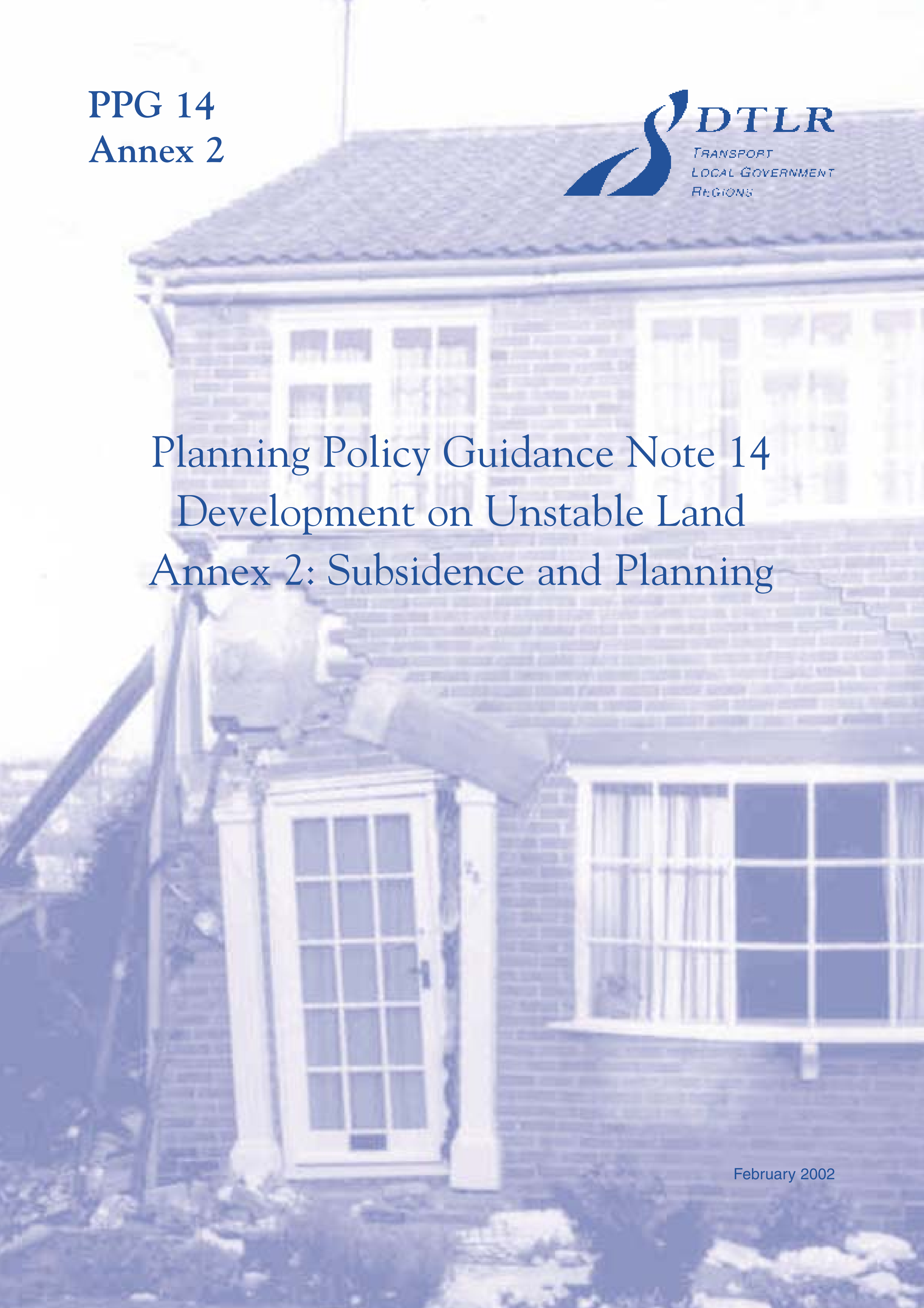
PPG 14
Annex 2

DTLR
Transport
Local Government
Regions



Planning Policy Guidance Note 14
Development on Unstable Land
Annex 2: Subsidence and Planning

February 2002

PPG 14
Annex 2

DTLR
Transport
Local Government
Regions

Planning Policy Guidance Note 14
Development on Unstable Land
Annex 2: Subsidence and Planning

February 2002

London: The Stationery Office

Department for Transport, Local Government and the Regions
Eland House
Bressenden Place
London SW1E 5DU
Telephone 020 7944 3000
Internet service http://www.dtlr.gov.uk

ISBN 0 11 753628 8

Printed in Great Britain for The Stationery Office
Printed on material containing 75% post-consumer waste and 25% ECF pulp.
82579 C30 02/02 698429 02/02

Planning Policy Guidance
Development on Unstable Land

Annex 2: Subsidence and Planning

Planning Policy Guidance Note 14 set out the broad planning and technical issues to be addressed in respect of development on unstable land; Annex 1 developed that guidance in relation to landslides and unstable slopes. This second Annex to PPG 14 deals with problems caused by subsidence and should be read in conjunction with it. It replaces and extends Minerals Planning Guidance Note 12 *Treatment of disused mine openings and availability of information on mined ground*, which is hereby cancelled.

This guidance advises that:

- local planning authorities should identify areas where consideration may be needed of the potential impact of subsidence on development;

- within these areas, policies should seek to minimise the impact of subsidence by controlling or restricting development where appropriate;

- policies in development plans should outline the consideration which will be given to subsidence, indicating any information that will be required to be provided in support of planning applications; and

- where appropriate, planning applications should be accompanied by a stability report which demonstrates that the site will not be affected by subsidence or that the development will be able to withstand the effects of any subsidence that takes place.

Appendices advise on causes and distribution of subsidence, relevant research on subsidence potential on a national and locally targeted basis, mitigation of subsidence and treatment of mine openings, appropriate data systems for information on mined ground and on the contents of stability reports.

CONTENTS

2B: RELEVANT RESEARCH ON SUBSIDENCE POTENTIAL

2C: MITIGATION OF SUBSIDENCE AND TREATMENT OF MINE OPENINGS

2D: INFORMATION ON MINED GROUND AND MINING DATA SYSTEMS

2E: CONTENT OF STABILITY REPORTS

BIBLIOGRAPHY

Introduction

1. It is the policy of the Government to encourage the full and effective use of land within the framework of its policies for sustainable development. In particular, the maximum beneficial use should be made of previously developed land. However, this aim may be hindered where land is liable to subsidence due to underground cavities or to variable ground conditions of both natural and human origin. Subsidence may damage or destroy existing buildings and structures and threaten public safety. It can also lead to increased costs of construction or even the abandonment of development and dereliction.

2. Identification of such problems in advance allows the risks of subsidence to be avoided or minimised by the use of appropriate remedial or preventive measures. Given proper safeguards, land which has been made unstable by previous mining or other industrial activities, or which is naturally liable to subside, can be put to suitable uses. This contributes to the Government's objectives for sustainable development through economy and efficiency in the use of land.

Purpose of this Annex

3. This guidance advises local planning authorities, landowners, and developers on the exercise of planning controls over land use and development on land liable to subsidence. The Government looks to all parties to the development process to:

- recognise the occurrence and potential for subsidence at the earliest possible stage in preparing development plans and in considering proposals for development;

- take appropriate action in accordance with good practice to assess the risks of subsidence and, where practicable, to deal with them by ground treatment or by designing new buildings and structures to withstand the subsidence expected;

- take due account of the constraints imposed by ground subsidence at all stages of the development process; and

- ensure that new development is suitable for the ground conditions at its location and will not be threatened by subsidence in the future.

4. This Annex should be read in conjunction with Planning Policy Guidance (PPG) Note 14 *Development on unstable land*, which sets out the Government's policy and the wider planning and administrative issues. It is a companion to PPG 14 Annex 1 *Landslides and planning*. It replaces and extends Minerals Planning Guidance (MPG) Note 12 *Treatment of disused mine openings and availability of information on mined ground*, which is hereby cancelled.

Problems due to subsidence

5. Subsidence is common in England. Its causes and distribution are described in Appendix 2A. Subsidence varies in scale from the sudden collapse of ground into mineshafts or shallow voids (either natural cavities or due to mine workings) to the more general subsidence associated with deep coal mining. Similar effects arise from the settlement of ground due to consolidation of near-surface materials or to shrinking and swelling of certain clays with seasonal variations in moisture. Loss of life is fortunately rare, although it does occur occasionally. Life may be threatened through the appearance of holes in the ground, collapse of buildings or structures, or the fracturing of gas mains and other services. Subsidence can also open pathways by which hazardous gases and other pollutants may move, increasing the risks of contamination. Subsidence within alluvial or coastal flood plains can increase the risk of flooding, as well as producing low-lying areas that do not drain.

6. Subsidence is an important cause of damage to buildings. The resulting insurance claims have, in recent years, reached £300-500 million per annum. Within the active coalfields, where subsidence is a continuing feature of deep longwall mining operations; damage is subject to the provisions of the Coal Mining Subsidence Act 1991. Damage may require expensive remedial action or, in the worst cases, result in loss of buildings or structures. Subsidence in the course of development causes delays and increased costs. In most cases, however, the potential for subsidence can and should be foreseen as part of the professional work in preparing development proposals. The risk of damage and additional costs, therefore, should largely be avoided. The costs of investigation and precautionary or remedial measures are generally more than offset by the savings in terms of construction costs, damage and repair, disruption or destruction that would otherwise occur.

Strategies for dealing with the problems

7. A number of well recognised responses to the problems of subsidence can be appropriate depending on the circumstances. These include emergency response and crisis management, planning for losses, modifying the hazard and controlling the effects. Since subsidence can happen unexpectedly, an emergency-response and crisis management strategy should be drawn up to cope with events affecting existing development. Planning for losses under the provisions of the Coal Mining Subsidence Act 1991, as amended by the Coal Industry Act 1994, is long-established and familiar in the coalfield districts. For other types of subsidence, most household insurance policies and many industrial and commercial buildings policies provide cover, though these may be subject to premium rates, exclusions and excess provision reflecting the degree of risk in particular areas.

8. Modifying the hazard generally involves some form of engineering treatment of the ground to reduce the potential for subsidence to occur. This can often constitute good practice for new developments. Such treatment has also been applied to existing development threatened by subsidence, eg, by infilling abandoned mine voids or other action by local authorities under the former derelict land programme (now the land stabilisation programme operated by English Partnerships). The effects of subsidence can be avoided by not developing in areas at most risk and controlled by incorporating appropriate preventive or precautionary measures in the design of new buildings or structures or modifying existing developments. While all these responses have their place and should continue to be applied, controls on proposed development and land use through the Building Regulations and the planning system are the most effective means of minimising the effects of subsidence on new development.

BUILDING REGULATIONS

9. Engineering controls are generally specific to particular structures. They are intended to make them better able to withstand the effects of subsidence. The Building Regulations 1991 specify in Requirement A2 of Schedule 1 that:

> "The building shall be constructed so that ground movement caused by -
>
> (a) swelling, shrinkage or freezing of the subsoil; or
>
> (b) landslip or subsidence (other than subsidence arising from shrinkage), in so far as the risk can be reasonably foreseen,
>
> will not impair the stability of any part of the building."

10. However, these Regulations relate only to buildings and controlled services or fittings. Some buildings, not occupied by people, are exempt. A wide range of other activities that may be affected by subsidence or that may, by changing groundwater conditions, trigger the occurrence of subsidence, do not require approval under the Building Regulations. Nor can the Regulations be used to enforce maintenance of a property in order to ensure that the effects of any subsidence are minimised.

11. While a wider consideration of subsidence has been introduced into the Building Regulations since the publication of PPG 14 in 1990, they do not cover all developments. Reliance on building control procedures alone will, therefore, limit the consideration given to subsidence across the full range of potential land uses. The Regulations cannot ensure that all the issues relevant to subsidence are taken into account before development takes place. An active planning response, closely co-ordinated with the operation of the Building Regulations, is required to ensure that adequate consideration is given to the issues of subsidence when considering proposals for development and changes in the use of land.

PLANNING

12. Planning responses to subsidence should be specific to individual developments as well as relating to wider areas of land through policies in development plans. It is material in

planning terms to assess whether a development will be affected by subsidence and, where appropriate, to consider the acceptability of any proposed mitigation measures. A precautionary avoidance strategy can seldom be justified on risk grounds, since most potential subsidence problems can be minimised by careful site investigation followed by appropriate ground treatment or the adoption of sufficiently robust foundation and/or superstructure designs. However, except for the most prestigious developments, or those that would be particularly sensitive to subsidence, such comprehensive measures may not always be justifiable in terms of cost. In such cases, the costs of mitigation may be so high that avoidance of land liable to subsidence by certain types of development might be the basis for finding a more effective, economical and, therefore, sustainable use of land. For example, built development on some previously developed land may be so costly that agriculture, woodland or recreational/amenity uses may be more appropriate.

RESPONSIBILITIES AND LIABILITIES

13. Landowners and developers should ensure that their land and developments are safe and will not put people at risk. The planning system is concerned with the public interest rather than the interests of individuals. It is for the developer to demonstrate that the effects of subsidence will not be unacceptably adverse or that they can be successfully mitigated. Developers should seek appropriate expert advice and procure any necessary technical investigations to ascertain the effects of subsidence on their proposed developments and how they can be mitigated. The local planning authority should then consider proposals in the light of that advice and such consultations as it considers necessary alongside other material considerations in reaching decisions on policies and proposals in development plans and on whether applications should be permitted.

14. Landowners generally have a Common Law right of support for land in its natural state, except where there are statutory rights of withdrawal of support or rights granted by a mining lease. Where the loss of support results from human activities, there may be a liability on the person that caused the damage, eg the mine owner or operator. In cases of historic rather than recent mining, however, it may be extremely difficult to establish the mine owner's liability. In such cases, the liability would appear to revert to the landowner unless he can show negligence by another party. For subsidence due to natural causes, the responsibility for subsidence damage remains with the landowner/developer.

Coal mining

15. Coal mining is a special case. The ownership of virtually all unworked coal, mines of coal and coal mine entries transferred to the Coal Authority under the Coal Industry Act 1994. Liabilities under the Coal Mining Subsidence Act 1991 are borne by the Coal Authority and/or their licensees. Additionally, any disturbance to or works affecting a disused mine entry in the Authority's ownership or any site investigation and/or treatment of shallow coal workings requires the written permission of the Coal Authority. Developers should keep proper records of investigations and land stabilisation works undertaken with the Coal Authority's agreement and should provide particulars of those works to the Coal Authority. This will enable its records to be updated to assist other developers and persons acquiring interests in land and property in the vicinity. Local planning authorities should consult the Coal Authority about all applications for development within areas of past, present or possible future coal mining.

Planning control

16. PPG 14 states that, in so far as it affects land use, land stability is a material planning consideration. PPG 3 identifies stability as one of the physical and environmental constraints that local planning authorities should consider in assessing the potential and suitability of a site prior to its allocation for housing development. The maintenance of a safe physical environment has been identified[1] as one of the priorities to be weighed in the public interest in determining policies for land use. The planning system should assist in ensuring that proper precautions are taken against the risks posed by subsidence to public safety, the built environment and economic activities. The potential for subsidence to occur should be considered in drawing up regional planning guidance and development plans as well as in decisions on planning applications.

