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THE DEPARTMENT OF TRANSPORT

Calculation of Railway Noise

1995

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CALCULATION OF RAILWAY NOISE 1995

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CORRECTION

Page 26

Paragraph 1. line 3. Delete the words "the height of the barrier above the railhead is <1.0m or if".

Page 59

Chart 6(c). Delete the line "(NB Only valid where barrier is 1m or more above the railhead)".

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CONTENTS

PREFACE

This Technical Memorandum, published by the Department of Transport, sets out the method to be used for determining eligibility for insulation of residential property from railway and other guided transport system noise under the conditions specified in the Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1995. The document was produced by the following group formed by the Transport Research Laboratory, which was commissioned by the Department to prepare the Technical Memorandum.

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INTRODUCTION

1. This Memorandum is primarily concerned with the procedures for calculating noise from moving railway vehicles as defined in the Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1995, referred to hereafter as the Railway Noise Insulation Regulations. These procedures are necessary to enable entitlement under the Railway Noise Insulation Regulations to be determined but they also provide guidance on the calculation of railway noise for more general applications eg the assessment of the noise impact of railways, the design and location of new tracks and land use planning in the vicinity of existing or planned railways.

In addition to the assessment of noise from railways, the Memorandum also describes the procedures needed to determine the noise from other guided transport systems covered in the Railway Noise Insulation Regulations. These systems include other types of vehicles which run on rails, such as trams; vehicles which use other forms of guidance systems, such as road based vehicles with cable and tracked guidance systems; and monorail and magnetic levitation systems.

2. The Memorandum is divided into three main sections. In section I, a general method of calculation is set out, step by step, for predicting noise levels at a distance from a railway, taking into account such factors as the noise from individual trains running on each segment of track, the intervening ground cover, the alignment of the track and the site layout. In deriving this prediction method, account has been taken of existing prediction methods, together with additional published and unpublished data. The aim has been to permit prediction in as many cases as possible. Examples of the application of the prediction method are given in Appendix A2. A bibliography of relevant publications is given in Appendix A3.

Section II contains some additional procedures to deal with the prediction of railway noise in some specific cases where the general method cannot be applied. This section covers the determination of noise from locomotives and other rolling stock moving into, through, and out of, stopping places stations and sidings as well as the assessment of noise from guided transport systems which are not included in Section I of the Technical Memorandum.

Although calculation will constitute the preferred prediction technique, it is anticipated that in some cases the railway traffic and/or the site layout conditions will fall outside the scope of the method and it will then be necessary to resort to measurement. The procedures and requirements to be met for the measurement of railway noise and other guided transport system noise are given in Section III of the Memorandum.

DEFINITIONS OF TERMS AND SYMBOLS

3. TERMS

Angle of view:

The angle subtended by the railway segment at the reception point.

Background noise:

Noise from all sources unrelated to the noise from the railway vehicles operating on the railway. Consequently noise from public address systems which may emanate from the railway would be classed as a component to background noise in this Technical Memorandum.

NB This definition of 'background noise' also applies to the term 'residual noise' which is a term used in BS 7445 and ISO 1996-1.

Ballasted track:

This refers to track where the rails have been fastened to concrete or wooden sleepers which are supported by a layer of ballast (a coarse stone material usually of broken granite, limestone or basalt or in some cases broken slag, ash or pebbles). Because of the open structure of the ballast, some degree of noise reduction can be expected when sound propagates over the surface.

Barrier:

An acoustic barrier is a purpose-built screen, wall, building or other obstacle which obscures the source line from the reception point. Commonly, the term barrier is used to describe a thin screen erected close to the side of the track and which may range in height from approximately 1m to 3m.

Coach:

Railway vehicle, which may or may not be powered, used for carrying passengers.

Continuously Welded Rail (CWR):

This is a type of track which is constructed so that the joints between adjacent sections of rail are welded to form a continuous running surface. This type of surface normally leads to lower noise levels than jointed track.

Diffraction (Diffracting edge):

This refers to the change in direction of the propagation of sound in the neighbourhood of a boundary such as the edge of a reflective or absorptive surface.

Eligible room/building:

An eligible room is a living room or bedroom having a qualifying door or a qualifying window in an eligible building. An eligible building has the meaning assigned to it in regulation 7 of the Railway Noise Insulation Regulations.

Equivalent Continuous Sound Level, L_{Aeq}:

In all cases the levels of train noise, railway noise and other guided transport system noise used in the Memorandum are expressed in terms of the Equivalent Continuous (Steady) Sound Level, L_{Aeq}. The following definitions apply:-

$L_{Aeq,\,T}$ is the level of a notional steady sound which, at a given position and over a defined period of time, T, has the same A-weighted acoustic energy as the actual fluctuating sound. (NB In order to calculate eligibility for sound insulation treatment according to the Railway Noise Insulation Regulations, the values of $L_{Aeq,\,18h}$ and/or $L_{Aeq,\,6h}$ are required[1].)

$L_{Aeq,\,18h}$ is the Equivalent Steady Sound Level for the 18 hour period between 0600 hrs - midnight and $L_{Aeq,\,6h}$ is the Equivalent Steady Sound Level for the period midnight to 0600 hours.

The **level** of a quantity is the logarithm of the ratio of that quantity to a reference quantity of the same kind.

The **Sound Pressure Level** is 10 times the common logarithm of the ratio of the square of sound pressure under consideration to the square of the standard reference pressure of $2.\,10^{-5}$ Pa (Pascals)[2]. The quantity so obtained is in decibels.

A-weighted sound levels are sound pressure levels which have been adjusted to take account of the fact that human hearing is not equally sensitive to all frequencies. The A-weighting therefore attenuates low frequencies, which are less readily detectable by humans and, to a lesser extent, high frequencies (ie > 4kHz) which also require progressively higher sound levels for detection by the human hearing system as the frequency is raised. The specification for A-weighting has been agreed in various national and international standards (British Standard 5969 :1981 ; IEC 651:1979). A-weighted decibels are, therefore, measured by instrumentation fitted with an electrical weighting circuit which complies to the specifications given in these standards. The A-weighting is now used for practically all assessments of noise. Its units are expressed as dB(A).

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[1] The Railway Noise Insulation Regulations refer to L_{Aeq} (day-time) and L_{Aeq} (night-time). These terms have the same meaning as $L_{Aeq,\,18h}$ and $L_{Aeq,\,6h}$ respectively.

[2] 1 Pascal = 1 N/m^2

Facade noise level:

For the purpose of the Railway Noise Insulation Regulations, predictions or measurements of noise are required at a reception point located 1 metre outward of the external side of a qualifying window. This is referred to as the facade noise level.

Free field noise level:

This is the noise level measured at a point in space such that the effects of reflections from facades and other objects are negligible.

Freight loop:

This is a section of track which would normally run parallel to a main line, and which is used primarily by slow moving trains to allow free passage of higher speed trains along the main line. Trains using the loop will generally stop until the main line is cleared.

Ground absorption:

This refers to effects of absorbing ground on the propagation of sound from the railway to the reception point. The process is complex, but can be related to the acoustic impedance of the ground, and the positions of the source and reception point. The ground effect is absent if the ground is an acoustically highly reflective surface such as concrete or water.

Illuminated zone:

The illuminated zone is the region which is not screened by a noise barrier but which is close to the screened area and where the barrier therefore does offer some screening effect. See also shadow zone.

Locomotive:

Separate vehicle which provides motive power for the whole train.

Path difference:

The path difference is a term used in connection with determining the screening afforded by a barrier. The path difference is the difference in the geometric path drawn between the source position and the reception point, and the path which connects the source and reception point, but which passes over the top of the noise barrier.

Prevailing noise level:

This is the level of noise ('night' time or 'day' time according to the Railway Noise Insulation Regulations) caused by the movement of vehicles using the relevant systems concerned, expressed as the level of L_{Aeq} over the relevant time period, immediately before the construction of initial works or additional works or the carrying out of altered works, as the case may be, were begun.

Qualifying window:

This has the meaning assigned to it in Schedule 1 of the Railway Noise Insulation Regulations.

Railhead:

The railhead is the upper part of the rail. The top surface of the railhead forms part of the running surface in contact with the wheels. In the Technical Memorandum the top surface of the near-side railhead of a particular track defines the source line for noise generated by moving railway vehicles, apart from diesel locomotives operating at full power settings. (See also source line.)

Reception point:

The point at which predicted noise levels are calculated, or measurements are taken, for the purpose of the Railway Noise Insulation Regulations.

Relevant noise level:

This is the level of noise, expressed as $L_{Aeq,\,18h}$ (L_{Aeq} day-time) or $L_{Aeq,\,6h}$ (L_{Aeq} night-time), as the case may be, caused or expected to be caused, by the movement of vehicles using, or expected to use, any relevant systems.

Rolling noise:

This is the noise generated by moving railway vehicles, produced by the wheels running over the track surface. It needs to be considered for all types of railway vehicles apart from diesel locomotives operating at full power. For this type of vehicle and operation the noise from the power unit will generally be greater than the noise generated by the rolling process.

Segment:

A section of the railway such that the variation of noise within the segment is small, (ie less than 2 dB(A)). All segments are assumed in the calculation method to be straight line sections.

Shadow zone:

The area that is screened by a barrier. By analogy with light, a barrier placed close to a sound source will cast a sound shadow and the sound field located within the shadow zone will be reduced by the presence of the barrier. (See also Illuminated zone.)

Sound Exposure Level (SEL):

This is the level at the reception point which, if maintained constant for a period of 1 second, would cause the same A-weighted sound energy to be received as is actually received from a given noise event. The SEL is used in this Memorandum to categorise and quantify the noise generated by individual railway vehicles and individual trains. As such it serves as a 'building block' to determine the L_{Aeq} for the total flow of trains over a given time period. (The abbreviation SELs will be used throughout this Technical Memorandum to denote the plural of SEL.)

Source line (Extended source line):

The source line relates to the notional position of the main source of noise from vehicles operating on the railway. For all vehicles other than diesel locomotives operating under full power, the source line is taken to occur at the near-side railhead of the appropriate track. For diesel locomotives on full power, the source line is elevated to 4m above the near-side railhead. An extended source line is one which is drawn beyond the end of the relevant segment in the same plane as the actual source line.

Source position (effective source position):

The source position is the point at which the normal drawn from the reception point intersects the source line or extended source line (effective source position).

Specified levels

The specified day-time level is 68 dB L_{Aeq} (day-time). The specified night-time level is 63 dB L_{Aeq} (night-time).

Thin screen:

A thin screen is a wall or purpose-built barrier where the thickness of the barrier is significantly less than the wavelength of the sound waves which pass over the barrier. This type of barrier presents an effective sharp edge to the sound waves which are then diffracted.

Track:

For conventional railways this is the system of two separated, parallel steel rails which provide support and means of guidance for railway vehicles. A railway can consist of a number of tracks.

Train:

One or more railway vehicles which are coupled together to form a single operating unit.

Railway Vehicle:

See **wagon** and **coach**.

Wagon:
Railway vehicle used for carrying freight.

4. SYMBOLS

By convention, sound levels used both in the text and in the mathematical expressions in the Technical Memorandum have either been represented by the letter L, with an appropriate suffix, or by an acronym. For example, the Equivalent Continuous Noise Level appears as $L_{Aeq,\,T}$ in both the text and formulae, whereas the Sound Exposure Level is written as SEL. In the formula for the Equivalent Continuous Sound Level the letter A signifies that the sound level has been A-weighted and the letter, T, refers to the time period over which the level has been determined. Consequently the 18-hour value of the Equivalent Continuous Noise Level is written as $L_{Aeq,\,18h}$.

The SEL used in this Technical Memorandum is also A-weighted.

A barrier screening potential determined from the path difference, δ, described below.

a mean opening between buildings measured along a row of buildings (metres).

α angle of orientation of the segment. More precisely it is the acute angle between the line drawn through the reception point position, parallel to the track, and the line bisecting the angle of view of the segment (degrees).

b mean length of buildings evaluated along a row of buildings (metres).

d shortest horizontal between the reception point and the source line (metres).

d' shortest slant distance from the reception point to the source line (metres).

D shortest horizontal distance between the source line and the near-side face of a noise barrier (metres).

δ path length difference between the direct ray and the diffracted ray due to screening of the source line (metres).

h height of the reception point relative to the source line (metres).

h_s height of the source position above the ground (metres).

H average height of propagation between the reception point and the effective source position above the intervening ground (metres).

I proportion of sound absorbing ground between the segment source line and the reception point.

N number of vehicles on a train.

Q_{DAY} total number of trains of a particular type passing the reception point during the period 0600-2400 hrs.

Q_{NIGHT} total number of trains of a particular type passing the reception point during the period 0000-0600 hrs.

ϱ_s the minimum surface density of a noise barrier which ensures that the sound transmitted through the barrier is always less than the sound propagating over the top and around the edges of the barrier (kg/m^2).

θ angle of view of the segment (degrees).

θ' combined angle of view of reflecting surfaces on the far-side of the traffic stream facing the reception point (degrees).

REQUIREMENTS FOR USE WITH THE RAILWAY NOISE INSULATION REGULATIONS

5. The procedures assume typical railway (and other guided transport system) traffic and noise propagation conditions which are consistent with wind direction from source to reception point during the specified periods. In accordance with the Railway Noise Insulation Regulations only noise from moving railway vehicles is considered. Therefore, no account is taken of noise from stationary railway (or other relevant) vehicles or any non-railway source.

6. The charts which form part of the Memorandum include, where appropriate, a formula which is valid over the quoted range. While extrapolation outside these ranges can lead to progressive and significant error, calculations can be extended outside the quoted ranges for cases where reduced accuracy can be accepted (eg. for predicting changes in noise levels or for calculating noise levels beyond the 300m limit specified in the regulations.) For entitlement calculations, however, extrapolation beyond the quoted ranges is not valid.

7. When applying the Memorandum for the purpose of calculating entitlement for noise insulation treatment under the Railway Noise Insulation Regulations, three conditions have to be tested:

(i) the relevant noise level, for new or additional railways/guided systems (and in some cases where a relevant railway/guided system is altered, as provided for in the Railway Noise Insulation Regulations), together with other railway/guided transport system noise in the vicinity, must not be less than the specified noise levels;

(ii) the relevant noise level must be greater by at least 1.0 dB(A) than the prevailing railway/guided transport system noise (ie the total noise level from railway/guided transport systems existing before the works to construct or improve the system were begun);

(iii) the contribution to the relevant noise level from the new, additional or altered railway/guided transport system must be at least 1.0 dB(A).

8. The calculations shall be worked to 0.1 dB(A)[3], keeping within the quoted range of validity of the charts or formulae, and the resulting values used to determine whether the requirements under paras 7(ii) and 7(iii) are met. For comparison with the specified noise level, para 7(i), the relevant noise level, being the combined effect of traffic expected to use the transport system including the new/altered system, is to be rounded to the nearest whole number (0.5 being rounded up.)

9. Noise shall be assessed at a reception point located 1 metre outward of the external side of a qualifying window, according to the requirements of the Railway Noise Insulation Regulations.

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[3] Each step, involving a separate chart or formula, shall be rounded to the nearest 0.1 dB(A). Exact values of 0.5 dB(A) being rounded in such a direction that the overall predicted noise level is the highest. This should ensure that different calculation processes give the same result and marginal variations are avoided.

10. The traffic flows to be used in the calculation shall be as required in the Regulations and shall represent the noisiest expected traffic flows occurring during the specified day and night periods given in the definition of $L_{Aeq, 18h}$ and $L_{Aeq, 6h}$ above, within a period of 15 years after opening the system.

SECTION I

THE PREDICTION METHOD (General Procedures)

11. This part of the Technical Memorandum is concerned with the calculation of noise from moving trains. Section II of the Technical Memorandum includes guidance on the assessment of noise from other guided transport systems which are included in the Railway Noise Insulation Regulations (see also paragraphs 1 and 2).

The method of predicting noise from a railway consists of six main parts or stages:

Stage 1. Divide the railway into one or more segments such that the variation of noise within the track segment is less than 2 dB(A) (paragraph 12).

For each segment determine the following for each train and track (ie Stages 2-5):

Stage 2. The reference SEL (ie SEL_{ref}) at a given speed and at a distance of 25m from the near-side railhead of the track segment taking into account the length of the train and the type of track and track support system (paragraphs 13-17).

Stage 3. Corrections to the SEL_{ref} for distance of the reception point from the track, ground and air absorption, the effect of screening by barriers etc., and the angle of view at the reception point (paragraphs 18-30).

Stage 4. Corrections to SEL_{ref} to take account of reflection effects at the reception point (paragraph 31).

Stage 5. The SEL at the reception point by applying the corrections determined at stages 3 and 4 to the SEL_{ref}, and convert the resulting SEL values to values of L_{Aeq} taking into account the time period required and the number of trains (paragraph 32).

Having determined the values of L_{Aeq} at the reception point for each segment,

Stage 6. Combine the L_{Aeq}s for each segment to obtain the total day and night L_{Aeq} for the railway (paragraph 33).

The above steps are described in detail below and are shown diagrammatically in Chart 1.

STAGE 1 : DIVIDE THE RAILWAY INTO SEGMENTS

12. In a few simple cases the railway will be found to consist of a very long straight and level section with essentially constant noise generation and propagation properties. For these ideal situations, the calculation of noise can proceed by assuming that each track comprising the railway can be approximated by a single segment. However, in practice, situations will be encountered where, due to changes in traffic flow, speed, gradient of the track, or due to progressive variation in screening, the noise generated by railway vehicles travelling along each track will vary significantly along its length. In such cases the railway shall be divided into a number of segments, in order to ensure that the variation of noise within each segment is less than 2 dB(A). Each segment is then treated as a separate railway source, and the noise contribution evaluated according to the procedure given below. Some of the conditions which may give rise to the need to segment the railway are:

* where the railway runs in a cutting along part of its length;

* where there is screening to part of the railway or where the degree of screening changes significantly over the length of railway being considered;

* where the railway runs on a viaduct or other construction which could significantly change the noise emitted by passing trains;

* where the speed of passing trains changes significantly over the length of railway being considered[4];

* at junctions where significant flow changes occur between segments located either side of the junction;

* at points and crossings;

* at stations, particularly where station buildings offer some degree of screening and/or reflection of noise from passing trains.

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[4] When a train accelerates from a low initial speed over the section of railway, a large number of segments may be indicated in order to comply with the general rules regarding segmentation. In such cases it should be assumed that for the section of track where the train speed is below 20km/h (ie below the speed range for the calculation method) the noise level at a speed of 20 km/h should be taken and the section of track where this speed range exists shall form a single segment unless, for other reasons, further segmentation is required. Further segments may be indicated as the speed of the train increases. Generally, where the average speed over the section of railway changes by more than 25%, further segmentation of the railway may be needed.

