WATER PROBLEMS ASSOCIATED WITH UNDERSEA COAL MINING

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ABSTRACT

In this paper, United Kingdom undersea design criteria will be defined. Some case histories from the North East of England undersea workings will be described and related to empirical strata movement measurements and to physical models.

Guide lines will be postulated for the design of workings to reduce the possibility and the quantity of water inflow when working under the sea and under heavily water-bearing strata.

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1. INTRODUCTION

Coal mining under the sea has been carried out in many different parts of the world. The first consideration associated with undersea mining or for that matter under bodies of water or under sub-surface aquifers, is to limit disturbance of the strata above the working faces, in order to prevent water entering the working areas.

Off the coast of North East England, a number of the pits have been affected by the inflow of significant quantities of water on to working coal faces. Although the workings are under the sea, the origin of the water, except in one or two cases, is not the sea but subsurface aquifers.

Chemical analyses have shown that the waters from different aquifers most frequently have characteristic chemical content, for example, water from Coal Measure aquifers often contain Barium, and water from the Base of Permian often contains in the order of 500.000 parts per million of solids being particularly high in chlorides and sulphates. When the water in the Base of Permian is encountered in boreholes, hydrostatic pressures equivalent to sea level pressure are measured. Water encountered on faces changes in chemical characteristics as breaks tap water from higher aquifers and there is consequent mixing. The manner in which these breaks form over longwall faces is difficult to predict and appears to be dependant on the position and thickness of the aquifers, and preexisting breaks such as faults and jointing. The dip of the strata is often significant. In some cases igneous dykes have been identified as transmitting bodies.

The object of this paper is to examine the behaviour of the strata above the working faces with respect to water occurrences, by using the results from operational observations, some in-situ measurements and a physical model.

Guidelines have been postulated in order to reduce the probability of inflow and the quantity of water inflow when working under the sea and under heavily water-bearing strata.

2. WORLD WIDE EXAMPLES OF UNDERSEA COAL MINING

In the U K., according to historical records, mineral extraction has taken place under large bodies of water since the 13th century. Coal mining has also been carried out under the sea in several other countries. In each country, there are rules which govern working under the sea. These rules have been evolved, and are generally based on local practical experience and occasionally on the results of some investigations.

Codes of practice for mine workings under the sea and the bodies of water are reviewed in Table 1. Several parameters should be taken into consideration in order to determine design rules for undersea mining. Garrity(4) listed 17 parameters which may affect the flow of water from the sea or an aquifer into a working face. However, even with these parameters there is still uncertainty about some water occurrences, so more of different parameters may be needed.

Because undersea coal has been mined without major inundations of water in recent years, there is a general feeling and confidence that there is *no* significant difference from mining underland. Historical records however show some catastrophic accidents due to undersea mining. Some of the major inrushes are given in Table 2. It can be seen from the Table that, as might be expected, the risk of inundation increases when working close to the sea-bed or near to a fault.

Table 1- Review of codes of practice for working under the sea and bodies of water.

Country	Minimum Cover (m)	Minimum Carboniferous Strata (m)	Limiting Tensile Strain (mm/m)	Reference	Remarks
Australia	120			Kapp, W.A. and Williams R.C. (1972) Williamson, W.H. (1978) Cartwell, B.L. and Whitfield L.M. (1984)	For panel and pillar method mining is being undertaken both by bord and pillar method and panel and pillar mIning under the stored water of the Sydney Basin and the Pa clflc Ocean near Sydney, Australia. The Panel width does not exceed D/3 and pillar width be not less than D/5 where D is the thickness of cover. Cover should be at least 60m for partial extraction.
Canada	213	-	6	Garritty, P. (1980)	In the Sydney coalfield, Nova Scotia there are three collieries beneath the Atlantic Ocean. Current mining operations are located up to 7 km from shore.
Chile	150	Only 15 m in one area worked	5	Garritty, P. (1980)	At present long wall mining is taking place at Lota, near Concepcion.
India	-	-	3	Saxena, N.C. and Singh, B. (1982)	If in an area, the percentage of shale is found to be greater than 35% a higher limit of strain may be considered.
Japan	60	-	8	Kapp, W.A. and Williams R.C. (1972) Garritty, P. (1980)	Coal mine safety regulations apply to drilling in advance of mining and to various other aspects of undersea mining.
Turkey	160	-	-	Birön, C. (1964)	Coal mining has been carried out under the Blacksea since 1956. Extraction using stowing methods is permitted.
U.K.	105* 60**	60* 45**	10	N.C.B. Mining Department Instruction (1968/Revised 1971)	'Limits for longwall extraction **Limfts for pillar and stall Partial extraction
U.S.A.	18.3M	-	8.75	Babcock, CO. and Hooker, V.E. (1977)	M : thickness of the extraction

Coal mining has been carried out under the sea In the Soviet Union and off the north coast of Taiwan, but no Information is available at present.

