General
The purpose of this letter is to provide design procedures for stepped columns that are used to support the crane runway in industrial buildings.

Stepped columns at either the exterior or interior location are generally used when;

a. Maximum bracket load with no vertical impact exceeds 55 kips.
b. Stiffer frames are required for cranes.
c. Maximum crane coverage is desired.
d. Existing structure geometry has to be matched.

See Attachment #1 for typical exterior and interior configuration.

Summary of Changes
General revision, superseding DPL 27-0.

Author
Letter edited by Mike Pacey, Division Engineer.

Design Loads
The vertical crane load must be the maximum reaction from the crane runway. This is to ensure proper foundation design. Note in most instances that impact need not be included in the reaction. Note also that the maximum reaction doesn't always generate the maximum eccentricity. See attachment #2 for a discussion of eccentricity.

The lateral crane loads are applied to the upper columns at the level of the crane rail. Note if a load sharing system is used this is typically input with this load.

The longitudinal tractive forces are normally taken by the crane bracing. Typically, this should be in line with the step column and therefore might induce some additional axial loads. These can typically be ignored. See discussion in attachment #2.

Seismic loads due to cranes are usually small, even for large cranes. In calculating the loads for lateral forces use W equal to the bridge weight (exclude the lifted load and the trolley dead load). Unless specifications state otherwise, longitudinal seismic forces due to cranes can be ignored.

Load Combinations
Per the discussion above, the vertical loads and horizontal loads are input separately. This means 4 additional load cases for each code required case. Ignore the internal pressure or internal suction or endwall pressure. (See attachment #3 for a typical input.)

Design Procedure
1. Design the crane beams. This is necessary to get the proper loads and also to establish the geometry of the step. Normally the minimum step should be 0.5 * max cap channel width plus 5", i.e., a cap channel of 18" would require a minimum step of 0.5 * 18 + 5 = 14".

2. Determine the joint fixities. Typically, the bases of the step column are fixed in the major axis and pinned in the minor. Because of this, the roof beam to column connection can be restrained or unrestrained. The allowable upper column depth determines the approach. The deeper the upper column the more likely a restrained joint will work. Restrained joints typically are better because of sidesway and roof beam weights.
3. Input the frame geometry on FFAD. See attachment #1 for typical member geometry. Note that due to web stiffeners and base plates, the widths of members for the bottom section should be compatible, i.e., if a 12” WF section is used for the step flange, then the outside flange should be at least 10” wide.

4. Input the crane loads. See attachment #3 for suggested format load designation, etc.

5. Review the output. Particularly important is the feasibility of the column to concrete connection and the sidesway. Adjust depths as necessary and finalize design.

**Effective Lengths**
The effective lengths in the major axis of stepped columns are not only dependent on the end fixity, but also on the ratios of the axial load, length and moment of inertia of the upper column and the lower column. Each segment of the column has different effective length in a given condition and the effective length factor for each segment changes as the parameters change.

When the column sections are predominantly controlled by bending stresses, the exact analysis of the effective lengths in the major axis may not be significant enough to affect the design. It is also often seen that the slenderness ratio in the minor axis controls the allowable axial stress. However, when large axial loads are applied to tall stepped columns, the conventional application of a single effective length for the entire column could result in erroneous answers. An HP-97 program is available for the exact analysis. For further detail, refer to "Calculation of Effective Lengths of Stepped Columns", by Agrawal and Stafiej, AISC Engr. Journal, Fourth Quarter, 1980.

Note that the current "FFAD" program uses single Kx factor for the entire column and the slenderness ratio in the major axis is computed based on weighted average of Rx. In stepped column design, girts should not be considered to brace the lower column for axial loads.

**Stress Check**
The section of the column shall meet the following requirements. Note that the upper column is not subjected to minor-axis bending.

\[
\frac{f_a}{F_a} + \frac{C_{mx} * f_{bx}}{(1 - f_a / F_{ex}) * F_{bx}} + \frac{C_{my} * f_{by}}{(1 - f_a / F_{ey}) * F_{by}} \leq 1.0
\]

\[
\frac{fa}{0.60F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0
\]

See Table 1 for definition and discussion of the terms used in the above equations.