REGIONAL PLANNING GUIDANCE

17. Regional planning guidance (RPG) provides a framework for the preparation of development plans and informing other strategies and programmes (PPG 11 gives further guidance). It should concentrate on those matters that genuinely need to be considered at the regional or sub-regional level rather than duplicating all topics that should be covered in development plans. However, there are clear regional or sub-regional concentrations of potential subsidence, particularly those due to coal mining, to metalliferous mining in Cornwall and Devon and to natural underground cavities in some chalk and limestone areas. Those preparing and appraising RPG and development plans should take these into account. The same would apply to the regional spatial strategies and local development frameworks proposed in the Planning Green Paper[2] published in December 2001. The constraints imposed by concentrations of potential subsidence in certain localities should also feed into the RDA regional strategies for economic development and regeneration.

18. The Department has carried out a number of national reviews of physical constraints and their significance for planning and development. These are briefly described in Appendix 2B. The databases of both subsidence incidents and subsidence potential are available on a commercial basis[3]. The reports from these projects and 1:250,000 scale maps showing the distribution of the physical constraints are available from the research contractors[4]. The Department will commission further research to provide regional summaries to assist in providing the basic information on subsidence and other physical constraints that might be of regional or sub-regional significance.

1 *This common inheritance*. CM1200, September 1990.
2 DTLR 2001. *Planning: delivering a fundamental change*, DTLR, December 2001.
3 Licence holders for the instability databases include BRITISH GEOLOGICAL SURVEY, Sir Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG; LANDMARK, 7 Abbey Court, Eagle Way, Exeter, Devon EX2 7HY; PETER BRETT ASSOCIATES, 16 Westcote Road, Reading, Berkshire RG20 2DE; CATALYTIC DATA LTD, The Spinney, 19 Woodlands Road, Bickley, Kent BR1 2AD.
4 ARUP GEOTECHNICS, 1991. *Review of mining instability in Great Britain* - from Arup Geotechnics, Bede House, All Saints, Newcastle-upon-Tyne NE1 2EB; APPLIED GEOLOGY LTD, 1994. *Review of instability due to natural underground cavities in Great Britain* - from Kennedy & Donkin Ltd, 44 Calthorpe Road, Edgbaston, Birmingham B15 1TH; WIMPEY ENVIRONMENTAL LTD & NATIONAL HOUSE BUILDING COUNCIL, 1995, *Foundation conditions in Great Britain, a guide for planners and developers* - from ENSR International Ltd, 16 Frogmore Road, Hemel Hempstead, Hertfordshire HP3 9RW.

DEVELOPMENT PLANS

19. PPG 14 (paragraphs 25-30) outlines the approach that local planning authorities should follow in dealing with land instability issues in their development plans. PPG 12 provides general guidance on the preparation of development plans. The considerations set out in this annex apply to the regional spatial strategies and local development frameworks and the new arrangements for development plans as proposed in the Planning Green Paper. However, the considerations set out in this annex apply equally to the present and any likely future arrangements for development plans.

20. The Coal Authority notifies local planning authorities of the areas where coal mining has taken place or is likely to take place in the future, within which it is a statutory consultee. Such areas should, therefore, normally be identified in the relevant development plan. For other types of mining and other causes of subsidence, the extent of knowledge about subsidence potential is more variable. Where good information is available, planning authorities should indicate the areas within which particular consideration of subsidence potential is needed. Structure plans need only include a general description of where local plans should consider such issues. Local plans and the proposed new-style area or topic action plans should use a constraints map and/or narrative description at an appropriate place. Appendix 2B briefly describes approaches to the identification and consideration of subsidence constraint areas. These were examined in demonstration projects in the South Wales coalfield, Norwich and Ripon, and provide models to be followed elsewhere.

21. Policies at the detailed level of area or topic action plans and in current local plans in any transitional period may be needed to control or restrict development in areas of particular vulnerability to subsidence. However, the precise location and effects of subsidence are in some cases too difficult to predict in such a way as to merit a general presumption against development on this account. Additionally, the problems posed by subsidence can usually be overcome by appropriate ground treatment or by the design and construction of suitable foundations and/or superstructure, paving the way for the beneficial use of land. Policies should also recognise that modern deep mining is not an absolute constraint on surface development but that developments particularly sensitive to movement could sterilise coal reserves that might otherwise be worked in future. Mineral extraction prior to development may allow development to proceed without unacceptably adverse impact from subsidence as well as preventing mineral resource sterilisation.

22. Mitigation of the effects of mining, natural underground cavities and adverse foundation conditions due to inadequately compacted fill can be expensive. Developers need to be aware of the likelihood of such measures being required in the relevant areas. Plan policies should, therefore, clearly indicate how subsidence will be considered in assessing applications for development and the procedures that will be followed to take adequate account of the risks involved and the need for mitigation. For other adverse foundation conditions, particularly shrinking and swelling clays, mitigation may be relatively straightforward and is fully covered by the requirements of the Building Regulations 2001. Detailed plan policies for this condition are thus unlikely to be needed.

23. Development proposals in local plans or the proposed local development frameworks should also take account of the potential for subsidence from various causes since it can influence their feasibility and sustainability. Where, for example, in combination with other constraints, mitigation against the potential adverse effects of subsidence might impose excessive costs for built development, consideration should be given to alternatives, such as open space, recreational and amenity uses, which may be more tolerant of potentially unstable land. Alternatively, the redevelopment of areas prone to subsidence may provide an opportunity and incentive to carry out the necessary investigation and treatment to remove the existing risk to public safety. It may be appropriate to identify such areas for regeneration in drawing up development proposals, indicating the constraints to be overcome. Where development plans or the proposed local development frameworks allocate land for built development that may be subject to subsidence from future coal mining, local planning authorities should seek expert advice on the potential effects of mining and whether to require developers to take special preventative action or to delay the development until mining has taken place and subsidence has ceased.

24. In areas of existing or potential future mining, minerals plans should identify the constraints which could be imposed on mining by the need to limit or control subsidence in order not to unacceptably adversely affect surface features or developments. In areas of past shallow mining, minerals plans should consider the possibilities of removing the threat of subsidence by excavation and controlled backfill of shallow mines to allow development to proceed safely. Where surface coal mine schemes can be carried out in accordance with the guidance in MPG 3 *Coal mining and colliery spoil disposal*, they can provide opportunities for ground stabilisation as well as dealing with surface dereliction and facilitating the economic and social regeneration of coalfield areas. While the primary objective of such schemes might be the stabilisation of land and regeneration of previously developed land, they should be regarded as mining operations rather than engineering operations.

DEVELOPMENT CONTROL

25. General guidance on the handling of applications for development on land that is known or suspected to be unstable is given in PPG 14 (paragraphs 31-45). Potential subsidence problems can generally be minimised by ground treatment or by suitably designing the foundations and superstructure of any building or structure. The effects of shrinkable clay are sufficiently well known and its mitigation sufficiently straightforward that the Building Regulations 2001 provide full control. It is therefore most unlikely that clay shrinkage would need to be considered in relation to individual planning applications in affected areas.

26. However, other causes of subsidence are not so straightforward and their mitigation can be expensive. Appendix 2C describes the range of mitigation measures that may be appropriate. Mitigation may require treatment of ground beyond the boundaries of the site for which application has been made. Such treatment may also have wider effects on groundwater flows and mine gas migration, as well as having potential impacts on the amenity of neighbouring land. These wider implications of subsidence and its mitigation should be taken into account in determining planning applications on sites where they are likely to apply.

27. The consideration of subsidence is required in three main situations:

- where proposals are made for new mining or underground construction/tunnelling;
- where remedial or preventive action is proposed after subsidence has occurred or to reduce to an acceptable level the potential impact of subsidence on current or future land uses; and
- where new development is proposed on land that may be liable to subside for any reason.

Mining or underground construction

28. Specific advice on subsidence and support in respect of underground mineral working is published in MPG 2 *Applications, permissions and conditions* (paragraphs C51-C60 of Annex C). While the scale of operations and the engineering design requirements may differ, similar considerations apply to underground construction or tunnelling for other purposes.

29. Applications for mining or civil engineering tunnelling should be accompanied by a detailed assessment, prepared by a competent person, of the subsidence predicted from these underground operations, its potential impact on buildings, structures and surface land use and any proposed mitigation measures. Mineral and local planning authorities, respectively, should consider such an assessment in the light of existing statutory and common law rights to require support to be left and duties to maintain support when deciding whether planning powers should be used to control subsidence.

30. Mineral and local planning authorities should consider the interests of owners, users and occupiers of land and property at the surface, the extent of damage that may be caused and the prospects of repairing or mitigating it alongside the case being advanced for the minerals or underground construction project. The need to reach an appropriate and reasonable balance between the potentially conflicting interests may require conditions to be imposed. Such conditions may restrict the area or method of underground excavation and/or require a monitoring scheme to be put in place incorporating any necessary mitigation should defined trigger levels of subsidence or settlement be exceeded. The views of the applicant and HM Inspectorate of Mines should be sought and appropriate expert advice taken on the practicality and efficacy of proposed conditions and to ensure that they do not conflict with legal obligations of the owner or operator under the Health and Safety at Work etc Act 1974. Where the potential adverse effects are unacceptable and cannot be successfully mitigated, refusal of permission, in whole or in part, may be justified.

31. When granting permission for new underground construction or mining, planning authorities should consider what will happen when mining or the use of underground space ceases. To prevent a further legacy of potential problems due to voids being left untreated, planning authorities should consider requiring a closure scheme, whereby the mine or tunnel voids are treated to minimise the risks of future subsidence. Where dewatering has been undertaken to allow mining or the use of underground space, consideration will need to be given to the potential effects of stopping pumping on stability, water quality and gas emissions. Openings from the surface into mines and other underground space are required under the Mines and Quarries Act 1954 to be closed to prevent accidental or unauthorised access and may need to be maintained to vent mine gas in a controlled manner. Conditions may be required to ensure further treatment of

mine openings as part of the closure scheme to maintain their stability and prevent them becoming uncontrolled pathways for contamination.

Remedial or preventive action for public safety reasons

32. Remedial or preventive action may be required to protect public safety:

- as emergency action following the collapse of a mine entry, shallow mine workings or shallow natural cavities; or
- to prevent such a situation arising.

33. The level of treatment will vary according to circumstances and may involve no change in land use or development. Methods of treatment of mine workings and of mine openings are briefly described in Appendix 2C. Development required for the maintenance or safety of a mine or disused mine or for the purposes of ensuring the safety of the surface of the land at or adjacent to a mine or disused mine is permitted, generally with the prior approval of the mineral planning authority, under the General Permitted Development Order 1995 (GPDO Part 19 Class C and Part 20 Class E).

34. Emergency action following surface subsidence above shallow mine workings or the collapse of a mine shaft usually comprises filling of the collapse depression from the surface and appropriate capping and/or cement grouting operations. In coal mining areas, the Coal Authority provides a 24-hour emergency call-out procedure to deal with surface hazards and to ensure that the site is made safe as quickly as possible. Such emergency action can generally be taken to be permitted development under the GPDO but that should be checked in case of doubt. So too can the treatment of mine openings to meet the statutory requirements to provide "an efficient enclosure, barrier, plug or other device so designed and constructed to prevent anyone from accidentally falling down the mine shaft or entering the mine opening accidentally" (Mines and Quarries Act 1954, Section 151) or to abate a statutory nuisance under Part III of the Environment Protection Act 1990.

35. Emergency action following subsidence into natural cavities is of a similar nature but would not be permitted development. It is often necessary to take action immediately to prevent subsidence developing more extensively and to guard against risks to health and safety until an event can be fully assessed. Local planning authorities should therefore consider the introduction of procedures for the grant of planning permission quickly in cases of emergency, possibly by means of delegation to officers. Such delegation need be related only to the immediate need to protect public safety. Any subsequent remedial or preventive action would be subject to the normal development control procedures.

36. In areas of shallow mine workings, where actual or apprehended subsidence may threaten the existing use of land and buildings and people on it, treatment of the underground voids to reduce the risk of subsidence to an acceptable level may be necessary. For mines other than coal, funding for local authorities to undertake such works to protect public safety may be available through the land stabilisation programme operated by English Partnerships. Such treatment works are likely to be on a larger scale than those required in response to specific subsidence events. They may be of such a scale that environmental assessment under the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 is required. A planning application and possibly an appropriate environmental statement would therefore be required for such works. Owners or prospective developers of land and property affected in this way should consult the local planning authority before commencing any remedial works.

37. Local planning authorities should assess the impact of any proposed land stabilisation works on local amenity and the environment and consider the benefits to be derived from treating former mine workings or other underground voids to prevent subsidence. Planning authorities should consult the mine owners, where they can be identified, and the Environment Agency in respect of potential impacts on groundwater and mine gas flow patterns and quality will be essential. The prior consent of the Coal Authority is required for works involving coal mines or coal. Conditions to limit the potential adverse effects of remedial works should be imposed where required. Local planning authorities should require the submission at the end of the works of a "completion report" that describes the works undertaken and their effect in mitigating the apprehended subsidence, together with any future monitoring and maintenance that may be required. Completion reports should be passed to the Coal Authority for works involving coal mines or coal. Advice on the recording of information on mined ground and its treatment is contained in Appendix 2D.

Development on land liable to subsidence

38. When proposing development on land potentially liable to subsidence, applicants should provide such information as is necessary to assess the effects of possible ground movements and the measures proposed to mitigate them. This may require the submission of a stability report, prepared by a competent person, as defined in Appendix 2E. This should demonstrate that the effects of subsidence will not be unacceptably adverse or can be minimised through appropriate site layout, ground treatment or foundation/superstructure design. Stability and mine gas reports should be required for all development on sites previously subject to shallow coal mining. Applicants should consult the Coal Authority for all development in areas of past, present or possible future coal mining and seek their prior approval for any works affecting a disused coal mine entry or any site investigation or treatment of shallow coal workings. Guidance on the preparation, content and format of stability reports is contained in Appendix 2E.

39. Where development proposed in an area of potential subsidence is subject to an environmental assessment under the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999, that assessment should have regard to the potential for subsidence, its effects and the effects of any proposed mitigation measures.

Consultation

40. While applicants for planning permission are responsible for determining the potential effects of subsidence on their proposed development, local planning authorities should consult relevant bodies where subsidence is likely to be material to the determination of the application. The Coal Authority is a statutory consultee for development in areas notified by it to the local planning authority. It owns, with limited exceptions, all mines of coal and coal mine shafts and its consent is required for any works which are liable to intersect its workings. The Coal Authority should be informed of the results of any site investigation or treatment affecting coal mine workings or shafts.

