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16. Abstract

To answer questions being raised by abutting residents and businesses about proposed elevated and/or depressed freeway improvements in the urban and suburban areas of Texas, a four-year study has been conducted to estimate the social, economic, and environmental effects of such freeway designs. Eight existing, two under-construction, and one approved-for-construction freeway sections have been studied on a before-, during-, and after-construction basis. The sections selected for study range from being in predominately residential suburban areas to predominantly commercial-industrial downtown areas. The specific effects of the three types estimated for each study section are as follows: (1) social impacts: population changes, neighborhood accessibility, neighborhood cohesion and community services; (2) economic impacts: relocation and mitigation costs, business sales, property uses and values, tax revenues, employment, and income and user costs; and (3) environmental impacts: aesthetics, drainage and erosion, noise and air pollution, vibration and hazardous spills. The literature review and a survey of highway agencies in other states were used to determine the appropriate procedures or models and mitigation measures to implement in estimating the social, economic, and environmental impacts of elevated and depressed freeways.

The results of the study, presented in six separate reports according to types of effect, can be used by highway planning and designing engineers to prepare environmental statements and documents of the expected social, economic, and environmental impacts of proposed elevated and depressed freeway projects. Also, the results can be disseminated at the public hearings for a proposed project. This report presents the findings of the traffic noise effects of elevated, depressed, and at-grade level freeways. In summary, it was found that the depressed freeway sections provide the greatest reduction of traffic noise in areas near and far from the roadway, especially if the walls of the depression are sloped or acoustically treated. The next best condition is an elevated freeway section using solid concrete guardrails. The traffic noise is shielded by the solid deck and rails. The reduction is measurable near the elevated section, but at greater lateral distances, away from the roadway, levels approach those of at-grade roads because all traffic is not shielded by the deck and rail. At-grade roads produce the highest noise levels, but the addition of solid guardrails, median rails, and the use of smooth texture pavements provide noticeable quieting.

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TRAFFIC NOISE EFFECTS OF ELEVATED, DEPRESSED, AND AT-GRADE LEVEL FREEWAYS IN TEXAS

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Research Report 1327-3
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IMPLEMENTATION STATEMENT

The findings of this study can be used by TxDOT to improve its procedures for estimating, evaluation, and abatement of traffic noise generated from proposed elevated, depressed, and at-grade freeways. However, the study findings do support the continued use of the computer program noise estimating model called STAMINA 2.0 without modification. Noise levels at selected study locations were measured and modeled by STAMINA 2.0, which generated comparable results. This program will model depressed, elevated, and at-grade roadways, with and without guardrails, with good results. Also, the study findings can be implemented immediately to present at public hearings and prepare environmental impact statements.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented within. The contents do not necessarily reflect the views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes. The report was prepared by Richard A. Zimmer, Research Specialist, and Jesse L. Buffington, Research Economist.

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Dallas District:

Richard H. Rawles, Jr., Former Director of Construction; Gary W. Taylor, Project Manager of North Central Project Office; and Terry L. May, District Right-of-way Engineer.

Houston District:

Hans C. Olavson, Director of District Transportation Planning; Dennis W. Warren, Director of Construction; and Thomas N. Lou, Assistant to Director of Transportation and Planning.

Harris County Toll Road Authority:

Wesley E. Freise, Executive Director.

Lubbock District:

Carl R. Utley, District Engineer; V. G. Chetty, Former Deputy District Engineer; John E. Rantz, Director of Operations and Construction; Steven P. Warren, Director of Transportation Planning and Development; Ted Copeland, Traffic Engineer; Mike Craig, Assistant District Design Engineer; Davis Melton, Environmental Coordinator; and Claude C. Kneisley, Right-of-way Supervisor.

San Antonio:

John P. Kelly, District Engineer; Julie Brown, Director of Transportation Planning and Development; Mary T. Richards, Environmental Coordinator; Gilbert G. Gavia, District Design Engineer; Felix A. Lemra, District Design Section; and Herbie L. Belvin, District Right-of-way Administrator.

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SUMMARY

Highway traffic noise is an ever-increasing problem for transportation agencies charged with the task of increasing traffic volume while maintaining a quiet environment. The challenge presented to transportation agencies is to determine during the planning stages of construction projects increasing traffic volume, the appropriate estimating procedures or models, and mitigation measures that will maintain or improve the noise levels near homes, churches, parks, and other noise sensitive areas at preconstruction levels. This study looks at the effect of various grade levels used in highway construction that are at ground level (at-grade), below ground level (depressed) and above ground level (elevated).

In an effort to assist highway designers, a combination approach was taken that included a review of the existing literature and visiting selected study sites to measure actual noise levels before, during, and after construction. At some sites, these conditions were available, but in others, the length of construction dictates that the "after" condition will need to be evaluated during subsequent studies. Also reviewed were the current traffic noise modeling methods used to predict future noise levels.

In examining the three vertical alignments for differences in noise levels, researchers determined that the depressed sections of roadway provide the greatest reduction in traffic noise in areas near and far from the roadway, especially if the walls of the depression are sloped or acoustically treated. The next best condition is an elevated roadway using solid concrete guardrails. The traffic noise is shielded by the solid deck and rails. The reduction is measurable near the elevated section, but at greater lateral distances away from the roadway, levels approach those of at-grade roads. At-grade roads produce the highest noise levels, but the addition of solid guardrails, median rails, and the use of smooth texture pavements provide noticeable quieting.

The techniques for modeling and planning of noise abatement by TxDOT have been found quite adequate with substantial noise reductions after the completion of major projects.

INTRODUCTION

BACKGROUND

Study Problem Statement

The Texas Department of Transportation (TxDOT) is continually upgrading the existing highway system in the state, especially in urban and suburban areas. This upgrading involves improving existing highways or freeways on the existing route or on a new route paralleling the old route or bypassing the central city. Such freeway improvements are made at varying grade levels, i.e, at-grade, elevated grade, and depressed grade, depending on the terrain, land use, and other factors. The choice of grade level at a particular point may be an attempt to mitigate negative noise and aesthetics impacts on a residential neighborhood. The current trend in design is toward elevated and depressed sections to gain additional lanes. The elevated sections may be either earthen or bridge in form. Many sections of each type of grade level have been built over the years since the late 1950s. Many are more than 20 years old. However, quite a few sections have been built during the last 5 to 10 years, and some sections are either under construction or in the planning stages.

Though many sections of elevated and depressed freeways have been built over the years in the state, more questions are being raised by abutting or nearby residents and businesses about the possible negative impacts of such freeways. In recent years, stiff resistance has been given to the proposed elevated section of the Dallas North Central Expressway and more recently to the proposed elevated or depressed section of U.S. Highway 287 in Wichita Falls. Also, the elevated sections of U.S. Highway 183 now under construction in Austin have caused similar concerns.

Any highway improvement, regardless of grade level, not only impacts users but also impacts abutting and nearby property owners, businesses, and residents in some manner. The entire city or community is impacted in some way during and after construction. Elevated and depressed freeway designs raise particular questions concerning noise and air quality

impacts, but vibration in moving vehicles and in structures adjacent to the freeway and flooding of depressed freeways are additional concerns. The recent flooding of a depressed section of I.H. 10 in Houston dramatized the latter problem. Soil erosion, at the point of drainage discharge can cause a problem. Last, aesthetic qualities of elevated and depressed sections are matters of concern.

Impacts that result from elevated and depressed freeway improvements can be classified into three major types: (1) social, (2) economic, and (3) environmental. A partial list of the specific impacts of each of the major types is given below. The social impacts are: population changes, neighborhood accessibility, neighborhood cohesion, and community services. The economic impacts are: relocation and mitigation costs, business sales, land uses and proper values, tax revenues, employment and income, and user costs. The environmental impacts are: aesthetics, drainage and erosion, air quality, noise and vibration, and hazardous spills.

A preliminary search of the literature reveals very few case studies that have measured many of the social, economic, and environmental impacts of depressed and elevated freeways, especially those in Texas. Therefore, the highway decision-makers have very little relevant impact data to write and support the environmental assessment statements and to present at public hearings for proposed elevated and depressed sections of existing or proposed freeway.

Study Objectives

The general objective of the study is to determine the social, economic, and environmental effects of elevated and depressed freeways in urban and suburban areas. The more specific objectives of the study are as follows:

1. Determine the appropriate estimating procedures or models and mitigation measures to be used in this study to estimate the social, economic, and environmental effects of elevated and depressed freeways.
2. Estimate the social, economic, and environmental effects of several existing, contracted and proposed elevated and depressed freeway sections situated in

urban areas in Texas, and recommend a final set of impact estimating procedures for use by TxDOT.

Selection of Freeway Study Sections

At the beginning of this study, a survey was conducted of all of TxDOT's districts to locate all of the elevated and depressed freeway sections at least 1.295 kilometers (one-half mile) long that were planned, under construction, or recently constructed during the last 10 years. (Copies of the survey forms appear in Appendix A.) Also, the survey asked for TxDOT to indicate the location (downtown or suburban), abutting land use, and age (less than five years or more than five years) of each qualifying freeway section. Later, it was determined whether each freeway section was on an existing highway route or a new location. These were considered primary characteristics to be used in selecting the freeway study sections.

Thirty freeways (11 elevated and 19 depressed) were identified and reported by the TxDOT districts. Twelve (six elevated and six depressed) were planned; three (one elevated and two depressed) were under construction; and 15 (four elevated and 11 depressed) were recently constructed. Each of the 30 candidate study sections was personally inspected by TTI researchers accompanied by a TxDOT district official.

With the help of TxDOT's study panel members, 11 freeway sections were selected for study. Of those selected, two (one elevated and one depressed) were planned; two (one elevated and one depressed) were under construction; and seven (three elevated and four depressed) were built. Of the seven already built, three (two elevated and one depressed) were less than four years old, and four (one elevated and three depressed) were more than four years old.

Location and Characteristics of Study Freeway Sections

Table 1 shows the selected study sections. As can be seen, an attempt was made to have a fairly good mix of study sections representing different types of location, stages of construction, and ages and land uses for each of the study grade levels.

The 11 study sections are located in four Texas cities: one depressed section on U.S. Highway 75 in Dallas; one depressed section on the Sam Houston Tollway in Houston; and four sections in Lubbock. Two of these are located on I.H. 27 (one elevated and one depressed), and two are located on the planned East-West Freeway (U.S. Highways 62/82), one elevated and one depressed. Figures 1–4 show the specific location of the study sections within Dallas, Houston, San Antonio, and Lubbock, respectively.

Table 1. Freeway Sections Selected for Study by Type of Grade Level Design and Key Characteristics.

TYPE OF DESIGN/Number/ STATUS	CITY & HIGHWAY Type/Number	ROUTE LOCATION	SECTION LOCATION	ABUT LAND USE
Elevated Sections				
No. 11-Planned	Lubbock-U.S. 62/82	Existing	Suburban	Res/Com
No. 8-Built Under 4Yrs	Lubbock-I.H. 27	New	Downtown	Com/Ind
Depressed Sections				
No. 10-Planned	Lubbock-U.S. 82	Existing	Downtown	Com/Pub/ Res
No. 7-Under Construction	Dallas-U.S. 75	Existing	Downtown & Suburban	Com/Res
No. 9-Built Under 4 Yrs	Lubbock-I.H. 27	New	Suburban	Res/Com
No. 5-Built Under 4 Yrs	San Antonio-U.S. 281	Existing	Suburban	Vacant/ Res/Com
No. 1-Built Over 4 Yrs[1]	San Antonio-I.H. 35	Existing	Downtown	Res/Com
No. 6-Built Over 4Yrs	Houston-Beltway 8	New	Suburban	Res/Com
Combination Elevated & Depressed Sections				
No. 2-Built Under 4 Yrs	San Antonio-I.H. 35	Existing	Downtown	Res/Com
No. 3-Built Under 4 Yrs	San Antonio-I.H. 10	Existing	Downtown	Res/Com
No. 4-Built Over 4 Yrs	San Antonio-I.H. 10/35	Existing	Downtown	Com/Ind

[1]No basic grade level change in this section, but it is adjacent to a new elevated/depressed section having feeder ramps extending into this section.

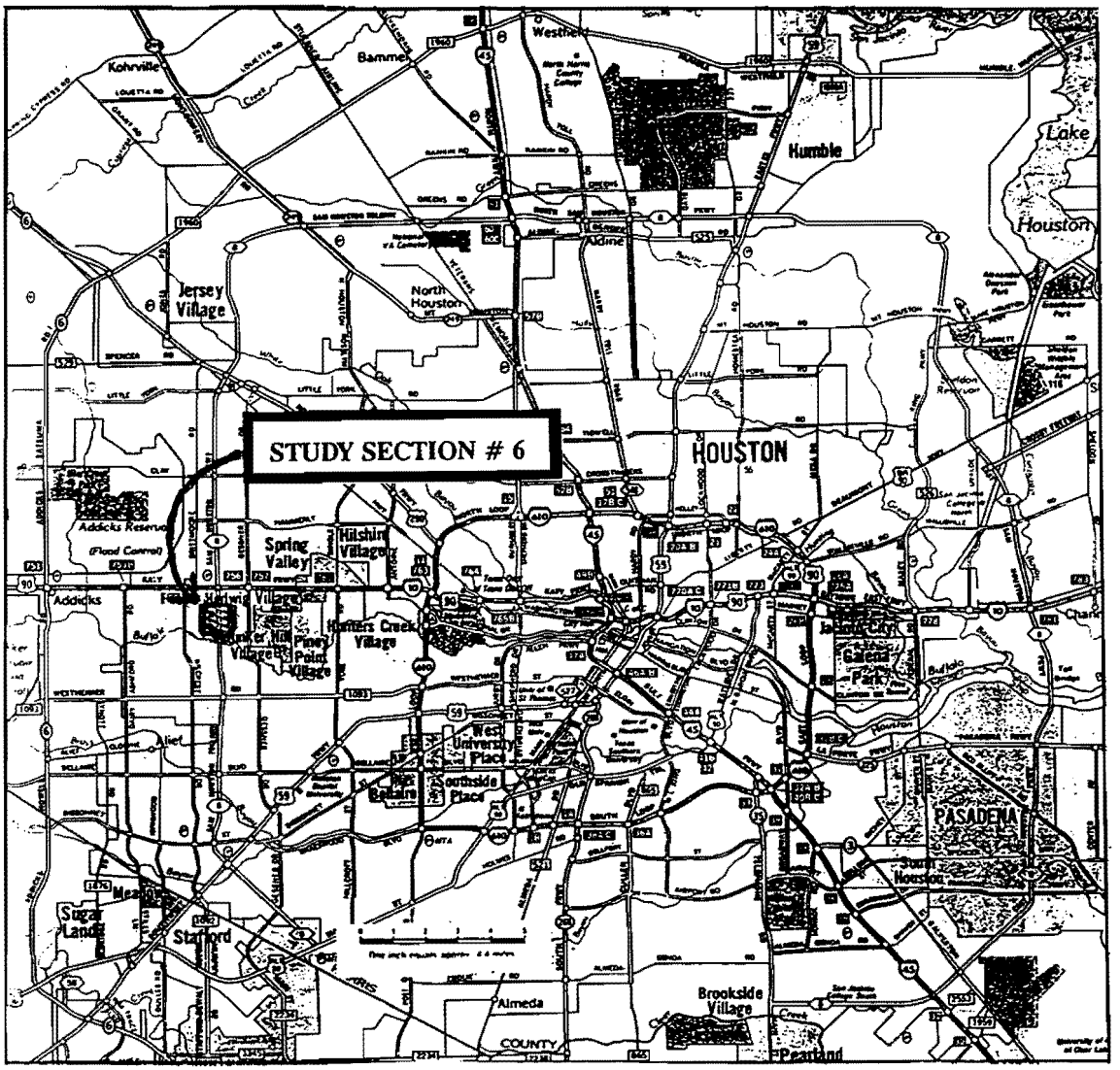
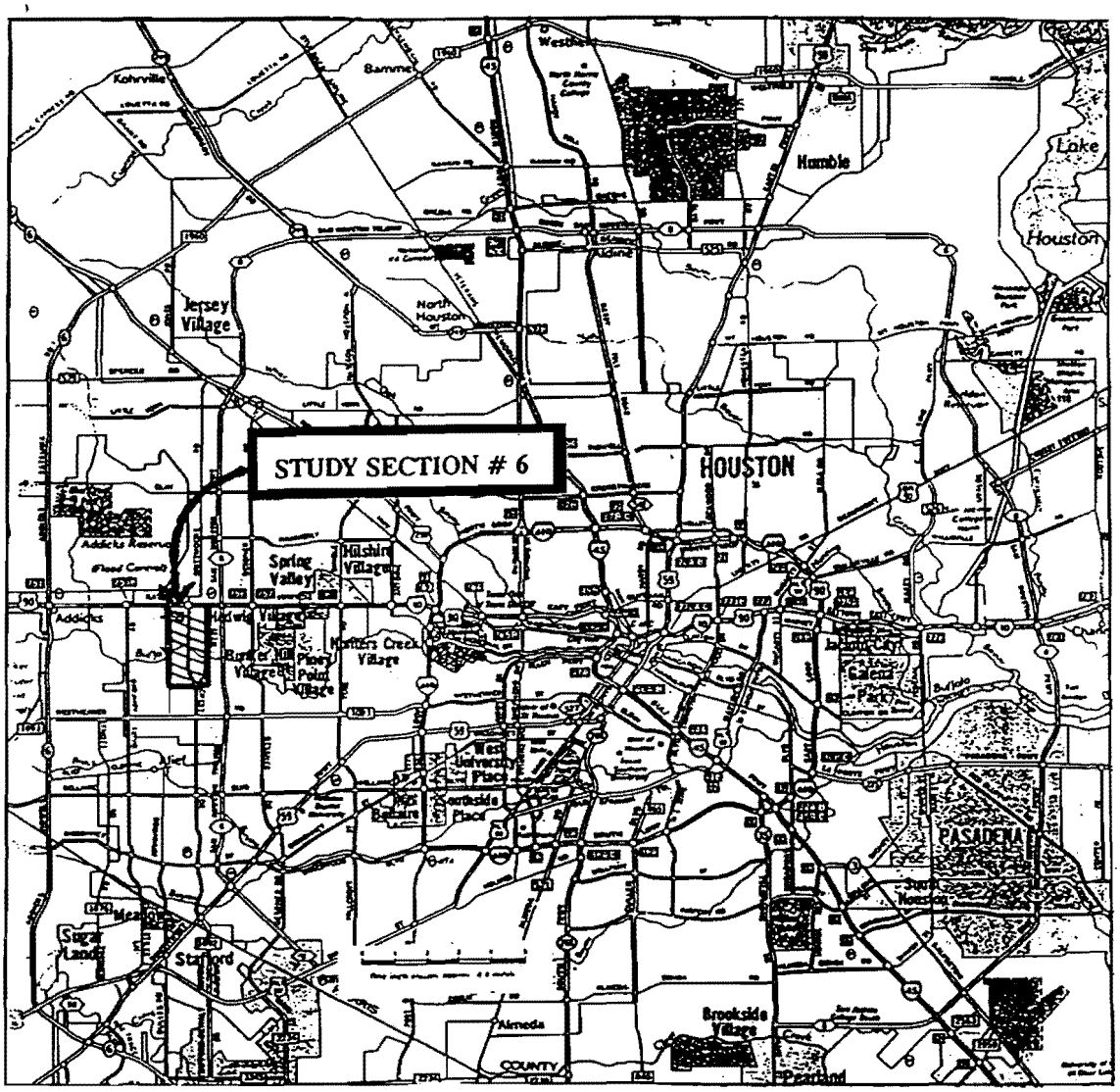


