**The design and construction of water impounding plugs in working mines**

**Background**

1. The failure of any watertight plug at a working mine, or of the strata around it, could lead to rapid flooding putting lives at risk. The Health and Safety Executive's, HM Inspectorate of Mines' report ['The circumstances surrounding the flooding and closure of Longannet Mine, Fife, Scotland' (2002) ](http://www.hse.gov.uk/mining/longannet.pdf)concluded that some failure in the vicinity of one of two such plugs on 23 March 2002 probably caused the flooding, and prompted the production of this guidance.

**What this guidance is about**

2. This guide is about the design and construction of watertight (hydrostatic) plugs in **working** mines. It sets out good engineering practice in relation to the design and construction of such plugs to guarantee their long-term security and in so doing avoid risks to workers from the rapid flooding that would follow a catastrophic failure of a plug or the strata around it.

3. It relates only to parallel type mass cement, concrete or grout type plugs. The UK mining industry has used tapered plugs only occasionally as the relatively large excavations required in the weak sedimentary rocks present in many UK mines are difficult to support and can give rise to increased risk to those constructing them.

4. Further information on the design of these and other types of plug can be found in the [references](http://www.hse.gov.uk/mining/circulars/waterplu.htm#references) at the end of this guide.

**Who should read this?**

5. The guidance is aimed principally at the owners of working mines intending to construct watertight plugs to impound water in old workings. It will also help mine managers, engineers, surveyors, geologists, design engineers and those constructing such plugs determine what they need to do to reduce risks to as low as reasonably practicable.

6. While this guidance relates principally to securing the safety of workers in working mines, the procedures it describes are relevant to those dealing with closed or closing mines where watertight plugs are installed in roadways and shafts to prevent or limit mine water outflows for environmental reasons.

7. It can also be used as a basis against which to assess or review the adequacy of other structures, such as explosion-proof stoppings, not designed to retain water but which may do so as mine water levels rise.

**Design objectives**

8. Mines should install watertight plugs only when there is no reasonably practicable alternative for the long-term management of mine water inflows.

8. The main design objective of such plugs is to prevent water flowing through or around them into active mine workings and reduce to as low as is reasonably practicable the additional risks to which workers will be exposed. The design and construction of watertight plugs must therefore follow best mining and civil engineering practice, following a step by step approach, involving people with the necessary range of competencies, to build a safe structure that will remain secure for the remaining life of the mine.

10. The design and construction process is likely to involve elements of mining and civil engineering, surveying, geology and hydrogeology, rock mechanics and rock testing, coupled with the expertise and knowledge of construction teams. Because of the need to manage these interfaces effectively mine owners need to consider the way in which they procure such projects. A partnering arrangement may be the best way forward as it offers the opportunity to utilise fully the range of expertise necessary to deliver a plug engineered in line with best practice. Inviting tenders against a pre-prepared design may not deliver the same benefits.

**Design head**

11. The design head has a bearing on both the assessment of the strata and the plug design.

12. Among factors to consider when determining the maximum possible head of water above the plugs are:

* Maximum ground water levels, including artesian heads.
* The surface levels of unsealed boreholes, shafts or adits.
* The effect of old mine workings, including water levels in adjacent mines.
* Surface water flow and pooling patterns.

13. Those calculating the maximum head need to obtain the most accurate information available. Where precise levels are not known and can't be determined, designers should estimate conservatively and record their assumptions and the extent of any uncertainties.

14. The design head should not normally be less than the full head to the surface. An exception might be where plugs are built to raise mine water levels to flow to pumps at a higher level in the mine rather than the surface. However, in these circumstances mine owners need to look ahead and assess whether or not the plug would eventually have to withstand a greater head in the longer term, for instance when the mine closes, and if so procure a plug designed on that basis.

**Site assessment and selection**

15. The selection of a site for a watertight concrete plug is critical. It requires careful and thorough assessment of the geology, hydrogeology and engineering properties of the strata around potential sites to come to a conclusion about their suitability.

16. Section 7 of the old NCB guide 'The Treatment of Disused Mine Shafts and Adits'[1](http://www.hse.gov.uk/mining/circulars/waterplu.htm#a1) contains information on matters to consider in relation to the geology and hydrogeology of potential sites.

