DESIGN & DEVELOPMENT OF STEEL SETS AS STANDING SUPPORT FOR UNDERGROUND OPENINGS

For
Virginia Coal & Energy Alliance Annual PE Mining Seminar
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Today’s Speakers

- Dr. Kevin J. Ma, PE - Senior Ground Control Engineer, KMS
- Jacob Hunter - Project Engineer, Jennmar VAS
Outline

- Introduction
- Jennmar Steel Set Design Methodology
  - Geological evaluation
  - Loading condition determination
  - AISC-based steel structural design
  - Design optimization
  - Adequacy verification
- Case 1: steel set design for inclined slope
- Case 2: impact resistant steel set for roof fall rehab
- Case 3: steel canopy for highwall portal
- Case 4: tunnel rings
- Jennmar Virginia Specialty (VAS)
Introduction
About Us


We’re JENNMAR, a global, family-owned company that is leading the way in ground control technology for the mining and tunneling industries. Since 1972 our mission has been focused on developing and manufacturing quality ground control products. Today we make a broad range of reliable products, from bolts and beams, to channels and trusses, to resin and rebar. We’re proud to make products that make the industries we serve safer and more efficient.

JENNMAR continues to grow, but our focus will always be on the customer. We feel it is essential to develop a close working relationship with every customer so we can understand their unique challenges and ensure superior customer service.

Our commitment to the customer is guided by three words; SAFETY, SERVICE and INNOVATION. It’s these words that form the foundation of our business. It’s who we are.
JENNMAR United States Facilities

1. JENNMAR Corporate HQ - Pittsburgh, PA
2. JENNMAR Pennsylvania
3. J-LOK Resin - Pennsylvania
4. JENNMAR West Virginia
5. JENNMAR Kentucky - Winchester
6. JENNMAR Kentucky - West
7. J-LOK Resin - Kentucky
8. JENNMAR Virginia – Pounding Mill
9. JENNMAR Virginia - East
10. JENNMAR SanShell - Bits
11. TungsteMet - Carbide

12. JENNMAR Specialty Products (VAS)
13. JM Steel - South Carolina
14. Keystone Mining Services
15. JENNMAR McSweeney - Drill steel
16. JENNChem Mid-West
17. Elite Storage Solutions
18. JENNChem - Grand Junction
19. JENNMAR Utah - Clearfield
20. JENNMAR Utah – West Jordan

JENNMAR-DSI Joint Ventures

21. ROCBOLT Technologies, South Africa
22. ROCBOLT Resins, Australia
23. ROCBOLT Technologies, China - Jining City
KMS - Keystone Mining Services

Founded in 1997, KMS (Keystone Mining Services, LLC) is a wholly owned affiliate of JENNMAR Corporation providing ground control engineering services to JENNMAR customers as well as conducting research and development of new JENNMAR products.

KMS Leadership

Dr. John Stankus
President

Dr. Hanjie Chen
VP, Engineering

Our experienced KMS staff of mining engineers, geoscientists, and research & development engineers can provide analyses to develop ground support systems for the most challenging conditions. KMS uses the Roof Instability Rating (RIR) system, along with the latest in proprietary finite element modeling, to provide precise and accurate analysis, prediction, and site specific ground control design. Additional services include product development & testing, field services, data collection, and expert recommendations.
Ground Control Engineering Services include:

- Primary and Secondary Support Analysis and Design
- Underground Inspection
- Finite Element Analysis
- Roof Instability Rating (RIR)
- Multiple-Panel Orientation and Mining Sequence Analysis Pillar Stability Analysis and Design
- SGS® System for Slope Stability Analysis
- Subsidence/Multiple Seam Interaction Analysis
- Longwall Set-up and Recovery Entry Design
- Tunneling Design and Support
- Highwall/Slope Stability
- Structural Analysis for Steel Set Design
- Mine Seal Design
Typical Applications of Steel Sets as Standing Support

- Permanent support in inclined slopes
- Supplemental support in U/G entries
- Roof fall rehabilitation
- Overcast
- Rehabilitation of aged main entries
- Highwall portal canopy
- Railway tunnel
- Highwall tunnel
- Civil shaft ring
- Civil tunnel ring
- Others.
Problem Statement