**Web Stiffeners**
The large depth of the lower column gives a high h/t ratio to the column and this presents a handling problem during the fabrication and erection.

In order to stiffen the section torsionally, the lower column is reinforced with intermediate stiffeners by which the panel aspect ratio a/h is limited to not more than $\left[\frac{260}{(h/t)}\right]^2$, per section F of commentary, with a maximum spacing of three times the column depth.

The stiffeners in pair are welded to both flanges and intermittently welded to web.
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Figure 1

Upper Column

Lower Column

Combined Section

Crane Column

\[ wRx = \frac{(Rx_1 \cdot L_1 + Rx_2 \cdot L_2)}{L} \]
**Table 1**

<table>
<thead>
<tr>
<th></th>
<th>Upper Column</th>
<th>Lower Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_a$</td>
<td>$f_a = P_1/A_1$</td>
<td>$f_a = (P_1 + P_2)/A_2$</td>
</tr>
<tr>
<td>$f_a'$ (1)</td>
<td>N/A</td>
<td>$f_a' = f_a \pm f_{bx}$</td>
</tr>
<tr>
<td>$F_a$</td>
<td>$f(K_x L / wR_x \text{ or } K_y L_1 / R_y)$ (2)</td>
<td>$f(K_x L / wR_x \text{ or } K_y L_2 / R_y)$ (2)</td>
</tr>
<tr>
<td>$C_{mx}$</td>
<td>$C_{mx} = .85$</td>
<td>$C_{mx} = .85$</td>
</tr>
<tr>
<td>$C_{my}$</td>
<td>N/A</td>
<td>$C_{my} = .4$ if base is fixed in minor axis $C_{my} = .6$ if base is pinned in minor axis</td>
</tr>
<tr>
<td>$f_{bx}$</td>
<td>$f_{bx} = M_x/S_{x1}$</td>
<td>$f_{bx} = M_x/S_{x\text{Out}}$ or $M_x/S_{x\text{In}}$</td>
</tr>
<tr>
<td>$f_{by}$</td>
<td>N/A</td>
<td>$f_{by} = M_y/S_{y\text{Out}}$ (3)</td>
</tr>
<tr>
<td>$F_{bx}$</td>
<td>$f(L_b/R_{t1})$</td>
<td>$f(L_b/R_{\text{Out}} \text{ or } L_b/R_{\text{In}})$</td>
</tr>
<tr>
<td>$F_{by}$</td>
<td>N/A</td>
<td>$F_{by} = .6F_y$</td>
</tr>
<tr>
<td>$F'_{ex}$</td>
<td>$F'_{ex} = \frac{149,331}{(K_x L / wR_x)^2}$</td>
<td>$F'_{ex} = \frac{149,331}{(K_x L / wR_x)^2}$</td>
</tr>
<tr>
<td>$F'_{ey}$</td>
<td>N/A</td>
<td>$F'_{ey} = \frac{149,331}{(K_y L_2 / R_y)^2}$</td>
</tr>
</tbody>
</table>

**Notes:**
1. For crane column only
2. Or length between braced points.
3. Max. $M_y$ may not occur at the same point of max. $M_x$. 

---

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Attachment #1  
Typical Column Configuration

Exterior Column

![Exterior Column Diagram](image1)

Notes:
1. Top connection can be vertical or horizontal, pinned or fixed.
2. Middle connection (at step) can be bolted or welded (depends on how long overall piece becomes).
3. Normally girts are outset to facilitate base connection.
4. Normally base of column is 4" to 6" below finished floor due to exposed anchor bolts.
5. Stiffeners should be wide enough to brace WF section.

Interior Column

![Interior Column Diagram](image2)

Notes:
1. Top connection is normally pinned.
2. Middle connection (at step) can be bolted or welded (depends on how long overall piece becomes).
3. Normally base of column is 4" to 6" below finished floor due to exposed anchor bolts.
4. Steps can be one sided (not shown) or two sided.
5. Stiffeners should be wide enough to brace WF section.
Attachment #2

**Loads for (2) Four Wheel Cranes or (1) Eight Wheel Crane**

Given
80 ton, 8 Wheel Crane
Maximum wheel load: 60 kips (without impact)
Horizontal load / wheel: 4.6 kips
Bay spacing: 25 ft.  [Span for reaction purposes: 25'-1"]
Step crane column WF: 12" deep  [Depth for reaction purposes: 24"]
6' wheel base, 6' truck spacing

Note: since runway beams are normally the same size and length, they create no eccentricity, only vertical load.