17. Only competent people with the necessary range of skills should undertake site assessments. This is likely to require a team approach.

18. Those carrying out the site investigation need sufficient time and other resources to carry out a thorough survey and acquire sufficient samples representative of the strata around a potential site. In the case of a site that appears to be suitable, it is likely to require more than one visit to acquire all the necessary information. Mine managers will need to arrange for the safe removal of some of the roadway lining to expose more of the strata so that the ground assessment can be checked and refined.

19. The site assessment should cover the length of the potential plug location plus the roadway on either side of it for a distance of not less than 10% of the design head. For example, the site assessment for a plug designed to withstand a 400m head will extend over the length of the plug and 40m (10% of 400m) on either side of it.

20. The ground should be stable and the strata fracture incidence low. Mines should avoid building plugs:

* In fault zones;
* Where there are dykes or other igneous features;
* Where there are any other geological features that may give rise to leakage paths for water;
* Where mineral extraction might cause ground stresses to vary significantly (interaction);
* In highly stressed zones, such as in pillar areas or close to large mine openings such as junctions.

21. Strata around roadways driven by drill and blast methods are likely to contain blast-induced micro fractures. While this does not preclude them from being suitable sites for plugs, those making the assessment will need to determine the severity and extent of micro fracturing and take this into account when designing the plug and strata treatment.

22. Modern geophysical techniques such as 3D seismic tomography will help determine the bulk structure of the strata surrounding a potential site.

23. Drilling exploratory boreholes in the vicinity of the proposed plug can yield further detailed strata information and enable the assessment to be refined. This is particularly important where a plug will have to withstand a large head, or where the head will build up quickly, or where there remain significant uncertainties in the interpretation of other data.

24. Rock mechanics laboratories can establish the strength of the rock by preparing and testing specimens from core or other samples acquired on site. As the test specimens will usually be acquired from the better rock within the samples, they may not be representative of the rock mass. However, this information, together with assessments of the fracture incidence and characteristics of the strata will allow engineers to estimate the rock's:

* Bulk strength;
* Permeability;
* Its ability to withstand elevated hydraulic pressures for long periods.

This will help determine whether a particular site is suitable.

25. The geographical location of a potential plug site in relation to:

* Mine ventilation circuits;
* The transport infrastructure;
* Power distribution and pumping systems;

will have a bearing on how easy it is to construct the plug, and subsequently to maintain it and the host roadway. Where there is more than one suitable site, mine owners and managers should take account of these other factors when deciding where the plug should be.

**Preparing the site**

**Strata and roadway treatment**

25. Even in relatively strong rock, some preparation will be necessary to improve the condition of the strata. The nature and extent of strata and roadway treatments will depend on the characteristics of the strata in the vicinity of the proposed plug and on the condition of the host roadway.

27. This will include:

* Removing, where possible, lagging or cladding from the periphery of the roadway through the watertight plug site and carefully removing any broken rock;
* Excavating the periphery of the roadway to key in the front and rear shutters;
* Preparing one or more high points (domes) in the roof for the breather tube(s);
* Removing all plant and equipment, including rail track, pipes and cables;
* Thoroughly cleaning the roadway floor to remove all loose material, mud etc;

and may also include:

* Reinforcing the roadway over the length of the plug, and where necessary on either side of it, by rock bolting and/or cable bolting and removing some or all of the free standing supports;
* Setting additional support in the host roadway either side of the watertight plug, such as concrete or steel supports or sprayed concrete lining;
* Treating the exposed rock faces in the host roadway on either side of the plug with low permeability and/or strength enhancing materials.

28. Where all of the lagging cannot be removed safely, a longer plug may be needed to compensate for the likely effect of the lagging on the contact between the plug and the rock in that area.

29. The assessment of ground conditions will also help determine whether or not there is a need to set additional support in the host roadway on either side of the plug to resist the additional load developed by the increasing hydraulic head.

30. In the many of the weaker rocks that characterise most stratified deposits in the UK the host roadway will need stiffening; for example, using substantial steel or concrete supports or a sprayed concrete lining. Designers should specify at the outset whether or not the roadway requires additional support, and should set out clearly the reasons for their conclusions.

