Report No. CDOT – R1-R-2001-9

Noise and Skid Measurements on US285 in the Turkey Creek Canyon Area Project NH 2854-068

Robert LaForce

Jill Schlaefer

June 2001

Acknowledgments:

The authors would like to acknowledge the following for their help in completing this study.

Skip Outcalt from CDOT Research and Mick Barnhardt from David L. Adams Associates, Inc. for their work in taking the noise measurements with short notice and rapid turnaround time and again, Skip for the skid measurements.

Dennis Largent, CDOT Project Engineer for locating the test sections and scheduling and managing construction of the test site very soon after contract award.

Technical Report Documentation Page

1. Report No. **CDOT – R1 – R – 2001-9**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Noise and Skid Measurements on US285 in the Turkey Creek Canyon Area Project NH 2854-068		5. Report Date June 2001 6. Performing Organization Code
7. Author(s) Jill Schlaefer Robert LaForce		8. Performing Organization Report No. **CDOT – R1 – R – 2001-9**
9. Performing Organization Name and Address Colorado Department of Transportation, Region One 18500 E. Colfax Ave. Aurora, Colorado 80011		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Colorado Department of Transportation 4201 E. Arkansas Ave. Denver, Colorado 80222		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report documents the noise measurements taken using a single vehicle on four different pavement surface textures. The pavements were located on US285 southwest of Denver, Colorado.

Noise measurements were taken inside the vehicle, 25 feet from the center of the closest driving lane, and near the right rear tire. Skid testing was performed at 40 mph in conformance with the ASTM procedure E 274 for a ribbed tire.

The surface types included longitudinal tined concrete, transverse tined concrete, ground concrete, and an asphalt surface (3/8 inch nominal Stone Mastic Asphalt).

17. Key Words skid number, noise properties, surface texture, frictional characteristics, tining	18. Distribution Statement No restrictions. This document is available to the public through: National Technical Information Service. 5825 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	23	

Noise and Skid Measurements on US285 in the Turkey Creek Canyon Area
Project NH 2854-068

Executive Summary

Under Project NH 2854-068, Region 1 planned to construct several test sections of roadway to evaluate possible treatments to address noise problems on Phase I and II of US285 between mileposts 243.4 and 246.2. The tire noise from the transverse tining causes an objectionable whine, which has resulted in complaints from area residents.

The US285 location also offers the opportunity to measure noise and skid resistance from several pavement surface types in relatively close proximity. The project included an asphalt surface (SMA) in Turkey Creek Canyon immediately north of Phase I and longitudinally tined concrete immediately south of Phase II. The three pavement surface types are within four miles on the same highway.

Only one concrete treatment test section was constructed this fall. The concrete pavement surface was ground ¼ inch to remove the transverse tining.

Noise and skid measurements were taken both before and after construction on the test section as well as on the various pavement surface types available near the project area. Noise measurements were taken in exactly the same manner, using the same vehicle, as measurements taken on I-70 near Deer Trail in 1994. (See Report CDOT-DTD-95-2.) A-weighted sound level measurements and 1/3 octave band sound pressure level measurements between 25 and 10,000 Hz were taken inside the vehicle, inside the rear tire well, and at the roadside 25 feet from the center of the travel lane.

Following is a summary of sound level (dBA) measured 25 feet from the center of the travel lane and skid numbers for the various surface types:

	Noise Levels (dBA)	Skid Number 40 mph (SN40R)
Longitudinal Tined Concrete	75	43.3
Asphalt Surface (3/8 inch SMA)	74	51.5
Transverse Tined Concrete	82	43.5
1/4 inch Ground Test Section	76	47.6
Reduction in Noise Level (dBA) from Original Tining	**6**	**NA**

Conclusions drawn from this study are listed below:

- On the transverse tined concrete test section the ¼ inch grinding resulted in a reduction in the noise level of 6 decibels near the road. Although a noise level reduction of 6 dBA was achieved by this change in surface texture, this does not constitute a noise abatement under federal regulations.

- The majority of the annoying frequency components from tire/pavement noise lie between 700 and 2000 Hz[1]. The average reduction in sound pressure level between 800-2500 Hz inclusive was 7 decibels for this test section.

- The current standard surface finish for concrete pavement (longitudinal tining) resulted in comparable noise level values to the ground surface and the 3/8 inch SMA asphalt surfacing. The skid number for the asphalt is considerably higher than the concrete surfaces, but the concrete skid number is adequate. Many states take action when the skid number (SN40R) is below 30 to 35.[2]

- The reduction in noise level after grinding away the transverse tining is very similar to those reported in a recent Wisconsin report, "Noise and Texture on PCC Pavements" Report No. WI/SPR-08-99. The noise levels for the other surface treatments are also similar to those reported in the above-mentioned report.

Table of Contents

List of Tables

List of Figures

List of Graphs

Introduction

A multiple phase State Highway 285 project was undertaken to realign and improve roadway safety and capacity in response to increased commuter and regional travel demand. As highway traffic and speed increased, local residents began experiencing noise problems on some newly constructed pavement segments. It was quickly recognized that the most objectionable roadway noise was generated where transverse tining pavement texture treatments had been utilized. This easily discernable noise is characterized as a high pitched "whine" associated with tire and road surface interaction.

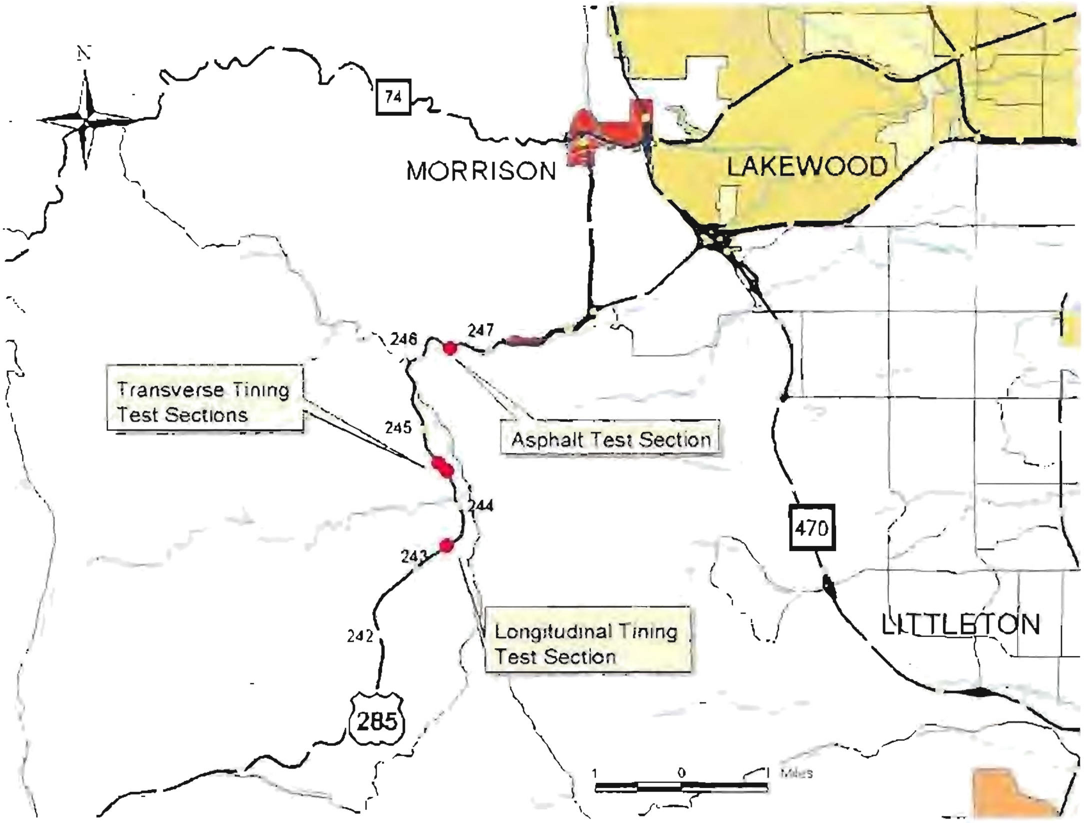


Figure 1. Location map of study area showing Test Sites 1 through 5.

