

# Accidents at Entrance Ramps in Long-Term Construction Work Zones

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Presented in this paper is an analysis of accidents in entrance ramp areas on two long-term freeway reconstruction projects in Texas. Entrance ramp areas were compared with nonentrance ramp areas to determine the proportionality of accident increases during construction. Accident data were collected for each project for 2 or 3 years before construction and for the duration of the construction phases studied. The two projects studied were on I-35W in Ft. Worth, Texas, and I-45 in Houston, Texas. Accident frequencies increased 35 percent in nonentrance ramp areas and 61 percent in areas of entrance ramps remaining open on I-35W during construction. Both increases were statistically significant at  $\alpha = 0.05$ . On I-35W, accident frequency increases were disproportionately higher in entrance ramp areas during construction (30 percent higher than increases in nonentrance ramp area accidents, statistically significant at  $\alpha = 0.05$ ). Additionally, on I-35W, property damage only accidents, severe accidents, daytime accidents, and multivehicle accidents (other than rear-end accidents) increased disproportionately in entrance ramp areas during construction. Conversely, accident frequencies did not increase significantly ( $\alpha = 0.05$ ) in either nonentrance ramp areas or entrance ramp areas considered as a group on I-45. No category of accident was found to have disproportionately increased in nonentrance ramp areas or entrance ramp areas on I-45.

Safety in urban freeway construction work zones is of major importance to the designers, builders, and users of these facilities. Many researchers have examined the issue of construction work zone safety. Their findings have often differed in magnitude but most researchers have reported that accident rates in construction work zones are greater than on highways not under construction (1–5).

Ullman and Krammes (1) reported that total mainline accidents on five urban freeway reconstruction projects in Texas increased an average of 28.7 percent during construction. They noted that the magnitude of the change in accident rates varied among the project sites studied. The researchers hypothesized that the observed variation in changes in accident occurrence may be better understood through detailed studies of the specific traffic control and geometric design features associated with those long-term freeway reconstruction sites. Ullman and Krammes (1) proposed that specific features to be studied should include shoulder widths, ramp geometry, advance signing, lighting, type and location of channelizing devices, and nature of the work activity.

Entrance ramps within construction work zones are areas where numerous decisions must be made by drivers in a limited amount of time. Merging operations at entrance ramps

are very complex as entering vehicles and vehicles already on the freeway compete for space (6). The merging process is presumably made more difficult in construction work zones when confounded by the presence of construction equipment and construction workers, the presence and proximity of traffic control devices, and geometric constrictions imposed by the work zone.

## SCOPE AND OBJECTIVES OF WORK

The two sites selected for analysis are in the two largest metropolitan areas in Texas: Houston and Dallas-Ft. Worth. The specific objectives of this research were as follows:

1. Determine changes in accident occurrence during construction at urban freeway entrance ramp areas compared with changes in accident occurrence at nonentrance ramp areas within the studied work zones.
2. Through regression analysis, explore the potential relationship between accident rates at entrance ramps in construction work zones and selected geometric factors that are believed to contribute to entrance ramp accidents.

I-35W in Ft. Worth and I-45 in Houston are both radial freeways reconstructed to serve the growing metropolitan areas. Segments selected for study are similar for each site in terms of adjacent land usage (primarily residential and strip commercial). The segment of I-35W studied was 6.4 mi long and extended north from Felix Street to Hattie Street. The segment of I-45 studied was 7.8 mi long and extended north from downtown Houston to North Shepard Drive. Construction phases studied on I-35W and I-45 consisted of similar types of work. Additional lanes were added outside the existing roadway, ramps were upgraded, and frontage roads were improved. These work efforts required that ramp geometrics sometimes be altered during construction to allow contractors room to build the additional lanes. Long-term ramp closures were common on I-35W. Short-term ramp closures were common on I-45. Typical traffic control at the entrance ramps on the two projects is shown in Figures 1 and 2.

Mainline traffic volumes at each site were only slightly affected by construction. Ramp volumes on I-35W appeared to have decreased slightly during construction, presumably because of the closure of several ramps. Ramp volumes on I-45 did not appear to have changed appreciably during construction (7).

