RELATIONSHIP BETWEEN SIDE SLOPE CONDITIONS AND COLLISION RECORDS IN WASHINGTON STATE

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16. ABSTRACT

Design guidelines for road side slopes in Washington State follow generalized methods and require cost-benefit analysis. Prior to this research project, the effects of current methodology had not previously been evaluated. This report outlines the results of research on the effectiveness of slope flattening in reducing the number and severity of collisions on Washington State highways in rural areas. A before and after study was performed by analyzing 3R and 2R projects in Washington State which included side slope flattening that were accomplished from 1986 through 1991.

The study shows that side slope flattening reduces both the number and severity of collisions when compared to highway sections without side slope flattening. Even when including the effects of various non-structural initiatives which have helped reduce collisions, slope flattened sections exhibited lower collision rates. The research lends credence to current design practice which utilizes benefit-cost analysis when prioritizing roadside safety improvement projects.

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Flattening Slopes - Effects on Collisions

RELATIONSHIP BETWEEN SIDE SLOPE CONDITIONS AND COLLISION RECORDS IN WASHINGTON STATE

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DISCLAIMER

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EXECUTIVE SUMMARY

This report documents research carried out for the Washington State Department of Transportation on the effectiveness of side slope flattening in reducing the frequency and severity of run-off-the-road collisions on Washington State highways. Competing priorities for available highway funds have placed a premium on accurate predictions of the effectiveness of various roadside safety improvements. The costs of earthwork and wetland mitigation (which is sometimes necessary when flattening side slopes) have prompted this long overdue assessment of the effectiveness of current design guidelines.

The findings in this report substantiate a considerable reduction in both the frequency and severity of run-off-the-road collisions attributable to side slope flattening on selected Washington State highways. Even when including the effects of various non-structural safety initiatives which have helped to reduce collisions, side slope flattened sections exhibited lower collision rates. Comparisons are included for slope flattening on high accident corridors.

Because of incomplete data in many of the contract files which were reviewed in this research, pre-project conditions could not be accurately determined. Therefore, precise reduction percentages attributable to side slope flattening were not developed.

Current design procedures which call for cost-benefit analysis of roadside safety improvements are validated by the findings of this research. It is recommended that design engineers be given the ability to use a cost-benefit analysis approach in lieu of strict application of standards when designing road side safety improvements for all types of highway construction projects.

INTRODUCTION

RESEARCH OBJECTIVES

The principal objectives of this research were to evaluate the validity of current guidelines for design of side slopes and to provide information that can be used in safety benefit-cost analysis of side slope flattening projects. Other objectives included the generation of run-off-the-road (ROR) collision data for selected side slope flattened sections of highway in Washington State and the provision of recommendations for future roadside safety research.

THE PROBLEM

Competing priorities for available highway funds have placed a premium on being able to accurately predict the effectiveness of various roadside safety improvements in reducing the number and severity of ROR collisions. Current Washington State design guidelines for roadside slope conditions imply that applicable slope flattening or guardrail protection practices provide cost-effective prevention or reduction in the number and severity of run-off-the-road collisions. However, evaluative research has not previously been performed to indicate the cost effectiveness of actual practices on Washington State's existing highways. Washington State Department of Transportation design engineers posed the cogent question: Has there actually been a reduction in ROR collisions where side slopes have been flattened? The long overdue answer to this question may assist in future decision making, such as in trade-off decisions between slope flattening and wetland mitigation or whether to provide costly cut or fill sections in mountainous terrain.

STATE OF THE ART SURVEY

HISTORY

Prior to the 1960's, the highway community focused its attention on roadside safety for interstate highways while overlooking lower class highway systems. Run-off -the-road collisions were considered the fault of careless drivers (Ross 1995).

In 1960, K.A. Stonex's publication, "Roadside Design for Safety," focused attention on roadside hazards on non-interstate roadways. Stonex applied fundamental principles of industrial safety to the roadways of the General Motors Proving Grounds in an attempt to prevent run-off-the-road collisions. At the Proving Ground, the attitude of the test track engineers about collisions was that they were bound to happen. However, industrial safety engineers had shown that accidents which occurred in General Motor's assembly plants were preventable, and that accidents in the plant were usually caused by human error. While recognizing that collisions are preventable, some are inevitable.

The Proving Grounds were constructed using design standards comparable to those of a state highway department. The roadway was a one-way system with limited access and few at-grade intersections on main test routes. A review of the collision statistics from 1953 to 1958, covering nearly 65 million test miles, was performed. There were a total of 236 collisions. Seventy-two percent of these were run-off-the-road collisions. To reduce the number of run-off-the road collisions, General Motors took the following actions:

- Increased education programs for test drivers
- Gave reprimands for safety violations
- Discharged drivers who committed flagrant violations

- Evaluated vehicle safety features

In spite of these efforts, General Motors concluded that drivers will infrequently leave the roadway because of normal human fallibility. To minimize the effects of run-off-the-road collisions, the safety engineers provided every safeguard they could imagine for all types of driver errors.

General Motors initiated several actions to improve the safety of the test track roadside. The first was to recognize that the most severe hazards were fixed objects adjacent to the roadway. Test track design recommendations called for a roadside recovery area of one-hundred feet from the edge of the roadway. Trees were systematically eliminated. Low impact light poles replaced conventional light poles. All directional signing was mounted above 60 inches. In the event of a collision, test vehicles could safely run under the signs. V-ditches along the roadside were modified to traversible flat-bottom ditches. Banks were cut back to more gradual slopes of 4:1 to 6:1. Where natural terrain prevented reasonable modification of the roadside, guardrails were installed. General Motors tested several guardrail end treatments such as flared, angled, and buried. The results of safety improvements dramatically reduced losses during testing. During the review period (1953 to 1963), 64 man days were lost due to test driver injuries sustained in roadside accidents. In the six year period following the clearing and flattening efforts, lost time attributed to roadside collisions was totally eliminated.

In a 1966 study by Hutchinson and Kennedy, "Safety Considerations in Median Design," the distribution of vehicles encroaching on highway medians was studied. Their study recommended a 30 foot width of obstacle-free median with mild cross slopes (24:1 for a 30-foot median width and steeper allowable slopes for greater median widths). These were the absolute minimum requirements for safe stopping and control of vehicles encroaching on medians at rural highway operating speeds. The authors reported that very few vehicles encroached beyond 30 feet. This study contributed to the acceptance of the 30 foot clear zone. In Stonex's research, roughly 80 percent of the vehicles involved in ROR collisions stayed within 29.5 feet of the roadway.

In 1967, the Special American Association of State Highway Officials (AASHO) Traffic Safety Committee published a report entitled "Section Design and Operational Practices Related to Highway Safety." The report brought attention to an increasing number of ROR collisions and identified a roadside design policy to mitigate roadside hazards. The report called for a 30 foot clear recovery area. All unnecessary objects were to be removed; those that could not be moved were to be altered to reduce collision severity or shielded using attenuators or deflective devices. Side slopes were to be 6:1 (Ross 1995). The foregoing document, which was called the "Yellow Book," was republished in 1974 in a second edition. In 1977, AASHTO published the "Guide for Selection, Locating and Designing Traffic Barriers," which established clear zone criterion based on side slope and speed. The 1989 AASHTO "Roadside Design Guide" uses the variables of speed, fore slope, back slope and average daily traffic (ADT) to determine clear zone requirements.

CROSS SECTION RESEARCH

In 1988, the Transportation Research Board published "Safety Effects of Cross-Section Design for Two-Lane Roads" by Zegeer, Hummer, Reinfurt, Herf, and Hunter. The study quantified the relationship between cross section geometry and collisions. Such factors as lane width, shoulder width and type were found to influence collision rates for ROR, head-on, and sideswipe collisions. The study included a qualitative summary of over 30 articles and reports. Included in the study conclusions were the following:

- Lane and shoulder conditions directly effect ROR collisions.
- Rates of ROR collisions decrease as lane widths are increased.
- Rates of ROR collisions decrease as shoulder widths are increased.
- For lane widths of 12 feet or less, lane widening has a greater effect than shoulder widening in reducing collisions.
- Non-stabilized shoulders have higher collision rates than stabilized shoulders.

Using the database created from approximately 4,700 miles of roadway in six states, the researchers developed a mathematical model to predict collisions. This analytical approach was chosen over a before and after study. The authors realized it would have been difficult to collect data from appropriate control sites. The authors used guidance from previous research where predictive models were developed. In building the model, the researchers selected variables based on: (1) logical relationship to collisions (lane width, shoulder width, shoulder type, and roadside conditions), (2) Chi-square analysis, (3) stepwise linear regression and (4) analysis of variance and covariance. This approach by Zegeer, Reinfurt, Hummer, Herf, and Hunter developed collision reduction factors for lane widening and shoulder improvements. The study was careful to point out that simultaneous improvements would not produce an additive result (i.e. a one foot lane widening reduction of 12% cannot be added to a two foot paved shoulder reduction factor of 16% to achieve a reduction of 28%). The collision reduction factors developed by Zegeer in 1988 were similar to those found in a study on rural roads in Texas (Griffen 1987). This study addressed the cost effectiveness of roadway improvements related to ADT groupings.

CLEAR ZONE RESEARCH

The idea of a clear recovery area is one component of the "forgiving roadside" concept. The term refers to a roadside that is relatively as flat as possible, easily traversed and free of unyielding obstacles (AASHTO Roadside Design Guide 1988). The "forgiving roadside" concept recognizes that errant vehicles will enter the roadside. In his 1960 report, Stonex concluded that drivers will leave the roadway regardless of their driving experience or competence and no matter the degree of safety features built into their vehicles. Many of the tenets of the "forgiving roadside" concept were derived from the successes at the General Motors Proving Grounds. How these concepts should be applied has been the subject of debate by researchers.

In 1987, Daniel Turner of the University of Alabama published "A Primer on the Clear Zone." This represented an attempt to summarize available literature on clear zones. Turner's paper was intended to assist local agency engineers in decision making and development of clear zone policies. According to Turner, the clear zone philosophy has been defined at the federal level, but engineers at state and, especially, local levels have not fully learned how to translate clear zone policies into site specific applications.

Turner's paper received criticism from researchers who questioned whether clear zones led to safer roads or whether the results and recommendations from Stonex's 1960 report were appropriately applied to public highways. For example, a response to Turner's "A Primer on the Clear Zone" by Dunlap and Merrihew in 1987 pointed out that Stonex recommended a 100 foot clear zone for speeds between 35 and 40 miles per hour. At the same time, the 1977 American Association of State Highway and Transportation Officials (AASHTO) "Guide for Selecting, Locating and Designing Traffic Barriers" recommended a 15 foot clear zone for an operating speed of 40 miles per hour. The 1988 AASHTO "Roadside Design Guide" recommends clear zones of 7 to 18 feet based on side-slope conditions. Dunlap and Merrihew question the consequence of the national clear zone policy. The authors point out that 32.8 percent of fatal collisions in Michigan during 1971 resulted from striking fixed objects, while the statistics for 1984 show an insignificant reduction to 32.2 percent. What had occurred between the 1960 Stonex report and publication of the 1977 AASHTO clear zone guidelines to justify a reduction in the requirements if the accident statistics had not changed? The authors concluded that it is important to distinguish between the work done at General Motors and the work done by public agencies. General Motors is responsible for the total cost of collisions on its test track. Public agencies are generally not required to pay for both the cost of collisions and for providing a safe roadway, except if the agency is a defendant in a lawsuit. Dunlap and Merrihew believe there is a tendency by public agencies toward inaction in connection with safety and that standards and policies have been developed to defend inaction. As a result, there are presently inadequate requirements for clear zones.

Another argument for providing clear zones can be drawn from research by P. Cooper of Canada in 1980. Cooper's study of vehicle encroachments lends support to providing additional clearance beyond highway shoulders. Cooper developed an extensive database of vehicle encroachments on relatively flat, straight sections of four-lane, divided, and two-lane highways. The study found that few encroaching vehicles stayed within 10 feet of the roadway.

SLOPE FLATTENING RESEARCH

A 1988 study by Zegeer, Reinfurt, Hunter, Hummer, Stewart, and Herf called "Accident Effects of Side Slope and Other Roadside Features on Two Lane Roads" addressed the issue of side slopes and ROR collision rates. Prior to the 1988 study, side slope design criterion had been based on findings from running computer simulations and controlled vehicle test runs as well as being based on best engineering judgment (Zegeer 1992). The 1988 study looked at single vehicle and roll over collision histories of 595 rural sections covering just under 1,800 miles of roadway in Michigan, Alabama, and Washington. The study concluded that single vehicle ROR collision rates (in collisions/100 MVM) dropped in a linear relationship to flatter slopes. This linear relationship was then used to develop collision reduction factors for various side slope flattening projects. The study developed collision models using a roadside hazard rating system and an average roadside recovery area. One conclusion of this study was that rollover accidents comprise the third highest incidence of injury, behind pedestrian related accidents and head-on collisions. In order to significantly reduce rollover accidents, side slopes must be reduced to 5:1 or flatter.

EVALUATING ROADSIDE SAFETY FEATURES

Studies dealing with the effectiveness of roadside safety features have almost invariably recommended further study. The problem facing highway engineers is not the construction of new highways, but in upgrading old facilities to current standards (Mak 1995). With finite resources, engineers are now forced to use objective and rational means to assess where to spend highway funds. In 1995, Mak indicated that it is intuitive that providing an adequate clear recovery area will reduce the severity of related accidents. Similarly, slope-flattening will improve overall safety. If an errant vehicle leaves the roadway, provided there is an adequate clear zone and a gradual side slope, the only immediate danger to the driver is the potential overturn of the vehicle. The issue that remains is the degree of safety that will be achieved using clear zone and slope flattening standards.

