VOLUME 10 ENVIRONMENTAL DESIGN AND MANAGEMENT

SECTION 5 ENVIRONMENTAL BARRIERS

PART 2

HA 66/95

ENVIRONMENTAL BARRIERS: TECHNICAL REQUIREMENTS

SUMMARY

This Advice Note accompanies HA 65/94 (DMRB 10.5.1) and gives guidance on acoustic performance, forms of construction and physical properties of materials.

INSTRUCTIONS FOR USE

1. Remove existing title page, content page and General Preface page on the Goods Roads Guide series of Advice Notes.

2. Insert new title page.

3. Archive this sheet as appropriate.

Note: A new contents page for Volume 10 dated September 1995 is available with HA 75/95.

THE HIGHWAYS AGENCY

THE SCOTTISH EXECUTIVE DEVELOPMENT DEPARTMENT

THE NATIONAL ASSEMBLY FOR WALES
CYNULLIAD CENEDLAETHOL CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT*

Environmental Barriers: Technical Requirements

* A Government Department in Northern Ireland

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REGISTRATION OF AMENDMENTS

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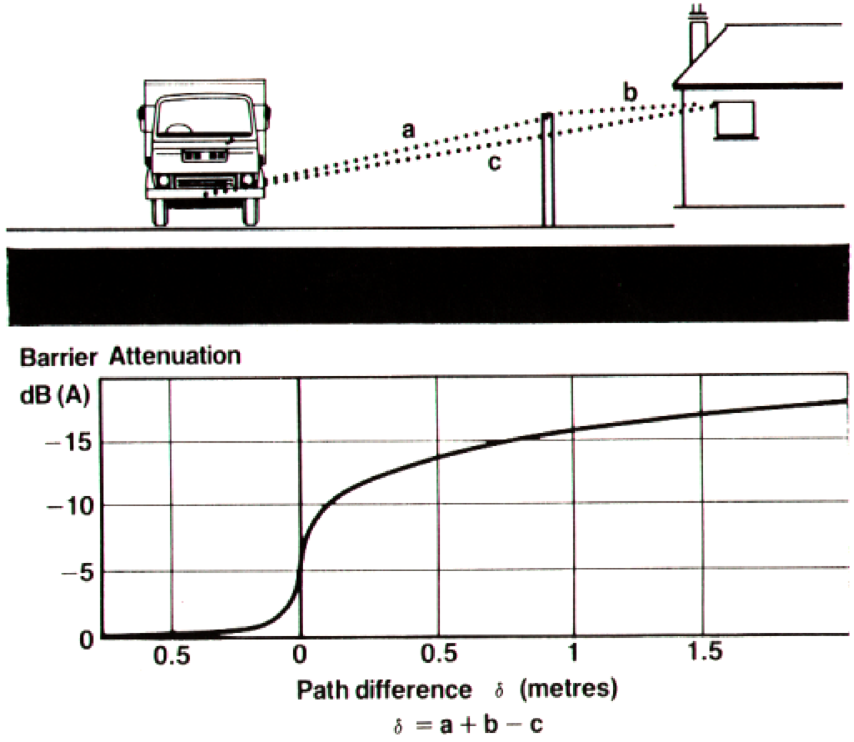

ENVIRONMENTAL BARRIERS

TECHNICAL REQUIREMENTS

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1.0 INTRODUCTION

General

1.1 This document should be read in conjunction with HA 65 (DMRB 10.5.1) Design Guide for Environmental Barriers. It supports the overall advice given in the Design Guide with guidance on acoustic performance, forms of construction and physical properties of materials and supersedes H14/76: Noise Barriers - Standards and Materials (DMRB 5.2).

Scope

1.2 The essentials of noise propagation and attenuation are summarised and the basis of standard noise calculations are explained, covering the effect of barriers in particular. The relative effectiveness of different forms of barrier are discussed and references provided to permit further reading. Environmental barriers in the form of thin panel constructions are given particular attention under the general heading of acoustic screens.

1.3 The later chapters in this document describe the materials and construction techniques which can be used in environmental barriers. Basic engineering requirements for the design of different structural forms are given with reference to the appropriate documents. A design method is provided for acoustic screens, together with a review of current information on a range of materials which may be used in their construction. Indicators of relative costs, including those of maintenance, are given for various forms of environmental barrier.

Implementation

1.4 This document provides general guidance on the criteria used in designing environmental barriers. The Overseeing Organisations' requirements for approval on the grounds of structural integrity are contained in BD 2/94: Technical Approval of Highway Structures - Part 1: General Procedures (DMRB 1.1). The particular features required of contractor designed environmental barriers on individual schemes are set out in Appendix 3/2 of the contract documents.

1.5 The procurement of environmental barriers will normally be carried out under contracts incorporating Overseeing Organisations' Specification for Highway Works (MCHW 1). Products conforming to equivalent standards and specifications of other states of the European Economic Area and tests undertaken in other states of the European Economic Area will be acceptable in accordance with the terms of clauses 104 and 105 of MCHW 1. For contracts not incorporating this form of specification, advice should be sought on suitable clauses of mutual recognition which would have the same effect.

2.0 NOISE FUNDAMENTALS

Vehicle and Traffic Noise

2.1 The level of noise received at some distance from the source is affected by a number of factors relating firstly to the amount of noise generated and secondly to the amount by which it is attenuated as it travels through the air. These effects are briefly summarised here but covered in more detail in Chapter 10.

2.2 Vehicle noise arises in different ways from the engine, transmission, bodywork, suspensions and tyres. The most significant factors affecting the noise are the engine speed and the speed on the road. The dominant source of noise from vehicles cruising in high gear often arises from the interaction of tyres on the road surface, but the engine noise of heavy vehicles can be significant, especially when they are going up hill.

2.3 The noise generated by large numbers of vehicles passing a continuous stream merges together and can be characterised by a representative level of noise at a given distance from the road (for example 10 metres from the edge of carriageway). The noise level depends principally on the total flow of traffic, its average speed and the proportion of heavy vehicles, but may be modified by different road surfaces.

2.4 For the purpose of assessment, the source of noise from traffic on a trunk road or motorway is normally taken as a line 3.5 metres from the near edge of the carriageway and 0.5 metres above it. Allowance is made for various factors which affect the noise reaching a distant receiver. The factors affecting propagation are:

i) ***Distance*** - starting from any reference point, the noise level at another point which is twice as far from the line source will be approximately 3dB(A) less because of the dispersion of sound energy.

ii) ***Soft Ground*** - The simple reduction with distance assumes that sound either travels through free space or passes over a hard reflecting surface. If sound passes over a more absorbent form of surface such as grassland, it will be attenuated more rapidly.

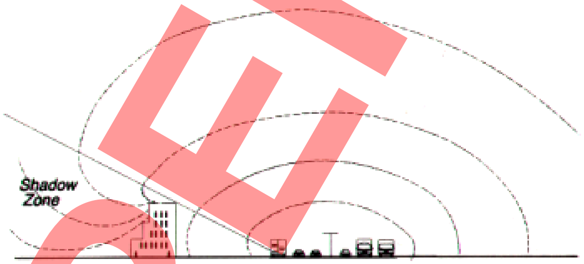
iii) ***Angle of View*** - The treatment of traffic noise as a line source assumes that it stretches to infinity in either direction. When the length of road under consideration is comparable with the distance to the reception point, the overall noise level is reduced in relation to the angle subtended by the road at that point.

iv) ***Screening*** - Solid objects which interrupt the line of sight between source and receiver will block the noise passing directly to the receiver. Screening may be provided by hills or buildings, by boundary walls, by cutting slopes, or by environmental barriers included in the scheme design.

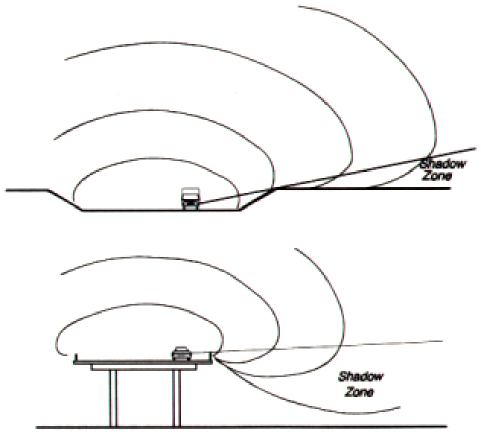
v) ***Wind*** - Standard calculations of average noise levels (CRTN) allow for a light breeze blowing from the road towards the reception point. In most locations wind direction varies considerably and it is usually not necessary to take the prevailing wind into account in assessing average noise levels.

Screening and Reflection

2.5 Noise tends to be diffracted around obstacles, but its intensity is reduced in the “shadow”. Examples of screened propagation are illustrated here. The basis of calculations used in assessing noise impacts and designing environmental barriers is further explained in chapter 3. It should be noted that discontinous visual barriers such as vegetation or anti-dazzle screens have very little effect on noise levels.



Screening by Buildings



Screening by Cutting or Elevated Structure

2.6 Noise can be reflected off large flat surfaces such as building facades, retaining walls and acoustic screens. This can increase the noise level in some areas. The benefits of screening may also be reduced by multiple reflections and reverberation if there are reflecting surfaces on both sides of a road. This case is illustrated on page 4/2.

3.0 NOISE CALCULATIONS

Prediction Methods

3.1 The approved method for assessing road traffic noise in England and Wales is set out in “Calculation of Road Traffic Noise 1988” (CRTN). This provides charts and formulae which allow the noise generated by a specified traffic flow to be estimated and also defines the criteria to determine entitlement under the Noise Insulation Regulations. For Scotland, a Memorandum on the Noise Insulation (Scotland) Regulations 1975 gives the approved method for assessing entitlement to noise insulation. This contains similar calculations to CRTN, except for the correction allowing for alternative forms of road surface. It also provides a nomogram for assessing the most effective height and location for a noise barrier.

3.2 In calculations, the road is modelled by a series of segments which can be treated as line sources of noise. A basic noise level generated by the traffic on each segment is calculated from the flow, average speed and proportion of HGVs. Corrections are applied for the effects of gradients and road surface texture. The noise levels at which properties are then calculated by summing the contributions from each segment, suitably reduced by the effects of distance, soft ground and screening and increased by reflections where appropriate.

Porous Surfacing

3.3 A porous road surface reduces both the amount of noise generated by tyres and the energy of sound waves as they spread across it. CRTN permits a reduction of 3.5 dB(A) in the basic noise level calculated from the traffic flow. This may be helpful in reducing noise over a wide area provided conditions are suitable and its use may be justified where the benefits outweigh the additional costs of construction and maintenance.

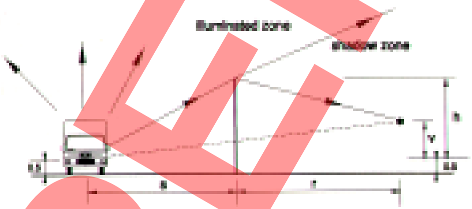
3.4 Advice on the specification and use of porous asphalt is given in HD27: Pavement Construction Methods (DMRB 7.2.4). However, where it is proposed to use porous asphalt in combination with environmental barriers, acoustic interactions between them may need to be considered and advice should be sought from the Overseeing Organisation.

Noise Propagation

3.5 Average noise levels predicted by CRTN make allowance for light wind blowing from the road towards the reception point. Chart 7 shows the effect of distance and Chart 8 allows for the attenuation of noise as it spreads across “soft” ground cover such as grassland. Soft ground absorption is very sensitive to the height of propagation above the ground. An obstacle such as a barrier obstructs noise which would have been attenuated had it spread across soft ground. The noise which is diffracted at the top of the barrier travels more freely through the air. The net benefit of a barrier can thus be less than expected.

Screening by Barriers

3.6 A barrier creates a "shadow zone" behind it, reducing the energy of the sound waves in a comparable way to a breakwater protecting a harbour. Because of the diffraction of sound by the edge of a barrier, the benefits decrease as the point of reception moves further away from the barrier. CRTN Chart 9 relates the reduction in noise level behind the barrier to the difference in distance traversed by the sound waves following the unobstructed and the diffracted paths as illustrated below.



Path Difference

3.7 The path difference is affected by the distance of the source and the receiver relative to the height of the barrier, and to the relative elevation of the receiver. CRTN assumes the source of traffic noise is 0.5m above the carriageway, but if heights are measured relative to the source, the path difference is given by:

$$\boldsymbol{\delta} = \sqrt{[s^2 + h^2]} + \sqrt{[(h - v)^2 + r^2]} - \sqrt{[(s + r)^2 + v^2]}$$

where s is the distance between the source and the barrier, h is the height of the barrier above the source, r is the distance of the reception point behind the barrier and v its elevation relative to the source. It can be seen that increasing h increases **δ**, while increasing any of the other factors s, r or v reduces **δ**.

Variation of Path Difference with Barrier Position and Height

3.8 It can be shown that the change in path difference caused by a small displacement **Δ**x of a barrier away from the source towards the receiver is

$$\Delta A_x = \frac{\Delta x}{\sqrt{(1 + \boldsymbol{a}^2)}} - \frac{\Delta x}{\sqrt{(1 + \boldsymbol{\beta}^2)}} \qquad \text{where } \boldsymbol{a} = \frac{h}{s} \text{ and } \boldsymbol{\beta} = \frac{(h-v)}{r}$$

The increase in path difference caused by a small change in height **Δ**h is correspondingly

$$\Delta A_h = \frac{\boldsymbol{a}.\Delta h}{\sqrt{(1 + \boldsymbol{a}^2)}} + \frac{\boldsymbol{\beta}.\Delta h}{\sqrt{(1 + \boldsymbol{\beta}^2)}}$$

These expressions may by useful to determine the amount by which the height of a barrier needs to be adjusted to counteract the effect on performance of a small change in its location.

3.9 Diffraction also reduces the energy of sound to a degree in the "illuminated zone" - this is indicated in CRTN by a curve which rapidly tends to zero for waves which clear the barrier by a significant amount. But for grazing incidence, where the line of sight just touches the top of the barrier, the benefit is about 5dB. Diffraction also occurs at the ends of a barrier. CRTN allows for the effect of finite length as a reduction of the barrier effect by the angle of view (CRTN, Chart 10). See also advice in paragraph 4.10 on the length of barrier needed to avoid significant leakage of noise around the ends.

Noise Reflections

3.10 A barrier which protects properties on one side of a road can also reflect noise back across it, increasing noise levels on the opposite side. If the barrier is imagined as a mirror, the reflected noise appears to come from an image source on the far side. CRTN indicates that the effect of this reflected noise may increase noise levels at protected properties by up to 1.5 dB(A). But the effect decreases as the distance across the road increases relative to the distance between the source and the receiver. If vertical barriers or retaining walls are relatively tall and close together, reflections can increase noise levels in the shadow zone significantly. Inclining reflecting surfaces away from the source by 10 ° from the vertical will usually prevent the noise reflected by the distant barrier being diffracted into the shadow zone by the nearer barrier.

3.11 Reverberation between reflective barriers on opposite sides of a road reduces their screening effect. There is also the possibility of reverberation between high sided vehicles and barriers which are placed close to the carriageway. CRTN provides a method of calculating the loss of screening caused by reflections from both vertical and inclined barriers.

3.12 However, if noise is reflected upwards, there is a possibility that atmospheric effects will cause it to be redirected over longer distances and increase noise levels at distant points of reception. Consequently, the use of noise absorbent facing materials should be considered for deep retained cuts and very tall dual barriers where reverberation could cause such problems.

