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A PRELIMINARY INVESTIGATION INTO LORRY TYRE NOISE

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ABSTRACT

Recent research has indicated the possibility that with reduced power unit noise, tyre to road surface noise could become the predominant source of lorry noise. An investigation at the Transport and Road Research Laboratory has shown that, although tyre noise does not contribute and is unlikely to contribute significantly to levels measured in the British Standard drive-by-test, tyre road surface noise will be the predominant source of noise from envisaged quieter heavy lorries when they are travelling at speeds approaching 100 km/h on dry roads and at speeds over 50 km/h on wet roads. The parameters that most markedly affect tyre noise are vehicle speed, tyre tread pattern, road surface texture and whether the surface is wet or dry.

1. INTRODUCTION

The Working Group on Research into Road Traffic Noise has indicated the urgent need for research and development towards the production of a quiet heavy vehicle (1), and a sub-group was established to initiate such a project. The project, which is funded by the Laboratory, is a co-operative exercise involving the Institute of Sound and Vibration Research, the Motor Industry Research Association, B.L.M.C., Foden Limited and Rolls Royce. The Laboratory, with the help of the Vehicle Engineering (VE) Division of the Department of the Environment (DOE) has undertaken that part of the research and development programme concerned with the reduction of vehicle rolling noise. Liaison has been established between the two Laboratory divisions involved in the research (Environment Division and Vehicles Division) and representatives of the British Rubber Manufacturer's Association Tyre Test Committee, and an ad hoc Tyre Group has been established.

In the specifications for the quiet heavy vehicle, the target sound level for the exterior noise of the vehicle is set at at least 10dB(A) less than the current levels not only under the conditions specified in British Standard BS 3425:1966, but also under any operating condition. This implies that the total exterior noise emitted by the vehicle should be about 80 dB(A). This imposes limits on the sound levels of the individual component noise sources on the vehicle. Table 1 summarizes the component sources and the target levels for each of these. The target maximum sound level for the noise resulting from the tyre/road surface interaction is between 75 and 77 dB(A) at 7.5m from the vehicle centre-line. The Tyre Group recommended a preliminary investigation of the performance of existing lorry tyres to provide some assessment of the likely difficulty in achieving the stated target and to give some understanding of the effects of certain tyre and surface parameters. After the following brief review of research this report gives an account of that investigation.

TABLE 1

Upper limits of sound levels to be emitted by quiet heavy vehicle components

Source	(Maximum Level dB(A))	
	at 1 m	at 7.5 m
Engine including gear box	92	77
Air intake	84	69
*Tyre/road surface interaction	-	75 - 77
Rear Axle	84	69
Cooling System	84	69
Exhaust System	84	69

1.1 Review of past research into tyre noise

Up to the last few years most research into tyre noise has been concerned with the reduction of noise inside passenger vehicles, and much attention has been given to the reduction of structure borne noise and vibration. Airborne noise, which affects the external environment directly, has largely been neglected, although the design of car tyres to reduce the noise transmitted to the passenger compartment has achieved some reduction in the sound level of the noise radiated to the environment. Lorry tyres have received little attention, even to reduce structure borne vibration inside the cab, and most of the development of these tyres has been concerned with producing greater tyre mileage.

Robertson and Cox (2,3) investigated lorry tyre noise by fitting the tyres to a lorry and supporting the back wheels of the lorry on a chassis dynamometer. The rear wheels were then accelerated to the equivalent of a road speed of 60 mph and then allowed to coast to a stop. Tape recordings were made and these were analysed

a. subjectively by playing them back to an audience and

b. objectively by a measuring instrument in terms of phons.

They found that smooth treaded tyres were quietest followed in order of increasing noisiness by tyres with a tread pattern of widely spaced transverse grooves, tyres with a pattern of blocks, and tyres with a pattern of uniform pockets.

Wiener (4) has investigated the tyre noise from a car travelling at 33.8 km/h (20mph) and 80.5 km/h (50 mph) on rough and smooth roads with tyres of different tread designs. Randomised tread patterns were used and the third octave spectra of tyre noise did not show any indication of pronounced peaks. The spectra on rough roads were approximately level up to 800 hertz and then decreased at about 30 dB per decade at higher frequencies. Changes in speed changed the level of the spectrum without significantly changing its shape. Reduction of the excitation by changing to a smooth road reduced the levels in the 100 hertz to 1,500 hertz range. Changes of tyre carcase material and tread rubber produced only minor changes in the spectrum and levels. No wet road tests were carried out.

Rathe (5) investigated the noise from four saloon cars coasting at 40, 60 and 80 km/h on various surfaces and obtained a relation of the form:

$$\text{Sound level [dB(A)]} = 0.2\,V + K$$

Where V was the vehicle speed [km/h] and K depends on the surface.

The range of speeds used was small and the data could equally well have been described by

$$\text{Sound level dB(A)} = 30 \log_{10} V + K$$

Rathe also investigated wet road conditions. He found that splash caused a broad band noise at frequencies above 1,000 hertz. On smooth asphalt rolling noise was increased by 15 dB(A) over levels on the dry; while on a rougher concrete surface the increase compared with the dry was 8 dB(A). He found no significant difference of noise level between wet concrete and wet asphalt.

Waters (6) has found that on average the rolling noise for a selection of vehicles increased at a rate of 30 dB(A) per tenfold increase in speed but that the rates for the individual vehicles tested varied from 13 to 50 dB(A) per tenfold speed increase. The heavier vehicles tended to be noisier than the lighter vehicles, but the effect of load variations was slight. He, therefore, concluded that tyre size was a more important factor than wheel load. He showed that for an estate car and a lorry at any given speed on dry surfaces rolling noise increased by 5 dB(A) from the quietest surface to the noisiest, but on the wet surfaces the range of noise levels was wider, at about 7 dB(A). On the wet surfaces the noise was on average 10 dB(A) higher than on the dry surfaces.

Mills working at M.I.R.A. has analysed a large set of data (7) and has found that on a smooth tarmacadam surface, the realation between rolling noise and gross vehicle weight, and speed was:

$$R = 15 + 30 \log_{10} V + 7 \log_{10} W,$$

where R = rolling noise [dB(A)]

V = vehicle rolling speed in [km/h]

W = gross vehicle weight [tons].

He also reported that if the tyres of a saloon car were changed, the rolling noise on smooth tarmacadam changed by 2 to 4 dB(A). He obtained a few measurements of coasting noise on the smooth tarmacadam surface in the wet and the dry and found that coasting noise was more sensitive to surface wetness at low rather than high vehicle speeds. Mills also found that rolling noise on a rough surface, was on average 4 dB(A) noisier than a smooth surface, and that on a cobbled surface the level was about 8 dB(A) noisier

Flanagan (8) has summarized work carried out by four different American research organisations into lorry tyre noise. These were the National Bureau of Standards (9), General Motors (10), the Rubber Manufacturers Association*, and the SAE Truck Tyre Noise Sub-committee (11). This research covered

* Flanagan gives no bibliography for the RMA work.

tyres with transverse grooved tread patterns, with pocket retread patterns, and with circumferentially grooved patterns. The tyre noise was measured in 'A' weighted decibels - dB(A) - using the standard slow response instead of the fast response commonly used in vehicle measurement. The slow response involves a rectifier time constant of one second compared with 0.2 seconds for the fast response and it was thought that the use of the slow response improved repeatability by damping the meter needle so that the operator could get a better reading and that it accounted better for the spectral content and the persistance of tyre noise.

The correlation coefficients for the relation between the various objective measurements tested and the subjective ratings were from the General Motors data 0.95 for dB(A) and 0.96 for phons and from the SAE data 0.89 to 0.915 for dB(A). Both these coefficients for dB(A) were for the slow response network. With the fast response setting the relation between rating and sound level was shifted by 0.9 dB(A) upwards and the correlation coefficients were 0.87 - 0.89.

The National Bureau of Standards found that a pocket retread tyre was 5 to 10 dB(A) noisier than the loudest transverse grooved patterned tyre, and the transverse grooved tyre was 4 dB(A) noisier than the loudest circumferentially grooved patterned tyre. All four organisations found that on average tyre noise increased by 30 dB(A) per tenfold increase in speed. In general tyre noise increased as the tyre became worn, and this was thought to be due to irregular wear. The effect tended to be more marked on a smooth concrete surface. Tetlow of General Motors investigated the effect of decreasing tread curvature as the tyre wore and he found that in the case of a transverse grooved patterned tyre, when a worn tyre was reground to its original curvature,the noise levels from the tyre reverted to their original values. The National Bureau of Standards found that an increase of load from 0.91 to 2.72 Mg (2000 to 6000 lb) per tyre increased the noise from circumferentially grooved tyres by 1 to 3 dB(A), from transverse grooved tyres by 6 to 8 dB(A), and from pocket retreads by 4 to 8 dB(A). In measurements of rolling noise on a surface, wetted by a tanker, the Bureau observed no significant change of 'A' weighted sound level but in the third octave spectra there was a noticeable shift of energy from the low frequency bands to bands above 1000 Hz.

Sakagami (12) has described some lorry tyre noise research carried out by the Automobile Research Institute of Japan. He found that lorry tyre noise increased about 10 dB(A) per doubling of vehicle speed. Below 80.5 km/h the effect of tyre noise on the overall noise of the vehicle was insignificant compared with the noise from the engine, exhaust etc, but above this speed tyre noise dominated. A 5 to 8 dB(A) difference was observed between measurements of the rolling noise of the vehicles tested when unladen and fully laden (no details of the payloads were given) when the vehicles were equipped with transverse grooved patterned tyres, but this difference became negligible when the vehicles were fitted with circumferentially grooved tyres. A decrease in tyre pressures of 30% caused as much as 5 to 8 dB(A) increase in the noise from the transverse grooved patterned tyres, but had little effect on the noise from the circumferentially grooved tyres. This was explained as being due to an increase in contact patch area in the case of the transverse grooved tyre and was likened to the effect of increased load.

Three types of road surface were tested. These were polished concrete, asphalt and rough concrete. For the dry surfaces in the high frequency range above 800 hertz the noise level increased slightly as the roughness of the surface increased. On a wet surface tyre noise tended to be masked by splash, a difference of 10 - 20 dB was found in the rolling noise spectra above 600 hertz between the wet and dry surfaces. The rolling noise in the wet for the transverse grooved tyres was at about the same level as in the dry but for the circumferentially grooved tyres a significant increase occurred. Sakagami did a regression analysis of his results and derived a formula:

$$R = 40 \log_{10} V + C$$

where R = rolling noise in dB(A)

V = vehicle speed [km/h]

C = a constant

The dependence on speed is greater than that reported by Mills (7) and the American workers (8) but within the range observed by Waters (6). Some measurements were made of the directivity of the rolling noise. Sakagami found that in the vertical plane directivity patterns had a flat ellipse form with the noise level to the side of the vehicle being 4 to 12 dB(A) higher than that directly above it. In the horisontal plane the noise was found to be virtually non-directional (12).

2. EXPERIMENTAL METHOD

This chapter describes the experimental technique adopted at the Laboratory to study the rolling noise from a lorry fitted with various sets of tyres, on three road surfaces.

2.1 Tyres, tread patterns, tread materials and road surfaces

The tyres tested were 10.00 x 20.0 16 ply rating cross-ply lorry tyres inflated to a pressure of 620.5 KN/m^2 (90 lb/sq in). The tread patterns used are shown in Plate 1. They were a transverse grooved traction tyre, two circumferentially grooved patterned tyres one with five ribs (highway A) and one with seven ribs (highway B) and a smooth tyre. The traction tyre is normally used for off-the-road purposes in this country and the highway tyres are general purpose tyres. The smooth tyres were specially moulded and were of normal tread thickness. To investigate the effect of tread material, the traction tyres and the smooth tyres were duplicated in a high hysteresis rubber compound. Therefore six different types of tyre were tested in all.

Plate 2 shows the three types of road surface used. These were a motorway wearing course (a rolled smooth asphalt surface to BS 594 with added ¾" precoated chippings), a coarse quartzite wearing course (a ⅜" stone bituminous/macadam quartzite carpet to BS 1621), and a smooth concrete surface (a monolithic granolithic artificially polished concrete flooring).

2.2 Measurement technique

The six sets of tyres were in turn fitted to a two axle, six-wheeled lorry. Table 2 shows how the vehicle mass was distributed between wheels for both the loaded and the unloaded lorry. For most of the tests the lorry with a mass of 5.58 Mg was unladen, but a few measurements were made with the lorry carrying 7.67 Mg (6.53 tons) of concrete blocks making a total vehicle mass of 13.23 Mg (13.03) tons). For each set of tyres noise measurements were made on the three selected surfaces, dry and wet. The measurements on each surface were made at speeds of approximately 35, 50, 65, 80 and 100 km/h. For each test run the lorry was accelerated to just above the target speed, then the engine was turned off, declutched, and the lorry coasted over the test surface. The driver observed and reported the actual speed of the lorry past the noise measuring microphones which were placed on either side of the test surface, at 7.5m from the vehicle centre line. One of the microphones was connected to a sound level meter on fast response, which was used to determine peak 'A' weighted sound level, whilst the other was connected through a second sound level meter switched to 'C' weighting to a tape recorder. The recordings were subsequently analysed on a third octave real-time analyser, the attenuators of which were set both to compensate for the 'C' weighting, the tape recorder response and, when required, to 'A' weight the output spectra.

TABLE 2

VEHICLE MASS

Total weight unladen = 5.58 Mg [5.50 tons]

Total weight fully laden = 13.23 Mg [13.03 tons]

WHEEL LOADS

1. Unladen

Front nearside = 1.50 Mg [1.48 tons]

Front offside = 1.59 Mg [1.57 tons]

Rear nearside = 1.26 Mg [1.24 tons]

Rear offside = 1.23 Mg [1.21 tons]

2. Laden

Front nearside = 2.42 Mg [2.38 tons]

Front offside = 2.63 Mg [2.59 tons]

Rear nearside = 4.10 Mg [4.04 tons]

Rear offside = 4.08 Mg [4.02 tons]

The repeatability of the experimental method was investigated by repeated measurements on two natural rubber tyre sets (highway type A and traction) rolling on the dry motorway type surface. Figures 1 and 2 show the results of the tests. For both the tyres the sound level varied linearly with the logarithm of speed and a linear regression analysis of the results was made. Table 3 gives the values of the regression parameters obtained. The standard error of sound level about the regression line was found to be 0.55 for the highway tyre and 0.64 for the traction tyre. The dotted line shows the standard deviation of sound levels. During these tests tyre temperatures varied from 25 to 52^{o} but this did not significantly affect the emitted sound level.

TABLE 3

Standard deviation of test results

Tyre	Correlation Coefficient	dB(A) = a $\log_{10}$ V + b		Std Error of dB(A)
		a	b	
Highway Type A	0.995	36.0	9.5	0.56
Traction (Natural Rubber)	0.993	36.9	8.5	0.64

Figure 3 shows the repeatability of the measurement of the third octave spectra. This was investigated by analysing five consecutive runs of the natural rubber traction tyre at 80.5 km/h (50 mph) on the motorway surface. The dotted line on the graph shows the standard deviation arising from the statistics of making a third octave analysis of a signal lasting 1/8th of a second. The close agreement between the measured standard deviation and the instrument deviation over the frequency range 100 hertz to 10.0 kilohertz suggests that the sampling statics are the major source of variance for the spectra over this range. Outside this frequency region, where the spectra have low sound levels, factors such as instrument noise, tape noise and the lower range limits of the analyser interact to create discrepancies between the observed deviations and the instrument deviation predicted from the statistics of third octave analysis.

3. RESULTS

The parameters examined were speed, tread patterns, road surface texture, tread material and load.

3.1 The effects of the parameters on peak sound pressure level

3.1.1 Speed

Table 4 summarizes the regression parameters obtained by applying a linear regression technique to the measured values of sound level [dB(A)] and the logarithm of vehicle speed (km/h). The mean value of all the slopes obtained was 34.4 on the dry surfaces (standard deviation 5.3) and 25.9 on the wet surfaces (standard deviation 4.7). These slopes correspond to a noise increase of 10 dB(A) with a doubling of speed on the dry surfaces and 8 dB(A) on the wet. The slopes corresponding to tyres of similar tread pattern but different material are of the same order on each surface both in the wet and the dry, with the exception of the smooth tyres on the smooth concrete. In this case the slope of the natural rubber tyre was much less than the slope of the high hysteresis tyre.

TABLE 4

REGRESSION EQUATIONS OF FORM

$$S = m \log_{10} V + C$$

1. HIGHWAY TYPE A

Type of Surface	Slope m	Intercept C	Number of Data Points	Correlation Coefficient
Dry smooth concrete	34.4	9.1	5	0.996
Dry coarse quartzite	32.8	12.5	5	0.990
Dry motorway	38.2	6.2	5	0.999
Wet smooth concrete	22.6	41.2	5	0.998
Wet coarse quartzite	20.6	41.5	5	0.892
Wet motorway	24.4	39.7	5	0.972

TABLE 4 (CONTINUED)

2. TRACTION (NATURAL RUBBER)

Type of Surface	Slope m	Intercept C	Number of Data Points	Correlation Coefficient
Dry smooth concrete	42.8	-3.8	5	0.996
Dry coarse quartzite	39.0	3.1	5	0.996
Dry motorway	36.9	8.4	5	0.998
Wet smooth concrete	32.9	22.1	5	0.952
Wet coarse quartzite	25.1	37.4	5	0.988
Wet motorway	26.4	37.1	5	0.998

3. TRACTION (HIGH HYSTERESIS RUBBER)

Type of Surface	Slope m	Intercept C	Number of Data Points	Correlation Coefficient
Dry smooth concrete	45.1	-8.7	5	0.992
Dry coarse quartzite	34.9	10.2	7	0.978
Dry motorway	36.1	9.9	5	0.997
Wet smooth concrete	34.3	18.4	5	0.999
Wet coarse quartzite	24.1	39.6	7	0.997
Wet motorway	31.1	28.1	5	0.997

4. SMOOTH NATURAL RUBBER

Type of Surface	Slope m	Intercept C	Number of Data Points	Correlation Coefficient
Dry smooth concrete	19.7	32.3	5	0.996
Dry coarse quartzite	29.4	17.2	5	0.987
Dry motorway	34.6	9.4	5	0.999
Wet smooth concrete	31.5	16.9	4	0.992
Wet coarse quartzite	21.4	43.4	5	0.987
Wet motorway	26.3	32.1	5	0.995

TABLE 4 (CONTINUED)

5. SMOOTH (HIGH HYSTERESIS RUBBER)

Type of Surface	Slope m	Intercept C	Number of Data Points	Correlation Coefficient
Dry smooth concrete	32.2	9.2	5	0.996
Dry coarse quartzite	28.6	19.0	5	0.981
Dry motorway	35.5	8.9	5	0.999
Wet smooth concrete	32.9	17.3	5	0.992
Wet coarse quartzite	24.7	39.0	5	0.996
Wet motorway	24.0	42.6	5	0.993

6. HIGHWAY TYPE B

Type of Surface	Slope m	Intercept C	Number of Data Points	Correlation Coefficient
Dry smooth concrete	32.6	11.7	7	0.992
Dry coarse quartzite	34.2	9.2	6	0.998
Dry motorway	32.1	15.8	5	0.999
Wet smooth concrete	22.1	39.4	8	0.991
Wet coarse quartzite	20.3	42.6	5	0.983
Wet motorway	21.0	43.0	5	0.986

3.1.2 **Tread patterns**

This was investigated by measuring the noise emitted when the lorry rolled over the smooth concrete surface. Figure 4 shows the results of the measurements. At 35 km/h on the dry surface there is little difference between the various tread patterns because, at this speed, tyre noise was the same for all tyres or possibly because at the low sound level observed 63 dB(A), the dominant noise generator was not the tyre/road surface interaction. At higher speeds on the dry the traction tyres became noisier than the highway tyres which were in turn noisier than the smooth tyres. On the wet surface at low speed the traction tyre was as quiet as the 7 rib highway tyre and about 3 dB(A) quieter than the 5 rib highway tyre. However at 50 km/h the traction tyre levels had increased to the 5 rib tyre level and thereafter these tyres were about equal in noisiness.