41. English Nature is a statutory consultee for any works affecting sites of special scientific interest. English Nature should also be consulted on proposals likely to result in harm to species and habitats protected under the EC Directives on the conservation of wild birds (79/409/EEC) and the conservation of natural habitats and wild fauna and flora (92/43/EEC) and other conservation legislation (see PPG 9 *Nature conservation*). Where works affect a scheduled ancient monument, consent under the Ancient Monuments and Archaeological Areas Act 1979 may also be required from the Secretary of State for Culture, Media and Sport, who is required to consult English Heritage. The Inland

Revenue Mineral Valuers Office may be an important source of information and advice to local authorities in old mining areas. The British Geological Survey maintains the national geological database and is an important general source of information and advice. British Waterways Board has statutory duties in relation to safe operation, maintenance and public access to inland waterways and should be consulted with regard to issues affecting them.

42. Treatment of underground voids to prevent subsidence may pose a hazard to underground water sources or divert, interrupt or affect the quality or quantity of underground or surface flows of water or mine gas. Planning authorities should, therefore consult the Environment Agency on any such treatment proposed to enable surface development to proceed. The disposal of wastes into mines as a means of stabilisation may require a waste disposal licence from the Environment Agency.

The decision and the use of conditions

43. Failure to satisfy the local planning authority that the potential for subsidence has been adequately considered may be grounds for refusing an application for planning permission. However, most forms of subsidence can be overcome by engineering techniques in relation to built development, though these may be expensive. Local planning authorities should consider, therefore, whether the objectives of safe development in the public interest can be achieved by imposing conditions requiring appropriate site investigation and the submission of a scheme of remedial/ preventative works to be agreed in writing before development begins.

44. Where a stability report contains recommendations on layout, ground treatment or preventive design, conditions specifying such measures should be attached to the planning permission. To confirm that the works have been carried out and the risks adequately mitigated, local planning authorities should consider imposing conditions requiring the submission of a completion report containing full information on the investigation and treatment of the site, including, where relevant, arrangements for longer-term monitoring and maintenance. In coal mining areas, such information relating to investigation and treatment of coal mine workings and mine openings should be copied to the Coal Authority.

Conclusion

45. The Secretary of State looks to local planning authorities and developers to implement the advice in this annex. Both parties should work together to agree the measures necessary to assess and mitigate the potential risks of subsidence. Early consideration of potential subsidence and its mitigation will allow the safe, efficient and cost-effective redevelopment of previously developed land consistent with the principles of sustainable development. The detailed policies and practices to be adopted by local planning authorities to implement the guidance in this annex are, however, for them to determine in the light of local circumstances. The Government will monitor the effectiveness of this annex and keep it under review.

APPENDIX 2A
Causes and Distribution of Subsidence

2A1. Subsidence occurs when the ground moves vertically downwards, usually accompanied by horizontal strains, due to it not being supported by underlying material. This loss of support may arise from the presence of underground cavities of both artificial and natural origin or to the presence of adverse foundation conditions in the near-surface materials. The effects can range from settlements of the order of a few millimetres to sudden collapse of the ground into cavities several metres deep. PPG 14 Appendix A (paragraphs A4-A42, A50-A56 and Figures A1-A4 illustrate the various causes and types of subsidence that occur. A brief summary is given below.

ARTIFICIAL CAVITIES

2A2. England has a long history of mining but relatively complete and reliable records are available only since the latter part of the 19th century. PPG 14 Appendix A (paragraphs A12-A42 and Figures A3-A4) describes the different methods of mining and the effects likely to arise.

2A3. Mining has taken place in every county in England and one third of them have more than 20% of their area within which mining is known or suspected to have taken place. Figure 2A1 illustrates the general extent of mining areas in England. The most prominent are those of the coalfields, within which mining extends from very near the surface to depths in excess of 1000m. As well as coal, sandstone, fireclay, ironstone and limestone have all been mined within the coalfields. Other widespread areas of mining include the metalliferous mining fields of Cornwall and Devon, the Mendip Hills, the Peak District, north Pennines and the Lake District. Significant concentrations also occur in the Cheshire saltfield, the ironstone mines of the North York Moors, the Weald and Northamptonshire, stone mines in the Bath, Cotswolds and Purbeck areas and chalk mines in the Chilterns and North Downs. In some areas, the existence of only scattered examples of very old mining of which there are no coherent records can lead to its existence being overlooked until subsidence happens and causes problems.

2A4. The effects of subsidence from mining depend on the type of mining and the depth of workings. The principal types are:

- collapses of mine entries, crownholes (collapses into shallow mine voids, which break through to the surface - generally less than 30m below the surface but they have been recorded from depths of more than 100m); and

- general subsidence (widespread depression of the ground surface due to collapse of longwall mines and deep room and pillar mines).

2A5. The risk of subsidence depends on the nature and properties of the rocks surrounding the mine voids and the behaviour of groundwater and surface water. Secondary effects can include the triggering of landslides on steep slopes, effects on groundwater flow patterns and the opening of fractures through which mine gases can be emitted at the surface.

2A6. Mine entries are a special case since they all come to the surface, though many may now be concealed. They range in size from less than 1m to over 7m in diameter. They may be unlined, lined throughout or lined through superficial deposits overlying bedrock. Some shafts have been filled above one or more intermediate platforms of wood or iron girders, which may rot away with time. Many were abandoned as they stood and remain open; others were covered at or just below the surface, often with timber, or they have been used as convenient rubbish pits with loose fill often bridging the shaft. Collapses of filled or partly filled shafts or of the roof of shallow mine and drainage adits may occur rapidly without any prior warning. The area of ground affected may be several times the shaft diameter, particularly where there is any thickness of superficial deposits resting on bedrock.

2A7. Experience in most coalfields and in other mining areas indicates that failures at mine entries are, by far, the commonest cause of ground collapse due to former mining activities. Open or barely concealed shafts also present an obvious life-threatening hazard to people (and livestock) and mine adits invite exploration and consequent exposure to secondary hazards from roof fall, getting lost in workings, hazardous gases, deep water and internal shafts or raises. Mine entries are often the most obvious pathway for pollutant transport of contaminated water or hazardous mine gases.

2A8. Other artificial cavities, which may cause subsidence, include transportation and service tunnels, culverts, cellars and basements. Construction and ventilation shafts for such tunnels and wells may pose similar problems to those of mine entries. These features are common in all urban areas and in other areas affected by industrial activity, including past railway and canal development. The redevelopment of previously developed land, therefore, requires that particular consideration is given to the possibility of such cavities, as well as to the mining features which may also occur.

2A9. While the principal hazard from artificial cavities arises from those that are now disused and often unknown, present and future underground excavation may also be a cause of subsidence. Modern room and pillar mining is generally designed to avoid subsidence by leaving sufficient support in place. Longwall coal mining, however, is designed so that the roof of workings begins to collapse immediately the working face advances, resulting in subsidence taking place generally within months of the mining. Once the surface has fully stabilised (usually within 6-12 months), any damage is repaired under the provisions of the Coal Mining Subsidence Act 1991. After this time, movements will generally have ceased. Civil engineering tunnelling and other underground works are also designed to minimise subsidence at the surface. However, inappropriate design and construction techniques, including meeting unforeseen ground conditions during the course of excavation, have occasionally resulted in more subsidence than was expected.

NATURAL CAVITIES

2A10. Most natural cavities in England are due to dissolution by percolating groundwater of limestone, chalk, rock salt or gypsum-bearing rocks. Most dissolution activity is within the upper zone of soluble rocks but it can also take place at depth. In salt and gypsum-bearing rocks, zones of complete or partial dissolution grade downwards into fresh undissolved material. Cambering (down-slope bending of rigid surface rocks on the crests of slopes) due to movement largely associated with past climatic conditions also produces fissures. Coastlines composed of hard rocks are prone to sea-cave formation where marine erosion is concentrated along joints, bedding planes or faults.

2A11. Natural cavities are widespread but not uniformly distributed. Figure 2A2 shows the distribution of natural underground cavities contained within the 20,000 record database compiled as part of the Department's *Review of instability due to natural underground cavities in Great Britain*. The most significant recorded concentrations of dissolution cavities are in the Chalk from Wiltshire to Norfolk, and from Dorset to Kent; the Carboniferous Limestone of the Mendip Hills of Somerset, the Peak District of Derbyshire, and the north Pennines of North Yorkshire, Cumbria and Durham. Fewer, but locally significant, cavities occur in other limestone and salt- and gypsum-bearing strata, such as the Devonian limestones of Devon, Triassic salt beds in Cheshire and Permian gypsum beds of North Yorkshire. Figure 2A3 shows the general distribution of soluble rocks in England and Wales. Cavities formed by cambering are most frequently found in Jurassic strata, such as the Cotswolds, the East Midlands and the North York Moors, and the Lower Cretaceous of the Weald of Kent. Sea-caves tend to be more common in south-west and northern England and are infrequent in the softer rocks of eastern and southern England.

2A12. Subsidence of the ground above natural cavities may be caused by instability of the material infilling the cavity or of the surrounding rock. The downward movement of cover deposits or of cavity-infill material is more common than the sudden collapse of the host rock. Rapid ground subsidence may occur when large air-filled voids become unstable, suffer progressive roof falls and migrate upwards to breach the ground surface. When natural cavities are intersected by mine workings, infill deposits can be mobilised rapidly to flow into the mine workings resulting in sudden collapse of the surface. Compaction and consolidation of loose cavity-infill deposits causes slower rates of movement. Both types of movement can give rise to substantial damage to property and infrastructure and can endanger public safety. The most common subsidence trigger involves water flow through and around cavities and the lowering of the water table to allow water to percolate downwards through a previously saturated feature. Changes in surface and groundwater movement arising from both new and existing development are often significant in triggering subsidence, eg through the concentrated water flows arising from soakaways, leaking water services and trenches. Loading of the surface during construction works can also trigger subsidence but this is less common.

ADVERSE FOUNDATION CONDITIONS

2A13. Natural materials affected by development activity range from soft weak sediments to hard strong rocks. Human activities may introduce major variations in local conditions. PPG 14 Appendix A (paragraphs A50-A56) describes the range of conditions leading to ground compression, some of which may be significant in causing vertical settlement of the ground.

2A14. The most commonly quoted cause of subsidence is due to the impact of variations in moisture content on shrinkable/swelling ground. In dry conditions, clay minerals shrink as water is removed causing subsidence; in wet conditions clay minerals take up the water and expand causing heave. These effects are associated with some types of clays and occur mainly south-east of a line from the Tees to the Exe.

2A15. While all ground is compressible to some extent, some materials have a compressibility that is high enough to warrant special precautions in design and construction of even light structures. These materials include loose wind-blown sands, loose or soft silts, soft clays, organic clays and silts and peat. These materials occur principally in wetland areas such as the Fens, Norfolk Broads, The Wash and bordering estuaries; some deposits in river valleys and upland peats are also compressible. Changes in groundwater conditions, particularly drainage, may lead to subsidence; peat is particularly susceptible. Saturated and loose granular deposits may liquefy when loaded or be subject to excessive settlement. They may be found in low-lying alluvial deposits and in fluvio-glacial deposits, as well as in poorly compacted fills or tips. Their distribution is similar to that of compressible ground. Figures 2A4-A6, with Table 2A1, show the distribution of shrinkable and swelling ground, compressible ground and saturated and loose granular deposits.

2A16. Previous development often leaves a legacy of buried foundations, underground voids and other problems, which may lead to differential settlement or subsidence. Such problems are largely but not exclusively associated with urban areas. The redevelopment of previously developed land will need to pay particular attention to these problems. Potentially more widespread and of greater concern is the extent of filled ground, where large depressions such as old quarries (or smaller World War 2 bomb craters and former ponds) have been filled in or fill material has been used to raise the land surface. The fill used for this purpose can be a very variable category of materials, ranging from disturbed and redistributed natural strata, as in back-filled opencast mines and quarries to domestic and industrial wastes. These materials may have been placed by a variety of techniques, largely by loose tipping in the past, but in more recent cases the filling process may have been controlled to enable development to proceed on the made ground. Difficulties may arise due to poor compaction, leading to open structure with voids and possible collapse on inundation, and the variability of the material, leading to differential settlement. Corrosion of ferrous metals and degradation of organic materials could induce severe settlement or collapse at some time in the future. Changes in water table regime in areas of fill may induce swelling or collapse of materials leading to subsidence. Fill is extensive in most urban areas but it is not confined to these.

APPENDIX 2B
Relevant Research on Subsidence Potential

2B1. A number of research projects in the former Department of the Environment's (DOE's) Planning research programme examined the nature and significance to planning and development of different causes of subsidence[5]. A series of national reviews were carried out to identify the scale and nature of problems arising from mining instability, natural underground cavities and adverse foundation conditions. A number of demonstration projects, based on particular areas, examined how specific problems could be addressed through the planning system. These included coal mining in South Wales, chalk mining, natural cavities and other causes of subsidence in Norwich and dissolution of gypsum in Ripon. In addition, generic studies were carried out on the treatment of and methods of storing and retrieving data on mine openings and on the use or earth science information in planning. Many of the projects carried out under the former DOE's applied geological mapping programme also address problems due to subsidence from various causes. This research has formed the basis for this annex and, particularly, of the detailed guidance in Appendices 2C, 2D and 2E.

REVIEW OF MINING INSTABILITY IN GREAT BRITAIN

2B2. This study was undertaken to establish the general extent of mining in Britain, to review and assess:

- the effects of mining on the land surface;
- methods of investigation and monitoring of mined ground and of mining instability;
- preventive and remedial measures and their effectiveness.

2B3. Because problems associated with mining in coalfield areas are relatively well known, coalfields were considered in only a generalised way and the main emphasis was placed on other types of mining, particularly those at relatively shallow depth. The studies of technical issues were partly based on a series of 11 case studies selected to illustrate the range of mining and subsidence circumstances found in Great Britain.

2B4. For the purposes of the review, minerals were classified into 5 types - metalliferous (non-ferrous) ores, rocks (eg sandstone, limestone), coal and associated minerals (eg fireclay), iron ore outside coalfields and evaporites (eg rock salt, gypsum). The principal methods of mining identified were strata mining (partial or total extraction of seams or beds of mineral, eg coal, rocks, iron and evaporites), orebody mining (extraction from veins or irregular orebodies, eg non-ferrous metals, iron ore) and solution mining (by pumping of mineral dissolved in water, eg salt). The principal types of instability which may affect the ground surface are collapses of mine entries, crown holes (localised collapses into mine voids) and general or areal subsidence.

5 The research reports described are listed in the bibliography.

2B5. A summary report and 1:625,000 scale maps summarises the results, which are presented in 3 volumes:

- Regional reports, accompanied by 1:250,000 scale maps for Scotland, Wales and English planning regions, describing the extent of mining for the 5 mineral types on a County and District basis, with advice to planners to be used in conjunction with PPG 14. Comprehensive schedules of mining areas are contained in each report. The maps show areas, coloured according to mineral type and referenced to the schedules in the report, of areas beneath which mining is known or suspected to have taken place, within which it should be regarded as a material consideration;

- Technical reports on the effects of mines, investigation methods for disused mines, preventive and remedial measures and monitoring methods for mining subsidence and procedures for locating disused mine entries; and

- Case study reports illustrating the variety of subsidence problems experienced throughout Britain, each outlining the characteristics of mining and associated subsidence events in a specific area and summarising the site investigations and preventive and remedial measures used to deal with the problem.

