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Handbook on ground control at small coal mines

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Handbook on ground control at small coal mines

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This handbook contains advice on geotechnical aspects of ground control intended for small coal mine operators. It should be read in conjunction with the Health and Safety Executive (HSE) document *Guidance on the design, installation and use of free standing support systems (including powered supports) in coal mines* (HSE, 2000), which gives specific advice on support systems, including those typically used in small mines. The handbook is the result of a research project funded by HSE and undertaken by Rock Mechanics Technology Ltd to assist small mines to improve support safety and comply with the new ground control regulations which came into force in December 1999.

A full report on the research project is available through HSE Mines Inspectorate (Contract R33.67). The handbook contains specific advice derived from the research undertaken.

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1. INTRODUCTION

1.1 PURPOSE OF THIS HANDBOOK

This handbook contains advice on geotechnical aspects of ground control intended for small coal mine operators. It should be read in conjunction with the HSE document, "Guidance on the design, installation and use of free standing support systems (including powered supports) in coal mines (HSE, 2000), hereinafter referred to as "the HSE standing support guidance document", which gives specific advice on support systems, including those typically used in small mines. The handbook is the result of a research project funded by the HSE and undertaken by Rock Mechanics Technology Ltd to assist small mines to improve support safety and comply with the new ground control regulations which come into force in December 1999.

A full report on the research project is available through the HSE Mines Inspectorate (Contract R33.67). The handbook contains specific advice derived from the research.

1.2 NEW GROUND CONTROL REGULATIONS

New mining legislation came into force on 1st December 1999.

This legislation is the Mines (Control of Ground Movement) Regulations, 1999. The regulations describe the provision of ground control measures as comprising four stages:

Stage 1 (regulation 5) – is the assessment of ground conditions. This will provide information about the area of the mine to be excavated which will help decide which measures should be taken to control ground movement, including the choice of support system.

Stage 2 (regulation 6) – is the design of the support system, taking account of the findings of the assessment of ground conditions.

Stage 3 (regulation 7) – is the making of rules for implementing the design. These will provide sufficient information and instructions for those who are to install the support system.

Stage 4 (regulation 10) – is the assessment of the adequacy of ground control measures, or support system. This is the monitoring process.

Each stage acts as a check on the effectiveness of the previous stage, and opens up the whole process to continual review.

The HSE standing support guidance document describes in general terms recommended procedures to comply with the new regulations. The intention is that the new procedures should improve ground control safety by encouraging simple checking and assessment procedures without adding a significant administrative burden onto small mines operators.

The most obvious difference between larger deep mines and small coal mines lies in the methods of working. Many small mines have methods of working, which although long established, may not have been subject to rigorous risk assessment. In this case, the system needs to be assessed in order to comply with the new regulations. This could be by reference to a previous history of safe working, in which case the ground conditions for which the system is appropriate need to be defined.

Other main differences are related to the shallow working depths, possible weathering effects and open joints. Many small mines have strong roof rock, but the presence of open joints results in possible danger from falling roof blocks. These are all conditions which are not typically seen in large coal mines.

Part of the research project was therefore aimed at assessing small mine working methods and assisting small mines to comply with the new legislation. Simple guidance on these aspects is available in this handbook to help small mines improve safety in practical ways.

1.3 TERMINOLOGY FOR WORKING METHODS

Terminology for the various mining systems in use in small mines varies between regions.

Historically the terms ‘bord and pillar’, ‘room and pillar’ and ‘pillar and stall’ have been used interchangeably to describe the same systems. In addition there are ‘side stalls’, ‘stoops’ and ‘Welsh bords’. Systems may be advance, retreat or some combination of the two. For the purpose of this handbook, a few definitions are needed as follows:

Longwall or shortwall implies the extraction of the whole coal seam in one operation, with workings advancing in a continuous line (the face). The transition between a shortwall and a longwall is defined as a face width of 100m.

Bord and pillar, also known as room and pillar, pillar and stall or stoop and room in Scotland involves driving roadways through the seam and leaving coal pillars behind.

Stall working as described in this handbook is taken to mean the advancing or retreating of working sections of 8 – 20m wide, supported by combinations of wood posts, wood or steel bars, cribs or packs.

Side stalls are formed by widening a roadway by extracting the seam on one or both sides. This is commonly practised in access roadways. However, the ‘Welsh bord’ system as currently practised at several small Welsh mines involves driving a roadway (or bord) and then working the stall formed by widening the roadway on one or both sides on retreat, leaving pillars between adjacent stalls. This is effectively a retreating stall system. The various methods are illustrated in Figure 1.

1.4 TERMINOLOGY FOR SUPPORT SYSTEMS

The following terminology is adopted for support systems:

Arch – One or more lengths of rolled steel section joined together to form an arched profile to provide support for the roof and sides of a roadway.

Bar – A support set parallel to the roof

Chock – A type of support usually formed from layers of wooden chock pieces or concrete blocks. Also known as a crib or a cog.

Foot block – A wooden foundation block which is positioned between the floor and the bottom of a prop or leg.

Ground control measure – A measure designed to control the movement of ground, including the provision and installation of support material.

Hydraulic prop – A roof support dependant for its setting and yield on hydraulics.

Leg – An alternative name for a prop (see below) especially where used in conjunction with a bar.

Lid – A compression piece, usually of wood, placed between a prop and a bar, or between a prop and the roof.

Pack – A stone, cementitious or composite support built between the roof and floor.

Powered support – A support which is advanced and set to the roof by mechanical energy, and uses an external power supply to provide the initial setting resistance.

Prop – An individual straight support member set between the roof and the floor.

1.5 METHODS OF WORKING SMALL MINES

Small mines generally exploit shallow workings accessed by adit or drift and often mine thin seams or remnant coal left by now closed collieries.

Methods of development and coal extraction can be classified as follows:

Coal extraction:

(i) Fully mechanised shortwall production: at present this is limited to one mine.
(ii) Partially mechanised shortwall or bord and pillar production: in these cases, coal is won by a combination of chain cutter and explosive and loaded by hand, mechanical shovel, or auger loading device.
(iii) Unmechanised bord or stall working: in these cases coal is won by pneumatic pick or explosive and loaded by hand.

Roadway development is in seam and usually unmechanised.

Arcwall cutters assisted by explosives are used at some mines. Others use explosives or hand held pneumatic picks or a combination of the two, together with hand filling. All small mines support developments using wood props or wood prop and wood or steel bar systems.

During mine visits a number of factors were identified which are relevant to ground control at small mines and have not therefore been considered in any detail during research work undertaken for conventional large UK mines.

There are a number of differences between larger mechanised mines and small mines related to ground control. The most obvious difference lies in the mine layouts and working methods, with advancing bords and stall work not being practised at large mines for many years.

Shallow bord and pillar mining is also now confined to one large mine in the UK, where pillar sizes are dictated by undersea working precautions. There is currently a trend towards the use of bord and pillar working in small mines. Pillar behaviour and sizing for shallow bord and pillar layouts is therefore of importance.

Other main factors are related to the working depths, possible near surface weathering effects and joints. Whilst many small mines have relatively strong roof rock the presence of joints results in the potential danger of falling roof blocks.

These are all conditions which are not typically seen in large coal mines.

2. ROCK FAILURE AND GROUND CONTROL ASSESSMENT

2.1 THE STRENGTH AND STRUCTURE OF COAL MEASURES ROCKS

The strength of Coal Measures rock varies widely depending both on the rock type and on planes of weakness present within it.

Well cemented sandstones and limestones are the strongest Coal Measures rocks, and mudstones and seatearths the weakest. However all Coal Measures rocks contain weak bedding planes, joints, faults and other disturbances. Failure of rock around shallow mine openings often results from loosening of blocks of rock on these planes of weakness under the influence of gravity.

Bedding plane strength can vary considerably. Often the boundary between two rock types is a 'shear' zone on which previous movement has occurred and this has little or no strength.

Joints are fractures or cracks in the rock. They form potential planes of weakness on which rock blocks can move. Particularly at shallow depth, joints may be open, filled with loose or weathered material, or flowing water. Jointing in coal is known as cleat.

Faults can have a major localised influence on rock failure. In relatively undisturbed coal measures strata the majority of faults tend to be normal faults hading at 60 – 70^{o} to the horizontal. Where erosion has taken place thrust faulting at 20 – 30^{o} to horizontal can also be found. In mountain building areas such as the South Wales coalfield, the main structures tend to be folds and thrust faults.

The actual fault plane, in the case of normal faults, can vary from a tight parting to a major fault shear zone and associated slips. Water may also be present on the fault plane.

Thrust faults are associated particularly with nearby bedding plane shears which can result in roof instability for a significant distance from the actual thrust plane.

Intersection of open joints, or intersection between joints, faults and bedding planes can result in rock blocks falling from the roof.

Weaker rocks such as mudstones have often suffered from disturbance when being laid down and compacted. These disturbances can be seen as weak highly polished surfaces known as 'slickensides' (figure 2), compactional faults and slumps, all of which further weaken the rock material. These effects are particularly likely to be seen where a relatively thin mudstone roof underlies a strong sandstone.

In addition fossilised features such as "tree trunks" can suddenly fall from the roof on weak boundary planes (figure 3).

2.2 EFFECT OF WATER

Water can have a major adverse effect on rock strength and ground control.

In stronger rocks, water under pressure in joints and fractures reduces the friction between rock blocks so that movement occurs more easily.

Weaker rocks such as mudstones and seatearths can soften in the presence of groundwater. This is often seen where a thin mudstone roof layer underlies a porous sandstone and water from the sandstone causes the mudstone to soften and degrade into clays.

Roof water is potentially a bad sign in terms of ground control. If strata water is observed, other than from drill holes, in roof material which is considered impermeable it may be implied that breaks due to rock failure or joints must also be present in the roof. Where water can be seen flowing from visible cracks or breaks in an impermeable roof this should be considered a high risk. Where the roof is generally wet, though no visible cracks are evident this may indicate rock softening or the presence of microfractures and should be considered to indicate increased risk.

2.3 ROCK WEATHERING AND NEAR SURFACE WORKING

Near surface mining may encounter ground control problems due to:

(a) weathered rock zones
(b) unconsolidated or water bearing deposits
(c) open rock joints and cracks due to near surface stress relief

Weathering is a process causing changes at or near the earths surface by interaction between the earths atmosphere (water, carbon dioxide, oxygen) and rock material.

The effect of weathering extends below the earth's surface by ground water movement and usually reduces the competency (strength) of rock material.

Shallow mining activity is therefore quite likely to encounter weathered rock – particularly during the formation of portals and adits.

In the context of shallow mines in Coal Measures rock, the rock material, most resistant to weathering is sandstone and the least resistant mudstone and seatearth. Mudstones vary in weathering susceptibility, depending on the type of clay minerals present. Both mudstones and seatearths are liable to swell and degrade when in prolonged contact with water.

The relative resistance of sandstones, depends on the chemical make up of the grains and cementing material. Quartz rich sandstones are most resistant.

Limestones are susceptible to replacement of Calcite by dolomite due to hydrothermal activity which spreads along faults and joints. The most common effect of dolomitisation is to render the limestone vuggy (containing voids) and porous, but in some cases dolomitisation produces loose aggregates of sand sized crystals which flow freely into underground openings.

The depth and extent of weathering from the surface is likely to vary considerably depending on the nature of the rocks, local geological history and topography. General weathering extending for more than about ten metres is unusual and requires circulation of ground water through porous rock or intersecting joint sets. It should not, however, be forgotten that buried weathered zones may be preserved under overlying younger rocks or surface deposits.

Near surface working may also run the risk of contacting unconsolidated deposits such as water bearing glacial sands and gravels or peat beds or boulder clays. Such material would prove very difficult to control with typical small mine support systems. These risks are currently addressed by the Mines (Precautions against Inrushes) Regulations, 1979 and associated ACoP (The Prevention of Inrushes in Mines, 1993).

A further risk of near surface working follows from the reduction of horizontal rock pressure (stress) as the surface is approached. The reduction in confinement could allow movement of rock blocks bounded by discontinuities to occur, and therefore increases the risk of roof falls from this cause.

2.4 ROCK PRESSURE (ROCK STRESS)

Rock at depth is subject to pressure, both from the weight of rock above and lateral pressures due to movement of the earth's crust (Figure 4).

These pressures are known as rock stress. In deep mines, rock stress can be high enough to exceed the rock strength and cause the rock around the mine opening to fail and break up. (Figure 5).

Lateral stresses usually have a dominant direction caused by continental drift. In Britain the maximum lateral rock pressure is roughly NW – SE due to opening of the mid Atlantic ridge (Figure 6). This effect can result in variations in roadway condition depending on the direction of drivage, with roof and floor failure often greater in roadways driven NE – SW (Figure 7). These effects have been seen in deeper mines throughout Britain.

However in the context of small mines, it is most likely to be seen in the deepest small mines with the weakest roof rock. If this effect occurs then ground control problems can be minimised by working in a NW-SE direction where possible.

Many small mines with stronger roofs may experience the opposite problem of too little lateral stress to hold jointed roof in place. At very shallow depths, lateral stresses in the roof (sometimes known as 'confining' stresses) are very low and roof blocks may then slide on joints or other planes of weakness (Figure 8). If open joints are present in the roof then the confining stress is effectively zero and there is a high risk of falling roof blocks.

2.5 ROCK FAILURE – LOW ROCK STRENGTH/HIGH STRESS CONDITIONS

Where the pressures in the rock are high in relation to rock strength, the roof fails in shear as shown in Figures 5 and 9. This type of behaviour is widespread in deep coal mines in the UK where mudstones and weaker siltstones and sandstones in the immediate roof shear and dilate as they fail.

In Britain the maximum lateral rock pressure is roughly NW-SE, due to continental drift and failure of deep coal mines' roof rock is often greater in roads driven NE – SW (figure 7).

In practice, for small mines, it is only in the weakest rocks such as mudstones in roadways in an unfavourable stress situation (e.g. driven NE or SW) that shear failure of roof rock material is likely to be seen. However, mudstone rock material strength is often reduced by the presence of small scale discontinuities, compactional features, slickensides, disturbed bedding etc. along which failure develops. Water or weathering may also play an important part in reducing the material strength.

Depending on the thickness of weak roof beds, failure may take the form of slabbing or flashing of immediate roof material, the formation of cavities, and loss of roof horizon on development, or in extreme cases large falls of failed roof material extending for several metres into the roof.

Weak floors can also cause ground control problems in small mines. Although floor heave is uncommon due to the shallow depths, setting of props on soft floors, such as water affected seatearths can result in them sinking into the floor under load and becoming unstable or dislodged.

2.6 ROCK FAILURE – HIGH ROCK STRENGTH CONDITIONS

The majority of small mines are currently operating at shallow depths with relatively strong roof – sandstone or siltstone.

In this case the rock material is strong in relation to the rock stresses. Rock material failure would not normally occur and roof falls are more likely to be associated with movement of intact blocks or slabs of rock bounded by discontinuities such as joints or cleat, weak bedding planes or shear zones.

Joints are especially important in this process. The conditions of the joint planes and their frequency and orientation will determine opening stability.

In the context of small mines the condition of joints is likely to be influenced by near surface working. Mine roof stability depends on sufficient horizontal pressure being present in the roof to hold jointed blocks firmly in place, taking into account frictional resistance along the joint planes and their orientation. Obviously if the joints are open, there is no horizontal pressure present and no frictional resistance, and if joint sets or joints and bedding planes combine to delineate a free block in the roof it will move and may fall from the roof.

Joints are particularly likely to be open close to the surface, in valley sides and where water percolation and weathering has occurred preferentially along joint planes. Where joints are filled, the geometry of the joints and the condition and strength of the fill will be important in determining the frictional resistance and therefore block stability. These are all situations which may be encountered in small mines.

Where other discontinuities, such zones, faults or slip planes, weak bedding planes or compactional features are present, the same principles apply. Roof stability will depend on the orientation, geometry and frictional resistance, in relation to existing lateral roof pressure.

This gives rise to the possibility of assessing the risk of roof block failure from the observed positions and conditions of joints and other discontinuities.

2.7 COAL PILLAR BREAKDOWN

Coal pillars are loaded vertically by the weight of overlying material. Pillars of small width to height ratio exhibit a peak strength at failure, followed by a rapid fall to a residual strength as the sheared material is displaced, (figures 10 and 11).

As the load on the pillar increases, the pillar ceases to behave elastically and the load is increasingly taken by a confined central core, surrounded by a yielded outer skin. At failure fracturing extends through the pillar. Coal pillars in small mines are likely to behave in this way.

'Yield' pillars are pillars which have been loaded beyond their peak strength and are in a residual strength condition. Where yield pillars are used, it is in combination with larger stable pillars which provide the main support to the roof. Use of yield pillars in room and pillar systems at shallow depths is extremely unusual, but one small mine currently operates such a layout with combined stable and yield pillars.