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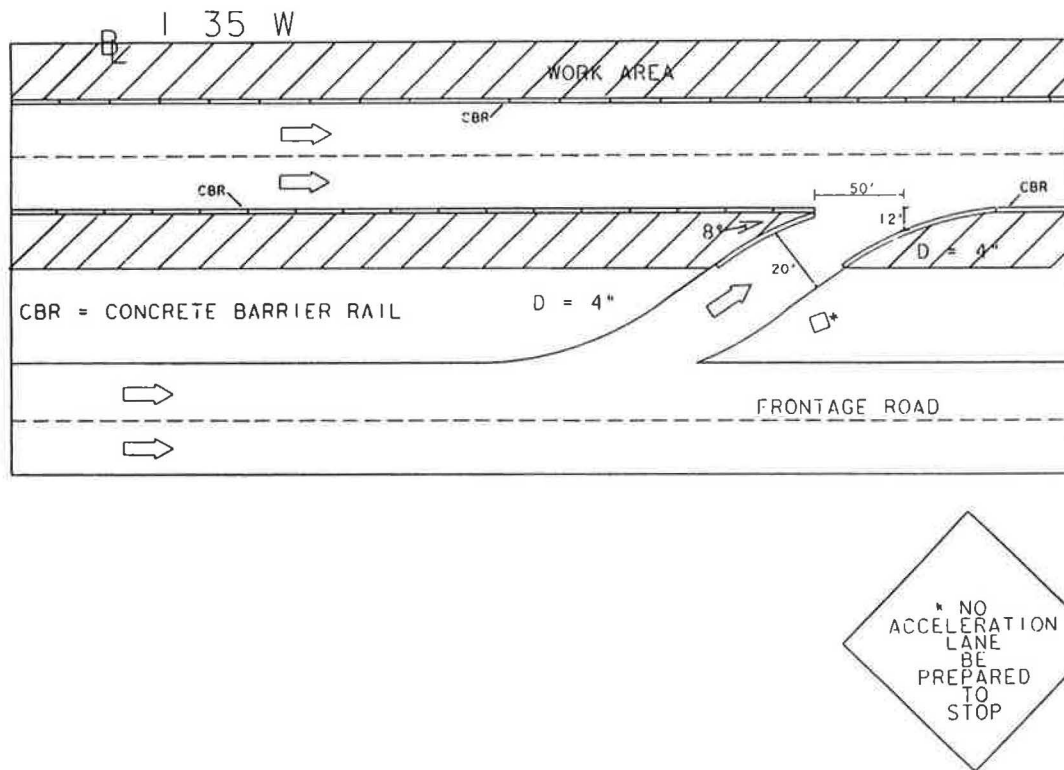


FIGURE 1 Typical traffic control at I-35W.

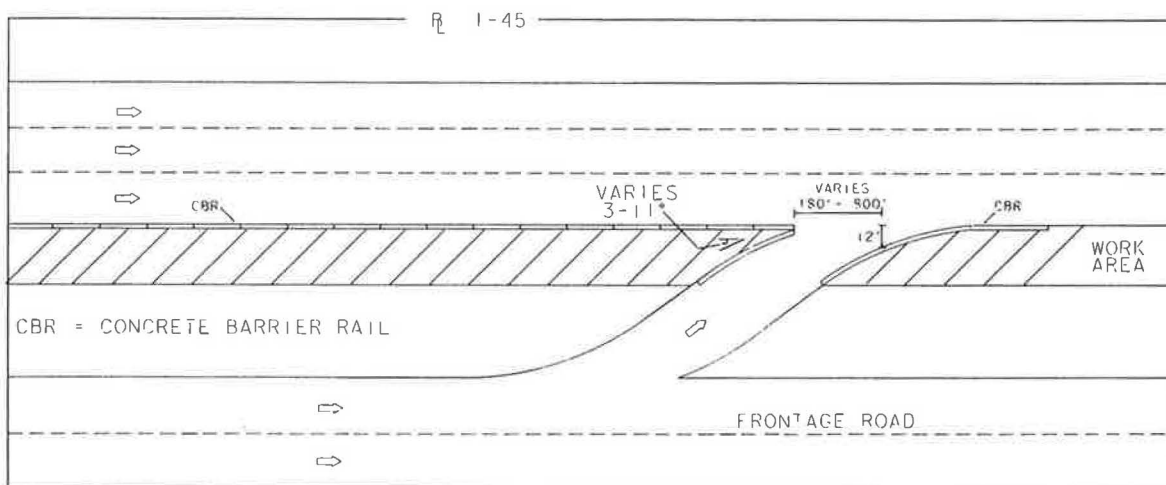


FIGURE 2 Typical traffic control at I-45.

