Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines

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3 Tiered Explosion Pressure Design Criteria

• Monitored seals with limited volume explosive methane-air mix – 345 kPa (50 ksi) pulse

• Unmonitored seals without possible detonation – 830 kPa (120 psi) pulse

• Unmonitored seals with possible detonation – 4.40-0.83 MPa (640-120 psi) pulse
Known explosions in sealed areas from 1993 to 2006

- 1993 – Mary Lee #1 Mine – (2 seals)
- 1994 – Oak Grove #1 Mine – (2 seals)
- 1995 – Gary 50 Mine – (none)
- 1996 – Oak Grove #1 Mine – (6 seals)
- 1996 – Oasis Mine – (3 seals)
- 1996 – Oasis Mine – (more seals)
- 1997 – Oak Grove #1 Mine – (1 seal)
- 2006 – Sago Mine – (10 seals)
- 2006 – Darby Mine
- 2006 – Jones Fork E-3 Mine
# Seal classification and considerations

<table>
<thead>
<tr>
<th></th>
<th>Explosive volume potential</th>
<th>Convergence loading potential</th>
<th>Leakage potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>District</strong></td>
<td>Very large</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Panel</strong></td>
<td>Large</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td><strong>Cross-cut</strong></td>
<td>Small</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
1. Volume filled with explosive atmosphere
   (Completely confined with no venting)

2. Leaking seals with explosive atmosphere behind seals
   (Partially confined with venting into inert atmosphere)

3. Volume filled with explosive atmosphere
   (Partially confined with partial venting into inert gob)

KEY
- Seals
- Explosive atmosphere
- Inert atmosphere
- Gob
Comparison of Gas and Dust Flammability
20-L Chamber data

Theoretical maximum explosion pressure for \( \text{CH}_4 \) - Air

Theoretical maximum explosion pressure range for coal dust - Air

Explosion pressure - MPa

Explosion pressure - psi

CV explosion pressure from methane-air and coal dust-air

Methane gas experimental data (average)
Pittsburgh coal dust experimental data (average)
Explosions in tunnels

deflagration to detonation
Explosion Chemistry and Physics for Ideal Mix of 10% Methane and Air

- **Fact 1** – 908 kPa (132 psi) constant volume (CV) explosion pressure for CH₄ and air
- **Fact 2** – 790 to 890 kPa (115 to 129 psi) CV explosion pressure for coal dust and air
- **Fact 3** – 1.76 MPa (256 psi) Chapman-Jouguet (CJ) detonation wave pressure
- **Fact 4** – 4.50 MPa (653 psi) reflected detonation wave pressure
Stage 2 Models -
Larger explosion volume models

Stage 2
Models
Large
volume,
confined
explosions
Calculated pressure-time history at Seal B for large volume confined explosions

AutoReaGas (top)

FLACS (bottom)
Stage 3 Models -
Leaky seal models

Stage 3 Models partially confined, partially filled, volume behind leaking seal
Peak explosion pressure versus length of explosive cloud behind leaking seal

Peak Explosion Pressure versus Length of Explosive Cloud Behind Seal

- AutoReaGas
- FLACS
- LLEM Experiments
3-tiered explosion pressure design criteria

SCENARIO 1
Unmonitored seals
- No monitoring
- No inertization

Panel and District Seals

A

Panel and District Seals

B

Cross-cut Seals

C

SCENARIO 2
Monitored seals
- Managed atmosphere behind seals
- Inertization as necessary

D

E

F

KEY
- Seals
- Explosive atmosphere
- Inert atmosphere
- Gob
Three Analysis Methods

• Wall Analysis Code – dynamic & arching
• Simple plug analysis - static
• Anderson’s arching analysis - static (check)

• Convergent analyses, similar results
• Sensible comparison to limited LLEM tests
Design chart for 640-120 psi pulse

- **WAC - 24 MPa (3500 psi) 2.40 S.G. (150 pcf) - 28 day regular concrete**
- **WAC - 17 MPa (2500 psi) 1.92 S.G. (120 pcf) - concrete blocks & mortar**
- **WAC - 10 MPa (1500 psi) 2.40 S.G. (150 pcf) - 1 day HES concrete**
- **WAC - 8 MPa (1200 psi) 1.76 S.G. (110 pcf) - 1 day gypsum**
- **Plug - 5 MPa (750 psi) 1.60 S.G. (100 pcf) - 1 day fly ash / cement**
- **Plug - 3.5 MPa (500 psi) 1.60 S.G. (100 pcf) - sprayed gypsum**
- **Plug - 2.8 MPa (400 psi) 0.80 S.G. (50 pcf) - lightweight foam cement**

Seal height - inches

4.4 Mpa (640 psi)
800 kPa (120 psi)
Design chart 3 for 50 psi pulse

Seal height - m
Minimum seal thickness - m

WAC - 24 MPa (3500 psi) 2.40 S.G. (150 pcf) - 28 day regular concrete
WAC - 17 MPa (2500 psi) 1.92 S.G. (120 pcf) - concrete blocks & mortar
WAC - 10 MPa (1500 psi) 2.40 S.G. (150 pcf) - 1 day HES concrete
WAC - 8 MPa (1200 psi) 1.76 S.G. (110 pcf) - 1 day gypsum
WAC - 5 MPa (750 psi) 1.60 S.G. (100 pcf) - 1 day fly ash / cement
WAC - 3.5 MPa (500 psi) 1.60 S.G. (100 pcf) - sprayed gypsum
WAC - 2.8 MPa (400 psi) 0.80 S.G. (50 pcf) - lightweight foam cement
Plug - 1.4 MPa (200 psi) 0.18 S.G. (11 pcf) - lightweight foam cement

345 kPa (50 psi)
Design chart for number of rebar

Minimum number of reinforcement bars to raise design safety factor by 0.5
(assuming 6.1 m (20-ft) wide entry, No. 6 bar, Grade 40 steel)

![Design chart image]
Recommended procedure for seal design
(outline for new seal rules)

1. Information gathering by licensed, professional engineer

2. Seal engineering by licensed, professional engineer

3. Seal construction monitoring by licensed, professional engineer

4. Regular, post-sealing inspection
3 Tiered Explosion Pressure Design Criteria

- Monitored seals with limited volume CH4-air mix – 345 kPa (50 ksi) pulse
  - Monitoring assures < 5 m explosive mix at seals
  - Explosive volume < 40% of sealed volume
  - Detonation unlikely

- Unmonitored seals without possible detonation – 830 kPa (120 psi) pulse
  - Sealed volume < 50 m (165 ft) long
  - Run-up length < 50 m (165 ft)
  - Detonation less likely

- Unmonitored seals with possible detonation – 4.40 MPa (640 psi) pulse
  - Sealed volume > 50 m (165 ft) long
  - Run-up length > 50 m (165 ft)
  - Detonation possible
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Review comments welcome