

Noise Exposure of Truck Drivers

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THIS PAPER PROVIDES DETAILS of a study undertaken to determine the magnitude of the noise exposure of truck drivers running heavy vehicles under commercial operating conditions. Since a number of standard procedures have been developed for in-cab noise measurements, the relationship between these measurements and the noise exposure of the driver has been investigated. Also, an effort was made to identify and quantify various noise sources which contribute to the drivers' exposure during normal operations.

The evaluation of the driver's noise exposure from in-cab noise measurements with standard procedures does not take into account variations in vehicle operation, tire and aerodynamic noise. Additional errors are introduced by placing the microphone at some prescribed distance from the ear, since in that region the sound field can vary significantly. These errors are only partially reduced by the use of noise dose meters.

In this investigation a specially developed, continuously recording instrument is used for measuring the

noise exposure of drivers. It is equipped with a sub-miniature microphone which can be easily placed in the cavum of the concha. In previous studies it was shown that the measurement of the sound pressure level at this point was least influenced by extraneous effects.

GENERAL CONSIDERATIONS

The evaluation of exposure from noise measurements requires integration with respect to time and in accordance with the relationship defined by a particular hearing conservation criterion or regulation. If the noise level is relatively constant, the exposure can be evaluated by approximate integration using sound level meter measurements.

In most applications, however, owing to variations of noise level and movement of the subject, continuous measurement, integration and updating storage are required. Those functions are effectively performed by noise dose meters and several models are now commercially available. The information provided by these instruments is generally restricted only to the numerical

ABSTRACT

The noise exposure of truck drivers was measured during normal commercial payload runs with special instruments, which are equipped with subminiature microphones. These can be mounted within the cavum of the concha, where measurements are least affected by extraneous effects.

By means of these instruments sound levels were continuously recorded within both ears of the driver and

at the centre of the cab. Analysis of results shows that the driver's exposure is highest during freeway hauls and that permanent hearing loss hazard may exist. Frequent use of radio or CB radio can significantly increase this hazard. It is also evident that the sound levels measured within the ears of the driver are generally significantly higher than at the centre of the cab.

value of the noise dose relative to a particular noise regulation or criterion.

Under certain measuring conditions significant errors may arise due to the location of the microphone on the subject's body. When used in industrial situations, in broadband and diffuse sound fields, these errors are generally relatively small and have a negligible effect on the exposure measurement (1)*.

In the presence of dominant discrete frequency components large measuring errors can result from body reflections and shielding. Under these conditions the location of the microphone on the body, the relative positions of the noise sources and their spectral content have significant influence (2,3). Even placing the microphone near the ear does not offer an acceptable improvement. The use of appropriate transfer functions for eliminating the undesirable extraneous influences is, in addition to being very laborious, almost impossible in practice owing to difficulties in determining some of the governing variables. The simplest and most effective solution is to select a measuring location at which the influence of these factors becomes negligibly small. Brammer and Piercy (4) have shown that the cavum of the concha is such a location. This reading can also be relatively easily converted to the sound level at the ear drum, since the corresponding transfer function is independent of the extraneous variables.

The sound field within the truck cab is complex. The main contributors are engine, exhaust, intake, fan, aerodynamic, tire and road noise. The noise transmission is partly airborne and partly structure borne and it is influenced by the construction and shape of the cab. The sound field itself is dominated by discrete frequency components. Spatial variations of the sound level will thus exist in the cab and will change with operating conditions. Results obtained in a previous investigation (5) display the non-uniform and unpredictable distribution of noise levels in truck cabs. Since it is practically impossible to predict or control such variations, the ideal solution is to select a microphone location for exposure measurements at which the influence of these variables is smallest. The cavum of the concha satisfies this requirement.

Therefore the basic operator ex-

posure and cab noise measurements were made using the "Ear Bug" unit. This instrument, which was originally developed by the Acoustics Section, Division of Physics, National Research Council of Canada, consists of a sub-miniature microphone coupled to a modified commercial cassette tape recorder. The system is small and light and can be carried without impediment of normal activities. The microphone can be attached anywhere on the subject and, what is perhaps more important, it is sufficiently small to be placed in the cavum of the concha. A complete temporal record of the A-weighted sound level at the microphone position is available from the cassette tape and can be further analyzed to provide any required information.

PROCEDURE

All 58 tested vehicles were supplied by commercial fleet operators. Measurements were performed during normal long distance payload runs. For economic reasons the choice of vehicles, routes and operating conditions was restricted to routine availability. The type of road over which the vehicle travelled was considered to be the operating variable of greatest significance. Each test run was selected to be predominantly of one type i.e. city, highway or freeway. In cases of combined trips, recordings for each road type were analyzed separately.