Table 2— Historical record of some major inundations of undersea coal workings

Country	Date	Name of the Colliery	Cover (m)	Total dead	The cause of the inrush
Canada	1909	Mabou (Nova Scotia)	33.5	-	Working close to the seabed (4)
Canada	1911	Port Hood	287	—	Large fault (4)
Chile	1881	Two mines flooded		—	Close to the seabed and vicinity of the fault (4)
Japan	30.12.1900	Santagumi	14	25	Working very close to the seabed (2)
Japan	11. 3.1910	Santagumigata	15	75	Working very close to the seabed (2)
Japan	12. 4.1915	Higashimisome	72	235	Fault (2)
Japan	6. 2.1942	Chosei	37	183	Fault (2)
U.K.	28. 7.1837	Workington Colliery (Main Band) Cumberland	27.545	27	Only 7.3m of the cover thought to be rock (11)
U.K.	1883	Mostyn Colliery, North Wales	22-29		The colliery was closed due to sea water breaking into workings (11)

3. UNDERSEA COAL MINING IN THE NORTH EAST OF ENGLAND

Under the U.K. sector of the North Sea, coal seams of up to 15m in thickness have been found at depths between 600-30O0m. Deposits of coal have been located in areas where the sea depth varies from less than 25m to 200m, and at distances of up to 100 km from the east coast of the U.K.(5). Up to the present time the mining of deposits under the sea has been confined to coastal areas where coal seams were accessed from land-based operations mainly as an extension of existing underground mines. At present, mining can be undertaken at the 9 coastal pits up *to* 8-10 km from the coastline by the use of conventional ventilation methods supplemented by underground booster fans. These collieries are Ellington, Lynemouth, Bates, Westoe, Wearnouth, Vane Tempest, Dawdon, Easington and Horden.

4. U.K. UNDERSEA COAL MINING DESIGN CRITERIA

The design criteria are very important in working under the sea because of the potential danger of inrush of sea water.

After extraction, the increased permeability of the ground may allow water flow into the mine and consequently the cost of extraction increases.

In the U.K., the method of working under surface and sub-surface water bodies is defined by The Mines (Precautions Against Inrushes) Regulations 1979 and the N.C.B's Mining Department Instruction for working under the sea. The legislation (Precautions Against Inrushes) prohibits working within 45 metres of any potentially existing water bodies without special consent of the Inspectorate.

The codes of practice in the N.C.B. Mining Department Instruction P.I. 1968/8 (Revised 1971) explain in more detail and give some specifications for longwall extraction:

> "No longwall extraction shall be carried out where the thickness of cover between the top of the seam and the seabed is less than 105 metres where the total thickness of carboniferous strata above the top of the seam is less than 60 metres. Seams shall be extracted at such thicknesses and depths that the tensile strain induced at the seabed shall not exceed 0.01 (10 mm/m)."

This applies both to the first and successive seams worked, the accumulated affect of all workings has to be taken into consideration.

Pillar and stall partial extraction and Pillar extraction is also covered in the instruction.

In recent years, the North East Area of the N.C.B. has produced a graph which shows wet and dry faces in relation to cover to the base of the Permian which overlies the carboniferous strata and to distance to the seabed.

As can be seen from Figure 1, in this area, above a certain value the cover to the seabed does not affect water conditions at the face. Cover to the base of the Permian is clearly a major factor. If the cover to the base of the Permian is less than 150m a high percentage of the faces are wet whereas if the cover is greater than 150m only a few of the faces are not dry.

There is also a factor that the greater the depth from the sea level, because of the higher hydrostatic head at the Base of Permian, the greater the amount of carboniferous cover required to maintain dry conditions.

5. THE MECHANISM OF THE STRATA BEHAVIOUR ABOVE A CAVING LONGWALL FACE

Initially when a longwall face begins to advance the immediate roof beds start to sag, slip and separate. As the face advances, failure of the immediate roof is induced, and a zone of caving is formed.

The roof caves to a height (C)

$$C = \frac{M}{(F-1)}$$

were M is the height of the extraction
and F is the bulking factor of the caved material.

