A COMPARISON OF THE SAFETY POTENTIAL OF THE RAISED VERSUS DEPRESSED MEDIAN DESIGN

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This paper examines the safety benefits of the mound (raised) median design as compared to the swale (depressed) median design for Interstate highway medians having an 84-ft (25.6-m) design width. The effects of each median design on the frequency and severity of median-involved single-vehicle accidents, on the path of the encroaching vehicle, and on the vehicle's tendency to overturn were studied. Approximately 130 miles (209 km) of 4-lane, divided highway with each median design were studied, and the accident experience from 1969 through 1971 was analyzed. The results indicated that the 84-ft median of either cross-sectional design provides a generally adequate recovery area for encroaching vehicles, although the swale median appears to provide more opportunity for encroaching vehicles to regain control and return to their roadway. The use of either cross-sectional design for medians of this width has no effect on the primary path of the vehicle, on the vehicle's tendency to overturn, or on the resulting severity of the accident when a median encroachment results in a reported accident.

•THE current emphasis on highway safety as evidenced by the Interstate Upgrading Program and the Spot Improvement Program has once again raised the question concerning the safety benefits of the raised (mound) median design when compared to the depressed (swale) median design. There are, of course, other factors, primarily economic, that may influence the final selection of the median design. Although the effects or potential benefits of these economic factors are easily predicted, the potential safety benefits of the median design are not so easily predicted.

Ohio is in the unique position of being able to determine empirically the safety benefits of the mound median design and the swale median design because it constructed a significant portion of its Interstate System with the mound design. Ohio also has a computerized accident record system, which makes the determination of safety benefits a feasible undertaking.

PURPOSE AND SCOPE

The objective of this study was the determination of the safety potential of the mound (raised) median design versus the swale (depressed) median design. The safety potential of each design was determined by the frequency and the severity of median-involved single-vehicle accidents occurring on sections of Interstate highway with each type of median design.

The study involves 125 miles (200 km) of Interstate with the mound median design and 135 miles (217 km) of Interstate with the swale median design. Both types of median have a design width of 84 ft (25.6 m) (Figure 1). Three sections with the mound median design were selected for study. These were I-75 near Toledo, I-71 between Cincinnati and Columbus, and I-70 from the Indiana border to Dayton and

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Figure 1. Typical median cross sections.

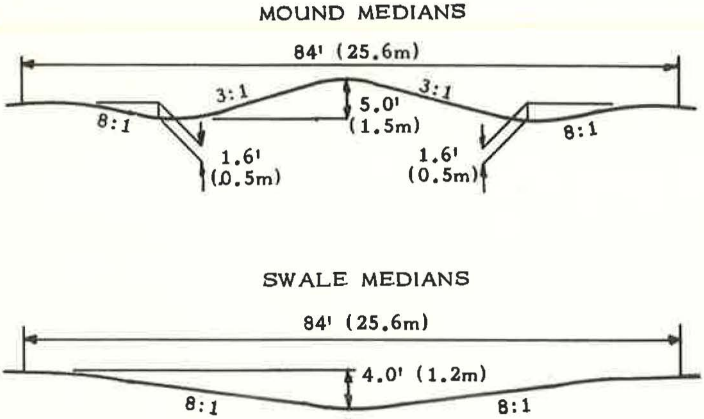
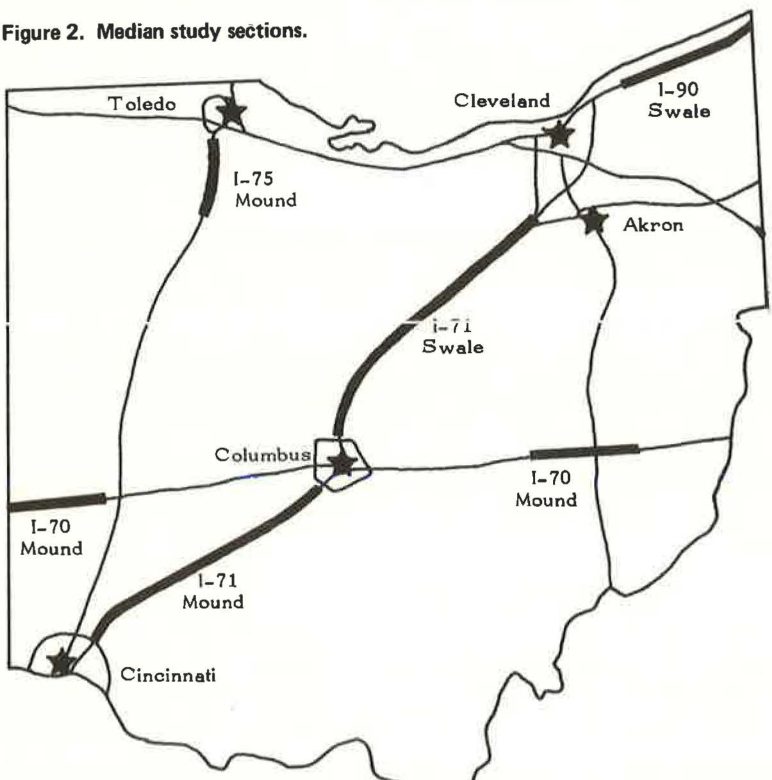


Figure 2. Median study sections.



from Zanesville to Cambridge. Two sections with the swale median design were selected for study. These were I-71 between Columbus and Medina and I-90 east of Cleveland (Figure 2). All sections selected for study were 4-lane, divided highways. Accident records for 3 years, 1969, 1970, and 1971, were used in the investigation.

