THEORETICAL MANUAL

FOR

QCONBRIDGE II
A MEMBER OF THE ALTERNATE ROUTE PROJECT

VERSION 1.0

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1. INTRODUCTION

1.1 Overview

The purpose of this document is to provide a detailed description of how QConBridge II performs its analytical work.

1.2 Document Organization

This document is broken into seven main sections: Section 1 - Introduction explains the purpose of this document. Section 2 - Material Properties details how QConBridge II computes material properties. Section 3 - Flexible Span Lengths details how the various geometric parameters effect the flexible span length used in several of the analyzes. Section 4 - Section Properties describes how QConBridge II computes section properties for the supported product models. Section 5 - Live Load Distribution Factors details how distribution factors are calculated and how the ambiguous portions of the LRFD specification are dealt with. Section 6 - Longitudinal Bridge Analysis Models describe in detail how LBAMs are created, loaded, analyzed, and how the raw results are post-processed. Section 7 - Transverse Bridge Analysis Models provides in-depth coverage of TBAMs.

2. MATERIAL PROPERTIES

Material properties will be determined as described in this section. All materials must have a modulus of elasticity, unit weight/density for weight calculations, unit weight/density for strength calculations, and a coefficient of thermal expansion.

2.1 Concrete

Properties for concrete will be as specified in LRFD 5.4.2. The 28 day compressive strength must be between 4ksi and 10ksi (28MPa and 70MPa).

The modulus of elasticity of concrete will be computed in accordance with LRFD 5.4.2.4.

US - For unit weights between 0.090 and 0.155 kip/ft^3, E_c is computed as $E_c = 33{,}000 y_c^{1.5} \sqrt{f_c'}$. For analyses done in accordance with WSDOT criteria the range of unit weights is 0.090 to 0.160 kip/ft^3.[1]

SI - For densities between 1440 and 2500 kg/m^3, E_c is computed as $E_c = 0.043 y_c^{1.5} \sqrt{f_c'}$. For analyses done in accordance with WSDOT criteria the range of densities is 1440 to 2560 kg/m^3.[1]

2.2 Steel

Properties for reinforcing steel will be as specified in LRFD 5.4.3

Properties for structural steel will be as specified in LRFD 6.4.1

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[1] See Design Memorandum 03-2000 (Dated 4/18/2000)

3. FLEXIBLE SPAN LENGTHS

In product models, the pier-to-pier span length is generally not the same as the flexible span length for a girder line. Skew, horizontal curvature of the roadway, and connection details all factor into the flexible span length. Flexible span lengths are used in analysis models.

The flexible span length of a girder is computed as $L = L_{pp} - E_{skew} - E_{curve} - E_{connect}$, where:

L_{pp}	Pier to pier span length - For curved structures, this may be measured as a chord or a distance along the curve. Built-up steel plate girders are generally curved. Rolled-I beams and Precast Beams are generally straight.
E_{skew}	Effect of skew at start and end of the girder
E_{curve}	Effect of horizontal curve at start and end of girder
$E_{connect}$	Effect of connections at start and end of girder

3.1 Skew Effects

Skew effects occur when the piers at either end of a span are skewed.

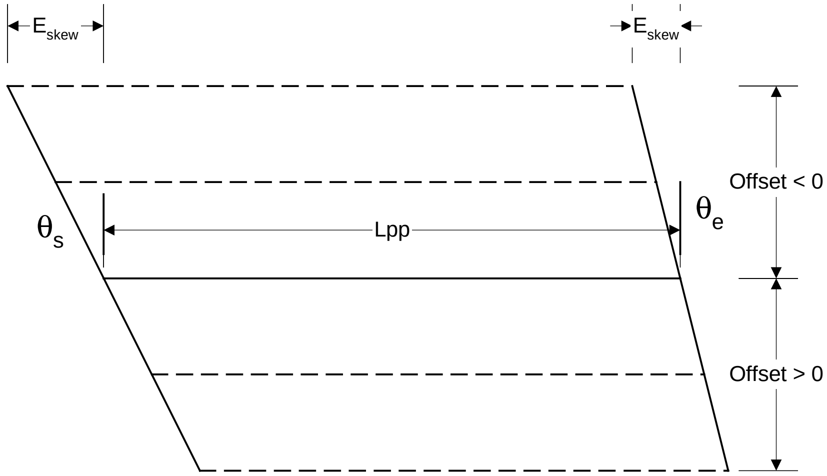


Figure 1 Skew Effects for computing Flexible Span Length

$$E_{skew} = Offset(\sin\theta_e - \sin\theta_s)$$

3.2 Horizontal Curvature Effects

Horizontal curve effects occur when a bridge is curved in plan. The pier to pier span length is measured long a survey line. Girder lines that are offset from the survey line are either longer or shorter because the radius of the curve defining the girder line (or the end points of the girder line if it is a chord) is larger or smaller.

