EFFECTS OF PAVEMENT SURFACE TEXTURE ON NOISE AND FRICTIONAL CHARACTERISTICS

Final Report
Iowa Highway Research Board
Project HR-281

February 1987

Planning and Research Division
Iowa Department of Transportation

DISCLAIMER

The contents of this report reflect the views of the author and do not necessarily reflect the official views of the Iowa Department of Transportation. This report does not constitute a standard, specification or regulation.

Gra. 393
2410 3/6/87

Final Report
For
Iowa Highway Research Board
Project HR-281

Effects of Pavement Surface Texture on Noise and Frictional Characteristics

Ron Ridnour and Dale Vander Schaaf
515/239-1613
Office of Project Planning
Planning and Research Division
Iowa Department of Transportation
Ames, Iowa 50010

In Cooperation With
the Federal Highway Administration

February 1987

ABSTRACT

An experimental modification of the transverse groove surface texture of a section of an urban interstate highway was performed by the Iowa Department of Transportation. Transverse groove texturing is a design feature required by the Federal Highway Administration to reduce skidding under wet pavement conditions. Adjacent residents claimed the texturing was the cause of especially annoying tonal characteristics within the traffic noise. A research proposal to modify the existing texture pattern by surface grinding and to study the noise and friction effects was approved for funding by the Iowa Highway Research Board. Results in the form of a comparison between traffic noise before modification and traffic noise immediately after and 15 months after modification indicate that the change in surface texture has lowered overall traffic noise levels by reducing a high frequency component of the traffic noise spectrum. Friction testing data show reduced capacity of the roadway to inhibit wet pavement skidding as a result of the surface modification.

TABLE OF CONTENTS

Page

Part I - Initial Study

Part II - Final Study

Effects of Pavement Surface Texture on Noise and Frictional Characteristics

I-380 Pavement Texture Modification Research Project Part I - Initial Study

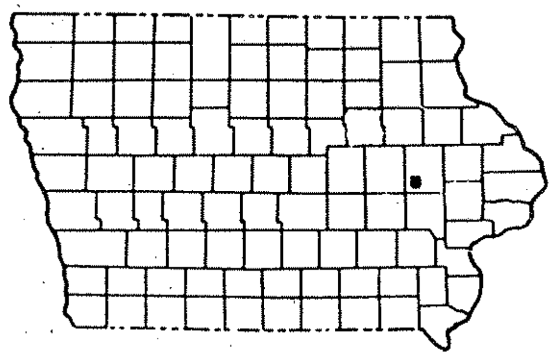
Introduction

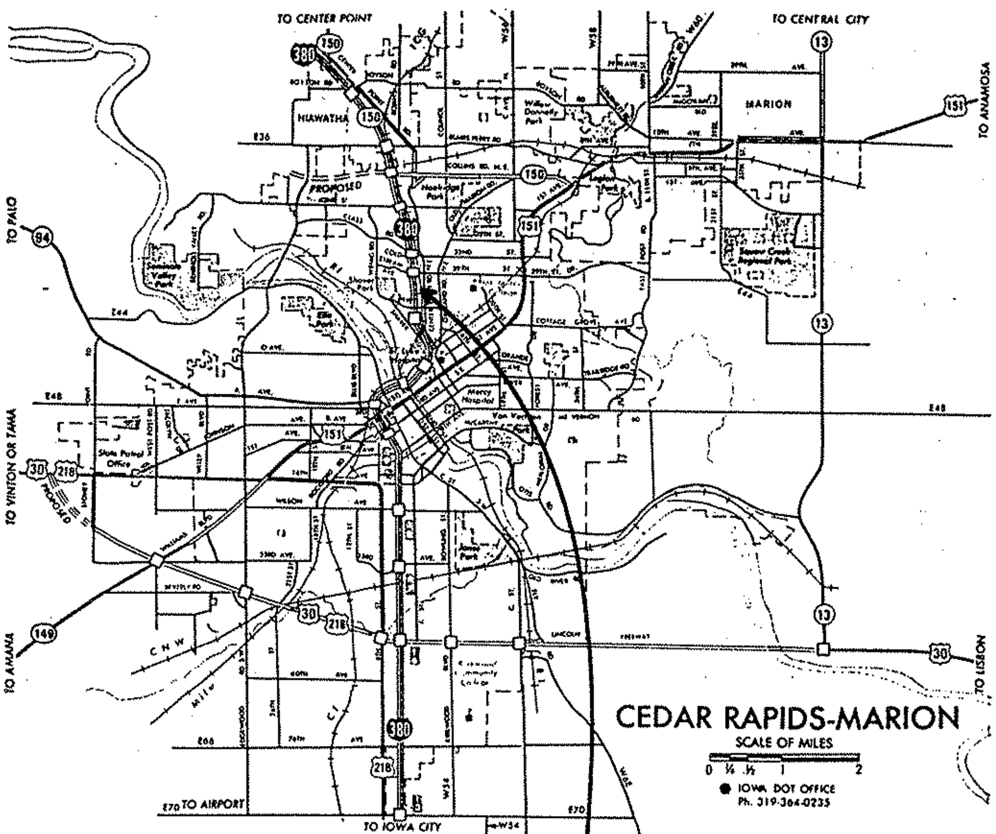
Shortly after I-380 was open to traffic through the northern portion of Cedar Rapids, Iowa, the Iowa Department of Transportation received complaints from residents whose properties adjoined the highway right-of-way. Peak noise levels at worst case locations were confirmed at that time by field measurement to exceed the Federal Highway Administration design criteria for residential land use. Traffic noise levels have since increased as subsequent sections of I-380 have been completed. Aside from the overall noise levels the residents pointed to the transverse groove texturing on the pavement surface as the cause of especially annoying tonal qualities. This research study is being conducted for the purpose of documenting the change in traffic noise and pavement frictional characteristics when the federally specified pavement texture is modified by surface grinding.

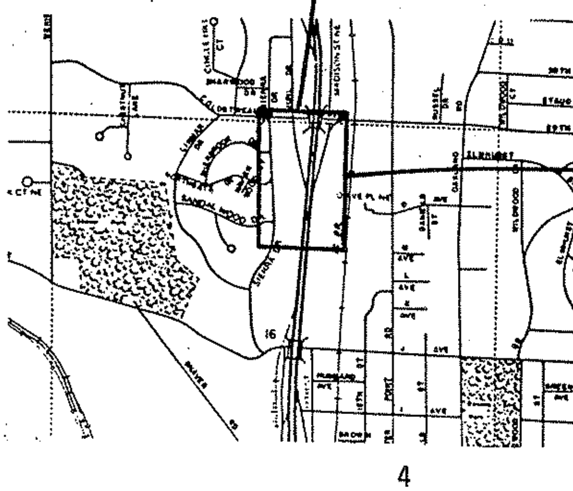
Background

Interstate 380 extends from I-80 in Johnson County to the City of Waterloo in Black Hawk County, Iowa. The Cedar Rapids metropolitan area is bisected by the highway. The study area is a section of I-380 in northeast Cedar Rapids that parallels a residential street, Sierra Drive, which lies to the west (Figure A). Seventeen residences are located between Sierra Drive and the highway with their backyards facing I-380. This residential development occurred generally concurrently with the final development stages of the actual highway project. The general highway corridor had been originally recommended by local planners in the early 1960s.

FIGURE A
PROJECT LOCATION



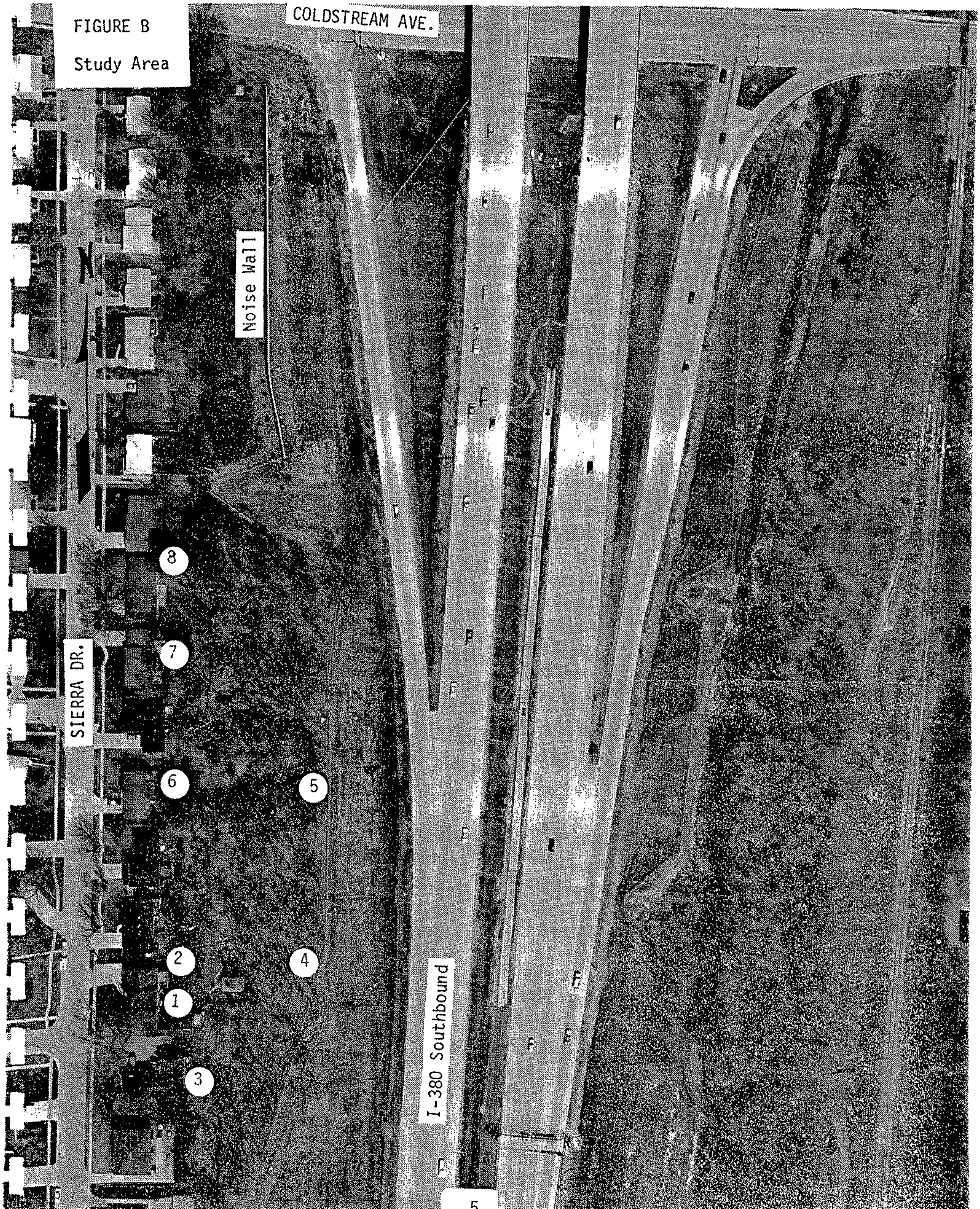




AERIAL PHOTO
COVERAGE IN
FIGURE B

FIGURE B

Study Area



Environmental studies were completed in 1975 (Draft EIS) and 1977 (Final EIS). Design information was presented at public hearings in 1975 and in 1978 (as a part of another segment of I-380). Residential development in the study area began at the north end of Sierra Drive at Coldstream Avenue in the early 1970s and was completed in the late 1970s.

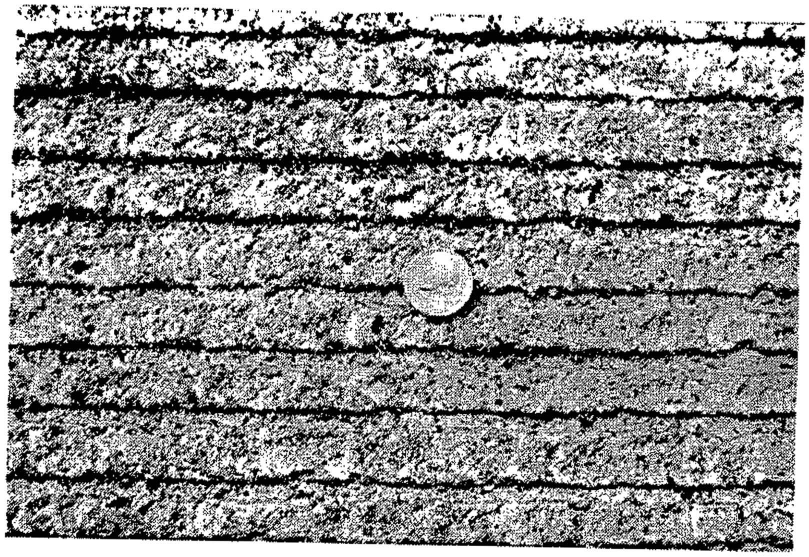
Because of the availability of open space an earth berm/solid wall noise barrier was incorporated into the design of I-380 to protect the eight northernmost homes along Sierra Drive. Preservation of the existing trees to the south of this wall was an important concern of the residents at that time. It has been the position of Iowa DOT that constructing a wall at either the roadway or the right-of-way line to benefit the most exposed of the remaining residences to the south would not provide sufficient noise reduction to justify the estimated costs. As an alternative approach to the problem an experimental modification of the surface texture was suggested to determine if the overall noise levels and/or the annoying "whine" identified by the residents might be reduced. The Iowa Highway Research Board approved the proposal for funding, a contractor was hired and a 1,700-foot section of the southbound lanes of I-380 were modified by longitudinal surface grinding in October 1985 (Figure C). The purpose of this research is to document the effects of pavement surface modification on traffic noise levels while also monitoring changes in frictional characteristics.