- Steel sets traditionally utilized as standing support in last several decades. Mostly trial-and-error, experienced-based, either over-designed or under designed.
- No well-accepted steel set design methodology exists.
- Jennmar started to provide cost-effective steel set since 2006.
- KMS and VAS have designed and fabricated various customized steel sets for U/G mining and/or civil tunneling industry in last 10 years.
- A practical steel set design methodology was developed.
- Steel set products derived were installed in various U/G mines and civil tunnels in North America, and have received positive comments from industry and agencies.
Jennmar Steel Set Design Methodology
Major Steps

- Geological condition evaluation.
- Loading condition determination.
- AISC-based steel structural design.
- Design optimization.
- Connection design.
- Adequacy verification.
Geological Condition Evaluation

- **If U/G:**
  - **If inclined slope:**
    - Surface topo, coal seam contour, structural map, mine layout map, etc.
    - Slope grade, opening shape (rectangular or arch), opening configuration (over-under or side by side).
    - Borehole data (log, description, e-log, etc), rock mechanics data.
  - **If U/G entries:**
    - Field visit, stratascope, and dimension measurement.
    - Existing ground support and geological info.
- **If above ground (mostly highwall portal canopy):**
  - Surface topo
  - Highwall lithology
  - Dimensional data
  - Etc.
If inclined slope:
- Mostly backfill: static uniform load
- Sometimes blocked: static, uniform or localized area load

If U/G entries:
- Adverse condition: mostly blocked, static, uniform or localized area load
- Aged main entry rehab: mostly backfilled or blocked. Static uniform load
- Overcast: air pressure, moving equipment/personnel dynamic load
- Roof fall rehabilitation:
  - Void not backfill: dynamic impact load
  - Void backfilled: static uniform load

If highwall canopy: dynamic impact load
If civil shaft/tunnel: static uniform load
Once dimensional requirements, boundary condition, and loading conditions are determined, a steel structural analysis is conducted to evaluate:

- Axial stress distribution
- Shear stress distribution
- Bending moment distribution
- Deformation distribution
Example of a steel structural analysis of an square set design

Load

Axial

Shear

Moment
Once an optimal structural design is selected, a connection design is conducted to ensure that the product has a sufficient moment connection between major steel members, and enables an easy installation of the steel set in the field, including:

- Location and size of structural bolts
- Size, type, and length of structural welds
Adequacy Verification

- AISC code checking to ensure:
  - No material yielding
  - No lateral-torsional buckling occur at the flange and web of leg and beam
  - No flexural and shear failure
  - No buckling at legs
- Finite element analysis

[Graphs showing vertical deflection and safety factor]
Case 1: Steel Set Design for an Inclined Slope
2,221’ long, grade of 28.7% (or 16°), semi-circular over/under, and finished opening size of 15’ wide x 16’ high at crown.
Geological Condition Evaluation
Geological Condition Evaluation

- Symmetric model
- Full-scale 3D model is 2,154’ long, 586’ and 581’ high at toe and portal
- Contains more than 431,000 elements representing 65 layers of rock strata from the surface to the floor strata.
Loading Condition Evaluation
Steel Structural Analysis

- Axial
- Shear
- Moment
Design Optimization

<table>
<thead>
<tr>
<th>Design #</th>
<th>Set space, ft</th>
<th>Cross-member</th>
<th>Side leg</th>
<th>Divider</th>
<th>Support capacity, tons</th>
<th>Support capacity(^a), ft</th>
<th>Material efficiency(^b), tons/ton of steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>W8 x 31</td>
<td>W8 x 31</td>
<td>W6 x 25</td>
<td>69.72</td>
<td>11.1</td>
<td>79.59</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>W6 x 25</td>
<td>W6 x25</td>
<td>W6 x 25</td>
<td>44.09</td>
<td>8.8</td>
<td>58.08</td>
</tr>
</tbody>
</table>

Note:
1. \(^a\) Assumes 160 lb/ft\(^3\) rock density;
2. Uniformly-distributed static rock load on cross-member;
3. \(^b\) Material efficiency is defined as tons of support capacity generated by each ton of steel;
1. This ensures a sufficient moment connection between the leg and divider beam, the leg and cross arch, and the arch cross-members.