The driver was always accompanied by a technician who continuously logged operating and weather conditions and monitored instrumentation. Calibration procedures were carried out on relevant instrumentation and calibration signals were recorded on all magnetic tapes.

For the initial series of tests the noise exposure of the driver was recorded only at his right ear. The microphone was placed within the cavum of the concha near the entrance to the ear canal. To obtain worst noise conditions the window on the driver's side was fully opened. It was expected that noise levels at the left ear, which was nearer to the open window, would be higher. However, owing to the possibility of wind induced turbulence at the microphone, this measuring station was not used initially for continuous recording, but only for trial measurements. Evaluation of these results, in particular the narrow band frequency analyses, showed that the turbulence effect was negligible in comparison with other contributing sources and did not influence the noise exposure

*Numbers in parentheses designate References at end of paper

measurements. Consequently, after Vehicle #17, the exposure of the driver was monitored at both ears. In addition to the measurements made at both ears of the driver, an "Ear Bug" microphone was suspended from the cab ceiling to a position 150 mm to the right of the driver's ear and at the same level with it. This will be referred to as the centre of cab position.

To obtain a measurement of the basic noise making capacity of each vehicle, in-cab noise measurements were performed in accordance with standard measuring procedures SAE J336a and CSA Z107.23. The first procedure was significantly longer than the second and required a special test site, which was not readily available for routine testing. The results obtained by both methods were very close and since for the purpose of this study CSA Z107.23 was more acceptable, the use of SAE J336a was eventually discontinued. Measurements for both procedures were taken directly with a precision sound level meter.

DISCUSSION AND RESULTS

The specifications of the 58 heavy trucks tested are shown in Table 1. It should be noted that, since the fleet vehicles provided for test runs were, on the average, relatively new and well maintained, the results must therefore be expected to be marginally weighted in favour of lower noise exposures.

The Leq values obtained for each vehicle and the corresponding CSA Z107.23 value are summarized in Table 2. During some of the test runs, owing to low temperatures, it was found necessary to either close the driver's window partially or close it completely and open the vent window. Measurements taken under these conditions are appropriately marked in this table. In addition, all test runs noted in this table were made with radios off and conversation within the cab reduced as far as possible.

Narrow band frequency spectra were obtained at the three measuring stations (left ear, right ear and centre of cab) during city, highway and freeway driving. Figure 1 shows typical results of such an analysis of the noise recorded at the right ear of a driver during a highway run. It is quite evident that the noise is dominated by discrete frequency components. This was found to be the case at all three measuring stations within the cab and for each driving condition. Also a progressive reduction of the overall sound level from the left ear to the

Table 1 - Truck Specifications

VEHICLE	YEAR	DIESEL ENGINE SPECIFICATIONS	
		CYCLE	RATED POWER
1	1975	2	235 hp - 2100 rpm
2	1971	4	320 hp - 2600 rpm
3	1973	4	310 hp - 2100 rpm
4	1973	4	310 hp - 2100 rpm
5	1971	4	310 hp - 2100 rpm
6	1975	2	210 hp - 2500 rpm
7	1974	2	310 hp - 2100 rpm
8	1968	2	185 hp - 4000 rpm
9	1975	2	235 hp - 2100 rpm
10	1974	2	310 hp - 2100 rpm
11	1975	2	235 hp - 2100 rpm
12	1974	4	310 hp - 2100 rpm
13	1976	2	265 hp - 2150 rpm
14	1972	2	235 hp - 2100 rpm
15	1972	2	235 hp - 2100 rpm
16	1972	2	235 hp - 2150 rpm
17	1972	2	235 hp - 2150 rpm
18	1976	2	265 hp - 2100 rpm
19	1976	2	265 hp - 2100 rpm
20	1974	2	265 hp - 2100 rpm
21	1976	2	265 hp - 2100 rpm
22	1974	2	265 hp - 2100 rpm
23	1975	2	265 hp - 2100 rpm
24	1974	2	265 hp - 2100 rpm
25	1975	2	265 hp - 2100 rpm
26	1976	2	265 hp - 2100 rpm
27	1974	2	265 hp - 2100 rpm
28	1973	2	360 hp - 2100 rpm
29	1973	2	360 hp - 2100 rpm
30	1973	2	235 hp - 2100 rpm
31	1977	4	290 hp - 1900 rpm
32	1975	2	304 hp - 2000 rpm
33	1975	2	304 hp - 2100 rpm
34	1975	2	304 hp - 2100 rpm
35	1975	4	172 hp - 1900 rpm
36	1977	4	290 hp - 1900 rpm
37	1976	4	290 hp - 1900 rpm
38	1971	2	304 hp - 2100 rpm
39	1975	2	304 hp - 2100 rpm
40	1971	2	304 hp - 2100 rpm
41	1971	2	304 hp - 2100 rpm
42	1971	2	304 hp - 2100 rpm
43	1975	2	304 hp - 2100 rpm
44	1977	4	290 hp - 2100 rpm
45	1975	2	304 hp - 2100 rpm
46	1977	4	290 hp - 1900 rpm
47	1978	4	290 hp - 1900 rpm
48	1977	4	290 hp - 2100 rpm
49	1978	4	290 hp - 1900 rpm
50	1978	4	290 hp - 1900 rpm
51	1978	4	290 hp - 1900 rpm
52	1978	4	290 hp - 1900 rpm
53	1978	4	290 hp - 1900 rpm
54	1978	4	290 hp - 1900 rpm
55	1975	2	304 hp - 2100 rpm
56	1976	2	228 hp - 2100 rpm
57	1977	2	228 hp - 2100 rpm
58	1976	2	228 hp - 2100 rpm

