Coal Pillar Design for Longwalls under the Ocean

D.J. Forrester, D.A. Payne and J. Kochhar

MRL 93-028(OP,J) March 1993

presentation at 33rd US Symposium on Rock Mechanics, Sante Fe, New Mexico, U.S.A. and publication in the Proceedings of the Workshop on Coal Pillar Mechanics, June 1992.

Coal Pillar Design for Longwalls under the Ocean

by

D.J. Forrester[1], D.A. Payne[2] and J. Kochhar[3]

Abstract

Coal pillar design in longwall mining must balance the need to ensure roadway stability with economic extraction of reserves. In particular, the design must accommodate the effects of stress redistribution providing stability not only during roadway formation but also by the extraction of longwall panels.

There are four types of pillars usually involved, as illustrated in Figure 1, namely:

- Pillars between main access roadways;
- Pillars between access roadways and a longwall panel (start/stop pillars);
- Pillars between adjacent longwalls (rib pillars);
- Boundary pillars between adjacent mines.

This paper outlines the approach of the Cape Breton Development Corp. (CBDC), Nova Scotia, Canada, to meeting the challenges of designing pillars in modern longwall coal mining under the North Atlantic Ocean.

In addition to complying with regulatory requirements, other influences must be considered, such as:

- Protection from interaction effect of working other seams;
- Protection of the seabed by maintaining strata mass integrity.

After discussing the mainly empirical, current practices in pillar design, two longer-term strategies are discussed: (1) pillar reduction (smaller sizes), where appropriate, and (2) elimination of rib pillars completely, where possible. A key feature in developing these strategies is an innovative research and development program run jointly by CBDC and CANMET's Cape Breton Coal Research Laboratory (CBCRL). Several projects are summarized involving development of appropriate geotechnical monitoring and numerical modeling procedures.

---

[1]Group Leader and [2]Strata Mehanics Engineer, Cape Breton Coal Research Laboratory, MRL, CANMET, Energy, Mines and Resources, Sydney, Nova Scotia. [3]Chief Planning Engineer, Cape Breton Development Corp., Sydney, Nova Scotia.

Keywords
Strata Control, Coal Mining, Pillar Design, Submarine Mining

Conception de piliers pour l'extraction du charbon par longues tailles en milieu sous-marin

par

D.J. Forrester[1], D.A. Payne[2] et J. Kochhar[3]

Résumé

Dans le domaine de l'extraction du charbon par longues tailles, la conception des piliers doit assurer à la fois la stabilité des galeries et l'extraction rentable des réserves. Elle doit notamment permettre aux piliers de résister aux effets de la redistribution des contraintes, et ainsi d'être stables non seulement pendant le creusement des galeries, mais aussi pendant l'extraction des panneaux de longue taille.

Il existe quatre types courants de piliers, comme le montre la figure 1 :

- les piliers situés entre les principales galeries;
- les piliers situés entre des galeries et un panneau de longue taille (piliers frontaux);
- les piliers situés entre des longues tailles adjacentes (piliers de séparation);
- les piliers situés entre des propriétés minières adjacentes (piliers limites).

Le présent document décrit l'approche qu'utilise la Société de développement du Cap-Breton (SDCB) de la Nouvelle-Écosse (Canada), pour surmonter les difficultés qu'elle rencontre lorsqu'elle doit concevoir des piliers sous l'Atlantique Nord, à l'aide des technologies modernes d'extraction du charbon par longues tailles.

En plus de se conformer aux exigences réglementaires, les sociétés d'exploitation minière doivent tenir compte d'autres facteurs tels :

- la protection contre l'interaction de travaux en cours dans d'autres filons-couches;
- la protection du lit marin par le maintien de l'intégrité des strates.

Après avoir présenté les pratiques courantes de conception des piliers, qui sont essentiellement empiriques, les auteurs traitent de deux stratégies à plus long terme : 1) la réduction des dimensions des piliers, lorsque cela est utile, et 2) l'élimination complète des piliers de séparation, lorsque c'est possible. Un programme innovateur de recherche-développement exécuté conjointement par la SDCB et le Laboratoire de recherche sur le charbon du Cap-Breton, de CANMET, joue un rôle clé dans la mise en oeuvre de ces deux stratégies. Plusieurs projets, décrits dans des résumés, portent sur la mise au point des procédures appropriées de surveillance géotechnique et de modélisation numérique.

---

1. Chef d'équipe et 2. Ingénieur de la mécanique des strates, Laboratoire de recherche sur le charbon du Cap-Breton, LRM, CANMET, Énergie, Mines et Ressources Canada, Sydney (Nouvelle-Écosse).
3. Ingénieur en chef de la planification, Société de développement du Cap-Breton, Sydney (Nouvelle-Écosse).

Mots-clés
Contrôle des strates, extraction du charbon, conception de piliers, exploitation minière sous-marine.

Contents

Tables

Figures

COAL PILLAR DESIGN FOR LONGWALLS UNDER THE OCEAN

By D. J. Forrester,[1] D. A. Payne,[2] and J. Kochhar[3]

INTRODUCTION

Coal pillar design in longwall mining must balance the need to ensure roadway stability with economic extraction of reserves. In particular, the design must accommodate the effects of stress redistribution providing stability not only during roadway formation but also by the extraction of longwall panels.