NCHRP Project 17-5, "Effectiveness of Clear Recovery Zones," published in 1982, was conducted to help highway agencies develop rational criteria for making cost-effective application of clear zone policies. Using a collision model developed in NCHRP Report 148 to calculate expected reduction rates of collisions and collision costs from the National Safety Council and the National Highway Traffic Safety Administration, benefit-cost ratios for selected traffic volume levels on specific highway types were calculated. The data in Table 1 is taken from page 10 of NCHRP Project 17-5.

Table 1. Summary of Benefit-Cost Evaluations for Four Design Examples

Roadside Design Policy Improvement:	Freeway		Two-Lane Highways	
	Nonclear Zone to 4:1 Clear Zone	4:1 Clear Zone to 6:1 Clear Zone	Nonclear Zone to 4:1 Clear Zone	4:1 Clear Zone to 6:1 Clear Zone
Expected Accident Rate Reduction (accidents per million vehicle-miles)	0.118	0.107	0.277	0.149
Accident Cost Savings ($ per accident reduced)				
based on NSC accident costs	$7,748	$7,748	$9,266	$9,266
based on NHTSA accident costs	$10,977	$10,977	$14,502	$14,502
Improvement Construction Cost ($ per mile)	$31,265	$47,148	$19,029-$66,804	$22,984
Residual Value of Improvement after 20 years ($ per mile)	$14,753	$25,407	$8,873	$13,622
Break-even ADT (vpd) for B/C=1.0				
based on NSC accident costs	5410	8,650	1,180-4,930	2,450
based on NHTSA accident costs	3820	6,100	750-3,150	1,560

Additional studies have examined procedures for conducting benefit-cost analysis of roadside safety alternatives. Studies by both Sicking and Ross in 1986 and Mak in 1995 use benefit-cost methodology, a collision prediction model, an encroachment probability model, societal cost of collisions and construction and maintenance costs to evaluate safety alternatives. Sicking and Ross present a practical design example comparing installation of guardrail with slope flattening.

A study sponsored by the Illinois Department of Transportation investigated the effects of clear zone widths on collisions in an attempt to find a break-even relationship between traffic volumes and clear zone widths where accident savings equaled the cost of roadside improvements. This research found that, in most cases, the cost of clearing and flattening slopes on the roadside was greater than the present worth of the cost of all related roadside and side slope accidents (Boyce 1989). The report recommended it would be more effective to use "remedial" measures to reduce accidents on Illinois highways. However, the authors commented that slope flattening was not part of the 3R policy during the study period. Slope flattening costs were calculated using a cost model for the quantity of earthwork required to achieve different levels of slope-flattening. The cost of removing and relocating objects was assigned a mean value. The use of alternative remedial measures to slope flattening was also recommended by Griffen in 1987.

In 1991, J.W. Hall published a report detailing ROR collision history in the state of New Mexico. Hall reported that, in spot locations, ROR collisions were reduced by 50 percent with the use of remedial measures such as rumble strips, wider edgelines, and grooved shoulders.

RESEARCH IN PROGRESS

Two major research projects on roadside safety are in-progress or in the planning stage. One is NCHRP Project 17-13 titled "Strategic Plan for Improving Roadside Safety." This project is developing coordinated research sponsored by FHWA, TRB and state agencies with the objective of organizing one or more Roadside Safety Conferences. The results of the conferences will be compiled and published. The second project is NCHRP 17-11, "Recovery-Area Distance Relationships for Highway Roadsides." This project will address single vehicle ROR collisions and correlation with vehicle speed, driver behavior, and vehicle maneuvers.

SURVEY RESULTS

The literature search on the relationship between slope flattening and ROR collision frequency and severity produced limited resources. From the papers and research projects reviewed, several observations were considered pertinent to this research effort.

There is a general consensus that more research is needed to give engineers better tools for decision making and cost-benefit analysis of projects (Zegeer 1988, Boyce 1989, Crowly 1992). This includes research to test and improve existing ROR collision prediction and encroachment probability models as well as research to develop better software to analyze multiple scenarios.

Although several research papers address roadside characteristics such as cross section and alignment as the major contributing factors in single vehicle ROR collisions, further research is needed to assess quantitative impacts on ROR collision severity and frequency.

The literature suggests that there is significant misuse of roadside safety features because the current generation of engineers is not grounded in the history of highway safety. Engineers who have been practicing since the late fifties and early sixties (when roadside safety practices were pioneered) are beginning to retire (Crowly 1992).

The literature also suggests that routine application of standards to address safety concerns is not cost effective (Ross 1995, Viner 1995, Mak 1995). The current trend to address highway safety issues is through Safety Management programs.

Human factors and changing vehicle characteristics should be included as major elements in future research on the performance of roadside safety improvements.

Data collection and evaluation will be facilitated by more thorough cataloguing of roadside conditions. Research into methods and procedures to achieve this will allow more precise and presumably more productive studies and evaluations of roadside safety features.

PROCEDURES

BEFORE AND AFTER APPROACH

Estimates of the effectiveness of roadside safety improvements have been primarily derived from the study of models which attempt to emulate highway conditions. The reasons that have been given for avoiding before and after comparisons based on real world data include:

- The extensive effort involved in accomplishing before and after studies
- Incomplete data or non-availability of data
- Questionable accuracy and consistency of the recorded data

Despite the considerable effort required, before and after studies are useful for establishing trends which may, in turn, validate conclusions drawn from model studies.

A cogent question which prompted this before and after study was posed by Washington State Department of Transportation design engineers. They wanted to know if the considerable expense and effort that has gone into the flattening of side slopes has resulted in actual reductions in the number and severity of run-off-the-road collisions on Washington State highways.

To answer this question, methodology was developed to compare ROR collision history before and after slope flattening projects took place on Washington State highways. Two separate procedures were used. First, all highway sections that were slope flattened during a selected six year period were studied to determine the net result of those improvements on ROR collision statistics. Second, the results achieved by slope flattening on these same slope flattened highway sections were compared with the results achieved through other safety improvements on the same projects.

STEP BY STEP RESEARCH ACTIVITIES

The procedures which were followed are described in detail in the following sections for each of several approaches used in carrying out this research project.

Determining If Side Slope Flattened Sections Reduce ROR Collisions

A list of all highway construction contracts for which designs were prepared from 1983 through 1994 was obtained from WSDOT. Those contracts where construction work was completed in calendar years 1986 through 1991 were identified for further study. The construction period for a few projects extended beyond 1991 into 1992. In these instances, the subsequent ROR collision history period was extended to provide adequate "after" collision data for comparison. The as-built drawings of the construction contracts which included grading were specifically reviewed to determine those which called for side slope flattening. (For most of the projects, drawings available for review had not been marked "as-built.") A total of 750 contracts which were completed during the study time period were screened. Two hundred of these were identified as including grading. Further review of these projects disclosed that approximately 60 contracts called for slope flattening in at least some portion of the project. None of the projects called only for side slope flattening, but included other roadside safety improvements.

Work sheets were prepared for each section of highway where slope flattening was required. This necessitated the preparation of up to 65 work sheets per contract. The slope flattened sections ranged in length from 50 feet to 5 miles. The following data was entered on each work sheet:

- Mileposts between which flat sloping occurred.
- Before and after conditions, as follows;

    Finished side slope (e.g. 6:1) and initial side slope, when known.

    Extent of the clear zone.

    Lane width.

    Shoulder width.

    Horizontal alignment.

    Truck traffic (percent).

    Speed limit.

    ADT (average daily traffic).

    Delineators.

    Rumble strips.

- Run-off-the-road collision history in five categories (fatalities, disabling injuries, evident injuries, possible injuries and property damage only) for at least three years prior to and at least three years following construction. (Collision history for the first year after completion of each project was purposely not used to eliminate the possibility that highway revisions might spur a temporary increase in collisions that would not be representative of the long term effects of safety feature improvements.)

To obtain the foregoing data, it was necessary to review available design reports, contract quantity summaries, descriptions of work, cross sections, plan views and conversion equations to determine the extent of side slope flattening and the presence and addition of other roadside safety features. Video logs were visually analyzed to confirm before and after conditions and to ensure that the section mileposts captured on the work sheets matched the actual highway mileposts. The presence of roadside safety improvements and other highway features were also verified by observing the video logs. ADT, truck percentages and speed limit data were obtained from the annual State Highway Logs and Traffic Reports. ADTs were averaged for the periods before and after construction, respectively. A straight line relationship was used in predicting the effect of ADT on collision rates. Truck percentage and speed limit data were captured for future use, but were not used in calculations. Speed limits were unchanged throughout the study period.

There does not appear to be unanimity of opinion on the effect that truck traffic has on ROR collision rates. Data in a draft report by Milton in 1995 indicates that increases in truck traffic correspond with lower collision rates. The gradual increases in truck traffic percentages which were evidenced in this study were not used in calculations, nor were they considered significant.

Collision data was obtained from MicroCARS. In several instances, ROR collisions with fixed objects were reported as taking place in slope flattened sections. Therefore, accident reports were individually reviewed to verify that such collisions were actually run-off-the-road type, were properly recorded as to the milepost of occurrence and took place on the side slope flattened side of the road in those instances where only one side of the road had been flattened. This review resulted in corrected data for about 30 percent of ROR collisions in the fatality category.

The work sheet data was entered on EXCEL spreadsheets containing formulas which calculated "before," "predicted after" and "actual after" ROR collision rates for each of the five severity categories. With over 450 side slope flattened highway sections, a separate spreadsheet was prepared for each section. The specific percentage reductions which were used for various roadside safety improvements are shown in Table 2. These data were taken from WSDOT Safety Countermeasures Reference Summary (1995).

Table 2. Collision Reduction Percentages for Roadside Safety Improvement Features

Safety Improvement Features	Percent Reduction in Types of ROR Collisions				
	Fatality	Disabling Injury	Evident Injury	Possible Injury	Property Damage
Add Delineators on Curves	41	41	41	41	22
Add Delineators on Tangent	47	20	20	20	13
Widen Lanes 1'	12	12	12	12	12
Widen Lanes 2'	23	23	23	23	23
Widen Lanes 3'	32	32	32	32	32
Widen Lanes 4'	40	40	40	40	40
Widen Shoulders 2'- 2-Lane	16	16	16	16	16
Widen Shoulders 4'- 2-Lane	29	29	29	29	29
Widen Shoulders 6'- 2-Lane	40	40	40	40	40
Widen Shoulders 8'- 2-Lane	49	49	49	49	49
Widen Shoulders 4'- 4-Lane	69	53	53	53	29
Widen Shoulders 8'- 4-Lane	30	17	17	17	29
Widen Shoulders 16'- 4-Lane	16	44	44	44	31
Remove Obstacles on Steep Fill Slope	14	10	10	10	18
Remove Obstacles on Gentle Fill Slope	73	23	23	23	40
Remove Obstacles on a Cut Slope	35	15	15	15	30
Increase Clear Zone by 5'	13	13	13	13	13
Increase Clear Zone by 8'	21	21	21	21	21
Increase Clear Zone by 10'	25	25	25	25	25
Increase Clear Zone by 15'	35	35	35	35	35
Reduce Sharpness of Curve from 10 to 5 degrees	45	45	45	45	45
Reduce Sharpness of Curve from 15 to 5 degrees	63	63	63	63	63
Reduce Sharpness of Curve from 20 to 10 degrees	48	48	48	48	48

Information from the spreadsheets for the side slope flattened sections was consolidated by project on a second generation spreadsheet. This produced a single ROR collision rate for each severity category summarizing all of the side slope flattened sections included in each contract. These contract summaries were further consolidated on a third generation spreadsheet which included all of the side slope flattened sections constructed during the entire study period. Side slope flattened sections of 2-lane and multi-lane highways were identified separately to facilitate future study. For this research, the multi-lane sections were not analyzed separately because of the extremely limited number of multi-lane highway side slope flattening projects. Sections where side slope flattening had occurred on only one side of the highway (or in the median only on multi-lane highways) were included in each consolidated rate. The "one side only" sections comprised approximately 30 percent of the total length of side slope flattened highway sections.

Pertinent data from the third generation spreadsheet listed by contract is shown in Table 3. There were a total of 52 contracts that called for side slope flattening in one or more highway sections. The descriptions of the abbreviations used in the table headings are as follows:

Cont = Contract	MP = Milepost	SF = Slope flattening
HAC = High Accident Corridor	Fatal = Fatality	EI = Evident Injury
DI = Disabling Injury	PI = Possible Injury	PDO = Property Damage Only

Table 3. Summary of Collision History for Slope Flattened Portion of Projects

Cont No	Hwy No	Begin MP	End MP	Length w / SF	In HAC?	Pre-project Accident Data Fatal	DI	EI	PI	PDO	Post-project Accident Data Fatal	DI	EI	PI	PDO
2954	101	216.37	220.70	1.36	N	0	0	0	4	3	0	0	10	1	1
2987	501	16.91	19.74	0.02	N	0	0	0	0	0	0	0	0	0	0
XE 3009	16	22.94	28.33	0.69	Y	0	0	1	0	4	0	0	0	0	0
3277	12	44.37	44.70	0.33	N	0	0	0	0	0	0	0	0	0	0
3282	2	275.10	281.50	6.40	Y	0	0	1	0	0	0	0	1	2	2
3314	4	24.56	28.92	0.53	N	0	0	0	0	1	0	0	0	0	1
3325	395	72.33	82.47	1.31	N	0	0	0	0	0	1	0	0	0	2
3327	101	43.13	53.02	2.32	N	0	0	3	1	6	0	0	1	0	2
3331	395	210.59	229.82	2.05	N	0	1	2	0	2	0	0	1	1	2
3344	151	2.53	5.99	3.35	N	0	3	4	1	11	0	0	0	0	1
3357	410	88.45	108.46	11.38	N	0	3	4	4	11	0	0	0	0	2

Table 3. Summary of Collision History for Slope Flattened Portion of Projects (Cont.)