REVIEW OF NATURAL UNDERGROUND CAVITIES IN GREAT BRITAIN

2B6. This study was undertaken to obtain a general picture of the geological and geographical extent of significant occurrences of natural underground cavities, and to review and assess:

- the surface instability and other effects of such cavities; and

- investigation and remedial techniques and their effectiveness.

2B7. The main types of cavities considered were those produced by dissolution, mainly of limestone, chalk and gypsum, fissures produced by cambering and sea caves in coastal areas. Records were compiled of about 20,000 occurrences across Britain of natural underground cavities. Examples were recorded of problems being caused during construction and engineering works, mining and tunnelling, surface mineral extraction, development of water resources and waste disposal. Cavities may also be a resource for conservation, scientific study and education and some have been developed as show caves.

2B8. The study found there to be a general lack of awareness of potential problems and a need for better account to be taken of the possible presence of natural cavities in planning and site investigation. Maps prepared to show the extent of strata within which problems may occur can be used when considering whether natural cavities might be a material consideration in a specific area.

2B9. A summary report and 1:625,000 scale maps summarises the results, which are presented in a similar format to the mining review, in two volumes:

- Regional reports, accompanied by 1:250,000 scale maps for Scotland, Wales and English planning regions, present an overview summary of the geographical and geological extent of natural cavities in the region and assess their influence upon land-use planning and development;

- Technical reports present a more detailed overview of the nature and occurrence of natural cavities and their influence on planning and development, a review of site investigation techniques and their utilisation for natural cavity detection and a review of ground treatment and structural design techniques to mitigate against the potential effects of natural cavities.

REVIEW OF FOUNDATION CONDITIONS IN GREAT BRITAIN

2B10. This study was undertaken to review the nature and extent of problems associated with a number of adverse foundation conditions. These included compressible ground, shrinking and swelling of the ground, saturated granular deposits and previously developed ground, all of which could lead to subsidence or settlement to varying degrees. It also examined methods of site investigation, monitoring, ground improvement and remedial measures, including the circumstances in which particular types of foundations are likely to be appropriate.

2B11. Compressible ground occurs principally in wetland areas, such as estuaries and river valleys. Compression may give rise to differential movements within and damage to structures. Shrinking and swelling of the ground is associated with some types of clays. Heaving and settling due to volume changes in the ground are a common cause of structural damage. Saturated granular deposits occur mainly on the margins of estuaries and in river flood plains. These may give rise to settling of the ground surface and can collapse into excavations. Previously developed ground, mainly in urban areas contains a legacy of buried foundations, made ground, underground voids and contaminative land uses.

2B12. Both compressible and shrinking/swelling ground are predictable from site investigations, though it may be costly to overcome or mitigate the condition. Previously developed land, especially filled ground and saturated granular deposits are more difficult to predict and may also be hazardous to life and costly to overcome or mitigate.

2B13. A summary report and map at 1:625,000 scale summarises the results, which are presented as:

- review report, which describes the background to the study, explains how the results should be used and provides an introduction to aspects of ground conditions, site investigation and foundations;

- database, which consists of records of ground conditions abstracted from site investigation reports; and

- 1:250,000 scale maps showing the geographical extent of selected foundation conditions, based on an interpretation of soils data from the Soil Survey and Land Research Centre.

ASSESSMENT OF MINING SUBSIDENCE IN THE SOUTH WALES COALFIELD

2B14. A study of the area south of Ebbw Vale was undertaken to develop a methodology for assessment of mining subsidence potential in a coalfield area and, in particular, to produce maps giving advice to planners and developers. Information was collected from local authorities, the then British Coal and others on subsidence incidents above shallow mines throughout the South Wales coalfield. Together with information from opencast coal site records and from site investigation and drill and grout records, this was used to establish the characteristic behaviour of mines in individual coal seams. The results were then applied to those seams occurring beneath the study area, allowing a subsidence potential map to be prepared. The resulting map incorporated advice to planners and developers on how it should be used.

2B15. Following completion of this pilot study, further work was undertaken in part of Islwyn Borough, in another part of the coalfield to validate the technique. Working closely with the local planning authority, procedures, including guidance notes for applicants, were developed to incorporate the mining subsidence potential map into the planning process. The usefulness and effects of the maps and planning guidelines in determining planning applications were monitored for 15 months.

2B16. The monitoring confirmed that the maps were an accurate and reliable tool in assisting planners to make a rapid assessment of where further information is required in support of applications. There was no evidence that their use either slowed down or speeded up the determination of applications but they clearly improved the quality of information available to decision-makers. The planning guidelines developed during this research formalise the procedure for assessing mining issues and thus help to ensure consistency in decision-making. The research concluded that the mining subsidence development advice maps produced by this methodology were a valuable tool that could usefully be applied to other areas in the South Wales coalfield. The mapping process could also be extended to other coalfield areas, subject to a full review of subsidence incidents within any particular coalfield to allow local characterisation of coal seams. The approach that has been developed in these studies is of general validity and it is commended to local planning authorities in English coalfield areas seeking to manage subsidence risks in the consideration of new development proposals.

CAUSES AND MECHANISMS OF LAND SUBSIDENCE IN NORWICH

2B17. The City of Norwich was selected as a suitable area to develop a methodology to enable a planning response to ground instability in areas of mining and natural solution pipes within Chalk. Published and archive records held by a wide range of organisations and individuals and dating from medieval records to recent site investigation reports were used to establish:

- the general nature of chalk and flint mining and of occurrences of infilled natural cavities;
- the extent of other circumstances that might give rise to subsidence;
- the history, locations, scale and causes of subsidence; and
- a general strategy for responding to potential problems through planning and site investigation.

2B18. Apart from the association of several dramatic subsidence events with known chalk mines, no direct relationship was found between the frequency of subsidence and mapped areas of various geological formations. It was thus concluded that the available data does not offer the potential to produce an effective and sound subsidence hazard map. However, the research also concluded that the adoption of simple sensible measures and a controlled approach to development could greatly reduce the risk of subsidence damage. General guidelines for action by the local authority, developers, builders and householders emphasise the need to:

- recognise the potential for and need to detect underground voids to enable appropriate measures to be taken to mitigate against the more severe types of subsidence;
- prevent leakages from services and the uncontrolled discharge of water as these may trigger subsidence;
- undertake appropriate site investigations for new development, taking account of the history of the site; and
- design structures appropriate to the ground conditions to mitigate against the effects of potential subsidence.

2B19. Recommendations for the conduct of similar studies in other areas include a detailed list of potential sources of data and recommendations on the methods of storing and handling information effectively.

ASSESSMENT OF SUBSIDENCE HAZARD DUE TO GYPSUM DISSOLUTION - RIPON

2B20. This study of the assessment of subsidence hazard due to gypsum dissolution was undertaken to validate the irregular densities of records found during the review of natural cavities in Great Britain and to assess the feasibility of zoning areas in terms of subsidence hazard. Because it was well documented as an area of currently active subsidence, the City of Ripon was chosen as a demonstration area to develop for use by planning authorities an approach to the consideration of such issues in their strategic planning and development control procedures. Comparison was also made with selected areas of gypsum-bearing strata in north-east England to assess the wider extent of such problems. The geological and other controls on subsidence and the extent of existing and potential problems were assessed. A draft framework of advice suitable for use by planners, developers, land and property owners, insurers and others was prepared.

2B21. The relatively high incidence of subsidence events within the Ripon area, compared with other areas underlain by gypsum-bearing strata, can be largely explained by the presence beneath the modern River Ure of a buried valley filled with drift deposits. This presents optimum conditions for enhanced groundwater flow and gypsum dissolution. Most of the events have taken place in open countryside, with few buildings affected, generally with only minor damage. With one event per year on average over a total area of over 30km2, the risks to existing properties are small but they need to be taken into account in planning for new development in Ripon.

2B22. While a form of hazard map could be produced for the Ripon area, only limited confidence could be placed in the boundaries between zones subject to different levels of hazard. Thus the approach adopted was that of a development guidance map, which defined zones by the differing nature of the planning response required to subsidence potential. To minimise the impact on minor developments, including most householder developments, the planning requirements detailed below were recommended for larger developments only, reflecting the higher public interest factor involved. The local planning authority has incorporated these requirements in its local plan. They are generally waived for minor developments subject to the issue by the local planning authority of an advice note drawing the applicant's attention to the potential risk of subsidence.

2B23. The development control areas defined and appropriate planning responses identified in the local plan are:

- no gypsum present - areas suitable for development, no gypsum-related planning requirements;

- some gypsum present at depth, slight subsidence hazard - generally suitable for development with minor localised constraints on development - ground stability report required, generally based only on geotechnical desk study and site appraisal, often as a condition; and

- gypsum present and susceptible to dissolution, localised subsidence hazard, potentially subject to significant constraints on development - ground stability report required, generally based on geotechnical desk study and site appraisal followed by appropriate ground investigation, with permission conditional on implementation of approved foundation or other mitigation measures.

2B24. The study concluded that the procedures suggested for the Ripon area would generally not be required in most other areas in north-east England underlain by similar gypsum-bearing strata. However, some of the principles developed could usefully be applied in limited areas subject to more detailed assessments in those areas. The principles are also more generally applicable to the consideration of other causes of subsidence in the planning system.

OTHER RELEVANT RESEARCH

2B25. From 1981 to 1995, the Department of the Environment, in co-operation with the affected local authorities funded research, physical investigation and treatment of abandoned limestone workings in the West Midlands and Shropshire. Research was undertaken to establish the nature and extent of the workings, the mechanisms of collapse the degree of risk and methods of investigating, monitoring and treating the workings. Further studies examined novel infill materials, land-use, a methodology for risk and cost-benefit analysis, monitoring of the workings and of ground movement, a technical audit of investigation works and an evaluation of treatment works. Full details are contained in the Black Country Limestone Advisory Panel's *Seventh Annual and Final Report to the Secretary of State for the Environment.*[6]

6 Available from DTLR, Minerals & Waste Planning Division (PD2D), 4/B2 Eland House, Bressenden Place, London SW1E 5DU

2B26. Two studies on mine openings examined methods of treatment and methods of compilation, storage and retrieval of data. Current practices, procedures and costs in the treatment of mine openings were reviewed to determine the best approaches for cost-effective remedial action in a variety of situations and circumstances. Appendix 2C (Mitigation of subsidence and treatment of mine openings) draws on this work. A framework of guidance for considering mine openings in the context of land-use planning and development control was also developed. The methods, scope, content and cost of existing databanks of information on disused mine openings and workings were reviewed in a separate study. Recommendations on methods for use in areas of varying complexity have been incorporated in Appendix 2D (Information on mined ground and mining data systems).

2B27. Within the same programme, a number of other research projects were carried out in areas with different geological conditions to develop applied geological maps for planning and development. These were aimed primarily at the non-specialist and included maps showing issues relevant to subsidence. The lessons from these mapping studies were drawn together in a series of generic projects, which examined the contribution of environmental geology (ie the natural characteristics of the ground, the legacy of previous land use and the characteristics of natural physical processes) in particular planning situations. The reports:

- explain the importance of environmental geology in land-use planning;
- provide practical guidance on how environmental geology constraints (including subsidence) and opportunities can be identified and taken into account in the planning process;
- examine the implications of environmental geology factors for a wide range of strategic initiatives and emerging policy issues; and
- provide details of the wide range of relevant earth science information available to planners and developers.

APPENDIX 2C
Mitigation of Subsidence and Treatment of Mine Openings

2C1. The risks to land use and development from potential subsidence can generally be minimised either by the use of appropriate foundations and design of buildings and structures to cope with expected movement or by ground treatment measures to reduce the level of subsidence to acceptable levels. While it will seldom be necessary for development to avoid areas of subsidence risk entirely, the mitigation measures can be costly and planning policies that specify uses that will not be affected by the expected levels of subsidence may be appropriate in some circumstances. In addition, the nature and characteristics of mine openings and other similar features may require their treatment for public safety reasons, whether or not development is planned on the site.

STRUCTURE AND FOUNDATION DESIGN

2C2. For most types of subsidence, it may be possible to design buildings and structures to cope with the movement expected, provided the amount of differential subsidence is not excessive and that the structure is not especially sensitive to differential settlements.

2C3. For small structures such as houses, conventional but reinforced strip or pad foundations may be adequate to resist the effects of minor instances of subsidence. They should be laid on a suitable sliding layer and have compressible materials placed at external vertical faces. However, a raft foundation, as near square as possible, with no projections or indentations that would give rise to stress concentrations, will ride out subsidence better than strip footings. Raft foundations are used to spread the structural load over a wide area when founding on weak or variable ground and to remain intact following ground deformation. They should be close to the surface so that compressive strains induced by ground movements take place beneath them rather than directly affecting the edges. Rafts can be designed to span or cantilever over loss of ground due to the collapse of underground cavities, but are more generally used where old workings or cavities are largely collapsed, the objective being to overcome settlement within the cavity infill.

2C4. Where there are high individual column loads and a competent founding stratum is present at moderate depth, it may be preferable to use heavily reinforced concrete beams designed to span across or cantilever over subsided ground. Where underground cavities are present, the underside of the foundations needs to bear directly on the ground. In compressible or made ground, the beams may bear on concrete pads founded on a competent stratum.

2C5. For heavily loaded structures where the strata at shallow or moderate depth are too weak to support the required loads, piled foundations may be used to provide support. They are used to transfer the structural load through the zone of disturbance and into underlying stable material. They have occasionally been used in areas of shallow underground cavities.

2C6. The design of structures can also assist in their resisting subsidence movements by making them sufficiently flexible. Timber-framed structures are inherently more flexible than rigid concrete or brick-framed ones. Dividing larger structures into smaller units with expansion and compression joints between them provides additional flexibility. These principles have long been used in the CLASP (Consortium of Local Authorities Special Programme) system of flexible construction. CLASP was successfully used by local authorities for a large number of buildings, including schools and hospitals above active longwall mining areas. Gaps or joints can also be introduced into foundations, structures or services to compensate for strains and differential tilting. The provision of compression springs between the foundation and superstructure can combat tilting effectively when combined with the provision for jacking the structure level after movement has occurred.

2C7. For lightly loaded areas such as playing fields, car parks and local access roads, geotextiles (high strength polymer grids) may be used to support the ground as an alternative to expensive ground treatment methods. However, should localised subsidence then occur, action will need to be taken to protect public safety and deal with the subsidence.

GROUND IMPROVEMENT

2C8. The objective of ground improvement techniques is permanently to improve poor ground and so allow the use of more cost-effective foundation methods. They are particularly applicable to ground that is loose, soft or compressible. Such conditions may arise from the natural characteristic of the ground materials, the uncontrolled placement of material in or on the ground (eg made ground) or from broken ground due to the collapse of underlying cavities of natural or human origin.