Figure 2. Location of Study Section 6 on the Sam Houston Tollway in Southwestern Part of Houston



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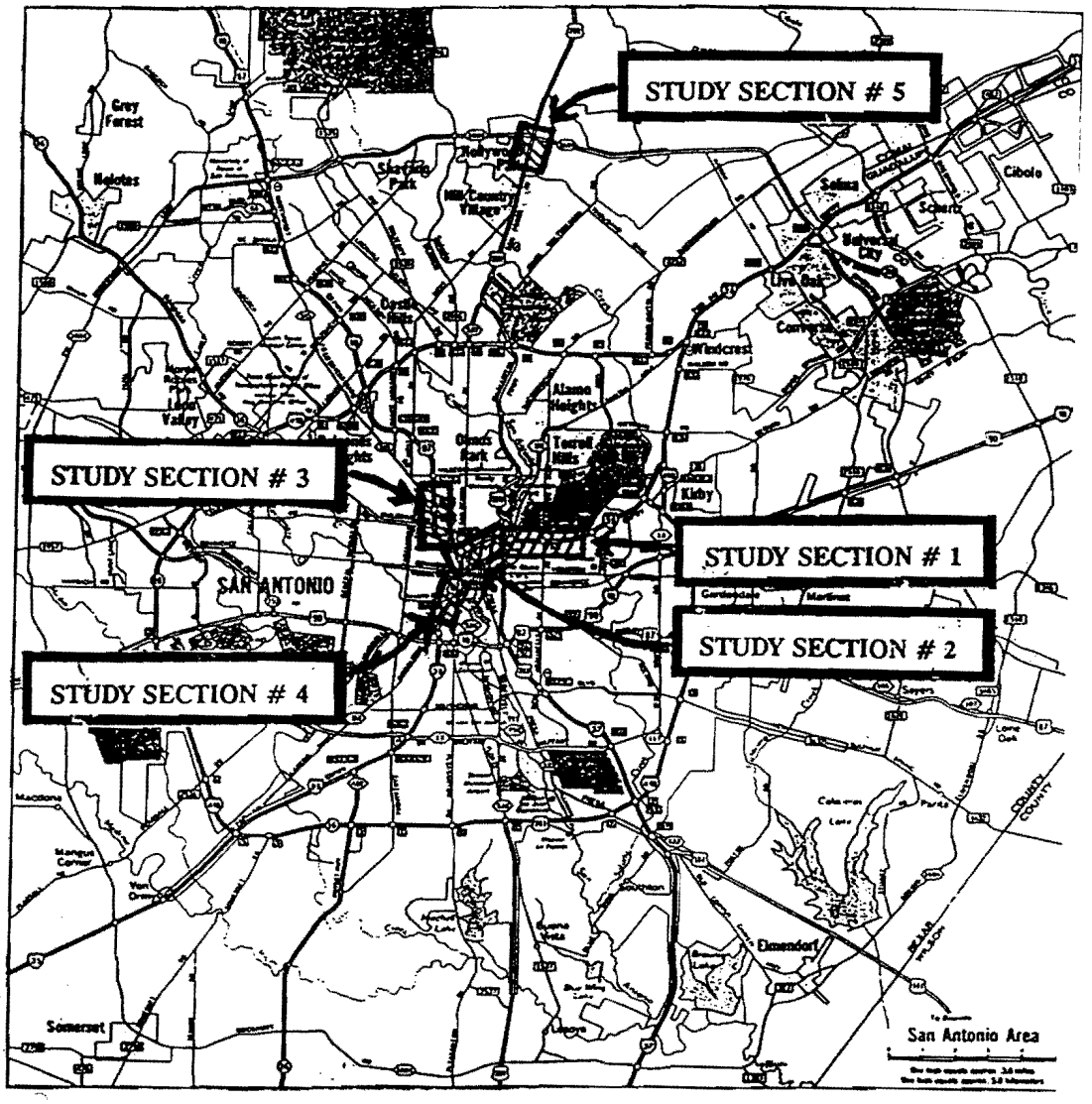


Figure 3. Location of Study Sections 1-5 on I.H. 10, 10/35, 35 and U.S. Highway 281 in San Antonio.

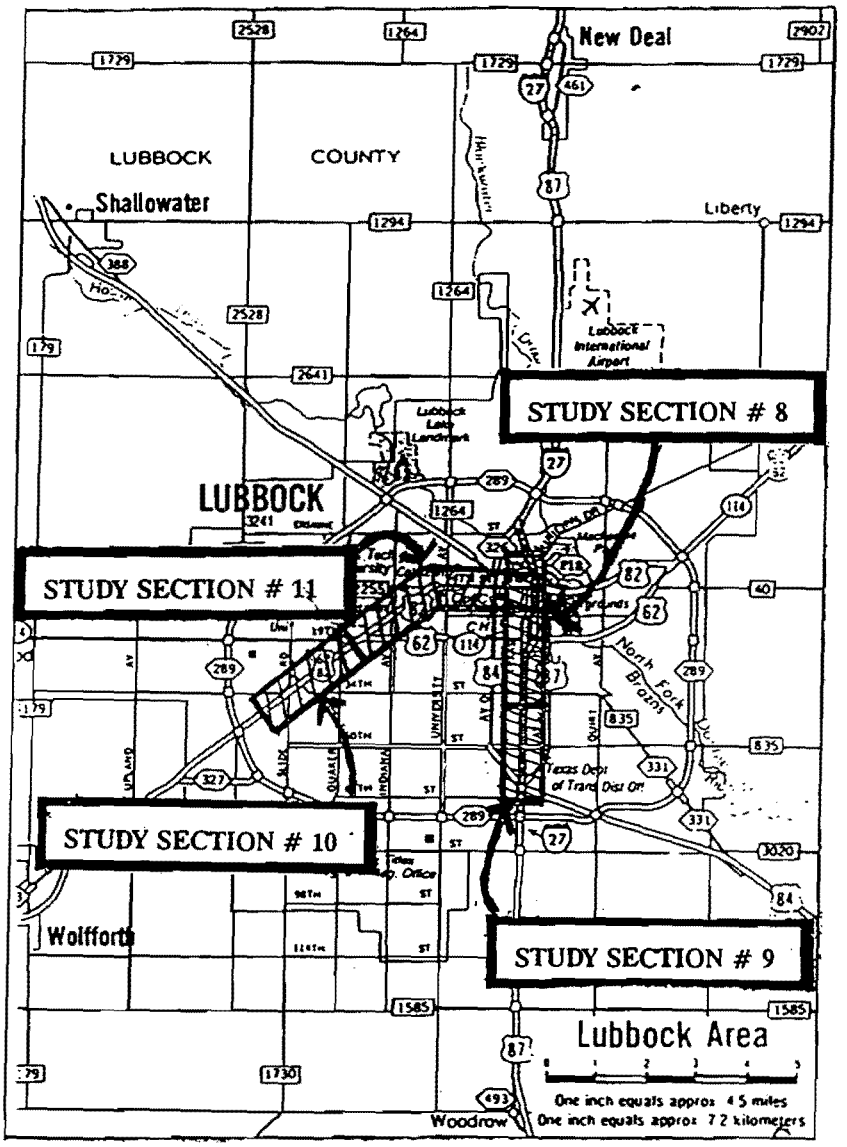


Figure 4. Location of Study Sections 8-11 on I.H. 27 and U.S. Highways 62/82 (Proposed East-West Freeway) in Lubbock.

Tables 2 and 3 show other important characteristics of each study section by study grade level. Some of these characteristics are used in evaluating the different impacts considered under this study.

Typical Cross-sectional Design of Study Freeway Sections

Figures 5–9 show the typical cross-sectional designs of the study freeway sections. There are some variations in cross-sectional design through each study section, depending on the specific location. For instance, only one of the cross sections shows the on and off ramp designs or the variation in the number of main lanes or frontage road lanes throughout the study section.

General Methodology and Data Sources

The general methodology planned for this study was to conduct a "before and after" construction period comparative analysis across time supplemented with a cross-sectional analysis at one point-in-time. The eight completed freeway study sections lend themselves easily to both analyses. The three others can be used to provide current before and/or construction period data to supplement these analyses. For instance, the two study sections still under construction, at time of selection, can be used to study some of the construction effects of each grade level. The two planned study sections can be used to estimate anticipatory effects by grade level.

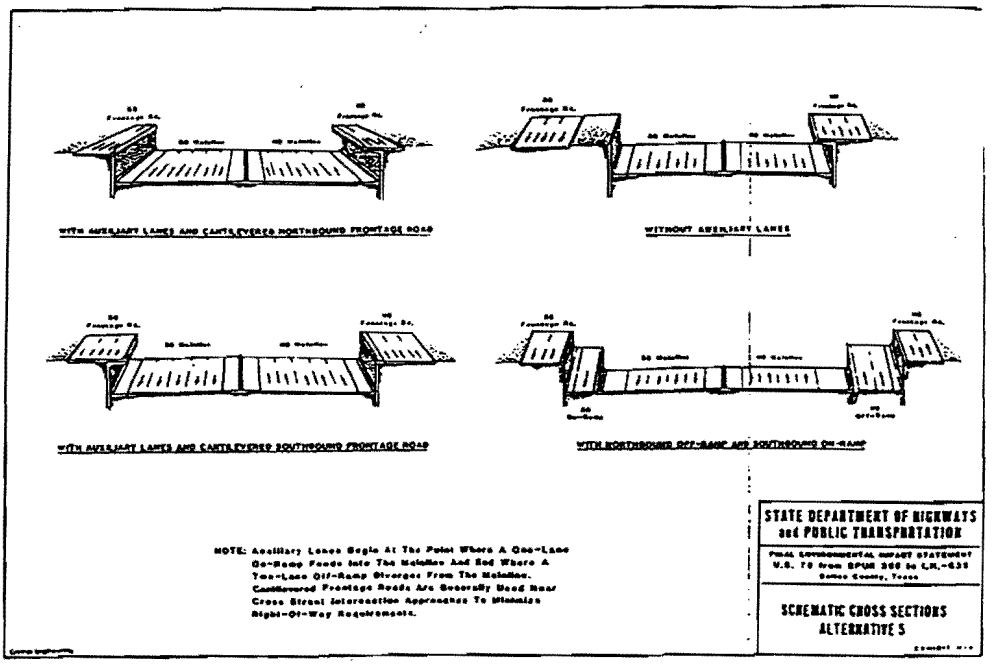
The before and after analysis can compare the elevated freeway sections with depressed freeway sections to ascertain any significant differences in various types of impact elements, i.e., air pollution, noise pollution, business activity, neighborhood cohesion, etc. The one point-in-time analysis can compare current level unit values of each impact element to determine significant differences between elevated and depressed freeway grade levels. For either of these analytical approaches, you can compare elevated study sections with depressed study sections and also compare these two grade levels with adjacent or nearby at-grade level sections. The at-grade sections, when available, can serve as a control or base section.

Table 2. Study Freeway Sections by Age, Grade Level Before, Length, Grade Level Depth, Right-of-Way Width, Type of Mainlane Access and ADT

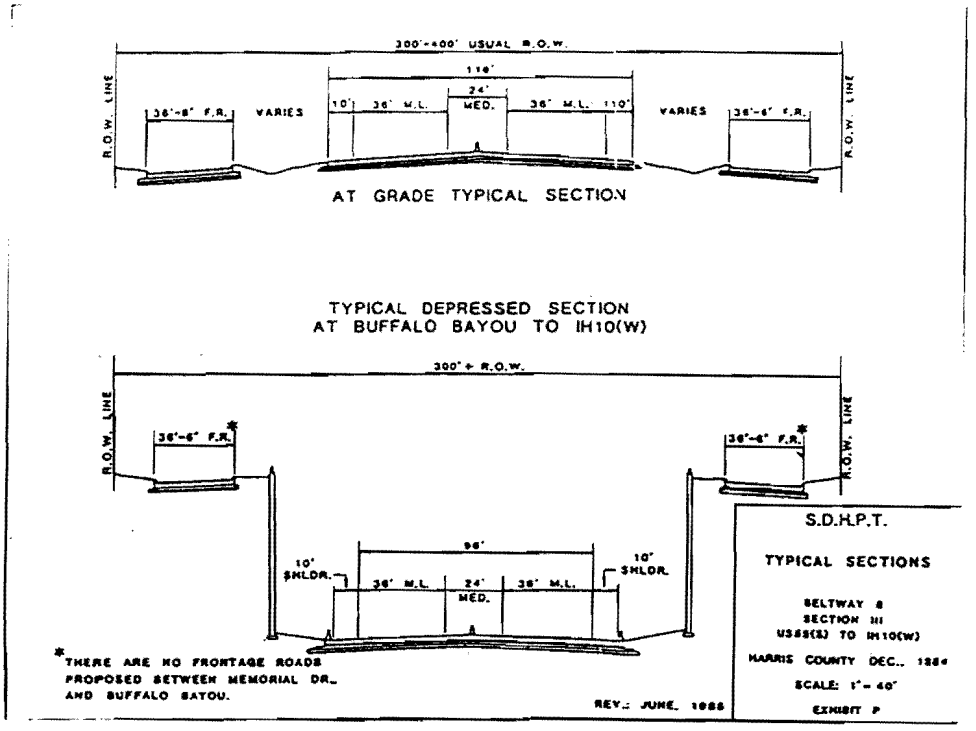
STUDY NO./ TYPE OF GRADE LEVEL AFTER CONSTRUCTION	AGE AFTER (yrs)	GRADE LEVEL BEFORE	LENGTH AFTER km(mi)	GRADE LEVEL HEIGHT/DEPTH m(ft)		RIGHT-OF-WAY WIDTH m(ft)		TYPE OF ACCESS TO MAINLANES		ADT	
				BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Elevated/Combination Elevated & Depressed											
No. 2 IH 35-San Antonio	1	depressed	2.01(1.25)	-4.6(-15)	+6.1(+20)	64.0(210)	70.7(232)	full	limited	75,600	188,300
No. 3 IH 10- San Antonio	3	Depressed	2.96(1.84)	0(0)	+6.1(+20)	65.5(215)	74.7(245)	limited	limited	94,100	198,500
No. 4 IH 10/35- San Antonio	6	elevated/ Depressed	2.28(1.42)	+6.1(+20)	+6.1(+20)	61.0(200)	76.2(250)	limited	limited	79,800	186,500
No. 8 IH 27- Lubbock	3	at-Grade	4.84(3.01)	0(0)	5.5(+18)	38.1(125)	121.9(400)	full	limited	42,352	77,350
No. 10 U.S.H. 62/82- Lubbock	0	at-Grade	2.32(1.44)	0(0)	+6.4(+21)	53.6(176)	97.5(320)	full	limited	22,493	52,533
Depressed											
No. 6 Sam Houston Beltway-Houston	6	at-Grade	2.09(1.30)	0(0)	-5.2(-17)	91.4(300)	91.4(300)	full	limited	84,000	168,000
No. 7 U.S.H. 75-Dallas	0	at-Grade	6.47(4.02)	0(0)	-6.7(-22)	67.1(220)	85.3(280)	limited	limited	155,000	217,700
No. 9 IH 27- Lubbock	3	at-Grade	2.32(1.44)	0(0)	-5.2(-17)	38.1(125)	121.9(400)	full	limited	42,356	77,350
No. 11 U.S.H. 62/82- Lubbock	0	at-Grade	6.63(4.12)	0(0)	-6.7(-22)	53.7(176)	102.1(335)	full	limited	22,656	34,483
No. 1 IH 35- San Antonio	10	depressed	2.22(1.38)	-4.6(-15)	-4.6(-15)	91.4(300)	91.4(300)	limited	limited	50,000	150,000
No. 5 U.S.H. 281- San Antonio	5	at-Grade	2.58(1.61)	0(0)	-6.4(-21)	91.4(300)	91.4(300)	full	limited	12,700	94,000

Table 3. Study Freeway Sections by Number of Structures, Crossing Streets, Main Lanes, On Ramps and Off Ramps.