Cont No	Hwy No	Begin MP	End MP	Length w / SF	In HAC?	Pre-project Collision Data Fatal	DI	EI	PI	PDO	Post-project Collision Data Fatal	DI	EI	PI	PDO
3369	172	0.01	5.00	4.99	N	0	0	0	0	0	0	0	0	0	0
3371	2	263.44	272.34	6.87	N	0	2	5	2	13	0	2	1	3	6
3419	12	319.34	324.72	0.59	N	0	0	0	0	0	0	1	0	0	0
3427	12	382.49	386.56	1.09	N	0	0	1	0	0	0	0	0	0	0
3433	101	275.80	282.03	0.35	N	0	0	0	0	2	0	1	2	0	1
3453	305	1.10	8.67	4.67	Y	0	2	1	1	7	1	1	3	3	4
3492	12	14.58	20.96	2.38	N	0	0	7	3	5	0	0	2	0	0
3497	101	93.18	101.92	8.74	N	1	2	6	8	16	0	4	2	5	6
3584	20	0.03	7.83	0.13	N	0	0	2	0	3	0	0	0	1	0
3587	27	68.73	75.69	6.61	N	0	1	2	1	6	0	0	0	1	7
3602	2	21.37	24.32	0.12	Y	0	0	0	0	0	0	0	0	0	0
3604	395	82.46	95.61	12.96	N	1	3	10	1	11	0	2	3	3	17
3641	28	93.30	103.13	8.06	N	0	1	3	0	4	0	0	0	1	3
3644	410	24.77	26.02	0.48	Y	0	0	0	0	1	0	0	0	0	0
3654	97	2.97	7.53	0.68	N	0	0	2	0	3	0	0	0	0	1
3661	546	0.00	8.00	3.68	N	0	1	1	1	0	0	0	2	2	3
3662	101	101.92	111.65	0.57	N	0	1	0	1	1	0	1	0	0	0
3670	12	8.13	14.60	0.40	N	0	0	0	1	2	0	0	0	0	0
3680	101	30.29	33.89	1.49	N	0	1	7	0	3	0	0	1	0	0
3755	2	207.78	214.72	2.71	N	0	0	0	0	0	0	0	0	0	2
3763	9	15.60	16.90	0.51	N	0	0	0	0	0	0	0	0	1	0
3766	395	25.42	39.68	1.49	N	0	0	1	0	0	0	0	0	0	2
3784	101	144.35	147.12	2.68	N	0	0	1	1	1	0	0	0	0	0
3790	90	66.62	69.49	2.87	N	1	5	13	6	70	1	0	7	5	18
3797	12	95.46	101.74	6.12	N	0	1	16	4	9	0	1	0	1	3
3802	12	66.76	74.38	2.17	Y	0	0	1	0	2	0	1	1	1	3
3805	195	25.81	30.94	3.72	N	0	0	2	2	1	0	0	2	2	1
3808	12	348.24	351.15	0.37	N	0	0	0	0	5	0	0	1	0	2
3861	2	132.27	140.26	0.85	N	0	0	0	0	0	0	0	1	0	0
3866	172	14.44	21.84	0.31	N	0	0	0	0	0	0	0	0	0	0
3875	28	103.15	117.74	1.06	N	0	0	0	0	0	0	0	0	0	0
3884	221	6.53	13.20	0.03	N	0	0	0	0	0	0	0	0	0	0
3927	12	307.60	311.39	0.04	N	0	0	0	0	0	0	0	0	0	0
3939	5	101.23	104.45	0.18	Y	0	0	0	0	1	0	0	0	0	0
3944	12	401.92	405.23	1.34	N	0	0	0	0	1	0	0	0	0	0
3946	706	0.00	7.86	0.10	N	0	0	0	0	0	0	0	0	0	0
3947	12	21.30	26.30	4.58	N	0	0	5	1	9	0	1	3	3	4
3948	27	75.65	82.97	6.50	Y	0	2	4	5	12	1	2	5	4	12
3966	7	36.07	39.76	3.69	Y	0	0	7	1	5	0	0	2	1	5
3996	12	134.04	138.67	0.09	N	0	0	0	0	0	0	0	0	0	0
4030	101	234.60	239.51	3.88	N	0	0	0	2	4	0	0	2	1	3
TOTAL 52			343.39	139.89		3	29	112	51	235	4	17	53	42	116

Determining If Side Slope Flattened Sections Outperform the Rest of the Projects

Separately, data on each of the contracts was analyzed to determine if there was a reduction in the ROR collision rate and/or severity associated with side slope flattening within the confines of that project. A principal difference in the roadside safety features throughout the length of many of the projects was that side slopes were flattened in only some sections. Therefore, ROR collision data was recorded for the entire length of each of these highway construction projects including those areas where side slope flattening occurred. This data was entered on spreadsheets to allow comparisons to be made with the reductions in ROR collision rates experienced in highway sections where side slope flattening had occurred. Actual before and after ROR collision rates of these highway sections were calculated through the use of spreadsheets.

The ROR collision rates for all projects were summarized on another spreadsheet to provide for comparisons of consolidated data on all of the studied projects. Data were recorded separately for two-lane and multi-lane highways. This data is shown in Table 4. The total number of ROR collisions that occurred within the projects are shown at the bottom of the table.

Table 4. Summary of Collision History for the Entire Length of the Projects

Cont No	Project Length	No. of lanes	Pre-project Collision Data					Post-project Collision Data				
			Fatal	DI	EI	PI	PDO	Fatal	DI	EI	PI	PDO
2954	4.33	4	0	0	0	2	3	1	2	8	1	7
2987	2.83	2	0	1	5	5	14	1	0	9	1	11
XE 3009	5.39	4,6	0	4	18	11	22	1	1	6	5	15
3277	0.33	2	0	0	0	0	0	0	0	0	0	0
3282	6.40	4	0	4	10	5	22	0	5	7	7	21
3314	4.36	2	0	0	4	1	6	0	1	2	2	11
3325	10.14	2	0	0	2	2	4	1	1	1	0	7
3327	9.89	2	1	4	17	4	22	0	0	12	4	13

Table 4. Summary of Collision History for Entire Length of the Projects (Cont.)

Cont No	Project Length	No. of lanes	Pre-project Collision Data Fatal	DI	EI	PI	PDO	Post-project Collision Data Fatal	DI	EI	PI	PDO
3331	19.23	2	2	6	9	2	25	0	6	6	3	24
3344	3.46	2	0	3	4	1	9	0	0	0	0	1
3357	20.01	2	0	4	6	5	20	0	0	8	2	14
3369	4.99	2	0	0	0	0	0	0	0	0	0	0
3371	8.90	2	0	2	6	2	14	0	2	1	3	7
3419	5.38	2	0	2	1	1	6	1	2	2	2	5
3427	4.07	2	0	0	2	1	2	0	0	0	1	3
3433	6.23	2	2	4	14	6	20	0	7	18	4	16
3453	7.57	2	0	5	8	4	19	1	1	5	2	10
3492	6.38	4	0	2	16	7	18	0	2	8	2	17
3497	8.74	2	1	4	21	7	22	1	5	3	5	8
3584	7.80	2	0	6	14	4	13	0	2	11	4	16
3587	6.96	2	0	3	5	4	14	0	0	6	3	8
3602	2.95	4	0	1	5	0	10	0	0	1	1	2
3604	13.15	2	1	3	10	1	11	0	2	3	3	16
3641	9.83	2	0	1	3	0	4	0	0	0	1	3
3644	1.25	2	0	0	2	0	1	0	1	0	1	4
3654	4.56	2	1	0	9	2	10	0	2	9	2	19
3661	8.00	2	0	2	7	3	8	0	0	5	4	11
3662	9.73	2	0	4	5	2	8	0	2	8	0	10
3670	6.47	4	0	1	14	6	50	1	1	2	9	25
3680	3.60	2	0	1	12	0	13	0	0	5	0	4
3755	6.94	2	0	0	2	1	1	0	0	2	1	3
3763	1.30	2	0	1	0	1	5	0	0	0	1	2
3766	14.26	2	2	3	9	1	15	0	4	13	2	14
3784	2.77	2	0	0	1	1	1	0	0	0	0	0
3790	2.87	4	1	6	27	6	78	1	4	23	18	65
3797	6.28	2	1	2	16	6	19	1	3	5	2	10
3802	7.62	2	0	4	10	4	16	0	4	9	6	21
3805	5.13	2	0	1	10	4	5	0	0	3	3	6
3808	2.91	2	0	3	0	0	6	0	1	1	0	4
3861	7.99	2	2	2	1	1	7	0	4	3	4	14
3866	7.40	2	0	0	0	1	0	0	1	2	0	1
3875	14.59	2	0	0	2	0	4	0	0	0	0	3
3884	6.67	2	0	0	1	0	1	0	0	0	0	1
3927	3.79	2	0	1	3	0	2	0	2	0	0	3
3939	3.22	6	0	2	18	13	43	0	1	7	7	13
3944	3.31	2	1	0	1	2	11	0	0	1	1	10
3946	7.86	2	0	2	4	8	6	2	1	4	1	5
3947	5.00	2	0	0	5	1	10	0	1	5	3	5
3948	7.32	2	0	2	4	5	13	1	2	6	4	15
3966	3.69	2	0	0	6	1	5	0	0	2	1	6
3996	4.63	2	0	0	2	0	3	0	0	7	2	3
4030	4.91	2	0	2	1	3	16	1	2	3	1	13
TOTAL 52	343.39		15	98	352	147	657	14	75	242	129	525

Determining the Effect of Other Safety Initiatives on ROR Collision Rates

Comparisons of ROR collision rates for the side slope flattened sections were also made with the overall ROR collision rate reduction on Washington State highways during the study period in an attempt to determine the extent to which non-structural highway safety initiatives have reduced ROR collision rates. The information used for the comparison was obtained from summaries of accident statistics from Washington State Highway Accident Reports (1983 through 1994). Only collision history for rural areas was utilized. The statewide statistics were recalculated on the basis of ROR collisions per mile to facilitate meaningful comparisons. The statewide data is shown in Table 5. For purposes of comparison, the percentage increase in miles traveled was calculated from the averages for the eight year "before" and seven year "after" periods. There was an increase of 10.5% in miles traveled.

Table 5. Summaries of Washington State Highway ROR Collisions in Rural Areas

Year	Miles of Rural Highway	Miles Traveled (billions)	Number of: Fatalities & Disabling Injuries	Number of: Evident Injuries	Number of: Possible Injuries	Number of: PDO	Collisions per Mile: Fatalities & Disabling Injuries	Collisions per Mile: Evident Injuries	Collisions per Mile: Possible Injuries	Collisions per Mile: PDO
1983	6,020	8.57	686	1,257	658	2,642	0.114	0.209	0.109	0.439
1984	5,979	8.52	702	1,347	686	2,982	0.117	0.225	0.115	0.499
1985	5,976	8.60	677	1,411	808	3,382	0.113	0.236	0.135	0.566
1986	5,978	9.19	670	1,338	693	3,114	0.112	0.224	0.116	0.521
1987	5,978	8.47	701	1,458	682	3,143	0.117	0.244	0.114	0.526
1988	5,979	8.91	721	1,438	748	3,483	0.121	0.241	0.125	0.583
1989	5,975	9.13	681	1,559	731	3,581	0.114	0.261	0.122	0.599
1990	5,992	9.61	615	1,428	784	3,448	0.103	0.238	0.131	0.575
1991	5,976	9.81	598	1,408	782	2,972	0.100	0.236	0.131	0.497
1992	5,978	10.03	511	1,309	774	2,975	0.085	0.219	0.129	0.498
1993	5,978	10.32	444	1,360	765	3,215	0.074	0.228	0.128	0.538
1994	5,978	10.83	453	1,399	828	3,102	0.076	0.234	0.139	0.519

Determining If Side Slope Flattened Sections Had More of an Effect on HACs

Highway construction projects with side slope flattened sections were screened to identify those that fell on High Accident Corridors (HACs). The ROR collision rates on the side slope flattened sections within the HACs were evaluated to see if there was a more or less pronounced effect from side slope flattening on those highways.

FINDINGS

In this section, results of the data are analyzed and compared. The ROR collision rate reductions in the various severity categories are presented first. These rates are then compared with the collision rates recorded for the entire length of all of the projects. Further comparisons are made with Washington State highway ROR collision rates in rural areas. These comparisons introduce the use of controls and further to indicate the extent of benefits achieved by slope flattening. Analysis of side slope flattening on High Accident Corridors, discussion of the statistical significance of the research results and other observations are also included.

ROR COLLISION RATES - PREDICTED VS ACTUAL

The "predicted after" and "actual after" consolidated ROR collision rates based on data from Table 3 are summarized in Table 6. The fatalities and disabling injury categories have been combined because separate treatment of the extremely small number of fatalities would not have produced statistically significant results. The "predicted after" rates do not include a reduction for side slope flattening.

The "actual after" rates in the slope flattened sections were less than the "predicted rates" in each of the listed severity categories. This indicates that slope flattening reduced the number of ROR collisions. It should be noted that an increase in fatalities is masked by having combined that severity category with disabling injuries.

Table 6. ROR Collision Rate Comparisons for Before and After Conditions of Side Slope Flattened Highway Sections

Collision Category	Slope Flattened Length	Before		Reduction Factor	After		Collision Rates		
		Number	YOD		Number	YOD	Before	Predicted	After
Fatalities and Disabling Injuries	139.89	32	3.35	0.92	21	3.08	0.068	0.063	0.049
Evident Injuries	139.89	112	3.35	0.92	53	3.08	0.239	0.220	0.123
Possible Injuries	139.89	51	3.35	0.92	42	3.08	0.109	0.100	0.097
PDO	139.89	235	3.35	0.93	116	3.08	0.501	0.466	0.269
Total	139.89	430	3.35	0.92	232	3.08	0.918	0.846	0.538

These tabulated comparisons are illustrated in Figures 1 through 5. Because the data was consolidated from all of the study projects, the "before," "after" and "construction and adjustment" time periods each span several years, as indicated.