**Case 1:**

\[ P_1 = \frac{60 \times 13 + 19}{24} = 80 \text{kips} \]

\[ P_2 = \frac{60 \times 24 + 19}{24} = 105 \text{kips} \]

\[ P_{\text{TOTAL}} = 185 \text{kips} \]

Horizontal = 8.1 kips

Eccentric Moment = \((105 - 80) \times 6" = 150 \text{ in-kips}\)

**Case 2:**

\[ P_1 = \frac{60 \times 19}{24} = 47.5 \text{kips} \]

\[ P_2 = \frac{60 \times (24 + 18 + 12)}{24} = 135 \text{kips} \]

\[ P_{\text{TOTAL}} = 182.5 \text{ kips} \]

Horizontal = 14.0 kips

Eccentric Moment = \((135 - 47.5) \times 6" = 525 \text{ in-kips}\)
Attachment #2

Loads for (2) Four Wheel Cranes or (1) Eight Wheel Crane (continued)

Case 3:

\[
P_1 = 0 \text{ kips}
\]

\[
P_2 = 60 \times \frac{24 + 18 + 12 + 6}{24} = 150 \text{ kips}
\]

\[
P_{\text{TOTAL}} = 150 \text{ kips}
\]

Horizontal = 11.5 kips

Eccentric Moment = \((150) \times 6" = 900 \text{ in-kips}

Summary
Case 3 actually governs the column design but shouldn't be used since it understates the vertical reaction. Conservatively you could use \(P = 185 \text{ kips (case 1)}\), \(H = 14 \text{ kips (case 2)}\) (see also DPL 60 for load sharing) and \(M_x = 900 \text{ in-kips (case 3)}\). Alternatively you could use a quick check of the column and add say 150 in-kips to the moment for case 2.
Attachment #3
Loads / Load Combinations

(CVL)
Crane Max. Vertical Left

(CVR)
Crane Max. Vertical Right

(CHR)
Crane Horizontal Right

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**Attachment #3**  
**Loads / Load Combinations** (continued)

![Diagram](image)

**CONC @ 36’**  
* Frame load sharing counter loads  
**Crane Horizontal Left**

**Additional Load Combinations**

- **DL + CLL + ½SL + CVL + CHL**  
  CVL + CHR  
  CVR + CHL  
  CVR + CHR

- **DL + CLL + ½WLL + CVL + CHL**  
  CVL + CHR  
  CVR + CHL  
  CVR + CHR

- **DL + CLL + ½WLR + CVL + CHL**  
  CVL + CHR  
  CVR + CHL  
  CVR + CHR
Attachment #4
Design Example

Stepped Crane Columns
The frame analysis for a crane building gave the following member forces in the stepped column for the condition of DL+½SL + Crane.

Check the section of stepped column by hand calcs.

Note this example is for illustration purposes only. Many times different load combinations govern the design of a particular node or section.

<table>
<thead>
<tr>
<th>Point</th>
<th>P (kips)</th>
<th>Mₓ (in-k)</th>
<th>Mᵧ (in-k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>20</td>
<td>-2000</td>
<td>0</td>
</tr>
<tr>
<td>Just below step</td>
<td>75</td>
<td>-1300</td>
<td>330</td>
</tr>
<tr>
<td>Mid. Ht.</td>
<td>75</td>
<td>700</td>
<td>0</td>
</tr>
<tr>
<td>Base</td>
<td>75</td>
<td>2400</td>
<td>0</td>
</tr>
</tbody>
</table>
Attachment #4

Design Example (continued)

Section Properties

Upper Column

Area = 12.14 in²
Iₓ = 1287 in⁴
Sₓ = 107.26 in³
rₓ = 10.297 in
rᵧ = 1.875 in
rᵣ = 2.133 in
d/Aᵣ = 6.00 in⁻¹
Qₑ = 1.0
Fᵧ = 50 ksi