STUDY NO./ TYPE OF GRADE LEVEL AFTER CONSTRUCTION	STRUCTURES (NO.)		CROSSING STREETS (NO.)		MAIN LANES (NUMBER)		ON RAMPS (NUMBER)		OFF RAMPS (NUMBER)	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Elevated/Combination Elevated & Depressed										
No. 2 I.H. 35-San Antonio	11	12	11	11	4	10	4	8	6	8
No. 3 I.H. 10- San Antonio	9	11	6	6	4	10	3	6	5	6
No. 4 I.H. 10/35- San Antonio	6	8	8	8	6	10	4	6	4	3
No. 8 I.H. 27- Lubbock	2	6	21	6	4	6	0	4	0	3
No. 10 U.S. 62/82-Lubbock	2	4	5	3	4	6	0	3	0	3
Depressed										
No. 6 Sam Houston Beltway- Houston	0	3	7	3	4	6	0	2	0	2
No. 7 U.S. 75-Dallas	13	14	13	13	4	8	16	5	16	5
No. 9 I.H. 27- Lubbock	0	7	11	4	4	6	0	2	0	2
No. 11 U.S. 62/82-Lubbock	4	21	22	15	4	6	0	8	0	8
No. 1 I.H. 35- San Antonio	9	9	7	7	6	6	3	3	3	3
No. 5 U.S. 281- San Antonio	1	2	2	2	4	6	0	3	0	3

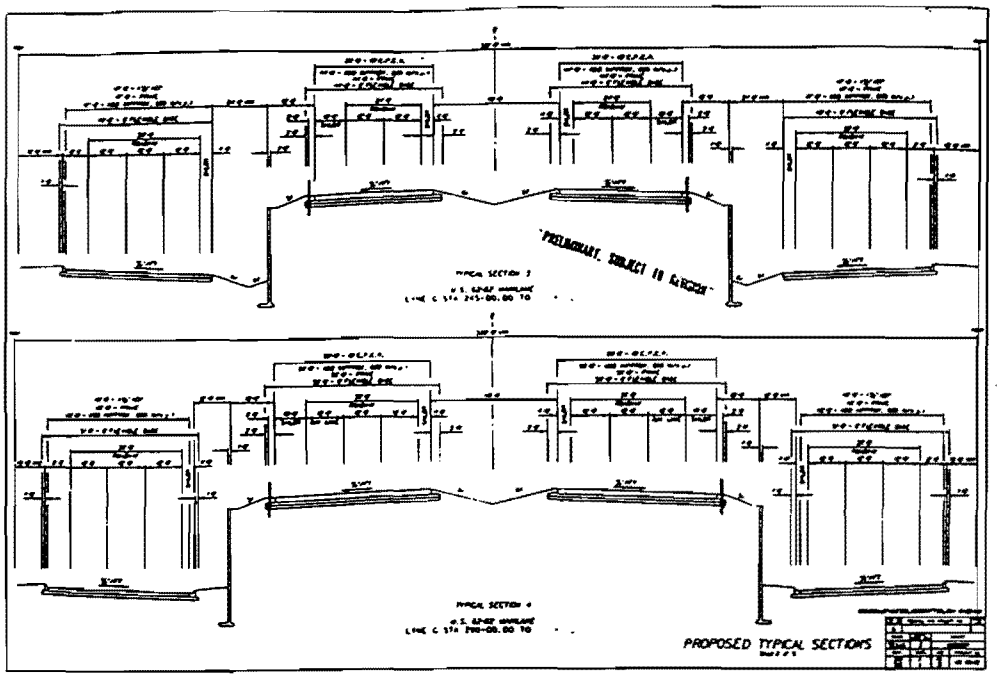


U. S. Highway 75 Section # 7, Dallas

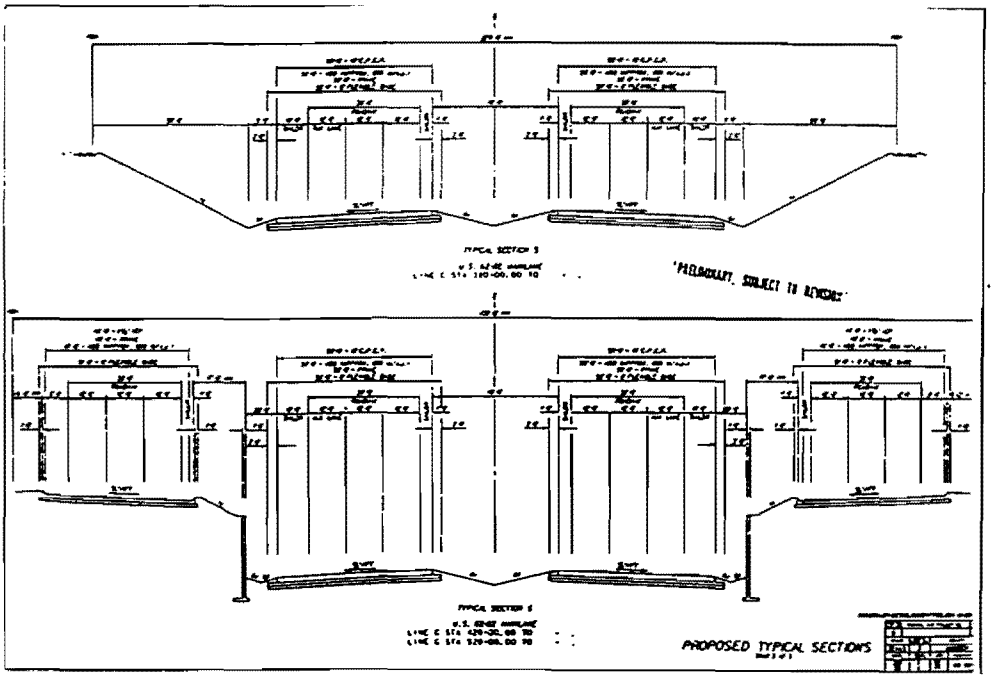


Sam Houston Tollway Section # 6, Houston

Figure 5. Typical Cross-sectional Design of Depressed Study Sections on U. S. Highway 75 in Dallas, Texas and Sam Houston Tollway in Houston, Texas.

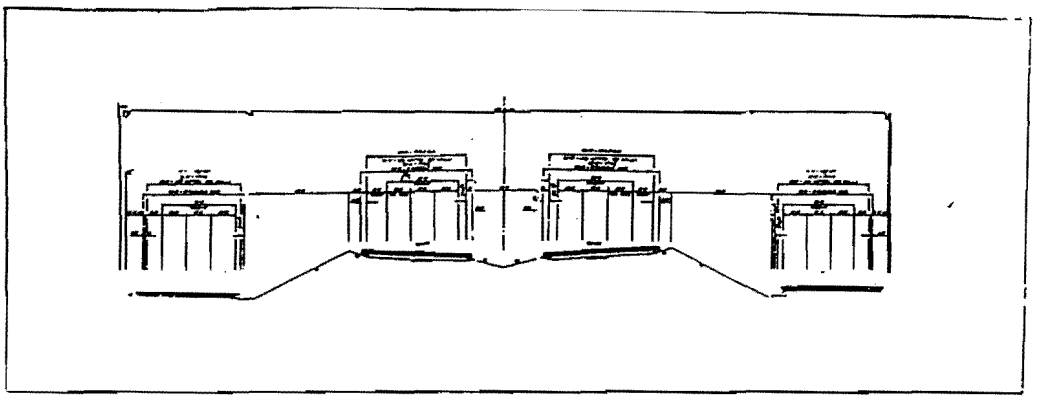


Elevated Section # 10

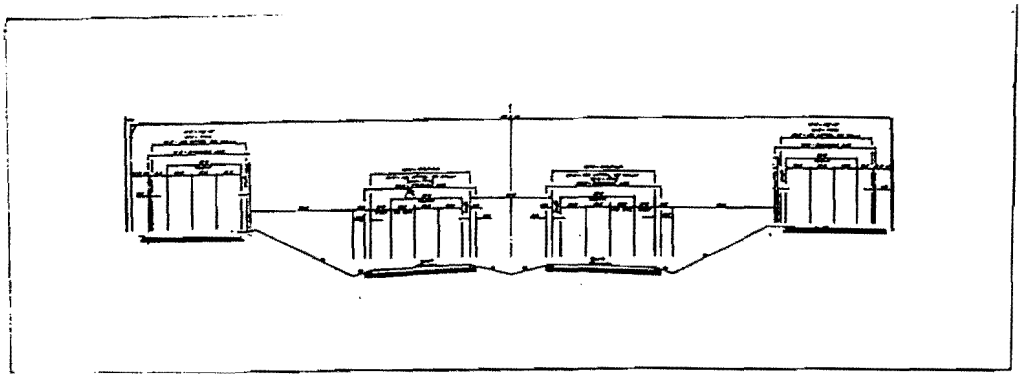


Depressed Section # 11

Figure 6. Typical Cross-sectional Design of the Depressed and Elevated Study Sections on the Planned East-West Freeway in Lubbock, Texas.

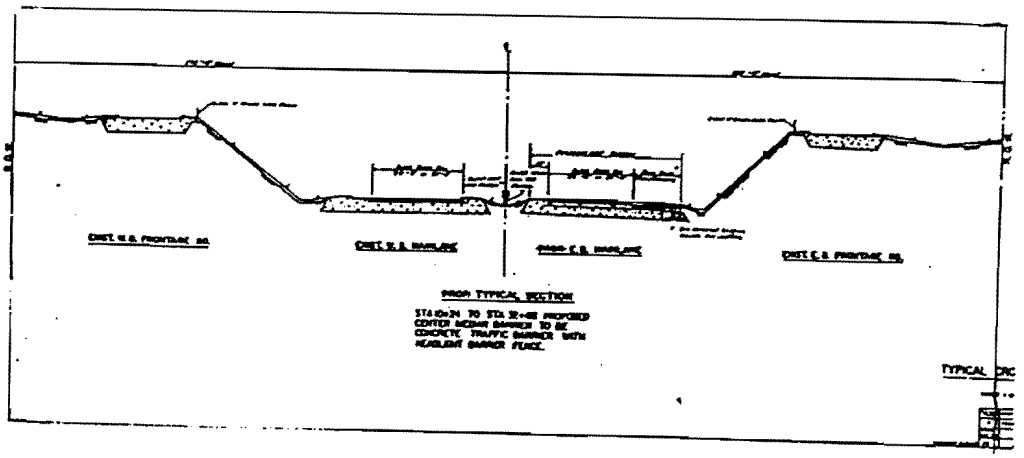


Elevated Section # 8

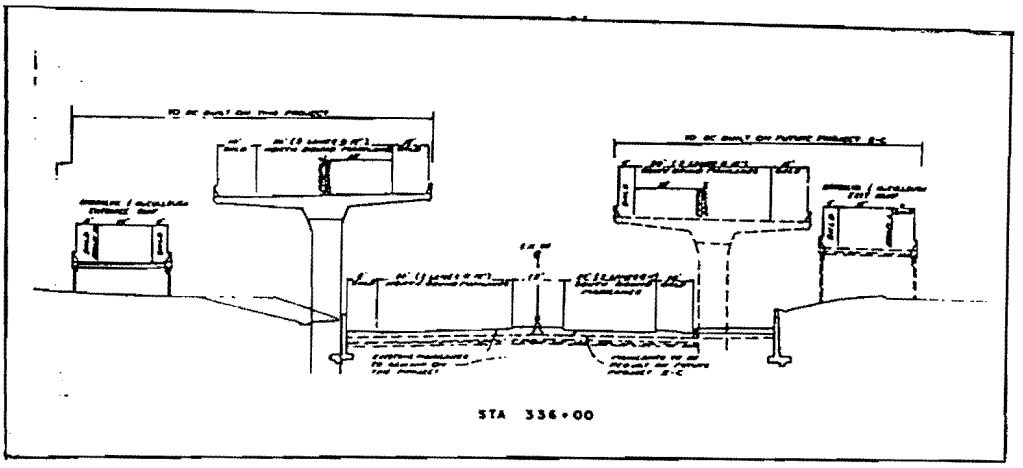


Depressed Section # 9

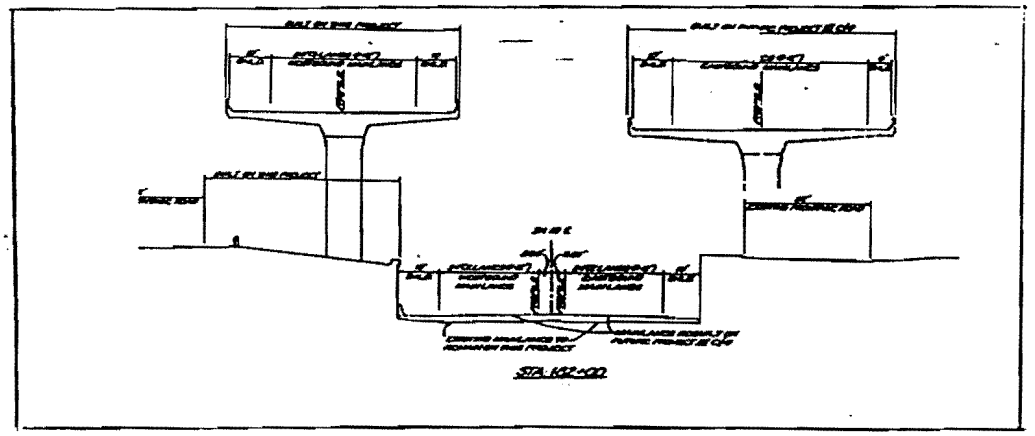
Figure 7. Typical Cross-sectional Design of the Elevated and Depressed Study Sections on the I.H. 27 in Lubbock, Texas.



