VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN
SECTION 3 GENERAL DESIGN

PART 14

BD 10/97

DESIGN OF HIGHWAY STRUCTURES IN AREAS OF MINING SUBSIDENCE

SUMMARY

Mining subsidence is ground movement caused by mineral extraction. In most cases, this movement extends to the ground surface. This Standard sets out the steps which must be taken to establish whether mining subsidence is likely to occur at a particular site and, for locations where the nature and extent of the mining activity can be established, explains how the possible magnitude of the movements may be predicted. For structures located where the movements may be significant, this Standard outlines the design and detailing requirements to minimise the effects.

INSTRUCTIONS FOR USE

1. Insert BD 10/97 into Volume 1, Section 3.

2. Remove BD 10/82 from Volume 1, Section 3.

3. Archive this sheet as appropriate.

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THE HIGHWAYS AGENCY

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF THE ENVIRONMENT FOR
NORTHERN IRELAND

Design of Highway Structures in Areas of Mining Subsidence

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Contents

Chapter

1. INTRODUCTION

1.1 This Standard outlines special requirements for bridges and other highway structures in mining areas. It supersedes BD 10/82 (DMRB 1.3).

Scope

1.2 Mining subsidence is ground movement caused by mineral extraction. In most cases this movement extends to the ground surface. This Standard sets out the steps which must be taken to establish whether mining subsidence is likely to occur at a particular site and, for locations where the nature and extent of the mining activity can be established, explains how the possible magnitude of the movements may be predicted. For structures located where the movements may be significant, this Standard outlines the design and detailing requirements to minimise the effects.

1.3 Opencast mining is outside the scope of this Standard.

Equivalence

1.4 The construction of highway structures will normally be carried out under contracts incorporating the Specification for Highway Works (MCHW 1). In such cases products conforming to equivalent standards or technical 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 the 104 and 105 Series of Clauses of that Specification. Any contract not containing these Clauses must contain suitable clauses of mutual recognition, having the same effect regarding which advice should be sought.

Implementation

1.5 This standard should be used forthwith on all schemes for the construction and improvement of trunk roads, including motorways currently being prepared, provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

Where contract documents are based on the Specification for Highway Works (MCHW1), use of this Standard is mandatory.

For use in Northern Ireland, this Standard will be applicable to those roads designated by the Overseeing Organisation.

Mandatory Sections

Sections of this document, which form part of the standards the Overseeing Organisations expect in design, are highlighted by being contained in boxes. These are the sections with which the Design Organisation must comply, or must have agreed a suitable departure from standard with the relevant Overseeing Organisation. The remainder of the document contains advice and enlargement which is commended to designers for their consideration.

2. PREDICTION OF SUBSIDENCE

Investigation of Records

2.1 Before field investigations begin, designers of highway structures, or their specialist advisers, must consult all available sources of local mining knowledge to find out if mining has ever taken place near the site, or if an unworked mineral of potential commercial value is present. This information is essential if the site investigation is to be properly planned and the correct consultations are to be carried out. Old workings may not be obvious from surface features, and designers should remember that not only coal but gypsum, anhydrite, salt, chalk, flints, oil shale, building materials and many metal ores have at some time been extracted in underground workings, or may be so in the future. Old workings must be expected in any areas in which these minerals exist at shallow depth, and with the discovery of one working, others must be suspected close at hand. Indications of old workings may be found on old Ordnance Survey maps.

2.2 A general idea of the rock structure under a site may be obtained from Geological Survey Maps. These show the approximate location and depth of minerals, and provide information about surface deposits, dip of strata and known faults. Each map also indicates the position of some bores, shafts and surface openings, but only a small proportion of the total number is shown. The British Geological Society (BGS) may be able to supply geological field notes and the results of further bores.

2.3 Further information may be found in the Geological Memoirs, a series of books published by BGS in conjunction with their Geological Maps which give additional information about each area including, where appropriate, details of the history and extent of mineral working. The Memoirs also give references to other sources of information.

2.4 Since the mid-nineteenth century, mining undertakings have been under a statutory obligation to keep plans of their workings, and since 1872 they have been required to deposit plans of abandoned mines or seams. Abandonment plans for coal mines, other mines and oil shales are held by the Coal Authority.

2.5 Detailed reports on mining activity can often be obtained from the Mineral Valuer and the County Mining Engineer/Minerals Officer, where the post exists. Other local authorities, local Record Offices, Museums and Libraries may also be able to assist.

In Northern Ireland, information on mining activity may be obtained from the Geological Survey of Northern Ireland.

Details of the custodians of mining plans for abandoned mines are listed in HA 34 (DMRB 4.1) Appendix C.

Site Investigations

2.6 Site investigation procedures for all structures must be in accordance with the following Specifications, Standards and Advice Notes as implemented by the Overseeing Organisation:

Specification for Ground Investigation Works (MCHW 5.3), HD 13 (DMRB 4.1): Documentation Requirements for Ground Investigation Contracts, HD 22 (DMRB 4.1.2): Ground Investigation and Earthworks - Procedure for Geotechnical Certification, and HA 34 (DMRB 4.1), Ground Investigation Procedure.

BS 5930: 1981, Code of Practice for Site Investigations and CIRIA Special Report 25, Site Investigation Manual should be used as guides to the planning and investigation of the site work.

In addition, the references listed in HA 34 (DMRB 4.1) should be consulted and full use made of the recommendations for dealing with mining subsidence.

2.7 When in doubt about the implications of geological and mining features, designers must seek specialist advice. Any interpretive recommendations made by the specialist must, however, be subjected to the same scrutiny as that required for all reports on ground conditions. (HD 22 (DMRB 4.1.2))

2.8 In coal mining areas, designers must seek the advice and recommendations of the Licensed Operator (as defined by The Coal Industry Act

1994), or the Coal Authority, at an early stage. The Law affecting rights of support is complicated but, as for much of the coal mined at present, the Licensed Operator or the Coal Authority is statutorily bound to compensate for, or make good, damage resulting from lawful mining. The Coal Authority can be expected to co-operate fully in providing information to assist designers in taking structural precautions to minimise the possible effects of subsidence from active and closed mines. While the Licensed Operator or the Coal Authority may not wish to exercise their right to make specific requirements on precautionary structural measures under enabling statute in any particular case, designers should note that, if the right is exercised, any eventual compensation for structural damage may be reduced if the specific requirements of the Licensed Operator or The Coal Authority under this statute are not carried out.

2.9 For all trunk road (including motorway) schemes in mining areas, the Mineral Valuer shall be consulted, and full account taken of all relevant information obtained.

Old Mine Workings

2.10 If the study of records, or the site investigation, reveals the presence or the likelihood of old mine workings below or in the vicinity of the site, the prediction of mining subsidence becomes more difficult and the accuracy of prediction less reliable than if the extraction is active. The difficulty stems from the ‘pillar and stall’ or ‘room and pillar’ methods often employed in the past. The retention of pillars of unworked mineral influences the subsequent collapse of the mine, and subsidence prediction is complicated by the fact that later extraction of the pillars was often practised but poorly documented. Surface movement resulting from old shallow coal workings is usually the result of a simple breakdown of the bridging strata between coal pillars, occasionally due to pillar failure, or the ‘punching’ of the pillars into either the roof or floor strata. Surface subsidence due to such void migration is unpredictable in time, although an assessment of the maximum subsidence, should such occur, is sometimes possible given a knowledge of the mining method, general geometry of the workings, and local geology. The opinion of a mining engineer or subsidence engineer should be obtained in such cases.

2.11 In relatively level strata, if an old pillar and stall working exists at more than 30m (or ten times the thickness of extraction if greater) below rockhead, or foundation level if in rock, designers may assume that subsidence from these old workings is unlikely. In all other cases, it must be assumed that unpredictable subsidence can occur and steps must be taken to reduce the vulnerability of the structure.

2.12 Consideration shall be given to the degree of consolidation in old shallow workings mined by total extraction methods before it is assumed that no further subsidence will occur.

2.13 It will rarely be possible to design highway bridges to be capable of accommodating the large, unpredictable movements of unknown magnitude which would be associated with the collapse of an old, partially extracted working at shallow depth. Unless the foundations can be placed below the workings, designers should consider measures to prevent subsidence taking place. If the working is very near the surface, excavation and refilling may be possible. In other cases it may be feasible to fill the void with grout. Whatever method is selected, additional site investigation will be necessary to establish the full extent of the working.

