituminous) bordered with not more than one foot of untreated or soft shoulder, as an average for the section. Roads were excluded if they adjoined long stretches of firm ground which could readily be used as shoulders by a motorist. Shoulder widths were generally uniform throughout a section, with a maximum variation of about one foot from the typical width used for the section. Practically all shoulders were easily visually distinguishable from the roadway, and none were in general use as extensions of the traveled way.

The condition of traveled way and of shoulders varied, of course, from road to road and from time to time during the two years considered. It is probable that the roads with narrow shoulders were in slightly poorer condition as a group than those with wider shoulders, but all the roads appeared to be in fairly good shape. Few of the roads are ever subject to snow or ice.

A list of sections which seemed generally suitable (two-lane, paved shoulders, etc.) was prepared originally on the basis of a 1952 survey of California roads. The sections were resurveyed in 1954 for the purposes of this study, and those sections were deleted that failed to satisfy fully the above conditions.

Accident data were taken from state records for 1951 and 1952. In order to minimize variation between the number of accidents which occurred and the number which were reported, only accidents involving personal injury were used. Accidents at structures and at intersections were excluded. Accidents involving private driveways were noted.

Estimates of average traffic volume (to the nearest 100 vehicles per day) were provided by the state division of highways for each section, for 1951 and 1952 separately.

Nearly every section was used for 2 years of data (two elements); a few were used for only 1 year (one element) because of extensive road work during the other year. In all, the data consist of 1,122 elements, each a 1-mile section with its shoulder width, traffic volume, and number of accidents, for either 1951 or 1952. The sections are nonoverlapping and each is essentially continuous. The data include 771 injury accidents.

ANALYSIS, UNGROUPED DATA

In choosing a theoretical curve to fit observed accident data, there is an advantage in using the square root of the number of accidents as the independent variable. It permits a fit to the data which is not unduly influenced by high-volume roads, since the variance of the square root is relatively constant[1] for all values of the dependent variables.

[1] Assuming that, under similar conditions of road and traffic, the number of accidents resembles a Poisson distribution.

The results of an earlier paper (1) suggested that, for roads of uniform length there should be a linear relation between the square roots of the number of accidents and of the traffic volume.

Accordingly, for each road section listed in Table 1, there were computed the square root of the number of accidents ($\sqrt{A}$), and the square root of the average traffic volume ($\sqrt{v}$). For each shoulder width (S), from S = 2 to S = 8, there was found the best-fitting line[2] of the form

$$\hat{\sqrt{A}} = a_0 + a_1\sqrt{v} \qquad (1)$$

The resulting values of the constants are:

S	a_0	a_1
2	+.022	+.104
3	-.058	+.084
4	-.081	+.125
5	-.208	+.124
6	-.201	+.138
7	-.406	+.180
8	-.369	+.172

It is seen that there is a pronounced tendency, as S increases, for a_0 to decrease and for a_1 to increase. (The relative steadiness of this variation is the basis for the principal conclusions of this study.) The relation may be well enough expressed by the equations

$$a_0 = .169 - .0710\ S \quad \text{and} \qquad (2)$$

$$a_1 = .0594 + .0146\ S \qquad (3)$$

These, substituted in Equation 1, yield

$$\hat{\sqrt{A}} = .169 + .0594\sqrt{v} + .0146\ S\sqrt{v} - .0710\ S \qquad (4)$$

(Throughout the paper, v is the average traffic volume, in hundreds of vehicles per day.)

It may be concluded that as shoulder width increases, the average square root of the number of accidents tends to increase for traffic volumes over about 2500 vehicles per day.

Equation 4 was based on shoulder widths S = 2 to S = 8 only, since for other widths the data were insufficient to establish reliable lines of form 1. The usual regression analysis, for all shoulder widths, yields a very similar equation:

$$\hat{\sqrt{A}} = .164 + .0548\sqrt{v} + .0155\ S\sqrt{v} - .0719\ S \qquad (5)$$

(The very low value of the correlation index, $R^2 = .18$, makes it difficult, however, to derive conclusions directly from this regression equation by testing for the significance of its coefficients.)

TABLE 1
INJURY ACCIDENTS, BY WIDTH OF PAVED SHOULDER AND TRAFFIC VOLUME

S	v	A	n	S	v	A	n	S	v	A	n	S	v	A	n
1	5	0	8	4	35	0	11	6	45	0	1	8	55	0	13
		1	2			1	8			1	6			1	8
	15	0	6			2	4			2	2			2	4
	35	0	1		45	0	3		55	0	6			3	3
		2	1			1	3			1	15			4	1
						2	1			2	5			5	1
2	5	0	4			3	3			3	3			6	1
		1	2		55	0	3		65	0	9		65	0	6
		3	1			1	2			1	3			1	6
	15	0	11			2	1			2	7			2	5
		1	2			4	2		75	0	1			3	4
	25	0	7		75	1	1			2	2			4	1
		1	5			2	1		85	3	1			5	2
		2	1		85	0	1						75	0	2
		6	1			1	1	7	5	0	3			1	2
	35	0	7						15	0	27			2	1
		1	5	5	5	0	39			1	8		85	2	6
		2	2			1	4			2	2			3	2
		3	1			2	1		25	0	14			8	1
	45	0	3		15	0	15			1	3		105	0	1
		1	1			1	1			3	1			1	1
		2	2		25	0	5			4	2			3	1
	55	0	1			1	2		35	0	2			6	1
		2	1		35	0	3			1	2		135	2	1
		4	1			1	3		45	0	1			3	3
						2	2			2	2				
3	5	0	11			4	1			3	1	9	15	0	16
		1	3		45	0	8		55	0	2			1	3
	15	0	11			1	6			1	2				
		1	2			2	1			4	2	10	45	0	2
	25	0	25		55	0	3		65	2	2		55	1	2
		1	8			1	1		75	1	1		85	3	1
		2	1			3	1		105	2	2			4	1
		4	1		65	0	3			3	4				1122
	35	0	17			1	1			4	1				
		1	9			2	1		135	0	1				
		2	4			3	1			2	2				
		3	1			4	1			3	1				
	45	0	10		75	1	1			4	1				
		1	6			2	2								
	55	0	4					8	15	0	31				
		1	3	6	75	0	21			1	16				
		3	1		15	0	46			2	2				
	65	2	1			1	21		25	0	46				
						2	5			1	18				
4	5	0	20		25	0	99			2	4				
		1	2			1	46			3	3				
		2	1			2	15			7	1				
		4	1			3	4		35	0	13				
	15	0	16			4	3			1	12				
		1	8		35	0	7			2	4				
	25	0	18			1	4		45	0	8				
		1	11			2	1			1	3				
		2	5							2	6				
		3	1							3	2				
										4	1				

Key. S - paved shoulder width in feet.
v - average traffic volume in hundreds of vehicles per day
A - number of injury accidents in one year for a one-mile section, as reported for 1951 or 1952
n - number of one-mile sections having the indicated values of S, v, and A.

[2]The line such that, for the (ungrouped) data of a given shoulder width, $\Sigma(\sqrt{A} - \hat{\sqrt{A}})^2$ is a minimum.