I.H. 35 Section # 1

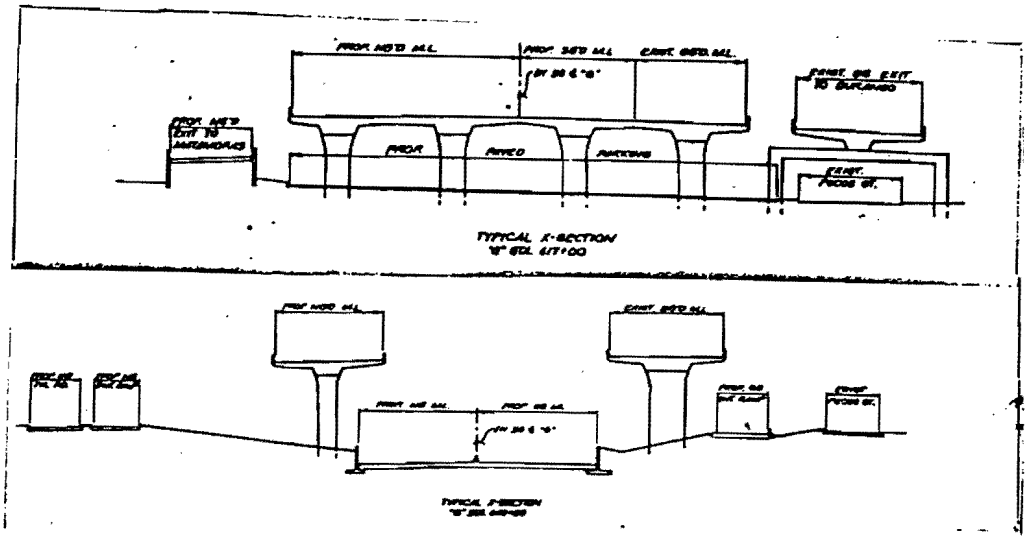


I.H. 35 Section # 2

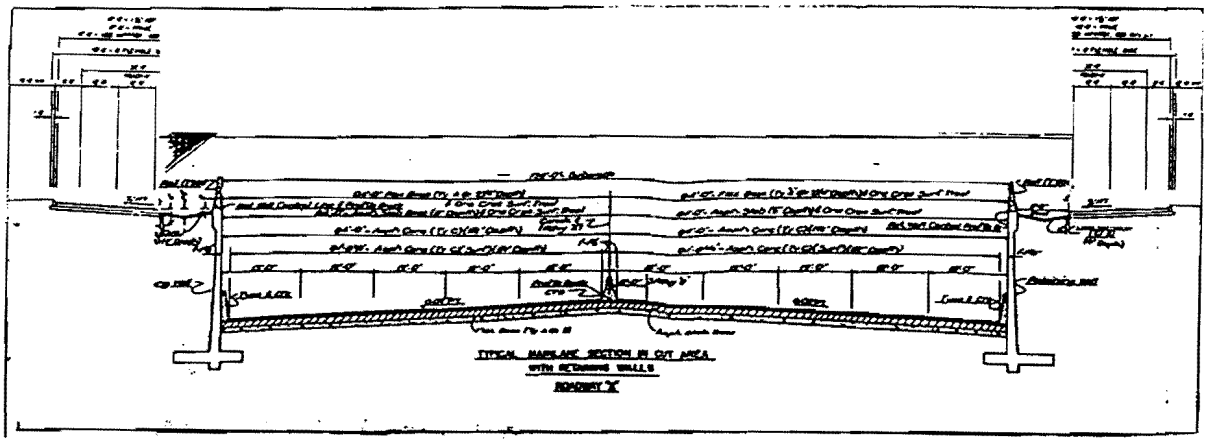


I.H. 10 Section # 3

Figure 8. Typical Cross-sectional Design of the Combination Elevated/Depressed Study Sections on I.H. 10 and 35 in San Antonio, Texas.



I.H. 35 Section # 4



U. S. Highway 281 Section # 5

Figure 9. Typical Cross-sectional Design of the Depressed Study Sections on U. S. Highway 281 and I.H. 35 in San Antonio, Texas.

Sources of data used in the study ranged from a review of the literature to "on-site" data collection. The prior studies found in the literature, as well as data obtained from a national survey of state transportation agencies, helped to determine the different methodologies used in the study. The data obtained to estimate the effects of the different impact elements came from the literature, national survey, United States Census Bureau, Texas State Comptroller and Employment Commission, TxDOT, Environmental Impact Statements (EIS) of each of the study sections, city crisscross directories, site surveys of businesses and residents, traffic volumes and composition, air and noise levels and drainage, erosion, and other environmental conditions.

Reports of Findings

Since this study involves many different impact elements, the findings are presented in several reports by type of impact. The reports are as follows:

- Research Report 1327-1:
  Social and Economic Effects of Elevated and Depressed Freeways in Texas;
- Research Report 1327-2:
  Land Value and Use Effects of Elevated and Depressed Freeways in Texas;
- Research Report 1327-3:
  Noise Pollution Effects of Elevated and Depressed Freeways in Texas;
- Research Report 1327-4:
  Air Pollution Effects of Elevated and Depressed Freeways in Texas;
- Research Report 1327-5:
  Drainage, Erosion, Hazardous Spill, and Vibration Effects of Elevated and Depressed Freeways in Texas; and
- Research Report 1327-6F:
  Social, Economic and Environmental Effects of Elevated and Depressed Freeways in Texas.

Research Report 1327-1 will contain a summary of the findings from the national survey of state transportation agencies and the Texas survey of TxDOT districts, and a description of the cities and areas of the cities where the freeway study sections are located.

This report, Research Report 1327-3, contains the findings on the effects of elevated and depressed freeways on noise pollution.

BACKGROUND AND LITERATURE SUMMARY

The subject of transportation noise has been thoroughly researched and documented over the years. In fact there are, for example, documented cases of noise control ordinances dating from the Romans. It was not until more modern times that environmental factors were considered formally in any major transportation decisions. It was not until the early 1960s and 1970s that the environmental quality of transportation was recognized as a powerful force affecting the course of new development. The planning and building of urban freeways affects the lives and livelihoods of many members of the urban community, particularly those living near the freeway right-of-way. Although the development of highway systems has produced both economic and social benefits to large numbers of people, traffic can also pollute the environment.

- An excellent text covering many aspects of transportation noise is the *Transportation Noise Reference Book*, (1) edited by Paul Nelson and published by Butterworths of London. This is almost certainly the most comprehensive international reference book on all aspects of noise generated by road, rail, and air transportation and deserves to be on the bookshelf of anyone dealing with transportation noise. This major work has been written by a team of experts from both sides of the Atlantic. Among other topics, this text discusses the effects of elevated and depressed roads (11.1.2.2). Observations in the text agree with the findings in this study, for example, that elevated structures provide lower levels of noise below the roadway (65 dBA L_{eq}) than at the road height at 25 m (82 ft) distance (70–75 dBA L_{eq}).

- A publication by Milton D. Harmelink and Jerry J. Hajek entitled "Highway Noise Control" (2), published by Traffic Engineering, September 1973, addressed elevated and depressed sections as governed by the same relationship as sound attenuation due to barriers. They indicate those sound level reductions obtained are likely to be less than the design charts predict. As found in our study, "The most effective section appears to be a depressed section with some barrier on the crest."

- A Transportation Research Board paper entitled "Residential Noise Damage Costs Caused by Motor Vehicles" (3), written by Daniel Haling and Harry Cohen, addresses the change in property values per decibel of traffic noise. The survey they conducted concluded that the average of the noise impact studies estimated that housing units lose 0.4 percent of their value for every decibel above the threshold level of 55 dBA. The study goes on to conclude that transportation planners and policy makers should be aware of the significant variation of noise damage costs depending on the vehicle type, operating conditions, and location of the roadway, in order to make informed decisions on infrastructure expansion and rehabilitation. Another interesting fact in this study is the point that a heavy-duty diesel truck causes up to 150 times the noise damage of a passenger car.

- A study of noise reflecting from the underside of an overhead roadway was undertaken by Grant S. Anderson and reported in "Noise Studies for the San Antonio "Y" Project" (4), Transportation Research Record 983. This study investigated the effect of traffic noise reflecting from the underside of an elevated roadway. They studied a portion of I-35 in Austin, Texas, where the interstate is split level: half the traffic is depressed, and the other half is elevated. The study showed an amplification range between zero and 12 dB in Austin and zero to 3 dB in San Antonio from traffic under an elevated section.

- An informational report was produced by ITE Council Committee 6A9 entitled "Environmental Impacts of Elevated and Depressed Urban Freeways" (5) and published in *Traffic Engineering*, February 1976. The scope was to establish relevant key parameters, factors, and criteria used in the evaluation of impact for alternative urban freeway design types—elevated or depressed. Among environmental factors were air, noise, visual quality, vibration, and vegetation. One finding was that "if trends could be concluded from the analyses of the case studies, they may show a tendency to

elevate in industrial areas and to depress in residential areas or in areas in which the community places heavy emphasis on sites of historic or aesthetic value."

- Texas Transportation Report 148-1, "Experiences and Opinions of Residents along Elevated, Depressed, and On-Grade Freeway Sections in Houston, Texas" (6), by Jesse Buffington and others, describes the effects of a new freeway through a residential area. They found that "the most often mentioned negative effect was noise." Most of the respondents, who were 60 years of age and older, said that the freeway noticeably raised the noise level. The higher percentage of complaints came from the at-grade and elevated locations. Many respondents said that "the noise annoyed them at first, but that they got accustomed to it as time passed." Results reported in Table 22 showed the same trend as found in this study, which is that depressed freeways produce the least noise impact or noticeable increase among 76% of the residents. The elevated sections produced the next higher increase at 85% of the residents, and the highest level of 100% noticed a noise increase with the at-grade conditions. These residents were all within 183 m (600 ft) of the right-of-way. Those interviewed beyond that distance reported noticeable increases of 21%, 86%, and 62% for the depressed, elevated, and at-grade conditions respectively. This again agrees with this study in that the elevated sections tend to block noise near or under the roadway, but the noise travels further because of the lack of shielding from buildings and foliage at the higher altitude. The study did not indicate if the guardrail on the elevated section was a solid or open design.

Other publications found in the noise literature search will be noted throughout the following text and referenced at the end.

NOISE DATA COLLECTION PROCEDURES

To establish existing sound levels at the case study and control sections, measurement procedures were used that are in line with current TxDOT and FHWA guidelines. According to FHWA procedures (7), the following instrumentation is required to measure existing traffic sound levels:

- Sound Level Meter (Type 2),
- Sound Level Calibrator,
- Earphones or Headphones (optional),
- Wind Speed Indicator,
- Sling Psychrometer (optional),
- Watch with "seconds" Display,
- Windscreen,
- Data Sheet,
- Microphone Cable,
- Tripod, and
- Spare Batteries.

All of these items were used during this study except those that were optional.

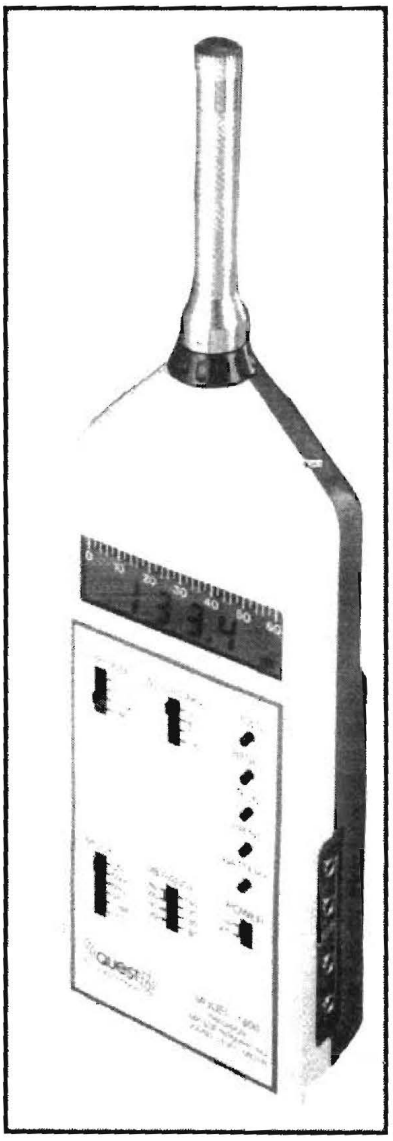


Figure 10. Sound Level Meter.

SOUND LEVEL METER

The sound level meters chosen for the study were Quest Electronics (8) Model 1800 Precision Integrating Sound Lever Meters, shown in Figure 10. Two of these units were used in the study and were chosen because of features needed for traffic noise surveys. The Model 1800 functions as a Precision Sound Level Meter, Impulse or Integrating Sound Level Meter and is classified as Type 1. The Type 1 units

provide a ±1dB accuracy, while the FHWA recommended Type 2 provides a ±2dB accuracy. The Model 1800 is either hand-held or tripod-mounted with a digital display of the current sound pressure level, the average integrated sound level accumulated while in the RUN mode, and the total run time in minutes and seconds. The microphone is attached to the sound level meter at all times. A foam windscreen the size of a tennis ball was used over the microphone to prevent erroneous measurement of sound levels caused by wind blowing across the microphone. Acoustic attenuation effects of the windscreen were measured to be less than 0.5%. The meter/microphone was mounted on a tripod with the microphone element 1.5 m (4.9 ft) above the ground, as recommended by FHWA. It was elevated approximately 70 degrees and pointed in the direction of the sound, as recommended by Quest. The meters were used in the L_{eq} mode with 'A' weighting for all measurements. The integration time period was 10 minutes. This period was recommended in several publications and is a compromise between an acceptable statistical period of average noise and obtaining as many measurements in a given time period as possible.

Traffic noise studies in the past used the L_{10} method that provides the sound level exceeded 10% of the time during the measurement period. After the L_{10} values were measured, the L_{eq} values were calculated. Since modern sound level meters such as the Quest Model 1800 incorporate a digital processor, it can measure L_{eq} directly. For freely flowing traffic, an empirical relationship between l_{10} and l_{eq} is:

$$L_{10} \simeq L_{eq} + 3dB(A).$$

This equation, however, does not hold for vehicle flows of less than about 100 vehicles per hour.

SOUND LEVEL CALIBRATOR

As recommended by the FHWA report, an acoustic calibrator was used in the field to validate the operation of the sound level meters. As with the sound level meters, the calibrator was provided by

Figure 11. Sound Level Calibrator.

Quest Electronics. The coupler cavity of the calibrator is lowered over the microphone forming a tight seal. The unit is then switched on and set to 1 kHz and 94 dB. After 15 seconds the sound level meter, which has been set to SPL 'A' Weighting, is read. The reading must be 94 ±.5 dB. During the study, this test passed every time except once. The meter that failed the test was not used again until it was returned to the factory and repaired.

WIND SPEED INDICATOR

Wind speed was measured during the sound measurements with a hand-held anemometer. The small plastic unit has two scales. One is graduated from 3–16 km/h (2–10 mph) and the other from 16–106 km/h (10–66 mph). Temperature was measured at each site with a standard thermometer. Other optional meteorological instruments such as the Sling Psychrometer were not used.

TRAFFIC SPEED RADAR

Though not required in the FHWA procedure, a hand-held traffic radar was used to determine average traffic speed at each study site. The first part of the project used an X-band unit similar to a police radar to measure speed only. The latter part of the measurements used a Laser Radar that provided both vehicle speeds and distance readings. The Laser distance readings proved to be very beneficial since the site diagram could be scaled by reflecting the beam off objects in the median and points of interest across the roadway to take accurate measurements to the nearest 0.3 m (1 ft).

TRAFFIC COUNTS

To arrive at a basis for comparing sound level readings in this study, previous studies and future studies, traffic was counted during the measurements. This was done using two people and two hand-operated, mechanical counters. With three buttons on each counter, the total count for three categories of vehicles could be displayed on each unit. The three

categories were passenger cars, light trucks, and heavy trucks. Each person counting traffic would observe and count vehicles in one direction. The count was initiated shortly after the sound meter or meters were started in the L_{eq} mode of operation. The counts were then terminated just after the 10 minute measurement period was completed.

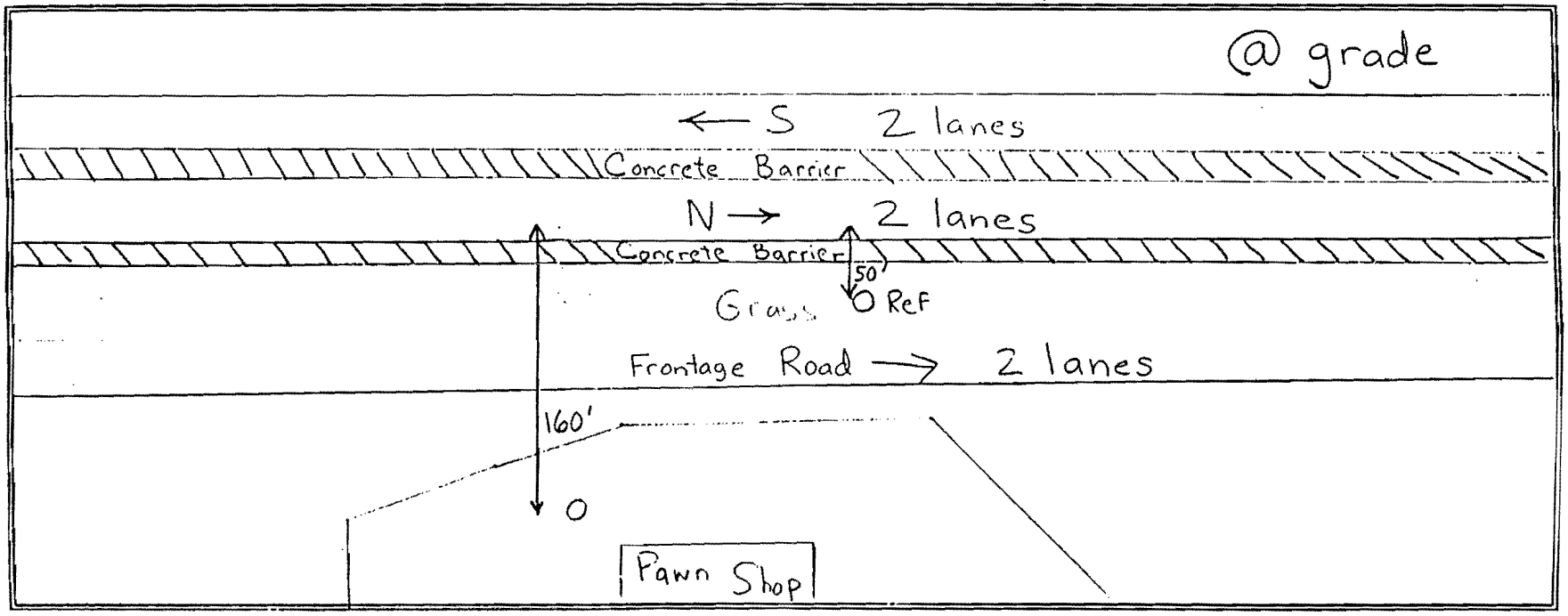
REPORTING FORMS

Field data collection forms were developed and used as recommended by the FHWA Sound Procedures for Measuring Highway Noise (7). These forms, Figure 12, were used to describe the location with a site sketch, and to record the time, date, sound levels, traffic count, and weather conditions.