2.14 If subsidence preventive measures are not feasible, and the possibility of future collapse cannot be ruled out, designers must make suitable provision for subsidence effects in accordance with this Standard.

2.15 Guidance on the treatment of old filled mine shafts and disused shallow coal workings are contained in Advice Note HA 34 (DMRB 4.1), Ground Investigation Procedure.

Active Mine Workings

2.16 If the initial investigations reveal that mineral is being mined by a total extraction method in the vicinity of the site, or that the site is underlain by unworked but workable mineral, the possibility and magnitude of future subsidence can normally be established with greater accuracy than for old workings. In the case of coal mining, this is because the roof collapses behind the advancing face as the coal is extracted. Using the established principles of ground movement, subsidence at the surface may then be predicted in position, extent and magnitude, although actual movements when they occur may be influenced by the local geological structure.

2.17 If a new highway structure is to be located over an active coal mine, designers must make provision for the maximum subsidence movements which would affect the structure from individual faces as they are worked and when all the working is complete. For some smaller structures, such as steel footbridges, the best provision may be temporary dismantling during mining operations followed by re-erection afterwards. For others, it may be possible to plan for temporary preventive works to be installed just before mining takes place. For the remainder, permanent provision must be made for the estimated movements and strains in the structural design and detailing in accordance with this Standard. Highway works shall as far as possible be programmed so that construction does not take place while significant movements are taking place.

2.18 In areas of possible future mining activity it may not be possible to ascertain the intended date of extraction or the exact location or direction of advance. Unless the mining authority has advised that there are no plans to extract the mineral in the foreseeable future, designers must make provision for the mining activity. Design should be based on the mine development which, within the context of normal colliery practice, is judged to have the most severe effect on the structure.

Preventive Measures

2.19 It is theoretically possible to develop a mine in such a way that the full effects of ground subsidence do not occur at any particular location. Methods range from the sterilisation of areas of unworked mineral to the harmonisation of extraction operations to reduce travelling and transverse ground strains. While consultation with the mining authority about the possibility of an agreement on mine development is encouraged, designers should accept that permanent constraints on mining activity are, in general, not a realistic option for the sake of highway structures alone.

Principles of Ground Movement

2.20 As a result of many observations by Subsidence Engineers of the National Coal Board and others, the principles of the ground movement which follows the extraction of coal by traditional mining methods are now well established. Less is known about the ground movement which follows the extraction of other minerals.

2.21 When the supports to a coal mine roof are taken away, the immediate roof breaks and falls into the cavity. This collapsed material, being of greater bulk than the natural rock, only extends some 6 to 10 metres above the worked seam. Higher levels of strata tend to sag into a fairly regular trough shaped curve which develops up to the surface and extends with the advancing face.

The area of the ground surface affected is greater than the worked area of the seam. While the majority of measurable subsidence will occur within about 12 months of working, subsequent residual (or time dependent) subsidence, amounting to about 5% of the total amount of subsidence, may continue to occur over the following 6 to 12 months. Residual subsidence is normally not of such magnitude as to influence construction work.

2.22 An empirical method for the prediction of the shape of the subsidence trough is contained in the Subsidence Engineer's Handbook (1975) produced by the National Coal Board Mining Department. This method may be used by engineers as the basis for their assessment of predicted slopes and ground strains above mining activity, but designers are reminded that actual movements may be distorted by the influences of local geology and faulting, old workings nearer the surface, and surface features. In particular, sand or alluvium has been shown to cause movements to spread over a wider area. Predictions of subsidence by the National Coal Board method should be correct to 10% in the great majority of cases, but an intermediate stratum of fractured or fissured limestone or sandstone has been found to affect these predicted movements. Furthermore, because ground flows past the structure, final structural curvatures, slopes and strains after subsidence may not be the same as ground curvatures, slopes and strains.

2.23 Ground movement predictions received from mining operators may be in a form not suitable for direct use in structural design. In making their own assessment of this information in the light of other local knowledge and specialist advice, designers may wish to use other empirical or analytical methods, but any proposal to design for subsidence effects less than those predicted by the mining undertaking will require the approval of the Technical Approval Authority.

2.24 To assist designers in preliminary assessments, Annex A summarises the basic principles of ground movement and empirical subsidence calculation. Use of the annex must not, however, be a substitute for proper consultation and detailed investigation.

3. DESIGN AND DETAILING OF STRUCTURES

Siting and Clearances

3.1 The site of a highway structure is normally dictated by route selection requirements derived from planning considerations and topographical features. Mine development programmes may not be known years in advance, and may be subject to change. It will thus rarely be possible to locate and orientate a highway structure to minimise subsidence effects.

3.2 In applying headroom and clearance standards to structures over highways, railways, navigable waterways, etc, generous allowance must be made for any reduced clearance consequent upon mining movement.

Structural Type

3.3 All structures in mining areas, including relatively flexible reinforced earth structures, must be designed for the effects of the maximum predicted differential movements. Apart from the provision of simple longitudinal articulation and transverse joints, the structural form will not generally need to be specifically influenced by mining considerations, unless the relative displacement between any two points of the structure in any plane exceeds 1/1000 times the distance between these points. For greater displacements the special considerations appropriate to structures in mining areas described in this Standard shall be taken into account in the choice of structural type and the design of structural elements.

3.4 It will rarely be economical to design structural members to resist the effects of large ground movements. In normal circumstances, if a structure is too large to 'ride' the subsidence wave, it should be articulated so that subsidence will have the minimum effect on each member. The aim should be for the structure to remain serviceable during the passage of the subsidence wave, but there may be occasions when repairable damage to minor members and finishes may be acceptable on the grounds of overall economy. Ideally, the structural type should be statically determinate in two or three dimensions with a simple and accessible support system and adequate provision at joints for movement or tilt.

3.5 For retaining walls and bride abutments, reinforced earth structures, being inherently more flexible, may prove to be more economical than other type of structure in areas of mining subsidence. Where the settlement of the structure relative to the ground water level is likely to be substantial, consideration should be given to its effect on the properties of the fill, the maintenance requirements and the risk of added corrosion of any metallic elements. Tensile strain in the ground beneath reinforced earth structures can lead to a tear failure mechanism and must be guarded against. (*Earth Reinforcement and Soil Structures*, Jones.) Durability of these structures and the effect of subsidence on their reserves of strength need careful consideration.

3.6 The design and detailing requirements for each separate part of a bridge or an earth retaining structure and for various types of buried structures are given in the following clauses, 3.8 to 3.45.

3.7 The requirements of BD 57 (DMRB 1.3.7): Design for Durability and the advice given in BA 57 (DMRB 1.3.8): Design for Durability, are to be read in conjunction with the following clauses, 3.8 to 3.45.

Foundations and Substructure

3.8 Piled foundations are not suitable for areas liable to be affected by future mining subsidence. This is because differential vertical subsidence can withdraw end support, disrupt material within the pile group block, and cause shear failure of certain pile types. However, piles may be suitable in areas previously undermined by longwall or pillar and stall methods. The guidance given in CIRIA Special Publication 32, 'Construction over abandoned mine workings' shall be followed.

3.9 To minimise the effects of changes in ground slope and ground strains on foundations, the plan dimensions shall normally be as small as possible. In so doing, consolidation settlement may increase but this is likely to be small in relation to the mining subsidence for which provision has to be made. In some cases, it may be necessary to balance the advantages of a small base against the need to reduce potential problems from high ground pressures under the toe after subsidence has taken place.

3.10 Guidance on the use of raft foundations is given in 'Ground Subsidence' published by the Institution of Civil Engineers.

3.11 Footings shall be constructed at as shallow a depth as possible to reduce horizontal forces induced by ground strains acting on the sides and ends. Exceptionally, it may be necessary to surround the footing or substructure with a protective wall, but trenches excavated closely round the footings will usually suffice to absorb significant compressive strains. Trenches should, however, be used with caution, especially where they may be subjected to tensile strains, as they tend to concentrate ground displacements. Trenches should be filled with a material which will be strong enough to support the trench sides, but more compressible than the surrounding soil. Care must be taken that the trenches do not act as drains causing deterioration of the bearing material.