PROCEDURE

To make a determination of the safety potential of each median design, it was felt that the following questions would have to be answered:

1. Does the median design affect the frequency of reported traffic accidents involving the median?
2. Does the median design affect the severity of accidents involving the median?
3. Does the median design affect the path of the vehicle after it enters the median during an accident?
4. Does the median design affect the roll-over tendencies of vehicles after they enter a median during an accident?

The sections of Interstate under study were field-inventoried to determine the location of all interchanges, structures, and median abnormalities (catch basins, roadways of unequal elevation, crossovers, etc.), and to verify the widths shown in the Road Inventory File prepared by the Bureau of Transportation Technical Services. The finite lengths of roadway to be included in the study were then formulated by eliminating all lengths of roadway between interchange terminals, all roadway 0.01 mile (0.16 km) either side of a structure, and all roadway 0.01 mile on either side of an abnormality.

These finite lengths of roadway were then matched with the computerized accident records in order to determine the accident frequency subdivided by the following types:

1. Median-involved single-vehicle accidents,
2. Non-median-involved single-vehicle accidents, and
3. All multivehicle accidents.

Once the frequencies were obtained, copies of the police investigation reports for those accidents involving the median were obtained for detailed analysis. These reports were reviewed manually to determine the path of the vehicle involved in the accident, the type of vehicle involved in each accident, and whether or not the vehicle rolled over during the accident.

ANALYSIS AND RESULTS

The analysis was structured to answer each of the four questions given previously. The first question concerned whether or not the median design affected the frequency of reported accidents. The term "reported" is used to emphasize the fact that the number of accident reports may not accurately indicate the number of incidents in which a vehicle leaves the roadway but, more accurately, will show the number of times in which the result of leaving the roadway was severe enough to be reported to the police. One valid measure of the safety potential of a given median design would be the number of times that "incidents" involving vehicles entering the median did <u>not</u> become "reported accidents". However, since figures such as these are not currently available, it is necessary to interpret reported accidents only.

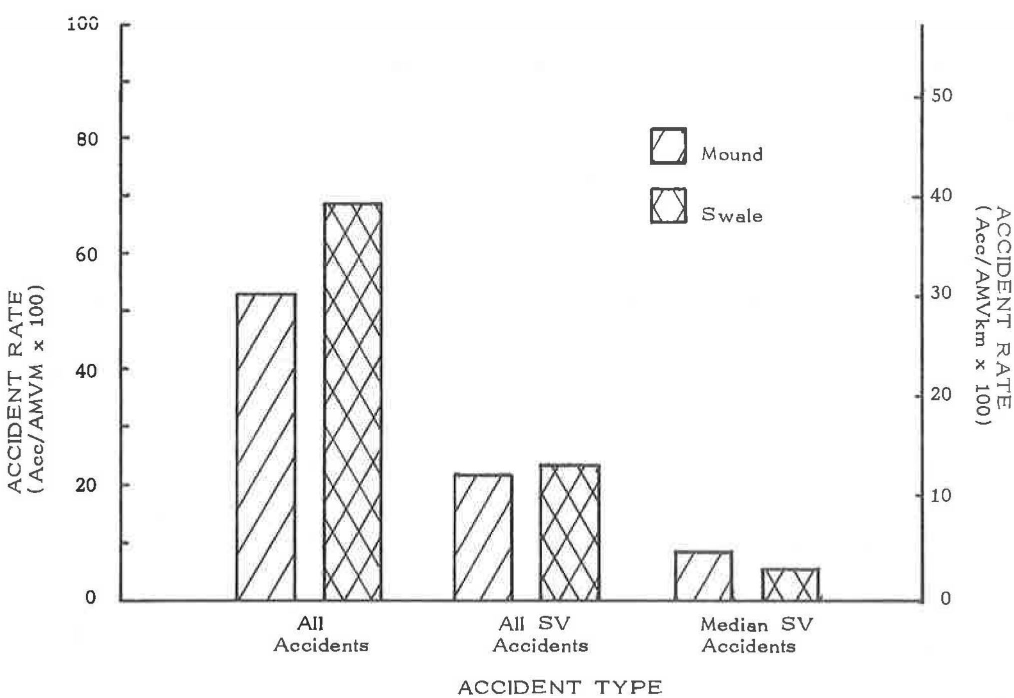
In this analysis, it is assumed that the frequency of vehicles leaving the roadway is primarily proportional to the volume of traffic, since all other design features are similar except the median design. It is then assumed that any difference in the reported accident frequency, after taking volume into account, would be the result of the median design. This assumption is substantiated by previous research for volumes in excess of 6,000 average daily traffic (1, 2, 3). Table 1 gives a summary of the accident statistics for each median design and includes a general description of the volume characteristics of each type of design. It can be noted that the average daily traffic for the two types of median design differs by approximately 1,600 vehicles (11 percent), with the higher volume being carried by the sections with the swale

Table 1. Summary of accident statistics for study sections.

	Median Design	
Category	Mound	Swale
Routes		
Sections	I-71 S. of Columbus I-70 I-75	I-71 N. of Columbus I-90
Length, miles	124.19	135.23
AMVM, 3 years	1,838.62	2,409.85
ADT (average)	14,011	15,617
Total accidents		
Number	952	1,604
Fatal accidents	12	29
Severity index	0.41	0.32
Accidents/mile	7.67	11.86
Accidents/AMVM	0.52	0.67
All single-vehicle accidents		
Number	378	541
Fatal accidents	2	13
Severity index	0.43	0.33
Accidents/mile	3.04	4.00
Accidents/AMVM	0.21	0.22
Median single-vehicle accidents		
Number	125	122
Fatal Accidents	1	4
Severity index	0.40	0.43
Accidents/mile	0.99	0.90
Accidents/AMVM	0.07	0.05
Other single-vehicle accidents		
Number	253	419
Fatal accidents	1	9
Severity index	0.39	0.33
Accidents/mile	2.05	3.10
Accidents/AMVM	0.14	0.17

Note: Severity index = Fatal accidents + Injury accidents ÷ (Total accidents).