NOISE MEASUREMENT DATA

DATE TIME	LOCATION	STUDY SITE POINT	REFRNC MSRMNT	STUDY SITE MSRMNT	NUMBER CAT 1 VHCLS	NUMBER CAT 2 VHCLS	NUMBER CAT 3 VHCLS	SPEED	WTHR	WIND SPD/ DRCTN
3/10/94 2:20 PM	Dallas-12 75 south of 635 Pawn Shop	A	76.1 dBA	67.7 dBA	N 540 S 504 T 1044	N 11 S 16 T 27	N 21 S 7 T 28	50 MPH	TEMP 65°F clear SKY	5 SW
		B			N S T	N S T	N S T	MPH	TEMP SKY	
		C			N S T	N S T	N S T	MPH	TEMP SKY	

SITE SKETCH (WITH MEASUREMENTS)



TRAFFIC NOISE CASE STUDIES

As addressed in the introductory section, four cities were selected for conducting traffic noise studies of at-grade, elevated, and depressed freeway sections. These cities were San Antonio, Dallas, Lubbock, and Houston. The study sites in these cities were chosen because of either proposed construction, current construction, or recently finished construction. This would allow comparisons of the various grade levels in a before and after improvement condition. In some study sites, this was accomplished. In others, only one condition was observed since the length of time needed for freeway improvements was not in the time frame of this study. Still, valuable information was gathered that can be compared with previous measurements made by TxDOT or may be compared with future measurements in subsequent research.

The techniques used at each case study section to collect traffic noise were consistent throughout the study and have been described in previous sections. To summarize, high quality sound level meters were used that provide readings directly in units of L_{eq}, dBA. These units were standardized and are comparable to other research and TxDOT measurements.

SAN ANTONIO - I.H. 35 & I.H. 10 Downtown "Y"

Study sections 1, 2, 3, and 4 lie within the city limits of San Antonio, in Bexar County, Texas. The improvements to the routes were along Interstate Highways 35 and 10. The southern terminus of the I.H. 35 section is its interchange with I.H. 10E and U.S. 90W. Its northern terminus is the interchange with I.H. 37 and U.S. 281. Work on I.H. 10 extended from its interchange with I.H. 35 to just north of Fredericksburg Road, Loop 345. The project length was 4.8 km (3.0 miles) on I.H. 10, 2.6 km (1.6 miles) on I.H. 35, and 4.3 km (2.7 miles) on the jointly designated I.H. 10 and I.H. 35.

Study section #1 covers I.H. 35 between the San Antonio River and Walters St. and is a depressed section. Study section #2 continues south on I.H. 35 between the San Antonio River and Martin St. and is a combination elevated and depressed section. Section #3 is I.H. 10 between Comal St. and Kings Highway and is a combination elevated and depressed section. Finally, study section #4 extends down I.H.10/35 between Martin St. and South Laredo St. and is another combined elevated and depressed section.

With the major portion of the project "double decked" or combined depressed and elevated, a unique traffic noise situation exists. The before and after construction of these corridors is shown in Figure 13. Prior to construction of the "double decked" roadways in San Antonio, a portion of I.H. 35 in Austin was similarly constructed and resulted in many complaints about increased traffic noise. A study by Grant Anderson in 1984 (4) describes the noise problems in Austin and theories of what would happen in San Antonio with the combined elevated and depressed roadways. He found that noise amplification caused by the combination in Austin was between zero and twelve decibels, primarily due the use of precast concrete deck supported on steel "I" girders. This level of increase is significant. For example, if a noise were increased by 10 dBA, its apparent loudness would double. The girders allowed the noise from the depressed roadway traffic to reflect and scatter, adding to the normal traffic noise.

By comparison, the San Antonio elevated structure used a Composite Wing Girder design consisting of broad expanses of flat concrete, devoid of any exposed beams. This surface produces a specular reflection where the angle of reflection equals the angle of incidence. This reflection is theorized to stay on or near the right-of-way and not scatter as shown in Figure 13. Mr. Anderson concluded that the amplification of traffic noise due to the addition of elevated roadways in San Antonio would be between zero and three decibels off the right-of-way, which is insignificant since the average ear cannot usually detect a change in sound intensity less than three decibels.

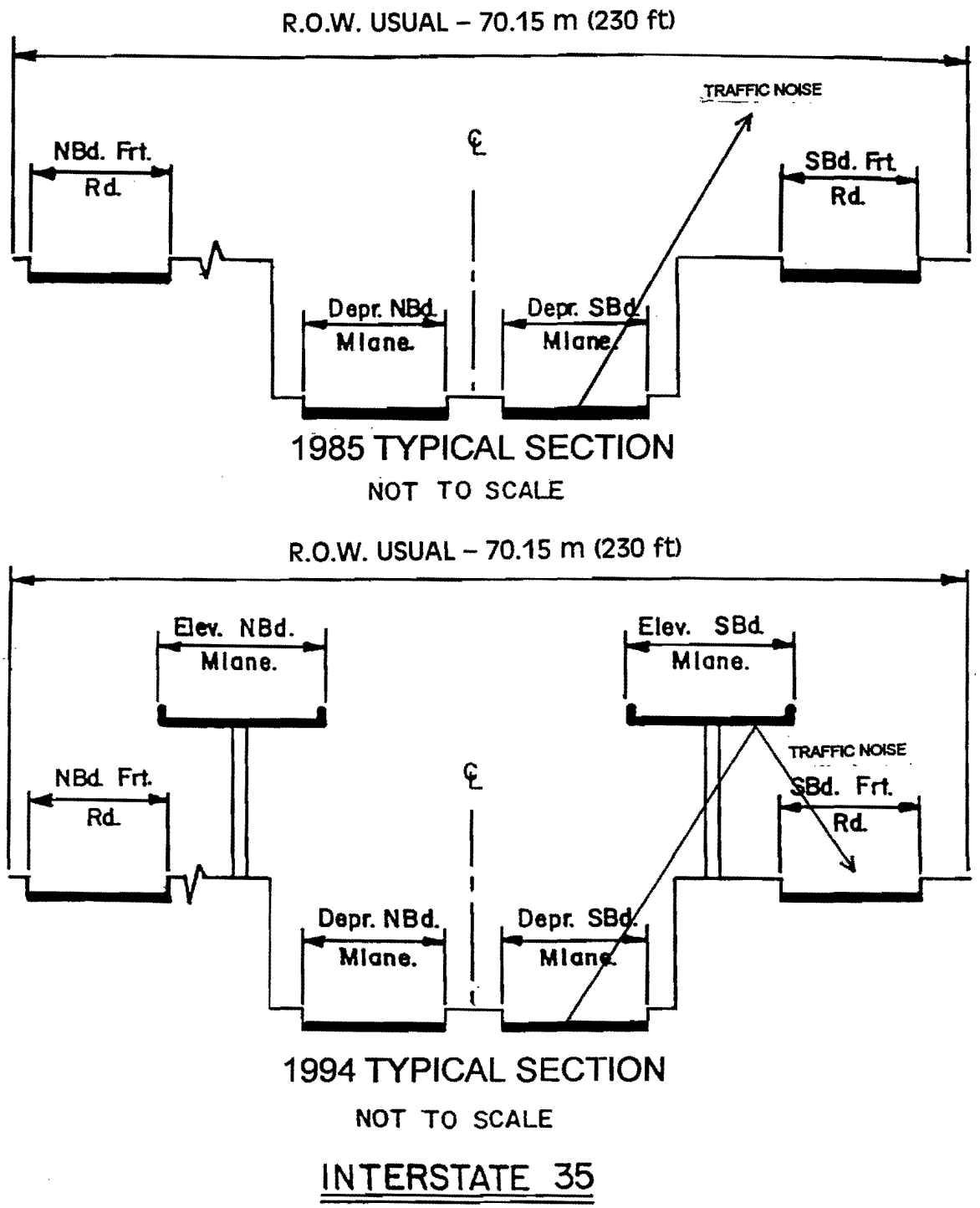


Figure 13. Before and After Construction of Roadway Improvements.

Prior to improvements in the "Y," extensive noise analyses were performed by TxDOT in 1985 and 1986. Their analysis involved field measurements, modeling of existing and design year levels. As part of this current TTI study, field measurements were conducted in 1994 after improvements were completed. The same techniques were used with other sites in this report. Sound measurements were made using the Leq10 dBA method. The receptors were located 24.40 m (80 ft) from the R.O.W. Results of the before and after measurements are shown in Table 4. This particular table contains only study sections 2, 3, and 4 which are combined elevated and depressed sections. Table 5 shows the comparison of the remaining sections of the "Y" that were primarily elevated, depressed or at-grade.

Since these readings were obtained at one point in time, they can only reflect the conditions at that moment. Day to day and hour to hour traffic volumes and speeds will introduce some uncertainty into the data. Despite this, the trend from location to location does show consistent patterns that are discussed in the Observation section of these study sites. This study was made six years before the design year 2000. Considering that, the predicted levels for the year 2000 may be quite close since the measured values were three to four dBA lower and will probably increase that much in the next six years due to increased traffic flow.

Observations at San Antonio "Y," Combined Depressed/Elevated Sections

- The conclusions of the 1984 study by Grant Anderson (4) concerning the possible amplification of traffic noise by combined depressed/elevated sections in San Antonio were proven correct. He stated that there should be insignificant amplification of noise, off the R.O.W., by adding elevated roadways above existing roadways using Composite Wing Girder design.
- Measurements during this study showed noise levels less than or equal to the 1985 measurements in approximately the same locations before improvement.

Table 4. Combined Depressed and Elevated Sections of San Antonio I.H. 10 and I.H. 35 "Y."

LOCATION	LANES & GRADE	1994 L_{eq}	1985 L_{eq}*	2000 L_{eq}**	LAND USE	94' TRAFFIC SPEED	94' AVERAGE HR. TRAFFIC	Noise Abatement
I.H. 10 @ HUISACHE	6 ELEVATED 4 DEPRESSED 6 F.R. GRADE	67.0 dBA	72.0 dBA	73.0 dBA	Residential Cat. B	89 km/h (55 mph)	6792	>67 dBA marginal
I.H. 10 @ COLORADO	6 ELEVATED 4 DEPRESSED 4 F.R. GRADE	69.8 dBA	72.0 dBA	73.0 dBA	Commercial Cat. C	89 km/h (55 mph)	7212	>72 dBA below
I.H. 35 @ McCULLOUGH	6 ELEVATED 6 DEPRESSED 6 F.R. GRADE	71.3 dBA	72.0 dBA	75 dBA	Commercial Cat. C	89 km/h (55 mph)	6075	>72 dBA below
I.H. 35 @ RICHMOND	6 ELEVATED 4 DEPRESSED 5 F.R. GRADE	68.6 dBA	78.0 dBA	77 dBA	Commercial Cat. C	89 km/h (55 mph)	6375	>72 dBA below

* Originally measured in L_{10} dBA. Corrected to L_{eq}

** Computed in 1985

Table 5. Depressed, Elevated, and At-Grade Sections of San Antonio I.H. 10 and I.H. 35 "Y."

LOCATION	LANES & GRADE	1994 L_{eq}	1985 L_{eq}*	2000 L_{eq}**	LAND USE	94' TRAFFIC SPEED	94' AVERAGE HR. TRAFFIC	Noise Abatement
I.H. 35/10 @ KEMP	10 DEPRESSED 6 F.R. GRADE	65.9 dBA	74.0 dBA	65.0 dBA	Residential Cat. B	89 km/h (55 mph)	9096	>67 dBA below
I.H. 35/10 @ NUEVA	8 ELEVATED 3 F.R. GRADE	65.3 dBA	73. dBA	66.0 dBA	Commercial Cat. C	89 km/h (55 mph)	4010	>72 dBA below
I.H. 35 @ NORTH PINE	8 DEPRESSED 4 F.R. GRADE	63.5 dBA	---	---	Residential Cat. B	89 km/h (55 mph)	6996	>67 dBA below
I.H. 35 @ N. PALMETTO	8 AT-GRADE 4 F.R. GRADE	67.6 dBA	---	---	Residential Cat. B	89 km/h (55 mph)	7482	>67 dBA above
I.H. 35 @ HORMEL	6 AT-GRADE 5 F.R. GRADE	68.5 dBA	---	---	Residential Cat. B	89 km/h (55 mph)	10302	>67 dBA above

* Originally measured in L_{10} dBA. Corrected to L_{eq}

** Computed in 1985

- Measurements during this study showed noise levels 3 to 6 dBA less than the predicted design year 2000 levels.
- In the locations measured, noise levels were below the Noise Abatement Criteria.

Observations at San Antonio "Y," Elevated, Depressed, and At-Grade

- Measured noise levels made during this study were less than the 1985 measurements by about an 8 dBA average.
- Measurements during this study were nearly equal to the 1985 computed design year 2000 predictions, within 1 dBA.
- The lowest readings were obtained from depressed sections. The next best readings were obtained from elevated sections, followed by readings from at-grade sections. All sections were within 3 dBA, which could be considered an undetectable difference. This small difference could be partly due to traffic on the frontage roads that were all at-grade.
- In the locations measured, noise levels were below the Noise Abatement Criteria except some at-grade conditions.

SAN ANTONIO - U.S. 281

The noise study site in San Antonio was U.S. 281 from Bitters Road to 4.0 km (2.5 mi) north of loop 1604 on the north side of the city. This new section is composed of the three grade levels in the study, namely "at-grade," "elevated," and "depressed." These sections are shown in Figures 14, 15, and 16.

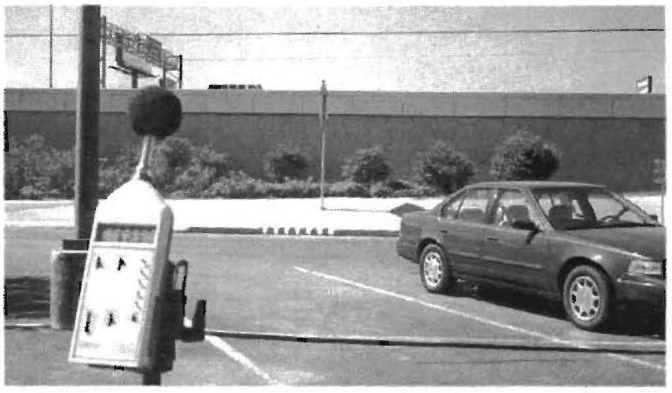


Figure 14. U.S. Hwy 281 in San Antonio, Elevated Section.

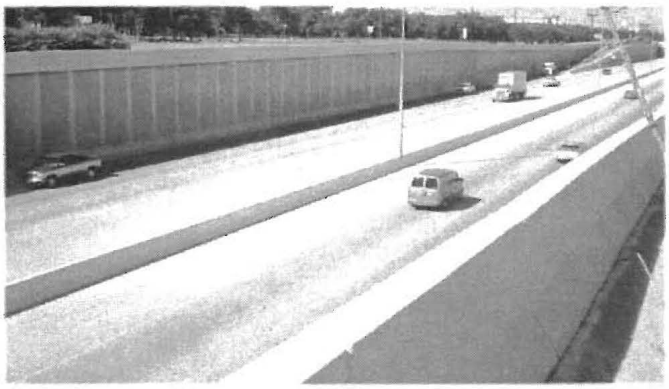


Figure 15. Depressed Section of U.S. 281 in San Antonio.

Prior to the improvements, an Environmental Assessment was conducted by TxDOT in 1984. The highest average annual daily traffic (AADT) in that section was determined to be 42,000 vehicles per day (vpd) between Sandau and Bitters. The assessment projected the same area to have an AADT of 108,000 in the year 2000. In 1987, TxDOT submitted a noise analysis for the above described project. The study indicated that "recommended levels are currently exceeded and will also be exceeded in the design year." In this study, three business establishments and one church adjacent to the right-of-way were selected for analysis. These same locations were found during this study, and two were measured.