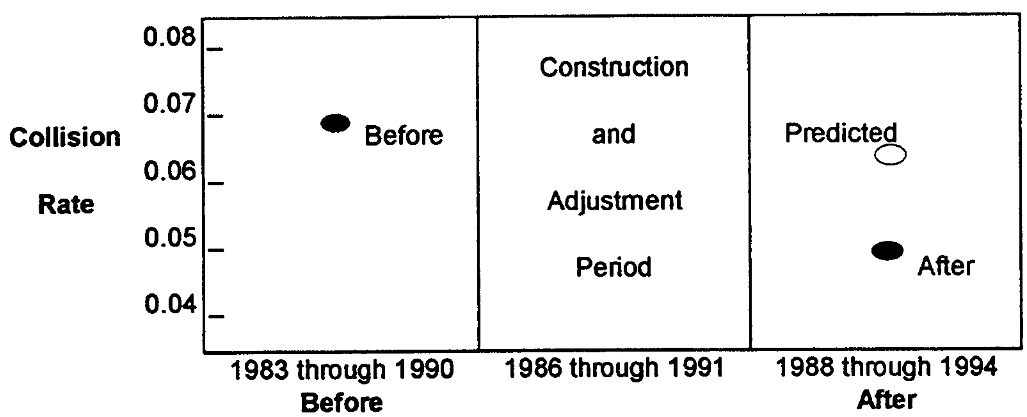

Figure 1. Comparison of Predicted and Actual ROR Collision Rates After Side Slope Flattening for Fatalities and Disabling Injuries

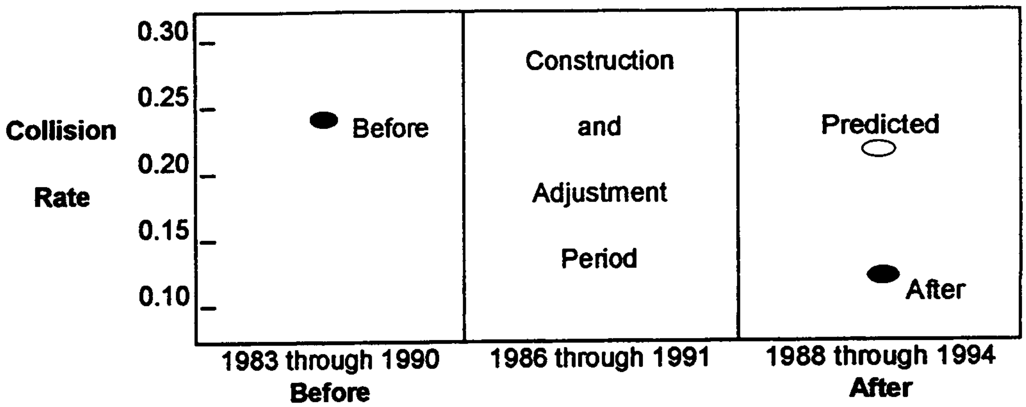

Figure 2. Comparison of Predicted and Actual ROR Collision Rates After Side Slope Flattening for Evident Injuries

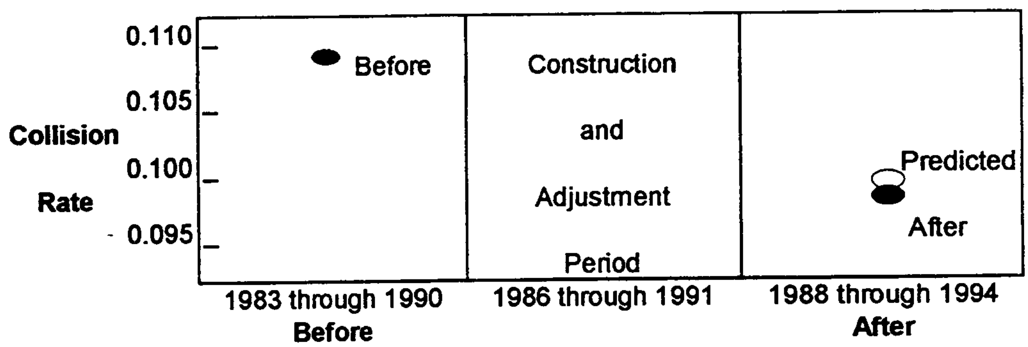

Figure 3. Comparison of Predicted and Actual ROR Collision Rates After Side Slope Flattening for Possible Injuries

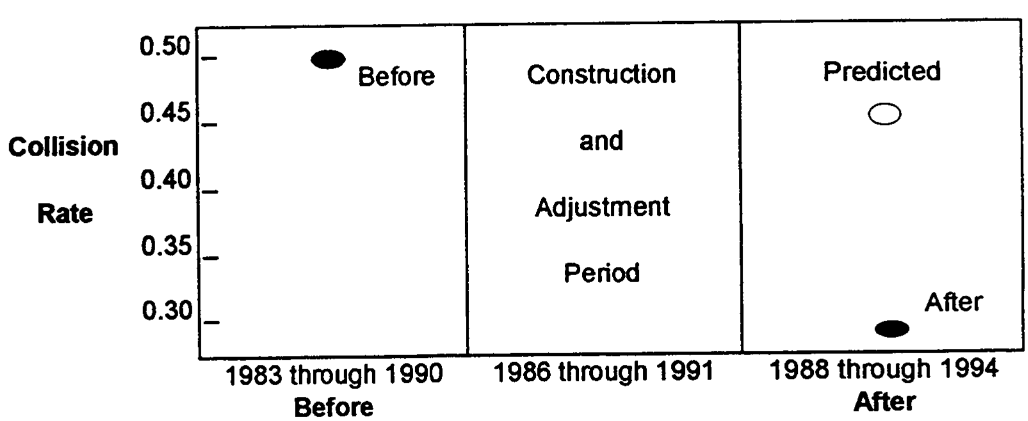

Figure 4. Comparison of Predicted and Actual ROR Collision Rates After Side Slope Flattening for PDO (Property Damage Only)

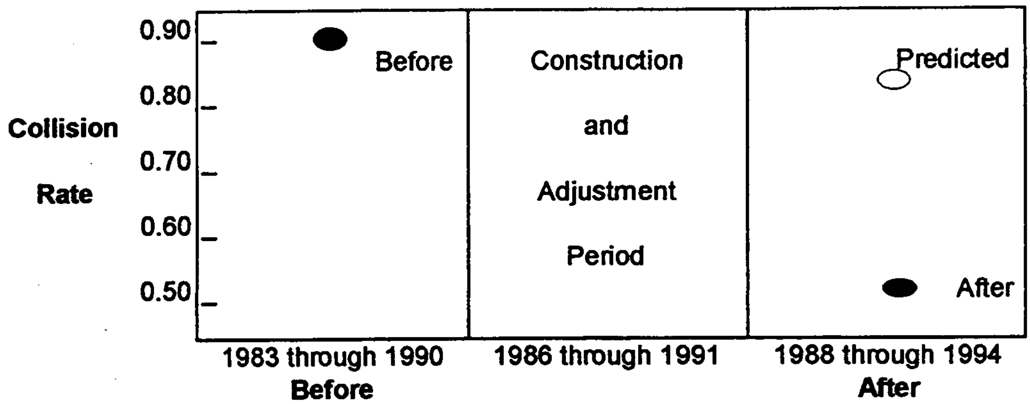

Figure 5. Comparison of Predicted and Actual ROR Collision Rates After Side Slope Flattening for All Collision Categories

SLOPE FLATTENED SECTIONS COMPARED WITH PROJECTS

In order to establish "control" sections which could validate the apparent reduction in ROR collision rates, the "actual after" ROR collision rates for each of the highway construction projects were determined. These control sections comprised the lengths of highway from beginning to ending mileposts of each of the construction projects which were studied. These ROR collision rates were compared with those recorded earlier for the side slope flattened sections of each project. Lower actual ROR collision rates and reduced collision severity were evident in the side slope flattened sections. This data is summarized in Table 7 and graphically portrayed in Figures 6 through 10. The fatalities and disabling injuries categories have again been combined.

Table 7. Summary of ROR Collision Rates for the Entire Length of the Projects

Severity Category	Entire Project Lengths							With Slope Flattening		
	No. of Collisions		Years of Data		Project Length	Collision Rate		Collisions After	Length	Collision Rate
	Before	After	Before	After		Before	After			
Fatalities and Disabling Injuries	113	89	3.35	3.08	343.39	0.098	0.084	21	139.89	0.049
Evident Injuries	352	242	3.35	3.08	343.39	0.306	0.229	53	139.89	0.123
Possible Injuries	147	129	3.35	3.08	343.39	0.128	0.122	42	139.89	0.097
PDO	657	525	3.35	3.08	343.39	0.571	0.496	116	139.89	0.269
Total	1269	985	3.35	3.08	343.39	1.103	0.931	232	139.89	0.538

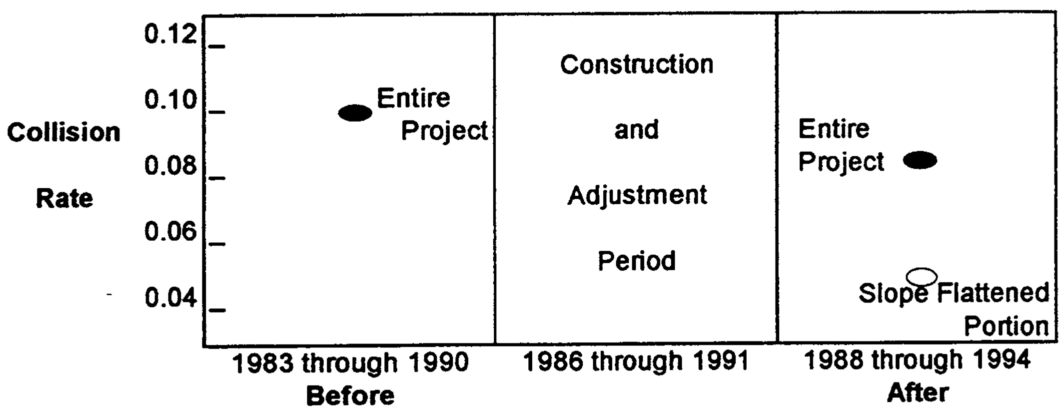

Figure 6. Comparison of ROR Collision Rates for Fatalities and Disabling Injuries on Side Slope Flattened Sections With Rates for the Entire Length of All Projects

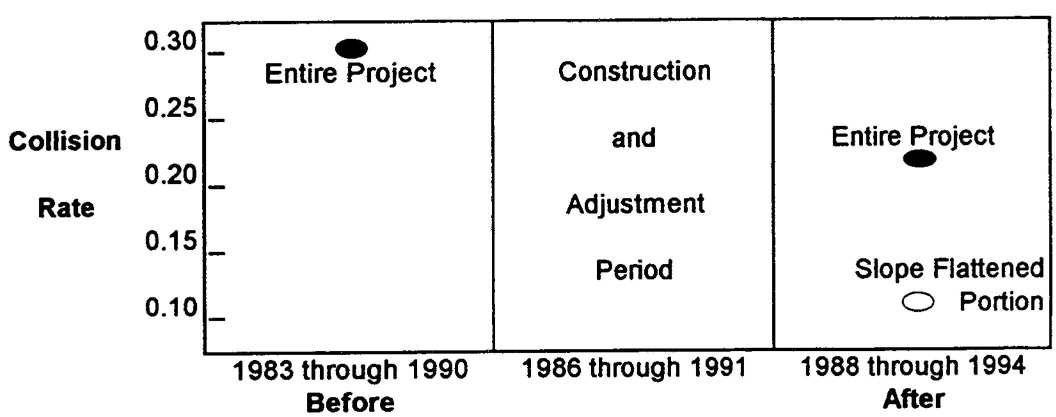

Figure 7. Comparison of ROR Collision Rates for Evident Injuries on Side Slope Flattened Sections With Rates for the Entire Length of All Projects

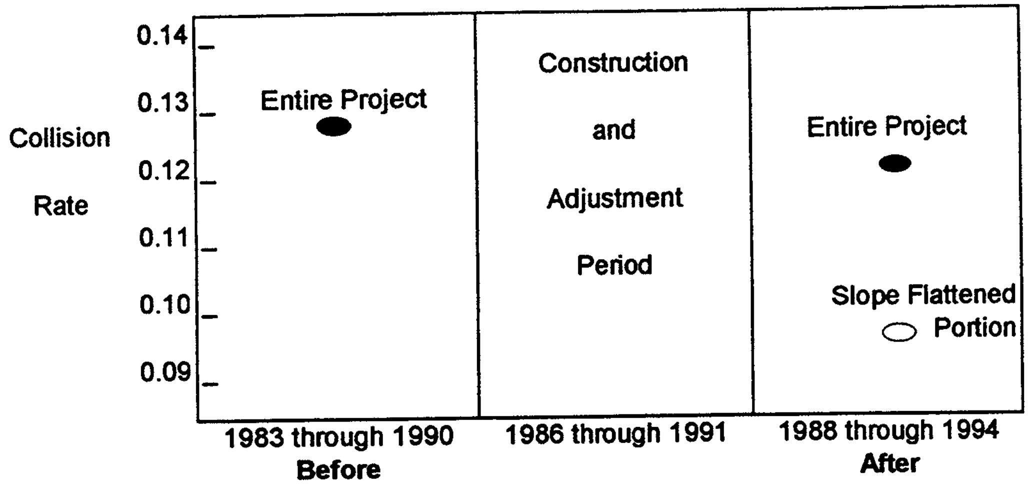

Figure 8. Comparison of ROR Collision Rates for Possible Injuries on Side Slope Flattened Sections With Rates for the Entire Length of All Projects