3.13 Several organisations have developed computer programs to carry out the detailed CRTN calculations needed to assess eligibility of properties for noise insulation. It should be noted that the method was calibrated to provide sufficient accuracy within 300 metres of a road. It may be used in order to justify discretionary treatment to properties somewhat outside this corridor, but its accuracy in predicting noise levels at much larger distances might be questioned. A simplified (but no more accurate) method for estimating noise at large distances is described in TRL report SR 425.

3.14 There is no allowance in CRTN for absorbent surfaces on barriers. But an estimate of the benefit may be obtained by carrying out the noise calculations with and without a reflection correction. This will slightly overestimate the potential benefit of absorbent surfaces as their overall performance will fall somewhat short of perfection, depending on the basic absorptive material performance and on the proportion of reflective material used in the barrier construction.

Wide Carriageways

3.15 CRTN indicates that the opposing traffic flows should be modelled independently in the case of dual carriageways with a central reserve wider than 5 metres or where there is a difference in level between the carriageways of greater than 1 metre. It may be prudent to examine the effect of using separate noise sources when considering the effectiveness of barriers adjacent to widened motorways where the distance between opposing slow lanes has a significant effect on the calculation of path difference. The basic noise level will be reduced by moving half of the traffic further away. But this benefit will be offset by the relative loss of effectiveness of the barrier at screening the more distant source.

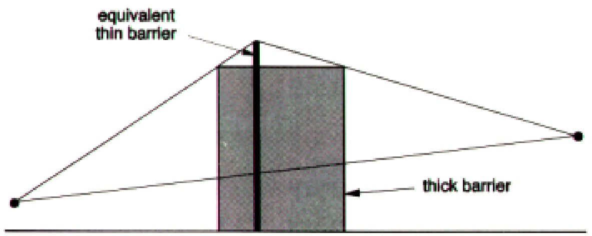
Dual Source Modelling

4.0 BARRIER EFFICIENCY

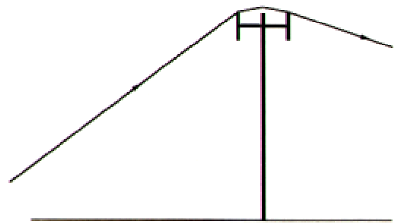
4.1 CRTN assumes that a barrier has insignificant thickness, but diffraction over the top edge of a barrier is affected by its cross section. It may be appropriate to use an effective height for barriers which are very wide such as buildings. This can be estimated from the geometry as shown opposite. Barriers with cross sections having corners and curved shapes are not as effective at reducing noise as those with sharp edges. Wedge shapes with internal angles greater than 90 ° and rounded shapes are least effective. It may therefore be advantageous to use an acoustic screen on the top of a mound, to increase its effectiveness.

4.2 The effectiveness of a thin barrier of given height may be increased by bringing the diffracting edge nearer to the source of noise - thus increasing the path difference. Where a tall barrier is placed near to the carriageway, tilting the upper section towards the source can provide additional benefit. Increasing the number of diffracting edges can also improve attenuation considerably.

4.3 In most cases it will be relatively expensive to provide more than one barrier, but the number of diffracting edges may be increased by attaching short side panels to a barrier so that there are several edges at the same level. Full scale trials with a triple edged barrier have shown benefits of as much as 3 dB(A) in certain circumstances. Enquiries should be made of the Overseeing Organisation to ascertain whether these benefits would be achievable in particular cases. Such modifications may increase the wind loading on the barrier slightly, but probably by less than would occur if the barrier was made taller to achieve the same acoustic benefit.



Representation of a thick barrier



Multiple Edged Barrier

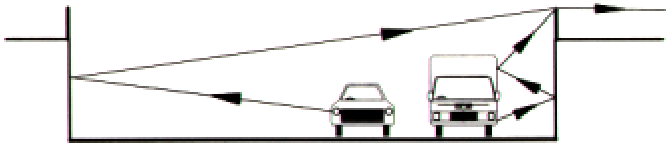
4.4 Other modifications to improve the efficiency of barriers have been proposed. The benefits of some commercially available systems appear to be marginal; acoustically more effective modifications, such as horizontal “caps” have not been developed as fully engineered solutions. The effect of a cap on wind loading is unknown and consideration of the effect of water and snow on the exposed surface would also need to be investigated.

4.5 Barriers do not necessarily have to be of constant height - it may be cost effective to increase the height in the vicinity of isolated properties and to reduce it between them. Some computer programs can optimise the profile of a barrier to screen such properties efficiently. Varying the height of the barrier may also help to alleviate the monotonous appearance of long lengths of barrier, but the calculation of wind loading is more complicated. The height of a barrier can often be reduced at each end if acoustic efficiency is considered. This also reduces problems caused by end effects on wind turbulence and may lessen the visual impact of the barrier as well.

4.6 The efficiency of all types of barrier appears to be reduced when the ground surface on either side is sound absorbent. For example, a simple thin 3 metre high barrier should reduce noise at a distance of 100 metres behind it by about 13 dB(A) when the intervening ground is hard, but if the ground is level and absorbing, the net benefit may be halved. The loss of effectiveness increases with distance, so while the benefit of the barrier at 100 metres is still significant when the ground is absorbing, beyond about 300 metres the net effect of a barrier is likely to be negligible unless the sound travels across valleys or over hard surfaces.

Reflection and Absorption

4.7 Noise reflections can reduce the effectiveness of tall barriers sited close to the traffic, as there may be some reverberation between the traffic stream and the barrier. Reverberation may also amplify the noise emitted by vehicles in tunnels. Noise absorbent materials can be used very effectively to control reflected noise and may be especially useful in eliminating reverberation within the portals and between flanking walls of tunnels. The specification of noise absorbing materials is discussed in chapter 7.



Multiple reflections

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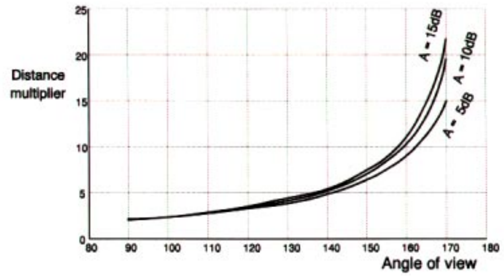
4.8 Where there are barriers on both sides of a road, it may not be always necessary to use absorbing materials, provided the noise reflected from one barrier passes well above the other so that it is not diffracted down into the shadow zone. Barriers may be tilted slightly away from the vertical in order to achieve this affect (see section 3.11), but this solution may increase costs and cause aesthetic problems. CRTN indicates that cutting slopes and earth mounds also reduce the effect of reflections considerably.

4.9 Proprietary designs of barrier which present a heavily faceted surface on the road user side are claimed to disperse traffic noise and prevent reverberation. This is because noise is reflected in different directions and does not form a coherent image. There is as yet little experience of how effective this type of barrier is in practice. Advice should be sought from the Overseeing Organisation if their use is being considered in a particular case.

Length of Barrier

4.10 A rule of thumb has been that the length of noise barrier provided needs to be 20 times the distance between the road and property being protected. This may be unduly conservative where the road only subtends a small angle at the property as shown on the graph opposite. The length of barrier needed also depends on the intended noise reduction. For properties on the inside of a curve, a wider angle of view needs to be screened.



The vertical axis gives the factor by which the distance from the road needs to be multiplied to ensure that the noise received from around the ends of the barrier will be insignificant, for a range of segment angles less than 180°. For angles greater than 180°, two segments will need to be considered. A is the barrier correction shown on CRTN Chart 9.

Relative Efficiency of Various Barrier Cross-sections

4.11 Mathematical and scale models have indicated that the efficiency of a plain vertical screen as a barrier can be increased by modifying the diffracting edge. Full scale measurements have confirmed that noise levels behind it might be reduced by as much as 3.5 dB(A) in favourable circumstances. The most effective shape which did not create obvious engineering difficulties was the addition of 0.5m deep vertical panels offset on either side of the top edge, so that the incident sound passed over three parallel edges. This form of improved barrier provided an average of 2.5 dB(A) reduction, and trials at a number of locations have been undertaken to verify its effectiveness under different conditions.

4.12 Mathematical modelling has also been used to examine the relative efficiency of various solid cross sections, typical of earth retaining structures and mounds. Broadly, the modelling has indicated that sound is diffracted to a greater extent by obtuse angles and curved surfaces than sharp edges. This suggests that for the same height, an earth mound would be less effective than a thin acoustic screen .It might therefore be beneficial to provide a short acoustic screen on top of an earth mound to obtain maximum benefit, but the noise absorbent effect of the vegetated slopes may be diminished.

4.13 There are indications from mathematical modelling that sound energy is attenuated as it passes over horizontal areas of absorbing material on barriers, but the presence of such material on vertical surfaces had relatively little effect on performance. While it is known that vegetation helps to increase the absorption of “soft” ground over some distance, it is possible that planting on an earth mound might have a beneficial effect on its overall acoustic performance. Current research may indicate whether this effect is significant.

Efficiency at Different Frequencies

4.14 Traffic noise contains a broad spectrum of frequencies which are diffracted by a barrier more and less strongly according to their wavelength. The wavelengths of the lower frequencies are comparable to the scale of a barrier. For example at 200 Hz the wavelength is about 1.7 metres. These wavelengths are less strongly diffracted by a barrier than those with higher frequencies and so the spectrum of noise diffracted into the shadow zone may be biased towards lower frequencies. For simplicity, CRTN indicates the overall reduction in the level of noise behind a barrier, based on the assumption that the maximum intensity of traffic noise will be in the mid range of frequencies around 1000 Hertz.

5. EARTH MOUNDS AND RETAINING STRUCTURES

5.1 If a road construction contract would otherwise have surplus material, landscaped mounds can be provided at negligible cost; at the same time the inevitable impact on the surrounding area of hauling the surplus material off site can be avoided. The design of mounds should be compatible with the local landscape character and topography. The surplus material may only be suitable for gentle slopes and large quantities may be needed to achieve a significant amount of screening . Long roadside slopes are visually attractive but acoustically inefficient and increase landtake. On the protected side, gentle slopes may serve other design objectives such as returning landscaped areas to agriculture.

5.2 Where insufficient land is available to construct earth mounds high enough with natural slopes, geotextile reinforcement may be used to steepen slopes, but at the risk of being visually incompatible. Alternatively, retaining methods such as reinforced and anchored earth construction, gabions, concrete or timber cribs, and other proprietary support systems may be used to support the traffic face with advantage. In some cases, it may be considered acceptable to use an earth retention system for the protected side of a barrier as well, but the adverse effect on vegetation of relatively rapid moisture loss from a reduced soul mass should be taken into account.

5.3 Advice on the design of reinforced slopes is contained in HA 68: Design Methods for Reinforcement of Highway Slopes by Reinforced Soil and Soil Nailing Techniques (DMRB 4.1.4). Overseeing Organisations' requirements for gabions are contained in the Specification (MCHW 1/626). Advice should be sought from the Overseeing Organisation on design standards for crib walls. There are as yet no standards applicable to vegetated barriers and further advice should be sought from the Overseeing Organisation on the fitness for purpose and cost effectiveness of particular systems.

5.4 Retained slopes steeper than 70° and with vertical faces more than 1.5 metres high are classed as highway structures and designs must be approved by the Technical Approval Authority. Overseeing Organisations' requirements for checking designs and drawings submitted for approval are contained in BD 2: Technical Approval of Highway Structures - Part 1: General Procedures (DMRB 1.1).

5.5 Where acoustic screens are constructed on top of earth mounds the fill needs to be adequately compacted to support the post foundations. In poor quality fill, a pad foundation or ground beam may provide a solution. Piling into sound underlying material may be feasible for a screen on a low embankment. In some cases, it may be appropriate to extend an earth retaining structure on the road user side as an environmental barrier.

5.6 Designers should have regard to potential hazards posed by low earth mounds and earth retaining structures near to the edge of carriageway - see also 4.19 in HA 65: Design Guide for Environmental Barriers (DMRB 10.5.1).

6.0 ACOUSTIC SCREEN DESIGN

General

6.1 An acoustic screen is an environmental barrier in the form of relatively thin panels. In most cases these span between supports which resist horizontal overturning forces. For the purposes of technical approval, acoustic screens up to 3 metres high may be treated as Category 0 structures; those taller than 3 metres should be treated as Category 1. The major force to be resisted by an exposed surface is that caused by wind. When the acoustic screen is relatively close to the carriageway, other forces may need to be considered, such as aerodynamic forces caused by passing vehicles, the possibility of impact by errant vehicles and the effect of snow being thrown against the face by clearing equipment. These additional forces are to be considered as acting independently of each other and of the design wind loading. In some circumstances, vertical forces may also increase overturning moments.

Wind loading

6.2 The action of wind on an acoustic screen depends on its exposure relative to the surrounding topography. The basic wind speed appropriate to the area varies with latitude and longitude, but is significantly modified by local features. Large scale features such as hills accelerate wind speeds; smaller scale features such as housing causes surface roughness which reduces speeds in the boundary layer within about 20 metres of the ground. The design method in this document assumes that acoustic screens are erected on the ground or on embankments within this boundary layer. The Overseeing Organisations' requirements for design loads applying to environmental barriers on elevated structures are contained in BD 37 Loads for Highway Bridges (DMRB 1.3).

6.3 Wind calculations are based on the assumption that the annual probability of the basic wind speeds shown in Fig A2 being exceeded is 0.02 (1 in 50 year return period). It should be noted that these are characteristic speeds at 10 metres above mean sea level. The effect of elevation is taken into account as one of the factors which affect the reference wind speed for the site. The wind pressure is then calculated

form the reference wind speed $\overline{V}_{ref}$ as:

$$q = 0.613\overline{V}^2_{ref} \quad (N/m^2)$$

The basic wind force acting at the mid height of a panel of area A is:

$$P_{bas} = C_p . C_R . A ._q$$

where the pressure coefficient C_P is 1.2 in the middle of a long wall; the pressure increases near the exposed ends of a wall and is defined in three zones relative to its height H as:

within 0.3H	- C_P = 3.41
between 0.3H and 2H	- C_P = 2.13
between 2H and 4H	- C_P = 1.66

the structure response factor C_R is 1.16 for a fairly stiff plain cantilever wall.

6.4 The coefficient of pressure C_p is further modified at the ends if the screen or wall has a return corner. Inclining the barrier to the vertical also affects C_p. The structure factor C_R is increased if the structure responds dynamically - this is not generally the case for steel or concrete supports, but the loss of stiffness at free ends may need to be considered. Multiple edges at the top of the screen to increase its acoustic efficiency tend to increase wind drag to some extent, but the extra drag force is very dependent on how the air flow is affected.

6.5 In calculating the reference wind speed, the altitude of the site above see level and relative to the surrounding countryside are taken into account separately. The roughness of the general area for about 5 km either side of the site also affects the wind approaching from each direction. Proximity to a large body of water tends to increase wind speeds. The probability of gusts in excess of the basic wind speed depends on the scale of the element under consideration. A five second gust acting on the structure should be used for the purpose of designing supports, but a one second gust is appropriate for checking the strength and stiffness of panels between supports.