31. Where additional roadway support is necessary, it should extend for a distance equivalent to at least 2.5% of the design head on either side of the plug. For example, for a plug with a 400m design head in a roadway that requires additional support, this should extend for at least 10m (2.5% x 400m) on either side of the plug.

**Concrete plug design**

32. The most critical design factor of a watertight plug is the plug length required to ensure proper sealing rather than the strength of the concrete or structural grout used to build it.

**Minimum plug length**

33. Designers should assume that interface shearing is the governing failure mechanism and allow a 4:1 factor of safety against interface shear failure. This is to take account of:

* The inherently weak nature of many rock types in stratified deposits in the UK;
* The fact that plugs are likely to be constructed parallel or near parallel to any bedding planes;
* Stress variations around the perimeter of a roadway;
* The likely presence of fracture zones around the roadway.

34. The minimum plug length should be such that it satisfies the following conditions:

* The length of the plug is at least twice the maximum 'rock face to rock face' dimension of the host roadway (width or height).
* The hydraulic gradient across the plug at maximum hydrostatic head does not exceed 500kN/m2 per metre length.
* The shear stress at the interface between the plug and the rock does not exceed 350kN/m2 unless the bulk strength of the rock is known accurately and it is safe to specify a higher figure.

**Permissible interface shear stress**

35. The permissible interface shear stress used to determine plug length will be the lesser of the permissible shear stress in the plug material and the permissible shear stress in the host rock.

36. For a 4:1 factor of safety the permissible shear stress **in the fill material** can be calculated on the basis of its characteristic strength using the following formula:

Permissible shear stress = 0.2 x 0.67 x UCS x 0.25

For a Grade 30 concrete (UCS = 30 MN/m2) the maximum permissible interface shear stress is 1,005 kN/m2. There are a number of sources of information on permissible stresses in concrete [2, 3](http://www.hse.gov.uk/mining/circulars/waterplu.htm#ftn).

37. It is often impossible to calculate the permissible shear stress **in the strata** around the host roadway as its variable nature makes it difficult to determine accurately its bulk strength. In most circumstances it will be necessary to use the relatively low value of 350kN/m2 for the permissible shear stress in rock to reflect this variability and to cater for unknowns. In such cases this 350kN/m2 target value will be lower than the permissible shear stress in the fill material, and therefore it will be the permissible shear stress in the rock that sets the permissible shear stress at the plug/rock interface.

38. Only where designers can determine accurately the bulk strength of strata around the plug site and have calculated that a greater shear stress is permissible is it safe to use a value greater than 350kN/m2.

39. Where design calculations indicate that the permissible shear stress in the rock is less than 350kN/m2 designers should use the lesser figure as the permissible interface shear stress. See Examples of Plug Design Calculations in [Annex 1](http://www.hse.gov.uk/mining/circulars/waterplu.htm#annex1).

**Construction materials**

40. In designing the bulk fill designers should specify only materials with predictable and consistent properties that meet a recognised and relevant product standard; for example British, European Union or American Standards. Any pre-mixed materials (e.g. structural grout or concrete) should contain only such materials.

41. Any other materials, such as injection grouts, strata sealants, rock bolts and resin etc, should also conform to recognised standards.

42. The bulk fill specification will be based on an assessment of the minimum requirements for strength, durability, permeability and ease of placement.

43. A PFA/cement structural grout will be suitable in most circumstances. Compared to most concrete it:

* Has a lower heat of hydration;
* Is more resistant to chemical attack;
* Shrinks less during curing, and is therefore less prone to cracking;
* Is easier to pump.

44. Where designers specify a concrete fill it should be at least as strong as a C30 concrete. Suitable aggregates could include:

* Sand and gravel;
* Ground granulated blast furnace slag (GGBS).

45. The PFA/cement or aggregate/cement ratio should not exceed 1; in other words the weight of PFA or aggregate should not exceed the weight of dry cement.

46. The water/solids ratio should not exceed 0.4.

47. The bulk fill can contain additives to improve its flow and setting characteristics etc.

48. There is no need to specify steel reinforcement as meeting the basic design criteria outlined above will ensure that the plug has sufficient bulk strength in all circumstances.