There are four types of pillars usually involved, as illustrated in figure 1, namely:

- Pillars between main access roadways;
- Pillars between access roadways and a longwall panel (start/stop pillars);
- Pillars between adjacent longwalls (rib pillars);
- Boundary pillars between adjacent mines.

This paper outlines the approach of the Cape Breton Development Corp. (CBDC), Nova Scotia, Canada, to meeting the challenges of designing pillars in modern longwall coal mining under the North Atlantic Ocean.

In addition to complying with regulatory requirements, other influences must be considered, such as:

- Protection from interaction effect of working other seams;
- Protection of the seabed by maintaining strata mass integrity.

After discussing the mainly empirical, current practices in pillar design, two longer-term strategies are discussed: (1) pillar reduction (smaller sizes), where appropriate, and (2) elimination of rib pillars completely, where possible. A key feature in developing these strategies is an innovative research and development program run jointly by CBDC and CANMET's Cape Breton Coal Research Laboratory (CBCRL). Several projects are summarized involving development of appropriate geotechnical monitoring and numerical modeling procedures.

BACKGROUND

The remaining economical reserves within the Sydney Coalfield mainly lie far from shore under the North Atlantic Ocean. Historically, as reserves under land were exhausted, workings extended out under the ocean. CBDC currently operates three underground coal mines using state-of-the-art longwall methods and producing approximately 3.5 million metric tons per annum salable coal. Colliery surface facilities are located on seam outcrops not far from the cliffs above the seashore. Main access roadways follow the seams, sloping down under the ocean at gradients up to 30%. Longwalling usually commences when solid cover exceeds 500 ft.

The Phalen Colliery is located in the Phalen Seam approximately 450 ft directly below Lingan Colliery in the Harbour Seam forming the second seam workings (fig. 2), whereas Prince is a first-seam working. Prince Colliery is located in the Hub Seam about 20 miles to the west. Current production features are listed in table 1.

Table 1.—Current production features

	Height, in	Panel width, ft	Panel length, ft	Metric tons/ Shift R.O.M.
Lingan Colliery:				
12E advancing wall . .	70	718	9,350	800
Prince Colliery:				
10W retreating wall . .	92	470	8,225	2,500
Phalen Colliery:				
4E retreating wall . . .	100	705	7,314	3,500

[1]Group leader.

[2]Strata mechanics engineer.

Cape Breton Coal Research Laboratory; Canada Centre for Mineral and Energy Technology (CANMET); Energy, Mines and Resources; Sydney, Nova Scotia, Canada.

[3]Chief planning engineer. Cape Breton Development Corp., Sydney, Nova Scotia, Canada.

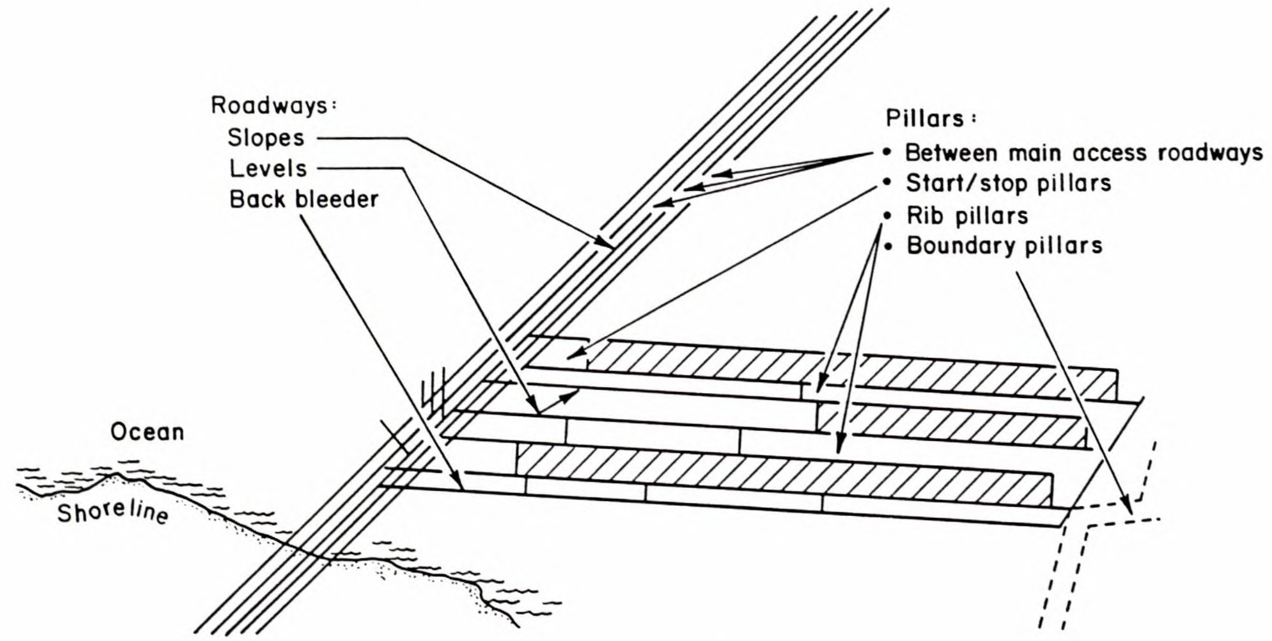

Figure 1.–Schematic mine plan: definition of types of pillars and roadways.