Figure 3. Comparison of accident rates.



median design. Figure 3 shows the difference in the accident frequency between the median designs, expressed as the number of accidents per 100 annual million vehicle-miles of travel. It can be seen that the accident rate for the swale design is higher for total accidents and for single-vehicle accidents. However, when considering median-involved single-vehicle accidents, the accident rate is higher for the mound median design. The significance of this difference in accident frequency was ascertained by employing a chi-square contingency test (Table 2). In this test, the number of median-involved single-vehicle accidents was compared with the number of non-median involved single-vehicle accidents and the multivehicle accidents. The underlying hypothesis in this test is that if the median design had no effect on the frequency of reported accidents, the distribution of accidents for all accident types for each median design would be equal. The results of this test indicate that the difference in the number of reported accidents between the median designs is significant.

The significantly lower number of reported median-involved single-vehicle accidents occurring on sections with the swale median design implies that more vehicles encroaching into the median are able to regain control and return to the proper roadway on sections with the swale median design than on sections with the mound median design.

The second question to be answered concerned the effect of median design on the severity of reported accidents involving the median. Figure 4 shows the percentage of median-involved accidents by severity for both the mound median design and the swale median design. In order to test for a statistical difference in the number of injury-producing accidents, a chi-square contingency test was used (Table 3). The results of this test indicate that there is no difference in the number of injury-producing median-involved accidents for the two median designs.

The third question concerned the path of vehicles after entering the median. For the purposes of this analysis, the following vehicle paths were defined:

1. Vehicle entered the median, traveled across the median, entered the opposing roadway, and came to rest either on or off the opposing roadway;
2. Vehicle entered the median, traveled along the median, and came to rest in the median; and
3. Vehicle entered the median, was redirected by the median, reentered the original roadway, and came to rest either on or off the original roadway.

These paths were titled "crossover", "median", and "redirect" respectively. All head-on multivehicle accidents that involved the median were included in the crossover category.

Figure 5 shows the percentage of median-involved accidents by vehicle path for both the mound and swale median designs. Approximately 81 percent of the vehicles entering the median of either design remained in the median. The proportion of crossover accidents was approximately equal for both median designs, as was the proportion of redirect accidents. Table 4 gives the results of the chi-square contingency test conducted to ascertain the significance of the slight differences in the number of accidents of each type between the two median designs. The results indicate that there is no difference between the two median designs in the number of accidents for each vehicle path.

The next step in the analysis was to determine the effect of vehicle path on the resulting severity of median-involved accidents. Figure 6 shows the severity index (ratio of injury-producing—including death—accidents to total accidents) by vehicle path for both median designs. A chi-square contingency test was employed to test the difference in the number of injury-producing accidents between the two median designs for each of the median paths individually. The results of these tests, at the 5 percent significance level, are as follows:

1. For the median path (81 percent of the median-involved accidents), there is no difference in the number of injury-producing accidents between the designs.
2. For the crossover path (11.5 percent of the median-involved accidents), there is a significant difference in the number of injury-producing accidents between the

Table 2. Chi-square test for difference in number of reported accidents.

Accident Type	Median Design	
	Mound	Swale
Multivehicle	574 (609)	1,063 (1,027)
Non-median single-vehicle	253 (250)	419 (422)
Median single-vehicle	125 (92)	122 (155)

Note: ( ) = Expected cell frequency.

Hypothesis: There is no difference in the number of reported accidents between the two median designs.

$\chi^2 = 22.193 \qquad \chi^2_{0.05} = 5.991$

Result: Reject hypothesis.

Figure 4. Severity of median accidents.

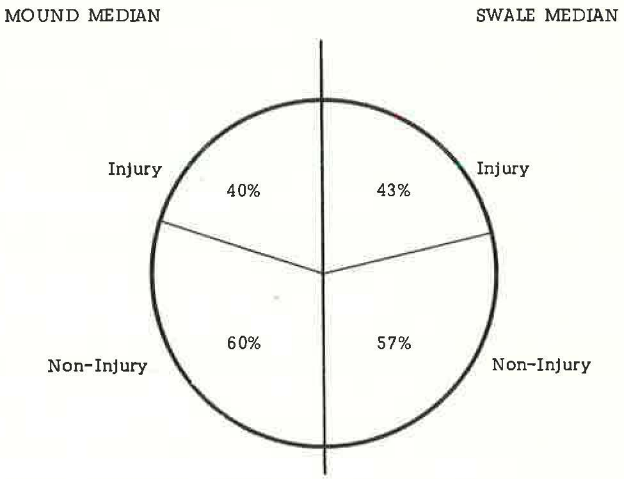


Table 3. Chi-square test for difference in number of injury-producing accidents.

Accident Type	Median Design	
	Mound	Swale
Injury	50 (52)	52 (50)
Non-injury	75 (73)	70 (72)

Note: ( ) = Expected cell frequency.

Hypothesis: There is no difference in the number of injury-producing accidents between the two median designs.

