AREMA UNLOADING PIT CALCULATIONS

AUTHORS

Steven P. Lorek, PE (Principal Author)
HDR Engineering, Inc.
9987 Carver Road, Suite 200
Cincinnati, OH 45242
Phone: 513.984.7557
Fax: 513.984.7580 |
Email: Steve.Lorek@hdrinc.com

ABSTRACT
The paper submitted for publication will document the process taken to revise the unloading pit section of the AREMA manual. The original section on unloading pits was incorporated into the Manual in 1993. Upon review of Section 8.4 for reaffirmation in 2010, it was determined that the figures in section were developed prior to the implementation of the alternate loading and the concrete figures should be removed from Chapter 15. Figures 15-8-5 and 15-8-6 were reviewed in relation to current live load and fatigue criteria specified in Section 1. The documentation will include commentary of the history of the section, steps take to revise the section, and the detailed calculations required to make the table changes.

AREMA MANUAL OF RECOMMENDED PRACTICE
PUBLICATION ARCHIVE

ARCHIVE REASON: TABLE CALCULATIONS UPDATE
PUBLICATION YEAR: 2012
COMMITTEE: 15 - Steel Structures
SUBCOMMITTEE: 08 – Painting & Special Construction
REVISION: Figure 15-8-6 Unloading Pit – Fifteen Foot Maximum Span
ATTACHMENTS: Executive Summary
AREMA MRE Figure 15-8-6 (2011)
Letter Ballot 15-12-06
AREMA MRE Figure 15-8-6 (2014)
Calculations

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EXECUTIVE SUMMARY

In order to determine the capacity of both the supporting steel beams and concrete structure of the unloading pits under alternate loading, a preliminary analysis was performed. The unloading pit can be found in the 2011 American Railway Engineering and Maintenance (AREMA) Chapter 15 Section 8.4. The current tables of the beam requirement and concrete pit reinforcing were developed under E80 loading. The following is a summary of the findings and analysis of the unloading pit under alternate loading.

SUPPORTING BEAM

Using a MathCAD template, the supporting beams were analyzed for the alternate loading in both bending and shear. The investigation used the same steel beam section with respect to the varying span length as that of the AREMA - Figure 15-8-6. We used the same design requirements such as A.S.T.M A36 structural steel and live impact of 28%. As shown on the enclosed table most of the supporting steel beams were determined deficient for the alternate loading condition. All other design assumptions are included with this document. A summary is enclosed.

CONCRETE PIT STRUCTURE

A structural analysis (computer model) was performed on the concrete pit structure. The walls are design per foot and the footing length varied with respect to wall height at a 1:1 ratio to sustain the applied loads. The pit was analyzed using the same restrictions and design requirements stated in the AREMA section 15-8.4. It is determined that the proposed reinforcing would not work for the E80 or alternate loading conditions. A complete wall model will need to be developed in order to obtain an exact result for the proposed reinforcing listed in AREMA figure 15-8-6. Enclosed in this document is the model used to evaluate the concrete pit. A spreadsheet with the number of proposed iteration is also included in order to full analyze the pit as the span length the wall height the wall thickness and footing thickness varies.

CONCLUSIONS

Supporting Beam - The enclosed table demonstrates that three beam sections would still work for the alternate loading with the respective listed span length; HP12X74 for 8 and 9 feet spans, W16X89 for 12ft span and W21X101 for 15ft span. All other beams are deficient in either bending or shear or both. For these failing sections, larger sections would need to replace the present proposed beams, given that their structural capacity does not permit the alternate loading at the stated span length.

Concrete Pit Structure - The concrete pit structure needs further analysis by the committee in order to accurately determine the capacity of the reinforcing as the wall height and span varies.
AREMA MRE Figure 15-8-6 (2011)
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Figure 15-8-6. Unloading Pit – Fifteen Foot Maximum Span
(Sheet 2 of 3)
Steel Structures