3.12 A subsidence wave may produce permanent withdrawal of support to a spread footing to an extent dependent on the elasticity of the structure and the foundation material. For reinforced earth structures, it is not necessary to make any allowance for the permanent withdrawal of support. The behaviour of such structures is discussed in 'Reinforced soil in areas of mining subsidence' by Murray et al. However, for any rigid foundation such as a bank-seat built on the top of a reinforced earth abutment or for other types of highway structures, in the absence of a more detailed assessment, it shall be assumed that for a foundation of length L, withdrawal of support may occur over 0.25L from both ends of the footing, or over the central portion of 0.5L. Top and bottom longitudinal reinforcement shall be provided to resist the resulting bending moments under all load combinations. For the most economic design it may be necessary to choose a section incorporating the stem of a leaf pier or abutment wall or, for discrete columns, provide a beam upstand. Bearing capacity calculations must take account of the reduced area of contact.

3.13 To allow for the effects of significant ground strain, a layer of bitumen or polythene sheeting should be placed below spread footings.

A recommended form of construction is (materials to conform to MCHW):

> 75mm blinding ordinary structural concrete (top layer)
> Two layers of sheeting
> 75mm blinding ordinary structural concrete with Class U2 finish
> 150mm 6N or 6P granular fill (20mm max size)

The granular fill may be omitted for footings of maximum dimensions not exceeding 10m in sands or gravels.

3.14 For calculating frictional forces due to ground strain, unless data from appropriate tests are available, the coefficient of friction across a sheeting layer shall be taken to be 0.6. The frictional force may be considered as an eccentric force acting at the bottom of a footing, applied to the full section of the pier, abutment or retaining wall. It may be assumed that this frictional force will occur as a separate loading case from withdrawal of support and, when considered in combination with other permanent loads, an overstress of 50% on elastic concrete and steel stresses may be permitted to allow for the fact that it will occur only during periods of mining movement. For limit state design to BS 5400*, the frictional force obtained from factored dead loads shall be included without further factoring in an additional Combination 5 loading case at the Ultimate Limit State, as defined in BD 37 (DMRB 1.3): Loads For Highway Bridges.
*All references to BS 5400 in this document are to BS 5400 as Implemented by the Overseeing Organisation.

3.15 For spread footings on rock, a layer of granular material giving a bearing capacity less than that of the rock shall be provided between the footing and rock to prevent the occurrence of line support at the footing edge under rotation and integral action between rock and footing. Care shall be taken, however, that granular materials, particularly sands, are not lost into rock fissures.

3.16 Differential vertical subsidence may cause downdrag on buried columns or walls. Where significant downdrag is a possibility, the frictional force must be added to the total load on the footing unless a slip layer is to be added to the columns or walls to limit the effect.

3.17 Rigid materials such as old footings, carriageways or runways, which might normally be left below embankments or structures, shall be broken up or removed before new highway structures are constructed, unless they are assessed to have a beneficial effect by distributing pressures and strains.

Abutments, Retaining Walls and Buried Structures

3.18 Ground subsidence affects earth retaining structures by withdrawal of support, and by imposing horizontal strains and tilts. Withdrawal of support within any one panel between vertical joints can be dealt with as for foundations generally, but for retaining walls - where some settlement is allowable - care should be taken that unrealistic subsidence assumptions do not lead to uneconomic designs. Requirements for the design of reinforced earth retaining walls and bridge abutments are given in clauses 3.25 to 3.32. The rest of this sub-section does not apply to these types of structure.

3.19 Where horizontal ground strains can occur along the line of a retaining wall, dowelled or keyed vertical joints shall be provided at frequent intervals. In no case shall the distance between joints exceed 10m. Where ground strains are significant, a granular sub-base layer and a sliding layer shall be provided below retaining wall bases as for foundations generally.

3.20 A subsidence wave moving across a retaining wall or abutment may produce pressures greater than active at the back of the wall. As an additional case to normal design, and in the absence of a detailed analysis based on the interaction between the soil and the wall under the influence of the predicted horizontal strains, it shall be assumed that the forces on the back of the structure can increase until it moves bodily forward (coefficient of friction on a sheeting layer 0.6), and that a triangular distribution of pressure behind the structure is equal to the sliding force. Passive resistance on the front face of the wall stem and base shall be ignored. In recognition of the transient nature of the pressure increase, and the low probability that the full sliding force will occur, a 50% overstress in the reinforcement and concrete of the wall stem and base may be permitted for this loading case only. For limit state design to BS 5400, the frictional force obtained from factored dead loads shall be included without further factoring in an additional Combination 5 loading case at the Ultimate Limit State, as defined in BD 37 (DMRB 1.3): Loads For Highway Bridges.

3.21 For compatibility with the above assumptions, care shall be taken that yielding of the toe material and failure by overturning will not take place under the above forces. A factor of safety of 1.5 against overturning at the point of sliding shall be provided. Rock or strongly supportive material at the toe shall be removed and replaced by compressible material.

3.22 If, after the passage of a subsidence wave, it is possible that a freely cantilevering abutment wall could become permanently propped by the super-structure, at rest earth pressures shall be used for the normal wall design.

3.23 If a highway structure includes provision for jacking of the superstructure and regrading of the approach roadworks, the increased height shall be used as the basis for the earth pressure calculations of normal wall design.

3.24 Transition slabs shall normally not be provided at the abutments of structures liable to mining subsidence as they are liable to mask any voids or disruption of the fill behind the abutment and increase the difficulty of remedial work.

Reinforced earth retaining walls and bridge abutments

3.25 Reinforced earth structures shall be designed in accordance with BS 8006, as implemented by BD70 (DMRB 2.1): Strengthened/Reinforced Soils and other fills for retaining walls and bridge abutments. When the relative movement of any two points within the structure, with respect to the distance between them, exceeds 1 in 1000, the following additional design requirements shall be applicable.

3.26 The design of any facing shall take into account the effect of movement and additional loading due to subsidence. The joints between the facing units shall be capable of opening and closing as the tensile and compressive phase of the subsidence wave pass. Design of the joint spacing and joint detail shall involve consideration of the following:

(i) Expected differential settlement, and the radii of curvature of the subsidence wave;

(ii) Wall face and individual facing unit dimensions;

(iii) Face material and details, particularly the joints between the various members of the facings;

(iv) Maintenance of effective joint sealing to prevent the loss of backfill material through any gaps resulting from subsidence;

(v) Aesthetic appearance of the facing after subsidence.

3.27 Rigid face detail, load bearing joints or any other detail which depends on panel to panel contact or support shall not be used. Facing posts or other face elements which support movable members for connecting reinforcement, and which could lose contact with such members due to the opening or closing action during the passage of the subsidence wave shall also not be used.

3.28 For relative movements in excess of 1 in 300, vertical movement joints, additional to those between individual facing units, shall be placed at intervals of 5m to 10m along the run of the wall. Movement joint gaps may vary between 50mm and 100mm, and the gap provided shall be calculated ignoring any facing deformation that takes place within the plane of the panel between vertical joints. These vertical movement joints shall also be designed to prevent the loss of fill material through any gaps resulting from subsidence.

3.29 When the predicted relative movement between any two points in the wall exceeds 1 in 300, the at rest earth pressure coefficient K_o shall be used for the calculation of earth pressure and reinforcement tension for internal stability. A 50% overstress in the soil reinforcement and in the components of the facing and the connections may be permitted for this load case only. Furthermore, in such situations, for the calculations of external stability against tilting, the compressive force at the back of the structure shall also be determined using the at rest earth pressure coefficient K_o.

3.30 A special horizontal layer of soil shall be provided below the base of the structure to prevent any propagation of cracking when the reinforced fill and the foundation material are non frictional. This layer shall consist of a 200mm thick layer of granular material of uniformity coefficient of 5 or more and with the maximum particle size not exceeding 25mm. An alternative is to provide a layer of suitable geotextile material such as those used for soil reinforcement. Where such special layers are used, the resistance to sliding shall be assessed using the interface friction between this layer and the adjacent soil.

3.31 Strip footings supporting the facings shall be detailed in accordance with clauses 3.11 to 3.13, as required for spread footings, except that the granular blinding may be omitted. Possible interaction between a reinforced earth structure and any adjacent rigid structure such as a concrete abutment shall be considered. Where necessary, a layer of compressible fill may be interposed.

3.32 Experience shows that mining subsidence can seriously damage service ducts, drainage channels and pipes, which may lead to erosion of backfill materials. Where there is a corrosion hazard, rupture of drainage can have a particularly adverse effect on reinforced earth structures.