The behaviour of coal pillars is strongly influenced by the pillar width/height ratio. The sudden failure behaviour is typically exhibited by pillars with low width to height ratios. 'Squat' pillars with width to height ratios beyond about six are effectively 'indestructible', in that sudden failure no longer occurs. Continued loading results in development of yield further into the pillar and failure is progressive. In these cases however the damaging effect of lateral deformation of the highly loaded pillar on the roof and/or floor rock may limit allowable pillar loads. This is typically the case for longwall finger and barrier pillars at depth. However, highly loaded squat pillars are unlikely to be encountered in shallow mines with shortwall or room and pillar layouts.

2.8 ACTION OF SUPPORTS

The basic requirement of any support system is to prevent falls of material and control deformation or convergence by providing resistance to further movement.

Strata reinforcement systems provide this support in an efficient manner as they effectively maintain the inherent strength of surrounding rock material so that it becomes part of the support system.

Conventional standing support systems (e.g. steel arches) however do little, or nothing, to modify the failure behaviour of surrounding rock material and merely act to prevent failed material from falling into the opening. To do this effectively the supports must have sufficient capacity and stability to withstand the loads imposed as the surrounding rock fails.

For typical small mine support systems the load capacity is much lower than a steel arch. However, in the context of small mines much of the failure may involve loosening of individual blocks of rock bounded by joints or other weakness planes. Release of immediate roof blocks held in place by frictional resistance will be facilitated by lack of support allowing initial movements to occur. It is therefore important for small mine support systems to be as stiff as possible and for support to be tightly set before initial movements can occur.

Where slabbing of the immediate roof is also of concern, support coverage is important in preventing loose pieces from falling between support positions.

The main requirements for small mine support systems are therefore:

a) Sufficient stiffness, load capacity and stability to hold roof blocks and failing roof in position.
b) Sufficient coverage to prevent loose roof material (if present) falling between supports.
c) Capable of being set tight to the roof close to the heading face.
d) Capable of being implemented safely, with use of temporary support if required.

2.9 GROUND CONTROL ASSESSMENT

Regulation 5 of the Mines (Control of Ground Movement) Regulations, 1999, requires assessment of ground conditions before any excavation is undertaken. The degree of detail required depends on the situation. Where the mining conditions are known and the mining and support systems are unchanged, this should be a straightforward process and could be based on knowledge of rock behaviour and failure as described in the preceding sections.

The HSE standing support guidance document describes the type of information to be collected and possible sources as follows:

Collecting the information

The type of information collected will include:

- *geological information, such as the type, thickness and condition of the rock beds adjacent to the proposed extraction including any geological disturbances;*
- *the properties of the various rock types that may be encountered;*
- *the findings of any site investigation relevant to the area to be worked including whether or not water is present and, if so, its likely effect;*
- *previous experience, and the relevant historical data.*

Information on the type of strata above and below the excavation may be determined from:

- *site investigation of existing roadways in the vicinity of the proposed workings;*
- *knowledge and experience of ground conditions from comparable workings;*
- *examination of old mine plans;*
- *examination of exploratory borehole records;*
- *examination of the strata at either side of any exposed geological fault.*

When the assessment has been completed it should be summarised in a document containing:

- *the assessment procedure, including where appropriate, details of the type and nature of any site investigation;*
- *assumptions made;*
- *significant findings; and*
- *conclusions.*

For most free-standing support systems, the assessment document will be both simple and brief.

For small mines, inspection of existing workings combined with mining history may prove to be the most valuable source of information. It is unlikely that detailed information on rock properties will be available.

The regulations call for an assessment document. For most small mines it is suggested that this could be based on the proforma which follows.

SIMPLE GROUND ASSESSMENT PROFORMA

MINE:	SITE / WORKING AREA:
SEAM:	SEAM DIP:
PROPOSED WORKING METHOD:	SEAM THICKNESS:
	DEPTH OF WORKING:

METHOD OF GROUND ASSESSMENT AND SOURCES OF INFORMATION:

	ROADS	EXTRACTION AREAS
HEIGHT		
WIDTH		

GEOLOGY:	
SEAM ROOF:	
SEAM:	
SEAM FLOOR:	
GEOLOGICAL VARIATION?:	
ARE MINING CONDITIONS KNOWN FROM PREVIOUS EXPERIENCE	Y / N ?
IS THERE ANY PROPOSED CHANGE TO MINING OR SUPPORT SYSTEMS	Y / N ?
COMMENT ON PAST MINING EXPERIENCE AND PROBLEMS AT THIS SITE	

POSSIBLE GROUND CONTROL RISKS:	IF YES PLEASE COMMENT:
SHALLOW WORKING? (<45M)	Y / N
GEOLOGICAL CHANGE?	Y / N
WEATHERED ROOF ROCK?	Y / N
ROOF GEOLOGICAL DISTURBANCE?	Y / N
FAULTING?	Y / N
OPEN / WEAK ROOF JOINTING?	Y / N
ROOF WATER?	Y / N
SOFT FLOOR?	Y / N
RIB SPALL?	Y / N
PILLAR FAILURE?	Y / N
INTERACTION WITH OTHER WORKINGS?	Y / N
CONTACT WITH OLD WORKINGS?	Y / N

CONCLUSIONS: (Delete or complete as appropriate)

1. Mining conditions are known / not well known
2. The existing mining and support system is proven / not well proven in these conditions
3. Change / no change is needed to existing mining and support systems
4. Additional precautions may be needed to deal with (List)
5. Further investigation is needed as follows: (List)

Assessment undertaken by:

Date:

3. SUPPORTS AND SUPPORT METHODS

3.1 SUPPORT SYSTEMS USED IN SMALL MINES

This section provides information on the strength of typical small mine supports and examples of application in small mine working systems.

It should be read in conjunction with the HSE standing support guidance document which gives specific advice on the installation and regulatory aspects of the use of these supports.

3.2 WOOD PROPS AND BARS

Wood props or wood prop and bar systems are the main support elements in small mines.

The wood props used are normally round with a typical diameter of 125mm (5”) and lengths to suit the extraction but typically 0.5m to 1.7m long. They are generally produced from locally sourced softwoods – fir or spruce.

The breaking load of 1.7m 5” wood props is around 16 tonnes, but there is considerable variation depending on the presence of knots or other imperfections.

The failure of wood legs occurs by buckling, generally at a knot or by splitting close to the ends as shown in Figure 12 at a displacement of 10 – 20mm. There is a rapid drop off in resistance beyond the peak load, giving the potential for rapid failure. Apart from deformation of the leg, the main warning of overloading is cracking sounds as the wood splits.

Square section props are more prone to sudden failure, generally at a well defined knot, and gave less audible warning of overloading prior to failure.

Because failure is usually by buckling, short legs are stronger than long ones.

The Schedule to Regulation 8(3) of the Mines (Control of Ground Movement) Regulations, 1999 requires that, for face workings, where the extraction height exceeds 0.6m bars should be used with the props. Roof bars (half round or split bars) are used with the sawn face uppermost, as laboratory testing has shown this orientation to be stronger (figure 13). The strength of half round wood bars, when loaded at mid span, with a span of 1.2m is 1.5 tonnes (figure 14).

In heavy conditions, larger section wood props and bars are sometimes used. The beams are often individually notched on site to positively locate the legs (figure 15). Typical strengths for 0.22m (9”) diameter wood props, loaded axially is 48 hours, and the lateral strength when centrally loaded is up to 5 tonnes.

In all cases the measured strengths will only be obtained if the props are installed on a firm foundation and well secured in place.

3.3 STEEL BARS AND STEEL ARCHES

A variety of steel bars are used at some small mine sites in preference to wood bars. These include 75mm x 75mm RSJs and corrugated bars (‘Ripple’ bars). Some mines set steel legs and beams in faulted areas or when operating within 45m of the surface.

Steel beams are generally salvaged and reused when possible.

Steel arches are the usual support in mine portals and access adits and drifts. They are generally used with lagging boards, corrugated sheets or mesh panels. Information on steel arches is available in BS227.

3.4 WOOD CHOCKS

Most small mines make use of wood chocks or stone packs to provide additional support to the roof. Where the former are used, the wood chock pieces should be rectangular or least have flat bearing surfaces. Hardwood is better than softwood and putting in more chock pieces or constructing a solid chock makes it stronger.

Figure 16 shows typical test results for 4 point chocks as used in small mines. The load at 100mm deflection was around 70 tonnes (1 tonne≡10kN).

The performance of 2 x 2 chock construction can be optimised by:-

i) Overhanging timber construction

Chocks constructed with timber ends protruding beyond the timber intersection contact area by a minimum distance of one half the width of the timber can increase the capacity by 10 – 15%.

ii) Timber orientation

The contact area between the layers of timber is maximised by horizontal placement of the wide side of the timber cross-section. This maximises stiffness and capacity.

iii) Wood species

Ideally construct the chock from same wood species. The mixing of hardwood and soft wood to be avoided. Differential compression may lead to support instability.

iv) Aspect ratio

This is the height to width ratio. The height should be no more than four times the width. An aspect ratio of around 2 to 3 is commonly used.

Signs of overloading of wood chocks are squeezing, distortion and crushing of chock pieces and lateral bulging or buckling of the chock.

3.5 STONE PACKS

The strength and stiffness of stone packs depends on the quality of construction and particularly on high tightly they are set between the roof and floor. Figure 17 shows load against closure for a well built and a loosely built stone pack. In each case the pack stiffness increases with increasing load, but significant deformation occurs before high loads are achieved. However, the ultimate strength of a stone pack is well over 100 tonnes/metre run.

The results show the importance of packing tight to the roof to give early resistance to closure.

The load achieved in practice may be limited by floor failure if the pack is constructed on a soft floor or by collapse, if badly constructed.

The main indicator of load on a stone pack, is closure of the opening, together with crushing and displacement of lumps from the pack outer wall (figure 18).

3.6 THE ROLE OF SUPPORT SYSTEMS IN SMALL MINES

Roof rock failure in small mines may take the form of failure of immediate roof – slabbing or ‘flashing’ or larger scale movement of blocks of stronger rock or at the extreme a large scale fall of weaker roof, perhaps extending up to a stronger bed or shear zone which could be 2-3m above the roof horizon.

The dead weight of failing roof material could therefore vary from a few kilograms to as much as 45 tonnes per metre run of roadway. The latter far exceeds the support capacity of typical small mine systems.

The measured maximum loads in section 3.2 would only be achieved in ideal circumstances. Any eccentric loading, misalignment of the support or bearing failure of the floor under load would result in lower maximum loads being achieved. These support systems are prone to sudden failure as the capacity is exceeded or the support becomes dislodged.

It is clear that loads imposed by failing roof rock could exceed the support capacity. The main practical role of small mine prop and bar systems is to protect against falls of immediate roof. In addition the support system does play an important role in warning of roadway deformation through visual signs of support loading and distress. The observation and correct interpretation of these signs can form the basis of risk assessment for larger scale roof falls.

The role of observation of rock failure and support loading in assessing risk requires that the roof rock be visible and the supports be in good contact with it. Systems including corrugated steel sheeting which conceal the roof strata prevent this assessment from being done and should be avoided with this type of support system.

Chocks and packs are of high load capacity but low stiffness. They allow significant deformation of roof to occur and their role lies in controlling this deformation and providing protection from roof falls. However they do not act to prevent roof failure. In contrast properly sized pillars of coal do provide a high capacity, stiff support, and can modify the behaviour of the roof they are supporting.

The use of coal pillars therefore represents the highest level of support available to small mine operators.

3.7 IMPLICATION OF NEW REGULATIONS FOR SMALL MINE SUPPORT SYSTEM DESIGN

The HSE standing support guidance document gives detailed advice on the application of support systems to coal mines, including systems typically used in small mines.

Wood supports, unlike steel, are not subject to procedures to establish suitability but the HSE standing support guidance document confirms that all support materials including wood must be suitable for the purpose for which they are used.

Suitability of the steel bars used has been established in many cases by previous practice but due regard should be paid to possible changes in conditions for which some of the lighter section bars may be unsuited. Reference should be made to the ground control assessment in confirming the suitability of the chosen support system.

It should be noted that the HSE standing support guidance document explains the circumstances in which a change in the support system to be used should be notified to the HSE. This notification has to be made at least 28 days before implementation of the proposed change.

Notification also has to be made if there is any proposal to work outside the minimum support system standards in the Schedule to Regulation 8(3) of the Mines (Control of Ground Movement) Regulations, 1999. This schedule includes maximum support spacings and unsupported spans in the various circumstances relating to face workings and roadways.

The HSE standing support guidance document describes the preparation of the design and the information required. Normally this information is included in the Managers support rules. Information on potential ground control risks identified from the ground control assessment should also be included, together with the measures to be taken to reduce these risks – for example procedures for dealing with abnormalities.

4. SUPPORT RULES FOR TYPICAL SMALL MINE MINING SYSTEMS

4.1 DESIGNING THE SUPPORT SYSTEM

The support rules should be drawn up by undertaking the design process described in the HSE standing support guidance document. A ground control assessment should form the basis for establishing the suitability of any given mining system.

The HSE standing support guidance document describes the preparation of the design and gives full details on support rules and their implementation.

The design is a summary of the findings of the ground control assessment, together with details of the proposed support system which should include the following:

The design should include as appropriate:

- *excavation dimensions, e.g. the roadway size or face layout;*
- *the limits of extraction;*
- *minimum pillar sizes where necessary;*
- *the support density, e.g. spacing between adjacent supports;*
- *details of any material or equipment forming part of any ground control system, including, if appropriate, any specifications;*
- *the proposed method of work;*
- *procedures for dealing with abnormalities*
- *information on other hazards such as known zones of weakness, proximity to other workings, or boreholes.*

There are some minimum requirements for the spacing or density of support which have been determined after years of experience in a wide range of conditions. These are set out in the Schedule to Regulation 8 of The Mines (Control of Ground Movement) Regulations 1999.

The HSE standing support guidance document also describes the circumstances in which the HSE must be notified of significant changes proposed to support systems. This has to be done at least 28 days before any proposed change is made.

In the case of small mines significant change is most likely to involve a new system of working e.g. bord and pillar instead of stall work, or the introduction of a new type of support (e.g. powered face supports).

The HSE standing support guidance document describes in detail the requirements for support rules as follows:

What should be in the rules?

In addition to the method of work, the rules should include.

(a) the type(s) of support materials and equipment to be used;

(b) the support density

(c) the layout and dimensions of any system of support designed to control the movement of ground, including where appropriate the maximum distance(s) between;

(i) adjacent powered support centres;
(ii) the roof beam tip of any powered roof support and the face;
(iii) the front row of props and the face;
(iv) adjacent props;
(v) adjacent bars;
(vi) adjacent arches to other free standing roadway support;
(vii) adjacent rockbolts (where rockbolts are used systematically as a supplementary means of support);
(viii) subsequent support setting cycles;
(ix) the last free standing support (or the last row of rockbolts in the roof, when rockbolts are used systematically as a supplementary means of support) and the roadhead at its furthest point;
(x) the front of the pack or packs and the face;

(d) details of temporary support procedures, including, the procedure for providing ground reinforcement or support to:

(i) the face and exposed roof where mineworkers are required to work on the face side of the AFC spill plates;
(ii) exposed ground where mining machinery can't be withdrawn from the face of the heading for repair;

(e) procedures for dealing with abnormal situations, such as a fall or cavity;

(f) where powered supports are used, the design pressure and flow rate of the hydraulic supply system, including minimum hydraulic pressure requirements;

(g) where conventional prop-and-bar face support are used, the method and equipment for withdrawing and advancing them;

(h) details of monitoring arrangements for confirming that the support system continues to be effective. For example: inspection; examination; maintenance;

The key measurements should be clearly shown, including details of temporary support.

The rules should also make it clear that support materials additional to those specified in the rules can be installed if this is necessary to secure safety.

For the simpler small mines working systems the design document and support rules could be the same document.

5. ESTIMATING PILLAR SIZE FOR BORD AND PILLAR WORKINGS

5.1 SCOPE

This section of the handbook gives guidance on pillar design for bord and pillar working in coal mines using square pillars.

For mining layouts which utilise rectangular, irregular or complex shaped pillar geometries specialist geotechnical advice should be obtained.

5.2 ROLE OF COAL PILLARS IN SMALL MINES

Pillars may be required to fulfil a number of functions any of which may influence their size and disposition. They may be required merely to remain stable, to yield when subjected to load, to shield roadways from the effects of workings elsewhere, or support the surface above. Pillars can therefore be categorised by their function, as follows :-

a. Support
- systematic layout (e.g. Welsh Bord workings)
- bord and pillar layouts

b. Protective
- barrier pillar
- shaft pillar
- maintenance of surface structure integrity (buildings, railroads etc.)

c. Control
- systematic layout
- stabilising pillar (rockburst alleviation)

In the case of small mines pillars are predominantly used to provide support, maintain acceptable working conditions and to separate working areas.

5.3 PILLAR DESIGN FOR BORD AND PILLAR WORKING

When coal pillars are formed during mining, they have to carry the weight of overlying rock. When a bord and pillar district is formed, each pillar has to carry its share of the overlying rock load. This is known as the 'tributary area' as illustrated in Figure 19. The load on the pillar will increase with depth of working and with the extraction ratio.