centre of cab position was noted. This appears to be predominantly due to a distinct attenuation of frequency components above 1.5 kHz. The most likely explanation of this effect is increased absorption within the cab of high frequency sound energy and shielding of wind noise.

During initial measuring runs it was observed that to be heard and be intelligible, levels of speech, radio and CB radio had to be set several decibels above the environmental noise level. Typical examples are shown in Figure 2 and Figure 3. It is interesting to note

Table 2 - Summary of Noise Measurements

VEHICLE	L _{eq} (CITY) - dBA			L _{eq} (HIGHWAY) - dBA			L _{eq} (FREEWAY) - dBA			CSA STANDARD Z107.23
	MICROPHONE POSITION			MICROPHONE POSITION			MICROPHONE POSITION			
	LEFT EAR	RIGHT EAR	CAB	LEFT EAR	RIGHT EAR	CAB	LEFT EAR	RIGHT EAR	CAB	
1	-	85	83	-	85	83	-	89	90	81
2	-	-	-	-	-	-	-	90	91	85
3	-	86	84	-	-	-	-	88	84	80
4	-	-	-	-	-	-	-	87	87	88
5	-	82	82	-	-	-	-	-	-	-
6	-	86	84	-	-	-	-	-	-	83
7	-	85	84	-	85	-	-	87	86	82
8	-	82	83	-	-	-	-	87	86	80
9	-	-	-	-	-	-	-	87	87	81
10	-	89	-	-	-	-	-	89	88	86
11	-	-	-	-	-	-	-	91	86	83
12	-	-	-	-	-	-	-	88	-	85
13	-	83	83	-	-	-	-	88	86	82
14	-	-	-	91	87	84	-	-	-	91
15	-	-	-	-	87	88	-	-	-	84
16	-	-	-	-	87	89	-	-	-	89
17	-	-	-	-	90	87	-	-	-	85
18	-	-	-	-	87	87	-	-	-	85
19	83	81	80	-	86	84	87*	86	85	82
20	90	86	85	-	-	-	90	87	86	86
21	84	81	80	86	83	83	87*	86	84	81
22	-	-	-	-	-	-	91*	90	88	89
23	84	82	80	85	83	81	88	86	83	81
24	86	86	86	87	88	86	89**	90	86	87
25	83	82	81	84	85	81	88	85	83	81
26	84	83	81	86	83	83	87*	87	85	83
27	-	82	81	87	84	81	89	85	82	83
28	90	88	88	-	-	-	92	90	90	88
29	87	89	88	-	-	-	-	-	-	86
30	-	87	86	-	-	-	-	-	-	88
31	88	89	90	-	-	-	-	-	-	91
32	90	89	87	92	90	88	96	90	90	87
33	90	90	89	91	90	88	93	91	90	88
34	-	-	-	-	-	-	91*	91	90	90
35	90	91	91	91	91	91	92**	94	91	90
36	-	-	-	-	-	-	91**	94	90	93
37	89	87	86	-	-	-	89**	91	88	86
38	92	88	87	91	90	89	92	91	89	87
39	-	-	-	88**	89	86	94	90	89	87
40	88**	86	86	89**	90	88	88**	90	85	87
41	89	88	86	-	-	-	89**	90	87	87
42	90	90	88	-	-	-	91*	91	89	88
43	88**	91	89	89**	89	88	90**	94	90	87
44	-	-	-	-	-	-	87	88	87	86
45	-	-	-	92	91	90	93	91	91	86
46	-	84	83	-	86	86	90	88	88	84
47	-	83	81	-	-	-	88	88	85	84
48	-	-	-	-	-	-	91	-	87	86
49	-	-	-	-	-	-	92	-	88	83
50	-	-	-	-	-	-	-	86	88	82
51	-	-	85	-	-	-	-	89	88	84
52	-	-	-	-	-	-	87	87	86	84
53	-	88	-	-	-	-	91	88	87	82
54	88	-	85	-	-	-	89	-	87	84
55	89	86	85	-	-	-	90	88	86	86
56	85	88	84	87	88	87	-	-	-	85
57	-	-	91	-	-	-	92	-	-	88
58	85	84	81	88	87	86	-	-	-	82