2. The connections enable an easy installation of the steel set in the field.

Galvanized, 19.5” x 46” x 12 gage V deck lagging panel installed.
Adequacy Verification
Case 2: Impact Resistant Steel Sets for Roof Fall Rehabilitation
Geological Condition Evaluation

Fall Area
Geological Condition Evaluation

Thinnly laminated weak shale interbedded with coal streaks, 4.5’

Laminated dark gray shale, 5 – 6’

Coal Seam
Rehabilitation Plan

20’ IR steel canopy to be built at adjacent safe entry then pushed/dragged by a CM into roof fall area while being able to clear rocks and debris.
Loading Condition

- Entire system = Steel set + IR lagging

- Impact capacity depends on the impact location.

- The worst loading condition:
  - A piece of rock falls at mid span of the steel set, and
  - Rock impacts at mid span of the lagging panel
Impact Resistant Lagging™
Full Scale Drop Test
Typical Drop Results

Drop weight: 1541.53 lbs
Drop height: 63"
Peak z-acceleration: 49.95 g
Peak vector sum acceleration: 75 g
Peak vertical impact load: 76.99 kips
Duration 1st impact: 0.04 sec
Total duration of impact: 0.702 sec
Updated Impact Capacity Evaluation

- Applicable roof fall scenarios *(lagging only, <6” mid-span deflection)*

<table>
<thead>
<tr>
<th>Fall Height, ft.</th>
<th>Falling Rock Size</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Lbs</td>
</tr>
<tr>
<td>2</td>
<td>4046.5</td>
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<tr>
<td>4</td>
<td>2023.3</td>
</tr>
<tr>
<td>5.25</td>
<td>1541.5</td>
</tr>
<tr>
<td>6</td>
<td>1348.8</td>
</tr>
<tr>
<td>8</td>
<td>1011.6</td>
</tr>
<tr>
<td>10</td>
<td>809.3</td>
</tr>
<tr>
<td>12</td>
<td>674.4</td>
</tr>
<tr>
<td>14</td>
<td>578.1</td>
</tr>
<tr>
<td>16</td>
<td>505.8</td>
</tr>
<tr>
<td>18</td>
<td>449.6</td>
</tr>
<tr>
<td>20</td>
<td>404.7</td>
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<tr>
<td>22</td>
<td>367.9</td>
</tr>
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<td>24</td>
<td>337.2</td>
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<td>26</td>
<td>311.3</td>
</tr>
<tr>
<td>28</td>
<td>289.0</td>
</tr>
<tr>
<td>30</td>
<td>269.8</td>
</tr>
</tbody>
</table>
Dynamic Impact Simulation - Lagging
Steel Structural Analysis

Axial stress diagram

Shear stress diagram

Bending moment diagram
- Per AISC a three piece W8 x 31 Long Radius Impact Resistant Arch Set* will meet design and engineering requirements.
Adequacy Verification
Post-installation Evaluation

- 56 months after installation.
- Max fall height about 14.5’.
- Rock size varies, mostly irregular shaped, and piled one on another.
- Large piece landed across several lagging panels and steel sets
- Largest piece estimated as 3’ x 7.5’ x 10” (or 18.75 ft³).
Post-installation Evaluation
Post-installation evaluation

- Performed very good.
- No lagging panels or SLBs knocked off.
- Steel set did not exhibit any measurable deflection where impacted.
- IR steel set has a higher capacity than previously reported.
- The design should be applicable to any comparable roof fall areas in other coal mines.
Other Applications
Additional Evaluation