If F = 1.5, then C = 2M. This value of C = 2M gives results consistant with many observations, and has had general acceptance in the U.K. and Germany(20).

The higher strata, which consist of the main roof and lower parts of the intermediate strata, behaves as a series of beams or plates and bed-separation becomes apparent.

The loosened character of the goaf material and the existence of fractures in the separated beams is accepted. A further advance of the coal face is followed by weighting and the occurence of major breaks. Eventually it ends in collapse of the main roof. Meantime the bed-separation voids close. The closing mechanism is not very effective in the upper strata. In other words, separated-bed voids can still remain in the upper strata. Finally, the remaining upper strata up to the surface slumps over the underlying strata. As the face continues to advance, this mechanism will repeat again.

The existence of the bed-separation has been widely investigated in the U.K. by using boreholes and physical models which have produced good results in some cases.

6. BED SEPARATION OVER THE LONGWALL FACE

"The bed separation" phenomenon is widely invoked in order to explain sudden water inrushes on to working coal faces in the U.K. Therefore, in this part of the paper,

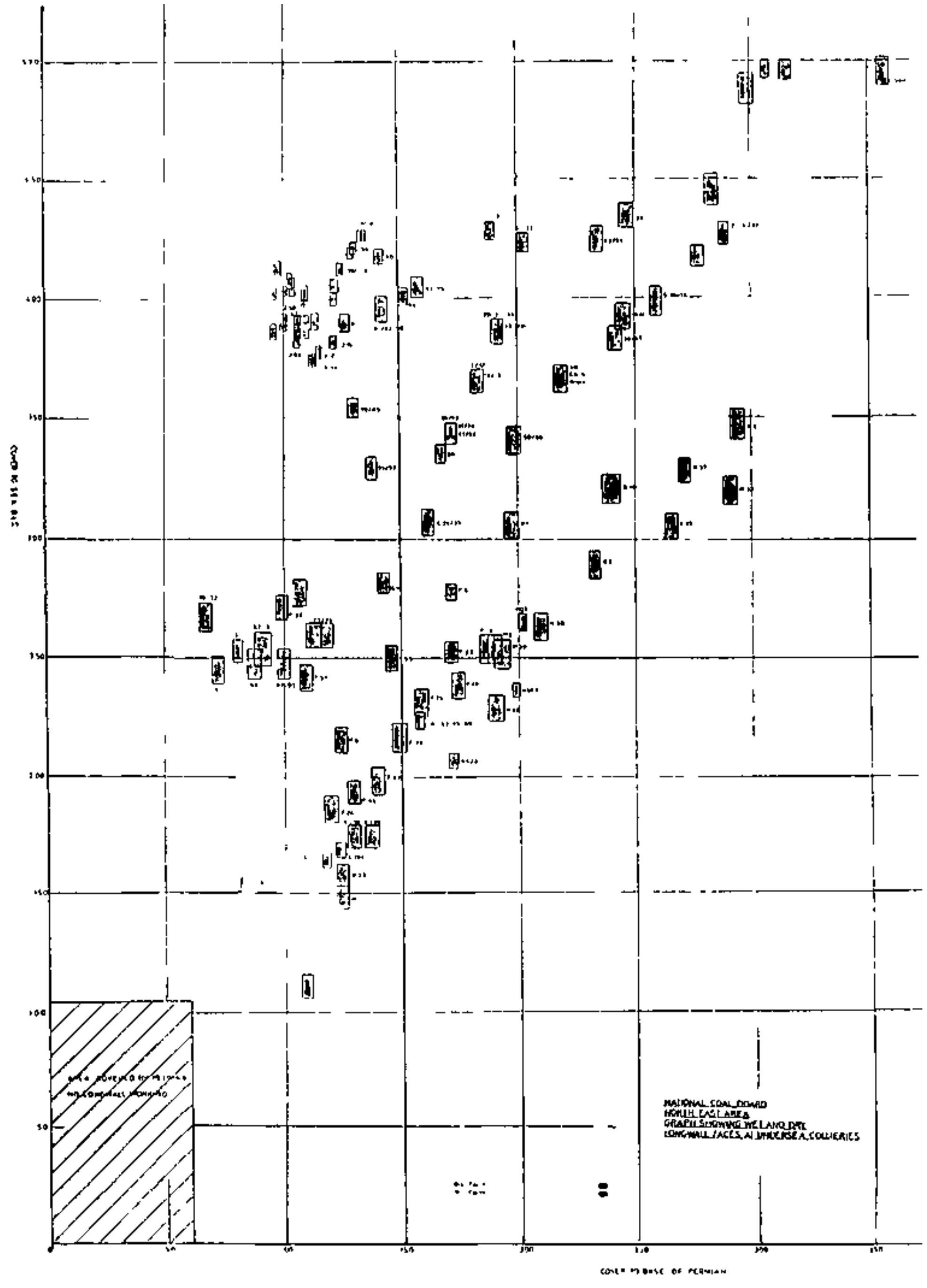

Figure 1