49. Designers should avoid gypsum-based products, as these are insufficiently durable for use in structures that have to maintain their strength over long periods.

**Shutters (stop-ends)**

50. Shutters must be capable of withstanding the maximum loads likely to be placed on them by the wet bulk fill during the construction phase. The designs will need to take account of the maximum shear stresses and bending stresses induced in the shutters as the bulk fill is pumped in. In calculating the maximum wet head, designers will need to take account of the gradient of the roadway, as in steep roadways this will significantly increase the wet head, and hence the load, on the lower shutter.

51. The shutters should include provision for:

* A sufficient number of pipes to cater for breather tubes and for both strata grouting and interface grouting following the completion of the plug. This guide contains further information on grouting in a later section.
* Ensuring a close fit to the periphery of the roadway to minimise the amount of sealing necessary between the shutter and the surrounding rock.
* Access for final inspection prior to pouring;

and where necessary for:

* Maintaining a flow of air past the plug site until final sealing.
* Maintaining services until final sealing.

**Penetrations**

52. The plug design should cater for the fixing of breather tubes and grout pipes that the bulk fill will encase. The plug may also contain other penetrations such as pipes for pumping, drainage, sampling or hydrostatic pressure monitoring, and sometimes access or ventilation tubes left open until final sealing.

53. All penetrations through hydrostatic plugs should be designed so that they properly key into the bulk fill and can resist the hydrostatic forces on them. As with the plug/rock interface, designers should assume that the maximum permissible shear stress at the penetration/plug interface is 350kN/m2.

54. Where penetrations are to be filled with grout during final sealing, they should have properly designed end stop valves to allow the [pressurising of the grout](http://www.hse.gov.uk/mining/circulars/waterplu.htm#grouting) to the maximum allowable pressure.

55. For penetrations that are left empty (such as sample, monitoring or pump pipes), the pipes and their fittings should be designed to withstand an external pressure equivalent to 4x the maximum hydrostatic head.

56. All plug penetrations should be made from long-term corrosion-resistant materials.

**Construction sequence design**

57. Where possible mines should introduce the fill material in one continuous operation, usually lasting several days. However, where a long plug is needed in a large roadway it may not be possible to store, or to transport quickly enough, sufficient materials to allow the bulk fill to be poured continuously. The mine will therefore have to build the plug in sections or stages, the size of each being limited by the amount of bulk fill that can be stored or transported to complete each pour.

58. Plugs more than about 20m long will have to be built in sections so that each section of the plug can be properly grouted and sealed.

59. A plug may be constructed in sections from inbye to out, each section being grouted and sealed prior to constructing the next section against the previous one.

60. Alternatively, where treatment of roof falls or grouting of the strata is required either side of the plug, the back and front sections can be constructed, grouted and sealed in turn prior to infilling between them.

61. A long plug can also be built in a number of pours forming horizontal layers between a pair of shutters. Provided the plug is pressure grouted following construction the 'cold' (or 'day') joints between layers will not give rise to significant planes of weakness. However, the construction method statement should include effective measures to ensure the removal of any dust, water, mud, laitance or other debris from the top of set fill material before pumping the next layer. One drawback of this method is the large number of strata and interface grout injection pipes that need to penetrate the front shutter.

**Plug construction**

**Equipment**

62. In selecting mixing, pumping and other equipment mines will need to have regard to:

* The Provision and Use of Work Equipment Regulations 1998, which require that all equipment is suitable for its intended use;
* The Pressure Systems Safety Regulations 2000. In particular, design engineers will need to consider the maximum pressure that the pumping system can develop when specifying delivery pipes, grout injection tubes, valves etc.

and in safety lamp mines:

63. The Dangerous Substances and Explosives Atmospheres Regulations 2002, which from 30 June 2003 prohibited the use of equipment not complying with The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996. Compliant equipment is 'ATEX' marked



however, older ignition protected equipment (commonly known as 'flameproof equipment' FLP) can still be used.

64. The diameter of the delivery lines should be matched to the pump capacity to ensure that the velocity within the pipes is sufficient to give a fully turbulent flow to avoid grout or concrete settlement or setting in the pipes.

