ERRATA

BELT CONVEYORS FOR BULK MATERIALS, 7th edition

As of February 1, 2015

PLEASE NOTE: The Errata Summary below is listed by chapter and page numbers, with the original and correction pages after the Errata Summary. The following pages to the Errata Summary List will show the "error" in red on the Left Page and then the "correction" will be on the Right Page. To view two-page mode, select View, then Page display, then two-page.

CHAPTER 4

- Page 69
  - Move close parenthesis in equation 4.15
  - Change of equation reference in “A” meaning (Equation 4.12 should read “Equation 4.5”)

- Page 72
  - Change of figure reference in figure 4.21 (Figure 4.24 should read “Figure 4.11 or 4.13”)

- Page 74
  - Change of equation reference in equation 4.25 (Equation 4.26 should read “Equation 4.15”)
  - Change in elements of equation 4.26 (w should read “w_s” in denominator)
  - Change in elements of equation 4.28 as follow:
    \[ d_s = \frac{w_s - b_s}{2} \times \tan(\beta) + d_{ms} + \frac{w_s}{2} \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right) \]

- Page 75
  - Change of figure reference in figure 4.29 (Figure 4.25 should read “Figure 4.23 or Figure 4.21 with A=As”)
  - After value of A_s, add “w_s = 0.6667”
  - Change in elements of d_s formula as follow:
    \[ d_s = \frac{w_s - b_s}{2} \times \tan(\beta) + d_{ms} + \frac{w_s}{2} \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right) \]

- Page 76
  - Lacks a Square function (It should read “b_{w_f}^2”) in equation 4.32

- Page 78
  - Change of equation reference in figure 4.37 (Figure 4.28 should read “Equation 4.11 and 4.13”)
  - Remove one of sub w’s (should read “b_{w_f}^2”) in the formula of A_f.
• Page 80
  - Change table reference in figure 4.38 (Table 4.44 should read “Table 4.43”)

CHAPTER 5
• Page 109
  - Change in figure 5.31. (It should read $K_{3a} \approx 500 \text{ (rpm)}/n \text{ (rpm)}$)

CHAPTER 6
• Page 148
  - Change in elements of formula in figure 6.15 as follow:
    \[
    \Delta T_{hs} = H_b \times (W_b + W_m) = 52.9 \text{ ft} \times \left( 26.3 \frac{\text{lbf}}{\text{ft}} + 138.9 \frac{\text{lbf}}{\text{ft}} \right) = 8,738.4 \text{ lbf (3,958 kgf)}
    \]
• Page 151
  - Change $C_{ss} = 2 \times m_{ss}$ to $2 \times \mu_{ss}$ in nomenclature table.
• Page 153
  - Change $R_{ls}$ to $R_{ris}$ in equation 6.25
• Page 154
  - Add “ft(m)” at the end of $S_{in}$ meaning (It should read “n” ft (m))
• Page 160
  - Change in elements of formulas in figure 6.40 as follow:
    \[
    X_{sl} = \gamma_m \times \frac{S_i}{X_{stref}}
    \]
    \[
    X_{stref} = 5.22 \frac{\text{lbf}}{\text{in}^2} \left( 36,000 \frac{\text{N}}{\text{m}^2} \right)
    \]
• Page 161
  - Change in the $k_{bbl-L}$ meaning (Equation 6.60 should read “Equation 6.57”)
• Page 163
  - With: $D_m$ Equation 6.70... should read “$d_m$ from Equation 4.17 for $D_m$ using $A$ from Equation 4.5 for $A_s$, $\gamma_m$ = bulk density, $S_i$ = idler spacing”
• Pages 164
  - Corrections in table 6.47 to Type 2 Rubber values from constant $a_1$ to the end.
• Page 165
  - Type 1 table should be labeled Type 3 and Type 3 table should be labeled Type 1 in table 6.48.
• Page 167
  - In figure 6.50, Typos (9.4° C) should read (-9.4° C) in operating temperature.

• Page 169
  - \( P_{j2} \) should to be added in \( K_{b_{ir-S}} \) formula
  - \( T_0 = 9.4^\circ C \) should read \( T = -9.4^\circ C \)
  - Move the 3 lines starting at “From table 6.47...” up to ahead of “s = ...”
  - Replace \((15^\circ F - 32^\circ F)/1.8\) with \(-9.4^\circ C\); \(9.4^\circ C\) in the numerator should read \(-9.4^\circ C\)
  - The value of “s” should read 0.754 in \( x_f \) formula

• Page 170
  - \( P_{j2} \) should to be added in \( K_{b_{ir-S}} \) formula
  - Move “From F calculation: ...” down to directly above “Since the value \( w_{W_w} \)...”
  - Move the finish \( x_p \) calculation below of “From Table 6.47...”
  - \( 9.4^\circ C \) should read \(-9.4^\circ C\) in \( x_p \) formula (2 Places)
  - Eliminate “-0.756” from \( x_p \) calculations

• Page 171
  - Remove \( P_{j2} \) in \( \Delta T_{bi2} \) formula
  - Add formula for \( K_{b_{ir-S}} \) including \( P_{j2} \) below “Calculate \( K_{b_{ir-S}} \)...”
  - Delete entire line "BW = 48 in ....”
  - Move the line "\( X_{ld} =..." \) to below "Use \( R_0 = 1.0" \) line
  - Add \( x \) \( P_{j2}; x \) 0.0792 and change the result to \( 0.02064 \) in \( K_{b_{ir-S}} \) formula and move it up to under “For fabric belts: \( c_{sd} =..." \)
  - Remove \( x \) \( P_{j2} \) in the Note and 0.25 should read \( 0.0206 \)

• Page 173
  - Change in \( w_{RRIR} \) and \( w_{RL} \) meanings (lbf/im should read “lbf/in”).

CHAPTER 8
• Page 328
  - In Equation 8.33, 2 in superscript should be added in D formula as follow:

\[
D = \sqrt{\frac{12 F.S. \times \left( \frac{M}{s_f} \right)^2 + \frac{3}{4} \times \left( \frac{T}{s_f} \right)^2}{\pi}}
\]

CHAPTER 12
• Page 538
  - In Figure 12.73, \( \phi \) in the drawing should be \( \phi_i \)
• **Page 552**
  - In Figure 12.95, **Replace**: 'Vs=Tangential Velocity, fps, of the cross-sectional area center of gravity of the load shape' **with**: “Vs=Velocity of the load cross section used for plotting the trajectory”

• **Page 559**
  - In Figure 12.109, Greek letters are incorrect, there is a font error for “phi” describing the angle of incline of the conveyor. It is showing the 'capital phi' not in lower case as it should be. (ϕ should be φ (2 places) and γ should be Υ (1 place)).

• **Page 560**
  - In the paragraph between Equation 12.111 and Equation 12.112; the reference to Table 4.4, should read “Table 4.6”.
  - In the Figure 12.110, this should read: $V_s = \text{Velocity of the load cross section used for plotting the trajectory}$:
    1. Belt velocity, $V$, is used as the velocity of the material at its center of mass if the discharge point is at the tangency of the belt-to-discharge pulley ($V_s = V$)
    2. Velocity of the material at its center of mass, $V_{cg}$, is used as the velocity of the material for all other conditions of discharge after the point of belt-to-discharge pulley tangency. ($V_s = V_{cg}$)
CEMA Standard Cross Sectional Area, $A_s$

Equation 4.15 is used to calculate, $A_s$, for standard CEMA three equal roll troughing idlers based on the average CEMA center roll length circular surcharge surface and the CEMA standard belt edge.

With $b_{\text{wing}}$, calculated from $b_w$ and with $b_{\text{we}}$ set to the standard dimensions:

$$A_s = 2 \times BW^2 \times [r_{\text{sch}}^2 \times \left( \frac{\Phi_s}{2} - \frac{\sin(\Phi_s) \times \cos(\Phi_s)}{2} \right) + \frac{b_c}{2} \times b_{\text{wing}} \times \sin(\beta) + b_{\text{wing}}^2 \times \frac{\sin(\beta) \times \cos(\beta)}{2}]
$$

Equation 4.15

$A_s$ CEMA standard cross section area

Tables 4.41 through 4.48 were generated using equation 4.15.

$$w = b_c + 2 \times b_{\text{wing}} \times \cos(\beta)
$$

Equation 4.16

$w$, Dimensionless ratio for maximum width of bulk material with standard cross sectional area $A_s$

Where:

- $A_m$ = Standard material cross sectional area based on design criteria [ft$^2$ (m$^2$)] (Equation 4.12)
- $A_s$ = CEMA Standard Cross Sectional Area, bulk material cross sectional area based on three equal roll CEMA troughing idler, the surcharge angle with circular top surface, and standard edge distance [ft$^2$ (m$^2$)]
- $BW$ = Belt width, [in (mm)]
- $b_c$ = Dimensionless ratio of the effective upper surface of the belt above the center roll to the belt width, BW
- $b_d$ = Dimensionless ratio of maximum depth of material above the belt at the center roll to the belt width, BW
- $b_{we}$ = Dimensionless ratio of the standard edge distance to the belt width, BW
- $b_{wing}$ = Dimensionless ratio of the length of material on the wing roll to the belt width, BW
- $d_m$ = Dimensionless ratio of depth of the material above the belt at the center roll to the belt width, BW
- $w$ = Dimensionless ratio of the widest part of the load to the belt width, BW
- $\beta$ = Idler trough angle, (degrees when used with a trig function, otherwise radians)
- $\Phi_s$ = Material surcharge angle, (degrees when used with a trig function, otherwise radians)
- $r_{\text{sch}}$ = Dimensionless ratio of the radius tangent to the surcharge angle at the belt edge to the belt width, BW

$$d_m = b_{wing} \times \sin(\beta) + \left[ \frac{b_c}{\sin(\Phi_s)} + \frac{\cos(\beta) \times b_{wing}}{\sin(\Phi_s)} \right] \times \left(1 - \cos(\Phi_s)\right)
$$

Equation 4.17

d$m$, Dimensionless ratio to belt width for maximum bulk material depth on a belt with CEMA standard cross sectional area, $A_s$
CEMA Standard Cross Sectional Area, $A_s$

Equation 4.15 is used to calculate, $A_s$, for standard CEMA three equal roll troughing idlers based on the average CEMA center roll length circular surcharge surface and the CEMA standard belt edge.

With $b_{wmc}$ calculated from $b_w$ and with $b_{we}$ set to the standard dimensions:

$$A_s = 2 \times BW^2 \times \left[ \left( \frac{r^2 \times \Phi_s}{2} \right) \times \frac{\sin(\Phi_s) \times \cos(\Phi_s)}{2} \right] + \left[ \frac{b_c^2}{2} \times b_{wmc} \times \sin(\beta) \right] + \frac{b_{wmc}^2 \times \sin(\beta) \times \cos(\beta)}{2}$$

Equation 4.15

$A_s$ CEMA standard cross sectional area

Tables 4.41 through 4.48 were generated using equation 4.15.

$$w = b_c + 2 \times b_{wmc} \times \cos(\beta)$$

Equation 4.16

$w$, Dimensionless ratio for maximum width of bulk material with standard cross sectional area $A_s$

Where:

$A = $ Standard material cross sectional area based on design criteria [$ft^2$ (m$^2$)]  (Equation 4.5)

$A_s = $ CEMA Standard Cross Sectional Area, bulk material cross sectional area based on three equal roll CEMA troughing idler, the surcharge angle with circular top surface, and standard edge distance [$ft^2$ (m$^2$)]

$BW = $ Belt width, [in (mm)]

$b_c = $ Dimensionless ratio of the effective upper surface of the belt above the center roll to the belt width, BW

$b_d = $ Dimensionless ratio of maximum depth of material above the belt at the center roll to the belt width, BW

$b_{we} = $ Dimensionless ratio of the standard edge distance to the belt width, BW

$b_{wmc} = $ Dimensionless ratio of the length of material on the wing roll to the belt width, BW

$d_m = $ Dimensionless ratio of depth of the material above the belt at the center roll to the belt width, BW

$w = $ Dimensionless ratio of the widest part of the load to the belt width, BW

$\beta = $ Idler trough angle, (degrees when used with a trig function, otherwise radians)

$\Phi_s = $ Material surcharge angle, (degrees when used with a trig function, otherwise radians)

$r_{sch} = $ Dimensionless ratio of the radius tangent to the surcharge angle at the belt edge to the belt width, BW

$$d_m = b_{wmc} \times \sin(\beta) + \left[ \frac{b_c^2}{2} \times \frac{\cos(\beta) \times b_{wmc}}{\sin(\Phi_s)} \right] \times (1 - \cos(\Phi_s))$$

Equation 4.17

d_m, Dimensionless ratio to belt width for maximum bulk material depth on a belt with CEMA standard cross sectional area, $A_s$
Example: Non-standard Edge Distance

Assume: CEMA standard three equal roll troughing idler,
\[ Q = 1800 \text{ tph}, \ V = 500 \text{ fpm}, \ \gamma_m = 60 \text{ lbf/ft}^3 \]

Given: \( BW = 48.0 \text{ inches}, \ \beta = 35 \text{ degrees}, \ \Phi_s = 20 \text{ degrees} \)