bed separation will be discussed. In an earlier paper at the International Conference on Rapid Advance of Workings in Coal Mines, Professor Labasse(8) described the strata movement above a working longwall face with respect to mining experience in the Liege area. He suggested that the more flexible beds become separated from the more rigid superincumbent beds. There is no doubt that a stiff continuous bed can bridge over a void but under some circumstances a beam which is fractured can behave as a continuous beam of lower stiffness and may be able to bridge voides and thus produce bed separation.

In South Staffordshire, K.R. Whitworth(18) proved the existence of narrow bed separation zones at various horizons by using dewatering boreholes.

Figure 2 shows a series of bed separation horizons above a typical longwall face. The postulated locations of the horizons, independently of lithology, is somewhat surprising.

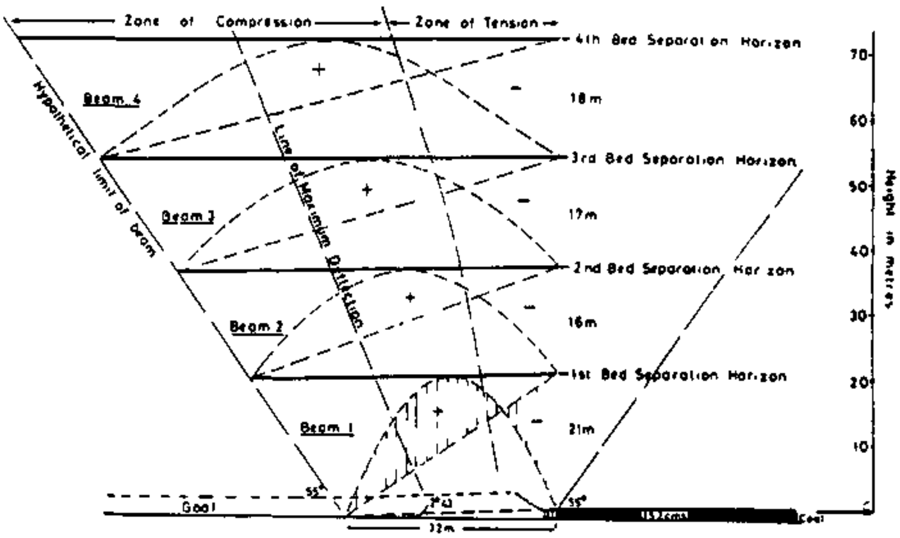

Figure 2— Section through a typical longwall face showing the bed separation horizons between a series of beams and the stress distribution within the beams.

7. PHYSICAL MODELLING

In the Department of Mining Engineering at the University of Newcastle upon Tyne a self loading physical model has been constructed using Lynemouth colliery as prototype.

Results obtained from the model suggest that bed separation does occur at various distances above the longwall face. As the face advances the model shows an opening and a closing mechanism operating, as shown in Figure 3.

Unfortunately, the model work stopped after the first main roof broke. A further model is needed in order to gain definition of the continuous bed separation mechanism.

