Bridge Design Details 2.1 October 2022

Bridge Layout

This section describes vertical and horizontal curve information used to establish the control points and primary geometric characteristics of a structure.
Vertical Curves

A vertical curve is used to change the profile of a highway to provide a smooth transition between two sloped grades. The design of a vertical curve is dependent on the intended design speed for the roadway, required drainage, slope, friction, sight distance, and acceptable rate of change.

It is recommended that the vertical curves extend beyond the bridge length, where possible, to minimize the design, drainage issues, and construction complexity of the bridge structure.

There are two types of vertical curves, sag curves and crest curves.

Vertical curve data is shown with a PROFILE GRADE detail on the GENERAL PLAN sheet. Vertical curve data includes:

- Begin Vertical Curve (BVC) station
- End Vertical Curve (EVC) station
- Point of Reversing Vertical Curve (PRVC) station
- Profile Grade approaching the vertical curve (G1%)
- Profile Grade departing the vertical curve (G2%)
- Length of curve (L) feet
- Rate of Change ($R/c \%$) per station
Rate of Change of Vertical Curves

Normally the Rate of Change is given on the PROFILE GRADE and shown on the GENERAL PLAN sheet above the ELEVATION view, where:

\[ R/C = \text{Rate of Change of Grade per Station (\% Station)} \]
(Carry this value to four significant figures to maintain accuracy)

The Rate of Change Formula is:

\[ R/C = \frac{G_2 - G_1}{L} \]

\( G_1 \) = Grade at first point on curve (\%)
\( G_2 \) = Grade at last point on curve (\%)
\(+G\) = ascending grade
\(-G\) = descending grade
\( L \) = Length of vertical curve in stations

Example:

\[ \begin{align*}
650 + 00.00 \text{ BVC} & \quad \text{Elev XX.XX} \\
+3.00\% & \\
1000' \text{ VC} & \\
660 + 00.00 \text{ EVC} & \quad \text{Elev XX.XX} \\
-2.50\% & \\
\end{align*} \]

\[ R/C = \frac{-2.50 - (+3.00)}{10} = \frac{-5.50}{10} = -0.5500/\text{Station} \]

**Figure 2.3.1 Vertical Curve Profile Grade**
Rate of Change per Station Method Equations:

1. \( \frac{R}{C} = \frac{G_2 - G_1}{L} \)

2. \( V = L \times \frac{G_2 - G_1}{2} \)

3. \( H = L \times \frac{G_2 + G_1}{2} \)

From these equations, or a combination of these, any point on a vertical curve can be determined.

- \( V \) = Tangent offset from the first point to the second (feet)
- \( H \) = Difference in elevation from BVC to EVC (feet)
- \( PI \) = Projected intersection of the approaching and departing grades
- \(+ (V \text{ or } H)\) measured upward
- \(- (V \text{ or } H)\) measured downward
Combining equations (1) and (2) given in Bridge Design Details: 2A, the Middle Ordinate is derived and equation (4) is as follows:

\[(4) \quad V = \frac{R/C \times L^2}{2}\]

For Length = \(P/2\), then:

\[V = \frac{R/C \times (P/2)^2}{2}\]

Using the figure and equation above, set \(M\) equal to \(V\) to get the following:

\[V = \frac{R/C \times (P/2)^2}{2} = M\]

Then simplify to get:

\[M = \frac{R/C \times P^2}{8}\]

\((P)\) measured horizontally

\((M)\) measured vertically
High Point and Low Point Formula

\[ l = \frac{G_1}{R/C} \]

- Length at high point or low point.