ANALYSIS, GROUPED DATA

We are concerned primarily with the relation between shoulder width and the expected number of accidents ($\hat{A}$), rather than the expected square root ($\sqrt{\hat{A}}$). This cannot be obtained by squaring both sides of Equation 4 since the square root of an average of values is not equal to the average of the square roots of the values. Grouping the data may, however, smooth out the scatter in accident rates sufficiently to permit valid analysis directly in terms of $\hat{A}$.

Table 2 shows the data of Table 1 combined into 22 points. From these the following regression equations were obtained:

$$\hat{A} = .243 + .00644v + .00225Sv - .0286S \quad (6)$$

$$\hat{A} = .092 + .00956v + .00171Sv \quad (7)$$

$$\hat{A} = -.006 + .02200v \quad (8)$$

TABLE 2
GROUP ACCIDENT DATA

Number of Road Sections	Shoulder Widths	Average Shoulder Width	Average Traffic Volume	Average No. of Accidents	
				Actual	Theoretical[a]
n	S	S	v	A	$\hat{A}$
31	1, 2, or 3	2 1	5	.32	24
32		2.2	15	.13	.35
49		2 7	25	55	.48
48		2 6	35	71	.60
22		2 7	45	.50	73
12		2 8	56[b]	1 17	88
89	4, 5, or 6	5.0	5	16	19
112		5 4	15	36	.37
209		5 6	25	.60	.56
44		4 8	35	75	.71
34		5 0	45	.94	.90
42		5 5	55	1.19	1 12
26		5 7	65	1 04	1.33
11		5 0	78[b]	1.45	1.48
108	7, 8, 9, or 10	7 8	15[b]	.32	.38
92		7 8	25	61	62
33		7 9	35	.67	86
26		8 0	45	1 23	1 11
39		7 9	55	1 33	1.35
26		7.9	65	1.77	1 59
17		8 2	81[b]	2.24	2.02
20		7 4	119[b]	2.60	2.78
1122					

[a] From Equation 6
[b] Volume groups of Table 1 combined to provide group of size n ≥ 10.

with values of R^2 of .946, .944, and .890 respectively. There is little to choose between Equations 6 and 7, but both fit the data significantly better[3] than does Equation 8, in which no effect is given to shoulder width.

Equation 6 indicates that accidents tend to increase with shoulder width for traffic volumes over about 1300 vehicles per day; Equation 7 indicates that the increase tends to occur at all volumes. The analysis of the ungrouped data agrees generally with Equation 6, which should therefore be favored — practically, the differences involved are small enough to neglect.

The scatter in the individual data is such that conclusions from grouped data may be affected by the method of grouping. The grouping used above is a natural one; produces a very high correlation for the theoretical formulas; the conclusions are consistent with those from the ungrouped data. For these reasons, the grouping used should yield results of fair reliability. Numerical values in the equations are not advanced, however, with any claim to precision for purposes of general prediction.

INFLUENCE OF OTHER FACTORS

The above analysis indicates that wider shoulders tend to be associated with higher accident rates in the data examined. It is important to try to determine whether this is a direct effect of shoulder width, or whether other factors correlated with shoulder width are responsible.

High traffic volumes were found predominantly in the wider shoulder-width sections. Restriction of the data to sections of less than 7000 vehicles per day produces a reasonably equable distribution of shoulder widths over the range of traffic volumes. The analysis of the ungrouped data was repeated for this restricted set of data, with very similar results. Hence, the conclusions reached do not appear to be due to an association between high traffic volumes and wide shoulders. This may be confirmed to some extent by examination of Figure 1, based on the grouped data.

Lane width varied only between 10 and 12 feet in the roads examined, but differences in lane width conceivably could be affecting the conclusions. To test this, best-fitting lines of the form

$$\sqrt{A} = a_0 + a_1\sqrt{v} \quad (9)$$

were found for the individual sections of 2- and 3-foot shoulder widths[4] and of 8-foot

[3] The F test shows that the differences in R^2 are significant at the .01 level.
[4] The widths were combined in order to obtain enough points for analysis.

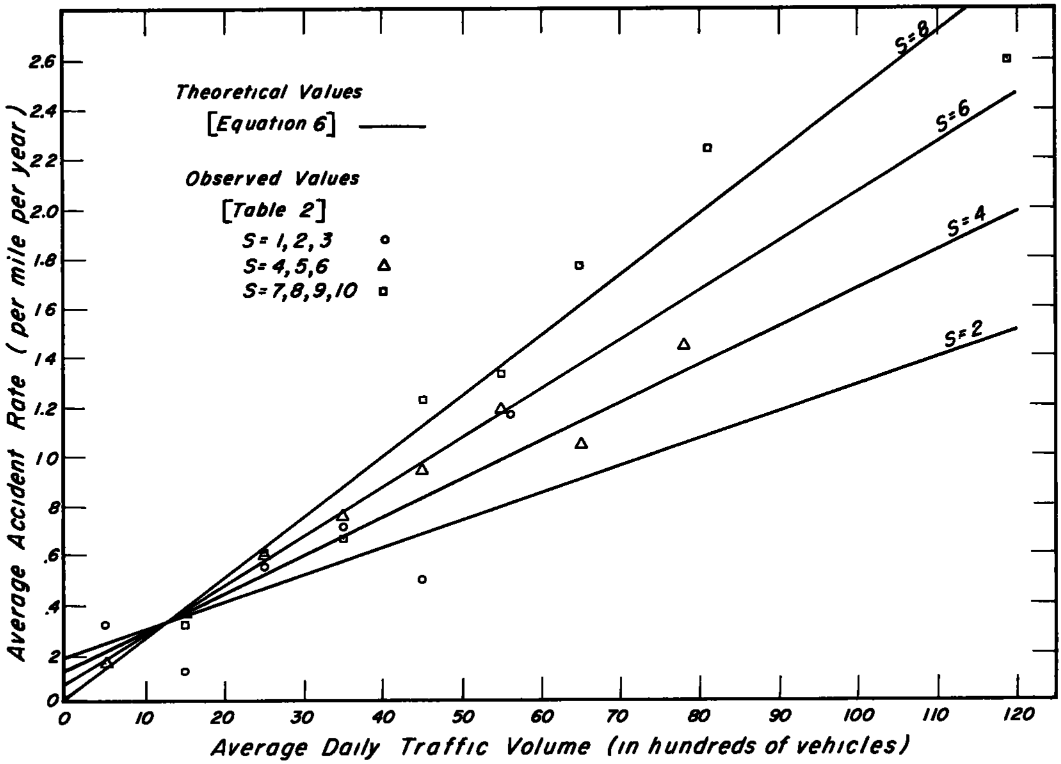

Figure 1. Average accident rate by shoulder width and traffic volume.

TABLE 3

Shoulder Width	Lane Width	No. of Sections	a_0	a_1
2 or 3	10	87	+.026	.075
8	10	44	-.795	.229
2 or 3	11	73	+.017	.084
8	11	145	-.317	.156
2 or 3	12	16	-.211	.128
8	12	58	-.413	.197
2	all	58	+.022	.104
3	all	118	-.058	.084
8	all	247	-.369	.172

shoulder width, keeping lane width constant. Resulting values of the constants are shown in Table 3, with comparisons from the previous analysis of the ungrouped data.