The spread of noise from quietest to noisiest tyre on the dry surface ranged from 0 dB(A) at 40 km/h to 10 dB(A) at 100 km/h. On the wet surface the spread ranged from 11 dB(A) at 35 km/h to 6 dB(A) at 80 km/h, the highest safe speed at which the smooth tyre could be driven on this surface.

3.1.3 **Road surface texture**

The effect of road surface texture which was tested by measuring the noise emitted when the lorry, fitted with smooth tyres, rolled over three different surfaces is shown in Figure 5. The noisiest surface was the motorway surface and the quietest the smooth concrete surface. At speeds above 55 km/h (34 mph) the smooth concrete was 2.5 dB(A) quieter than the coarse quartzite, which in turn was 2 dB(A) quieter than the motorway. Wetting the coarse quartzite and motorway surfaces increased levels by 10 dB(A) while wetting the smooth concrete caused an increase of 7.5 dB(A). The smooth concrete when wet was 7.5 dB(A) quieter than the wetted coarse quartzite and 8.5 - 10.0 dB(A) quieter than the wetted motorway.

3.1.4 **Combined effect of tread pattern and a textured road surface**

Figures 6 and 7 show the noise emitted by the tyres rolling on the coarse quartzite and motorway surfaces. Comparing these figures with figure 4, which shows the noise levels of the tyres rolling on the smooth concrete, it can be seen that the ranking of the tyres, in order of increasing noisiness, observed on the dry smooth concrete is preserved on the coarse quartzite and motorway surfaces; ie smooth, highway type B, highway type A and traction, but the differences between the tyres are much reduced. On the wet surface these rankings do not reproduce. On the wet coarse quartzite, while the rolling noise of the patterned tyres is similar to that on the wet smooth surface, the smooth tyre has become 10 dB(A) noisier than on the smooth surface and as noisy as the traction tyre. On the wet motorway surface levels from the smooth tyre, highway A and traction tyres are barely distinguishable from each other and are slightly higher than the levels for the smooth and traction tyres on the wet coarse quartzite surface.

The noise from the highway B tyre did not vary much between the wet surfaces and on the wet motorway surface was 5 dB(A) quieter than all the other tyres.

3.1.5 **Tread material**

To assess the performance of tyres made from materials with a higher hysteresis than natural rubber, sets of smooth tyres and of traction tyres manufactured from a high hysteresis rubber compound were tested. Figures 8 and 9 show how these tyres compared with their counterparts in natural rubber when rolling on the smooth concrete and motorway surfaces. On the dry smooth concrete surface at the lower speeds the high hysteresis tyres were quieter than the natural rubber tyres. On this surface with the smooth tyre at 40 km/h the difference was 3 dB(A). On the dry motorway surface the high hysteresis smooth tyre was 1 to 2 dB(A) noisier than the natural rubber tyre, but no significant difference was observed for the two traction tyres.

Figure 8 shows that, for the smooth tyres, the high hysteresis tyres were about 2 dB(A) noisier than on the others on both the wet surfaces but, as figure 9 indicates, the traction tyres did not show this. On the wet motorway surface and at high speeds on the wet smooth surface there is little difference between the traction tyres in either material, but at low speeds on the wet smooth surface the hysteresis tyres tend to be quieter.

3.1.6 The effect of load

Measurements were made with the lorry loaded to 13.23 Mg (13.03 tons), an increase of 7.65 Mg (7.53 tons). Table 2 shows the distribution of vehicle load between the various wheels. The loaded lorry was tested with the patterned tyres on all three surfaces, and the smooth tyres on the coarse quartzite and motorway surfaces. The high hysteresis tyres were not used in this test.

Table 5 shows the observed increases of sound level in dB(A) with increased loading. Figures 10, 11 and 12 show the effects of different tread patterns at the increased vehicle load, on the smooth concrete, dry coarse quartzite and motorway surfaces.

TABLE 5

SOUND LEVEL INCREASE FROM UNLADEN (5.6 Mg) TO LADEN (13.2 Mg) VEHICLE

Tyres	INCREASE IN SOUND LEVEL dB(A)		
	Smooth Concrete	Coarse Quartzite	Motorway
Smooth	No Test	2.5–6.0	1.0–3.0
Highway Type B	2.0	3.0	3.0
Highway Type A	1.0	1.0–2.0	1.0–2.0
Traction	5.0–7.0	2.0–3.0	2.0–4.0

3.2 Third octave spectra of lorry tyre noise

Figures 13 and 14 show the unweighted spectra for the highway type B tyre and the traction tyre travelling at various speeds on the smooth concrete. These spectra in common with those of the other tyres on the same surface show a fairly level region between 100 hertz and 2.0 kilohertz and a steep downwards slope starting around 2.0 kilohertz. Increasing the vehicle rolling speed gave a rise in levels throughout all the frequency bands but the spectra did not change their basic shape or shift along the frequency axis except for certain peaks in the spectra of the traction tyre, which relate to the angular rotation of the transverse grooves that make up the tread pattern of that tyre.

Figure 15 shows the 'A' weighted spectra for the highway type A and B, traction and the smooth tyres rolling on the concrete at 96.6 km/h. The maximum in these spectra occur in the frequency range 1–2 kilohertz. The traction tyre spectra show a peak at 400 Hz that was associated with the angular rotation of the transverse grooves. The position of this peak on the frequency axis shifted by about 1/3 octave band per 16 km/h increase of vehicle speed, from the 200 Hz band in spectra for the lorry travelling at 50 km/h to the 400 Hz band at 96 km/h.

Figure 16 shows the spectra of the highway type A and B, and the traction tyres rolling on the wet smooth concrete. There is a marked increase of sound level in the bands above 1000 Hz. This is the hissing commonly heard on wet roads. Figure 17 shows the spectra for the highway type A and B tyres, the traction and the smooth tyres on the motorway surface at 96.6 km/h. The levels in the 1/3 octave bands are greater than they were in the spectra for the tyres on the smooth concrete surface (Figure 15). The traction tyre spectra again show their characteristic peak but it is not so dominant because of the general increase in levels. Figure 18 shows the spectra for the same tyres on the wet motorway surface. As with the smooth surface the hiss has caused a marked increase of level at the higher frequencies.

Figure 19 shows the spectra obtained for the smooth high hysteresis and natural rubber tyres rolling on the motorway surface. At low speed there is a marked difference between the spectra, but at high speeds the spectra are almost identical. For the traction tyres the comparison of the natural with the high hysteresis rubber revealed no apparent effect of material type on either the low or the high speed spectra as figure 20 shows. Figures 21 and 22 show that on the wet motorway surface at both high and low speed there was little difference between the two rubber compounds.

Figure 23 illustrates the effects of loading on the spectra of the highway type B tyre. The change in 'A' weighted level, shown in table 5, evidently arose from the slight increase of band levels above 800 Hz. Figure 24 shows the spectra for the traction tyre rolling on the smooth concrete. The peaks, characteristic of the transverse groove rotation, are much more pronounced than in the unladen spectra (of the traction tyre on figure 15) and secondary resonance peaks occur in the spectra at all speeds. This is due to the increased contact between the tread pattern and the road surface, and the subsequent increase in tread distortion and air displacement.

4. SKID RESISTING PROPERTIES OF THE TYRES

The skid resisting properties of each set of tyres were measured by the Vehicles Division of the laboratory. Front wheel braking techniques were used, and the peak and locked wheel brake force coefficients (BFC) were found for a range of vehicle speeds on the motorway and smooth concrete surface. Tests on the coarse quartzite were not made because the surface was so abrasive that the tyres would have become significantly and unevenly worn. Best fit lines were drawn through the measurement points, and the results presented in the form of a graph of BFC against vehicle speed (km/h). For comparison the BFCs for a typical car tyre were drawn on the same axes as the lorry tyres.

Figures 26 and 27 show the relations between speed and peak BFC for the various tyres on the two surfaces, while figures 28 and 29 show similar relations for the locked wheel BFC. All the graphs show that under any specified conditions the car tyre gives noticeably higher BFC values than any of the lorry tyres. On the smooth concrete surface the smooth tyre BFC values are markedly lower than the patterned tyre values, but on the motorway surface this difference is not so obvious. Comparing the peak BFC levels with the locked wheel BFC levels it can be seen that peak BFC values for the patterned lorry tyres exceeds the locked wheel BFC value for the car tyre.

Stopping distance may be calculated by evaluating the integral.

$$S = \int_{o}^{V} \frac{v}{BFC} \, dv$$

where S is the stopping distance and V the vehicle speed before the brakes were applied. Thus the ratio of stopping distances is, to a reasonable approximation, proportional to the ratio of the reciprocals of the

BFC values, The implications of the observed BFC values are that a car will stop in about 3/4 of the distance needed by a lorry shod with patterned tyres.

5. DISCUSSION AND CONCLUSIONS

5.1 A comparison with previous research

The review of research in section 1.1. revealed considerable agreement between various authorities but some discrepancies of detail. The experiments undertaken at the Laboratory sought to confirm that typical UK tyres and surfaces followed the general published pattern and to explore some of the discrepancies between the various authors. The measured levels and the change of noise level with speed were in good agreement with the relations described by Mills [7]. Waters found no significant effect of load in his lorry experiment [6]. His measurements involved highway tyres rolling on a hot rolled asphalt comparable with the motorway surface on the laboratory track. It can be seen from Table 6 that for at least one of the highway tyres used in the laboratory's investigation the increase of 1 to 2 dB(A) is quite slight and possibly not much greater than the experimental error of measurement. The most serious discrepancy in the literature relates to the National Bureau of Standards finding that rolling noise on a wet surface was not significantly greater than noise on the dry surface [9]. This was contrary to the view of the other authors and was also contradicted by the measurements made at the laboratory. A possible source of this difference may be the different methods used to wet the test surface. At the laboratory a spray-bar system was used and the surfaces were as wet as they would be during a moderate to heavy rainfall. In the American study the surface was wetted by a tanker preceding the test vehicle and it may be that much of the water drained away or evaporated before the noise measurement could be made.

5.2 Prospects for the quiet lorry project

The research described in this report was conducted with the intention of assessing the possible difficulties tyre to surface noise could cause in the quiet lorry development project . Table 1 shows that for the achievement of the quiet lorry target levels tyre to surface noise should not exceed 77 dB(A) at 7.5m from the vehicle centre line. Table 6 shows the sound levels measured in the experiments for lorry speeds of 40 and 100 km/h. In selecting tyre and surface combinations even for a quiet vehicle one must remember that the principal function of tyre and surface is to provide adequate traction and safe control under the most disadvantageous conditions that may be expected in normal running. Table 7 therefore shows the values at 40 and 100 km/h of the peak and locked wheel brake force coefficients for all the tyres and two of the surfaces considered in the noise study. Because the abrasiveness of the coarse quartzite aggregate could have damaged the experimental tyres brake force coefficients on this surface were not measured but previous experience suggests that they would not differ significantly from the values observed on the motorway surface.

TABLE 6

RANGE OF SOUND LEVELS MEASURED IN INVESTIGATION

Tyres	Load	Sound Levels in dB(A) Speed Range 40–100 Km/h — Surfaces: Smooth Concrete Dry	Smooth Concrete Wet	Coarse Quartzite Dry	Coarse Quartzite Wet	Motorway Dry	Motorway Wet
Cross-ply - (16 ply) Tyre Pressures 620 KPa							
Smooth (Natural Rubber)	U	64–72	67–(81)	64–77	78–86	65–79	78–88
	L	nt	nt	66–(78)	nt	66–(81)	nt
Smooth (High Hysteresis Rubber)	U	61–74	70–83	64–77	78–89	66–80	81–90
Highway Type B (7-ribbed Natural Rubber)	U	64–77	75–83	64–78	76–84	67–80	76–85
	L	65–(78)	nt	66–(79)	nt	66–(83)	nt
Highway Type A (5-ribbed Natural Rubber)	U	64–79	77–87	65–78	75–84	67–83	79–88
	L	64–(80)	nt	67–(79)	nt	67–(83)	nt
Traction (Transverse Grooved Natural Rubber)	U	65–83	75–89	65–81	77–87	68–83	79–91
	L	69–(88)	nt	67–(82)	nt	67–(86)	nt
Traction (Transverse Grooved High Hysteresis Rubber)	U	62–82	73–90	66–79	79–89	68–83	78–90

Loads are shown in Table 2
U means unladen lorry
L means laden lorry
nt not tested
() extrapolated results.

TABLE 7

RANGE OF BRAKE FORCE COEFFICIENTS MEASURED

Tyres Cross-ply – (16 Ply)	Brake Force Coefficients Speed Range 40–100 Km/h			
	Smooth Concrete		Motorway	
	Peak	Locked Wheel	Peak	Locked Wheel
Smooth (Natural Rubber)	.39–(.03)	.23–(.03)	.58–(.46)	.33–(.22)
Smooth (High Hysteresis Rubber)	.54–(.05)	.25–(.03)	.66–(.48)	.40–(.16)
Highway Type B (7-ribbed Natural Rubber)	.63–(.66)	.42–(.24)	.68–(.75)	.42–(.25)
Highway Type A (5-ribbed) Natural Rubber)	.58–(.47)	.38–(.20)	.65–(.54)	.40–(.24)
Traction (Transverse Grooved Natural Rubber	.58–(.30)	.38–(.14)	.62–(.58)	.36–(.26)
Traction (Transverse Grooved High Hysteresis Rubber)	.58–(.36)	.38–(.22)	.70–(.77)	.43–(.25)

() extrapolated results

The main test of vehicle noise is set out in British Standard BS 3425:1966, "Methods for the measurement of noise emitted by motor vehicles". This standard specifies an acceleration test on a dry surface with the vehicle unladen and driven under closely specified conditions. For diesel lorries with manual gear boxes these conditions usually mean that the lorry goes through the test area at 30 to 40 km/h. It can be seen from Table 6 that under such a test no tyre surface combination generates levels in excess of 68 dB(A), which is a comfortable 9 dB(A) below the target set for the tyres of the quiet lorry. Consequently tyre to surface noise will not prevent the quiet lorry meeting the target level in the BS test.

As speed doubles tyre to surface noise increases by about 10 dB(A) on the dry surfaces and only the smooth tyres running on the smooth concrete and coarse quartzite surfaces fall within the limit specified at speeds of 100 km/h. However inspection of Table 7 indicates clearly how unsafe the smooth tyre smooth surface combination can be at high speeds and such a solution of a noise problem would not produce a viable vehicle. The smooth tyre brake force coefficients on the rough motorway surface tempt one to consider the smooth tyre rough surface combination as a possible solution. The peak force values in Table 7 clearly indicate that on a rough surface even with smooth tyres a lorry fitted with an anti-locking brake system could stop in less distance than a lorry with patterned tyres but with a conventional braking system. However the low peak coefficient on the smooth surface suggests that even the most advanced braking system can be of little help in stopping a smooth tyred lorry on such a surface. Consequently if smooth tyred lorries with anti-locking brake systems were to be authorized for environmental reasons there would be a very great responsibility on the highway authorities to maintain their surfaces with a persistent coarse and rugous surface texture even where traffic noise is not a serious problem. At the moment this seems to be an impractical requirement. It follows that in the immediate future smooth tyres in combination with an anti-lock braking system, cannot be considered for the quiet heavy vehicle. Of the patterned tyres, the two highway types only just exceed the target level on the dry coarse quartzite surface at speeds of 100 km/h. The brake force coefficients for these tyres seem typical of patterned tyres and would raise no specific safety problem. It would seem then advisable, in the short term, to consider what practical modifications could be made to this sort of tyre to reduce the noise at high speed by 2 to 3 dB(A). The amount of reduction obtained would then condition one's preference for surface type; with the present tyres surface dressing, as exemplified by the coarse quartzite, would appear to have a slight but clear advantage over hot rolled asphalt, exemplified by the motorway surface.

An alternative approach to meet the quiet heavy lorry levels on dry roads would be to design the vehicle with a maximum operating speed of 80 km/h. While this would allow the use of current tyres on dressed surfaces or the use of slightly quietened tyres on a hot rolled asphalt surface the imposition of such a maximum speed limit would disadvantage the user of the quiet vehicle unless the limit was generally agreed and enforced. Since for economic reasons UK vehicles including any quiet lorry must be competitive in the export market international agreement on a maximum lorry speed limit would need to be reached. For this reason it seems impractical to consider an 80 km/h limit as a solution.

On the wet surfaces at 100 km/h all the tyres give noise levels well in excess of the limit and even at speeds as low as 40 km/h some of the tyre-surface combinations give levels above the limit. It seems clear that under wet conditions the tyre to surface noise target cannot be met without some major innovation and at present the nature of this innovation is not known. It may be argued that in seeking to meet the quiet lorry target in wet weather one is being unnecessarily ambitious. In our climate falling rain perhaps provides sufficient discomfort to temporarily overcome one's awareness of other annoyances such as noisy vehicles and having reached some refuge the process of shutting out the elements must also shut out the noise. Given such behaviour the important step in reducing wet road noise would seem to be to design the road so that the surface dries rapidly once the rain stops and this could well be achieved by the use of such pervious surfacing as those at present under development at the Laboratory for the reduction of spray.

5.3 Further work

The agreement between the laboratory measurements and the results reported by previous authors suggest that the existing knowledge of tyre to surface noise is adequate for the assessment of the noise from existing vehicles on existing surfaces. The levels measured are comparable with existing engine noise only at the highest speeds on the wet surfaces. Thus work to reduce tyre noise on existing vehicles would probably not bring sufficient environmental benefit to justify the cost of the research. If the quiet heavy vehicle is to meet its target levels at high speeds on dry roads some work into the modification of the existing highway type tyres to achieve reductions of about 2 dB(A) will be required. It is hoped that the tyre manufacturers will be able to continue their collaboration with the laboratory and assist in this work.

The importance of surface drainage in the control of wet road noise needs further study. Such studies will be undertaken when the length of pervious surfacing constructed in the test track is available.

While it is anticipated that the quiet lorry rolling noise target can be met by the completion of the project the previous research and measurements reported in this paper do indicate that tyre to surface noise will be the predominant noise on this vehicle and any further dramatic reduction of lorry noise will not be possible until a commensurate reduction of rolling noise can be achieved. Such a reduction, much in excess of the 2 dB(A) envisaged in the preceding paragraph, presumably can arise only from some significant insight into the nature of the tyre to surface noise interaction. The reported work, in particular the 1/3 octave spectra, provide useful information particularly of the nature of the noise from transverse grooved tyres and pocket retread tyres but they do not provide sufficient information to give a deep understanding of the tyre to surface noise generator. Towards this further understanding it is proposed that the Laboratory should, with the aid of the industry and the Institute of Sound and Vibration Research, mount an experiment to determine the noise transfer function for lorry tyres subject to radial and tangential impulses. At the same time the Laboratory will also develop a measurement technique involving microphones mounted on the lorry to permit a finer frequency analysis than that given by the 1/3 octave analysis of the vehicle pass-by recordings.