* WINDOWS PARTIALLY OPEN
 ** WINDOWS CLOSED - WINDOW VENT OPEN

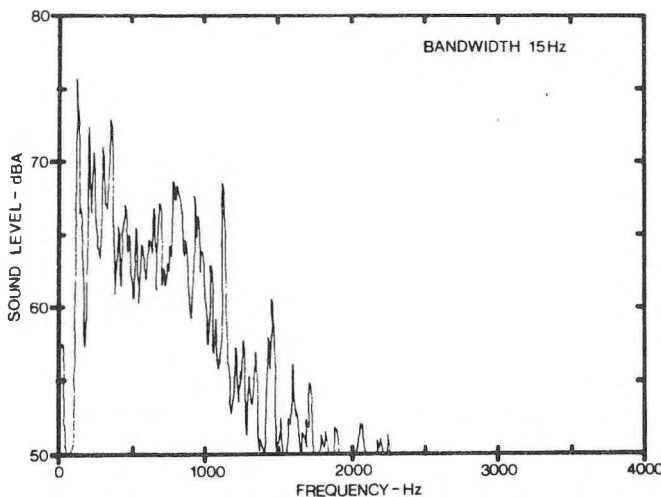


Fig. 1 - Frequency analysis of highway driving monitored at right (inner) ear

that the use of a CB radio resulted in increases in instantaneous sound level of up to 10 dB. The influence on the driver's noise exposure depends, in addition to sound levels, also upon the duration of use and location of the source. The combined effect is adequately defined by the energy equivalent level, Leq, at the reception point. Recordings were taken on several vehicles at all three measuring stations during freeway runs at a steady 100 km/h, with normal use of CB radio and without it. The results are shown in Table 3. It can be seen that this effect is highest at the centre of cab position and lowest at the left ear. At the right ear an average increase in Leq of 2.7 dB was measured, which will increase the Noise Exposure Rating by approximately 50%.

With reference to the Leq values shown in Table 2, it can be seen that they depend upon the measuring location and their magnitudes increase in the order: CSA standard procedure, centre of cab, right ear and left ear. These increases and overall values of Leq are lowest for city driving and highest for freeway hauls. The average value of the Leq difference between freeway and city driving, measured at the right ear, is 2.9 dB with a standard deviation of 1.6 dB. Although these results are not completely consistent, which appears to be primarily due to the inherent non-uniformity of the sound field in the cab, a definite trend is quite evident.

Figure 4 indicates both the variation in the Leq value for each of the three driving conditions and the corresponding sound level distributions obtained for a particular vehicle.

For freeway driving, the sound level at the left ear is on the average 5.7 dB higher than that measured with the CSA standard procedure. This suggests that any method of determining noise exposure which is based on measurement of sound level at some distance from the subject's ear, may result in significant underestimate. Errors in excess of 100% appear to be quite possible.

Correlations between data for the right ear, left ear and centre of cab positions, for each of the three driving conditions, were also determined. The results of two such correlations are shown in Figure 5 and Figure 6. In these graphs, r represents the correlation coefficient and σ the standard deviation. Generally, the best correlation exists between the right ear and centre of cab with the value of correlation coefficient highest for city