This site selective study was conducted in October 2000 under Project NH 2854-068. The study area is shown in Figure 1. The purpose of the project was to acoustically assess the impact of various paving surfaces inside a vehicle, at the tire of a vehicle, and at the roadside. Additionally, the skid numbers of both original and reconstructed pavement surfaces were compared to evaluate safety impacts due to noise reduction techniques. Region 1 planned to construct several test sections of roadway to evaluate possible treatments to address noise problems on Phase I and II of US285. Only one concrete treatment test section was constructed this fall. The concrete pavement surface was ground ¼ inch to remove the transverse tining. (See Figures 2 through 4.)

The US285 location also offers the opportunity to measure noise and skid resistance from several pavement surface types in relatively close proximity. The project included an asphalt surface (SMA) in Turkey Creek Canyon immediately north of Phase I, longitudinally tined concrete immediately south of Phase II, and transverse tined concrete pavement in Phase I. The three pavement surface types are within four miles on the same highway.

Figure 2. Oblique view looking east at Test Sections 1 through 3 along US285.

Methodology

Base-Line Measurements

The study was designed and implemented for CDOT by Davis L. Adams Associates to accommodate noise and skid measurements from several road surface types. Three different road surface pavements and textures were identified within a four mile distance. Noise and skid measurements were taken both before and after construction on the test sections as well as on the various pavement surface types available near the project area. Noise measurements were taken in exactly the same manner, using the same vehicle, as measurements taken on I-70 near Deer Trail in 1994. (See Report CDOT-DTD-95-2.)

A-weighted sound level measurements and 1/3 octave band sound pressure level measurements between 25 and 10,000 Hz were taken inside the vehicle, inside the rear tire well, and at the roadside 25 feet from the center of the travel lane. Before-grinding noise base-line measurements were recorded on October 4, 2000. Noise measurements for the after-grinding test section were taken on October 31, 2000. The grout-filled test section had not been constructed at the time of this report.

All measurements were taken with a Larsen-Davis Model 2900 sound level meter on "fast" response, together with a Bruel & Kjaer Type 4165 microphone. Calibration was checked before, during and after this series of measurements with a Larsen-Davis CA250 Precision Acoustic Calibrator. A windscreen covered the microphone during all outside measurements.

The weather was mild at 65 degrees Fahrenheit with no noticeable breeze. A-weighted sound level measurements were recorded as well as 1/3 octave frequency bands between 25 and 10,000 Hz.

The vehicle used was a 1994 Oldsmobile Cutlass Sierra station wagon provided by the Colorado Department of Transportation. The Oldsmobile station wagon was traveling in the right lane at a speed of 50 miles per hour. Due to the slight uphill grade of the road, it was impractical to idle the engine during the tests while maintaining speed. For comparison purposes, similar grades were chosen for all three test samples.

Three conditions were assessed as follows:

1. Sound measurements were taken with the microphone inside the vehicle at center, front seat position. The microphone was positioned at ear height. The sound measurements reported reflect the average sound pressure levels sampled throughout the period in which the vehicle was traveling over sections of each pavement surface, typically about 2 seconds.

2. A mounting bracket was fabricated to allow sound measurements to be taken near the rear tire well away from the exhaust pipe. See Figure 5 for illustration of microphone configuration. The sound measurements reported reflect the average sound pressure levels sampled throughout the period in which the vehicle was traveling over sections of each pavement surface.

3. Sound measurements were taken 25 feet from the center-line of the travel lane closest to the highway shoulder. The height of the "roadside" microphone above road level is shown in Table 1. The height of the microphone was dictated by the topography and limitations of the tripod.

Table 1. Height and location of the microphone relative to road

Location	Description	Microphone Height
1	Transverse Tining Road to be Ground. MP 244.42-244.45	41 inches
2	Transverse Tining Road to Remain Unchanged, MP 244.45-244.49	51 inches
3	Transverse Tining to be Grout-Filled, MP 244.49-244.53	58 inches
4	Asphalt, SMA, ~MP 246.3	34 inches
5	Longitudinal Tining, MP 243.20-243.49	34 inches

Since there was interference from other vehicles in both eastbound and westbound lanes, a number of measurements were taken. The sound level meter was set to "maximum spectrum" which records the spectrum of the sound when the highest A-weighted overall level is reached as the vehicle passes by. Due to consistent traffic flow, it was difficult to absolutely isolate the station wagon from other traffic in the distance. Sound pressure levels reported are the lowest levels from multiple tests with the assumption that these levels most closely represent the sound generated by the subject vehicle.

Follow-up Measurements

Measurements were taken in Turkey Creek Canyon on US285 in the same manner and the same equipment used in the previous study conducted October 4, 2000. We conducted measurements for Test Section 1 only. This section of transverse tining had been ground down since previous measurements. See Figures 3 and 4.The weather was mild at 42 degrees Fahrenheit with no noticeable breeze The road was dry.

Figure 3. View looking east at transverse tining Test Sections 1, 2 and 3 along US285 mileposts 244.42 to 224.53.

Figure 4. A detailed view of transverse tining at Test Section 1 between mileposts 244.42 and 244.45, eastbound US285. The right-hand ½ of the photograph shows where transverse tining has been ground. The grinding tapers to the left showing remnant transverse tining texture. Note pen for scale.

Analysis

Noise

The results of the base-line noise measurements are provided in Tables 2 through 4. Frequency spectra data has also been plotted in Graphs 1 through 3 to compare the five roadway test sections under the three measurement conditions of inside vehicle, at the tire well, and at the roadside.

Two sound pressure anomalies occurred within data collection. The first anomaly is a consistent 6 to 9 decibel (dB) spike at 100 Hz frequency in all noise measurements. This frequency has been identified as engine noise