General Notes:
1. Spec.: Design, material and workmanship shall be in accordance with Chapter 8, Concrete Structures and Foundations and this chapter.
2. Live Load: Cooper E50 with 28% impact.
4. Concrete shall be proportioned to provide a minimum 28 day compressive strength of 3,000 psi.
5. Reinforcing steel shall be deformed bars conforming to A.S.T.M. A615, Grade 40 or Grade 60.
6. Foundation material shall be adequate to support a load of 2.0 ton per square foot.
7. This drawing is intended as a guide in preparing a construction drawing. If pit is to be constructed under traffic, include plans for supporting the track. If pit is located adjacent to an operating track, include sheeting plans to support the operating track. All plans shall be submitted to the railway’s chief engineer for approval.
8. No traffic will be permitted over pit until concrete has reached 2500 psi compressive strength.
9. Pits are to be located on tracks having a maximum speed of 10 mph.
10. Ground water pressure was not considered in the design and provisions must be made for drainage if necessary.
11. See Figure 15-8-7 for reinforcing steel details.
12. Suggested plan only.
13. Plan must be adjusted to local conditions.
14. Construction plans must be submitted to railroad’s chief engineer for approval.

Note “A”: Bolted rail clips may be used as alternate provided there is sufficient flange width and provision is made for loss of section in the holes.

Figure 15-8-6. Unloading Pit – Fifteen Foot Maximum Span
(Sheet 3 of 3)
Letter Ballot Number: 15-12-06

Title: Proposed Revisions to 15-8-6 for alternate live load criteria

Proposed Letter Ballot:
Proposed revisions to the section include updates to the following figures:

Figure 15-8-6 (Sheet 2 of 3) revision. (See attached)
Figure 15-8-6 (Sheet 3 of 3) revision. (See attached)

Rationale:
Table 15-8-6 is being revised to accommodate the alternate live loading criteria.

Figure 15-8-6. Unloading Pit – Fifteen Foot Maximum Span

To comply with the current live load criteria specified in Section 1, the beam supported superstructure is being upgraded to accommodate the current alternate live loading. In addition, the welded diaphragm connection to the main supporting beams of Figure 15-8-6 is being revised to represent a bolted diaphragm connection. This will improve the fatigue category and extend service life while allowing for a reduced beam section.
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**General Notes:**
1. Spec: ...
2. Live Lo Superstructure - Alternate Loading with 29% Impact in accordance with Chapter 15
3. Substructure - Cooper E80 with 29% Impact in accordance with Chapter 8

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**Figure 15-8-6. Unloading Plt - Fifteen Foot Maximum Span**

(Sheet 2 of 3)
### Steel Structures

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<td>7 × 21</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W18 × 106</td>
<td>8 × 18</td>
<td>5.25</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>9.7</td>
<td>222.8</td>
<td>W18 × 119</td>
<td>8 × 18</td>
<td>5.25</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W21 × 101</td>
<td>9 × 15</td>
<td>5.25</td>
<td>2</td>
</tr>
</tbody>
</table>

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**Figure 15-8-6. Unloading Pnt – Fifteen Foot Maximum Span**  
(Sheet 2 of 3)

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AREMA Manual for Railway Engineering

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Notes:
1. Design, material and workmanship for all structural steel shall conform to the requirements of this chapter.
2. Design, material and workmanship for all excavation, shoring, backfill, reinforced concrete, and foundation shall conform to the requirements of Chapter 8, Concrete Structures and Foundations.
3. Live Load: Superstructure - Alternate Live Load with 28% impact in accordance with Chapter 15. Substructure and surcharge as applicable in accordance with Chapter 8.
4. Structural steel shall have a minimum yield stress of 36,000 psi and conform to Table 15-1-1.
5. No loading will be permitted to be transferred to new pit until concrete has reached a compressive strength acceptable to the Engineer.
6. Design speed for tracks with unloading pits shall be 10 mph.
7. If pit is to be constructed under traffic, include plans for temporary track support.
8. If pit is to be constructed adjacent to existing track, building, or other structures, include shoring plans to support the adjacent facilities.
9. All design work and plans shall be prepared by a licensed professional engineer experienced in railway structure design.
10. All designs and plans shall be submitted to the Engineer for approval.