While it is not possible to give precise guidance on the procedures to adopt to determine the segment boundaries for all railway schemes, Appendix A3 contains examples of segmenting a railway which illustrate the basic principles to be adopted.

STAGE 2: CALCULATE THE REFERENCE NOISE LEVEL (SEL_{ref}) FOR EACH TRAIN TYPE

13. The calculation process requires information on the Sound Exposure Level (SEL_{ref}) dB(A) for each different train type using the track segment at a reference distance of 25m from the track[5].

The SEL_{ref} is determined by firstly determining the Sound Exposure Level (SEL_V) generated by a single railway vehicle running at grade (ie on a level track), on good condition[6] continuously welded track supported by concrete sleepers laid on ballast. For the purpose of the calculation a railway vehicle is either a coach, in the case of a passenger train, or a wagon, when a freight train is being considered. (NB A locomotive hauling either a passenger train or a freight train is considered as a separate train - see paragraph 14.2 below). The SEL_{ref} for each train type is then determined by correcting each single vehicle SEL to take into account the total number of vehicles (coaches or wagons) comprising the total train. In addition, further corrections may be needed to take account of the type of track and rail support system if this differs from the standard track assumed.

14. **Single vehicle noise level (SEL_V)**

The single vehicle SEL_V for different types of trains are given in Appendix A1. The data needed to obtain the values of SEL_V are contained within Chart A1.1 which give Sound Exposure Levels for rolling vehicles and Chart A1.2 which covers the specific case of a diesel locomotive operating at full power (see paragraph 13.2 below). Table A1.1 gives corrections to apply to the values obtained from the Charts according to the type of railway vehicle being considered.

The procedure to adopt to determine the SEL_V for a railway vehicle is to enter the appropriate speed of the train into either Chart A1.1 or A1.2 and then to correct the resulting SEL obtained from the Charts according to the type of railway vehicle using the data contained in Table A1.1. For example, the SEL_V for a MkI passenger coach travelling at 100 km/h would be obtained by entering the speed into Chart A1.1 to give a value of 71.2 dB(A), and then adding the appropriate correction obtained for this type of vehicle using the data contained in Table A1.1 (ie 14.8 dB(A)) to give a total of 86.0 dB(A).

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[5] The source position for a diesel locomotive operating under full power is considered to be located at a point 4m above the nearside railhead of the track segment under consideration. For all other railway vehicles and locomotives operating with different power settings the source of railway noise is taken to be at the nearside railhead.

[6] The definition of good condition track is given in Appendix A1 of this Technical Memorandum.

Although the information given in Appendix A1 is intended to be representative of current generation railway vehicles, this information will need to be updated from time to time as new types of railway vehicles are brought into service. In such circumstances it will be necessary for the user to obtain appropriate values of SEL_V for the new vehicles before using the calculation method.

14.1 When a new vehicle type is required to be included in the calculation and is not included in Appendix A1 then measurements of individual vehicle SELs at different passing speeds will need to be taken. Measurements may also be required where existing trains are intended to be used on a new type of track or track support system, which is not considered in the corrections given for track type in paragraph 16. Details of the method of measurement to be adopted to determine SEL_V for a new railway vehicle for use in entitlement calculations are included in Appendix A1.

14.2 It will be noted from Appendix A1 that the SELs for individual railway vehicles are largely dependent on the type of braking system employed. For example the noise from British Rail MkI and MkII passenger trains fitted with tread brakes is greater than that from British Rail MkIII and MkIV disc braked passenger trains.

In some cases trains will comprise a mixture of vehicles with different noise characteristics. In order to account for this in the calculation procedure consideration should be given to dividing the train into two or more trains. For example, a passenger train composed of four MkIII coaches fitted with disc brakes and four MkII coaches fitted with tread brakes would be assessed as two separate trains for noise calculation purposes, each consisting of four coaches. An example of this type of calculation is included in Appendix A2.

Locomotives (diesel or electric) should also be treated as a separate train in the calculation method and, therefore, they will not be included as part of the train comprising the coaches or other rolling stock. Information on the noise from locomotives is included in Appendix A1 and is given for both steady speed running and, for diesel locomotives, for full engine power operations. For conditions where the diesel locomotive is either accelerating or is on a segment where it is expected to operate under full power, for example on an ascending gradient, the SEL should be obtained from Chart A1.2 and the correction for type of locomotive, given in Table A1.1, added to the value given by the Chart to obtain the value of SEL_V. For all other diesel locomotive operations and for all electric locomotive operations, Chart A1.1 should be used and the appropriate correction applied using Table A1.1.

14.3 The value of the speed used to determine the SEL_V for each train in Appendix A1 may depend upon such factors as the track type, gradient, track curvature, the signalling system, scheduling requirements of the operator and the speed limit which is in force for the track segment. In some cases it will be appropriate to use the maximum permissible speed for the segment or the maximum attainable or permissible speed for the train type in question. However, train speeds dictated by the local conditions or set by the operator will determine the choice of speed for each train type in most cases. For locomotives accelerating under full power either from rest or from an initial low steady speed, the speed used in determining the reference noise level shall be the average speed over the segment.

15. Correction for number of vehicles

The SEL_V given in Appendix A1 refers to the noise generated by a single railway vehicle. To calculate reference Sound Exposure Level (SEL_{ref}) for the complete train it is necessary to take into account the number of vehicles of the appropriate type which are contained within the train. Chart 2 gives the correction to be applied to arrive at the SEL_{ref} for the total train.

It should be noted that in most cases where a train is hauled by a diesel locomotive, only a single locomotive will be involved and so there will be no further correction to be applied to the single vehicle SEL obtained for the locomotive to account for train length. However, in some cases more than one locomotive will be involved and Chart 2 will then be needed to arrive at an appropriate correction.

16. Correction for source enhancement

It is known that augmentation of rolling noise levels can occur when trains pass over different types of track or structures such as bridges. This augmentation is also related to the type of locomotive and rolling stock and also the speed of the train. While it is not possible to provide accurate guidance for all cases, the correction factors given in Table 1 should be used in the absence of more detailed or local information. It is recommended that, particularly when attempting to calculate noise levels in the vicinity of railways running on steel bridges, the measurement method is employed to assess eligibility to entitlement when the calculated noise levels are found to lie within ±3 dB(A) of the relevant criterion noise level.

17. Correction for gradient

The SEL_{ref} for each train type already takes into account the speed of the train, which may have included some adjustment for trains travelling on a gradient. As indicated in paragraph 15, it may also be appropriate to differentiate locomotives operating under full power from locomotives operating at steady speed. This may be particularly relevant for locomotives operating on a segment with a gradient. In most cases the operator will be able to advise where the diesel locomotive would normally be on power, which will then dictate the choice of reference level. Apart from these considerations no further corrections are needed for gradient.

TABLE 1

CORRECTION TO ROLLING NOISE FOR DIFFERENT TRACK AND TRACK SUPPORT STRUCTURES

Type/Description	Correction Factor dB(A)
Continuously Welded Rail (CWR)	
Concrete sleepers + Ballast	0
Timber sleepers + Ballast	0
Jointed track (18.3m lengths). Points and crossings.	+2.5
Slab track	+2
Concrete bridges and viaducts*	+1
Steel bridges*	+4
Box girder with rails fitted directly to girder + orthotropic slab. Rail bearer + cross girder + lattice girder.	+9

* Concrete and steel bridges will normally incorporate a parapet running along the length of the bridge and located at the edge of the bridge deck. The parapet may act as a barrier providing some screening at the reception point. The degree of screening provided should be determined using the procedures described in paragraph 25. The corrections for bridges given in the above table give the source enhancement adjustment to be made excluding the parapet.

STAGE 3: PROPAGATION

18. Corrections are given to allow adjustments to be made to take account of the actual distance of the reception point from the track, the nature of the ground between the track segment and the reception point, the effects of atmospheric absorption and the angle of view of the segment at the reception point. The influence of screening by barriers, topography of buildings and land and reflections from the facades of buildings are also considered in this part of the calculation.

19. Distance correction (geometric correction)

The correction for distance requires the use of Chart 3 and the determination of the shortest slant distance d' separating the source position, S, from the reception point, R.

Figure 1 illustrates the geometry involved in the determination of d' for situations where the source position is located at the near-side railhead and, for diesel locomotives under power, where the source position is located 4m above the near-side railhead. In the Figure, d is the shortest horizontal distance from the source position, S. The height, h, determines the position of the reception point and is determined relative to the source line, ie at the point where the slant line intersects the source line at the source position, S.

19.1 It will be noted that Chart 3 should only be used for values of d' which are greater than or equal to 10 metres. For reception points located close to the railway such that d' is less than 10 metres, the measurement method described in Section III should be used.

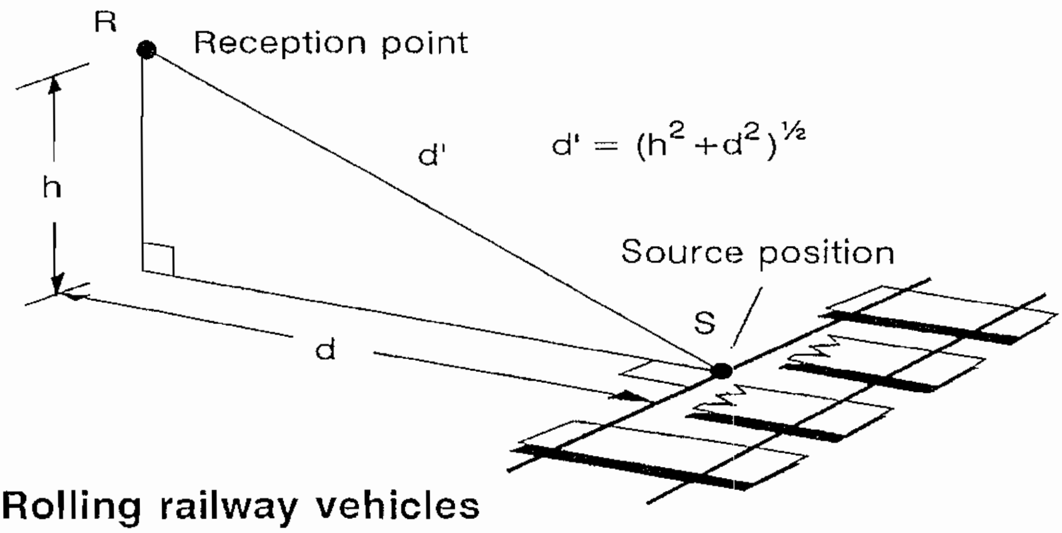
19.2 It will be clear that for some segments it will be necessary to extend the source line, so that d' is calculated along the line which passes through the reception point and is perpendicular to the extended source line. In such cases, the value of h is the height of the reception point relative to the source line at the *effective* source position (ie where the slant line intersects the extended source line.)

19.3 Extending the source line as described above may exceptionally cause it to pass directly through or within 10 metres of the reception point, thereby precluding the use of Chart 3. Where the railway is assumed to comprise a single segment and extending the source line of this segment causes it to pass within 10m of the reception point then the measurement method described in Section III should be used. (NB This situation may occur where the line enters a tunnel.)

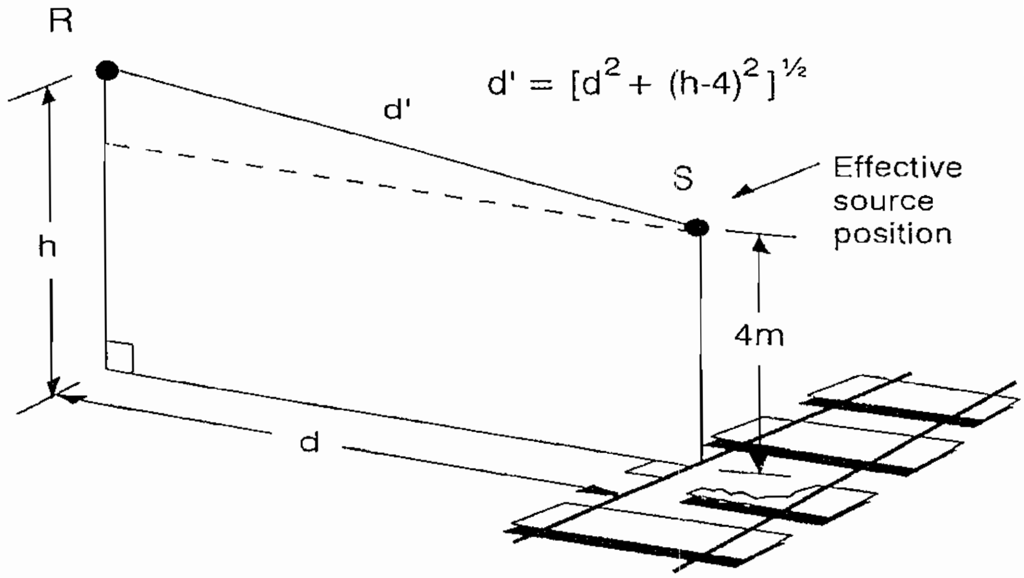
For cases where the railway has been divided into more than one segment, and where extending the source line of at least one of the segments causes it to pass within 10 metres of the reception point, then the noise level for this, and other similarly affected segments, is to be calculated for at least two positions located either side of, and equidistant from, the reception point for which this anomaly does not occur, and the mean value adopted. Appendix A2, example 7, illustrates the principles to adopt in these cases.

FIGURE 1.

SOURCE AND RECEIVER GEOMETRY FOR THE CALCULATION OF THE DISTANCE CORRECTION (CHART 3)



(a) Rolling railway vehicles



(b) Diesel locomotive on power

20. Air absorption correction

As sound propagates through the air some additional attenuation will occur due to absorption by the atmosphere. The correction for air absorption is given in Chart 4.

It should be noted that the correction should not be applied to noise levels from diesel locomotives operating under full power.

21. Ground correction (unobstructed propagation)

For conditions where the segment is not obstructed at the reception point and where propagation is over an absorbing ground surface such as grassland, cultivated fields or plantations of trees and shrubs, an additional correction for ground cover (often referred to as ground absorption) needs to be taken into account. The correction is progressive with distance and particularly affects reception points located close to the ground. No ground cover correction is needed when the ground is an acoustically hard, reflecting surface such as concrete or water.

21.1 In order to determine the correction for absorbing ground it is first necessary to define the surface area that should be considered. For this purpose the area that is contained within the boundary defined by the segment should be determined. Figure 2 illustrates the area involved in two specific cases. It can be seen that for large segments where the segment area could, in principle, be infinitely large, the effective area to be considered for ground cover correction calculations can be approximated by taking the finite area defined in the Figure. It can be seen that the effective ground is considered to be contained within a finite area extending 5d either side of the intersection of the normal from the reception point to the source line where d is the perpendicular distance from the source line to the reception point.

21.2 Having determined the ground area to be considered for a particular segment the proportion of absorbing and hard, reflecting ground can then be determined. (NB In general, when the intervening ground cover is partially absorbent and partially reflecting, further segmenting of the railway may be considered in order to define segments where the ground cover is clearly either absorbent or reflecting).

21.3 Chart 5 gives the correction for ground absorption in terms of the mean height of propagation (H), the distance of the source line from the reception point, (d) and the proportion of absorption ground, (I). (NB The Chart only illustrates the case when I = 1.)

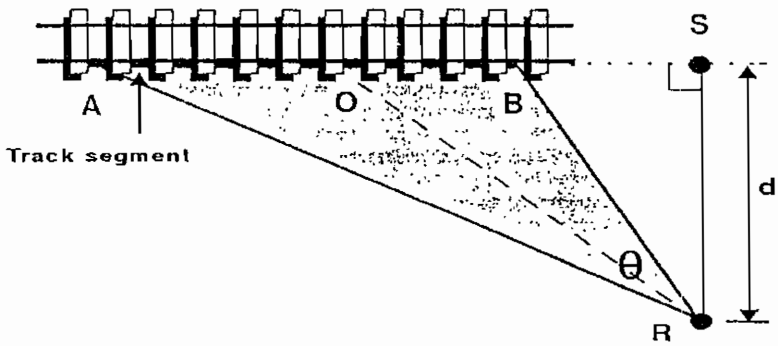
The correction strictly only applies to propagation over grassland surfaces although the correction given in Chart 5 is to be used for all predominantly absorbent surfaces such as ploughed fields or heathland. This approach avoids the difficulty of defining the various types of absorbent ground cover that will be encountered in practice. It is to be expected, however, that, as a result, the calculations will tend to underestimate attenuation effects where the intervening ground is intensively cultivated or planted.

21.4 It should be noted that the distance term, d, in Chart 5, is the distance from the reception point to the source line measured along the normal to the source line, extended if necessary. The relevant geometry is also illustrated in Figure 2.

FIGURE 2.

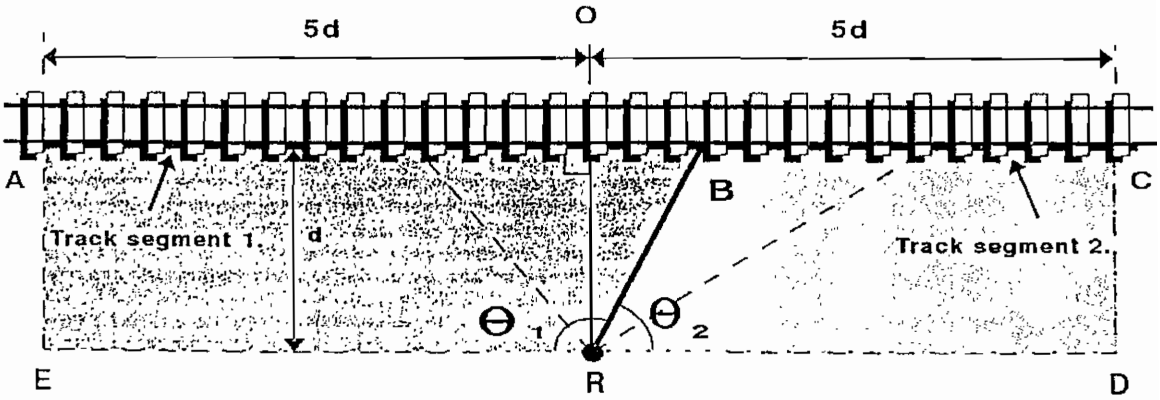
SITE GEOMETRY IN RELATION TO DETERMINING THE GROUND CORRECTION

(a) For a simple track segment



(i) The value of mean height is calculated along the line RO which bisects the segment angle
(ii) The area of ground cover to be considered is contained within the area defined by RAB
(iii) The distance, d, is determined along RS which is the normal to the extended source line AB

(b) For large segment areas



(i) For track segment 1, the ground cover area is REAB
(ii) For track segment 2, the ground cover area is RBCD
(iii) The value of mean height is calculated along the segment bisector in each case

The value of H is taken to be the average height above the intervening ground of the propagation path between the segment source line and the reception point, and is calculated along the bisector of the angle subtended by the segment at the reception point. Where the intervening ground is effectively horizontal and mainly flat, and the source of noise is considered to be located at the railhead, the value of H can be approximated by $h_s + 0.5h$, where h_s is the height of the source above the ground in metres, and h is the height of the reception point relative to the source line also in metres. When the source of noise is a diesel locomotive operating on full power the source position is located 4m above the near-side railhead (see Figure 1) and in this case the value of H can be approximated for essentially horizontal and flat ground surfaces by $(h+4)/2$ metres.