6.6 A method for estimating wind loading on acoustic screens is provided in Appendix A, based on the following assumptions:

i) the screen is fully resistant to wind pressure and is not inclined at more than 15° from the vertical;

ii) structure does not act dynamically and the top edge is simple;

iii) height is constant along the length, except for tapers at the ends, for which a correction can be applied;

iv) changes of direction in plan limited to less than 10° between adjacent panels, or radius of curvature greater than 30 metres.

Advice should be sought from the Overseeing Organisation in cases where any of the above conditions are not met.

6.7 Wind loads on acoustic screens increase rapidly with their height and simple cantilever posts may become unreasonably heavy. It may be desirable to use space frames or buttresses to restrain high barriers against wind. Subject to the view of the Overseeing Organisation, such structures should be treated as category 2 for the purpose of technical approval. The use of transparent panels to mitigate the visual impact of very high barriers is recommended, but these may place constraints on structural design.

Aerodynamic Loading

6.8 If large vehicles pass at high speed close to environmental barriers, the dynamic pressure caused by the dynamic pressure caused by the displaced air can be significant. As an example, a pressure reversal of ± 0.5 kN/m^2 may be caused by vehicles passing at 100 km/hr within 3 m of a free standing barrier. Much larger pressure changes may be experienced in the confined vicinity of tunnels and can be an important consideration in the design of fixings for noise absorbent panels attached to walls.

Vehicle Impact

6.9 An acoustic screen closer than 4.5 m from the carriageway should be protected from the impact of errant vehicles by a vehicle restraint system. Where the clearance is less than 1.5 m, the environmental barrier should be combined with a safety barrier. An approved design for a combined safety barrier and environmental barrier is shown in drawing EOB 38 of the Highway Construction Details (MCHW 3). Alternative designs will be acceptable provided they been verified by full scale impact testing.

6.10 Where acoustic screens are required to continue across structures, these should only be combined with a parapet if the assembly has been designed to accept the consequences of vehicle impact. The Overseeing Organisations' requirements for vehicle parapets are to be found in BD 52/93 (DMRB 2.3.3). Materials and finishes for attached environmental barriers need to allow for the considerable distortions of metal parapets under impact. It is desirable for the adequacy of such combinations to have been demonstrated by full scale impact tests. Limited testing of combinations carried out so far have indicated that metallic sheeting attached to the traffic face of the parapet rails is liable to become detached under impact. Further information on suitable combinations should be sought from the Overseeing Organisation. A free standing environmental barrier which would be vulnerable to impact on a structure should be located, with adequate clearance for deflection, behind a vehicle parapet.

Supports

6.11 Steel Universal Beam sections have been found to provide a convenient means of supporting acoustic screen panels. Where panels are simply supported between posts and do not apply significant bending moments or axial forces on them , sections may be selected to resist wind loading using the charts in Appendix B. If a barrier is inclined, or eccentrically loaded by attachments modifying the top edge, an appropriate allowance should be made for the increased moment at the base of the post.

6.12 Other materials may be used provided they are cost effective and fit for the purpose of supporting an environmental barrier. When considering ultimate load conditions, the following partial load factors are appropriate;

dead loads	- steel	1.05
	- concrete	1.15
wind loads		1.40

6.13 Serviceability should be taken into consideration, including the maximum allowable elastic deflection of the top of the posts. Higher strength materials if used will not necessarily increase the stiffness of a given cross section. Where posts of varying height are used, the effect of differential deflections of adjacent posts on the panels may need to be considered.

Foundation Design

6.14 Foundation stability can be affected by variations in soil properties, the degree of ground compaction, the proximity to service trenches or embankment edges, the degree of ground or surface water; frost susceptibility, ground loading and other ground conditions. Mass concrete foundations are adequate for relatively lightly loaded posts. Appendix C provides a table of safe working moments at mid depth of an economic range of mass concrete foundations with square or circular cross section. It should be noted that the resistance of circular foundations is considerably less than square ones of comparable size, but the latter are not so easily excavated.

6.15 The area of the foundation must be sufficient to provide cover for the post, which should be embedded to at least 75% of the depth of the foundation. Formulae provided in Appendix C allow for loss of lateral resistance at the edge of embankments and for foundations to be depended to compensate. Care should be exercised in extrapolating these formulae to predict moments of resistance for foundations larger that those tested.

6.16 Foundations for posts to which safety barrier is attached in accordance with drawing EOB 38 should be designed to resist the collapse load of the hexagonal spacers (44 kN at 0.67m above ground level). In checking such limit state conditions, a factor of 1.5 may be applied to safe working moments.

6.17 Mini-piles, ground beams, or pad foundations may well be more economical for tall barriers and long spans. Cantilever post supports may be bolted to holding down brackets cast into foundations or into the top of retaining structures designed to withstand the additional overturning moments. Base fixings should be well protected against corrosion or electrolytic action.

6.18 Pad foundations should be designed on the basis of drained shear strength of the fill material, unless the foundation is below the water table. Sufficient resistance to overturning should be provided so that, in resisting the design moment, the base rotation is not greater than 0.5°.

6.19 Where a foundation block is deep relative to its width, the normal assumption that rotation tends to occur about the leading edge at the base may not be valid. Friction on the sides may play a significant part and active pressure zones may develop on front and rear faces. Trial solutions may be needed with the axis of rotation at different distances above the base in order to determine the minimum moment of resistance. In the extreme case, a post type foundation is assumed to rotate about its mid-depth.

Dynamic Loads from Snow Clearance

6.20 In areas where snow of some depth is cleared by equipment which ejects a stream of snow some distance to the side of the road, the impact of this on an acoustic screen can be considerable. Table 6.1 provides a method of calculating an equivalent horizontal load appropriate to the speed and relative position of the equipment. The load given in the table is assumed to be distributed over a square patch 4 m^2 in area, with its centre 1.5 m above the road.

Table 6.1

	Load (kN) on 2m x 2m patch				
Distance from edge of carriageway (metres)	<4	5	6	7	8
Speed 50 km/hr - load	10	7.5	5	0	0
Speed 60 km/hr - load	15	12.5	10	7.5	5

Vertical Loads

6.21 Infill panels may need to be checked for vertical loads such as self weight. Where sound absorbent materials are to be used, the self weight should include an appropriate allowance for absorbed water. If all or part of the whole barrier is inclined from the vertical, a component of self weight may be transmitted to the supporting posts. Snow loading and the vertical component of wind loading may also need to be considered for inclined or horizontal elements.

7.0 BARRIER MATERIALS

7.1 A service life of 40 years is desirable, with no major maintenance required for 20 years. It is therefore inappropriate for environmental barriers to meet requirements of BS 5400 for highway structures based on a life of 120 years. The Overseeing Organisations' requirements for the materials commonly used for environmental barriers are contained in the Specification for Highway Works (MCHW 1) - 300 series. The Specification also indicates appropriate test methods for assessing acoustic performance (absorbency and insulation). The Overseeing Organisations' requirements for non-structural timber in environmental barriers are contained in Highway Construction Details (MCHW 3) - drawings H37 and H38.

Timber
Specification for Highway Works (MCHW 1) clauses 304, 310, 311

7.2 Timber is a common fencing material, but its maximum height is restricted by structural requirements (see BS 5268 Part 2 "Structural Use of Timber"). It is a requirement of the specification that timber screens remain serviceable for 40 years and require no maintenance for 20 years. Factory treatments can provide this life but on site modifications may significantly reduce the durability of timber. Timber panelling is versatile in that it can be readily modelled around existing ground features such as over the root systems of retained trees, thus ensuring the continuity of noise barriers. Noise absorbent timber barriers have been developed incorporating cavities and dispersing elements behind timber battens, which can be arranged in various patterns.

Brick Walls
Specification for Highway Works (MCHW 1) Series 2400.

7.3 The height to which unreinforced brick and masonry barriers can be built is limited by structural considerations, but their height can be increased considerably with reinforcement. Reference should be made to BS 5628 "Code of Practice for Use of Masonry" Part 2. Brick and masonry need little maintenance apart from occasional cleaning to rectify uneven discolouration from pollutants and rainwash. In general, masonry walls are assumed to be acoustically reflecting. But absorbent bricks and blocks are available which have a perforated surface and resonant cavities filled with fibrous material.

Concrete
Specification for Highway Works (MCHW 1) Series 1700 and 2000.

7.4 Concrete is used in various ways in the construction of environmental barriers. Structural aspects are covered in BS 8110 Part 1 "Structural Use of Concrete". Precast planks slotted into H shaped uprights provide a rapid means of construction and can be easily repaired. One form of proprietary concrete barrier is constructed from linked precast panels set at varying angles so as to obviate the need for separate post supports. Concrete barriers benefit from low maintenance, but prefabricated barriers are relatively expensive. On a highway contract involving other structures it may be economical to use in-situ concrete barriers. Tall barriers may be realised using retaining wall design methods. Concrete barriers are usually sufficiently robust to withstand vehicle impact damage, but a safety barrier may be needed to prevent excessive damage to vehicles if the surface finish is heavily textured.

Alternative Materials

7.5 A variety of materials can be used in barriers including glass, acrylic and other synthetic materials, hollow sheet metal box sections, porous concrete and ceramics, none of which are covered by the Specification. Vegetated barrier systems, including living barriers of willow or similar woody plants may also be aesthetically attractive. Approval to use any of the above or other materials not covered by the Specification should be sought from the Overseeing Organisation on the grounds of their fitness for purpose and cost effectiveness.

Metal

7.6 Metal noise barriers can be painted or coated in a wide range of colours. Steel is commonly used for supports - the Overseeing Organisations' requirements for protective coating of steel are contained in the Specification (MCHW 1). Weathering steel may be used as an alternative in some situation, however, it has been shown to be vulnerable to attack by deicing salts if used within 3 metres of the carriageway. Sheet metal can be formed into lightweight hollow sections, which may contain fibreboard or mineral wool absorbent materials. A number of profiled barrier systems, comprising horizontal panels spanning between galvanised steel posts, are commercially available. The metal sheeting on one side may be perforated to allow sound to interact with absorbent material within, and the corrugated profile provides structural rigidity. Aluminium is often used in proprietary systems because of its strength to weight; large panels may be easily erected with fewer supports (up to 5 metre spans). Structural advice is contained in BS 5950 Parts 1 and 5, "Structural Use of Steelwork in Building" and BS 8118 "Structural Use of Aluminium".

Transparent Materials

7.7 Transparent materials allow light to properties or areas which would otherwise be placed in the shadow of the barriers. At the top of a barrier, transparency will reduce the visual impact of tall barriers and tinted material may enhance the appearance. "Windows" will allow road users to orientate themselves by providing views of the surrounding area. But designers should be aware of the oblique and narrow angle of view from the driving position and of the obscuring effect of supporting structures. Potential problems with birds flying into transparent barriers may be reduced by either using tinted material or by superimposing a pattern of thin opaque stripes.

7.8 Transparent materials are noise reflecting and their use might therefore be restricted where reverberation would cause problems. Transparent panels may need to be protected from impact by errant vehicles. Consideration should also be given to the use of laminates, toughened glass, embedded mesh or other systems in order to control the spread of fragments in the event of damage. If transparent barriers offered by suppliers comply with the German design standard ZTV Lsw-88, they will have passed a test which limits the size and shape of fragments produced when a sample is shattered.

7.9 Some transparent panels can become semi-opaque relatively quickly, either though superficial or material deterioration. It may be appropriate to make some allowance for this in specifiying requirements. Salt and grime can obscure sections near to the road surface. Grit can abrade surfaces - plastics are more vulnerable to this than glass. Maintenance requirements and expected life need to be considered when the use of transparent materials is proposed.

7.10 Vandalism may also be a material factor. Laminated safety glass has the advantage that fly posters can be removed easily and that it also tends not to accumulate static electricity which would attract dirt. Polycarbonate may become opalescent over time as it can absorb water, especially at exposed edges.

Plastics

7.11 Apart from their use in transparent panels, plastics have also been used in absorbent panels and for supporting planted systems. Plastics may be coloured as required, but colour may bleach in strong sunlight. Susceptibility to bleaching can be tested in a weatherometer. Plastics are prone to damage from fire and vandalism and some, eg polyethylene, become brittle after prolonged exposure to sunlight. Advice on the use of structural plastics may be sought from the Overseeing Organisation on grounds of fitness for purpose and cost effectiveness.

Recycled materials

7.12 An increasing number of products are available which claim to be “environmentally friendly” by incorporating various recycled materials in their manufacture. Examples are: recycled plastics in supporting structures, waste materials from industrial processes in absorbers, sections of old tyres as planters domestic waste transformed into compost. There may be limitations in the suitability of recycled products. The use of mixed scrap and surplus may affect choice of colour; eliminating contamination and reprocessing reclaimed materials will add to costs. It is important to establish whether the recycled product is comparable with new material and to ensure it will not tend to degrade more quickly.

Airborne Sound Insulation

7.13 A generally applicable acoustic requirement for a barrier material is to limit the component of sound passing through it to 10dB(A) less than the predicted noise level due to sound diffracted over the barrier. For a thin sheet of solid material, this is achieved by ensuring that it is sufficiently massive to resist the sound vibration. This is not a governing criterion for concrete or masonry, but can be important for timber and for glazing panels.

The thickness of material (in mm) required can be calculated from:

$$t = \frac{3000}{w} \text{ Antilog}_{10} [(A-10)/14]$$

where A = barrier potential (CRTN88 Chart 9)
and w = density (kg/m^3).

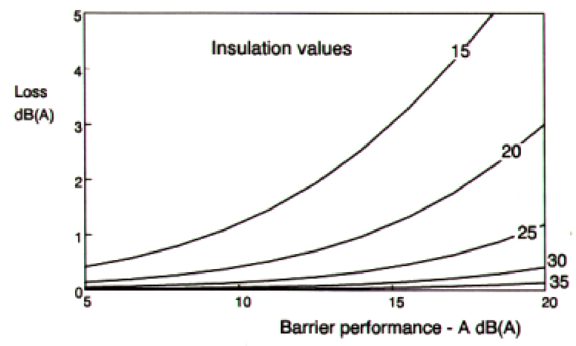
Densities of materials commonly used in sheets are as follows:

Glass	-	1700
Acrylic	-	1000
Timber	-	650

It should be noted that while the thickness needed is inversely proportional to the density for a given attenuation A, it increases exponentially with increases in A. This may be an important consideration when designing “windows” in very tall barriers.

7.14 Where an acoustic screen is assembled by butting or overlapping components, it is important that the joints are well sealed to prevent leakage. This is particularly the case where the barrier is tall or on an embankment so that the noise reduction in the shadow zone is large. The diagram opposite shows how the reduction of insulation affects overall performance As an indication, it is common for timber barriers to be manufactured from 19mm thick material. This would provide a sound reduction index of 20 dB(A) if joints are tight - as indicated by the mass law, this is quite sufficient for barriers designed to provide an attenuation of 10 dB(A).

7.15 The Overseeing Organisations' requirements for the effectiveness of composite forms of acoustic screen are contained in Clause 310.18 of the Specification for Highway Works (MCHW 1). This requires a sample to be tested in accordance with the British Standard for sound insulation of partitions in buildings. Direct measurements of sound levels are recorded at different frequencies in a room one side of the partition when a given source of random noise is in a similar room on the other. An overall rating of performance may be quote for some products. This is obtained by combining the measurements at different frequencies using a standard spectrum to weight the contributions at different frequencies. The method of calculation and weighting factors appropriate to a typical (urban) traffic noise spectrum is given in Chapter 10. The single number rating of performance has been adopted in the draft European standard, using the reference traffic noise frequency spectrum given in Table 10.1. It is necessary for the overall insulation performance to be at last 10 dB better than the barrier is designed to achieve in the shadow zone, but good performance in the mid frequency range (500 - 1500 Hz) is especially important.