Figure 15-8-6. Unloading Pit – Fifteen Foot Maximum Span
(Sheet 3 of 3)
CALCULATIONS

DESIGN ASSUMPTIONS:

Design Method: (Steel) Service Load Design - Steel Beam
Structural Steel Yield Strength: $F_y = 36$ ksi
Live Load: AREMA - Alternate Live Load
Impact (Steel Beams only): 28%
Maximum Speed on tracks: 10 MPH

Design Method: (Concrete) Load Factor Design - Concrete Pit
Concrete Compressive Strength: $f'_c = 3$ ksi
Reinforcing Steel Yield Strength: $f_y = 60$ ksi
Unit Weight of Soil: $w_s = 120$ pcf
Angle of Internal Friction: $\Phi = 0^\circ$
Horizontal Earth Pressure: $E = \frac{1}{2}w_s h^2$ AREMA - 8-5.3.2 (Case 6)
Horizontal Live Load Surcharge: $h' = h^*q$ AREMA - 8-5.3.2 (Case 6)
Surcharge Load $q = 4$ ksf

Reference: Chapter 15 - Section 8.4 - Unloading Pit

Structural Steel Beam Simple Beam
Structural Steel (Fatigue) Diaphragm Connection
Fatigue was evaluated assuming that the channel-section diaphragm is bolted to the web of the Unloading Pit beam at mid-depth with matched angles or a T-section. The bolted detail is evaluated at the bolt furthest from mid-depth according to AREMA Table 15-1-10, Section 2 for bolted connections. (See figures, below)

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Single Track Beam DESIGN (Unloading Pit):

Units Definition: \[
\begin{align*}
&k = \text{1000 lb} \quad \text{ksi} = \frac{k}{\text{in}^2} \quad \text{psf} = \frac{\text{lb}}{\text{ft}^2} \quad \text{plf} = \frac{\text{lb}}{\text{ft}} \quad \text{kcf} = \frac{k}{\text{ft}^3}
\end{align*}
\]

Material Properties:
Steel Modulus of Elasticity: \[E_s := 29000 \text{ ksi}\]
Girder Steel Strength: \[F_y := 36 \text{ ksi}\]
Misc. Steel Strength: \[F_{ym} := 36 \text{ ksi}\]
Poisson’s Ratio: \[\nu := 0.3\]

Geometry:
No. of Beams: \[N_{dg} := 2\]
Beam C-C Spacing: \[s_{Beam} := 5 \text{ ft}\]
Span Length: \[L_{Beam} := 5 \text{ ft}\]

Beam Design - Two Beam System:

Dead Loads (AREMA 15-7.3.1.1):

Track/Rail: \[\omega_T := 1.200 \frac{\text{lb}}{\text{ft}} \quad \omega_T = 200 \text{ plf}\]
Beam Self Weight: \[\omega_{Beam} := 77 \text{ plf}\]
(Additional 10% for Self Weight to account for Stiffeners Diaphragms added below)

Total Superimposed Dead Load (per Beam): \[\omega_{SDL} := \frac{\omega_T}{N_{dg}} = 100 \text{ plf}\]

Dead Load Shear: \[V_{DL} := \frac{1.1 \omega_{Beam} L_{Beam}}{2} + \frac{\omega_{SDL} L_{Beam}}{2} = 0.462 \text{ k}\]

Deal Load Moment: \[M_{DL} := \frac{1.1 \omega_{Beam} L_{Beam}^2}{8} + \frac{\omega_{SDL} L_{Beam}^2}{8} = 0.577 \text{ k ft}\]
CALCULATIONS

Live Loads (AREMA 15-7.3.3.2) Alternate Loading:

Live Load Shear:

\[ V_{LL} \geq V \left( \frac{L_{Beam}}{ft} \right) k \]

\[ V_{LL} = 50.00 \text{ k} \]

Live Load Moment:

\[ M_{LL} \geq M \left( \frac{L_{Beam}}{ft} \right) k \text{ ft} \]

\[ M_{LL} = 62.50 \text{ k ft} \]

Impact (Open Deck) (AREMA 15-7.3.3.3):

Impact (use 29% per AREMA Notes)

\[ I_2 \geq 28\% \]

Beam Spacing:

\[ S_{Beam} = 5.0 \text{ ft} \]

Deck Girder Length:

\[ L_{Beam} = 5 \text{ ft} \]

Rocking Effect:

\[ RF_{Beam} \geq \left( \frac{1000}{S_{Beam}} \right) \% \]

\[ RF_{Beam} = 20\% \]

Impact:

\[ I \geq \left( \frac{40 - \frac{3 I_{Beam}}{S_{Beam}}^2}{1600 \text{ ft}^2} \right) \%
\]

\[ I = 40\% \]

At the unloading pit, speeds will never exceed 10 mph and therefore an Impact Reduction Factor (IRF) may be applied per AREMA 15-7.3.3.3.