65. The design should incorporate arrangements for water flushing at the end of a pour or if there is a delay exceeding half the initial setting time of the fill. Flushed material should not be pumped into the plug.

66. A spare pump and spare delivery line should be provided in order to avoid any delay exceeding the initial set time of the concrete.

**Pre-pour examination**

67. Immediately before the pour commences, the manager should ensure that a competent person or people carry out a thorough examination between the shutters to confirm that the site preparation is properly completed to a satisfactory standard.

**Mixing the bulk fill**

68. The bulk fill should only be mixed in batches. Batch size should be as large as practicable to reduce the effect of any miscounting or measurement errors.

69. Mine managers should ensure that there is a written procedure for mixing the bulk fill to achieve the design specification. In practice, plug design engineers will draw up the procedure for the manager to approve.

70. Where cement and aggregates are to be mixed on site, designers will need to specify the numbers of bags of cement and aggregate to be put into each batch, as well as the amount of water. Cement and aggregate mixed by the manufacturer and delivered to site will ensure a consistent solids mix and designers need specify only the number of bags and amount of water needed for each batch.

71. A simple depth gauge should be provided to ensure the correct amount of water is put into the mixing tanks at the start of the process. Its design should be such that workers can read it to within an accuracy of ± 1%. Alternatively, the correct amount of water can be measured from calibrated tanks, as this is potentially more accurate than a depth gauge.

72. The procedures for pumping and placing the bulk fill should detail the measures necessary to ensure that it is properly settled and contains no voids; for example, by using vibro-compactors.

73. To ensure that the fill material is in full contact with the roof the design should include provision for one or more air relief pipes to intrude into the high points made in the roof during the preparation phase. These will also assist at the interface grouting stage.

74. Managers should ensure that accurate records are kept of the amounts of solids and water used to manufacture each batch. When the pour is complete the total amount of solids used should be compared to the design amount and any discrepancies explained.

**Testing the fill material**

75. Design engineers should draw up a scheme for the mine manager's approval for the testing of fill material during the pour and for more thorough assessment afterwards. For concrete, it should include provision for either slump testing or flow-trough testing material from each batch prior to pumping[4](http://www.hse.gov.uk/mining/circulars/waterplu.htm#a4).

76. The scheme should also set out the procedures for the casting, curing and testing of specimens for strength and shrinkage at 28 and 56 days. The interval between successive series of specimens should not exceed eight hours.

77. While there is no current British Standard for shrinkage testing it is expected that it will form one of the parts of harmonised standard Pr EN 12390:1999 'Testing Hardened Concrete'.

78. If those overseeing the mixing process suspect that any batch might not meet its design specification, for example, if the slump or flow-trough tests fall outside expected limits, they should arrange the casting of further specimens. Where the reason for the failure is not apparent, and the mix cannot be adjusted, the batch should be rejected.

79. Those overseeing the testing and sampling should record the times and outcomes of all slump or flow-trough tests. They should also ensure that all specimens are tagged and recorded to enable them to be identified and correlated.

80. Specimens should be representative of the material being pumped to form the plug and can be acquired either from the mixing tanks immediately prior to pumping or from the delivery nozzle. Once the specimens have passed the initial curing stage, they should be stored in accordance with standard conditions. It is advisable to transfer them quickly to a testing laboratory, which will have the facilities to store them as required.

81. If the specimen tests indicate that the properties of the fill material as placed fail the meet the design specification, mine managers should ensure that designers make a thorough assessment of the impact against the design strength and then instigate appropriate remedial action where necessary. If calculations indicate that the plug might not be able to withstand the full design head over its design life it may be necessary to extend its length.

**Grouting**

82. When the plug or one of its sections is complete it should be allowed to cure for at least seven days before starting strata or interface grouting.

83. The plug design should cater for a two stage process for both strata and interface grouting:

* **A low-pressure phase**

between 350 and 500kN/m2 (50-70lb/in2), to seal larger cracks and voids.