Loss of Performance through Leakage

The curves indicate that higher insulation values permit high performance barriers to be constructed - 20 dB(A) is achieved with a path difference of 3 metres.

Sound Absorbent Materials

7.16 The Overseeing Organisations' requirements for the acoustic performance of absorbent materials are specified by the Engineer in accordance with clause 310.16 of the Specification for Highway Works (MCHW 1). Values for the absorbency coefficients in third octave frequency bands between 100 Hertz (cycles per second) and 5000 Hertz are to be supplied in Appendix 3/3 of the contract documents. Materials will have been tested in accordance with the procedures laid down in UK or continental standards. Products tested in accordance with other national standards may be considered for equivalence in accordance with clauses 104 and 105 of the Specification.

7.17 Tests in a reverberation chamber (BS 3638 or similar) will produce a frequency response curve. It is desirable for absorption coefficients to be better than 0.8 at frequencies which are significant in the traffic noise spectrum. In general, the peak traffic noise frequencies lie between 500 - 1500 Hz (also see section 10.12). In some cases, tests will indicate absorption coefficients larger than 1. Although theoretically impossible, this can occur with highly absorbent materials where the shape of the product differs markedly from the ideal of a flat sheet. Some products are strongly tuned to prevent reverberation of low frequencies (100 - 300Hz). These re unlikely to prove useful in connection with high speed roads, but may be appropriate in urban centres where heavy vehicles will be stationery at junctions and accelerating in low gear.

7.18 Acoustic requirements should be specified for the whole structure and allowance should be made for a proportion of reflective supporting elements. An overall performance rating may be quoted for products, obtained by combining sound absorption coefficients in a similar manner to that described above for insulation performance. This approach has been adopted in the draft European standard, using the reference traffic noise frequency spectrum given in Table 10.1.

7.19 Sound absorbent material may be fixed to a backing structure such as a framework of timber or steel, or the surface of a solid wall. Sound absorbent panels are often based on noise absorbent products developed for use in industrial environments and may be available in a range of colours. Architectural advice should be sought on the shape, colour and surface texture which might be appropriate.

7.20 If placed in close proximity to the carriageway, absorbent panels will usually need to be protected with a safety barrier. The case for using absorbent barriers in specific situations must be argued on the basis of their cost effectiveness, but where a high quality finish is already required, the additional cost of similar absorbent panels may not be excessive. The geometry of sound reflections may also permit the use of the absorbent material to be limited to that part of the surface where it will be most effective. Materials placed close to the carriageway can quickly become dirty and clogged with pollutants.

8.0 MAINTENANCE CONSIDERATIONS

Design Life

8.1 Environmental barriers should be designed so that they require minimal maintenance other than cleaning or repair of damage for at least 20 years. In situ concrete or masonry walls require little or no maintenance during the desirable service life of 40 years, but transparent sections need frequent cleaning and might well need replacing after 10 or 15 years. Careful design can prevent the need for on-site modifications or other damage during construction which might considerably reduce the life of barriers. Plastics should incorporate resistance to the effects of ultra-violet light. Surfaces and joints should not include dirt or moisture traps or other details liable to cause rust staining. The effects of weathering on colour and of rainwash on accumulated surface grime should also be considered.

8.2 It may be necessary to provide access from the protected side for maintenance purposes and where there is a right of way for pedestrians or cyclists. This may render a barrier vulnerable to vandalism and the choice of form and materials should take this factor into account. It may be appropriate for pedestrian and cycle paths to be lit; where painted surfaces are required, polyamide based finishes will enable easier removal of graffiti. It may be advisable to avoid the use of flammable materials (eg creosote treated timber, acrylics) in some areas, although lightning and fires in dry undergrowth may also need to be considered as a potential risk elsewhere. Where there is such a risk, it may be appropriate to install fire breaks to limit the spread of fire in a flammable type of barrier.

Materials and Detailing

8.3 In order to minimise the need for maintenance, attention should be paid to the selection of materials used in the construction of barriers. The quality of materials used should be appropriate to the location. For example, barriers built in relatively inaccessible locations or in areas likely to be subject to extreme weather conditions will need more durable components than those which can be more easily maintained or are in relatively sheltered positions. Care should be taken over design details in order to eliminate possible moisture traps which would encourage rot or chemical attack. Alloy and metal fittings should be carefully selected to avoid differences in electrochemical potential which would accelerate corrosion. Plants selected for use in conjunction with a barrier should generally be of hardy species which require a low level of maintenance.

Cleaning

8.4 With passage of time, barrier surfaces may become stained by contaminants such as water-splash from the road surface, airborne grime, bird droppings, honeydew or sap from overhanging trees. Concrete or masonry may not need cleaning in certain locations as the surfaces would be washed by rain water and their textured finish may control staining. Flat surfaces, however, will require regular cleaning as contamination will be more apparent and will detract from the appearance of the barrier. High pressure water jets mounted on purpose built tankers, or hand washing with brushes and low pressure water are suitable treatments.

8.5 The frequency of cleaning required will depend on the degree of contamination that occurs. Water splash contamination can be reduced by distancing the barrier from the edge of the carriageway, although this will have the drawback of reducing its efficiency in attenuating the road traffic noise. Efficient road surface drainage will also reduce splash effects by preventing puddles from forming. Bird dropping staining can be controlled by the use of designed details or chemical repellents that deter birds from perching on the barrier. Trees and other overhanging vegetation may need trimming or cutting back to prevent abrasion and marking of the barrier. Transparent barriers will need to be cleaned more frequently than other types because they will show any contamination more readily or surface treatments can be used.

8.6 Purpose-made vehicles fitted with water tanks, hoses, brushes and access platforms would reduce the cost of cleaning barriers but long lengths of barrier will be required to justify the necessary investment. In the short term, access platforms can be used to reach the far sides of barriers in order to carry out cleaning and other maintenance. Barriers erected near to the carriageway may require lane closures during maintenance; traffic management will be especially important for access to any barriers in the central reserve. Their use is not encouraged, but zero maintenance barriers (self cleaning, impact resistant) would be appropriate in this location.

Other Maintenance Tasks

8.7 In addition to cleaning, other maintenance tasks include:

a) Tightening joints and fixings after initial construction. This should take place at the end of the construction maintenance period.

b) Painting and treating of metal or timber surfaces. This requirement can be reduced by using anodised aluminium, galvanised or weathering steel, or by pressure treating timber. But colours may need to be refreshed periodically if they are an important element in the design.

c) Periodic maintenance of planting - weeding, replacement of failed plants and, if necessary, watering to secure the proper establishment of the vegetation in the initial period, followed by periodic thinning, or pruning as necessary. (Barriers composed of living material retaining earth require a more intensive management regime).

Access

8.8 The need for future maintenance should be taken into account when deciding on the form and location of a barrier. Where it will need to be inspected from time to time, screen planting should be placed with sufficient space to permit easy access. Doors or gaps should be provided at reasonable intervals to give access to either side of the barrier (see also HG 65, section 7.7). Frequent access will be needed to clean both sides of a transparent barrier - on bridges and viaducts, this might necessitate the use of specialised equipment.

9.0 BARRIER COST COMPARISONS

9.1 The cost of barrier construction depends on a variety of factors and the balance of these should be determined for each site. Table 9.1 provides general guidance on the relative order of costs for a selection of typical forms of construction at a standard height of 3 metres, indicating the specific factors relating to different systems. It should be noted that this scale only gives a broad indication of relative costs and the designer should seek detailed information when options are being evaluated.

9.2 The maintenance of environmental barriers depends on many factors. Their construction and their environment will dictate what degree of maintenance is necessary and how frequently inspection will be required to maintain the appearance and the structural and acoustic integrity. Table 9.2 compares the anticipated maintenance requirements for a range of environmental barriers. Only the order of costs are indicated because many factors can affect maintenance at different sites.

TABLE 9.1: CONSTRUCTION COST INDICATORS

	Barrier Type	Assumed features of design	Relative cost
1.	Earth Mound	- agricultural land price, landscape planting excluded - local source of fill assumed	Very Low
2.	Timber Screen	- designed in accordance with current standards	Low
3.	Concrete Screen	- precast pier, beams and panels	Fairly Low
4.	Brickwork/Masonry Wall	- standard facing brick	Moderate
5.	Plastic/planted System	- plastic building 'blocks' (planters)	Moderate
6.	Metal Panels	- plastic coated metal panels with steel supports	Moderate
7.	Absorbent Panels	- perforated (absorbent) metal panels with rockwool infill	Moderate
8.	Transparent Panels	- steel piers, etched glass panels	Fairly High
9.	Crib Wall (concrete or timber)	- proprietary system or purpose designed - high labour costs, agricultural land price	Very High

NOTE:

Piling, statutory undertakers diversions, safety fencing and accesses not included.
Costs for these items will be additional and requirements will vary for different systems.

TABLE 9.2: MAINTENANCE COST INDICATORS

	Barrier Type	Factors taken into consideration	Relative Cost
1.	Earth Mound	- grass cutting, planting maintenance	Fairly Low
2.	Timber Screen	- inspection/repair, periodic treatment	Low
3.	Concrete Screen	- inspection/repair, periodic cleaning	Very Low
4.	Brickwork Wall	- inspection/repair, periodic cleaning/repointing	Very Low
5.	Plastic/planted system	- inspection/repair, periodic cleaning, planting maintenance, irrigation	Moderate
6.	Metal Panels	- inspection/repair, repainting/treatment - tighten bolts, check earthing	Fairly Low
7.	Absorbent Panels	- inspection/repair, periodic cleaning	Fairly Low
8.	Transparent Panels	- inspection/repair, regular cleaning/treatment	Fairy High
9.	Crib Wall	- inspection/repair	Low

NOTES:

Costs of the following items not included -abnormal access, damage repair, traffic management.
Construction standards assumed to current specifications.

10. NOISE AND TRAFFIC

Definition of Noise

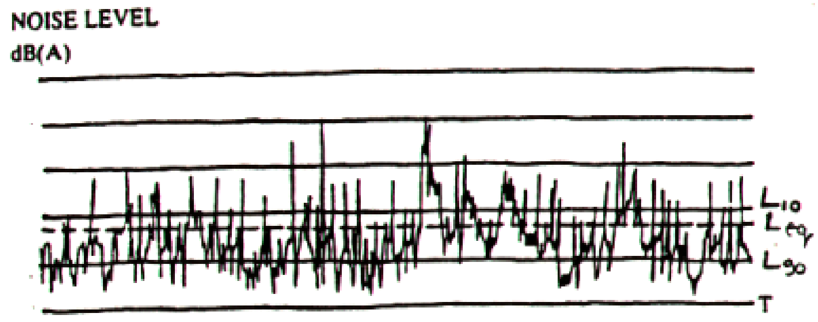
10.1 For the purposes of this document, noise is defined as the broad band random varying sound emitted by road traffic. A sound wave is propagated through the air as rapid, small fluctuations in the atmospheric pressure. The human ear can respond to these tiny pressure fluctuations over a wide range of frequencies. The amplitude of the pressure wave corresponds to the loudness of the sound and the frequency governs the pitch.

Measurement of Noise (see also DMRB 11.3.12)

10.2 Sound pressures are usually compared with what can be detected at the threshold of hearing; the pressure at the pain threshold is about six orders of magnitude greater. The loudness or energy of sound is related to the square of the sound pressure and commonly expressed on a logarithmic scale as decibels (dB). On this scale, a doubling of sound energy is represented by 3 dB, whilst an increase of 10 dB is experienced as a doubling of loudness.

10.3 Human perception of the loudness of different sounds in the audible range varies with frequency. In order to indicate the overall level of random noise, the levels at different frequencies are combined by weighting them in accordance with sensitivity of the human ear. The 'A' weighting has been found to give a good correlation between perceived and measured loudness. Noise measurements are therefore normally described in units of dB(A).

10.4 The noise received at some distance from a stream of traffic is sum of noise emmitted by different vehicles at various distances. The peak noise level at the point of reception is continually varying and it is therefore necessary to identify a characteristic noise level which can be used to assess the degree of nuisance.



Noise Level Measurements

Each peak represents the passage of a vehicle.

10.5 The index used for the purposes of traffic noise appraisal is based on the arithmetic mean of the noise levels in dB(A) exceeded for 10% of the time in each of the 18 hours between 6am and midnight. This is the $L_{A10(18\text{-hour})}$ index, often contracted to L_{10}. A fairly good relationship has been found between this index and residents' dissatisfaction with traffic noise over a wide range of exposures.

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Sources of Road Noise

10.6 Noise emanates from a number of sources in vehicles, such as mechanical noise from the engine and transmission, body rattles, air turbulence and tyre vibrations. The large engines of heavy goods vehicles make a significant contribution to their overall output of noise. However, for vehicles cruising at moderate to high speeds, the major contribution to traffic noise arises from the interaction of tyres with the road surface.

10.7 The overall noise from a stream of traffic depends on the average speed of vehicles and the proportion of heavy lorries. Both power train noise and rolling noise are functions of speed. The significantly different frequency range of noise from heavy vehicles requires their contribution to be counted separately. The additional contribution from heavy vehicle engines is amplified when they are climbing hills, so a further factor is introduced into calculations to take account of gradients. (CRTN88, Charts 2 - 5).

10.8 Road surface characteristics have a considerable influence on tyre noise. Conventional road surfaces are given a positive texture to provide resistance to skidding in wet conditions. Tyres are designed with tread patterns for the same reason. The interaction between tyres and surface texture is complex, but noise is generated in several ways as the tyres deform and the tread blocks react. The peak noise level as a vehicle passes by is highly correlated with the skidding performance parameter ΔBFC. This is defined as the percentage change in braking force coefficient measured at high (130 km/hr) and low (50 km/hr) speeds, so represents the loss of skidding resistance with increasing speed. ΔBFC and noise are also related to texture depth, but the relationships vary with the type of surface.

10.9 Traffic noise is always estimated for dry surfaces; when the road surface is wet, tyre noise is increased considerably as the water film is broken up. The difference can be as much as 15 dB(A) on bituminous surfaces and 8 dB(A) on brushed concrete. Porous surfaces can provide significant noise reductions by removing the water from the road; they also tend to have a smoother running surface than conventional textured roads which reduces rolling resistance. In addition, the porosity eliminates noise made by the release of air compressed within the tread pattern and attenuates noise from all sources as it propagates across the road surface towards the listener.

10.10 The average difference in vehicle noise measured in dry conditions on porous asphalt surfaces compared with similar measurements on new conventional (hot rolled asphalt) is approximately 4 dB(A) less for light vehicles and 3 dB(A) less for heavy vehicles. By contrast, surface dressing may cause noise levels 3 or 4 dB(A) higher than new HRA; but badly fretted or worn roads are also relatively noisy. Alternative forms of maintenance treatment in the form of thin overlays are now available which are substantially quieter than surface dressing.