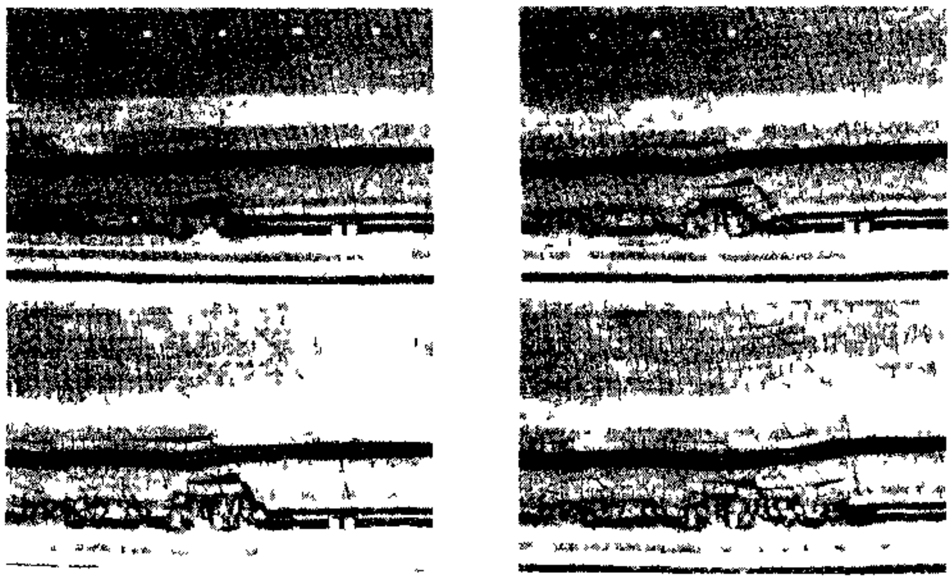

Figure 3

8. FIELD INVESTIGATION

In research investigations Malone and Tomlin(l7) indicated that substantial permanent gaps were produced between the rock layers above a longwall face. Using a borehole extensometer and by levelling, the opening and closing of gaps between rock layers was observed. Figure 4 shows the relative strata *movement* from which it can be concluded that permanent gaps remain in the overlying beds after the extraction. This appears *to* indicate that the closing mechanism after bed separation is incomplete. This conclusion is supported by field measurements by King, Whittaker and Batchelor(17) and Oyanguren(12). However, unless the gaps postulated are not continuous in the horizontal direction it is difficult to reconcile these results with the observed reconsolidation of goaf which must need the transmission of high vertical stresses through the overlying rocks.

9. WATER PROBLEMS IN THE NORTH EAST OF ENGLAND

Production at a number of pits operating off the North East coast of England has been significantly affected by the flow of important quantities of water on to working coaf faces.

Especially significant quantities of water have disturbed working conditions in the south east of Durham, particularly at the Blackhall and Horden collieries. Easington colliery will have similar conditions in the near future. The results obtained from the water analyses show that the main disturbance is by water coming from the Permian which is the main aquifer in the area.

9.1. <u>Blackhall Colliery</u>

A total of 35 faces within the Low Main (J) seam were worked between 1967 and 1979, as shown in Figure 5. The working faces were badly affected by significant quan-

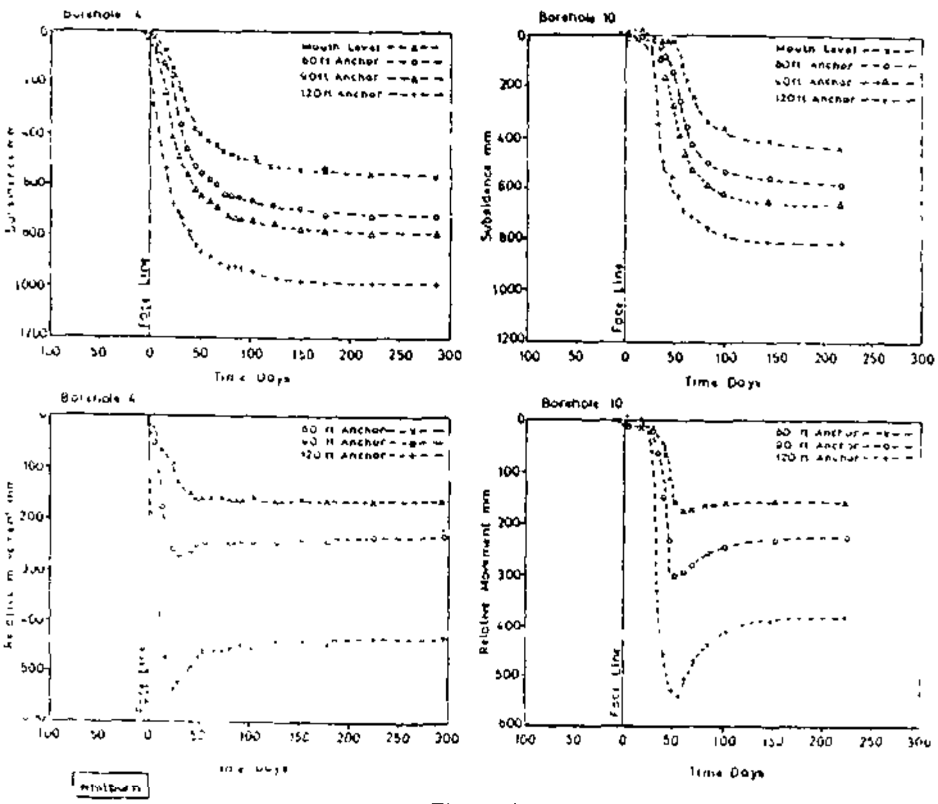
Figure 4

tities of water. In order to reduce water inflow on to the working faces, the length of the faces was changed.