* **A high-pressure phase**

between 1.25x maximum hydrostatic pressure (1.25x full design head) and 0.8x geostatic pressure (where geostatic pressure = average weight of rock (20kN/m3) x depth in metres). This is high enough to seal seepage paths through and close to the plug, but not high enough to induce hydro fracturing in the rock.

84. During the design phase mines should make arrangements for acceptance tests to determine the most appropriate type of grout and the injection pressures. This will involve drilling a series of holes into the strata and injecting water under pressure to determine the acceptance characteristics of the local rock; in other words, the rate at which the rock will take up grout at given pressures.

85. During the acceptance tests mines will need to monitor carefully the height and width of the roadway where the tests are being carried out to determine whether the injection pressure is causing the roadway to deform and whether or not this will prejudice its stability. Where deformation occurs at relatively low pressures then it may be necessary to reinforce and/or set additional support in the roadway before continuing with the acceptance tests, or to identify a better site.

86. Managers should ensure that there are written procedures for both strata and interface grouting. The procedures should include the requirements for the grouting process as well as the measures to take to minimise risks to people carrying out or supervising the operation.

87. The spacing between grout holes should be such to ensure that injection zones overlap and form a watertight curtain around the roadway to minimise seepage as the hydraulic head builds up. Where the ground conditions permit, the use of grout "bandages" (seals) will enhance the sealing properties [(see Annex 2)](http://www.hse.gov.uk/mining/circulars/waterplu.htm#annex2).

88. Each strata-grouting phase should be carried out after the corresponding interface grouting phase. For both phases, grouting should start at the bottom beneath the plug and work around either side to the top.

89. Each of the grout injection tubes should incorporate a suitable valve that can be shut off under pressure during the grouting operation.

90. Properly calibrated pressure gauges are needed at both the pump and the delivery end of the grout range to assess whether target pressures are being achieved. The method statement should include the length of time the target pressure has to be held before the grout pipe end valves can be closed under pressure. Alternatively, where electro-hydraulic pumps are used a target hydraulic pressure for the pump hydraulics should be specified and monitored.

91. Mine managers should ensure that there is adequate provision to ream out grout pipes after each phase.

92. Records should be kept of grout usage at each stage, and whether or not holes achieved target pressures.

**Quality assurance and control**

93. Competent people should oversee both the design and construction of concrete plugs. Independent third parties should oversee:

* Site assessment and selection;
* Design of concrete plugs and the design of roadway and strata treatments;
* Roadway and strata preparation, including the thorough examination immediately prior to the pour beginning;
* Construction processes;
* Acquisition, storage and testing of samples of the fill materials.

**Monitoring**

94. Once complete both the plug and the host roadway should be monitored. Where practicable, access to the dry side of the plug should be maintained.

95. The minimum requirements for monitoring should be:

* Hydraulic pressure on the dam.
* Seepage or leakage through or around the dam. These can be monitored by channelling water either through a V-notch, or to tanks where the volume between the high and low float levels is known and pump running times monitored.
* Stability of the host roadway in which a dam is situated for a distance equivalent to 10% of the design head. The monitoring for dilation etc should be to a standard sufficient to determine whether the roadway is under stress. The type of monitoring will depend on potential failure modes. Any significant changes should be referred back to the design team for further assessment.
* Where access is still available, inspections of the roadway and the dry side of the plug at intervals not exceeding 24 hours. Inspection officials should have a simple checklist to work to.

**Additional grouting**

96. When the design load has been reached, or when the hydrostatic head on the plug has stabilised at some lesser value, further grouting will be required for sealing purposes.

**Maintenance**

97. Where practicable, managers should ensure that there are adequate arrangements for transporting support and other materials that may be needed to carry out remedial work at or close to the plug site.

98. Where practicable, there should be set levels of deterioration that trigger maintenance of both the dam (pressure gauges and other monitors etc.) and the host roadway. These maintenance requirements might derive from deviations with respect to the original design parameters of the dam or the original (prepared) condition of the roadway.

99. If the water flow through and around the plug exceeds 225 litres per minute (50 gallons per minute) additional grouting should be carried out for sealing purposes.