## STUDY DESIGN

### Data Collection and Analysis

The *Highway Capacity Manual* (8) definition of the influence area of an entrance ramp was used to identify the limits of entrance ramp areas for this analysis. This area is defined as extending 500 ft upstream and 2,500 ft downstream of the nose of the entrance ramp. However, the presence of downstream exit ramps can affect the influence area of the entrance ramp, depending on their proximity. The *Highway Capacity*

*Manual* (8) specifies the influence area of an exit ramp as extending from 2,500 ft upstream of the ramp to a point 500 ft downstream. Therefore, at entrance ramps with downstream exit ramps in close proximity, the entrance ramp was defined as extending from 500 ft upstream of the nose of the ramp to a point approximately one-half way to the downstream exit ramp, or 2,500 ft, whichever was less.

Considering the ramp area to be much larger than the actual area of influence would act to dilute the effects of the entrance ramp on accidents in the selected section by including an increased number of purely nonentrance ramp area accidents.

Conversely, an area confined to the immediate entrance ramp acceleration lane is not practical because of the nearest 0.1-mi coding procedure used to establish the location of accidents. Also, an entrance ramp conflict may manifest itself in an accident some distance away (if, for example, two motorists already on the freeway are so concerned with entering traffic that they fail to adequately consider the other's position and are involved in an accident with each other).

Conceptually, differences in accident occurrence between entrance ramp areas and nonentrance ramp areas should be the result of the effects of the entrance ramp, provided there were no other localized changes in construction methods or traffic control in either of the areas.

Roadway inventory logs and construction plans furnished by the Texas Department of Transportation (TxDOT) were used to determine the location and geometrics of entrance ramps. Accident data were obtained primarily from Department of Public Safety (DPS) accident file tapes.

### Comparative Analysis of Entrance and Nonentrance Ramp Area Accidents

The first objective of this study was to examine the change in the accident frequency of entrance ramp area accidents in relation to the remainder of the construction work zone (nonentrance ramp areas). Accident frequencies were used as the basis of comparison because consistently defined areas were evaluated over time to determine whether accidents increased disproportionately in these areas. The areas were defined as entrance ramp areas and nonentrance ramp areas and the physical dimensions of each of the areas compared remained constant throughout the analysis. In each case, accidents within a control section were compared over time with the construction work zone under study. Comparisons were made of multiple years before and during construction. The analysis methodology followed the procedure outlined by Griffin for the evaluation of the effectiveness of safety improvements at a site (9). The methodology has also been used by others for the evaluation of the effects of construction on accidents over a specific length of roadway (1,10).

The use of a control section helps to factor out the effects of extraneous variables, and the use of multiple years of data provides some control for the regression-to-the-mean phenomenon. Control sections for the study sites were located immediately upstream or downstream of the construction work zones. The control sections were characterized as having similar before-construction geometrics to the construction work zone areas. Control sections allow for an estimation of how accidents in the construction area would have changed over time if there had been no construction. In other words, if the control and construction sections are comparable before construction, then differences between the changes in accident frequency at the work zone and control section over time are assumed to be caused by construction efforts.

Three phases were used to systematically analyze the effect of construction on accident frequency. The first phase of the analysis was to determine whether accidents increased in the nonentrance ramp areas during construction. The second phase was to determine if there was an increase in accidents in the entrance ramp areas. The third phase was conducted to determine if accidents increased disproportionately in the en-

trance ramp areas within the construction work zone compared with nonentrance ramp areas within the work zone.

Each phase of the analysis was performed in two steps: (a) check for comparability and (b) determine the impact of construction.

In the analysis of nonentrance ramp areas, the check for comparability was between nonentrance ramp areas in the control section (considered as a group) and nonentrance ramp areas in the work zone (also considered as a group). Likewise, in the second analysis phase, a comparability check was made between entrance ramp areas in the control section and entrance ramp areas in the work zone. Finally in the third phase, a check for comparability was made between nonentrance ramp areas and entrance ramp areas in the work zone.

Analyses of the comparability of control sections and construction work zones were performed for the before-construction period using the maximum-likelihood goodness-of-fit statistics,  $G^2_B$ , proposed by Griffin (9) and previously employed by Texas Transportation Institute (TTI) researchers (1,10). The  $G^2_B$  statistic is used to determine whether the rates of change in accident frequencies between the two sites (control and construction sections) are comparable over periods of time.

The second step in each phase of the analysis, determination of the impact of construction upon accident frequencies, was accomplished by computing the differences in the rates of change at the areas under study, either nonentrance or entrance ramp areas, and the control sections for which comparability was established in the preceding step.

Accident frequencies in entrance and nonentrance ramp areas were compiled for several years before and during construction. Several categories of accidents were evaluated. These categories were total accidents, accident severity, time of day, and type of accident. Severe accidents were classified as fatalities, injury, and possible injury accidents. Noninjury accidents were classified as property damage only (PDO) collisions. Dawn, dusk, and night accidents were classified as nighttime accidents; others were classified as daytime collisions. Three types of accidents were classified: single vehicle, rear-end, and other multiple-vehicle accidents.