$\chi^2 = 0.96 \qquad \chi^2_{0.05} = 3.84$

Result: Accept hypothesis.

Figure 5. Path of vehicle in median accidents.

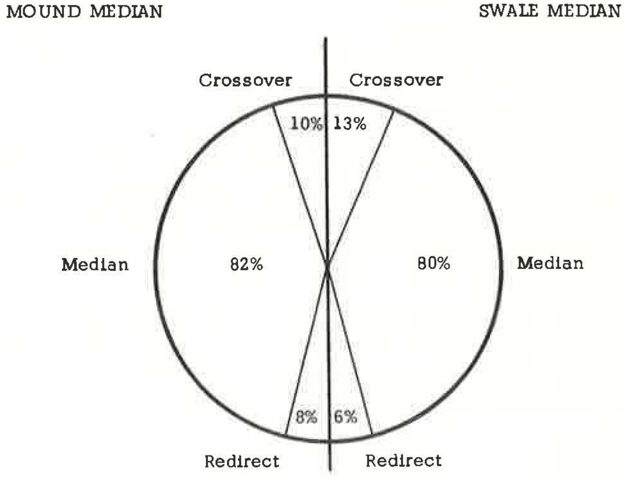


Table 4. Chi-square test for difference in number of accidents for each vehicle path.

	Median Design	
Vehicle Path	Mound	Swale
Crossover	12 (14)	16 (14)
Median	103 (102)	98 (99)
Redirect	10 (9)	8 (8)

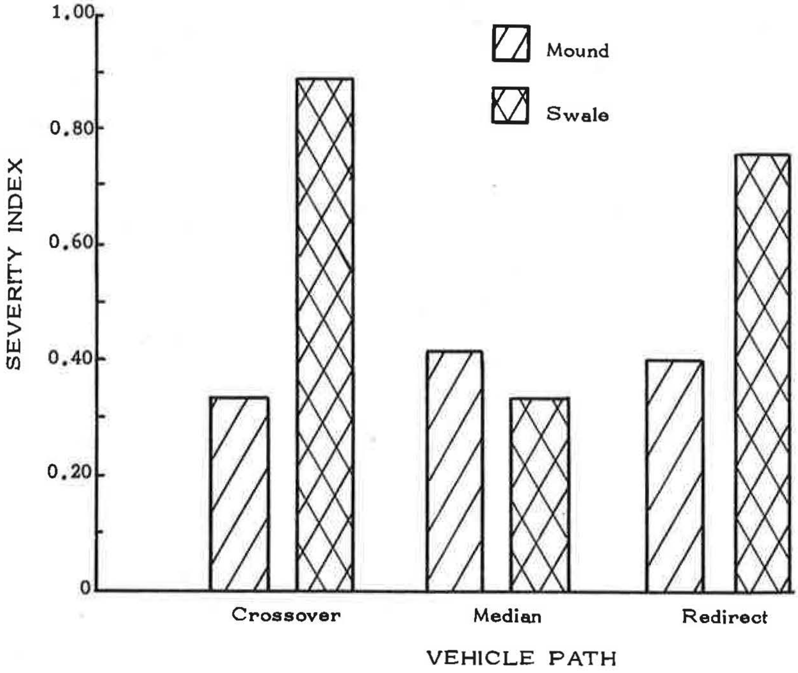
Note: ( ) = Expected cell frequency.

Hypothesis: There is no difference in the number of accidents for each vehicle path between the two median designs.

$\chi^2 = 0.814$ $\chi^2_{0.05} = 5.991$

Result: Accept hypothesis.

Figure 6. Comparison of severity index for vehicle paths.



designs. There is a disproportionately higher number of injury-producing accidents on sections with the swale median design than on sections with the mound median design for this path.

3. For the redirect path (7.5 percent of the median-involved accidents), there is no difference in the number of injury-producing accidents between the designs.

When these results are compared with the severity indexes shown in Figure 6, it can be seen that the severity for the paths in which the vehicle leaves the median are generally higher for the swale median design, although the only significant difference is for the crossover path.

To investigate the reason for this difference between the two median designs in accident severity for the crossover path, the accidents included in the crossover category were examined further. Although examination of the single-vehicle crossover accidents revealed no apparent reason for this difference in severity, it was noted that six head-on median-involved accidents occurred on sections with the swale median design, all of them involving injury, while no head-on median-involved accidents occurred on sections with the mound median design.

The effect of these head-on median-involved accidents on the safety potential of the median designs can be determined by an examination of several factors regarding the nature of the occurrence of head-on median-involved crossover accidents. Of primary consideration is the fact that a median-involved crossover accident becomes a head-on accident only if another vehicle is present in the opposing lanes and is struck during the crossover. The presence of a vehicle in the opposing lanes is a chance occurrence on which the median design has no effect. A second consideration is the effect of volume on the chance of a vehicle being present in the opposing lanes at the time of the occurrence of a crossover accident. During the examination of crossover accidents, it was noted that the swale median section on which the six head-on median-involved accidents occurred (I-71 between Columbus and Medina) experienced an average volume of 17,500 ADT over the study period. This volume is higher than that experienced on the other swale median section (14,033 ADT) or on the mound median sections (14,011 ADT). Although beyond the scope of the study to verify, this increase in volume and the resulting increase in head-on median-involved accidents imply that, as the volume on sections with the swale median design increases, the proportion of crossover accidents that result in head-on collisions also increases.