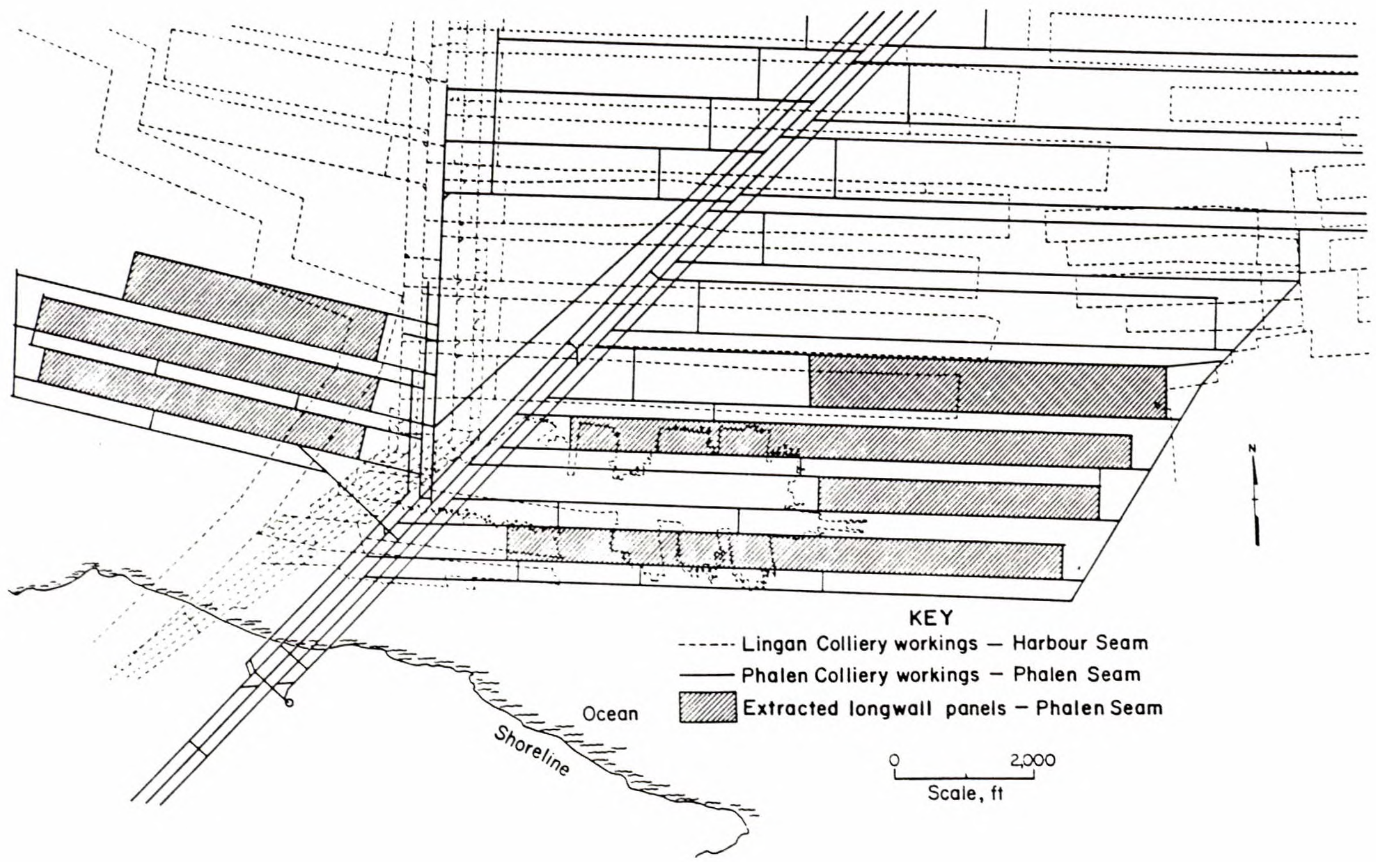

Figure 2.–Lingan and Phalen Collieries–superimposed mine plan.

For reference, the current production record is held by 4E wall at 5,618 mt in one 8-h shift.

CBDC has traditionally followed European mining practices adopting single-entry longwall methods usually supported by steel arch or rectangular supports. Seabed protection requirements have until now dictated a panel and pillar layout for modern heavy-duty mechanized longwalls. Relentless commercial pressures have led CBDC to adopt state-of-the-art technologies whenever possible, such as an electric shearer, 2/550-mt supports, etc. The best of ongoing technical developments have been examined, such as roof bolting, use of continuous miners, single-roadway shortwalls, yield pillars, etc. The first two of these have recently been introduced at Phalen Colliery. Such continual improvements are enabling CBDC to successfully compete in the international market.