If the control sections and work zones were found to be comparable, the magnitude of the impact of construction on accident frequency was computed through the use of a cross-product ratio on a collapsed  $2 \times 2$  (before-during, control-construction) contingency table. The percentage change in accident frequencies caused by construction was then computed using this cross-product ratio. The significance of the percentage change was determined using a two-tailed z-statistic.

The statistical analysis procedure is analogous to a before-after analysis with a control section and check for comparability with only one after period. The duration of the construction period is analogous to the one after period. The procedure is more fully explained by Griffin (9) and Ullman and Krammes (1).

### Ramp Geometrics and Accident Rate Analysis

Research indicates that acceleration lane length, angle of convergence, and ramp grade are important geometric factors that affect the safety of entrance ramps (11-13).

The second objective of this study dealt with the possible relationship between geometric factors and accidents occurring in entrance ramp areas within freeway work zones. Multiple variable linear regression analysis was used to investigate these relationships. In this analysis, accident rates, instead of accident frequencies, were used as the basis of comparison because individual entrance ramp areas were being compared with other individual entrance ramp areas. The exposure factor used to determine the accident rate was the sum of the volume on the freeway mainlanes just before the entrance ramp and the volume entering on the ramp.

## STUDY RESULTS

Summarized in Table 1 are the periods of analysis and accident frequencies analyzed for the two projects. The construction studied on the I-35W project lasted from August 1984 through June 1988. The nonentrance ramp areas were the freeway mainlanes between the 15 entrance ramp areas before construction. The areas at the eight entrance ramps that were closed for extended periods during construction were not included in the analysis. The construction activities studied on I-45 in Houston extended from March 1985 through May 1987. There were 17 entrance ramps in the I-45 construction section.

### I-35W, Ft. Worth: Analysis of Nonentrance Ramp Areas

Summarized in Table 2 are the results of the I-35W Phase One analysis. It was determined that nonentrance ramp areas

in the construction work zone and the control section were comparable for almost all the categories of accidents studied. Total accidents, PDO accidents, daytime accidents, rear-end accidents, and other multivehicle accidents were found to have followed similar trends in the control and construction section nonentrance ramp areas during the before-construction period. Statistically significant ( $\alpha = 0.05$ ) increases in accident frequencies were found for several categories of accidents. Total accidents increased significantly (35 percent) during construction in nonentrance ramp areas. Likewise, the 31 percent increase in PDO accidents was found to be statistically significant, as was the 44 percent increase in severe accidents. Additionally, daytime accidents increased 29 percent and rear-end accidents increased 73 percent, both statistically significant ( $\alpha = 0.05$ ).

### I-35W, Ft. Worth: Analysis of Entrance Ramp Area Accidents

Summarized in Table 3 are the results of the second phase of the I-35W analysis. Comparability between the construction section entrance ramp areas and the control section entrance ramp areas was accepted for all but the PDO accident frequencies ( $\alpha = 0.05$ ).

Total accidents increased significantly (61 percent) during construction in the entrance ramp areas. Statistically significant increases in severe accidents were computed to be 95 percent; likewise, daytime accidents were found to have increased 64 percent, whereas nighttime accidents increased 56 percent. Increases in rear-end accidents were computed to be 64 percent and increases in other multivehicle accidents were found to be 97 percent (both statistically significant).

TABLE 1 Summary of Analysis Periods and Accident Frequencies

I 35W, FT. WORTH		
Section	Accident Frequency Before-Construction January, 1982 - July, 1984	Accident Frequency During-Construction August, 1984 - June, 1988
Construction Section:		
Non-Entrance Ramp Areas	591	1155
Entrance Ramp Areas	294	749
Control Sections:		
Non-Entrance Ramp Areas	284	412
Entrance Ramp Areas	521	823
I 45, HOUSTON		
Section	Accident Frequency Before-Construction January, 1982 - December, 1983	Accident Frequency During-Construction March, 1985 - May, 1987
Construction Section:		
Non-Entrance Ramp Areas	1054	1282
Entrance Ramp Areas	902	1137
Control Sections:		
Non-Entrance Ramp Areas	110	105
Entrance Ramp Areas	62	70