For conditions where the ground is undulating, the mean height of propagation is to be calculated by taking the height of propagation above the ground at approximately equal intervals along the bisector, taking at least 5 height readings and averaging the result. It should be noted that for values of H greater than 6 metres, no ground cover correction is required and for exceptional circumstances where $H < 1.0$ metre, H may be set equal to 1.0 metre and Chart 5 applied as before. Figure 3 illustrates the method of calculating the mean height of propagation for two specific conditions.

The proportion of absorbing ground, I, is determined as a ratio of the total area of absorbing ground to the total area defined by the segment boundaries as described in Figure 2. Consequently, $I=1$ when the ground is totally absorbing and $I=0$ when the ground is totally reflecting.

Having determined the value of I for a particular segment it is entered into the formulae given on Chart 5 together with the distance, d, and the mean height of propagation, H. It should be noted that the Chart only applies for the situation where the value of $I=1$ and for all other values of I the formula given on the Chart should be used.

22. Correction for ballast

In many situations, the rails will be fastened to sleepers supported by a layer of coarse aggregate ballast. Because of the open structure of the ballast layer, some additional attenuation of noise will occur when the noise generated by the railway vehicles propagates over ballasted track. The amount of this attenuation is primarily related to a complex interference effect between the direct sound waves generated from the rolling process and sound waves reflected from the ballasted layer.

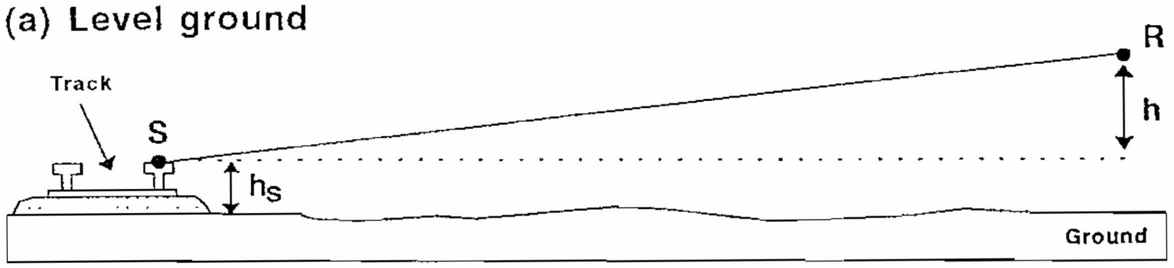
To account for this effect the SEL should be reduced by 1.5 dB(A) for noise generated by railway vehicles running on all segments of the track apart from track segments taken from the nearest track to the reception point. The correction should not be applied for the case of a single track railway, or for a locomotive on power. In addition, the correction should not be applied for any other type of track support structure, or for screened propagation. Example 5 in Appendix A2 illustrates the use of this correction for the case of a two-track railway.

CORRECTION FOR BALLAST = -1.5 dB(A)

FIGURE 3.

CALCULATION OF THE MEAN HEIGHT OF PROPAGATION (GROUND CORRECTION)

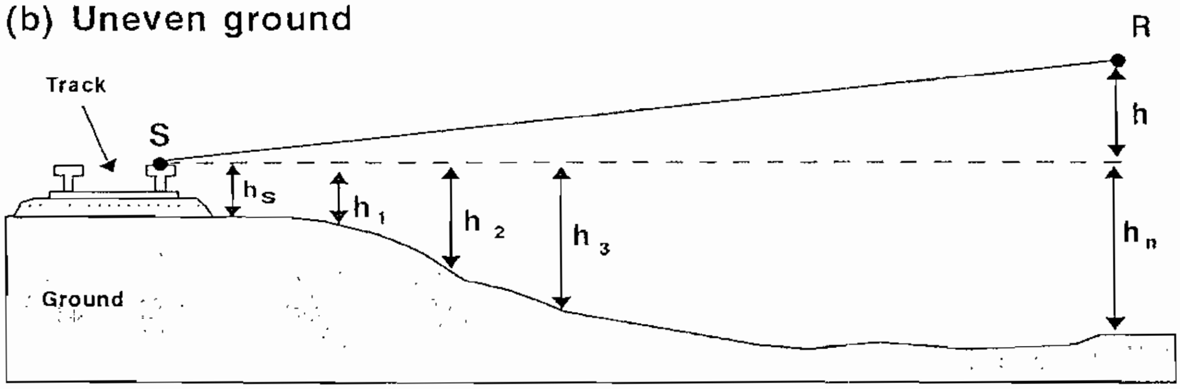
(a) Level ground



Ground between source and receiver is relatively flat, so the mean height of propagation is given by,

$$H \approx h_S + \frac{h}{2}$$

(b) Uneven ground



Ground between source and receiver is undulating, so the mean height of propagation is given by,

$$H \approx \frac{h_S + h_1 + h_2 +, \dots, + h_n}{n + 1} + \frac{h}{2}$$

where $n \geq 5$.

NB. In these examples the source position is taken to be at the nearside railhead.

23. Partially obstructed propagation

The previous paragraph deals with propagation where the railway segment is clearly unobstructed at the reception point. In general, segments will have been chosen such that within any segment the source line is either clearly visible at the reception point or is obstructed by a barrier, building or other obstacle in order to comply with the basic rules governing segmentation (see paragraph 12). In some cases, however, the source line may be partially obscured by intervening obstacles or the degree of screening may be slight. Such situations may occur, for example, where the ground falls steeply away from a railway line and where the edge of the embankment partially screens the source. For these cases it may be necessary to calculate the noise levels assuming both obstructed and unobstructed propagation taking the lower of the two resulting levels as the correct result (see also paragraph 25.4). In most cases, when predicting for reception points located 4 metres or more above the ground, the presence of low garden walls, fences etc. may be ignored. Below 4 metres the screening effects of reasonably continuous walls and other permanent features should be taken into account.

In summary, for clearly unobstructed propagation a correction for the prevailing ground cover may be needed and paragraphs 21 and 22 above give the procedure to adopt. Where the segment is obstructed, a correction for screening will be needed and the procedure described in paragraph 24 will apply. For this condition no correction for ballast or ground should be made and therefore paragraphs 21 and 22 should not be applied. For cases where the segment is partially screened and it is unclear whether to treat the segment as an obstructed segment or an unobstructed segment, both corrections should be applied and the lowest of the two resulting noise levels taken.

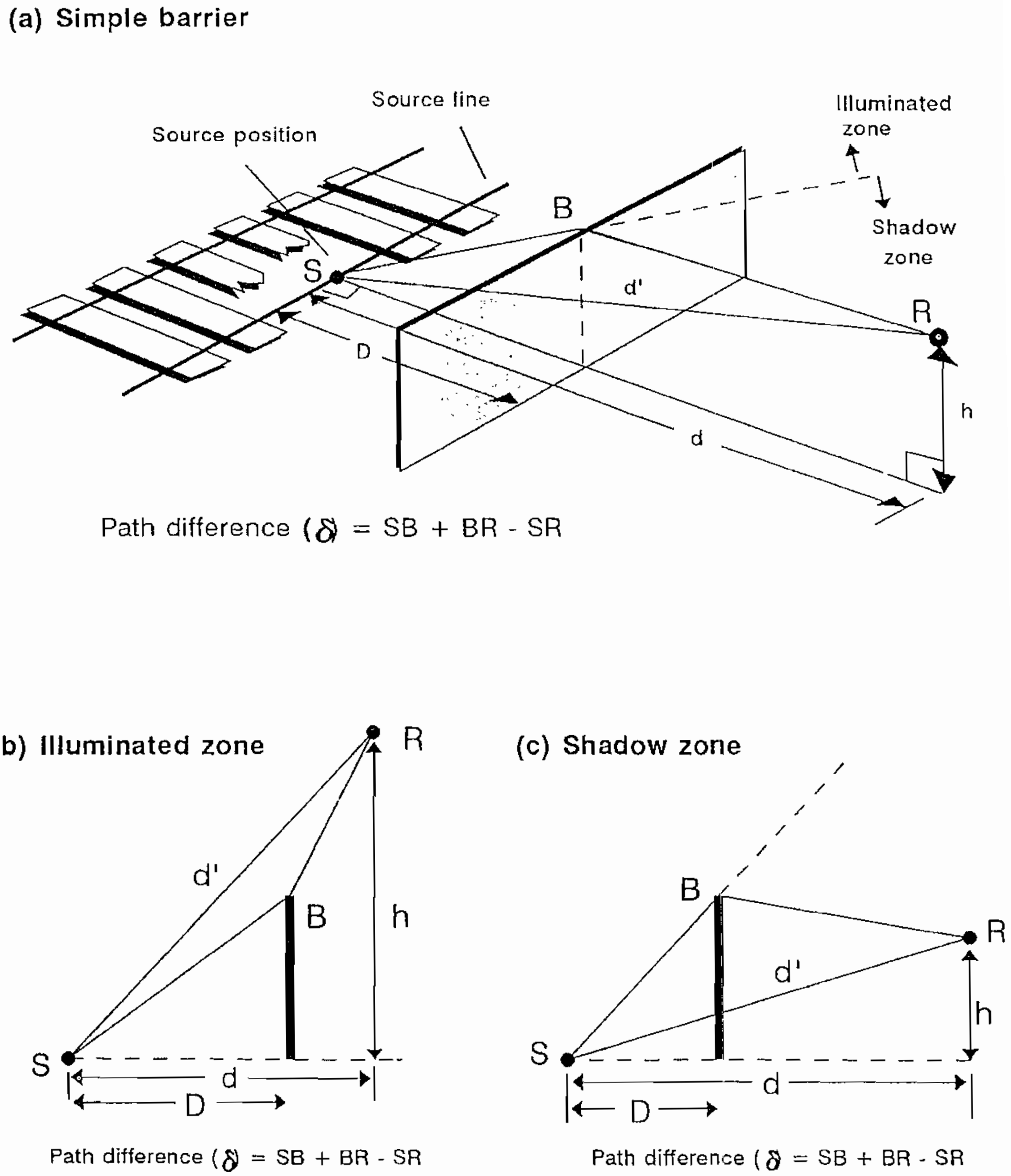
24. Obstructed Propagation

The screening effect of intervening obstructions such as noise barriers, walls and buildings needs to be taken into account. The screening provided by hedges, bill hoardings and temporary structures should be ignored for the purpose of entitlement calculations.

The degree of screening depends on the relative positions of the source S, the reception point R and the point B where the diffracting edge along the top of the obstruction cuts the vertical plane, ie normal to the track, containing both S and R. Figure 4(a) illustrates the site geometry for a simple thin barrier obstructing the reception point R. The degree of screening is calculated by first determining the path difference, δ, of the diffracted ray path SBR and the direct ray path SR shown in Figure 4(a). This value is then entered in Chart 6(a)[7] or Chart 6(b) to determine the potential barrier correction (A). If the barrier has a reflective surface on the side facing the railway, then the correction given in Chart 6(c) should be determined and added to the barrier potential (A) obtained from Chart 6(a) or (b). (NB The correction for reflective barriers always reduces the barrier potential (A).)

[7] Chart 6 gives the correction due to a massive barrier. The minimum superficial surface density ϱ (ie the mass per unit area) required to approximate this condition varies with the value of the potential barrier correction (A) and for a solid barrier can be estimated from the formula $\varrho_s = 3 \times 10^{[-(A+10)/14]}$ kg/m^2. It should be noted that the value of (A), as derived from Chart 6, will always be negative. As an example, a close boarded wooden fence would normally have a surface density, ϱ_s, of about 10 kg/m^2 which, according to the above relation, could give a maximum barrier potential of approximately -17 dB(A).

FIGURE 4.
SITE GEOMETRY TO EVALUATE THE PATH DIFFERENCE (δ)
FOR OBSTRUCTED PROPAGATION



When the barrier has an acoustically absorbing surface on the railway side of the barrier then Chart 6(c) should not be used and no further correction to the barrier potential (A) should be made. In addition the correction for reflective barriers will not apply if the height of the ~~barrier above the railhead is < 1.0m or if~~ the source is a diesel locomotive on power.

Figures 4(b) and 4(c) show the calculation of the path difference depending upon whether the reception point is in the illuminated zone or the shadow zone of the barrier respectively. **(NB In all calculations involving a correction for screening, the correction for ballasted track (paragraph 22) should not be applied.)**

24.1 For the purpose of the Railway Noise Insulation Regulations, it is necessary to calculate the path difference to the nearest 0.01 metres.

24.2 The above procedure can be applied to thin screens, particularly those which have been purposely constructed as acoustic barriers, and walls and fences provided they have been constructed with no significant air gaps either between panels and the supporting framework or along the bottom edge of the barrier. (NB See footnote regarding the surface density of a barrier.)

The above method can also be applied to determine the screening provided by a continuous row of buildings or an embankment or cutting, although the method of determining the path difference may differ depending upon the type and geometry of the obstruction. The following paragraphs (25 - 29) deal with different types of obstructions and to the specific procedures to adopt in each case. **(NB In all cases the potential barrier correction is to be calculated in the same vertical plane as the distance correction, ie normal to the track.)**

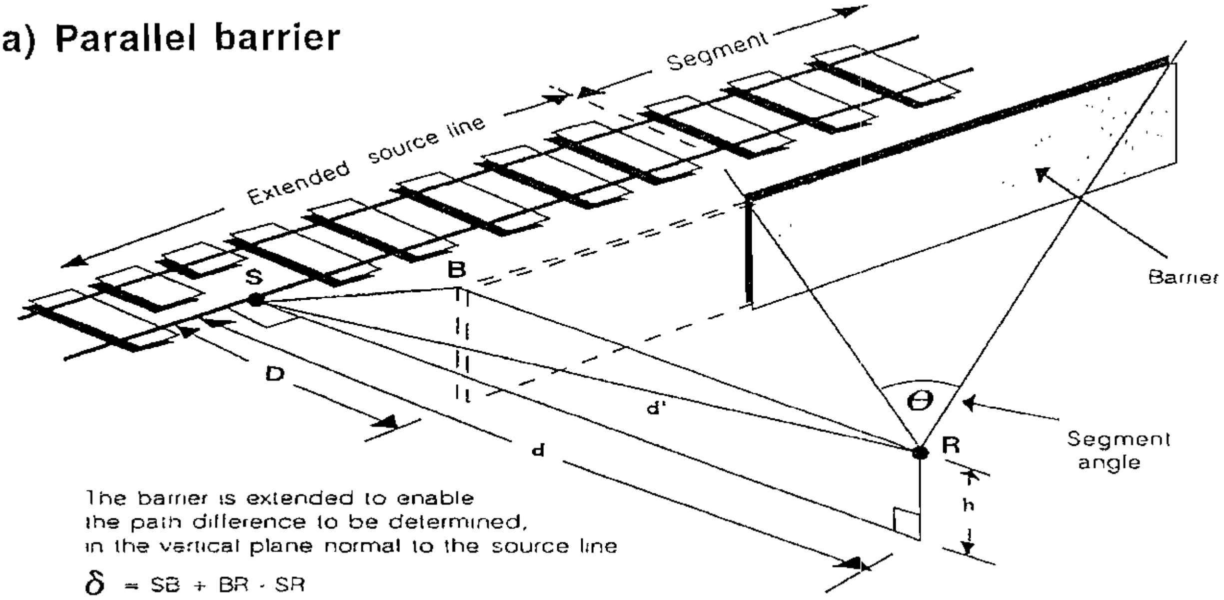
25. Barriers

25.1 If the barrier is parallel to the source line but screens only part of the track segment then the barrier and the source line contained within the segment may need to be extended to enable the potential barrier correction to be calculated in the same vertical plane (ie normal to the track surface) as the distance correction. This procedure follows that already described for extending the source line when determining the distance correction in paragraph 20. Figure 5(a) illustrates the generation of the effective barrier and source position for a generalised case where a barrier runs parallel to the railway.