Buried Structures

3.33 Buried structures which retain fill, such as subways or culverts, shall be designed for passive pressures unless a layer of compressible material is to be provided. In the latter case, design shall be either to the pressures obtained by consideration of the characteristics of the layer material under the maximum predicted compressive strain, or at rest earth pressures, whichever is the greater. For permissible stress calculations which include passive earth pressures or pressures derived from predicted strains, a 50% overstress on elastic concrete and steel stresses may be permitted. For limit state design to BS 5400, γ_{fl} shall be taken as

1.15 for these pressures, at the Ultimate Limit State. This is an exception to BD 31 (DMRB 2.1): Buried Concrete Box Type Structures. As with retaining walls, subways and culverts shall be divided into short lengths with the distance between joints not exceeding 10m.

3.34 The behaviour of corrugated steel buried structures (BD 12 (DMRB 2.2)) during and after mining subsidence is largely unknown. For the time being, any proposal to use such structures shall be dealt with as a departure from standards and each case shall be treated individually. Approval may be given if supported by any research work on the subject.

Superstructure

3.35 The supports to a highway bridge superstructure may be subjected to any of the following effects:

(a) Differential horizontal displacement along the longitudinal centre-line;

(b) Differential horizontal displacement transversely;

(c) Differential vertical displacement;

(d) Differential tilt in the vertical plane of the bridge about the longitudinal centre-line;

(e) Differential tilt transversely;

(f) Differential plan rotation.

Where subsidence calculations show any of these effects to be significant, consideration shall be given to the provision of suitable structural articulation and jointing to eliminate the structural implications for the bridge superstructure. (But see 3.36 below.) Any loads derived from residual differential movements shall be considered as permanent for load combination purposes.

3.36 In view of the durability problems associated with deck expansion joints, consideration should first be given to the use of continuous structures even when mining subsidence is predicted.

However, where continuous structures are unsuitable, simply supported spans on bearings capable of accepting the likely magnitude of displacement and rotation may provide an acceptable solution. A superstructure of this type can be designed to be immune to all of the effects except differential transverse tilt between span supports. Where the degree of differential transverse tilt is small, any type of beam-slab construction without diaphragms, including prestressed concrete box beams, is suitable. For larger differential tilts, beams of lower torsional stiffness such as steel beams, or precast prestressed concrete beams, may be satisfactory.

3.37 For the highest degrees of differential transverse tilt, a deck supported at three points should be considered. Subsidence of any one support point relative to the others causes such decks to tilt without inducing stress, but they need to be stiff in bending and torsion.

3.38 For long span bridges, where simple support may not be economical, consideration may be given to moment reduction by the use of cantilevers and suspended spans, provided that the deck torsions and eccentric loadings at the half joints resulting from differential transverse tilt can be accommodated in the design. Half joints should be pinned, and movements due to mining accommodated at the abutments.

There are serious maintenance problems with half joints and they shall not be provided unless absolutely unavoidable. The agreement of the Overseeing Organisation must be obtained.

Articulation, Bearings and Expansion Joints

3.39 Provision for the longitudinal deck movement of highway bridges shall normally be made at the abutments, with spans pinned at the piers. Multispan structures may, however, require alternate pinned and free articulation. Exceptionally, for three-dimensional statically determinate structures, or for structures with intermediate piers hinged at the base, it may be necessary to anchor spans longitudinally by reinforcement concentrated at the deck centre-line - but such joints are difficult to inspect and repair.

3.40 Intermediate piers hinged at the root shall only be considered where normal impact requirements and progressive collapse considerations allow, and where any likely permanent tilt after mining movements is sufficiently small as to be both visually and structurally acceptable.

3.41 All bearing seating gaps shall be detailed with generous allowance for the full predicted movements, with faces battered or chamfered as necessary to allow for rotation and differential tilt of structural elements.

3.42 Bearings, which shall be chosen to accommodate the increased rotations, displacements and forces resulting from mining movements, shall be specified and detailed with a view to ease of future replacement, reseating or resetting. Lateral restraint at sliding bearings shall be provided where required by special bearings, dowels within slots, or inclined bearings within V-notches. Provision for severe mining movements by three-point systems may require the use or development of special bearings.

3.43 Concrete hinges shall not be used. They are difficult to inspect and remedial works are a problem when they fail.

3.44 Small, longitudinal mining movements can be accommodated at normal expansion joints designed to allow for the increased displacement. Larger movements will need special joints at surfacing level to permit normal thermal variations and the passage of traffic at all displacements within the design range. All structures should have a generous gap - say 300mm - between the superstructure and the abutment wall, or between spans at an expansion joint, with the expansion joint supported where necessary on concrete nibs which can be cut back if necessary to free the joint during or after mining movement.

3.45 Parapet rails shall be provided with expansion/contraction provision at all deck movement joints, or be made capable of disconnection during periods of mining activity if traffic containment can be provided by alternative means.

4. MONITORING

4.1 Structures liable to move during mining activity shall be detailed so that the maintaining authority can readily monitor levels, dimensions, tilts and crack development. For this purpose, the maintaining authority shall be consulted at an early stage in design. Guidance is given in 'Ground Subsidence' published by the Institution of Civil Engineers.

4.2 In providing adequate access to all parts of the structure, particular attention shall be given to the need to inspect, replace, or carry out jacking at bearings.

4.3 Provision for levelling may require the installation of purpose-made levelling stations, and possibly a stable datum outside the plan limit of influence of the working.

5. PROVISION FOR REMEDIAL WORK

5.1 Consideration must be given to the likely need for future re-levelling and special provision made as necessary. Jacking provision can be costly and care shall be taken that the expense is justified. The cost may normally be minimised by providing numerous jacking points to match the superstructure reactions. If large jacks are unavoidable, the provision of winch anchorages for easier handling should be considered.

5.2 Lifting during jacking must take place without the bridge deck jamming against the substructure. Joints and seatings shall be detailed with larger clearances as necessary. If possible, gaps shall be detailed to become wider as a lift proceeds, making allowance for the rectification of tilt.

5.3 Clearances and jacking plinth dimensions shall allow for alternative jacking systems, and a minimum tolerance of 30mm on the height of jacking pockets, plus constructional tolerances, is recommended. Dimensions should allow for jacks to act at not more than two-thirds of the specified working load. It should be recognised that jacking equipment changes over the years.

5.4 For bridges where jacking or support from shoring towers may be necessary, consideration shall be given to the provision of suitable hard standings.

5.5 The maintenance manual shall be written for all structures. The as-built drawings must clearly show any jacking positions and jacking loads, together with levels and alignments at the completion of construction. The drawings should also show the sites of the permanent levelling stations. The maintenance manual should have provision for maintenance and survey work to be recorded at a later date.

6. DRAINAGE AND SERVICES

6.1 Mining subsidence can have a major effect on natural hydrological networks and consideration shall be given to the effect of changed ground slopes on bridge deck and abutment drainage. Drainage runs shall be as short as possible and installed at generous slopes. Wherever possible, appropriate provision shall be made for bridge drainage to outfall in the opposite direction should subsidence change the direction of fall. Unless allowance has been made in design, care shall be taken that retained or superimposed fills cannot become saturated and so impart additional loads to the structure.

6.2 Ground movements may damage or otherwise affect any drainage within the structure. This can potentially have very adverse effects on all types of retaining structures. Provision shall be made for the protection of all services within or adjacent to highway structures in mining areas by the use of flexible supports and articulation and expansion joints. Service Utilities shall be consulted for this purpose.

6.3 Further guidance is contained in ‘Ground Subsidence’ published by the Institution of Civil Engineers.

7. REFERENCES

7.1 The following documents are referred to in the text:

1. The Design Manual for Roads and Bridges (DMRB). Stationery Office Ltd.

BD 37 Loads for Highway Bridges. (DMRB 1.3).

BD 57 Design for Durability. (DMRB 1.3.7).

BA 57 Design for Durability. (DMRB 1.3.8).

BD 31 Buried Concrete Box Type Structures. (DMRB 2.1).

BD 70 Strengthened/Reinforced Soils and other Fills for Retaining Walls and Bridge Abutments. (DMRB 2.1).

BD 12 Corrugated Steel Buried Structures. (DMRB 2.2).

HA 34 Ground Investigation Procedure. (DMRB 4.1).

HD 13 Documentation Requirements for Ground Investigation Contracts. (DMRB 4.1).

HD 22 Ground Investigation and Earthworks - Procedure for Geotechnical Certification. (DMRB 4.1.2).

2. Manual of Contract Documents for Highway Works (MCHW). Stationery Office Ltd.

MCHW 1 Volume 1: Specification for Highway Works.

MCHW 5.3 Specification for ground investigation for highway works.