It is indicated that the previously noted effect of shoulder width on a_0 and a_1 holds also at constant lane width. Hence, the tendency for accident rates to increase with shoulder width does not seem to be attributable to an effect of lane width. (No attempt is made here to find the effect of lane width or of lane width plus shoulder width.)

Accidents at intersections were excluded from the data. Less than 2 percent of the accidents were reported to involve private driveways. Their exclusion would have an insignificant effect on the analysis.

More interesting is the influence of road condition and alignment. The roads with wider shoulders are generally the more recently constructed. They should be "better" roads: smoother, straighter, etc. No quantitative measure was taken, but in surveying the roads it appeared that there was such a tendency. It is thus possible that better surface or alignment[5], rather than wider shoulders, was responsible for the observed increase in accident occurrence. This possibility cannot be ruled out mathematically from the data at hand. However, it seems unlikely that such improvement in the roads would be sufficiently regular to account for the relatively steady progression observed in the values of a_0 and a_1 as shoulder width increases.

[5]The effect of occasional moderate curves, such as were present in some sections, is obscure[2].

A similar argument applies to other factors. Difference in type of traffic, difference in degree to which accidents are reported — these are important indeed, but unless they closely parellel shoulder width (at constant traffic volume) they can hardly be the major factors in the observed tendency for accident rates to vary with shoulder width.

Since the analysis was limited to injury accidents, the conclusions should refer only to such accidents. Injury accident rates sometimes diverge sharply from the trend of corresponding total accident rates, and it is conceivable that they do so with variation in shoulder width. Limitation to injury accidents would not seem, however, to detract greatly from the value of the conclusions.

CONCLUSIONS

In the roads examined a tendency was found for injury accident rates to increase with (paved) shoulder width, except at traffic volumes of less than about 2000 vehicles per day, where the trend may be reversed.

The indicated increase, as given by Equations 6 or 7, could be substantial. At 6000 vehicles per day the accident rate would be about 70 percent higher for 8-foot than for 2-foot shoulders, the difference decreasing linearly for decreasing volumes. These values may not be very accurate; they undoubtedly reflect to some extent the influence of hidden factors. In general form, however, the equations indicate what appears to be a primary association between shoulder width and accident occurrence.

This result differs in several respects from that of an earlier investigation (1). (They agree, however, that shoulders 6 feet in width are safer than wider shoulders at high traffic volumes.) The data on which the present study is based were collected under much better control than was possible for the earlier data. The conclusions of the present paper may therefore be advanced with more confidence than was justifiable for the previous work.

In the earlier paper, it was suggested that 6-foot shoulders should be safer than narrower shoulders because they afford greater emergency maneuverability and space to park off the roadway[6], and, perhaps, lead to greater average clearance between passing vehicles. Apparently these advantages are more than offset by a tendency for drivers to be less careful. As shoulder width increases, drivers may gain an unjustified feeling of security. Speed may increase, with an attendant rise in accident rate.

In the roads examined, shoulder width appears to control a significant portion of the accident rate over a considerable range of traffic volumes. For a very dissimilar set of roads, the effect may be different. Only a thorough understanding of the mechanism by which shoulders affect accidents would permit safe extrapolation. It would be remarkable indeed, however, if this study described a merely local phenomenon.

ACKNOWLEDGMENTS

The data for this study were provided by the Traffic Department of the California State Division of Highways, through the courtesy of George M. Webb, state traffic engineer. The cooperation of R. J. Israel, of the Accident Analysis Section, was of the greatest assistance throughout. Israel and Oliver Arnold undertook much of the road survey on which the quality of the data so largely depends.

References

1. Belmont, D. M., "Effect of Shoulder Width on Accidents on Two-Lane Tangents," Highway Accidents and Related Factors, Bulletin 91, Highway Research Board, 1954, p. 29-32.

2. Raff, Morton S., "Interstate Highway — Accident Study," Traffic-Accident Studies, Bulletin 74, Highway Research Board, 1953, p. 29.

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[6] Most of the roads here studied afforded fairly frequent opportunities for a vehicle to park off the roadway, regardless of shoulder width.

Discussion

J. AL HEAD, Oregon State Highway Department — The evidence given in Belmont's paper appears to prove conclusively that there is a marked tendency for personal injury accident rates to increase with the width of paved shoulders, except at traffic volumes of less than 2,000 per day. Belmont has statistically excluded traffic volume and lane width as the cause of relationship between the number of personal injury accidents and shoulder width and has logically, though not statistically, excluded most other possible causes. He concluded that wide shoulders result in the tendency for drivers to be less careful and possibly to drive at an increased speed, thereby increasing the injury rates. It is unfortunate that speed checks weren't made to prove this point, since this seems to be the problem.

It should be stressed that these findings apply only to personal injury accidents. This is an important qualification, since motor-vehicle accidents not involving personal injury constitute the major portion of total accidents. In Oregon 85 percent of all accidents reported in 1953 were noninjury accidents. Reported accidents in Oregon cover approximately 75 to 80 percent of total accidents, and those not reported are virtually all of the noninjury type. It is expected, though not proved conclusively, that Belmont's findings do not apply to the noninjury rate.

The phenomenon of higher injury and fatality rates, but lower noninjury rates on "better" roads with wider shoulders has been observed in Oregon. In a preliminary cost-of-accidents study for Oregon highways it was found, in fact, that the monetary loss resulting from accidents on improved roads — with wider shoulders — may be higher in an extreme case than for the road before improvement, because of the increase in the personal injury and fatal accident rates. This results from the fact that the personal injury and fatal accidents which are assigned high monetary values, tend to increase as the road becomes "better," although total accidents may decline.

In view of this, it would appear that further study of shoulder widths to total accident rates should be made. Belmont's previous study on shoulder widths, included in Highway Research Board Bulletin 91, was made on a total-accident basis, and this may have been, in part, the reason for the different conclusions. That is, that wider shoulders may tend to increase the personal-injury accident rate but decrease the total rate.

Finally, it may be concluded that the answer to the findings might be to improve the signing, or the center striping, or the lighting, or possibly to increase state patrolling on the wide-shouldered highways rather than recommend narrow shoulders. Such steps might reduce speed, cause drivers to be more careful, and allow the advantages of wider shoulders. Belmont enumerates these advantages as greater maneuverability, space to park off the roadway, and greater passing clearance. It also appears that there is an area for greater study of this subject which Oregon is undertaking under Belmont's direction.

W. R. BELLIS, Chief, Traffic Design and Research Section, New Jersey State Highway Department — I must compliment Belmont on his courage to face the facts even though they are apparently contrary to his own previous convictions. Too often such observations are filed in the waste paper basket.

I have for a long time advocated wide shoulders; in fact, I have considered shoulders as wide as 18 feet (in order to get stopped vehicles at a comfortable distance from the pavement) and I feel that I would still advocate wide shoulders in spite of the Belmont report.