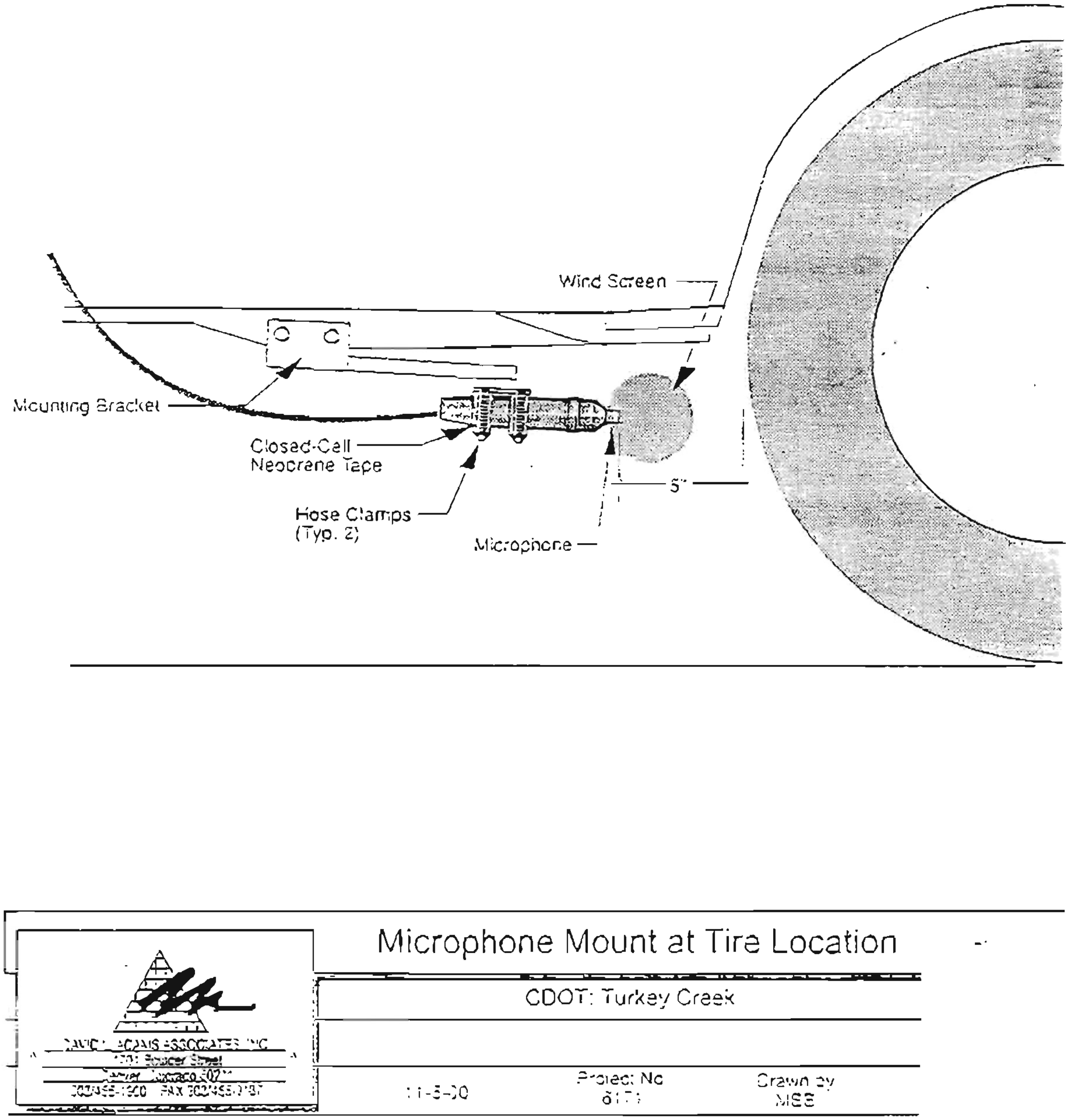


Figure 5. Microphone mount at the tire location.

Table 2: Results of Sound Measurements Taken inside the Vehicle — Measurements Taken: 10/4/00

SPL at 1/3 Octave Band Frequency

	25.0	31.5	40.0	50.0	63.0	80.0	100.0	125.0	160.0	200.0	250.0	315.0	400.0	500.0	630.0	800.0	1000.0	1250.0	1600.0	2000.0	2500.0	3150.0	4000.0	5000.0	6300.0	8000.0	10000.0	dBA
Section 1	90	85	84	79	72	66	74	67	65	63	62	61	54	53	51	55	50	49	51	46	40	35	31	28	27	27	27	64
Section 2	88	86	86	82	72	69	73	69	66	61	62	61	55	54	53	58	53	50	51	47	41	37	35	35	36	34	30	65
Section 3	89	86	86	85	72	66	74	66	63	61	61	59	55	52	50	59	49	46	49	45	40	34	31	28	27	29	29	64
Section 4	91	88	83	78	72	66	74	72	67	62	64	62	56	54	55	55	52	49	47	42	37	34	32	28	27	27	27	65
Section 5	89	85	84	82	71	72	73	65	63	60	60	60	54	51	50	51	49	45	44	41	36	33	30	27	26	26	26	62

Table 3. Results of Sound Measurements Taken at the Tire of the Vehicle — Measurements Taken: 10/4/00

SPL at 1/3 Octave Band Frequency

	25.0	31.5	40.0	50.0	63.0	80.0	100.0	125.0	160.0	200.0	250.0	315.0	400.0	500.0	630.0	800.0	1000.0	1250.0	1600.0	2000.0	2500.0	3150.0	4000.0	5000.0	6300.0	8000.0	10000.0	dBA
Section 1	98	94	92	90	87	85	94	83	87	88	85	87	85	88	90	100	95	96	102	100	94	85	81	77	72	69	68	107
Section 2	97	95	92	90	89	86	94	84	87	86	84	85	84	86	89	101	93	93	99	97	93	85	80	77	73	70	68	106
Section 3	94	92	89	88	86	84	93	82	86	85	83	83	82	85	88	104	91	92	98	96	93	84	79	76	72	69	67	106
Section 4	98	96	93	92	89	86	94	86	86	86	86	85	85	87	90	92	95	94	95	91	84	80	76	75	72	70	69	102
Section 5	93	91	90	88	85	84	93	82	84	84	83	82	81	84	87	92	91	90	92	90	85	81	78	75	72	69	68	99

Table 4: Results of Sound Measurements Taken at the Roadside — Measurements Taken: 10/4/00

SPL at 1/3 Octave Band Frequency

	25.0	31.5	40.0	50.0	63.0	80.0	100.0	125.0	160.0	200.0	250.0	315.0	400.0	500.0	630.0	800.0	1000.0	1250.0	1600.0	2000.0	2500.0	3150.0	4000.0	5000.0	6300.0	8000.0	10000.0	dBA
Section 1	50	51	50	49	49	54	60	55	59	59	59	59	60	65	67	78	73	71	75	74	67	61	58	52	47	43	39	82
Section 2	51	46	49	51	52	53	59	53	57	58	61	57	59	62	66	76	69	69	72	69	62	60	56	52	48	44	40	79
Section 3	51	52	52	54	55	59	59	55	57	60	62	59	61	62	65	75	71	71	74	71	64	61	55	51	46	42	38	80
Section 4	51	56	49	55	55	56	54	54	58	57	61	60	59	61	64	64	68	66	64	62	58	54	52	49	45	43	38	74
Section 5	45	45	52	53	51	54	59	55	53	58	60	55	58	62	64	67	66	67	66	64	62	58	55	50	46	41	37	75

related to the subject vehicle. Graph 1 illustrates an anomaly at the high frequency tail of sound measurements taken inside the vehicle for Test Section 2. This deflection of 2 to 5 dB from the data trend occurs only once and is attributed to extraneous noise generated inside the car, such as driver movement.

During the measurements, other random vehicles were sampled on the transverse tined roadway. No record of type of vehicles is provided. The frequency readings for the Oldsmobile station wagon tended to peak at 800 Hz at the roadside (see Graphs 1-3), whereas other vehicles peaked at 1000 Hz or 1250Hz (see Graph 4).

The audible range of frequencies for humans is between 20 and 20,000 Hz. In general, all highway noise frequency spectral measurements peaked within a range between 800 and 2000 Hz. The distribution within this range was slightly bimodal with peaks at 800 Hz and 1600 Hz respectively. The exterior vehicle sound measurements best demonstrated the noise (decibel) increases and frequency (Hz) peaks at both base-line and after grinding surface texture treatment sections.

The peak frequency-noise level increase band or "prominence" represents the whine heard by local residents as cars pass over the transverse tining.[1] Although these noise measurements indicate that the prominence occurs in all test sections, the before-grinding transverse tining surface texture generated the highest values. Peak prominence values for base-line Test Sections 1, 2 and 3 average 7 dB (roadside) to 4dB (tire well) higher than corresponding peak values on asphalt and longitudinally tined surfaces.