The first site measured was the church, just north of Bitters on the west side of U.S. 281. The TxDOT measurement in 1987 was made at 59 m (195 ft) west of the center line, which is the closest point of the church to the right-of-way, a distance of about 13.7 m (45 ft). The 1995 TTI measurement was made at the same location. Before and after construction, the roadway at this location was at grade level. The second location was near a commercial shopping area near Winding Way on the west side of U.S. 281. The original measurement was made at 47.8 m (157 ft) east of the center line. At that time, U.S. 281 was at grade level at Winding Way. The same receptor location is now about 2.1 m (7 ft) off the right-of-way, and U.S. 281 is now depressed as it passes under Winding Way, while the frontage road is at grade level. The

Figure 16. At-Grade Section of U.S. 281 in San Antonio.

measurement location is in the parking lot of a doughnut shop whose employees commented that the traffic noise is less after the improvement except for the frontage road traffic. The recent measurements taken at that location also show that noise levels have improved.

The results of the 1987 measurements (before improvement), our 1995 measurements, (after improvement) and the projected year 2000 model, are shown as follows:

LOCATION	1987 Measured Before*	1995 Measured After	2000 Predicted*
Church	72 dBA L_{eq}	70.5 dBA L_{eq}	73 dBA L_{eq}
Comm. #1	71 dBA L_{eq}	67.1 dBA L_{eq}	72 dBA L_{eq}
Comm. #2	76 dBA L_{eq}	68.1 dBA L_{eq}	74 dBA L_{eq}

* 1987 Measurements were made using L_{10} and were converted to L_{eq} for this comparison.

These data are shown graphically in Figure 17. The traffic volume in 1987 was reported to be 56,000 vehicles per day, while the design year predictions used 103,000 vehicles per day. During this study, traffic volume was measured at 5,900 vehicles per hour.

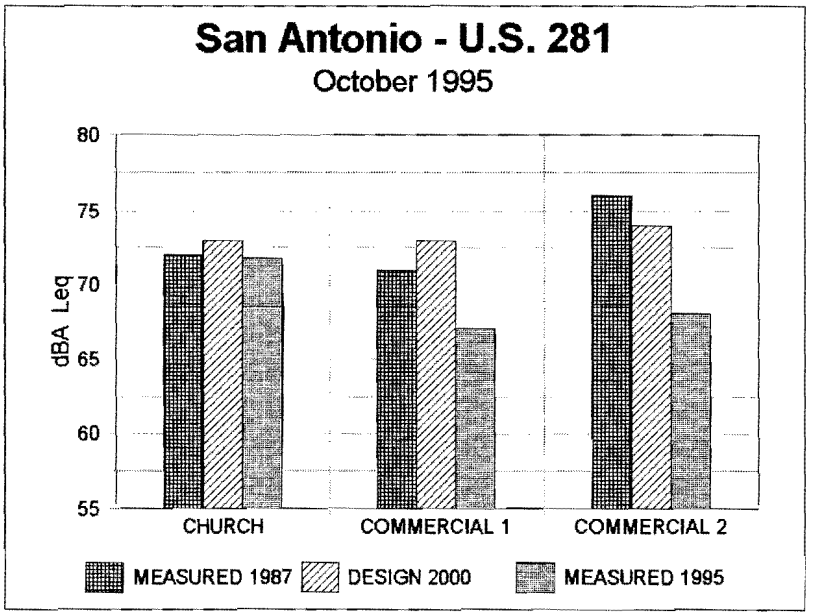


Figure 17. Measured and Predicted dBA Leq Values for the Three Locations.

Observations

- The 1995 measured noise levels, after construction, are less (better) than the 1987 measured values, before improvement and less than the design year predicted values. The at-grade conditions of this could be due to the solid 813 mm (32-in) concrete median barrier that shields the tire noise from the far lanes. Another theory is that standards for automobile noise emission have produced quieter passenger vehicles between 1987 and 1995.
- The three church values, which were all at-grade, show a small difference of less than 3 dB, which is undetectable by the human ear. This shows the highway improvement caused little change in noise at this location, as predicted.
- The large difference in the commercial #2 values are due to U.S. 281 being depressed at that location. This may not have been considered or accurately modeled in the 1987 design year prediction. By depressing the highway at this location, traffic noise was reduced by about 8 dBA even though the business in question was at the edge of the right-of-way. Another reason for the low noise level is the treatment of the far wall of the depression. It has corrugated texture which, though visible from the receptor, scatters rather than reflects noise in the depression (Fig. 15).

Lateral Distance from Elevated, Depressed, and At Grade Sections

The preceding study investigated the noise differences in before and after conditions. The next investigation looks at differences in distance from the roadway at the three grade levels. This was accomplished by locating the three conditions on U.S. 281 and measuring traffic noise at 15.2 m (50 ft), 45.7 m (150 ft), and 76.2 m (250 ft) from the right-of-way.

The results of these tests are shown below and in Figure 18, which includes the Noise Abatement Criteria levels.

Distance from ROW	Distance from C.L.	At-Grade dBA, L_{eq}	Elevated dBA, L_{eq}	Depressed dBA, L_{eq}
15.2 m (50 ft)	61 m (200 ft)	70.8	65.4	63.1
45.7 m (150 ft)	91.5 m (300 ft)	66.6	63.7	59.4
76.2 m (250 ft)	122 m (400 ft)	63.0	62.6	54.5

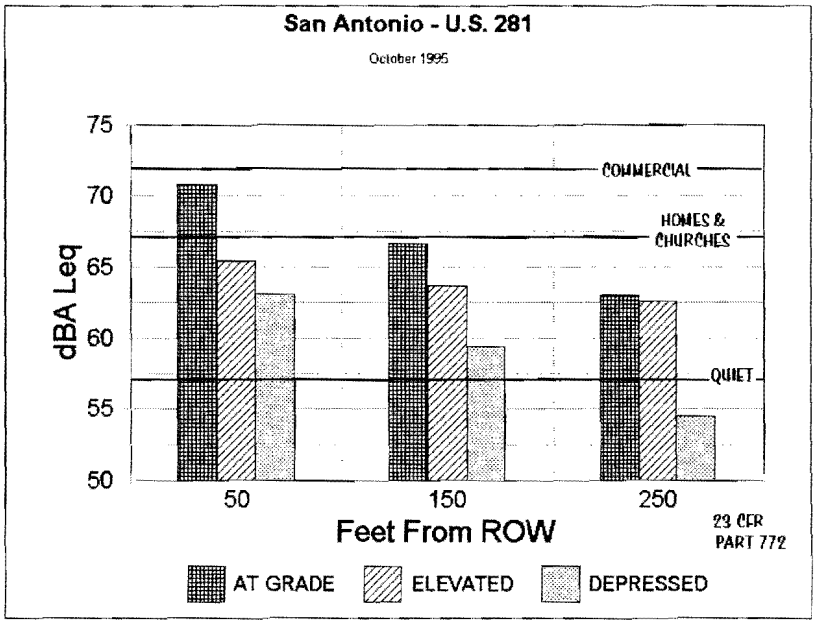


Figure 18. Increasing Lateral Distance from the Three Grade Levels.

Observations

- All noise values are within the 23 CFR, Part 772 recommendations for commercial land use.
- All noise values except "at-grade 15.2 m (50 ft)" are within recommendations for residences and churches.
- Depressed and elevated main lanes produce lower noise levels than those at-grade.
- Depressed main lanes produce the lowest noise levels.
- The reduction in noise as distance from the roadway increases follows the normal logarithmic function, in the at-grade condition.

- The elevated section produces less noise than the at-grade section up to 122 m (400 ft) from the right-of-way. Past that point, they are about the same. This is due to the shielding effect of the solid concrete barriers on either side of the elevated roadway.
- The new 813 mm (32 in), concrete median barriers appear to have a significant benefit in reducing vehicle tire and exhaust noise, which are the primary source of automobile noise.

Stamina Noise Prediction Model

To evaluate the STAMINA 2.0 FHWA traffic noise prediction model in this area, one site was chosen and modeled in the computer. The site was the church that was an at-grade condition. The roadway geometries were entered into the program as well as the 813 mm (32 in) concrete median barrier on the center line. The two receptor or sound meter locations were modeled in the same locations used for the actual measurements. Traffic volume counts during the measurements were also used in the model. The following results were produced:

Distance from center line	Measured L_{eq}	STAMINA Predicted L_{eq}
59.5 m (195 ft)	70.5 dBA	70.5 dBA
106.7 m (350 ft)	62.7 dBA	64.8 dBA

As can be seen, the near location was measured at the same value as the computer prediction. The further location was different by about 2 dBA. The reason for the distant measurement being lower than the predicted model could be that the church building was shielding some sound from the north part of the roadway, which was not accounted for in the model. Also, the far receptor was slightly downhill, which was modeled, but may need refining. Overall, the STAMINA model did an excellent job of predicting the traffic noise at this location. Other comparisons between actual measured noise levels and STAMINA 2.0 results are shown in the study section results.

DALLAS U.S. 75 (NORTH CENTRAL EXPRESSWAY)

This traffic noise study section involves the reconstruction of U.S. 75 (North Central Expressway) between Spur 366 (Woodall Rodgers Freeway) and I.H. 635 (Lyndon B. Johnson Freeway) in Dallas County, Texas. The Project Corridor is approximately 14.8 km (9.2 miles) long. This corridor is made up of a large mix of land use areas located close to the right-of-way (ROW). These land use areas include retail and commercial buildings, offices, industrial sites, residential areas, parks, and churches.

This section was selected for this study because it provided an excellent "before" and "after" situation that used several grade level conditions. The study section was visited twice, once at the beginning of construction in March 1994 and again in August 1996. Unfortunately, the reconstruction project was not totally complete at the end of this study, but valuable information was gathered on the portions that were completed. After the completion of construction, any subsequent follow-up can gather the remaining data. Used in conjunction with the site visits was the Final Environmental Impact Statement produced by TxDOT in July 1986. This very detailed and extensive study did a thorough examination of the Expressway Corridor for noise-sensitive land uses; a group of 30 individual sites was selected for noise measurements. Nineteen additional sites were monitored in November 1985 for specific inclusion in the report. Eleven of these sites were selected for this study.

The results of the TTI, 1994 measurements compared favorably with the TxDOT study in 1985 in the areas not yet improved, in the south end of the project. These values are shown below.

Location	Edge of Pavement	Grade	TxDOT dBA L_{eq}	TTI dBA L_{eq}
Retirement Home	21.3 m (70 ft)	At-grade	70	68.5
Park	114.4 m (375 ft)	Depressed	65	63.8
Church	41.2 m (135 ft)	At-grade	64	63.5
Cemetery	38.1 m (125 ft)	Elevated	70	69.8

In areas of completion in the north end of the project, the sound levels showed a definite improvement between the 1985 TxDOT readings and the 1994 TTI readings at the same locations. These are illustrated below.

Location	Edge of Pavement	Grade	TxDOT dBA L_{eq}	TTI dBA L_{eq}
Motel	36.6 m (120 ft)	At-grade	69.0	64.9
Town homes	24.4 m (80 ft)	Slight Ele.	74.0	65.8
Recreation Area	244 m (800 ft)	At-grade	63.0	57.5

The construction of concrete barriers and sound walls resulted in lessening of traffic noise. At the motel and town homes, a 1.2 m (4 ft) wall provides shielding between the main lane vehicles and the noise-sensitive areas as shown in Figure 19.

Figure 19. Concrete Noise Barriers and Slightly Depressed Main Lanes.

Also, 813-mm (32-in) concrete median barriers are located on the main lane center lines, providing additional shielding at the tire level of the far main lane traffic. As with many sites evaluated in this study, a great amount of effort has been devoted to the main lanes, but the frontage roads usually remain at-grade, near to the edge of the right-of-way, and close to

noise sensitive areas as shown in Figure 19. If the traffic is light on these roads, there is no problem. It is when the frontage or access roads contain a high volume of medium to high speed traffic that the treatment of the main lanes is defeated by the noise generated on these roadways. To illustrate, one study site was 45.7 m (150 ft) from the edge of the frontage road. Part of the new construction was the addition of a 1.2 m (4 ft) aesthetically pleasing sound wall as shown in Figure 20.

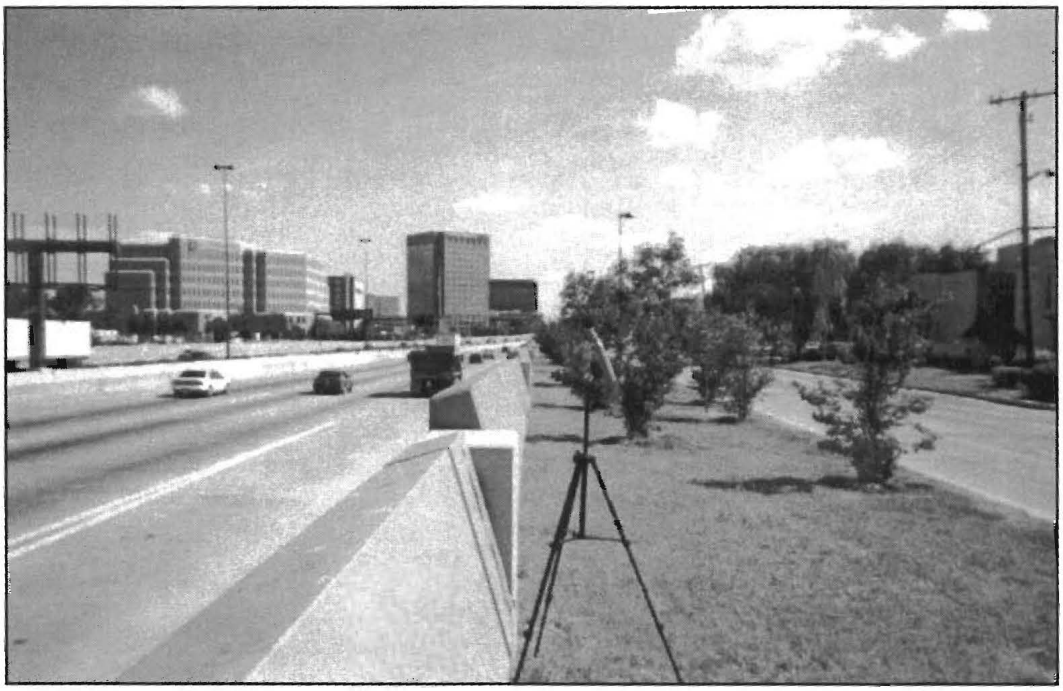


Figure 20. North Central Expressway in Dallas, Sound Barrier at Main Lanes Only.

Sound measurements made with only main lane traffic at the apartment complex produced only 69 dBA L_{eq} noise levels, while measurements during main lane and frontage traffic produced 80 dBA L_{eq} for the short time the traffic was present.

North of Lover's Lane on the west side of Central Expressway was another study location for both TxDOT and TTI. In both the original TxDOT study and the 1994 TTI study, this location near a church was at grade level. Upon our return in 1996, the roadway had been depressed below grade and a 4.3 m (14-ft) tall, aesthetically pleasing, sound wall built. The traffic and residence sides of the wall are shown in Figures 21 and 22, respectively. Sound

Figure 21. Traffic Side of Sound Wall, U.S. 75 in Dallas (68 dBA).

level measurements were made in the same location as the previous TxDOT and TTI studies, which placed the microphone behind the sound wall. The measured L_{eq} value was 56.3 dBA at a distance of 45.8 m (150 ft) from the main lanes. The sound wall ended just north of this site, and another reading was obtained 45.8 m (150 ft) from the main lanes with no sound wall. The result was a level of 68 dBA L_{eq}. This impressive difference is a 11.7 dBA insertion loss. The insertion loss is the amount of acoustical energy loss encountered when sound rays are required to travel over and around a wall by diffraction. This large reduction in the traffic noise level is due primarily to the sound wall and to some extent on the depressed roadway.

Figure 22. Residence Side of Same Sound Wall (56 dBA).

Though sound walls are not part of this study, they should be considered in the at-grade and elevated situations where the FHWA Noise Abatement Criteria (NAC) cannot be met.

LUBBOCK - U.S. 82

The proposed East-West (U.S. 82) freeway in Lubbock was chosen as a study section for part of this project. This freeway will undergo substantial improvements in the next few years. The study section runs from Southwest Loop 289 to 19th Street. Sound level data were taken along this corridor in anticipation of returning after the construction project. The proposed improvements include depressed sections that would provide excellent research sites for this project. Since this research project concluded before the completion of the East-West freeway, subsequent projects will need to complete the work.

It is possible, though, to compare the noise level readings obtained in this project with the environmental impact study completed by TxDOT in 1990. The same locations as those modeled in the TxDOT study were located and measured. The environmental study modeled the 1990 current year, 2010 No Build, and 2010 Build conditions by computer using Stamina 2.0, the Federal Highway Administration's (FHWA) program for calculating highway traffic noise. Traffic volumes used in the analysis represented slightly higher than typical rush hour traffic to create a worst case scenario, which may slightly over-predict noise levels. All of the sites selected were Activity Category 'B' and 'C' of the FHWA, Noise Abatement Criteria (NAC). These categories limit the traffic noise level to 67 dBA L_{eq} in areas such as residences, churches, schools, and motels and 72 dBA L_{eq} in commercial areas.