When the study data were being reduced, it was observed that many vehicles that crossed over the median also collided with a fixed object such as a guardrail, ditch, or fence when they came to rest off the roadway. On sections with the mound median design, the presence of the mound may tend to reduce the speed of the vehicle as it traverses the mound. This reduction in speed may result in a less severe accident if the vehicle collides with a fixed object before coming to rest. This is supported by the severity indexes shown in Figure 6, in which the severity index for the mound design is less than that for the swale design for the crossover path.

The relative safety potential of each median design must, however, be based on the largest possible portion of the accident phenomenon. Thus, for 89 percent of all median-involved accidents (the median and redirect paths), no difference exists between the two median designs in the number of injury-producing accidents. On this basis, the safety potential of the two median designs is equal in terms of the effects of median design and vehicle path on the number of injury-producing accidents.

The final question to be answered concerned the effects of median design on the roll-over tendencies of vehicles entering the median. Figure 7 shows the percentage of median-involved accidents by vehicle action for both median designs. A chi-square contingency test was again employed to determine if the proportion of median-involved accidents involving roll-over was different for the two median designs. The results of this test indicate that there is no difference between the two median designs in the number of roll-over accidents at the 5 percent significance level.

Because certain vehicle types may be more prone to roll-over than others—e.g., tractor-trailers versus passenger cars—the frequency of roll-over was computed for the various vehicle types, as given in Table 5. A chi-square contingency test was

Figure 7. Action of vehicles in median accidents.

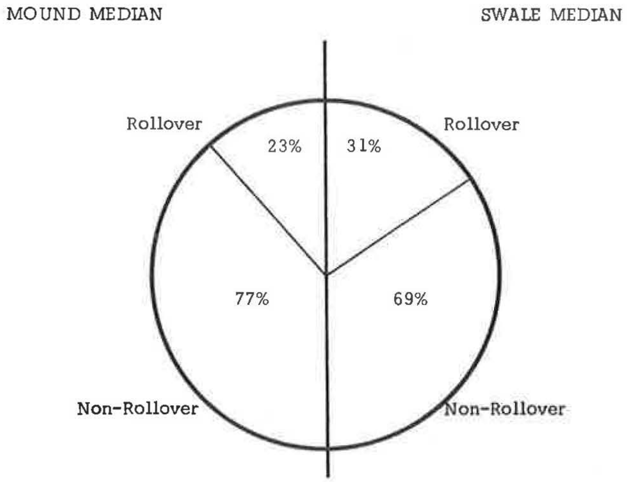


Table 5. Summary of vehicle path statistics for median-involved single-vehicle accidents.

	Crossover					Median					Redirect				
Category	PC	TT	C	O	TV	PC	TT	C	O	TV	PC	TT	C	O	TV
Mound															
Frequency															
No. by vehicle type	10	1	0	0	1	57	34	4	0	8	5	3	1	0	1
No. by path	12 →					103 →					10 →				
Percent of median type	9.6 →					82.4 →					8.0 →				
Injury accident[a]															
No. by vehicle type	4	0	0	0	0	28	10	3	0	1	3	0	1	0	0
No. by path	4 →					42 →					4 →				
Percent of median type	8.0 →					84.0 →					8.0 →				
Rollover															
No. by vehicle type	0	0	0	0	0	17	2	3	0	5	0	0	1	0	1
No. by path	0 →					27 →					2 →				
Percent of median type	0.0 →					93.1 →					6.9 →				
Swale															
Frequency															
No. by vehicle type	13	2	0	0	1	50	32	2	4	10	7	0	0	0	1
No. by path	16 →					98 →					8 →				
Percent of median type	13.1 →					80.3 →					6.6 →				
Injury accident[a]															
No. by vehicle type	11	2	0	0	1	20	7	2	2	1	5	0	0	0	1
No. by path	14 →					32 →					6 →				
Percent of median type	26.9 →					61.5 →					11.6 →				
Rollover															
No. by vehicle type	1	1	0	0	1	18	4	2	3	6	1	0	0	0	1
No. by path	3 →					33 →					2 →				
Percent of median type	7.9 →					86.8 →					5.3 →				

Notes: Vehicle Type: PC = Passenger car; TT = Tractor-trailer; C = Commercial (bus); O = Other (motorcycle); TV = Towed vehicle.
Vehicle Path: Crossover = Vehicle crossed median into opposing roadway; Median = Vehicle remained in median; Redirect = Vehicle redirected from median into orginal roadway.

[a]Injury accident category includes fatal accidents.

again employed to ascertain the significance of the difference in the number of roll-overs in each vehicle category between the two median designs. Low frequencies in certain vehicle categories required that all vehicles except passenger cars be combined into one group labeled "other". The results show no difference between the two median designs in the number of roll-overs for each vehicle category at the 5 percent significance level.

SUMMARY OF RESULTS

The results of the analysis can be summarized as follows:

1. In answer to question 1, there is a significant difference in the number of reported median-involved accidents between the two median designs. A disproportionately high number of single-vehicle median-involved accidents occur on sections with the mound median design. This implies that a greater number of nonreported (i.e., less severe) "incidents" of median encroachment occur on sections with the swale median design. However, documentation of this implication is not currently possible.
2. In answer to question 2, there is no difference between the two median designs in the number of injury-producing accidents.
3. In answer to question 3, first, there is no difference between the two median designs in the number of accidents for each vehicle path (crossover, median, or redirect); second, for both median designs, in approximately 81 percent of the median-involved single-vehicle accidents, the vehicle remained in the median; and third, when the numbers of injury-producing accidents for each vehicle path are examined, in 89 percent of the median-involved accidents (median and redirect paths), there is no difference between the two median designs in the number of injury-producing accidents.
4. In answer to question 4, first, there is no difference in the number of roll-over accidents between the two median designs; and second, there is no difference in the number of roll-over accidents for each vehicle type between the two median designs.