The shortwall system was partially effective in reducing the make of water but some water feeders did occur but these were frequently associated with faults or natural breaks. The partial extraction system, in the northern undersea part of the coalfield, has been very successful in preventing the influx of water. The modern mechanised systems are very productive and overall, extract a higher percentage of reserves than longwall methods. Therefore, they would appear to have many advantages.

The N.C.B. North East Area Surveying Department prepared a Table (13) for these faces in order to compare dry and wet faces according to estimated tensile strains at the base of the Permian (B.O.P.). It can be concluded from Table 3 that if the tensile strain was less than 4 mm/m the faces were almost dry. On the other hand, most of the faces appeared to be wet where estimated tensile strains at the B.O.P. were more than 6 mm/m.

Production at the Blackhall Colliery ceased in 1981 due to several problems associated with water coming on to working faces.

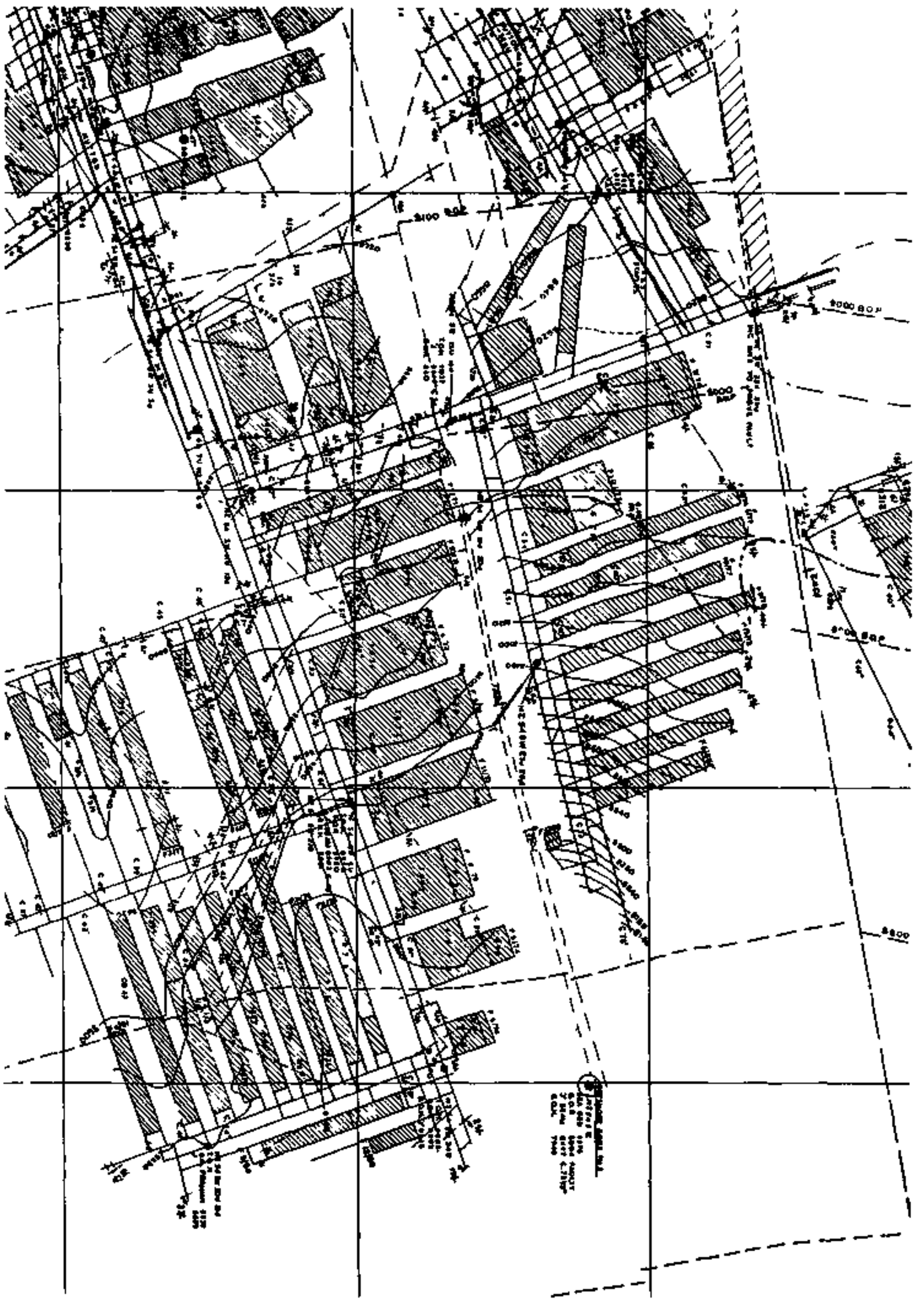

Figure 5

9.2. Horden Colliery

Another case study has been carried out at Horden Colliery where conditions are similar to those at the Blackhall Colliery. The formation of the workings in the 5 different seams are shown in Figure 6-10, where an area between selected co-ordinates has been chosen for the case study. In this area five different seams have been worked over the years. These are in order of increasing depth: High Main (E), Main (F), Yard (G), Low Main (J) and Hutton (L). Of these, the Low Main (Figure 9) and Hutton (Figure 10) were worked between 1947 and 1950 and between 1947 and 1953 respectively, by the room and pillar method and eventually the