25.2 If the barrier is not parallel to the source line, then the potential barrier correction will vary along the length of the barrier, and it may be necessary to segment the track further. The number of segments required to calculate the screening of the barrier should be limited, such that the variation in the barrier potential correction within each segment is less than 2 dB(A). The barrier potential correction is then determined in the following way. The bisector of the barrier segment angle is drawn to determine the point where the bisector intersects the top of the barrier. A line is then drawn through this position and parallel to the source line to intersect the vertical plane drawn normal to the source line through the reception point. The point of intersection defines the top edge of the effective barrier and the path difference can then be determined as before and Chart 6(a) or 6(b) used to determine the barrier screening potential. This procedure is illustrated in Figure 5(b). (NB Chart 6(c)

FIGURE 5.
EVALUATING THE PATH DIFFERENCE (δ) FOR PARALLEL AND NON-PARALLEL BARRIERS

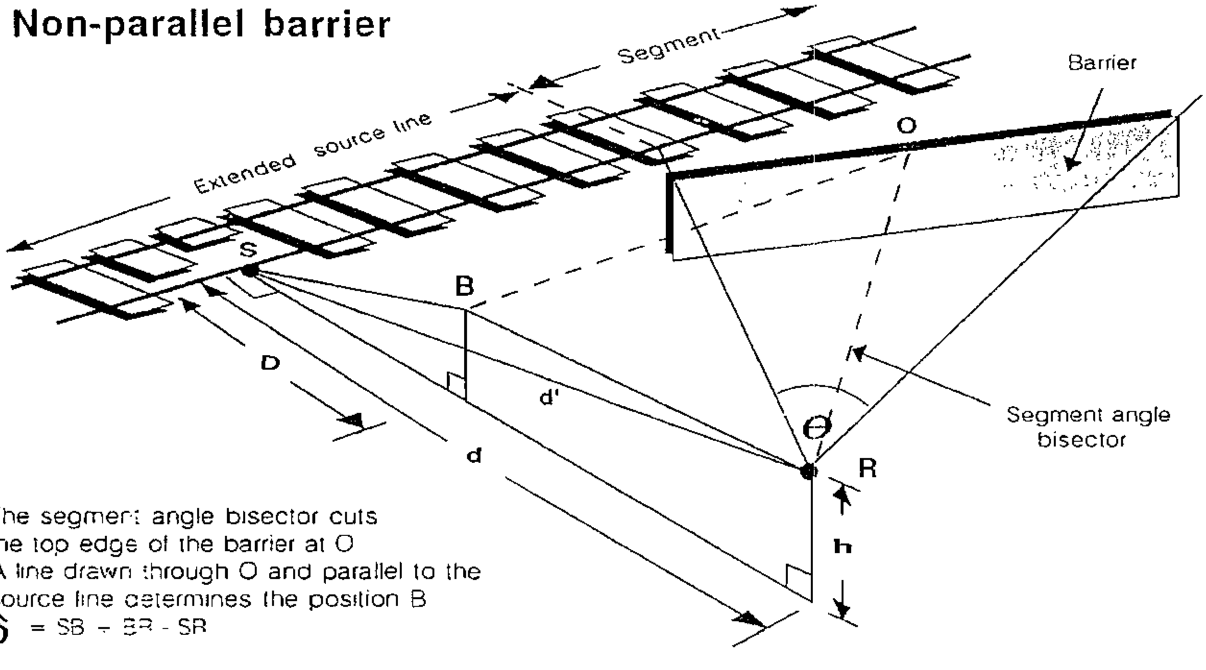
(a) Parallel barrier



The barrier is extended to enable the path difference to be determined, in the vertical plane normal to the source line

δ = SB + BR - SR

(b) Non-parallel barrier



The segment angle bisector cuts the top edge of the barrier at O
A line drawn through O and parallel to the source line determines the position B

δ = SB + BR - SR

should be used to calculate any additional correction to the barrier potential in the same way as was described earlier for barriers orientated parallel to the source line.)

25.3 The additional attenuation referred to earlier as ground correction (paragraph 21), or ballast correction (paragraph 22) are ignored when calculating the effect of barriers since the sound propagating close to the ground is obstructed by the barrier. However, under certain conditions (eg low barriers erected on grassland), it is possible for these ground absorption effects to exceed the calculated screening provided by the barrier. Under these circumstances the noise levels with and without the barrier should be calculated and the lower of the noise levels used.

25.4 Where more than a single barrier is interposed between the source line and the reception point then the screening provided by each barrier should be calculated separately, including any additional corrections to allow for reflecting barriers, and the lower of the two resulting noise levels used.

26. Buildings

When considering the calculation of noise levels at locations situated behind a row of buildings located alongside a railway, consideration has to be given to whether the buildings form an effective continuous barrier or whether there are substantial gaps between individual buildings or building clusters. However, it should be realised that the prediction method cannot cater for every possible potential screening situation that might occur in practice, and the user is therefore required to use judgement in many cases in order to match the site conditions to the cases covered in this Memorandum. When in doubt as to the correct procedure to adopt, the measurement method should be employed.

The following paragraphs describe the method to adopt in certain idealised cases. The principles indicated will serve to illustrate the procedures that will be needed to cater for most cases of screening by buildings likely to be encountered in practice.

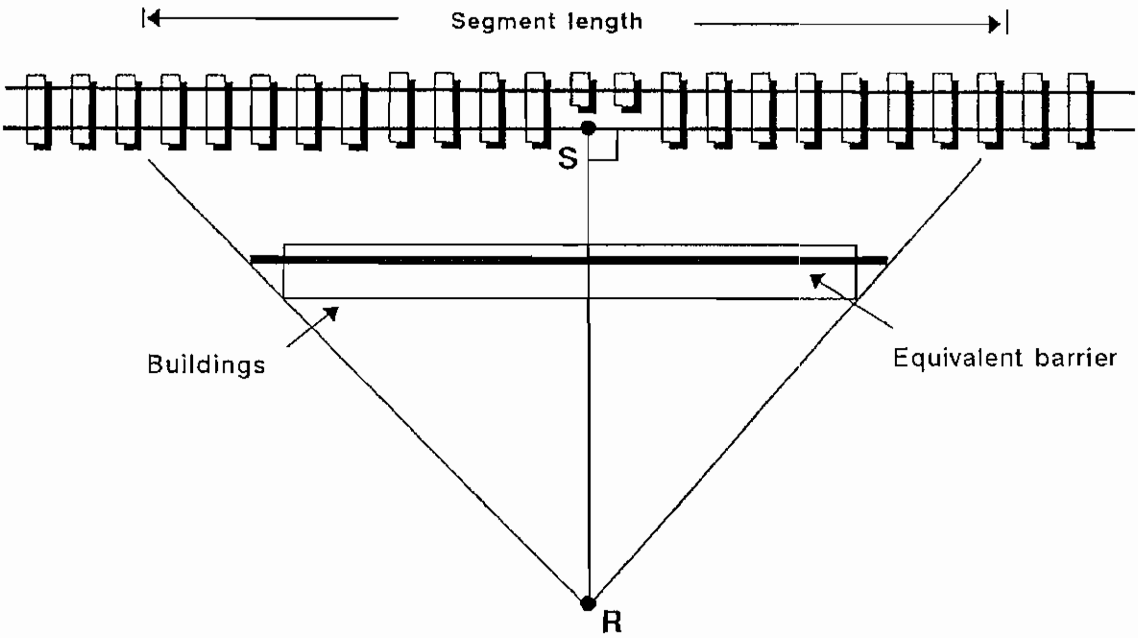
26.1 Where a row of buildings forms a continuous, unbroken line, the buildings can be considered to form an acoustic barrier and the shielding should be calculated. Clearly, this situation will exist for a row of terraced buildings running alongside a railway. Additionally a continuous barrier can often be assumed for semi-detached or detached buildings where garages or other substantial constructions bridge the gaps between adjacent buildings. In some cases judgement will be needed by the user to determine whether a particular building development constitutes a continuous barrier for the purpose of the calculation method.

To evaluate the potential barrier correction due to an intervening continuous row of buildings, the effective height and position of the **equivalent** barrier should be determined geometrically. This is defined by the intersection of two straight lines both just grazing the top edge of the row of buildings in question, one drawn from the reception point, the other drawn from the effective source position. Figure 6(a) illustrates the geometry involved for the particular case of a continuous row of buildings. For equivalent barriers which are parallel to the source line the procedure given in paragraph 25.1 applies, whereas for equivalent barriers not parallel to the source line the procedure given in paragraph 25.2 applies.

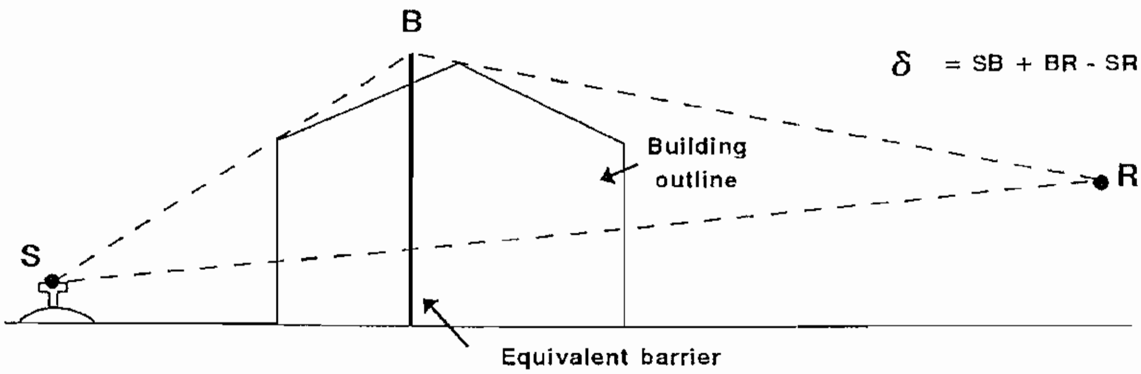
FIGURE 6.
SCREENING BY BUILDINGS

(a) CONTINUOUS ROW OF BUILDINGS

PLAN VIEW



CROSS-SECTION SR



26.2 For situations where some degree of screening is clearly indicated by the presence of buildings, but where the building development cannot be considered to form a continuous barrier as described above, then some further corrections may still be needed. In such cases it will be necessary to consider each building or building block as a separate barrier and segment the railway accordingly. Then for each separate building construct the equivalent barrier using the method described in paragraph 26.1 to determine the path difference and the barrier screening potential using Chart 6. The method for constructing the equivalent barrier in such cases is illustrated in Figure 6(b).

26.3 Due to the need to take into account a large number of finite barriers, it may become tedious to calculate the received noise level behind a reasonably uniform row of houses which face on to a railway using the procedure described above. In such cases an approximate solution can be found by determining the equivalent barrier segment whose subtended segment angle θ is reduced to θY where Y is defined as

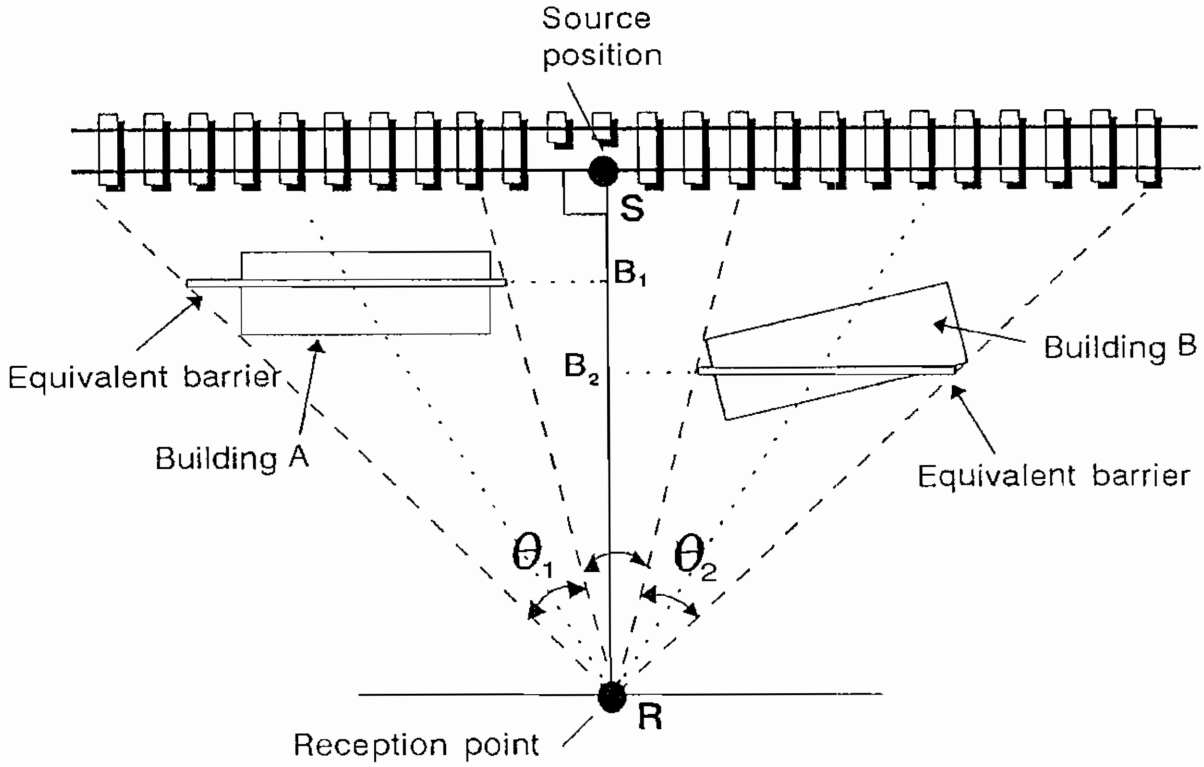
$$Y = b/(a + b),$$

where a is the mean opening between buildings and b is the mean length of building evaluated along the row of buildings. The original segment can then be treated as two separate segments whose subtended angles are θY (the screened segment) and $\theta(1 - Y)$ which represents the unscreened portion. (NB when evaluating the contribution from the unscreened segment an appropriate ground cover correction may apply (para 21).) In such cases the mean height of propagation (H) may be determined along the original segment bisector, ignoring the presence of the houses, and the proportion of absorbent ground determined from the type of ground enclosed by the original segment boundaries. Figure 6(c) illustrates the simplified procedure to adopt for a row of buildings with gaps.

Since the procedure described above can only give an approximation to the correct noise level it is necessary to use the measurement method to determine eligibility under the Railway Noise Insulation Regulations when the calculated noise levels obtained using this approximate method are found to be within ± 3 dB(A) of the specified noise level. It follows that if the noise from the partially screened segment is found not to contribute significantly to the overall calculated noise level from the total railway, then no measurements need be taken even if the total noise level is within ± 3 dB(A) of the specified level.

FIGURE 6.

(b) SCREENING BY BUILDINGS, WITH GAPS



Building A

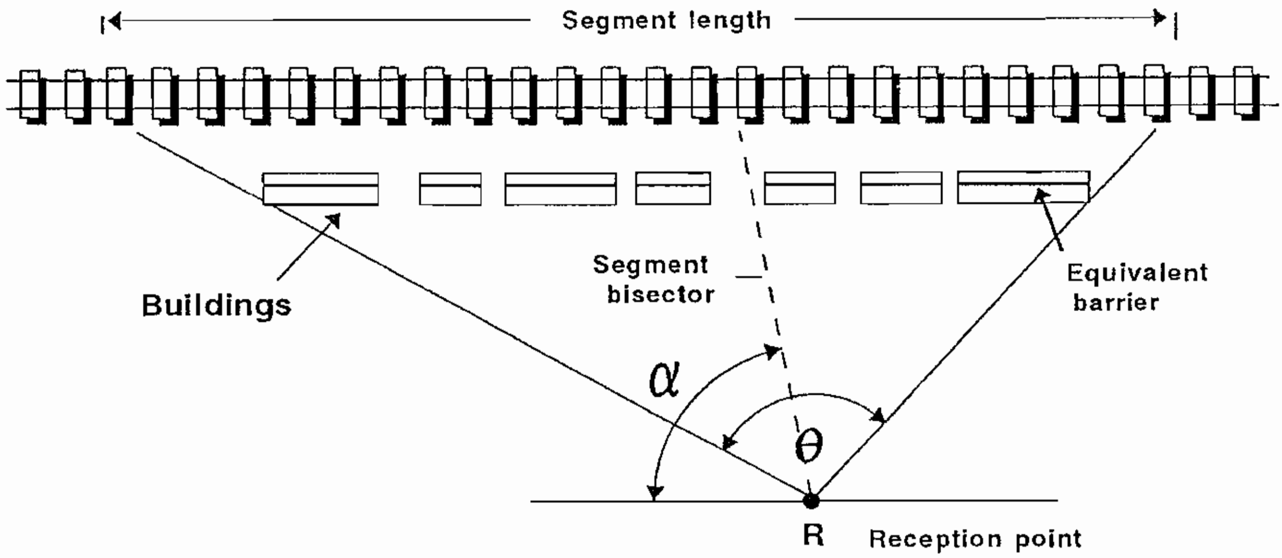
is parallel to the source line; the equivalent barrier is determined along the segment bisector using the same procedure used in Figure 6(a). The equivalent barrier is then extended parallel to the source line and the path difference, δ, is determined in the vertical plane normal to the source line through RS. ie. $\delta = RB_1 + B_1S - RS$.

Building B

is not parallel to the source line; the equivalent barrier is determined along the bisector to the segment defined by the building. The equivalent barrier is then extended parallel to the source line as in the previous example and the path difference, δ, is determined in the vertical plane normal to the source line through RS. ie. $\delta = RB_2 + B_2S - RS$.

FIGURE 6.

(c) SCREENING BY A ROW OF BUILDINGS, WITH GAPS (APPROXIMATE METHOD)



(i) Total segment angle is θ ; segment orientation angle is α

(ii) Screened segment angles are θY and α (see Fig 9)

Where $Y = b / (a+b)$

b is the mean length of buildings

a is the mean length of gaps between the buildings

(iii) Unscreened segment angles are θ (1-Y) and α (see Fig 9)

27. **Embankments and cuttings.**

For situations where the railway does not run at grade a correction for the screening provided by the embankment or cutting may need to be applied. (NB In most cases where a railway runs on an embankment the source line will be unobstructed at most reception points. However, situations may occur where the edge of the embankment effectively screens the source line from adjacent reception points.)

To evaluate the potential barrier correction for a railway running on an embankment or in a cutting, the position of the equivalent barrier should be determined geometrically. This is defined by the intersection of two straight lines, both just grazing the top edge of the embankment or cutting. Figures 7(a) and 7(b) illustrate the determination of the path difference for an embankment and a cutting respectively. Having determined the equivalent barrier, the barrier correction for absorbent barriers given in either Chart 6(a) or 6(b) should be used. **(NB In all calculations involving a correction for screening, the correction for ballasted track (paragraph 22) should not be applied.)**

28. **Retained cutting**

The previous consideration for a railway running in a cutting assumes that the cutting was formed with the sides of the cut constructed from earth embankments with appropriate slope to ensure stability. Where the cutting has vertical or near vertical sides (ie $< 15^0$ slope to the vertical plane) then additional complications may arise when determining the screening correction.

For a single screening wall the barrier potential correction is determined as before by constructing the appropriate geometry to determine the path difference to enter into Chart 6(a) or 6(b). Figure 8(a) illustrates a general case for the determination of path difference for a section of retained cut. However, where the cutting consists of vertical or near vertical walls on both sides of the railway, then reflections of noise from the far-side wall of the cutting could reduce the predicted screening performance of the near-side wall. The degradation of screening performance becomes greater as the depth of the cutting increases and an approximation to this effect can be obtained by subtracting 0.5 dB(A) from the potential barrier correction for each metre depth of the reflecting wall (rounded to the nearest metre.)