From Figure 4.24: \( b_c = 0.3762 \) and \( b_v = 0.3119 \)

\[ A = \frac{Q}{V \times \gamma_m} = \frac{1800 \frac{\text{t}}{\text{h}}} {500 \frac{\text{ft}}{\text{min}}} \times \frac{2000 \frac{\text{lbf}}{\text{t}}} {60 \frac{\text{min}}{\text{h}}} \times \frac{60 \frac{\text{lbf}}{\text{ft}^3}} {1800000 \frac{\text{lbf}}{\text{h}}} = 2.0 \text{ ft}^2 \]

\[ a' = \frac{\cos(\beta)^2}{\sin(\Phi_s)^2} \times \left( \Phi_s - \sin(\Phi_s) \times \cos(\Phi_s) \right) + \cos(\beta) \times \sin(\beta) \]
\[ = \frac{(0.8192)^2}{(0.3420)^2} \times \left( 0.3491 - 0.3420 \times 0.9397 \right) + 0.8192 \times 0.5736 \]
\[ = 5.7359 \times 0.02774 + 0.4699 = 0.6290 \]

\[ b' = b_c \times \sin(\beta) + b_c \times \frac{\cos(\beta)}{\sin(\Phi_s)^2} \times \left( \Phi_s - \sin(\Phi_s) \times \cos(\Phi_s) \right) \]
\[ = 0.3762 \times 0.5736 + 0.3762 \times \frac{0.8192}{(0.3420)^2} \times (0.3491 - 0.3420 \times 0.9397) \]
\[ = 0.2158 + 2.6349 \times 0.02774 = 0.2889 \]

\[ c' = -\frac{A}{BW^2} + \frac{1}{4} \times \frac{b_c^2}{\sin(\Phi_s)^2} \times \left( \Phi_s - \sin(\Phi_s) \times \cos(\Phi_s) \right) \]
\[ = -\frac{2.0 \times 144 \text{ in}^2}{(48.0)^2} + \frac{0.25 \times 0.3762^2}{0.3420^2} \times 0.02774 \]
\[ = -0.125 + 0.3024 \times 0.02774 = -0.1166 \]

\[ b_{wmc} = \frac{-b' + \sqrt{(b')^2 - 4 \times a' \times c'}}{2 \times a'} = \frac{-0.2889 + \sqrt{(0.2889)^2 - 4 \times 0.6290 \times (-0.1166)}}{2 \times 0.6290} \]
\[ = -0.2889 + \frac{\sqrt{0.3769}}{1.2580} = 0.2583 \]

\[ b_{we} = b_w - b_{wmc} = 0.3119 - 0.2583 = 0.05360 \]

\[ B_{we} = b_{we} \times BW = 0.05340 \times 48.0 \text{ in} = 2.6 \text{ in} \]

Figure 4.21
Example of calculating non standard belt edge distance from known idler, belt width and cross sectional area, A
Example: Non-standard Edge Distance

Assume: CEMA standard three equal roll troughing idler,

\[ Q = 1800 \text{ tph}, V = 500 \text{ fpm}, \gamma_m = 60 \text{ lbf/ft}^3 \]

Given: \( BW = 48.0 \text{ inches}, \beta = 35 \text{ degrees}, \phi_s = 20 \text{ degrees} \)

From Figure 4.11 or 4.13: \( b_c = 0.3762 \) and \( b_w = 0.3119 \)

\[ A = \frac{Q}{V \times \gamma_m} = \frac{1800 \text{ t}}{500 \text{ ft/min} \times 60 \text{ min/h} \times 60 \text{ lbf/ft}^3} = \frac{3,600,000 \text{ lbf}}{h} = 2.0 \text{ ft}^2 \]

\[ a' = \frac{\cos(\beta)^2}{\sin(\phi_s)^2} \times \left( \frac{\phi_s - \sin(\phi_s) \times \cos(\phi_s)}{\frac{b_w^{2}}{\sin(\phi_s)^2}} \right) + \cos(\beta) \times \sin(\beta) \]

\[ = \left( \frac{0.8192}{0.3420} \right)^2 \times \left( \frac{0.3491 - 0.3420 \times 0.9397 + 0.8192 \times 0.5736}{0.3420} \right) = 5.7359 \times 0.02774 + 0.4699 = 0.6290 \]

\[ b' = b_c \times \sin(\beta) + b_c \times \frac{\cos(\beta)}{\sin(\phi_s)^2} \times \left( \frac{\phi_s - \sin(\phi_s) \times \cos(\phi_s)}{\frac{b_w^{2}}{\sin(\phi_s)^2}} \right) \]

\[ = 0.3762 \times 0.5736 + 0.3762 \times \frac{0.8192}{0.3420} \times \left( \frac{0.3491 - 0.3420 \times 0.9397}{0.3420} \right) = 0.2158 + 2.6349 \times 0.02774 = 0.2889 \]

\[ c' = -\frac{A}{BW^2} + \frac{1}{4} \times \frac{b_c}{\sin(\phi_s)^2} \times \left( \frac{\phi_s - \sin(\phi_s) \times \cos(\phi_s)}{\frac{b_w^{2}}{\sin(\phi_s)^2}} \right) \]

\[ = -\frac{2.0 \times 144 \text{ in}^2}{(48.0)^2} + 0.25 \times \frac{0.3762}{0.3420} \times 0.02774 = -0.125 + 0.3024 \times 0.02774 = -0.1166 \]

\[ b_{wmc} = -\frac{-b' + \sqrt{(b')^2 - 4 \times a' \times c'}}{2 \times a'} = -\frac{-0.2889 + \sqrt{(0.2889)^2 - 4 \times 0.6290 \times (-0.1166)}}{2 \times 0.6290} = -0.2889 + \frac{0.3769}{1.2580} = 0.2583 \]

\[ b_{wo} = b_w - b_{wmc} = 0.3119 - 0.2583 = 0.0536 \]

\[ B_{we} = b_{we} \times BW = 0.05340 \times 48.0 \text{ in} = 2.6 \text{ in (65 mm)} \]

Figure 4.21

Example of calculating non standard belt edge distance from known idler, belt width and cross sectional area, A.
It is necessary to verify that the skirtboard width, $W_s$, is greater than the standard center roll effective width, $b_c \times BW$.

If $w_s > b_c$ recalculate $A_s$ (Equation 4.26) using:

$$b_{wmc} = \frac{b_s - b_c}{2 \times \cos(\beta)}$$

**Equation 4.25**

Standard skirtboard width vs. center roll effective width check

$$d_{ms} = \frac{A}{BW^2} - \frac{1}{4} b_s^2 \left( \frac{\Phi_s}{\sin(\Phi_s)^2} - \cot(\Phi_s) \right) - \frac{\sin(\beta)}{4} \frac{b_c^2 - b_s^2}{\cos(\beta)}$$

**Equation 4.26**

$d_{ms}$: Dimensionless ratio for calculating height of bulk material rubbing on skirtboards

$$D_{ms} = d_{ms} \times BW$$

**Equation 4.27**

$D_{ms}$: Height of bulk material rubbing on the skirtboards

$$d_s = \frac{b_s - b_c}{2} \tan(\beta) + b_{ms} + \frac{b_s}{2} \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right)$$

**Equation 4.28**

$d_s$: Dimensionless ratio for calculating maximum depth of material in the skirted profile
It is necessary to verify that the skirtboard width, $W_s$, is greater than the standard center roll effective width, $b_c \times BW$.

If $w_s > b_c$ recalculate $A_s$ (Equation 4.15) using: $b_{wmc} = \frac{w_s - b_c}{2 \times \cos(\beta)}$

**Equation 4.25**
Standard skirtboard width vs. center roll effective width check

$$d_{ms} = \frac{A}{BW^2} - \frac{1}{4} \times \frac{w_s^2}{w_s} \times \left( \frac{\Phi_s}{\sin(\Phi_s)^2} - \cot(\Phi_s) - \frac{\sin(\beta)}{4} \times \frac{b_c^2 - w_s^2}{\cos(\beta)} \right)$$

**Equation 4.26**
$d_{ms}$: Dimensionless ratio for calculating height of bulk material rubbing on skirtboards

$$D_{ms} = d_{ms} \times BW$$

**Equation 4.27**
$D_{ms}$: Height of bulk material rubbing on the skirtboards

$$d_s = \frac{w_s - b_c}{2} \times \tan(\beta) + d_{ms} + \frac{w_s}{2} \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right)$$

**Equation 4.28**
$d_s$: Dimensionless ratio for calculating maximum depth of material in the skirted profile
Example: Height of Bulk Material between Skirtboards, $D_s$ and $D_{ms}$

Given: $BW = 48.0$ inches, $\beta = 35$ degrees, $\Phi_s = 20$ degrees

From Figure 4.25 $b_c = 0.3762$, $b_s = 0.6667$, $A_s = 1.8$ ft$^2$, $W_s = 0.6667$

Calculate the height of material rubbing on the skirtboards:

$$d_{ms} = \frac{A_s}{BW} - \frac{1}{4} \times b_s^2 \times \left( \frac{\Phi_s}{\sin(\Phi_s)} - \cot(\Phi_s) \right) - \frac{\sin(\beta)}{4} \times \frac{(b_c^2 - b_s^2)}{\cos(\beta)}$$

$$= \frac{1.8 \times 144 \text{ in}^2}{(48.0)^2} - \frac{1}{4} \times 0.4445 \times \left( \frac{0.3491}{(0.3420)^2} - 2.7475 \right) - \frac{0.5736}{4} \times \frac{(0.3762^2 - (0.6667)^2)}{0.8192}$$

$$= 0.1125 - [0.1111 \times (0.2272) - (0.1434 \times 0.3699)] = (0.1125 - 0.07828) = 0.05133$$

$D_{ms} = d_{ms} \times BW = 0.05133 \times 48.0 = 2.5 \text{ in (62.5 mm)}$

Calculate the maximum depth of material between the skirtboards:

$$d_s = \frac{b_s - b_c}{2} \times \tan(\beta) + b_{ms} + \frac{b_s}{2} \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right)$$

$$= \frac{0.6667 - 0.3762}{2} \times 0.7002 + 0.05133 + \frac{0.6667}{2} \times \left( \frac{1}{0.3420} - \frac{1}{0.3640} \right)$$

$$= 0.1017 + 0.05133 + 0.05890 = 0.2119$$

$D_s = d_s \times BW = 0.2119 \times 48.0 = 10.2 \text{ in (232 mm)}$

The width, height and length of the skirtboards is defined by equations in this manual, but designers often make experience based choices to modify the recommended measurements. The width of the skirtboards is sometimes modified to accommodate a particular edge sealing design, installation of accessories such as, samplers or dust collection, or anticipated mistracking. Multiple loading points on a belt require either skirting the multiple load points as one continuous skirtboard, or making successive skirtboards wider in the direction of belt travel. The lump size discussion in this chapter governs the belt width and therefore the width between the skirtboards. Because the skirtboards are most often covered, the height of the skirtboard should be generous enough to handle the lump sizes, and to allow for the material volume in the turbulent loading area having a loose bulk density. The height and length of the skirtboard is often further modified to reduce air speed and increase air-flow dwell time in the transfer point, in an effort to aid in controlling dust exiting the skirtboarded area.
CAPACITIES, BELT WIDTHS AND SPEEDS

Example: Height of Bulk Material between Skirtboards, $D_s$ and $D_{ms}$

Given: $BW = 48.0$ inches, $\beta = 35$ degrees, $\Phi_s = 20$ degrees

From Figure 4.23 (or Figure 4.21 with $A = A_s$) $b_c = 0.3762$  $w_s = 0.6667$  $A_s = 1.8 \text{ ft}^2$

Calculate the height of material rubbing on the skirtboards:

$$d_{ms} = \frac{A_s}{BW^2} \left( \frac{1}{4} b_c^2 \times \left( \frac{\Phi_s}{\sin(\Phi_s)} - \cot(\Phi_s) \right) - \frac{\sin(\beta)}{4} \times \frac{(b_c^2 - b_s^2)}{\cos(\beta)} \right)$$

$$= \frac{1.8 \times 144 \text{ in}^2}{(48.0)^2} \times \left( \frac{1}{4} \times 0.4445 \times \left( \frac{0.3491}{(0.3420)^2} - (2.7475) \right) \right) - \frac{0.5736 \times \left( (0.3762)^2 - (0.6667)^2 \right)}{4}$$

$$= 0.05133$$

$$D_{ms} = d_{ms} \times BW = 0.05133 \times 48.0 = 2.5 \text{ in (62.5 mm)}$$

Calculate the maximum depth of material between the skirtboards:

$$d_s = \frac{w_s - b_s}{2} \times \tan(\beta) + \frac{w_s}{2} \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right)$$

$$= \frac{0.6667 - 0.3762}{2} \times 0.7002 + \frac{0.6667}{2} \times \left( \frac{1}{0.3420} - \frac{1}{0.3640} \right)$$

$$= 0.2119$$

$$D_s = d_s \times BW = 0.2119 \times 48.0 = 10.2 \text{ in (232 mm)}$$

Figure 4.29
Example calculation of height of bulk material on skirtboards and depth of material between skirtboards

The width, height and length of the skirtboards is defined by equations in this manual, but designers often make experience based choices to modify the recommended measurements. The width of the skirtboards is sometimes modified to accommodate a particular edge sealing design, installation of accessories such as, samplers or dust collection, or anticipated mistracking. Multiple loading points on a belt require either skirting the multiple load points as one continuous skirtboard, or making successive skirtboards wider in the direction of belt travel. The lump size discussion in this chapter governs the belt width and therefore the width between the skirtboards. Because the skirtboards are most often covered, the height of the skirtboard should be generous enough to handle the lump sizes, and to allow for the material volume in the turbulent loading area having a loose bulk density. The height and length of the skirtboard is often further modified to reduce air speed and increase air-flow dwell time in the transfer point, in an effort to aid in controlling dust exiting the skirtboarded area.
100% Full, Edge To Edge, Cross Sectional Area, $A_f$

Occasionally the conveyor will be loaded completely full edge to edge or 100% full. The structure supporting the conveyor system should be designed for the dead loads plus the live material load as if the belt were 100% full, rather than the design capacity assuming the material is loaded to the standard edge distance. For clarity and consistency new variables $b_i$, $d_i$ and $r_{schf}$ are introduced for calculations for a 100% full belt. For a 100% full belt, $b_{wc} = 0.0$ so $b_{w} = b_{w}$ and $b_{w}$ is used to calculate $A_f$ and $d_i$. The values for a 100% full belt could be obtained from the equations for $A_s$ with $b_{wc}$ set to zero.