3. Geological Memoirs, British Geological Survey. Stationery Office Ltd.

4. BS 5930: 1981 British Standard Code of Practice for Site Investigations. BSI.

5. Site Investigation Manual. CIRIA Special Publication 25.

6. Coal Industry Act 1994. Stationery Office Ltd.

7. Subsidence Engineers' Handbook (1975). National Coal Board Mining Department.

8. Earth Reinforcement and Soil Structures. Colin JFP Jones. Butterworths Advanced Series in Geotechnical Engineering.

9. Construction over abandoned mine workings. CIRIA Special Publication 32.

10. Ground Subsidence. Institution of Civil Engineers. 1977.

11. Reinforced soil in areas of mining subsidence. R T Murray, C J F P Jones and R J H Smith. 12th International Society for Soil Mechanics and Foundation Engineering. Rio de Janeiro. 1989.

12. BS 5400: Steel, Concrete and Composite Bridges. BSI.

13. BS 8006: Code of practice for Strengthened/Reinforced soils and other fills. BSI.

14. Site Investigations in Areas of Mining Subsidence. FG Bell. Newnes - Butterworths.

15. Review of effects of mining subsidence on reinforced earth. TRRL Contractor Report 123, C J F P Jones.

7.2 The following documents provide useful information:

1. Pile Design and Construction Practice. MJ Tomlinson. Viewpoint Publications.

2. Structures in Areas of Mining Subsidence. J D Geddes and D W Cooper - Institution of Structural Engineers, March 1962.

3. Bridge Design in Areas of Mining Subsidence. F A Sims and R J Bridle. Institution of Highway Engineers, November 1966.

4. Computer Predictions of Ground Movements due to Mining Subsidence. C J F P Jones and J B Bellamy. Geotechnique 23 No. 4 1973.

5. Prediction of Ground Movement in Areas of Mining Subsidence. B I G Barr and R Delpak. Institution of Highway Engineers June 1974.

6. Ground Movements and Structures. Proceedings of the Conferences held at University of Wales, Institute of Science and Technology, Cardiff, July 1977 and April 1980.

7. Some Observations on Swallow Holes and Mines in Chalk - G West and M J Dumbleton. The Quarterly Journal of Engineering Geology Vol 5, Nos 1 and 2 1972.

8. Coal Mining Subsidence Act 1991, Stationery Office Ltd.

9. The Response of a Reinforced Earth Wall to Differential Settlement. KC Brady, MJ Greene, DA Barratt and PJM Bullman. TRL.

10. Mining Subsidence Engineering, Helmut Kratzsch. Springer - Verlag.

11. Soil Structure Interaction. The real behaviour of structures. Institution of Structural Engineers. 1989.

12. Bridges - Design for improved durability. CIRIA Report 155.

13. Design and construction of joints in concrete structures. CIRIA Report 146.

Many other references will be found listed in those given above.

8. ENQUIRIES

Approval of this document for publication is given by the undersigned:

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All technical enquiries or comments on this document should be sent in writing as appropriate to the above.

ANNEX A

METHOD FOR SUBSIDENCE CALCULATION

A1. Introduction

An approximate method for subsidence calculations is given in this Annex. It is based on the method given in the Subsidence Engineers' Handbook (NCB 1975) with adaptations derived from the references given in section 7.1 of the main text. Most, but not all, of the symbols correspond with those used in the handbook.

The method is considered to be appropriate for the majority of structures over Coat Measure strata, but designers should satisfy themselves that it is applicable for any particular site. The method calculates the basic ground movements which develop at the surface resulting from the underground extraction of coal. It should not be used without reference to a mining engineer where the prediction is complicated by the presence of any of the following features:

(a) Extraction of minerals other than coal;

(b) Extraction of any method other than the 'longwall' method;

(c) Old mine workings at shallower depth;

(d) Overlying strata of unusual configuration, faulting or hardness;

(e) Steeply sloping ground surface;

(f) Workings of irregular shape in plan, or of face advance less than 1.4h;

(g) Workings having centre gates or other zones of special packing apart from those at the main and tail gates;

(h) Shallow, highly inclined workings;

(i) Coincident ribsides with earlier working in the same seam.

A2. Information Required

Thickness of seam (m).
Depth of seam (h).
Dip of seam (α).
Position of working face in plan.
Width of working face (w).
Rate and direction of working.
Date of future working.

A3. Limit Angle (ξ)

Vertical subsidence, which in the case of a level seam is at a maximum over the centre of the working, normally diminishes to zero at a maximum distance of 0.7 times the depth of the seam (h) outside the limit of extraction, ie in level seams at a 'limit angle' of 35^{o} from the vertical.

Workings outside an area of influence defined by a circle in level seams of diameter 1.4h, centred about a surface point cannot cause subsidence at that point. Likewise, maximum possible subsidence at a point on the surface will only occur if all the mineral within the circle of influence of that point is extracted (see Figures 1 and 2).