Atmospheric Conditions

10.11 Sound does not always radiate uniformly in all directions. Wind distorts the sound waves so that they rise progressively above the ground upwind and curve down towards the ground downwind. Noise levels at the same height and equal distances upwind and downwind from the source may differ by as much as 10 dB(A). Certain other atmospheric conditions can distort the propagation of sound. If the air near to the ground is warmer than that above, sound will tend to be attenuated more quickly at ground level. Conversely, if there is a “temperature inversion”, noise at ground level will be increased.

Traffic Noise Spectrum

10.12 Traffic noise assessments are based on L_{10} measurements of A-weighted noise levels. The weighting allows for the varying sensitivity of the ear to sounds of different frequencies. Measurements of the efficiency of acoustic materials in standard tests are taken over a series of frequency bands and the results may be shown as a frequency response curve. In order to characterise overall performance, it is necessary to combine the responses at different frequencies making allowance for the relative importance of these frequency ranges in the source of noise.

10.13 The internationally agreed spectrum of traffic noise for the purpose of calculating single number ratings is given in Table 10.1. The ratings for insulation and absorption are calculated as follows:

insulation: $\mathbf{DL_R = -10\log[\Sigma n_i \,.\, 10^{-0.1R_i}]}$

absorbtion: $DL_\alpha = -10\log[1 - \Sigma n_i \,.\, \alpha_i]$

where $n_i = 10^{0.1L_i}$

R_i and $\boldsymbol{a}_i$ are the one third octave performance values measured in tests; L_i are the spectral weights given in Table 10.1.

Table 10.1: Reference Spectrum

frequency Hertz	L_i dB(A)	weighting $n_i = 10^{0.1L_i}$
100	-20	0.010
125	-20	0.010
160	-18	0.016
200	-16	0.025
250	-15	0.032
315	-14	0.040
400	-13	0.050
500	-12	0.063
630	-11	0.079
800	-9	0.126
1000	-8	0.158
1250	-9	0.126
1600	-10	0.100
2000	-11	0.079
2500	-13	0.050
3150	-15	0.032
4000	-16	0.025
5000	-18	0.016

11.0 REFERENCES

Standard Texts

Acoustics and Noise Control - B J Smith, R J Peter, S Owen, 1982

Covers the theory of noise and its measurement, vibration, noise control and law. Perception of noise and hearing defects, room acoustics, measurement and control of reverberation using absorptive materials are also considered.

Transportation Noise Reference Book - (Ed) P Nelson, Butterworths, 1987

Comprises contributions from international specialists on characteristics of vehicle and traffic noise for all modes. Includes methods of prediction and mitigation, effects on people, particular problems and future developments.

Wind Loading of Building Structures - N J Cook, Butterworths, Part 1: 1986, Part 2: 1990

Consolidates work carried out at the Building Research Establishment on the effect of wind on different types of structure, including freestanding structures, as well as walls and roofs of buildings.

TRL Reports - Noise Models and Measurements

Rural Traffic Noise Prediction - An Approximation - SR 425 (1978)

Describes a method of predicting noise levels over a wide area from traffic on rural roads.

Acoustic Performance of M6 Noise Barriers - LR 731 (1976)

A report on both single and dual barriers erected alongside the M6 where the elevated motorway runs close to an estate of 2-storey dwellings.

A Field Investigation of Noise Barrier Performance and Wind Dependent Noise Propagation - SR 388 (1978)

A report on the acoustic performance of a noise barrier erected alongside the M40 at a point where the motorway passes within 150 metres of a residential estate.

The Use of Vegetation for Traffic Noise Screening -RR 238 (1990)

A report on a field study of traffic noise attenuation within five types of mature vegetation, up to a depth of 30m. Also contains references to other work on the effectiveness of vegetation.

The Costs of Conforming to Standards for Noise From Road Traffic - SR 475 (1980)

Compares the relative cost of achieving different levels of noise attenuation using insulation, screening or construction in cutting. Three schemes near concentrations of houses in SE Region were used as examples.

A Model to Calculate Traffic Noise Levels from Complex Highway Cross Sections - RR 245 (1990)

Describes a semi-empirical model using ray acoustics to predict traffic noise levels near roads in situations where noise is partially screened and reflected by intervening structures. Examples include the use of multiple noise sources and screens, and varying degree of absorbency for horizontal and vertical surfaces.

Prediction of Noise from Road Construction Sites - LR 756 (1977)

A method is described for predicting the energy equivalent continuous noise level (Leq) for road construction sites. The use of this method is discussed with reference to the noise control legislation applicable to road construction.

Road Construction Noise Prediction and Measurement - A Case Study - LR 758 (1977)

Compares noise predictions and measurements during the earthworks phase of a road construction scheme; illustrates the roles that prediction and measurement can play in assessing noise control strategies in earthworks operations.

A Comparison Between Road Construction Noise in Rural and Urban Areas - LR 858 (1978)

A study of the noise from construction activities on six road schemes chosen to represent different standards of road in rural and urban locations.

Foreign Publications

Noise Barriers - A Catalogue of Ideas, Road Data Laboratory, Ministry of Transport, Denmark, 1991

Summarises the main issues covered in HA 65/94 but includes copious colour illustrations and brief descriptions of environmental barriers in Denmark, Germany, the Netherlands and France.

Additional Technical Regulations and Guidelines for the Design of Noise Protection Barriers along Roads - (ZTV Lsw 88), Ministry of Traffic, Federal Republic of Germany, 1988

Many products have been designed to meet this exacting specification, which covers acoustic and mechanical requirements for a wide variety of constructions, including transparent materials and thin walled composite barriers.

Guidelines for Noise Barriers - (GCW 1986), Rijkswaterstaat, Netherlands 1986

Provides guidance both on aesthetics and on constructions standards for noise screens using timber, metal or glass, and earth retaining structures including vegetated systems.

Codes and Standards not included in SHW - Appendix F (MCHW1)

CP 112 : Pt 2	The Structural Use of Timber
CP 116	The Structural Use of Precast Concrete
CP 121 : Pt 2	Brick and Block Masonry
BS 743	Materials for Damp Proof Courses
BS 2750 : Pt 5	Field measurements of airborne sound insulation of facade elements and facades.
BS 5950 : Pt 1 & 5	Structural Use of Steelwork in Building CP for design in simple and continuous construction: Hot Rolled Sections and CP for design of Cold Formed Sections
BS 6399 : Pt 1	CP for Dead and Imposed Loads (Crawl Load)
BS 8110 : Pt 1	Structural Use of Concrete - CP for Special Circumstances
BS 8118	Structural Use of Aluminium

12. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:

Head of Division Road Engineering and Environmental Division St Christopher House Southwark Street London SE1 0TE	N S ORGAN Head of Division

The Deputy Chief Engineer The Scottish Office Industry Department National Roads Directorate New St Andrew's House Edinburgh EH1 3TG	N B MACKENZIE Deputy Chief Engineer

Head of Roads Engineering (Construction) Division Welsh Office Y Swyddfa Gymreig Government Buildings Ty Glas Road Llanishen Cardiff CF4 5PL	B H HAWKER Head of Roads Engineering (Construction) Division

Assistant Chief Engineer (Works) Department of the Environment for Northern Ireland Road Service Headquarters Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	D O'HAGAN Assistant Chief Engineer (Works)

SUMMARY OF SIMPLIFIED WIND CALCULATION METHOD

1. Read basic wind speed $\overline{V}_B$ (m/sec) from Figure A1

2. Adjust wind speed for altitude A of site

$$\overline{V}_{SITE} = \overline{V}_B (1+0.001A)$$

3. Calculate wind effects for:
a) wind in direction normal to one face of the barrier
b) wind in opposite direction

4. Read factors for fetch S_{SC} and turbulence S_{TSC} from Figures A2 and A3, and town adjustment factors S_{CT} and S_{TCT} from Figures A4 and A5 (Note logarithmic scale for distance)

5. Calculate terrain and building factor, using g_{GUST} = 3.44 for post and panel structures. For continuous walls, g_{GUST} may be reduced to 2.76
$S_{TB} = S_{CS} S_{CT} (1 + g_{GUST} S_{TSC} S_{TCT})$

6. With reference to Figure A6, calculate average slope of terrain and site upwind: $\psi = \frac{Z}{L}$

7. Go to step 16 unless average slope of ground ψ within 1km of the site is greater than 0.05 or barrier is on top of an isolated embankment with upwind slope ψ greater than 0.05

8. If ψ is greater than 0.3: L_E = 3.33Z, otherwise: L_E = L

9. If barrier is <u>not</u> within region $-1.5L_E < x < 2.5L_E$ affected by topography, go to step 16 (see Figure A6)

10. From position and height of barrier, calculate $\frac{x}{L_E}$, $\frac{H}{L_E}$

11. Read speed coefficient s from Figure A7

12. If ψ is less than 0.3: $S_{TOP} = 2\psi s$, otherwise: $S_{TOP} = 0.6\ s$

13. With reference to Figure A8, calculate difference in altitude ΔA of barrier site above average ground level

14. Adjust wind speed for relative altitude

$$\overline{V}_{SITE} = \overline{V}_{SITE} (1 - 0.001\ \Delta A)$$

15. Adjust terrain and building factor for topography
$S_{TB} = S_{TB} + S_{SC} S_{CT} S_{TOP}$

16. Repeat calculations from step 4 for opposite wind direction

17. Calculate design wind speed (m/sec)

$$\overline{V}_{REF} = \text{largest } \{\mathbf{S}_{TB} \,.\, \overline{\mathbf{V}}_{SITE}\}$$

EXAMPLE 1

An environmental barrier 3m high is needed adjacent to a new road on top of an embankment 7m above the surrounding area; the side slope is 1 in 2. The road is within the urban fringe to the east of Doncaster and the surroundings include houses, blocks of flats and industrial buildings.

The basic wind speed from figure A1 is 23 m/sec; the altitude of Doncaster is about 10m above sea level, so the site altitude correction is 1.0017 and $S_{TB} \,.\, \overline{V}_{SITE}$ = 23.039 m/sec.

Doncaster is about 75 km from the east coast, but about 130 km from the west and so:
S_{SC} = 0.82 and S_{TSC} = 0.2 for easterly winds and
S_{SC} = 0.81 and S_{TSC} = 0.206 for westerlies

Assuming that the site is 0.3 km into the urban area, which is about 10 km across
S_{CT} = 0.712 and S_{TCT} = 1.819 for easterly winds and
S_{CT} = 0.628 and S_{TCT} = 1.826 for westerlies.

The corresponding terrain and building factor for each direction will be:
$S_{TB} = 0.82 \star 0.712 \star (1+3.44 \star 0.2 \star 1.819) = 1.314$ in the first case and
$S_{TB} = 0.81 \star 0.628 \star (1+3.44 \star 0.206 \star 1.826) = 1.167$ in the second.

The surrounding countryside is flat, but the embankment slope gives ψ = 0.5. As this exceeds 0.3, the effective slope length in metres is L_E = 3.33 * 7 = 23.31. Assuming that the barrier is to protect housing to the west of the road and that it is just at the top of the western embankment slope, for westerly winds x = 0.

$$\mathbf{\frac{H}{L_E} = \frac{3}{23.31} = 0.13 \text{ and } \frac{X}{L_E} = 0}$$

so the corresponding speed factor from Figure A7 is s = 1.

For easterly winds, assuming that the cross section is dual three lane motorway with standard verges and central reservation,

$$\mathbf{\frac{X}{L_E} = \frac{35.6}{23.31} = 1.53}$$

and the speed factor s = 0.4 from Figure A7.

As the effect of the embankment will be taken into account as a topography correction, the effect of its height above the surrounding countryside should be eliminated from the altitude correction. This requires a multiplier of (1 - 0.0007) = .9993, so $\overline{V}_{SITE}$ = 23.02 m/sec.

For westerly winds, S_{TOP} = 0.6 and so S_{TB} is increased by $0.81 \star 0.206 \star 0.6 = 0.100$, to become S_{TB} = 1.267. For easterly winds, $S_{TOP} = 0.6 \star 0.4$, so S_{TB} is increased by $0.82 \star 0.2 \star 0.6 \star 0.4 = 0.039$, to become S_{TB} = 1.353.

The greatest value of $S_{TB} \cdot \overline{V}_{SITE}$ is 1.353 ⋆ 23.02 = 31.15 m/sec, which should be used as the design wind speed.

EXAMPLE 2

On the same scheme, a 2 metre high barrier is needed to protect an isolated group of properties. The surrounding areas is otherwise open countryside and the road is on a 10 metre high embankment.

As before the basic wind speed is 23 m/sec, which corrected for altitude gives $\overline{V}_{SITE}$ = 23.046 m/sec.

In this case, there is no need to adjust the fetch and turbulence coefficients for town conditions in calculating the terrain and building factor. So S_{TB} = 0.82 ⋆ (1+3.44 ⋆ 0.2) = 1.384 for easterly winds and S_{TB} = 0.81 ⋆ (1+3.44 ⋆ 0.206) = 1.384 for westerlies.

For a 10 metre high embankment, the effective slope length L_E = 33.3 metres and $\frac{\mathbf{H}}{\mathbf{L_E}} = \frac{\mathbf{2}}{\mathbf{33.3}} =$ **0.06**. For a barrier on the upwind side of the embankment, x = 0 and s = 1. For a barrier on the downwind side of the embankment, $\frac{\mathbf{X}}{\mathbf{L_E}} = \frac{\mathbf{35.6}}{\mathbf{33.3}} =$ **1.07** and from Figure A7, s =0.3.

The greatest value of topography factor is S_{TOP} = 0.6 so the largest correction to S_{TB} is 0.81 ⋆0.206 ⋆ 0.6 = 0.100 and thus the maximum value of S_{TB} = 1.484.

The effect of the embankment height is again subtracted from the altitude correction, so that $\overline{V}_{SITE}$ = 23.02 m/sec as before. The reference wind speed can therefore be calculated as $S_{TB} \cdot \overline{V}_{SITE}$ = 1.484 ⋆ 23.02 = 34.25 m/sec.

CALCULATION OF POST LOADS

1. Calculate wind pressure (N/m²)

$$q = 0.613\overline{V}_{REF}^{\,2}$$

2. Calculate wind load for internal vertical post

$$P_{bas} = \frac{1.2C_R.q.H.p}{1000} \quad (\text{kN/m}^2)$$

where C_R = 1.16 for a reasonably stiff structure

3. Apply post load factors for end effects: using Figure A9 for vertical barriers or Figures A10 or A11 for inclined barriers.

4. If ends of barrier are tapered, reduce post loads pro rata:

$$\text{reduction factor} = \frac{H_{AB}}{H}$$

where H_{AB} is the mean height of barrier panels on either side of the post under consideration.