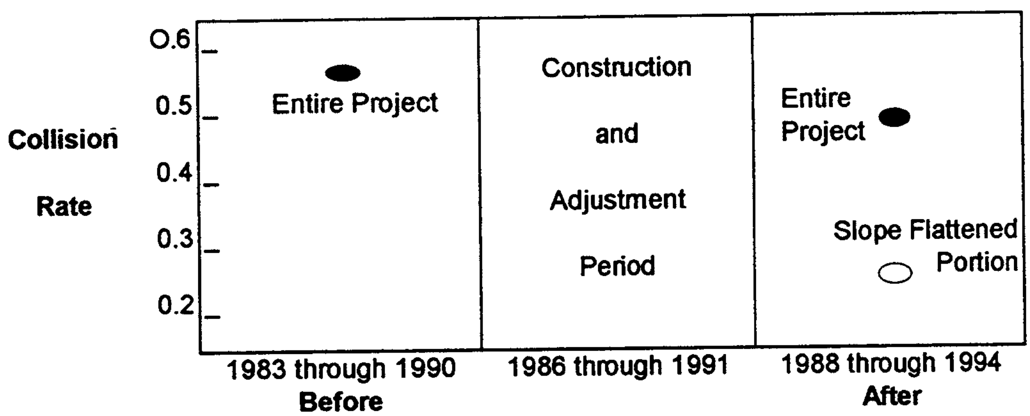

Figure 9. Comparison of ROR Collision Rates for PDO on Side Slope Flattened Sections With Rates for the Entire Length of All Projects

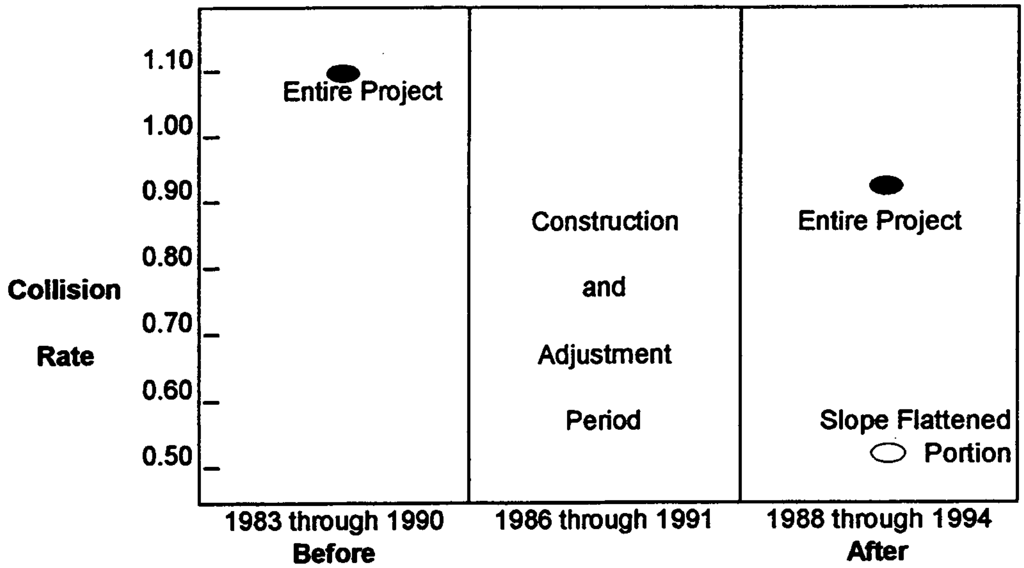

Figure 10. Comparison of ROR Collision Rates for All Collision Categories on Side Slope Flattened Sections With Rates for the Entire Length of All Projects

EFFECT OF OTHER SAFETY INITIATIVES

The difference between the actual and predicted ROR collision rates cannot be attributed entirely to side slope flattening. Numerous safety initiatives have collectively helped to reduce the number of fatalities, the severity of injuries and the real dollar value of property damage. Some of these initiatives are:

- Introduction of anti-lock brake systems
- Improved side impact attenuation on motor vehicles
- Increased emphasis on DWI (ticketing drivers and designated driver program)
- Enactment and enforcement of a statewide seat belt law
- Increased availability and use of air bags
- Improved lighting

Just how much of the reduction in ROR collision rates may have been the result of the other initiatives? To answer this question, the statewide trend in collision statistics for the study period (1983 to 1994) were analyzed. The information from Table 5 was averaged for the "before" and "after" periods of the study. Changes in ROR collision rates between these periods were calculated for each severity category as shown in Table 8.

Table 8. Changes in ROR Collision Rates for Washington State Highways in Rural Areas

Severity Category	Collision Rate Before (1983-1990)	Collision Rate After (1988-1994)	Percent Reduction	Reduction Factor
Fatalities and Disabling Injuries	0.116	0.092	24.00	0.760
Evident Injuries	0.230	0.236	(2.61)	1.026
Possible Injuries	0.119	0.130	(9.24)	1.092
PDO	0.522	0.537	(2.87)	1.029

The percent reduction column in Table 8 shows the net changes in collision rates and conceivably represents the effect of all roadside safety improvements, including non-structural initiatives, in reducing the number and severity of ROR collisions. There is a decrease in the combined severity categories of fatalities and disabling injuries, while the less severe categories show slight increases in ROR collision rates.

Using the reduction factors from Table 8 and a traffic adjustment factor (based on increased ADT) to calculate collision rates similar to those illustrated earlier in Figures 1 to 4, the comparisons shown in Figures 11 through 14 are generated. The calculated rates are included in Table 9.

Table 9. Collision Rate Comparisons for Before and After Conditions Using Washington State Highway Accident Report Data

Collision Category	SF Length	Before		Reduction Factor	After		Collision Rates		
		Number	YOD		Number	YOD	Before	Predicted	After
Fatalities and Disabling Injuries	139.89	32	3.35	0.760	21	3.08	0.068	0.052	0.049
Evident Injuries	139.89	112	3.35	1.026	53	3.08	0.239	0.245	0.123
Possible Injuries	139.89	51	3.35	1.092	42	3.08	0.109	0.119	0.097
PDO	139.89	235	3.35	1.029	116	3.08	0.501	0.516	0.269

The trends seen earlier in Figures 1 through 4 remain the same for all severity categories. However, the percent reduction attributable to side slope flattening improves sufficiently for the possible injury severity category that the reduction becomes statistically significant. (See the section "Statistical Significance of the Research Results" on page 39 of this report.)

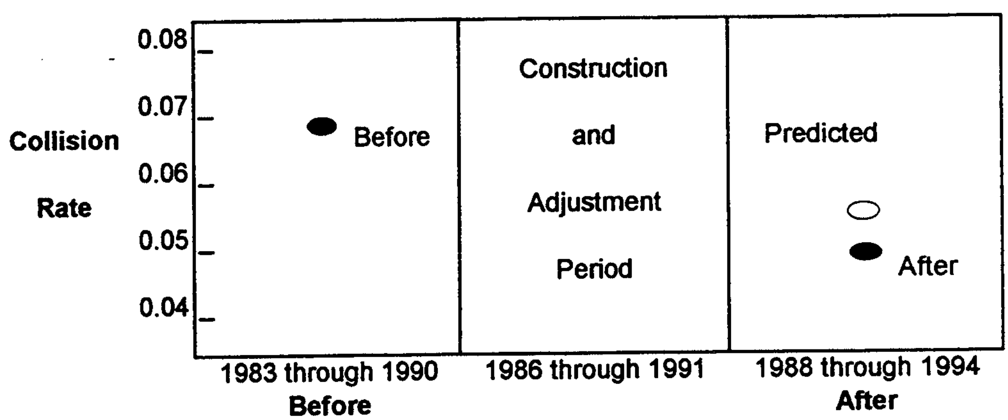

Figure 11. Comparison of Actual ROR Collision Rates with Those Predicted Based on Washington State Collision Reports of Fatalities and Disabling Injuries

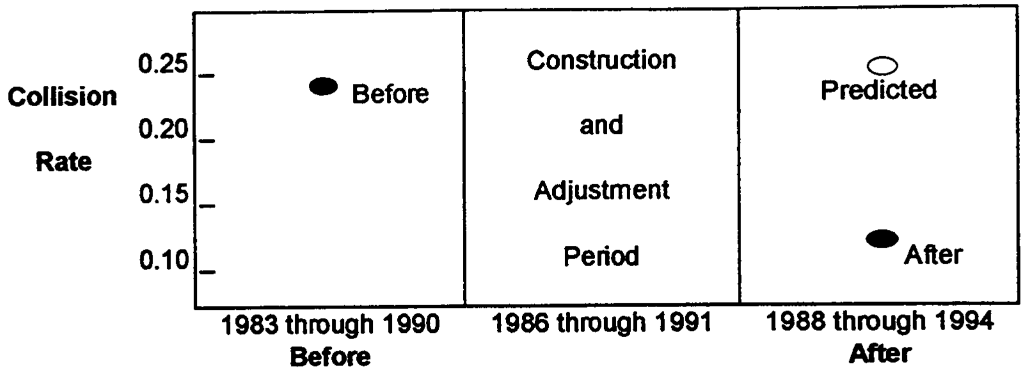

Figure 12. Comparison of Actual ROR Collision Rates with Those Predicted Based on Washington State Collision Reports of Evident Injuries

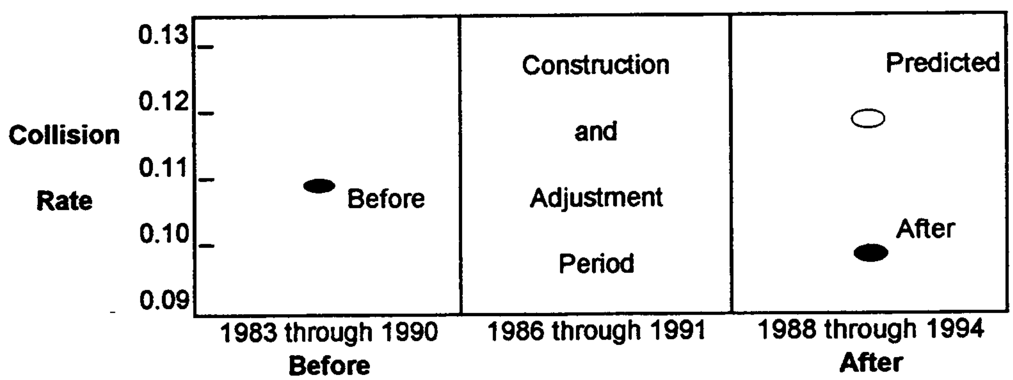

Figure 13. Comparison of Actual ROR Collision Rates with Those Predicted Based on Washington State Collision Reports of Possible Injuries

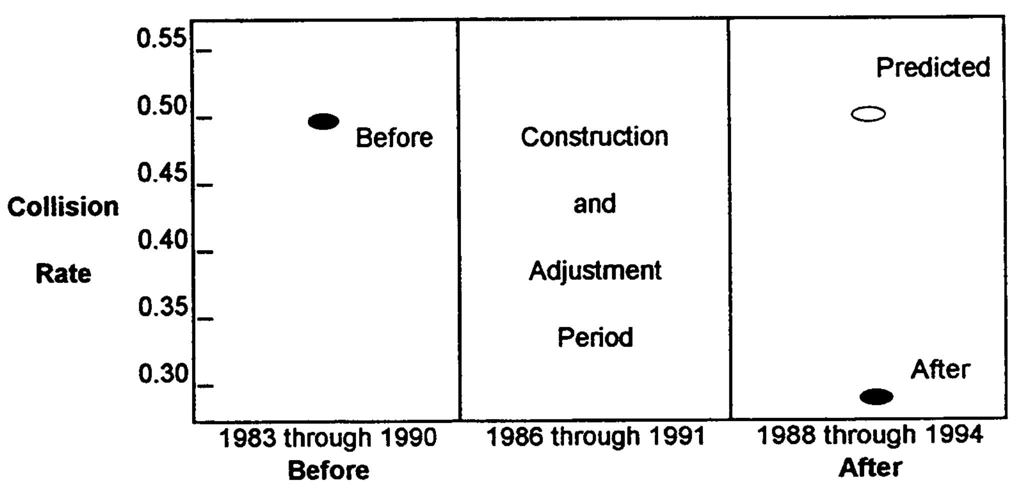

Figure 14. Comparison of Actual ROR Collision Rates with Those Predicted Based on Washington State Collision Reports of PDO (Property Damage Only)

IMPACT OF SIDE SLOPE FLATTENING ON HIGH ACCIDENT CORRIDORS

When the effects of side slope flattening on the HACs are compared with the effects on the rest of the projects, an increase in ROR collisions is noted in the combined categories of fatalities and disabling injuries and in the possible injuries category. These increases are offset by less pronounced decreases in the evident injuries and PDO categories. The comparisons are shown in Table 10.

Table 10. Comparison of the Reduction in ROR Collision Rates on HACs with All Side Slope Flattened Sections

Severity Category	Slope Flattened Length		% Reduction Attributable to SF		Number of ROR Collisions in HAC	
	Overall	HAC Portion	Overall	HAC Portion	Before	After
Fatalities and Disabling Injuries	139.89	24.90	22.2	(48.1)	4	6
Evident Injuries	139.89	24.90	44.1	21.5	15	12
Possible Injuries	139.89	24.90	3.0	(53.1)	7	11
PDO	139.89	24.90	42.3	20.4	32	26
Total	139.89	24.90	36.4	6.5	58	55

The small number of collisions in the 25 miles of slope flattened HAC sections preclude drawing meaningful conclusions. More roadside safety improvements may have been incorporated into the HACs in relatively short time frames. Additional safety improvement projects may have taken place during the eight to ten year study periods reviewed for this research. It will be shown later that the data recorded is not statistically significant.