6. ACKNOWLEDGEMENTS

This report is based on work carried out in the Environment Division (Division Head Mr.L.H. Watkins) of the Transport Systems Department, Transport and Road Research Laboratory. The author wishes to record the cooperation of Mr.B.E. Clapson (Avon Tyre Company), Mr.J.Trimble (Avon Tyre Company), and Mr.J.C. Walker (Dunlop Rubber Company) who are all members of the British Rubber Manufacturers Association Tyre Test Committee. The author is grateful for assistance in the research program given by Mr.E.G. Parrett of the Vehicle Engineering Division (DOE Headquarters), and Mr.N.F. Ross of the Environment Division (TRRL) and members of the Vehicles Division (TRRL) for making the skidding tests on the tyres. The author would also like to record the valuable assistance given by Mr. D.G.Harland (TRRL) in compiling this report.

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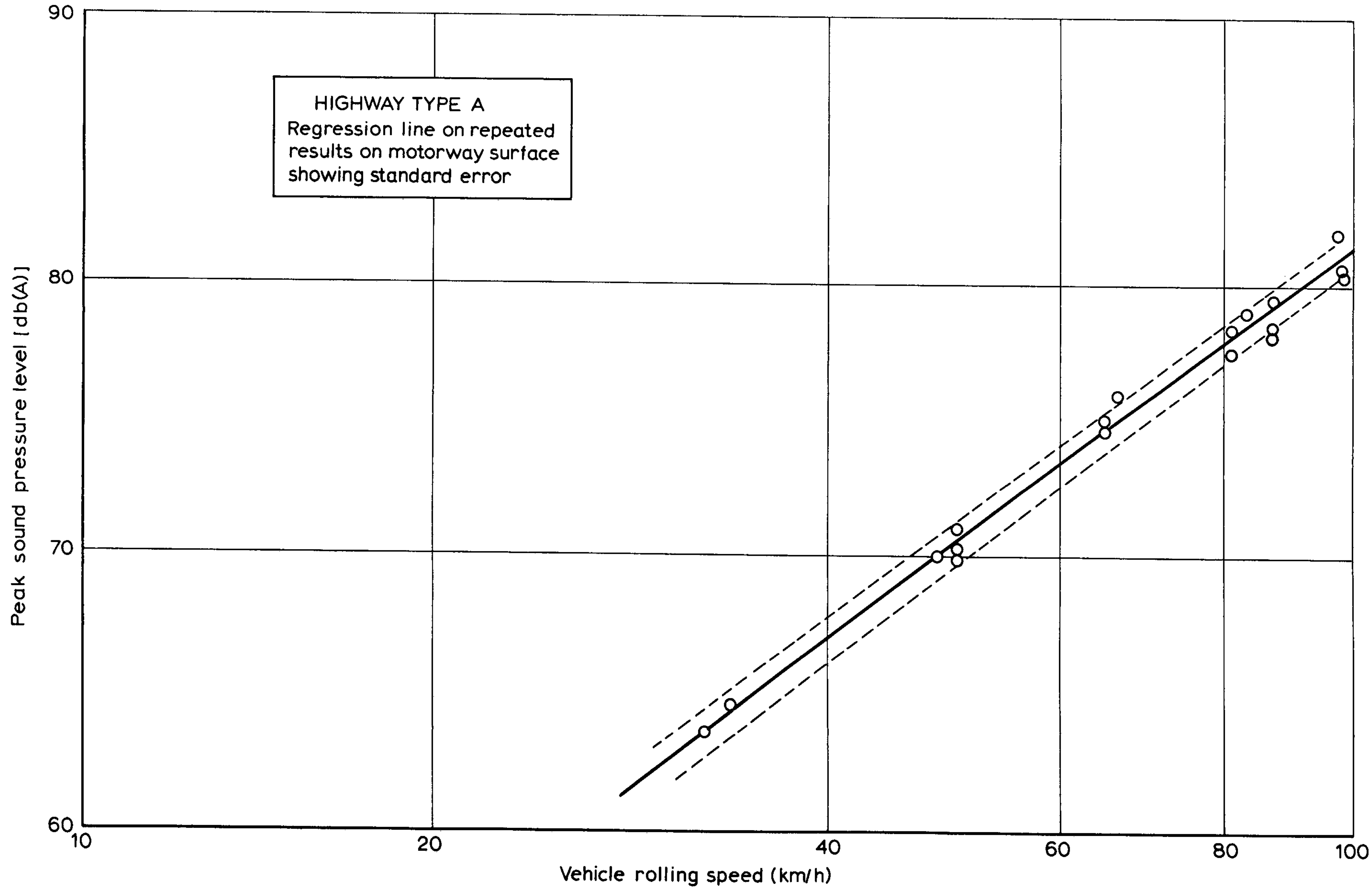