These results indicate a difference in the safety potential between the mound median design and the swale median design only in the area of the frequency of reported accidents. The difference in the number of head-on accidents cannot be used as a measure of safety potential since the number of crossover accidents was statistically equal for both median designs and since the element of chance determines the crossover collision occurrence. For all other factors analyzed, no difference between the two median designs exists.

CONCLUSIONS

On the basis of the results, the following conclusions concerning the safety potential of 84-ft (25.6-m) medians of the mound and swale designs can be drawn:

1. The 84-ft median of either cross-sectional design provides a generally adequate recovery area for encroaching vehicles.
2. Based on the disproportionately low frequency of reported accidents, the swale median design on 84-ft medians appears to provide more opportunity for encroaching vehicles to regain control and return to their roadway.
3. The use of either cross-sectional design with an 84-ft median does not have any effect on the primary path of the vehicle, on the vehicle's tendency to roll over, or on the resulting severity of the accident where the median encroachment results in a reported accident.

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DISCUSSION

H. L. Anderson, Office of Development, Federal Highway Administration

The report by Foody and Culp provides some interesting statistics and information to be considered in freeway designs. I have a number of reservations that may warrant review.

In the section on analysis and results the authors state that, since the geometrics of the sections of Interstate highways analyzed are similar except for the median design, it can be assumed that any difference in accident frequency would be the result of the median design. This assumption, although substantiated by references, cannot in my opinion be logically made when you consider the extremely large differences in accident rates on the sections involved. A rate of 11.86 accidents per mile for the swale design compared to 7.67 for the mound and a record of 29 fatal accidents for the swale compared to 12 for the mound and 13 fatal single-vehicle accidents compared to only 2 for the mound lead me to conclusions that are quite contrary to the authors'. Nor can the 10 percent additional ADT on the swale design in itself result in a significantly larger fatality rate and accident rate for the swale design. I believe the sections require a much more detailed analysis to account for the relative safety in the mound freeway sections. Certainly the percentage of trucks or the mix of traffic has a bearing on accident rates, and certainly vehicle speeds have a large bearing on severity indexes. An inventory and accounting of fixed objects, drainage ditches, guardrail, and other hazards should be studied. All of these must be considered in addition to median design and traffic volume, and therefore I think the assumption that median design is the only variable is generally an improper or incomplete one.

From Table 1 there is no basis for picking the very minor differences that exist in the median single-vehicle accidents and arriving at the conclusion that one is safer than the other, because the difference in accidents per million vehicle-miles is not significant. A difference of 0.02 accidents per million vehicle-miles is so small that a very few additional accidents one way or the other would have a radical effect on the accident rate. One snowstorm or icy condition can alter a difference this small. Of significance, however, is the total rate of 0.52 accidents per million vehicle-miles for the mound compared to 0.67 for the swale, a difference of 0.15. This leads me again to believe that a more thorough analysis of the differences between comparative sections is required. There must be a difference in the character of either the traffic or the roadway itself other than just the median. This was noticed in passing and discarded when the authors stated that most of the crossover accidents resulted in some injuries due to the striking of guardrails or other fixed objects when the vehicles did not strike each other.

Table 4 states that for the median path there is no difference in the number of injury-producing accidents between the two median designs. With this I agree—the differences are insignificant—if we can forget fatalities or equate them to being no worse than a broken finger or a bumped forehead. In my opinion the one advantage of wide medians or even alternative median designs is the elimination or reduction of fatalities. The swale design evidently produced 4 times as many fatalities within the median as did the mound design.

The authors state that there is no difference between the two designs in the number of injury-producing accidents for the redirected vehicle. Figure 6, however, indicates that the severity index for the redirected vehicle again is almost twice as high for the swale design as it is for the mound design. Thus, I cannot understand the conclusion drawn by the authors when they state that the only significant difference in the severity indexes is for the crossover path. Figure 6 indicates that the severity indexes for both the crossover and the redirected types of accident for the swale median were almost double those in the mound design. This again is borne out by the fatal accidents that occurred, where 29 people were killed in the swale median and only 12 in the mound median. It is again my opinion that much more analysis must be made on these significant differences. I agree with the authors when they state that the presence of a vehicle in the opposing lanes is a chance occurrence and is proportionate to the volumes of traffic in those lanes. I do not agree, however, that the chances of hitting another car in other lanes is a function of only the traffic volume. It is also a function of the speed of the vehicle and the angle at which the vehicle is crossing the path of the opposing traffic. It is entirely possible that the swale median might tend to flatten the angle at which the vehicle leaves the median and enters the opposing lane of traffic, whereas the mound design may have an opposite effect, thereby reducing the chances of head-on collision in the opposing lane. It should also be noted that in 13 percent of all accidents in the swale design the vehicle did cross the median, whereas only 10 percent crossed it in the mound design. This is a 30 percent increase in the crossover type and, except for the small sample size, is significant and again is discounted by the authors.

The purpose of the report was to answer four questions; however, three of the four questions were, in my opinion, either not answered or only partially answered. To question 2, Does the median design affect the severity of accidents involving the median?, the authors reply that there is no difference between the two designs in the number of injury-producing accidents. This is not a responsive answer to the question since there is a radical difference; the swale design severity and fatalities are considerably higher than those of the mound. Reference should be made to Figure 6.