Belmont has stated that a reason to support the findings could be that drivers become less attentive with wide shoulders than with narrow shoulders. I cannot concur with this excuse. Neither can I concur with the deduction that because speeds are higher with wider shoulders accidents are higher.

Shoulders, narrow or wide, do not cause accidents. The use of these shoulders could cause accidents. I would assume that a 2-foot-wide shoulder would not be used as often as an 8-foot-wide shoulder and that a significant number of accidents are caused directly or indirectly by vehicles slowing down on the pavement to use the shoulder or accelerating on the pavement after having stopped on the shoulder. The large

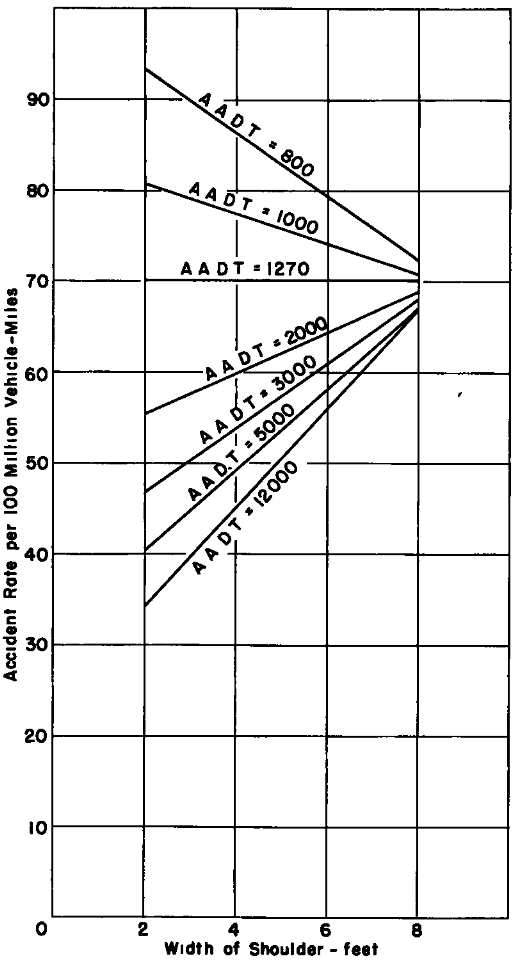

Figure A.

differential in speed between the through vehicle and the shoulder user could produce accidents which, in accident reports, appear as many types not necessarily directly related to the shoulder.

I feel sure that the belief that speed causes accidents can be, or has been, satisfactorily disproven. Some of our highest speed roads prove to be the safest. The New Jersey Turnpike has a very low accident rate compared to other highways in New Jersey.

I imagine that the two lane tangents selected for the Belmont report experience higher speeds than the average California highway and also has lower accident rates. I say this because this group of road sections has a low accident rate. As I interpret it, the rates vary from 39 to 68 injury accidents per 100 million car-miles. The injury accident rate per 100 million car-miles on New Jersey state highways was an average of 215 in 1951 and 208 in 1952.

On the New Jersey Turnpike it was found that a reduction in accidents followed the adoption of a regulation to use the shoulders for emergency breakdowns only. Off the road parking areas are now provided for leisure stops. We have found in a preliminary study that there is one emergency stop for each 7,500 car-miles and one stop, including emergency and leisure stops, for each 300 car-miles. The observation for the emergency stops was at a location where there were no shoulders and impossible to stop except on the roadway.

The function of the shoulder is closely related to the roadway capacity. For small volumes a two-lane road can serve satisfactorily without a shoulder but as the volume increases a volume is reached at which the emergency stops on the pavement restrict the capacity to less than the capacity of the two lanes unobstructed. Rather than providing additional roadway lanes, shoulders can provide a place for emergency stops without the restriction to capacity. But the shoulder then makes leisure stops inviting with a resulting increase in potential conflicts.

I have plotted the data differently using Belmont's Equation 6 (see Figure A). Note that the low volume roads follow the general logical assumption; that is, that wider shoulders produce greater safety. The vast majority of roads nationwide have volumes of less than 1,000 cars per day, therefore, our thinking has developed along experiences on these roads and, therefore, we expect that wider shoulders produce safety. For the larger volumes apparently our experiences are not sufficient to develop logical thinking which agrees with fact.

Although I am willing to accept the possibility indicated in this study, I am not willing to recommend narrow shoulders. Although Belmont's Figure 1 indicates that wider shoulders have a higher rate of accidents, the attached figure shows that wide shoulders on high volume roads are safer than narrow shoulders on low volume roads.

I would like also to see these data analyzed on a basis of hourly volume instead of average daily traffic volume. A study that I am making shows a possibility that the accident rate per 100 million car-miles is high during low hourly volumes and low during high volume hours and follows a definable variation.

KARL MOSKOWITZ, California Division of Highways — The pains with which seemingly extraneous factors were excluded from Belmont's analysis may have resulted in excluding so many road sections and accidents that the remaining sample is too small for conclusions. By the time all of these data were rejected, the number of accidents was so small (one accident for each 2 million vehicle-miles) that it would indeed prove difficult to show any association of rates with either wide or narrow shoulders. There simply isn't any room for improvement.

Fortunately (or unfortunately, if Belmont's conclusions are correct) for the California motorist, almost all roads carrying considerable volumes of traffic have either "wide" shoulders or all-paved sections (and even the narrow-shoulder roads almost always have widened, nongraded areas where disabled vehicles may seek refuge). This made it difficult to obtain a sample which was well distributed both as to shoulder width and traffic volume. As a result, it is noted that 350 of the 1.122 sections are in the 2,500 ADT group, and 259 of the 350 are in the 6-, 7-, 8-foot group. The 6-, 7-, 8-foot group includes 526 of the 771 accidents and 669 of the 1,122 1-mile-year elements.

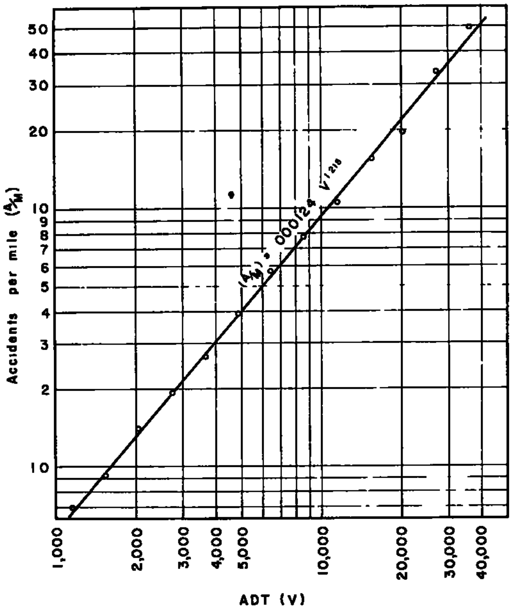

Figure A. Accidents versus traffic volume, 120,675 accidents 1944-1950, 1 to 4 lanes.