PILLAR DESIGN

Historically, a variety of mining methods have been adopted in the Sydney Coalfield. These have included room-and-pillar, depillaring, advance and retreat longwalls (early mechanized), and pillarless shortwall panels. Significant experience with pillar design was developed over the last century, through extensive workings in up to four successive seams. During the 1960's and 1970's, however, as modern fully mechanized longwalls evolved utilizing shearer, panline, and powered support technologies, production rates increased enormously. This in turn led to associated ground movements of a larger and more rapid nature. Pillar design reflected this, and all mechanized longwalls since the mid-1970's in the Sydney Coalfield have been in panel/pillar layouts.

Reviews of design methods were also made by CBDC in the mid-1970's, and proven empirical methodologies developed elsewhere were evaluated against Sydney Coalfield experience. These resulted in two empirical design methods that are still used for coal pillar design in the coalfield:

- A pillar load formula;
- A maximum cumulative tensile strain on the seabed.

These are applied within the regulatory requirements, which stipulate minimum pillar sizes and cover depths for CBDC workings under the ocean. Section 55 of the Coal Mines (CBDC) Occupational Safety and Health Regulations (1990)(*1*)[4] requires that no coal mine shall be worked below the sea bottom or below a body of water or material that may flow, except under the following conditions:

1. A solid barrier of unworked mineral of 50 m (164 ft) or more shall be left between the workings of a submarine lease and another submarine lease.
2. Subject to paragraph (c), where coal seam or stratified deposit is worked, there shall be a cover of 55 m (180 ft) or more of solid measure.
3. Where a passageway is driven, there shall be a cover of 30 m (98 ft) or more of solid measure.

[4]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

PILLAR DESIGN FORMULA

The pillar design formula developed is based on ratio of extraction by area and back calculation of a maximum pillar load required to maintain stability:

$$L = \frac{s \cdot D}{1 - r} = 7{,}500 \text{ psi}$$

where, L = pillar load, psi,

s = cover loading of 1 psi per ft of solid cover,

D = depth of cover, ft,

r = ratio of extraction by area = (w/w + p),

w = panel width, ft,

and p = pillar width, ft.

This has served well since 1977, providing for roadway stability from workings in the same seam. Occasionally, however, for example at Lingan, where pillar widths have at times been less than recommended (e.g., reduced from 0.11 × depth to 0.08 × depth), roadway deformation and floor heave have increased noticeably. The original Phalen Mine design was based on Wilson's revised analytical method also giving similar sizes (*2*). Typical pillar parameters adopted in CBDC's three submarine mines are shown in table 2.

Table 2.—Typical pillar parameters

	Lingan 11E/12E, ft	Prince 9W/10W, ft	Phalen 3E/4E, ft
Water depth	130	105	75
Depth of solid cover	2,050	600	1,360
Pillar Widths:			
Main access roadways	230	70	140
Stop/Start pillars	300	300	300
Rib pillars	250	200	230
Boundary pillars	>300	—	>300

SEABED PROTECTION

The United Kingdom approach to seabed protection based on a maximum tensile strain on the seabed was evaluated against key CBDC subsea workings in the mid-1970's. A figure of 8.5 mm/m was found to be more appropriate than the United Kingdom limit of 10 mm/m. This procedure ensures strata mass integrity and the necessity of preventing ingress of seawater into the workings.

The maximum tensile strain calculations are made by using a modified National Coal Board Subsidence Engineers Handbook (*3*) approach. The formula, for strain calculations, states:

$$E_{max} = \frac{kS_{max}}{D} = \frac{k\,a\,t}{D} \leq 8.5\ \text{mm/m (total cumulative)}$$

where E_{max} = maximum tensile strain,

k = a numerical constant, taken to be 0.75,

S_{max} = maximum subsidence caused by extraction of a critical or supercritical area in a given coal seam,

D = depth of cover between the workings and seabed,

a = subsidence factor, taken to be 0.65,

and t = thickness of total extraction.

It is critical to note that 8.5 mm/m is the maximum, whether from a single longwall, adjacent walls in the same seam, or in overlying seams. The individual subsidence and strain profiles must therefore be combined (fig. 3).