2C9. The simplest ground improvement technique is the removal of the poor material and its replacement with a suitable inert and stable fill that is capable of achieving satisfactory compaction. Such fills could include controlled deposition of the material removed. Where old mine-workings or natural cavities lie at shallow depth, it may prove economic to excavate down to the voids and either replace the excavated material in a controlled manner or replace it with compacted backfill. This technique is generally limited to depths of about 5m, though occasionally up to 10m unless economic benefit can be derived from the material excavated. Thus opencast extraction of coal can be used as a means of stabilising ground liable to subsidence due to shallow mine workings, provided that any adverse environmental consequences of doing so can be controlled to an acceptable level, as required by MPG 3 *Coal mining and colliery spoil disposal.*

2C10. Larger areas of poor ground generally require treatment *in situ*. The most frequently used techniques are those for compacting back-filled sites where the soil properties are highly variable. They can also be used to improve low-strength natural soils, such as loose granular deposits.

2C11. Pre-loading or surcharge involves placing a temporary bank of soil on the position of a proposed structure in order to compress the ground prior to construction. The weight of the embankment causes settlement of the ground, which would otherwise have affected the structure. The surcharge material will often be subsequently used in landscaping the site.

2C12. Dynamic compaction involves repeatedly dropping a heavy weight (of 5-20 tonnes) onto the ground from a height of up to 20m on offset grid patterns. This technique can improve the ground to depths of 5m or more. The process is generally only cost-effective in treating large areas due to the high costs of plant mobilisation. It also creates significant ground vibration, noise and disruption.

2C13. Vibro-compaction and vibro-replacement involves the compaction of soils using a vibratory poker lowered into the ground. Vibro-compaction is generally only suitable for weak or loose granular soils. For more cohesive material, the hole is filled around the poker with coarse stone, which is compacted (vibro-replacement) and forms a reinforcing stone column in the ground.

2C14. Grouting involves injecting a slurry into the ground under pressure. The grout is used primarily as a filler and its structural properties are often of minor importance. Minimum amounts of cement are used to achieve the required strength. The technique is widely used to fill both natural and mined cavities, as well as in broken ground above mine-workings. It can also be used to compact and strengthen poor quality soils. Chemical or resin grouts may be used to strengthen soils or reduce their permeability. Cement or lime may also be mixed with soft surface soils to stabilise them.

2C15. Grouting is only of significant value where open voids or grout-permeable materials exist within the area of treatment. The technique requires careful control of the grout composition, viscosity and injection pressure. Given correct controls and programming, grout injection can prove an economical and effective approach to ground treatment for a range of underground conditions. It can, however, be difficult to predict accurately the total cost, particularly when treating large volumes of broken ground above mine workings or natural cavities.

TREATMENT OF CAVITIES

2C16. Where the potential for subsidence arises from underground cavities, and excavation and back-filling is not viable, three alternative approaches may be adopted:

- inducing subsidence;
- providing support to the cavity, which remains open; and
- infilling the cavity to prevent excessive ground movement.

Inducing subsidence

2C17. Subsidence may be induced directly by dynamic compaction, as described above, or indirectly by demolishing supporting pillars or the roofs of rooms. Dynamic compaction has been used on a limited basis. Where the mineral can safely be extracted, pillars can be removed on retreat to allow collapse of the workings and subsidence to occur. Pillars may also be demolished by blasting but this is only applicable with small pillars and a high level of extraction (generally greater than 75%). This technique has been used for some mines in France but no examples are known in England, except as a means of blocking access to underground mine cavities.

2C18. Collapsing a mine to induce subsidence has an inherent element of risk. In particular, it is likely to cause damage to on-site and nearby structures, an irregular topography, which may have to be restored by regrading and intermittent surface settlements as the collapsed debris consolidates (unless the broken ground created is treated). Any proposals to treat cavities by inducing subsidence will need very careful consideration after taking appropriate expert advice. The alternative methods of cavity treatment described below are likely to be more effective and more economical.

Providing support to the cavity

2C19. At sites where the risks of subsidence are relatively low, it may be more economical to keep mine or other cavities open than to induce subsidence or infill them. In particular, this may allow the underground cavities to be used for some other purpose, such as the many show caves/mines. It may also allow the continued use of the cavities by bats and the preservation of features of geological, biological and archaeological interest. When considering the use of the techniques described below, the importance of ensuring competent engineering design and supervision cannot be over-emphasised.

2C20. Pillars in mines can be strengthened to provide support to the roof. A number of techniques are available (illustrated in Figure 2C1), including wrapping pillars with wire rope/mesh and spraying with shotcrete, corsetting them with reinforced concrete, buttressing with steel or concrete members, bolting to improve pillar strength and relieving the load by surrounding pillars with artificial columns. Any pillar strengthening should take account of the potential value of pillars as geological exposures or structures of archaeological significance.

2C21. Roof support may be increased by the use of steel or concrete beams with blockwork or steel columns, steel arches and mesh sprayed with shotcrete. Packing, involving the hand placement of rock blocks has often been used to support the roof of coal, ironstone and stone mines. Similarly, masonry or reinforced concrete pillars, walls and piers can be installed or timber baulks can be inserted to slow down the rate of collapse or provide temporary support. The use of rock bolts, dowels and rock anchors to reinforce the rock is a common method of support in underground excavations (Figure 2C1 shows examples), often in combination with welded steel mesh and sprayed concrete. Artificial pillar support may also be provided by placing cones of granular material or low-slump concrete through an array of closely spaced boreholes.

Filling cavities

2C22. Underground cavities can be filled from underground (stowing) or via boreholes from the surface. A number of different techniques is available. Stowing techniques are occasionally used during the mining operation to reduce the impact of subsidence but they can also be used in abandoned mines where access is or can be made available. Depending on the depth and nature of workings, the strength of material used will be governed by whether it needs to support the ground above the cavity or merely to fill it in order to prevent further deterioration.

2C23. Solid stowing is the placing of fractured mine waste or imported fill in the mine void by manual or mechanical means. It was commonly used in older pillar and stall mines both as a means of support and to avoid bringing waste to the surface. Although it was used to some extent in early longwall mining, it is now unlikely to be economically justifiable as a means of reducing subsidence in active mines, as well as posing potential risks to the mining workforce.

2C24. Pneumatic stowing uses compressed air as the transport medium to place material underground. It can only be used in dry accessible workings. Materials which may be stowed include sand and gravel, pulverised fuel ash and colliery spoil. It can produce tightly packed stowing which will prevent subsidence in room and pillar mines and can reduce subsidence by almost half in longwall mining.

2C25. Hydraulic stowing uses water as the transport medium to place granular material in the workings. It is not applicable to active mines where inundation of the working face may occur. Gravel, masonry or other barriers may be required to contain the infill material within the area to be stabilised.

2C26. Coarse-grained fill of suitable size and shape may be used to free fall and form cones within the mine void. This is particularly useful where drainage through the mine must be maintained. Blind flushing uses water to flush granular material down a number of closely spaced boreholes to form overlapping cones of material within the mine. Although complete filling cannot be ensured, it can fill sufficient of the void space that any further roof falls will choke and not progress to the surface. The method is more suitable for inaccessible and flooded workings. However, access to the whole of the land above the workings is required.

2C27. Where mine cavities are not water-filled, the pumped slurry technique may be used. A slurry of sand and water is pumped from a few injection points under sufficiently high pressure to maintain a high flow velocity and keep the sand in suspension. This enables it to flow through the workings. Fewer injection points are required than for blind flushing. However, large quantities of water are required and this may exacerbate any potential groundwater problems.

2C28. As described above, grouting is widely used to fill both mine and natural cavities and to treat broken ground above them (see Figure 2C1). Infill grout is generally composed of pulverised fuel ash and ordinary portland cement in a ratio of between 9 and 12 to 1. Where large voids are present, bulk fillers such as sand and pea gravel may be added. Where grout can flow freely through areas of open cavities, injection hole spacings of 3-6m are common. Injection holes are drilled on a systematic grid, with infill holes once the primary grid has been grouted. Grouting is an expensive method of treating large cavities, though it can be an economical method for areas of broken ground with relatively small cavities.

2C29. The rock paste method (see Figure 2C1) was developed for infilling large and extensive cavities. Low-cost materials (screened colliery spoil and/or pulverised fuel ash with additions of lime or cement) are pumped under pressure down widely spaced boreholes to flow through the mine and fill the cavities. The method is applicable to air-filled or flooded mines and no preparatory work is required inside the mine. The wide borehole spacing minimises the disturbance to surface land use.

2C30. In general the objective is to fill the cavity with material which has sufficient strength to prevent collapses within the mine progressing to the surface to form crown holes. Where total overburden support is required in very shallow cavities, or where lateral support is needed for mine pillars in deeper workings, a pulverised fuel ash/cement paste rapidly develops the necessary strength.

2C31. Depending on the circumstances, a wide range of materials can be used for cavity infilling. Examples include crushed demolition waste, lightweight aerated concrete and waste foundry sand as well as the conventional granular material, pulverised fuel ash and colliery spoil.

TREATMENT OF DISUSED MINE OPENINGS

2C32. Mine openings are a special case in the management of subsidence and underground hazards because of the evident direct threat posed to health and safety. This is recognised in the requirement under the Mines and Quarries Act 1954 for abandoned mine entries to be closed to prevent anyone falling down a shaft or entering a mine opening accidentally. Any mine entry not so closed may be designated as a statutory nuisance under the Environment Protection Act 1990 and the local authority may serve an abatement notice on the owners. However, this requirement relates only to mines abandoned since 1872 and pre-1872 mines accessible to a highway or place of public resort. Thus many mine entries still remain open and unprotected. Small-diameter shafts may be concealed by vegetation. Others were covered at or near the surface with timber or other materials and have subsequently become concealed. Uncontrolled tipping into shafts has resulted in unconsolidated fill that can collapse laterally into mine workings or may pile up on blockages within the shaft above voids in the shaft below.

2C33. Mine openings, both vertical shafts and shallow horizontal or inclined adits, are the most significant cause of ground collapse. Since many are concealed, with no sign at the surface of anything untoward, a significant number of early shafts are unrecorded and unsuspected. While more recent mine openings may have been treated adequately to meet the legal requirements for mine closure, the treatment will not necessarily have been to a standard suitable for specific subsequent use of the site.

2C34. The first requirement in treating mine openings is to locate them. This may be difficult. Indirect methods, such as geophysical techniques can be useful but are not always successful. Excavation of trenches or drilling of boreholes are commonly used site investigation techniques but even these can miss openings. Stripping the surface of the site is the best method but may be too costly or impractical. In any mined area, the site investigation objective must be to achieve a reasonable measure of certainty that mine openings have been located. Additional inspection of the ground is required at the construction stage to ensure that none have been missed. Volume 2/v of the *Review of mining instability in Great Britain* outlines procedures for locating disused mine openings.

2C35. The objectives of treatment of mine openings vary from deterring entry to complete closure. Where no development of land is involved, the minimum requirements of preventing accidental entry may involve relatively simple expedients. For public safety reason, however, the owner, occupier or local authority might carry out treatment to more than the minimum standard to reduce the risk and consequent liabilities. Where development is proposed, treatment should be to a standard suitable for safe subsequent use of the land. The variety of approaches adopted for dealing with disused mine openings is shown in Table 2C1. Some of these are illustrated in Figure 2C2.

2C36. The method of treatment selected for any particular mine opening will depend on:

- the permanence of the treatment works - temporary measures may be cheap initially but the need for maintenance may render them more expensive in the longer term;

- any requirement for continued access to the opening, including the need to vent mine gas in a controlled manner;

- the numbers of openings to be treated - metalliferous mining fields may have large numbers of openings in a limited area;

- the type of subsequent land use - eg protection for occasional visitors near a rural footpath in contrast to built development in an urban area;

Table 2C1. **Types of treatment of disused mine openings**		
General protection (suspected opening cannot be located)	Geotextile grid	
Deterrents to entry	Warning signs Mounds Fences Walls	
Partial closure of opening	Grid Door Beams Cabin	Grille Gate Cage
Complete closure of opening	Cover* Plug*	Cap* Infilling/grouting

Note: *these can be provided with openings such as manholes if access needs to be maintained or to provide for gas or water venting or drainage pipes.

- the budget available, though treatment works should always be suitably designed and executed; and
- the need to comply with the requirements of the Coal Authority in respect of treatment of coal mine openings.

2C37. Prevention of accidental or unauthorised entry to an adit opening may be achieved by low-cost fencing or grilles. These can be specially designed to permit continued use by bats or a gate can be incorporated to allow continued access, eg for inspection. Internal supports may be required to protect against subsidence. If no access is required, an adit can be sealed by a mound or bund of soil, or a masonry wall and the entry can be selectively infilled to prevent subsidence.

2C38. A minimum standard against accidental entry into mine shafts is a sturdy fence and warning notices. However, additional measures are likely to be required in most circumstances to prevent unauthorised entry. The additional need to protect against forced entry through vandalism should also be taken into account. The measures available rangefrom a simple cover, using concrete or wooden sleepers or a proprietary mine cap as a temporary provision where limited use of the land is likely, to provision of a reinforced concrete cap or plug in more demanding situations. A manhole can be included to provide continued access. Where access for bats must be safeguarded, a suitably designed grille can be incorporated. When no future access is required shafts may be infilled and, if necessary, grouted. Even when an opening is permanently sealed, it may be prudent to mark its location to warn future users of the land and the details of treatment should be recorded and stored in an appropriate location (see Appendix 2D).

2C39. In some instances, even diligent searches for recorded mine openings during site investigation may be unsuccessful. This may result from an incorrect record, with the shaft not being there at all, or an unlocated opening may be present on a development site. In such cases, the risk may be low but it is prudent to restrict the loading on the suspect part of the site by using it for open-space - gardens or parking - after strengthening the ground with a geotextile grid. Although this cannot offer complete protection, it will provide sufficient security to allow people to evacuate the risk area in the event of subsidence occurring.

2C40. Treatment of mine openings should be fit for purpose and should not create a false sense of security. The method selected should take account of the characteristics of the location, the use of the land, any need for continued access and the scale of hazard arising as well as the environmental impact of the treatment proposed. Fuller information on methods of treatment is contained in the report of the study of *Treatment of disused mine openings*. A key source of information on treatment of coal mine shafts is the National Coal Board Handbook *Treatment of disused mineshafts and adits*. It is essential that the investigation of sites and the design and execution of any works is undertaken by suitably qualified and experienced people.

APPENDIX 2D
Information on Mined Ground and Mining Data Systems

2D1. This appendix summarises the nature, condition and principal sources of information on mined ground, the types of data system, their preparation and maintenance, limitations and costs. It is specifically directed at information on mined ground but its principles could be applied to systems for recording, maintaining and retrieving data on other forms of subsidence. Authorities with significant numbers of land stability cases may wish to consider developing a suitable information system to hold and transmit relevant data on these matters.

TYPES, CONDITIONS AND SOURCES OF DATA

2D2. Information on mined ground is varied. It includes maps, plans, cross-sections, drawings, aerial and other photographs, geophysical records, written accounts and other documents such as legal agreements, sales ledgers, transport records and newspaper accounts of subsidence. Some of this information is published but a great deal is manuscript material held in archives and files. Useful incidental information can also come from accounts by travellers and historians and personal knowledge of researchers and residents in areas of past mining. Thus mining information is often found amongst a great deal of other data.