**TABLE 2 Accident Analysis Table for I-35W Nonentrance Ramp Areas**

Accident Category	Check for Comparability Before- Construction $G_B^2$	Percent Change in Accident Frequency	Significance of Percent Change in Accident Frequency (Z-Statistic)
Total Accidents	0.46 <sup>a</sup>	+ 34.7 <sup>b</sup>	3.23
Accident Severity: PDO	0.48 <sup>a</sup>	+ 30.7 <sup>b</sup>	2.46
Severe	0.69 <sup>a</sup>	+ 44.0 <sup>b</sup>	2.08
Time-of-Day: Daytime	2.87 <sup>a</sup>	+ 29.0 <sup>b</sup>	2.20
Nighttime	8.20	+ 46.1	2.49 <sup>c</sup>
Type of Collision: Single Vehicle	7.47	+ 38.3	1.89 <sup>c</sup>
Rear-End	4.74 <sup>a</sup>	+ 73.0 <sup>b</sup>	3.05
Other Multi- vehicle	1.40 <sup>a</sup>	+ 16.1	1.07

<sup>a</sup> Control and construction sections are statistically comparable prior to construction ( $\alpha = 0.05$ );  $G_B^2 < 5.99$ .

<sup>b</sup> Percent Change due to construction is statistically significant ( $\alpha = 0.05$ );  $|z| > 1.96$ .

<sup>c</sup> Conclusions concerning statistical significance cannot be made due to lack of comparability before construction.

**TABLE 3 Accident Analysis Table for I-35W Entrance Ramp Areas**

Accident Category	Check for Comparability Before-Construction $G_B^2$	Percent Change in Accident Frequency	Significance of Percent Change in Accident Frequency (Z-Statistic)
Total Accidents	3.83 <sup>a</sup>	+ 61.3 <sup>b</sup>	5.39
Accident Severity: PDO	6.45	+ 50.4	3.94 <sup>c</sup>
Severe	1.51 <sup>a</sup>	+ 95.1 <sup>b</sup>	3.82
Time-of-Day: Daytime	1.49 <sup>a</sup>	+ 63.7 <sup>b</sup>	4.59
Nighttime	4.75 <sup>a</sup>	+ 55.9 <sup>b</sup>	2.81
Type of Collision: Single Vehicle	3.40 <sup>a</sup>	+ 5.8	0.30
Rear-End	0.27 <sup>a</sup>	+ 64.2 <sup>b</sup>	2.90
Other Multi- Vehicle	1.84 <sup>a</sup>	+ 97.4 <sup>b</sup>	5.33

<sup>a</sup> Control and construction sections are statistically comparable prior to construction ( $\alpha = 0.05$ );  $G_B^2 < 5.99$ .

<sup>b</sup> Percent Change due to construction is statistically significant ( $\alpha = 0.05$ );  $|z| > 1.96$ .

<sup>c</sup> Conclusions concerning statistical significance cannot be made due to lack of comparability before construction.



### I-35W, Ft. Worth: Analysis of Nonentrance Ramp Areas Versus Entrance Ramp Areas

Summarized in Table 4 are the results of the third phase of the analysis of the I-35W accident frequency data. Comparability was computed between the nonentrance and entrance ramp areas within the construction work zone for the before-construction period. All categories of accidents were found to be comparable before construction. This was expected because the two areas being compared were merely parts of the same section of roadway and thus should have been exposed to the same extraneous events during the before-construction period.

The item of interest in this analysis was the relative difference in the change in accident frequencies between nonentrance and entrance ramp areas. This difference was computed using the cross-product ratio outlined previously, and indicates the magnitude to which increases in accident frequencies between entrance and nonentrance ramp areas were disproportionate. A ratio greater than 1 indicated that accident frequencies increased more in entrance ramp areas than in nonentrance ramp areas. Conversely, a ratio less than 1 indicated that accident frequencies increased more in nonentrance ramp areas than in entrance ramp areas.

Five categories of accidents were found to have increased significantly ( $\alpha = 0.05$ ) more in entrance than in nonentrance ramp areas. No category of accidents was found to have increased disproportionately more in the nonentrance ramp areas. It was determined that total accident frequencies increased significantly (30 percent) more in entrance ramp areas than in nonentrance ramp areas during construction on the I-35W project in Ft. Worth. Likewise, PDO accident frequency in-

creases were 26 percent greater and severe accident increases were 46 percent greater in entrance ramp areas than in nonentrance ramp areas. Daytime accident increases in entrance ramp areas were 35 percent greater than in nonentrance ramp areas. Finally, multivehicle accidents (other than rear-end accidents) were found to have increased 49 percent more in entrance ramp areas during construction.