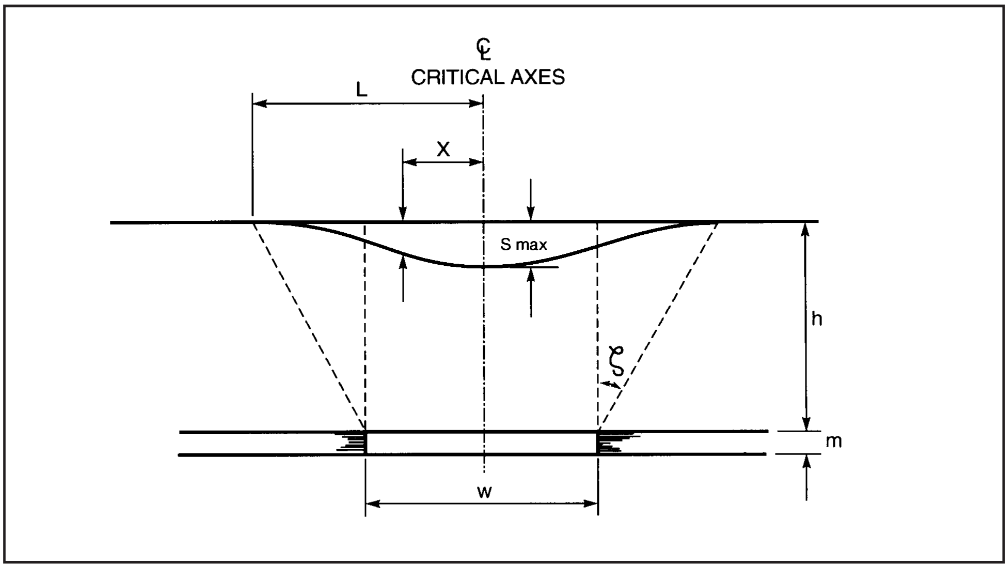

Figure A1 Symbols

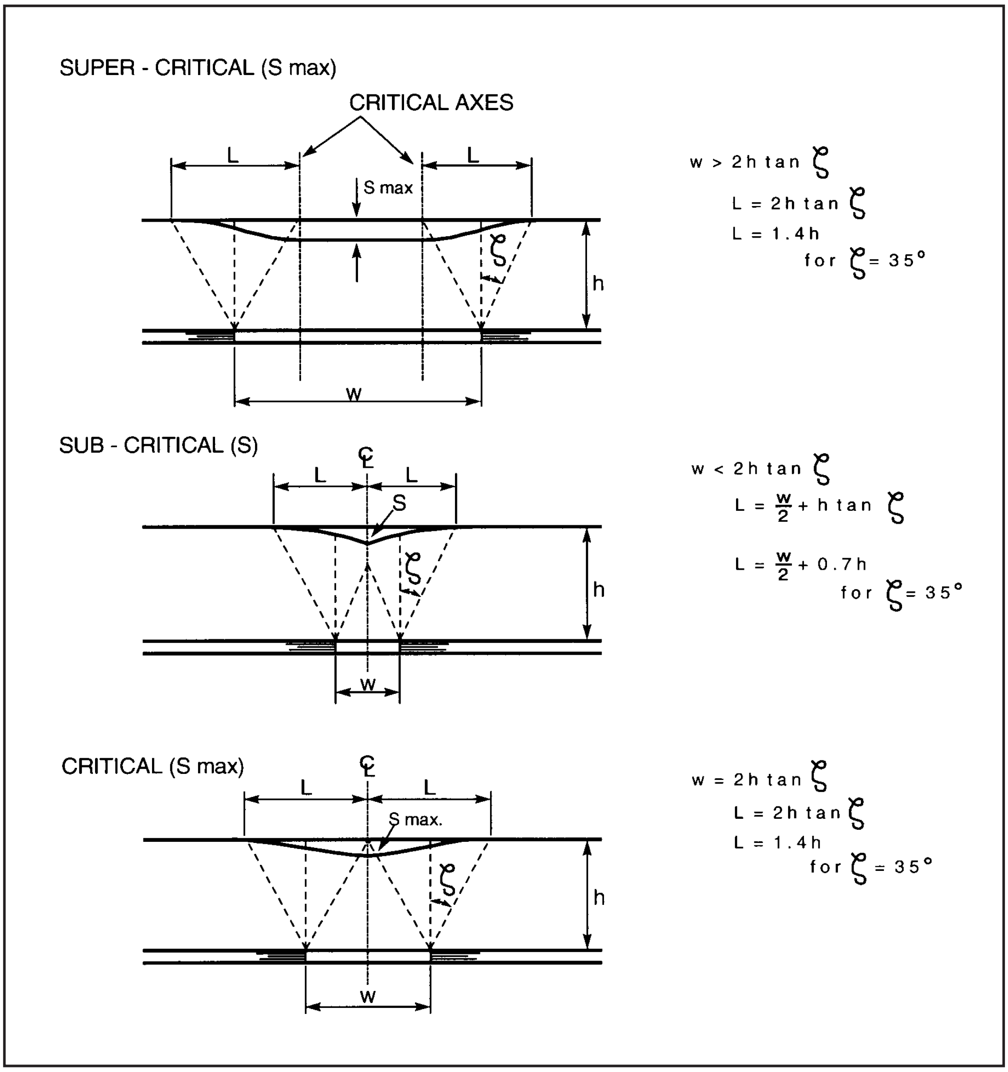

Figure A2 Limit of Curvature of Subsidence Profile (L)

A4. Subsidence Development and Influence

The limit of Subsidence Development is approximately 0.7h in front of, and 0.7h behind, a working face.

The limit of Subsidence Influence on each side of a panel is defined in Figure 2.

NB: In Figure 2, L is the distance from zero to maximum subsidence and is, therefore, not the total distance from zero subsidence to the panel centre where w/h > 1.4.

A5. Maximum Possible Vertical Subsidence (S max)

The maximum possible vertical subsidence which can occur when complete mineral extraction and subsequent roof caving has taken place within the circle of influence is 90% of the seam thickness.

ie S max = 0.9m

A6. Maximum Vertical Subsidence (S) in Relation to the Width/Depth Ratio (w/h)

For a given width of working (w), the maximum vertical subsidence (S) decreases with increased seam depth (h) once w/h becomes sub-critical. The value of S may be calculated for sub-critical subsidence profiles from Figure 3.

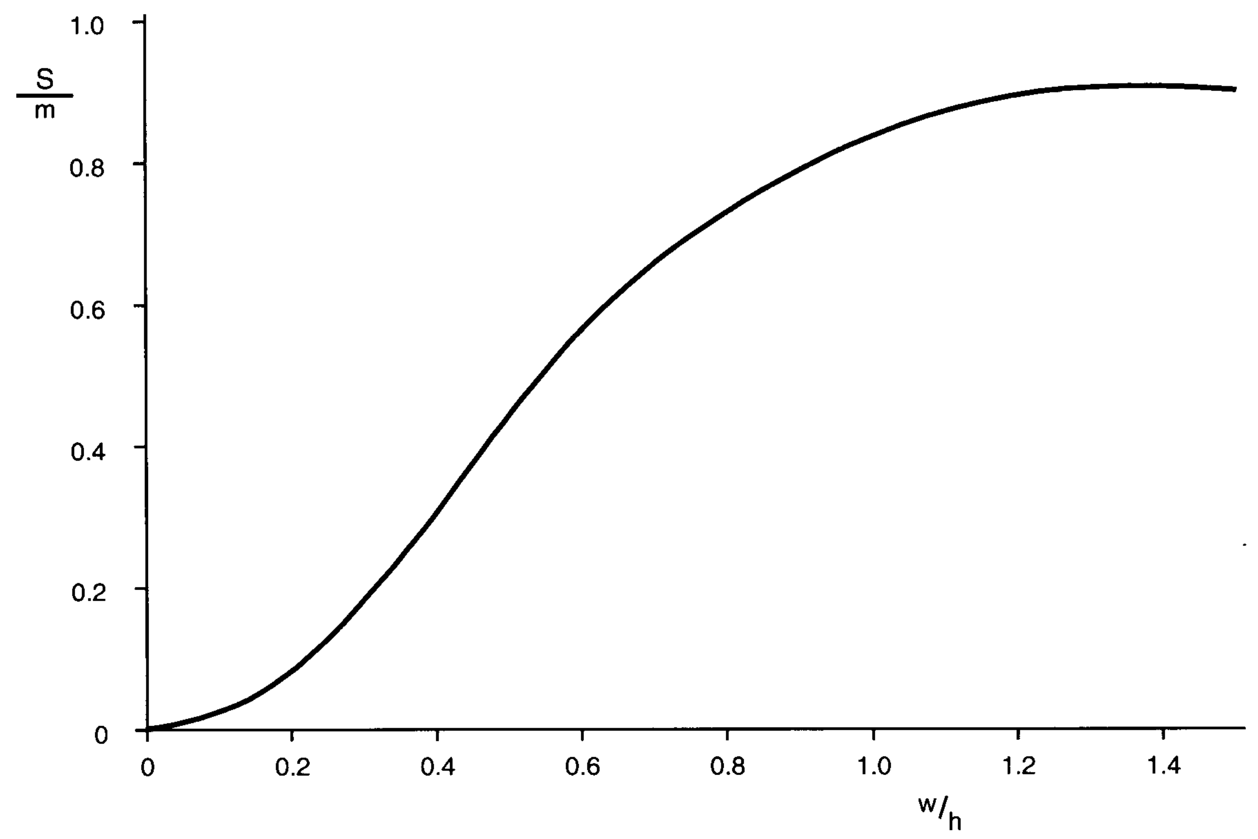

Figure A3 Subsidence at Various Width/Depth Ratios of Extraction

A7. Vertical Subsidence (s) away from the Centre Point of the Working

The vertical subsidence (s) distance X from the centre of working may be expressed as:

$s = K_1$ S max where w/h ≥ 1.4
$s = K_1$ S where w/h < 1.4

The coefficient K_1 is plotted against X/L for two values of w/h in Figure 4.