• In 2011, KMS reported a methodology and an IR lagging as the solution.
• Since then, IR steel sets installed in more than 140 roof fall sites / 43 different coal mines. However:
  • Installed IR steel set exhibits much higher support capacity.
  • 2011 guidelines are too conservative. Reasons:
    • IR lagging only
    • Conservative lab testing
    • Ignored energy absorption by steel set
• Then, what is reasonable estimate of IR steel set capacity?
• JENNMAR®’s elasto-plastic design and dynamic impact simulation offer a solution.
Elasto-Plastic Structural Design

\[ W = \frac{F_u y_{\text{max}} - \frac{F_u y_u + (y_{\text{max}} - y_u)^2}{2} K_2}{12H + y_{\text{max}}} \times 1000 \]
Static non-linear numerical model of the W8 x 31 square set

<table>
<thead>
<tr>
<th>Steel Type</th>
<th>Young’s Modulus, psi</th>
<th>Poisson’s Ratio</th>
<th>Yield Strength, psi</th>
<th>Ultimate Strength, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>A36</td>
<td>2.90E+07</td>
<td>0.3</td>
<td>36259</td>
<td>66717</td>
</tr>
<tr>
<td>A992</td>
<td>2.90E+07</td>
<td>0.3</td>
<td>50000</td>
<td>75000</td>
</tr>
<tr>
<td>A325</td>
<td>2.90E+07</td>
<td>0.3</td>
<td>92000</td>
<td>120000</td>
</tr>
</tbody>
</table>
IR Capacity - Steel Set

- Load vs deflection curve of W8 x 31 square set
Dynamic Impact Simulation – Steel Set

(1937 lbs @ 30’ drop height)

LS-DYNA user input
Time = 0
Contours of Effective Stress (v-m)
min=0, at elem# 15895
max=0, at elem# 15895
Dynamic Impact Simulation - Entire System
(1541.5 lbs @ 63” drop height)
**Comparison: Dynamic Impact Capacity**
*(1541.5 lbs @ 63” drop height)*

<table>
<thead>
<tr>
<th>Evaluation Case</th>
<th>Mid-span Deflection, in.</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lagging</td>
<td>beam</td>
</tr>
<tr>
<td>1   IR lagging</td>
<td>5.5</td>
<td>N/A</td>
</tr>
<tr>
<td>2   IR lagging</td>
<td>5.25</td>
<td>N/A</td>
</tr>
<tr>
<td>3   Steel set</td>
<td>N/A</td>
<td>.41</td>
</tr>
<tr>
<td>4   Entire system</td>
<td>1.375</td>
<td>0.125</td>
</tr>
</tbody>
</table>

**Conclusions:**

- Steel set should not be ignored.
- IR capacity should be evaluated for the whole system.
- IR capacity of entire system is significantly higher than that of IR lagging alone.
## IR Capacity - Entire System

<table>
<thead>
<tr>
<th>Fall Height, ft</th>
<th>Maximum allowable rock slab thickness, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>If fall on IR lagging ¹</td>
</tr>
<tr>
<td>2</td>
<td>16.9</td>
</tr>
<tr>
<td>4</td>
<td>8.4</td>
</tr>
<tr>
<td>5.25</td>
<td>6.4</td>
</tr>
<tr>
<td>6</td>
<td>5.6</td>
</tr>
<tr>
<td>8</td>
<td>4.2</td>
</tr>
<tr>
<td>10</td>
<td>3.4</td>
</tr>
<tr>
<td>12</td>
<td>2.8</td>
</tr>
<tr>
<td>14</td>
<td>2.4</td>
</tr>
<tr>
<td>16</td>
<td>2.1</td>
</tr>
<tr>
<td>18</td>
<td>1.9</td>
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<tr>
<td>20</td>
<td>1.7</td>
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<tr>
<td>22</td>
<td>1.5</td>
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<tr>
<td>24</td>
<td>1.4</td>
</tr>
<tr>
<td>26</td>
<td>1.3</td>
</tr>
<tr>
<td>28</td>
<td>1.2</td>
</tr>
<tr>
<td>30</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Note:

1. Estimated on a unit basis (12 inches long x 18 inches wide) based on actual drop test results.
2. Determined on a unit basis (48 inches long x 18 inches wide) based on elasto-plastic structural analysis results of a W8 x 31 square set.
Case 3: Highwall Steel Canopy Design
Geological Condition Evaluation

• Three benches (65’ bottom, 45-50’ 2nd bench, and 55’ 3rd one). Each bench is 40 – 50’ wide.