3.2.1 Left Curves

For curves towards the left, when looking ahead on station, the horizontal curve effect can be computed as $E_{curve} = -Offset \cdot \Delta \cdot \frac{\pi}{180}$.

3.2.2 Right Curves

For curves towards the right, when looking ahead on station, the horizontal curve effect can be computed as $E_{curve} = Offset \cdot \Delta \cdot \frac{\pi}{180}$.

3.3 Effects of Connections

Connections define the location of the point of bearing relative to the centerline of the pier. The flexible span length must be adjusted for the effects of the Girder Bearing Offset defined in Section 3.1.2.5 of the System Design Manual. The Girder Bearing Offset is measured normal to the pier centerline and must be adjusted for skew angle.

The effects of connections can be computed as $E_{connect} = {GBO_s}\big/{\cos|\theta_s|} + {GBO_e}\big/{\cos|\theta_e|}$

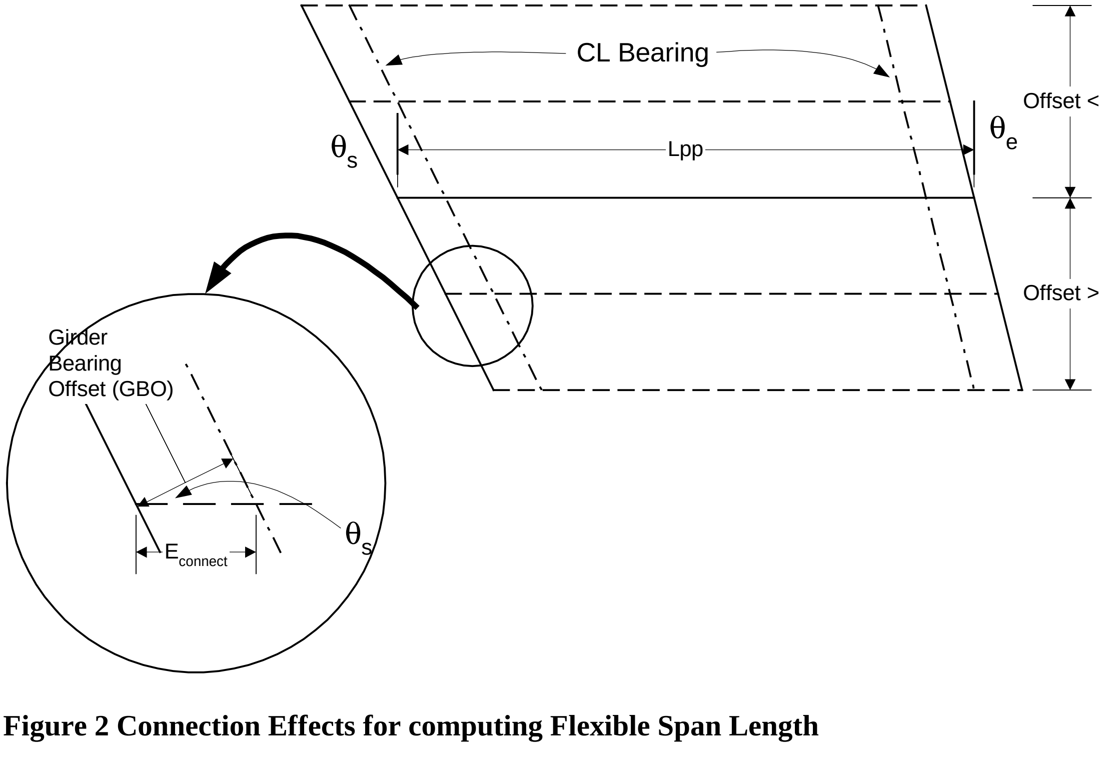


Figure 2 Connection Effects for computing Flexible Span Length

4. SECTION PROPERTIES

QConBridge II will perform its structural analysis using stiffness methods. In order to perform this analysis, section properties need to be computed.

4.1 General

Section properties can be changed at each analysis stage. For Bridge Analysis Model Projects, the user is responsible for computing and inputting section properties. For Product Model Projects, QConBridge II will compute the appropriate section properties for each stage of analysis.