If the pillar load exceeds its strength, then the pillar will fail, resulting in added load on the surrounding pillars. These in turn could fail leading to the sudden collapse of a bord and pillar district as has happened in the past. Selection of the right pillar size for the depth of working and roadway width/height will prevent this happening.

The strength of a pillar is basically determined by the magnitude of vertical stress (load) which can be sustained within the strata/coal sequence forming and bounding it. The vertical stress developed through this sequence can be limited by failure of one or more of the units which make up the pillar system. This failure may occur in the coal, roof or floor strata forming the system, but usually involves the coal in some manner. The failure modes can include shear fracture of intact material, lateral shear along bedding or tectonic structures, and buckling of cleat bounded ribsides. These factors can generally be observed once the pillars are formed, as illustrated in Table 5.1.

In pillar systems having strong roof and floor, the pillar coal is the limiting factor. In coal seams surrounded by weak beds, a complex interaction of strata and coal failure will occur and this will determine the pillar strength. The strength achievable in various elements is largely dependent on the confining stresses developed. As confinement is developed in a pillar, the axial strength of the material will increase significantly, thereby increasing the actual strength of the pillar well above its unconfined value.

Table 5.1 - Observed pillar condition

Factors relevant to pillar system strength	STRONG System	WEAKER System
Roof / floor strength	Strong	Weak
Slip planes at roof/floor contact	No slip	Slip present
Slip planes present within the pillar (i.e. dirt/clay bands etc.)	No slip	Slip present
Coal cleat or spalling	Absence of cleat or pillar spalling	Pronounced cleat / spalling
Geological disturbance (shear planes, faulting, folding etc.)	No geological disturbance	Geological disturbance(s) present
Consequence with regard to design factor of safety	Potential to reduce factor of safety slightly	Should increase factor of safety

In determining suitable pillar dimensions account should be taken of the loads expected to be imposed on the pillars, the estimated pillar strengths and the influence of the width to height ratio on pillar failure behaviour. Several methods of estimating pillar strength have been developed from experience in room and pillar mining in a number of countries and provide a guide to the pillar sizes found applicable elsewhere for this method of mining. The imposed loads are estimated based on the tributary area and compared with the estimated pillar strengths obtained from equations to ensure a satisfactory margin for the anticipated conditions.

Pillar strengths are dependent on their width to height ratio. Squat pillars with larger width to height ratios are considerably stronger than narrow pillars with smaller width to height ratios. In addition, the strength of squat pillars is less likely to be influenced by localised weaknesses in the coal seam. They are less likely to be subject to failure in the sense of a rapid reduction in load bearing capacity. This reduces the potential for progressive failure or collapse of the pillars. The increase in pillar strength with increased width to height ratio is dependant on the development of confinement within the coal pillar. Weak strata bounding the pillar may limit the development of confinement and reduce the pillar strength. The general design equations used do not take this factor into account.

It is recommended that for simplicity the Bieniawski approach is adopted in small mine pillar design for situations where the width to height ratio ranges between 2 and 10 (Bieniawski, 1992).

Width to height ratios of less than 2 result in slender pillars which are susceptible to structural failure within the pillar and therefore warrant careful consideration and further investigation before being adopted.

For width to height ratios in excess of 10 the pillars become more squat and the Bieniawski method may be overly conservative. In such situations other techniques such as the Wagner squat pillar formula (Wagner, 1992) may be more appropriate. For width to height ratios in excess of 10 the limiting factor is most likely to be related to the condition of the roadways surrounding the pillar than stability of the pillar itself.

Nomograms have been constructed to assist in determining minimum widths for square pillars. In constructing the nomograms a factor of safety for pillar stability of 1.6 and an in-situ coal strength of 6.2 MPa (k_1) have been used. These factors may require modifying depending upon the conditions found at a particular site.

Nomograms for a range of roadway widths are contained in Figures 20 to 25. The nomograms are relatively simple to use and are a quick method for determining a minimum pillar size for square pillars using the following procedure :-

1 The nomogram appropriate to the planned roadway width is selected.
2 A horizontal line is projected from the appropriate depth below the surface shown on the y axis.
3 Where this line crosses the appropriate roadway height (diagonal lines crossing nomogram) a line is projected vertically down to the x axis to give the minimum recommended pillar size for a square pillar.

Visual assessment based on Table 5.1 may indicate that a higher factor of safety is appropriate in which case a larger pillar size should be chosen.

5.4 BARRIER PILLARS

Bord and pillar workings should be laid out in a compartmentalised form with individual working panels being separated by barrier pillars. This will limit the spread of any progressive deterioration of the pillars due to localised weaknesses or geological structures.

Unless special circumstances exist the following general rules should be complied with:

- Solid barrier pillars should be left on both sides of the panel.
- The barrier pillar width should be at least eight times the mining height (i.e. $w/h > 8$) or twice the width of normal district pillars, whichever is the greater.
- Cuts into the barrier pillar should be avoided.
- For new mining sections developed normal to the main mine developments, a row of long pillars should be left at the start of the new section and the number of access roads into the new section minimised, as shown in Figure 26.

5.5 MULTI-SEAM INTERACTION

Interaction can redistribute the vertical stress field and can affect the stability of pillars. Therefore due cognisance should be taken in areas of interaction and, if necessary, the mine layouts should be adjusted to minimise these effects.

5.6 MONITORING AND INSPECTION OF PILLARS

There are many uncertainties in estimating pillar strengths and strengths may vary significantly due to geological factors. In recognition of this, it is recommended that a system of underground monitoring be devised to determine if the surrounding strata is behaving in the anticipated manner and that the pillars are fulfilling their required role. This could involve visual examination, simple roof to floor convergence measurements or more sophisticated monitoring. The pillars should be regularly inspected for any visual evidence that could indicate unexpected or abnormal behaviour.

6. GROUND CONTROL RISK ASSESSMENT

6.1 THE NEED FOR GROUND CONTROL RISK ASSESSMENT

The HSE standing support guidance document gives advice on the design and use of support systems used in small coal mines, and refers to the relevant legislation (Mines (Control of Ground Movement) regulations, 1999). To comply with the new legislation it is necessary to undertake the following steps in conjunction with the use of support systems in coal mines:

(i) Assessment of ground conditions
(ii) Design of the support system based on the assessment
(iii) Preparing support rules
(iv) Assessment of ground control measures

Step (iv) involves continuing assessment and monitoring of the performance of the support system with time.

This can be undertaken in the form of a simple ground control risk assessment, which can be used to identify areas of high risk and the need for extra support or other actions to ensure safe working. If done on a regular basis during visits to working areas, this procedure could be valuable in giving early identification of problems.

6.2 HAZARDS, RISK FACTORS AND HOW TO IDENTIFY RISK AREAS

In order to undertake this risk assessment process, the following procedures are needed:

(a) Identify the potential hazard category or categories relevant to the site.
(b) Confirm the list of risk factors associated with each relevant category.
(c) List potential high risk areas at the site, based on these risk factors
(d) List risk reduction measures available
(e) Finalise a risk assessment check list similar to the examples given.
(f) Undertake regular surveys of conditions, using the checklist as mining proceeds paying particular attention to high risk areas.

These procedures are described in more detail below.

(a) Identify the potential hazard category or categories.

Ground control failure could occur as a roof fall or a fall of rib side. These are the two basic ground control hazards likely to be encountered in small mines. However both roof and rib falls can arise from several causes. To assess the risk in these different conditions, the roof and rib fall hazards are subdivided as below:

Category 1 Roof fall hazard – strong roof conditions
Category 2 Roof fall hazard – weaker roof conditions
Category 3 Roof fall hazard – pillar collapse
Category 4 Rib fall hazard

Several of these hazard categories could be present at one site.

If the main roof is strong, for example a sandstone or limestone, then **hazard category 1** applies. This is the type of roof which appears to be self supporting, but could be affected locally by faults, joints or other weaknesses. There are two roof failure mechanisms seen at small mines which can apply to roof of this type.

Category 1(a) – fall of roof blocks bounded by planes of weakness – can occur with little warning and is the cause of serious accidents in apparently 'good' roof conditions.

Category 1(b) – weighting of face supports or wind blast due to heavy caving could apply where shortwall faces are operated in massive roof conditions especially at shallow depths.

Hazard category 2 – fall of weaker roof can apply to the main roof section, category 2(a), or just to weak immediate roof beds or the top coal left up, category 2(b).

Category 2(a) applies to a fall of weaker roof material, typically mudstone which is subject to deterioration and failure especially when affected by geological disturbance or water.

If the weaker roof is thinly bedded immediate roof which may be subject to 'flashing' as it fails on bedding planes in the form of thin slabs, then category 2(b) applies.

In general therefore for any site, hazard category 1(a) or 2(a) will apply and category 2(b) could also apply in either case. Category 1(b) will only apply in the case of some shortwall faces.

Hazard Category 3 is a roof fall hazard due to pillar collapse and applies where coal pillars are left to support the roof in bord and pillar or stall workings, in addition to the relevant category 1 or 2 hazards.

Hazard Category 4 is rib fall hazard due to spalling or collapse of rib side material. This can arise in several ways but is only likely to be significant in small mines in higher roadways or bord and pillar districts. The most likely failure mechanism is due to overloading of pillars or overhanging rib profile.

Rib fall hazard could also arise due to fall of unconsolidated or loose rib material where pillar extraction is undertaken between areas of old backfilled workings. It could also apply where existing workings contact areas of old workings.

A decision on which of these categories applies at a particular mine site needs to be made. This means deciding which of these hazards could occur in any given area.

This decision should be based on knowledge of the site geology and strata behaviour, taking into account the information given in section 2 and previous mining history and ground control problems at the site.

At any given site either category 1(a) or 2(a) will apply. Hazard categories 1(b), 2(b), 3 or 4 could also apply. Figure 27 can be used to assist in this decision.

(b) Confirm the list of risk factors associated with each hazard category.

For each hazard category as listed above, a list of risk factors has been compiled.

These risk factors are detectable features which if present in or around the mine opening, indicate the potential for, or contribute towards, the risk of a fall of material.

The role of these factors is explained in more detail in section 2 of the handbook.

Key risk factors for the various hazard categories are listed below:

Roof fall hazard 1(a)

Failure mechanism	Fall of roof blocks bounded by faults or joints.
Risk factors	Observed block movement/support loading Faulting – depending on orientation, condition of fault plane Jointing – depending on persistence, orientation, condition Intersection of joints and faults Low stress mining geometry- ie. face, reused road etc near surface working

Roof fall hazard 1(b)

Failure mechanism	Shortwall weightings/heavy caving caused by delayed caving in massive roof conditions
Risk factors	Strong massive roof conditions - Increased face width when not previously caving. Roof Jointing/faulting orientation. Limited powered support capacity.

Roof fall hazard 2(a)

Failure mechanism	Fall of weak mudstone roof in developments
Risk factors	Observed roof deformation/support loading Span Roof disturbance (structure) or faulting Drivage direction (horizontal stress) Roof water Strata weathering (shallow working)

Roof fall hazard 2(b)

Failure mechanism	Flashing of top coal/weak immediate roof
Risk factors	Weak top coal/ immediate roof left up on drivage Visible spalling of immediate roof No lagging or other immediate roof support between main supports Weathering of immediate roof in older roadways Effect of roof water on immediate roof

Roof fall hazard 3

Failure mechanism	Roof fall due to pillar collapse
Risk Factors	Pillar failure due to overloading in bord and pillar districts Observed pillar deformation/spalling / weak pillars

Faulted/structured pillars
Increasing depth of working
Undersized pillars
Oversized roadways
Pillars with low width/height ratio
Increasing extent of district

Rib fall hazard 4

Risk Factors

Areas of observed poor rib condition and spalling
Areas of unfavourable rib profile with overhang of upper rib
Faulting/structures affecting ribside
High ribside
Depth, small pillar size etc
Contact with areas of unconsolidated or squeezing ribside from backfilled old workings

These risk factors can form the basis of a risk assessment check list.

Those listed have been identified as the most significant at small mines. It is possible that there are other risk factors more relevant to a particular site. This possibility should be considered in confirming the list of risk factors.

These risk factors need to be tailored to the site under consideration based on previous experience.

(c) List potential high risk areas at the site

High risk areas are those in which the risk factors present are considered to indicate an unacceptable risk of the hazard (roof or rib fall) occurring. ‘High’ risk combinations of the above risk factors need to be identified and listed for each hazard category and site under consideration. This may require additional detail adding to the list of risk factors.

We suggest below combinations of risk factors which would be expected to indicate high risk in each hazard category, but it must be strongly emphasised that these combinations are unlikely to be correct for all sites and additional details may well be required.

For example, where strong rock conditions exist and open or weak joints have previously caused problems, the circumstances in which these problems arose needs to be carefully considered, in order to confirm when visible joints in the roof represent high risk.

This additional detail is likely to include the number of open or weakly infilled joints present, their orientation and the resulting potential for formation of wedges of rock which could fall from the roof.

The suggested combinations indicating high risks are:

Roof fall hazard 1 (a)

Either:

Observed block movement/support loading

or

Faulting or open/weakly infilled joints in roof forming potential blocks which could fall.

or

Open/weakly infilled fault or joint not potentially forming blocks but in high risk area e.g. Face, reused roadway, close to surface.

Roof fall hazard 1 (b)

Either:

Past history of face weightings/heavy caving at the site.

or

Increased face width in strong massive roof conditions when caving has not previously occurred.

or

Change in face orientation in strong roof conditions with caving controlled by jointing.

Any of the above in combination with low capacity powered supports is likely to result in high risk.

Roof fall hazard 2 (a)

Either

Observed roof deformation/support loading

or

Roof water/particularly if associated with roof disturbance/faulting or jointing

or

Areas of severe roof or faulting disturbance

or

Areas of weathered/very weak roof

or

Drivages in an unfavourable stress direction if relevant (see section) combined with disturbance, faulting or weak roof.

The risk of roof fall is further increased in areas of increased span e.g. junctions, extraction areas or areas of overcutting.

Roof fall hazard 2(b)

Either

Visible spalling of weak immediate roof between supports

or

Weak top coal/immediate roof left up on drivage combined with lack of support to immediate roof e.g. no lagging between main supports.

or

Weathering of immediate roof in older roadways combined with lack of support to immediate roof.

or

Water effects on immediate roof combined with lack of support to immediate roof.

Roof fall hazard (3)

Either

Observed pillar failure/deformation/spalling or weak pillars in bord and pillar districts.

Or

Faulting/structures affecting pillars

Or

Increasing depth of working without increasing pillar sizes or undersized pillars or oversized roadways (reduced factor of safety), in extensive room and pillar districts.

Rib fall hazard (4)

Either

Observed upper rib side deformation/spalling in higher roadways especially with cleat or joints sub parallel to roadway.

Or

Areas of unfavourable rib profile with rib overhanging in higher roadways especially with cleat or joints sub parallel to roadway.

Or

Areas of disturbed rib side associated with faulting or old extraction areas in higher roadways.

(d) List risk reduction measures available

Where significant risks are identified, risk reduction measures should be put in place to reduce the risk to personnel from roof or rib falls of ground.

The most basic and effective means of controlling risk is to stop working in areas of high risk. This is a solution which may be available to the small mine operator where working methods allow individual roadways or working areas to be abandoned and barriers and warning signs to be erected.

A good example would be where bord and pillar or stall working contacts a fault or an area of open jointed roof. Subsequent workings can be planned to avoid the fault or joint(s).

Alternative means of reducing risk will usually involve the setting of additional support and/or reduced excavation width. In this case it is important to ensure that the additional support is capable of effective control of the ground in the risk area. Where feasible, dressing of weak immediate roof or loose rib material may also be effective.

(e) Finalise a risk assessment checklist and

(f) Undertake regular surveys of conditions.

In section 6.3 which follows, examples of a simple risk assessment survey sheet and checklists are given for each of the perceived hazard categories.

These are general checklists which should be tailored to the site in question.

A survey can then be undertaken, filling in a survey sheet for each potential high risk area, and ticking off the presence of the identified risk factors. Where these form a high risk combination, risk reduction measures should be implemented as soon as possible.

It is suggested that the survey should be undertaken in new developments as they are formed and repeated at suitable intervals – perhaps monthly – thereafter.

6.3 SAMPLE RISK ASSESSMENT SURVEY AND CHECKLISTS

The four tables in sections 6.3.2 – 6.3.5 give examples of risk factors, potential high risk areas and risk reduction measures for the four hazard categories discussed above. Section 6.3.1 below gives an example of a survey sheet compiled from the checklist in 6.3.3 and relevant to one of the hazard categories.