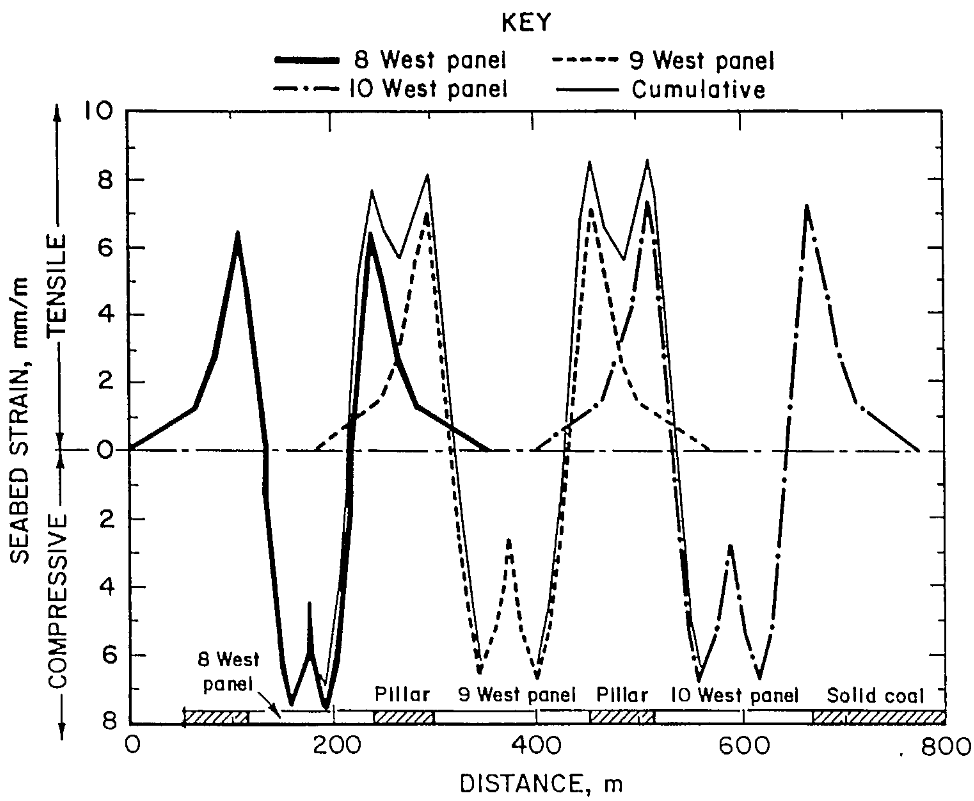

Figure 3.—Predicted seabed strains—panel and pillar layout.

PILLAR REDUCTION

While pillars are necessary, they do effectively sterilize coal reserves. The need to strive for optimum pillar size to maintain stability while minimizing sterilization continually drives coal operators to refine and improve pillar sizing methods. Two ways in which CBDC and CBCRL are doing this are outlined below.

MAIN SLOPE PROTECTION IN UPPER SEAM, FROM LOWER SEAM: STOP/START PILLARS

The Phalen west and center panels were designed with stop/start pillars large enough to prevent any disturbance in the overlying Lingan main slopes. However, the design criteria were largely based on appropriate European methodologies (predominantly surface subsidence-related, e.g., "angle of draw") owing to a lack of field data defining interseam interaction effects in the Sydney Coalfield.

To verify the design criteria, CBCRL monitored the Lingan slopes above first Phalen longwall, 1W, with no discernable interaction movements observed. Later, CBDC surveyed Lingan A above the third wall 2E stopline, with very little discernable movement observed. Thus, the original design intent was verified. However, this begged the question: How conservative is this design (i.e., how much coal is being unduly sterilized)?

To address this, CBCRL utilized horizontal borehole inclinometer and piezometer instrumentation techniques. A horizontal borehole was drilled in 1990 from Lingan 1 Slope over the underlying 2W stopline and its deformation monitored (*4*)(fig. 4).

While time-related movement is still occurring, the indication to date is that discernable strata movement ceases some 30 m away from the Lingan slopes (fig. 5). This represents apparent sterilization of coal worth several hundred thousand dollars. On this basis, the equivalent pillar on the next panel, Phalen 3W, was reduced by 20 m. A second instrumented horizontal borehole is being used now to verify that no movement will occur there in the Lingan slopes.