Lower Column

Area = 17.35 in²
Iₓ = 3,330 in⁴
SₓOUT = 153.90 in³
SₓIN = 213.37 in³
rₓ = 13.853 in
Sᵧ = 33.4 in³ (W12 x 26)
rᵧ = 3.561 in
rᵣOUT = 1.903 in
rᵣIN = 4.909 in
QₑOUT = 0.918
QₑIN = 1.00
weighted rₓ = \(\frac{(10.297\times9') + (13.853\times22.5')}{31.5}\) = 12.837in

Fᵧ = 50 ksi

Allowable Stresses

Assume that column is braced axially at step only.

\[ \frac{KₓL}{WRₓ} = \frac{1.2 \times 31.5 \times 12}{12.837} = 35.3 \quad F_{ₓex} = 119.60\text{ksi} \]

At Upper Column:

\[ \frac{KᵧL₁}{rᵧ} = \frac{1.0 \times 9.0 \times 12}{1.875} = 57.6 \quad F_a = 23.12\text{ksi} \]

At Lower Column:

\[ \frac{KᵧL₂}{rᵧ} = \frac{1.0 \times 9.0 \times 12}{3.561} = 75.82 \quad F_a = 19.82\text{ksi} \quad F'_{cy} = 25.97\text{ksi} \]
Attachment #4
Design Example (continued)

Allowable Stresses

**Fb**

At upper column:

\[
\frac{L_1}{r_t} = \frac{9 \times 12}{2.133} = 50.6
\]

\[
M_1 / M_2 = -1300 / 2000 = -0.65
\]

\[
C_b = 1.75 + 1.05 \times (-0.65) + 0.3 \times (-0.65)^2 = 1.194
\]

\[
F_{bx} = 29.82 \text{ ksi}
\]

At Inside flange of lower column:

\[
\frac{L_2}{r_{IN}} = \frac{22.5 \times 12}{4.909} = 55.0 < \sqrt{\frac{102 \times 10^3 \times C_b}{F_y}} = 68.5
\]

\[
M_1 / M_2 = 1300/2400 = 0.542
\]

\[
C_b = 1.75 + (1.05 \times 0.542) + (0.3 \times (0.542)^2) = 2.407 > 2.30 \quad C_b = 2.30
\]

\[
F_{bx} = 0.6 \times F_y = 30 \text{ ksi}
\]

At outside flange of lower column: (first girt @ 7'-6")

\[
\frac{L'}{r_{OUT}} = \frac{7.5 \times 12}{1.903} = 47.3 < \sqrt{\frac{102 \times 10^3 \times C_b}{F_y}} = 54.7
\]

\[
M_1 / M_2 = -700/2400 = -0.292
\]

\[
C_b = 1.75 + (1.05 \times -0.292) + (0.3 \times (-0.292)^2) = 1.469
\]

\[
F_{bx} = 0.6 \times Q_s \times F_y = 0.6 \times 0.918 \times 50 = 27.54 \text{ ksi}
\]

\[
F_{by} = 0.6 \times F_y = 30 \text{ ksi}
\]

Check Sections

At top (Point D)

\[
\frac{f_a}{F_a} + \frac{C_m \times f_{bx}}{\left(1 - \frac{F_a}{F_{ex}}\right) F_{bx}} = \frac{20 \times 12.14 \times 23.12}{107.26 \times \left(1 - \frac{20}{12.14 \times 119.60}\right) \times 29.82} = 0.071 + 0.539 = 0.61 < 1.0 \quad \text{OK}
\]

\[
\frac{f_a}{0.6F_y} + \frac{f_{bx}}{F_{bx}} = \frac{20 \times 0.60 \times 50}{107.26 \times 29.82} = 0.055 + 0.625 = 0.68 < 1.0 \quad \text{OK}
\]
Check Section at step of lower column (Point C)

\[ f_a' = f_a + f_{bx} = \frac{75 \text{k}}{17.35} + \frac{1300}{213.37} = 4.32 + 6.09 = 10.41 \text{ ksi} \]