Again, question 3, Does the median design affect the path of the vehicle after it enters a median during an accident?, is not answered, and the answer supplied for some of the accident information is evasive and incorrect. If in fact vehicle path was studied, it was not commented on in the report except to the degree that a vehicle crossed the median or was redirected.

To question 4, Does the median design affect the roll-over tendencies?, the authors' negative answer does not agree with their statistics in Figure 7 showing that 31 percent of vehicles entering the swale design median and 23 percent in the mound design rolled over. These percentage differences are significant.

In substance, I cannot agree with many of the conclusions of the authors or with much of the analysis and reasoning used. Ohio has more mileage and experience with these median configurations than any other highway organization. A vast amount of valuable information has undoubtedly been compiled in this study that is not available from any other source. I believe further review, analysis, and reporting would be worthy of consideration.

John C. Glennon, Traffic Safety Center, Midwest Research Institute

I would like to commend the authors on preparing this paper. They obviously put in a lot of effort.

My remarks are very brief. I do, however, have one major constructive criticism.

First, let me say that I find their conclusions 1 and 3 substantiated by the data. These conclusions say, first, that both median designs provide an adequate recovery area and, second, that both median designs exhibit similar characteristics of vehicle path, tendency for roll-over, and accident severity. One caution to the reader on the recovery conclusion, however, deals with their definition of recovery. What the conclusion implies is that, with an 84-ft median, very few vehicles encroach on the opposing lanes.

Their second conclusion is the one I question. This conclusion, based on a chi-square contingency test, touts the swale median design as providing the better opportunity for an encroaching driver to regain control. This conclusion may be incorrect because of the possible invalidity of their basic implicit assumption for the contingency test. This assumption is that the comparison samples are identical in every way except for median design and ADT.

If this assumption is valid, then a much more important conclusion has been overlooked. That is, the mound median is significantly better than the swale median. This conclusion would be based on the significant difference in total accident rates for the comparison samples as substantiated by the data. The accident rate was 0.52 for the mound median and 0.67 for the swale median.

I suspect the more likely possibility is that the basic implicit assumption is invalid.

Even though the comparison samples have significantly different rates, this difference is probably due to parameters other than median design. My questions are

1. Are the percentages of truck traffic similar?
2. Are the frequency and rigidity of roadside fixed objects similar?
3. Are the peaking characteristics on the sections making up the comparison samples similar?
4. Are the distributions of ADT within each comparison sample similar?
5. Are the combinations of other geometric features similar?

What I suggest is that the authors need to answer these questions and others to prove or disprove the validity of their basic implicit assumption. If, in fact, the assumption is valid, then the very important conclusion is that the mound median is significantly better than the swale median.

AUTHORS' CLOSURE

The basic questions raised by Anderson's and Glennon's reviews of this paper can be summarized as follows:

1. Given the differences in the total accident rate and the overall fatal accident frequency (Table 1), is the assumption correct that the two study groups (mound median sections and swale median sections) are equivalent except for the median design and the ADT? If this assumption is not correct, then is the conclusion correct that there are more unreported median encroachments in sections with the swale median design, thereby indicating that it is more conducive to driver-vehicle recovery?
2. Given the severity index figures (Figure 6) and the fatal accident frequency for median-involved single-vehicle accidents (Table 1), is the conclusion correct that the injury-producing potential of the two designs is not different?
3. Given the distribution of median-involved accidents by vehicle path (Figure 5), is the conclusion correct that there is no difference in the effect that each median design has on the vehicle path?
4. Given the percentage of roll-overs for each median design (Figure 7), is the conclusion correct that there is no difference in the effect that each median design has on the tendency for vehicles to roll over during a median-involved accident?

The objective of this study was to draw conclusions about the safety potential of each median design based on the analysis of the frequency and the severity of median-involved, single-vehicle accidents. The first question raised in the discussion refers to the analysis of the frequency of median-involved accidents. In analyzing the frequency of accidents involving the median, we did not merely compare the number of reported accidents per million vehicle-miles of travel for the two study groups for several reasons. First, it was known that the volume levels were different for the two groups. Second, it was possible that other unknown differences (such as percentage of truck traffic and frequency of roadside objects off of the right-hand side of the road) also existed. Third, it was known from the previously cited research by Hutchinson et al. that the number of vehicles leaving the roadway for a section of highway is proportional to the volume but not equal to the number of reported accidents. Given this fact, it was assumed that, if the two median designs had different effects on the vehicle encroaching the median, then the ratio of encroachments to reported accidents could be affected. Our intention was to obtain a measure of the effect of all accident-causative factors existing on the mileage within each study group. Therefore, in comparing the reported accident frequency distribution by accident type for the two study groups, it was assumed that the known factors (ADT) and unknown factors (percent truck traffic, etc.) had different order effects on the two study groups (mound versus swale), but that the effect within each study group was the same for the three types of accidents: multivehicle accidents (occurring on the roadway), non-median-involved single-vehicle accidents (occurring to the right of the roadway), and median-involved single-vehicle accidents (occurring to the left of the roadway). Implicit with this approach was the assumption that the 84-ft-wide median made the effect of oncoming traffic negligible as a primary factor in a multivehicle accident or in a vehicle initially leaving the roadway. Therefore, in comparing the distributions of reported accidents by accident type, it was assumed that differences between the distributions would be a direct indication of the effect of the median design since all the mileage included in the two study groups was constructed to Interstate standards, with the median cross section being the only pronounced difference. The validity of this approach would require that the cross section of the right-of-way beyond the right-hand shoulder and the frequency of fixed objects be shown to be no different. Information of this nature was not and is not available, and thus the validity of this assumption cannot be tested. Therefore, we agree with both discussants that the results of the analysis of the reported accident frequency by accident type do not clearly establish the validity of the conclusion that the use of the swale median design provides more opportunity for encroaching vehicles to regain control and return to the roadway.