The result of grinding down ¼ inch of transverse tining at Test Section 1 was a net noise reduction of 6 dB. This is a noticeable noise reduction for the area residents. FHWA noise abatement criteria cites a 5 dB sound level reduction as significant for residential areas. The before and after grinding noise level comparisons for Section 1 are presented in Table 5 and the frequency spectra are plotted as Graphs 5-7. The roadside before and after grinding noise frequency spectra comparisons are charted as Graph 8.

SPL at 1/3 Octave Band Frequency

	25.0	31.5	40.0	50.0	63.0	80.0	100.0	125.0	160.0	200.0	250.0	315.0	400.0	500.0	630.0	800.0	1000.0	1250.0	1600.0	2000.0	2500.0	3150.0	4000.0	5000.0	6300.0	8000.0	10000.0	dBA
In Car Before Grinding			64	79	77	66	74	62	55	63	62	61	54	53	51	55	50	49	51	46	43	35	31	28	22	22	22	[illegible]
In Car After Grinding	90	66	81	78	67	67	[illegible]	58	63	57	61	61	55	51	50	51	49	45	44	43	36	33	32	31	27	27	27	63
Difference	0	-1	3	1	3	1	1	1	2	-5	-1	-1	1	-2	-2	-4	-1	-4	7	6	-6	-1	1	-3	0	0	0	-1
At Tire Before Grinding	98	94	92	90	87	65	94	63	67	88	65	87	85	88	90	100	96	96	102	100	94	88	81	77	72	69	68	107
At Tire After Grinding	98	95	94	92	87	66	95	67	67	87	64	85	84	83	85	90	97	91	93	93	86	81	78	75	71	67	65	101
Difference	0	1	2	1	1	1	2	4	0	-1	1	-1	1	-3	-5	-9	1	-4	-8	-6	-7	-4	-2	-3	-1	2	-3	-6
Roadside Before Grinding	50	51	50	49	49	54	60	55	59	59	59	59	60	65	67	76	75	71	75	74	67	61	58	52	47	43	39	82
Roadside After Grinding	47	43	51	51	55	57	57	63	60	59	64	61	60	60	64	66	70	68	67	64	61	59	54	50	47	44	39	76
Difference	-3	-8	1	2	6	3	3	7	1	0	5	2	0	-5	-3	10	5	-3	-8	-9	-6	-2	-3	-2	-1	0	0	-6

Table 5. Before and after sound measurements for ground section of highway.

Skid Resistance

Road surface friction is measured to determine pavement skid resistance. Skid resistance is defined as the retarding force generated by the interaction between a pavement and a tire under locked, non-rotating wheel condition.[3] Measurements are standardized for tire and pavement surface conditions and the results from resistance testing are reported as friction numbers or skid numbers. Skid numbers were measured using a locked wheel tester in accordance with ASTM E 274, using a standard ribbed tire at 40 mph. The measurements were reported as SN40R, where SN refers to skid number, 40 refers to the speed in miles per hour, and R refers to the tire tread type, in this case ribbed tires.

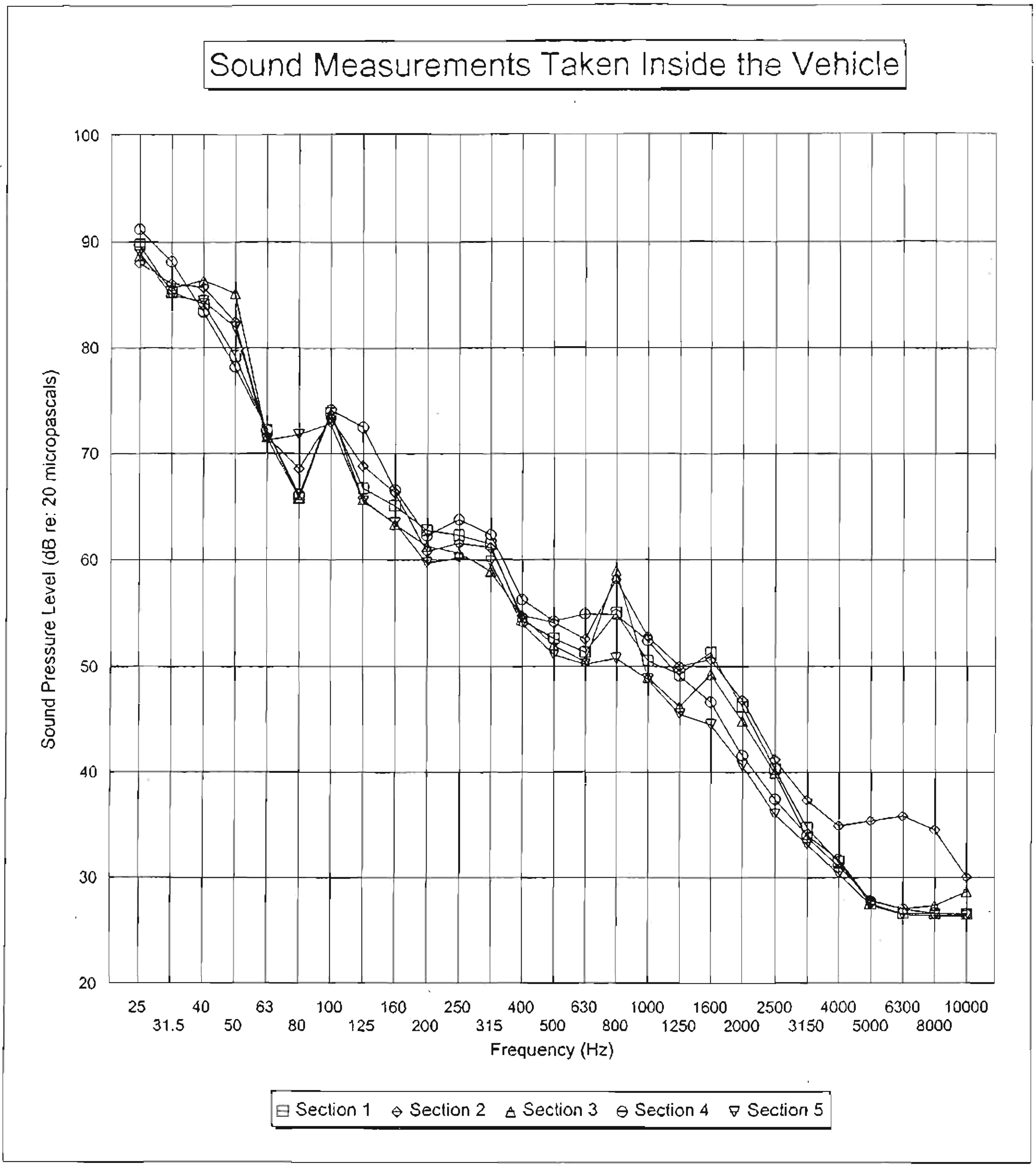
Table 6 compares base-line skid numbers for each pavement surface type and the after grinding transverse tining test section. Grinding improved the skid number from 43.5 to 47.6. This improvement is associated with the small grooves caused by the grinding wheels. Similar improvements in skid resistance have been reported in other locations where grinding was performed on concrete pavements.

Table 6. Skid resistance comparison of pavement surface types.