6.3.1 Example of Risk Assessment Survey Sheet

Risk Assessment – fall of weak roof in Development		
Mine:		
Site inspected: Date:		
Inspected by:		
Fall of weak mudstone roof in developments	Risk factor present	Perceived Risk
Observed roof movement, deterioration or support loading Excessive Span Roof disturbance (structure) Unfavourable drivage direction (horizontal stress Roof water Thick mudstone roof Mudstone weathering (shallow working)	Y/N Y/N slight/severe Y/N slight/severe Y/N Y/N Y/N Y/N	HIGH LOW
Comment:	Risk reduction measures required (select from list below): 1. Restricted access 2. Limited excavation span 3. Additional support	
Action Required? Y/N		

Notes: Potential high risk combinations are as follows:
Observed roof deformation/support loading
or Roof water plus roof disturbance/faulting/jointing
or Severe roof disturbance or faulting
or Weathered roof
or Areas of excessive span (greater than …..m)

6.3.2 Roof Fall In Strong Roof Rock Conditions - Checklist

Failure mechanism	**Fall of roof blocks bounded by faults or joints.**	**Shortwall weightings / heavy caving due to massive roof conditions**
Risk factors	Observed block movement or support loading Faulting - orientation, condition of fault plane. Jointing – persistence, orientation, condition Intersection of joints and faults Low stress mining geometry	Strong massive roof conditions. Face width. Roof Jointing / faulting orientation. Powered support design and capacity.
Potential High Risk Areas	Shortwall face Face end Faulted/jointed areas Large excavations Junctions Reused roads Contact with old workings Any areas of visibly loaded supports/block movement	Shortwall faces with massive roof conditions and delayed caving
Risk Reduction Measures	Correct orientation of roadways/faces in relation to faulting/jointing. High capacity additional support or long tendon reinforcement in high risk zones.	Correct choice of face width, face orientation and powered supports. Predictive techniques based on powered support monitoring Restricted access to face when caving expected

6.3.3 Roof Fall In Weaker Roof Rock Conditions - Checklist

Failure mechanism	**Fall of weak mudstone roof in developments**	**Flashing of top coal/weak immediate roof.**
Risk factors	Observed roof movement or support loading Span Roof disturbance (structure) Drivage direction (horizontal stress) Roof water Mudstone thickness Mudstone weathering (shallow working) Low support density (large spacings)	Top coal/weak immediate roof left up on drivage Low support density (large spacing) Under sized pillars increasing effective roadway spans Weathering effects Roof water
Potential High Risk Areas	Large excavations, junctions, overcut areas. Areas of roof disturbance Areas of weathered roof (shallow working) Any areas of visibly loaded support/deformed roof Roadways in unfavourable direction Areas of thicker mudstone Areas affected by roof water Contact with old workings	Areas of top coal/weak immediate roof left on drivage Areas of mudstone roof affected by water Where pillars have spalled significantly Salvaging supports from old districts Very shallow working
Risk Reduction Measures	Restricted access to high risk areas Limited excavation span in high risk areas Additional support in high risk areas	Dressing of roof/removal of weak immediate roof Correct pillar sizing and mine layout Additional immediate roof support (reduce support spacing) meshing, timbering. Caution zone associated with shallow working Risk assessment prior to support salvage

6.3.4 Roof Fall Due To Pillar Collapse - Checklist

Failure mechanism	**Pillar failure due to overloading in room and pillar districts**
Risk factors	Depth, pillar size and percentage extraction Pillar aspect ratios Roadway size Major faulting/structures Extent of working district Load transfer from adjacent extraction areas**.**
Potential High Risk Areas	Extensive room and pillar districts with undersized pillars or pillars with low width to height ratios. Room and pillar districts with faulting affecting pillar strength. Room and pillar districts affected by nearby extraction. Areas of poor observed pillar condition.
Risk Reduction Measures	Correct pillar sizing for depth and extraction ratios. Design of districts to incorporate barrier pillars at suitable intervals. Increase pillar sizes (factor of safety) adjacent to faulting or nearby extraction districts. Limits to pillar width to height aspect ratios. Access restricted/prevented in high risk district**.** Systematic working away from district boundaries towards access

6.3.5 Rib Fall - Checklist

Failure mechanism	**Spall of rib side**	**Fall/Squeezing of unconsolidated rib material**
Risk factors	Pillar size Depth Cleat orientation Rib profile Height of roadway	Areas of disturbance and backfilling from old extraction Contact with unconsolidated backfill
Potential High Risk Areas	Small pillars, isolated pillars in high roadways Pillars affected by faulting or structures or with cleat sub parallel to roadway Pillars in areas of high percentage extraction and/or at increased depths Unfavourable rib profile e.g. overhang due to excavation of dirt band or visible spall	Roadway through old extraction areas Bords adjacent to old extraction areas Roadways and bords contacting old workings
Risk Reduction Measures	Dressing of upper ribs Additional support to upper ribs Rib keep clear zones in high risk areas Access restricted/prevented in high risk areas	Additional rib support (Wood legs and boards) in roadways Restrict workings adjacent to old extraction areas

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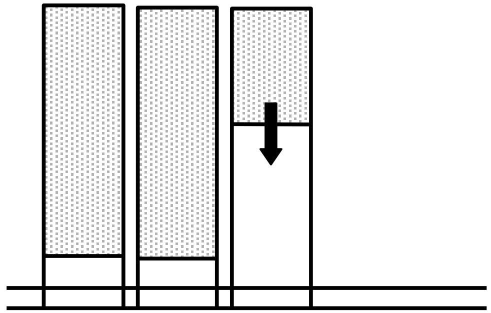
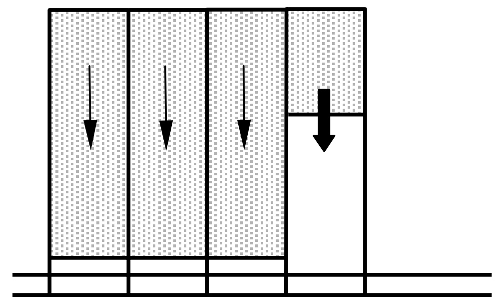
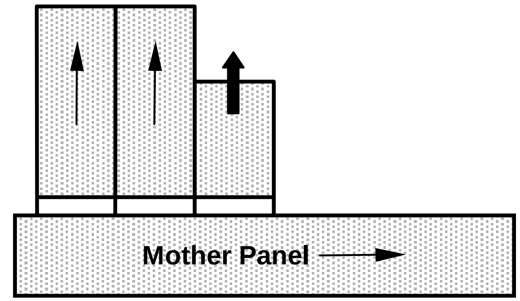


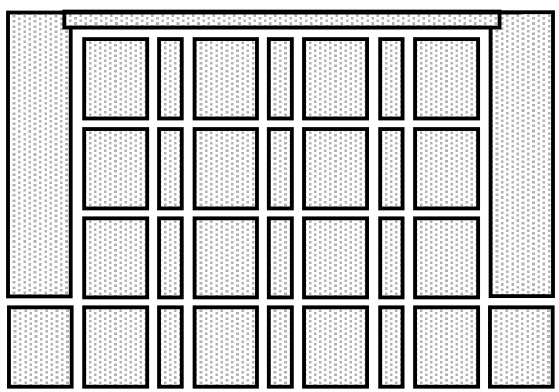
a) Retreating shortwall from development headings leaving stable pillars between panels.



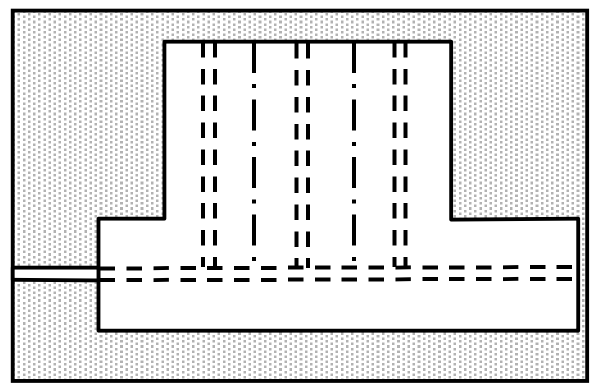
b) Retreating shortwall from development headings reusing previous maingate. Maingate protected by pillar with face salvage position leaving a stable pillar.



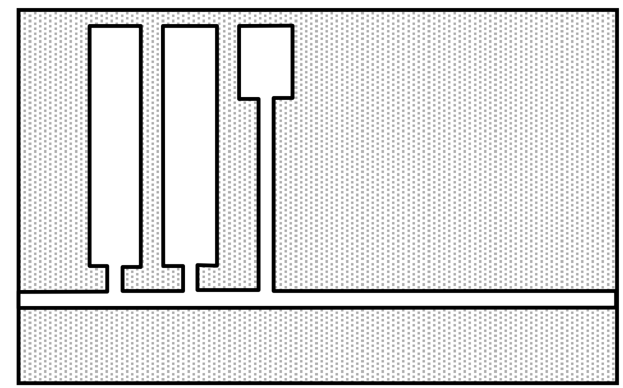
c) Advancing shortwall from “Mother” panel reusing previous maingate.



d) Bord and Pillar



e) Advancing stall system. Multiple stalls advanced off a development bord.



f) Welsh bord system. Advancing bord driven off development drivages then retreated taking side stalls.

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SMALL MINE WORKING METHODS

FIGURE 1

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Slickensides or polished places in mudstone roof strata

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FIGURE 2
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Fossilised tree trunk which has fallen from the roof

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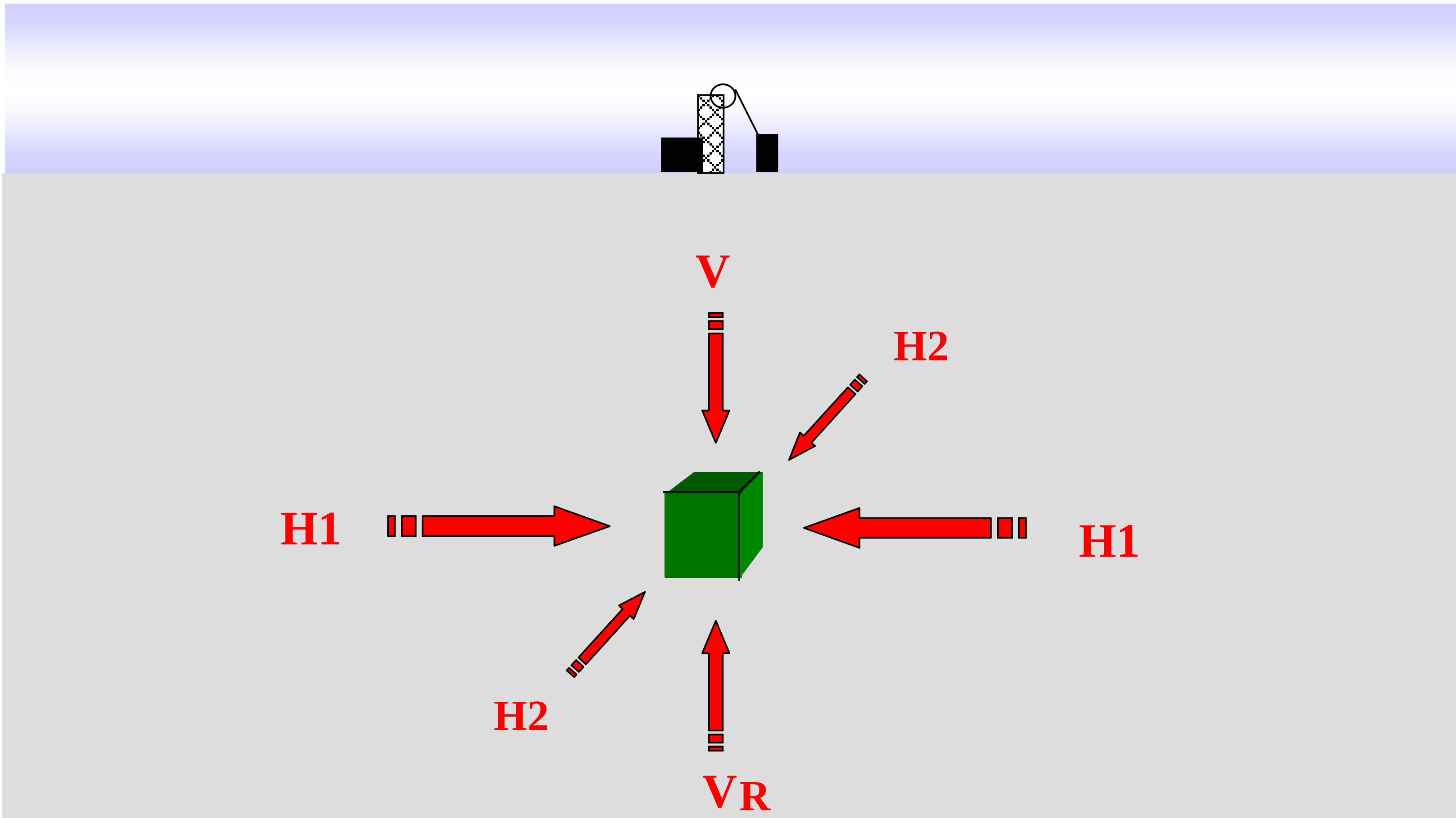
FIGURE 3

FORCES ACTING ON ROCK AT DEPTH



FORCES ACTING ON ROCK AT DEPTH
V= Weight of rock above
H1 and H2= Tectonic (Horizontal Stress)
Vr= Reaction to weight of rock above

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FIGURE 4
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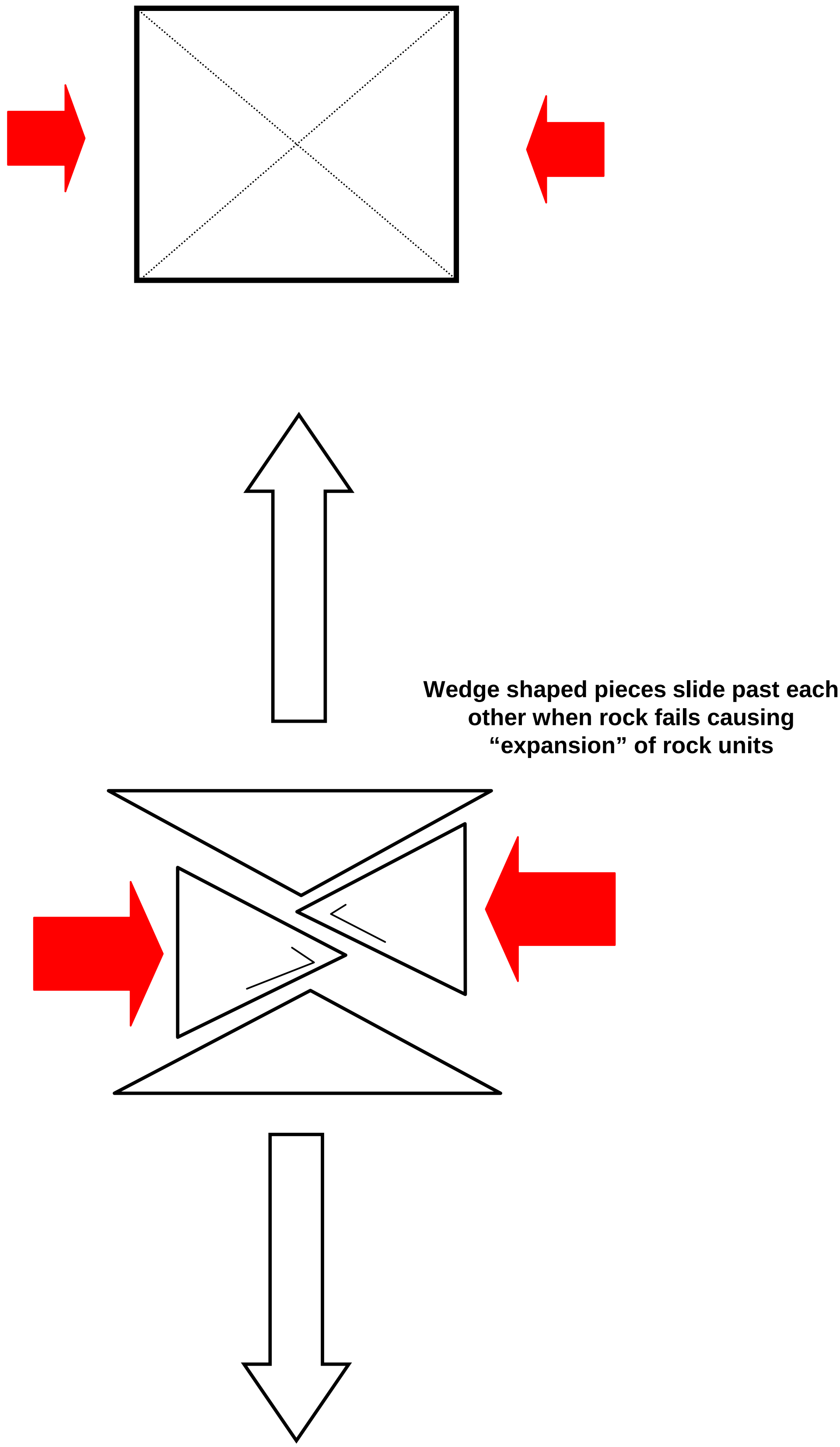

Shear failure of rock units due to horizontally applied loading

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FIGURE 5

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PLATE TECTONICS CONTINENTAL DRIFT