The elevation at any point along a curve is given by the following equation:

\[ \phi = G_1 + \frac{R/C}{l} \]
\[ l = \frac{G_1}{R/C} \]

Examples:

Figure 2A.C.1 Low Point (Sag Curve)

Figure 2A.C.2 High Point (Crest Curve)
Bridge Design Details 2D October 2019

To find the elevation at any given station on a vertical curve, use data given on the PROFILE GRADE and the following equation:

\[(5) \text{(Elev\_PG)}_D = \text{(Elev\_BVC)} + (D \times G_1) \times D^2 + \frac{R/C}{2}\]

Figure 2A.D.1 Vertical Curve Definition

Where:

- \(D\) = Distance from BVC to a point in stations

\[(6) \text{(Elev\_tan)} = \text{(Elev\_BVC)} + (D \times G_1)\]

\(H\) = Rise from Profile Grade to (Elev\_tan): \(H = \frac{D^2 + \frac{R/C}{2}}{2}\)

Example:

Find: Elevation at Sta 12 + 60.00

Thus: Elev PG (12 +60.00) = \[122.63 + (8.60)(2.00) + (8.60)^2(-0.19)\] \[= 122.63 + 17.20 - 7.03\] \[= 132.80\]

Figure 2A.D.2 Vertical Curve Example Calculations
Example:

The "Brownell" method for calculating elevations at given stations along a vertical curve.

Given:

![Vertical Curve Diagram]

\[
R_{c} = -0.1900\% / \text{Sta}
\]

**PROFILE GRADE**

**Figure 2A.D.3 Vertical Curve “Brownell” Example Calculations**

Find elevations at:
- Abutment 1 at 11+50
- Bent 2 at 12+60
- Abutment 3 at 13+70

<table>
<thead>
<tr>
<th>Station</th>
<th>( R_{c} ) (% / Station)</th>
<th>G (Grade at Station)</th>
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</thead>
<tbody>
<tr>
<td>4+00.00 BVC</td>
<td>-0.1900</td>
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<tr>
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<tr>
<td>12+60.00 Bent 2</td>
<td>-0.1900</td>
<td>+0.3660</td>
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<tr>
<td>13+70.00 Abut 3</td>
<td>-0.1900</td>
<td>+0.1570</td>
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<tr>
<td>24+00.00 EVC</td>
<td>-0.1900</td>
<td>-1.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance</th>
<th>L (Length - Stations)</th>
<th>( R_{c} \times L ) (Change in Grade)</th>
<th>L × Avg G (Change in Elevation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4+00.00 BVC to Abut 1</td>
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<td>-1.4250</td>
<td>+9.6562</td>
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<tr>
<td>Abutment 1 to Bent 2</td>
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<td>-0.2090</td>
<td>+0.5175</td>
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<tr>
<td>Bent 2 to Abut 3</td>
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<td>-0.2090</td>
<td>+0.2876</td>
</tr>
<tr>
<td>Abutment 3 to 24+00.00 EVC</td>
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<td>-1.9750</td>
<td>-8.4614</td>
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<table>
<thead>
<tr>
<th>Station</th>
<th>Elevation</th>
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<td>122.63</td>
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<tr>
<td>11+50.00 Abut 1</td>
<td>132.28</td>
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<tr>
<td>12+60.00 Bent 2</td>
<td>132.80</td>
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<tr>
<td>13+70.00 Abut 3</td>
<td>133.09</td>
</tr>
<tr>
<td>24+00.00 EVC (Calculated)</td>
<td>124.63</td>
</tr>
<tr>
<td>24+00.00 EVC (Given)</td>
<td>124.63</td>
</tr>
</tbody>
</table>
Horizontal Curves

Roadway Designers use simple arcs for the design of roadway horizontal curves. The horizontal curve length is the distance between two tangent lengths that provides a safe sight distance for traffic moving at a specified design speed.