area was totally extracted. There was no water incidence during this period. The High Main (Figure 6) seam was worked between 1968 and 1970 by the longwall method. During the extraction, heavy water incidence was encountered. In order to protect working faces, several dewatering boreholes were drilled under the supervision of H. Saul(14) who believed the main disturbance was from water coming from bed-separation voids filled with water. After drainage of water, working conditions became normal.

Table 3- Blackhall colliery low main (J) seam comparison of estimated tensile strains at base of permian

Face	Face Length (ml	Seam Thickness (cm)	Cover to BOP* (m)	Estimated Tensile Strain (mm)	Condition of the face Wet (W) Dry (D)	Remarks
J 25	200	152	105	8 3	W	
J 26	200/120	145	104	8 1/7 1	W	
J 27	120	145	98	7 7	W	
J 23	200	142	110	7*	W	
J 24	200	140	110	7 3	W	
J 66	64	156	87	6 8	O	
J 31	202	142	122	6 7	W	
J 11	165	132	113	6 6	D	
J 32	200	142	122	6 6	W	
J 13	145	137	113	6 5	D	
J 22	200	122	110	6 3	W	
J 20	156	122	110	6 1	W	
J 121	64	161	98	6j0	D	
J 21	156	122	113	5 9	W	
J 120	64	159	96	5 9	W	
J 67	64	146	92	5 9	D	
J 55	64	154	98	5 7	D	
J 54	64	147	97	5 6	W	
J 56	64	154	100	5 6	D	Current Face
J 12	110	137	116	5 5	D	
J 53	60	156	101	5 4	W	
J 65	64	148	98	5 1	W	
J 15	195	137	134	5 0	W	
J 64	58	148	98	4 7	D	
J 50	56	157	107	4 2	D	
J 34	75/65	157	125	4 2/3 7	D	
J 51	64	157	107	4.0	W	
J 52	64	127	107	4.0	D	
J 63	55	127	101	3 8	W	
J 60	56	127	101	3 8	D	
J 62	55	127	101	3 8	W	
J 93	62	122	107	3 5	D	
J .61	55	122	101	3 S	D	
J 33	65	152	125	3 5	O	
J 17	64	150	125	3 5	D	
J 40	64	174	158/122	3 3/2 9	D	
J 3«	64	168	134	3 2	D	
J 37	64	162	130	3J0	D	
J 39	64	180	146	3 0	D	
J36	60/50	162	131	2 7/1 9	O	
J 35	54/45	162	130	2 5/1 4	W	
J 16	50	137	122	24)	D	