However, we must also disagree with the implication by both discussants that the mound median design is superior to the swale median design based on subjective comparisons of the total accident rate and fatal accident frequency. The interpretation of the data in this manner requires the assumption that the median design has a major effect on the frequency and severity of the non-median-involved accidents, both multivehicle and single-vehicle. Previous research by Kilhburg and Tharp (4) established that the total accident rate increases with increasing ADT, as the result of a large increase in the frequency of multivehicle accidents and a leveling off of single-vehicle accident frequency. These research results tend to explain the difference in the multivehicle accident rate, and, since no other research results were found that supported the assumption that an 84-ft median has a major effect on the total accident rate, we question the validity of drawing conclusions about the effect of median design based on the total accident rate.

Our reply to the second question raised in the discussion is directed to Anderson's comments regarding the severity of median-involved accidents. Anderson states that he "... cannot understand the conclusion ... that the only significant difference in the severity indexes is for the crossover path" and that the severity indexes shown in Figure 6 indicate a difference between the two designs for the redirect path as well. Anderson apparently arrived at this deduction through a subjective evaluation of the data presented in Figure 6 and an inappropriate reference to the total number of fatal accidents.

In the study, the conclusion that there was no difference between the two designs with respect to the effect of median design on the severity of median-involved accidents was based on the results of two separate, objective analyses. In the first analysis (Table 3), it was found that there was no difference in the proportion of accidents resulting in injury between the two designs for all reported accidents involving the median. This test was then repeated for the data in each of the three vehicle path categories, once it was established that there was no difference in the proportion of accidents for each vehicle path between the two designs (Table 4). Tables containing the raw data used in these three tests were not given in the report to conserve space but can be generated by multiplying the severity indexes shown in Figure 6 by the total accident figures for each vehicle path shown in Table 4. The results of these tests indicated that only for the crossover path was there a difference in median-involved accident severity between the two designs. This difference (involving only 11.5 percent of all median-involved accidents) must be balanced against the fact that no difference in severity exists for the remaining 88.5 percent of the median-involved accidents (median and redirect categories). Therefore, it is our opinion that the conclusion of the study concerning the severity of accidents involving the median is valid since it is based on objective, mathematical analyses.

The third question raised in the discussion refers to the analysis of the path of the vehicle after entering the median during an accident. Our response is directed to Anderson's comments questioning whether or not vehicle path was actually studied and stating that the results of the vehicle path analysis were not properly interpreted. As stated in the section on procedure, each police report for all median-involved accidents was manually reviewed and was classified into one of the three vehicle paths explicitly defined in the text of the report. The distribution of vehicle paths for all median-involved accidents for both designs was compared mathematically (Table 4) and found to be the same. The calculation that there was a 30 percent difference in the percentage of crossovers between the mound design (10 percent) and the swale design (13 percent) is not valid in that percentages taken from two different bases cannot be manipulated to form a valid third percentage. Therefore, it is our opinion that the conclusion reached in the study regarding the effect of median design on the path of vehicles entering the median during an accident is complete and correct since it was based on valid, mathematical analysis.

Although not specifically directed to a conclusion of the study, we feel that it is appropriate to respond to Anderson's comment regarding the occurrence of a head-on median-involved crossover accident. Anderson agrees with our statement that the presence of a vehicle in the opposing lanes is a chance occurrence that is unaffected by median design. He also implies that we reduced this chance occurrence to a function of only traffic volume. We did, however, offer traffic volume as one factor that may influence the crossover collision, realizing that an analysis of vehicle speed and encroachment angle, as suggested by Anderson, was far beyond the scope of this study and the data available to us.

The final question raised in the discussion refers to the analysis of vehicle roll-over frequency for median-involved accidents. Anderson's question concerns the evaluation of the proportion of roll-overs for the two median designs as shown in Figure 7. He states that the difference between the percentage of roll-overs for the mound design (23 percent) and the swale design (31 percent) is significant, but offers no mathematical justification to support this statement. However, the objective, mathematical analyses contained in the report indicate that not only is there no difference in the proportion of roll-over accidents between the two designs but that there is no difference in the proportion of roll-overs by vehicle type between the two median designs as well. It is therefore our opinion that the conclusion reached in the study with respect to the effect of median design on the roll-over tendency of vehicles in median-involved accidents is correct since it was based on established analytical procedures.

In summary, we agree with the discussants that the conclusion based on the analysis of the frequency of occurrence of median-involved accidents is not fully supported, since the assumption that the roadside design (to the right of the roadway) is the same for the two study groups cannot be documented. It is our opinion, however, that this assumption is less strenuous than the alternate assumption offered by the discussants: that the 84-ft median has a major effect on the total accident rate. With respect to the questions regarding the differences in the effect of the two median designs on the severity, vehicle path, and vehicle roll-over tendency for median-involved accidents, it is our opinion that the conclusions presented and supported in the report are correct.

We commend Anderson and Glennon for the thoroughness of their review efforts. We appreciate this opportunity to clarify those portions of our report that were subject to misunderstanding.

REFERENCE

4. Kihlberg, J. K., and Tharp, K. J. Accident Rates as Related to Design Elements of Rural Highways. NCHRP Rept. 47, Highway Research Board, 1968.