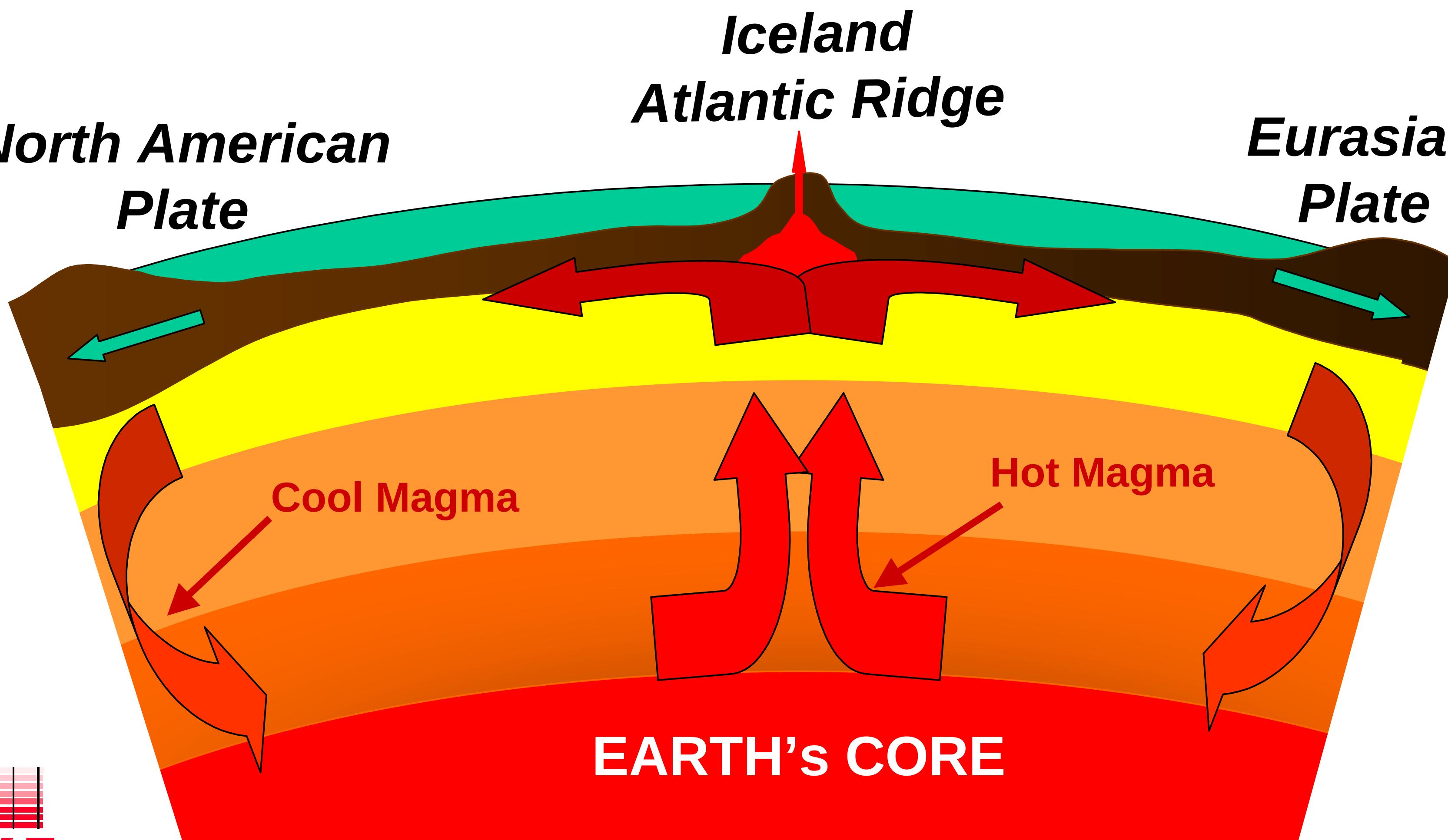

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FIGURE 6
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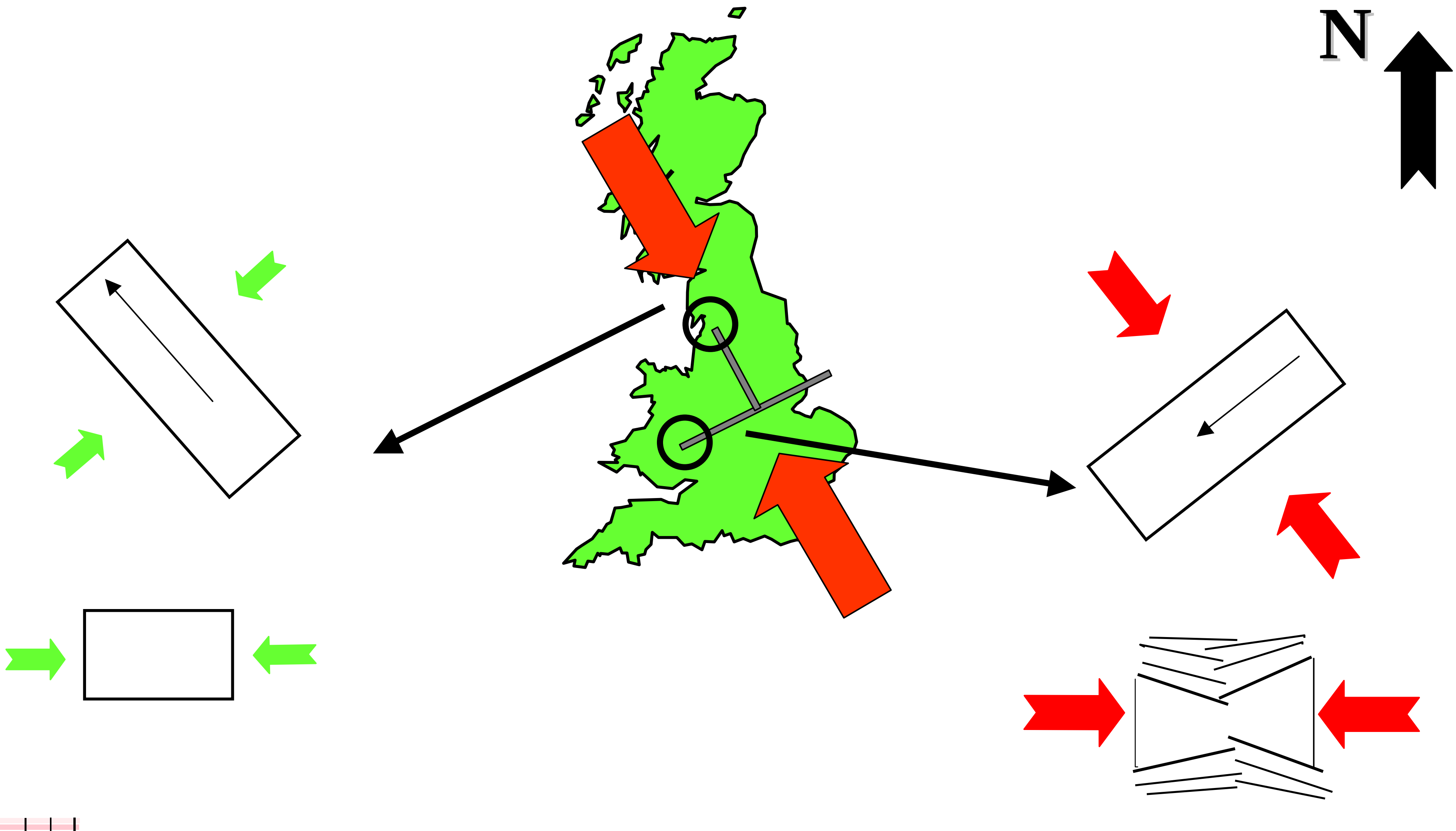

INFLUENCE OF DIRECTIONAL STRESS ON UK CONDITIONS

FIGURE 7

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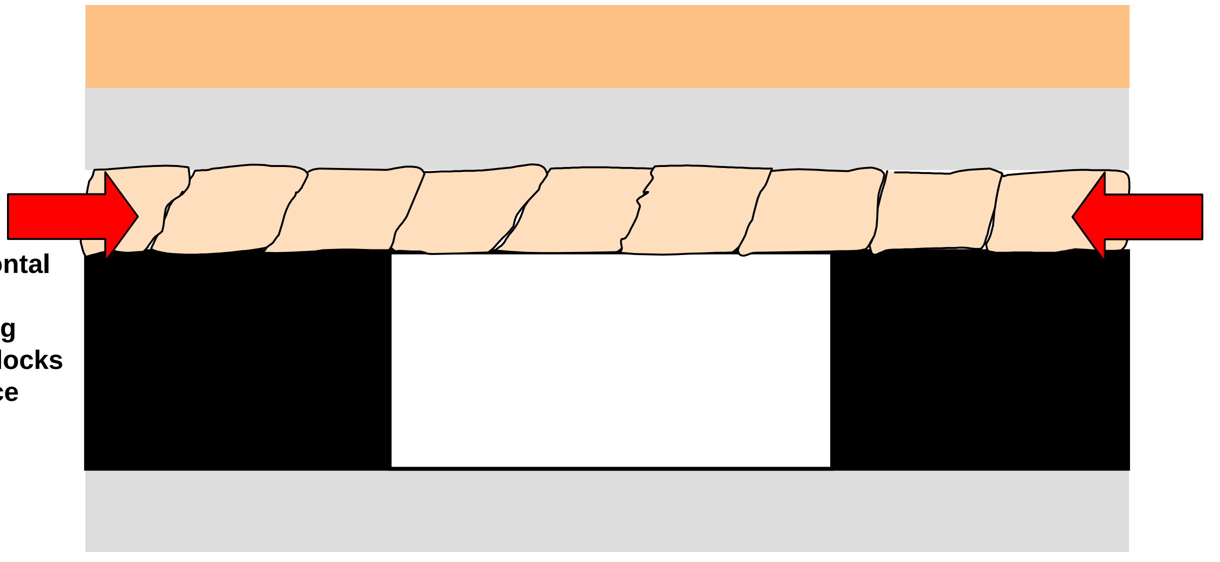

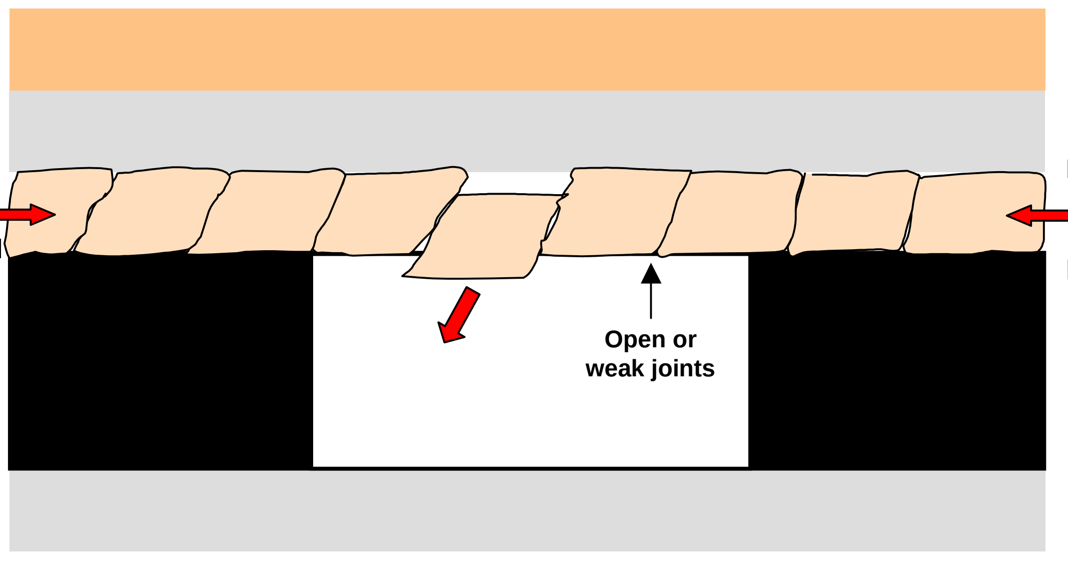

Fall of roof block by sliding on joints in low horizontal stress conditions

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FIGURE 8

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FIGURE 9
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FIGURE 10
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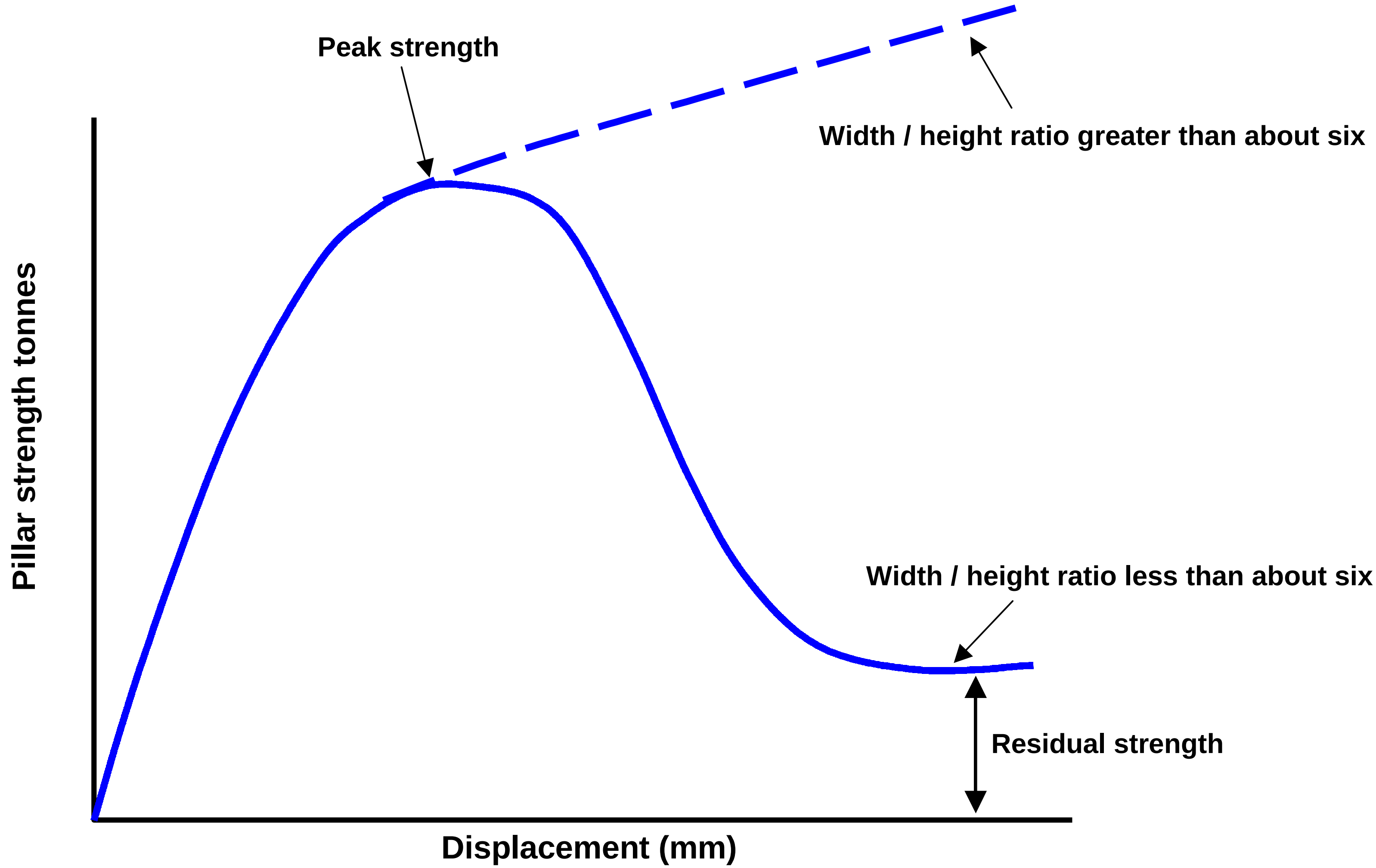

Typical pillar loading behaviour

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FIGURE 11
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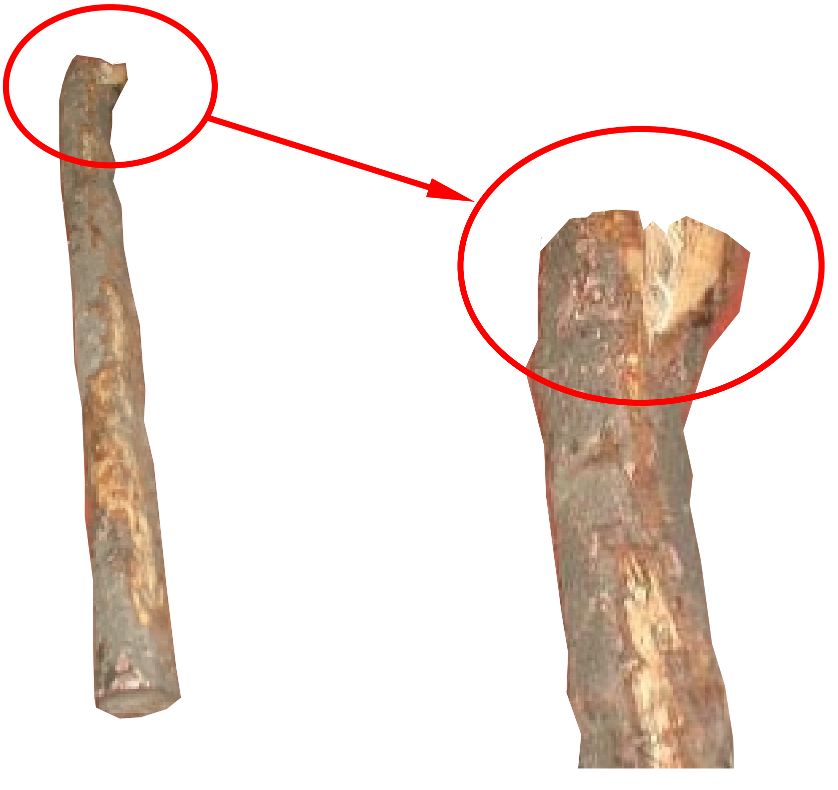