OTHER OBSERVATIONS

In the foregoing comparisons there was a marked reduction in the number of collisions in sections with flattened side slopes, especially when compared with sections with less forgiving roadside features such as guard rail. The percent reduction was appreciably less pronounced in the possible injury severity category. However, the statistical reliability of this data would be improved by further studies covering more extensive time frames and longer stretches of highway where side slopes have been flattened. Further exploration by studying projects completed in earlier years is not considered feasible because:

- Pertinent data may no longer be available
- There have been changes in side slope criterion (standards)
- Additional follow-on roadside safety improvements may have been made in ensuing years.

A lack of complete pre-project roadside inventory data was evident during this research because only 25% of the contract files reviewed at the Records Services office of WSDOT contained design reports. This precluded establishing pre-project side slope conditions. It was also noted that current policy, which calls for the destruction of such records after six years, severely limits the time span available for research.

There were several projects with flattened side slopes where no ROR collisions were recorded before and after construction. The purpose of reporting this fact is to add credence to the present policy of requiring benefit-cost analysis in determining the type and extent of roadside safety improvements and to allow deviations from a blanket application of standards. The past practice of bringing all highways to standards may not have resulted in the most efficient use of highway funds, although this approach continues to be employed on mobility and safety improvement projects.

One additional question was posed during the research: What might have been the result had benefit-cost analysis been used in deciding where to flatten side slopes on the highway construction projects reviewed in this research?

To answer this question, the side slope flattened sections that were "ROR collision free" both before and after the projects were removed from the data base. It was assumed that these sections would not have had a high enough benefit-cost factor to qualify for funding. The total side slope flattened length was reduced to 99.98 miles. The ROR collision rates that would have materialized under this scenario are shown in Table 11. An improvement of about forty percent in benefits can be expected as evidenced by the percentages shown in the "Differential Improvement in Rates" column.

Table 11. Hypothetical ROR Collision Rates When Excluding Collision Free Highway Sections

Severity Category	Number of Collisions		Years of Data		Reduced Project Length	Hypothetical Collision Rate		Differential Improvement in Rate (%)
	Before	After	Before	After		Before	After	
Fatalities and Disabling Injuries	32	21	3.35	3.09	99.98	0.096	0.068	42.9
Evident Injuries	112	53	3.35	3.09	99.98	0.334	0.172	39.2
Possible Injuries	51	42	3.35	3.09	99.98	0.152	0.136	NA
PDO	235	116	3.35	3.09	99.98	0.702	0.375	41.1
Total	430	232	3.35	3.09	99.98	1.284	0.751	39.6

STATISTICAL SIGNIFICANCE OF THE RESEARCH RESULTS

The results of this research project were tested for statistical significance following the approach outlined as Function D of the FHWA "Highway Safety Evaluation - Procedural Guide" (1981). A minimum confidence level of 80% was used to determine the statistical significance of the research data. Because the extent of side slope flattening (i.e. 2:1 flattened to 6:1 or 3:1 flattened to 4:1) could not be determined, the maximum reduction for slope flattening of 15% was taken from the WSDOT Safety Countermeasures Reference Summary (1995) and utilized in the significance testing. These percent reductions are shown in Table 12.

Table 12. ROR Collision Reductions Due to Side Slope Flattening

Safety Improvement Features	Percent Reduction for All Types of Collisions on 2-Lane Rural Roads
Flatten Side Slopes from 2:1 to 4:1	7
Flatten Side Slopes from 2:1 to 6:1	15
Flatten Side Slopes from 3:1 to 4:1	6
Flatten Side Slopes from 3:1 to 6:1	14

The outcomes of the statistical significance testing are shown in Tables 13 and 14 for actual versus predicted and slope flattened sections versus the entire projects, respectively. In Table 13 the reduction shown for the possible injury severity category is not statistically significant because the percent reduction is less than the 15% threshold. When the reduction for possible injuries is tested against the length of all projects, the outcome is statistically significant.

Table 13. Outcomes of Testing for Statistical Significance for Actual versus Predicted ROR Collisions

Severity Category Tested	Expected Number of Collisions	Actual Number of Collisions	Percent Reduction in Collision Rate	Statistically Significant? Yes or No.	Level of Confidence (%)
Fatality and Disabling Injury	29	21	22.2	Yes	90
Evident Injury	103	53	44.1	Yes	99
Possible Injury	47	42	3.0	No	
PDO	219	116	42.3	Yes	99
Total	365	232	36.4	Yes	99

Table 14. Outcomes of Testing for Statistical Significance for Slope Flattened Sections versus the Entire Projects

Severity Category Tested	Expected Number of Collisions	Actual Number of Collisions	Percent Reduction in Collision Rate	Statistically Significant? Yes or No.	Level of Confidence (%)
Fatality and Disabling Injury	36	21	41.7	Yes	99
Evident Injury	99	53	46.3	Yes	99
Possible Injury	53	42	20.5	Yes	90
PDO	214	116	45.8	Yes	99
Total	401	232	42.2	Yes	99

The outcomes of testing of the slope flattened sections of the HACs are shown in Table 15. The percent reductions in collisions from side slope flattening on the HAC sections were not statistically significant in any of the severity categories

Table 15. Outcomes of Testing for Statistical Significance for Actual versus Predicted ROR Collisions in HACs

Severity Category Tested	Expected Number of Collisions	Actual Number of Collisions	Percent Reduction in Collision Rate	Statistically Significant? Yes or No.	Level of Confidence (%)
Fatality and Disabling Injury	4	6	(48.1)	No	
Evident Injury	15	12	21.5	No	
Possible Injury	7	11	(53.1)	No	
PDO	33	26	20.4	No	
Total	60	55	6.5	No	

The outcomes of testing of the reductions in collisions based on Washington State ROR collision history on rural roads is shown in Table 16. Except for fatalities and disabling injuries the reductions were statistically significant.

Table 16. Outcomes of Testing for Statistical Significance for Actual versus Predicted ROR Collisions Based on Washington State Collision Reports

Severity Category Tested	Expected Number of Collisions	Actual Number of Collisions	Percent Reduction in Collision Rate	Statistically Significant? Yes or No.	Level of Confidence (%)
Fatality and Disabling Injury	24	21	12.5	No	
Evident Injury	115	53	53.8	Yes	99
Possible Injury	56	42	24.8	Yes	95
PDO	242	116	52.0	Yes	99

CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

CONCLUSIONS

The research results clearly indicate that side slope flattening reduces the number and severity of ROR collisions. This held true for comparisons within the slope flattened sections, within the entire length of all of the projects and when taking the effect of non-structural safety improvement initiatives into account. Except for the possible injury severity category, the reduction percentages attributed to side slope flattening were statistically significant. The overall percentage reduction in collisions exceeded the 15% currently used in cost-benefit analysis, thus validating present practice.

When evaluating the effect of side slope flattening on high accident corridors, there appeared to be no definite trend.

RECOMMENDATIONS

Following are recommendations based on this research effort:

- The use of benefit-cost analysis should be extended to evaluation of roadside safety improvements in all types of highway construction projects.
- Research should be conducted to evaluate the effects of other roadside safety improvements in order to validate the reduction percentages currently in use. Before and after studies similar to this research project may be appropriate.

- Research should be conducted on the impact and effect that human factors and non-structural safety initiatives have on highway safety.
- Consideration should be given to revising present policy on maintenance of historical data for construction projects by the Records Office and in the archives. Design reports should be submitted to the Records Office for all construction projects. All contract documents should be maintained in the archives for at least ten years.

IMPLEMENTATION

WSDOT should continue the practice of requiring benefit-cost analysis when planning and designing highway safety improvement projects and consider extending this methodology to all improvement projects. Design engineers should be given the ability to deviate from standards based on the most cost effective safety improvement.

Building to standards may not be the most cost effective way to expend limited highway funds. Some lane miles within HACs have had few, if any, ROR collisions. Therefore, deviations within projects should also be considered for benefit-cost analysis where there have been few ROR collisions and where there is a low probability of future ROR collisions.

The data generated for this research project should be maintained for use in future research to evaluate the effects of other roadside safety improvements. Although specific percentages for the reduction of ROR collision rates could not be ascertained for slope flattening in this research project, the overall reductions from side slope flattening and other non-structural initiatives could be assumed as constants in future research. This would allow the effects of other roadside safety improvements to be determined.

ACKNOWLEDGMENTS

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APPENDIX

Introduction

It was shown in previous research efforts, that slope flattening (SF) of clear zones on approximately 140 miles of State highways, reduced the number of collisions and injury severity related to run-off-the-road (ROR) collisions in the State of Washington. The research tallied collision types associated only with ROR collisions on sections of state highway where slope flattening was performed from 1983 to 1994. The study periods averaged three years prior to and three years after construction. The collision totals for each severity category were listed in separate worksheets for each project. All safety features included in each project were also listed. These consisted of delineation, lane and shoulder widening removal of obstacles, addition of rumble strips and curve realignment. These improvements had a positive effect on the overall safety of each highway section. The effects of these other initiatives were factored out leaving a residual reduction in the number and severity of collisions attributable to side slope flattening.

Further study was undertaken to determine trends or relationships between the study results and truck percentages, ADT and speed limits on those same sections of highway.

The severity categories of fatalities and disabling injuries were combined in this study because of a lack of collision data in the fatalities category. In conjunction with combining the two categories, the calculated reduction factors for each category were modified to accurately reflect the results of this combination.

Results

The results of this study agree with those of the previous research. Slope flattening does reduce the number of collisions in the studied severity categories by a significant amount. However, the rates of reduction for all categories of collisions are not equal and vary with the percentages of trucks and the magnitude of ADT. On highway sections with low speeds there was a hypothetical increase in collisions.

Percent Trucks: Truck percentages were divided into three series: 20% and greater, between 10% and 20%, and 10% or less. There was a greater pay-back where there were higher percentages of trucks in both lowering the number of collisions and in the dollar benefits realized as shown in Figures 1 and 3. Figure 1 shows the totals of all collision severity categories for pre-project, post-project and post-project due to side slope flattening. The side slope flattening effect was determined by multiplying the calculated percent reduction due to SF for each severity category by the pre-project number of collisions and then subtracting this value from the total number of pre-project collisions. The formula used is as follows:

Hypothetical post-project number of collisions due to SF = Pre-project number of collisions - (Pre-project number of collisions)X(Percent reduction due to SF)

The largest reduction (49%) due to slope flattening was realized in the >20% trucks series. This series covered about 40 miles of the 140 SF miles. The 10 to 20% series covered 54 SF miles and showed a reduction in all collision types of 46% but had 37% fewer collisions than the >20% series. The <10% series, which included 46 SF miles, experienced a reduction of only 16%. It was also noted that the ADT values were essentially the same in both the <10% trucks and the >20% trucks series.

Figure 3 represents the benefit values realized in each truck percentage category in dollars per mile of slope flattened highway per year. This shows that side slope flattening does not make sense except where there are high percentages of trucks.

Average Daily Traffic: The 140 miles of side slope flattened highway were divided into four approximate equal lengths to explore the effect of ADT on the reduction of collisions due to side slope flattening. Each quarter was listed from its lowest to highest ADT and the collision data subsequently listed and analyzed. The first one-fourth of the mileage (31.75 SF miles), with the lowest ADT, had recorded traffic ranging from 110 to 1675 vehicles per day. The second quarter ranged from 1675 to 3550 vehicles and spanned 37.9 SF miles. The third ranged from 3750 to 5000 vehicles, covering over 34.2 SF miles and the final quarter with ADT >5000 vpd covered the remaining 35.6 SF miles. The results are listed in Figure 2, a bar chart similar to the one created for truck percentages. Again the total number of collisions both before and after were plotted against the ADT for each of the four quarters of SF mileage. The reduction due to SF for each collision severity category was multiplied by the pre-project number of collisions. This number was then subtracted from the pre-project number of collisions. This gave a hypothetical reduction due only to SF. The formula used is as follows:

Hypothetical Post-project collisions due to SF = Pre-project collisions - (Pre-project collisions)X(Percent Reduction due to SF)

Oddly enough, the largest percent reduction in ROR collisions due to SF was greatest in the mileage quarter with the lowest ADT. This reduction was over 67%. The mileage quarter with the second lowest ADT had a reduction of 34%, while the 3rd and 4th quarters revealed reductions of 23.5% and 42%, respectively. Though the highest reduction was realized in the quarter with the lowest ADT, this mileage quarter of lowest ADT also had the least number of before and after collisions. There were nearly 79% fewer collisions in the mileage quarter with the lowest ADT than in the fourth mileage quarter with ADT >5000.

Speed limit: The contract data was divided into highway sections with speeds of 55 mph or higher and those with speeds of 50 mph and less. Nearly 123 SF miles were on sections of highway at speeds greater than 55 mph. On these highway sections there were 379 pre-project collisions. After side slope flattening only, this number would have been reduced to the hypothetical value of 239 collisions (calculated in the same manner described above). This represents a reduction of approximately 37%. There were 13.5 SF miles with speed limits of 50 mph or less. Here there was actually an increase of 9% between the total number of pre-project collisions and the hypothetical reduction due only to SF.

The extremely low number of miles of SF highway at less than 55 mph posted speeds precludes drawing finite conclusions from this part of this study.