![Figure 4.30](image)

**Figure 4.30**

$A_f$, Cross sectional area dimensionless nomenclature for 100% full, edge to edge, belt loading

$$r_{schf} = \frac{(1 - \cos(\beta)) \times b_w + \cos(\beta)}{2 \times \sin(\Phi_s)}$$

**Equation 4.31**

$r_{schf}$ Dimensionless ratio of radius of top of bulk material profile for 100% full, edge to edge, belt loading

$$A_f = 2 \times BW^2 \times \left[ r_{schf} \times \left( \frac{\Phi_s \times \sin(\Phi_s) \times \cos(\Phi_s)}{2} \right) + \frac{b_w \times b \times \sin(\beta)}{2} + b_w \times \frac{\sin(\beta) \times \cos(\beta)}{2} \right]^2$$

**Equation 4.32**

$A_f$, Cross sectional area of 100% full, edge to edge, belt loading

$$d_i = b_w \times \sin(\beta) + \left( \frac{b_w}{2} + b_w \times \cos(\beta) \right) \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right)$$

**Equation 4.33**

$d_i$, Dimensionless ratio for maximum depth of bulk material on 100% full, edge to edge, belt loading
100% Full, Edge To Edge, Cross Sectional Area, \( A_f \)

Occasionally the conveyor will be loaded completely full edge to edge or 100% full. The structure supporting the conveyor system should be designed for the dead loads plus the live material load as if the belt were 100% full, rather than the design capacity assuming the material is loaded to the standard edge distance. For clarity and consistency new variables \( b_t \), \( d_t \) and \( r_{schf} \) are introduced for calculations for a 100% full belt. For a 100% full belt, \( b_{we} = 0.0 \) so \( b_{we} = b_s \) and \( b_w \) is used to calculate \( A_f \) and \( d_t \). The values for a 100% full belt could be obtained from the equations for \( A_s \) with \( b_{we} \) set to zero.

**Figure 4.30**

\( r_{schf} \), Cross sectional area dimensionless nomenclature for 100% full, edge to edge, belt loading

\[
r_{schf} = \frac{(1 - \cos(\beta)) \times b_s + \cos(\beta)}{2 \times \sin(\Phi_s)}
\]

**Equation 4.31**

\( r_{schf} \) Dimensionless ratio of radius of top of bulk material profile for 100% full, edge to edge, belt loading

\[
A_t = 2 \times BW^2 \times \left[ r_{schf} \times \left( \frac{\Phi_s \times \sin(\Phi_s) \times \cos(\Phi_s)}{2} \right) + \left( \frac{b_s}{2} \times b_w \times \sin(\beta) \right) + b_w \times \frac{\sin(\beta) \times \cos(\beta)}{2} \right]
\]

**Equation 4.32**

\( A_t \), Cross sectional area of 100% full, edge to edge, belt loading

\[
d_t = b_w \times \sin(\beta) + \left( \frac{b_s}{2} + b_w \times \cos(\beta) \right) \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right)
\]

**Equation 4.33**

\( d_t \) Dimensionless ratio for maximum depth of bulk material on 100% full, edge to edge, belt loading
Example: 100% Full, Edge to Edge, Belt Cross Sectional Area, $A_f$

Given: $BW = 48.0$ inches, $\beta = 35$ degrees, $\Phi_e = 20$ degrees

From Figure 4.28

$$b_c = 0.3762 \quad b_w = 0.3119$$

$$f_{sclT} = \frac{(1 - \cos(\beta)) \times b_c + \cos(\beta)}{2 \times \sin(\Phi_e)}$$

$$= \frac{(1 - 0.8192) \times 0.3762 + 0.8192}{2 \times 0.3420} = \frac{0.06802 + 0.8192}{0.6840} = 1.2971$$

$$A_f = 2 \times BW^2 \times \left[ r_{scl} \times \left( \frac{\Phi_e}{2} \times \frac{\sin(\Phi_e) \times \cos(\Phi_e)}{2} \right) + \frac{b_c}{2} \times b_w \times \sin(\beta) + \frac{b_w^2}{2} \times \frac{\sin(\beta) \times \cos(\beta)}{2} \right]$$

$$= \frac{4608}{144 \text{ in}^2} \times \left[ 1.6825 \times \left( \frac{0.3491}{2} - \frac{0.3420 \times 0.9397}{2} \right) + 0.1881 \times 0.3119 \times 0.5736 + 0.09728 \times 0.2349 \right]$$

$$= 32.0 \times \left[ 1.6825 \times 0.01391 + 0.03365 + 0.02285 \right] = 32 \times 0.07990 = 2.6 \text{ ft}^2 (0.24 \text{ m}^2)$$

$$d_i = b_w \times \sin(\beta) + \left( \frac{b_c}{2} + b_w \times \cos(\beta) \right) \times \left( \frac{1}{\sin(\Phi_e)} - \frac{1}{\tan(\Phi_e)} \right)$$

$$= 0.3119 \times 0.5736 + \left( \frac{0.3762}{2} + 0.3119 \times 0.8192 \right) \times \left( \frac{1}{0.3420} - \frac{1}{0.3640} \right)$$

$$= 0.1789 + 0.4436 \times 0.1767 = 0.2573$$

$$D_i = d_i \times BW = 0.2573 \times 48.0 = 12.4 \text{ in} (314 \text{ mm})$$

Figure 4.37

Example calculations for 100% full, edge to edge, belt loading
Example: 100% Full, Edge to Edge, Belt Cross Sectional Area, \( A_f \)

Given: \( BW = 48.0 \) inches, \( \beta = 35 \) degrees, \( \Phi_s = 20 \) degrees

From Equations 4.11 and 4.13, \( b_v = 0.3762 \) \( b_w = 0.3119 \)

\[
f_{schf} = \frac{1 - \cos(\beta)}{2 \times \sin(\Phi_s)} = \frac{(1 - 0.8192) \times 0.3762 + 0.8192}{2 \times 0.3420} = \frac{0.06802 + 0.8192}{0.6840} = 1.2971
\]

\[
A_f = 2 \times BW^2 \times \left[ f_{schf} \times \left( \frac{\Phi_s}{2} \times \sin(\Phi_s) \times \cos(\Phi_s) \right) + \left( \frac{b_v^2}{2} \times b_v \times \sin(\beta) \right) + b_w^2 \times \frac{\sin(\beta) \times \cos(\beta)}{2} \right]
\]

\[
= \frac{4608}{144 \text{ in}^2} \times \left[ 1.6825 \times \left( \frac{0.3491}{2} - \frac{0.3420 \times 0.9397}{2} \right) + [0.1881 \times 0.3119 \times 0.5736] + 0.09728 \times 0.2349 \right]
\]

\[
= 32.0 \times [1.6825 \times 0.01391 + 0.03365 + 0.02285] = 32 \times 0.07990 = 2.6 \text{ ft}^2 (0.24 \text{ m}^2)
\]

\[
d_f = b_v \times \sin(\beta) + \frac{b_v^2}{2} + b_w \times \cos(\beta) \times \left( \frac{1}{\sin(\Phi_s)} - \frac{1}{\tan(\Phi_s)} \right)
\]

\[
= 0.3119 \times 0.5736 + \left( \frac{0.3762}{2} + 0.3119 \times 0.8192 \right) \times \left( \frac{1}{0.3420} - \frac{1}{0.3640} \right)
\]

\[
= 0.1789 + 0.4436 = 0.2573
\]

\[
D_f = d_f \times BW = 0.2573 \times 48.0 = 12.4 \text{ in} (314 \text{ mm})
\]

**Figure 4.37**
Example calculations for 100% full, edge to edge, belt loading
General Applications: Capacity Derating

In many applications loading is not uniform and even if running at 100% of CEMA standard capacity surges can result in chute pluggage, spillage and make it harder to control dust. When transferring from one conveyor to a common cause of transfer point spillage and plugging is the time it takes for the discharged load to settle down and reach the receiving belt speed and direction. It is common practice, in most applications, to derate the capacity of conveyors by using a capacity design factor, DF, of 1.18 (85% of CEMA standard capacity) to accommodate surge loading and to reduce dust, spillage, chute plugging and bulk material degradation.

Coal Fired Power Generating Plant: Capacity Derating

Lower belt speeds and derated capacities are often used for handling coal in coal fired power generating plants and handling other bulk materials subject to degradation and the hazards associated with spillage, leakage and dust generation. It is common practice not to load conveyors handling these bulk materials to their capacity in order to reduce degradation, accommodate surge loads and to reduce spillage and leakage due to mistracking. A capacity design factor, DF, of 1.25 (80% of CEMA standard cross sectional area) is often used in handling coal in coal and other dusty or degradable bulk materials.

Example: Capacity Derating

<table>
<thead>
<tr>
<th>Required capacity: Q = 2400 tph</th>
<th>Bulk Material Properties: $\gamma_m = \frac{90 \text{lbf}}{\text{ft}^2}$, $\Phi_s = 20 \text{deg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial design choices: BW = 48 in, $\beta = 35 \text{ deg}$, $V = 600 \frac{\text{ft}}{\text{min}}$, Angle of incline, $\theta = 0 \text{ deg}$</td>
<td></td>
</tr>
<tr>
<td>Calculate conveyed cross sectional area, A (Ref. Equation 4.5)</td>
<td></td>
</tr>
<tr>
<td>$A = \frac{Q}{V \times \gamma_m} = \frac{2400 \frac{\text{t}}{\text{h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times 2000 \frac{\text{lb}_f}{\text{t}}}{600 \frac{\text{ft}}{\text{min}} \times \frac{90 \text{ lbf}}{\text{ft}^2}} = \frac{80,000 \frac{\text{lb}_f}{\text{min}}}{54,000 \frac{\text{lb}_f}{\text{min}-\text{ft}^2}} = 1.48 \text{ ft}^2$</td>
<td></td>
</tr>
</tbody>
</table>

| Derate loading of cross section to 85%, DF = 1.18 |
| Minimum $A_s = A \times DF = 1.48 \text{ ft}^2 \times 1.18 = 1.75 \text{ ft}^2$ (0.16 m$^2$) |
| From Table 4.44 at $\beta = 35$ and $\Phi_s = 20 \text{ deg}$: 48-inch belt, $A_s = 1.804 \text{ ft}^2$ (0.168 m$^2$) |
| The initial design choice (BW = 48 in and $V = 600 \text{ fpm}$) appears appropriate from a capacity standpoint |

Figure 4.38
Capacity derating example
General Applications: Capacity Derating
In many applications loading is not uniform and even if running at 100% of CEMA standard capacity surges can result in chute pluggage, spillage and make it harder to control dust. When transferring from one conveyor to a common cause of transfer point spillage and plugging is the time it takes for the discharged load to settle down and reach the receiving belt speed and direction. It is common practice in most applications, to derate the capacity of conveyors by using a capacity design factor, $DF$, of 1.18 (85% of CEMA standard capacity) to accommodate surge loading and to reduce dust, spillage, chute plugging and bulk material degradation.

Coal Fired Power Generating Plant: Capacity Derating
Lower belt speeds and derated capacities are often used for handling coal in coal fired power generating plants and handling other bulk materials subject to degradation and the hazards associated with spillage, leakage and dust generation. It is common practice not to load conveyors handling these bulk materials to their capacity in order to reduce degradation, accommodate surge loads and to reduce spillage and leakage due to mistracking. A capacity design factor, $DF$, of 1.25 (80% of CEMA standard cross sectional area) is often used in handling coal in coal and other dusty or degradable bulk materials.

Example: Capacity Derating

- **Required capacity:** $Q = 2400$ tph
- **Bulk Material Properties:** $\gamma_m = 90 \frac{\text{lbf}}{\text{ft}^3}$, $\Phi_s = 20$ deg

- **Initial design choices:** $BW = 48$ in, $\beta = 35$ deg, $V = 600 \frac{\text{ft}}{\text{min}}$

- **Angle of incline, $\theta = 0$ deg

**Calculate conveyed cross sectional area, $A$ (Ref. Equation 4.5)**

$$A = \frac{Q}{V \times \gamma_m} = \frac{2400 \text{ tph} \times \frac{1}{60} \text{ h}}{600 \text{ ft/min} \times 90 \frac{\text{lbf}}{\text{ft}^3}} = \frac{80,000 \text{ lbf/min}}{54,000 \frac{\text{lbf}}{\text{min/ft}^2}} = 1.48 \text{ ft}^2$$

- **Derate loading of cross section to 85%, $DF = 1.18$**

- **Minimum $A_e = A \times DF = 1.48 \text{ ft}^2 \times 1.18 = 1.75 \text{ ft}^2$ (0.16 m$^2$)**

- **From Table 4.43 at $\beta = 35$ and $\Phi_s = 20$ deg: 48-inch belt, $A_e = 1.804 \text{ ft}^2$ (0.168 m$^2$)**

- **The initial design choice (BW = 48 in and V = 600 fpm) appears appropriate from a capacity standpoint**

---

**Figure 4.38**
Capacity derating example
Step No. 3: $K_2$ Effect Of Load On Predicted Bearing $L_{10}$ Life

When Calculated Idler Load (CIL or CIL$_k$) is less than the CEMA load rating of the class of idler selected, the bearing $L_{10}$ life will increase.

![Figure 5.30](image)

$K_2$, Effect of load on predicted bearing $L_{10}$ life (dimensionless)

Step No. 4: $K_{3A}$ Effect Of Belt Speed On Predicted Bearing $L_{10}$ Life

CEMA $L_{10}$ life ratings are based on 500 rpm. Slower speeds increase life and faster speeds decrease life. Figure 5.31 shows this relationship.

![Figure 5.31](image)

$K_{3A}$, Effect of belt speed on predicted bearing $L_{10}$ life (dimensionless)
Step No. 3: $K_2$ Effect Of Load On Predicted Bearing $L_{10}$ Life

When Calculated Idler Load ($CIL$ or $CIL_k$) is less than the CEMA load rating of the class of idler selected, the bearing $L_{10}$ life will increase.