• Highwall slopes 70-80 degrees.

• Topmost yellow shale strata is weathered, layered and fractured, and may be source of possible loose rock.
• Falling rock will be mostly stopped by any of three benches.
• Size of falling rock will likely be small since the exposed rock layer is layered, fractured and weathered.
• Highwall canopy needs to sustain an impact load generated by rock pieces rolling off the lowest benches.
Proposed Design
Structural Analysis
Case 4: Tunnel Ring
Geological Condition Evaluation

- Developed in 1980s.
- 2.2 miles long.
- 25’ diameter, supported with tunnel rings.
- Flooded and drained twice in the past.
- Roof fall occurred due to weathering of strata and rusting damage of the tunnel rings.
- Some areas were rehabilitated with square set by previous operator.
- Current operator rehabilitates the roof fall areas and needs to remove square sets for ventilation purpose.
Geological Condition Evaluation
Geological Condition Evaluation

Roof condition at top of dome

Rib condition of the dome
Rehab Plan – Roof Fall Area
Rehab Plan – Adjacent Areas

- Holes field cut in existing tunnel rings for new tie rod/pipe spacer connection.
- Existing HSS 4x4 tube spacers (require field cutting for placement of new rings).
- Tie rod & pipe spacer assembly:
  - 3/4 x 64" tie rod
  - (2) 1 1/4" x 30" pipe spacer
- New Jennmar tunnel rings W6x24
- Existing tunnel rings W6x15

Dimensions:
- 5'-0"
- 2'-0"
- 25'-0"
- 1.5'-0"
- 0'-59 3/4"
Structural Analysis

- Load
- Shear
- Axial
- Deformation
- Moment
JENNMAR Specialty Products

- Opened in 2007
- Provide fabrication services for the mining & underground construction industries
- Specialize in steel sets (arch & square)
Committed to the development, implementation and maintenance of our Quality Management System (QMS) and to continually improving its effectiveness

<table>
<thead>
<tr>
<th>Training</th>
<th>Safety</th>
<th>Control of Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audits</td>
<td>Calibration</td>
<td>Continual Improvement</td>
</tr>
<tr>
<td>CA/PA</td>
<td>Maintenance</td>
<td>Control of Materials</td>
</tr>
</tbody>
</table>

ISO 9001:2008 with Design
• Fabrication meets AWS D1.1 standards
  • Control welds by controlling welder settings, positions, and wire
  • 100% visual inspection on all welded parts

• QA Technicians on all shifts, perform frequent quality checks at all work stations

• Operators are required to perform regular quality checks

• All checks are documented
Drill Line

PCD 1100

- Beams, channel, tubing, angle, flat bar
- 3 spindle w/ CNC controls
- Part marking
- Beams up to 44” tall
- Beams up to 60’ long
- Drill flanges or webs up to 2-1/2” thick
Bending Capabilities

Roundo

- Down to W4 beam @ 3’ radius
- Angle
- Flat bar
- Pipe
- Tubing
- Channel
CNC Burn Table

- CNC Controls
- Plasma cut up to 1-1/2” thick
- Oxy cut up to 8” thick
- 5’ wide x 20’ long plate
Press Brake

Durma - E37300

- CNC controls
- Brake up to ½” material
- 10’ lengths
Prop Line

- Rapid Installation Prop (RIP™)
- Available in 50 ton or 100 ton supports
  - 50 ton has 12” of adjustment
  - 100 ton has 18” of adjustment
- Easy screw height adjustment
- 4 different style of tops
  - Piranha Plate
  - Mini Mat
  - Channel w/ beam
  - Yieldable Dish
Civil, Mechanical & Mining Engineers on staff equipped with the latest drafting and engineering software.
Pictures of Products Fabricated
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JENNMAR™ and KMS WOULD LIKE TO THANK YOU FOR THE OPPORTUNITY TO BE HERE TODAY.