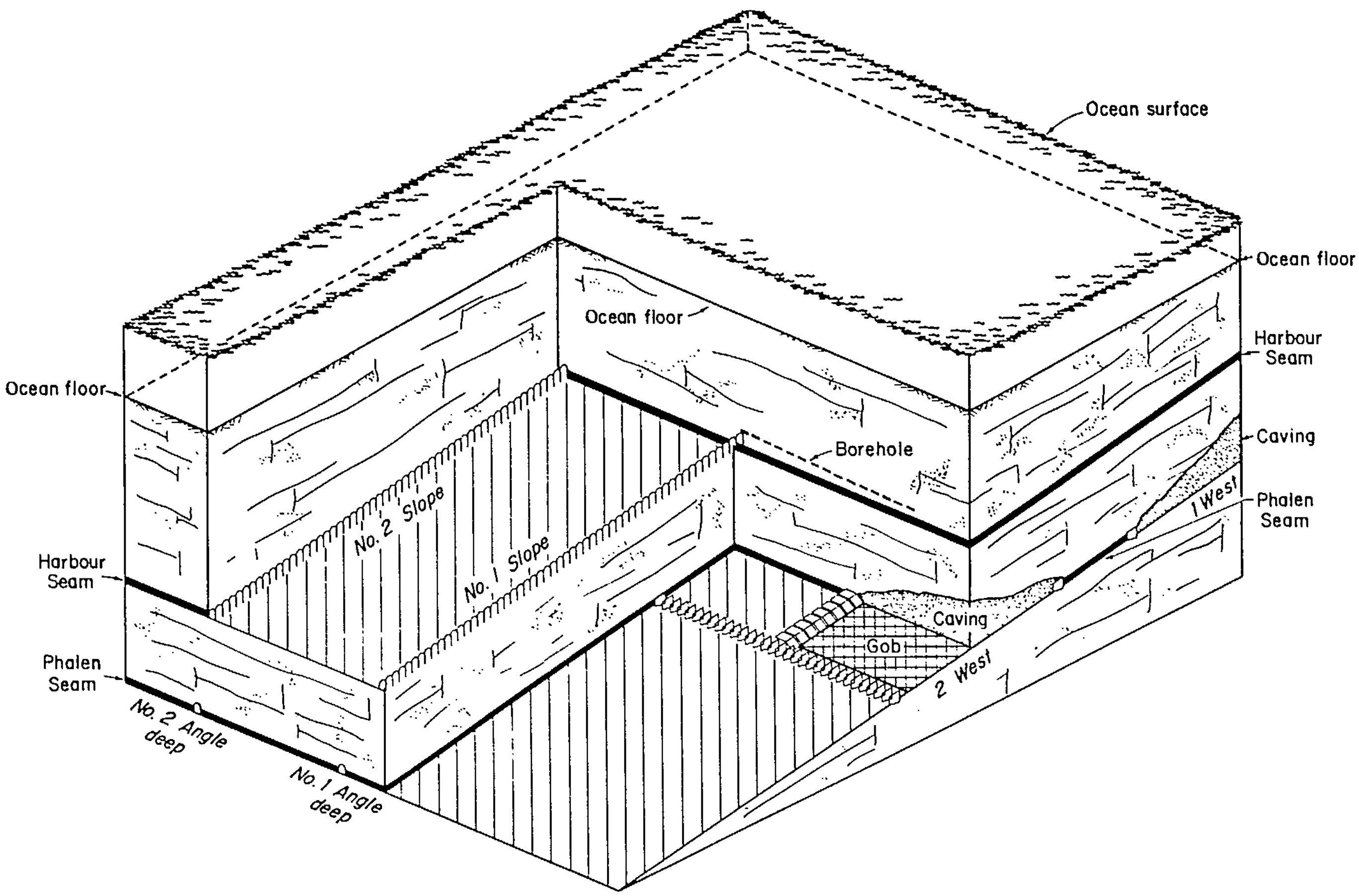

Figure 4.—Phalen 2W stopline: three-dimensional schematic of borehole.

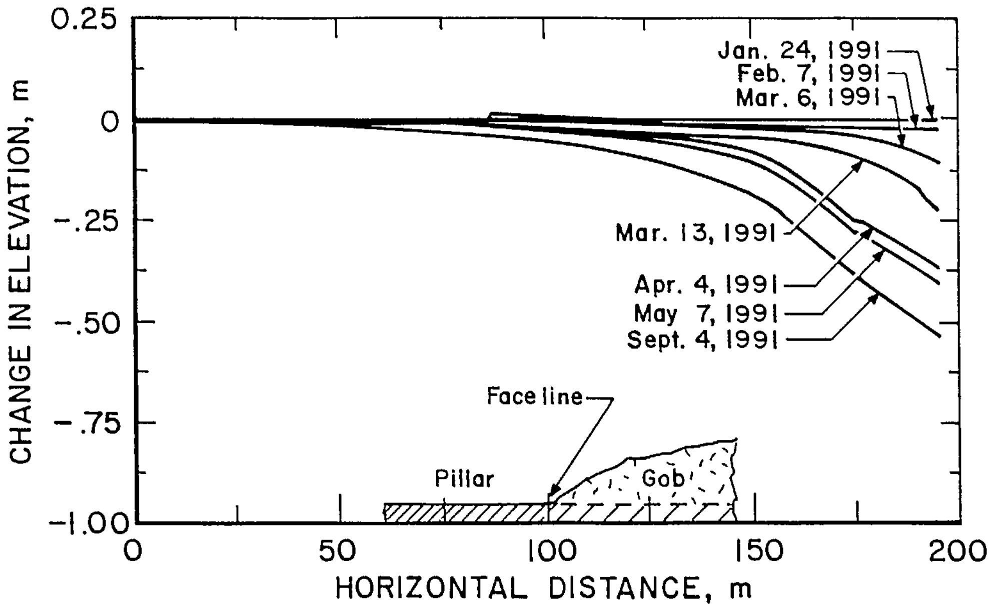

Figure 5.—Phalen 2W stopline: adjusted subsidence profiles.

SEABED PROTECTION: RIB PILLARS

While the pillar design approach outlined above accords sufficient support to the seabed, it is based on conservative interpretation of European-based empirical methodologies. Very few subsidence measurements are available over depillared workings under land in the coalfield. Thus, design verification is not possible without additional field data. The horizontal borehole program mentioned above will yield some data, but much more data are required.

CBCRL and CBDC started a long-term joint research project in 1983-84 to attempt to provide such data. This was to be accomplished by measuring seafloor subsidence directly, then producing a calibrated subsidence prediction model for more accurate seabed strain predictions.