Location	Speed	Skid Number
Transverse Tined Concrete Section	40 mph	43.5
After Grinding Transverse Tined Section	40 mph	47.6
Longitudinally Tined Section	40 mph	43.3
Asphalt Surface (3/8" SMA)	40 mph	51.3

Conclusions

- On the transverse tined concrete test section the ¼ inch grinding resulted in a reduction in the noise level of 6 decibels near the road. Although a noise level reduction of 6 dBA was achieved by this change in surface texture, this does not constitute a noise abatement under federal regulations.
- The majority of the annoying frequency components from tire/pavement noise lie between 700 and 2000 Hz[1]. The average reduction in sound pressure level between 800-2500 Hz inclusive was 7 decibels for this test section (measured 25 feet from the vehicle).
- The current standard surface finish for concrete pavement (longitudinal tining) resulted in comparable noise level values to the ground surface and the 3/8 inch SMA asphalt surfacing. The skid number for the asphalt is considerably higher than the concrete surfaces, but the concrete skid numbers are adequate.
- The reduction in noise level after grinding away the transverse tining is very similar to those reported in a recent Wisconsin report, "Noise and Texture on PCC Pavements" Report No. WI/SPR-08-99. The noise levels for the other surface treatments are also similar to those reported in the above-mentioned report.



DAVID L. ADAMS ASSOCIATES, INC.
1701 Boulder Street
Denver, Colorado 80211
303/455-1900 FAX 303/455-9187

Sound Measurements: In Vehicle

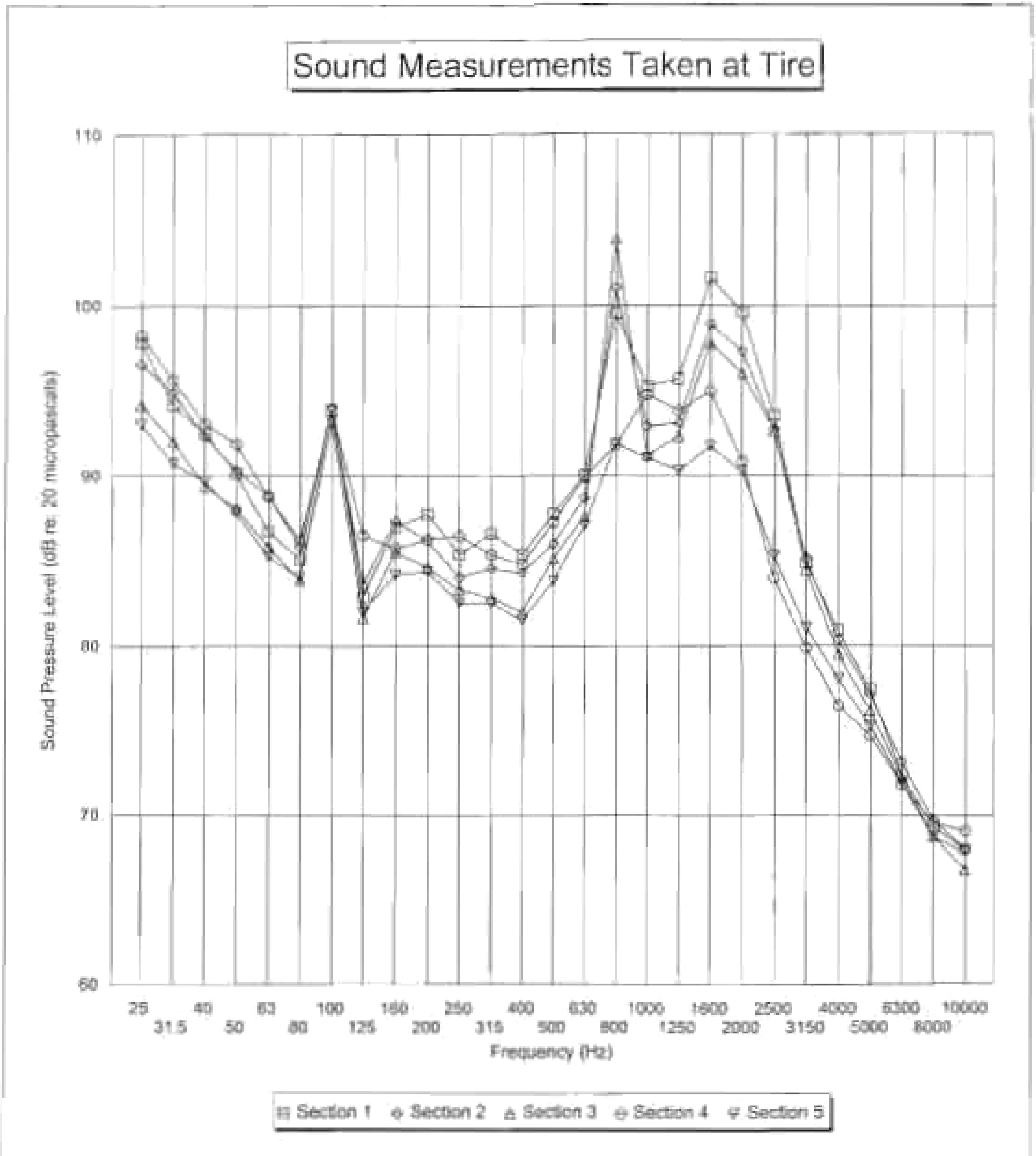
CDOT: Turkey Creek

Graph 1

11-5-00

Project No. 6171

Drawn by MBB



DAVID L. ADAMS ASSOCIATES, INC.
1701 Boulder Street
Denver, Colorado 80211
303/455-1900 FAX 303/455-9187