Rail Traffic Maximum Speed:

\[ \text{IRF: } \text{IRF} = 0.20 \]

\[ \text{Adjusted Impact Factor: } I_0 = RF_{Beam} \times IRF \]

\[ I_0 = 28.0\% \]

This is nearly 29%, therefore use 29% per AREMA Table 15-9-6 Notes.

Impact Shear:

\[ V_{LL-I} \geq I_2 V_{LL} \]

\[ V_{LL-I} = 14.0 \text{ k} \]

Impact Moment:

\[ M_{LL-I} \geq I_2 M_{LL} \]

\[ M_{LL-I} = 17.5 \text{ k ft} \]

Total Forces:

Total Shear:

\[ V_T \geq V_{DL} + V_{LL} + V_{LL-I} \]

\[ V_T = 64.5 \text{ k} \]

Total Moment:

\[ M_T \geq M_{DL} + M_{LL} + M_{LL-I} \]

\[ M_T = 80.6 \text{ k ft} \]

Bending Design:

Allowable Bending Stress:

\[ F_b = 0.55 F_y \]

\[ F_b = 19.8 \text{ ksi} \]

Required Section Modulus:

\[ S_{req} = \frac{M_T}{F_b} \]

\[ S_{req} = 48.83 \text{ in}^3 \]
CALCULATIONS

Project: AREMA 15
Computed: EJM
Date: 12/13/2011
Subject: Unloading Pit
Checked:
Date:
Task: Beam Sections
Page: 14
Job #: No:

Shear Design:
Allowable Shear Stress:
\[ F_s = 0.35 F_y \]
\[ F_y = 12.6 \text{ ksi} \]

Required Web Area:
\[ A_{req} = \frac{V_T}{F_y} \]
\[ A_{req} = 5.12 \text{ in}^2 \]

Select Beam:
BEAM: Existing - W10x58:
Beam Depth: 7.5 in
Flange Thickness: 0.5 in
Flange Width: 2.2 in
Web Thickness: 0.51 in
Section Modulus: \[ S_y = 52 \text{ in}^3 \]

BEAM: Proposed - W10x77:
Beam Depth: 7.5 in
Flange Thickness: 0.58 in
Flange Width: 0.3 in
Web Thickness: 0.53 in
Section Modulus: \[ S_y = 85.9 \text{ in}^3 \]
Moment of Inertia: \[ I_y = 435 \text{ in}^4 \]

Shear Check:
Web Area:
\[ A_w = d_b t_w \]
\[ A_w = 5.62 \text{ in}^2 \]

Check Web Area
check: “Satisfactory” if \( A_w \geq A_{req} \)
“Deficient” if \( A_w < A_{req} \)
\[ \frac{A_w}{A_{req}} = 1.098 \]

Bending Check:
Check Section Modulus
check: “Satisfactory” if \( S_y \geq S_{req} \)
“Deficient” if \( S_y < S_{req} \)
\[ \frac{S_y}{S_{req}} = 1.76 \]

Stiffener Bearing: (AREMA 15.1.7.7)
Allowable Stress:
\[ F_{br} = 0.83 F_y \]
\[ F_{br} = 29.88 \text{ ksi} \]

Area Required:
\[ A_{req} = \frac{V_T}{F_{br}} \]
\[ A_{req} = 2.157 \text{ in}^2 \]

Max Width of Stiffener:
\[ b_y = \frac{b_T - t_w}{2} \]
\[ b_y = 4.79 \]
use: \[ b_y = 5.0 \text{ in} \]
CALCULATIONS

Stiffener Thickness (assume 1" clips)
Required for Bearing:
\[ t_{sb} = \frac{A_{eq}}{2(h_a - 1) in} \]
\[ t_{sb} = 0.27 \text{ in} \]