This project is now nearing completion. Field work was done in 1987-89 (*5*), subsidence profile interpretation in 1990 (*6*) yielded six discernable seafloor subsidence profiles, and mining analysis is currently underway. The final stage will be to produce a calibrated prediction model, hopefully in late 1992. However, the data base is still severely limited, and efforts are continuing to expand it. Pillar sizes will subsequently be optimized for seabed protection.

PILLAR ELIMINATION

Prior to the introduction of modern longwall equipment, CBDC successfully deployed pillarless mining, whereby no rib pillars were left between panels (fig. 6). However, since the early 1960's, panel/pillar layouts have been adopted. These pillars not only sterilize reserves, but in retreat mining involve two costly single-entry drivages. There are great benefits potentially, in terms of resource recovery and economics of reduced development drivage, to be gained from trying to combine the old pillarless methods with current heavy-duty retreat methods. A recent review of European experience in applying pillarless mining to modern heavy-duty retreat workings revealed mixed results (*7*). Strata control aspects were found to be critical. If primary support and/or supplemental support is inadequate, then optimal support of the ground is lost. Subsequent floor heave can make mining the second panel very difficult due to crush of the common gate road (tailgate of second panel, fig. 7).

CBDC has therefore based its design approach for current effects on the successful designs in Europe. This incorporates heavy-duty primary roadway support, reinforcement of roadway support with additional roof bolts, center propping in the front abutment zone of the second wall, and packwalls behind the first wall to support the common gate during its second use.

A key factor in achieving success will be monitoring the first applications and feeding back findings to optimize both roadway and packwall designs. CBCRL will be closely involved in this work, designing and installing geotechnical monitoring for both roadway and packwall support performance throughout.

CBCRL has also been actively involved in researching the use of anhydrite packwalls to replace wood. Monitoring of initial trials, laboratory-scale testing, and a joint numerical modeling exercise with the U.S. Bureau of Mines (*8*) are currently underway. The modeling exercise is pursuing a threefold stepwise approach using the MULSIM boundary element, ADINA finite element, and USBMDE discrete element models. As mining trials unfold, field data are obtained to set up and later to refine modeling results. While such research and development is often long-term, CBDC is proceeding, with initial trials of pillarless retreat at Lingan with 13E wall scheduled to start in May 1992. Experience gained here will be fed back into the main trials with Phalen center panels scheduled for late 1992.

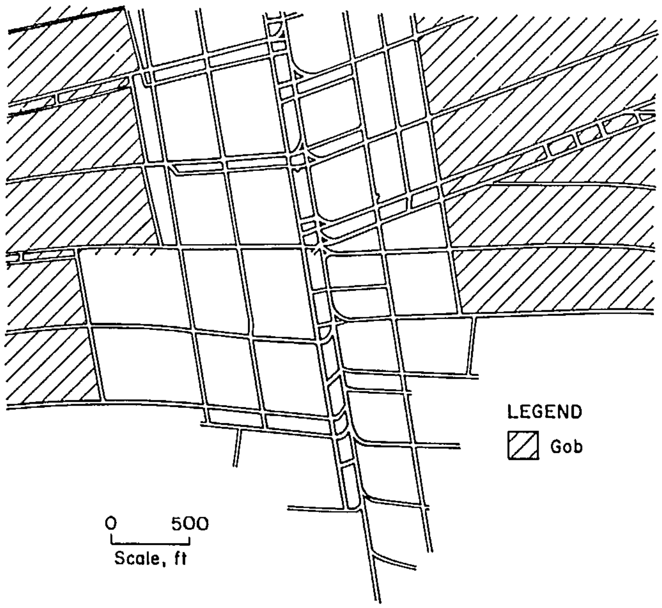

Figure 6.—Pillarless layout: No. 12 Colliery.