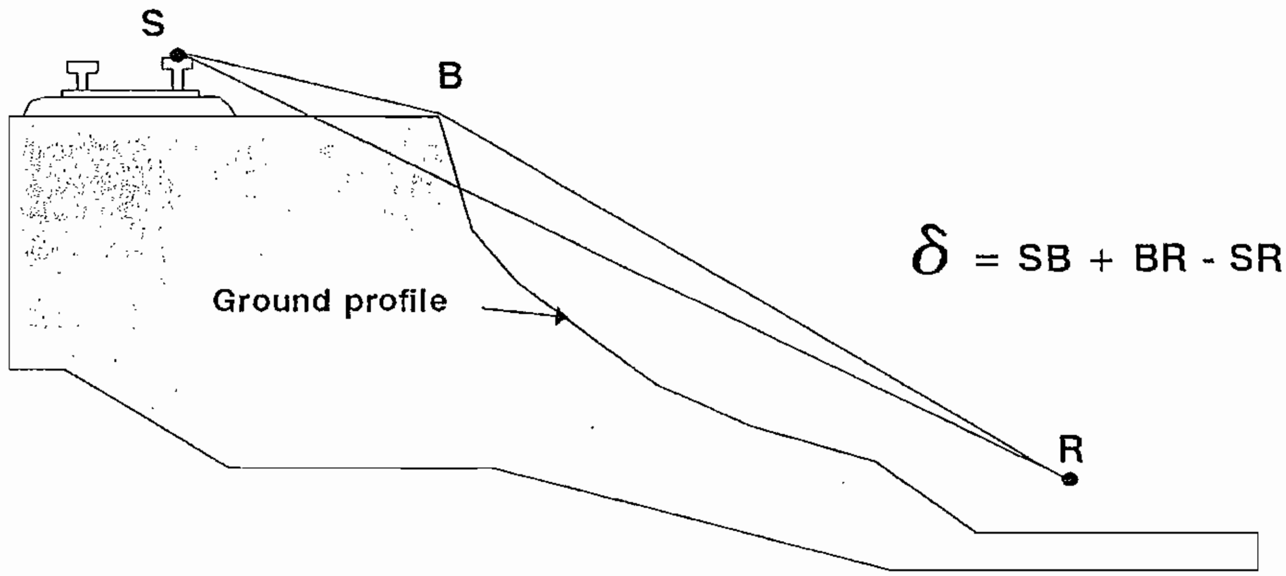
For situations where the reflecting wall has a slope of more than 15^0 to the vertical or where the height of the reflecting wall is less than 1.5m above the near-side railhead then no additional correction due to reflection will be made.

29. **Parallel noise barriers.**

Where noise barriers exist on both sides of a railway and are roughly parallel, a similar situation exists to that described in the previous paragraph for a retained cutting as noise reflected from the far-side barrier can degrade the screening performance of the near-side barrier. In this case the potential barrier correction calculated for the near-side barrier should be reduced by 0.5 dB(A) for each metre of the far-side barrier height (see also Figure 8(b)).

FIGURE 7.
SCREENING BY EMBANKMENTS AND CUTTINGS

(a) Embankment



(b) Cutting

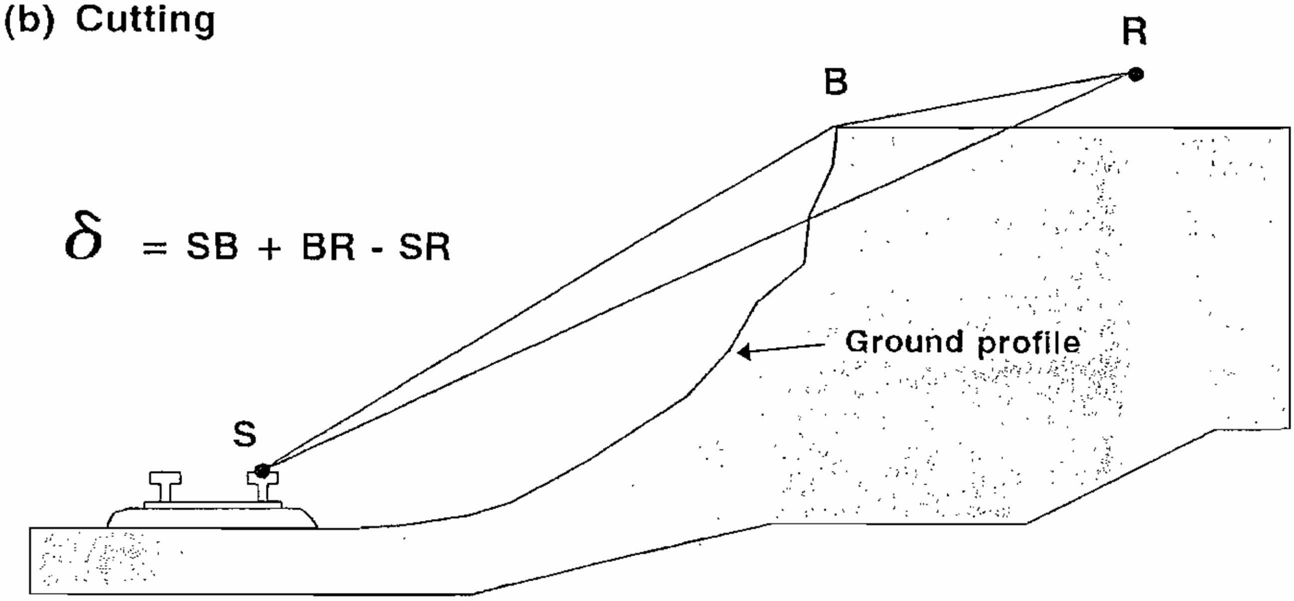
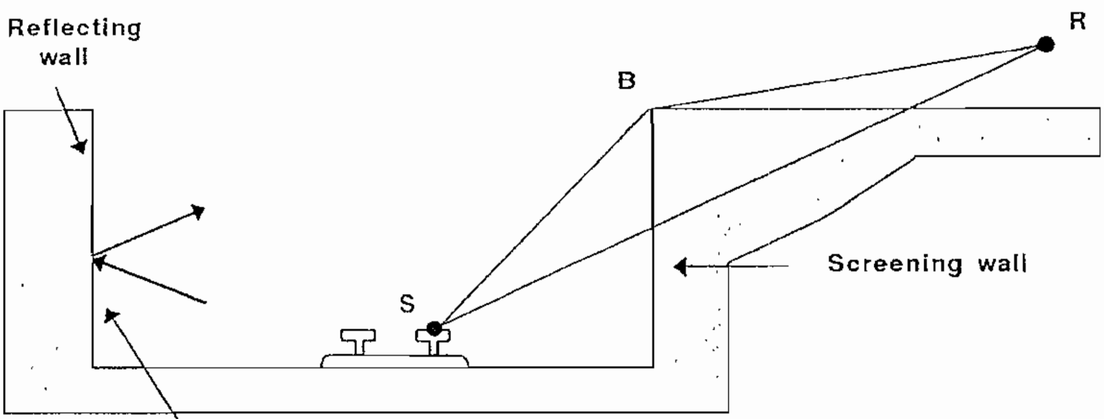


FIGURE 8.

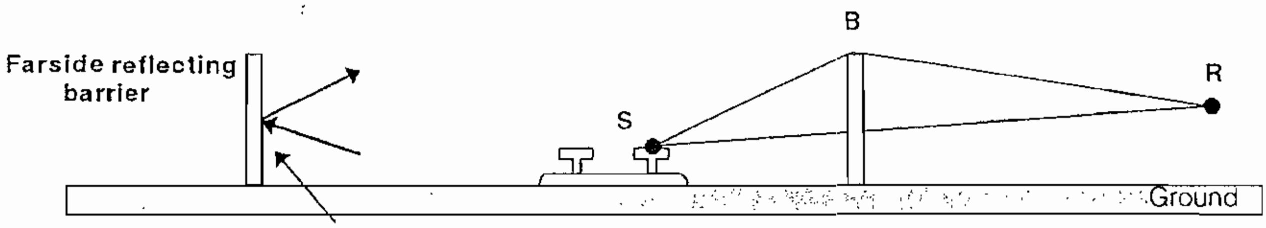
SCREENING BY RETAINED CUTTINGS AND DUAL BARRIERS

(a) Retained cutting



Reflected noise reduces the potential barrier correction, A , by 0.5 dB(A) per metre of cut depth of the reflecting wall.

(b) Dual noise barriers



Reflected noise reduces the barrier potential, A , by 0.5 dB(A) per metre height of the farside barrier.

NB (i) Reflecting wall or barrier must be at least 1.5m high.
(ii) Tilting the reflecting wall or barrier by 15° or more to the vertical removes the degradation of screening performance

It follows that when the far-side barrier is a purpose built acoustically absorbing barrier, then no degradation in the screening performance of the near-side barrier will occur as a result of reflections from the far-side barrier. In such cases the adjustment to the potential barrier correction to account for reflections should not be applied. Similarly if the far-side barrier is not vertical and the slope is greater than 15^0, or if the height of the far-side barrier is less than 1.5m above the near-side railhead, then the correction for reflection should also be ignored.

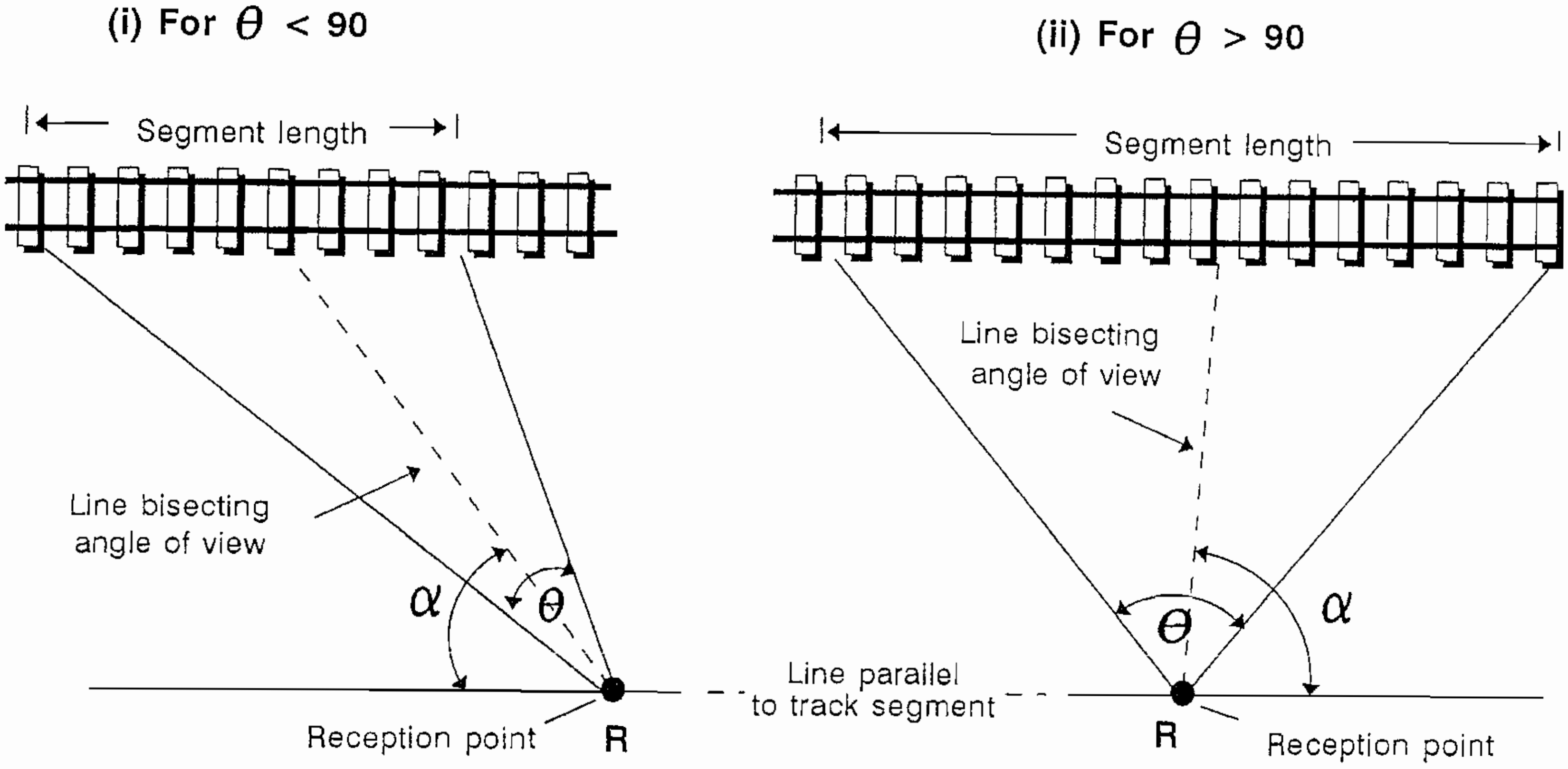
30. Angle of view correction

The SEL at the reception point from each train type will depend upon the angle subtended by the segment at the reception point, θ, and by the orientation of the segment along the trajectory of the track, α.

Chart 7 gives the corrections to apply for all railway vehicle and locomotive operating conditions apart from diesel locomotives on full power. For this type of railway vehicle and operation Chart 8 should be used. Figure 9 shows how to determine the angles α and θ for different segment orientations for use in Charts 7 and 8.

FIGURE 9.

DEFINITION OF α AND θ USED IN CHARTS 7 AND 8.



α = The acute angle between a line drawn through the reception point, parallel to the track, and the line bisecting the angle of view, θ.

STAGE 4. REFLECTION EFFECTS

31. Reflection of noise from hard rigid surfaces adjacent to the source or in the neighbourhood of the reception point increases the noise level compared with that determined using the above procedures, which give the free field values of SEL. The free field noise level applies where the site is open and clear and the reception point is well away from other facades.

31.1 Facade effect

For the purpose of calculating entitlement under the Railway Noise Insulation Regulations, it is necessary to calculate the noise 1 metre in front of a building facade. The correction, which should be added to the free field noise level, is +2.5 dB(A).

CORRECTION FOR FACADE EFFECT = + 2.5 dB(A)

However, where the building facade acts as a screen to the source line within the segment then no facade correction should be applied when calculating the contribution from that segment to the overall noise level from the railway.

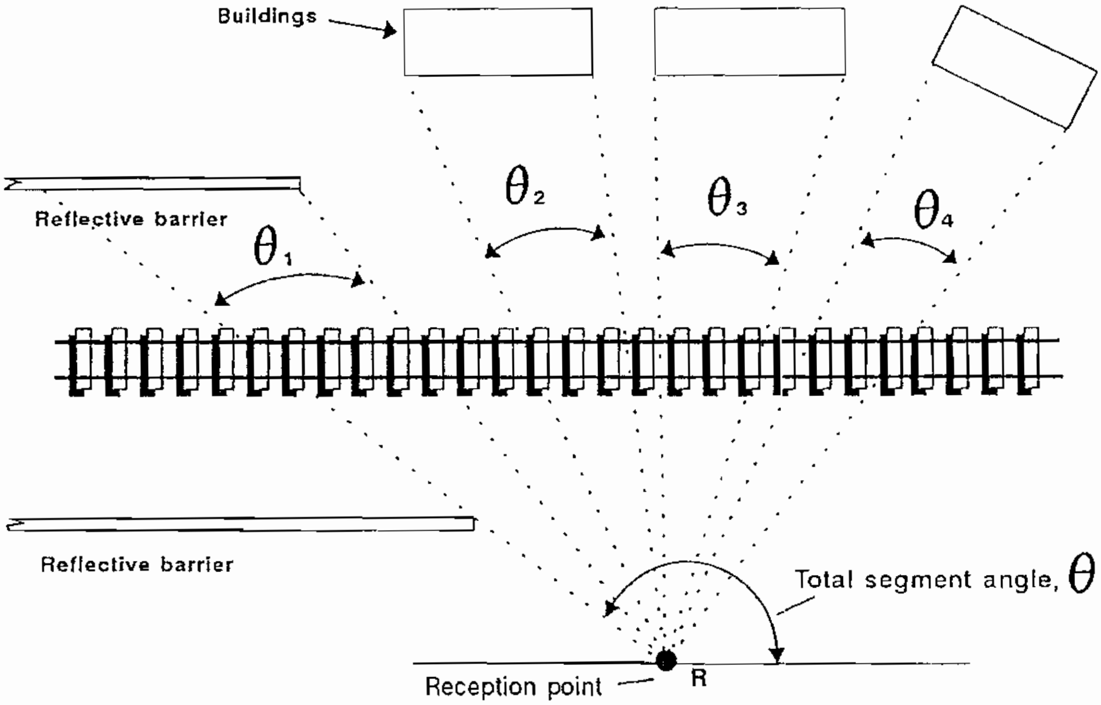
31.2 Reflection from opposite facades

Where there are houses, other substantial buildings or a noise fence or wall beyond the railway track(s) on the opposite side of the railway and approximately parallel to the railway, a correction for reflection from the opposite facades facing the reception point is required. The correction is required in addition to the facade correction given in paragraph 31.1. The correction only applies where the height of the reflecting surface is at least 1.5 metres above the near-side railhead. No correction should be applied when the opposite reflecting surface is a purpose built noise absorbing barrier.

The correction for reflection from opposite facades is $+\ 1.5(\theta'/\theta)$ dB(A). θ' is the sum of the angles subtended by all reflecting facades on the opposite side of the railway facing the reception point, and θ is the total angle subtended by the source line at the reception point (see Figure 10.)

FIGURE 10.

CALCULATING THE REFLECTION CORRECTION FOR FACADES FACING THE RECEPTION POINT ON THE FAR-SIDE OF THE RAILWAY TRAFFIC STREAM



$$\text{REFLECTION CORRECTION} = +1.5\left(\frac{\theta'}{\theta}\right)\ \text{dB(A)}$$

where $\theta' = \theta_1 + \theta_2 + \theta_3 + \theta_4$

and θ = TOTAL SEGMENT ANGLE

STAGE 5. CONVERT SEL TO L_{Aeq}

32. Previous stages of the calculation process have described the method of determining the SELs for each separate train/track segment identified at the outset of the calculation. This stage of the calculation process is concerned with converting these SELs to L_{Aeq}s taking into account the period over which the noise level is to be determined and the total number of trains of each type over the appropriate time period.

The relevant formulae to be used to carry out this conversion for each train/track segment are:-

$$L_{Aeq,\,6h} = SEL - 43.3 + 10\log_{10} Q_{NIGHT} \quad \text{.................. 5.1}$$

and

$$L_{Aeq,\,18h} = SEL - 48.1 + 10\log_{10} Q_{DAY} \quad \text{.................. 5.2}$$

Where Q_{NIGHT} is the total number of each train type passing the reception point during the time period (midnight to 0600 hrs,) and Q_{DAY} is the number of trains passing during the period (0600 hrs to midnight).