It is recommended that horizontal curves extend beyond the bridge length, if possible, to minimize the design and construction complexity of the bridge structure. Horizontal curve data includes:

- Beginning of Curve (BC) station
- End of Curve (EC) station
- Point on Curve (POC) station
- Point of Intersection (PI) station
- Bearings of Tangents
- Radius (R) feet
- Central Angle (∆) degrees
- Tangent Distance (T) feet
- Length of Curve (L) feet
- Point of Compound Curve (PCC) station
- Point of Reverse Curve (PRC) station
Horizontal Curve Equations

- BC = Beginning of Curve
- EC = End of Curve
- d = Deflection Angle for point on curve
- $\Delta = \text{Delta or Central Angle}$
- L = Length along Curve (BC to POC)
- $L = \text{Length of Curve} = \frac{2\pi R}{360^\circ \Delta}$
- LC = Long Chord $= 2R (1-\sin \frac{\Delta}{2})$
- M = Middle Ordinate $= R (1-\cos \frac{\Delta}{2})$
- PC = Point of Curvature
- PI = Point of Intersection
- POC = Point on Curve
- PT = Point of Tangency
- R = Radiu
- $T = \text{Tangent Distance} = R \tan \frac{\Delta}{2}$
- Ex = External $= R \left( \frac{\cos \frac{\Delta}{2}}{\cos \frac{\Delta}{2} - R} \right)$

All Curve Data may be obtained with two of the following curve parameters:
- Delta ($\Delta$)
- Radius
- Tangent
- Length
- External

Figure 2A.E.1 Horizontal Curve Functions
Example:

Given Length and Radius, solve for Delta $\Delta$.

\[
T = R \tan \frac{\Delta}{2} \quad L = \frac{2 \pi R}{360^\circ} \Delta
\]

\[
\tan \frac{\Delta}{2} \neq \frac{T}{R} \Rightarrow 2 \tan^{-1} \left( \frac{T}{R} \right), \Delta \text{ in degrees}
\]

\[
\Delta \text{ in degrees} = \frac{L \times 3.437.7467}{R}
\]

Example:

Given Radius and Delta $\Delta$, solve for L.

\[
L = \frac{2 \pi R \Delta}{360^\circ} \quad \text{or} \quad L = R \sin \Delta \Rightarrow \frac{L}{2 \pi R} = \frac{\Delta}{360^\circ} \Rightarrow L = \frac{2 \pi R}{360^\circ} \Delta \quad \text{where} \ \Delta \ \text{is in degrees}
\]

\[
d = \frac{\Delta \ell}{2} \quad \text{where} \quad \frac{\Delta \ell}{360^\circ} = \frac{\ell}{2 \pi R} \Rightarrow d = \frac{180 \ell}{2 \pi R} \quad \text{(in degrees)}
\]

\[
Ex = \frac{R}{\cos \frac{\Delta}{2}} - R \Rightarrow R \left( \frac{1}{\cos \frac{\Delta}{2}} - 1 \right)
\]

\[
R - R \cos \frac{\Delta}{2} \Rightarrow R \left( 1 - \cos \frac{\Delta}{2} \right)
\]
## Tangent Offset for Circular Curves

<table>
<thead>
<tr>
<th>Radius</th>
<th>50'</th>
<th>100'</th>
<th>150'</th>
<th>200'</th>
<th>250'</th>
<th>300'</th>
<th>400'</th>
<th>500'</th>
<th>600'</th>
<th>700'</th>
<th>800'</th>
<th>900'</th>
<th>1,000'</th>
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<td>1.56</td>
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<td>12.51</td>
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Table 2A.F.1 Distance from Beginning or End of Curve Along Tangents
### Table 2A.F.1 Distance from Beginning or End of Curve Along Tangents (continued)

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<tr>
<th>Radius</th>
<th>50'</th>
<th>100'</th>
<th>150'</th>
<th>200'</th>
<th>250'</th>
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<td>73.37</td>
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<tr>
<td>600'</td>
<td>2.09</td>
<td>8.39</td>
<td>19.05</td>
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<td>37.65</td>
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<tr>
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<td>23.03</td>
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<tr>
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<tr>
<td>300'</td>
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</table>

#### Derivation of Table

Given: Radius and $X$  
Find: Offset $Y$

1. $R \sin \Delta = X \implies \sin \Delta = \frac{X}{R}$
2. $R - R \cos \Delta = R(1 - \cos \Delta)$

Note:
For approximate results, the following simpler formula can be used.