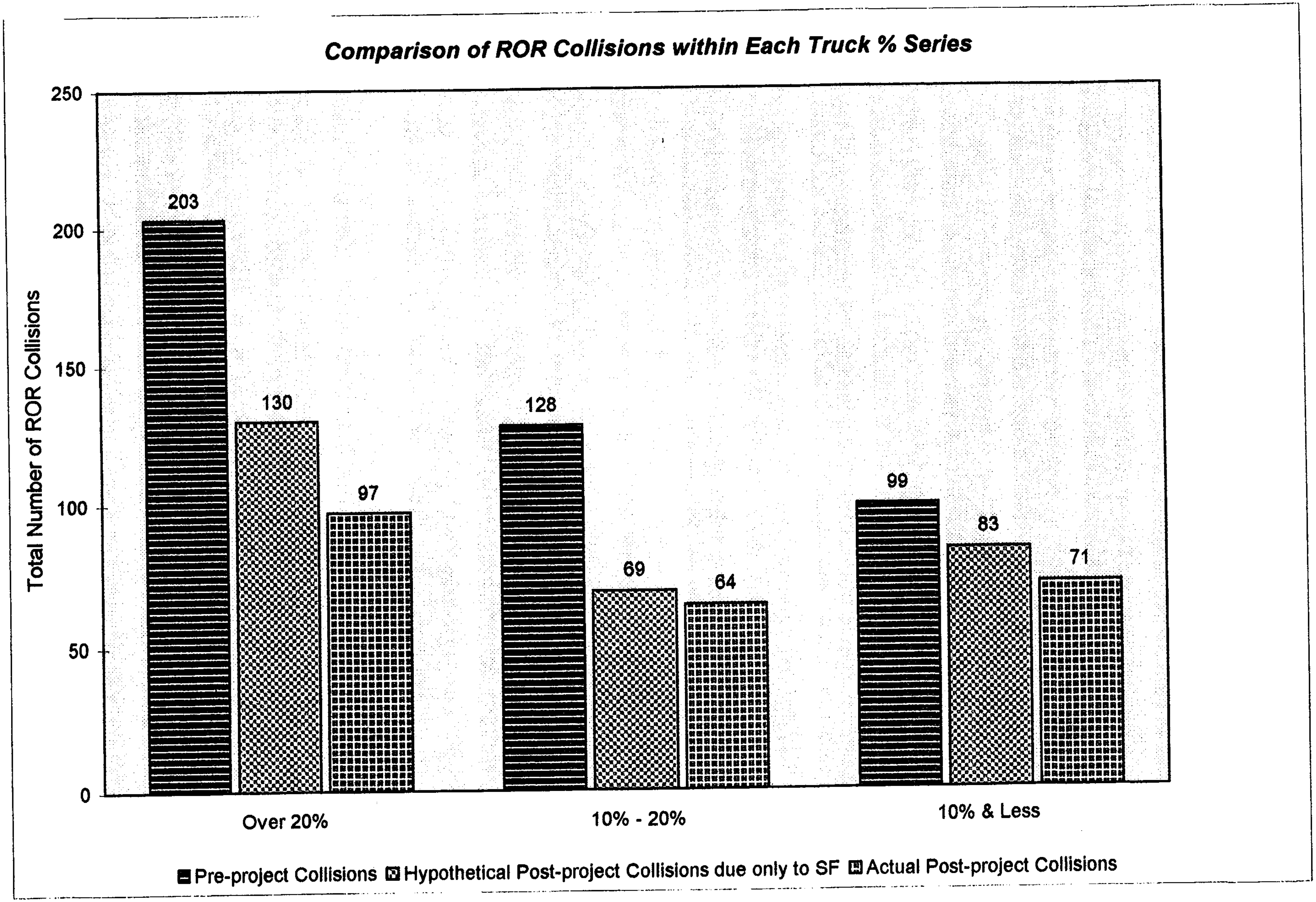
DATA CONFIDENCE

Truck percentages, ADT and speed limit data were taken from WSDOT Annual Traffic Reports and the 1993 Highway Log when not available in the contract data summaries of the previous research effort. The majority of ADT values were listed in the contract worksheets of the previous report, but a small percent were missing and had to be inserted into the new data summaries. Truck percentages are not precise and varied considerably from year to year and along various highway sections. Comparisons should probably be restricted to truck percentages >20% with those <10% to be considered valid.

SUMMARY

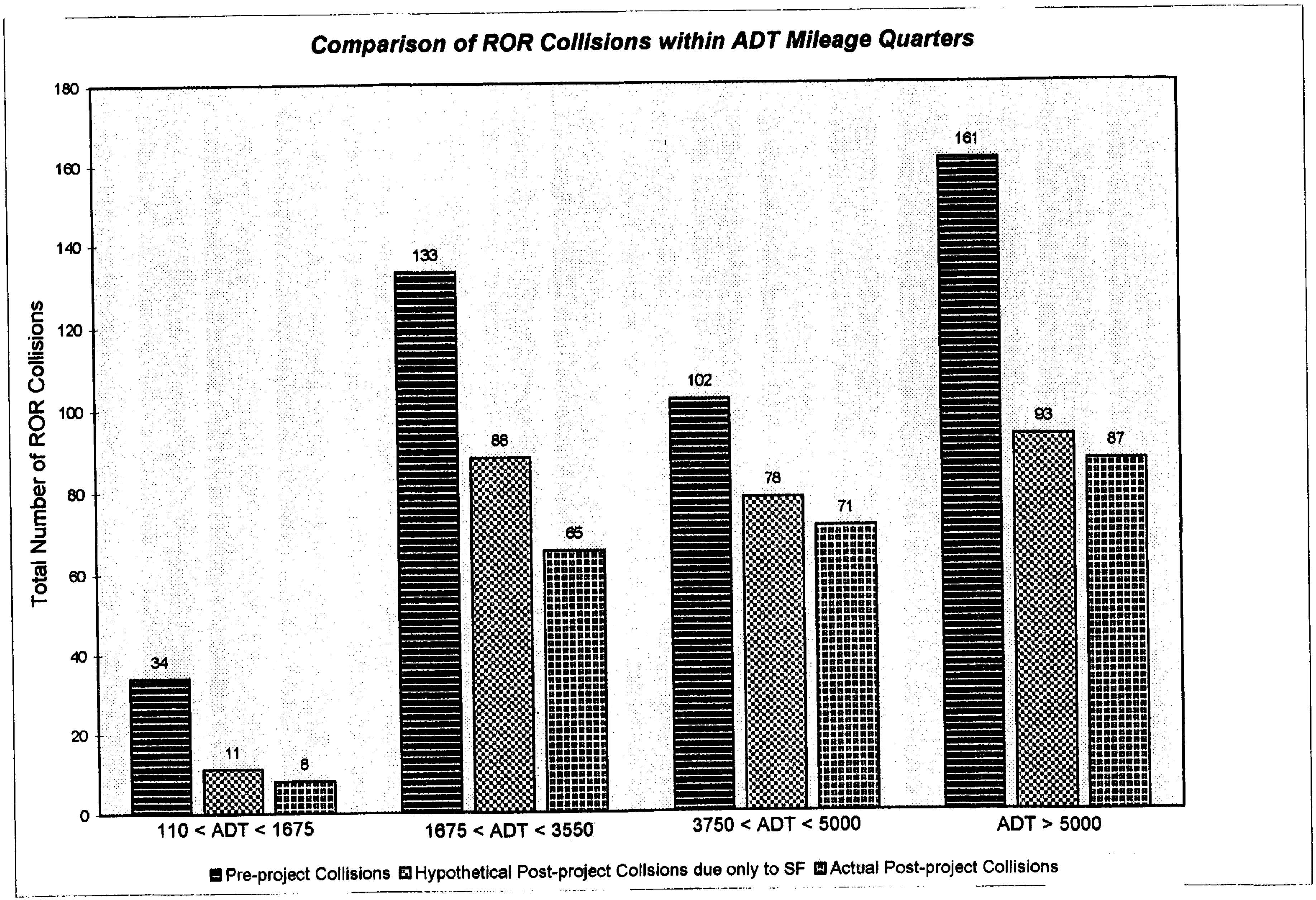
Slope flattening pays the greatest dividends on highway sections with high percentages of trucks and high ADT. Conversely, slope flattening is less likely to be cost effective on low-volume roads and/or on roads with little or no truck traffic.

Fig. 1



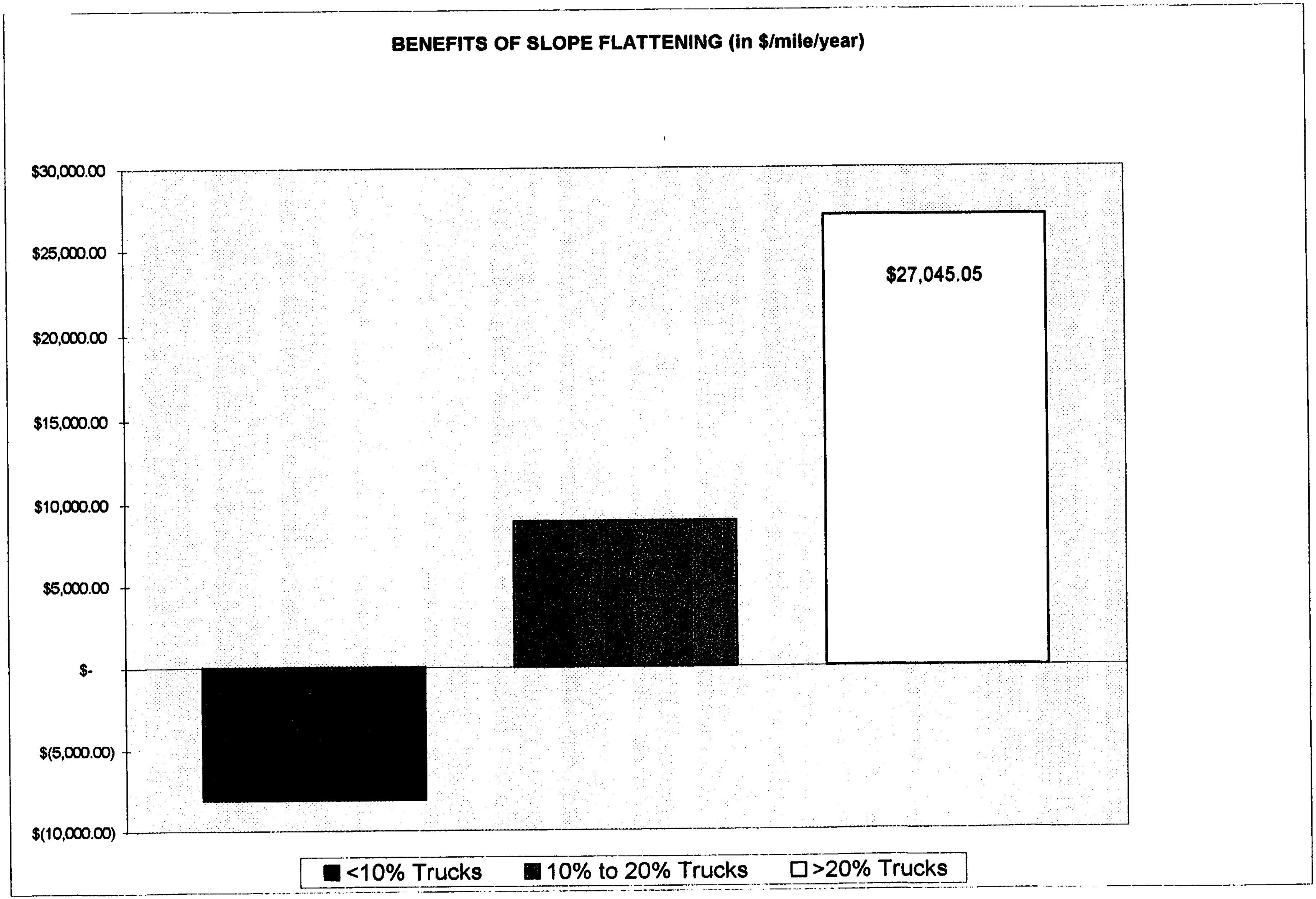
Source: Contract data summary

Fig. 2



Source: Contract data summary

Figure 3



BENEFITS OF SLOPE FLATTENING (in $/mile/year)
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
$(5,000.00)
$(10,000.00)
$27,045.05
<10% Trucks
10% to 20% Trucks
>20% Trucks

Table 1
Contract Data Summary
Truck % > 20%

	Cont	Hwy	Truck	Truck	ADT	ADT	Sect.	Sum SF	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)			
	#	#	Avg	% Wtd	Avg.	Wtd.	Spd.	Mileage	w/ SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO
1	3797	12	20	122.4	4250	26010	55	6.12	39.16	15	49	25	114	3.5	10	22	15	50	2.9	0.9	0.9	0.9	0.92	9.99	39.2	18.7	41.7
2	3927	12	21.5	0.9	4750	190	55	6.16																			
3	3784	101	22.5	60.3	1200	3216	55	8.84			Actual Accident Rate Reduct.(%)																
4	3654	97	23	15.6	4075	2771	55	9.52			F+D	EI	PI	PDO													
5	3866	172	23.5	7.3	185	57.35	50	9.83			18.8	45.3	26.9	46.6													
6	3790	90	25.5	73.2	16000	45920	65	12.70																			
7	3604	395	27	349.9	4025	52164	55	25.66	Acc./yr./mile =			F+D	EI	PI	PDO												
8	2954	101	27.5	37.4	2900	3944	45	27.02				0.1	0.28	0.16	0.7												
9	3662	101	27.5	15.7	2950	1681.5	55	27.59																			
10	3325	395	29	38.0	3750	4912.5	55	28.90																			
11	3766	395	32	47.7	6850	10207	55	30.39																			
12	3497	101	32.5	284.1	2965	25914	55	39.13																			
13	3884	221	36	1.1	1400	42	55	39.16																			
		Avg.	26.7	26.9	4254	4520.7																					
		Avg. Wtd. ADT / SF mile				115.4																					

Source: 93 Hwy. Log and Annual Traffic Reports.