EXAMPLES

Continuing the first example given above,
the design wind pressure $q = 0.613 \star (31.15)^2 = 594.8$ N/m^2
For a barrier with a uniform spacing of 2.5m between posts,
$P_{bas} = 1.2 \star 1.16 \star 0.5948 \star 3 \star 2.5 = 6.2$ kN

Using Figure A9 for a vertical barrier with H/p = 1.2, the design post loads at the ends are as follows:

Posts 1 - 3	:	12.4 kN
Posts 4 - 6	:	9.3 kN
remainder	:	6.82 kN

If the height of the barrier were either stepped or uniformly reduced in height to 1.5 metres over six bays, the end post loads would be modified by the following factors:

Post Number	1	2	3	4	5	6	7
Mean Height	1.625	1.75	2.0	2.25	2.5	2.75	2.94
Factor	0.542	0.583	0.667	0.75	0.833	0.917	0.979
Load (kN)	6.72	7.23	8.27	6.98	7.75	8.53	6.70

In the second example, $q = 0.613 \star (34.25)^2 = 719.1$ N/m^2.
For the same post spacing, $P_{bas} = 1.2 \star 1.16 \star 0.7191 \star 2 \star 2.5 = 5.0$ kN

Using Figure A9 for a vertical barrier with H/p = 0.8, the post loads at the ends are as follows:

Posts 1 - 2	:	10kN
Posts 3 -5	:	7.5 kN
remainder	:	5.5 kN

If the height were reduced to 1 metre over four bays, the post loads would be reduced as follows:

Post Number	1	2	3	4	5
Mean Height	1.125	1.25	1.5	1.75	1.94
Factor	0.563	0.625	0.75	0.875	0.969
Load (kN)	5.63	6.25	5.63	6.56	7.26

If the post spacing were increased to 5 metres P_{bas} would be doubled, but the loads on end posts for constant height with H/p = 0.4 would be:

Posts 1 - 3	:	15 kN
remainder	:	11kN

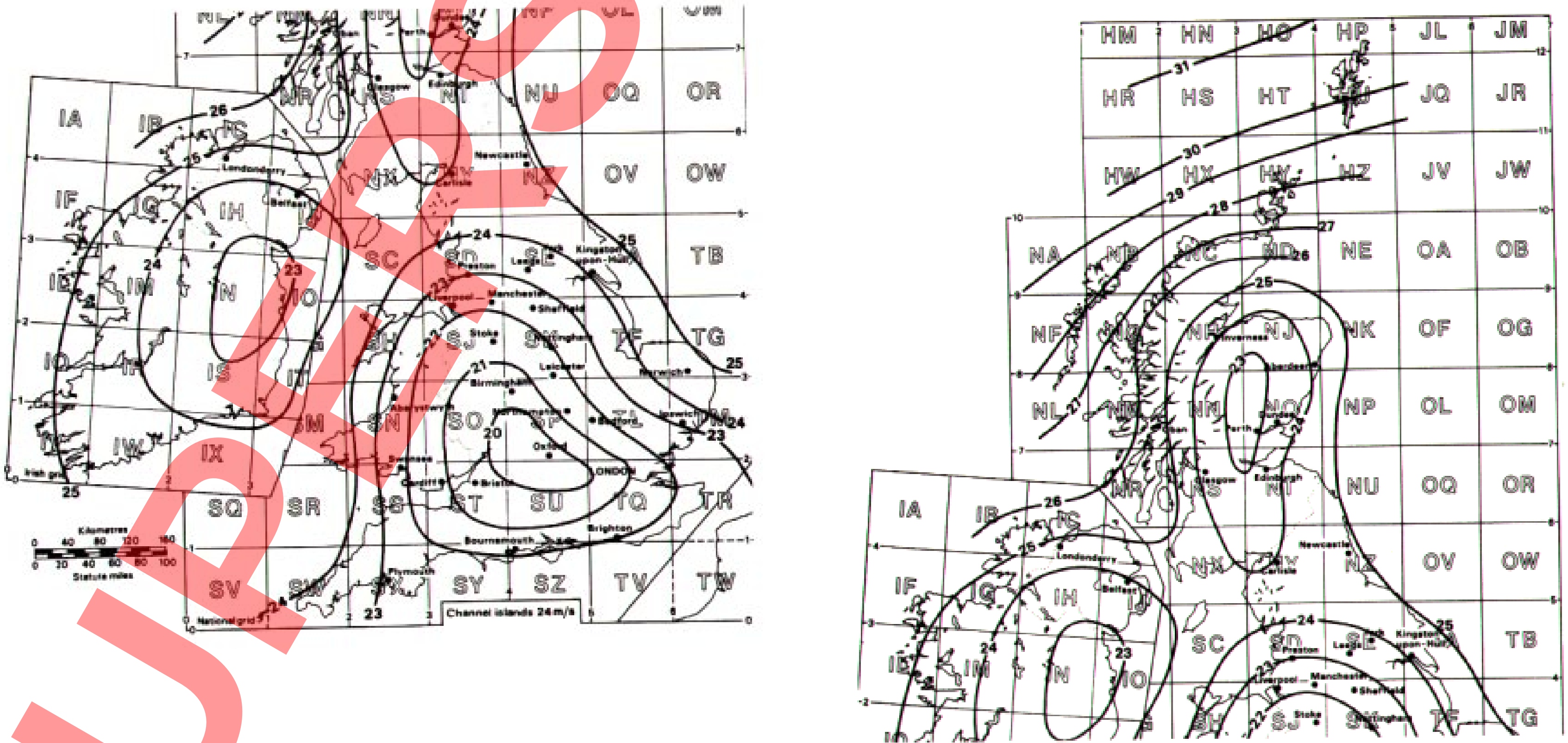

Figure A1: Basic Wind Speed at Sea Level (m/sec)

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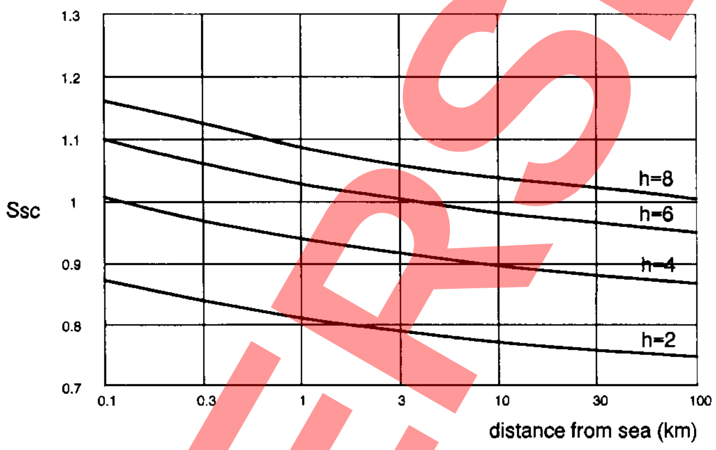

Figure A2: Fetch Factor S_{sc}

	Distance from sea (km)						
	0.0	0.3	1.0	3.0	10	30	100
height							
2	0.873	0.840	0.812	0.792	0.774	0.761	0.749
3	0.946	0.910	0.881	0.860	0.841	0.826	0.813
4	1.008	0.970	0.941	0.918	0.897	0.882	0.867
5	1.060	1.020	0.990	0.966	0.944	0.928	0.913
6	1.102	1.062	1.029	1.004	0.983	0.966	0.951
7	1.136	1.096	1.061	1.034	1.014	0.997	0.981
8	1.165	1.125	1.088	1.060	1.038	1.022	1.004

Interpolation table

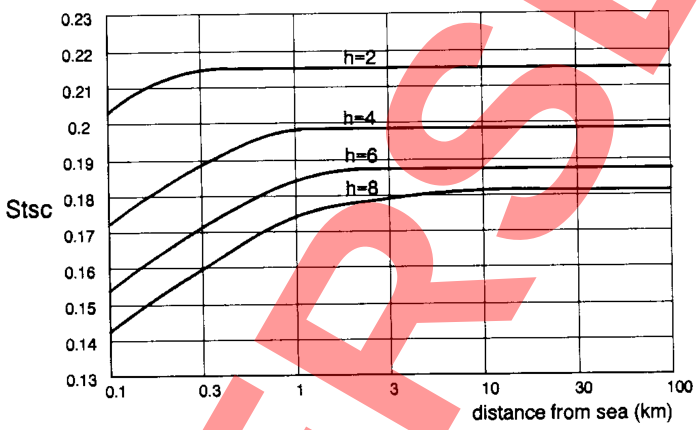

Figure A3: Turbulence Factor S_{TSC}

height	0.1	0.3	1.0	3.0	10	30	100
	Distance from sea (km)						
2	0.203	0.215	0.215	0.215	0.215	0.215	0.215
3	0.186	0.200	0.206	0.206	0.206	0.206	0.206
4	0.172	0.188	0.198	0.198	0.198	0.198	0.198
5	0.161	0.179	0.192	0.192	0.192	0.192	0.192
6	0.153	0.171	0.184	0.186	0.187	0.187	0.187
7	0.147	0.164	0.179	0.182	0.184	0.184	0.184
8	0.143	0.160	0.174	0.179	0.181	0.181	0.181

Interpolation table

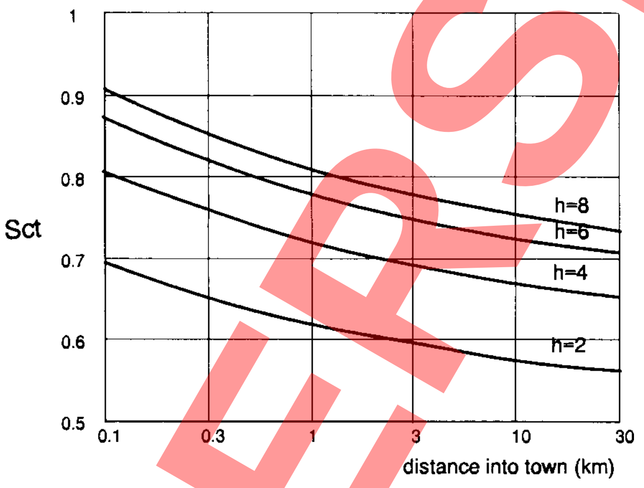

Figure A4: Fetch Adjustment Factor S_{CT}

	Distance from town (km)					
	0.1	0.3	1.0	3.0	10	30
height						
2	0.695	0.653	0.619	0.596	0.575	0.562
3	0.758	0.712	0.975	0.650	0.628	0.613
4	0.808	0.759	0.720	0.693	0.669	0.653
5	0.846	0.795	0.754	0.725	0.701	0.684
6	0.874	0.821	0.779	0.749	0.724	0.707
7	0.894	0.840	0.797	0.766	0.741	0.723
8	0.909	0.854	0.810	0.779	0.753	0.735

Interpolation table

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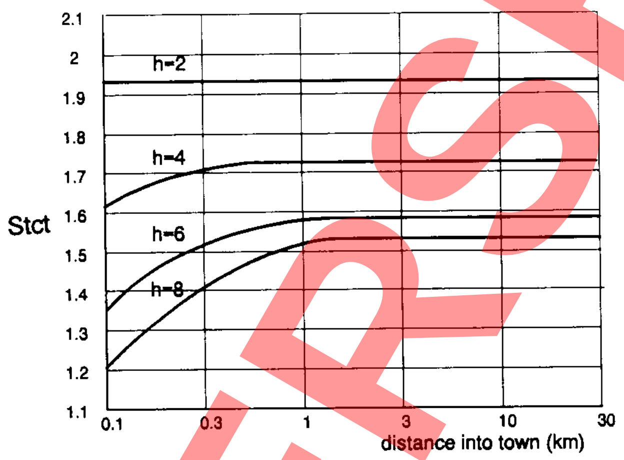
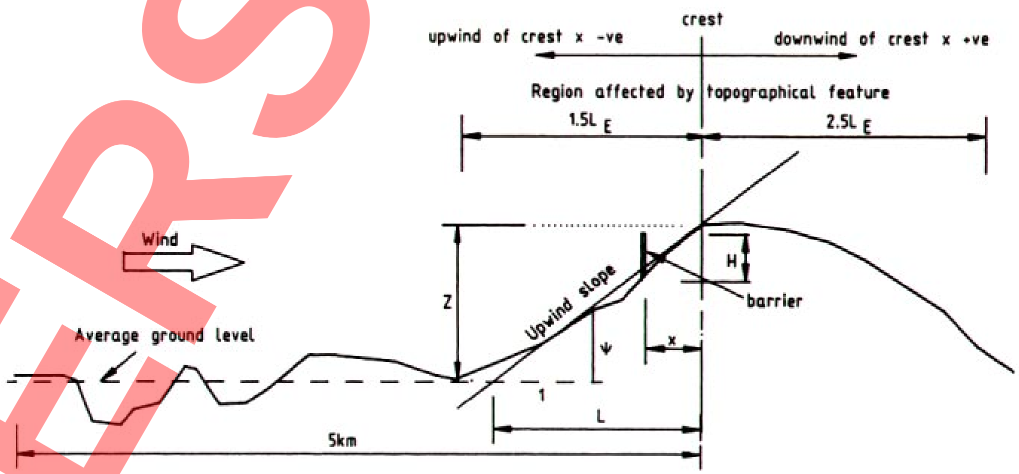


Figure A5: Turbulence Adjustment Factor S_{TCT}

	Distance from town (km)					
	0.1	0.3	1.0	3.0	10	30
height						
2	1.930	1.930	1.930	1.930	1.930	1.930
3	1.770	1.819	1.826	1.826	1.826	1.826
4	1.615	1.711	1.725	1.725	1.725	1.725
5	1.470	1.610	1.630	1.630	1.630	1.630
6	1.350	1.519	1.580	1.584	1.584	1.584
7	1.260	1.451	1.543	1.550	1.550	1.550
8	1.205	1.409	1.520	1.529	1.529	1.529

Interpolation table



L = Actual horizontal length of upwind slope measured from foot to crest on the upwind side of the feature.

L_E = Effective length of upwind slope

x = Horizontal distance from crest of feature to barrier site measured in wind direction (hence upwind negative; downwind positive).

Z = Vertical height between average ground level and crest of feature, measured on upwind side of feature.

ψ = Upwind slope (Z/L).