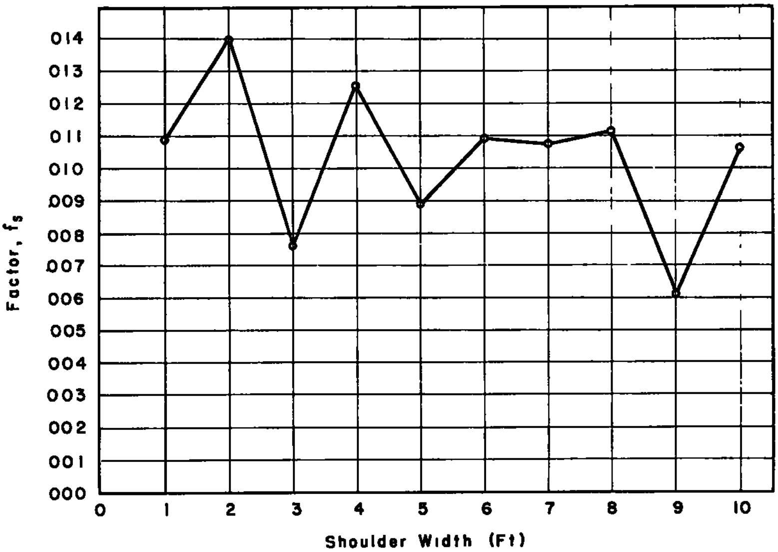

Figure B. Shoulder factor in equation $A = f_s V^{1.2}$.

It is believed that this bunching of the data in both directions on the plane of the independent variables may have obscured the relationship between those variables and the accident-per-mile rate. It is also believed that the 100 accidents which were recorded on narrow (1-, 2-, 3-foot) shoulder roads were not sufficient to establish the true effect of traffic volume in those ranges, and since the wide shoulder sections have considerably more traffic on the whole, the effect of traffic volume is extemely important. This belief is reinforced by the observation that all of Belmont's equations will give accidents with no volume at all.

It is the writer's opinion, based on an analysis of 120,000 accidents occurring during a 7-year period on 12,000 miles of rural undivided highways (Figure A) that the effect of volume may be expressed

$$A = bv^{1.2} \qquad (9)$$

where A and v are as in Belmont's paper and b is a constant when all other variables are distributed without regard to volume. If shoulder width has an effect, it should appear as

$$A = f_S V^{1.2} \qquad (10)$$

where f_S = a function of the shoulder width.

Equation 10 has been applied to Belmont's data. The data in Table 1 were divided

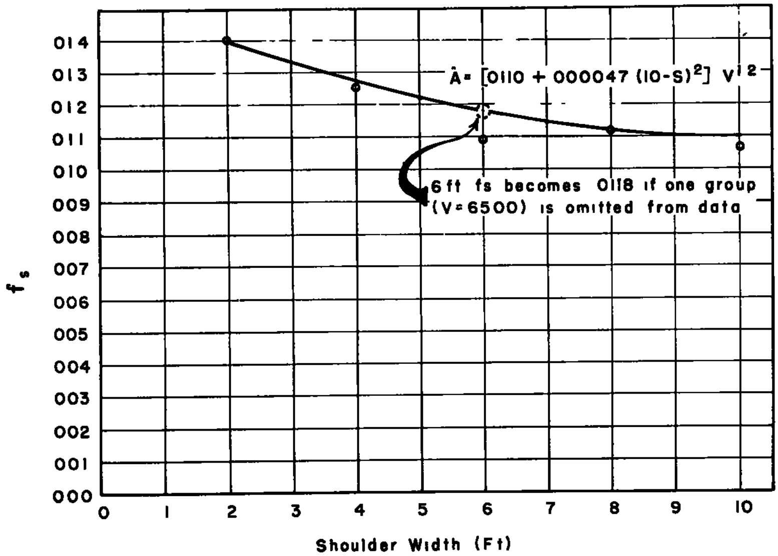

Figure C. Shoulder factor in equation $A = f_s V^{1.2}$, using even widths of shoulder.

into 64 groups, one group for each combination of S and V. The f_S shown on Figure B is from these groups, with $R^2 = 0.72$. Belmont's Equation 6 gives $R^2 = 0.78$ for the same groups.

Now, it will be noted that the data include nine elements with an ADT of 13,500. This is extremely high volume for a 55-mile-per-hour, rural, two-lane road. If these nine elements are excluded from the data, Figure b gives $R^2 = 0.76$ and Equation 6 gives $R^2 = 0.77$. It is recognized that a curve with as much freedom as that of Figure B would naturally have an advantage in R^2 over a more-rigid curve. Nevertheless, it is equally representative of the facts existing in the particular sample of 1,122 sections here considered; the sum of the squares of the deviations is no greater.

Instead of showing "a clear tendency for accident rates to increase as shoulder width increases," Figure B seems to show no clear tendency, unless it would be that shoulders of odd-numbered widths in feet have lower rates than those having even-numbered widths.

Figure B also suggests a tendency for the accident rate to decline as S increases among roads having shoulders of even-numbered widths in feet. If a relation between shoulder width and accident rates exists in the data as a whole, it should exist in the data for shoulders in the 2-, 4-, 6-, 8-, and 10-foot groups by themselves. Figure C shows this relationship. In this figure, the freedom was greatly restricted by giving the curve an equation,

$$A = [0.0110 + 0.000047(10-S)^2]\, v^{1.2} \qquad (11)$$

The index R^2 for this equation was $R^2 = 0.66$, but again omitting the 13,500 ADT groups is $R^2 = 0.68$, compared with 0.74 from Equation 6 using the same groups (which now comprise 572 accidents in 768 elements). In the writer's opinion, this difference in R^2 is not enough to explain the diametrically opposite conclusions of Equation 6 and Equation 11. Furthermore, if one group (S = 6, V = 65, A = 21, n = 22) is omitted (because it is clearly out of line with both equations), R^2 becomes 0.76 for both equations.

It is not contended that Equation 11 is a true picture of what all of the data show. It is contended that it is as good a picture of what three-quarters of the data show as Equation 6 is of what all the data show. Now, if three-quarters of the data, spread all the way through from 2-foot to 10-foot shoulder widths, show exactly the opposite of what all the data show, then it is contended that all the data don't show anything. And the reason is believed to be as stated in the opening paragraph of this discussion: there are so few accidents that there simply isn't any room for reduction.

Unfortunately (for science) there does not seem to be any prospect of obtaining, in California, sufficient "pure" data on roads having narrow shoulders and carrying large volumes of traffic ever to settle the question unequivocally.

Belmont's paper again reminds us that an accident is, literally, an accident. It is not an effect which can be attributed to a cause. Only by apposition of very large numbers of accidents with correspondingly large numbers of road-sections having measurable characteristics can reliable associations with those characteristics be established.

Belmont states at one place that we are concerned primarily with the expected number of accidents, rather than the expected square root. Likewise, are we not interested in total accidents, including PDO, intersection, and others, and are we not interested in finding the relation between total accidents and designed width of shoulder, because it is for design purposes that we want the information? If a designed 6-foot shoulder turns out to be 8 feet or vice versa, we still want to know the effect of designing it to that width.

The writer feels that the sample would be greatly expanded and more useful if total roadway width were used as the variable, instead of total width minus "surfaced" width divided by two. He also believed that cutting down the sample by eliminating PDO accidents not only increases the variability by reducing the size of sample, but also introduces an unnecessary item of chance, namely the chance that an injury may take place among identical collisions.