![Figure 5.30](image)

$K_2$, Effect of load on predicted bearing $L_{10}$ life (dimensionless)

Step No. 4: $K_{3A}$ Effect Of Belt Speed On Predicted Bearing $L_{10}$ Life

CEMA $L_{10}$ life ratings are based on 500 rpm. Slower speeds increase life and faster speeds decrease life. Figure 5.31 shows this relationship.

![Figure 5.31](image)

$K_{3A}$, Effect of belt speed on predicted bearing $L_{10}$ life (dimensionless)
Energy Related Tensions, $\sum \Delta T_n$

Gravity

A specific and often major source of belt tension is the work involved with inclined or declined conveyance paths due to the potential energy change in the bulk material and belt for a height change $H_n$. The tension is sensitive to the direction of travel so that with uphill movement the tension increases and a downhill or negative slope angle causes reduction in this component of tension along the conveyance direction as gravity pulls the conveyor down the slope.

Gravity or potential energy is considered to have a continuous effect on tension along the length of any slope from earth horizontal. It should be observed that the weight of the carry side belt and the return side belt cancel each other out from the perspective of total conveyor $T_c$ but need to be included in circuit calculations to identify the local tension at any point.

\[
\Delta T_{Hn} = H_n \times (W_b + W_m)
\]

*Equation 6.14*
Flight tension change due to elevate or lower, $(-H_n)$, the belt and the load.

Where:

\[
\Delta T_{Hn} = \text{Tension change in fligh "n" due to lift}
H_n = \text{Elevation change in flight "n"}
W_b = \text{Weight of the belt per unit length from manufacturer}
W_m = \text{Weight of the bulk material on the belt per unit length}
\]

Add $\Delta T_{H5} = H_5 \times (W_b + W_m) = 44.0 \text{ ft} \times \left(26.3 \frac{\text{lbf}}{\text{ft}} + 138.9 \frac{\text{lbf}}{\text{ft}}\right) = 7,268.8 \text{ lbf (3,304 kgf)}$

*Figure 6.15*
Example calculation of tension needed to elevate material in flight 5

For flights including belt curves in a vertical plane (See Chapter 9) use $H_n$ as the net change in elevation for that entire flight.

Bulk Material Acceleration

Work or kinetic energy must be provided to the bulk material to accelerate it to match the speed of the belt. The accelerating force is provided by the belt through an increase in tension at the loading point(s) in the direction of belt movement. Using the amount of Kinetic Energy added to the bulk material allows the calculation of belt tension effects without concern for the acceleration rate or the dynamics involved with impact, although these can be important issues for belt and chute wear and material degradation.
Energy Related Tensions, $\sum \Delta T_{nEnergy}$

Gravity

A specific and often major source of belt tension is the work involved with inclined or declined conveyance paths due to the potential energy change in the bulk material and belt for a height change $H_n$. The tension is sensitive to the direction of travel so that with uphill movement the tension increases and a downhill or negative slope angle causes reduction in this component of tension along the conveyance direction as gravity pulls the conveyor down the slope.

Gravity or potential energy is considered to have a continuous effect on tension along the length of any slope from earth horizontal. It should be observed that the weight of the carry side belt and the return side belt cancel each other out from the perspective of total conveyor $T_e$ but need to be included in circuit calculations to identify the local tension at any point.

$$\Delta T_{H_n} = H_n \times (W_b + W_m)$$

Equation 6.14

$\Delta T_{H_n}$ Flight tension change due to elevate or lower, $(+H_n)$, the belt and the load.

Where:

- $\Delta T_{H_n}$ = Tension change in flight "n" due to lift
- $H_n$ = Elevation change in flight "n"
- $W_b$ = Weight of the belt per unit length from manufacturer
- $W_m$ = Weight of the bulk material on the belt per unit length

$$\Delta T_{H_5} = H_5 \times (W_b + W_m) = 52.9 \text{ ft} \times (26.3 \text{ lbf/ft} + 138.9 \text{ lbf/ft}) = 8,738.4 \text{ lbf (3,958 kgf)}$$

Figure 6.15

Example calculation of tension needed to elevate material in flight 5

For flights including belt curves in a vertical plane (See Chapter 9) use $H_n$ as the net change in elevation for that entire flight.

Bulk Material Acceleration

Work or kinetic energy must be provided to the bulk material to accelerate it to match the speed of the belt. The accelerating force is provided by the belt through an increase in tension at the loading point(s) in the direction of belt movement. Using the amount of Kinetic Energy added to the bulk material allows the calculation of belt tension effects without concern for the acceleration rate or the dynamics involved with impact, although these can be important issues for belt and chute wear and material degradation.
Skirtboard Seal Friction

A skirt seal which rides on the belt is commonly used to contain dust and small particles. The calculation predicts the resistance as the product of a friction factor and the unit normal force between the moving belt and the seal without influence from the material loading. The values are provided below apply to a generic rubber edge seal as shown in Figure 6.20 for flight “n” that is sealed along its full length on both sides.

![Figure 6.20](image)

**Figure 6.20**
Skirtboard seal drag on conveyor belt

\[
\Delta T_{ssn} = C_{ss} \times L_n \times R_{rss}
\]

**Equation 6.21**
\( \Delta T_{ssn} \) Calculation of skirtboard seal drag

Where:
- \( \Delta T_{ssn} \) = Tension change due to belt sliding on skirtboard sealed flight, "n"
- \( C_{ss} \) = 2 \( \times \) \( m_{ss} \) \( \times \) \( F_{ss} \) \( \times \) \( R_{rss} \) Frictional resistance to the belt movement
- \( \mu_{ss} \) = Sliding friction coefficient between belt and seal rubber (dimensionless)
- \( F_{ss} \) = Effective normal force between belt and seal
- \( R_{rss} \) = Modifying Factor (dimensionless)

\[
L_1 = 15.0 \text{ ft} \quad \mu_{ss} = 1.0 \quad F_{ss} = 3.0 \text{ lbf/ft} \quad R_{rss} = 1.0
\]

\[
C_{ss} = 2 \times 1.0 \times 3.0 \text{ lbf/ft} \times 1.0 = 6.0 \text{ lbf/ft}
\]

\[
\Delta T_{ss1} = C_{ss} \times L_1 \times R_{rss} = 6.0 \text{ lbf/ft} \times 15.0 \text{ ft} \times 1.0 = 90.0 \text{ lbf (40.9 kgf)}
\]

**Figure 6.22**
\( \Delta T_{ss1} \) Skirtboard seal example calculation

Various specialty sealing products are available to perform this function with varying performance, life and drag. Typical values for design are \( \mu_{ss} = 1.0 \) and \( F_{ss} = 3.0 \text{ lbf/ft} \) (4.5 kgf/m) of skirt seal for conventional slab rubber skirt board seals shown in Figure 6.20. \( C_{ss} \) is calculated by multiplying by a factor of 2 because it is assumed that both sides of the belt have a skirt seal. Therefore an estimate of 6.0 lbf/ft (9.0 kgf/m).
Skirtboard Seal Friction
A skirt seal which rides on the belt is commonly used to contain dust and small particles. The calculation predicts the resistance as the product of a friction factor and the unit normal force between the moving belt and the seal without influence from the material loading. The values are provided below apply to a generic rubber edge seal as shown in Figure 6.20 for flight “n” that is sealed along its full length on both sides.

\[
\Delta T_{sn} = C_{ss} \times L_n \times R_{rss}
\]

**Equation 6.21**
\(\Delta T_{sn} \) Calculation of skirtboard seal drag

Where:

\(\Delta T_{sn} = \) Tension change due to belt sliding on skirtboard sealed flight, "n"

\(C_{ss} = 2 \times \mu_{ss} \times F_{ss} \times R_{rss}\) Frictional resistance to the belt movement

\(\mu_{ss} = \) Sliding friction coefficient between belt and seal rubber (dimensionless)

\(F_{ss} = \) Effective normal force between belt and seal

\(R_{rss} = \) Modifying Factor (dimensionless)

\[
L_1 = 15.0 \text{ ft} \quad \mu_{ss} = 1.0 \quad F_{ss} = 3.0 \text{ lbf/ft} \quad R_{rss} = 1.0
\]

\[
C_{ss} = 2 \times 1.0 \times 3.0 \text{ lbf/ft} \times 1.0 = 6.0 \text{ lbf/ft}
\]

\[
\Delta T_{ss1} = C_{ss} \times L_1 \times R_{rss} = 6.0 \text{ lbf/ft} \times 15.0 \text{ ft} \times 1.0 = 90.0 \text{ lbf} \ (40.9 \text{ kgf})
\]

**Figure 6.22**
\(\Delta T_{ss1}\) Skirtboard seal example calculation

Various specialty sealing products are available to perform this function with varying performance, life and drag. Typical values for design are \(\mu_{ss} = 1.0\) and \(F_{ss} = 3.0 \text{ lbf/ft} \ (4.5 \text{ kgf/m})\) of skirt seal for conventional slab rubber skirt board seals shown in Figure 6.20. \(C_{ss}\) is calculated by multiplying by a factor of 2 because it is assumed that both sides of the belt have a skirt seal. Therefore an estimate of 6.0 lbf/ft (9.0
Figure 6.24
Drag from a single idler roll

\[ \Delta T_r = \left[ K_v \times R_{nv} \times (N \cdot 500 \text{ rpm}) + K_s \times R_{ns} \right] \times \frac{2}{D_r} \]

Equation 6.25
\( \Delta T_r \), Drag from a single idler roll

\[ \Delta T_{isn} = K_{ir} \times \Delta T_r \times \frac{n_r}{S_{ir}} \times L_n \]

Equation 6.26
\( \Delta T_{isn} \), Idler seal friction
Figure 6.24
Drag from a single idler roll

\[
\Delta T_r = [K_r \times R_{s v} \times (N \cdot 500 \text{ rpm}) + K_s \times R_{s i}] \times \frac{2}{D_r}
\]

**Equation 6.25**
\(\Delta T_r\) Drag from a single idler roll

\[
\Delta T_{isn} = K_{ir} \times \Delta T_r \times \frac{n_i}{S_{ni}} \times L_n
\]

**Equation 6.26**
\(\Delta T_{isn}\) Idler seal friction
Where:

- $\Delta T_r$ = Change in tension for single roll from idler seal resistance (lbf (N))
- $\Delta T_{sn}$ = Change in tension in flight "n" from idler seal resistance (lbf (N))
- $D_r$ = Idler roll diameter (mm)
- $K_W$ = Slope of torsional speed curve per roll (lbf-in/rpm) (N-m/rpm) Table 6.29
- $K_s$ = Seal torsional resistance per roll at 500 rpm (lbf-in (N-m) Table 6.29
- $K_T$ = Temperature correction factor (dimensionless) Figure 6.27
- $K_{Tb}$ = Curve fit constants for temperature correction ($R^{-1}(K^{-1})$)

Note: $R = \text{Rankine}, K = \text{Kelvin}$

- $L_n$ = Length of flight "n" (ft (m))
- $n_r$ = Number of rolls per idler set
- $N_i$ = Actual rpm of idler based on diameter and belt speed (rpm)
- $R_{is}$ = Modifying Factor for seal torsional resistance (dimensionless)
- $R_{iv}$ = Modifying Factor for torsional speed effect (dimensionless)
- $S_{in}$ = Carrying or return idler spacing in flight "n" (ft (m))

![Figure 6.27](image-url)

**Figure 6.27**

$K_T$, Temperature correction factor curve for CEMA C, D and E idler rolls

Ambient temperature has a significant impact on idler seal drag and it is accounted for by the multiplying factor, $K_T$. CEMA Member products have been independently tested and the equations published reflect seal drag change with temperature. This comparison of results with the CEMA Historical correction is graphically shown in Figure 6.27. CEMA published $K_T$ values should only be used with published $K_s$ and $K_{Tb}$ values. Testing shows designs can vary widely and using design specific $K_T$ or $K_{Tb}$ values with the $K_s$ calculated by equations in Figure 6.32 can misrepresent true performance.
Where:

\[ \Delta T_r = \text{Change in tension for single roll from idler seal resistance, lbf (N)} \]
\[ \Delta T_{sn} = \text{Change in tension in flight "n" from idler seal resistance, lbf (N)} \]
\[ D_r = \text{Idler roll diameter, in (mm)} \]
\[ K_{iw} = \text{Slope of torsional speed curve per roll, lbf-in/rpm (N-m/rpm)} \]
\[ K_s = \text{Seal torsional resistance per roll at 500 rpm, lbf-in (N-m)} \]
\[ K_{IT} = \text{Temperature correction factor (dimensionless)} \]
\[ K_{ITb} = \text{Curve fit constants for temperature correction, } [R^{-1}(K^{-1})] \]
\[ L_n = \text{Length of flight "n", ft (m)} \]
\[ n_r = \text{Number of rolls per idler set} \]
\[ N_i = \text{Actual rpm of idler based on diameter and belt speed, rpm} \]
\[ R_{is} = \text{Modifying Factor for seal torsional resistance (dimensionless)} \]
\[ R_{iv} = \text{Modifying Factor for torsional speed effect (dimensionless)} \]
\[ S_{in} = \text{Carrying or return idler spacing in flight "n", ft (m)} \]

Figure 6.27

\( K_{IT} \), Temperature correction factor curve for CEMA C, D and E idler rolls

Ambient temperature has a significant impact on idler seal drag and it is accounted for by the multiplying factor, \( K_{IT} \). CEMA Member products have been independently tested and the equations published reflect seal drag change with temperature. This comparison of results with the CEMA Historical correction is graphically shown in Figure 6.27. CEMA published \( K_{IT} \) values should only be used with published \( K_s \) and \( K_{ITb} \) values. Testing shows designs can vary widely and using design specific \( K_s \) or \( K_{ITb} \) values with the \( K_{IT} \) calculated by equations in Figure 6.32 can misrepresent true performance.
There are no generally available tabulated indentation values for various belt constructions for either the small or large sample methods. CEMA does not endorse any particular method so long as it accurately predicts the indentation resistance on a single idler for different temperatures and loads and can be used to determine $\Delta T_{bin}$ for specific belt constructions being considered in the conveyor design.