Fig. 1. REPEATABILITY OF TEST RESULTS

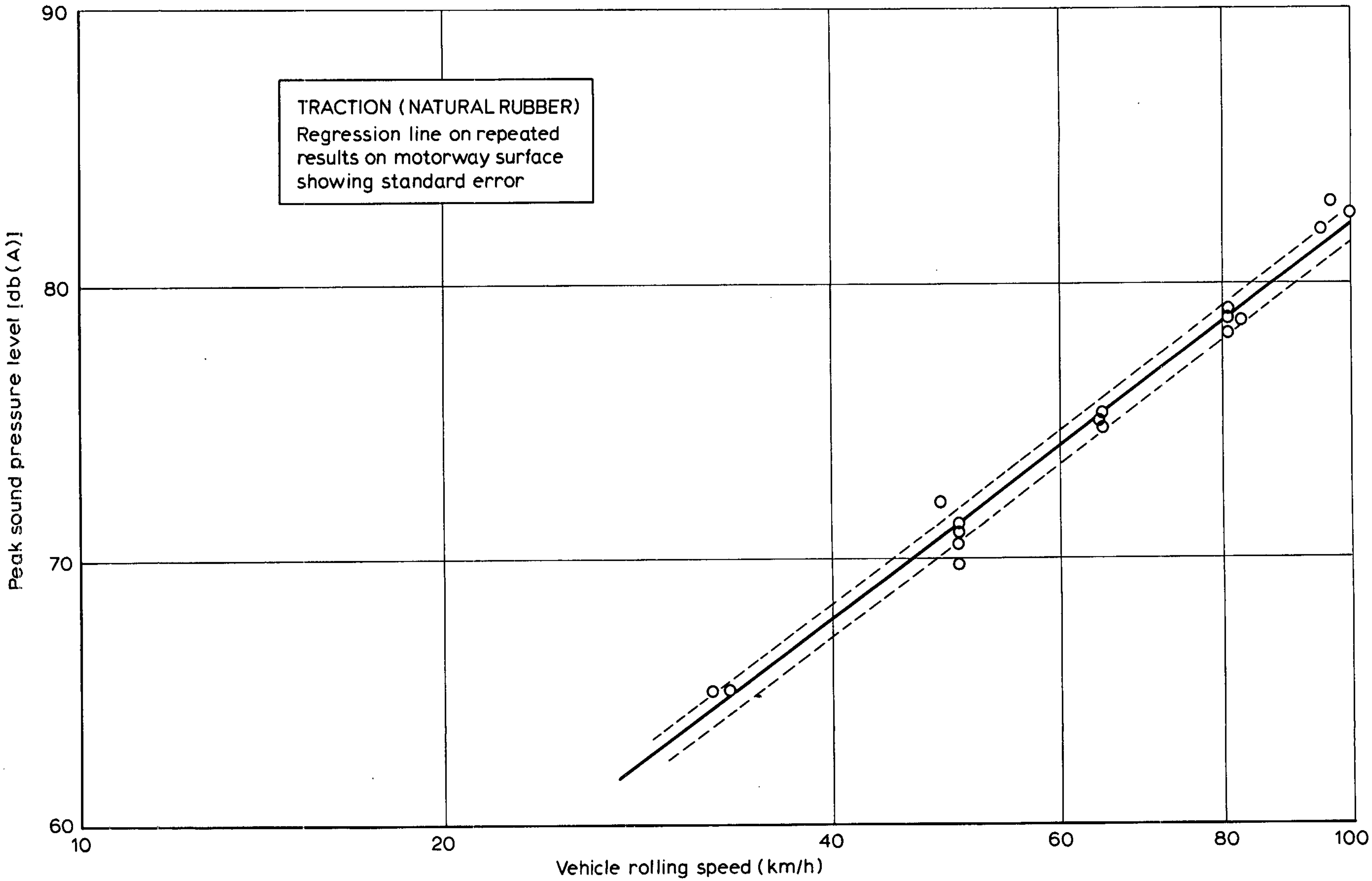


Fig. 2. REPEATABILITY OF TEST RESULTS

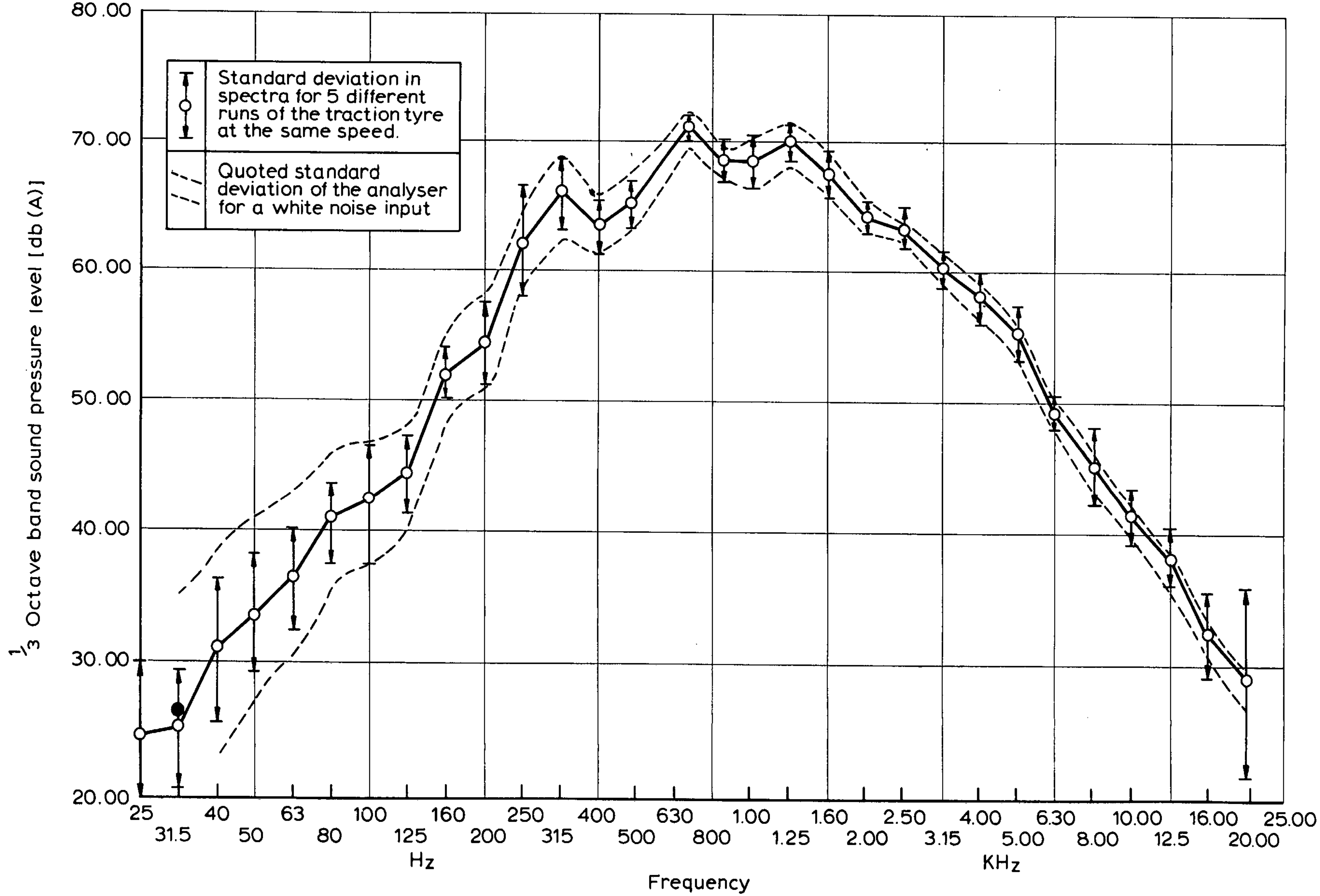


Fig. 3. THIRD OCTAVE SPECTRA REPEATABILITY

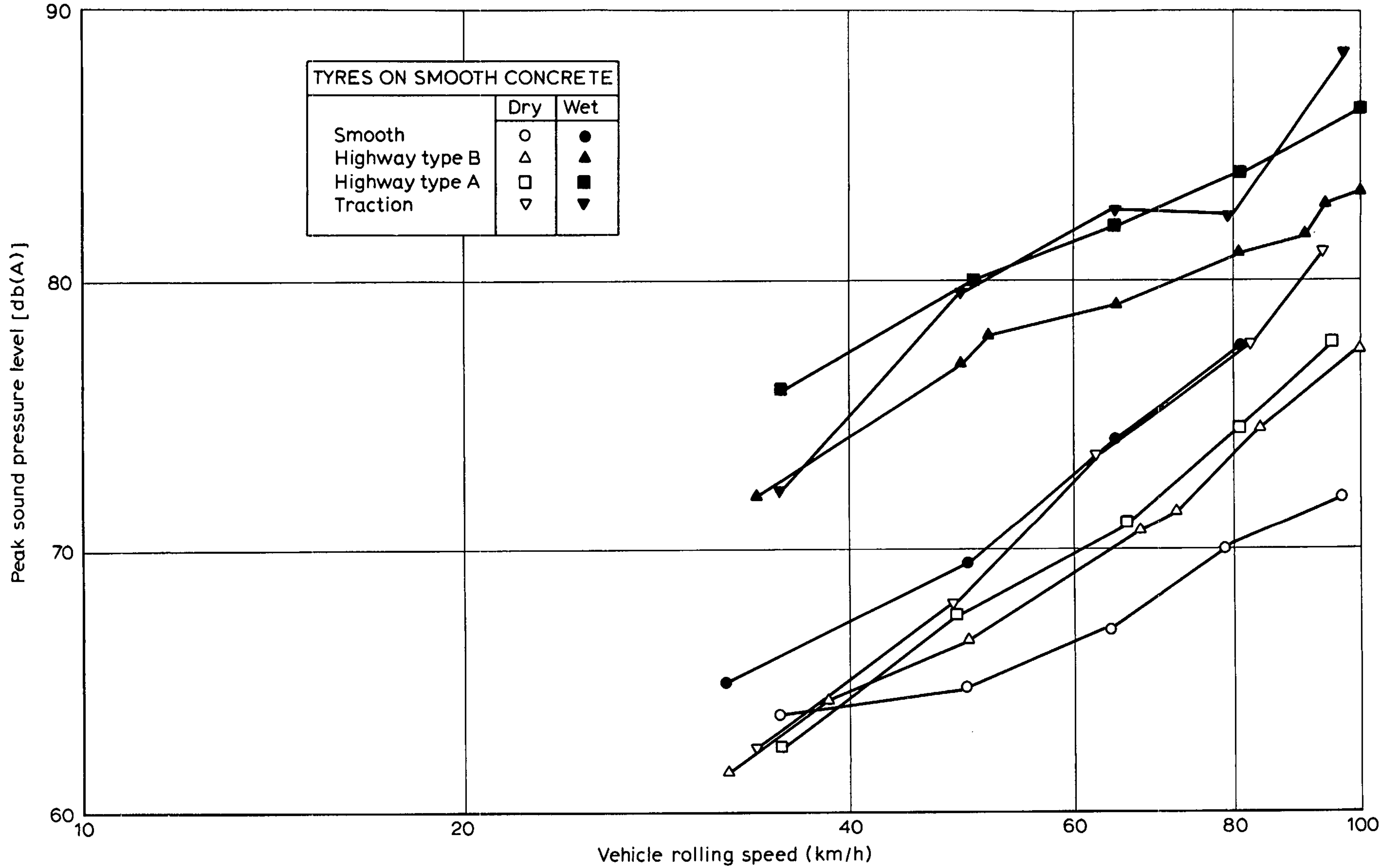


Fig. 4. THE ROLLING NOISE OF THE TYRES ON THE SMOOTH CONCRETE

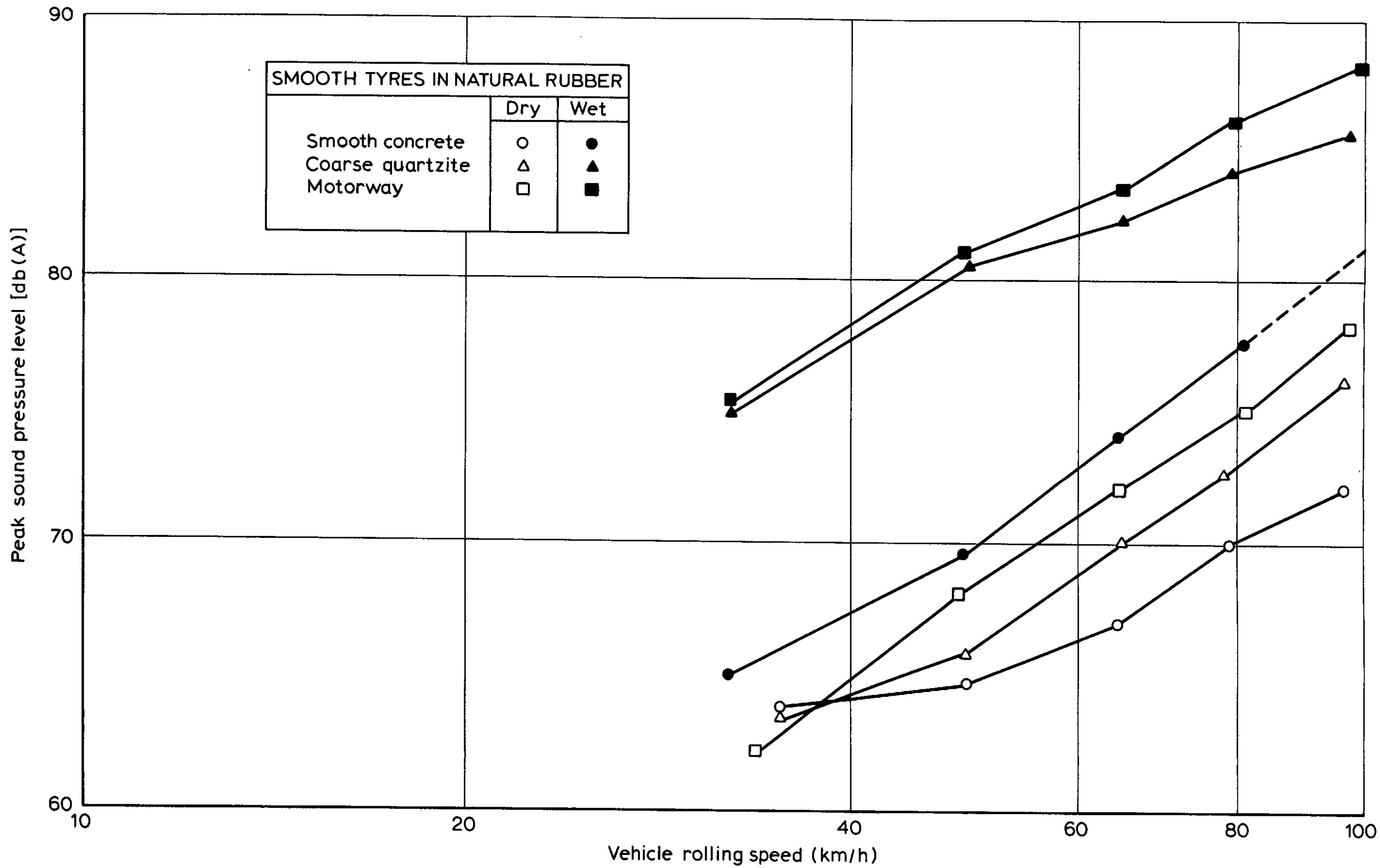


Fig. 5. THE ROLLING NOISE OF THE SMOOTH TYRES ON THE THREE SURFACES

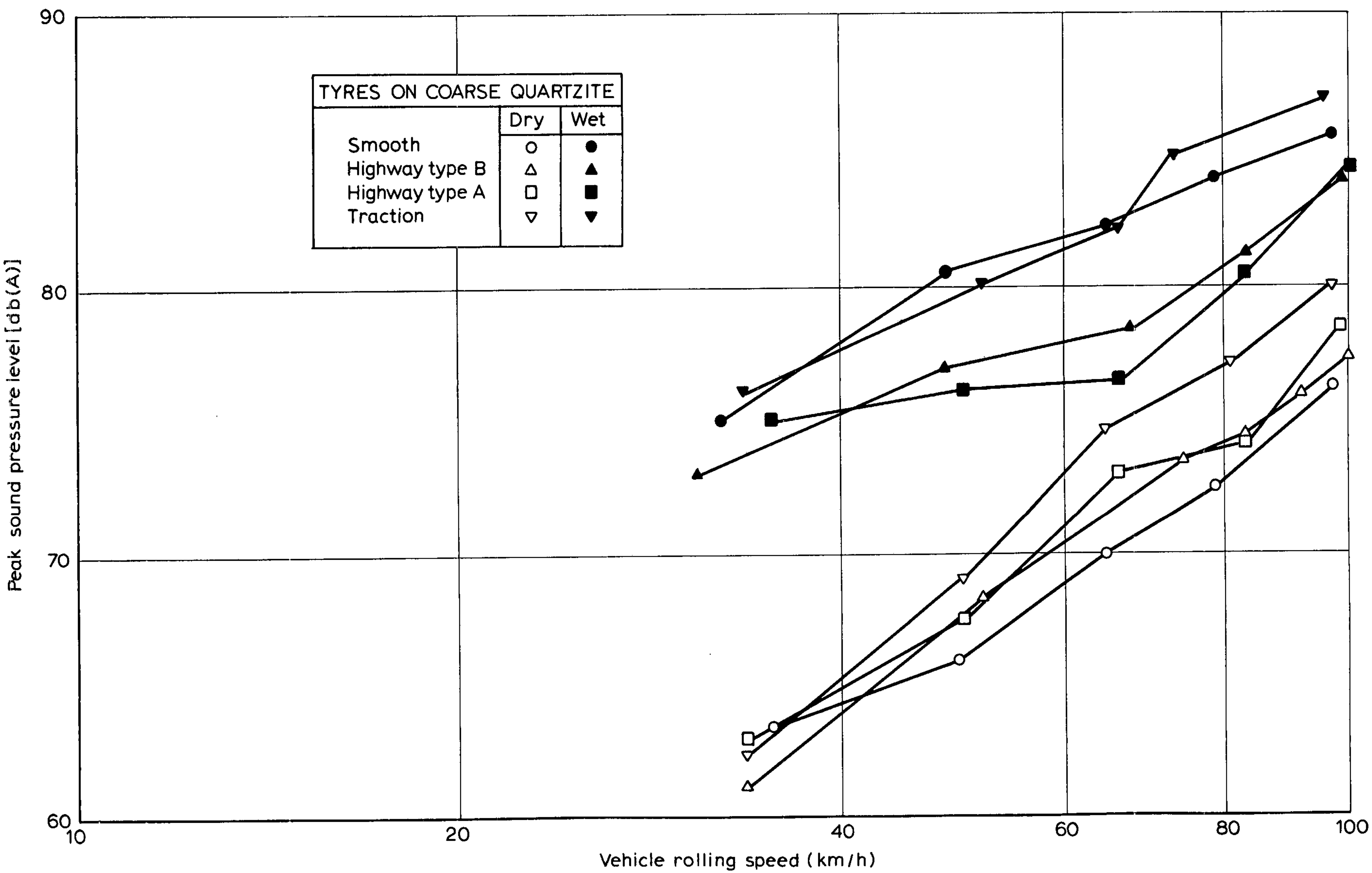


Fig. 6. THE ROLLING NOISE OF THE TYRES ON THE COARSE QUARTZITE

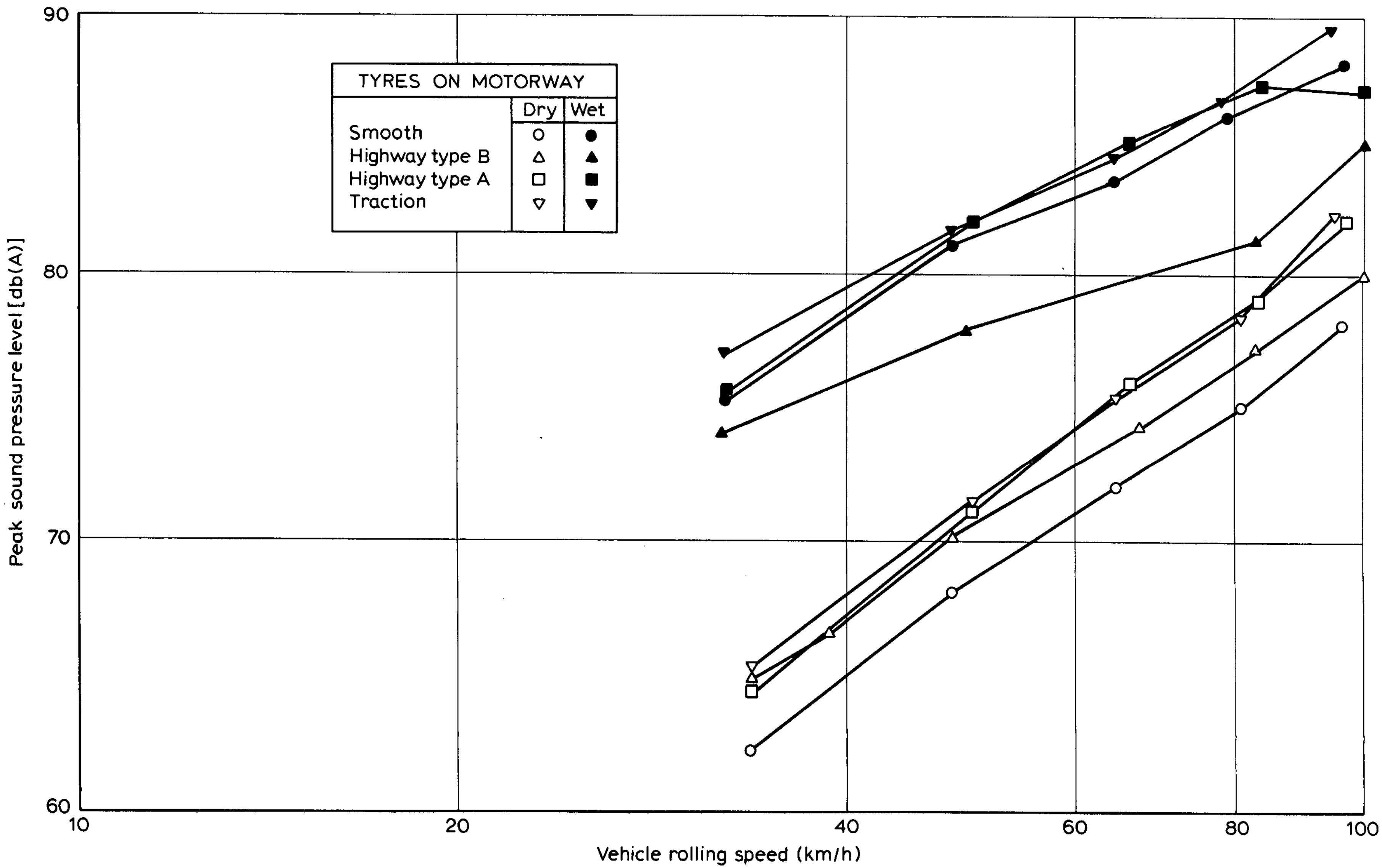


Fig. 7. THE ROLLING NOISE OF THE TYRES ON THE MOTORWAY SURFACE

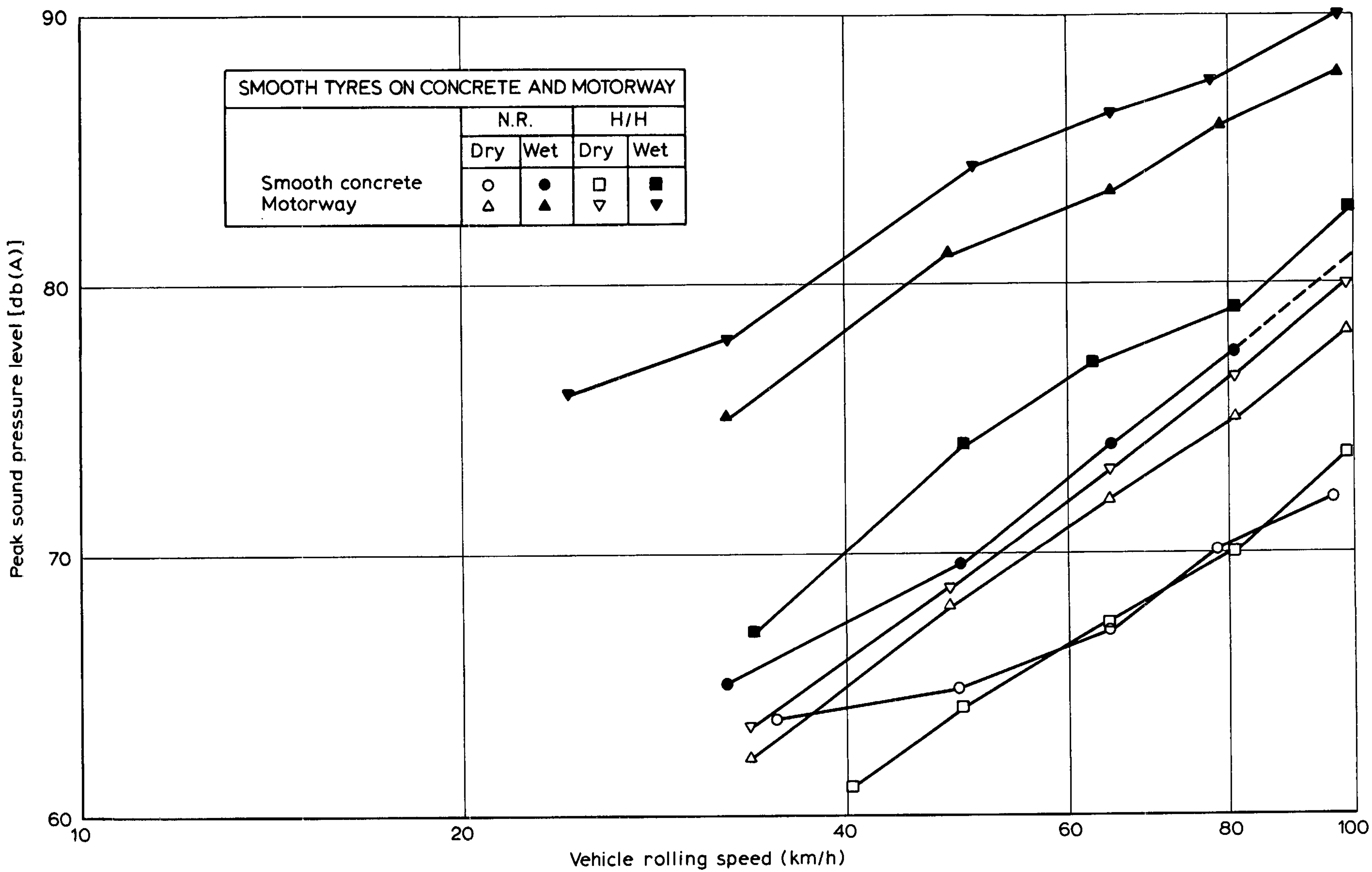


Fig. 8. THE ROLLING NOISE OF THE TWO SETS OF SMOOTH TYRES ON TWO SURFACES

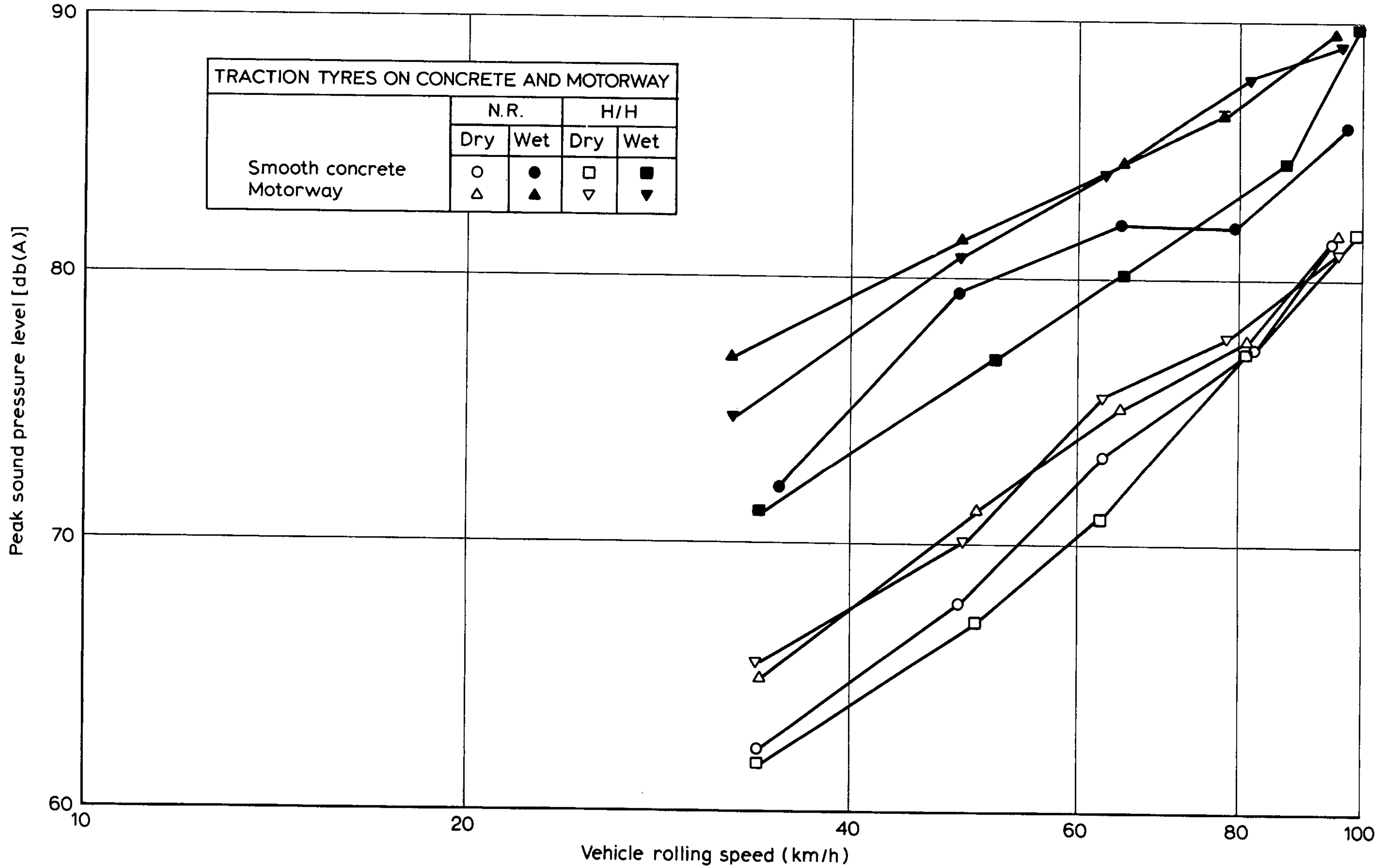


Fig. 9. THE ROLLING NOISE OF THE TWO SETS OF TRACTION

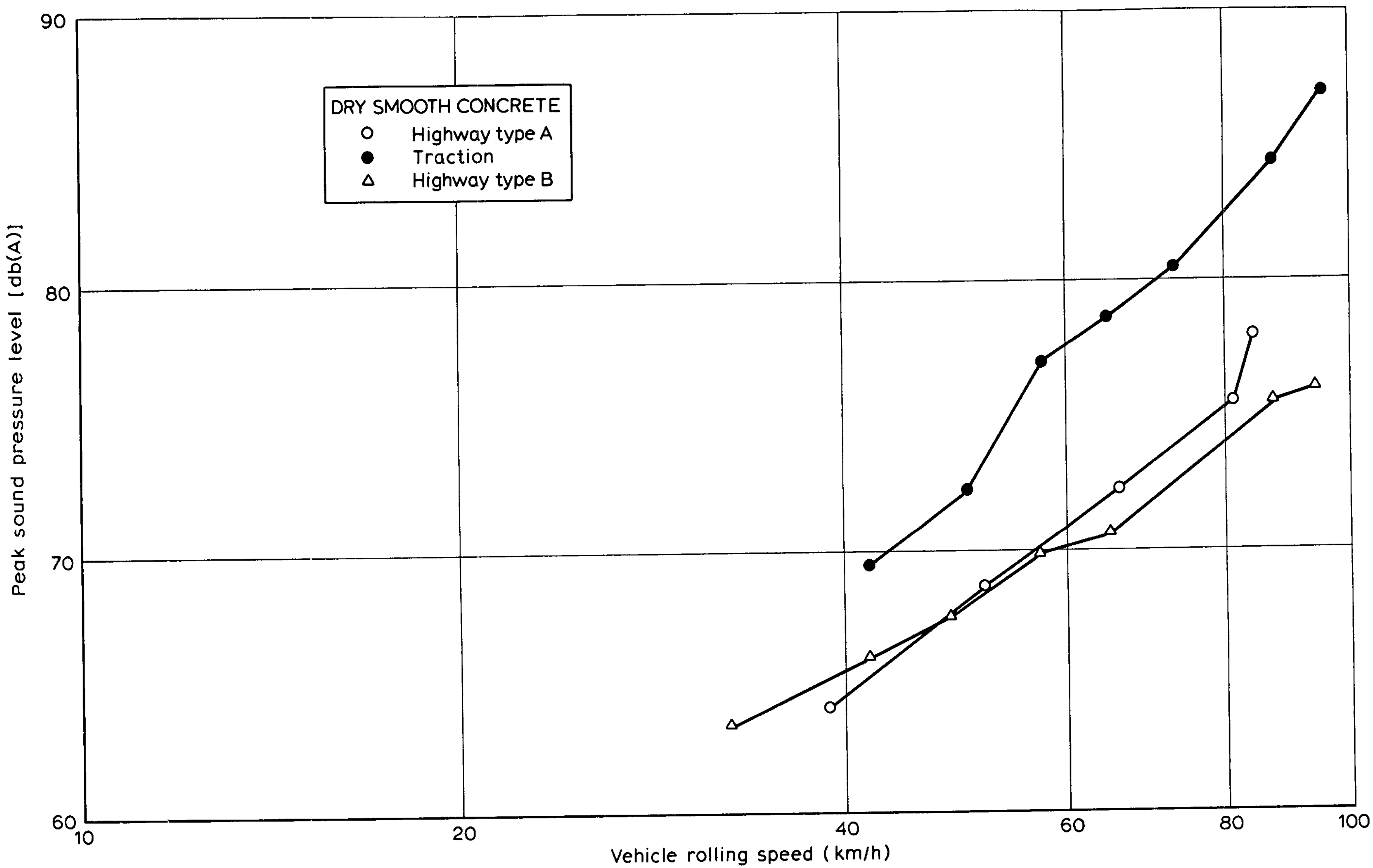


Fig. 10. THE ROLLING NOISE OF LADEN TYRES ON THE SMOOTH CONCRETE SURFACE

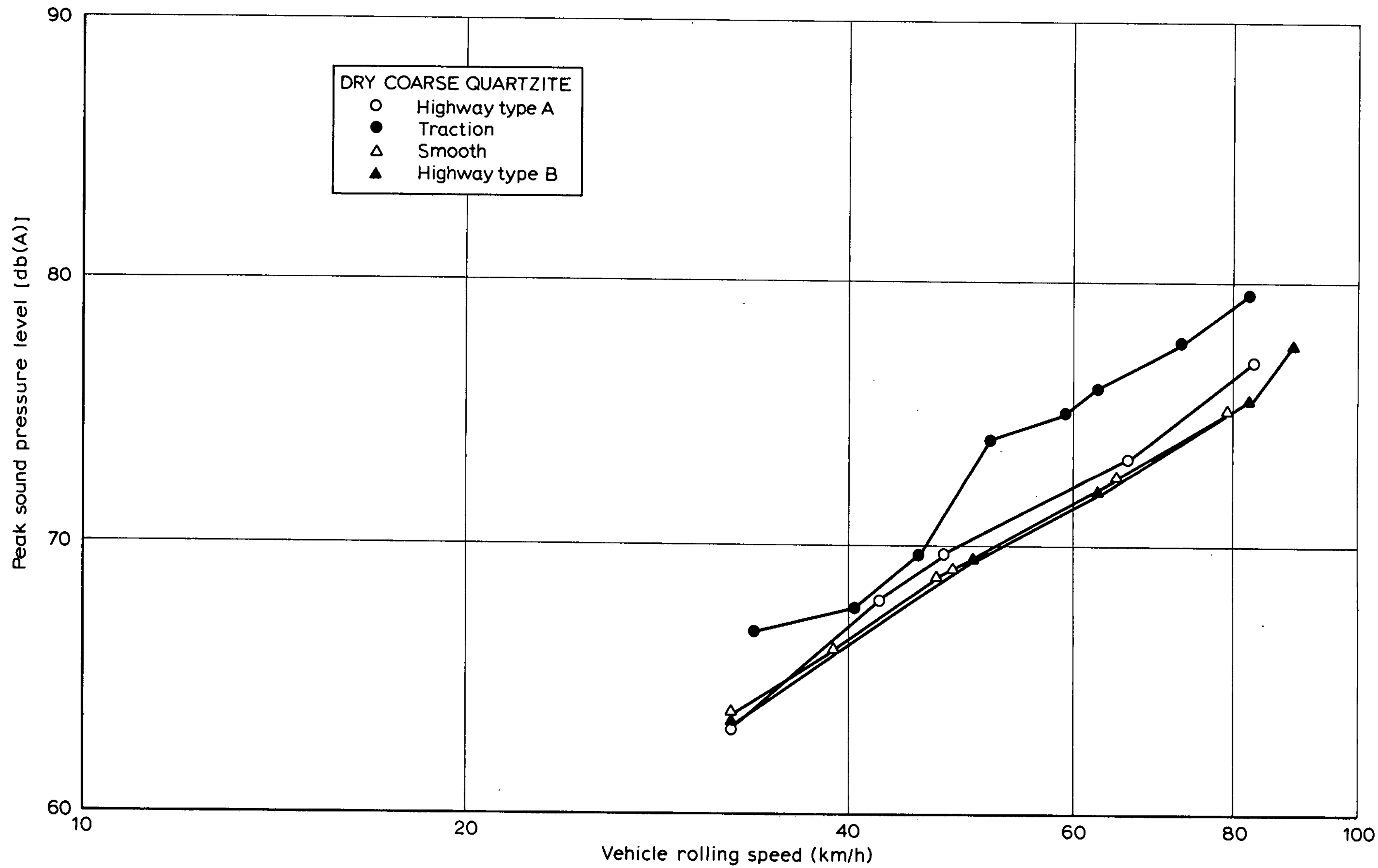