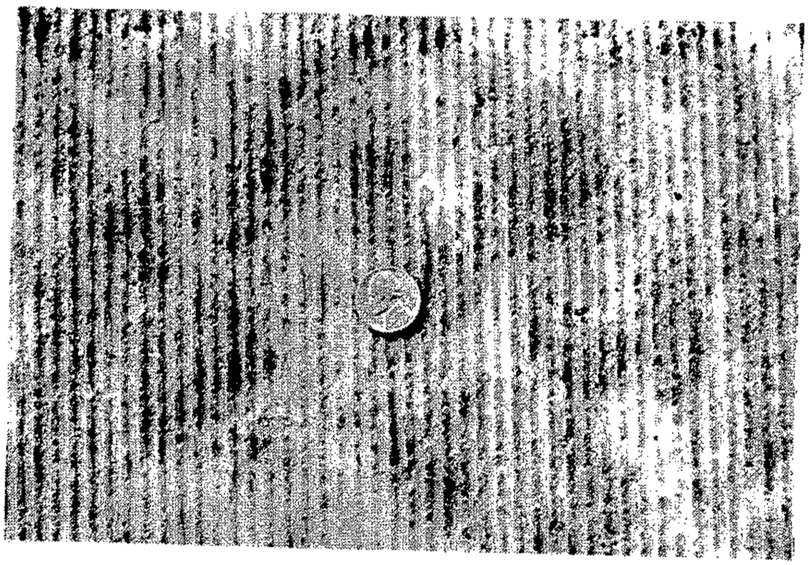
Traffic Noise Measurements

Noise data acquisition was made possible by the cooperative efforts of several offices within the Federal Highway Administration which resulted in the availability of FHWA's Demonstration Projects Division mobile noise laboratory. This equipment afforded simultaneous measurement of overall

FIGURE C
SURFACE TEXTURE MODIFICATION

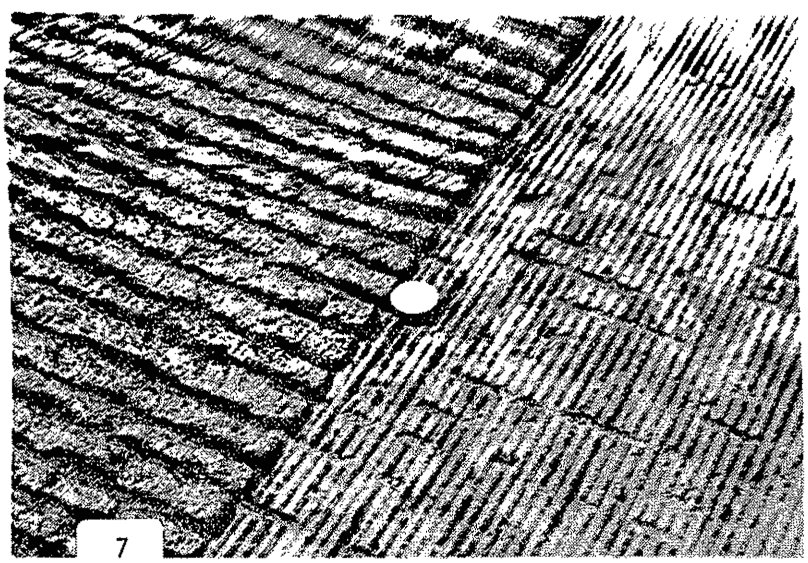
1. Before





2. After

3. Before/After



noise levels at multiple microphone locations. Additionally, frequency analysis at one microphone is possible for each monitoring period using this system. Traffic noise was monitored before the pavement surface was modified and immediately following surface modification. Eight microphone locations were used as described below and indicated on Figure B:

1. backyard deck at 1500 Sierra, elevation 162, 290 feet from roadway
2. backyard at 1500 Sierra, elevation 152, 290 feet from roadway
3. back deck at 1438 Sierra, elevation 167, 260 feet from roadway
4. ROW fence at 1500 Sierra, elevation 142, 110 feet from roadway
5. ROW fence at 1524 Sierra, elevation 136, 100 feet from roadway
6. backyard at 1524 Sierra, elevation 146, 305 feet from roadway
7. backyard at 1600 Sierra, elevation 144, 280 feet from ramp, 330 feet from main line
8. backyard at 1606 Sierra, elevation 144, 260 feet from ramp, 345 feet from main line

A total of 44 15-minute samples were taken prior to pavement surface grinding. Thirty-two 15-minute samples were taken after grinding was completed. Overall noise levels, described by Leq, were computed by the laboratory's data analysis system for each microphone during each sampling period. However, a frequency analysis report, in the form of a histogram of the Leqs of 27 frequency bands, can be produced for only a single microphone during each sampling period with this system.

The samples were obtained during morning and evening rush hours as well as off-peak traffic periods throughout a typical weekday. Total daily traffic volumes were observed during 15-minute counts to have increased slightly during the "after" measurements as a result of I-380 having been opened to traffic on the section which completed the highway to Waterloo. Larger volumes of medium and heavy trucks recorded during the after counts appear to be the primary cause of the increased noise.

In terms of general A-weighted noise levels without regard to frequency characteristics the before and after data are summarized in two tables. Table 1 indicates hourly Leqs for a 24-hour weekday sampling period for both before and after conditions at Site 1. This data was obtained by the use of a BBN 614 community noise analyzer. Table 2 shows before and after Leqs for typical weekday morning and evening peak traffic periods and also for a midday (off-peak) period at each study site, with accompanying traffic counts.

TABLE 1
24-Hour Sample at Site 1

Time	Hourly Leq, dBA Before Grinding*	Hourly Leq, dBA After Grinding**
0100	61	63
0200	59	59
0300	59	59
0400	59	59
0500	60	60
0600	63	63
0700	67	67
0800	69	69
0900	68	68
1000	67	68
1100	67	67
1200	67	69
1300	67	68
1400	67	68
1500	67	68
1600	67	69
1700	68	70
1800	68	69
1900	67	67
2000	67	66
2100	65	65
2200	65	65
2300	64	64
2400	61	63

* September 5, 1985
** October 28, 1985

TABLE 2

Representative Before and After Leqs at Each Study Site

15-Minute Leq, dBA

Site	Morning Peak Before	Morning Peak After	Evening Peak Before	Evening Peak After	Off-peak (Midday) Before	Off-peak (Midday) After
1	69.7	69.4	68.8	70.2	67.7	68.6
2	69.8	68.7	68.7	69.9	66.9	67.4
3	70.9	70.4	72.4	72.1	68.5	69.3
4	77.0	74.7	75.4	75.0	73.3	73.4
5	74.0	72.1	72.8	72.1	70.1	70.3
6	67.2	67.0	67.0	67.7	64.4	66.1
7/8*	67.8	66.6	66.1	67.7	64.3	65.5

	Morning Peak				Evening Peak				Off-peak (Midday)			
	Before		After		Before		After		Before		After	
	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
Autos	207	548	352	967	805	475	850	457	360	269	410	318
M Trks.	6	7	16	15	6	8	7	4	9	11	11	15
H Trks.	12	11	15	15	10	22	13	29	20	14	31	20

* "Before" measurements were made at Site 8;
"After" measurements were made at Site 7.

The data in Table 1 show slight but consistent increases in midday and evening rush hour Leqs ostensibly due to increased truck traffic resulting from I-380 completion to Waterloo. Traffic noise levels during the morning rush period, which has a higher southbound traffic volume, may have been affected by the pavement surface grinding. Table 2 data also suggest this effect. Morning peak noise levels at all study sites did not increase even with substantially higher traffic counts. In fact, noise reductions in the range of 2 dBA were observed at Sites 4 and 5, the two ROW line study sites. This was not the case during the evening peak traffic period where slight increases were the norm except at Sites 3, 4, and 5 which are most exposed to I-380. Slight decreases were measured at those sites. During the midday off-peak periods typical "after" noise levels were somewhat higher at each site, apparently due to increased traffic. Again only very minimal increases were observed at Sites 4 and 5 despite the larger traffic volume during this 15-minute sample. In terms of overall noise levels, these data indicate a quieting effect on southbound traffic as a result of the pavement surface modification. They further indicate that this effect is most observable at the nearest study sites.

In terms of frequency-specific noise levels, as described previously one microphone could be calibrated for frequency spectrum analysis during each 15-minute sampling period. Representative frequency analysis reports were obtained for each of the study sites for both before and after conditions. Actual traffic counts were not made during each of the 76 sampling periods. This precluded comparison of before and after spectra based on a constant traffic parameter. Instead, for each site an effort was made to compare frequency histograms where the overall before and after Leqs were the most similar. For example, Figures 1 and 1A are copies of the actual reports (produced by the FHWA noise analysis system printer) for Site 1 before and after, respectively. Additional information in the form of the date and time of the sample has been added. The frequency profiles of the before and after reports for each site can then be compared and any obvious change in the frequency characteristics of the monitored traffic noise can be identified.

Comparing these data, the general shape of the histograms formed by the Leqs of Channel 14 (25 Hertz) through Channel 40 (10,000 Hertz) are similar with peaks in the 80-100 Hertz and 1,000-1,250 Hertz ranges. Upon closer inspection of the before and after data, however, two areas of the frequency spectra show noticeable differences. First, the 80-100 Hertz peak in the after reports are generally higher; this would be expected from the increase in low frequency noise emissions from the observed higher truck volumes. The common higher frequency peak at the 1,000-1,250 Hertz

(1.0 KHZ - 1.25 K) range remained generally unchanged. A second dichotomy from before data, however, is identified in the highest frequency ranges, primarily at 8,000 Hertz. Here peaks that were consistently evident especially at the ROW sites (Sites 4 and 5) were clearly reduced (Figures 4A and 5A). This high frequency was less prominent in the before data at the more remote sites, with Site 6 (Figure 6) showing somewhat higher values in these ranges than the other sites near the houses. In all cases, however, this high frequency peak was reduced to below the 40 dB "floor" of the analysis system in the after data. These observations would suggest that the pavement surface modification has effectively eliminated a high frequency component of the before traffic noise spectrum.

The transmission of high frequency noise is affected by intervening ground cover and tree foliage. The difference in Site 6 compared to the other sites near the affected residences could possibly be a function of both overall exposure to the highway and intervening vegetation. Sites 1 and 2 are closer to the hill and highway cut at the south extremity of the exposed area while Site 7 is closer to the existing noise wall which defines the north extremity of the study area; Site 6 represents maximum horizontal exposure to I-380. Elevation differences among these sites may also affect exposure to high frequency noise. In the higher-elevated Sites, 1 and 2, there appears to be more mitigation of high frequency noise from intervening foliage. Sites 7 and 8 are less exposed to high frequency tire/surface interface noise by virtue of their lower elevation.

No survey of the adjacent residents was carried out to gauge their immediate opinion as to the effect of the surface modification on the quantity or quality of the traffic noise. During the after monitoring session one resident offered his judgement that the pitch of the traffic noise was less annoying. Another, however, testified that two tones were now noticeable and the noise was not improved by the project. It is the opinion of the authors that the immediate effect of the surface grinding was noticeable and one of improvement; the tire noise was appreciably quieter in our opinion.

Summary and Preliminary Conclusion

Based on measured overall noise levels and frequency analyses, the modification of transverse groove pavement surface texture by longitudinal grinding has lowered traffic noise levels by reducing a high frequency component of the total traffic noise spectrum. Calculation of the absolute degree of reduction is complicated by the change in traffic characteristics between before and after conditions. Applying the most recent version of FHWA's Traffic Noise Prediction Model, Stamina 2.0, to the morning rush hour conditions of Table 2, the predicted before noise levels are consistently lower than those actually measured while the predicted after noise levels agree much more closely with those observed. These data are shown in Table 3. The FHWA noise prediction model does not consider the effects of special pavement surface textures which might explain the discrepancy between the predicted and observed Leqs in the before situation. It appears that the increase in traffic has in effect offset the noise reduction benefits of the pavement modification in the study area. This also suggests the noise reduction benefits of the grinding project during the morning peak traffic hour may approach the 1-4 dBA range at the affected residences. While this degree of reduction is appreciably less than the 8-10 dBA reduction required to recommend construction of noise walls by the Iowa DOT, these preliminary data suggest that alternative surface treatments might be worthy of consideration in some situations.

TABLE 3

Application of Stamina 2.0 - Comparison With Observed Leqs
Morning Peak Hour Leq, dBA

Site	Before Predicted	Before Observed	Difference = Estimated Reduction	After Predicted	After Observed
1	67.3	69.7	2.4	69.3	69.4
2	66.1	69.8	3.7	68.2	68.7
3	68.0	70.9	2.9	70.0	70.4
4	70.7	77.0	6.3	72.8	74.7
5	68.8	74.0	5.2	71.9	72.1
6	66.0	67.2	1.2	68.1	67.0
7/8	65.7	67.8	2.1	67.8	66.6

Roadway Surface Friction Testing

Before and after friction testing was conducted on the experimental roadway section by the Special Investigations Section of the Iowa DOT's Office of Materials. A pavement surface friction testing unit, calibrated in accordance with standardized procedures at the Texas Transportation Institute in College Station, Texas, was used. The unit is towed over the test section and measures the coefficient of friction on the wetted pavement surface. Table 4 summarizes the friction data collected. These initial data indicate minor changes in the friction characteristics of the highly traveled center and right lanes as a result of the surface modification. More significant frictional changes resulted from the modification on the left and ramp lanes because of lesser texture wear on the before condition due to lighter traffic volumes. The speed gradient, which is the reduction in coefficient of friction per mile per hour increase in speed, indicates a consistently higher gradient for the after condition. This translates to a lower capacity of the roadway to reduce skidding on the wet pavement surface as travel speed increases. Further friction testing was conducted in parallel to the final noise monitoring portion of this research project. These final studies are discussed in Part II of this report.