QConBridge II requires cross sectional area and moment of inertias for superstructure and substructure elements

4.1.1 Superstructure Elements

Two sets of section properties are required for every superstructure element: One set is required for computing moments, shears, and reactions,another set is required for computing deflections.

Section properties for deflection are governed by LRFD 2.5.2.6.2 and 4.6.2.6.1. LRFD 2.5.2.6.2 applies to deflections from vehicular live load and states, *For composite design, the design cross-section should include the entire width of the roadway and any structurally continuous portions of the railings, sidewalks, and median barriers.* LRFD 4.6.2.6.1 applies to deflections from permanent loads in girder line models and states, *The calculation of deflections should be based on the full flange width.*

In order to compute limit state deflections for a longitudinal bridge analysis model, the live load deflection will have to be scaled to a single girder line. The details of this are described in Sections 5.6 and 6.4.2.

4.1.2 Substructure Elements

Only one set of section properties is needed for substructure elements. Section properties are required for elements that represent the columns and the cap beam.

4.2 Concrete Slab on Beam Bridges

The following sections describe how QConBridge II will compute section properties of superstructure elements for generic Slab on Beam Bridges. Section properties are based on gross or transformed cross section dimensions unless stated otherwise.

The slab on beam bridges supported by QConBridge II all have stages where the beams are non-composite and then later made composite with the concrete slab.

4.2.1 Section Properties for Non-composite Beams

Section properties for non-composite beams will be computed using conventional means.

4.2.2 Section Properties for Composite Beams

Composite cross sectional properties will be computed using transformed sections. The effective slab area will be transformed into an equivalent girder section by scaling its properties by $n = \frac{E_{slab}}{E_{beam}}$.

4.2.2.1 Effective Slab Area

An effective flange width and an effective slab depth define the effective slab area. For the purposes of computing section properties, the effective slab area is assumed to be directly on top of the top flange of the girder unless specified otherwise.

4.2.2.1.1 EFFECTIVE FLANGE WIDTH

The effective flange width is the limits of the width of a concrete slab, taken as effective in composite action for determining resistance for all limit states. The effective flange width is computed in accordance with LRFD 4.6.2.6.1

4.2.2.1.1.1 Effective Flange Width for Interior Girders

The effective flange width for interior girders is taken to be the lesser of:

- One-quarter of the effective span length
- 12.0 times the average thickness of the slab, plus the greater of web thickness or one-half the width of the top flange of the girder; or
- The average spacing of adjacent beams.

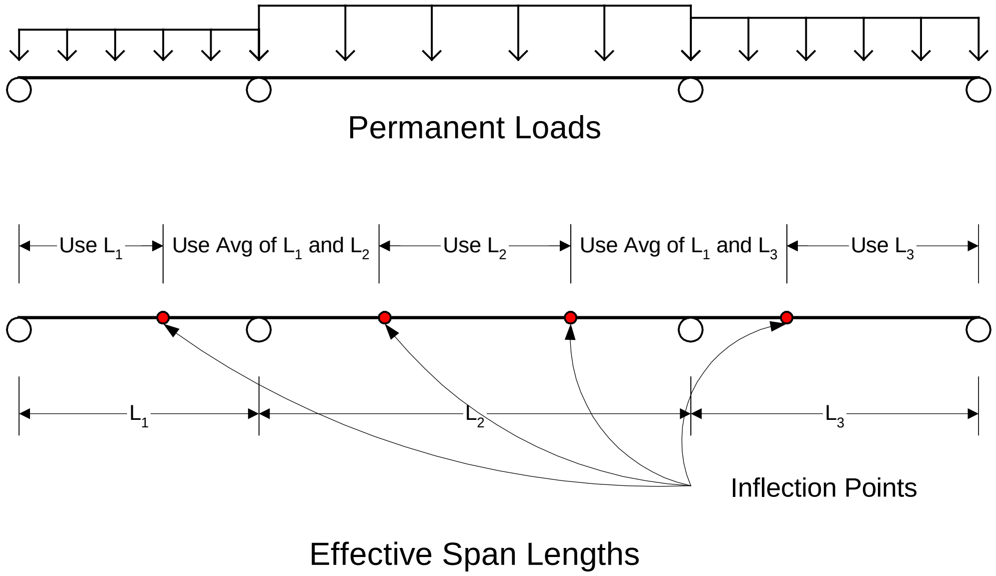
4.2.2.1.1.2 Effective Flange Width for Exterior Girders

The effective flange width for exterior girders is taken to be one-half the effective flange width of the adjacent interior girder plus the lesser of:

- One-eighth of the effective span length
- 6.0 times the average thickness of the slab, plus the greater of half the web thickness or one-quarter of the width of the top flange of the basic girder; or
- The width of the overhang.