Indentation loss is usually a major factor on long overland conveyors. The magnitude of the indentation loss for short horizontal or inclined conveyors is usually not a significant loss component in the total tension requirement. While the indentation qualities of the belt covers are an important consideration for energy consumption, it is important to balance other requirements for the cover design such as abrasion resistance or flame retardancy when considering rubber compounds including a low rolling resistance (LRR) conveyor belt cover.

$$\Delta T_{bin} = K_{bir} \times c_{wd} \times (W_o + W_m) \times L_n \times R_{tx}$$

*Equation 6.37*

$\Delta T_{bin}$, Tension increase from viscoelastic indentation reaction between roller and belt

![Area Distribution](image)

![Equivalent Load Distribution](image)

Two methods for $K_{bin}$ are provided for the small sample ($K_{bin,S}$) and large sample ($K_{bin,L}$) methods. To arrive at $\Delta T_{bin}$, it is necessary to adjust for the uneven loading (Figure 6.38) on the rollers to arrive at an average pressure between the belt and roller. The equation for $c_{wd}$ is derived from the geometry of the cross sectional area based on the load area, $A$ and represents a correction to the average line load, $w_{lw}$.

$$c_{wd} = 1.239 + 0.10866 \times X_{ld} + 0.00500 \times (3 - 0.00476) \times BW - 0.00263 \times \phi_s$$

*Equation 6.39*

$c_{wd}$, Load distribution factor

$$X_{ld} = \gamma_{m} \times S_i \times X_{ld,ref}$$

$$X_{ld,ref} = 5.22 \text{ lbf/in}^2 \left(36,000 \frac{N}{mm^2}\right)$$

*Equation 6.40*

$X_{ld}$, Loading pressure adjustment factor
There are no generally available tabulated indentation values for various belt constructions for either the small or large sample methods. CEMA does not endorse any particular method so long as it accurately predicts the indentation resistance on a single idler for different temperatures and loads and can be used to determine $\Delta T_{bin}$ for specific belt constructions being considered in the conveyor design.

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$$\Delta T_{bin} = K_{bi R} \times c_{wd} \times (W_o + W_m) \times L_i \times R_{tx}$$

Equation 6.37

$\Delta T_{bin}$, Tension increase from viscoelastic indentation reaction between roller and belt

Two methods for $K_{bi R}$ are provided for the small sample ($K_{bi r-S}$) and large sample ($K_{bi r-L}$) methods. To arrive at $\Delta T_{bin}$ it is necessary to adjust for the uneven loading (Figure 6.38) on the rollers to arrive at an average pressure between the belt and roller. The equation for $c_{wd}$ is derived from the geometry of the cross sectional area based on the load area, $A$ and represents a correction to the average line load, $w_{lw}$.

$$c_{wd} = 1.239 + 0.10866 \times X_{ld} + 0.00500 \times \beta - 0.00476 \times BW - 0.00263 \times \phi_s$$

Equation 6.39

$c_{wd}$, Load distribution factor

$$X_{ld} = \gamma_m \times \frac{S}{X_{ldw}}$$

$$X_{ldw} = 5.22 \frac{lbf}{in^2} \left(36,000 \frac{N}{m^2}\right)$$

Equation 6.40

$X_{ld}$, Loading pressure adjustment factor
Where:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T_{bin}$</td>
<td>Tension increase from viscoelastic deformation of belt cover rubber</td>
</tr>
<tr>
<td>$K_{bR-S}$</td>
<td>Viscoelastic characteristic of belt cover rubber from the small sample method Equation 6.42</td>
</tr>
<tr>
<td>$K_{bR-L}$</td>
<td>Viscoelastic characteristic of belt cover rubber from the large sample method Equation 6.60</td>
</tr>
<tr>
<td>$C_{wd}$</td>
<td>Load distribution factor (dimensionless)</td>
</tr>
<tr>
<td>$R_{bi}$</td>
<td>Modifying factor (dimensionless)</td>
</tr>
<tr>
<td>$S_i$</td>
<td>Idler spacing [ft (m)]</td>
</tr>
<tr>
<td>$X_{ld}$</td>
<td>Loading pressure adjustment factor (dimensionless)</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Troughing angle (deg)</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td>Surcharge angle (deg)</td>
</tr>
<tr>
<td>$\gamma_m$</td>
<td>Bulk density of conveyed material</td>
</tr>
</tbody>
</table>

Small Sample Indentation Loss Method

Rubber indentation energy loss varies with the idler roll's indentation into the belt cover thickness and, with the nominal deformation work as affected by the idler roll radius and the normal load. Just as important is the degree to which the rubber reacts elastically to return the energy of deformation to the system. This is affected by the rubber composition, the amount of deformation or strain, the rubber temperature and, to a lesser degree, the belt speed. The rubber composition is a design variable through the viscoelastic concepts of Storage Modulus and Loss Modulus with their ratio, known as tan delta, as an index of the rubber's loss characteristic. These properties are best obtained from harmonic testing and vary with frequency, temperature and strain, paralleling the idler indentation of interest. The loss may be then considered to be the area within the steady cycles of stress and strain along the transient path of the indentation.

The contribution of the rubber material is incorporated into the indentation prediction with $K_{bR-S}$. In effect, it sets the width of the ellipse in Figure 6.41. For a particular rubber, the applicable value varies with the temperature, belt speed and loading. This requires a series of calculations with application details and a set of numerical values for the particular rubber. Constants for several example rubber cover compounds are provided for evaluation and consideration. Belt manufacturer should be contacted for selection, application and specification of compounds for specific applications.
Where:

\[
\begin{align*}
\Delta T_{bin} &= \text{Tension increase from viscoelastic deformation of belt cover rubber} \\
K_{bR-S} &= \text{Viscoelastic characteristic of belt cover rubber from the small sample method \ Equation 6.42} \\
K_{bR-L} &= \text{Viscoelastic characteristic of belt cover rubber from the large sample method \ Equation 6.57} \\
C_{wd} &= \text{Load distribution factor (dimensionless)} \\
R_{bi} &= \text{Modifying factor (dimensionless)} \\
S_{i} &= \text{Idler spacing [ft (m)]} \\
X_{la} &= \text{Loading pressure adjustment factor (dimensionless)} \\
\beta &= \text{Troughing angle (deg)} \\
\phi_s &= \text{Surcharge angle (deg)} \\
\gamma_m &= \text{Bulk density of conveyed material}
\end{align*}
\]

**Small Sample Indentation Loss Method**

Rubber indentation energy loss varies with the idler roll’s indentation into the belt cover thickness and, with the nominal deformation work as affected by the idler roll radius and the normal load. Just as important is the degree to which the rubber reacts elastically to return the energy of deformation to the system. This is affected by the rubber composition, the amount of deformation or strain, the rubber temperature and, to a lesser degree, the belt speed. The rubber composition is a design variable through the viscoelastic concepts of Storage Modulus and Loss Modulus with their ratio, known as tan delta, as an index of the rubber’s loss characteristic. These properties are best obtained from harmonic testing and vary with frequency, temperature and strain, paralleling the idler indentation of interest. The loss may be then considered to be the area within the steady cycles of stress and strain along the transient path of the indentation.

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**Figure 6.41**

Harmonic stress/strain cycle
The contribution of the rubber material is incorporated into the indentation prediction with $K_{lbr,s}$. In effect, it sets the width of the ellipse in Figure 6.41. For a particular rubber, the applicable value varies with the temperature, belt speed and loading. This requires a series of calculations with application details and a set of constant values for the particular rubber. Constants for several example rubber cover compounds are provided for evaluation and consideration. Belt manufacturer should be contacted for selection, application and specification of compounds for specific applications.

$$F = \frac{b_1 + [b_2 \times (x_F)] + [b_3 \times (x_F^2)] + [b_4 \times (x_F^3)]^2}{b_5 + [b_6 \times (x_F)] + x_F^2} \quad \text{(dimensionless)}$$

**Equation 6.44**

F, Normalized indentation factor

Where:

$$x_F = \frac{- C_1 \times (T - T_0)}{C_2 + (T - T_0)} + \log(v_u) \cdot s \quad \text{(dimensionless)}$$

$$s = a_i + [a_2 \times (x_s)] + [a_3 \times (x_s^2)] + [a_4 \times (x_s^3)] \quad \text{(dimensionless)}$$

$T = \text{Operating temperature (°C)}$

$v_u = \text{Belt speed} \left( \frac{m}{s} \right) \quad \text{Note: } v_u \text{ must be in } \frac{m}{s} \text{ units in } x_F \text{ equation}$

$$x_s = \left( \frac{w_{iw}}{w_{max}} \right)^{1/3} \quad \text{(dimensionless)}$$

$d_m$ from Equation 4.17 for $D_m$ using A from Equation 4.5 for $A_s$

$w_{max} = 285.5 \frac{\text{lbf}}{\text{in}} \left( \frac{50,000 \ \text{N}}{\text{m}} \right)$

Note:

For constants $a_i$, $b_i$, $C_i$, $C_2$ and $T_0$ see Table 6.47

$$w_{iw} = \frac{D_m \times \gamma_m + \frac{W_b}{BW}}{S_i} \quad \text{(dimensionless)}$$

**Equation 6.45**

$w_{iw}$, Maximum line load at belt center

Where:

$BW = \text{Belt width in (mm)}$

$D_m = \text{Maximum depth of material on three roll idler in (mm)}$

$\gamma_m = \text{Bulk density } \frac{\text{lbf}}{\text{ft}^2} \left( \frac{\text{kgf}}{\text{m}^2} \right)$

$S_i = \text{Idler spacing ft (m)}$

$W_b = \text{Belt weight per unit length } \frac{\text{lbf}}{\text{ft}} \left( \frac{\text{N}}{\text{m}} \right)$
The contribution of the rubber material is incorporated into the indentation prediction with $K_{birs}$. In effect, it sets the width of the ellipse in Figure 6.41. For a particular rubber, the applicable value varies with the temperature, belt speed and loading. This requires a series of calculations with application details and a set of constant values for the particular rubber. Constants for several example rubber cover compounds are provided for evaluation and consideration. Belt manufacturer should be contacted for selection, application and specification of compounds for specific applications.

\[
F = \frac{b_1 + [b_2 \times (x_F)] + [b_3 \times (x_F^2)] + [b_4 \times (x_F^3)]}{b_5 + [b_6 \times (x_F)] + x_F^2} \quad \text{(dimensionless)}
\]

**Equation 6.44**

\(F\), Normalized indentation factor

Where:

\[
x_F = \frac{-C_1 \times (T - T_0)}{C_2 + (T - T_0)} + \log(v_u) \cdot s \quad \text{(dimensionless)}
\]

\(s = a_1 + [a_2 \times (x_s)] + [a_3 \times (x_s^2)] + [a_4 \times (x_s^3)] \quad \text{(dimensionless)}
\]

\(T = \) Operating temperature (°C)

\(v_u = \) Belt speed \(\left(\frac{m}{s}\right)\) \(\text{Note: } v_u \text{ must be in } \frac{m}{s} \text{ units in } x_F \text{ equation}\)

\[x_s = (\frac{w_{max}}{w_{max}})^{1/3} \quad \text{(dimensionless)}\]

With: $d_m$ from Equation 4.17 for $D_m$ using $A$ from Equation 4.5 for $A_s$,

\(\gamma_m = \) bulk density, \(S_i = \) idler spacing

\(w_{max} = 285.5 \text{ lbf in}^{-1} \left(\frac{50,000 \text{ N}}{m}\right)\)

**Note:**

For constants $a_i$, $b_i$, $C_i$, $C_2$ and $T_0$ see Table 6.47

\[
w_{\text{in}} = \left[\frac{D_m \times \gamma_m + \frac{W_e}{BW}}{BW} \right] \times S_i
\]

**Equation 6.45**

\(w_{\text{in}}\), Maximum line load at belt center

Where:

\(BW = \) Belt width in (mm)

\(D_m = \) Maximum depth of material on three roll idler in (mm)

\(\gamma_m = \) Bulk density \(\frac{\text{lbf}}{ft^2} \left(\frac{\text{kgf}}{m^2}\right)\)

\(S_i = \) Idler spacing ft (m)

\(W_e = \) Belt weight per unit length \(\frac{\text{lbf}}{ft} \left(\frac{N}{m}\right)\)
P = \frac{c_1 + [c_2 \times (x_p^2)] + [c_3 \times (x_p^3)] + [c_4 \times (x_p^4)]}{c_5 + [c_6 \times (x_p)] + x_p^2} \quad \text{(dimensionless)}

x_p = \frac{-C_1 \times (T - T_0)}{C_2 + (T - T_0)} + \log(v_u) \quad \text{(dimensionless)}

Notes:
For constants c_i see Table 6.48
For constants C_1, C_2 and T_0 see Table 6.47

\textbf{Equation 6.46}

P, Rubber strain level adjustment

Where:

\( T = \text{Operating temperature (°C)} \)

\( v_u = \text{Belt speed} \left( \frac{m}{s} \right) \quad \text{[Note: } v_u \text{ must be in } \frac{m}{s} \text{ units in } x_p \text{ equation]} \)

Temperature and belt speed are reflected in \( F \), while \( P \) adjusts the linear viscoelastic properties to the actual loading strain which is commonly in the range of nonlinear stress strain behavior.

A full set of constants representative of four types of example cover rubbers are provided in Tables 6.47 and 6.48. These constants are intended to approximate the performance of commercially available classes of conveyor belt rubber covers.