TABLE 4

Mean Coefficient of Friction Values - I-380 Test Section

Standard Tire (ASTM E-501)

	40 mph		55 mph		Calculated Speed Gradient	
	Before	After	Before	After	Before	After
Left Lane	53 (8)	49 (4)	51 (8)	41 (4)	.13	.53
Center Lane	42 (8)	46 (4)	38 (8)	38 (4)	.27	.53
Right Lane	42 (8)	43 (4)	40 (8)	37 (4)	.13	.40
Ramp Lane	51 (4)	43 (4)	(unable to run ramp lane at 55 mph)			

Smooth Tire (ASTM E-524)

	40 mph		55 mph		Calculated Speed Gradient	
	Before	After	Before	After	Before	After
Left Lane	50 (12)	42 (4)	45 (12)	35 (4)	.33	.47
Center Lane	38 (12)	40 (4)	33 (12)	34 (4)	.33	.40
Right Lane	37 (12)	36 (4)	34 (12)	30 (4)	.20	.40
Ramp Lane	46 (8)	37 (4)	(unable to run ramp lane at 55 mph)			

(Number of Samples)

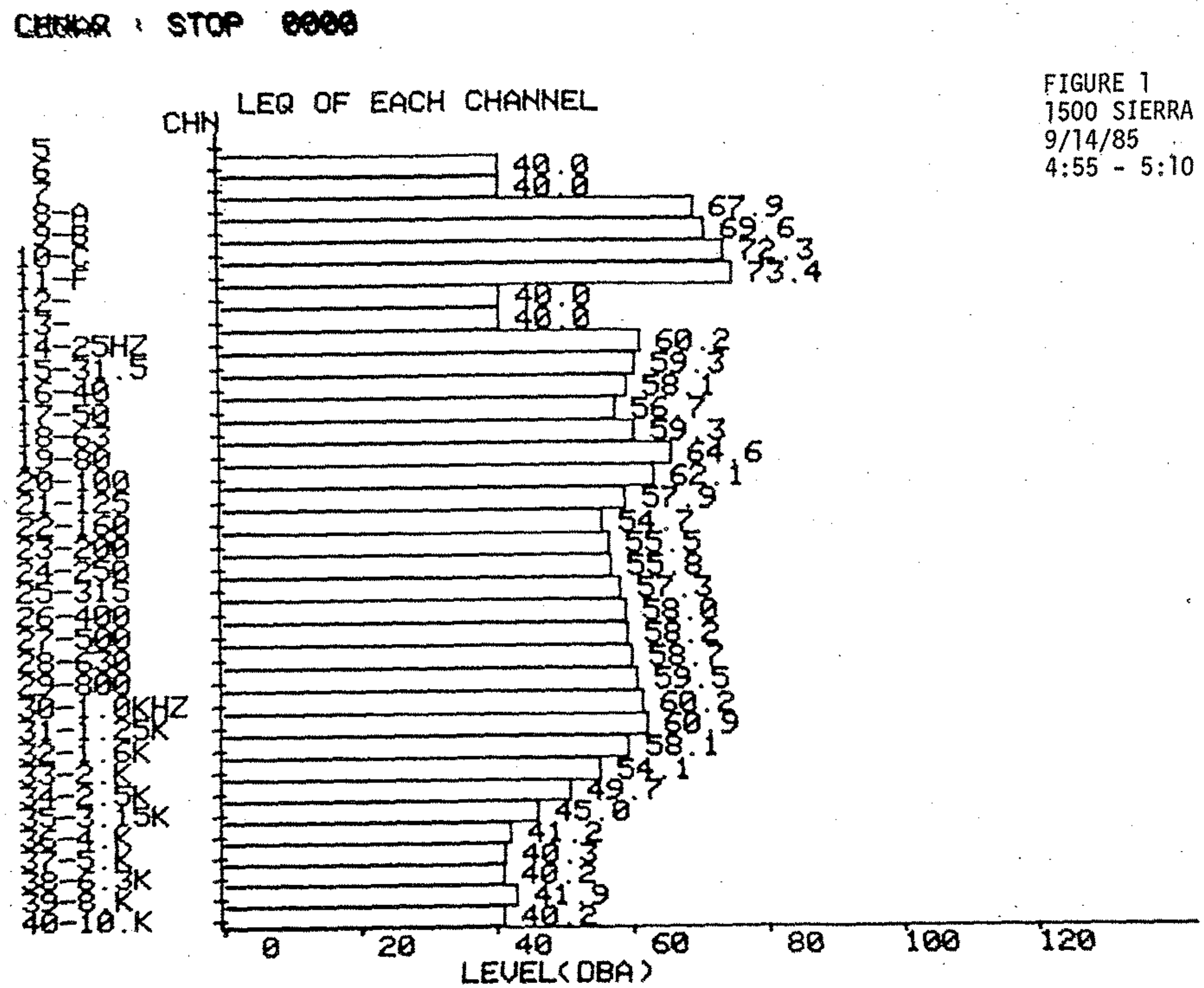


FIGURE 1
1500 SIERRA DRIVE DECK
9/14/85
4:55 - 5:10

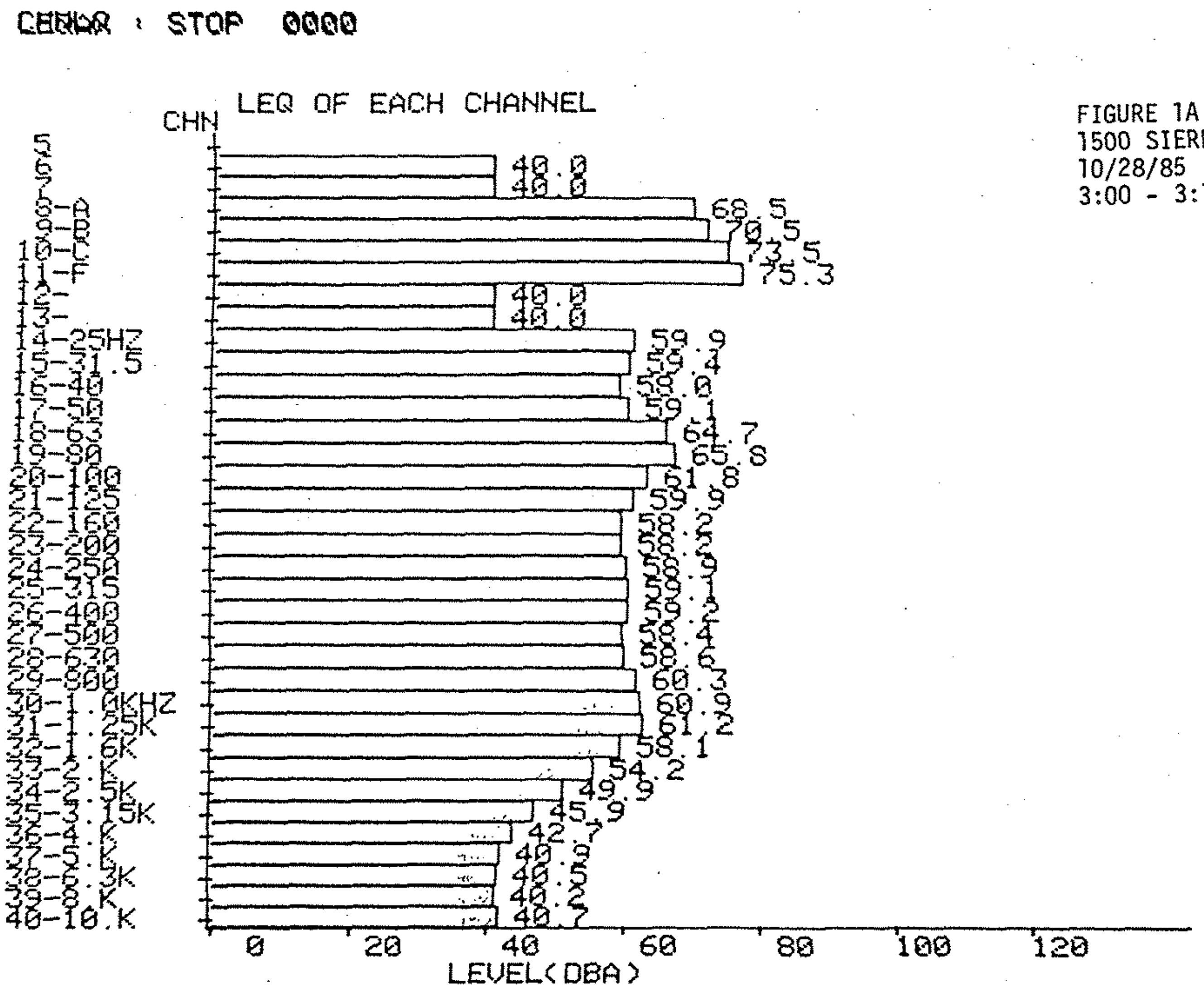


FIGURE 1A
1500 SIERRA DRIVE DECK
10/28/85
3:00 - 3:15 P.M.

CEQWR : STOP 0000

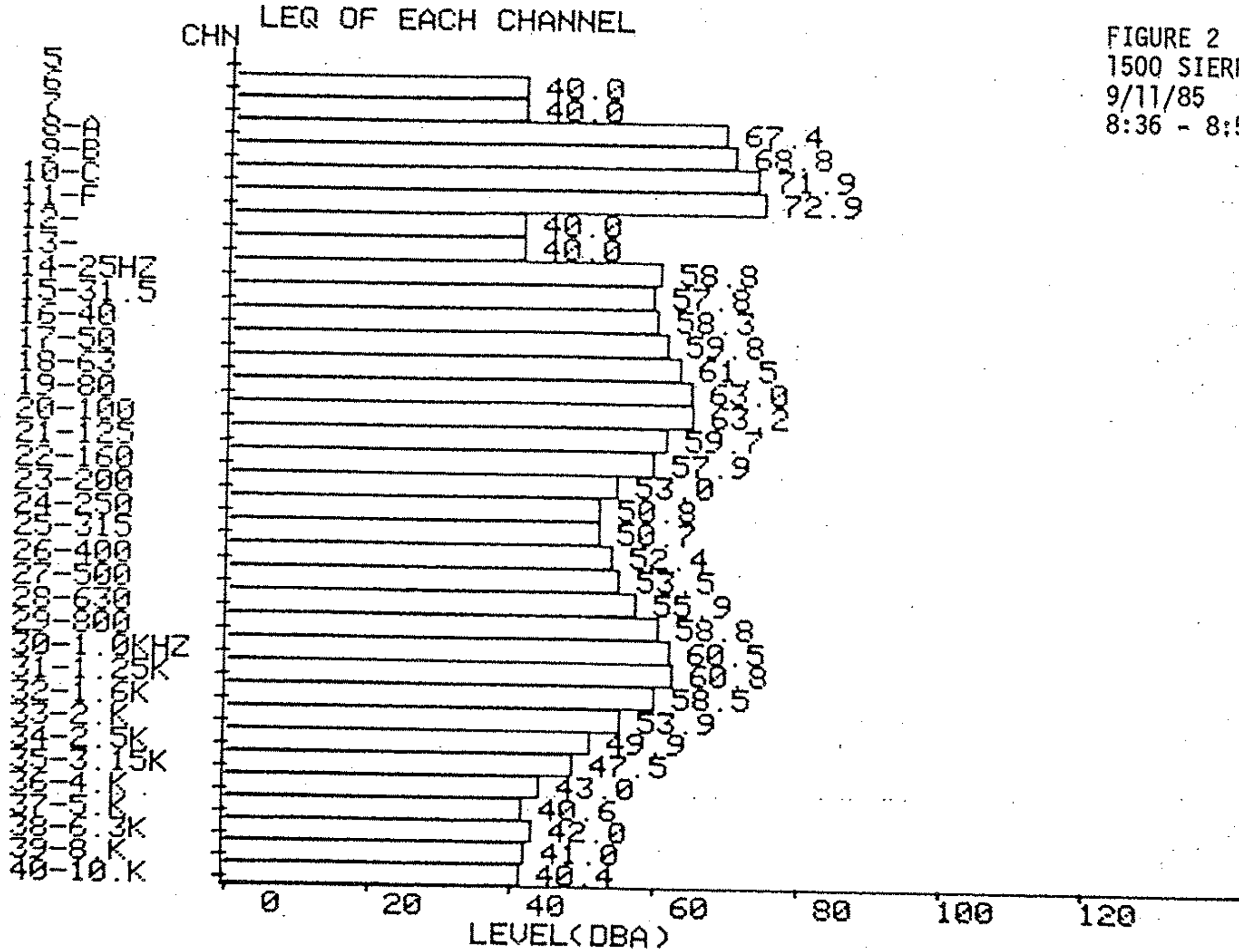


FIGURE 2
1500 SIERRA DRIVE BACKYARD
9/11/85
8:36 - 8:51 A.M.