2D3. The physical condition of original documents is variable. Early plans may be fragile and unwieldy. They may be valuable historical documents and owners may be reluctant to allow them to be handled, consulted or copied. The accuracy of records varies greatly. Many plans were prepared by specialists such as engineers, surveyors, geologists or other trained professionals. However, a substantial body of information was recorded by less expert observers or has been wrongly transposed from other documents. The scales of maps vary greatly and it may be difficult registering on modern maps the exact positions of features shown on earlier ones.

2D4. Despite the apparent abundance of documentary evidence of mining, significant numbers of unrecorded workings continue to be discovered in the course of site investigations, or when subsidence occurs. Many early mines were either not documented at the time or the records have been lost or destroyed. Only since 1856 has there been a legal requirement to make accurate mine plans and the requirement to lodge abandonment plans at the Mining Records Office was not introduced until 1872. There is still no requirement under the Miscellaneous Mines (General) Regulations 1956 to send plans of mines employing less than 12 people to the Inspector of Mines for the district. In addition illegal and thus unrecorded working is known to have taken place at various times, eg during the General Strike of 1926.

2D5. The records available may not, therefore, give an accurate and comprehensive indication of the distribution of mine workings and mine openings. They can be used, however, to define areas where there is a general local history of mining and where the geological conditions are suitable, within which mining may have taken place. This at least paves the way for further investigation where necessary. The interpretation of mining records requires considerable expertise. It is a matter for properly qualified, experienced specialists such as mining engineers, surveyors or geologists and mining historians.

2D6. Information additional to or in confirmation of past records is obtained in the course of site investigations. Information on the treatment of disused mine workings and openings is widespread in site development records. Only rarely, however has this information been collated and made readily accessible. It is desirable that such information should be recorded systematically and maintained in an accessible form so as to inform future consideration of proposed changes to land use in mining areas.

2D7. Important sources of information on mined ground are the Health and Safety Executive Inspectorate of Mines and the British Geological Survey. The database collated during the review of mining instability in Great Britain, along with those from the reviews of natural cavities and foundation conditions, is available on a commercial basis. The Coal Authority has detailed records of those coal mines for which it has a direct or inherited responsibility, including abandonment plans for mines of coal and associated minerals. It has established a centralised computerised data service. Abandonment plans for other minerals are now lodged with County Record Offices. Many local authorities hold their own records, as do organisations such as Railtrack and British Waterways and a number of long-established mining consultants. The National Association of Mining History Organisations[7], the Institution of Mining History Associations[8] and the National Caving Association[9] have access to extensive knowledge of mined ground.

2D8. However, much of the relevant information is widely dispersed and is not organised for rapid retrieval. Practical problems can arise in securing data including locating them, the absence of indexes, the staff effort involved in retrieving documents, commercial confidentiality and the value of some types of information. Major collections may have access arrangements for enquirers but many smaller sources do not.

2D9. Speedy and thorough compilations of relevant data may thus be difficult and important information may be missed. Searches for information prior to development are often duplicated unnecessarily. There are thus distinct benefits in collating and maintaining information in a readily accessible form that will improve efficiency. A rational and well indexed system vastly improves the usefulness of information.

2D10. The options and feasibility of developing such systems were examined through the then Department of the Environment research programme (Freeman Fox Ltd, 1988). The efficiency and cost-effectiveness of systems for handling collections of data of varying sizes, including manual (card-index) and computer facilities, were examined. In addition a computerised system was developed for a trial area in Cornwall (Freeman Fox Ltd, 1992) to test the feasibility of and best approaches for collecting and collating mining data. Since that time, some authorities have developed their own systems and, while there have been developments in computer software (particularly in the field of geographical information systems), the options identified are still relevant.

TYPES OF MINING DATA SYSTEMS

2D11. Information may be organised into:

- a cross-indexed catalogue of original documents allowing rapid location of the original data, which may be held by the authority or at the owner's premises; or

- a cross-indexed system containing data abstracted from original documents.

7 c/o Peak District Mining Museum, The Pavilion, Matlock Bath, Derbyshire DE4 3NR
8 Department of Economic History, Amory Building, Rennes Drive, Exeter EX4 4RJ
9 27 Old Gloucester Street, London WC1N 3XX

2D12. For a small data system, a simple catalogue may be all that is needed. For large collections, whose records are used frequently, data abstraction may be needed to increase their utility and protect the originals. For widely dispersed collections, a central register of data enables sources to be readily located and protects against the possibility of total loss of the information in its original form. Such systems do not dispense with the need for original documents since these may need to be referred to and re-interpreted during detailed work.

2D13. All such systems can be organised:

- on paper - card index and master map or maps; or
- as a computerised database, with or without facilities for graphical display of information and printing out data and maps.

2D14. The choice depends on cost-effectiveness for the size and frequency of use of the collection and the financial resources available to establish the system. A well designed system of either type will reduce the costs of staff time in locating files. Effective manual systems exist already in a number of places. These may meet the local requirement. However, recent computer and software development has been such that, for all but the smallest databases, a computerised system using a proprietary package may be the most cost-effective. While initial investment may be more costly, subsequent operational costs are substantially smaller. It should not be necessary, however, to commission an entirely bespoke system in order to meet the need effectively. Authorities are not advised to follow this course unless they are sure that it is fully justified within their wider information management strategies.

2D15. Computer systems have the advantage of being:

- easily reproducible for security of data and use in several places or by remote access;
- quicker for entry of new data;
- directly linkable to graphics packages, allowing custom-made maps to be produced quickly; and
- a basis for a geographical information system.

2D16. Possible disadvantages include:

- converting from a manual system is time-consuming and expensive;
- advances in technology and software may cause obsolescence over a fairly short time scale;
- problems due to incompatibility of equipment and software may arise when incorporating digital information or transferring records between organisations;
- computerised information may give a spurious impression of reliability and accuracy; and
- there may be a temptation to devise or purchase over-elaborate systems.

However, it should be noted that some of the disadvantages listed can be minimised or avoided altogether by adopting a standard format such as that developed by the Association of Geotechnical Specialists (AGS) for electronic transfer of geotechnical data from ground investigations. This format is not software-specific and can be used with word processing and spreadsheet applications as well as more complex packages. An evaluation copy can be downloaded from the AGS website - www.ags.org.uk.

2D17. For these reasons the design and operation of any system needs to be approached with a clear understanding of the limitations on reliability of the system and the data contained and of the continuing need to consult original records where appropriate in individual cases.

PREPARATION AND MAINTENANCE OF DATA SYSTEMS

2D18. The preparation of a data system requires the location, collection, collation and storage of data from a wide variety of sources. Records may be difficult to interpret and collection should be carried out by a mining surveyor, engineer, geologist or other appropriate specialist. Archivists and mining historians also have an important role. Much information will have to be located in terms of the National Grid and metricated from a variety of scales and units. This is time-consuming and can be expensive unless automatic methods are used.

2D19. The range of information stored can be as wide as that which is available. However, key categories include:

- mine openings - mainly point data;
- mine roadways and drainage galleries - essentially linear data;
- laterally extensive workings - essentially area data; and
- topographical and geological features within which unrecorded workings may be suspected.

2D20. Some basic sets of relevant data headings are summarised in Table 2D1. Where the information is available, more elaborate systems could include details of subsidence incidents or other relevant features, such as conservation interests, uses of mines and mine openings and any treatment works that have been undertaken to mitigate potential subsidence or to protect against accidental or unauthorised access. It is important that sources of data are recorded so that users of information can assess their reliability and original records can be readily traced.

2D21. Data collection exercises are a relatively expensive investment. Their full value is realised only if, after the initial effort, data is added as it becomes available. It is much more efficient for this to be done by planners, engineers, developers and others lodging data in appropriate databases as a matter of course rather than leaving it to periodic searches or updating exercises. Planning conditions requiring the lodging of completion reports on investigation or remedial or safety treatment can assist in achieving this objective. The information, or at least details of what information is available, then becomes a common benefit for all future users of mining information. For this to be widely achieved, the scope and location of data systems and the nature of information required need to be widely understood.

LIMITATIONS ON DATA SYSTEMS

2D22. The most important potential limitation on the content and use of mining databases is that of confidentiality. Owners of original data may not wish to be disturbed by enquirers and access to original records may not be possible. Where information has a commercial value or is of a sensitive nature, it may be placed in a confidential archive. Alternatively the database may contain only a brief reference to the existence of such information rather than details of its content.

2D23. In such cases, there are limitations on the information that can be supplied to enquirers. It may be possible to secure agreement with the owner of the data on the use to which such data can be put. The owner may agree to:

- the release of generalised but not detailed information;
- the operator of the data system seeking specific permission for release of the data; or
- the identification of ownership of the data so that any enquirer can seek permission directly from the owner.

2D24. The data recorded should be as factual and complete as possible. Interpretation should be left to the user. Guides to users should emphasise that no database of mining information is likely to be complete and that the onus rests on users to ensure that no additional unrecorded features are present in any particular site. Failure to make this clear could give rise to liability on the part of the owner of the data system. In addition, great care is needed in transcribing data from original records to avoid any charge of negligence. The accuracy of original records is, of course, the responsibility of those who made them but users are responsible for how original material is transcribed, interpreted and subsequently used.

COSTS OF DATA SYSTEMS

2D25. The costs of preparing new data systems rest principally in the collation and compilation of information using appropriate expertise. Equipment costs depend on the nature of the system and whether initial outlay can be reduced by using computers acquired for other purposes or by adapting existing systems. In local authority areas where mined ground is very limited, paper records may be cost-effective, though the unit costs of retrieving information may be higher.

2D26. The initial cost of establishing a 1,000-record database on a personal computer using proprietary software could be of the order of £20-25,000, (at 2000 prices) but with low running costs thereafter. In intensively mined areas, the number of records is likely to be larger and the costs of establishment would consequently be several times higher. However, mining data systems already exist for a number of such areas and adapting existing systems may be less expensive. Advantage should be taken of existing facilities wherever possible and care should be taken before decisions are made to develop any completely new systems. There may also be economies in collaborating with other authorities or organisations in developing a data system. Operational and maintenance costs might be defrayed by provision of a chargeable service.

Table 2D1. **Data heading for mine workings**				
Minimum heading for all workings				**Additional Information**
Common to all	**Openings**	**Roadways**	**Workings**	Ground surface profile Type(s) of overburden Thickness of overburden Type(s) of bedrock Groundwater level(s) Additional subsurface information Construction information Adjacent shallow workings Instability incidents Gas problems Existing condition Conservation interests Uses of mine opening Owner/tenant Access Interest groups Treatment: – Type and purpose – Undertaken by whom – Date – Subsequent monitoring
Identification code Name National Grid reference Mineral(s) extracted Whether directly surveyed Source(s) of information Location of original documentation Date(s) of working Comments	Depth (total) Date of construction Altitude (AOD) Size Shape Inclination Bearing	Line segment – position – width – end points – depths – purpose	Boundary – position – depths (or depth contours) seam thickness vein width method(s) of working	

Note: It will not be possible to fill in all headings for all mines and openings. A comprehensive record can be made only for those mines that have been directly surveyed and investigated.

APPENDIX 2E
Content of Stability Reports

2E1. For development in areas potentially liable to subsidence, or that is likely to cause subsidence, a local planning authority may request a ground stability report. This will allow the applicant to demonstrate that subsidence will not unacceptably adversely affect a proposed development or it can be satisfactorily mitigated in the design of the development.

2E2. The preparation of ground stability reports is a technical task demanding a wide range of expertise in engineering geology, geomorphology, hydrogeology, mining, geotechnical engineering and foundation design. Such reports should be prepared by a competent person with proven experience in the fields relevant to subsidence of natural and mining/industrial cavities and due to adverse foundation conditions. Appropriately qualified people would be expected to be chartered members of a relevant professional institution, such as the Geological Society, the Institution of Civil Engineers, the Institution of Mining and Metallurgy the Royal Institution of Chartered Surveyors or other relevant professional institutions. As a minimum, the competent person would be expected to qualify as a geotechnical specialist as defined by the Institution of Civil Engineers' Site Investigation Steering Group.[10]

2E3. The contents of a ground stability report will vary in detail from one site to another depending on the potential causes of subsidence that need to be investigated and the development that is proposed. However, all reports would be expected to cover a basic range of issues and there could be some merit in including a standard ground stability declaration form as illustrated in Table 2E1. This indicates the main categories of investigation which need to be covered and the report would be expected to provide detailed supporting information for each of the items listed that are appropriate to any particular development proposal. The report should identify the information used, reach conclusions on the potential for subsidence to occur and make recommendations for mitigation measures if considered necessary.

2E4. The purpose of the stability report is to present all the information obtained from an investigation in a logical and ordered format and to draw conclusions from the information presented as to the likelihood of subsidence and appropriate means of mitigation where necessary. It is important that any ground stability report should not merely examine the proposed development site in isolation but should examine it within its local context. It is often the case that information from neighbouring land gives the clue to what has happened on a site in the past. Ground stability investigations will normally comprise a desk-study and site inspection followed as necessary by appropriate ground investigations.

2E5. For some sites, a desk study and site inspection may provide sufficient information to enable conclusions to be made on the risk of subsidence and the effectiveness of mitigation measures. In such cases, the local planning authority may determine an application on that basis. Where the threat of subsidence is significant, particularly in the case of shallow mining or natural cavities, conditions may require ground investigation and the implementation of any necessary mitigation measures. For built development, the Building Regulations will ensure that the foundations are adequate to support the building in the event of subsidence.

10 Institution of Civil Engineers' Site Investigation Steering Group, 1993. *Without site investigation, ground is a hazard*. London, Thomas Telford Publications.

DESK STUDY AND SITE INSPECTION

2E6. A desk study is an examination of existing information from a wide range of sources. The objective is to identify and assess the possible ground conditions and to review both the past history of the site and any planned future development that might affect the site. It would normally involve:

- examination of topographical, geological and soils maps, together with any specialised mapping or databases such as those described in Appendix 2B;
- a literature search of information available from public records and technical libraries, including unpublished geological data from British Geological Survey files and mining records held by the Coal Authority and other relevant organisations;
- examination of aerial and other photographs; and
- assessment of information derived from local knowledge relating to past uses or particular problems on a site or in the general area.

2E7. The site inspection is an essential adjunct to the desk study, which helps to provide a check on the results of the desk study and in the appraisal of instability or difficult ground conditions. Detailed inspection should be carried out to identify whether or not there is any evidence of former, on-going or incipient subsidence activity within or adjacent to the site. Points that should be addressed in a site inspection include:

- ground slopes and changes in slope - abrupt changes in ground level may indicate former surface excavation or tipping;
- types and condition of surface vegetation - boggy ground may result from subsidence or indicate the presence of adverse foundation conditions;
- surface hollows, cracks, uneven ground, which may indicate subsidence into solution features or collapsed underground workings;
- damage to structures, such as cracks or repaired cracks in buildings, both on the site and in the neighbourhood, and other evidence of differential settlement;
- present land use, evidence of buried services and remains of structures identified during the desk study but no longer present on site; and
- materials exposed in nearby road or railway cuttings, pits or quarries and natural exposures of soils and rocks.