<table>
<thead>
<tr>
<th>Constant</th>
<th>Default Rubber</th>
<th>Type 1 Rubber</th>
<th>Type 2 Rubber</th>
<th>Type 3 Rubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_0 (°C)</td>
<td>-3.024038</td>
<td>-3.979867</td>
<td>-0.030701</td>
<td>0.005</td>
</tr>
<tr>
<td>E_0 (N/m²)</td>
<td>9945456</td>
<td>9757293</td>
<td>11035707</td>
<td>12468384</td>
</tr>
<tr>
<td>C_1</td>
<td>17.45185</td>
<td>23.24667</td>
<td>29.37737</td>
<td>25.41034</td>
</tr>
<tr>
<td>C_2</td>
<td>177.2557</td>
<td>169.8751</td>
<td>214.4231</td>
<td>179.3597</td>
</tr>
<tr>
<td>a_1</td>
<td>-0.35429</td>
<td>-0.421415</td>
<td>-0.35429</td>
<td>-0.336227</td>
</tr>
<tr>
<td>a_2</td>
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<td>4.865202</td>
<td>4.06002</td>
<td>3.859253</td>
</tr>
<tr>
<td>a_3</td>
<td>-4.54043</td>
<td>-5.748855</td>
<td>-4.54043</td>
<td>-4.195092</td>
</tr>
<tr>
<td>a_4</td>
<td>1.92861</td>
<td>2.47541</td>
<td>1.92861</td>
<td>1.826561</td>
</tr>
<tr>
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<td>1.053392</td>
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</tr>
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<td>b_3</td>
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<td>b_4</td>
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<tr>
<td>b_6</td>
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<td>-12.840972</td>
<td>-4.58769</td>
<td>-4.674162</td>
</tr>
</tbody>
</table>

\textbf{Table 6.47}

Constants for Equation 6.44, K_{str,b} F factor
Equation 6.46

\[ P = \frac{c_1 + [c_2 \times (x_p)] + [c_3 \times (x_p^2)] + [c_4 \times (x_p^3)]}{c_5 + [c_6 \times (x_p)] + x_p^2} \] (dimensionless)

\[ x_p = \frac{-C_1 \times (T - T_0)}{C_2 + (T - T_0)} + \log(v_u) \] (dimensionless)

Notes:
For constants \( c_i \), see Table 6.48
For constants \( C_1, C_2 \) and \( T_0 \), see Table 6.47

Where:

\[ T = \text{Operating temperature (°C)} \]
\[ v_u = \text{Belt speed (m/s)} \] [Note: \( v_u \) must be in \( \text{m/s} \) units in \( x_F \) equation]

Temperature and belt speed are reflected in \( F \), while \( P \) adjusts the linear viscoelastic properties to the actual loading strain which is commonly in the range of nonlinear stress strain behavior.

A full set of constants representative of four types of example cover rubbers are provided in Tables 6.47 and 6.48. These constants are intended to approximate the performance of commercially available classes of conveyor belt rubber covers.

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<th>Type 2 Rubber</th>
<th>Type 3 Rubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_0, (^\circ \text{C}) )</td>
<td>-3.024038</td>
<td>-3.979867</td>
<td>-0.03070089</td>
<td>0.005</td>
</tr>
<tr>
<td>( E_0 ) (N/m²)</td>
<td>9945456</td>
<td>9757293</td>
<td>11035707</td>
<td>12468384</td>
</tr>
<tr>
<td>( C_1 )</td>
<td>17.45185</td>
<td>23.24667</td>
<td>29.37737</td>
<td>25.41034</td>
</tr>
<tr>
<td>( C_2 )</td>
<td>177.2557</td>
<td>169.8751</td>
<td>214.4231</td>
<td>179.3597</td>
</tr>
<tr>
<td>( a_1 )</td>
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<td>-0.421415</td>
<td>-0.323058087</td>
<td>-0.336227</td>
</tr>
<tr>
<td>( a_2 )</td>
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<td>4.865202</td>
<td>3.644338997</td>
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</tr>
<tr>
<td>( a_3 )</td>
<td>-4.54043</td>
<td>-5.748855</td>
<td>-3.392291798</td>
<td>-4.195092</td>
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<tr>
<td>( a_4 )</td>
<td>1.92861</td>
<td>2.47541</td>
<td>1.302375425</td>
<td>1.826561</td>
</tr>
<tr>
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<td>0.048174509</td>
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<td>22.77865292</td>
<td>8.698437</td>
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<tr>
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<td>-12.840972</td>
<td>-8.787259779</td>
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</tr>
</tbody>
</table>

Table 6.47

Constants for Equation 6.44, \( K_{sr-s} F \) factor
## c_i Intervals:
Each c_i constant is linearly interpolated for w_{ref} relative to the seven levels of w_{ref} and extrapolated past the last row.

<table>
<thead>
<tr>
<th>Cover Compound</th>
<th>w_{ref} (N/m)</th>
<th>c_1</th>
<th>c_2</th>
<th>c_3</th>
<th>c_4</th>
<th>c_5</th>
<th>c_6</th>
</tr>
</thead>
<tbody>
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<td>0.000441</td>
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<td>0.000214</td>
<td>39.279478</td>
<td>-12.129204</td>
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Table 6.48
Constants for Equation 6.46, K_{br.s} P factor at several w_{ref} values

Type 2 constants are for typical rubber cover compounds while Type 3 constants may also apply to cover compounds for common covers for more conservative designs that operate at lower temperatures. Type 1 constants are for a low rolling resistance rubber cover compound considered for applications where indentation losses are a significant contributor to the belt tension. These, especially, must be specified and verified by the manufacturer to apply to final designs. The default constants are intended for designs
**Table 6.48**

<table>
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<tr>
<th>Cover Compound</th>
<th>( w_{\text{ref}} ) (N/m)</th>
<th>( c_1 )</th>
<th>( c_2 )</th>
<th>( c_3 )</th>
<th>( c_4 )</th>
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**c_i Intervals:**

Each \( c_i \) constant is linearly interpolated for \( w_{\text{ref}} \) relative to the seven levels of \( w_{\text{ref}} \) and extrapolated past the last row.

**Type 2 constants** are for typical rubber cover compounds while **Type 3 constants** may also apply to cover compounds for common covers for more conservative designs that operate at lower temperatures. **Type 1 constants** are for a low rolling resistance rubber cover compound considered for applications where indentation losses are a significant contributor to the belt tension. These, especially, must be specified and verified by the manufacturer to apply to final designs. The default constants are intended for designs.
**Small Sample Indentation Loss Example**

The following example of the small sample method for belt cover indentation loss is divided into several steps for clarity. The example calculation is for the carrying run of flight 2 for the conveyor described in Tables 6.11 and 6.13 and, Figure 6.12. As with other example calculations rounding of intermediate results can have a minor affect on the final results.

<table>
<thead>
<tr>
<th>Belt Cover Indentation Loss Example Assumptions</th>
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<tr>
<td><strong>Design capacity:</strong> Q = 2,500 tph</td>
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<td><strong>Belt width:</strong> BW = 48 in</td>
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<td><strong>Cover thickness in contact with the rollers:</strong> ( h_b = 0.375 ) in</td>
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<td><strong>Unit weight of the belt,</strong> ( W_b = 26.3 ) lbf/ft, fabric belt</td>
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<td><strong>Default rubber cover compound,</strong> ( E_0 = 9,945,456 ) N/m² = ( 207,715 ) lbf/ft²</td>
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<td><strong>Belt speed:</strong> ( V = 600 ) ft/min, ( v_u = 3.05 ) m/s</td>
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<tr>
<td><strong>Three equal roll troughing idler angle:</strong> ( \beta = 35 ) deg</td>
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<tr>
<td><strong>Idler roll diameter:</strong> ( D_i = 6.0 ) in</td>
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<tr>
<td>**Idler spacing ( S_i = 5.0 ) ft</td>
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<tr>
<td><strong>Bulk material surcharge angle:</strong> ( \phi_s = 20 ) deg</td>
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<tr>
<td><strong>Material bulk density:</strong> ( \gamma_m = 90 ) lb/ft³</td>
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<td><strong>Operating temperature:</strong> ( T_f = 15 ) °F ( ( -9.4 ) °C)</td>
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<tr>
<td><strong>Length of the flight:</strong> ( L_2 = 500 ) ft</td>
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Constants used in \( \Delta T_{bin} \) calculation: \( w_{max} = 285.5 \) lbf/in, \( X_{dref} = 5.22 \) psi

**Figure 6.50**

\( \Delta T_{u2} \). Example small sample method cover indentation loss assumptions for flight 2
Small Sample Indentation Loss Example
The following example of the small sample method for belt cover indentation loss is divided into several steps for clarity. The example calculation is for the carrying run of flight 2 for the conveyor described in Tables 6.11 and 6.13 and, Figure 6.12. As with other example calculations rounding of intermediate results can have a minor affect on the final results.

Belt Cover Indentation Loss Example Assumptions
Design capacity: \( Q = 2,500 \text{ tph} \)
Belt width: \( BW = 48 \text{ in} \)
Cover thickness in contact with the rollers: \( h_0 = 0.375 \text{ in} \)
Unit weight of the belt, \( W_b = 26.3 \frac{\text{lbf}}{\text{ft}} \) fabric belt
Default rubber cover compound, \( E_a = 9,945,456 \frac{N}{m^2} = 207,715 \frac{\text{lbf}}{\text{in}^2} \)
Belt speed: \( V = 600 \frac{\text{ft}}{\text{min}} \), \( V_t = 3.05 \frac{\text{m}}{\text{s}} \)
Three equal roll troughing idler angle: \( \beta = 35 \text{ deg} \)
Idler roll diameter: \( D_i = 6.0 \text{ in} \)
Idler spacing \( S_i = 5.0 \text{ ft} \)
Bulk material surcharge angle: \( \lambda \approx 20 \text{ deg} \)
Material bulk density: \( \gamma_m = 90 \frac{\text{lbf}}{\text{ft}^3} \)
Operating temperature: \( T = 15^\circ \text{F} (-9.4^\circ \text{C}) \)
Length of the flight: \( L = 500 \text{ ft} \)

Constants used in \( \Delta T_{\text{min}} \) calculation: \( W_{\text{max}} = 285.5 \frac{\text{lbf}}{\text{in}}, \ X_{\text{shelf}} = 5.22 \text{ psi} \)

Figure 6.50
\( \Delta T_{bi2} \), Example small sample method cover indentation loss assumptions for flight 2
Figure 6.52

\[ \Delta T_{w2} \] Example F calculation
Figure 6.52
ΔT_w2: Example F calculation

**Calculate F:**

\[ F = \frac{b_1 + b_2 \times (x_1) + b_3 \times (x_1^2) + b_4 \times (x_1^3)}{b_3 + b_4 \times (x_1) + x_1^2} \]

\[ x_r = \frac{-C_1 \times (T - T_0)}{C_2 + (T - T_0)} + \log(v_r) \cdot s \quad \left[ T = -9.4 \, ^\circ C \text{ and } V = 600 \, \frac{ft}{min} \right. \text{ or } 3.05 \frac{m}{s} \quad \therefore \, v_r = 3.05 \]

\[ s = a_1 + a_2 \times (x_1) + a_3 \times (x_1^2) + a_4 \times (x_1^3) \]

\[ w_w = \left( D_n \times \gamma_n + \frac{W}{BW} \right) \times S = \left\{ \frac{90 \, \text{lbf}}{1728 \, \text{ft}^2} + \frac{26.3 \, \text{lbf}}{12 \, \text{in}} \right\} \times 5 \, \text{ft} \times 12 \, \text{in} = 0.504 \, \text{lbf in} \times 60 \, \text{in} = 30.24 \, \text{lbf in} \]

\[ x_s = \left( \frac{w_w}{W_{\text{max}}} \right)^{\frac{1}{3}} = 0.473 \]

From Table 6.47 for Default Rubber: \( C_1 = 17.45185, C_2 = 177.2557, T_0 = -3.024038 \, ^\circ C \)

\( b_1 = 1.053392, b_2 = -0.182956, b_3 = 0.026214, b_4 = -0.002687, b_5 = 13.072109, b_6 = -4.58769 \)

\( a_1 = -0.35429, a_2 = 4.06002, a_3 = -4.54043, a_4 = 1.92861 \)

\[ s = a_1 + a_2 \times (x_1) + a_3 \times (x_1^2) + a_4 \times (x_1^3) = -0.35429 + 4.06002 \times (0.475) - 4.54043 \times (0.473)^2 + 1.92861 \times (0.473)^3 \]

\[ = -0.35429 + 1.92039 - 1.01583 + 0.20409 = 0.754 \]

\[ x_r = \frac{-c_1 \times (T - T_0)}{c_2 + (T - T_0)} + \log(v_r) \cdot s = \frac{-17.45185 \times (-9.4 \, ^\circ C - (-3.024038 \, ^\circ C))}{177.2557 + (-9.4 \, ^\circ C - (-3.024038 \, ^\circ C))} + \log(3.05) - s \]

\[ = \frac{112.047}{170.835} + \log(3.048) - 0.754 = 0.656 + 0.484 - 0.754 = 0.386 \]

\[ F = \frac{b_1 + b_2 \times (x_1) + b_3 \times (x_1^2) + b_4 \times (x_1^3)}{b_3 + b_4 \times (x_1) + x_1^2} \]

\[ = \frac{1.053392 \times 0.182956 \times (0.386) + 0.026214 \times (0.386)^2 - 0.002687 \times (0.386)^3}{13.072109 \times 4.58769 \times (0.386) + (0.386)^2} \]

\[ = \frac{1.053392 \times 0.003906 - 0.000155}{13.072109 \times 1.770848 + 0.148996} = 0.98652 = 0.0862 \]
Figure 6.53
\[
\Delta T_{bc}, \text{ Example P calculation}
\]
Figure 6.53
\[ \Delta T_{bo} \text{ Example P calculation} \]
\[
\Delta T_{bl2} = K_{bhS-S} \times X \times (W_b + W_m) \times c_{wa} \times L_2 \times R_{wa}
\]