• BOP Bctt of the Permim

Figure 6

Figure 7

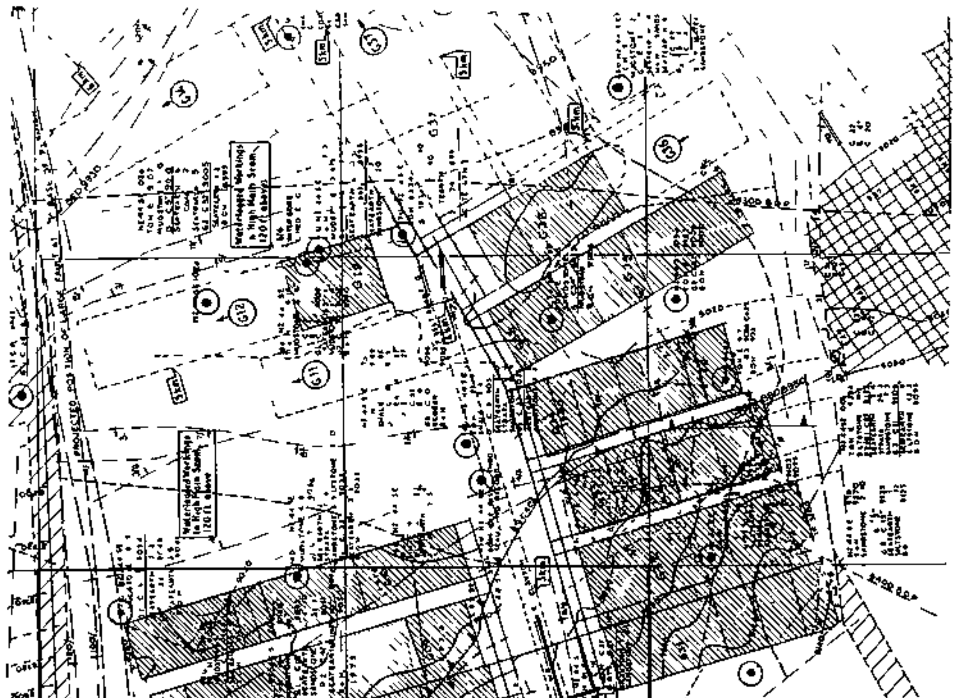

Figure 8

Figure 9

Between 1972-1976 the Yard Seam (Figure 8) and 1976-1980 the Main Seam (Figure 7) were extracted by the longwall method without causing a water problem. From the Horden colliery water occurrences, it can be concluded that the Low Main and Hutton Seams were both comparatively dry because there was thick cover to the base of the Permian.

On the other hand, the High Main was worked very close to the Permian. Water occurrences were periodic and large in quantity. It is presumed that this type of flow is associated with significant bed separation in the overlying strata.

The Yard Seam and the Main Seam were worked after the High Main, so the strata above these two seams were already disturbed, broken and loosened. As a result there would not be large bed separation. The reduced water quantity in these two seams indicated that water inflow was as a percolation. It did not occur as a sudden flush.

10. CONCLUSIONS

1) Mining under the sea or under water bearing strata can often be practiced without incurring major problems.

2) In order to formulate rational designs for undersea workings some experimental work, mainly in the mine, will be needed to obtain information about the parameters which may effect working conditions.

Major factors will include information about aquifers such as their permeability, general rate of dip and source of recharge, since these will affect the potential quantity and rate of flow of water from the aquifer into the mine workings. Obviously faults and dykes may have a significant influence on water problems. The mining operations will affect the superincumbent beds creating fractures which can establish direct connection to aquifers and become water channels. Also the creation and closure of bed-separation openings is believed to be an important component of the overall mechanism of water inflow.

The interrelationship between geological factors, geometry and the mechanical behaviour of the strata is crucial and is much more important than any individual factor.

3) Thus, in each coalfield the local conditions should be considered and appropriate design guidelines devised.

4) In the Durham coalfield it appears that considering the strain at the base of the Permian which is the nearest major aquifer above the coal seams, if the tensile strain is less than 4 mm/m most of the faces are dry, whereas if the strain exceeds 6 mm/m most of the faces are wet. The strain on the seabed is necessarily less than that at the B.O.P. and would thus be less than the P.I. seabed limit of 10 mm/m. Consequently, even for undersea workings it is essential to consider the strain induced at the base of the nearest major aquifer rather than at the seabed. In Durnam the B.O.P. was more significant than aquifers within the coal measures.

5) For multiple seam extraction under a major aquifer it is suggested that the first extraction should be in the bottom seam as this may reduce bed separation over subsequent extraction areas.

6) The inflow of water into mine workings is very complex and in many specific areas there is today a dearth of accurate information; hypotheses are based on conjecture rather than real data. Therefore, to make significant advances much more research is necessary. This will probably be expensive and time consumting.

7) From a practical viewpoint the adoption of highly mechanised partial extraction with effective pillar design would appear to offer the best available solution. Generally this prevents the inflow of water and increase the total amount of reserves which can be extracted.

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