The following are some of the values computed by TxDOT and measured by TTI:

Location	Existing Computed 1990 L_{eq}	No Build Measured 1996 L_{eq}	No Build Computed 2010 L_{eq}	Build Computed 2010 L_{eq}
Apartments 1	63.5 dBA	64.4 dBA	65.3 dBA	72.8 dBA
Apartments 2	63.9 dBA	64.0 dBA	65.7 dBA	71.0 dBA
Livestock Arena	61.3 dBA	60.0 dBA	------	68.2 dBA
Apartments 3	51.1 dBA	59.0 dBA	------	63.5 dBA

As can be seen, the levels measured recently agree well with the TxDOT computed levels for 1990. As stated in the TxDOT study, "the 2010 No Build noise levels would be approximately 1.8 Decibels higher than the 1990 levels." This is due solely to increased traffic volume.

Observations

- The TxDOT Environmental Noise Study appears comprehensive with 76 locations modeled.
- Locations sampled during this study closely match the modeled 'No Build' between 1990 and 2010 with a few ambiguous readings.
- Noise levels will generally decrease on both sides of depressed main lanes.
- Future measurements will determine if the Stamina 2.0 program accurately models depressed sections of roadway.
- The TxDOT study states, "Roads that are built at ground level are noisier than depressed or elevated roadways." This agrees with the findings of this study.

LUBBOCK - I.H. 27

Study Sections 8 and 9 in Lubbock were chosen because of recent rebuilding of Interstate Highway 27, through the center of the city, that was completed in 1992. This North-South corridor is 9.66 km (6 mi) long, from Loop 289 North to Loop 289 South. Prior to construction, the corridor was entirely at-grade level. Upon completion, I.H. 27 between Loop 289 North and 36th St. is primarily elevated and between 36th St. and Loop 289 South is primarily depressed below grade. All frontage roads remained at grade level.

In November 1978, TxDOT completed an "Environmental Impact Statement" for the proposed project. The study was revised in March 1981. The "Sound Evaluation Study" portion of the Impact Statement was used in this project as a "before" condition of the traffic noise at that time. It also contained model data to predict what the traffic noise impact

would be in the year 2007. In 1994, as part of this study, TTI researchers measured sound levels along the newly completed I.H. 27, at elevated, depressed, and grade levels. These included some of the same locations measured and modeled in the 1978 study.

Land use along the corridor was described in 1978 as "primarily commercial, with clusters of low density housing and scattered industrial." The predicted land use was shown to remain about the same with commercial gains and industrial development. The majority of the corridor was then considered Activity Category 'C' (commercial/industrial) with some locations classified as Category 'B' (residential, schools, and churches) according to 23 CFR, Part 772.

Noise level values measured in 1978 were in L_{10} dBA units. Current traffic noise is measured in L_{eq} dBA units. The 1978 values have been corrected to modern units by applying the standard correction of subtracting 3 dB from the L_{10} values to arrive at L_{eq} values. These corrected levels are used in all subsequent discussion of the initial study results to compare with the 1994 readings. Traffic noise level readings in the 1978 study were taken at the edge of the right-of-way. This is a little unusual since this location is quite near any traffic on the frontage road that will dominate the readings. During the 1994 measurements, TTI personnel measured sound near the edge of the right-of-way and again 15.25 m (50 ft) further from the roadway. For comparison purposes, the following discussion will use only TTI's near readings, but it should be understood that they will be higher than typical.

Table 6 summarizes the findings of the 1978 preconstruction and 1994 post construction traffic noise levels as well as the predicted 2007 levels. The table contains four sections. The first six lines describe the results of the TTI study in 1994. Sound levels, average speed, and total traffic counts were made in ten minute periods. Traffic counts were multiplied by six to arrive at an approximate hourly volume. Results of the 1978 TxDOT study are shown on the next three lines. Below that are comparisons between the before and

Table 6. Summary of 1978 vs. 1994 Traffic Noise Level Findings for I.H. 27 in Lubbock.

1994 Study Loc. #	8	9	18	15	13	14	10	11	12
Grade Level	At-grade	At-grade	Elevated	Elevated	Elevated	Elevated	Depressed	Depressed	Depressed
Land Use	Residential	Comm.	Residential	Comm.	Comm.	Comm.	Comm.	Residential	Residential
1994 Measured	69 dBA	67 dBA	61 dBA	70 dBA	68 dBA	69 dBA	66 dBA	67 dBA	59 dBA
Vehicles Per Hour	1560	1344	1386	1280	2460	2148	2784	2922	3456
Speed km/h (mph)	88 (55)	88 (55)	97 (60)	88 (55)	80 (50)	93 (58)	77 (48)	72 (45)	88 (55)
1978 Study Loc. #	---	---	10C	7A	6A	4A	3A	1C	---
1978 Measured	---	---	73 dBA	68 dBA	77 dBA	70 dBA	72 dBA	61 dBA	---
2007 Predicted Leq	---	---	71 dBA	74 dBA	76 dBA	74 dBA	74 dBA	74 dBA	---
1994 vs. 1978 meas.	---	---	-12 dBA	+2 dBA	-11 dBA	-1 dBA	-6 dBA	+6 dBA	---
1994 vs. 2007 pred.	---	---	-10 dBA	-4 dBA	-8 dBA	-5 dBA	-8 dBA	-7 dBA	---
Noise Abatement	67 dBA	72 dBA	67 dBA	72 dBA	72 dBA	72 dBA	72 dBA	67 dBA	67 dBA
1978 levels	---	---	Above	Below	Above	Below	Below	Below	---
1994 levels	Above	Below	Below	Below	Below	Below	Below	Below	Below
2007 predicted levels	---	---	Above	Above	Above	Above	Above	Above	---

after improvement with the 1978 study values subtracted from the 1994 values at the same locations. A negative value indicates that the traffic noise is less in 1994 than it was in 1978. The same was done for the predicted values of the year 2007 modeled in 1978. It is not clear if the engineers modeled the roadway as elevated and depressed in those locations.

The final four lines of the table relate to the federal Noise Abatement Criteria levels for the land use types and if the measurements were above or below the suggested levels. The 1978 levels were measured by TxDOT. Year 2007 levels were modeled by TxDOT in 1978 using the STAMINA program. Year 1994 levels were measured by TTI personnel.

Observations

- 1994 traffic noise levels along this corridor did not increase over the 1978 levels and, in fact, were reduced by an average of 3.3 dBA.
- The model data developed in the 1978 study appears to overestimate the future noise levels by about 7 dBA. In other words, the model thought there would be more noise than there actually is. This could be due to overestimating the traffic volume or not considering the elevated and depressed main lanes.
- All 1994 study locations along this corridor were below the federal Noise Abatement Criteria except one that was at-grade level. The 1978 study predicted the majority to be above the recommended limits.
- Traffic noise level measurements should not be taken on the right-of-way line. This location is not typical of living and working conditions. It is also quite close to traffic on the frontage road that would outweigh traffic noise from the main lanes and cloud the results.
- Average depressed sections were 4 dBA quieter than the at-grade control sections, and average elevated sections were 1.7 dBA quieter than the at-grade control sections.

HOUSTON

The project study site in Houston was the W. Sam Houston Tollway. This roadway provided elevated, depressed, and at-grade sections of eight main lanes and three frontage lanes on the east and west sides. Measurements were made during the day, during non-rush hour traffic times. The total vehicle per hour count ran between 4800 and 6000 at a nominal speed of 88 km/h (55 mph).

The same problem was encountered at these sites as in other cities with the difficulty of separating traffic noise of the main lanes and the frontage roads. Obtaining a pure elevated or depressed condition was not possible because the three lane frontage roads were all at-grade level. The frontage roads then would produce the majority of the noise since they were at-grade and closer to the receptors than the main lanes. The problem is not only one of acquiring research measurements but one that annoys those living and working near the right-of-way by high noise levels from the frontage roads. This should be considered in future designs.

Measurements at this study section were taken at two distances from the nearest road edge. At each location, these were nominally 15.3 m (50 ft) and 45.8 m (150 ft). At the 15.3 m (50 ft) location, all the traffic in a depressed section was visible, and all line of sight noise was recorded. This is obviously a worse case situation as indicated by the reading at Harwin Rd. of 76.7 dBA L_{eq}, one of the highest in this study. The benefit of depressed sections is obvious at this location by the much lower reading 30.5 m (100 ft) away of 66.7 dBA, a 10 dBA reduction. This large reduction in traffic noise can be attributed to the greater than normal depth of the depression and sloped concrete side walls. This slope allows the noise to be reflected upwards instead of back to the people on the opposite side of the roadway. This point will be discussed further in the Recommendations section of this report.

Below are the results of the 15.3 m (50 ft) and 45.8 m (150 ft) readings at the three grade levels:

Elevated:	15.3 m (50 ft)	45.8 m (150 ft)	Difference
	71.9 dBA	66.1 dBA	-5.8 dBA
	69.8 dBA	67.7 dBA	-2.1 dBA
	69.4 dBA	63 dBA	-6.4 dBA
		Average	-4.77 dBA

Depressed:	15.3 m (50 ft)	45.8 m (150 ft)	Difference
	76.7 dBA	66.7 dBA	-10 dBA
	68.0 dBA	61.4 dBA	-6.6 dBA
		Average	-8.3 dBA

At-Grade:	15.3 m (50 ft)	45.8 m (150 ft)	Difference
	69.7 dBA	64.0 dBA	-5.7 dBA
	70.8 dBA	67.0 dBA	-3.8 dBA
		Average	-4.8 dBA

Though there exists a considerable scatter in the data because of the complexity of each site, the trends are evident, especially in the depressed sections, which show a much more rapid reduction in noise as distance from the roadway is increased. The elevated sections show traffic noise levels comparable to the at-grade conditions, but based on other study sites, values should be lower. The explanation for this could be the amount of traffic flowing under the elevated sections. The noise from this traffic is not only recorded directly, but what is reflected from the bottom of the elevated section is added in for an apparent amplification.

HUMAN RESPONSE TO TRAFFIC NOISE

Research has shown that there is enormous individual variability in human reactions to traffic noise. The large amount of variance in annoyance which is unexplained by the various acoustical factors has led to a number of hypotheses about personal and other attitudinal factors which might be associated with noise annoyance responses. The six most consistently reported are *fearfulness*, *preventability*, *noise sensitivity*, *perceived neighborhood quality*, *health effects*, and *non-noise impacts of the source* (1).

- Annoyance is generally higher for people who are *fearful* that some danger to themselves or other people in the local area may be associated with the transportation activities which they can hear (9).
- A second attitude which is related to annoyance is the belief that there are *reasonable actions* which it would be feasible for authorities to take to reduce the noise levels (10).
- The reported *sensitivity* to other noises or to noise in general is associated with increased annoyance with a particular noise source (11). These measures of sensitivity to noise, in general, have never been found to be related to environmental noise levels.
- The fourth attitude is *neighborhood evaluation* which seems to be related more to the evaluations of the neighborhood environment and of the neighbors than to evaluations of the quality of the public services (11).
- Few people who believe that their *health* is affected by noise from the particular source are also likely to be annoyed by the source.
- The last finding is that people's rating of other aspects of the *noise source's intrusion* in the area (dirt, dust, lights, loss of privacy) are related to their evaluations of the noise in the area.

To illustrate the complexity in relating traffic noise to a level of annoyance, Figure 23 shows a study (9) of individual responses to noise (1150 interviews) comparing noise in dB(A) to a level of annoyance. The plot shows that even at high levels of noise (73 dB), some respondents reported a very low level of annoyance (1-2). The converse is true of others who were very annoyed (level 4) by low noise levels (50 dB).

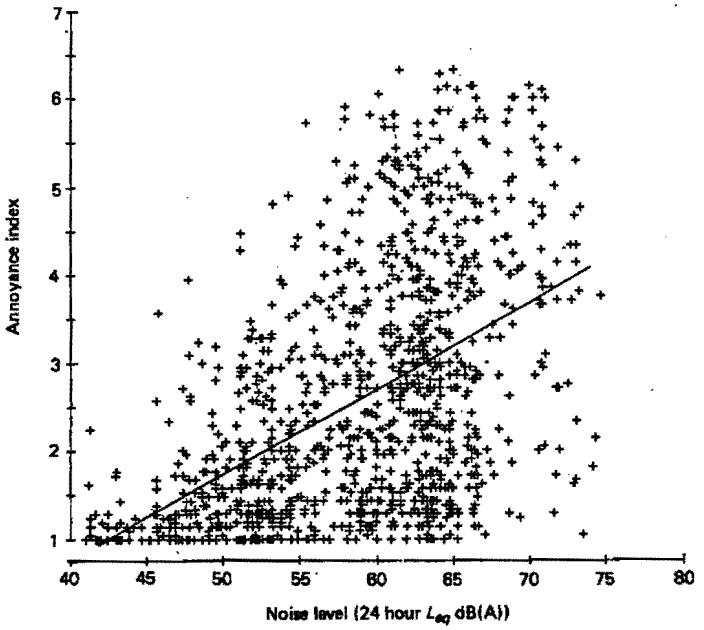


Figure 23. Individual Responses to Noise.

Though this plot is very scattered because of human nature, a trend line is shown by the author that indicates an increase in annoyance with increased levels of dB, which should be the case.

Another study that relates annoyance with traffic noise (12) was done in Toronto. The results, reproduced in Figure 24, show how the percentage of people highly annoyed by road traffic and aircraft varies with the noise level expressed in dBA(A) L_{DN}. This Day/Night rating is a standard L_{eq} sound measurement averaged over 24 hours; however, the noise level during the nighttime period, 2200–0700 hours, is penalized by the addition of 10 dBA(A). In

other words, a 60 dBA traffic noise at night would become 70 dBA when figured in the day's average. As the chart indicates, aircraft noise at the same level as traffic noise annoys roughly twice the percentage of people. The reason for this perceived difference in the same amount of noise from two different sources is often contradictory as found in several studies (11, 13).

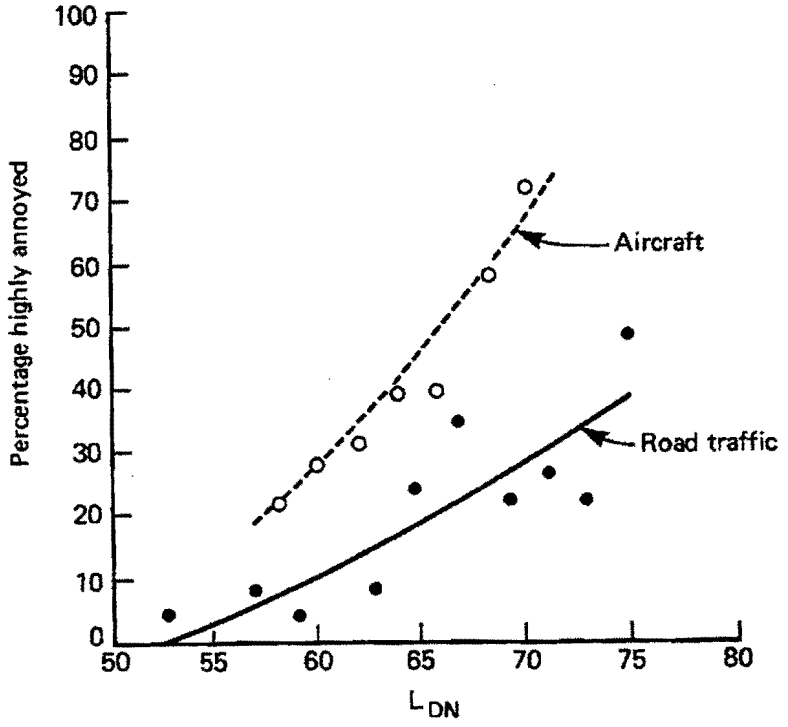


Figure 24. Percentage of People Highly Annoyed by Road Traffic and Aircraft Noise.

As indicated by the preceding data, the old saying "you cannot keep all the people happy all the time" certainly holds true for traffic or transportation noise. Each person who is exposed to traffic noise reacts in different ways. Some will tolerate a high level background noise, while others will be highly annoyed by traffic noise at low levels.

To provide planners a method of dealing with the human perception of highway noise, without needing to deal with the highly variable and subjective data presented above, the

Federal Highway Administration (FHWA) set forth the 23 Code of Federal Regulations Part 772 (23 CFR 772 in Appendix C). The noise level criteria associated with this regulation is shown below.

Table 7. 23 CFR 772 Noise Abatement Criteria

NOISE LEVEL CRITERIA		
ACTIVITY CATEGORY	Leq (h)* (dBA)	DESCRIPTION OF ACTIVITY CATEGORY
A	57 Exterior	Lands on which serenity and quiet are of extraordinary significance and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 Exterior	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 Exterior	Developed lands, properties, or activities not included in Categories A or B above.
D	----------	Undeveloped lands.
E	52 Interior	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

*"Leq" means the equivalent steady-state sound level which in a stated period of time contains the same acoustic energy as the time-varying sound level during the same period. For purposes of measuring or predicting noise levels, a receptor is assumed to be at ear height, located 1.53 m (5 ft) above ground surface.
"Leq(h)" means the hourly value of Leq.
Use of interior noise levels shall be limited to situations where exterior noise levels are not acceptable.