**The safety file**

100. The manager should prepare and retain a file containing adequate information on the design and construction of the plug, including:

* All relevant design information, including:
	+ Design parameters.
	+ Details of any design assumptions.
* Details of the strata surrounding the host roadway, including the results of any sampling and specimen testing, the assessment of bulk strength and the determination of permissible shear stress.
* A diagram showing the strata and interface grouting pattern detailing target pressures for the low-pressure and high-pressure phases.
* Results of the acceptance tests and conclusions drawn from them.
* Records of fill materials used during construction. Copies of shift supervisors' reports and inspection officials' MASHAM reports should be included.
* Strata and interface grout injection records, including whether or not target pressures have been achieved.
* Specimen test results.
* Significant issues arising from post-construction monitoring, including;
	+ Rate of increase and final hydrostatic head.
	+ Seepage or leakage rates through or around the dam.
	+ Roadway dilation above trigger levels.
* Details of any post construction maintenance and the reasons why it was necessary.

101. On mine abandonment, the file should be included with the mine abandonment plans and working papers sent to HSE in accordance with the requirements of MASHAM regulation 31, for archiving at the Coal Authority Mining Records Office (coal mines) or in the relevant local record office (non-coal mines). [HSE's Mines Inspectorate's address](http://www.hse.gov.uk/mining/circulars/waterplu.htm#address) is at the end of this document.

**Associated health and safety issues**

**Ground control and support**

102. Mine managers will need to ensure that the removal of lagging, dressing of the exposed rock and the acquisition of sample is carefully planned to control properly the risks to workers from falls of ground. Managers must include in the rules required by regulation 7 of The Mines (Control of Ground Movement) Regulations 1999, usually known as the 'manager's support rules', the sequence of operations and the procedures that people should follow to ensure they are not exposed to undue risk.

**Concrete and grout**

103. Work procedures need also to spell out the preventative and protective measures to avoid and control the risks to workers arising out of the concrete or grout mixing operation, such as local exhaust ventilation systems to remove airborne cement dust.

104. Even with engineering controls, workers at the mixing plant are still likely to come into contact with both dry and mixed cementitious materials and will therefore need appropriate personal protective equipment, and instruction in its proper use, and means of washing off any splashes etc.

**Manual handling operations**

105. Mines should avoid manual handling operations that give rise to a risk of injury (e.g. by using mechanically-handled 'big bags') or control the risks from them (e.g. by keeping small bags to a weight where they can be handled without undue risk). For further information see the Manual Handling Operations Regulations 1992 and its associated guidance.

**Vibrating tools and equipment**

106. There are a number of operations where vibrating tools and equipment may expose workers to high levels of hand-arm vibration (HAV). These include:

* Excavating or breaking rock using hand-held pneumatic picks;
* Certain drilling operations;
* Reaming out the grout tubes.

107. Mines should avoid these operations where practicable; for example by using:

* Mechanised excavation techniques;
* Machine-mounted rigs;
* Borers that clamp onto the end of grout injection tubes.

108. Where the risk assessment indicates that it is not practicable to avoid exposure to HAV mines should put in place measures to control the exposure of workers; for example, to reduce individuals' HAV exposure time.

109. Workers with category 3 HAV Syndrome should not use any vibrating tools or equipment.

**Annex 1**

**Examples of PLUG design calculations**

**Basic design criteria**

* Minimum length = 2 x maximum excavation dimension
* Rock/plug interface shear stress < 350kN/m2
* Hydraulic pressure gradient <500kN/m2/m

**Grouting pressure - high pressure phase**

* >1.25x maximum hydrostatic pressure
* <0.8x geostatic pressure (g.p. = average rock weight (20kN/m3) x depth)