### I-45, Houston: Analysis of Nonentrance Ramp Areas

Summarized in Table 5 is the first phase of the analysis of the I-45 accident frequency data. All categories of accidents were found to be statistically comparable between the control section and work zone before construction. Construction was found to have a significant ( $\alpha = 0.05$ ) impact on only two categories of accidents. Severe accidents were found to have increased 64 percent and nighttime accidents increased 123 percent during construction in nonentrance ramp areas.

### I-45, Houston: Analysis of Entrance Ramp Areas

A summary of the second phase of the I-45 analysis is shown in Table 6. Work zone entrance ramp areas and control section entrance ramp areas were found to be comparable before construction for all of the categories of accidents studied.

No percent change in accident frequencies in entrance ramp areas was found to be statistically significant ( $\alpha = -0.05$ ). The failure to find the percentage changes in accident frequencies to be significant may have been because of Type II errors in many cases. Also it should be noted that some of

**TABLE 4 Accident Analysis for I-35W Nonentrance Ramp Areas Versus Entrance Ramp areas in Construction Section**

Accident Category	Check for Comparability Before-Construction $G_B^2$	Percent Difference in Change in Accident Frequency	Significance of Percent Change in Accident Frequency (Z-Statistic)
Total Accidents	0.57 <sup>a</sup>	+ 30.4 <sup>b</sup>	3.10
Accident Severity:			
PDO	0.29 <sup>a</sup>	+ 26.1 <sup>b</sup>	2.33
Severe	4.96 <sup>a</sup>	+ 45.6 <sup>b</sup>	2.23
Time-of-Day:			
Daytime	0.62 <sup>a</sup>	+ 34.7 <sup>b</sup>	2.86
Nighttime	1.59 <sup>a</sup>	+ 22.5	1.36
Type of Collision:			
Single Vehicle	3.00 <sup>a</sup>	+ 4.4	0.24
Rear-End	0.50 <sup>a</sup>	+ 15.4	0.90
Other Multi-Vehicle	0.50 <sup>a</sup>	+ 49.2 <sup>b</sup>	3.23

<sup>a</sup> Control and construction sections are statistically comparable prior to construction ( $\alpha = 0.05$ );  $G_B^2 < 5.99$ .

<sup>b</sup> Percent difference in the change in accident frequencies due to construction is statistically significant ( $\alpha = 0.05$ );  $|z| > 1.96$ .

**TABLE 5 Accident Analysis Table for I-45 Nonentrance Ramp Areas**

Accident Category	Check for Comparability Before-Construction $G_B^2$	Percent Change in Accident Frequency	Significance of Percent Change in Accident Frequency (Z-Statistic)
Total Accidents	2.40 <sup>a</sup>	+ 27.4	1.70
Accident Severity:			
PDO	2.42 <sup>a</sup>	+ 5.2	0.26
Severe	0.15 <sup>a</sup>	+ 64.3 <sup>b</sup>	2.34
Time-of-Day:			
Daytime	2.81 <sup>a</sup>	- 14.4	- 0.81
Nighttime	1.02 <sup>a</sup>	+ 122.8 <sup>b</sup>	3.58
Type of Collision:			
Single Vehicle	1.10 <sup>a</sup>	+ 40.8	1.20
Rear-End	1.00 <sup>a</sup>	+ 22.9	0.80
Other Multi-Vehicle	0.38 <sup>a</sup>	+ 27.4	1.12

<sup>a</sup> Control and construction sections are statistically comparable prior to construction ( $\alpha = 0.05$ );  $G_B^2 < 3.84$ .

<sup>b</sup> Percent Change due to construction is statistically significant ( $\alpha = 0.05$ );  $|z| > 1.96$ .

**TABLE 6 Accident Analysis Table for I-45 Entrance Ramp Areas**

Accident Category	Check for Comparability Before- Construction $G_B^2$	Percent Change in Accident Frequency	Significance of Percent Change in Accident Frequency (Z-Statistic)
Total Accidents	0.10 <sup>a</sup>	+ 11.7	0.61
Accident Severity:			
PDO	1.06 <sup>a</sup>	+ 7.8	0.29
Severe	0.17 <sup>a</sup>	+ 32.2	1.09
Time-of-Day:			
Daytime	0.25 <sup>a</sup>	- 8.9	-0.41
Nighttime	0.06 <sup>a</sup>	+ 57.4	1.52
Type of Collision:			
Single Vehicle	0.005 <sup>a</sup>	+ 25.5	0.63
Rear-End	0.18 <sup>a</sup>	+ 52.9	1.19
Other Multi-Vehicle	0.02 <sup>a</sup>	- 10.1	-0.41

<sup>a</sup> Control and construction sections are statistically comparable prior to construction ( $\alpha = 0.05$ );  $G_B^2 < 5.99$ .