Fig. 11. THE ROLLING NOISE OF LADEN TYRES ON THE COARSE QUARTZITE SURFACE

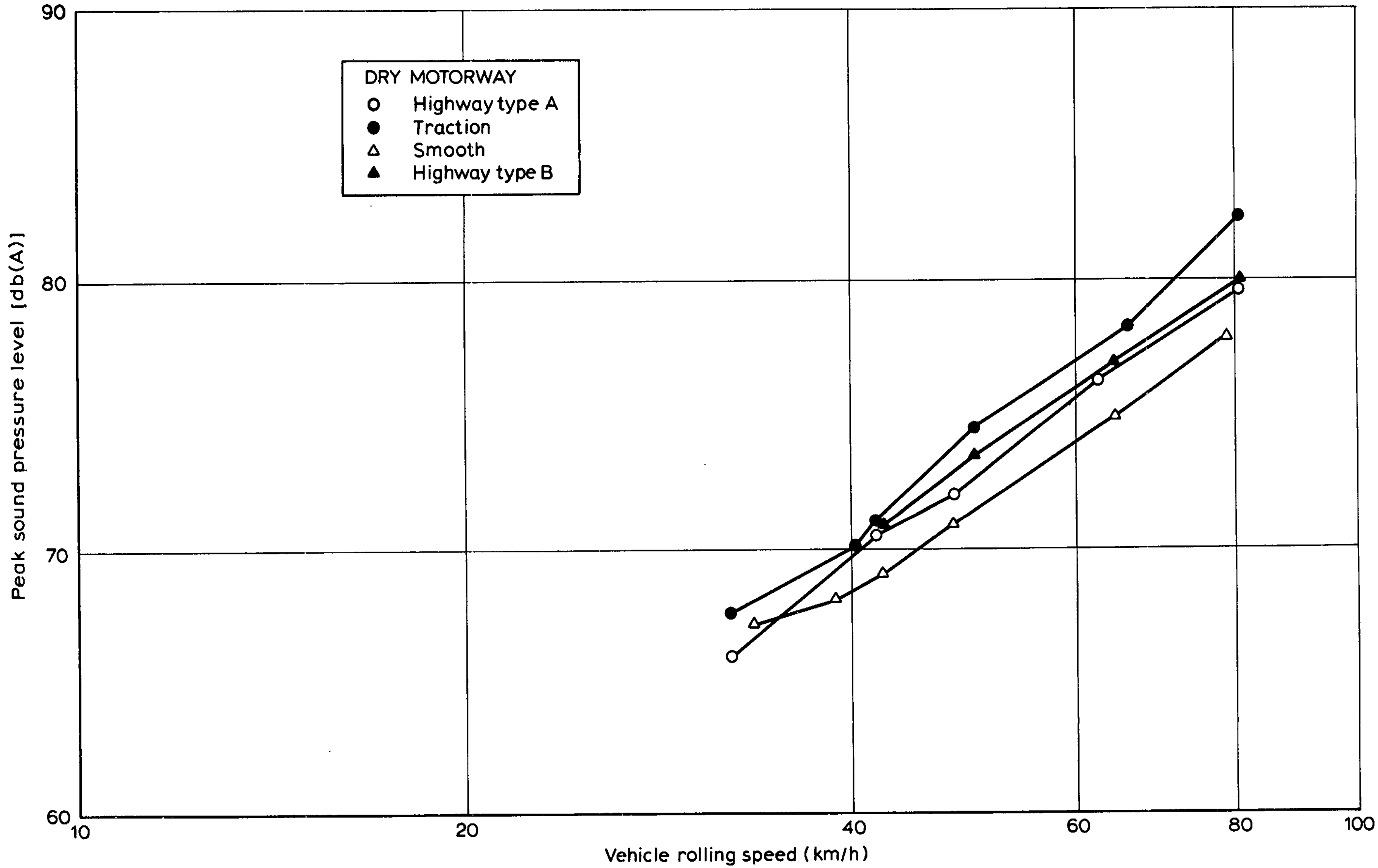


Fig. 12. THE ROLLING NOISE OF LADEN TYRES ON THE MOTORWAY SURFACE

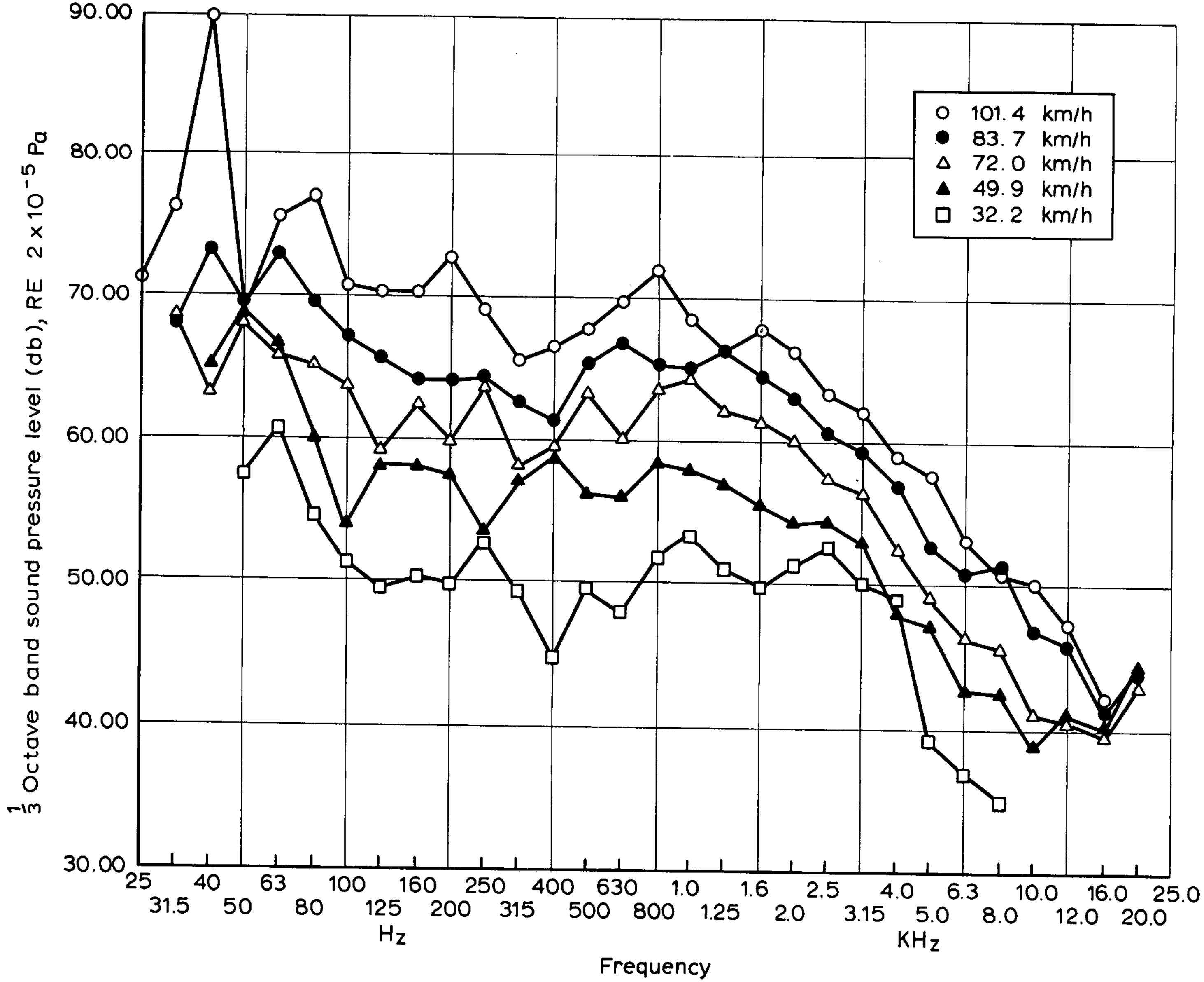


Fig.13 HIGHWAY TYPE B ON SMOOTH CONCRETE

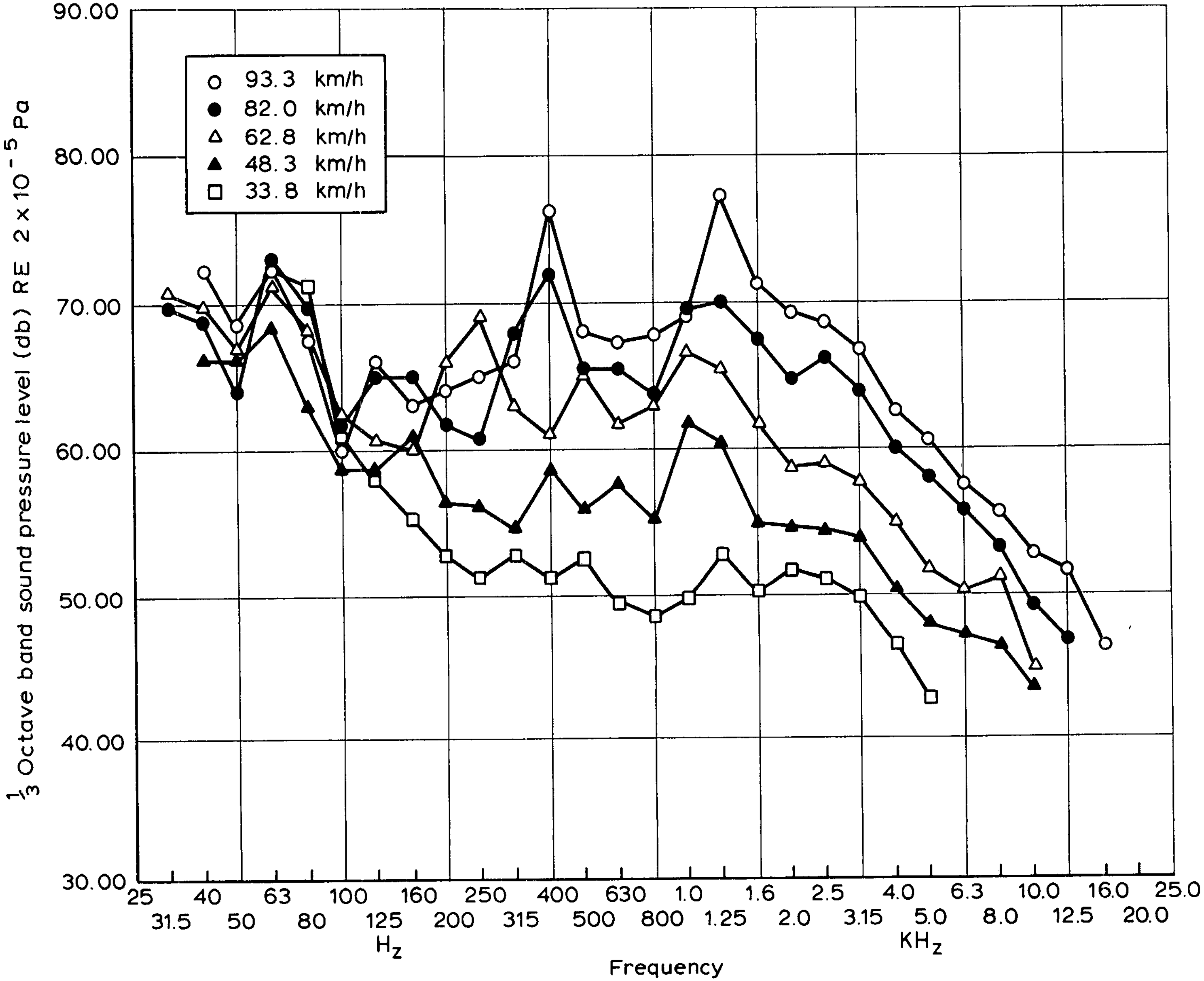


Fig.14. TRACTION (N.R) ON SMOOTH CONCRETE

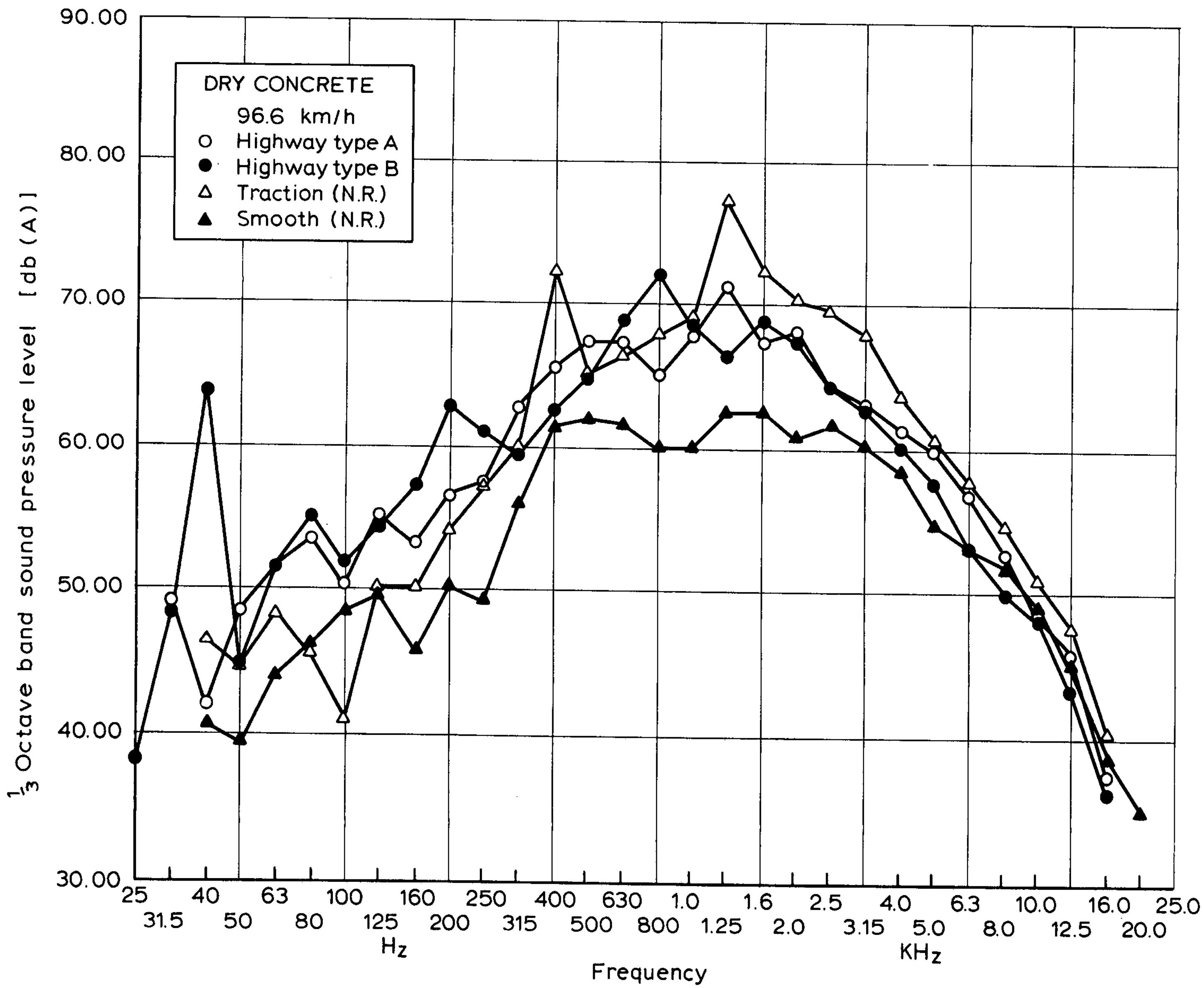


Fig. 15. TYRES ON A SMOOTH SURFACE AT HIGH SPEED

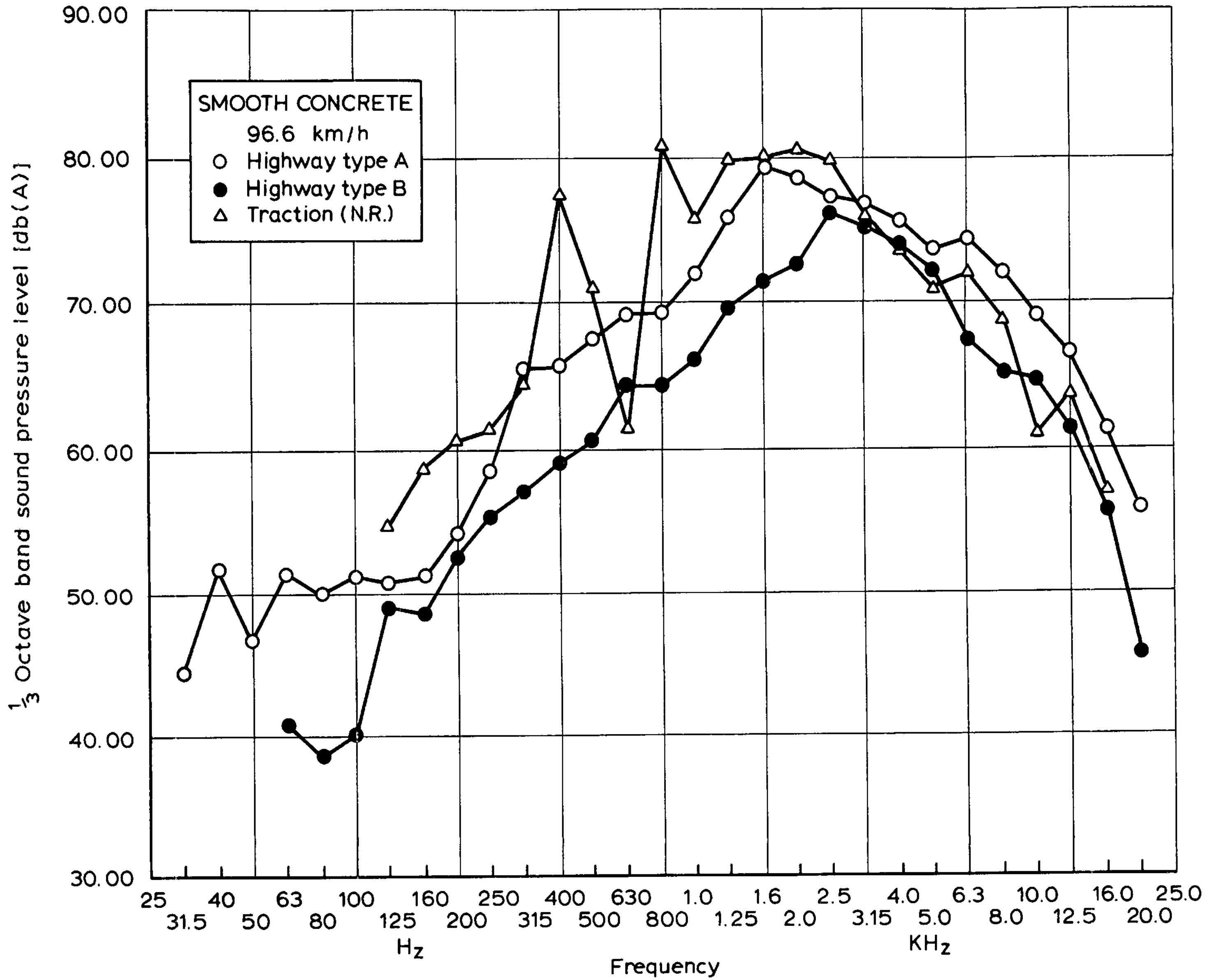


Fig.16. PATTERNED TYRES ON A WET SMOOTH SURFACE AT HIGH SPEED

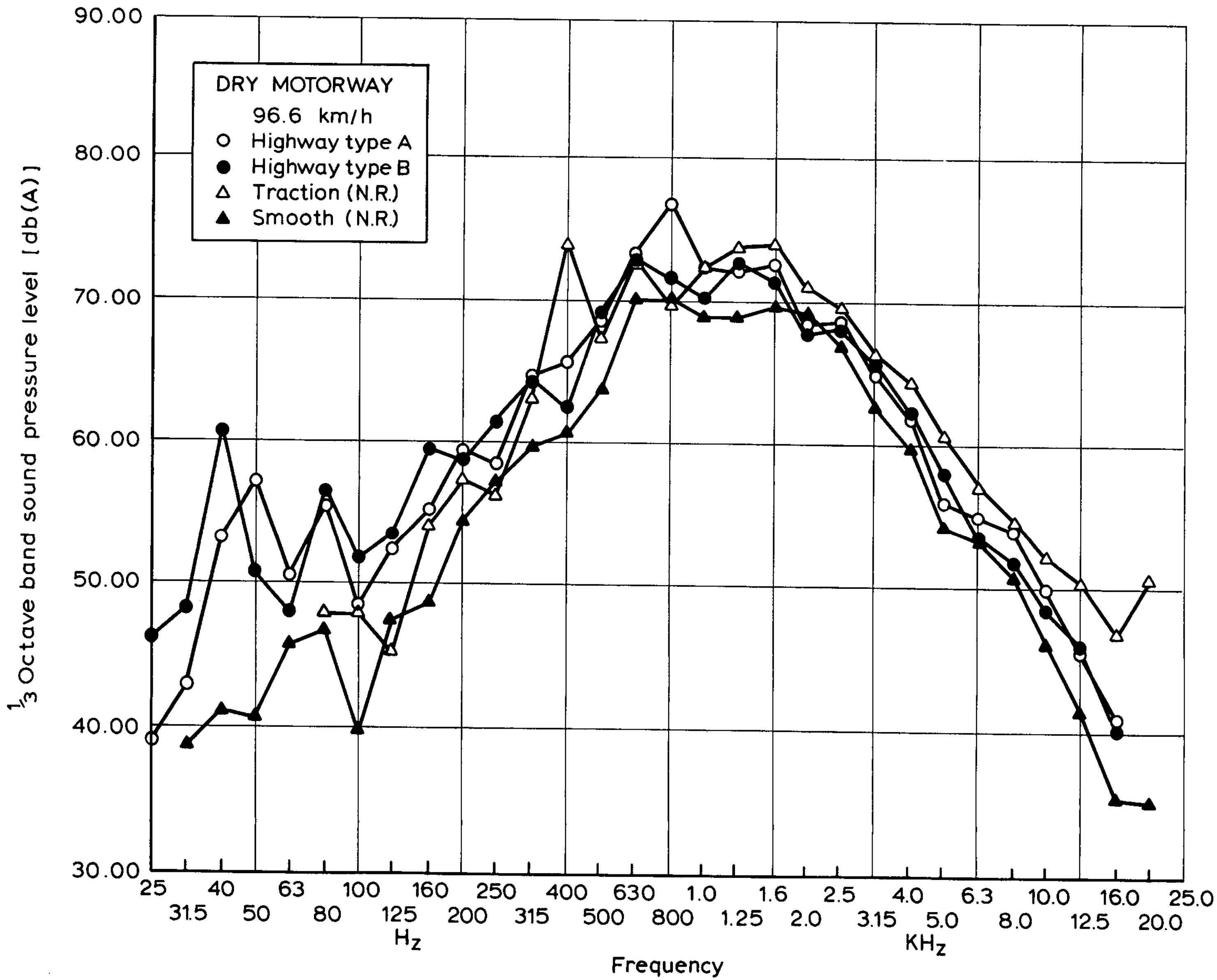


Fig. 17. TYRES ON A ROUGH SURFACE AT HIGH SPEED

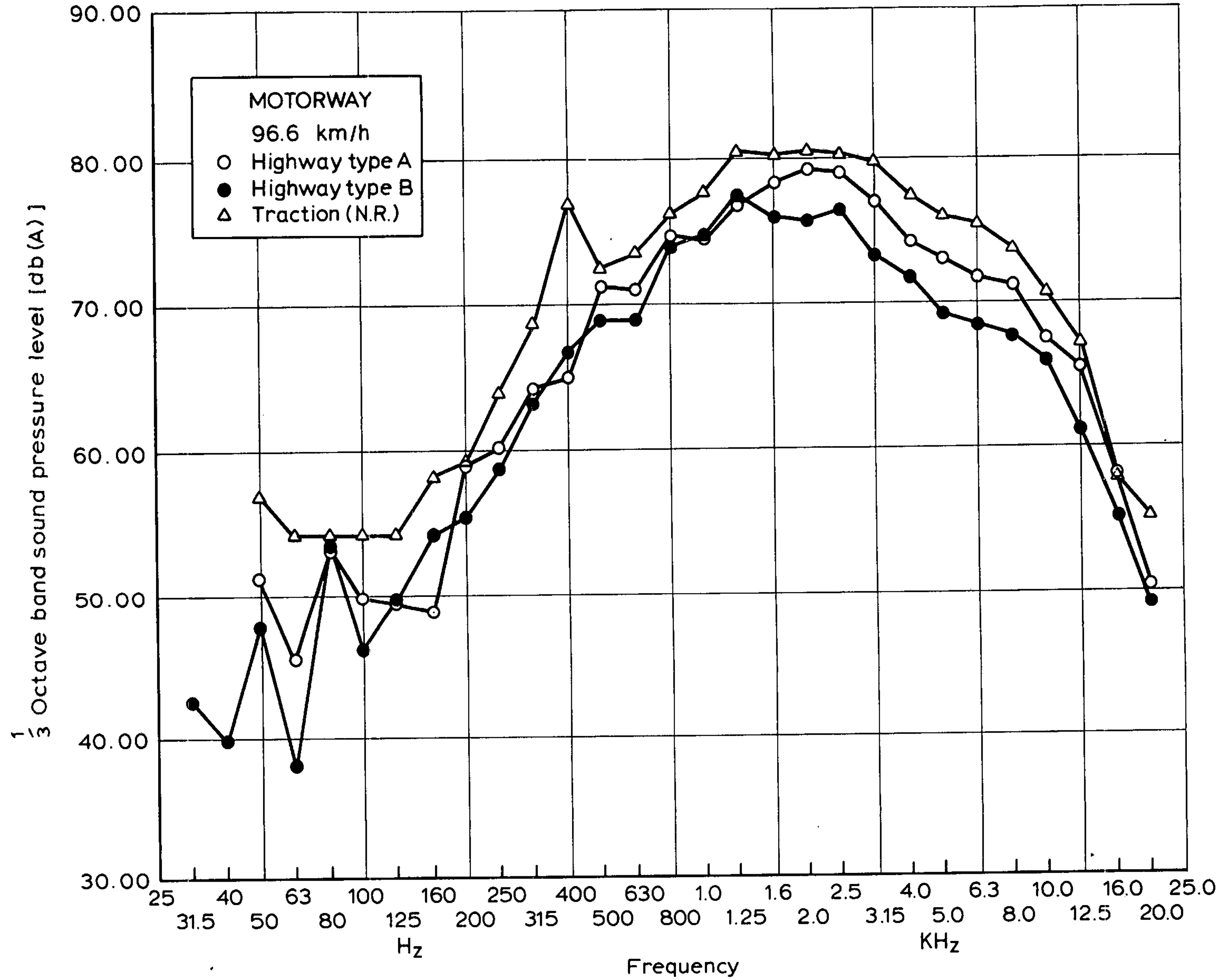


Fig. 18. PATTERNED TYRES ON A WET ROUGH SURFACE AT HIGH SPEED

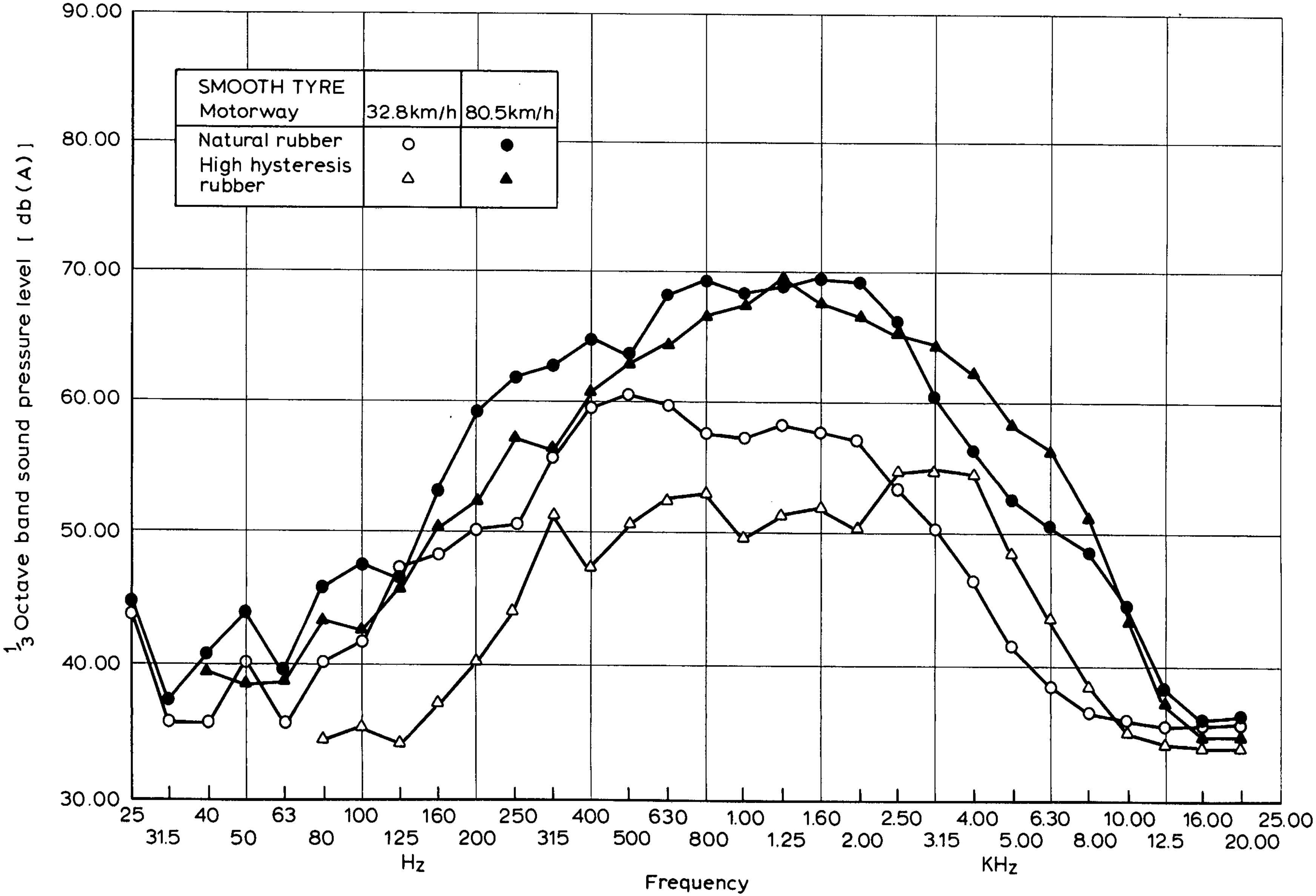


Fig. 19. COMPARISON OF SPECTRA FOR SMOOTH TYRES ON DRY MOTORWAY

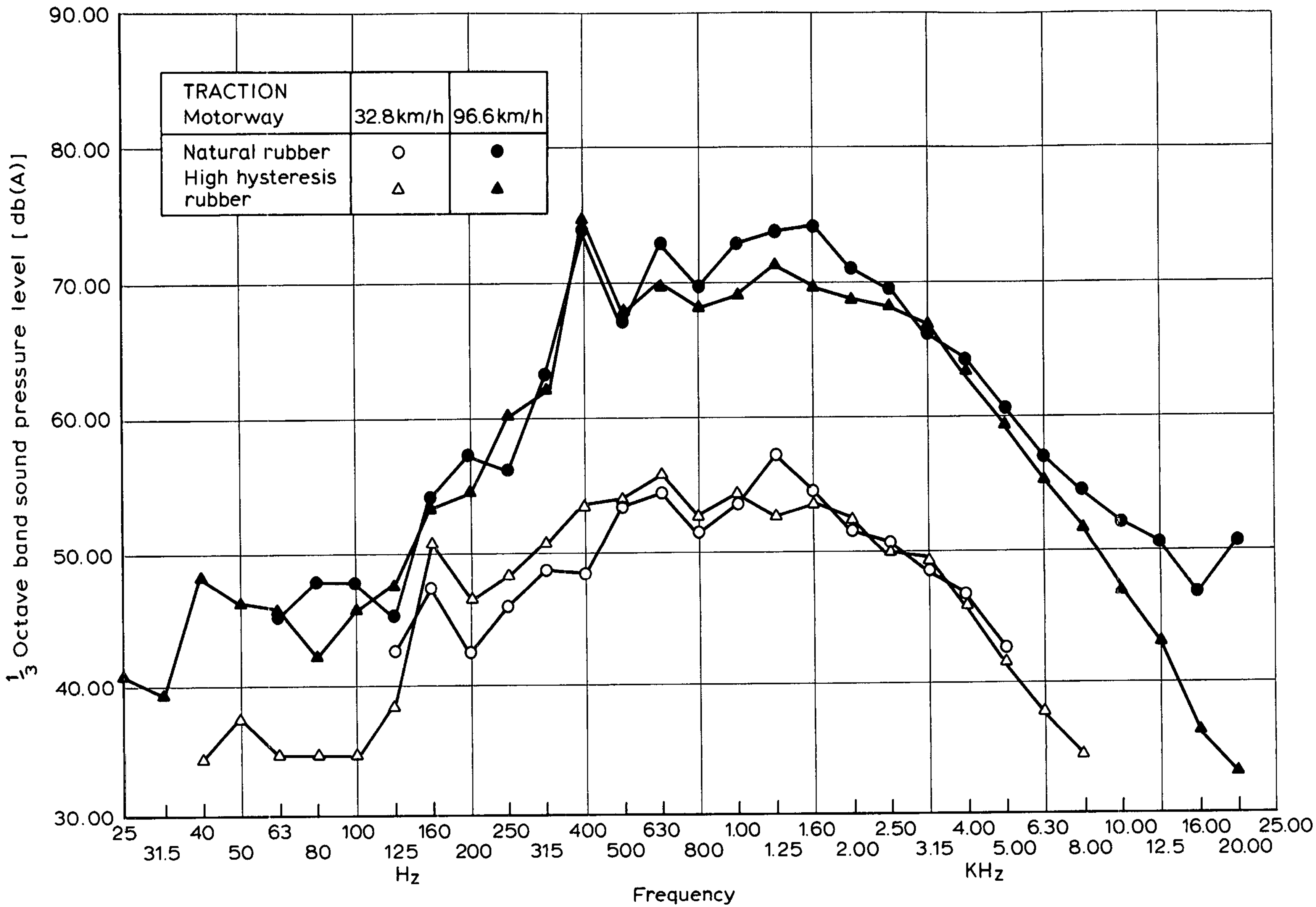


Fig. 20. COMPARISON OF SPECTRA FOR TRACTION TYRES ON DRY MOTORWAY

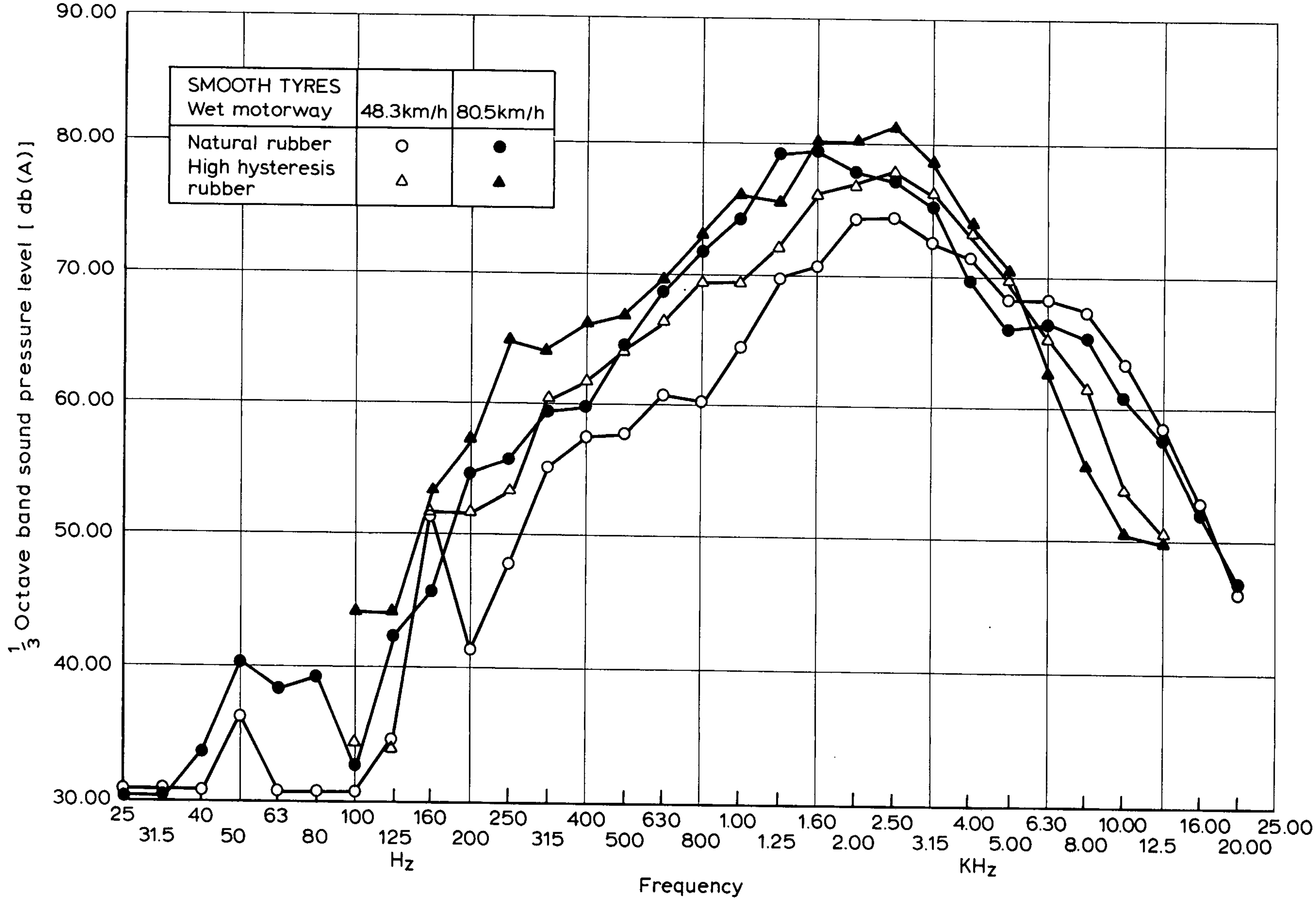