(1) $\tan \frac{\Delta}{2} = \frac{Y}{X}$
(2) $R = \frac{X}{\sin \Delta}$

#### Example:

Given Radius = 900’.

---

![Diagram](image-url)

**Figure 2A.F.1 Example of Distances along Tangent from Curve**
Bridge Design Details 2G October 2019

Parabolic Curve Flares

\[ y = \frac{Wx^2}{L^2} \]

- \( x \) = distance along base line in feet
- \( y \) = offset from baseline in feet
- \( L \) = length of flare in feet
- \( W \) = maximum offset in feet*

**Width to Length Ratio = 1.5**

<table>
<thead>
<tr>
<th>Flare Length</th>
<th>X=10</th>
<th>X=15</th>
<th>X=20</th>
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<td>5.00*</td>
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<tr>
<td>50</td>
<td>0.40</td>
<td>1.60</td>
<td>3.60</td>
<td>6.40</td>
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**Width to Length Ratio = 1.10**

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<th>Flare Length</th>
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<td>1.80</td>
<td>3.20</td>
<td>5.00*</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Flare Length</th>
<th>X=10</th>
<th>X=20</th>
<th>X=30</th>
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<td>4.90</td>
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**Width to Length Ratio = 1.15**

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<th>X=30</th>
<th>X=40</th>
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</thead>
<tbody>
<tr>
<td>45’</td>
<td>0.15</td>
<td>0.59</td>
<td>1.33</td>
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<td>3.00*</td>
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<tr>
<td>75’</td>
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<td>0.36</td>
<td>0.80</td>
<td>1.42</td>
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<td>90’</td>
<td>0.07</td>
<td>0.30</td>
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<td>1.19</td>
<td>1.85</td>
</tr>
<tr>
<td>120’</td>
<td>0.06</td>
<td>0.22</td>
<td>0.50</td>
<td>0.89</td>
<td>1.39</td>
</tr>
</tbody>
</table>

**Table 2A.G.1 Offset "y" in Feet for Given Distance "x"**
Bridge Design Details 2.5 October 2019

Horizontal Alignment

A horizontal alignment is provided in the Bridge Site Submittal from the District and is given as a stationed layout line for highways, off-ramps, walls, or other structures. All horizontal alignments are laid out by stations, which are given as 100-foot increments along the layout line. For smaller structures, the station line may be given as 20-foot increments along the layout line (e.g., +20, +40, +60, etc.). Whole stations shall not include “plus stations” (e.g., 10+00).

**Stations**

Locations along a station line are generally shown to the nearest hundredth of a foot and without the station abbreviation (Sta).

**Example:** 12+56.00 "A" LINE

**Bearings**

Bearing direction for tangent lines, follows the direction of increasing stationing and north arrow.

**Offsets**

Any location within the same plane of a given horizontal alignment can be found using a station-offset from a specific alignment. Offsets are distances, left or right, from any given station line to the location of a specific point.

**Example:** P₁ is offset 2.00 feet left of station 12+10.00.

---

*Figure 2.5.1 Point Offset Location*
It is common practice to either begin retaining wall layout lines at 10+00.00 or to match the beginning station to the corresponding mainline alignment.