<sup>b</sup> Percent Change due to construction is statistically significant ( $\alpha = 0.05$ );  $|z| > 1.96$ .

the ramps within the work zone maintained fairly good operations during construction. Considering all entrance ramps together within the work zone may have diluted the effects at ramps where conditions were not so favorable. Nevertheless, it was felt that it was not appropriate to attempt to isolate only those ramps on which problems existed, and so all entrance ramps were considered as a group.

#### I-45, Houston: Analysis of Nonentrance Ramp Versus Entrance Ramp Areas

The results of the third phase of analysis of accidents on I-45 are summarized in Table 7. Trends in all categories of accidents were found to be comparable between nonentrance and entrance ramp areas in the construction section before construction.

There were no statistically significant ( $\alpha = 0.05$ ) differences in the effect of construction on entrance and nonentrance ramp areas on I-45. Differences in the change in total accident frequencies between entrance and nonentrance ramp areas were less than 4 percent. Thus, the relative effect of construction on these areas appeared to be about equal.

#### Results of Entrance Ramp Geometric Feature Analysis

The dependent variable and independent variables used in the multiple linear regression analysis for I-35W, Fort Worth, are summarized in Table 8, and those for I-45, Houston in Table 9. Ramp geometrics on I-35W in Ft. Worth were greatly altered during construction. Conversely, ramp geometrics on

I-45 in Houston were not as greatly affected during most of the construction efforts. Most of the entrance ramps in Ft. Worth had approximately the same angles of convergence and acceleration lane length. The geometrics of the ramps in Houston varied considerably.

From Tables 8 and 9, it can be seen that accident rates during construction were generally higher in Ft. Worth than they were in Houston. Because of the apparent differences in the two projects and the lack of range in the independent variables on the I-35W project, separate regression models were developed for the two projects. A multiple regression analysis, which combined the two projects, may have been misleading because interactions among some of the independent variables may not have been similar among projects.

A summary of the regression analysis of the I-45 data is shown in Table 10. The overall model was found to be statistically significant ( $F$ -value = 4.15), and the coefficient of determination ( $R^2$ ) was computed to be 0.58 (that is, 58 percent in the variation in the data could be explained by the model). However, only the entrance ramp accident rate before construction was found to be a significant variable in the prediction of accident rates at the ramp during construction. The final model related accident rates before construction to the natural logarithm of accident rates during construction. Hence, the model indicates that accident rates during construction are exponentially related to accident rates before construction. That is, those ramps already experiencing higher accident rates before construction will be more adversely affected by construction than those with lower accident rates initially.

A similar analysis performed on the I-35W data did not yield a statistically significant model. A possible reason for

**TABLE 7 Accident Analysis Table for I-45 Nonentrance Ramp Areas Versus Entrance Ramp Areas in Construction Section**

Accident Category	Check for Comparability Before- Construction $G_B^2$	Percent Difference in Change in Accident Frequency	Significance of Percent Change in Accident Frequency (Z-Statistic)
Total Accidents	0.07 <sup>a</sup>	+ 3.6	0.59
Accident Severity:			
PDO	0.18 <sup>a</sup>	- 2.0	-0.28
Severe	0.01 <sup>a</sup>	+ 19.0	1.55
Time-of-Day:			
Daytime	0.02 <sup>a</sup>	+ 10.0	1.28
Nighttime	0.44 <sup>a</sup>	- 7.3	-0.71
Type of Collision:			
Single Vehicle	2.54 <sup>a</sup>	+ 9.8	0.59
Rear-End	0.22 <sup>a</sup>	+ 1.4	0.10
Other Multi-Vehicle	1.50 <sup>a</sup>	- 1.7	-0.21

<sup>a</sup> Control and construction sections are statistically comparable prior to construction ( $\alpha = 0.05$ );  $G_B^2 < 5.99$ .

<sup>b</sup> Percent difference in the change in accident frequencies due to construction is statistically significant ( $\alpha = 0.05$ );  $|z| > 1.96$ .



TABLE 8 Summary of Geometric Factors During Construction at Entrance Ramps, I-35W, Ft. Worth

RAMP ID *	ANGLE OF CONVERGENCE (DEG.)	LENGTH OF ACCEL. LANE (FT)	RELATIVE GRADE (%)	AVG. ACC. RATE BEFORE (ACC/MVM)	AVE. ACC. RATE DURING (ACC/MVM)
S358	8	50	-1.7	1.40	11.76
N265	8	50	-1.8	2.45	9.10
N414	8	50	-2.1	2.93	4.25
S278	8	50	-2.3	3.95	9.51
S433	8	50	-3.7	3.84	7.63
N340	8	50	-4.1	3.84	4.95

\* Ramps identified by direction of travel and approximate station number.