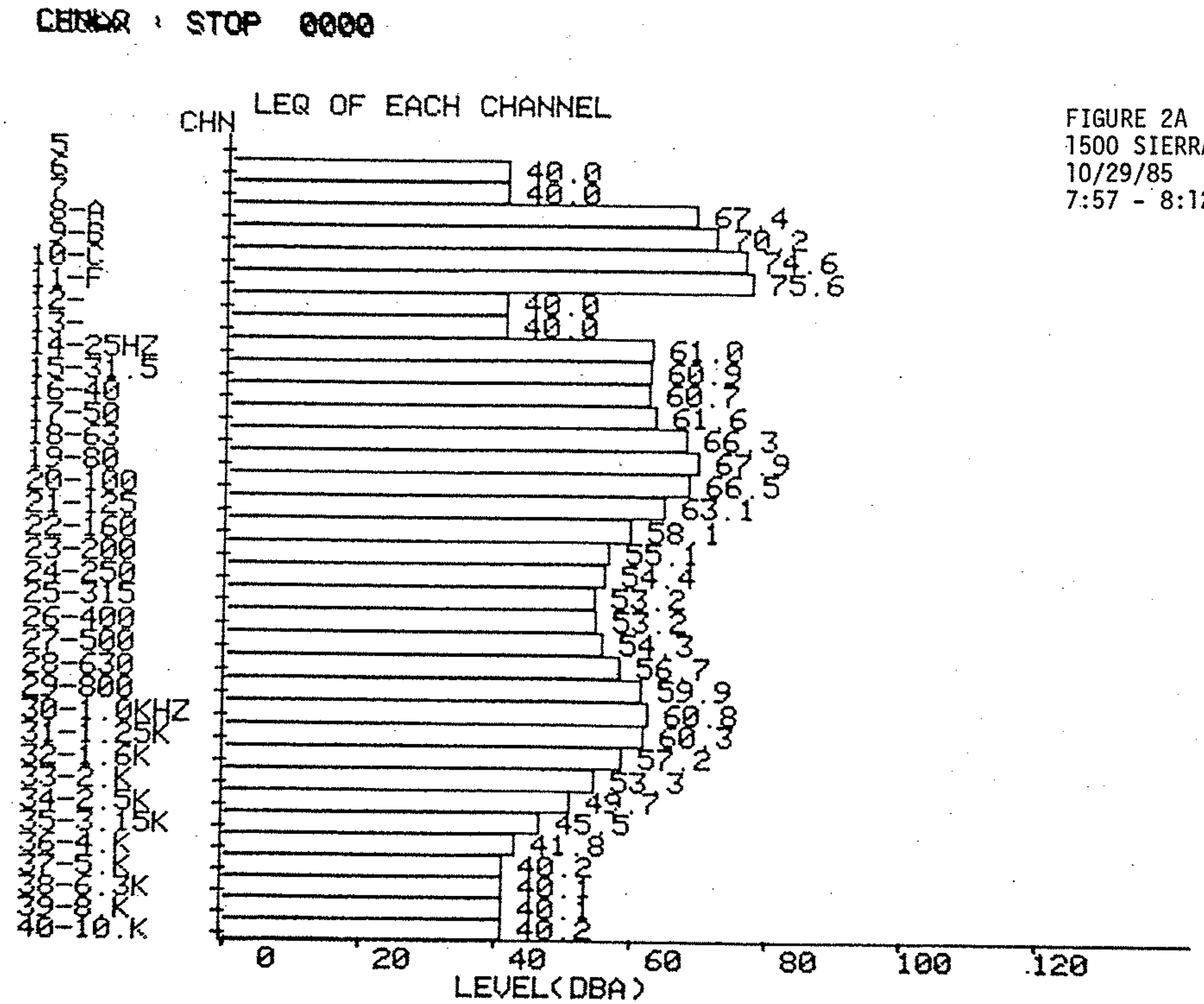
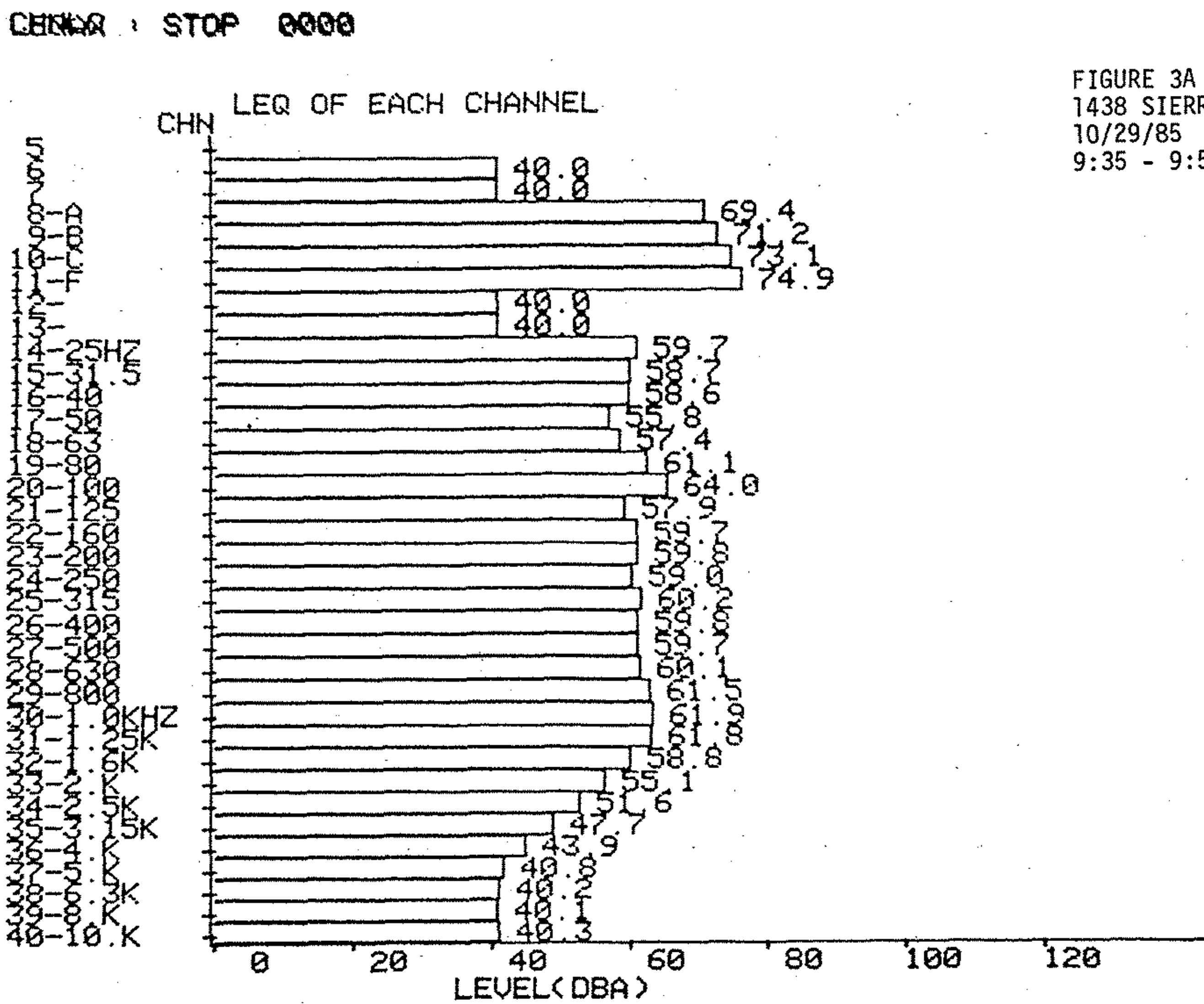


FIGURE 2A
1500 SIERRA DRIVE BACKYARD
10/29/85
7:57 - 8:12 A.M.

FIGURE 3A
1438 SIERRA DRIVE DECK
10/29/85
9:35 - 9:50 A.M.