Fig. 21. COMPARISON OF SPECTRA FOR SMOOTH TYRES ON WET MOTORWAY

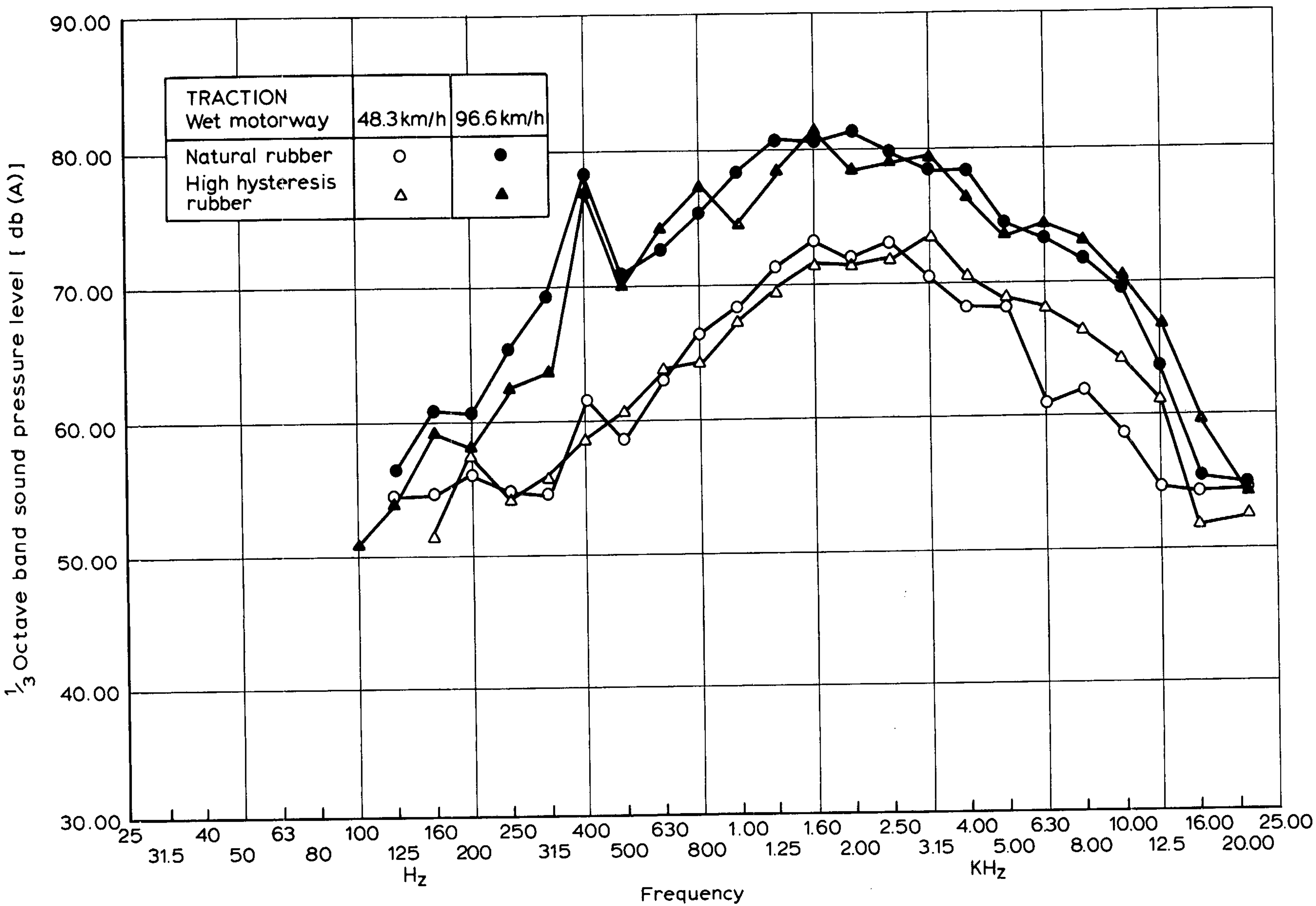


Fig. 22. COMPARISON OF SPECTRA FOR TRACTION TYRES ON WET MOTORWAY

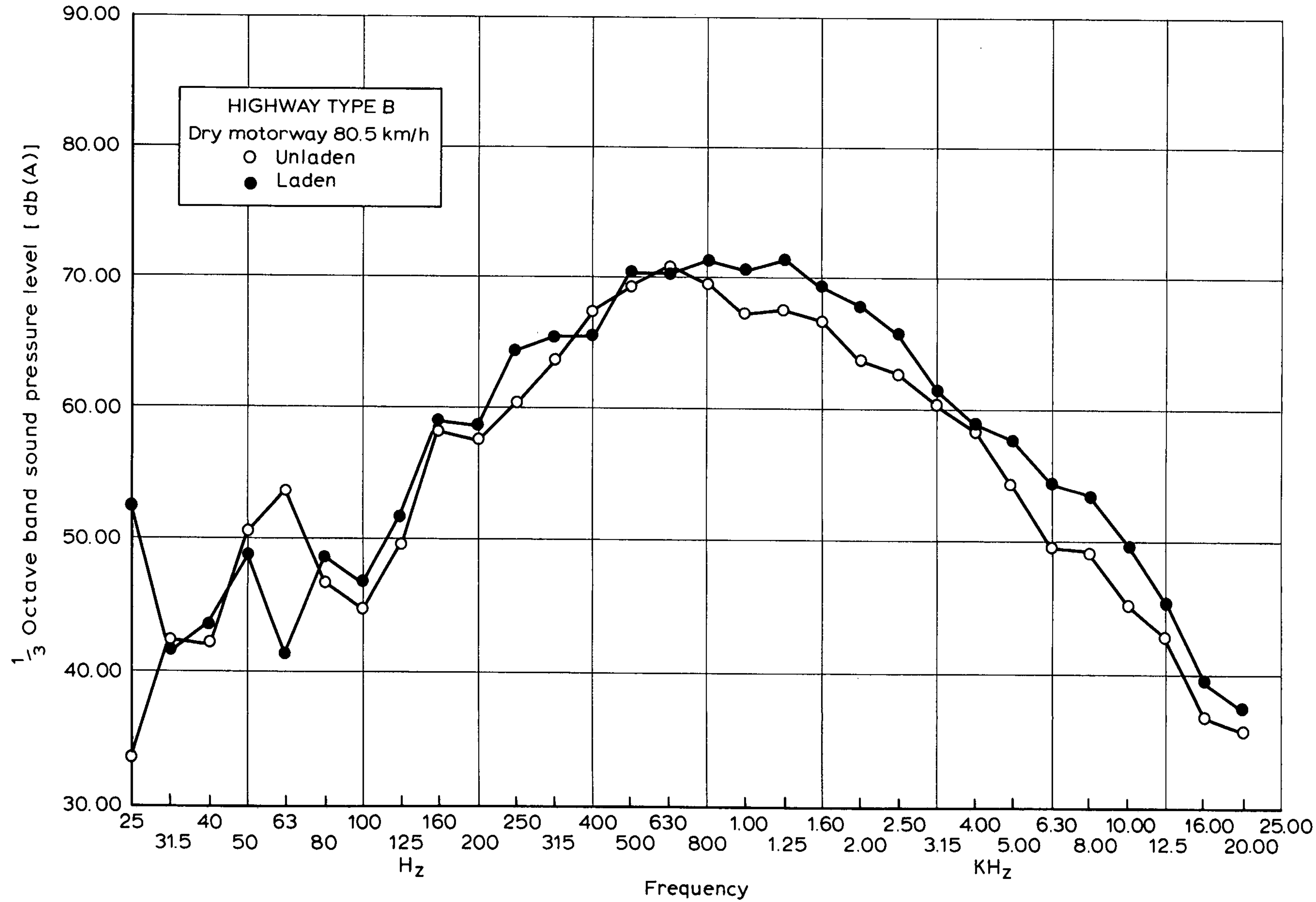


Fig. 23. THE EFFECTS OF LOADING

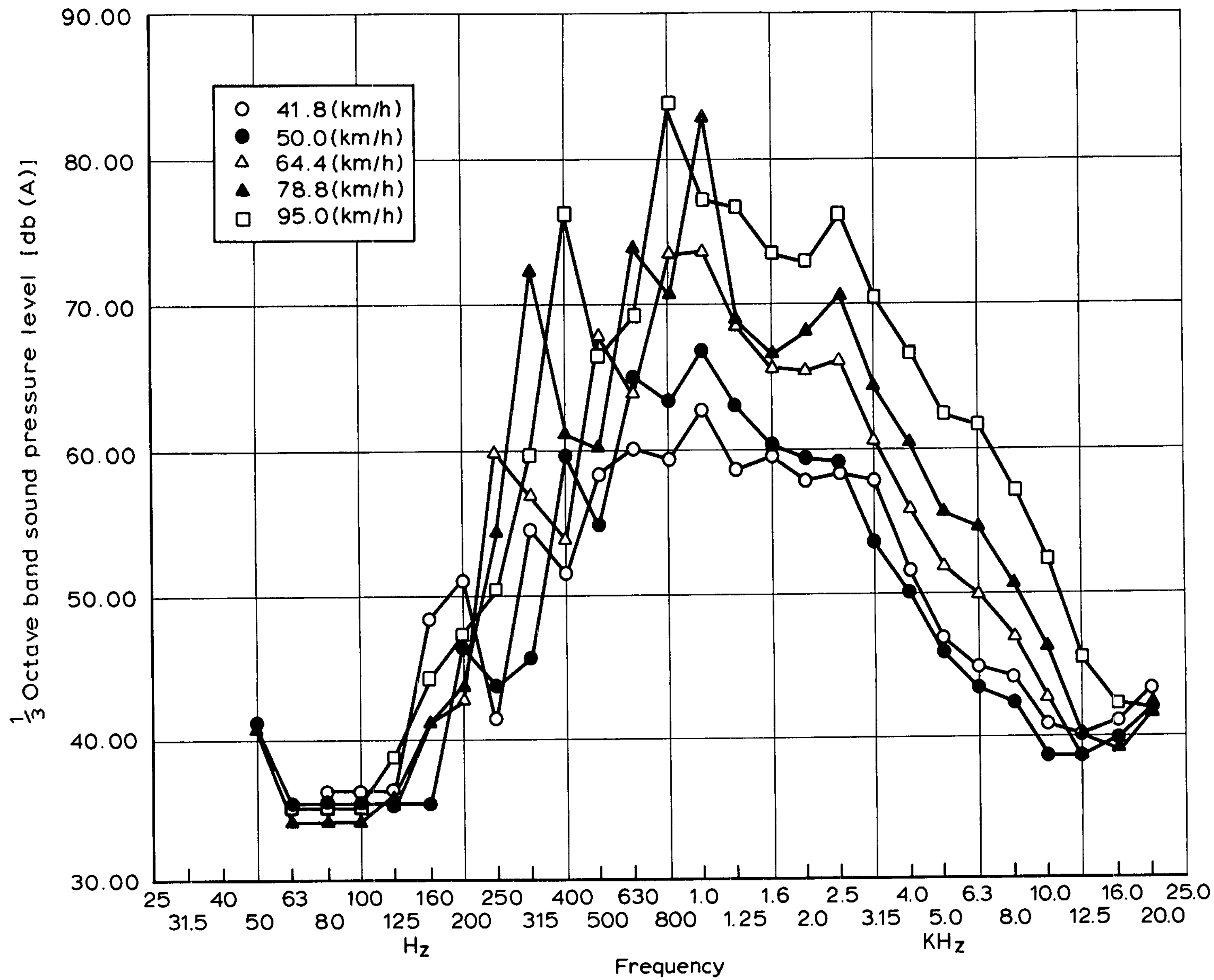


Fig. 24. LADEN TRACTION TYRES (N.R.) ON DRY SMOOTH CONCRETE

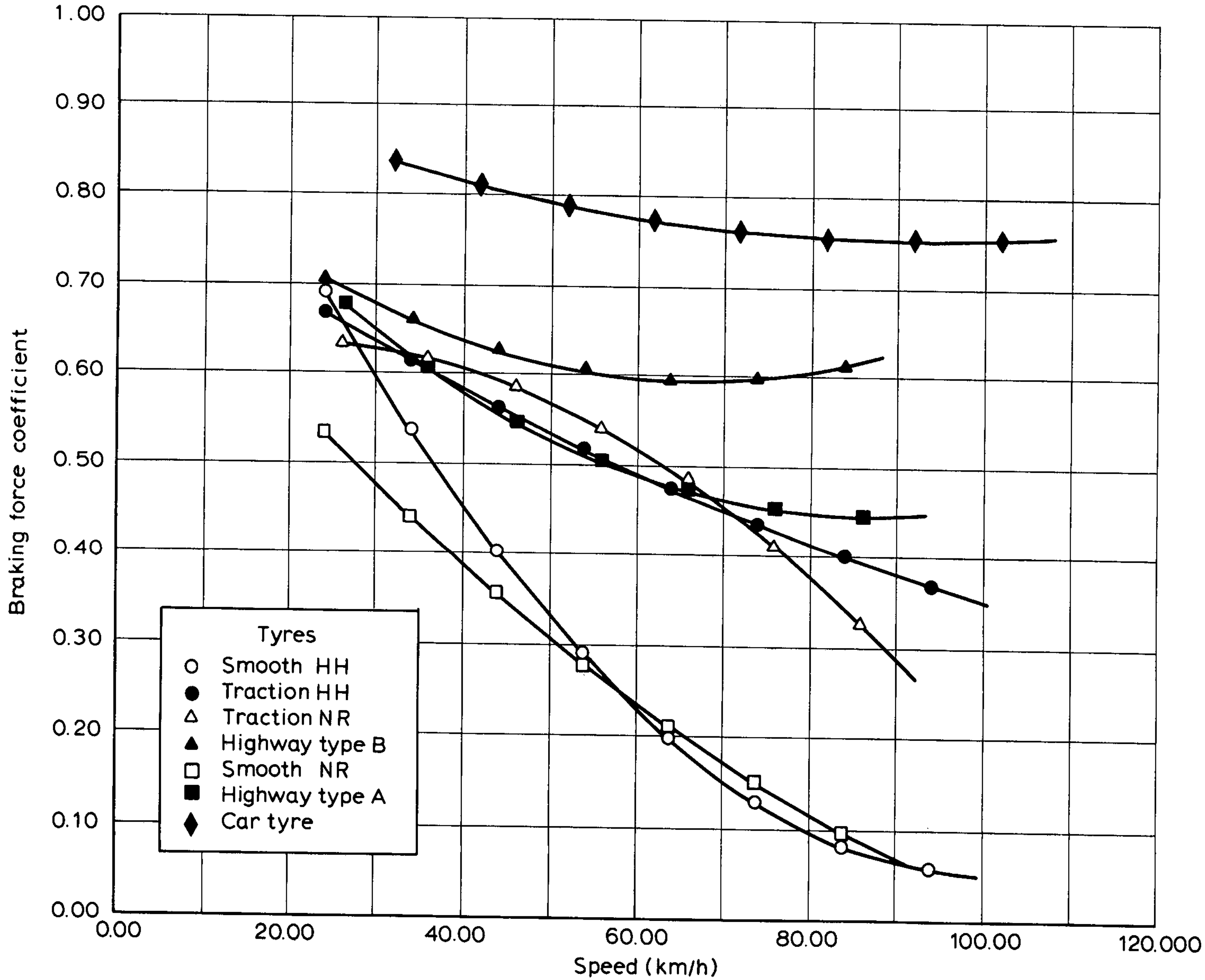


Fig. 25. PEAK BRAKING FORCE COEFFICIENT ON THE SMOOTH CONCRETE

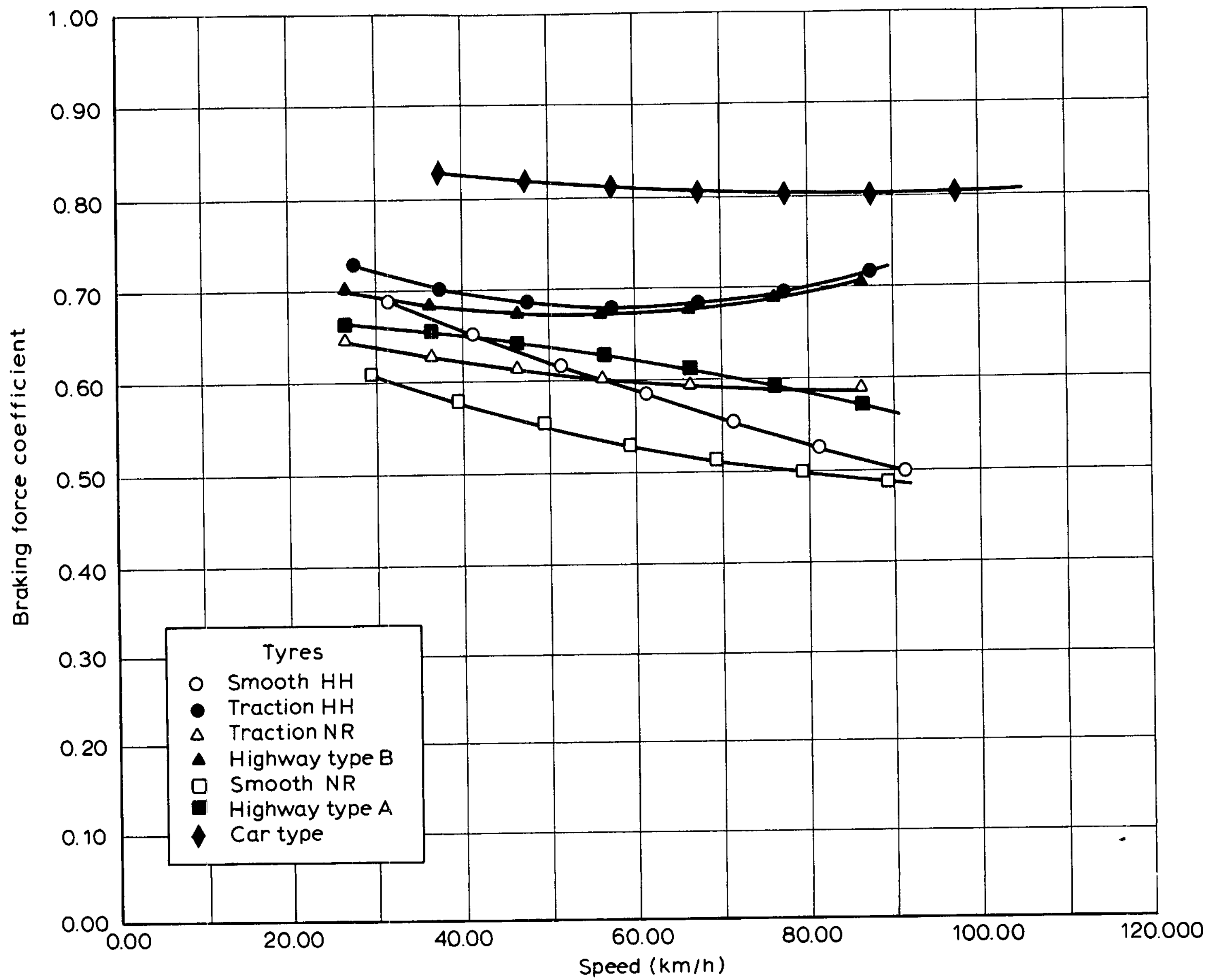


Fig. 26. PEAK BRAKING FORCE COEFFICIENT ON MOTORWAY SURFACE

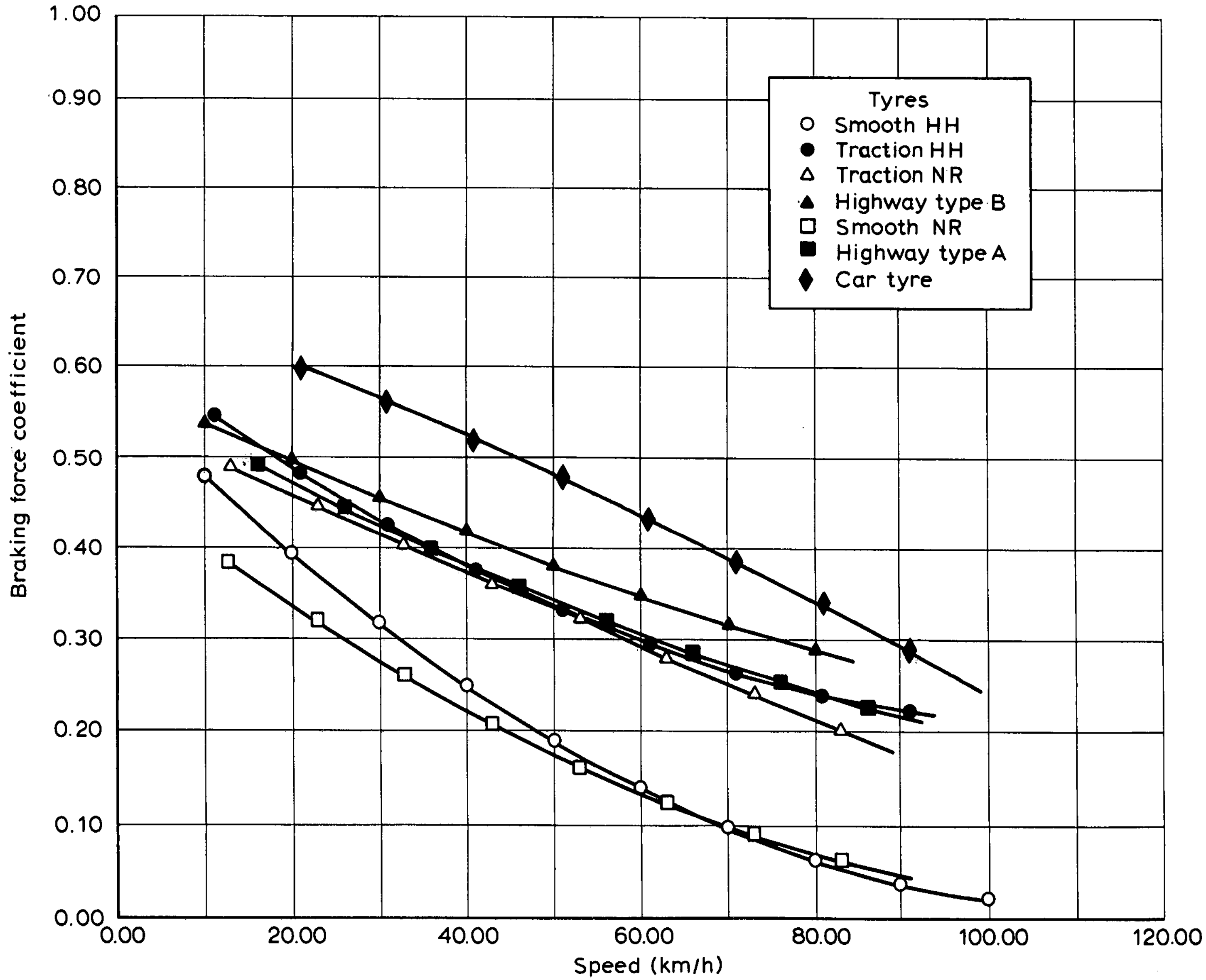


Fig. 27. LOCKED BRAKING FORCE COEFFICIENT ON THE SMOOTH CONCRETE

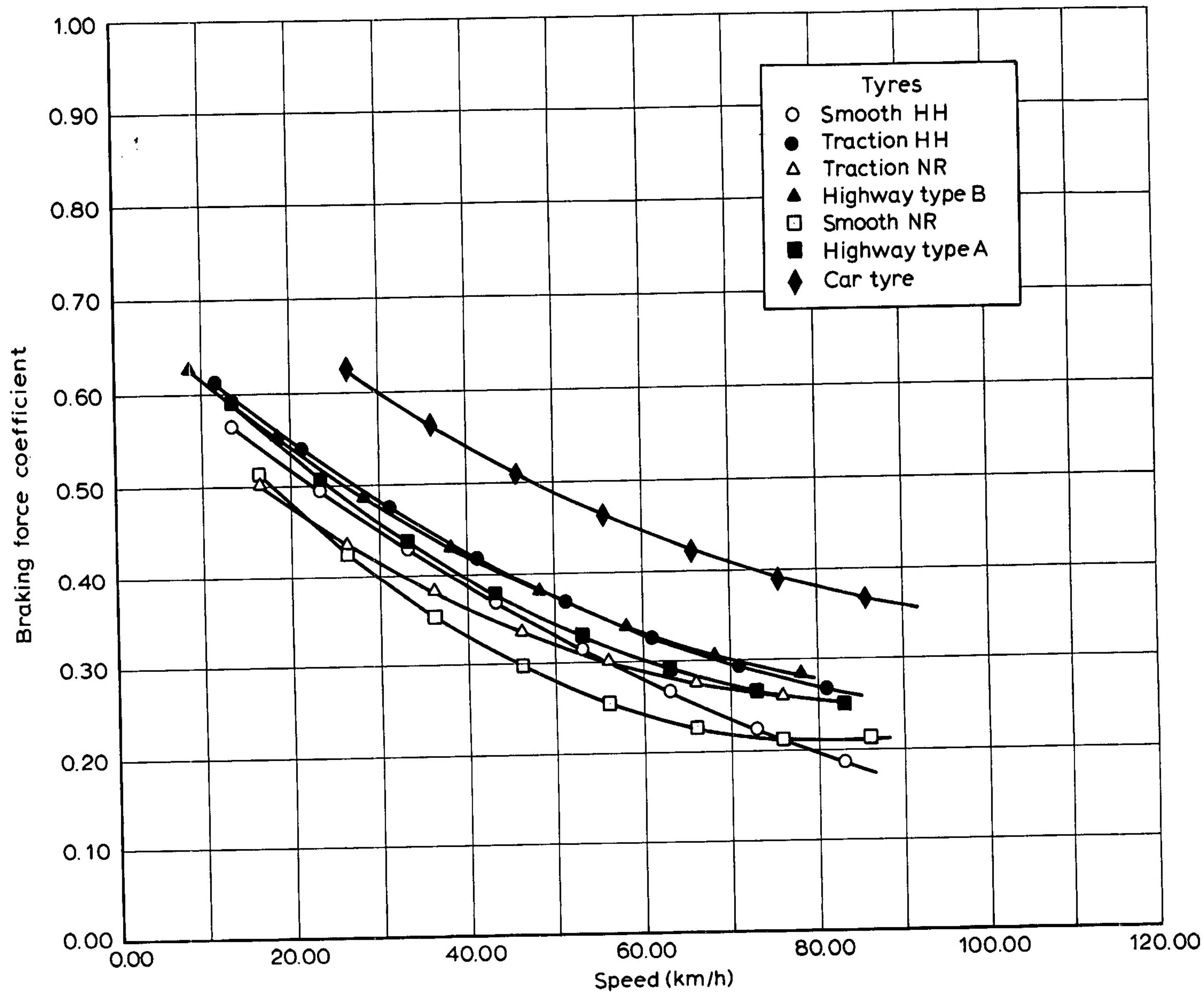
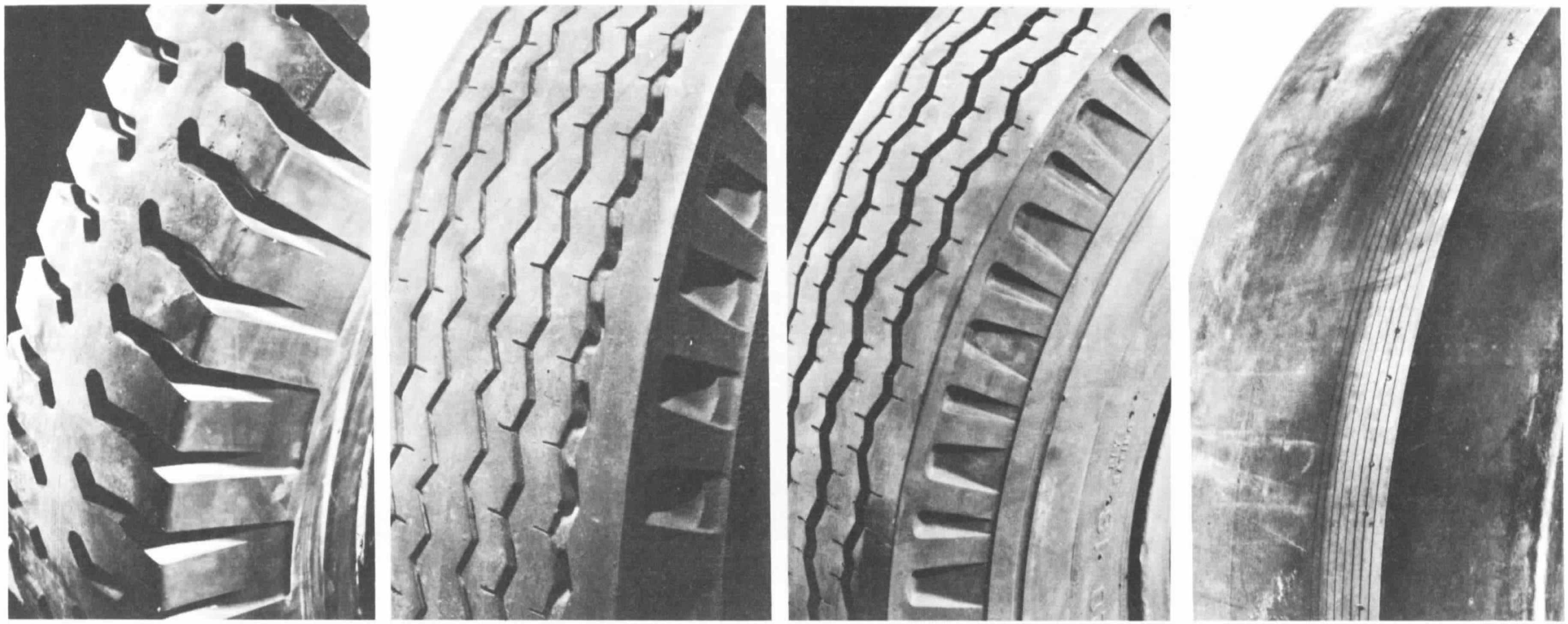


Fig. 28. LOCKED BRAKING FORCE COEFFICIENT ON THE MOTORWAY SURFACE



Neg No E56/72

Traction tyre

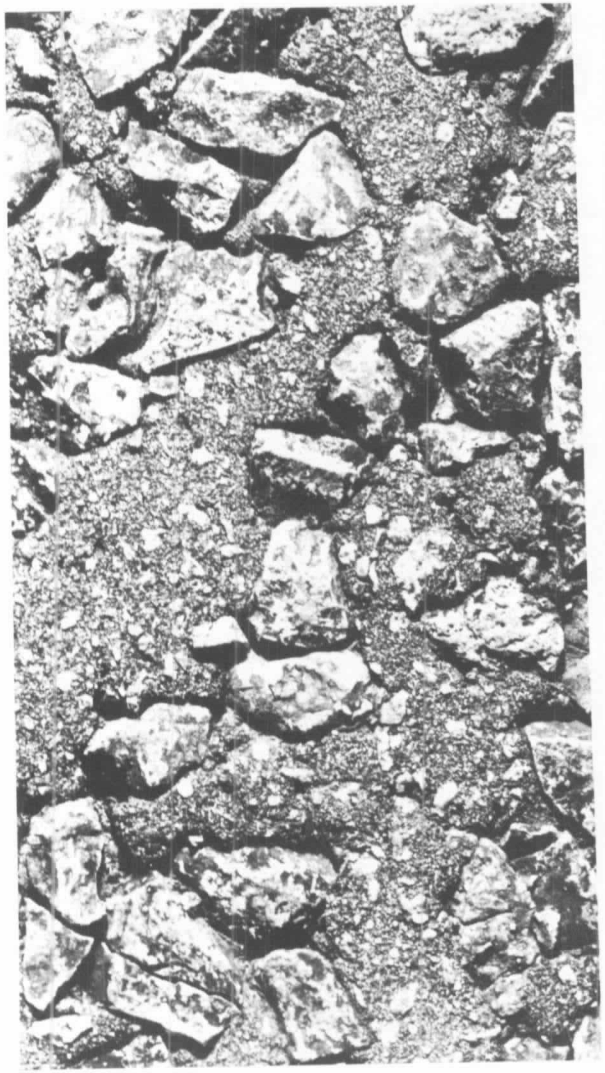
Highway type B tyre

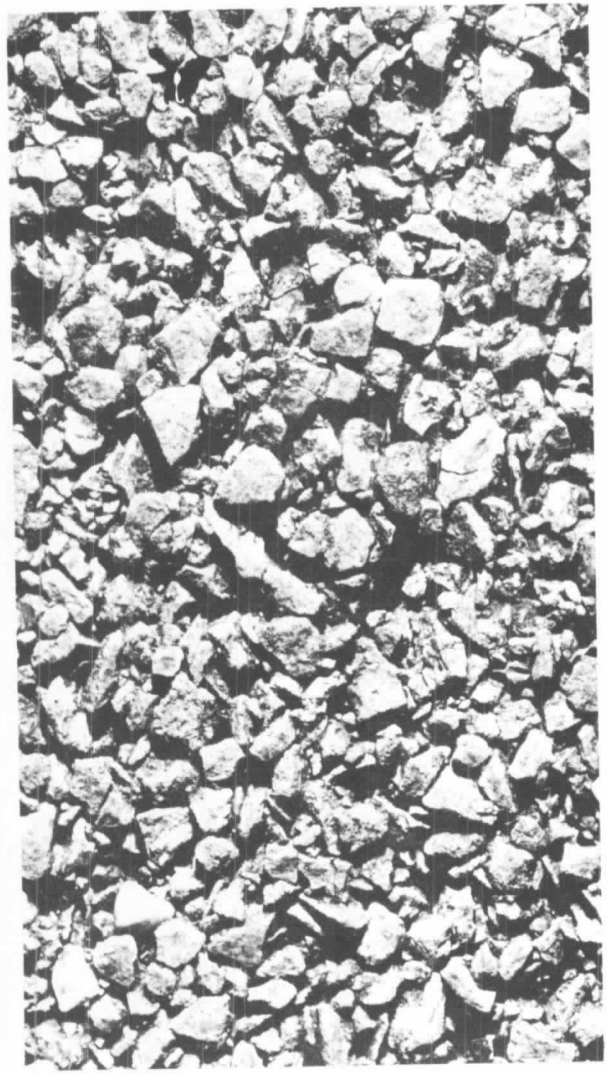
Highway type A tyre

Smooth tyre

PLATE 1

Experimental tyres