STAGE 6. CALCULATE THE TOTAL L_{Aeq} FOR THE RAILWAY

33. The final stage of the calculation process, to arrive at the predicted noise levels at a reception point, requires the combination of the L_{Aeq}s from each train/track segment which comprise the total railway. For a single train/track segment, of course, there is no further adjustment to be made. However, for nearly all cases there will be more than one track and more than one train type operating on the railway and it will be necessary therefore to combine each relevant component L_{Aeq} from all segments. The procedure to adopt is set out in Chart 9.

In carrying out this calculation a few additional points need to be noted:-

(i) All noise levels are combined logarithmically using the formulae given on the Chart.

(ii) Care should be taken to ensure that the component values of $L_{Aeq,6h}$ and $L_{Aeq,18h}$ are kept separate in the calculation process.

(iii) In some circumstances a large number of separate train/track segments will have been defined, and care will be needed to organise the combination of each component noise level if the Chart is to be used. The examples given in Appendix A2 illustrate how the calculation might be laid out in order to avoid errors.

SECTION II

THE PREDICTION METHOD (Additional Procedures)

34. The procedures given in Section I of this Technical Memorandum provide a general method of predicting the relevant values of L_{Aeq} at the facades of buildings located within 300 metres of a railway, where the trains that are operating on the railway are reasonably well defined and the propagation and site layout conditions are not too complex. However, situations will occur where noise levels are required in the vicinity of railways where the operations of the railway vehicles cannot be defined with sufficient precision or where the complexities of propagation, including screening and reflection from buildings etc. are not straightforward. This Section of the Technical Memorandum describes some additional procedures which will be needed for some situations which are not specifically catered for in the preceding paragraphs.

In addition, this section deals with the assessment of noise from tramways and other guided transport systems which are included in the Railway Noise Insulation Regulations but which cannot be treated as a conventional railway.

In all cases, consideration is restricted to movement of trains/guided vehicles and no consideration is given to the noise generated by other noise sources which may be attributable to the railway or other relevant guided transport system being considered.

35. Sidings

When sidings are constructed the noise from trains and railway vehicles using these facilities may affect residential communities and eligibility for noise insulation will need to be assessed. In many cases the general prediction method will be suitable for this purpose but its accuracy will depend greatly upon the ability of the user, in consultation with the owners of the railway and the operators of the trains, to determine the train types and frequency of use of the siding. It is likely that in some cases this cannot be accurately estimated before the siding has been constructed although some preliminary estimate of use and associated noise levels can normally be made. Once the siding has been opened to railway vehicles, a more accurate re-assessment of the predicted worst case noise level can be made. It should be noted that prediction will need to take account of the likely change of use of the siding over the relevant period in order to determine the worst case conditions.

36. Stations

When determining the noise levels from a railway in the vicinity of a station, it will normally be necessary to treat the railway station or stopping place as a separate segment. An additional point to note is that the noise generated by the station public address system or other non-train related noise sources should not be considered for the purpose of calculating the relevant noise levels. In addition, the noise generated by trains which have stopped at the station should not be considered and it is only trains moving through the station that should be included in the calculation method for the station segment. The noise from trains stopping at the station and then moving away under full power will normally be accounted for by including their contribution in adjacent segments.

For trains passing through the station segment, it will be necessary to take account of the screening and possible reflection effects from the station buildings and platforms. It may be possible for some simple station constructions to approximate the station by a barrier. Where there are station buildings on either side of the railway then the procedures described in paragraph 29 which deal with parallel barriers may apply. For more complicated building structures where the station consists of several tracks and buildings extending over a large area, then the measurement method will be needed. Platform canopies may exert a particularly strong effect regarding reflections of noise from passing trains, and where such constructions exist the measurement method is advised.

For some railway systems scheduled stopping points may be assigned similar to bus stops where passengers may enter or leave the railway vehicles. In such cases the procedure to adopt is identical to the method described above for stations; ie segment the railway such that adjacent segments span the stopping point, then calculate separately the noise from railway vehicles decelerating to the stop and moving from rest in adjacent segments using the procedures described in Section I of this Memorandum.

37. Stopping places

On occasions, trains will be required to make unscheduled stops on a section of railway either as a result of signalling, track maintenance or other operational reasons. These situations should not be considered as part of entitlement calculations, and the noise from the relevant section of railway should be determined assuming normal operation with freely moving trains. However, in a few cases the railway will have been designed to allow trains to stop as part of scheduled procedures. For example, situations occur where a freight loop has been constructed to maintain operational efficiency by allowing freight trains to move from the main line and give free access to faster moving passenger trains. Such operations may well be infrequent and consequently the number of trains using the facility over the relevant time period may be both low and variable. However, a reasonably accurate schedule of planned movements can be obtained from the operator and the prediction method used to determine the noise from trains in the loop segments.

The noise associated with the train entering the loop and coming to a stop will need to be determined separately from the noise of the train moving from rest and rejoining the main line. These entry and exit phases should be treated as two train operations even for the same physical track segment.

Additional segments may be required within the loop to cover train movement either side of the stopping signal. The number of segments chosen will depend on the location of the signal and the speeds at which trains exit or enter the main line segments. Average speeds over each relevant segment can be assumed for each operation.

When considering the train moving away from rest, the locomotive will normally be considered to operate at full power and in the case of diesel locomotives the reference noise level should be chosen from the data given in Appendix A1.

38. Guided transport systems other than railways.

It may be necessary to use this Technical Memorandum to assess the noise from guided transport systems other than conventional railways. The modes of guided transport that are to be considered for noise insulation purposes are described in Schedule 2 of the Railway Noise Insulation Regulations. Alternative systems to railways include tramways, where the vehicles run on steel rails set in the road surface, trains which run on roads with cable or track guidance, monorail and magnetic levitation systems.

38.1 Tramways

Trams run on conventional steel rails which may form part of a conventional railway but, more often, the rails are set in a road surface. Alternatively a corridor may be set aside for the use of trams which is separated from the road traffic by a barrier. In all such cases, trams can be considered to be a special type of conventional railway vehicle and Section I of the Technical Memorandum will therefore apply for the assessment of noise from tramways. Initially, SELs for the type of trams running on a particular system will be needed in order to carry out the calculations required (see also Appendix A1). It may be necessary to differentiate between trams running on roads and trams running on conventional tracks and to determine appropriate SELs for each type of operation.

38.2 Other forms of guided transport system

When assessing the noise from guided transport systems where the guidance system is not based on a dual running rail as for conventional railways and tramways, it is not possible to use the calculation procedures described in Sections I of the Technical Memorandum as these procedures are only applicable for railway vehicles running on steel rails. Consequently for other forms of guided transport system included in the Railway Noise Insulation Regulations, assessments of noise should be carried out using the measurement method described in Section III of the Technical Memorandum. The measurement method may be used where it is impractical to obtain reference SELs.

SECTION III

THE MEASUREMENT METHOD

39. The method consists of measuring the noise from an actual flow of trains on a railway. For the purposes of the Railway Noise Insulation Regulations, and where there are no other significant noise sources in the area (or they are separately identifiable), measurements shall be made at a reception point located 1 metre outward of the external side of the most exposed qualifying window. The measured level shall be for the time period 0600-2400 hrs and/or 0000-0600 hrs, whichever is appropriate depending on the train movements in any particular period.

40. When to measure

The measurement method may be used where:

(i) railway traffic conditions fall outside the range of validity of the Charts;

(ii) railway traffic or site layout conditions are sufficiently complex or unusual to make the use of standard railway traffic data unreasonable;

(iii) the guided transport system under consideration is not a railway where the vehicles run on steel rails (see also paragraph 38);

(iv) or where new types of vehicles are to be used and where it is impractical to obtain reference SELs.

However, the prediction method shall be used unless it is considered it is inappropriate to the circumstances of the case.

41. Physical conditions for measurement

The following conditions should prevail throughout the measurement period.

41.1 Track conditions

The measurements shall be made with the ballast bed not frozen and preferably dry. The running rails shall be dry.

41.2 Wind

Measurements should be made where:

(i) the wind direction is such as to give a component from the nearest part of the rail towards the reception point which exceeds the component parallel to the rail;

(ii) the average wind speed at a height of 1.5 metres close to the reception point but not affected by the facade is not more than 2m/s in the direction from the rail to the reception point;

(iii) the wind speed at the microphone in any direction should not exceed 5m/s.

In all cases it is recommended that a wind shield be used on the microphone and that measurements should only be carried out when the peaks of wind noise at the microphone are 10 dB(A) or more below the measured or anticipated value of L_{Amax}.

42. Measuring equipment

Equipment used for the measurement of L_{Aeq} shall meet the specification to type 1 for Integrating - Averaging Sound Level Meters given in BS 6698:1986. Compliance to this standard shall have been verified at least every 2 years. Guidance on minimum calibration requirements are given in paragraph 44.

43. Measurement procedure

The following procedure should be adopted when carrying out the measurements. In order that the measurement of railway and other guided system noise is not affected by extraneous noise from other sources (eg road traffic, aircraft) which would make a significant contribution to the period L_{Aeq}, it is recommended that the SEL of individual train pass-bys should be measured. The following procedure should be adopted.

43.1 Microphone Position

The measurement point should be chosen so as to be one metre outward from the most exposed facade of the building. The microphone should normally be placed at a height representative of the window height (typically 4.5 metres for a first floor bedroom) and with the diaphragm or any other sound sensitive surface horizontal (grazing incidence).

43.2 Sampling

In order to determine the $L_{Aeq,18h}$ or $L_{Aeq,6h}$ noise level it may be necessary to carry out SEL noise measurements of each train pass-by over the full time period of interest. Exceptions to this may occur when the train mix and speed of individual train types remain reasonably constant over the relevant time period. For this situation, it is acceptable to measure a representative sample of individual train pass-bys of each train type running on each track and determine an arithmetic mean value for the SEL in each case.

It should be noted that:-

(i) Where integrating sound level meters are used with a triggering device, it will normally be sufficient to set the trigger to 10 dB below the lowest anticipated value of L_{Amax} from trains except where this would otherwise capture other extraneous noise events.

(ii) Where equipment is switched on manually to record SELs, it will generally be reasonable to start recording at the onset of first hearing the noise event and switching off when the noise event is no longer audible.

During each measurement of the SEL it will be necessary to determine the type of train, its direction and speed. Slight variations in speed for different trains of the same type can then be taken into account using Chart A1.1 or, if the train is a locomotive on power, Chart A1.2. When normalised for train type, direction (track) and speed a standard deviation of ±2.5 dBA in the SELs would be considered reasonable and the mean of the measurements can then be taken to represent the noise from the train type operating on the railway for a given track.

43.3 Determining the values of $L_{Aeq,\ 18h}$ and $L_{Aeq,\ 6h}$

Having established by measurement the mean values for the SELs of each train type operating on the railway, the procedure described previously in paragraph 32 should be employed to convert the SELs to L_{Aeq} levels over the relevant time periods, and for the anticipated traffic flows. The L_{Aeq} levels for the total railway can then be determined by combining the L_{Aeq} levels for each train type/track using the procedure described in paragraph 33.

44. On-site sensitivity checks

Immediately prior to and following each noise measurement period the overall sensitivity of the electroacoustical system should be checked using an acoustic calibrator with a known sound pressure at a known frequency. Measurements may be accepted as valid only if calibration levels agree within 1 dB.

Note 1: Sometimes a pistonphone operating at a nominal level of 124 dB at a frequency of 250 Hz is used for this purpose. As this level is generally outside the range required for noise measurements, it will be necessary to introduce known additional attenuation (eg using a 'range-switch'). Care will therefore need to be exercised when interpreting the calibration signals and it is recommended that the same attenuation (eg 50 dB) be adopted as routine. Attention is also drawn to the fact that where the A-weighting network is permanently connected in circuit due allowance must also be made relative to the response of the A-weighting network at the frequency used (eg 8.6 dB at 250 Hz).

45. System Calibration

The conformance of the measuring system to BS 6698:1986 shall be verified according to BS 7580:1992 or directly compared with an independent measuring system that has been thus verified within the previous 2 years.

CHARTS

and

APPENDICES

CHART 1.

FLOW DIAGRAM FOR THE CALCULATION OF NOISE FROM RAILWAYS

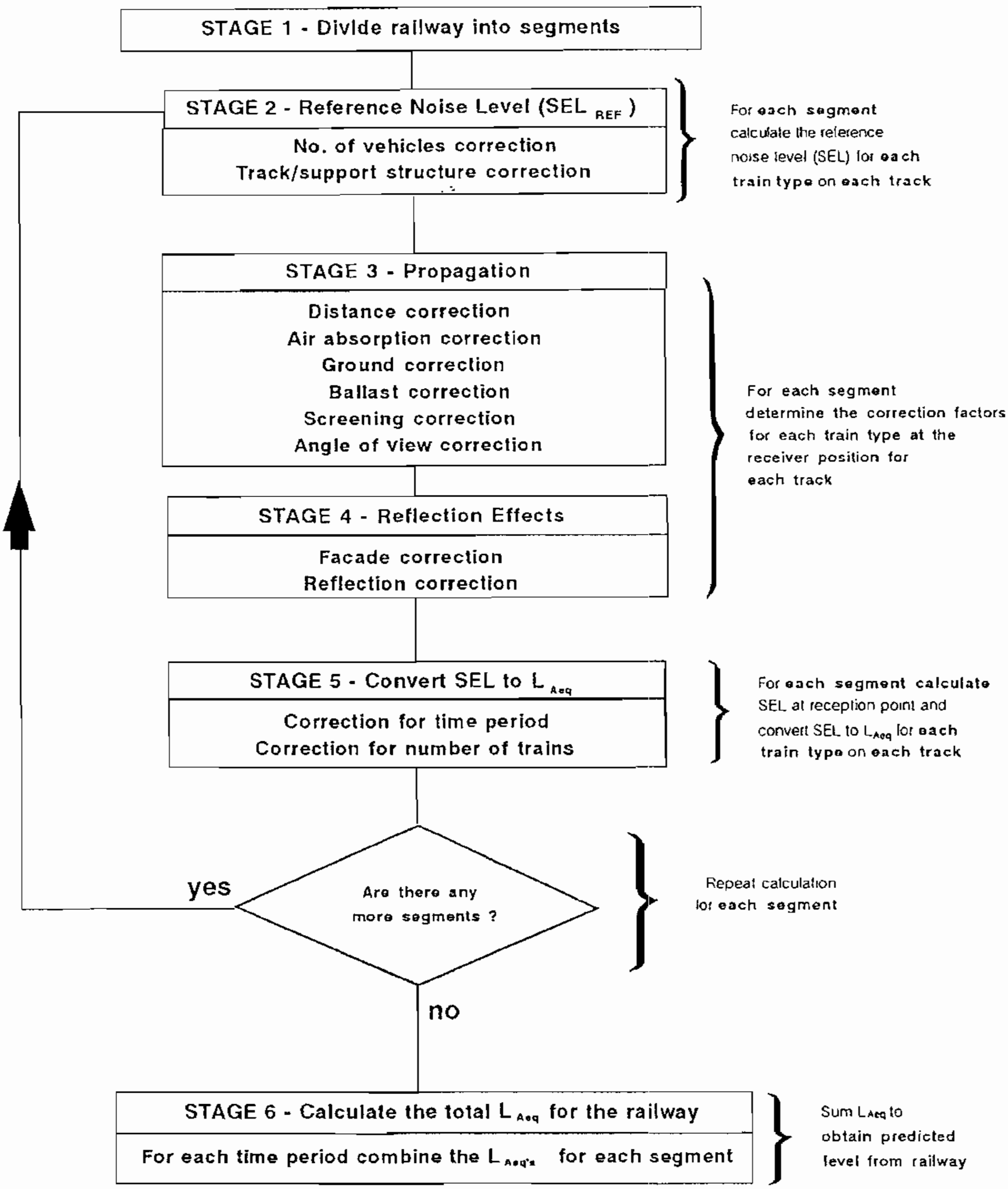
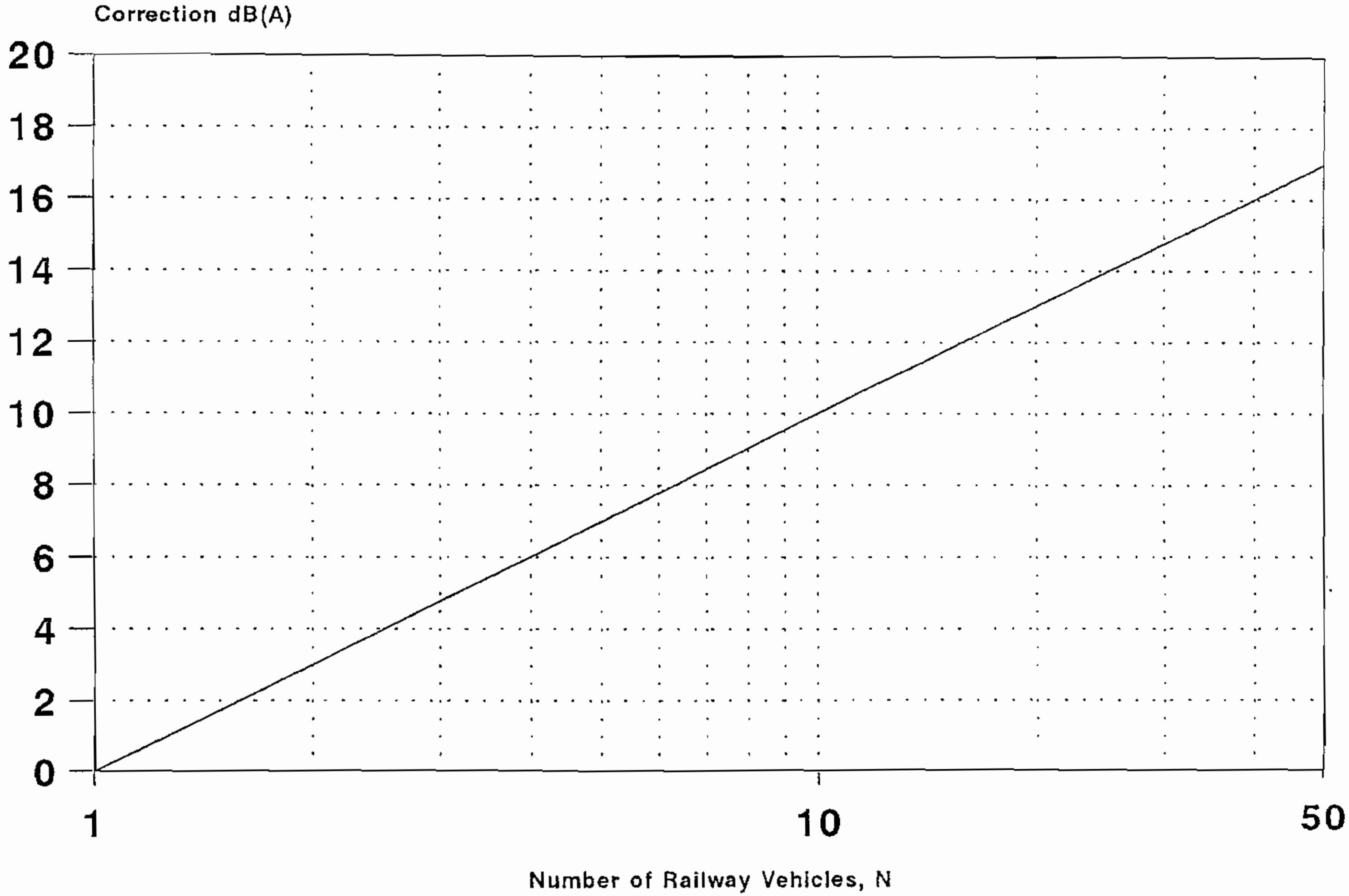