CHNAR : STOP 0000

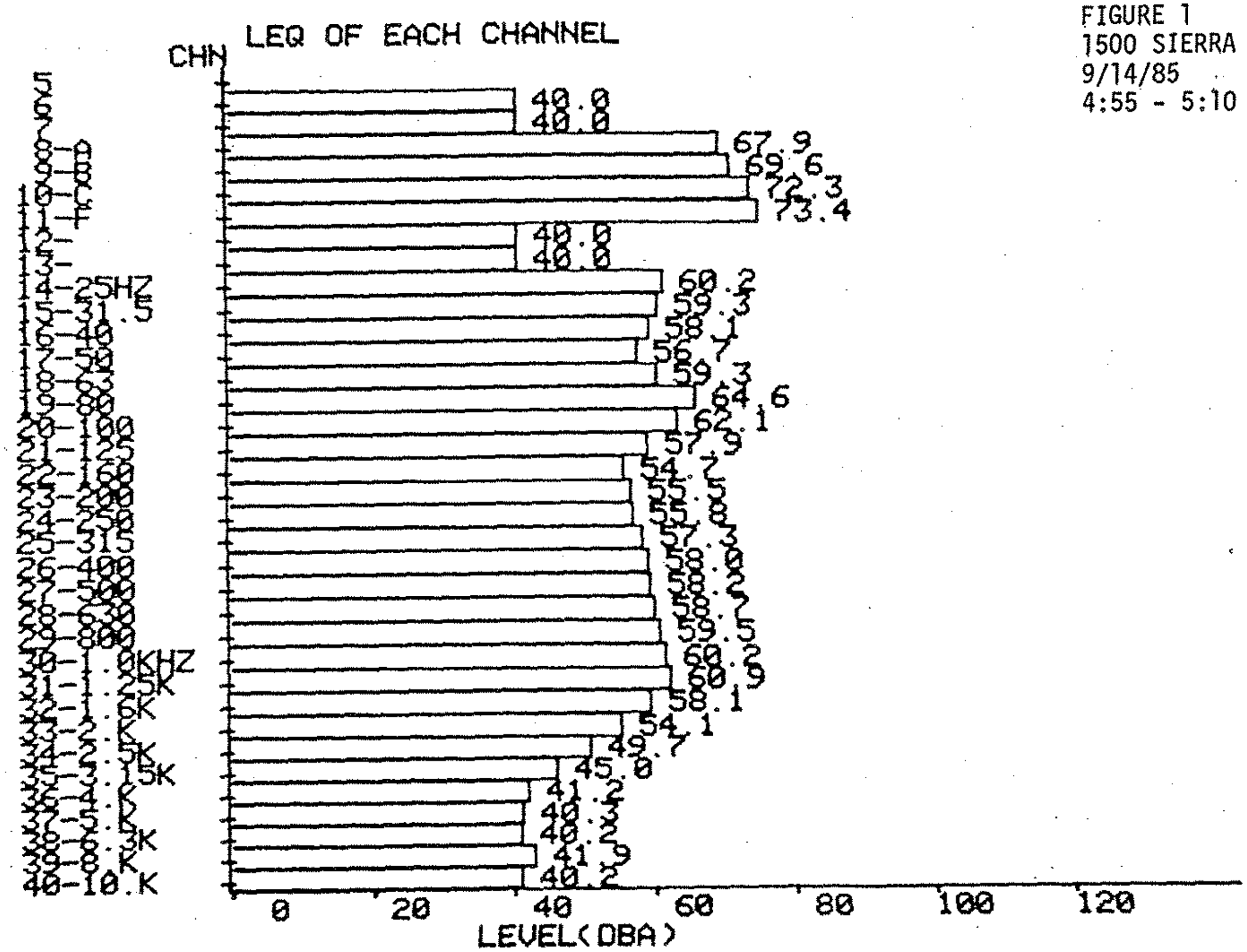


FIGURE 1
1500 SIERRA DRIVE DECK
9/14/85
4:55 - 5:10

CENWR : STOP 0000

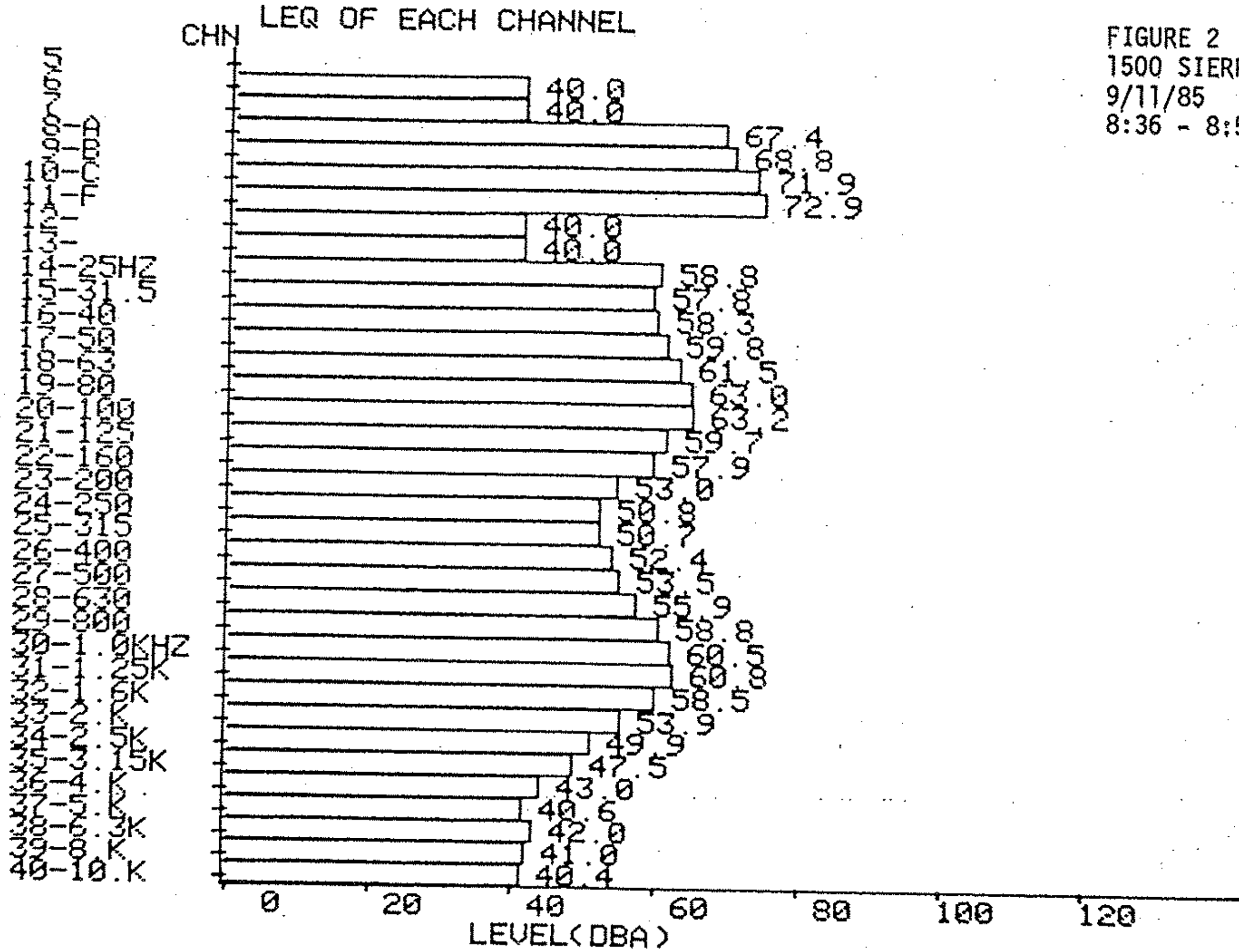
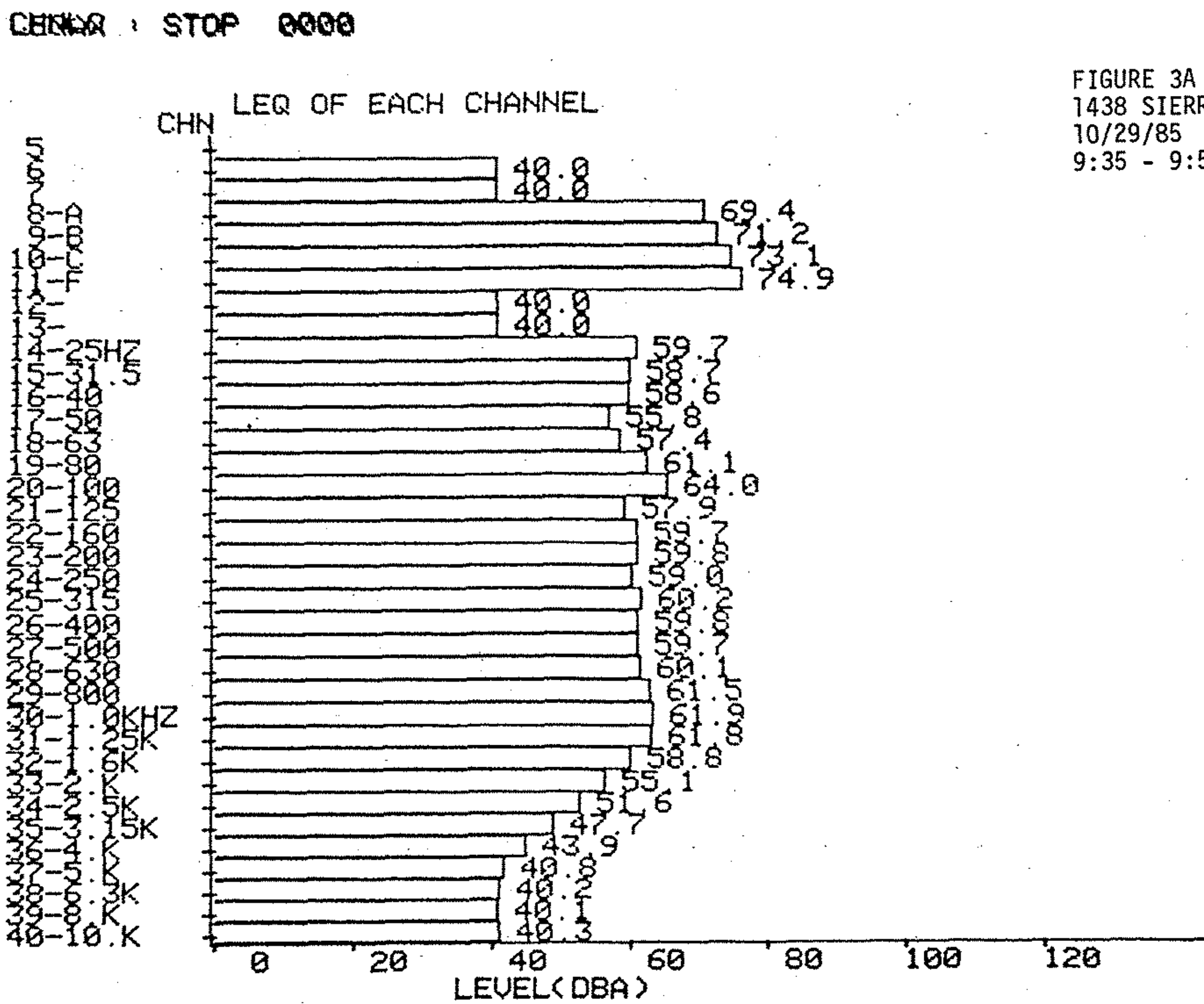


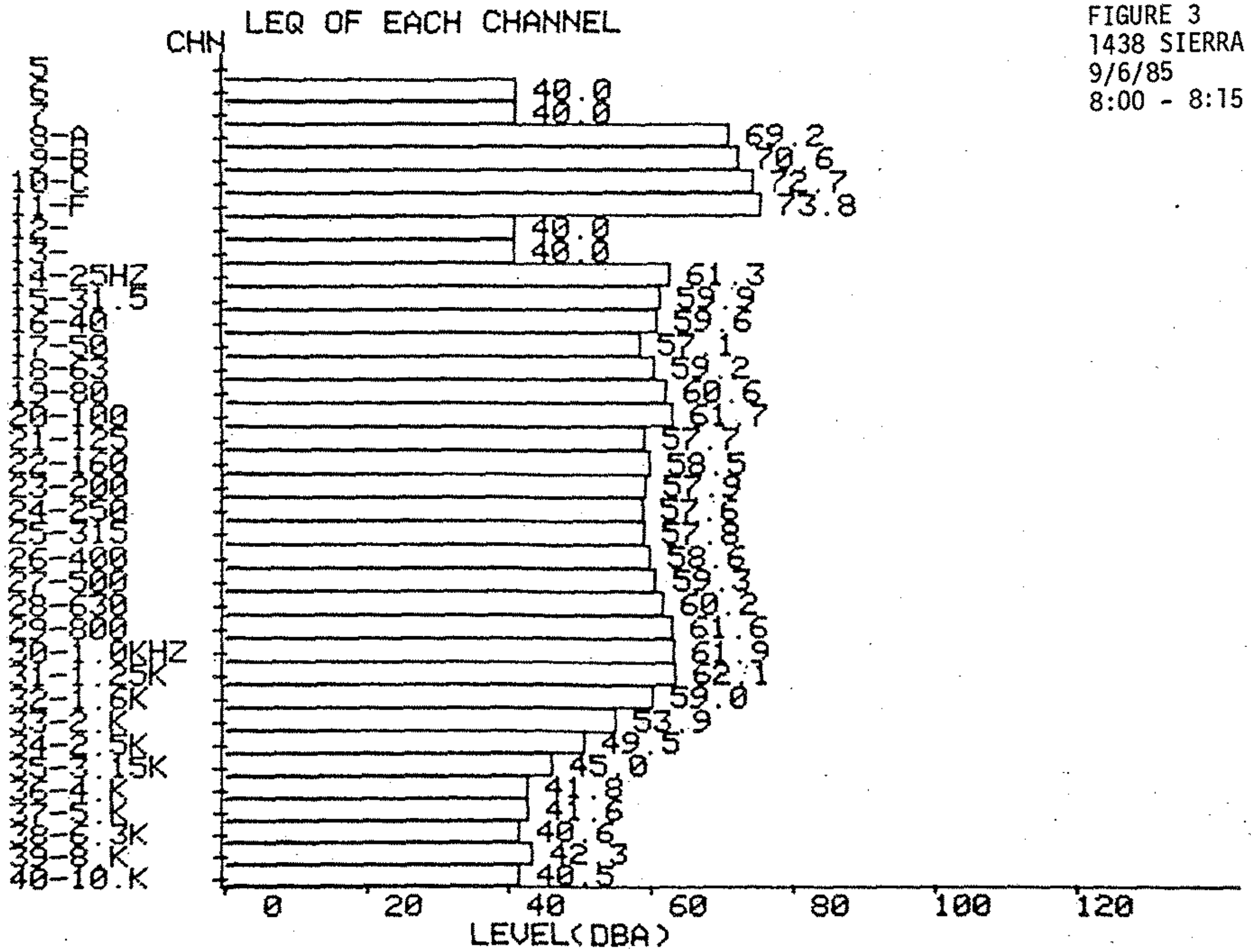
FIGURE 2
1500 SIERRA DRIVE BACKYARD
9/11/85
8:36 - 8:51 A.M.

FIGURE 3A
1438 SIERRA DRIVE DECK
10/29/85
9:35 - 9:50 A.M.



CHNQR : STOP 0000

FIGURE 3
1438 SIERRA DRIVE DECK
9/6/85
8:00 - 8:15 A.M.



CHNNR : STOP 0000

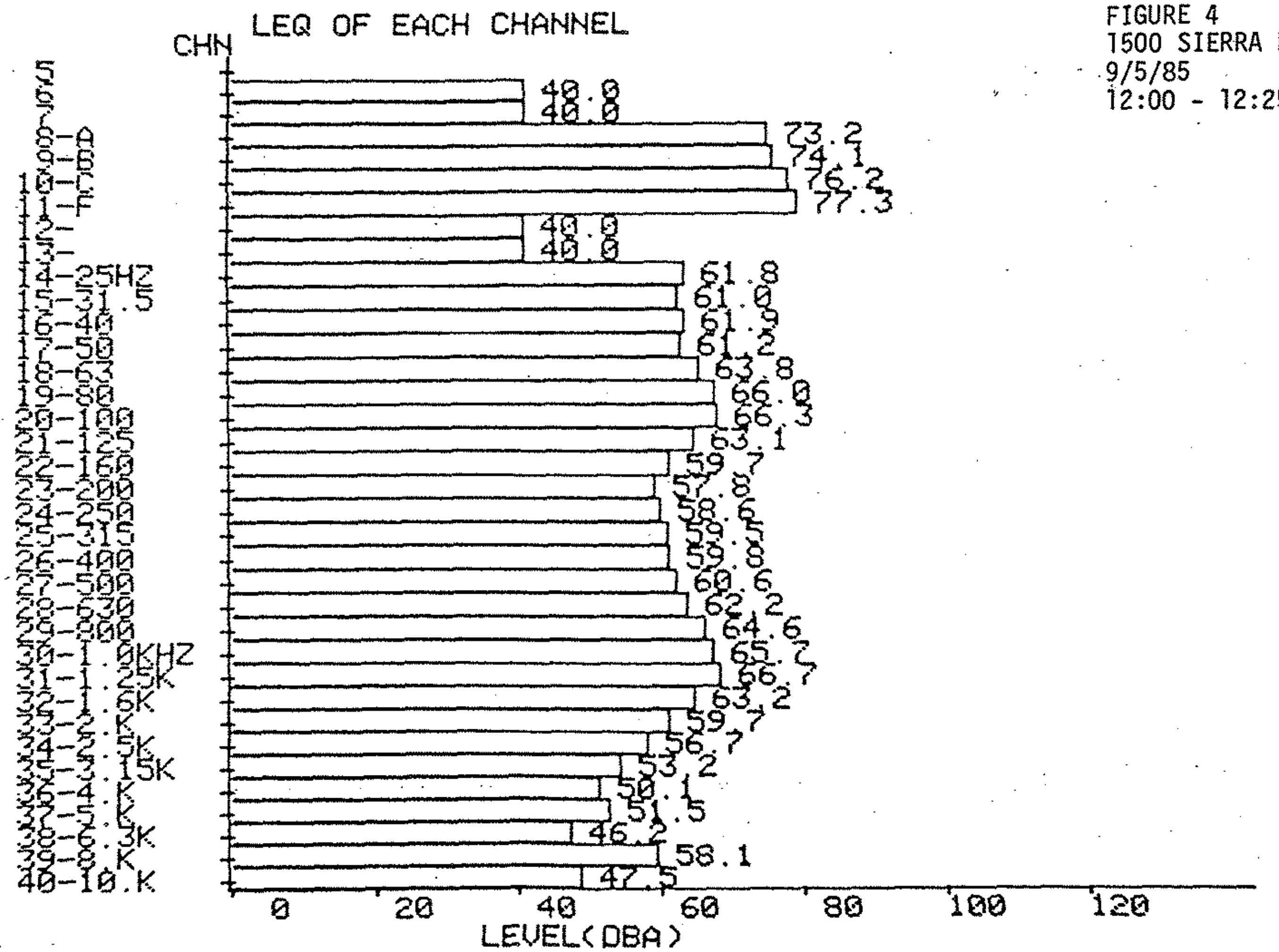


FIGURE 4
1500 SIERRA DRIVE ROW
9/5/85
12:00 - 12:25 P.M.