C. E. BILLION, Principal Civil Engineer, Vehicle Operation Section, Bureau of Highway Planning, New York State Department of Public Works — Belmont is to be commended for continuing his efforts to evaluate the relation between shoulder width and injury-accident rates. While the author's evidence of this relationship is quite persuasive, the meaning of it based on the basic data involved is not clear. If wide shoulders create traffic turbulence, the essential elements indicating the why and when are still unknown. Until additional and more-extensive studies yield conclusive results, the effect of shoulder width on traffic should not be adopted for design purposes.

It is of prime importance to keep in mind that Belmont's analysis pertains only to two-lane rural highways with paved shoulders and that most of the sections in the study afforded frequent opportunities for a vehicle to park off of the shoulder in event of an emergency or leisurely stop. This is a study of special-type shoulders and certainly the results can not be interpreted as applying to highways with unpaved shoulders.

Due to differences in functional use of shoulders throughout the country, the term shoulder should be defined in definite terms as a guide for future studies.

Some thoughts provoked by the conclusions of the Belmont report are as follows: Suppose the statistical results of both studies are sufficiently accurate to warrant the given conclusions. These studies were made exclusively on predominantly straight and level sections with: "paved or treated shoulders, some of concrete but the large majority bituminous with not more than a foot of untreated or soft shoulder. Practically all shoulders were easily visually distinguishable from the roadway and none were, in general, used as extensions of the traveled way."

From the 1948 study and to some extent from this study, the author arrived at basically the same conclusion, that for volumes of 5,500 vehicles per day or less, corresponding to approximately the peak hour practical capacity, wider shoulders appear to be as safe as the 6-foot shoulders. At volumes greater than 5,500 vehicles per day, or at volumes in excess of the practical peak hour capacity, the accidents per mile of highway for wide shoulders equal those on the narrow shoulders and exceed those on the 6-foot shoulders.

Exploring these results for a possible explanation, consider a narrow shoulder, say 2 to 4 feet wide. There is insufficient room for a vehicle to pull off the pavement, except at turnouts, but how many drivers run a flat tire very far, and how far will a dead engine run in order to park off the pavement? Under these conditions, narrow shoulders conceivably contribute to accidents at any volume, with more effect at high volumes. Consider a 6-foot shoulder, or one just sufficiently wide to enable a disabled or parked

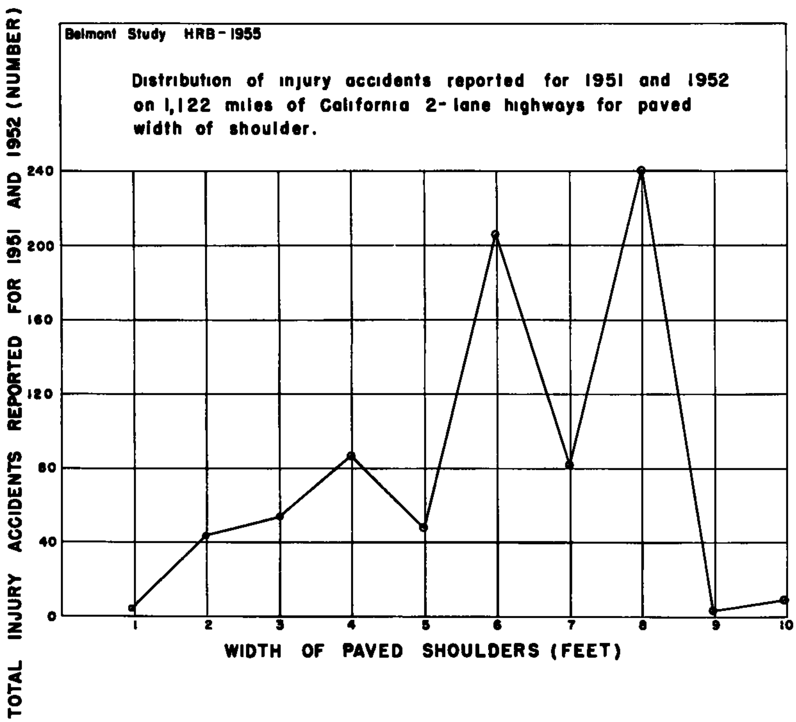

Figure A.

car to get completely off the pavement. This is a safe width perhaps for cars but not for trucks, and truck traffic runs up to 25 percent of the total traffic on rural roads.

Consider a shoulder wider than 6 feet, paved with bituminous-surface treatment or possibly concrete, which in most cases is visually distinguishable from the pavement itself. Both studies show that up to practical capacity wide shoulders are as good as others, if not better; but over that volume, wider shoulders seem to induce more accidents than do the narrow, 6-foot shoulders. It seems logical that a wide paved shoulder in a rural area would tend to attract traffic if the pavement itself was carrying traffic beyond its practical capacity. A careful and detailed analysis of actual operation during peak hours of traffic should be made before assigning accidents to shoulder width when the shoulders are paved and apparently fit for traffic. In New York an addition of concrete to the edge of the pavement is certainly considered as part of the pavement, in the nature of widening. In California, possibly these wide paved areas lead to partial three- or four-lane operation during peak hours. It appears that paving wide shoulders would encourage drivers to use them for traffic.

We would be remiss not to mention that in New York the state waiver of immunity in the Court of Claims Act does not accept explanations for defective shoulders. The shoulders must be considered an integral part of the highway, both as a necessary part of the construction and as a safety precaution to afford a refuge in case of emergency and to give clear vision for safe and comfortable driving.

The following nonstatistician engineer analysis using a linear relation has been made with Belmont's data, in an attempt to compare the theoretical data against the actual data: In this study, as well as in the Belmont study using the 1948 data, multiple regression formulas to fit the data into a statistical pattern were derived as a basis for a theoretical analysis. The basic data are quite erratic in distribution, as shown by Figures A and B. Figure A shows the distribution of the injury accidents for the various widths of paved shoulders, while Figure B shows the accident distribution by ADT. Tables A and B contain the supporting data.

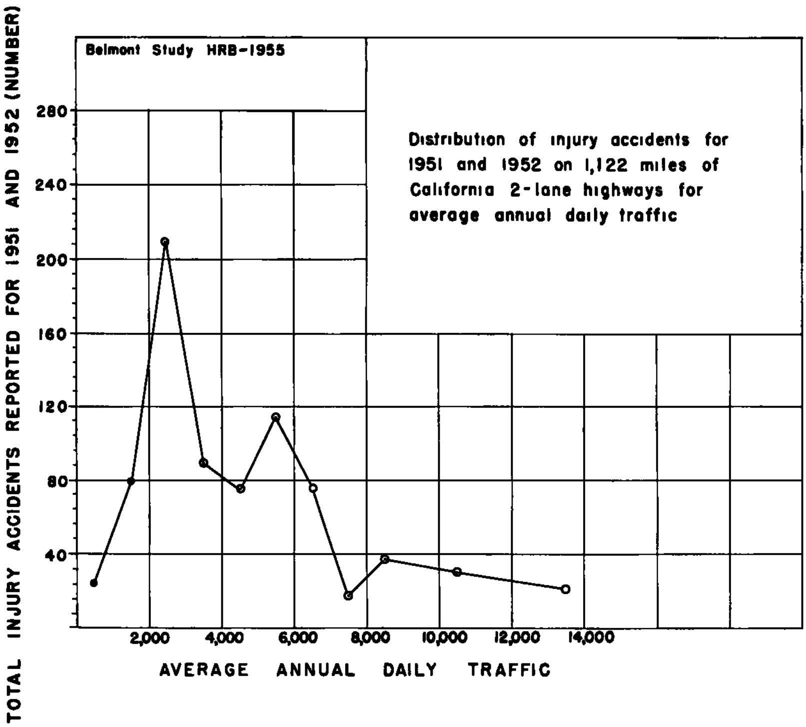

Figure B.