Required for Compression:
\[ t_{sc} = \frac{b_a}{\sqrt{F_y \left[ 0.43 \left( \frac{F_y}{F_y} \right) \right]}} \]
\[ t_{sc} = 0.41 \text{ in} \]

Design Thickness:
\[ t_d = \frac{96 \max \left( t_{sb}, t_{sc} \right)}{96} \]
\[ t_d = 0.42 \text{ in} \]

Use:
\[ \Delta = 0.5 \text{ in} \]

Stiffener Web Compression (AREMA 15.1.7.7)
Distance from Centerline of Stiffener to End of Beam:
\[ d > 6 \text{ in} \]

Length of Web Under Consideration:
\[ l_w = (6 - t_w) + \min(6 - t_w, d) \]
\[ l_w = 6.36 \text{ in} \]

Moment of Inertia:
\[ I_{aw} = \frac{t_w (2 h_a + t_w)^3}{12} + \left( l_w - l_d \right) t_w^3 \]
\[ I_{aw} = 48.722 \text{ in}^4 \]

Compression Area:
\[ A_c = 2(t_a b_a) + t_w l_w \]
\[ A_c = 8.371 \text{ in}^2 \]

Radius of Gyration:
\[ r = \sqrt{\frac{I_{aw}}{A}} \]
\[ r = 2.413 \text{ in} \]

Effective Length Factor:
\[ k_e = 0.75 \]

Height of Stiffeners:
\[ l_e = d_a - 2 t_f \]
\[ l_e = 8.86 \text{ in} \]

Slenderness Ratio:
\[ SR = \frac{k_e}{r} \]
\[ SR = 2.754 \]

Allowable Stress (psi):
\[ F_a = \begin{cases} 
0.629 \frac{F_y}{0.55 F_y} & \text{if } SR \leq 0.629 \\
0.584 \left( \frac{F_y}{F_y} \right) - \left( \frac{17500 F_y}{E_y} \right) \left( \frac{SR}{3} \right) & \text{if } SR \leq 0.584 \\
0.66 \frac{F_y}{k_i} - \left( \frac{17500 F_y}{E_y} \right) (SR) \left[ \frac{514 \pi^2 F_y}{k_i SR^2} \right] & \text{if } SR > 0.584 
\end{cases} 
\]
\[ F_a = 19.8 \text{ psi} \]

Actual Stress:
\[ \sigma_a = \frac{V_T}{A k_i} \]
\[ \sigma_a = 7.7 \text{ ksi} \]

Check:
- "Stiffener is Satisfactory" if \( F_a \) ksi > \( f_a \) ksi
- "Increase Stiffener Thickness" if \( F_a \) ksi < \( f_a \) ksi
CALCULATIONS

Check Fatigue in Welded Diaphragm Connection (15-1.3.13):

Number of Stress Cycles = 2,000,000
Stress Category = D, Diaphragm Welded to the Web with 2" < Channel Flange Width < 12" or 4"

Allowable Stress Range (AREMA Table 15-1-10, Section 7.1): $S_{Rg} = 7\text{ ksi}$

Diaphragm properties (based on section depth)

$\frac{d_{\text{channel}}}{2} = \begin{align*} &\text{in} \quad \text{if} \quad 8 \text{ in} \leq d_h \leq 10 \text{ in} \\
&\text{in} \quad \text{if} \quad 10 \text{ in} < d_h \leq 14 \text{ in} \\
&\text{in} \quad \text{if} \quad 14 \text{ in} < d_h \leq 16 \text{ in} \\
&\text{in} \quad \text{if} \quad 18 \text{ in} < d_h \leq 21 \text{ in} \\
\end{align*}$

Distance to fatigue connection detail: $c = \frac{d_{\text{channel}}}{2} = 4.00 \text{ in}$

Fatigue Stress at detail:

$f_{Rf} = \frac{M_{J,t} \left(1 + 0.35 \frac{l_{s}}{I_{s}}\right)}{l_{s}}$

Check Connection Fatigue:

- "OK" if $S_{Rg} > f_{Rf}$
- "No Good...Reduce Stress Range" if $f_{Rf} \geq S_{Rg}$

Check Connection Fatigue = "No Good...Reduce Stress Range"

7 ksi = 7 ksi, therefore design is satisfactory