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Example of wood prop failure by splitting close to end

FIGURE 12

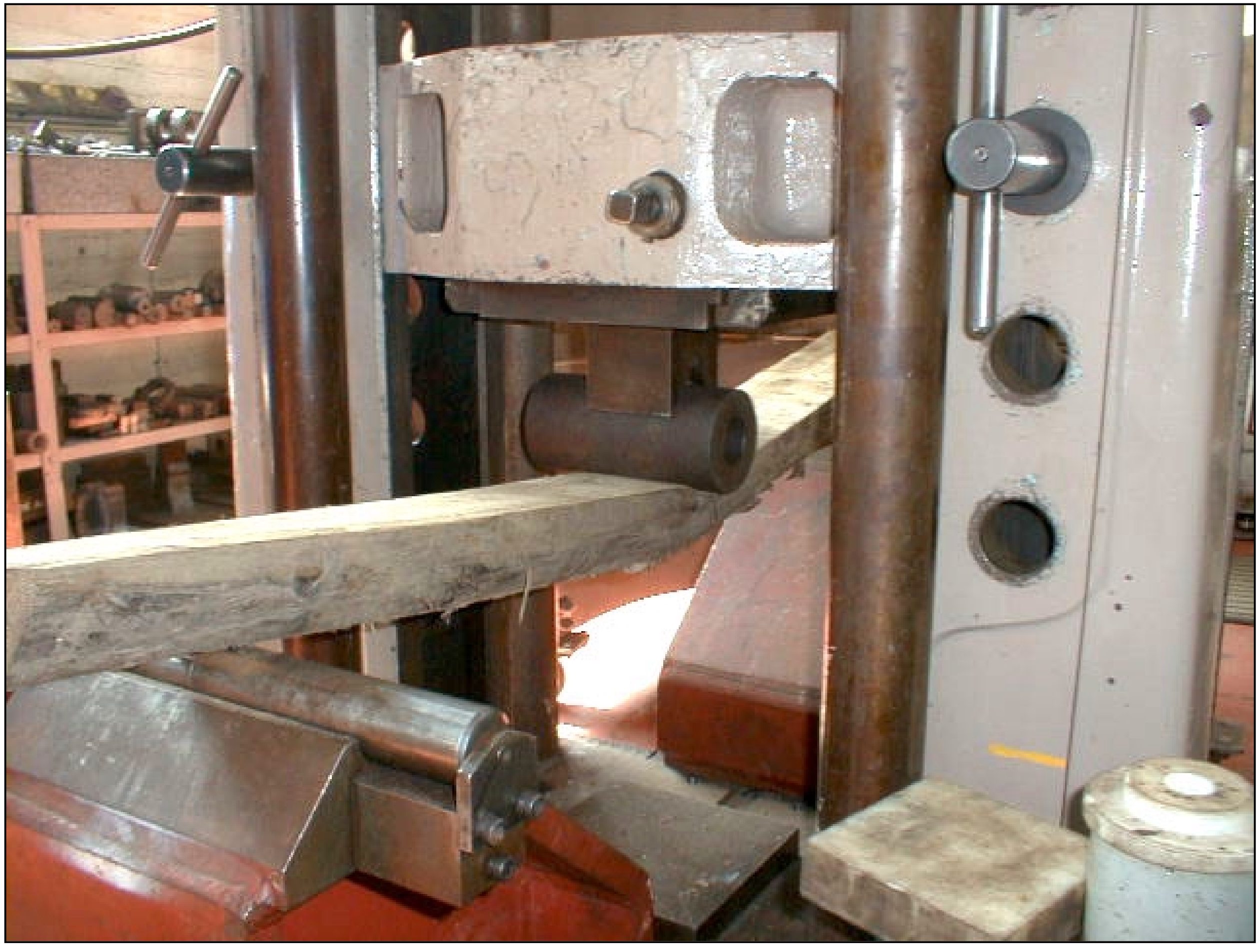

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FIGURE 13
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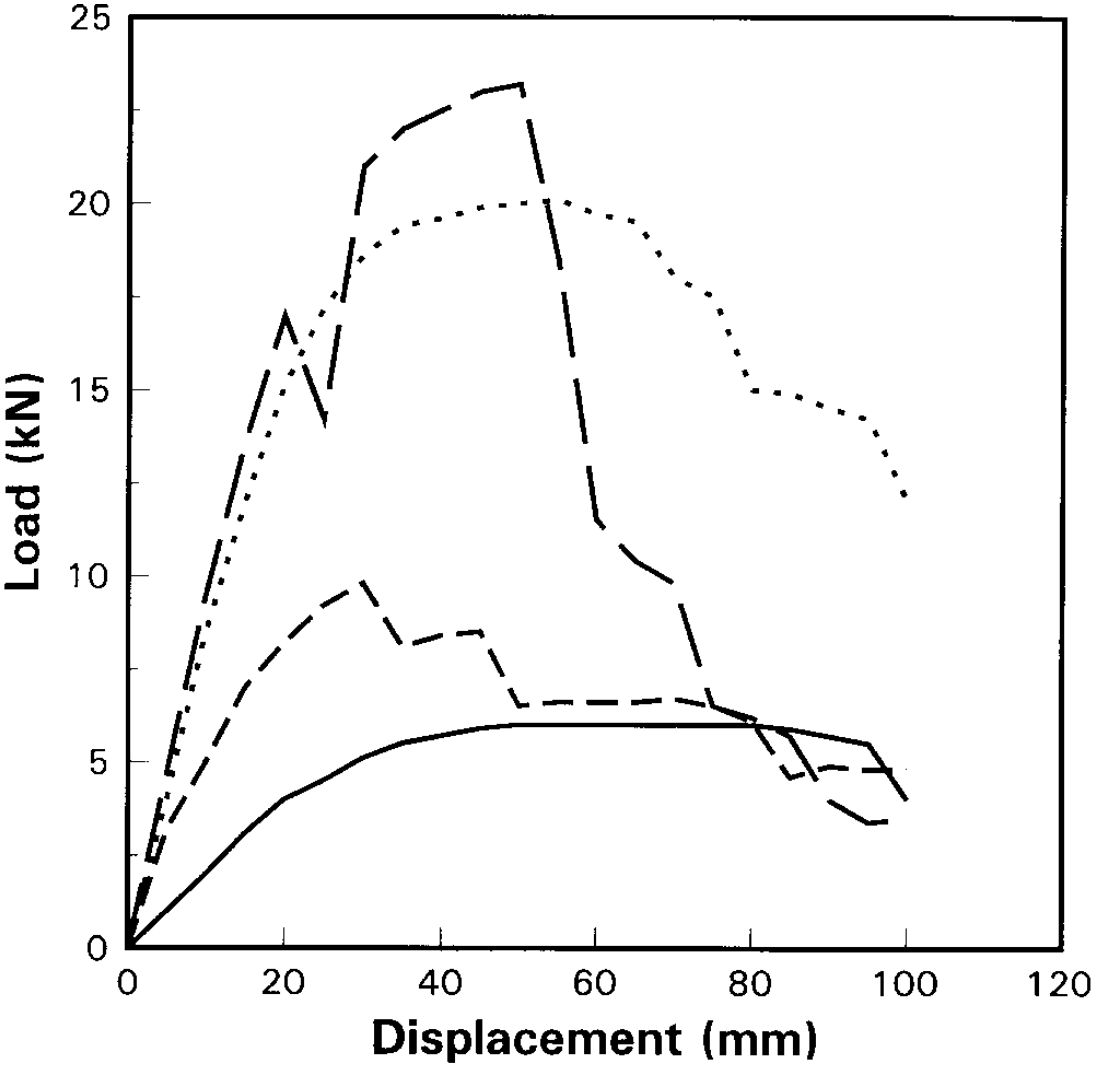
POINT LOAD TESTS
1/2 ROUND TIMBER ROOF BAR



125mm x 55mm x 1570mm
Max Load 6.0kN
———

105mm x 60mm x 1565mm
Max Load 10.1kN

131mm x 75mm x 1570mm
Max Load 20.3kN
....

138mm x 72mm x 1573mm
Max Load 23.3kN
— — -

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FIGURE 14

Notched Timbers

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FIGURE 15
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SYSTEM PERFORMANCE TESTS
4-POINT CRIBS

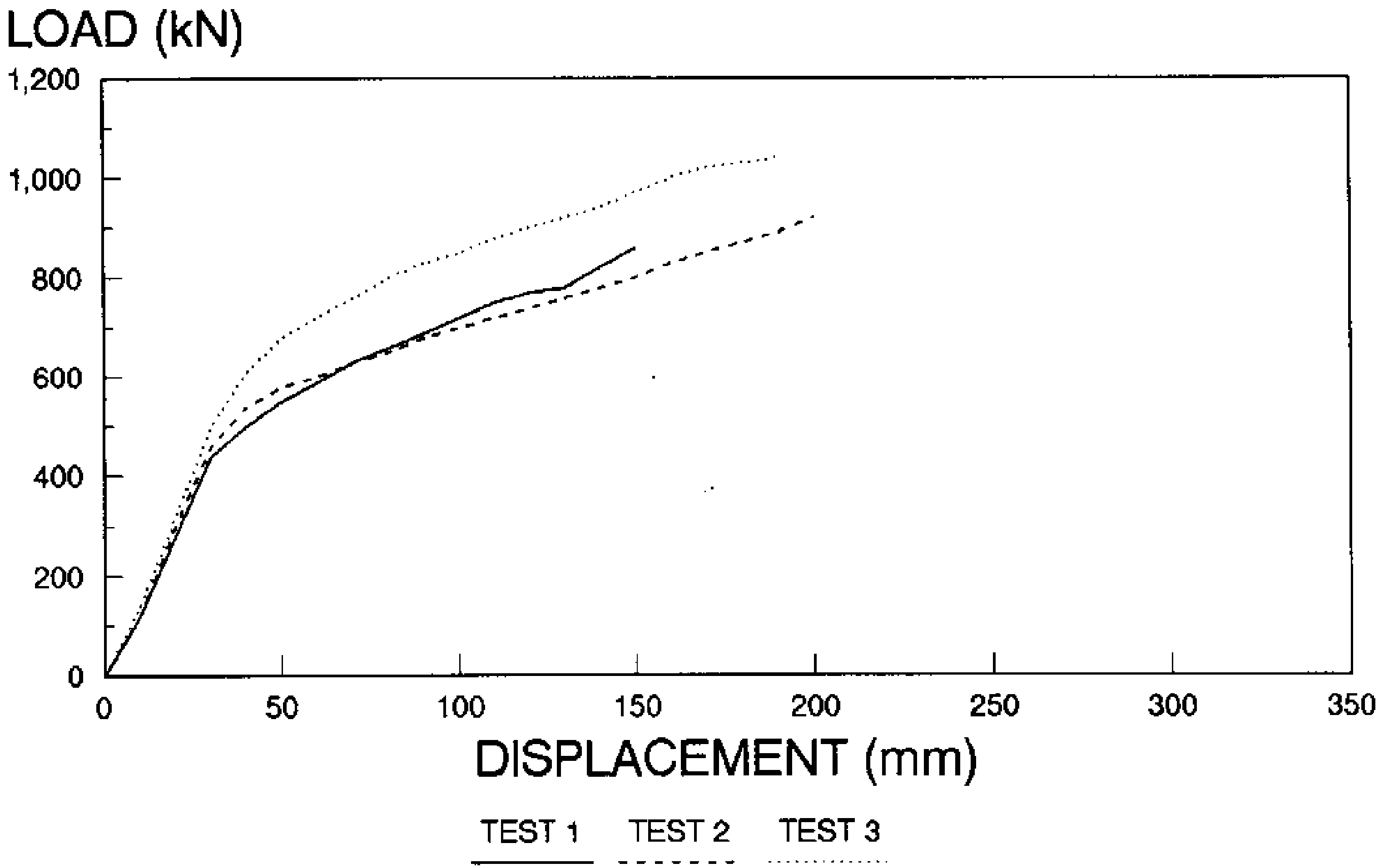

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FIGURE 16
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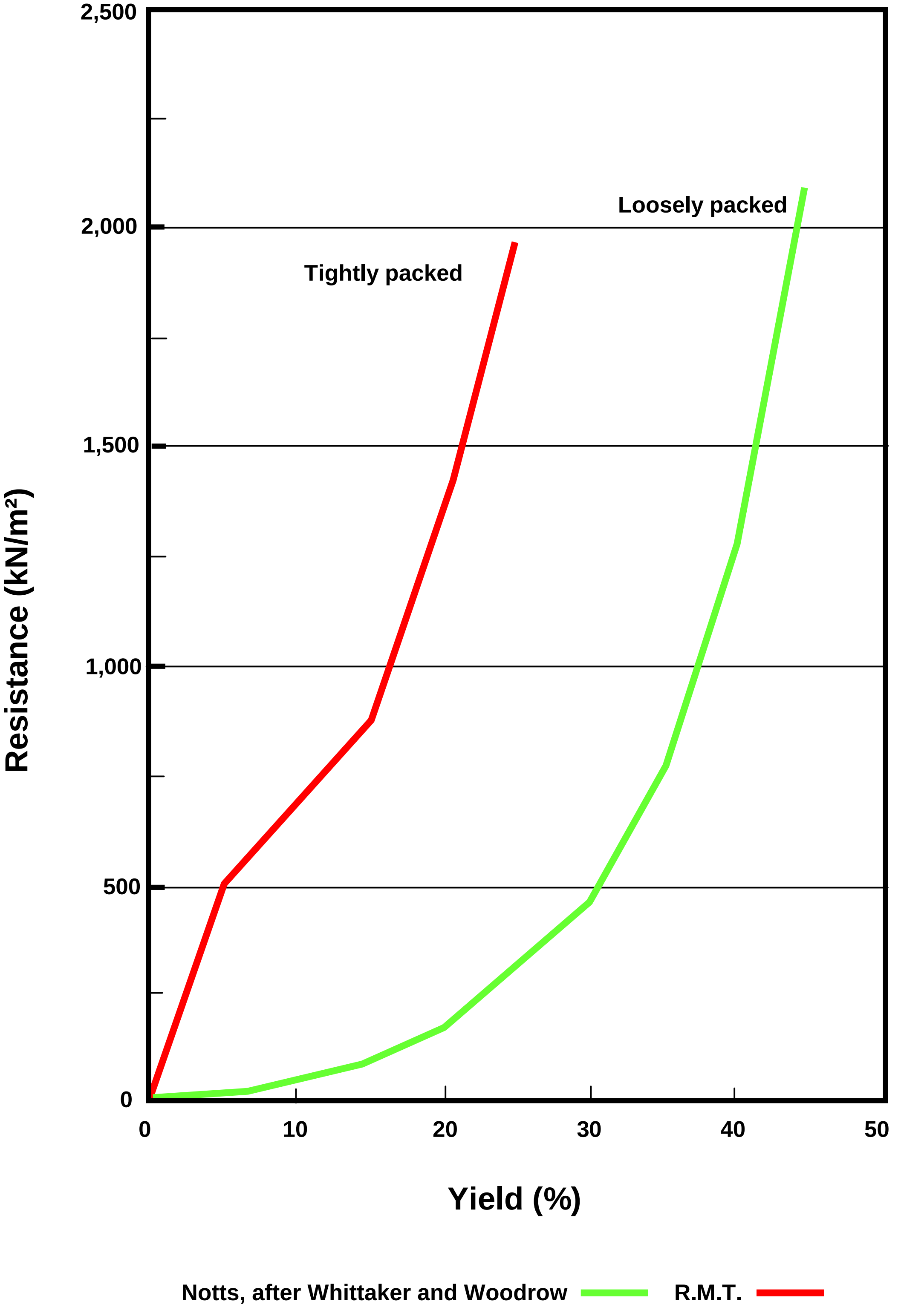