**Example:**  Beginning of wall is 2.00 feet left of station; 12+15.00 "A" Line.

![Figure 2.5.2 Retaining Wall Offset Locations](image-url)
Develop Horizontal Alignment Stations

Examples:

Figure 2A.H.1 Alignment Stationing without Horizontal Curve

Figure 2A.H.2 Revised Alignment Stationing with Horizontal Curve
Figure 2A.1.1 Horizontal Alignment Examples
Figure 2A.J.1 Projecting Parallel Horizontal Alignment Example

**Figure Details:**
- **BB 36,23' L+14+12,00 "B" LINE**
  - Elev 242.00
- **BB 37,12' L+14+88,00 "B" LINE**
  - Elev 256.60
- **POC 14+45,00 "B" LINE = POT 20+25,00 "C" LINE**
- **ANGLE POINT @ BC: CURVE SUBTANGENT**
  - BEARING = N 80°50.57' E
- **BC 9+50.00 "B" LINE**
- **EC 15+06,00 "B" LINE**

**Curve Data:**
- **R = 500,00**
- **Δ = 83°50'00''**
- **T = 310.70'**
- **L = 556.00'**
Bridge Layout - Checklist

<table>
<thead>
<tr>
<th>Structure:</th>
<th>Structure Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract Number:</td>
<td>Project Number &amp; Phase:</td>
</tr>
<tr>
<td>Detailer:</td>
<td>Date:</td>
</tr>
<tr>
<td>Designer:</td>
<td>Date:</td>
</tr>
<tr>
<td>Checker:</td>
<td>Date:</td>
</tr>
</tbody>
</table>

Information Required

1. Bridge Site Submittal (BSS). The BSS shall be reviewed for completeness by Structure Design Preliminary Investigations Branch (PI), and any missing information shall be requested from the District Project Engineer. Once the BSS is processed by PI, the Structure Design Branch Project Engineer shall also perform a cursory check for all items that specifically relate to the structures work for the project. Some of the structure related information to identify includes:

   a) Typical sections and required horizontal clearances for all roadways
   b) Horizontal and vertical alignments for all roadways, railroads, and channels (existing/proposed) which are over, under, or near bridge
   c) Structure barrier type(s)
   d) Approach slab limits see Memo to Designers: 5-3 Structure Approach
   e) Locate limits of cut and fill grading, slope values, and determine whether slope paving is required at abutments
   f) Construction stage information and traffic handling requirements (e.g., available detours, lane requirement charts, etc.)
   g) Falsework traffic opening requirements
   h) Planned and future utilities
   i) Restrictions on support placement, such as sight distance set back, utility clearance, and environmental restrictions

2. Foundation Plan. The Foundation Plan is provided by Preliminary Investigations and should be reviewed for completeness and whether the survey datum used matches that of the District site data provided in the BSS.
3. Final Hydraulic Report. The information to identify includes:
   a) Design high water flood elevation(s) and minimum soffit elevation. Bridge profile adjustment may be required.
   b) Minimum freeboard clearance requirements for drift and debris issues
   c) Recommended pier type and skew
   d) Slope protection requirements, such as Rock Slope Protection (RSP)

4. Preliminary Foundation Report. Information to identify includes:
   a) Foundation recommendations
   b) Seismic data information
   c) Groundwater, corrosion, and scour evaluations

5. As-Builts and existing maintenance reports for any adjacent structures, the information to identify includes:
   a) Conflicts with existing structures, foundations, and utilities that will not be removed
   b) Previously completed maintenance work or proposed work

6. Aesthetic input from Bridge Architecture and Aesthetics Branch for bridge type selection, column shape, slope paving, and treatment for abutments, wingwalls, and barriers

7. Previous Advance Planning Studies

**Bridge Layout Procedure**

1. Plot clearances, right-of-way lines, and other controls in PLAN view to determine logical location of bridge supports.

2. Verify the provided bridge profile to determine critical elevations along the bridge layout. Plot the proposed abutment location and points of minimum vertical clearance.
   a) Determine abutment type, see *Memo to Designers: 5-1 Abutments*.
   b) Abutment location should allow 5 feet wide maintenance berm at the face of the abutment, with 3 feet vertical clearance to the soffit. If slope paving is used, do not use a berm; instead use a maximum 1.5:1 slope.
3. Determine the structure type and geometry of the typical section:
   a) Locate the point of minimum vertical clearance and calculate the preliminary structure depth.
   b) Using the depth to span ratio for the assumed structure type, determine the estimated longest span (Note: Bridge length and depth varies for each type of structure considered).