RECOMMENDED PROCEDURES FOR NOISE REDUCTION IN SENSITIVE AREAS

Studies have shown that noise pollution is one environmental attribute that affects the value of the property. As transportation noise levels increase, the value of the property decreases. The assumption is that home buyers and renters are willing to pay more for an identical house in a quiet neighborhood versus a noisy neighborhood with all other factors remaining constant. Work in this area done in the 1970s and reported by Apogee Research, Inc., estimated that background noise in a typical urban neighborhood was roughly 55 dBA L_{DN} and that housing prices decreased by 0.2 to 0.6 percent for every one dBA increase in L_{DN}. Also, a report by Hokanson assumed a 0.4 percent decrease in the value of housing units for each dBA L_{eq} increase over a threshold of 55 dBA (14).

To provide the least impact on property values adjacent to a proposed new freeway or freeway improvement, one area of consideration by the planners must be the possible increase in traffic noise. It has been found during this study that TxDOT is indeed planning for the reduction or abatement of traffic noise and providing good and innovative solutions in current construction. Below are listed points to consider during roadway planning to help produce the lowest noise impact on existing and future property values. These recommendations were obtained from observations during this study, which include: good TxDOT designs, publications, results from other states, and international studies. These are general recommendations that should be further tested with computer models or other means because of the very complex nature of traffic noise in real-world situations.

- If a choice of grade condition is available between at-grade (same as other ground level in the area), depressed (below surrounding ground), or elevated (above surrounding ground), the choice should be depressed. By placing the flowing traffic below ground level, a natural sound barrier is created between the traffic and people adjacent to the roadway. Studies have shown that as the depth of the cut increases,

between 3 m (9.8 ft.) and 9 m (30 ft.), the noise levels were not greatly affected because the improved screening provided by the increased depth of cut is offset by the increase in reflected noise from the opposite wall of the cut (1). With a depressed roadway of 3 m (9.8 ft) or more, traffic noise has been shown to decrease from 74 dBA, at the cut, to 63 dBA at 10 m (32.8 ft) from the edge of the cut. This noise level remains at about the same level out to 50 m (164 ft).

- Reflections from the walls of a depressed roadway should be considered and reduced if possible. This may be accomplished in several ways. The first is sloping the reflecting wall away from vertical. A slope of 15 degrees is usually sufficient to ensure a substantial reduction in reflected noise. The next is the addition of a sound absorbent lining to a vertical wall starting 1.5 m (5 ft) above the roadway and ending at the top of the cut. It was found that sound absorbent lining placed on the retaining walls generally resulted in an additional noise reduction of 3 dBA within 25 m (82 ft) from the edge of the cutting and up to 6 dBA at greater distances. The effect of the slope of the reflecting wall has almost the same effect on noise reduction as the sound absorbent linings of the walls. Another treatment was observed in San Antonio in a depressed section of U.S. 281 near Donella Drive. This location used a corrugated concrete finish that worked well for aesthetics and for scattering the noise so as to not reflect to the opposite side.

- The next best grade level condition observed is elevated. The reason for the elevated sections producing less noise than at-grade conditions was the fact that the sites measured used 915 mm (36 in) solid concrete guardrails on each side and in the median. Along with the solid bridge deck, an elevated trough for the traffic was provided. With many of the vehicles out of sight, a straight line path did not exist for the noise. With the majority of the noise from passenger vehicles coming from the tires and engine, the solid rail provided shielding for the majority of the noise producers. When the choice is available, solid guard barriers should be used instead of the post and rail type for noise control. The elevated sections of this type have been

shown to reduce noise up to 6 dBA near the roadway out to about 92 m (300 ft). After that, the noise levels are about the same as at-grade because the angle of diffraction is less.

- When noise is a major consideration, designs that place traffic under an elevated roadway that uses steel "I" girder construction should be avoided. The noise from the lower level of traffic is reflected from the underside of the elevated section back toward the ground, off the R.O.W. This noise adds to the direct line of sight noise to produce an amplification. This effect exists if the lower level is at-grade or depressed. The use of "Composite Wing Girder" construction reduces this effect significantly due to the smooth underside of the elevated section, confining the reflected noise to within the R.O.W.

- One way noise has been reduced in the at-grade condition is to locate the right-of-way further from the people affected. It is obvious that the further one gets from a noise the quieter it becomes. With traffic noise, this rule of thumb becomes a little more complicated. Traffic noise is not in a spot but rather a line which becomes a spot if the distance is great enough. In general, the noise from a spot source will be attenuated by approximately 6 dBA per doubling of distance from the source or $20log_{10}d$ decibels for 'd' distance. With a high traffic flow, the geometric spreading approaches that of a line source that attenuates only 3 dBA per doubling or $10log_{10}d$. With other reflections and diffractions, a typical value for increasing distance is a 3–4.5 dBA noise reduction each time distance doubles.

- As the concrete guardrails and median barriers on the elevated sections reduced the noise transmitted downward, the same types of rails would provide some improvement of traffic noise in an at-grade condition. The amount of screening provided varies according to the amount of sound energy diffracted over the top of the barrier, which can be easily modeled by the STAMINA 2.0 computer program. The standard post and

rail system provides almost no noise shielding since the tire/road interface waves are passed under the rail.

- Another excellent noise abatement device observed is the full-size noise wall. This rather expensive form of noise abatement provides from 5 to greater than 20 dBA reduction in traffic noise. The wall tested in Dallas during this study showed a reduction from 63.5 dBA to 56.3 dBA in exactly the same location before and after the installation of a 4.3 m (14 ft) noise wall. This level is near 55 dBA, used for neighborhood background levels with no nearby traffic, but within 46 m (150 ft) of the North Central Expressway in Dallas. Use of these walls is thoroughly covered in a TTI report by B. B. Story and S. H. Godfrey (15).

- In all grade level conditions, an improvement of 3 dBA can be realized by road surface texture treatment. Road surface texture effects the noise level generated by traffic because it partially controls the road/tire interaction noise. Generally, the noise generated by vehicles traveling on coarse textured surfaces can emit up to 3 dBA more noise than vehicles traveling on a smooth concrete or asphalt surface.

- Though main traffic lanes of a freeway are depressed, elevated, or shielded for noise reduction, the frontage roads are usually still at-grade, near the edge of the right-of-way, and near noise sensitive areas (NAC Category A and B). Depending on the volume and mix of traffic on these frontage roads, the efforts to quiet the main lanes may be negated. This was noted while taking sound level measurements for this study in the various cities. Measurements would be indicating a low level of noise from the main lanes until trucks or a string of cars passed on the frontage road. These types of occasional, loud, and close-by noises are not always apparent on a L_{eq} type of sound measurement. The L_{eq} method integrates sound over a long time period where the short, loud noises disappear from the reading and modeling. For this reason, the L_{eq} method is not favored by some groups. By their nature, frontage roads must be where they are but should be taken into consideration when evaluating future noise levels.

- Modeling, or predicting, what noise levels will be in the future on new or remodeled roadways is currently done with a computer program called STAMINA 2.0. This program has undergone minor input changes but has remained essentially the same over the years. Actual traffic noise measurements compare very well to those predicted, to within 1 or 2 dBA. Selected locations in this study were measured and modeled by STAMINA 2.0 with comparable results. This program will model depressed, elevated, and at-grade roadways, with and without solid guardrails, with good results. The depressed and elevated conditions require special considerations when entering the roadway geometric data. Those not completely understanding the procedure should refer to the *Noise Barrier Cost Reduction Procedure STAMINA 2.0/OPTIMA: Users Manual* (16) or contact the TxDOT Pollution Prevention and Abatement Section, Environmental Affairs Division. STAMINA 2.0 has been proven to provide very good results in predicting traffic noise if all data are entered correctly, and its use should be continued practice until an improved program is available.

- Proposed freeway noise could be presented to the public by using technology that demonstrates the audio level of the future noise compared to the audio level of current traffic noise. Instead of relating decibel numbers, actual audio of the present and future levels and traffic mix may be more understandable. In working with the public early in the design phases of a construction project, a team approach has been shown to work well to produce benefits for all.

CONCLUSIONS

With the implementation of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1992, transportation agencies are challenged to provide a quality highway system for the public. This quality not only relates to the persons traveling on the roadways but to the people living and working near these transportation corridors. Not only does the traffic noise produce a daily annoyance, but it has been proven to produce lower property values. By making prudent choices in the early design stages of a freeway construction project and by working with the residents as a team, workable compromises may be met that produce maximum transportation with minimum impact on the environment. It has been apparent throughout this project that the TxDOT planners have been following this course. Noise levels along North Central Expressway in Dallas were measured twice during this project—once near the beginning of construction and again recently. Although construction is not finished, improvements in noise levels were observed in many locations, including those at-grade, elevated, and depressed. As studies have shown, improvements increase the property values. A dramatic reduction in traffic noise along this corridor was measured at the location of a newly installed noise wall. The neighborhood level before the wall was 68 dBA and after the wall was installed was 56.3 dBA, which is near the 55 dBA level used for rural neighborhood background sound.

It became obvious early in the project that depressed roadways provided the superior grade level for the suppression of traffic noise. The walls of the depression provided a natural sound wall that substantially reduced traffic noise near and far from the freeway. A problem with depressed roadways is noise reflecting from vertical, flat walls toward the opposite side of the right-of-way at ground level. This can be and has been eliminated by sloping the walls at least 15 degrees or by the application of a sound absorbing or scattering surface to the walls.

The elevated roadways evaluated provided good noise reduction near the roadway. The shadow zone extends out to about 100 m (328 ft). After that distance, the noise level was similar to at-grade or ground level roads. This was only true if the elevated sections used solid concrete guardrails to provide shielding. This improvement was negated when the post and rail systems were used on the elevated roadways, allowing tire and engine noise to pass under the rail.

The at-grade condition with no guardrails or the post and rail type provided the highest amount of traffic noise for the same speed and volume as the other two cases. When solid concrete guardrails or median barriers were added, the tire and engine noise from passenger cars was significantly reduced. The heavy and medium trucks still presented a noise problem with the engine and exhaust stacks above the height of the barriers.

Modeling, or predicting, what noise levels will be in the future on new or remodeled roadways is currently done with a computer program called STAMINA 2.0. This program, developed for the Federal Highway Administration (FHWA), was released to the TxDOT District offices in 1990 for use on personal computers. The program operates by asking a series of data questions about traffic volumes, roadway geometries, receiver locations, and barrier information. This program has undergone minor input changes but has remained essentially the same over the years. The program has been thoroughly validated using actual traffic noise measurements and compares very well, within 1 or 2 dBA where 3 dBA is a detectable difference by ear. Selected locations in this study were measured and modeled by STAMINA with comparable results. This program will model depressed, elevated, and at-grade roadways, with and without solid guardrails, with good results. The depressed and elevated conditions require special considerations when entering the roadway geometric data. Those not completely understanding the procedure should contact the Division of Highway Design, Environmental Section. STAMINA 2.0 has been proven to provide good results in prediction of traffic noise if all data are entered correctly.

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APPENDIX A

Recent Construction

Estimate the number of **recently constructed** (within the past 10 years) elevated and depressed freeway sections in your District [City].

☐ Number of elevated sections.

☐ Number of depressed sections.

Note: Please list only sections that would be viable for study, that is, sections that involve at least two over/underpasses, or are at least 0.40 km (1/4 mi) long.

Give the location and check the descriptive characteristics for each section.

Section Location (Hwy/Frwy Name or Number)*	Elevated	Depressed	Downtown	Suburban	Residential	Commercial	Age of Facility <5yrs	Age of Facility 6-10yrs	Facility Length km (mi)	Land Use Map Available	Aerial Map Available

*Please attach map with section identified.

Under Construction

Estimate the number of elevated and depressed freeway sections in your District [City] that are currently **under construction**.

☐ Number of elevated sections.

☐ Number of depressed sections.

Note: Please list only sections that would be viable for study, that is, sections that involve at least two over/underpasses, or are at least 0.40 km (1/4 mi) long.

Give the location and check the descriptive characteristics for each section.

Section Location (Hwy/Frwy Name or Number)*	Elevated	Depressed	Downtown	Suburban	Residential	Commercial	Construction Start Date	Facility Length km (mi)	Land Use Map Available	Aerial Map Available

*Please attach map with section identified.

Planned Construction

Estimate the number of **planned** elevated and depressed freeway sections in your District [City].

☐ Number of elevated sections.

☐ Number of depressed sections.

Note: Please list only sections that would be viable for study, that is, sections that involve at least two over/underpasses, or are at least 0.40 km (1/4 mi) long.

Give the location and check the descriptive characteristics for each section.

Section Location (Hwy/Frwy Name or Number)*	Elevated	Depressed	Downtown	Suburban	Residential	Commercial	Construction Start Date	Facility Length km (mi)	Land Use Map Available	Aerial Map Available

*Please attach map with section identified.

APPENDIX B

GLOSSARY

ABATEMENT: (As it relates to noise.) The process of reducing the degree or intensity of noise.

ABSORPTION: The method of noise attenuation that represents sound energy losses into or through a material.

ANGLE OF DIFFRACTION: The angle through which sound energy is diffracted as it passes over the top of a noise wall and proceeds toward a receiver. Receivers deeper into the shadow zone have larger angles of diffraction and, therefore, greater noise wall attenuation.

ATTENUATION: The change in the noise level at the receiver location caused by the diffraction of sound waves over the top or around the sides of a noise wall.

A-WEIGHTED SOUND LEVEL (dBA): The most generally used measure of the magnitude of traffic noise. It is defined as the sound level, in decibels, measured with a sound-level meter having the metering characteristics and frequency weighing specified in American National Standard Specification for Sound Level Meters, ANSI S1.4-1971. Colloquial practice often refers to values of A-weighted sound level as dBA. The A-weighing tends to de-emphasize lower-frequency sounds (e.g., below 1,000 Hz) and high frequency sounds (above 4 kHz). So, in principle, the meter has a frequency characteristic approximating, for low-level sounds, that of the human ear.

BARRIER: A solid wall, berm, or vegetation located between a source and receiver that breaks the line of sight between source and receiver.

DECIBEL: A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average pain level.

DESIGN NOISE LEVELS: Noise levels for various activities or land uses which represent the upper limit of acceptable traffic noise level conditions. These levels are used to determine the degree of impact of traffic noise on human activities.

DESIGN-YEAR NOISE LEVEL: The predicted noise level for a future year, usually 20 years, after the completion of a project.

DIFFRACTION: The bending of sound waves around an obstacle such that attenuation of their energy occurs in proportion to the degree of their bending into the shadow zone behind an obstacle. Only waves that are small compared to the obstacle will be affected in this way. Diffraction over the top of a noise wall generally accounts for the noise energy that appears in the shadow zone of the noise wall.

L_{DN}: This is a sound level rating based on L_{eq} . The energy is averaged over 24 hours, but the noise level during the nighttime period, 2200 to 0700 hours, is penalized by the addition of 10 dBA.

L_{eq}: The sound equivalent steady-state or average sound level that contains the same acoustic energy occurring during the time period when the measurements were made.

L_{10}: The sound level exceeded 10% of the time during the period measured. Generally, no longer used in prediction modeling. L_{10} (h) is the hourly value of L_{10} . For free flowing traffic: $L_{10} \simeq L_{eq} + 3dBA$.

LINE OF SIGHT: A straight line between the receiver location and a specific noise source.

MITIGATION MEASURES: Controls used to lessen adverse noise impacts.

NOISE: A sound of any kind, especially when loud and undesired.

NOISE ABATEMENT CRITERIA (NAC): An hourly A-weighted sound level in decibels (dBA) for five categories with varying degrees of activity. These are exterior measurements for exterior uses and interior measurements for a location that would require a minimum noise level be maintained inside (i.e., residences, schools, hospitals, etc.). The NAC is the maximum traffic noise level that can be approached, reached, or exceeded without considering noise abatement.

NOISE ABATEMENT MEASURES: Controls used to reduce the degree or intensity of noise impact at a given site. These may include physical barriers (sound wall, berm, etc.), psychological barriers (plant material to break line of sight), lateral clearance or buffer zones, or alteration of the vertical and/or horizontal alignment of a highway facility.

PROPAGATION: The passage of sound energy from a noise source to receiver.

REFLECTION: Bouncing back of sound waves away from an object that is larger in exposed section than the wavelengths and of sufficient surface weight density and stiffness to present a very large increase in impedance compared with the air surrounding it.

SHADOW ZONE: The area behind a noise barrier that is blocked from direct view from the source of noise.

SHIELDING: An obstruction that breaks the line of sight between the source and receiver, thereby lowering the level of sound to the receiver.

TRAFFIC NOISE IMPACTS: When the predicted traffic noise levels approach or exceed the noise abatement criteria in Title 23 Code of Federal Regulations Part 772 (23 CFR 772), or when the predicted traffic noise levels exceed the existing noise levels by 10 dBA or more.

23 CFR 772: Title 23 Code of Federal Regulations Part 772, Federal-Aid Highway Program Manual that explains processes to be followed in noise analysis.