2E8. Relevant factual information from plans or documents should be presented clearly in the report, by reproducing original material where possible. Where this is not possible, or the material is too bulky, it should be summarised as appropriate and illustrated appropriately with plans, cross-sections and photographs. The sources of all information used should be recorded and references given. The format of the report may vary according to the house style of the competent person and the development proposed but it should contain:

- a factual account describing the site location and topography, summarising the geological and other relevant information discovered and describing any previous development of the site, including mining, and any subsidence history;

- an interpretation of the data, assessing and concluding on the potential risk to the development proposed from subsidence due to natural cavities, adverse foundations or past, present or future mining beneath the site; an essential part of this stage is a detailed interpretation of the geology of the site; and
- recommendations for further action arising from the conclusions of the risk assessment.

2E9. The recommendations will probably fall into one of the following general categories:

- there is a negligible risk of subsidence affecting the site and development may proceed without special precautions related to subsidence;
- there is a risk of subsidence but it cannot be quantified on the basis of a desk study and site inspection and further investigation is needed to define the risk and any need for preventive measures - the site investigation proposals should be set out;
- there is a significant risk of subsidence that has been defined well enough by the desk study and site inspection to design detailed mitigation measures; or
- there is a significant risk of subsidence that requires a full ground investigation to enable mitigation measures to be designed - the nature of the risk should be outlined and typical mitigation measures should be given - the site investigation proposals should also be set out.

2E10. The progression from factual information to interpretation and recommendations should be clear, without gaps in the argument or logical flaws. The report should be written in plain language that is understandable by the non-expert. Conclusions and recommendations should be clear and unequivocal, with no disclaimers that devalue the study undertaken. However, technical interpretations and opinions can vary and there may be more than one valid approach to a problem. Alternative options and their consequences should be identified and assessed in order to arrive at appropriate recommendations.

GROUND INVESTIGATIONS

2E11. Where the desk study and site inspection does not provide sufficient information to discount the risk of subsidence or to design mitigation measures, a ground investigation will be required. It will be designed to fill in the missing factual data identified during the desk study and site inspection. Typically it should confirm:

- the geological sequence and structure of both solid geological and superficial deposits;
- the depth to strata liable to dissolution or to seams which may have been worked;
- the presence extent and condition of any underground natural cavities or abandoned mine workings, particularly mine entrances;
- the presence and nature of any made ground, broken ground or other adverse foundation conditions; and
- the groundwater regime, its potential influence on subsidence and the potential effects on it of mitigation measures.

2E12. The choice of ground investigation techniques will depend on the expected ground conditions and the nature of the proposed development. Direct techniques, such as trial pits, trenches or borehole investigations, involve actual examination of the ground. Indirect techniques, such as various geophysical methods provide interpretations of ground conditions that must be confirmed by direct techniques. These methods will often be supplemented, especially for adverse foundation conditions, by *in situ* testing and by laboratory testing of samples obtained from boreholes, pits or trenches.

2E13. For small sites of up to two or three houses and for most householder developments, the ground investigation is unlikely to be extensive unless the desk study and site investigation has indicated the presence of shallow cavities, extensive broken ground or mine entrances within or in close proximity to the site. For larger sites, however, sufficient boreholes would be needed to establish the general geological structure and the nature and condition of any cavities or broken ground. Geophysical techniques may assist in the targeting of boreholes as well as in providing 3-dimensional interpolation between boreholes. Correlation of strata is enhanced if at least some boreholes are rotary cored and intervening probeholes are subject to geophysical logging.

2E14. Where the investigation shows a site to be liable to subsidence, or where underground excavation is proposed, an assessment will be needed of the extent and nature of likely subsidence and its effects. This should identify:

- the type of subsidence likely, ie excessive settlement due to adverse foundation conditions, crownhole/sinkhole collapse into shallow cavities or general subsidence;
- the magnitude of likely subsidence and whether it will differ from one part of the site to another;
- ground tilt due to differential subsidence;
- ground strains induced by subsidence; and
- the influence of these movements on existing or proposed buildings and structures.

TABLE 2E1. Ground stability declaration form

Site Name	**Site Address**	**Proposed Development**

CATEGORY	**QUESTION**	**YES/NO /?/N/A**
Competent person	Has the report been prepared by a Geotechnical Specialist, as defined by the ICE Site Investigation Steering Group?	
A. Site history	Has the site been affected by known historical subsidence?	
	Is the site underlain by strata which may contain natural cavities or be liable to subsidence due to adverse foundation conditions?	
	Has there been previous development on the site such as mining or industrial development that could result in underground cavities or made ground?	
	Is mining or underground excavation proposed beneath the site?	
	Have any previous ground investigation reports and/or borehole records from this or nearby sites been consulted?	
	Have any cavities, broken ground, made ground or other adverse foundation conditions been identified beneath or near the site?	
B. Site inspection	Has a detailed site inspection been carried out?	
	Does the land within or adjacent to the site bear any geomorphological evidence of former, on-going or incipient subsidence?	
	Does the site or neighbouring property bear any evidence of structural damage or repairs that might be associated with subsidence or evidence of mine entries?	
C. Ground investigation	Has a ground investigation been carried out?	
	Have any cavities, broken ground, made ground or other adverse foundation conditions been identified beneath or near the site?	
	Have their locations and dimensions been properly identified?	
Assessment of subsidence	Is the information under A, B and C above adequate to assess the likely effects of subsidence on the site?	
	Can subsidence be reasonably foreseen within or adjacent to the site within the design life of the proposed development?	
	Have the potential effects of subsidence on existing or proposed development been assessed?	
Mitigation measures	Have mitigation measures been proposed with respect to subsidence?	
	Are these designed to reduce the effects of any actual or potential subsidence to an acceptable level?	
	Are they likely to have any adverse effects on other adjacent sites, eg by affecting the groundwater regime?	
Name, qualifications and signature of person responsible for this report	Full Name	
	Qualifications	
	Geotechnical Specialist?	
	Signature	
	Company Represented	

2E15. The ground investigation report, illustrated appropriately with plans and cross-sections, should be similarly organised to the desk study and site investigation report, ie:

- a factual account describing the findings of the ground investigation;
- an interpretation of the field data, in conjunction with the desk study and site inspection findings, to confirm the geological sequence and the potential for subsidence and its potential effect on the development proposed; and
- recommendations for action following the ground investigation.

2E16. The recommendations are likely to fall into one of the following categories:

- that the investigation has shown that the risk of subsidence is negligible and development may proceed without special precautions; or
- that there is a significant risk of subsidence, which will require mitigation measures to allow the development to proceed safely. These measures should be described sufficiently to allow detailed design to proceed.

2E17. The report should reach a clear conclusion on whether there is a potential for subsidence based on a logical discussion of all the data gathered. It should declare the method used to assess potential subsidence. Any recommendations for mitigation measures should be clear and unequivocal and should take account of the risks to people and property, the scale and type of the development and the consequences of subsidence occurring. In order to arrive at appropriate recommendations, alternative options and their consequences should be identified and assessed.

2E18. The desk study and site inspection and ground investigation reports should provide sufficient guidance for detailed design of foundations and other preventive measures to mitigate the potential for subsidence. It is important that there be dialogue between the competent person responsible for assessing the subsidence potential and the designers of any mitigation measures. Developers are therefore encouraged to make the designs available to the competent person to ensure that recommendations of the subsidence assessment have been carried forward fully into the design.

BIBLIOGRAPHY

DEPARTMENT OF THE ENVIRONMENT, 1990. *This common inheritance: Britain's environmental strategy*. Cm 1200, London, HMSO.

DEPARTMENT OF THE ENVIRONMENT, 1990. *Planning policy guidance note 14: Development on unstable land*. London, HMSO, 25pp.

DEPARTMENT OF THE ENVIRONMENT, 1994. *Minerals planning guidance note 12: Treatment of disused mine openings and the availability of information on mined ground*. London, HMSO, 31pp.

DEPARTMENT OF THE ENVIRONMENT, 1994. *Planning policy guidance note 9: Nature conservation*. London, HMSO, 59pp.

DEPARTMENT OF THE ENVIRONMENT, 1996. *Planning policy guidance note 14: Development on unstable land. Annex 1: Landslides and planning*. London, HMSO, 17pp.

DEPARTMENT OF THE ENVIRONMENT, TRANSPORT & THE REGIONS, 2000. *Planning policy guidance note 3: Housing*. London, TSO.

DEPARTMENT OF THE ENVIRONMENT, TRANSPORT & THE REGIONS, 2000. *Planning policy guidance note 11: Regional planning*. London, TSO, 83pp.

DEPARTMENT OF THE ENVIRONMENT, TRANSPORT & THE REGIONS, 2000. *Planning policy guidance note 12: Development plans*. London, DETR.

DEPARTMENT FOR TRANSPORT, LOCAL GOVERNMENT & THE REGIONS, 2001. *Planning: delivering a fundamental change*. London, DTLR, 67pp.

ARUP GEOTECHNICS, 1992. *Mining instability in Great Britain - Summary Report*. London, Department of the Environment.

ARUP GEOTECHNICS, 1991. *Review of mining instability in Great Britain*. Newcastle-upon-Tyne, Arup Geotechnics.

1.i	*South west England*	*1.ii*	*South east England*	*1.iii*	*Wales*
1.iv	*West midlands*	*1.v*	*East midlands*	*1.vi*	*East Anglia*
1.vii	*North west England*	*1.viii*	*Yorkshire & Humberside*		
1.ix	*Northern England*	*1.x*	*Scotland*		

2.i *The effects of mines*

2.ii *Investigation methods for disused mines*

2.iii *Mining subsidence: preventive and remedial techniques*

2.iv *Mining subsidence: monitoring methods*

2.v *Procedures for locating disused mine entries*

3.i *Metalliferous mines in Kerrier (Cornwall)*

3.ii *Bath stone mines, Combe Down, Bath (Avon)*

3.iii *Reigate silver sand mines (Surrey)*

3.iv *Barrow-on-Soar hydraulic limestone mines (Leicestershire)*

3.v *Norwich chalk and flint mines (Norfolk)*

3.vi *Stafford brine pumping (Staffordshire)*

3.vii Peak District lead mines (Derbyshire)

3.ix West Lothian oil shale mines (West Lothian)

3.x Santon Dragonby ironstone mine (Humberside)

APPLIED GEOLOGY LTD, 1993. *Review of instability due to natural underground cavities in Great Britain*. Royal Leamington Spa, Applied Geology Ltd
Summary Report.

1.1 South west England *1.2 South east England* *1.3 Wales*

1.4 West Midlands *1.5 East midlands* *1.6 East Anglia*
1.7 North west England *1.8 Yorkshire & Humberside*

1.9 Northern England *1.10 Scotland*

2.1 Nature and occurrence of natural cavities and their influence on planning and development in Great Britain.

2.2 Review of site investigation techniques and their utilisation for natural cavity location.

2.3 Review of ground treatment and structural design techniques.

WIMPEY ENVIRONMENTAL & NHBC, 1995. *Foundation conditions in Great Britain: a guide for planners and developers - Main report*. Hayes, Wimpey Environmental.

WIMPEY ENVIRONMENTAL & NHBC, 1995. *Foundation conditions in Great Britain: a guide for planners and developers - Summary report*. Hayes, Wimpey Enviironmental.

OVE ARUP & PARTNERS, 1985. *Mining subsidence South Wales Desk Study*. 5 vols. Open-file report.

OVE ARUP & PARTNERS, 1995. *Islwyn shallow mining: Final report*. Cardiff, Ove Arup & Partners.

OVE ARUP & PARTNERS, 1995. *Islwyn shallow mining: development advice maps*. Cardiff, Ove Arup & Partners.

OVE ARUP & PARTNERS, 1995. *Planning procedures and guidelines for the use of development advice maps: abandoned mining and development in Islwyn Borough*. Cardiff, Ove Arup & Partners.

HOWARD HUMPHREYS & PARTNERS, 1993. *Subsidence in Norwich*. London, HMSO.

SYMONDS TRAVERS MORGAN, 1996. *Assessment of subsidence arising from gypsum dissolution - Summary report*. East Grinstead, Symonds Travers Morgan.

SYMONDS TRAVERS MORGAN, 1996. *Assessment of subsidence arising from gypsum dissolution - Technical report*. East Grinstead, Symonds Travers Morgan.

BLACK COUNTRY LIMESTONE ADVISORY PANEL, 1995. *Seventh annual and final report to the Secretary of State for the Environment, 1994-95*. London, Department of the Environment.

FREEMAN FOX LTD, 1988. *Treatment of disused mine openings*. London, HMSO.

FREEMAN FOX LTD, 1988. *Methods of compilation, storage and retrieval of data on disused mine openings and workings*. London, HMSO.

ACER GEOTECHNICS LTD, 1992. *Investigations of ground characteristics in the area around Chacewater and St Day in the County of Cornwall*. Long Eaton, M1 Press Ltd.