4. Determine the profile grade at the outside face of the exterior soffit or girder at each side of the bridge, taking account of super elevation and cross slope.

5. Determine ground elevations along the bridge.

6. Roughly locate the beginning (BB) and end (EB) of bridge where the bridge profile grade and ground elevation lines intersect. Things to consider:
   a) Balance span lengths, frame stiffness, and column lengths
   b) End spans of (0.75 x Adjacent Span Length) are preferred; use of end spans closer to (0.40 x Adjacent Span Length) should only be used in special situations, uplift is not allowed
   c) Long structures with multiple frames should have a minimum of three bents per frame

7. Estimate number and size of columns. The guidelines below are general rules of thumb to be used as a starting point for design. Actual designs may fall outside of these guidelines depending on project constraints and as the designer exercises innovation to come up with a more feasible or economical solution.
   a) Column size ratio (Column Diameter / Structure Depth)
      • 0.7 < column size ratio < 1.0
   b) Column diameter ratio (Tallest Column Height (H))
      • H/12 < column diameter ratio < H/10
   c) Single column: adequate for structure width up to 40 feet
   d) Approximate number of columns for bridges wider than 40 feet (Note: More columns may be required on skewed bents)
      • Number of columns = bridge width / 25
   e) Location of exterior columns (distance from the edge of deck)
      • 0.4 x column spacing
   f) Bent Cap depth (Bent Cap Depth / Max Bridge Span Length)
      • Reinforced Concrete Box (0.15)
      • P/S Concrete Box (0.10)
8. Develop trial layouts and evaluate advantages and disadvantages of each alternative. Things to consider:
   a) Clearance from the proposed supports to traffic
   b) Balance between structure span length and stiffness
   c) Total cost of combined bridge, retaining walls, and roadwork
   d) Impact on utilities, traffic, and environment
   e) Good aesthetics
   f) Ease of access and safety during construction

9. Select the preferred bridge layout and verify original assumptions for bridge type, structure depth, span configuration, column length and size.

10. Verify minimum vertical and horizontal clearance requirements for final structure configuration.

Additional Considerations

1. Extend wingwalls about 8 feet beyond the grading slopes at each abutment; for minor structures less than 50 feet in length, wingwall limit may be reduced to 5 feet.

2. Minimize the number of deck joints on a bridge to avoid future maintenance.

3. Provide maximum practical clearance between traffic and columns, see Bridge Design Aids: 10-1 Clearance at Structures.
   a) Use 30-foot clear recovery distance whenever possible.
   b) Columns located near edge of traffic shoulders must be protected with MGS or other traffic barrier.

4. For footing, column, and falsework construction near traffic, see Memo to Designers: 21-19 Guidelines for Clearance to Construction Operations.

5. Identify falsework clearance issues with the construction of bridges that are skewed, curved, or widened with staged construction, see Bridge Design Aids: 10-1 Clearance at Structures.

6. Avoid skewed abutments to limit seismic concerns and constructability issues.
   • In freeze-thaw areas, avoid skewed abutments that could catch snow plough blade. Provide joint protection where skew cannot be avoided.
7. Locate hinges to facilitate falsework shoring during construction and future maintenance access. Things to consider:
   a) Avoid hinges over waterways and traffic.
   b) Do not place hinges over traffic falsework openings due to heavy construction load transfer during prestressing.
   c) Consider additional trial column designs and layouts on long bridges to evaluate various hinge spacing layouts.
   d) Place the high side of hinge nearest to the bent, to allow deck drain pipe to be routed to nearest column.
   e) A reasonable length to begin trial hinge layout is to place cantilevered hinge approximately (0.15 x Adjacent Span length) away from bent.