CENAR : STOP 0000

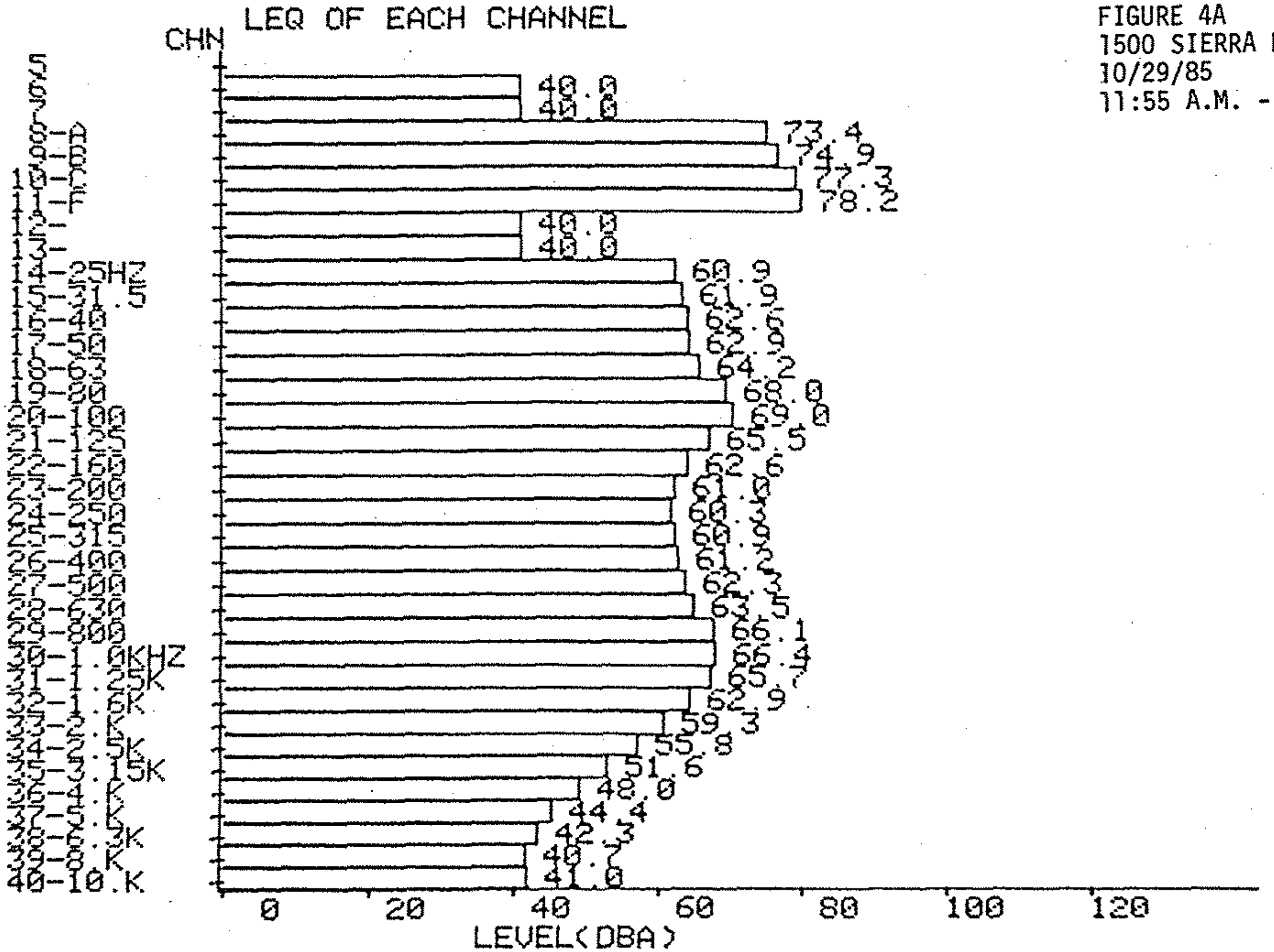
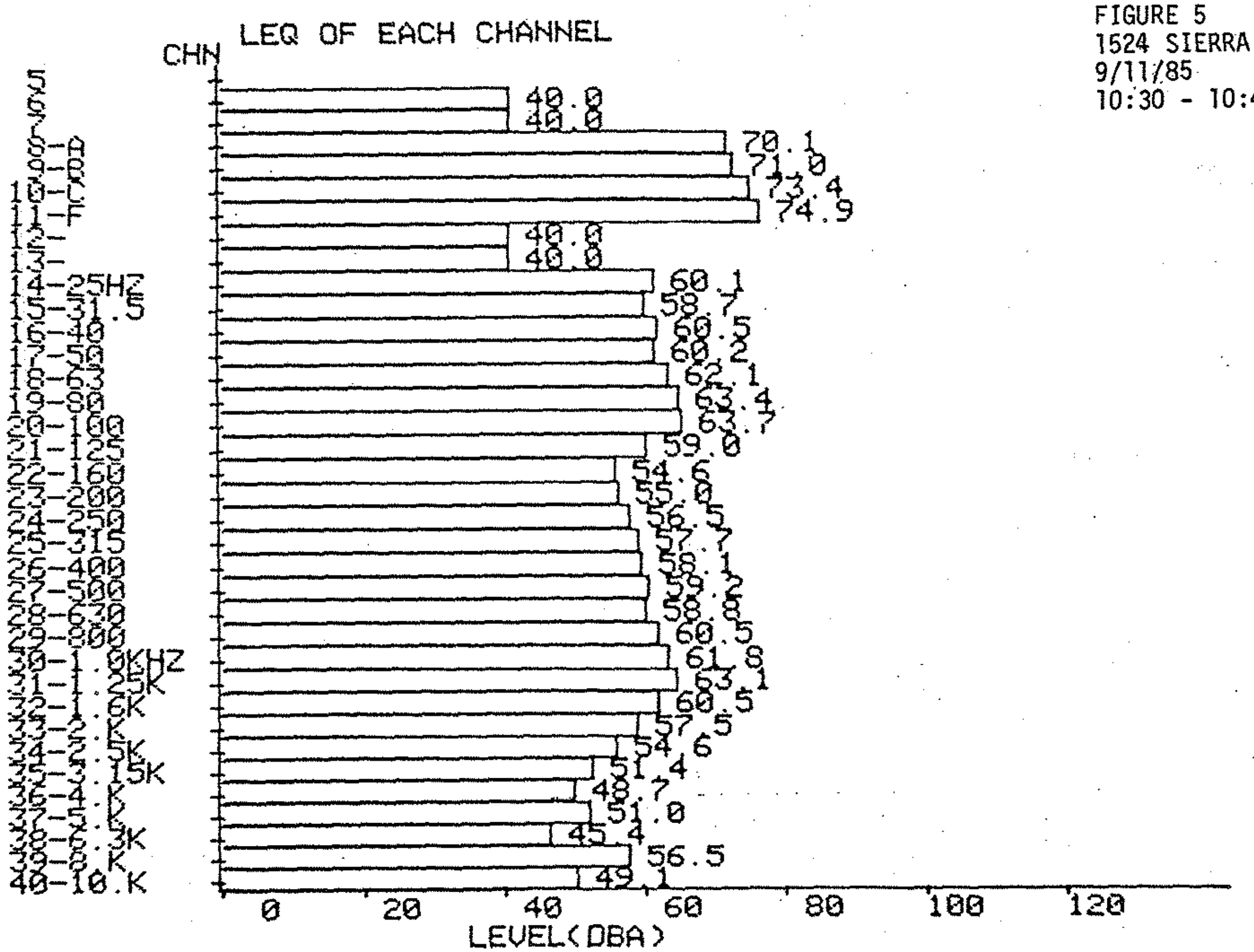


FIGURE 4A
1500 SIERRA DRIVE ROW
10/29/85
11:55 A.M. - 12:10 P.M.

CHNQR · STOP 0000

FIGURE 5
1524 SIERRA DRIVE ROW
9/11/85
10:30 - 10:45 A.M.



CHNAR : STOP 0000

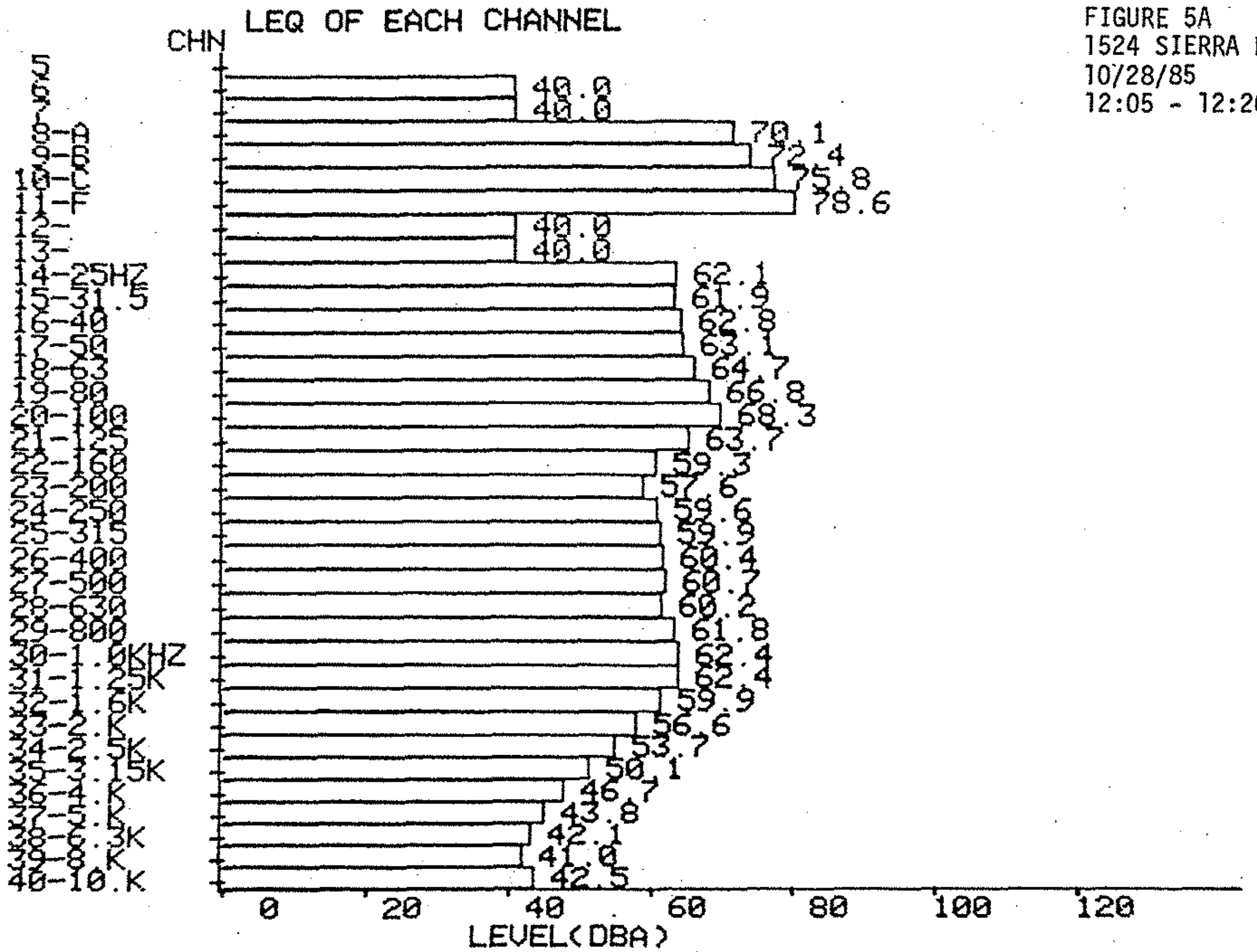


FIGURE 5A
1524 SIERRA DRIVE ROW
10/28/85
12:05 - 12:20 P.M.