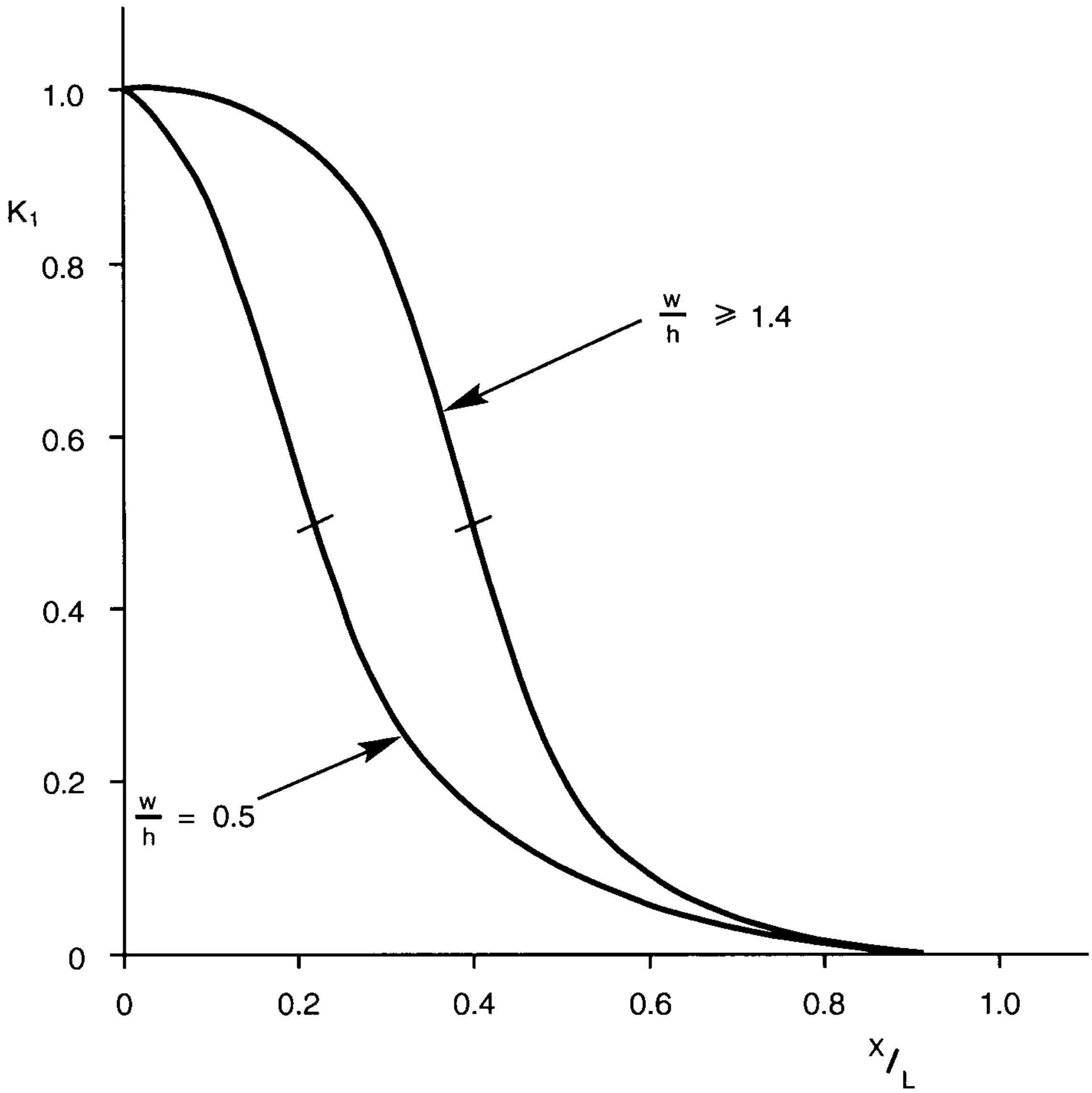

Figure A4 Vertical Subsidence Away From Centre Point or Critical Axis

A8. Horizontal Displacement (V)

The horizontal displacement (V) associated with a vertical subsidence (S) at a distance X from the critical axis is given by:

$V = K_2$ S max where w/h $\geq$ 1.4
$V = K_2$ S where w/h < 1.4

The coefficient K_2 is plotted against X/L for 3 values of w/h in Figure 5. All final horizontal displacements are towards the central section of the working.

From Figure 5, it follows that, for w/h $\geq$ 1.4

V max = 0.168 S max at X = 0.4L

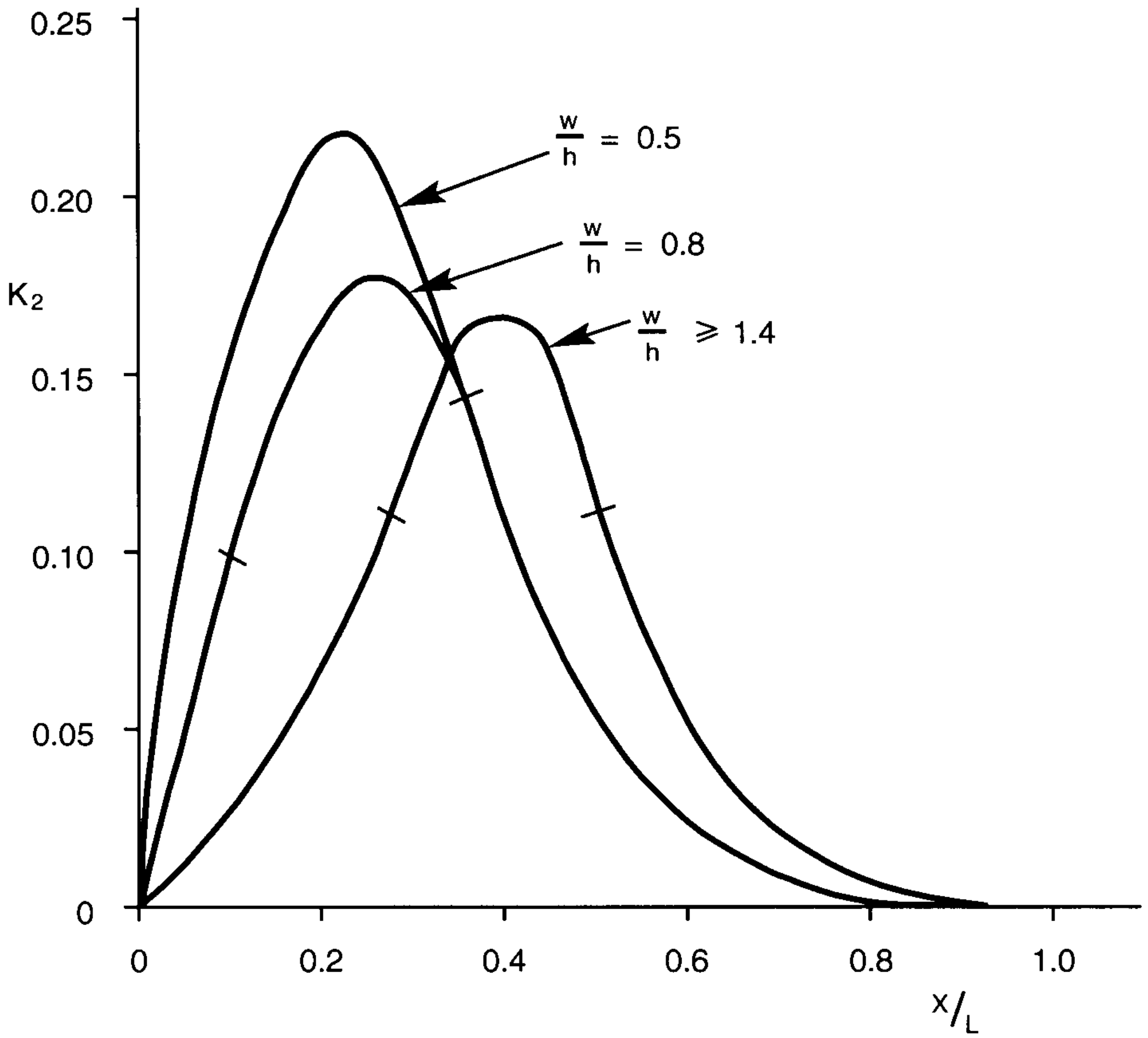

Figure A5 Horizontal Displacement

A9. Horizontal Strain (± E)

Horizontal strain, or change in unit length (± E), can be derived from horizontal displacement by considering 2 points a small distance apart (l), (see Figure 5).

ie Strain $\pm E = S \max dK_2/l$ for $w/h \geq 1.4$
Strain $\pm E = S\, dK_2/l$ for $w/h < 1.4$

It can be seen from Figure 5 that for w/h = 1.4 the maximum compressive strain occurs at a distance of about 0.28L from the critical axis, that the maximum tensile strain occurs at a distance of 0.5L from that axis. For w/h = 0.5, the maximum compressive strain occurs at the critical axis.

A more accurate estimate of strain, particularly for tensile strains where w/h < 0.6, may be obtained from the expression:

$\pm E = K_3\, S/h$

The coefficient K_3, for tensile strain, and for compressive strain, is plotted against w/h in Figure 6.