Strength characteristics of stone packs

Stone packs after loading showing displaced / crushed outer wall

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FIGURE 18

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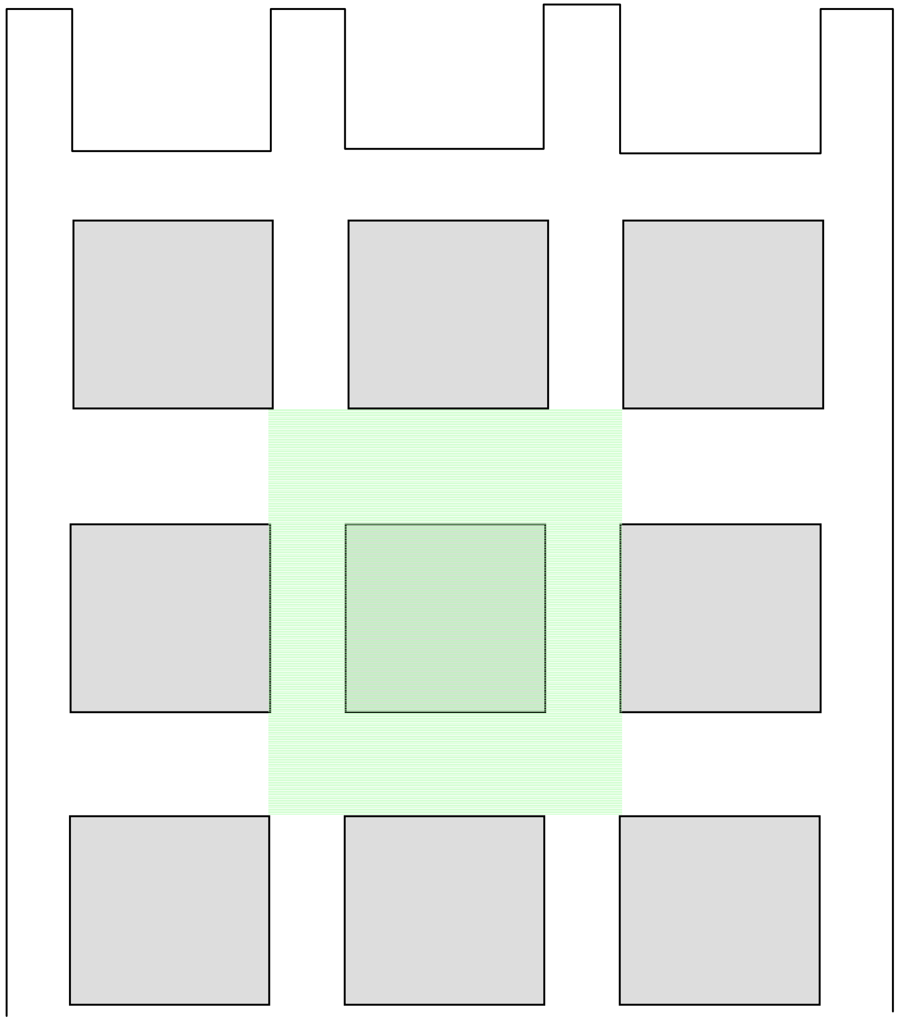
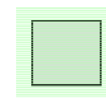


Tributary area for pillar A shown as;



Tributary area

- each pillar has to carry its share of the weight of overlying rock.