Neg No E57/72

Motorway surface — Coarse quartzite — Smooth concrete

PLATE 2

Track surfaces used

(1897) Dd635221 3,250 10/72 HP Ltd., G1415
PRINTED IN ENGLAND

ABSTRACT

A preliminary investigation into lorry tyre noise: M.C.P. UNDERWOOD: Department of the Environment, TRRL Report LR 601: Crowthorne, 1973 (Transport and Road Research Laboratory). Recent research has indicated the possibility that with reduced power unit noise, tyre to road surface noise could become the predominant source of lorry noise. An investigation at the Transport and Road Research Laboratory has shown that, although tyre noise does not contribute and is unlikely to contribute significantly to levels measured in the British Standard drive-by-test, tyre road surface noise will be the predominant source of noise from envisaged quieter heavy lorries when they are travelling at speeds approaching 100 km/h on dry roads and at speeds over 50 km/h on wet roads. The parameters that most markedly affect tyre noise are vehicle speed, tyre tread pattern, road surface texture and whether the surface is wet or dry.

ABSTRACT

A preliminary investigation into lorry tyre noise: M.C.P. UNDERWOOD: Department of the Environment, TRRL Report LR 601: Crowthorne, 1973 (Transport and Road Research Laboratory). Recent research has indicated the possibility that with reduced power unit noise, tyre to road surface noise could become the predominant source of lorry noise. An investigation at the Transport and Road Research Laboratory has shown that, although tyre noise does not contribute and is unlikely to contribute significantly to levels measured in the British Standard drive-by-test, tyre road surface noise will be the predominant source of noise from envisaged quieter heavy lorries when they are travelling at speeds approaching 100 km/h on dry roads and at speeds over 50 km/h on wet roads. The parameters that most markedly affect tyre noise are vehicle speed, tyre tread pattern, road surface texture and whether the surface is wet or dry.