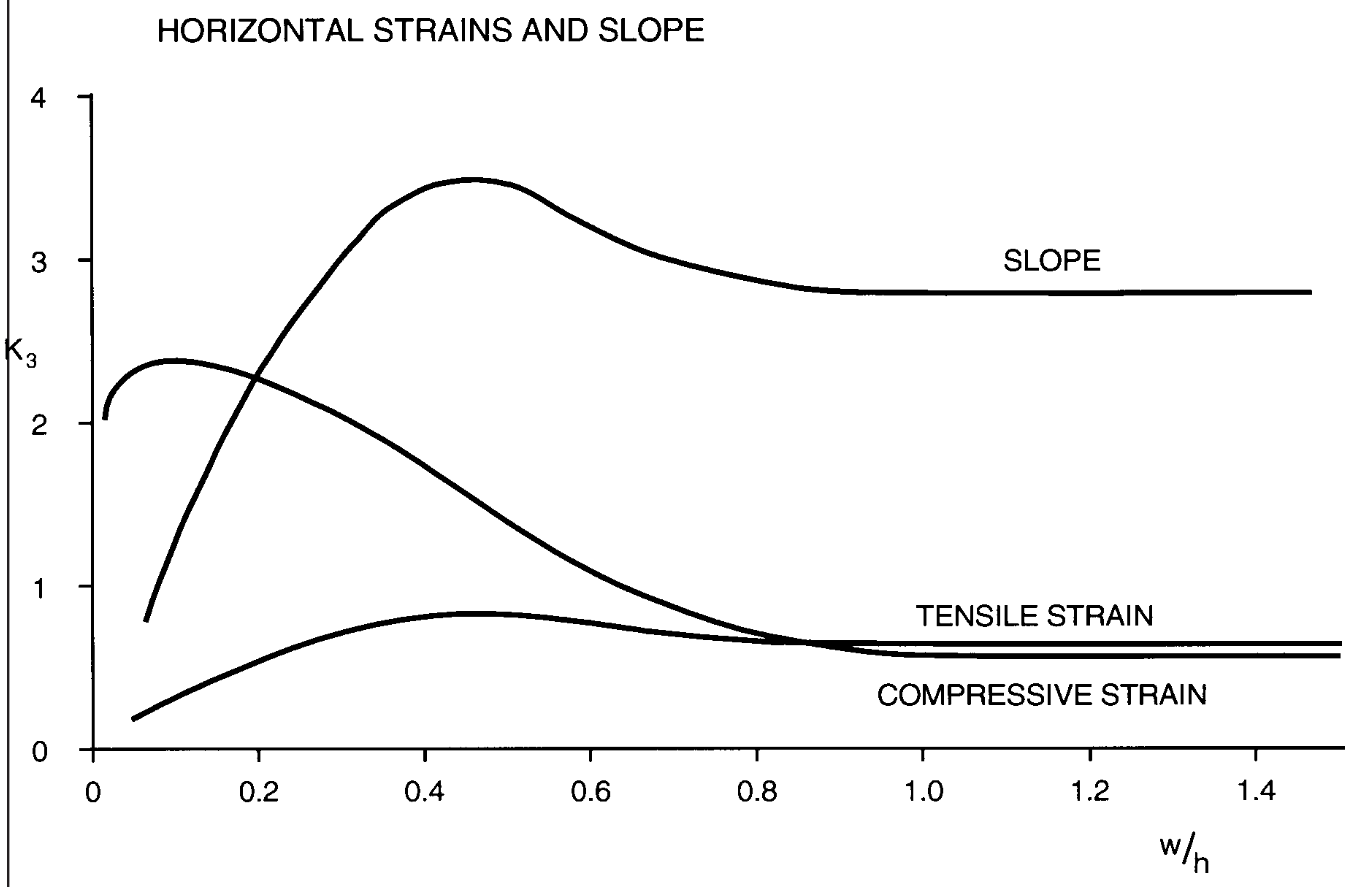

Figure A6 Horizontal Strains and Slope

A10. Ground Slopes or Rotations (G)

Change in ground slope, or rotation (G), can be derived from vertical subsidence by considering 2 points a small distance apart (l) in Figure 4.

ie Rotation $G = S\ dK_1/l$ where $w/h < 1.4$

It can be seen from Figure 4 that for $w/h \geq 1.4$ the maximum possible rotation (G max) occurs at a distance of about 0.4L from the critical axis.

ie Rotation $G\ max = S\ max\ dK_1/l$

A more accurate estimate of maximum rotation in a subsidence trough may be obtained from the expression:

$G = K_3\ S/h$

The coefficient K_3 for slope is plotted against w/h in Figure 6. From Figure 6 it follows that the maximum possible slope, ie for $w/h \geq 1.4$ is given by:

$G\ max = 2.75\ S\ max/h$

A11. Ground Curvature

Ground curvature may be calculated from the vertical subsidence at points a short bay length apart by the expression:

Radius of curvature (ρ) = Bay length ^{2}/Second difference of vertical subsidence.

A12. Dipping Seams

Extraction in inclined seams displaces the subsidence trough in the direction of the deeper part of the workings. For shallow workings the maximum subsidence actually occurs over the rise side of the panel centre. This phenomenon may be explained by the fact that the upper part of the extraction is so much shallower than the other part that a greater amount of subsidence is caused over the former; with deeper workings the difference in depth between the upper and the lower halves of an extraction becomes insignificant. However, for the majority of workings at moderate or considerable depth, where the dip does not exceed 30%, allowance may be made for inclined seams by assuming that the limit angle of 35^o is measured from the normal to the seam (see Figure 7). The subsidence profile of each half of the working should be estimated separately and a smooth transition drawn.

A13. Moving Faces

It may be assumed that no time-lag occurs between the extraction of mineral and the onset of subsidence, ie the limit of subsidence in front of a moving face is at a distance of 0.7h from that face.

A14. Additional Face and Seams

It may be assumed that the principle of superposition applies in the case of panels separated by stable pillars or in different seams, and that the total subsidence at any point in such cases is the algebraic sum of all individual subsidence effects. The principle of superposition does not apply when the edges of two adjacent panels coincide nor when the intervening pillar between panels is so small as to be subject to pillar failure.

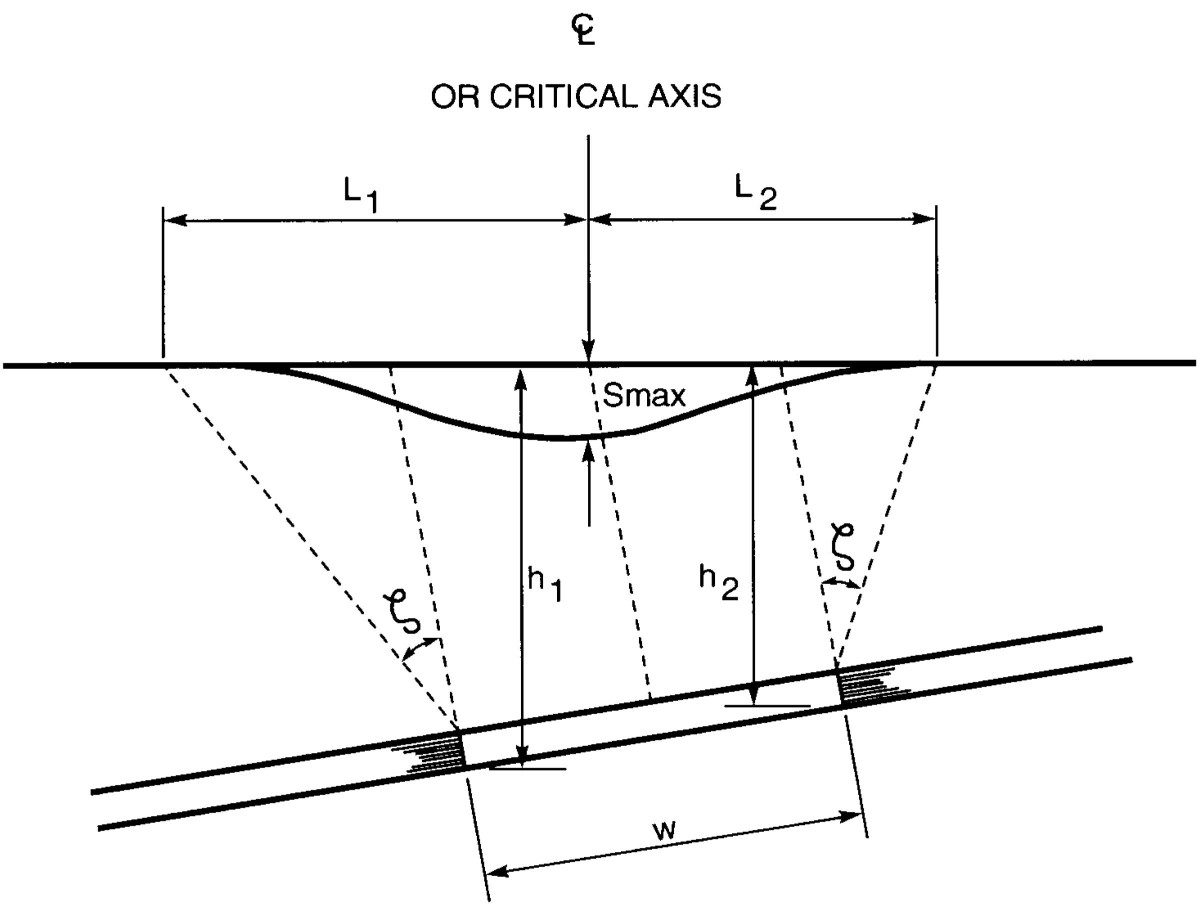

Figure A7 Dipping Seams