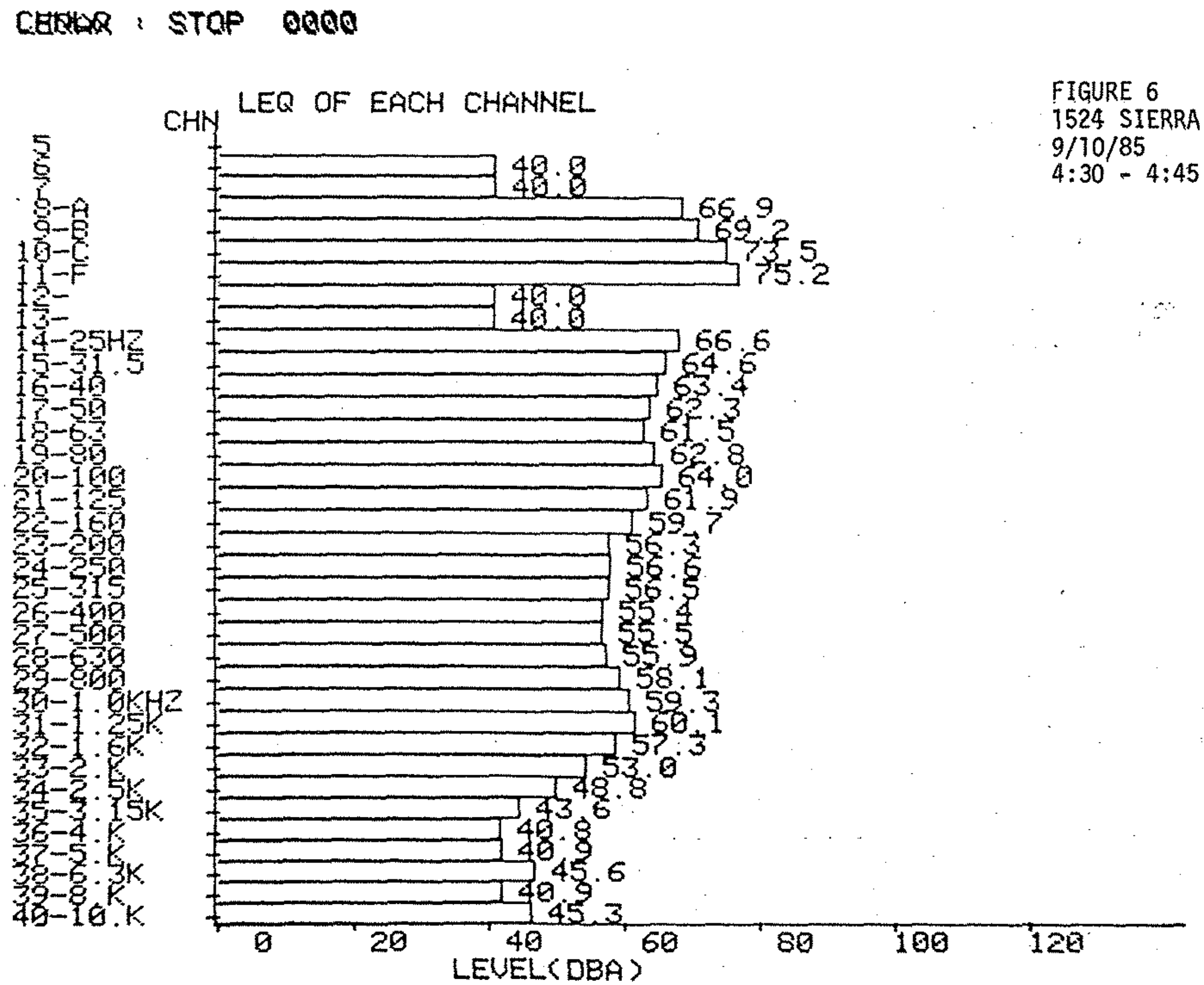
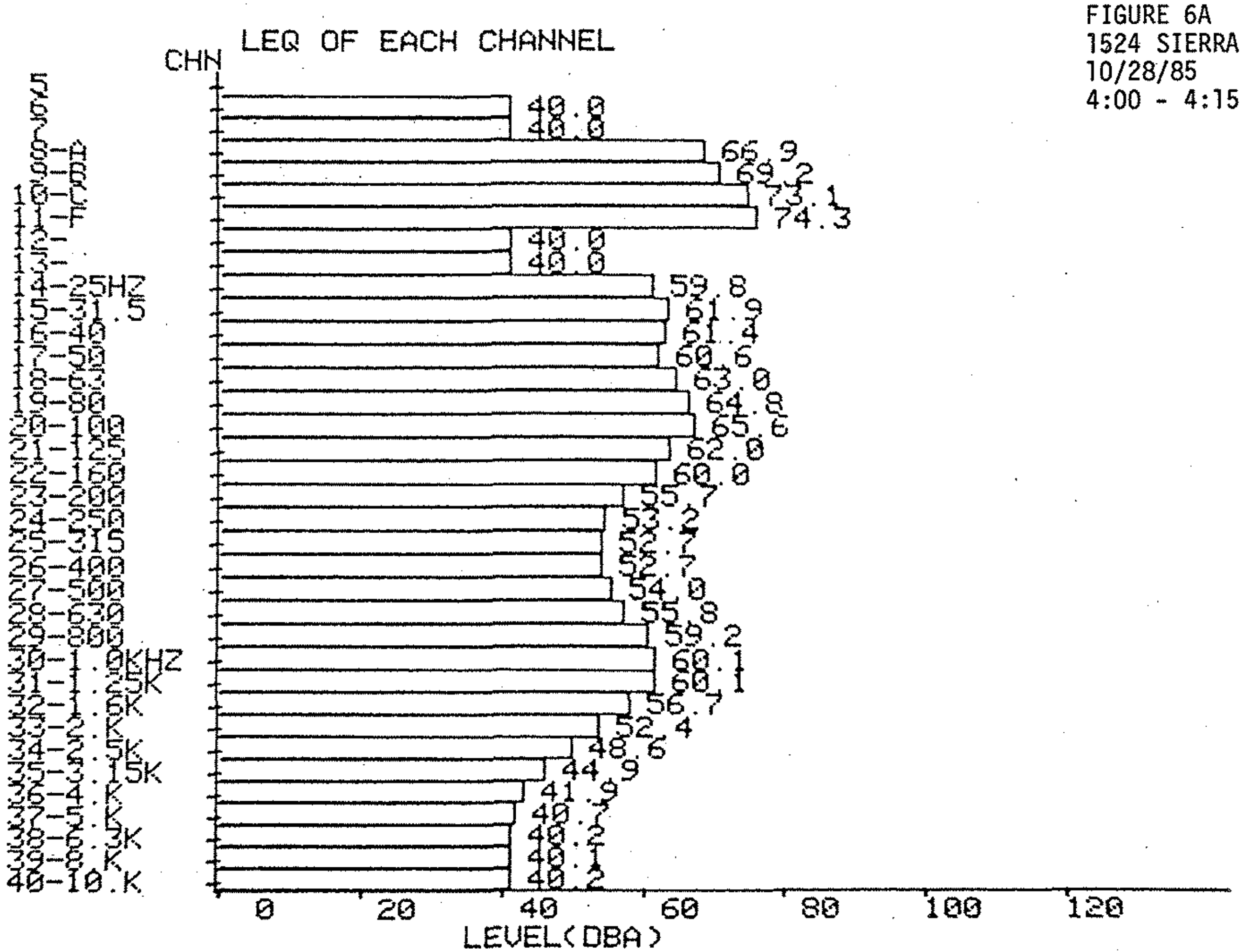


FIGURE 6
1524 SIERRA DRIVE BACKYARD
9/10/85
4:30 - 4:45 P.M.

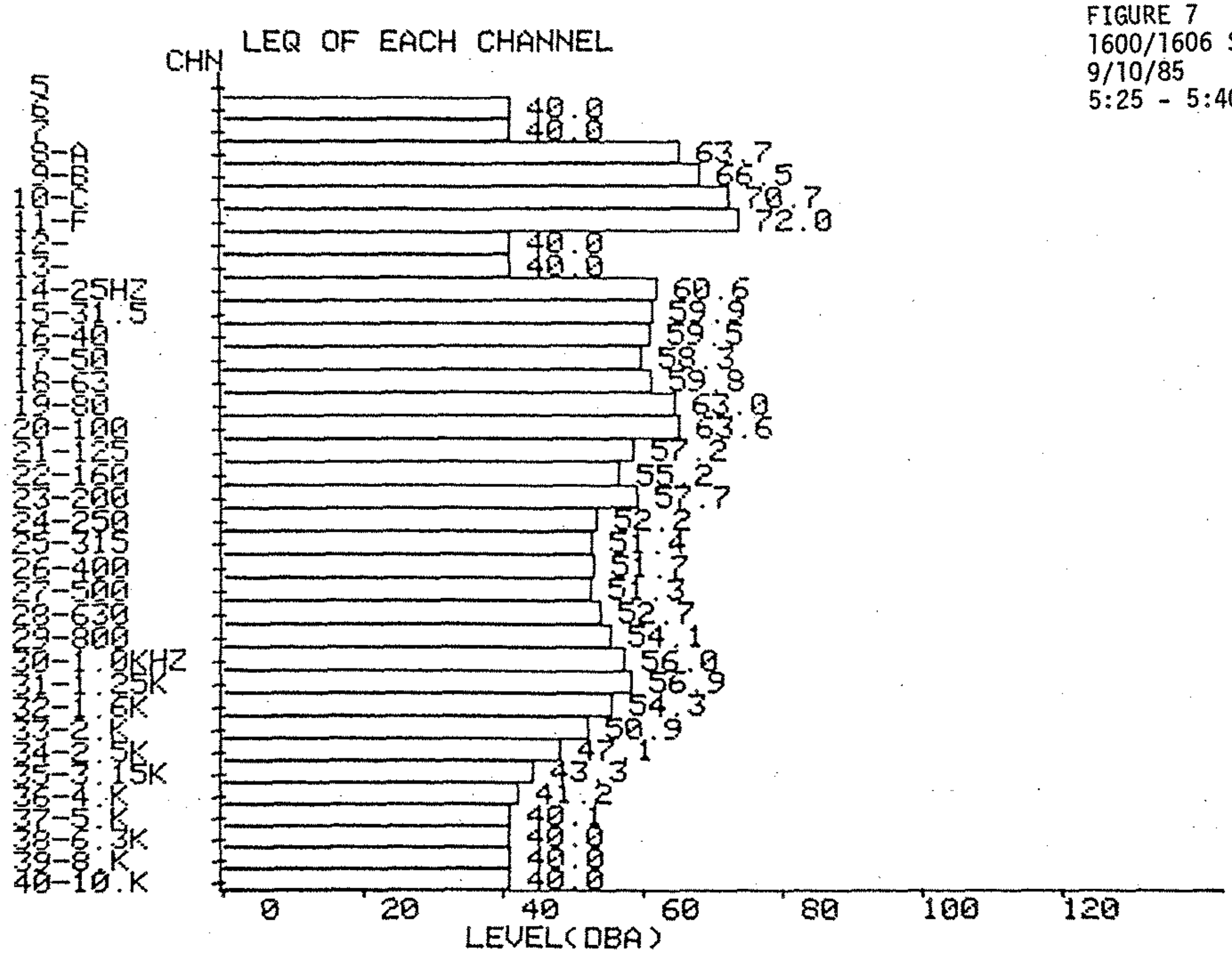
CENWR : STOP 0000

FIGURE 6A
1524 SIERRA DRIVE BACKYARD
10/28/85
4:00 - 4:15 P.M.



CENRR : STOP 0000

FIGURE 7
1600/1606 SIERRA DRIVE BACKYARD
9/10/85
5:25 - 5:40 P.M.



CHNKR : STOP 0000

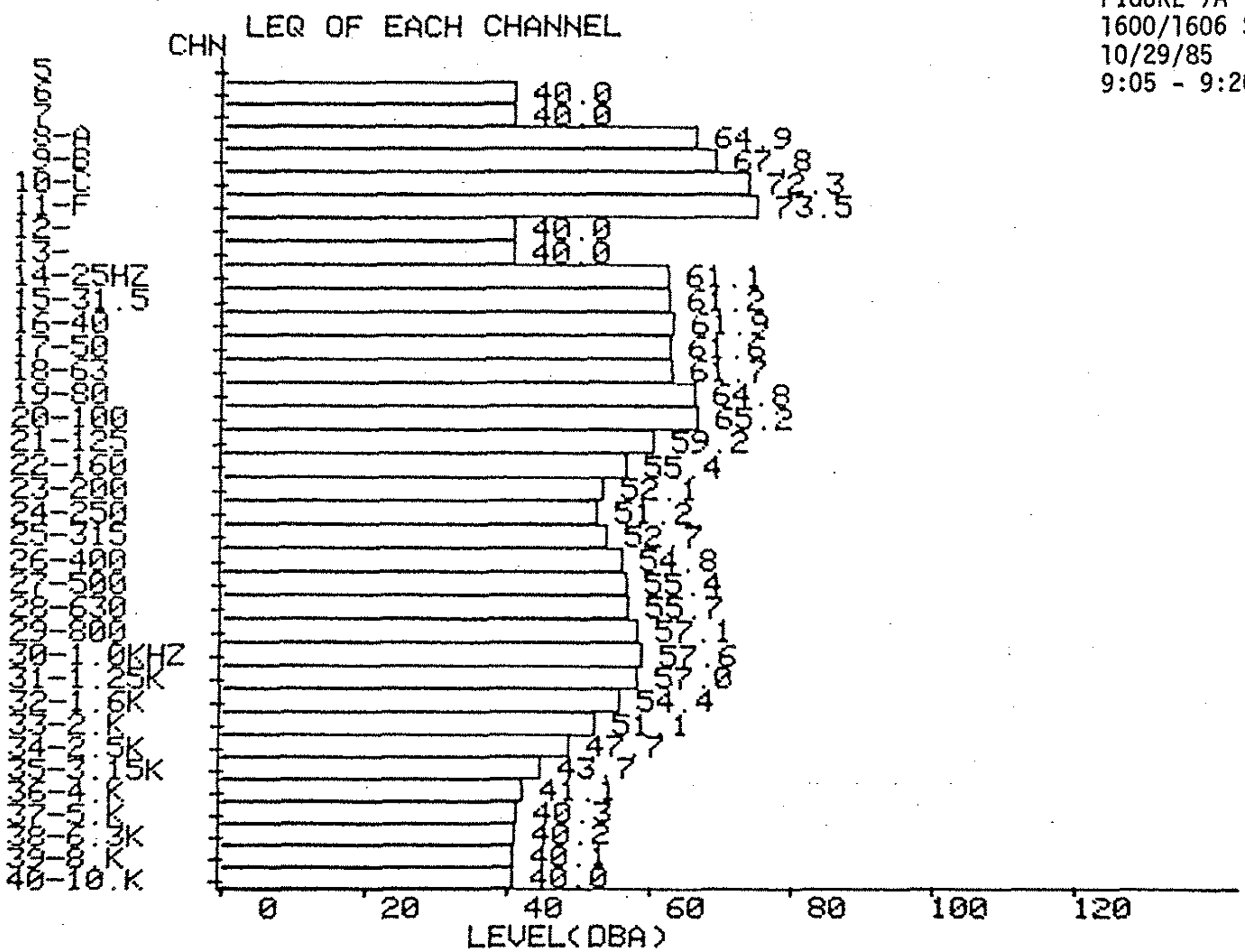


FIGURE 7A
1600/1606 SIERRA DRIVE BACKYAR
10/29/85
9:05 - 9:20 A.M.