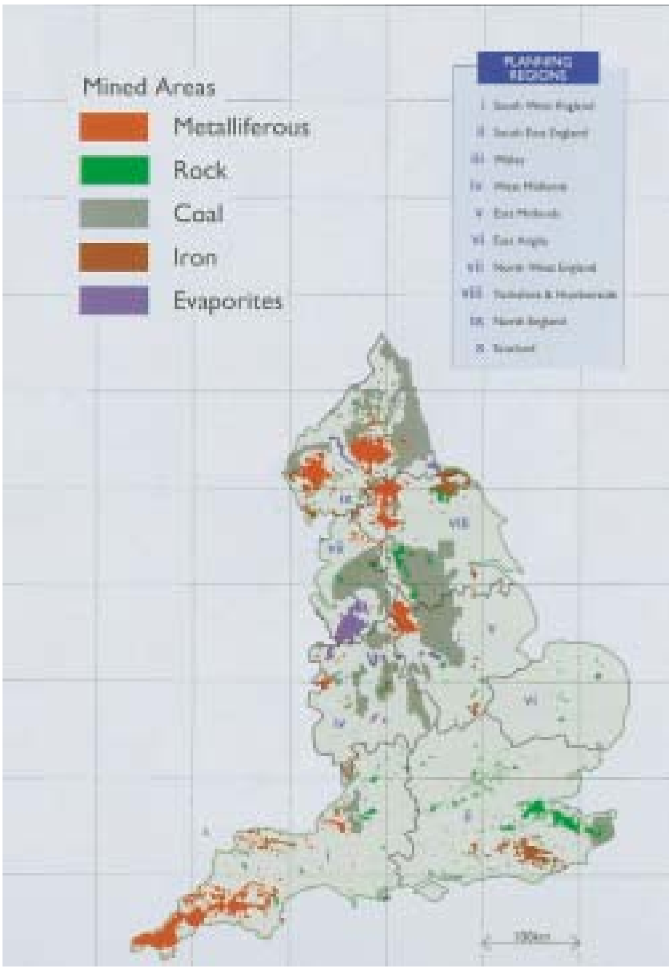


Figure 2A1. Distribution of mined areas in England (after Arup Geotechnics, 1992)

Figure 2A2. Distribution of natural underground cavities in England (after Applied Geology Ltd, 1992)

Figure 2A3. Distribution of soluble rocks in England (after Applied Geology Ltd, 1992)

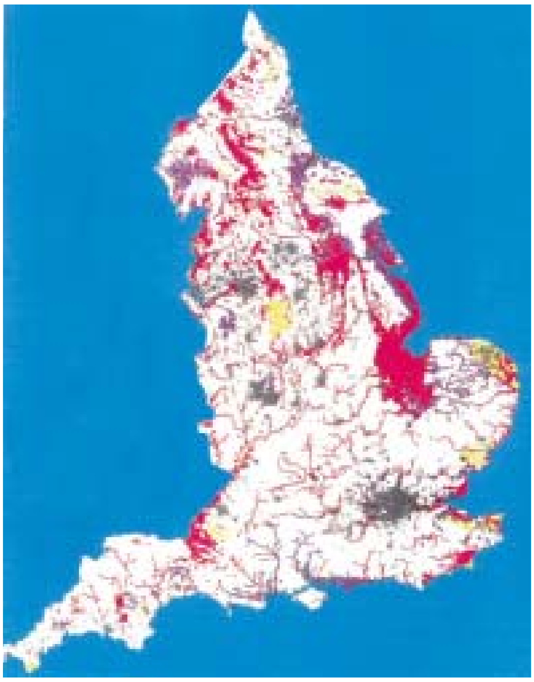


Figure 2A4. Compressibility of the ground in England (after Wimpey Environmental, 1995)

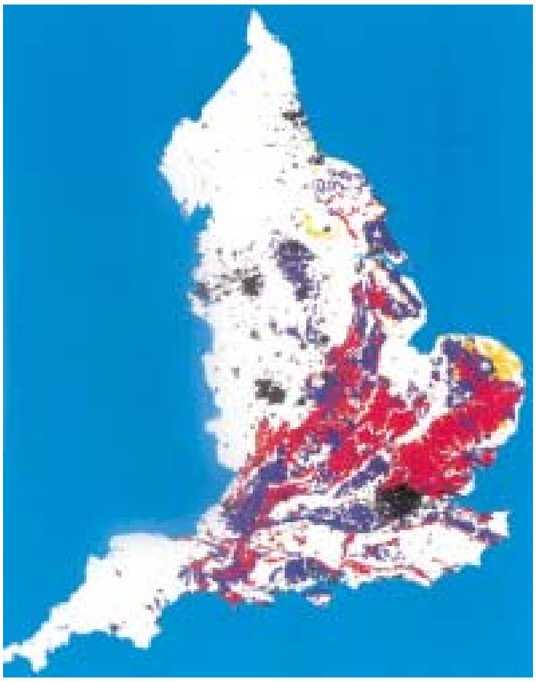


Figure 2A5. Shrinkable and swelling ground in England (after Wimpey Environmental, 1995)

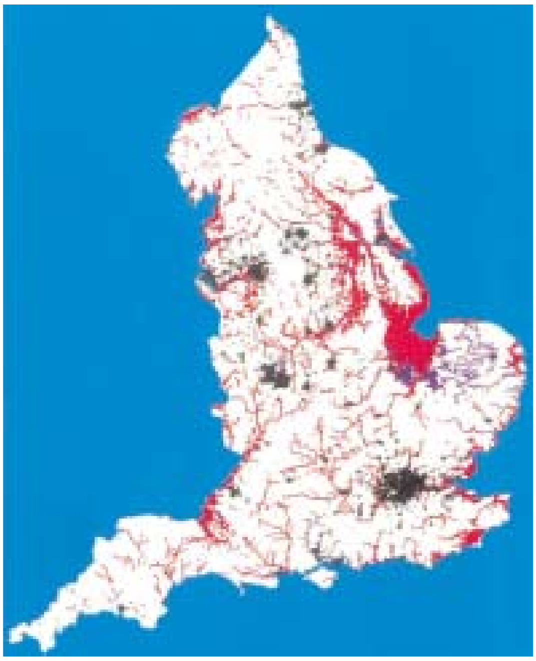
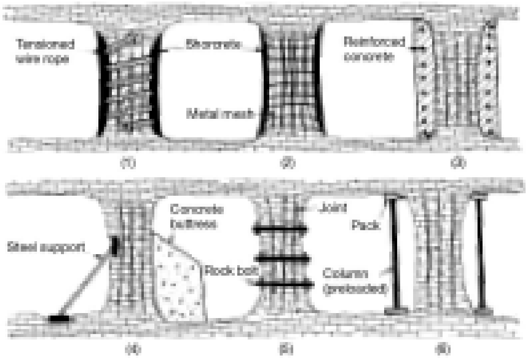
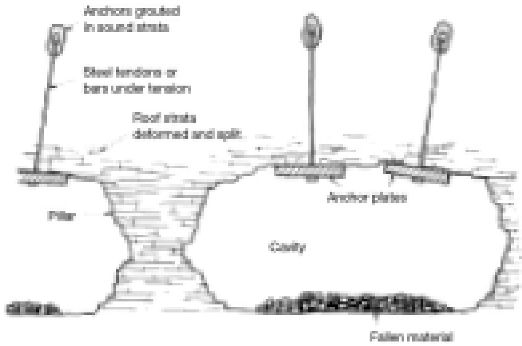


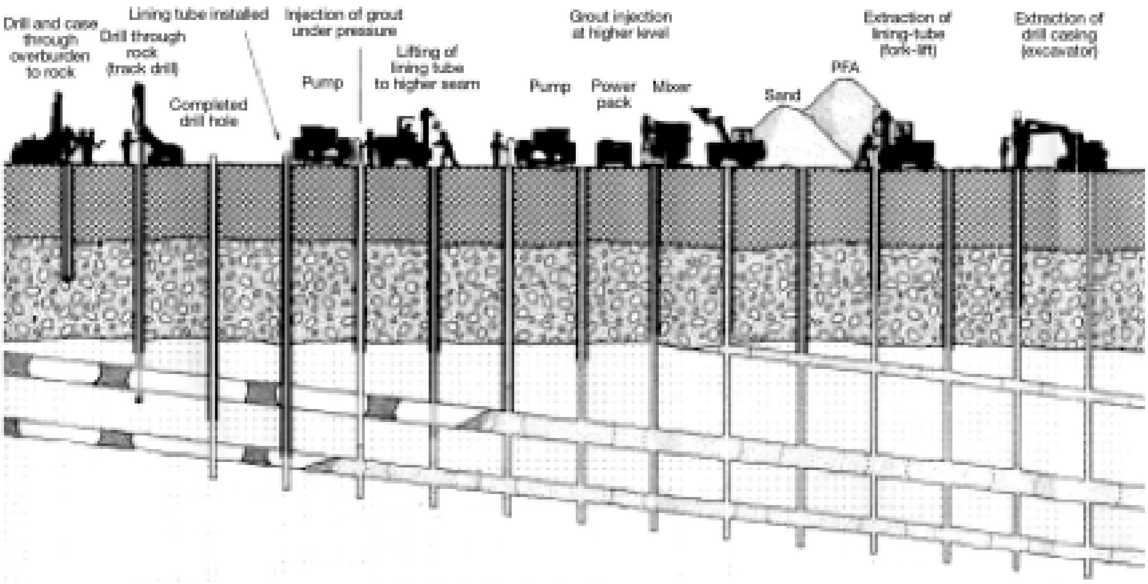
Figure 2A6. Saturated and loose granular deposits in England (after Wimpey Environmental, 1995)

Table 2A1 Key to foundation condition maps

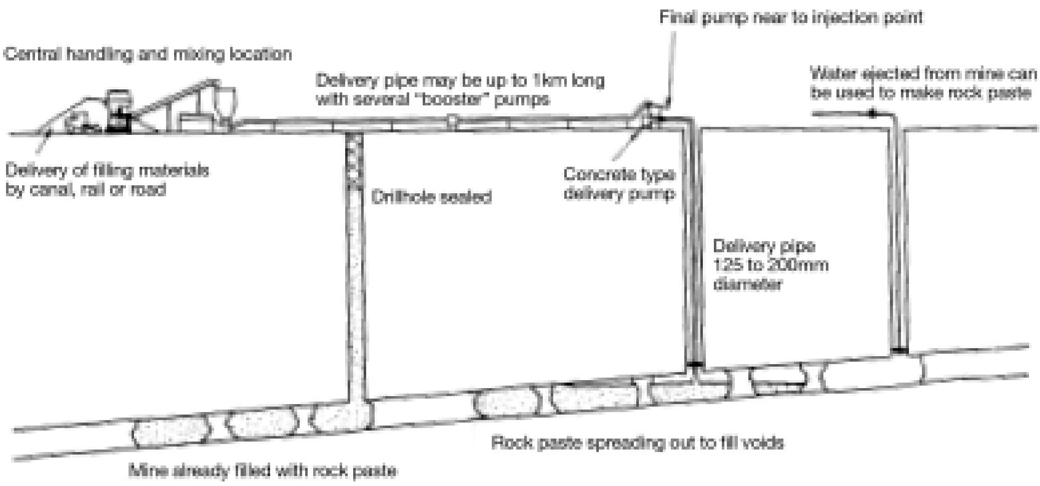
Colour	Class	Description
White	0	Areas in which the adverse foundation condition is unlikely to occur
Yellow	1	Areas moderately susceptible to the adverse foundation condition locally
Dark blue	2	Areas moderately susceptible to the adverse foundation condition throughout or highly susceptible locally
Red	3	Areas highly susceptible to the adverse foundation condition throughout
Black	Urban areas	
Light blue	Lakes, sea	







Pressure Grouting sequence



Mine infilling using rockpaste

Figure 2C1. Mitigation of subsidence by treating cavities (after Arup Geotechnics, 1992)

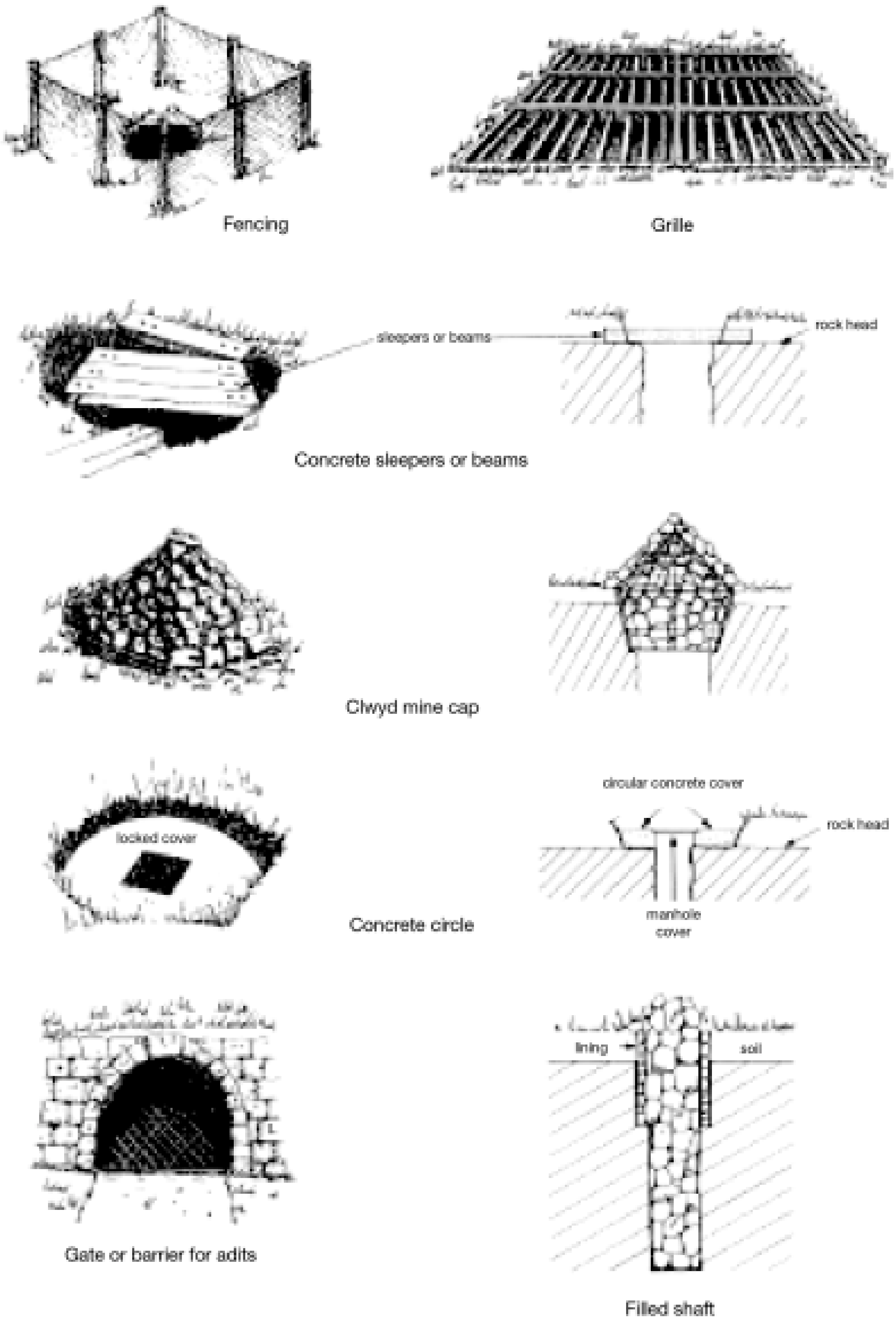


Figure 2C2. Examples of treatments carried out on disused mine openings (after Derbyshire County Council *Code of Practice for disused lead mine shafts)*

PPG 14 Development on Unstable Land Annex 2: Subsidence and Planning

Published by The Stationery Office Limited
and available from:

The Stationery Office
(Mail, telephone and fax orders only)
PO Box 29, Norwich NR3 1GN
General enquiries 0870 600 5522
Order through the Parliamentary Hotline *Lo-call* 0845 7 023474
Fax orders 0870 600 5533
Email book.orders@theso.co.uk
Internet http://www.clicktso.com

The Stationery Office Bookshops
123 Kingsway, London WC2B 6PQ
020 7242 6393 Fax 020 7242 6394
68-69 Bull Street, Birmingham B4 6AD
0121 236 9696 Fax 0121 236 9699
33 Wine Street, Bristol BS1 2BQ
0117 9264306 Fax 0117 9294515
9-21 Princess Street, Manchester M60 8AS
0161 834 7201 Fax 0161 833 0634
16 Arthur Street, Belfast BT1 4GD
028 9023 8451 Fax 028 9023 5401
The Stationery Office Oriel Bookshop
18-19 High Street, Cardiff CF1 2BZ
029 2039 5548 Fax 029 2038 4347
71 Lothian Road, Edinburgh EH3 9AZ
0870 606 5566 Fax 0870 606 5588

Accredited Agents
(See Yellow Pages)

and through good booksellers

£11

ISBN 0-11-753628-8
9 780117 536289

The Stationery Office