TABLE 9 Summary of Geometric Factors During Construction at Entrance Ramps, I-45, Houston

RAMP ID *	ANGLE OF CONVERGENCE (DEG.)	LENGTH OF ACCEL. LANE (FT)	RELATIVE GRADE (%)	AVG. ACC. RATE BEFORE (ACC/MVM)	AVE. ACC. RATE DURING (ACC/MVM)
N169	3	280	+0.5	1.83	2.05
S291	3	500	-3.0	4.85	4.68
S219	4	500	+2.5	1.45	2.45
S158	5	180	-0.5	1.02	2.74
S130	5	750	-3.0	1.49	2.44
N246	6	220	+2.0	5.90	6.76
N203	6	300	-4.0	2.39	1.37
S186	6	380	+4.0	1.59	2.56
S373	6	430	0	2.01	4.28
S250	7	700	0	4.80	5.40
S478	8	375	+4.0	1.71	1.94
N111	8	800	-1.1	1.31	1.86
S434	10	240	-0.5	1.59	2.14
N344	10	400	-0.5	1.63	3.25
N460	10	450	-1.0	2.14	3.08
S321	11	250	0	2.79	6.74
N409	11	425	0	1.63	2.99

\* Ramps identified by direction of travel and approximate station number.

this was that accident rates before construction did not vary as dramatically as at the I-45 site. Also, since entrance ramp geometrics during construction were somewhat similar, the regression analysis may not have been able to statistically account for their effect on accident rates.

#### SUMMARY OF FINDINGS

Both nonentrance and entrance ramp areas on I-35W experienced statistically significant ( $\alpha = 0.05$ ) increases in total accident frequencies during construction. Total accident frequencies increased 35 percent in nonentrance ramp areas and

61 percent in entrance ramp areas during construction. Increases in accidents in the entrance ramp areas during construction were found to be significantly greater than increases in accidents in the nonentrance ramp areas. On I-35W, total accident frequencies increased 30 percent more in entrance ramp areas relative to nonentrance ramp areas (statistically significant at  $\alpha = 0.05$ ).

On I-35W, PDO and severe accident increases were disproportionately concentrated in entrance ramp areas. Also, daytime and multivehicle accidents (other than rear-end accidents) were found to have disproportionately increased in entrance ramp areas on I-35W during construction.

TABLE 10 Summary of Regression Analysis for Exploratory Model, I-45, Houston

LOG (ACC RATE) = $\beta_0 + \beta_1$ (ANGLE OF CONVERGENCE) + $\beta_2$ (ACCEL. LANE LENGTH) + $\beta_3$ (RELATIVE GRADE) + $\beta_4$ (ACC RATE BEFORE)		
INDEPENDENT VARIABLE	PARAMETER ESTIMATE	$t_{calc}$
Intercept	0.23	0.61
Angle of Convergence	0.04	1.32
Acceleration Lane Length	0.00	-0.07
Relative Grade	0.03	0.70
Accident Rate Before Construction	0.25	3.98*
Model F-statistic = 4.15 ** Model $R^2$ = 0.58		

\* statistically significant at  $\alpha/2 = 0.025$ \*\* statistically significant at  $\alpha = 0.05$ 

On I-45, neither nonentrance ramp nor entrance ramp areas experienced statistically significant ( $\alpha = 0.05$ ) increases in total accident frequencies during construction, when examined separately. The increases for nonentrance and entrance ramp areas (though not statistically significant) on I-45 were found to have been 27 percent and 12 percent, respectively. Accidents in entrance ramp areas increased 4 percent more relative to accidents in nonentrance ramp areas on the I-45 project. This difference in proportional increase was not statistically significant at  $\alpha = 0.05$ . No accident category increased disproportionately in either nonentrance ramp or entrance ramp areas on I-45 in Houston.

Because of the limited data, relationships were not found between geometric data and accidents in the entrance ramp areas at either project. However, the I-45 data may suggest that entrance ramps having higher accident rates before construction were more adversely affected during construction than were ramps with lower accident rates before construction. It may be wise to give extra attention to the work zone traffic control at entrance ramps with higher accident rates. In some cases, it may be prudent to actually close these ramps during construction rather than further compromise ramp geometrics (or sight distance) during construction.

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