Sound Measurements: At Tire

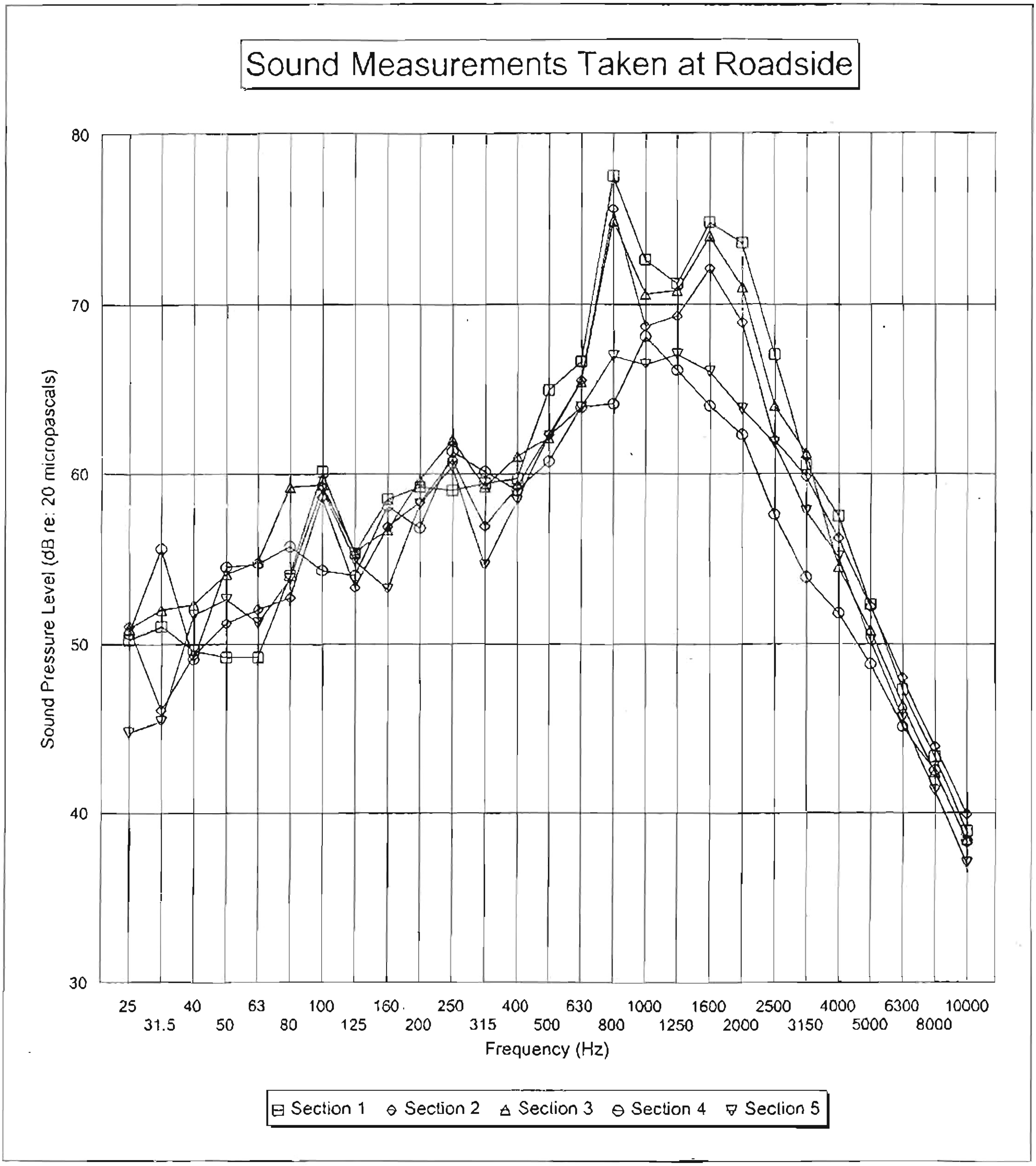
Graph 2

CDOT: Turkey Creek

11-5-00

Project No. 6171

Drawn by MBB



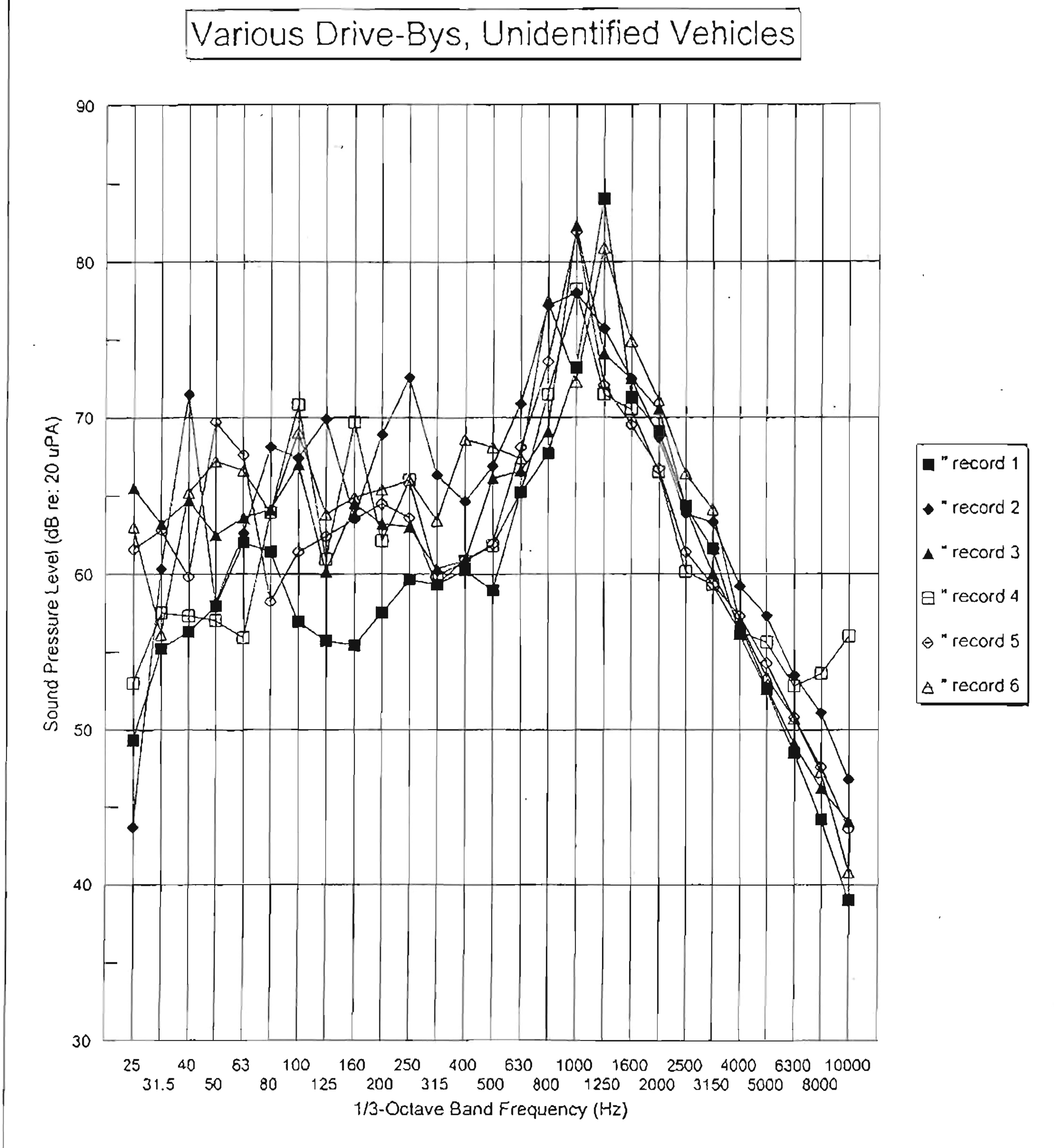
DAVID L. ADAMS ASSOCIATES, INC.
1701 Boulder Street
Denver, Colorado 80211
303/455-1900 FAX 303/455-9187

Sound Measurements: At Roadside

CDOT: Turkey Creek

Graph 3

11-5-00 | Project No. 6171 | Drawn by MBB



DAVID L. ADAMS ASSOCIATES, INC.
1701 Boulder Street
Denver, Colorado 80211
303/455-1900 FAX 303/455-9187