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FIGURE 19

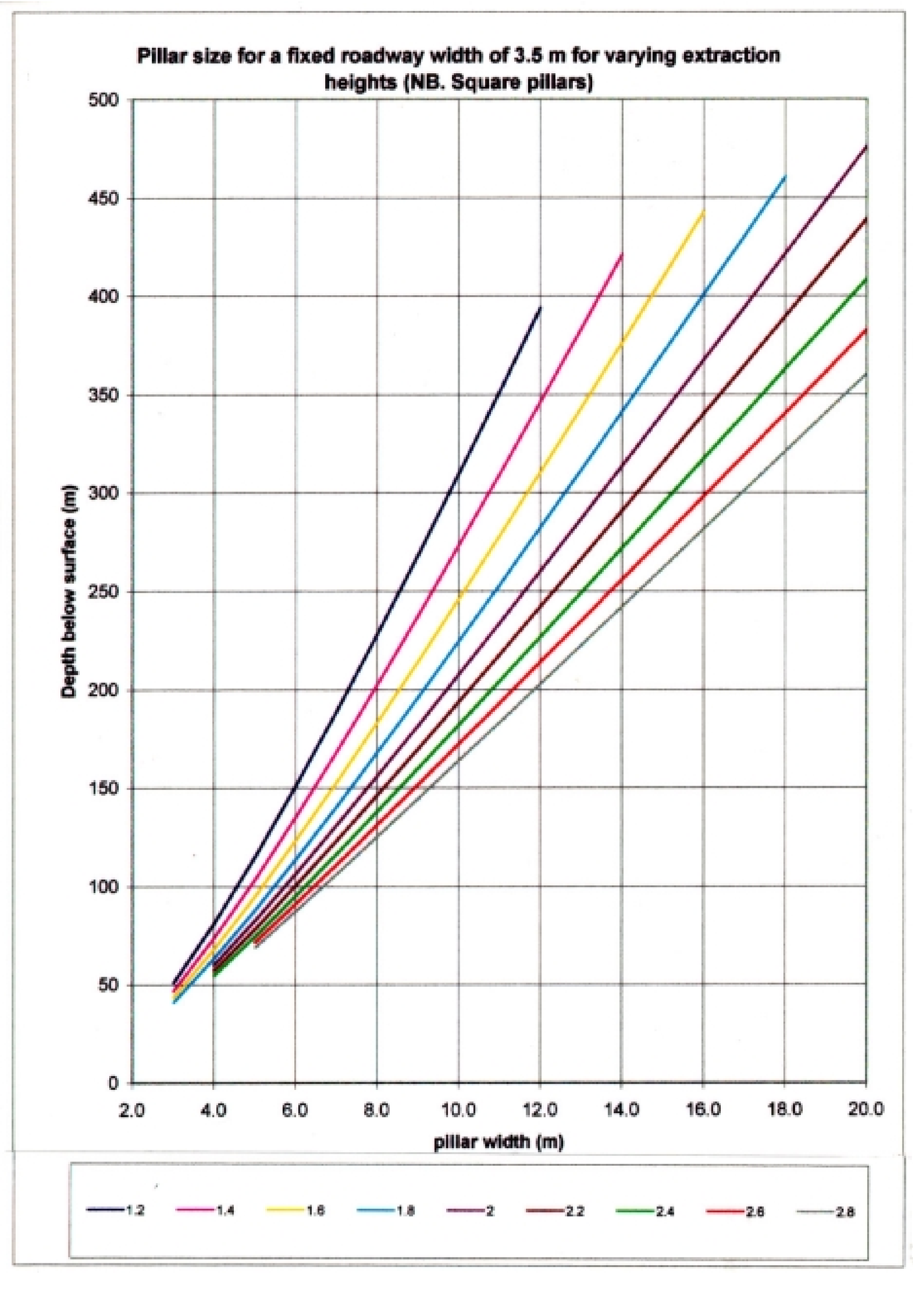

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FIGURE 20

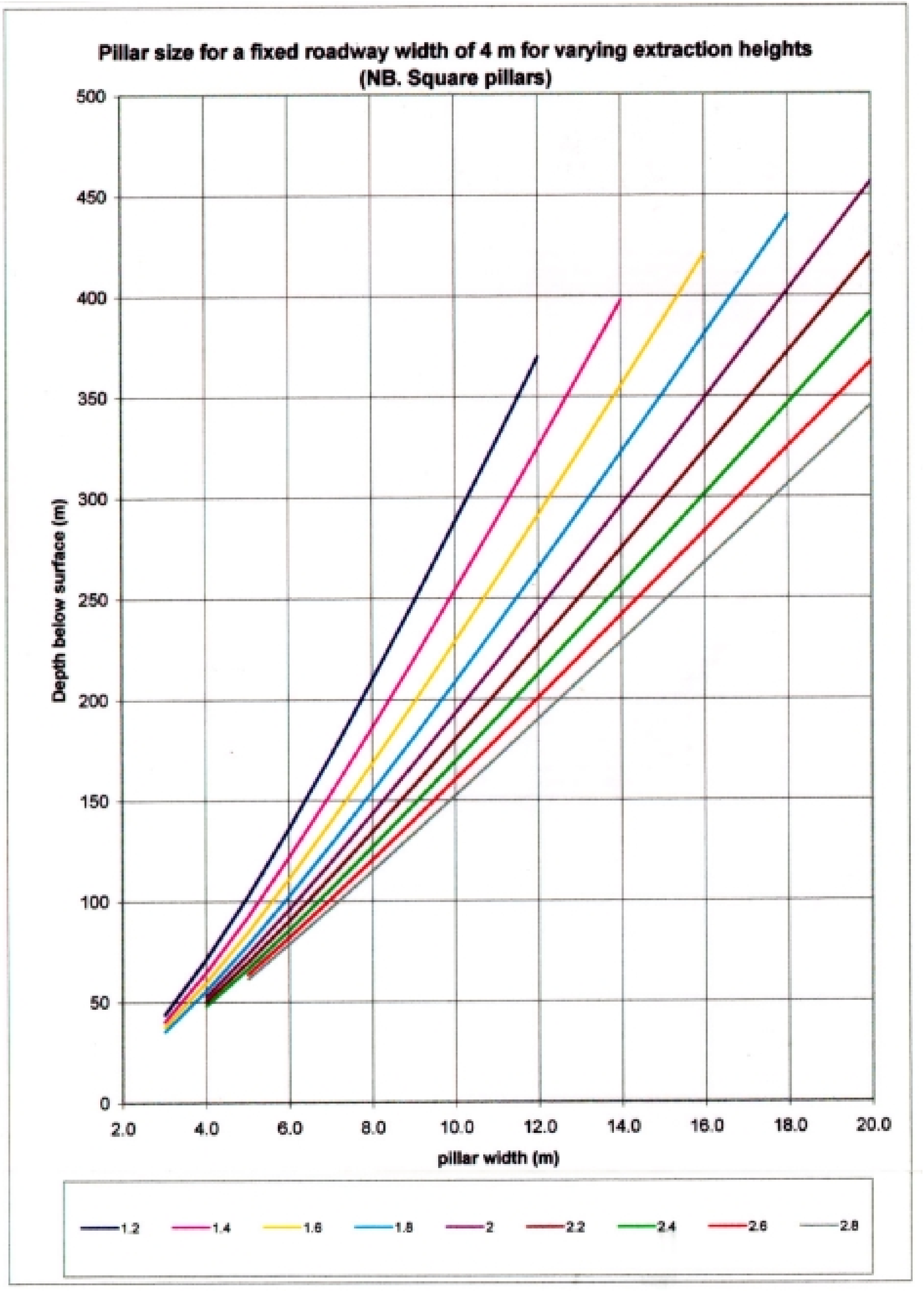

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FIGURE 21

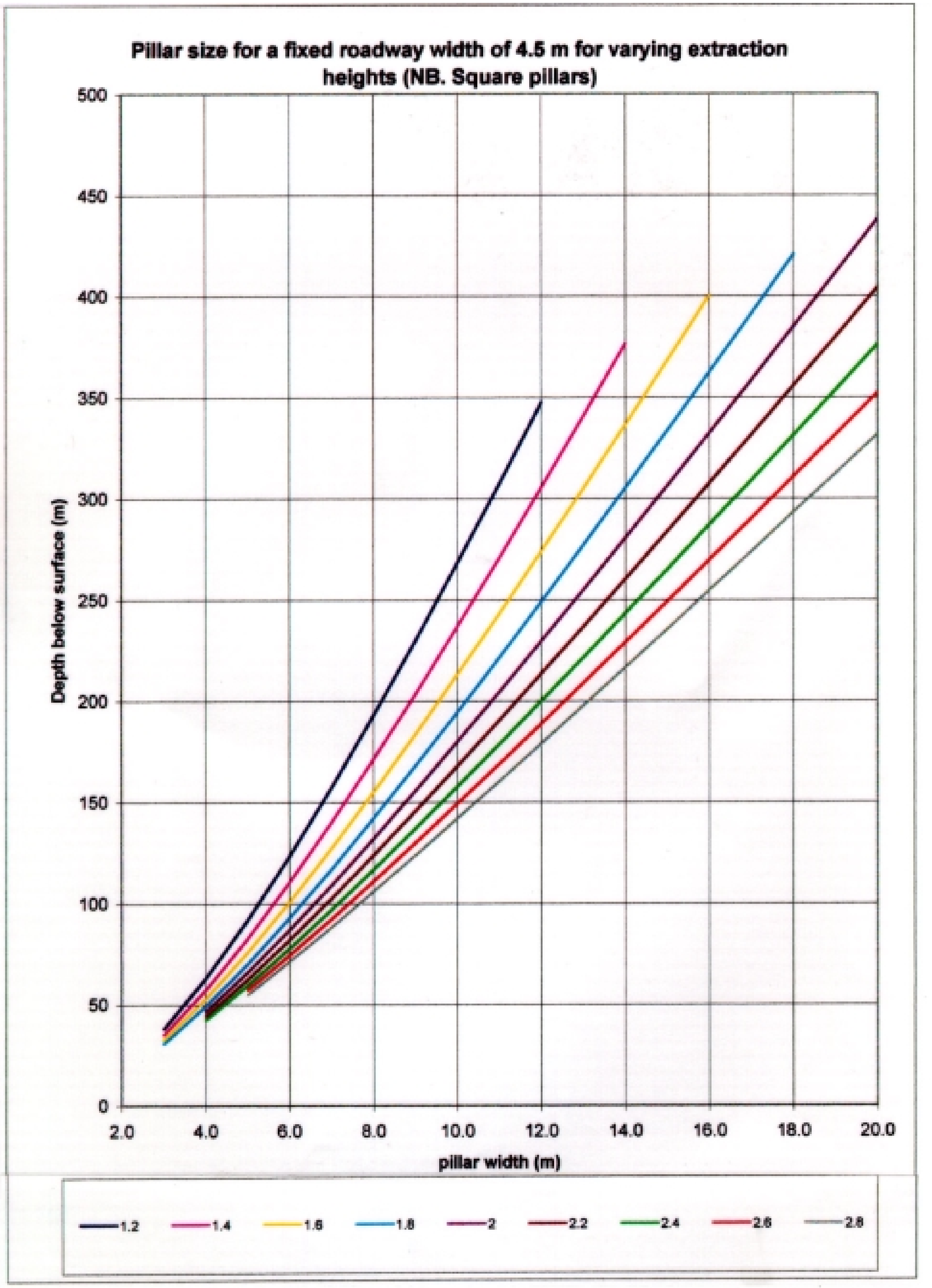

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FIGURE 22

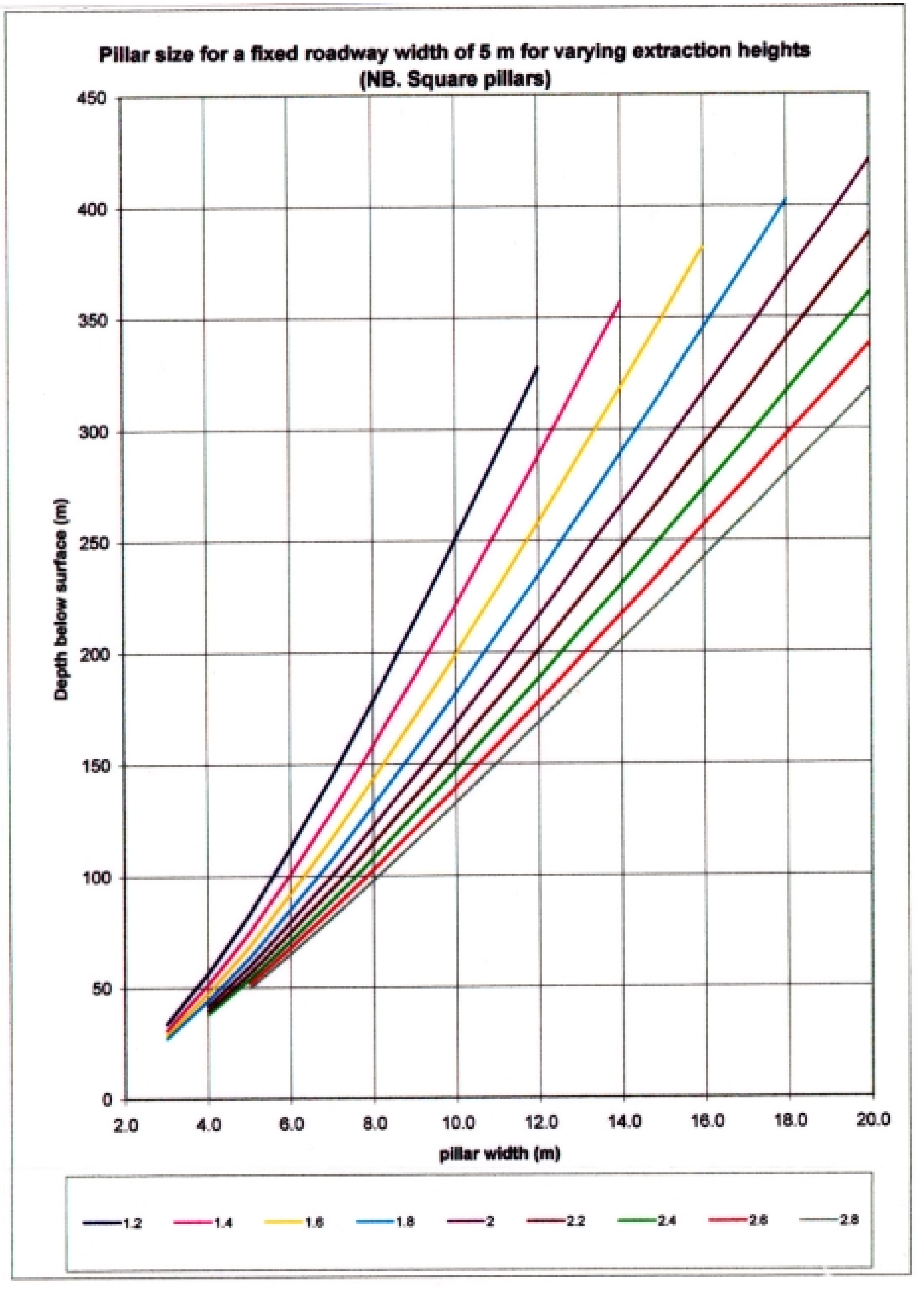

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FIGURE 23

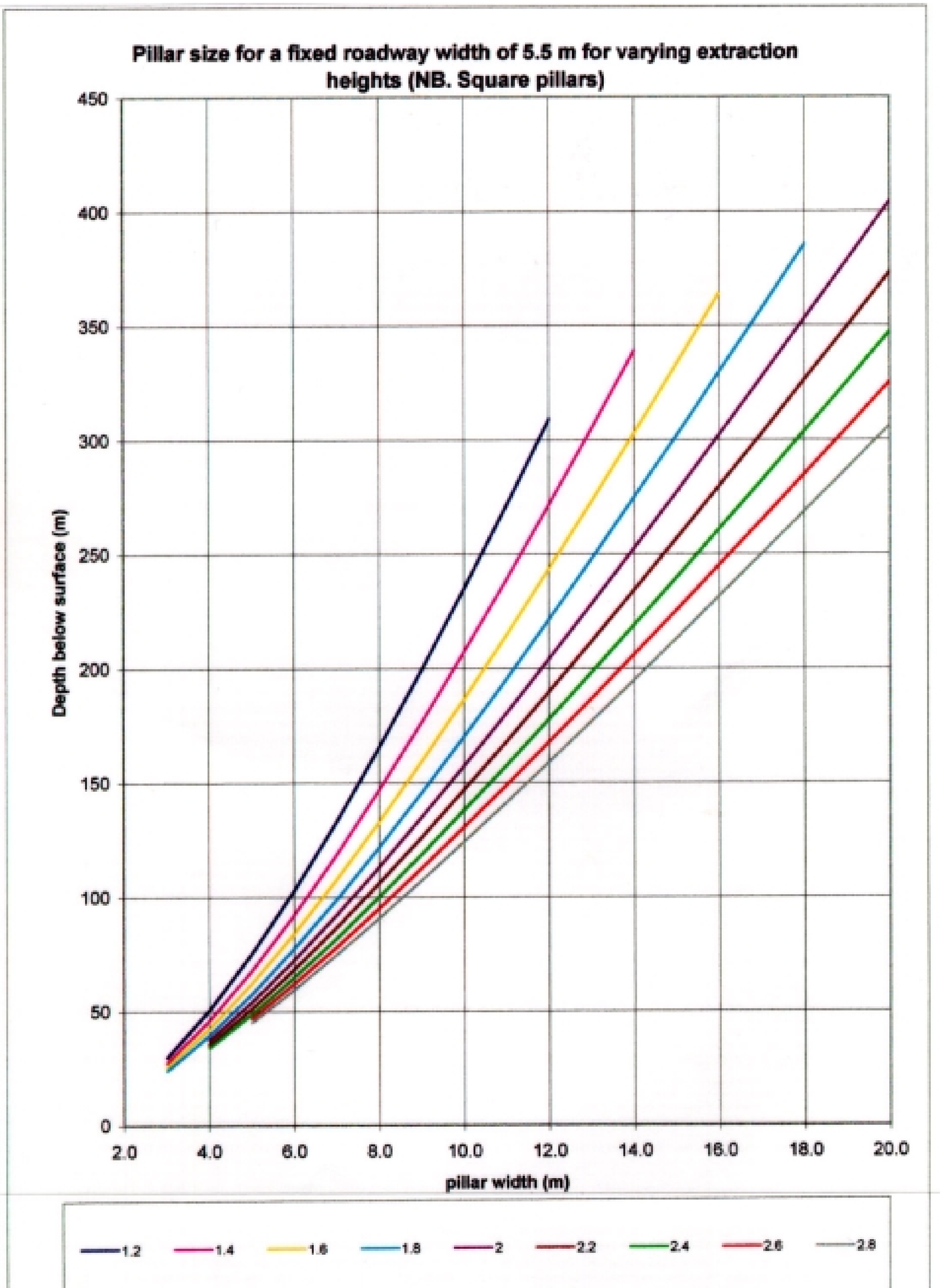

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FIGURE 24

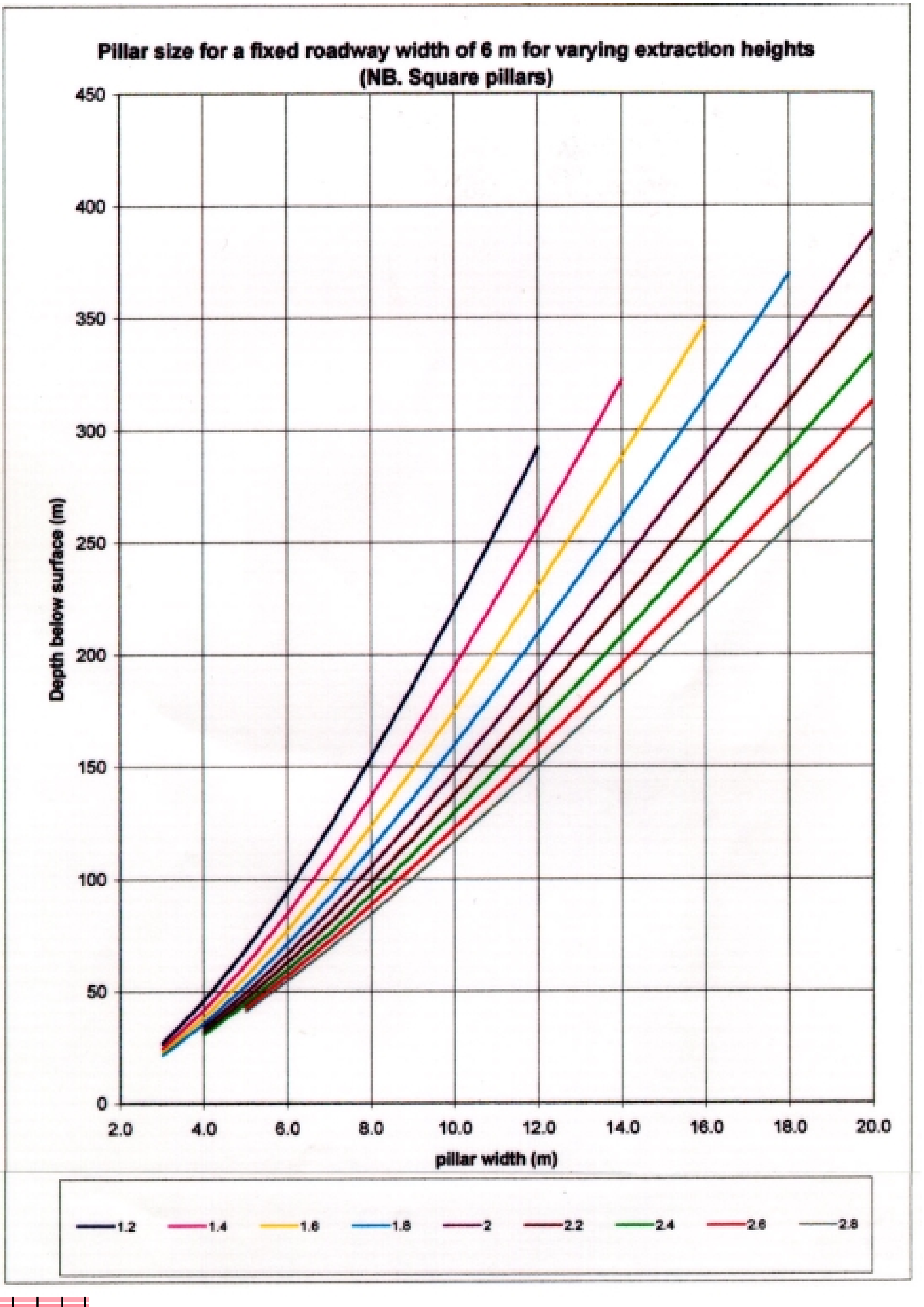

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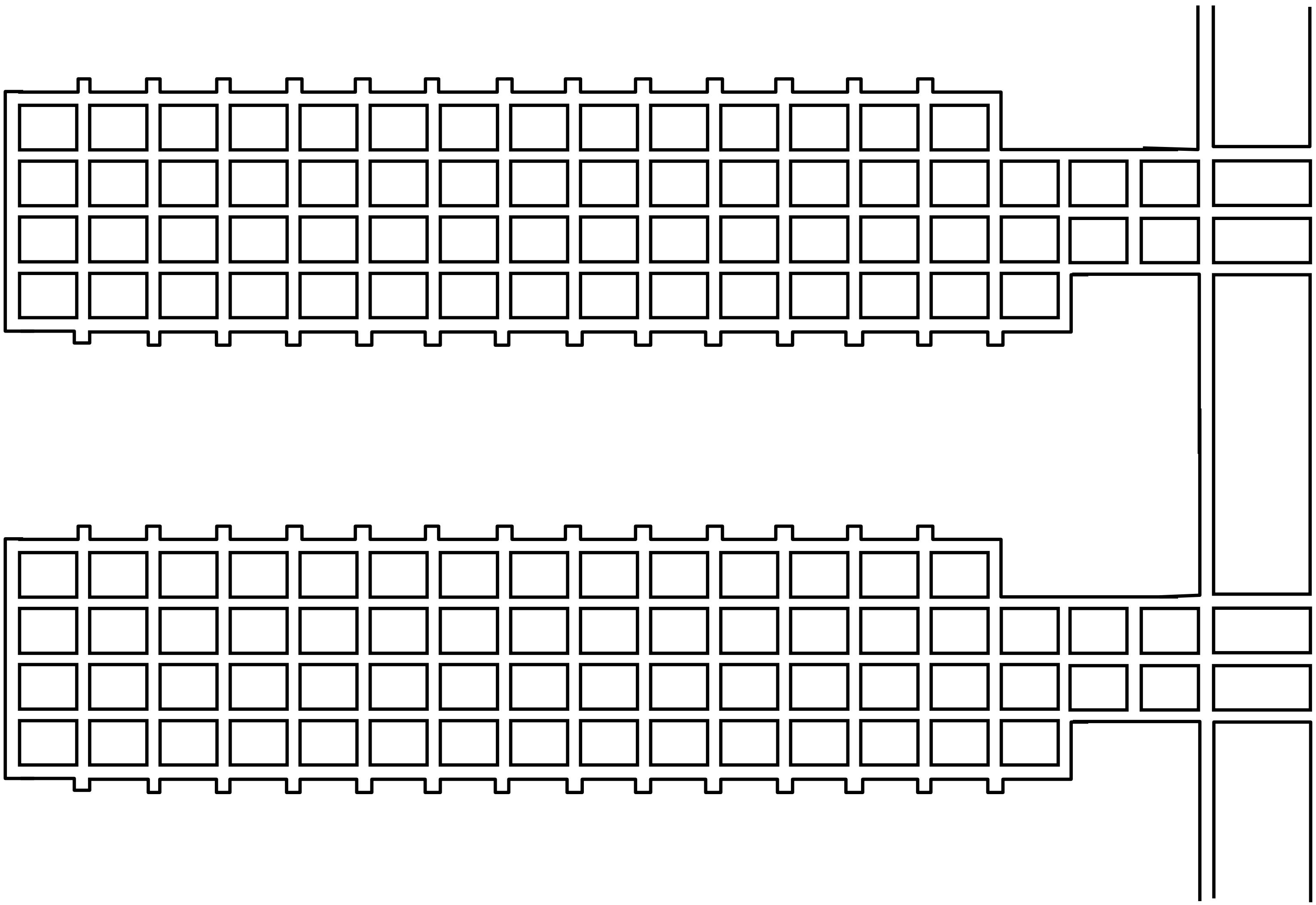
FIGURE 25



Room and pillar layout

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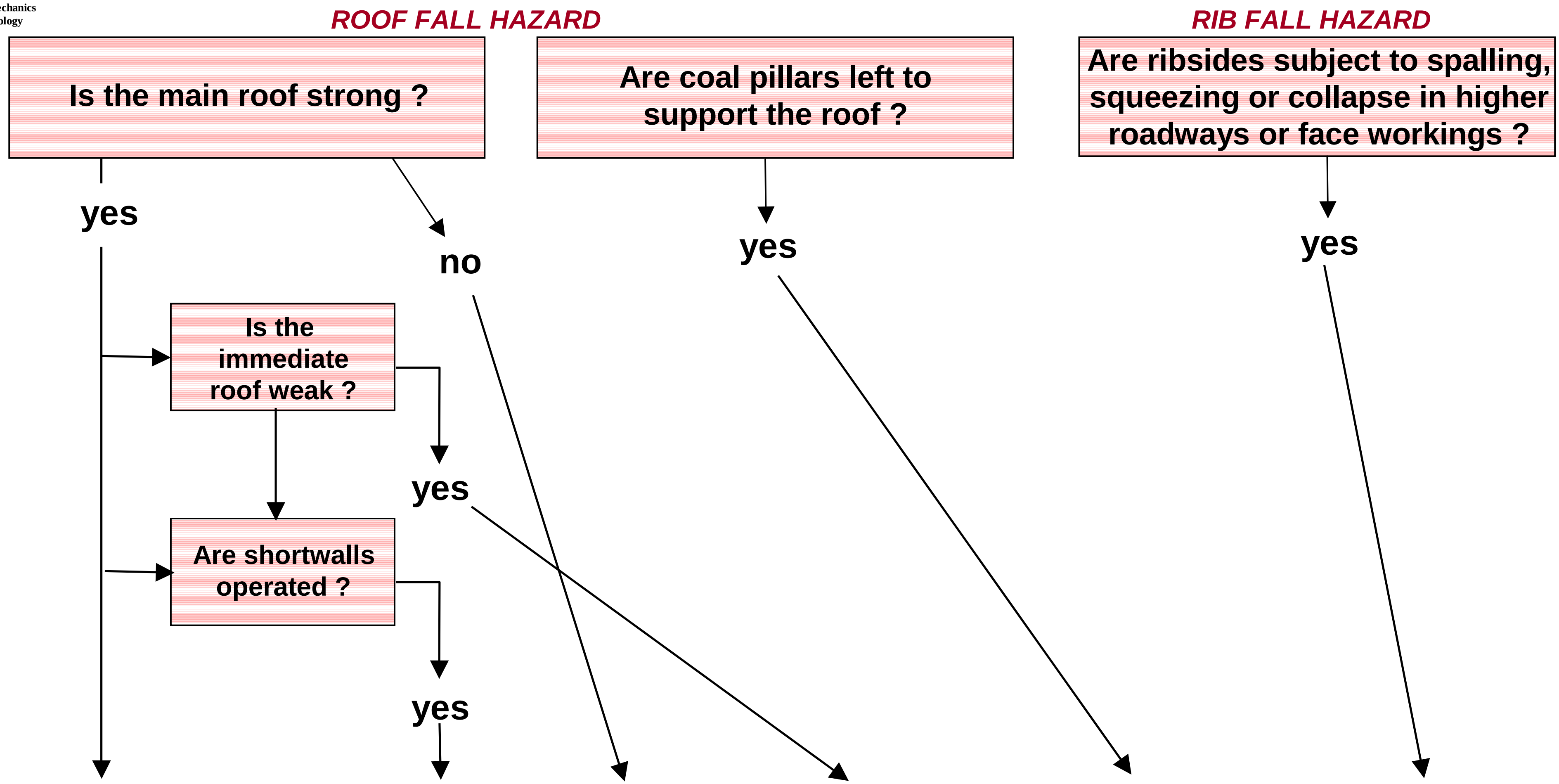
FIGURE 26

IDENTIFICATION OF HAZARD CATEGORIES



Fall of roof block 1a	Face weighting 1b	Fall of weaker roof 2a	Flashing of immediate roof 2b	Roof fall due to pillar collapse 3	Rib fall due to spalling or loose material 4
Y / N	Y / N	Y / N	Y / N	Y / N	Y / N

FIGURE 27

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