Follow-up Traffic Noise Measurements

Follow-up studies scheduled for the spring of 1986 and fall of 1986 were delayed because of operational problems within the FHWA mobile noise laboratory. The needed repairs involved replacing the system's computer and repairing the RMS detector which is the system's primary noise data acquisition component. In early January 1987 the laboratory was again fully operational and it was transported to the project site during a period of unseasonably favorable weather. Noise data were obtained in accordance with the previous sampling format on January 8 and 9, 1987. A total of 16 samples were collected representing both morning and evening rush periods and also off-peak traffic conditions. Sampling site conditions were the same as before except that the foliage was absent and overall traffic volumes were somewhat lower due to normal seasonal fluctuation. Overall truck volumes were similar to those counted during the earlier studies. Table 5 summarizes a final 24-hour sample of Site 1 using the BBN 614 community noise analyzer, and Table 6 provides the final representative Leqs at each site.

Table 5

Summary of Final 24-Hour Samples at Site 1

Time	Hourly Leq, dBA Before Grinding*	After Grinding**	Final Sample***
0100	61	63	61
0200	59	59	61
0300	59	59	60
0400	59	59	59
0500	60	60	59
0600	63	63	62
0700	67	67	66
0800	69	69	68
0900	68	68	68
1000	67	68	67
1100	67	67	67
1200	67	69	67
1300	67	68	67
1400	67	68	67
1500	67	68	68
1600	67	69	68
1700	68	70	68
1800	68	69	68
1900	67	67	66
2000	67	66	65
2100	65	65	64
2200	64	65	64
2300	64	64	63
2400	61	63	61

* September 5, 1985
** October 28, 1985
*** January 21, 1987

Table 5 summarizing 24-hour sampling at Site 1, indicates that overall noise levels at Site 1 are much the same as were measured 15 months earlier. The data in Table 6 likewise generally show very similar final values as compared to the after data (from Table 2) measured previously. The evening peak Leqs are consistently slightly lower owing to a significantly lower southbound heavy truck volume during that final sampling period. The morning peak and off-peak final values in Table 6 are quite similar to the after data, with the slightly higher southbound truck volumes offsetting to some extent the effects of lower auto volumes.

Table 6

Summary of Representative Leqs at Each Study Site
15-Minute Leq, dBA

	Morning Peak			Evening Peak			Off-Peak (Midday)		
Site	Before	After	Final	Before	After	Final	Before	After	Final
1	69.7	69.4	70.3	68.8	70.2	69.5	67.7	68.6	68.7
2	69.8	68.7	68.7	68.7	69.9	68.3	66.9	67.4	66.9
3	70.9	70.4	71.4	72.4	72.1	71.5	68.5	69.3	7.04
4	77.0	74.7	76.2	75.4	75.0	73.6	73.3	73.4	73.5
5	74.0	72.1	72.7	72.8	72.1	71.8	70.1	70.3	70.5
6	67.2	67.0	67.6	67.0	67.7	67.3	64.4	66.1	65.5
7/8*	67.8	66.6	--	66.1	67.7	--	64.3	65.5	65.1

	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
Autos	207	548	352	967	314	626	805	475	850	457	767	535	360	269	410	318	291	249
M. Trks.	6	7	16	15	10	5	6	8	7	4	5	10	9	11	11	15	9	8
H. Trks.	12	11	15	15	15	21	10	22	13	29	28	12	20	14	31	20	35	27

*"Before" measurements were made at Site 8; "After" and "Final" measurements were made at Site 7.

Finally, the frequency spectra data for four of the study sites were collected. These data are shown in tabular form in comparison with the two previous monitoring conditions (from histograms, Figures 1-7A) in Table 7. These values, too, are similar to those measured previously except that there continues to be reduction in the highest frequency ranges, most notably at the more remote sites near the residences, apparently due to a still smoother roadway surface after 15 months of wear (Figure D).

Final Roadway Surface Friction Testing

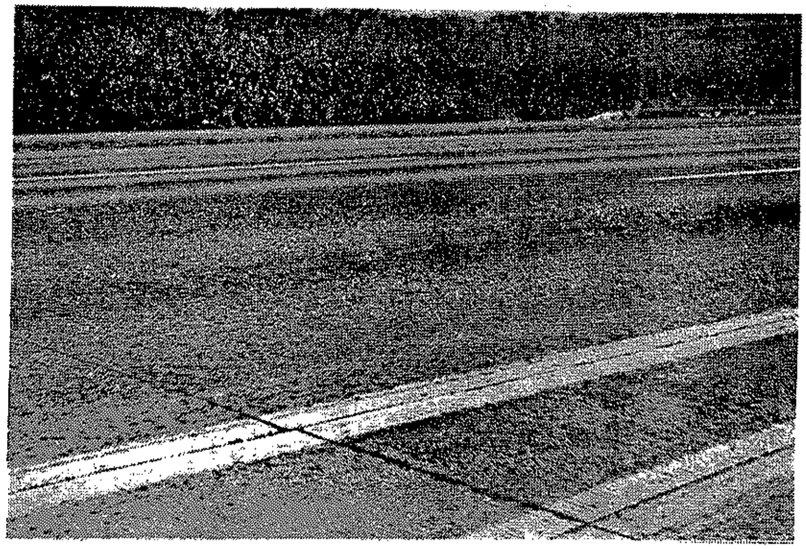
Table 8 compares the friction data which was collected 12 months after surface modification with that obtained earlier (from Table 4). The standard tire shows minor changes in friction numbers but continued increases in speed gradient. This indicates that wet pavement friction continues to decrease with increasing speed as the modified surface gets smoother with wear. As would be expected this trend is magnified, especially on the heavily traveled center and right lanes, when the test was conducted with the smooth tread tire. The speed gradient for the smooth tire increased markedly in all three lanes in this final test. These data indicate that the reduction in pavement texture results in less wet weather friction available to the motorist at both speeds tested.

Table 7

Individual Frequency Band Leq, dBA

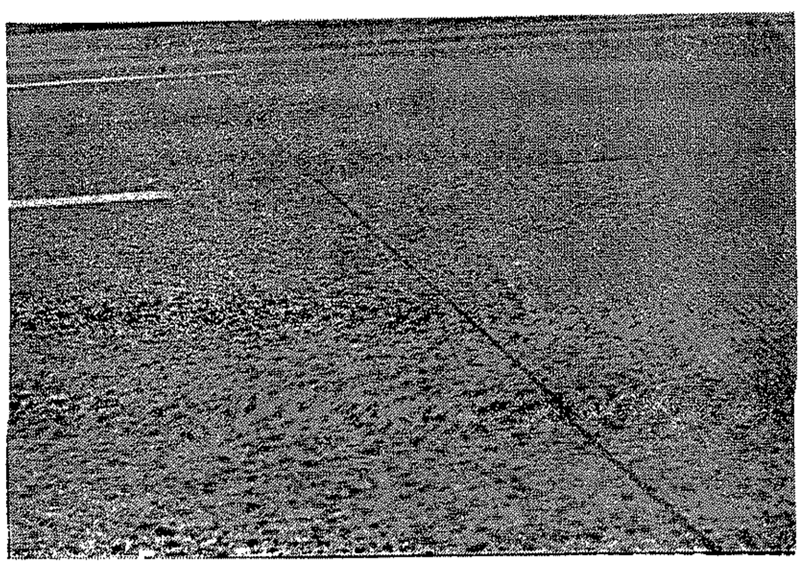
Center Frequency - Hertz	Site 1			Site 4			Site 5			Site 7		
	Before	After	Final	Before	After	Final	Before	After	Final	Before	After	Final
Overall Leq:	67.9	68.5	68.6	73.2	73.4	73.8	70.1	70.1	69.9	63.7	64.9	64.8
25	66.2	54.9	61.6	61.8	60.9	61.8	60.1	62.1	64.6	60.6	61.1	62.7
31.5	59.3	59.4	58.2	61.0	61.9	62.8	58.7	61.9	62.9	59.9	61.2	61.2
40	58.1	59.1	58.3	61.9	62.6	63.1	60.5	52.8	63.0	59.5	61.9	62.1
50	56.7	59.1	58.3	61.2	62.9	63.1	60.2	63.1	62.2	58.3	61.6	61.5
63	59.3	64.7	61.6	63.8	64.2	66.4	62.1	64.7	65.1	59.8	61.7	61.9
80	64.6	65.8	63.8	66.0	68.0	68.1	63.4	66.8	65.9	63.0	64.8	64.7
100	62.1	61.8	60.7	66.3	69.0	71.0	63.7	68.3	66.9	63.6	65.2	64.8
125	57.9	59.9	57.6	63.1	65.5	67.5	59.0	63.7	63.1	57.2	59.2	59.4
160	54.7	58.2	54.8	59.7	62.6	63.8	54.6	59.3	58.4	55.2	55.4	56.3
200	55.5	58.2	54.5	57.8	61.0	59.8	55.0	57.6	57.2	57.7	52.1	53.5
250	55.8	58.9	56.4	58.6	60.3	60.5	56.5	59.6	57.8	52.2	51.2	54.5
315	57.3	59.1	57.2	59.5	60.9	59.2	57.7	59.9	59.0	51.4	52.7	53.6
400	58.0	59.2	58.2	59.8	61.2	60.5	58.1	60.4	56.7	51.7	54.8	53.8
500	58.2	59.2	59.0	60.6	62.3	61.8	59.2	60.7	58.8	51.3	55.4	54.7
630	58.7	58.6	59.1	62.2	63.5	62.9	58.8	60.2	60.4	52.7	55.7	54.3
800	59.5	60.3	61.9	64.6	66.1	65.9	60.5	61.8	61.6	54.1	57.1	57.1
1KHZ	60.2	60.9	61.9	67.5	66.4	66.7	61.8	62.4	62.3	56.0	57.6	57.2
1.25K	60.9	61.2	60.9	66.7	65.7	67.1	63.1	62.4	63.0	56.9	57.0	57.0
1.6K	58.1	58.1	58.3	63.2	62.9	64.7	60.5	59.9	61.0	54.3	54.4	54.9
2K	54.1	54.2	54.3	59.7	59.3	61.3	57.5	56.6	57.2	50.9	51.1	51.5
2.5K	49.7	49.9	50.1	56.7	55.8	57.3	54.6	53.7	53.5	47.1	47.7	47.6
3.15K	45.0	45.9	45.1	53.2	51.6	52.9	51.4	50.1	49.8	43.3	43.7	43.4
4K	41.2	42.7	40.0	50.1	48.0	48.0	48.7	46.7	46.2	41.2	41.1	40.0
5K	40.3	40.9	40.0	51.5	44.4	44.3	51.0	43.8	43.6	40.1	40.3	40.0
6.3K	40.2	40.5	40.0	46.2	42.3	41.3	45.4	42.1	41.4	40.0	40.2	40.0
8K	41.9	40.2	40.0	58.1	40.7	40.3	56.5	41.0	40.4	40.0	40.1	40.0
10K	40.2	40.7	40.0	47.5	41.0	40.6	49.1	42.5	40.0	40.0	40.0	40.0

FIGURE D
SURFACE TEXTURE WEAR
AFTER 15 MONTHS



1. Test section and unmodified ramp gore

2. Test section showing lane wear



3. Terminus of test section/resumption of transverse groove

Table 8

Final Mean Coefficient of Friction Values - I-380 Test Section

Standard Tire (ASTM E-501)

	40 mph			55 mph			Calculated Speed Gradient		
	Before	After	Final	Before	After	Final	Before	After	Final
Left Lane	53 (8)	49 (4)	54 (4)	51 (8)	41 (4)	44 (4)	.13	.53	.67
Center Lane	42 (8)	46 (4)	44 (4)	38 (8)	38 (4)	33 (4)	.27	.53	.73
Right Lane	42 (8)	43 (4)	45 (4)	40 (8)	37 (4)	36 (4)	.13	.40	.60
Ramp Lane	51 (4)	43 (4)	46 (4)	(unable to run ramp lane at 55 mph)					

Smooth Tire (ASTM E-524)

	40 mph			55 mph			Calculated Speed Gradient		
	Before	After	Final	Before	After	Final	Before	After	Final
Left Lane	50 (12)	42 (4)	46 (4)	45 (12)	35 (4)	34 (4)	.33	.47	.80
Center Lane	38 (12)	40 (4)	27 (4)	33 (12)	34 (4)	19 (4)	.33	.40	.53
Right Lane	37 (12)	36 (4)	29 (4)	34 (12)	30 (4)	19 (4)	.20	.40	.67
Ramp Lane	46 (8)	37 (4)	33 (4)	(unable to run ramp lane at 55 mph)					

(Number of Samples)

Summary and Conclusion

Modification of transverse grooving by surface grinding on a 1,700-foot test section of I-380 has altered the quality of traffic noise monitored directly adjacent to the highway. Reductions in Leq in the highest frequency bands of the traffic noise spectrum were significant immediately following surface modification and these noise levels continue to show further slight decreases 15 months later. Although overall noise levels adjacent to the test section remain high, the data indicate that a smoother (non-5/8-inch-spaced transverse grooved) surface texture is of benefit in terms of both the quality and quantity of resultant changes in traffic noise. Based on this study alternate surface treatments in noise sensitive sections of high volume highways appear to be worthy of consideration. Also from this study the safety implications of a smoother, lower friction surface would play a major role in assessing the net public benefit of such alternate surface treatments.