Calculate \( P_{j2} \):

\[
W_m = \frac{Q}{V} = \frac{2500 \text{ t}}{60 \text{ min}} \times \frac{2000 \text{ lbf}}{60 \text{ min}} = 138.9 \text{ lbf/ft}
\]

\[
P_{j2} = \left( \frac{W_b + W_m}{E_n \times \left( \frac{D}{2} \right)^2 \times BW} \right)^{\frac{3}{4}} = \left( \frac{26.3 \text{ lbf/ft} + 138.9 \text{ lbf/ft}}{207,715 \text{ ft}^2} \times 5 \text{ ft} \times \frac{0.375 \text{ in}}{12 \text{ in/ft}} \right)^{\frac{3}{4}} = \left( \frac{25.81 \text{ lbf-ft}}{51,928.75 \text{ lbf-ft}} \right)^{\frac{3}{4}} = 0.0792
\]

Calculate \( K_{bhS-S} \):

Copy here \( K_{bhS-S} \) formula only

For fabric belts: \( c_{wa} = 2.0 \), \( c_{wc} = 1.2 \)

\[
BW = 48 \text{ in.} \quad \text{and} \quad \phi \text{ units} = \text{degrees}
\]

\[
X_{wa} = \frac{\gamma_{wa} \times S_n \times h_n}{5.22 \text{ psi} \times 5 \text{ ft} / \text{lbf} \times 144 \text{ in}^2 / \text{ft}^2} = 0.599
\]

Calculate \( \Delta T_{bl2} \):

Use \( R_{wa} = 1.0 \)

\[
c_{wa} = \left[ 1.239 + 0.10866 \times X_{wa} + 0.005 \times (\beta) \times 0.00476 \times (BW) \times 0.00263 \times (\phi_{c2}) \right] \neq \left[ 1.239 + 0.10866 \times 0.599 + 0.005 \times (35) \times 0.00476 \times (48) \times 0.00263 \times (20) \right] \neq 1.239 + 0.0651 + 0.1750 \times 0.2285 \times 0.0526 = 1.198
\]

\[
K_{bhS-S} = \frac{F \times c_{wa} \times c_{wc}}{0.0862 \times 0.794} \times 2.0 \times 1.2 = 0.026
\]

\[
\Delta T_{bl2} = K_{bhS-S} \times X \times (W_b + W_m) \times c_{wa} \times L_2 \times R_{wa} = 0.026 \times 0.0206 \times \left( \frac{26.3 \text{ lbf/ft}}{138.9 \text{ lbf/ft}} \right) \times 1.198 \times 500 \text{ ft} \times 1.0 = 2041 \text{ lbf} (927 \text{ kgf}) \text{ or } 4.08 \text{ lbf/ft} \text{ for flight 2}
\]

Note:

\( K_{bhS-S} \times X = 0.026 \) can be considered an equivalent indentation loss friction factor for the carrying run of flight 2 with the default rubber.

\[
\Delta T_{bl2} = 2041 \text{ lbf} (927 \text{ kgf}) \text{ or } 4.08 \text{ lbf/ft}
\]

**Figure 6.54**

\( \Delta T_{bl2} \): Example \( P_{j2} \) calculation and final \( \Delta T_{bl2} \) small sample method result
Figure 6.54
\[ \Delta T_{b2} \] Example \( P_{j2} \) calculation and final \( \Delta T_{b2} \) small sample method result

\[
\Delta T_{b2} = K_{bR-S} \times (W_b + W_m) \times c_{wf} \times L_2 \times R_{nf}
\]

Calculate \( P_{j2} \):

\[
w_m = \frac{Q}{V} = \frac{2500 \frac{t}{h} \times 2000 \frac{lbf}{ft}}{60 \frac{min}{h}} = 138.9 \frac{lbf}{ft}
\]

\[
P_{j2} = \left[ (W_b + W_m) \times S_m \times h_b \right]^{\frac{1}{3}}
\]

\[
= \left[ \frac{207.715 \frac{lbf}{ft^2}}{2 \times 12 \frac{in}{ft}} \times \frac{6.0 \frac{in}{ft}}{2 \times 12 \frac{in}{ft}} \times \frac{48 \frac{in}{ft}}{2 \times 12 \frac{in}{ft}} \right]^{\frac{1}{3}} = 25.81 \text{ lbf-ft}^{\frac{1}{3}}
\]

Calculate \( K_{bR-S} \):

\[
K_{bR-S} = \frac{F}{P} \times c_{sd} \times c_{bc} \times P_{j2}
\]

For fabric belts: \( c_{sd} = 2.0, c_{bc} = 1.2 \)

\[
K_{bR-S} = \frac{F}{P} \times c_{sd} \times c_{bc} \times P_{j2} = \frac{0.0862}{0.794} \times 2.0 \times 1.2 \times 0.0792 = 0.02064
\]

Calculate \( \Delta T_{b2} \):

Use \( R_{nf} = 1.0 \)

\[
X_{id} = \frac{\gamma_m \times S_i}{5.22 \text{ psi}} = \frac{90 \frac{lbf}{ft^2} \times 5 \text{ ft}}{5.22 \frac{lb}{in^2} \times 144 \frac{in^2}{ft^2}} = 0.599
\]

\[
c_{wf} = \left[ 1.239 + 0.10866 \times X_{id} + 0.005 \times (\beta) - 0.00476 \times (BW) - 0.00263 \times (\psi_b) \right]
\]

\[
= \left[ 1.239 + 0.10866 \times 0.599 + 0.005 \times 35 - 0.00476 \times 48 - 0.00263 \times 0 \right]
\]

\[
= 1.239 + 0.0651 + 0.1750 - 0.2285 - 0.0526 = 1.198
\]

\[
\Delta T_{b2} = K_{bR-S} \times (W_b + W_m) \times c_{wf} \times L_2 \times R_{nf} = 0.0206 \times \left( \frac{26.3 \frac{lbf}{ft}}{L_2} + \frac{138.9 \frac{lbf}{ft}}{L_2} \right) \times 1.198 \times 500 \text{ ft} \times 1.0 = 2.042 \text{ lbf}
\]

Note:

\( K_{bR-S} = 0.0206 \) can be considered an equivalent indentation loss friction factor for the carrying run of flight 2 with the default rubber.
Where:

\[ K_{\text{int-L}} = \text{Large sample method friction factor (dimensionless)} \]
\[ w_{\text{IRR}} = \text{Indentation loss from a single idler roll [lbf/im (N/mm)]} \]
\[ w_{\text{RL}} = \text{Width related load [lbf/im (N/mm)]} \]

\( w_{\text{RL}} \) used in the large sample method is the average line load on the belt as applied by the test roll and seen on the operating idler.

Measured values of \( w_{\text{IRR}} \) and \( w_{\text{RL}} \) on a steel cord belts with conventional (Type I) rubber and with LRR (Type II) rubber are tabulated for various temperatures in Table 6.61. Typical reults are illustrated in Figure 6.64. This table contain measurements from two real rubbers that are in common use today. \( K_{\text{biT}} \) values for these two rubbers are shown as a calculated result in Table 6.63. The small and large sample methods results are comparable but note that the large and small sample examples provided are for different rubbers and meant to be illustrative of the indentation phenomenon for typical rubber compounds. (Note: the data sets used in the large and small sample method examples are not for the same rubbers.) For final conveyor designs, actual test data from a test loop with the actual installed rubber should be used.

The width related load in the conveyor a designer is analyzing is computed using the following expression:

\[ w_{\text{RL}} = \frac{(W_b + W_m) \times S_i}{\text{BW}} \]

**Equation 6.59**

\( W_{\text{RL}} \): Width related load factor

Where:

\( \text{BW} = \text{Belt Width of the conveyor being evaluated} \)
\( S_i = \text{Idler spacing in the flight being evaluated} \)
\( W_b = \text{Weight of the belt per unit length} \)
\( W_m = \text{Weight of the bulk mateiral per unit length} \)

To determine the indentation resistance on a section of conveyor the designer simply finds the \( K_{\text{biT}} \) in the table that corresponds to the temperature, and computed the width related load on a particular section of conveyor.

The indentation resistances recorded in Table 6.63 were measured in a 219 mm (8.62 in) diameter idler roll pressed into a steel cord belt with 7 mm (0.28 in) bottom covers. To predict losses when idler diameters and belt cover thicknesses that are different from those tested, the designer can multiply \( K_{\text{biT}} \) by a constant, \( c_{\text{hr}} \), defined as follows:

\[ c_{\text{hr}} = \left( \frac{h_b}{H_{\text{test}}} \right)^{0.25} \left( \frac{D_r}{D_{\text{test}}} \right)^{0.7} \]

**Equation 6.60**

\( c_{\text{hr}} \): Modification factor for idler diameter and cover thickness
Where:

- \( K_{\text{L-L}} \) = Large sample method friction factor (dimensionless)
- \( w_{\text{RRIR}} \) = Indentation loss from a single idler roll [lbf/in (N/mm)]
- \( w_{\text{RL}} \) = Width related load [lbf/in (N/mm)]

\( w_{\text{RL}} \) used in the large sample method is the average line load on the belt as applied by the test roll and seen on the operating idler.

Measured values of \( w_{\text{RRIR}} \) and \( w_{\text{RL}} \) on a steel cord belts with conventional (Type I) rubber and with LRR (Type II) rubber are tabulated for various temperatures in Table 6.61. Typical results are illustrated in Figure 6.64. This table contain measurements from two real rubbers that are in common use today. \( K_{\text{L-L}} \) values for these two rubbers are shown as a calculated result in Table 6.63. The small and large sample methods results are comparable but note that the large and small sample examples provided are for different rubbers and meant to be illustrative of the indentation phenomenon for typical rubber compounds. (Note: the data sets used in the large and small sample method examples are not for the same rubbers.) For final conveyor designs, actual test data from a test loop with the actual installed rubber should be used.

The width related load in the conveyor a designer is analyzing is computed using the following expression:

\[
w_{\text{RL}} = \frac{(W_b + W_m) \times S_i}{BW}
\]

Equation 6.59

\( w_{\text{RL}} \) = Width related load factor

Where:

- \( BW \) = Belt Width of the conveyor being evaluated
- \( S_i \) = Idler spacing in the flight being evaluated
- \( W_b \) = Weight of the belt per unit length
- \( W_m \) = Weight of the bulk material per unit length

To determine the indentation resistance on a section of conveyor the designer simply finds the \( K_{\text{L-L}} \) in the table that corresponds to the temperature, and computed the width related load on a particular section of conveyor.

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\[
c_{hr} = \left( \frac{h_b}{H_{\text{test}}} \right)^{0.25} \left( \frac{D_r}{D_{\text{test}}} \right)^{0.7}
\]

Equation 6.60

\( c_{hr} \) = Modification factor for idler diameter and cover thickness
Shaft Sizing

Shafts are sized using both a Stress Limit and Deflection Limit. If there is an overhung load, it needs to be included in the Stress Limit calculations. The shaft is sized using the Stress Limit and then the Deflection limit. Then whichever gives the larger shaft size governs. The diameter is then increased to the next standard shaft size.

Shaft Sizing By Stress Limit

Equation 8.33 is given in CEMA B105.1 for the diameter of a pulley shaft loaded in bending and torsion (drive pulley with no overhung load) is:

\[
D = \sqrt{\frac{32 \times F.S.}{\pi}} \times \sqrt[4]{\frac{3}{4} \times \left( \frac{T}{S_f} \right)^2 + \left( \frac{M}{S_i} \right)^{1.5}}
\]

Equation 8.33

D, Shaft size based on stress

Where:

- \( D \) = Shaft Diameter  [in (mm)]
- \( F.S. \) = Factor of Safety = 1.5  (dimensionless)
- \( S_i \) = Corrected shaft fatigue limit = \( k_a \times k_b \times k_c \times k_d \times k_e \times S_f \)
- \( k_a \) = Surface factor = 0.8 for machined shaft  (dimensionless)
- \( k_b \) = Size factor = \((D)^{0.19}\) for \( D \) in inches or \( 1.85 \times (D)^{-0.19} \) for \( D \) in mm (used as dimensionless)
- \( k_c \) = Reliability factor = 0.897  (dimensionless)
- \( k_d \) = Temperature factor = 1.0  for -70 °F (-57 °C) to +400 °F (+204 °C) (dimensionless)
- \( k_e \) = Duty cycle factor = 1.0  provided cyclic stresses do not exceed \( S_f \)  (dimensionless)
- \( k_f \) = Miscellaneous factor = 1.0 for normal service (dimensionless)
- \( M \) = Bending moment  [lbf-in (N-mm)]
- \( T \) = Torsional moment.  [lbf-in (N-mm)]

### Table 8.34

<table>
<thead>
<tr>
<th>Steel</th>
<th>Profil Keyway</th>
<th>Sled Runner Keyway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annealed &lt;200 BHN</td>
<td>0.63</td>
<td>0.77</td>
</tr>
<tr>
<td>Quenched and drawn &gt;200 BHN</td>
<td>0.50</td>
<td>0.63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steel</th>
<th>( S_f^* ) psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAE 1018 &lt; 200 BHN</td>
<td>29,000 (200)</td>
</tr>
<tr>
<td>SAE 1045 &lt; 200 BHN</td>
<td>41,000 (283)</td>
</tr>
<tr>
<td>SAE 4140 , 200 BHN annealed</td>
<td>47,500 (328)</td>
</tr>
</tbody>
</table>

Table 8.35

\( S_f^* \) 50% of ultimate tensile strengths for typical pulley shaft materials
Shaft Sizing

Shafts are sized using both a Stress Limit and Deflection Limit. If there is an overhung load, it needs to be included in the Stress Limit calculations. The shaft is sized using the Stress Limit and then the Deflection limit. Then whichever gives the larger shaft size governs. The diameter is then increased to the next standard shaft size.