Table 2
Contract Data Summary
10% < Truck % < 20%

	Cont	Hwy	Truck	Truck	ADT	ADT	Sect	Sum SF	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)			
	#	#	Avg	% Wtd	Avg.	Wtd.	Spd.	Mileage	w/ SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PD	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO
1	3371	2	11	75.6	2100	14427	0/5	6.87	54.23	7	37	16	68	3.18	6	18	11	29	3.1	0.9	0.94	0.94	1	6.83	47.5	25.8	54.66
2	3805	195	11.5	42.8	5100	18972	55	10.59																			
3	3331	395	12	24.6	4695	9625	55	12.64			Actual Accident Rate Reduct.(%)																
4	3314	4	12.5	6.6	1325	702	55	13.17			F+D	EI	PI	PDO													
5	3808	12	12.5	4.6	3100	1147	55	13.54			13	50.7	30.4	56.8													
6	4030	101	12.5	48.5	3550	13774	55	17.42																			
7	3947	12	12.5	57.3	5000	22900	5/5	22.00	Acc./yr./mile =			F+D	EI	PI	PDO												
8	3492	12	12.5	29.8	15065	35855	55	24.38				0.04	0.16	0.08	0.28												
9	3670	12	12.5	5.0	15225	6090	55	24.78																			
10	3861	2	13.5	11.5	5000	4250	55	25.63																			
11	3433	101	14	4.9	7525	2634	55	25.98																			
12	3996	12	14.5	1.3	1800	162	55	26.07																			
13	3357	410	15.5	176.4	1675	19062	55	37.45																			
14	3944	12	15.5	14.1	2575	2343	5/3	38.36																			
15	3277	12	15.5	5.1	6800	2244	55	38.69																			
16	3369	172	16	79.8	110	549	50	43.68																			
17	3680	101	16	23.8	2030	3025	55	45.17																			
18	3327	101	16	37.1	2400	5568	55	47.49																			
19	3755	2	16.5	44.7	1055	2859	55	50.20																			
20	3802	12	17	36.9	5700	12369	5/5	52.37																			
21	3939	5	17	3.1	57000	10260	55	52.55																			
22	3427	12	17.5	19.1	1975	2153	55	53.64																			
23	3419	12	18	10.6	5150	3039	55	54.23																			
		Avg.	14.4	14.1	6781	3577																					
		Avg. Wtd. ADT / SF mile				66																					

Source: 93 Hwy. Log and Annual Traffic Reports.

Table 3
Contract Data Summary
Truck % < 10 %

	Cont #	Hwy #	Truck Avg	Truck % Wtd	ADT Avg.	ADT Wtd.	Sect. Spd.	Sum SF Mileage	Length w/ SF	Pre-proj. Accident Data F+D	Pre-proj. EI	Pre-proj. PI	Pre-proj. PDO	YOD	Post-proj. Accident Data F+D	Post-proj. EI	Post-proj. PI	Post-proj. PDO	Post-proj. YOD	Reduction Factor F+D	Reduction Factor EI	Reduction Factor PI	Reduction Factor PDO	Reduction due to SF (%) F+D	Reduction due to SF (%) EI	Reduction due to SF (%) PI	Reduction due to SF (%) PDO
1	3344	151	0	0.0	2700	9045	N/L	3.35	46.07	10	26	10	53	3.42	5	13	16	37	3.2	0.91	0.91	0.91	0.91	41.5	41.4	-87.5	17.8
2	3453	305	2.5	11.7	12100	56507	55	8.02																			
3	3946	706	4.5	0.5	2600	260	30/55	8.12		Actual Accident Rate Reduct.(%)																	
4	3587	27	5.5	36.4	1675	11072	55	14.73		F+D	EI	PI	PDO														
5	3661	546	5.5	20.2	5600	20608	55	18.41		46	46.5	-71	25.3														
6	3763	9	6.5	3.3	13725	7000	40/55	18.92																			
7	3282	2	7	44.8	6250	40000	55/45	25.32				F+D	EI	PI	PDO												
8	3644	410	7	3.4	12800	6144	40	25.80	Acc./yr./mile =			0.05	0.13	0.09	0.3												
9	3602	2	7.5	0.9	12625	1515	55	25.92																			
10	3009	16	7.5	5.2	39950	27566	55	26.61																			
11	3584	20	8	1.0	2900	377	50	26.74																			
12	3966	7	8	29.5	3865	14262	55	30.43																			
13	3948	27	8	52.0	4550	29575	55	36.93																			
14	2987	501	8.5	0.2	2700	54	25/50	36.95																			
15	3875	28	9.5	10.1	400	424	55	38.01																			
16	3641	28	9.5	76.6	800	6448	55	46.07																			
		Avg.	6.6	6.4	7828	5011																					
		Avg. Wtd. ADT / SF mile =				108.8																					

Source: 93 Hwy. Log and Annual Traffic Reports.

Table 4
Contract Data Summary
1st Quarter of Total SF Miles
110 < Avg. ADT < 1675

	Cont	Hwy	Truck	Truck	ADT	ADT	Sect.	Sum S	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)				
	#	#	Avg	% Wtd	Avg.	Wtd.	Spd.	Mileage	w/ SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO	
1	3369	172	16	79.8	110	549	50	4.99	31.75	4	8	5	17	3.29	0	0	1	8	2.97	0.93	0.92	0.92	0.9	100	100	75.9	42.1	
2	3866	172	23.5	7.3	185	57	50	5.30																				
3	3875	28	9.5	10.1	400	424	55	6.36			Actual Accident Rate Reduct.(%)																	
4	3641	28	9.5	76.6	800	6448	55	14.42			F+D	EI	PI	PDO														
5	3755	2	16.5	44.7	1055	2859	55	17.13			100	100	77.8	47.9														
6	3784	101	22.5	60.3	1200	3216	55	19.81																				
7	3314	4	12.5	6.6	1325	702	55	20.34	Acc./yr./mile =			F+D	EI	PI	PDO													
8	3884	221	36	1.1	1400	42	55	20.37				0.02	0.04	0.03	0.1													
9	3357	410	15.5	176.4	1675	19062	55	31.75																				
		Avg.	17.9	14.6	905.6	1051																						
		Avg. Wtd. ADT / SF mile =				33.1																						

Source: 93 Hwy. Log and Annual Traffic Reports.

Table 5
Contract Data Summary
2nd Quarter of SF Miles
1675 < Avg. ADT < 3550

	Cont	Hwy	Truck	Truck	ADT	ADT	Sect.	Sum SF	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)			
	#	#	Avg	% Wtd	Avg.	Wtd.	Spd.	Mileage	w / SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO
10	3587	27	5.5	36.4	1675	11072	55	6.61	37.90	11	30	20	72	3.71	7	18	12	28	3.42	0.78	0.78	0.78	0.83	11.2	16.7	16.7	48.9
11	3996	12	14.5	1.3	1800	162	55	6.70																			
12	3427	12	17.5	19.1	1975	2153	55	7.79		Actual Acc. Rate Reduct.(%)																	
13	3680	101	16	23.8	2030	3025	55	9.28		F+D	EI	PI	PDO														
14	3371	2	11	75.6	2100	14427	30/55	16.15		31	34.9	34.9	57.8														
15	3327	101	16	37.1	2400	5568	55	18.47																			
16	3944	12	15.5	14.1	2575	2343	25/35	19.38	Acc./yr./mile =		F+D	EI	PI	PDO													
17	3946	706	4.5	0.5	2600	260	30/55	19.48			0.07	0.18	0.12	0.37													
18	2987	501	8.5	0.2	2700	54	25/50	19.50																			
19	3344	151	0	0.0	2700	9045	N/L	22.85																			
20	2954	101	27.5	37.4	2900	3944	45	24.21																			
21	3584	20	8	1.0	2900	377	50	24.34																			
22	3662	101	27.5	15.7	2950	1682	55	24.91																			
23	3497	101	32.5	284.1	2965	25914	55	33.65																			
24	3808	12	12.5	4.6	3100	1147	55	34.02																			
25	4030	101	12.5	48.5	3550	13774	55	37.90																			
		Avg.	14.3	15.8	2558	2505																					
		Avg. Wtd. ADT / SF mile				66.1																					

Source: 93 Hwy. Log and Annual Traffic Reports.

Table 6
Contract Data Summary
3rd Quarter of Total SF Miles
3750 < Avg. ADT < 5000

	Cont	Hwy	Truck	Truck	ADT	ADT	Sect.	Sum SF	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)			
	#	#	Avg	% Wtd	Avg.	Wtd.	Spd.	Mileage	w / SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO
26	3325	395	29	38.0	3750	4912.5	55	1.31	34.20	8	41	11	42	3.20	7	12	10	42	2.82	1.02	1.03	1.03	1.03	3.15	67.7	-0.31	-10.3
27	3966	7	8	29.5	3865	14262	55	5.00																			
28	3604	395	27	349.9	4025	52164	55	17.96		Actual Accident Rate Reduct.(%)																	
29	3654	97	23	15.6	4075	2771	55	18.64		F+D	EI	PI	PDO														
30	3797	12	20	122.4	4250	26010	55	24.76		0.8	66.8	-3.1	-13														
31	3948	27	8	52.0	4550	29575	55	31.26																			
32	3331	395	12	24.6	4695	9624.8	55	33.31	Acc./yr./mile =		F+D	EI	PI	PDO													
33	3927	12	21.5	0.9	4750	190	55	33.35			0.07	0.26	0.1	0.4													
34	3861	2	13.5	11.5	5000	4250	55	34.20																			
		Avg.	18.0	18.8	4329	4203.5																					
		Avg. Wtd. ADT / SF mile				122.91																					

Source: 93 Hwy. Log and Annual Traffic Reports.

Table 7
Contract Data Summary
4th Quarter of Total SF Miles
Avg. ADT > 5000

	Cont	Hwy	Truck	Truck	ADT	ADT	Sect.	Sum S	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)			
	#	#	Avg	% Wtd	Avg.	Wtd.	Spd.	Mileage	w / SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO
35	3947	12	12.5	57.3	5000	22900	35/55	4.58	35.61	9	33	15	104	3.17	7	23	19	38	3.1	0.95	0.96	0.96	0.97	16.1	25.5	-35.3	61.2
36	3805	195	11.5	42.8	5100	18972	55	8.30																			
37	3419	12	18	10.6	5150	3039	55	8.89			Actual Accident Rate Reduct.(%)																
38	3661	546	5.5	20.2	5600	20608	55	12.57			F+D	EI	PI	PDO													
39	3802	12	17	36.9	5700	12369	45/55	14.74			20.1	28.4	-30	62.5													
40	3282	2	7	44.8	6250	40000	55/45	21.14																			
41	3277	12	15.5	5.1	6800	2244	55	21.47	Acc./yr./mile =			F+D	EI	PI	PDO												
42	3766	395	32	47.7	6850	10207	55	22.96				0.07	0.25	0.15	0.6												
43	3433	101	14	4.9	7525	2634	55	23.31																			
44	3453	305	2.5	11.7	12100	56507	55	27.98																			
45	3602	2	7.5	0.9	12625	1515	55	28.10																			
46	3644	410	7	3.4	12800	6144	40	28.58																			
47	3763	9	6.5	3.3	13725	7000	40/55	29.09																			
48	3492	12	12.5	29.8	15065	35855	55	31.47																			
49	3670	12	12.5	5.0	15225	6090	55	31.87																			
50	3790	90	25.5	73.2	16000	45920	65	34.74																			
51	3009	16	7.5	5.2	39950	27566	55	35.43																			
52	3939	5	17	3.1	57000	10260	55	35.61																			
		Avg.	12.9	11.4	13804	9262																					
		Avg. Wtd. ADT / SF mile =				260.1																					

Source: 93 Hwy. Log and Annual Traffic Reports.

Table 8
Contract Data Summary
Sections at 50mph or Less

Cont	Hwy	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)			
No	No	w / SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO
2954	101																			
2987	501	13.51	0	4	4	14	3.11	2	12	5	5	3.1	0.94	0.93	0.93	0.96	-100	-223	-34.6	62.51
3282	2																			
3369	172		Actual Acc. Rate Reduct. (%)																	
3371	2		F+D	EI	PI	PDO														
3584	20		-100	-201	-25	64.2														
3644	410																			
3763	9			F+D	EI	PI	PDO													
3802	12	Acc./yr/mile=		0.02	0.19	0.11	0.23													
3866	172																			
3944	12R																			
3944	12L																			
3946	706																			
3947	12																			

Note: Underlined contracts also appear on the sheet for contracts with speed > 55mph

Table 9
Contract Data Summary
SF sections > 55 mph

Cont	Hwy	Cont	Hwy	Length	Pre-proj. Accident Data					Post-proj. Accident Data					Reduction Factor				Reduction due to SF (%)			
No	No	No	No	w / SF	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	YOD	F+D	EI	PI	PDO	F+D	EI	PI	PDO
3009	16	3670	12	122.90	28	102	41	207	3.46	19	41	34	107	3.12	0.93	0.93	0.93	0.94	18.87	51.94	0.857	38.73
3277	12	3680	101																			
3282	2	3755	2		Actual Acc. Rate Reduct. (%)																	
3314	4	3763	9		F+D	EI	PI	PDO														
3325	395	3766	395		24.6	55.4	7.91	42.6														
3327	101	3784	101																			
3331	395	3790	90			F+D	EI	PI	PDO													
3357	410	3797	12	Acc./yr/mile =		0.06	0.18	0.09	0.39													
3371	2	3802	12																			
3419	12	3805	195																			
3427	12	3808	12																			
3433	101	3861	2																			
3453	305	3875	28																			
3492	12	3884	221																			
3497	101	3927	12																			
3587	27	3939	5																			
3602	2	3946	706																			
3604	395	3947	12																			
3641	28	3948	27																			
3654	97	3966	7																			
3661	546	3996	12																			
3662	101	4030	101																			
	Cont...																					

Note: Underlined contracts
are also included on sheet
for contracts with speed < 55 mph.