On a comparative basis, the sampling appears quite adequate for 3-, 4-, 5-, 6-, and 8-foot shoulder conditions but is small for the other widths. Also, the majority of the mileage studied has ADT counts of under 2,500. This may have been all properly weighed in the regression formulas.

Using the study data and combining all volumes recorded by shoulder width and relating the reported accidents by rates per million vehicle miles, the relation between shoulder widths and accidents per MVM, as shown in Figure C, was computed. There was about twice as much travel on the highway sections with even-width shoulders than on those with odd-width shoulders, with an accident ratio of three to one. Examining Figure C, it is seen that the highest accident rate for the highway sections with shoulders of odd-foot width is lower than the lowest accident rate for highway sections with shoulder widths of even footage.

Considering the even and odd shoulder sections separately, it is apparent that the accident rates decrease with the increase of shoulder width but that the decrease is too small to be significant. On this basis, and from the available data, one can not readily say that shoulder widths affect the accident rate. Surely it can not be said that the accident rate increases with increase in shoulder width after the "optimum" shoulder width of 6 feet is reached. Referring to Figure 1 of the Belmont report, it is noted that for the plotting of the observed values, values for the even-width shoulders are combined with

TABLE A
DISTRIBUTION OF INJURY ACCIDENTS FOR SHOULDER WIDTH AND MILEAGE

Shoulder Width	Total Accidents	Mileage
1	4	18
2	43	58
3	53	118
4	86	128
5	47	106
6	205	333
7	81	89
8	240	247
9	3	19
10	9	6
Totals	771	1122

TABLE B
DISTRIBUTION OF INJURY ACCIDENTS FOR ADT AND MILEAGE

ADT	Total Accidents	Mileage
500	24	123
1500	79	249
2500	209	350
3500	89	125
4500	75	82
5500	114	92
6500	75	53
7500	17	14
8500	37	14
10500	30	11
13500	22	9
Totals	771	1122

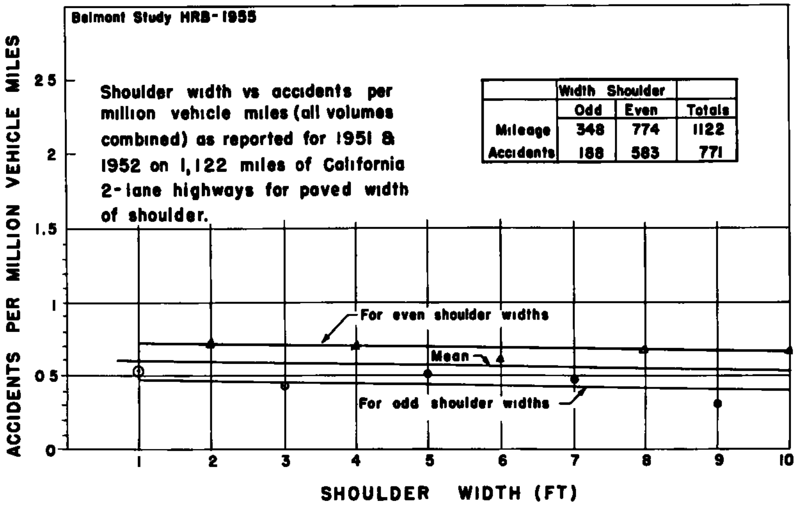

Figure C.

those for the odd-width shoulders. The impact of the above analysis may be balanced out by such combinations.

In this study, the statistical analysis indicates an extremely fine distinction in accident rates versus shoulder width for volumes projected far beyond those actually investigated. The plottings of the actual data gives curves which do not show a great deal of consistent significant variation in accident rates according to shoulder width.

Table C and Figures D and E, were compiled from the data shown in Table 1 of the report. It is apparent that there is little, if any, significant variation in accident rate by shoulder width (Figure D.)

Figure E shows the relation of accident rate to shoulder width for volumes under practical capacity and for volumes over practical capacity (practical capacity equals 900 VPH, peak hour = 0.167 ADT).

Design considerations are based on peak hour practical capacity. The lower curve (Figure E) then would be used for design and indicates that 6-foot shoulders would have no advantage over wider shoulders.

1. Considering the type of detail in the analysis, the quantity of data appears inadequate to support the conclusions.

2. It appears that the volume of traffic has a much greater effect on accident rates than shoulder width, i. e., accident rates on overloaded highways will jump.

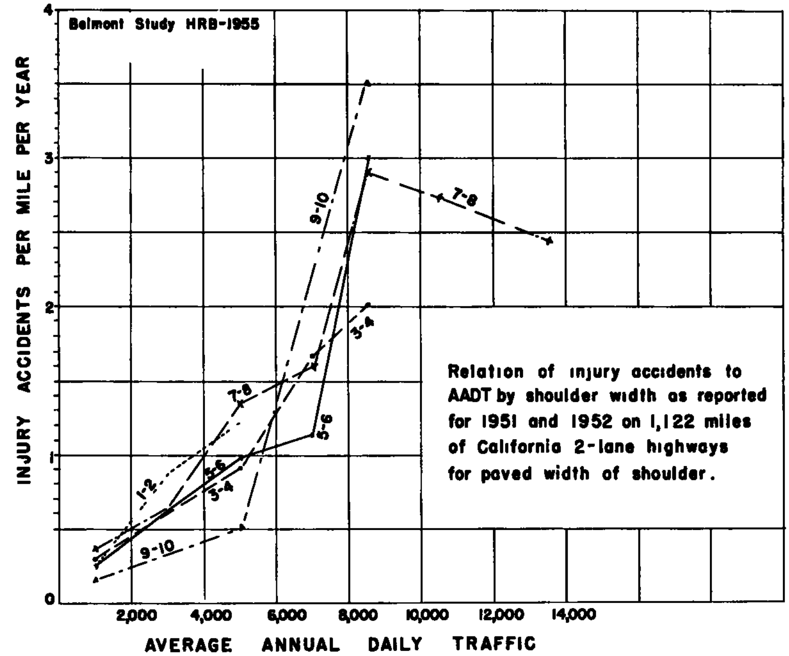

Figure D.