Shaft Sizing By Stress Limit

Equation 8.33 is given in CEMA B105.1 for the diameter of a pulley shaft loaded in bending and torsion (drive pulley with no overhung load) is:

\[
D = \sqrt[32 \times F.S. \pi x \left( \frac{M}{S_f} \right)^2 + \frac{3}{4} \left( \frac{T}{S_f} \right)^2}
\]

**Equation 8.33**

D, Shaft size based on stress

Where:

- **D** = Shaft Diameter [in (mm)]
- **F.S.** = Factor of Safety = 1.5 (dimensionless)
- **S_f** = Corrected shaft fatigue limit = \( k_a \times k_b \times k_c \times k_d \times k_e \times S_f^* \)
- **k_a** = Surface factor = 0.8 for machined shaft (dimensionless)
- **k_b** = Size factor = \((D)^{-0.19}\) for D in inches or \(1.85 \times (D)^{-0.19}\) for D in mm (used as dimensionless)
- **k_c** = Reliability factor = 0.897 (dimensionless)
- **k_d** = Temperature factor = 1.0 for -70°F (-57°C) to +400°F (+204°C) (dimensionless)
- **k_e** = Fatigue stress concentration factor due to keyway (dimensionless)
- **k_g** = Miscellaneous factor = 1.0 for normal service (dimensionless)
- **M** = Bending moment [lbf-in (N-mm)]
- **T** = Torsional moment [lbf-in (N-mm)]

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</tr>
<tr>
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<td>0.63</td>
</tr>
</tbody>
</table>

**Table 8.34**

Fatigue stress concentration factors for typical pulley keyway configurations

<table>
<thead>
<tr>
<th>50% of Tabulated Ultimate Tensile Strength, ( S_f^* )</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
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</tr>
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</tr>
<tr>
<td>SAE 4140 , 200 BHN annealed</td>
</tr>
</tbody>
</table>

**Table 8.35**

\( S_f^* \) 50% of ultimate tensile strengths for typical pulley shaft materials
φ, can be determined through shear cell testing and hopper geometry. Conservative values for φ for free flowing bulk solids are 70 to 80 degrees. The shearing force for simple feeder designs handling free flowing bulk solids can be estimated by calculating the volume of surcharge material above the shear plane, calculating the weight and applying the coefficient of internal friction of the material. For complex hopper or feeder designs consult a CEMA Member company for advice.

For consolidated materials the volume of the bulk material is:

\[
V_{fs} = \frac{1}{2} \times \left( \frac{b_1 + b_2}{2} \right) \times \left( \frac{h_1 + h_2}{2} \right) \times L_h
\]

**Equation 12.75**

\[V_{fs}, \text{ Consolidated pressure volume}\]

\[
Q_i = V_{fs} \times \gamma_m
\]

**Equation 12.76**

\[Q_i, \text{ Load on feeder belt}\]
ϕ, can be determined through shear cell testing and hopper geometry. Conservative values for ϕ for free flowing bulk solids are 70 to 80 degrees. The shearing force for simple feeder designs handling free flowing bulk solids can be estimated by calculating the volume of surcharge material above the shear plane, calculating the weight and applying the coefficient of internal friction of the material. For complex hopper or feeder designs consult a CEMA Member company for advice.

\[
V_{fs} = \frac{1}{2} \times \left( \frac{b_1 + b_2}{2} \right) \times \left( \frac{h_1 + h_2}{2} \right) \times L_h
\]

\textbf{Equation 12.75}

\( V_{fs} \), Consolidated pressure volume

\[
Q_i = V_{fs} \times \gamma_m
\]

\textbf{Equation 12.76}

\( Q_i \), Load on feeder belt
**Fundamental Force-Velocity Relationships**

Fundamentally, if the tangential velocity is \( V_t \), and if \( g \) is the acceleration due to gravity; \( r_s \) is the radial distance from the center of the pulley to the center of mass (i.e., the cross-sectional center of gravity of the material load shape); and \( W \) is the gravity weight force of the material acting at the center of mass, then the centrifugal force acting at the center of mass of the material is as follows:

\[
\text{Centrifugal Force} = \frac{W \times V_t^2}{g \times r_s}
\]

**Equation 12.92**

Centrifugal force

When this centrifugal force equals the radial component of the material weight force, \( W \), the material will no longer be supported by the belt and will commence its trajectory. At just what angular position around the pulley this will occur is governed by the slope of the conveyor at the discharge and pulley is described for the following three conditions: horizontal, inclined and declined conveyor trajectories. Equation 12.92 can be re-written to provide and expression used to determine where the material will start its trajectory.

\[
\text{Centrifugal Force} = \frac{V_s^2}{W} \times \frac{g \times r_s}{r_s}
\]

**Equation 12.93**

Relationship used to determine trajectory starting point, \( e_t \)

If \( \frac{V_{belt}^2}{g \times r_s} > 1.0 \) then \( V_s = V \), If no then: If \( \frac{V_{cg}^2}{g \times r_s} < 1.0 \) then: \( V_s = V_{cg} \), If no then: \( V_s = \sqrt{g \times r_s} \)

**Figure 12.94**

Test used to determine the tangential velocity, \( V_s \), used for plotting the trajectory

**Belt Trajectory Nomenclature**

- \( a_t \) = Distance from the belt to the center of gravity of the load shape
- \( c_{cg} \) = Center of gravity of the cross section of the load shape
- \( e_t \) = Point where the material leaves the belt
- \( g \) = Acceleration due to gravity
- \( h \) = Distance from the belt to the top of the load shape
- \( r_p \) = Radius of the pulley
- \( r_s \) = Radius from the center of pulley to the cross-sectional center of gravity of the load shape
- \( t \) = Thickness of the belt
- \( V \) = Belt speed
- \( V_s \) = Tangential velocity, fps, of the cross-sectional area center of gravity of the load shape
- \( W \) = Weight of bulk material acting at center of gravity
- \( \gamma \) = Angle between pulley vertical centerline and point \( e_t \) (degrees)
- \( \phi \) = Angle of incline of the belt conveyor to the horizontal (degrees)

**Figure 12.95**

Discharge trajectory nomenclature
Fundamental Force-Velocity Relationships

Fundamentally, if the tangential velocity is $V_s$, and if $g$ is the acceleration due to gravity; $r_s$ is the radial distance from the center of the pulley to the center of mass (i.e., the cross-sectional center of gravity of the material load shape); and $W$ is the gravity weight force of the material acting at the center of mass, then the centrifugal force acting at the center of mass of the material is as follows:

$$\text{Centrifugal Force} = \frac{W \times V_s^2}{g \times r_s}$$

Equation 12.92
Centrifugal force

When this centrifugal force equals the radial component of the material weight force, $W$, the material will no longer be supported by the belt and will commence its trajectory. At just what angular position around the pulley this will occur is governed by the slope of the conveyor at the discharge and pulley is described for the following three conditions: horizontal, inclined and declined conveyor trajectories. Equation 12.92 can be re-written to provide and expression used to determine where the material will start its trajectory.

$$\frac{\text{Centrifugal Force}}{W} = \frac{V_s^2}{g \times r_s}$$

Equation 12.93
Relationship used to determine trajectory starting point, $e_t$

If $\frac{V_{s_{\text{belt}}}^2}{g \times r_s} > 1.0$ then $V_s = V$, If no then : If $\frac{V_{s_{\text{cg}}}^2}{g \times r_s} < 1.0$ then: $V_s = V_{cg}$, If no then: $V_s = \sqrt{g \times r_s}$

Figure 12.94
Test used to determine the tangential velocity, $V_s$, used for plotting the trajectory

Belt Trajectory Nomenclature

- $a_1$ = Distance from the belt to the center of gravity of the load shape
- $c_g$ = Center of gravity of the cross section of the load shape
- $e_t$ = Point where the material leaves the belt
- $g$ = Acceleration due to gravity
- $h$ = Distance from the belt to the top of the load shape
- $r_p$ = Radius of the pulley
- $r_s$ = Radius from the center of pulley to the cross-sectional center of gravity of the load shape
- $t$ = Thickness of the belt
- $V$ = Belt speed
- $V_s$ = Velocity of the load cross section used for plotting the trajectory
- $W$ = Weight of bulk material acting at center of gravity
- $\gamma$ = Angle between pulley vertical centerline and point $e_t$ (degrees)
- $\phi$ = Angle of incline of the belt conveyor to the horizontal (degrees)

Figure 12.95
Discharge trajectory nomenclature
Declined Belt Conveyor Discharge Case 7

If the tangential speed is insufficient to make the material leave the belt at the initial point of tangency of the belt and pulley, the material will follow partly around the pulley. Tangential velocity, \( V_s \), is used for plotting the trajectory.

\[
\frac{V_s^2}{g \times r_s} > 1.0
\]

Equation 12.108
Discharge trajectory velocity test for case 7

These symbols should be lower case.
Declined Belt Conveyor Discharge Case 7

If the tangential speed is insufficient to make the material leave the belt at the initial point of tangency of the belt and pulley, the material will follow partly around the pulley. Tangential velocity, \( V_s \), is used for plotting the trajectory.

\[
\frac{V_s^2}{g \times r_s} > 1.0
\]

Equation 12.108
Discharge trajectory velocity test for case 7

Figure 12.109
Discharge trajectory case 7
PLOTTING THE TRAJECTORY

Before the trajectory of the discharged material can be plotted, it is necessary to calculate the values of \( V_s \) and \( r_s \) in order to solve the expression 12.94. If the value of expression 12.94 is less than 1.0 the trajectory starts at the position defined by the point of tangency between the belt and the pulley and the velocity used for plotting is the design belt speed, \( V \). If expression 12.94 is equal to or greater than 1.0 then the trajectory starts at a position other than the point of tangency between the belt and pulley and the velocity at the center of gravity, \( V_s \), is used for plotting the trajectory.

\[
a_1 = \text{Distance above the belt surface of the center of gravity of the cross-section shape of the load, at the point where the pulley is tangent to the belt}
\]

\[
h = \text{Distance above the belt surface of the top of the load, at the point where the belt is tangent to the pulley}
\]

\[
r_p = \text{Radius of the outer surface of the pulley and lagging}
\]

\[
r_s = \text{Radius from the center of the pulley to the center of gravity of the circular segment load cross section}
\]

\[
t = \text{Thickness of the belt}
\]

\[
V_s = \text{Velocity at the center of gravity of the load cross section used for plotting the trajectory:}
\]

1. Belt velocity is used as the velocity of the material at its center of mass if discharge point is at the tangency of the belt-to-discharge pulley (\( V \)).

2. Velocity of the material at its center of mass is used as the velocity of the material for all other conditions of discharge after the point of belt-to-discharge pulley tangency. (\( V_{cg} \)).

**Figure 12.110**
Trajectory plotting nomenclature

\[
r_s = a_1 + t + r_p
\]

**Equation 12.111**
\( r_s \), Radius from pulley center to load cross section center of gravity

The values of \( a_1 \) and \( h \) have been tabulated for the various belt widths, idler end roll angles, and surcharge angles, for troughed conveyor belts loaded to the standard edge distance \( 0.055 \times \text{BW} + 0.9 \text{ inch} \) \( (0.055 \times \text{BW}+23 \text{ mm}) \), as listed in Table 4.4. \( V_s \) should never be calculated from the nominal speed of the belt. It is also necessary to find the height of the flattened load of material on the belt, so that the upper limit of the material path can be plotted. The tangential velocity, \( V_s \), in distance per second, should be calculated from the relation:

\[
V = \frac{2 \times \pi \times (r_p + t) \times \text{rpm of discharge pulley}}{60}
\]

\[
V_{cg} = \frac{2 \times \pi \times r_s \times \text{rpm of discharge pulley}}{60}
\]

**Equation 12.112**
\( V_s \), Tangential velocity of the center of gravity of the load profile

These definitions are unclear and confusing when used with the Trajectory Section.
PLOTTING THE TRAJECTORY

Before the trajectory of the discharged material can be plotted, it is necessary to calculate the values of \( V_s \) and \( r_s \) in order to solve the expression 12.94. If the value of expression 12.94 is less than 1.0 the trajectory starts at the position defined by the point of tangency between the belt and the pulley and the velocity used for plotting is the design belt speed, \( V \). If expression 12.94 is equal to or greater than 1.0 then the trajectory starts at a position other than the point of tangency between the belt and pulley and the velocity at the center of gravity, \( V_s \), is used for plotting the trajectory.

\[
\begin{align*}
    a_1 & = \text{Distance above the belt surface of the center of gravity of the cross-section shape of the load, at the point where the pulley is tangent to the belt} \\
    h & = \text{Distance above the belt surface of the top of the load, at the point where the belt is tangent to the pulley} \\
    r_p & = \text{Radius of the outer surface of the pulley and lagging} \\
    r_s & = \text{Radius from the center of the pulley to the center of gravity of the circular segment load cross section} \\
    t & = \text{Thickness of the belt} \\
    V_s & = \text{Velocity at the center of gravity of the load cross section used for plotting the trajectory:} \\
    & \begin{align*}
        1. \ & \text{Belt velocity,} \ V, \ \text{is used as the velocity of the material at its center of mass if the discharge point is at the tangency of the belt} - \text{to} - \text{discharge pulley} \ (V_s = V) \\
        2. \ & \text{Velocity of the material at its center of mass,} \ V_{cg}, \ \text{is used as the velocity of the material for all other conditions of discharge after the point of belt} - \text{to} - \text{discharge pulley tangency.} \ (V_s = V_{cg})
    \end{align*}
\end{align*}
\]

**Equation 12.111**

\[ r_s = a_1 + t + r_p \]

The values of \( a_1 \) and \( h \) have been tabulated for the various belt widths, idler end roll angles, and surcharge angles, for troughed conveyor belts loaded to the standard edge distance \([0.055 \times \text{BW} + 0.9 \text{ inch} (0.055 \times \text{BW} + 20 \text{ mm})]\), as listed in Table 4.6. \( V_s \) should never be calculated from the nominal speed of the belt. It is also necessary to find the height of the flattened load of material on the belt, so that the upper limit of the material path can be plotted. The tangential velocity, \( V_s \), in distance per second, should be calculated from the relation:

\[
\begin{align*}
    V & = \frac{2 \times \pi \times (r_p + t) \times \text{rpm of discharge pulley}}{60} \\
    V_{cg} & = \frac{2 \times \pi \times r_s \times \text{rpm of discharge pulley}}{60}
\end{align*}
\]

**Equation 12.112**

\( V_s \), Tangential velocity of the center of gravity of the load profile