Figure A6: Topography Factors

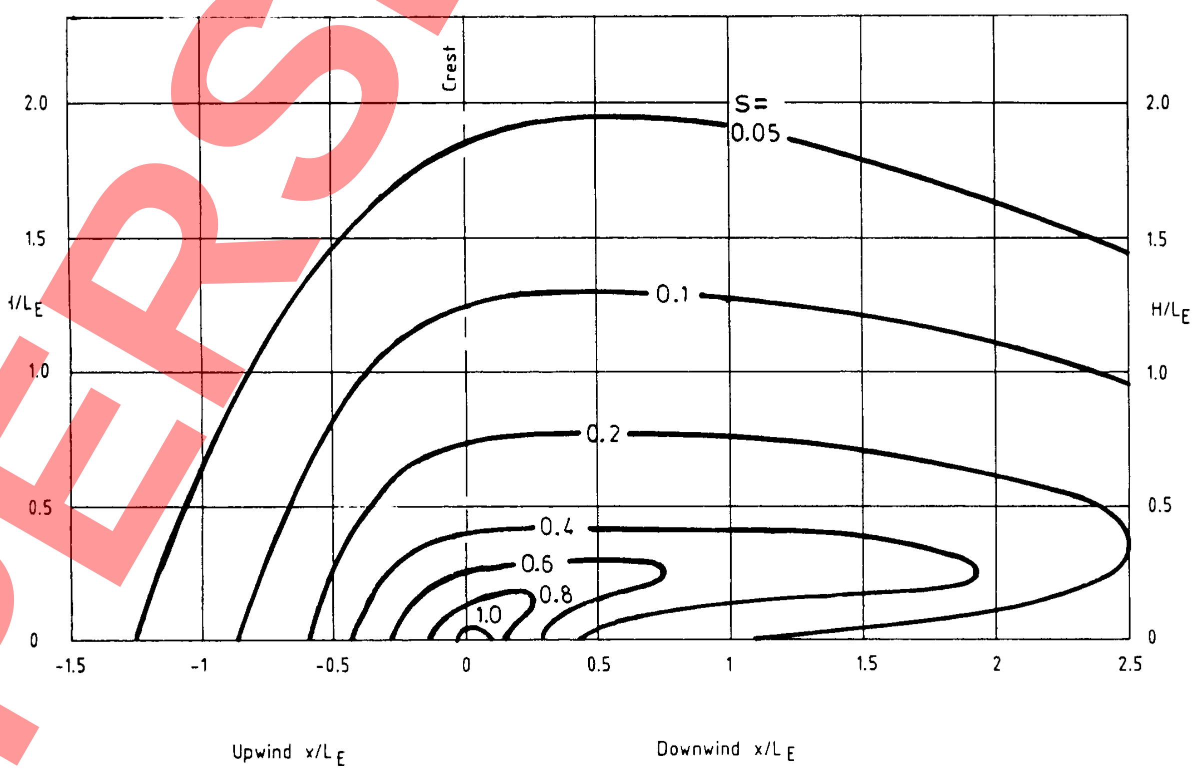


Figure A7: Wind Speed Coefficient

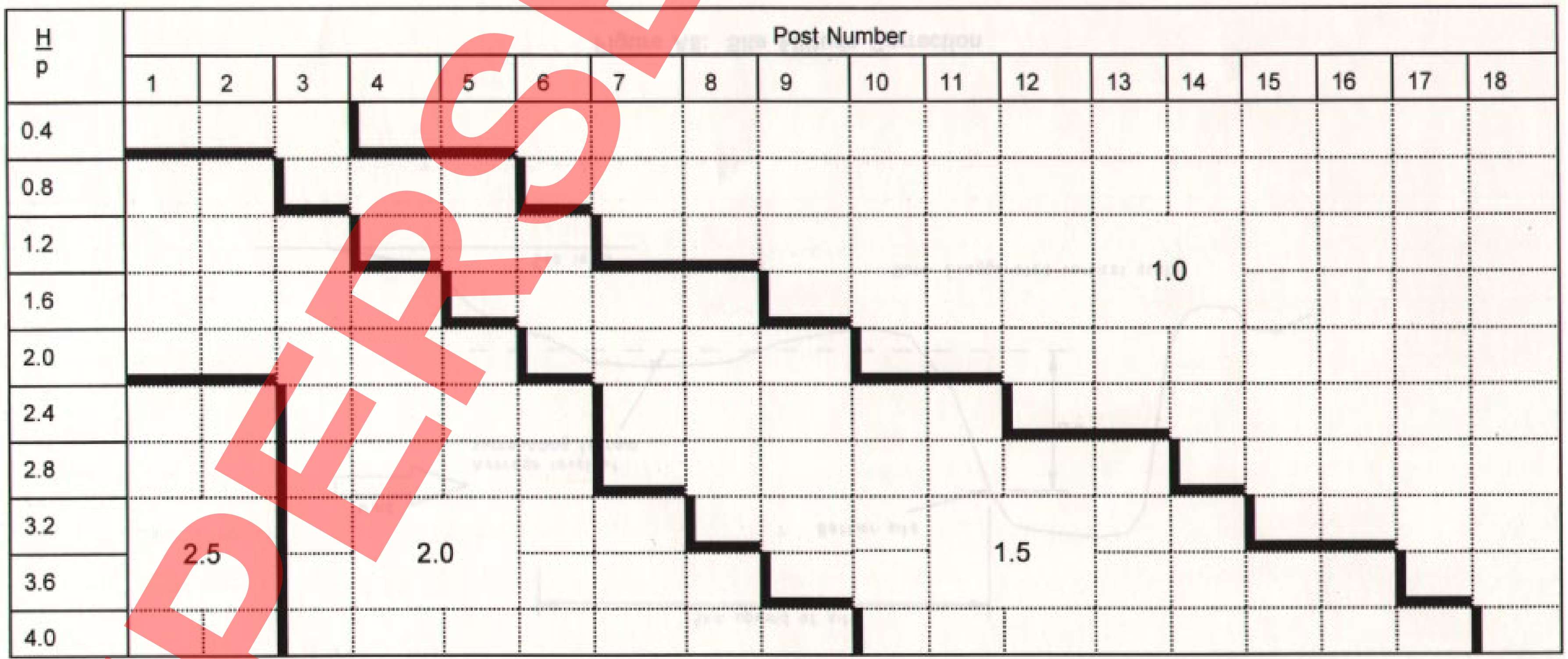


Figure A9: Multipliers for Post Loading P_{BAS} Near End of Barrier - Vertical Barrier

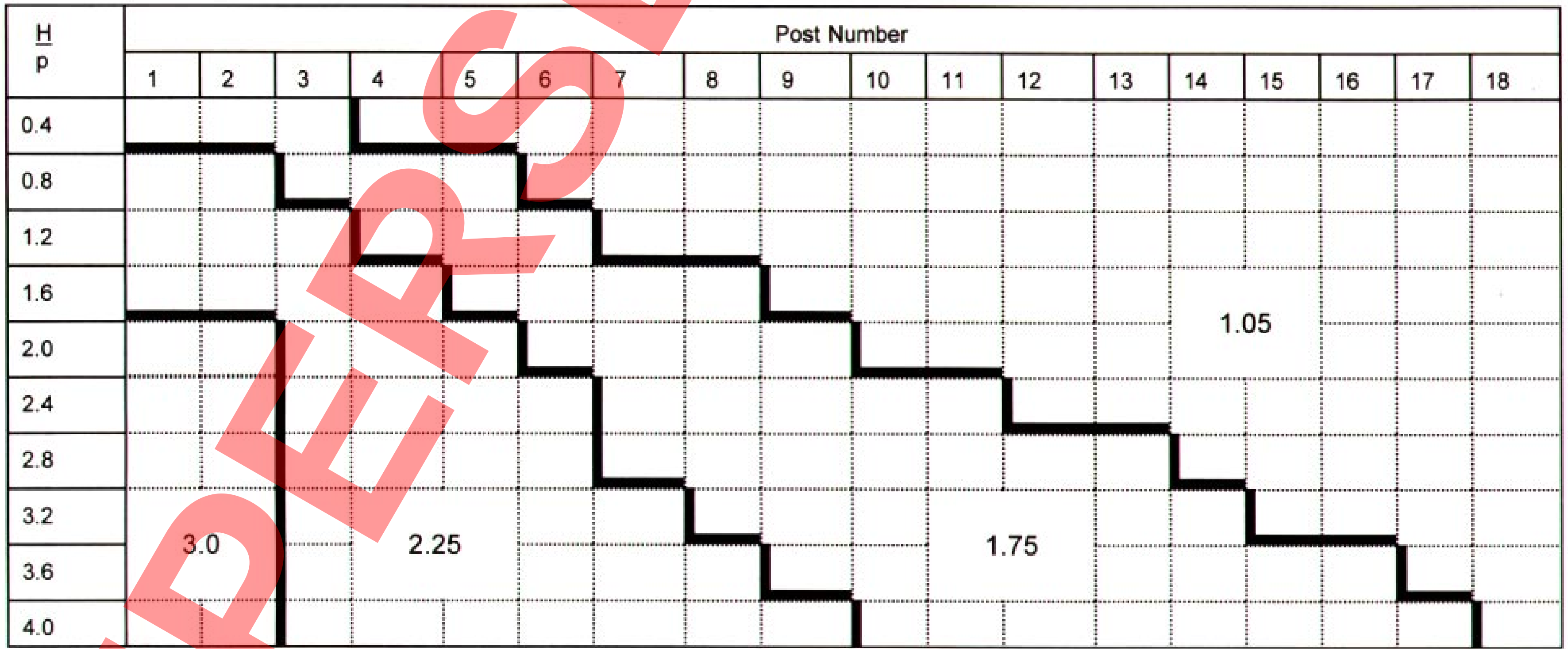


Figure A10: Multipliers for Post Loading P_{BAS} Near End of Barrier - Inclined Barrier 5°

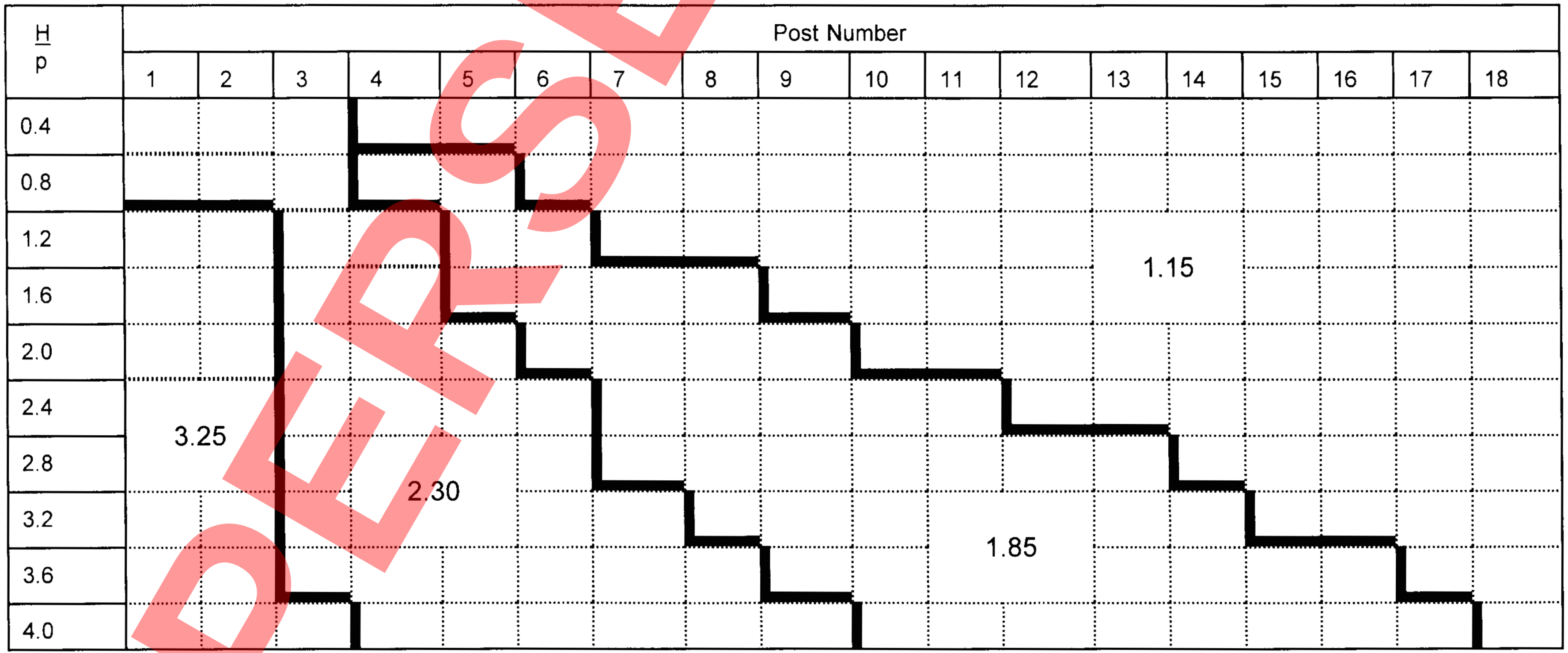


Figure A11: Multipliers for Post Loading P_{BAS} Near End of Barrier - Inclined Barrier 10° and 15°

STEEL POST SELECTION CHARTS

The charts in Figures B1 to B3 are valid for Universal Beam sections in grade Fe430 steel to BS EN 10025 in bending about the major axis. They are based on the requirements of BS 5400 Part 3. It is assumed that the cross section is not weakened by holes through the flanges. Maximum bending moment is assumed to be at the top of the foundation which is no more than 300mm below ground level.

The section which is heavier than the point representing the desired post load P and height H on the charts should be used. Not all available sections are shown and intermediate sizes may be adequate in some cases. Alternatively, design fully in accordance with BS 5400 Part 3 and Part 10 may also be more economical.

Steel sections in the shaded areas of Figures B2 and B3 are relatively heavy and designers may wish to consider other options, such as reducing post spacing or introducing braced supports.

Provided that a section is sufficiently stiff, grade Fe510 steel may be used for increased strength. In this case the design must be based on BS 5400 as no charts are included for this material. The horizontal deflection of the top of the post under the design load should be within H/150.