Sound Measurements: Roadside

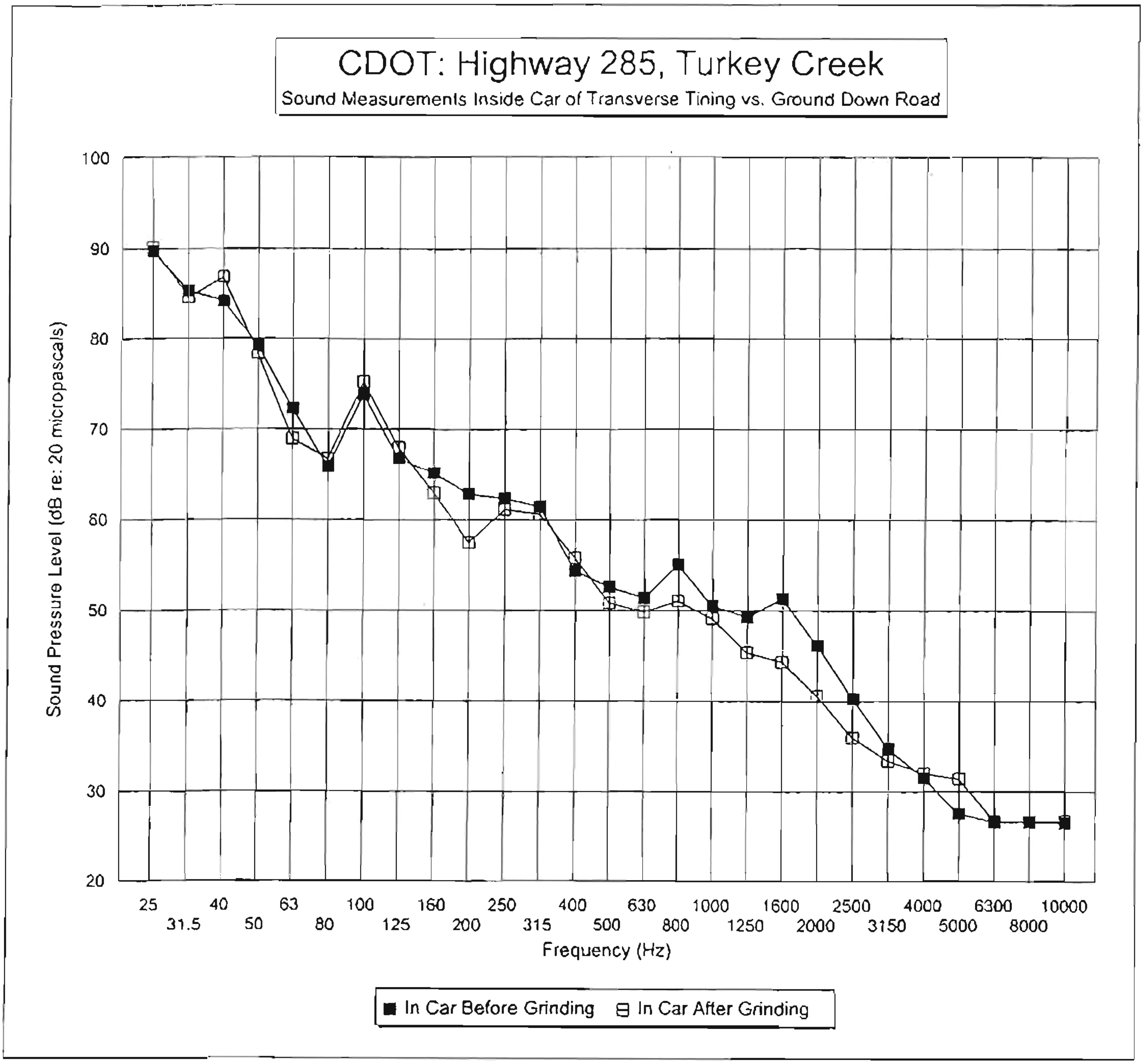
CDOT: Turkey Creek

Graph 4

11-5-00

Project No. 6171

Drawn by MBB



Sound Measurements: In Vehicle

CDOT: Turkey Creek

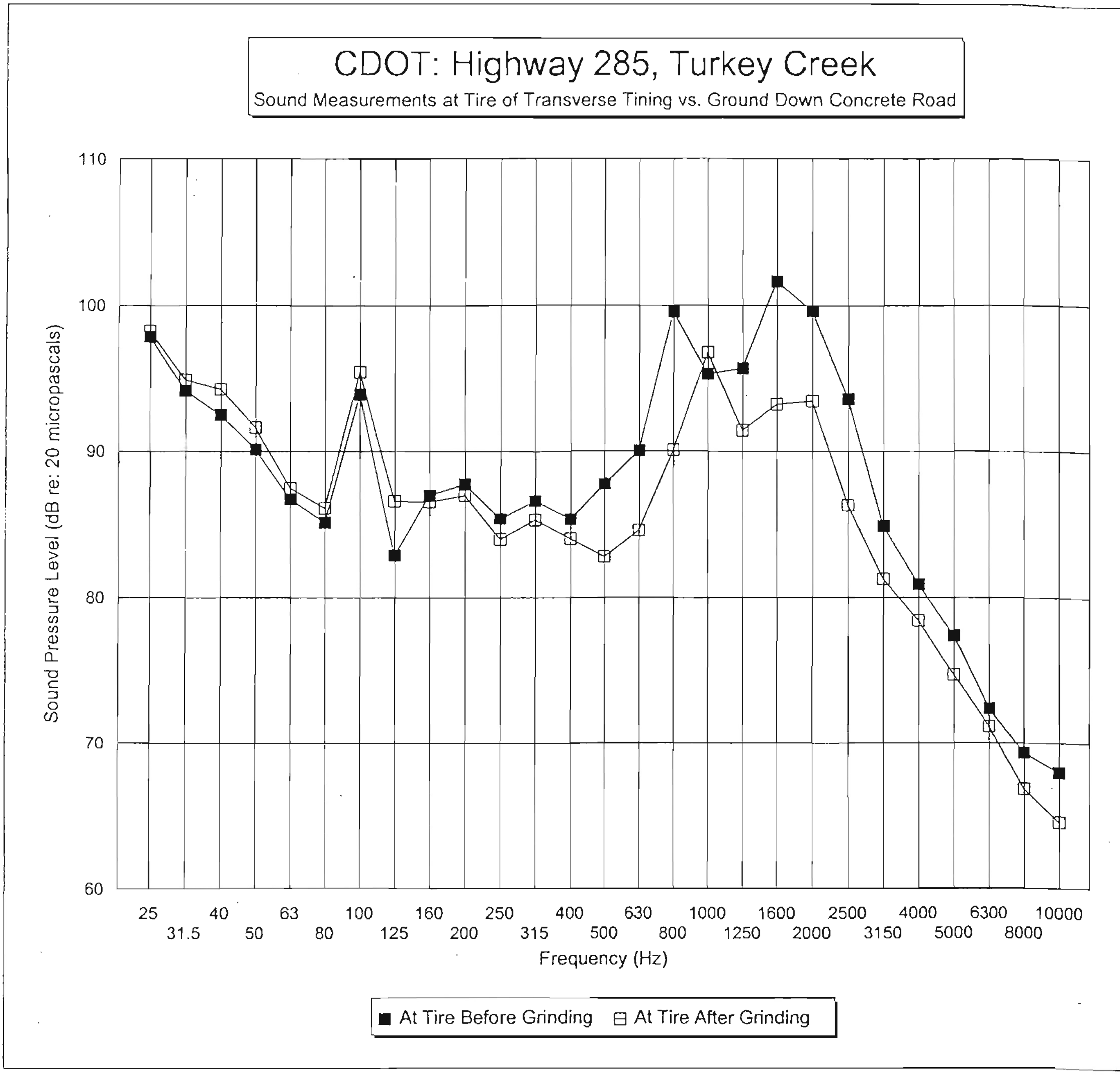
Graph 5

DAVID L. ADAMS ASSOCIATES, INC.
1701 Boulder Street
Denver, Colorado 80211
303/455-1900 FAX 303/455-9187

11-5-00

Project No. 6171

Drawn by MBB



DAVID L. ADAMS ASSOCIATES, INC.
1701 Boulder Street
Denver, Colorado 80211
303/455-1900 FAX 303/455-9187