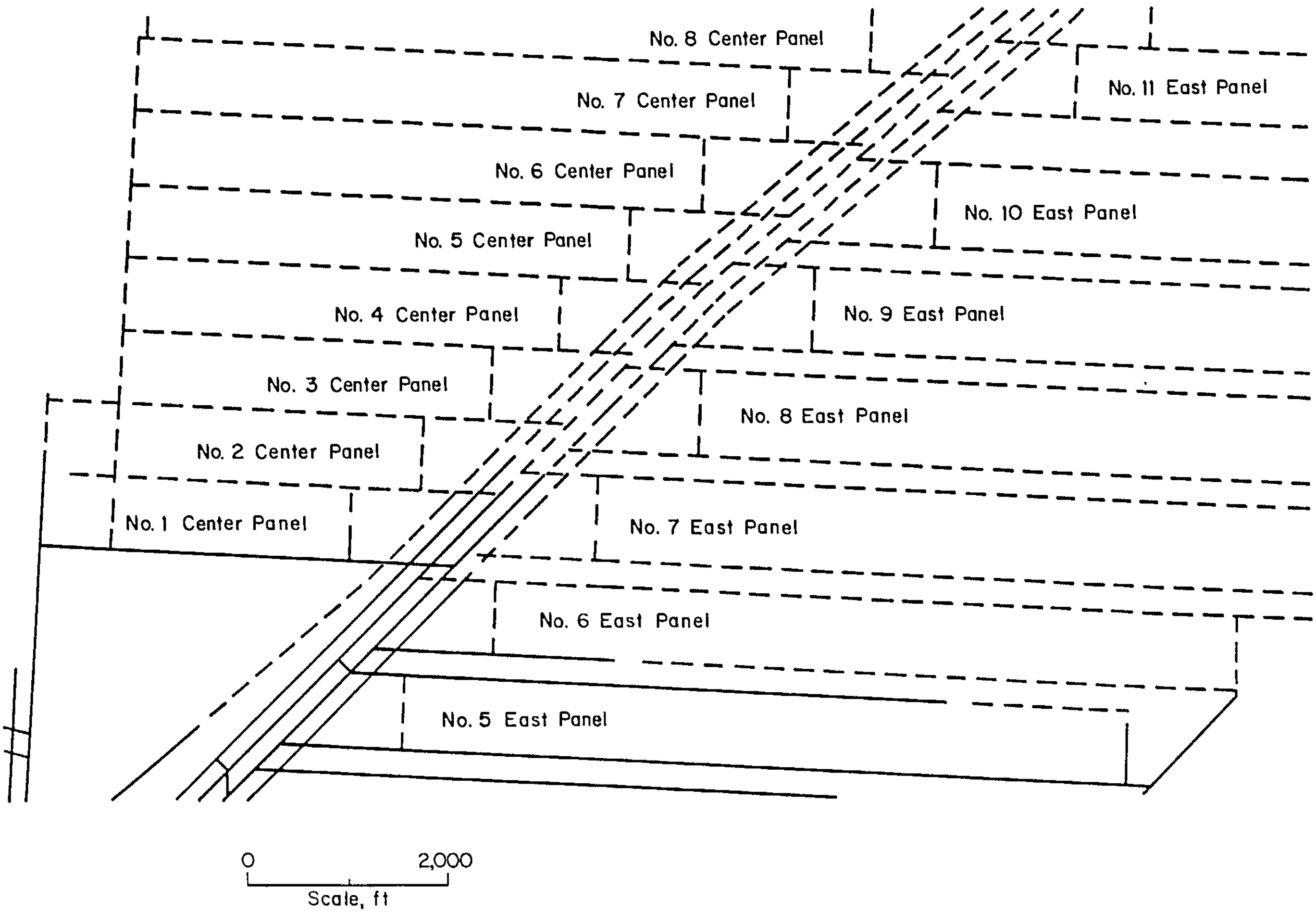

Figure 7.—Phalen center panels—pillarless layout.

CONCLUSIONS

Coal pillars in modern longwall mining under the ocean are essential but costly in terms of sterilized coal and additional development drivage. Traditional empirically based and pragmatic design approaches have largely provided sufficient and stable support. Relentless commercial pressures, however, are dictating that the successful operators are the most innovative ones. CBDC is not only using state-of-the-art technologies to improve longwall production and development performance, but is also devising long-term strategies to safely reduce and even eliminate some coal pillars whenever appropriate. Novel and innovative research and development projects have been carried out jointly by CBDC and CANMET to direct the development and implementation of these strategies. The critical trials needed to demonstrate the success of modern pillarless retreat mining will require intense and comprehensive monitoring. These needs will again be met by joint research and development activities. These modifications to traditional pillar design methods will significantly contribute to CBDC's continuing efforts to compete safely and successfully in the international coal industry.

REFERENCES

1. Coal Mines (CBDC) Occupational Safety and Health Regulations (1990).

2. Wilson, A. H. The Stability of Underground Workings in the Soft Rocks of the Coal Measures. International Journal of Mining Engineering, 1983, 1, 91-187.

3. National Coal Board Subsidence Engineers Handbook (1975).

4. Forrester, D. J., W. D. Gallant, and D. A. Payne. Determination of the Stopline Subsidence Profile of Phalen 2 West Panel From Within a Near Horizontal Borehole Over the Panel Stopline. Divisional Report CRL 91-39 (OP,J), 10th International Conference on Ground Control in Mining, June 10-12, 1991.

5. Aston, T. R. C., W. D. Gallant, A. Lapierre, and J. M. Stewart. Pre-Mining Seafloor Topography Determination Over the Phalen Mine Workings, Sydney Coalfield, Nova Scotia. Divisional Report CRL 89-1 (OP,J), Mining Science and Technology Journal.

6. Seabed Subsidence Profiles Over the Phalen Colliery Derived From Analysis of Seafloor Topography Data. McGregor Geoscience Ltd., CANMET/DSS Contract Report 33SQ.23440-0-9172, Mar. 1991.

7. Haslett, G. A. Longwall Retreat Mining - Its Practice With the Re-use of Single Gate Roads as Dual Life Gate Roads: Salvation or Suicide? Divisional Report CRL 91-47(CF), Sept. 1991.

8. 'Kripakov, N. Interim Report on Joint CBDC/USBM Numerical Modeling of Pillarless Mining. U.S. Bureau of Mines, Denver Research Center. In preparation, Feb. 1992.