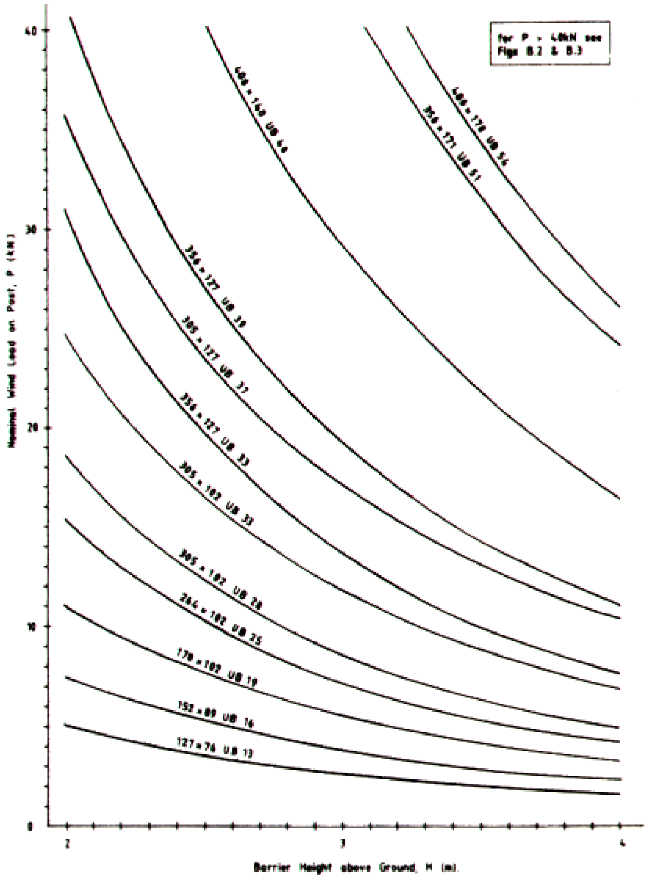


Figure B1: Post Selection Chart I

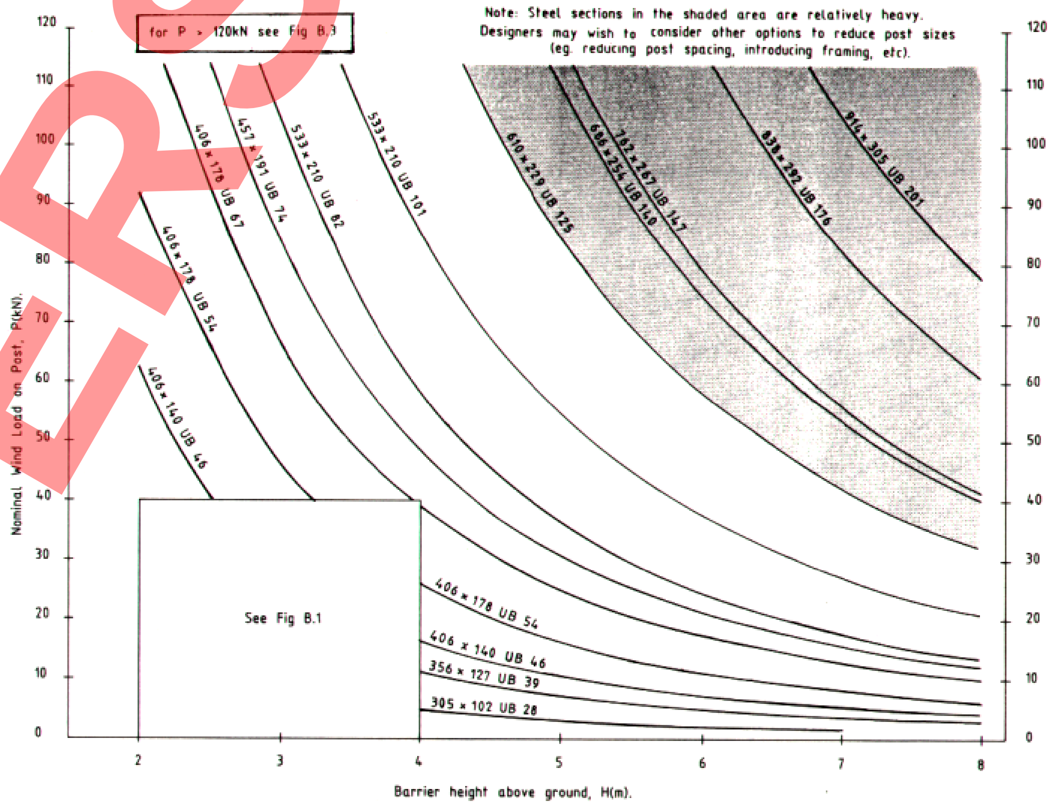


Figure B2: Post Selection Chart II

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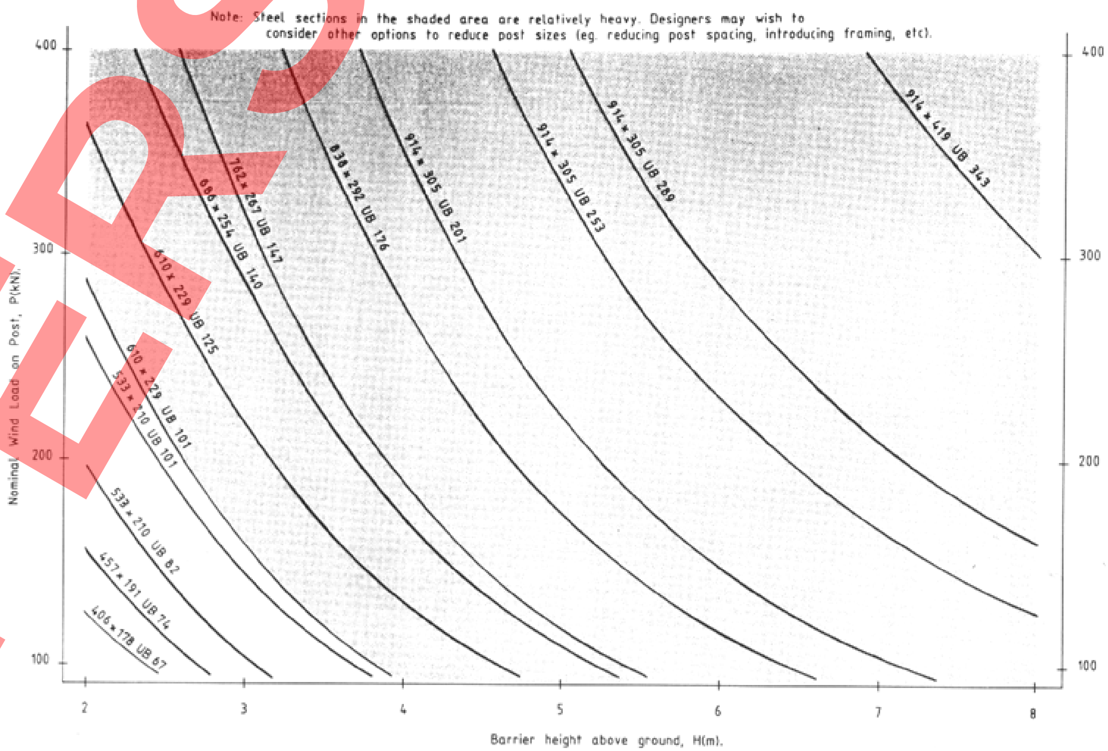

Figure B3: Post Selection Chart III

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EXAMPLE 1

Using the post loads calculated in Appendix A for a 3 metre high barrier of constant height, from chart B1:

posts 1-3: P = 12.4kN - 305 x 102 UB 33
posts 4-6: P = 9.3 kN - 305 x 102 UB 28
remainder: P = 6.8 kN - 264 x 102 UB 25

If the barrier were reduced to 1.5m in height over six bays at the ends, the maximum post load would be 8.5 kN on post number 6. This is effectively 2.75m high, for which a 264 x 102 UB 25 section would be adequate.

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DESIGN OF POST FOUNDATIONS

Notation

The following notation is used in this Appendix:

h	Depth of foundation block
f	Reduction factor to allow for an uncompacted surface layer of soil
h_1	Depth of uncompacted soil at the surface
k	Reduction factor near to crest of slope
x	Distance from crest of slope to centreline of foundation.
D	Cross section dimension - diameter for circle and side forsquare
M_B	Maximum theoretical resistance to overturning
T_d	Design overturning moment
W	Total weight of post and foundation block

Fundamentals

A typical cross-section is shown in Figure C1. The surface zone of soil to depth h_1 is considered to be relatively poorly compacted and to provide virtually no resistance. It is assumed that the foundation is otherwise fully embedded in well-compacted material. Tests which confirmed the validity of the proposed design method also indicated that solid type does not unduly influence the safe moments of resistance for foundations whose depth is not greater than four times the cross section dimension D. The post is assumed to be embedded in the foundation concrete to a depth of at least 0.75*h.

Theory and Experiment

It is generally assumed that a post foundation fails by rotation about a centre at mid-depth. It has been shown that the theoretical overturning moment of a post foundation is of the form:

$$M_B = f.D.(a.W+b.h^3)$$

Where f is a factor allowing for the depth of uncompacted soul, given in Figure C2.

Tests on a range of post foundations showed that actual performance differed from the theoretical relationship, with a best fit in the form:

$$T_d = K.\boldsymbol{a}.M_B^{\$}.$$

Where K is a factor allowing for the proximity of the foundation to the crest of a slope. If the distance x in Figure C1 (in metres) from the centre of the foundation to the crest of the slope is greater than 1, K = 1. If x is less than 1, K = 0.4 + 0.6x

The shape factors a, b, ***a*** and ***β*** for symmetrical cross sections are:

Shape	a	b	a	β
Square	0.00392	29.42	10	0.44
Circle	0.00314	23.54	4.3	0.57

Design Moments

A loaded factor of 2 was applied to failure moments to ensure that the test foundations did not rotate significantly under the resulting design moment. Thus, safe design moments shown in Figures C3 and C4 (for K = 1) are based on

$$T_d = 0.5 \star \boldsymbol{a}.M_B{}^{\$}.$$

The full lines indicate the scope of experimental data on which these curves are based. It should be noted that the concrete in 450mm diameter foundations failed at the higher overturning moments and so reinforcement of high strength concrete would be needed in foundations of this diameter deeper than 1.6 metres.

Where the depth of uncompacted soil is uncertain, an intermediate value h^1 = 0.3 may be used. Table C1 gives appropriate safe design moments for this case.

If in doubt about the resistance of the embedment material, post foundations may be tested by applying a horizontal force to a suitable test post (which may need to be stronger than called for in the design). The test post should resist an applied overturning moment of at least 1.5 ★ design moment. The precise method of applying the force and the appropriate height of its application may depend on site conditions and should be approved by the Engineer.

Example 1

Force on post for 3 metre high barrier: 10 kN, h^1 = 0.3m, x = 0.3m
Assume 1.6m deep foundation. For x = 0.3, K = 0.58
Therefore design moment = $\frac{10}{0.58} \star \frac{(3+1.6)}{2}$
= 39.7 kN.m

It can be seen from inspection of Table C1 that a 1 metre square section foundation would be needed.

Example 2

Force on post for 4 metre high barrier: 10 kN, h^1 = 0.1m, x = 1.2m
Assume 1.6 metre deep foundation; K = 1
Therefore design moment = $10 \star \frac{(4+1.6)}{2}$
= 28 kN.m

From inspection of Figure C3, it can be seen that a 0.75 metre diameter circular section would not provide adequate resistance, but a 0.8 metre square section foundation 1.2 metres deep would probably suffice when account is taken of the shorter lever arm.
Check design moment $10 \star \frac{(4+1.2)}{2}$
= 25.1 kN.m - OK

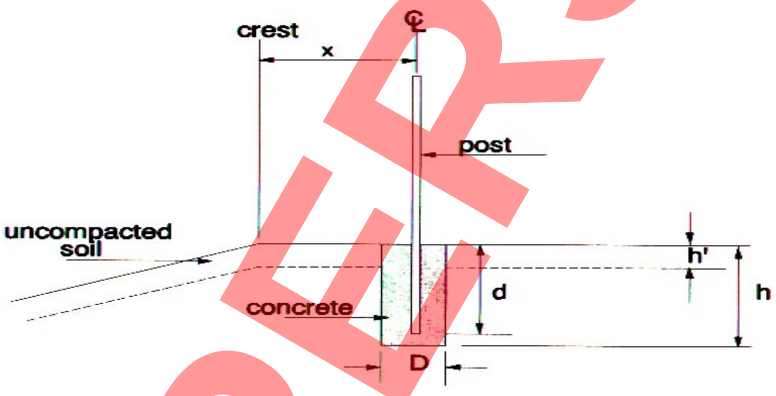

Figure C1: Post Foundation - Dimensions

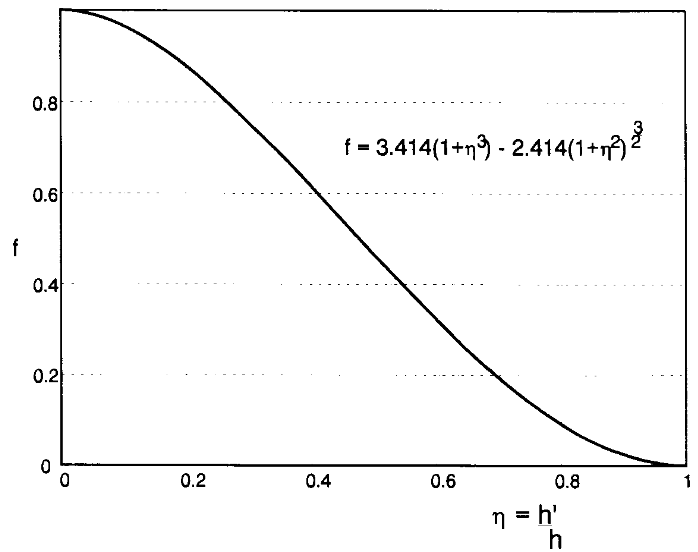

Figure C2: Correction for uncompacted topsoil

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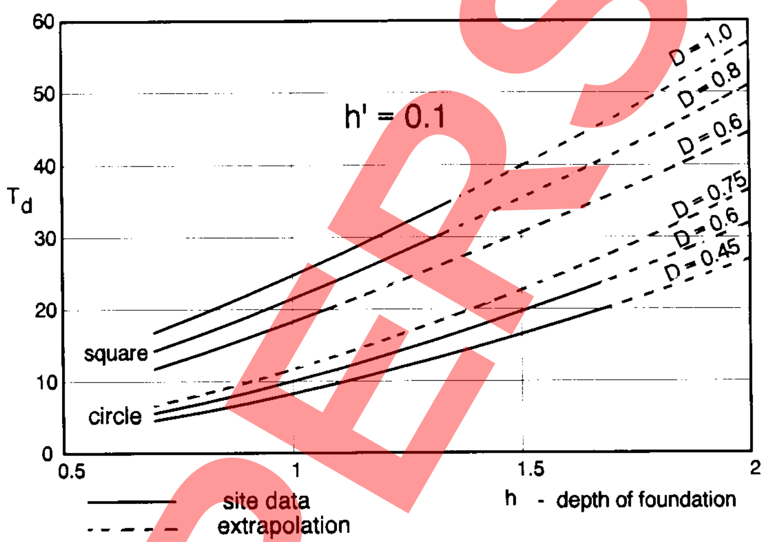

Figure C3: Safe Design Moments for Mass Concrete Post Foundations (100mm uncompacted topsoil)

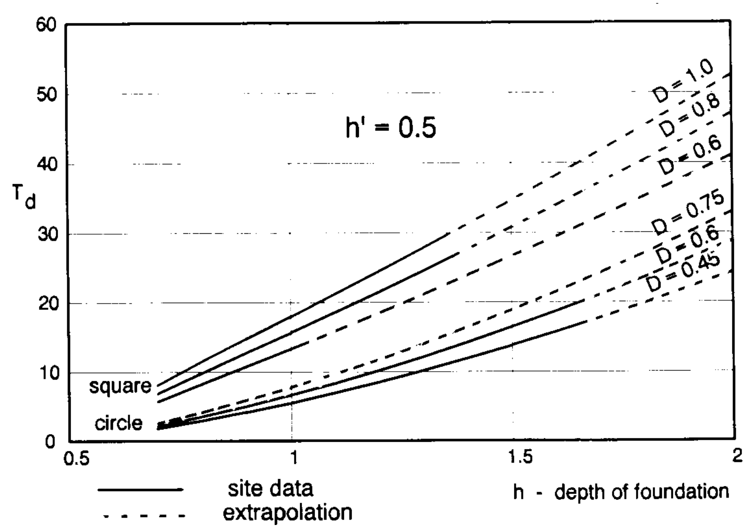

Figure C4: Safe Design Moments for Mass Concrete Post Foundations (500mm uncompacted topsoil)

shape	depth / size	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
square	0.6	**9.5**	**11.8**	**14.1**	**16.5**	**18.9**	**21.4**	**23.9**	*26.6*	*29.2*	*31.9*	*34.7*	*37.5*	*40.4*	*43.3*
	0.8	**11.5**	**14.1**	**16.7**	**19.4**	**22.1**	**24.9**	**27.8**	*30.7*	*33.7*	*36.8*	*39.9*	*43.1*	*46.4*	*49.6*
	1.0	**13.6**	**16.4**	**19.3**	**22.3**	*25.3*	*28.3*	*31.5*	*34.7*	*38.0*	*41.4*	*44.8*	*48.3*	*51.8*	*55.4*
circle	0.45	**3.5**	**4.6**	**5.9**	**7.3**	**8.7**	**10.3**	**12.0**	**13.7**	**15.6**	**17.5**	*19.5*	*21.6*	*23.8*	*26.1*
	0.6	**4.3**	**5.6**	**7.1**	**8.7**	**10.5**	**12.3**	**14.3**	**16.4**	**18.5**	**20.8**	*23.2*	*25.7*	*28.3*	*30.9*
	0.75	*5.1*	*6.7*	*8.4*	*10.2*	*12.2*	*14.3*	*16.5*	*18.8*	*21.3*	*23.9*	*26.6*	*29.4*	*32.3*	*35.4*

Table C1: Safe Design Moments (kN.m) for h' = 0.3m (Bold type indicates range of experimental data)