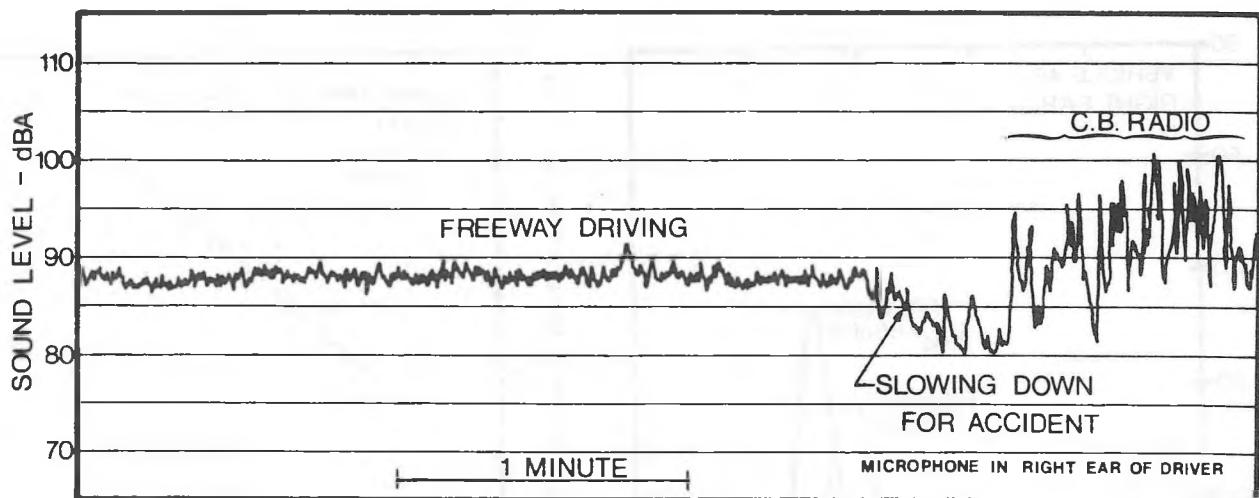


Fig. 2 - Vehicle #53: effect of CB radio on noise levels

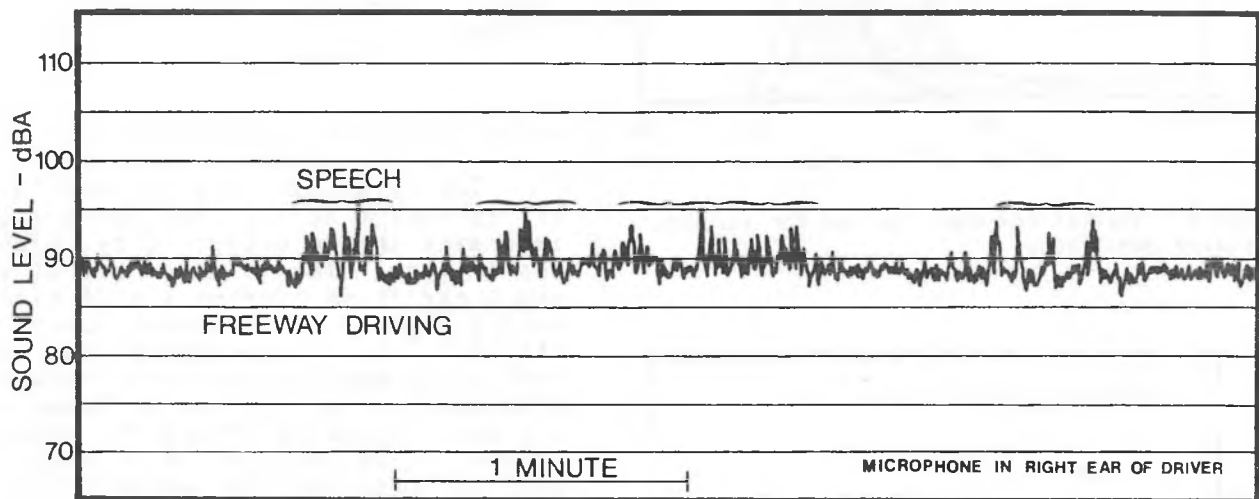


Fig. 3 - Vehicle #48: effect of speech on noise levels

Table 3 - Effect of CB Radio on Values of L_{eq}

VEHICLE	CSA STAMP Z10723 GBA	LEFT EAR - dBA		RELATIVE	RIGHT EAR - dBA		RELATIVE	CENTRE CAB - dBA		RELATIVE
		NO CB	WITH CB	EFFECT dBA	NO CB	WITH CB	EFFECT dBA	NO CB	WITH CB	EFFECT dBA
31	87	96	99	+3	-	-	-	90	95	+5
33	90	91	97	+6	95	98	+3	91	95	+4
34	90	92	92	0	94	97	+3	91	94	+3
36	86	89	91	+2	91	96	+5	88	91	+3
37	87	91	91	0	93	94	+1	89	92	+2
38	87	94	94	0	90	91	+1	89	91	+2
40	87	-	-	-	-	-	-	85	88	+3
41	87	89	91	+2	89	92	+3	-	-	-

driving and lowest for freeway driving. The results also indicate the highest noise levels exist at the left ear.