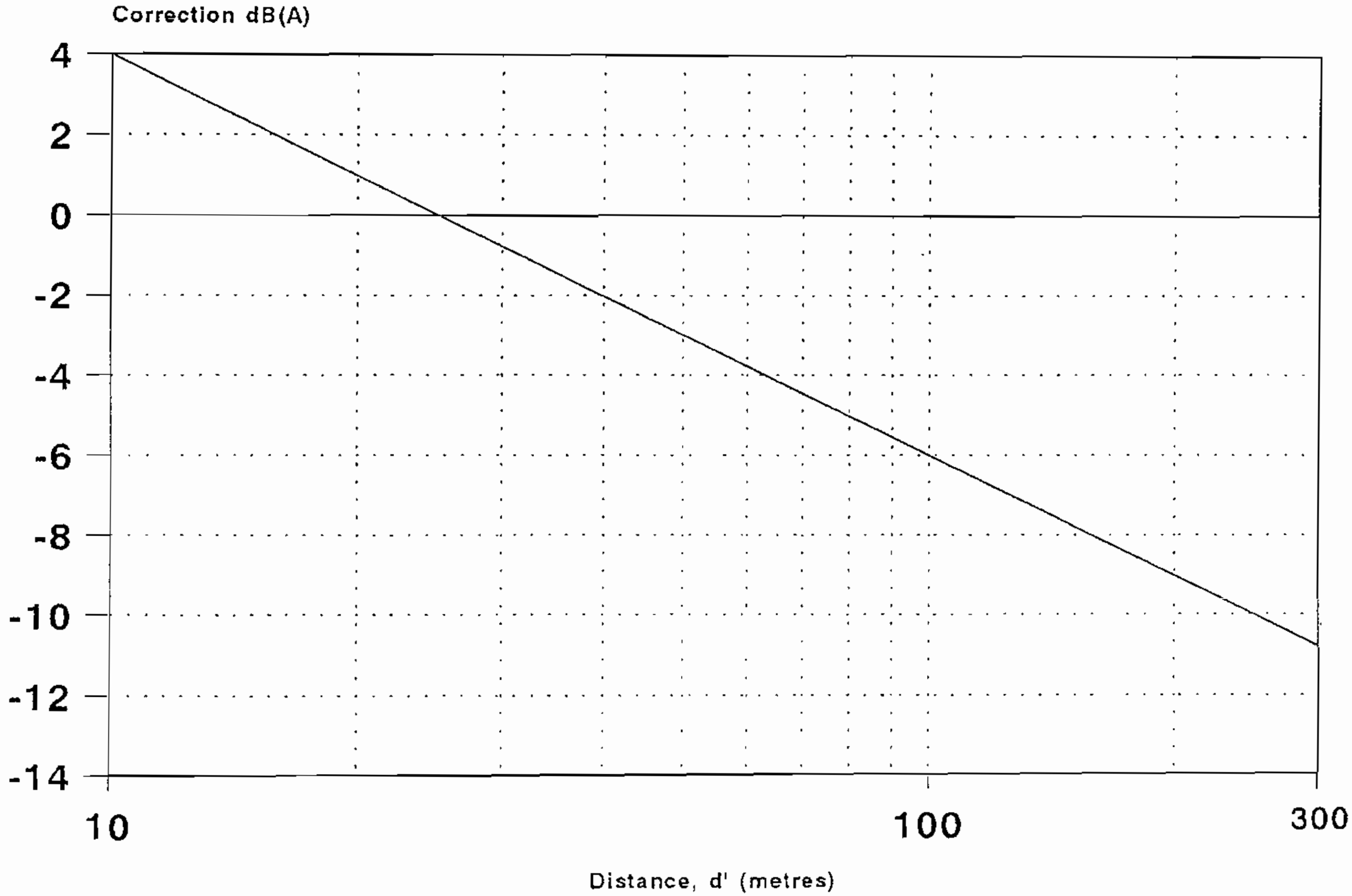
CHART 2.

CORRECTION FOR THE NUMBER OF RAILWAY VEHICLES, N, COMPRISING THE TRAIN



Correction = $10 \log_{10}(N)$ dB(A) where N is the number of vehicles comprising the train

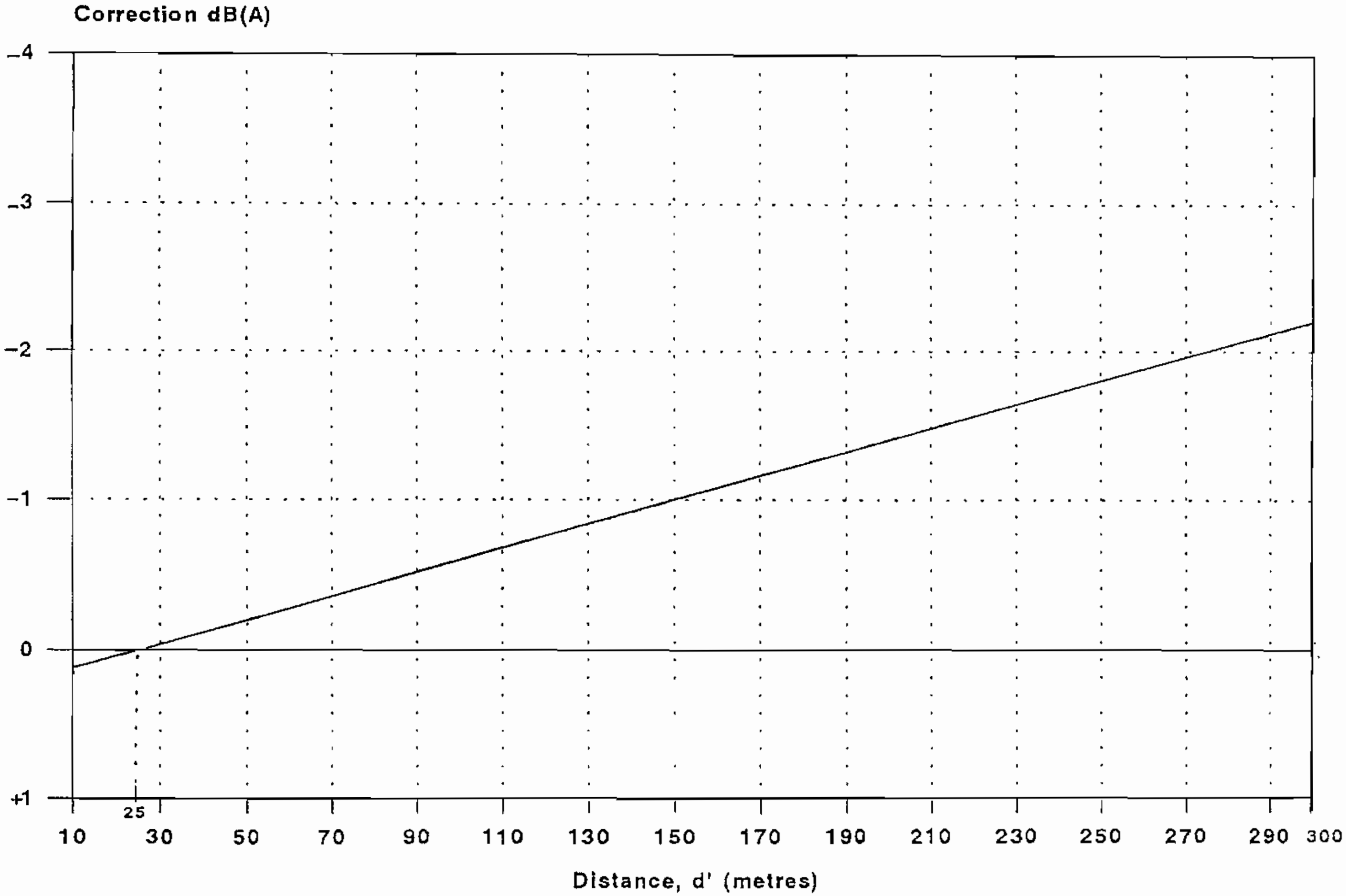
CHART 3.
CORRECTION FOR DISTANCE, d'



Correction = $-10 \log_{10}(d'/25)$ dB(A)   Valid for $d' \geq 10$m

CHART 4.

CORRECTION FOR AIR ABSORPTION AS A FUNCTION OF d'



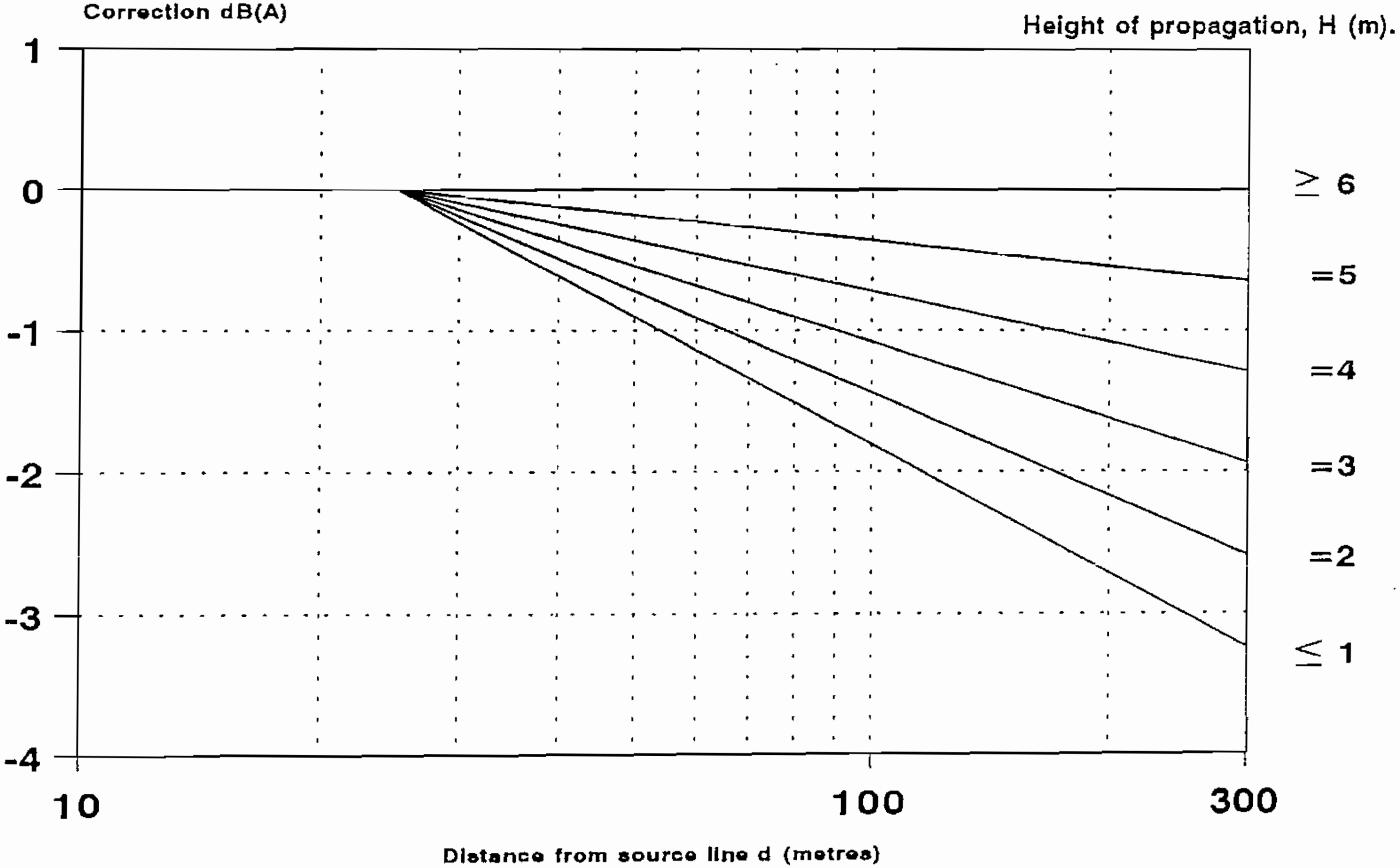
Correction = 0.2 - 0.008d' dB(A)

CHART 5.

GROUND CORRECTION AS A FUNCTION OF THE HORIZONTAL DISTANCE, d, MEAN HEIGHT OF PROPAGATION, H, AND THE PROPORTION OF ABSORBING GROUND, I .

The chart shows the correction when I = 1

The formulae below the chart give the correction for 0 < I < 1



For 10 ≤ d ≤ 25m Correction = 0 dB(A)

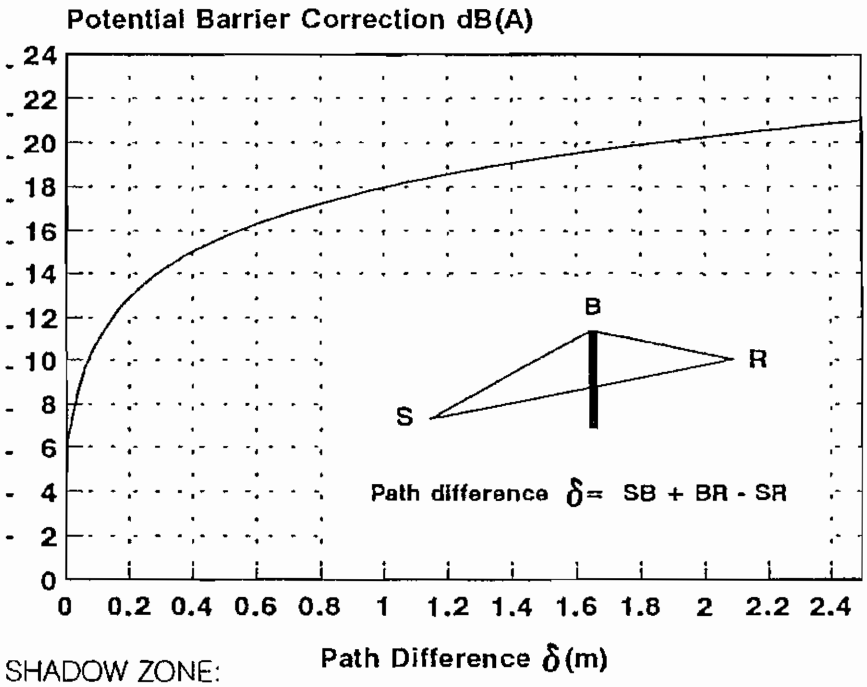
For d > 25m:

- For 1.0<H<6.0m Correction = $-0.6 I (6 - H)\log_{10}(d/25)$ dB(A)
- For H ≤ 1.0m Correction = $-3 I \log_{10}(d/25)$ dB(A)
- F[illegible] ≥ 6.0m Correction = [illegible] [illegible](A)

CHART 6(a).