Sound Measurements: At Tire

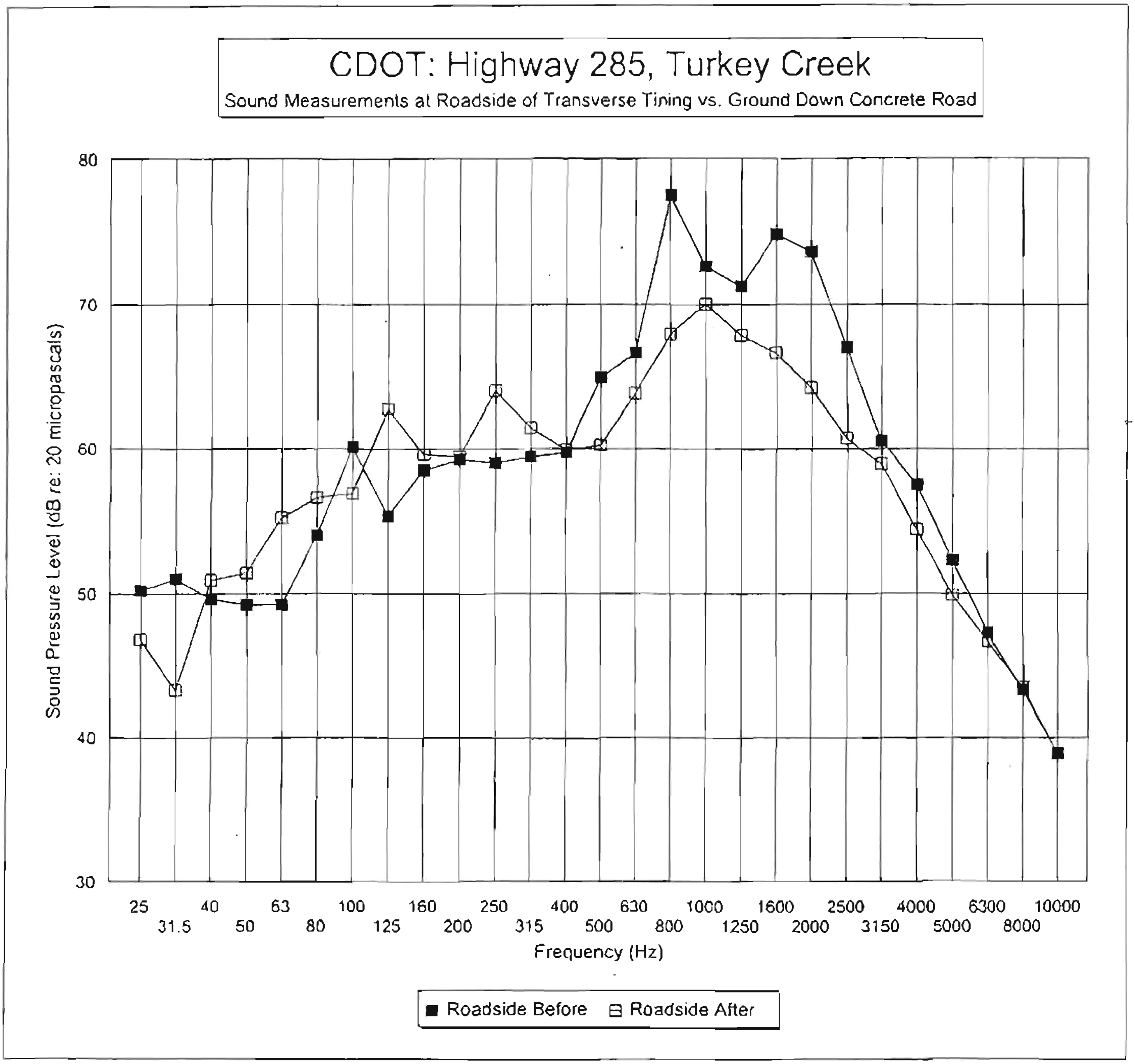
CDOT: Turkey Creek

Graph 6

11-5-00

Project No. 6171

Drawn by MBB

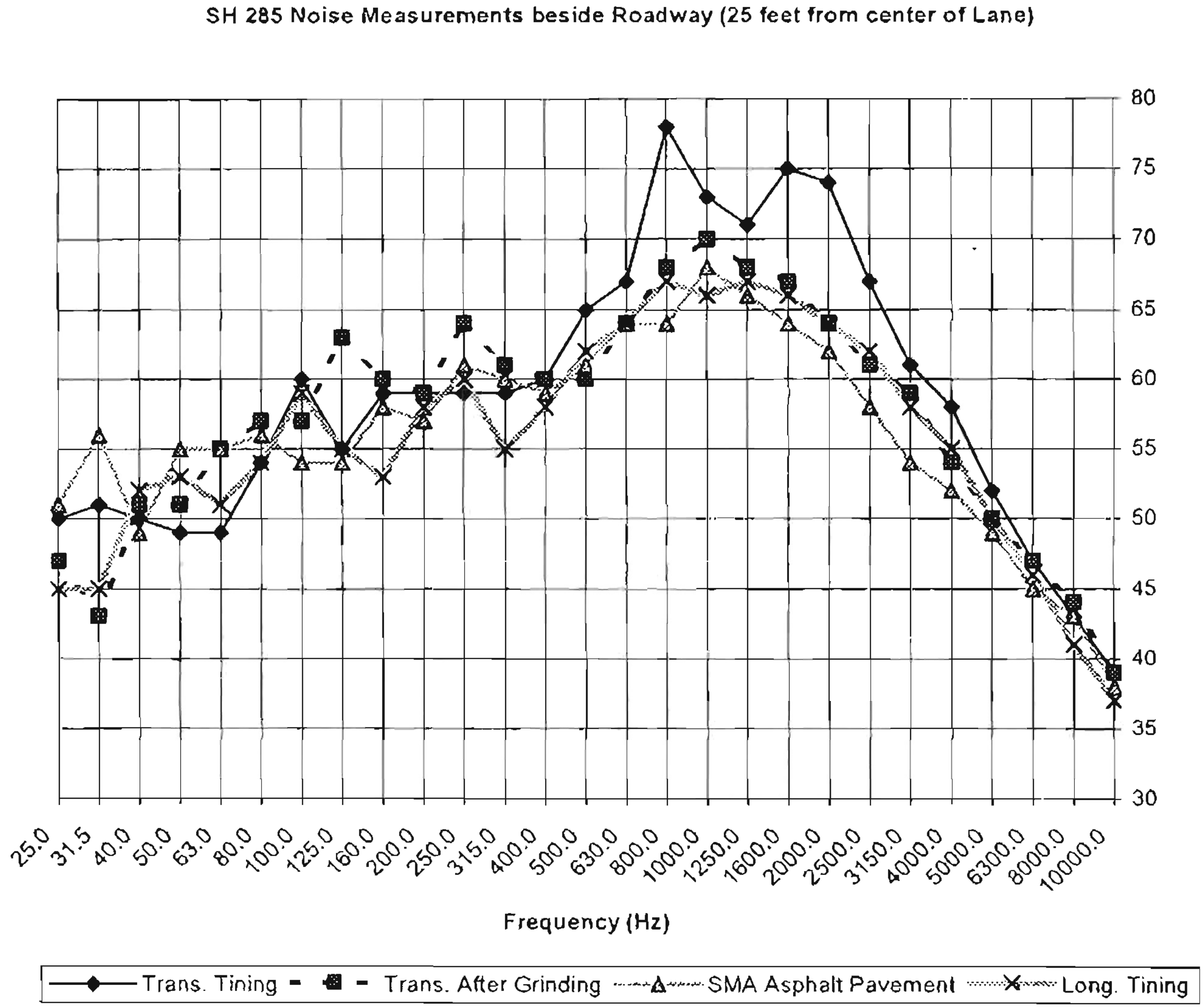


Sound Measurements: At Roadside

DAVID L. ADAMS ASSOCIATES, INC.
1701 Boulder Street
Denver, Colorado 80211
303/455-1900 FAX 303/455-9187

CDOT: Turkey Creek

Date	Project No.	Drawn by	Graph
11-5-00	6171	MBB	7



Graph 8. Comparison of all test sections at roadside to ground transverse tining section.

References

1. "Kuemmel,D.A. et al., 2000, "Noise and Texture on PCC Pavements – Results of a Multi-State Study," WisDOT Highway Research Study #93-05 SPR#0092-45-91, Final Report WI/SPR-08-99.

2. "Evaluation of Pavement Friction Characteristics," NCHRP Synthesis 291, National Academy Press, 2000.

3. "Kulakowski, B.T., et al., 1990, "Skid Resistance Manual," FHWA Report IP-90-13 Unpublished Final Draft, FHWA, Office of Implementation (HRT-10).