**Sample roadway**

* Arched 6m wide x 5m high (rock to rock), Area = 26.14m2, perimeter = 19.43m

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| **Example 1 - 100m maximum hydraulic head** |
| **Minimum length calculation**Minimum length = 2 x max dimension (6m width) = 2 x 6 = 12m |
| **Rock/plug interface stress calculation:**Hydrostatic pressure from surface = 100 x 10kN/m2 = 1,000kN/m2End force on plug = pressure x area = 1,000 x 26.14 = 26,140kNInterface shear area = perimeter x length = 19.43 x 12 = 233.2m2Interface shear stress = force/area = 26140/233.2 = **112kN/m2**(<350kN/m2 o.k.) |
| **Hydraulic gradient calculation**Hydraulic gradient along plug length = 1,000/12 = **83kN/m2**(<500kN/m2 o.k.) |
| **Comments**Roadway width is determining length factor. |
| **Target grouting pressure range calculation - high pressure phase**>1.25x maximum hydrostatic pressure = 1.25 x 1,000 = 1,250kN/m2 (162lb/in2)<0.8x geostatic pressure = 0.8 x 20 x 100 = 1,600kN/m2 (232 lb/in2)Therefore target grouting pressure is in the range 1,250-1,600kN/ m2 |

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| **Example 2 - 500m maximum hydraulic head** |
| **Minimum length calculation**Minimum length = 2x maximum dimension (6m width) = 2 x 6 = 12m |
| **Rock/plug interface stress calculation:**Hydrostatic pressure from surface = 500 x 10kN/m2 = 5,000kN/m2End force on plug = pressure x area = 5,000 x 26.14 = 130,700kNInterface shear area = perimeter x length = 19.43 x 12 = 233.2m2Interface shear stress = force/area = 130,700/233.2 = **560kN/m2**(>350kN/m2 so above target level) |
| **Hydraulic gradient calculation**Hydraulic gradient along plug length = 5,000/12 = **417kN/m2**(<500kN/m2 o.k.) |
| **Comments**Rock/plug interface shear stress > target valuePlug length would need to be > 19.22m to achieve target value (350kN/m2) |
| **Target grouting pressure range calculation - high pressure phase**>1.25 x maximum hydrostatic pressure = 1.25 x 5,000 = 6,250kN/m2 (870lb/in2)<0.8 x geostatic pressure = 0.8 x 20 x 100 = 8,000kN/m2 (1,160 lb/in2)Therefore target grouting pressure is in the range 6,250-8,000kN/ m2 |

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| **Example 3 - 1,000m maximum hydraulic head** |
| **Minimum length calculation**Minimum length = 2 x maximum dimension (6m width) = 2 x 6 = 12m |
| **Rock/plug interface stress calculation:**Hydrostatic pressure from surface = 1,000 x 10kN/m2 = 10,000kN/m2End force on plug = pressure x area = 10,000 x 26.14 = 260,140kNInterface shear area = perimeter x length = 19.43 x 12 = 233.2m2Interface shear stress = force/area = 26140/233.2 = **1,121kN/m2**(>350kN/m2, well above target level) |
| **Hydraulic gradient calculation**Hydraulic gradient along plug length = 10,000/12 = **833kN/m2**(>500kN/m2 above target level) |
| **Comments**Rock/plug interface shear stress > target valueHydraulic gradient > target valueMinimum plug length to achieve target hydraulic gradient = 10,000/500 = 20mInterface shear stress for 20m plug = 261,400/(20 x 19.43) = 673kN/m2 (>350kN/m2, therefore plug length would need to be > 38.44m to achieve this target value)Plug will need to be constructed in stages, both for amount of bulk fill needed and so that sections can be separately grouted |
| **Target grouting pressure range calculation - high pressure phase**>1.25 x maximum hydrostatic pressure = 1.25 x 10,000 = 12,500kN/m2 (1,740lb/in2)<0.8 x geostatic pressure = 0.8 x 20 x 100 = 16,000kN/m2 (2,320lb/in2)Therefore target grouting pressure is in the range 12,500-16,000kN/ m2 |

**Annex 2**

**Section through a typical concrete plug**

[](http://www.hse.gov.uk/mining/circulars/images/waterp2.gif)

Concrete plug section example

**References**

1. A revision is taking place and will be published on the website in the near future.
2. Table 10.1 in Chapter 10 'Design of Underground Plugs' FA Auld in 'Sealing of Underground Boreholes and Excavations in Rock' Edited by K Fuenkajorn and JJK Daemen. Published (1996) by Chapman and Hall ISBN 0 412 57300 8.
3. BS8110: Part 1: 1985
4. See BS EN 12390-3:2002 Testing hardened concrete (supersedes BS 1881-116: 1983, which will be withdrawn in 2003

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