\[ \frac{f_a}{F_a} + \frac{C_{mx} * f_{bx}}{S_x \left[ 1 - \frac{f_a}{F_{ex}} \right] * F_{bx}} + \frac{C_{my} * f_{by}}{S_y \left[ 1 - \frac{f_a}{F_{ey}} \right] * F_{by}} = \]

\[ \frac{75}{17.35 * 19.82} + \frac{0.85 * 1300}{213.37 \left[ 1 - \frac{75}{17.35 * 119.60} \right] * 30} + \frac{0.6 * 330}{33.4 * 30} = 0.218 + 0.179 + 0.33 = 0.727 < 1.0 \text{ OK} \]

\[ \frac{f_a}{0.60 * F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = \frac{75}{17.35 * 0.6 * 50} + \frac{1300}{213.37 * 30} + \frac{330}{33.4 * 30} = 0.144 + 0.203 + 0.329 = 0.676 < 1.0 \text{ OK} \]

Check Section at Column Base (Point D)

\[ \frac{f_a}{F_a} + \frac{C_{mx} * f_{bx}}{S_x \left[ 1 - \frac{f_a}{F_{ex}} \right] * F_{bx}} + \frac{0.85 * 2400}{153.9 \left[ 1 - \frac{75}{17.35 * 119.60} \right] * 27.54} = \]

\[ \frac{f_a}{0.60 * F_y} + \frac{f_{bx}}{F_{bx}} = \frac{75}{17.35 * 0.6 * 50} + \frac{2400}{153.90 * 27.5} = 0.144 + 0.566 = 0.710 < 1.0 \text{ OK} \]

Web Stiffener at lower column

\[ H/t = 33.51 / 0.20 = 167.55 \]

Maximum spacing = \[ 33.51 * (260/167.5)^2 = 80.7 \text{ in. or 6.72 ft.} \]

or \[ 3 \text{ * depth} = 3 * 33.51 = 100.5 \text{ in.} \]

Use 4 equal spaces: \[ a = 22.5 \text{ ft. / 4 = 5.63 ft. < 6.72 ft. OK} \]

Web stiffeners brace WF section used as the crane column for minor axis loading.

\[ M_1/M_2 = -0.75; \ C_b = 1.75 + (1.05 * -0.75) + (3 * (-0.75)^2) = 1.131 \]

\[ F_{by} = \frac{12 * 10^3 * C_b}{L d / A_f} = \frac{12 * 1000 * 1.131}{5.625 * 12 * 4.95} = 40.62 \text{ ksi} > 30 \text{ ksi} \]

\[ \therefore \text{assumption of } F_{by} = 30 \text{ksi is valid} \]
Attachment #4

Exact Analysis for $K_x$

By method of exact analysis, the $K_x$ values of the example problem are computed for various loading conditions.

End Conditions
- Fixed base, Roller at top

Parameters
- $L_1 / L_2 = 9 / 22.5 = 0.40$
- $I_1 / I_2 = 1287 / 2330 = 0.386$

$$K_1 = \frac{L_1}{L_{1\text{eff}}} / L_T$$
$$K_2 = \frac{L_2}{L_{2\text{eff}}} / L_T$$

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>DL+1/2SL+CR</th>
<th>DL+CR</th>
<th>DL+SL+DL of Crane Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$ (kips)</td>
<td>20</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td>$P_2$ (kips)</td>
<td>55</td>
<td>55</td>
<td>5</td>
</tr>
<tr>
<td>$P_1/P_2$</td>
<td>0.364</td>
<td>0.073</td>
<td>7.2</td>
</tr>
<tr>
<td>$K_1$</td>
<td>1.373</td>
<td>2.672</td>
<td>0.805</td>
</tr>
<tr>
<td>$K_2$</td>
<td>1.14</td>
<td>1.119</td>
<td>1.214</td>
</tr>
</tbody>
</table>

The assumed $K_x = 1.2$ in the example problem is OK for lower column, but not adequate for the upper column.

$$\frac{K_x \cdot L_T}{r_x} = \frac{1.373 \cdot 31.5 \cdot 12}{10.297} = 50.4 < \frac{K_y \cdot L_1}{r_y} = 57.6 \quad F'_{ex} = 58.78 \text{ ksi}$$