CONCLUSIONS

Under most operating conditions the sound field inside the cab is dominated by discrete frequency components. This suggests that the location of the microphone may have significant influence on measurements. For accurate determination of noise exposure the microphone should be placed within the cavum of the concha.

The use in the cab of radio or CB radio can significantly increase the noise exposure of the driver. Tests performed on a sample of 8 vehicles show that normal use of CB radio increases the value of L_{eq} at the right ear by an average of 2.7 dB. This corresponds to an increase on the noise dose of at least 50%. It can thus be a significant contributor to the over-

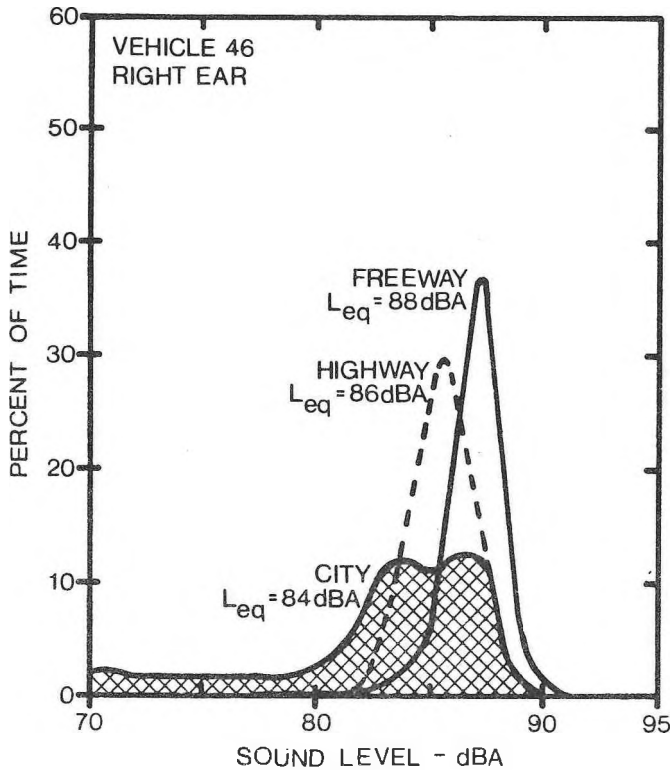


Fig. 4 - Statistical distribution for various driving conditions

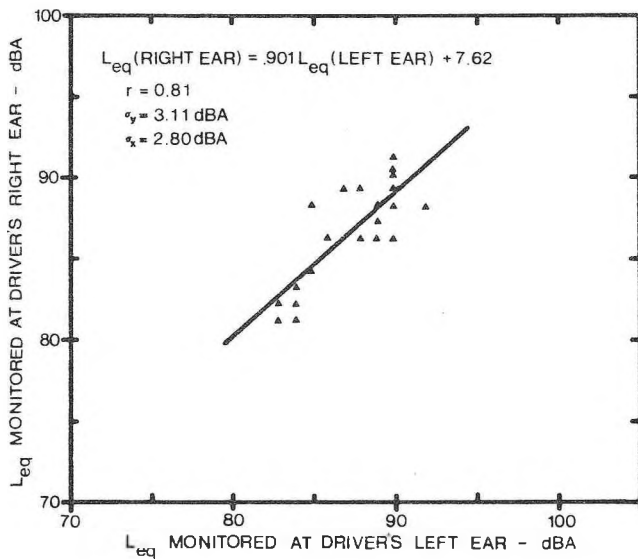


Fig. 5 - Comparison of sound levels for city driving

all noise exposure.

The sound levels measured at the centre of cab position, right and left ear of the driver, increase generally in that order. The value of the L_{eq} at the left ear is on average 6 dB higher than that at the centre of cab

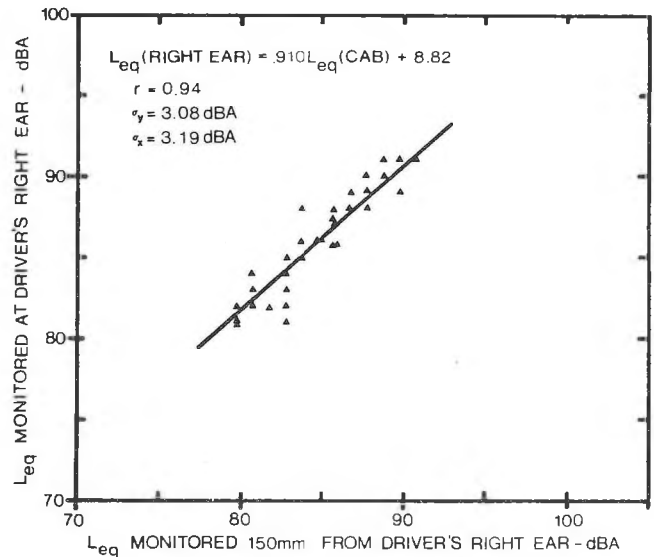


Fig. 6 - Comparison of sound levels for city driving

position, which is the measuring station used for standard procedures.