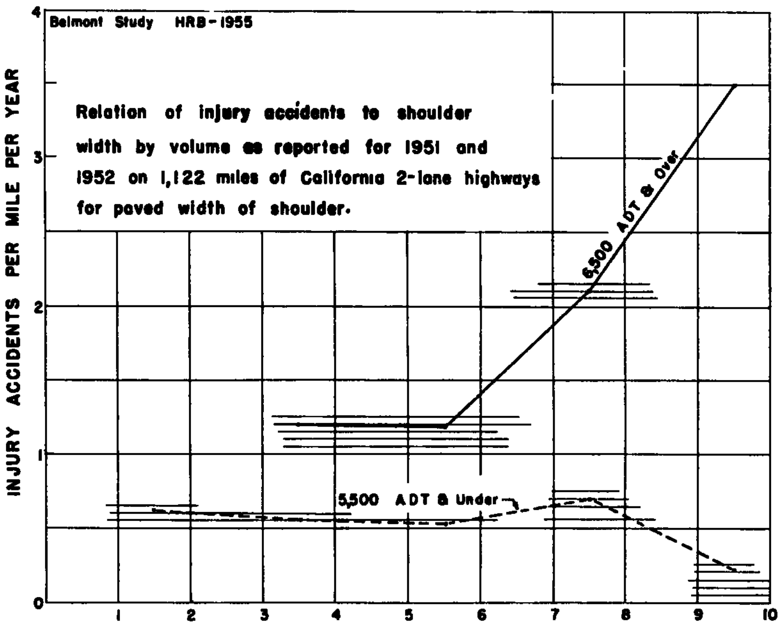

Figure E.

3. Extreme care should be used in the analysis of traffic operation on highways with wide paved shoulders in order to ascertain the reason for the seemingly unwarranted rise in accident rate.

TABLE C
ACCIDENTS BY SHOULDER WIDTH & ADT IN HUNDREDS
FROM BELMONT STUDY — TABLE 1

S	ADT	n	A	A/n	ADT	n	A	A/n
1-2	5-15	36	9	.25	5-55	76	47	.62
	25-35	31	27	87				
	45-55	9	11	1 22				
3-4	5-15	75	21	.28	5-55	241	133	.55
	25-35	124	74	.60				
	45-55	42	38	.90				
	65-75	3	5	1.67	65 & over	5	6	1.20
	85	2	1	2.00				
5-6	5-15	153	38	.25	5-55	406	213	.52
	25-35	195	119	.61				
	45-55	58	56	.97				
	65-75	32	36	1.13	65 & over	33	39	1.18
	85	1	3	3 00				
7-8	5-15	89	32	.36				
	25-35	125	78	.62	5-55	275	192	.70
	45-55	61	82	1.34				
	65-75	32	51	1.59				
	85	9	26	2.89	65 & over	61	129	2.11
	105	11	30	2.73				
	135	9	22	2 44				
9-10	15	19	3	.16	5-55	23	5	.22
	45-55	4	2	.50				
	85	2	7	3.50	65 & over	2	7	3.50
Totals		1122	771			1122	771	

S = Average paved shoulder width in feet
ADT = Average daily traffic in hundreds of vehicles per day
n = Number of one-mile road sections
A = Number of injury accidents in one year for a one-mile section as reported in 1951 or 52
A/n = Rate of injury accidents per mile per year

4. Comparison with unpaved shoulders would be very desirable.

It may be that the negative conclusions based on the absence of a significant linear relationship between accident rates and shoulder widths may be quite compatible with the more complicated relationship found in the report. However, it is quite apparent that a wide variety of data, over a comparatively long period, are necessary to arrive at significant relations between highway accident occurrence and shoulder width.

D. M. BELMONT, Closure — The criticisms are based on a preliminary draft of my paper, and advantage was taken of some of them in preparing the paper in its present form. I am grateful for the many useful suggestions and for the elaborate and interesting analyses of the data.

Before discussing some of the adverse criticisms it should perhaps be mentioned that I do not pretend that my paper proves conclusively any relationship between accidents and shoulder width. But proof in such matters is not yet a reasonable goal. We need first to accumulate much evidence. The question here is merely in what direction, if any, do the data seem to point.

Billion's main criticism is that, when all volumes are combined, accident rates show no tendency to increase with an increase in shoulder width (see his Figure C). My Equation 6 may suggest that the accident rate should increase, but only for ADT over about 1,300. And this increase does occur, on the whole. Shown below are the observed accident rates per million vehicle-miles for volumes over 1,000 vehicles per day.

S	acc/10^6v-m	
1	0.38	
2		0.69
3	.41	
4		.66
5	.48	
6		.61
7	.67	
8		.67
9[a]	.29	
10[a]		.67

[a] The rates for shoulder widths of 9 and 10 feet should be disregarded since they are based on very few sections. The 9-foot width is all at v = 15, consistently the volume with the lowest accident rate.

It is apparent that, in accordance with Equation 6, these accident rates increase with odd shoulder widths. The agreement is much poorer for the even widths, but not as bad as is suggested by Billion's curve. For shoulder widths as a whole, the tendency shown is for accident rates to increase with shoulder width.

The wide scatter in the data is unfortunate, but it does not follow that significant underlying patterns cannot be discerned. The apparent difference between the odd and the even widths is particularly puzzling, and I can offer no explanation. My analysis is based on the assumption that the difference is a random effect; it is hard to believe that the "real" accident rate zig-zags as shoulder width increases. Perhaps it is worth mentioning that the rate for the 2-foot shoulder width in the above table falls from 0.69 to 0.59 if the one mile of extremely high accident rate is omitted.

Moskowitz calculates a shoulder factor, f_s, for each shoulder width. He notes that f_s decreases with shoulder width (in Figure C) and claims that this sharply contradicts my conclusions for a large majority of the data. But variation in f_S need not correspond to variation in accident level.

Consider the following example:

S = 2

v	A	n
10	1	1
20	2	1

S = 8

v	A	n
10	1	1
20	2	1
30	3	1
40	4	1
50	5	1

The accident rate per vehicle mile is identical for each section. Yet f_S is here 0.049 for S = 2, and 0.043 for S = 8.

Actually f_S depends upon both the accident level and the extent to which accidents are proportional to $v^{1.2}$. The latter proportionality may hold for many roads, but it is not characteristic of our data (perhaps because of a difference between injury accident rates and total accident rates, or because of elimination of intersections in our data). If the appropriate corrections were made, Moskowitz's analysis would, I think, be practically identical with Billion's.

Moskowitz claims that the observed accident rates are so low that it must be difficult to show much connection with shoulder width. The difficulty lies, however, in the distribution of the accident rates, rather than in their absolute size. By changing only shoulder-width values, it would be easy indeed to produce a clear and impressive shoulder-accident relationship.

Bellis offers an interesting alternative to my conjecture as to why accidents may increase with shoulder width. Perhaps both our reasons apply. I agree with Bellis that analysis by hourly traffic volume would be most desirable.

Head stresses the probable difference between injury and noninjury accident trends. I feel that California records of noninjury accidents are inadequate for a study of the effect of shoulder width. The effect, if any, would be too easily swamped by the variance in degree of accident reporting. Oregon's remarkable accidents records, however, may well yield significant results in the study now being undertaken.