POTENTIAL BARRIER CORRECTION AS A FUNCTION OF PATH DIFFERENCE, δ

(i) SHADOW ZONE

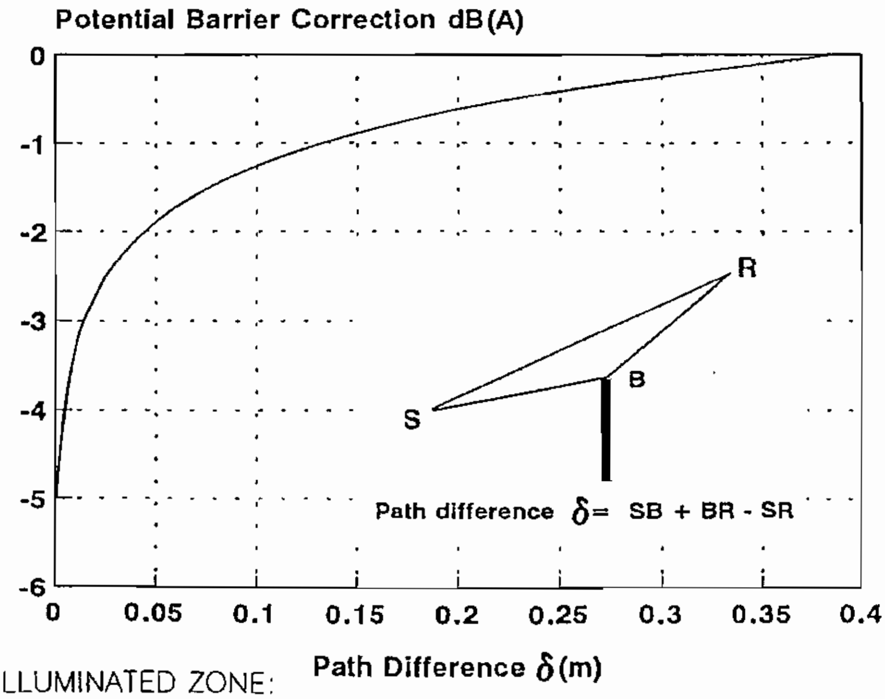


SHADOW ZONE:

FOR $\delta > 2.5$m CORRECTION = -21.0 dB(A)

FOR $0 < \delta < 2.5$m CORRECTION = $-7.75 \, LOG_{10}(5.2 + 203\delta)$ dB(A)

(ii) ILLUMINATED ZONE



ILLUMINATED ZONE:

FOR $\delta > 0.4$m CORRECTION = 0

FOR $0 < \delta < 0.4$m CORRECTION = $0.88 + 2.14 \, LOG_{10}(10^{-3} + \delta)$ dB(A)

CHART 6(b) POTENTIAL BARRIER CORRECTION A* dB(A) FOR PATH DIFFERENCES (δ = i + j)** CALCULATED TO THE NEAREST 0.01m

j	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
i	SHADOW ZONE									
0	5.5	6.7	7.5	8.2	8.7	9.2	9.6	10	10.3	10.6
0.1	10.9	11.2	11.4	11.6	11.8	12	12.2	12.4	12.6	12.7
0.2	12.9	13	13.2	13.3	13.4	13.5	13.7	13.8	13.9	14
0.3	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.8	14.9
0.4	15	15.1	15.2	15.2	15.3	15.4	15.5	15.5	15.6	15.7
0.5	15.7	15.8	15.8	15.9	16	16	16.1	16.1	16.2	16.3
0.6	16.3	16.4	16.4	16.5	16.5	16.6	16.6	16.7	16.7	16.8
0.7	16.8	16.8	16.9	16.9	17	17	17.1	17.1	17.2	17.2
0.8	17.2	17.3	17.3	17.4	17.4	17.4	17.5	17.5	17.5	17.6
0.9	17.6	17.7	17.7	17.7	17.8	17.8	17.8	17.9	17.9	17.9
1	18	18	18	18.1	18.1	18.1	18.2	18.2	18.2	18.3
1.1	18.3	18.3	18.3	18.4	18.4	18.4	18.5	18.5	18.5	18.5
1.2	18.6	18.6	18.6	18.6	18.7	18.7	18.7	18.8	18.8	18.8
1.3	18.8	18.9	18.9	18.9	18.9	19	19	19	19	19.1
1.4	19.1	19.1	19.1	19.1	19.2	19.2	19.2	19.2	19.3	19.3
1.5	19.3	19.3	19.3	19.4	19.4	19.4	19.4	19.5	19.5	19.5
1.6	19.5	19.5	19.6	19.6	19.6	19.6	19.6	19.7	19.7	19.7
1.7	19.7	19.7	19.8	19.8	19.8	19.8	19.8	19.9	19.9	19.9
1.8	19.9	19.9	19.9	20	20	20	20	20	20.1	20.1
1.9	20.1	20.1	20.1	20.1	20.2	20.2	20.2	20.2	20.2	20.2
2	20.3	20.3	20.3	20.3	20.3	20.3	20.4	20.4	20.4	20.4
2.1	20.4	20.4	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.6
2.2	20.6	20.6	20.6	20.6	20.6	20.7	20.7	20.7	20.7	20.7
2.3	20.7	20.7	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.9
2.4	20.9	20.9	20.9	20.9	20.9	20.9	20.9	21	21	21
	ILLUMINATED ZONE									
0.0	5.5	3.3	2.7	2.4	2.1	1.9	1.7	1.6	1.5	1.4
0.1	1.3	1.2	1.1	1.0	1.0	0.9	0.8	0.8	0.7	0.7
0.2	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3
0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0

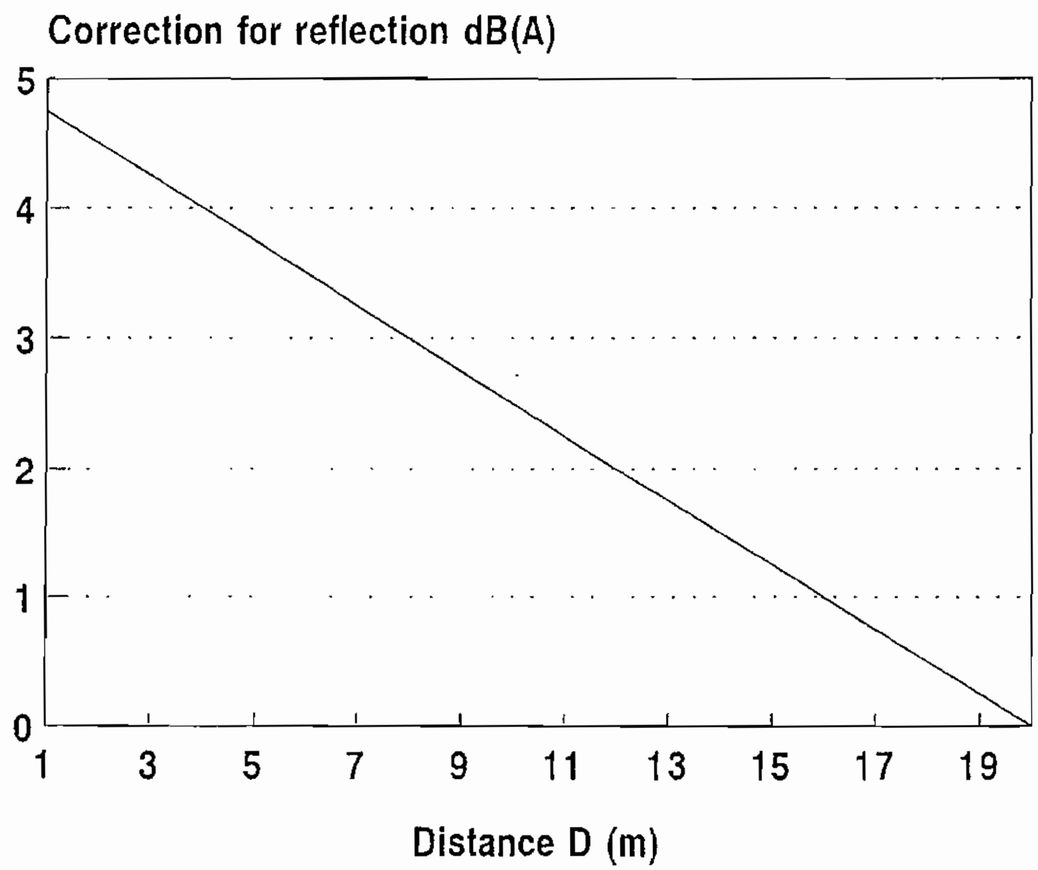
* Values of A are negative.

** eg where the reception point is in the SHADOW ZONE and δ = 1.45m : i = 1.4 and j = 0.05 from CHART 6(b) the value of A = - 19.2 dB(A)

CHART 6(c).

CORRECTION FOR REFLECTIVE BARRIER AS A FUNCTION OF DISTANCE D*

(ALL TRAINS EXCEPT DIESEL LOCOMOTIVES ON POWER)



For D > 20m Correction = 0 dB(A))

For 1m < D < 20m Correction = 5 - 0.25 D dB(A)

For D < 1m Correction = 4.8 dB(A)

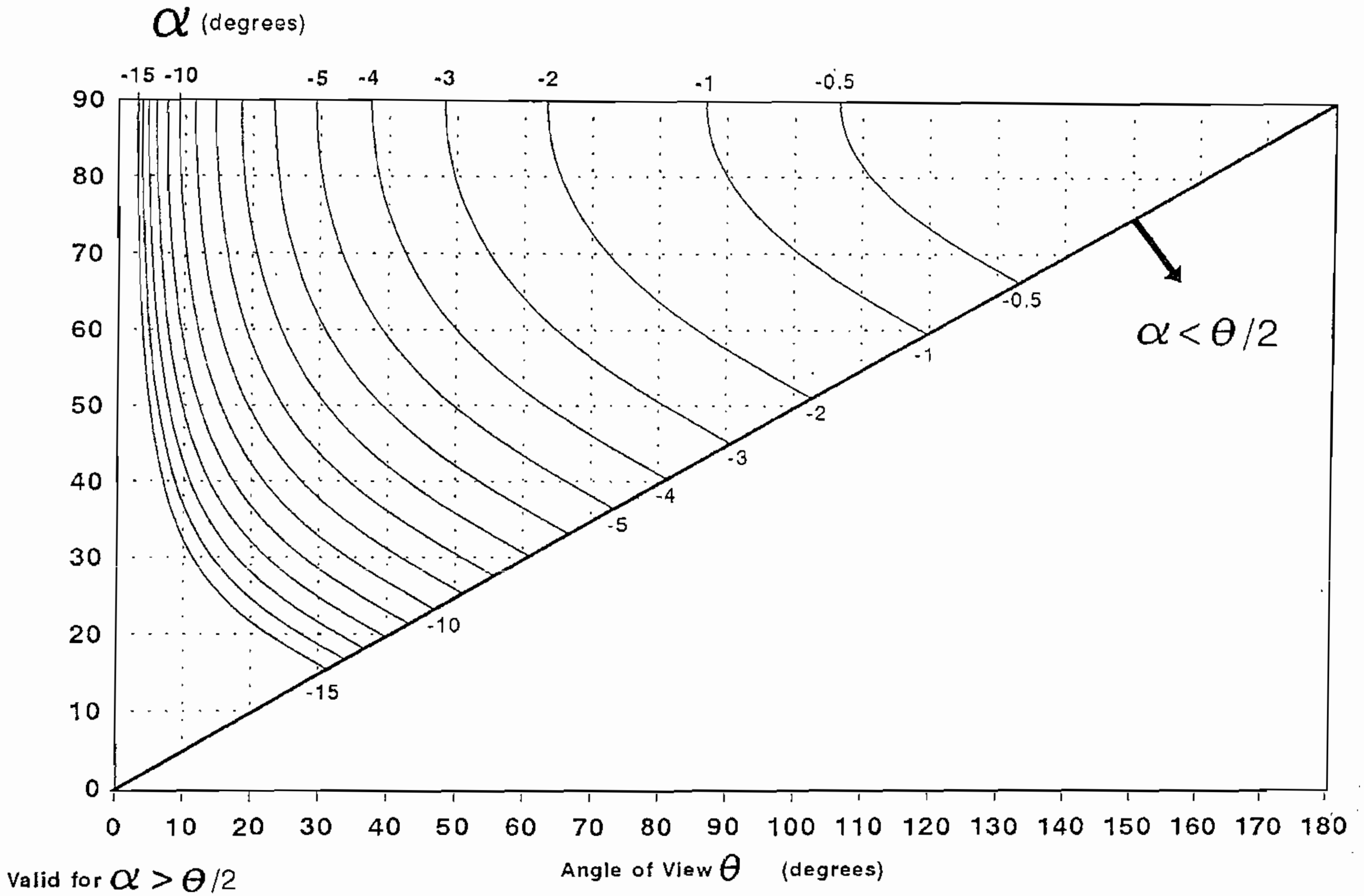
* D is the horizontal distance (metres) between the barrier and the railhead. (See also Figure 4).

(NB Only valid where barrier is 1m or more above the railhead)

CHART 7.

CORRECTION FOR ANGLE OF VIEW

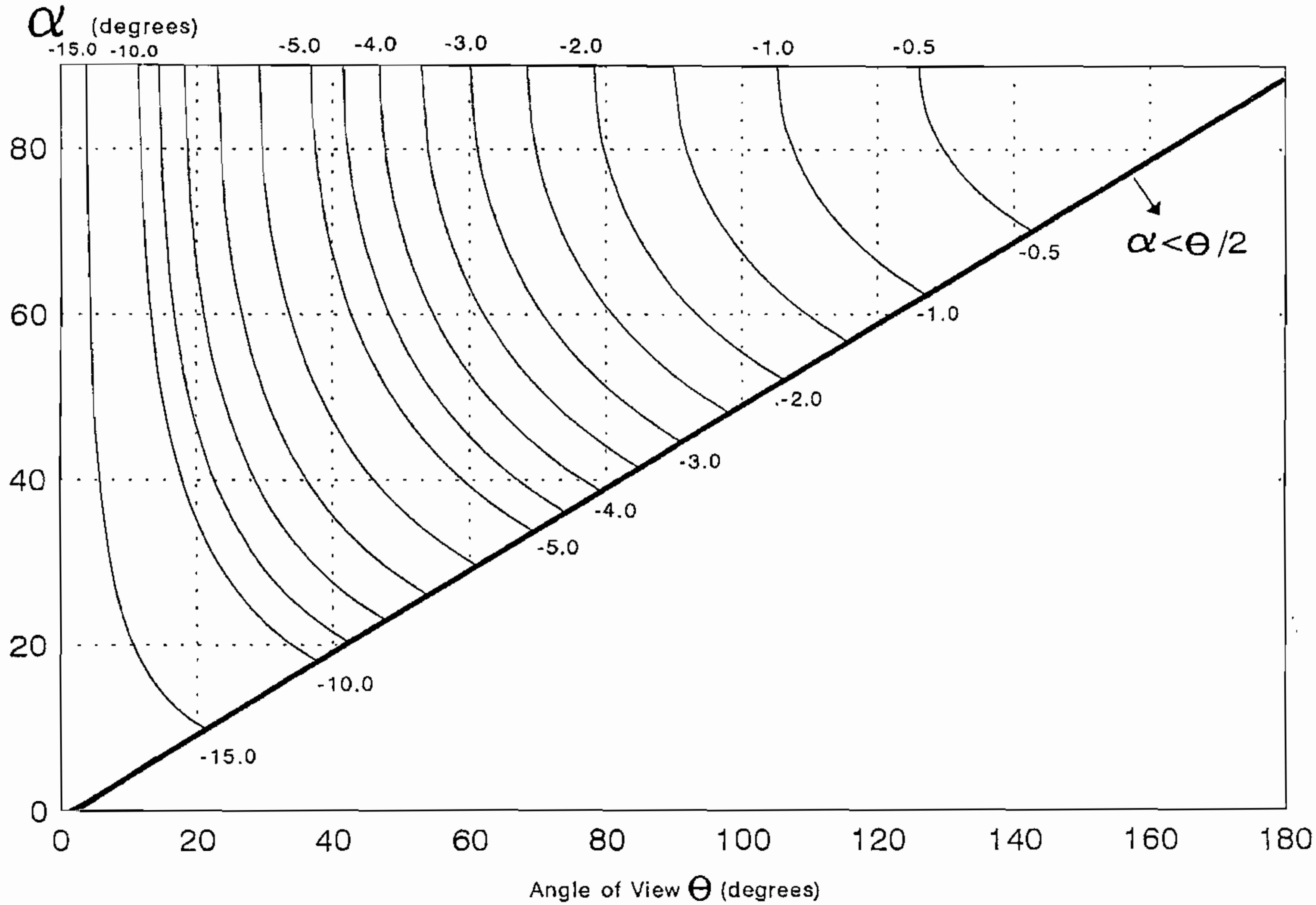
(ALL TRAINS EXCEPT DIESEL LOCOMOTIVES UNDER FULL POWER)



Correction = $10\log_{10}[\pi\theta/180 - \cos 2\alpha \sin\theta] - 5$ dB(A)

CHART 8.
CORRECTION FOR ANGLE OF VIEW

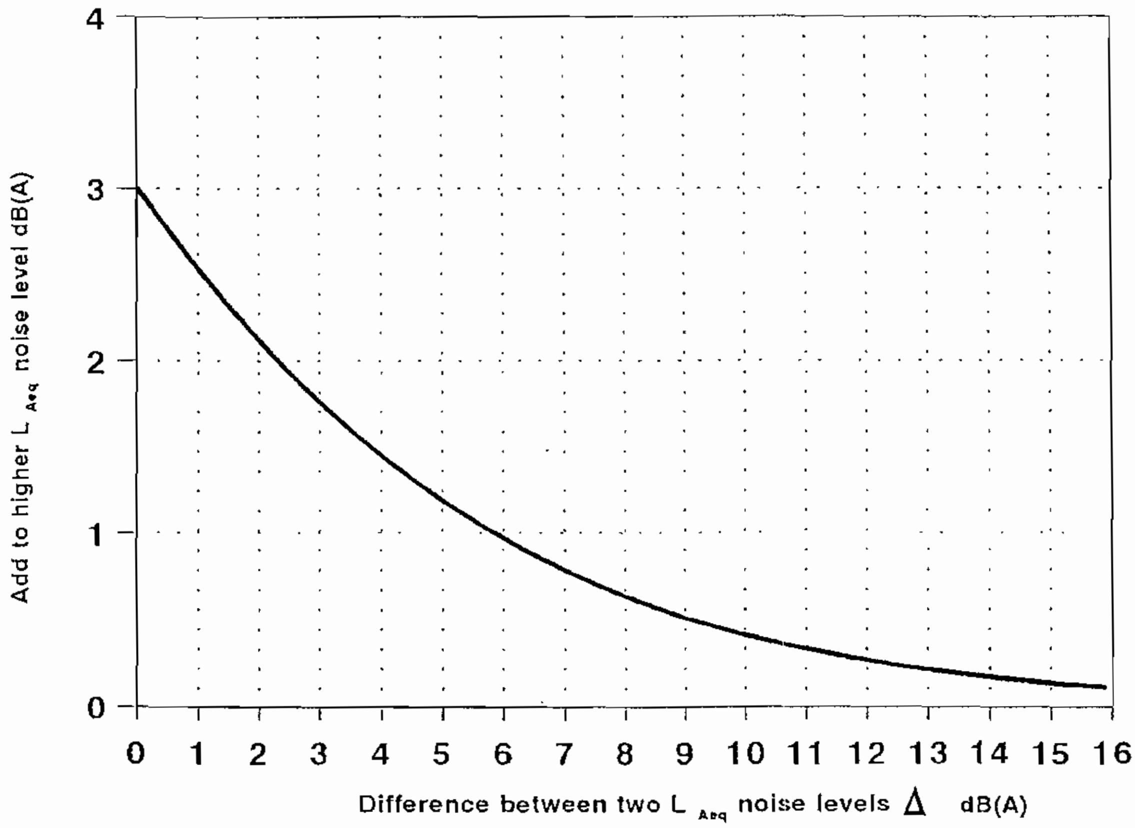
(VALID ONLY FOR DIESEL LOCOMOTIVES UNDER FULL POWER)



valid for $\alpha > \Theta/2$ Correction= $-10\log_{10}(\sin\alpha \sin\Theta/2)$ dB(A)

CHART 9.

PROCEDURE FOR COMBINING L_{Aeq} NOISE LEVELS



(i) Given two noise levels L_{Aeq} and $(L_{Aeq} - \Delta)$ then the combined level is

$$L_{Aeq} + 10 \ \mathrm{Log}_{10}[1 + \mathrm{Antilog}_{10}(-\Delta / 10)] \ \mathrm{dB(A)}$$

(ii) With n component noise levels $(L_{Aeq})_1$, $(L_{Aeq})_2$, ..., $(L_{Aeq})_n$ the combined noise level due to all n components is given by

$$L_{Aeq} = 10 \ \mathrm{Log}_{10}[\Sigma_1^n \ \mathrm{Antilog}_{10}((L_{Aeq})_n / 10)] \quad \mathrm{dB(A)}$$