The noise exposure of truck drivers is lowest during city driving and increases in the order: city, highway and freeway. The value of L_{eq} at the right ear is on average 1.5 dB higher during highway driving than during city driving. The corresponding comparison between highway and freeway driving shows an average difference of 1.6 dB. The value of L_{eq} for freeway driving is an average 2.9 dB higher than for city driving, which is approximately equivalent to an increase of noise exposure of 50%.

ACKNOWLEDGEMENT

The support of this investigation by Road and Motor Vehicle Traffic Safety Branch, Transport Canada, Contract No. OST 77-00081 and by National Science and Engineering Research Council of Canada, Grant No. A7439 is gratefully acknowledged.

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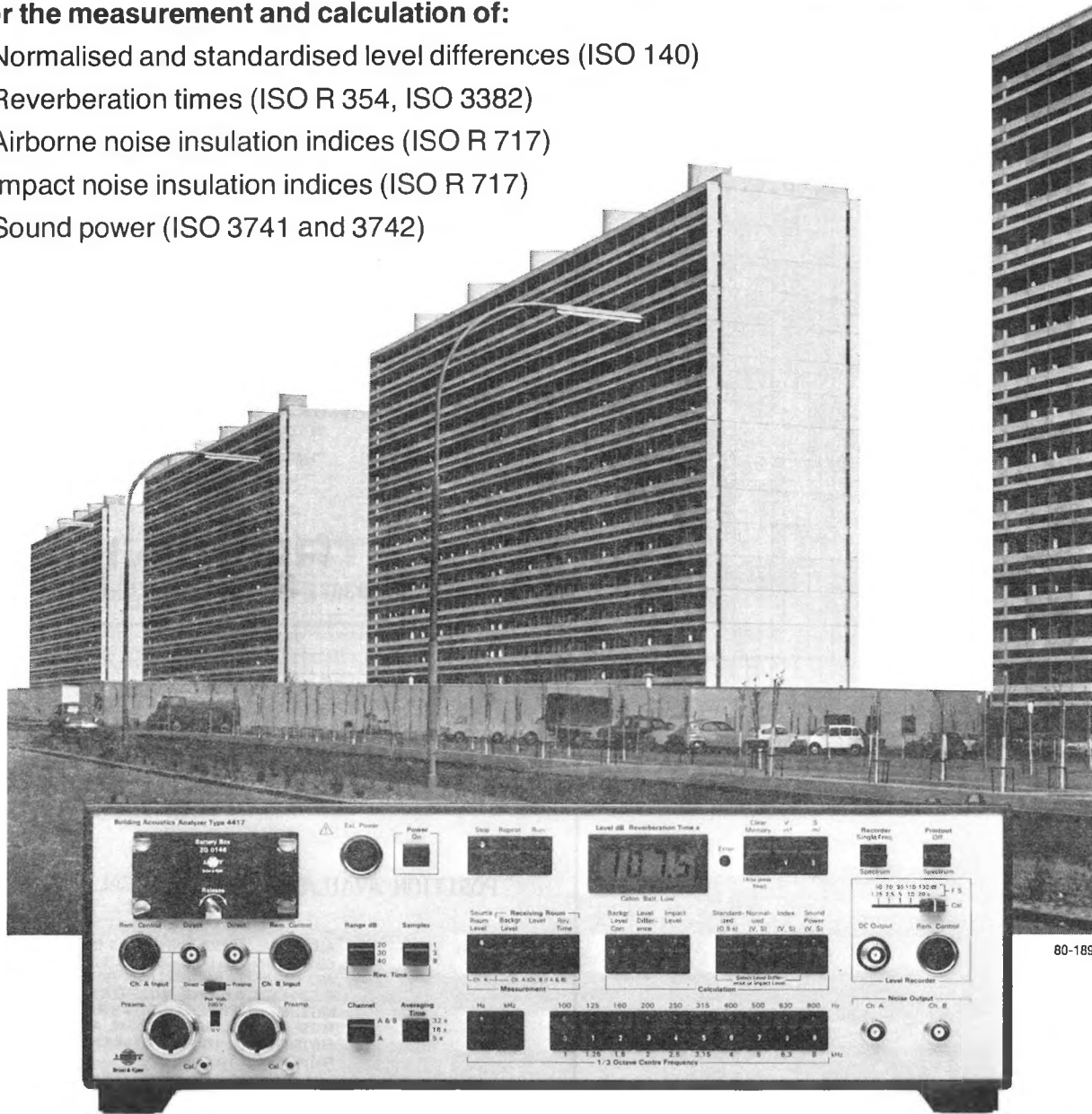
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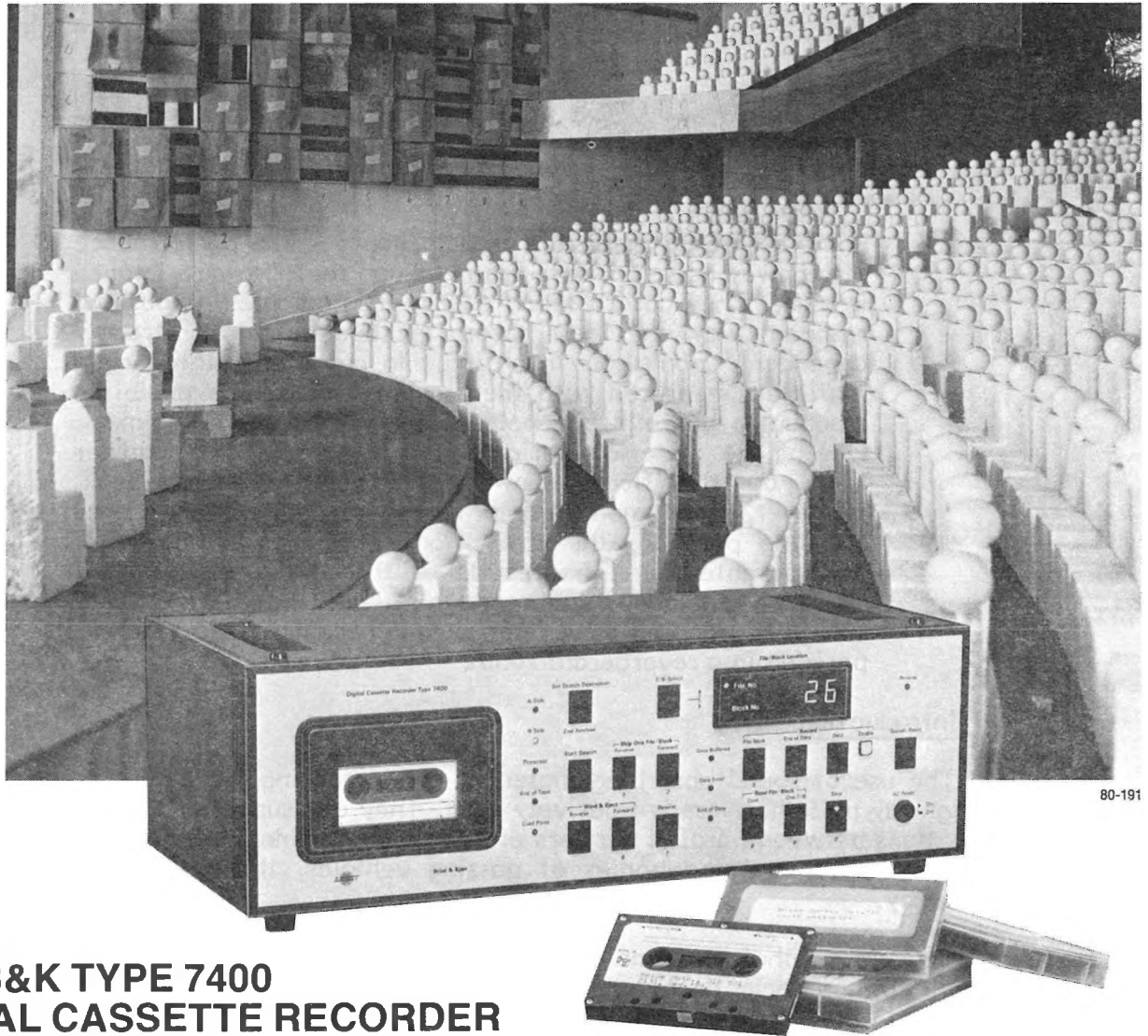
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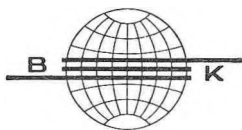


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