4.2.2.1.1.3 Effective Span Length

The effective flange width is based on the effective span length. The effective span length is defined as the actual span length for simply supported spans and the distance between points of permanent load inflection for continuous spans, as appropriate for either positive or negative moments. Figure 3 illustrates how the effective span lengths are determined for a three span continuous structure. If the effective span length controls the effective flange width calculation, an iterative solution for effective span length is required. When the effective flange width changes, the section properties change as well. This causes the inflection points due to permanent load to move. When the inflection points move, the effective span lengths change, the effective flange width changes, and the cycle repeats until you converge on the effective span length and effective flange width. This iterative computation is shown in Figure 4.



Permanent Loads

Effective Span Lengths

Figure 3 Effective Span Lengths for computing Effective Flange Width at Different Locations along a Bridge

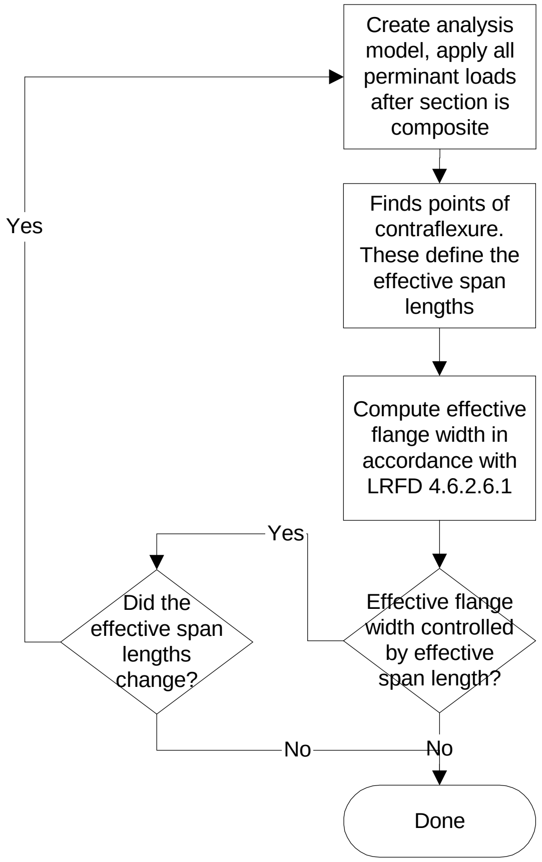


Figure 4 Procedure for computing Effective Flange Width

4.2.2.1.2 EFFECTIVE SLAB DEPTH

The effective slab depth is equal to the gross slab depth less the sacrificial depth. For exterior beams, the effective slab depth varies between the depth at the edge of the slab and the effective depth of the main slab.

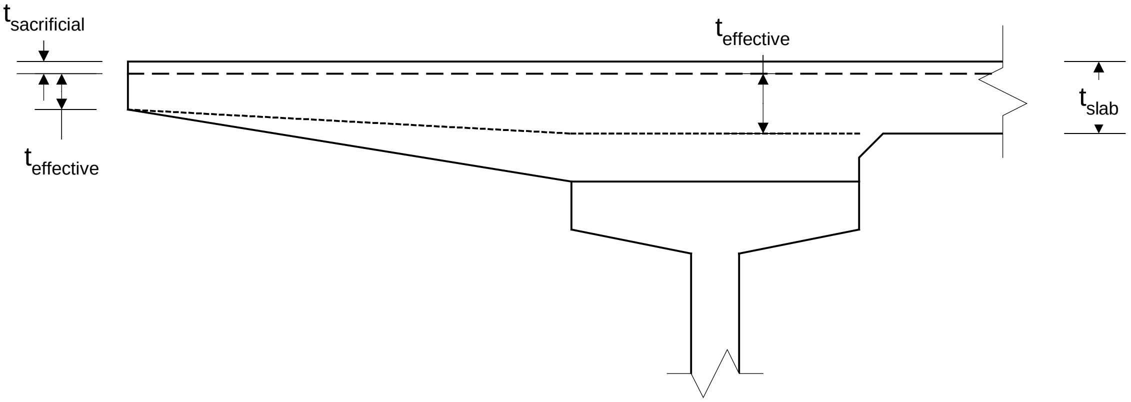


Figure 5 Effective Slab Depth

4.3 Cap Beams

Only one set of section properties need to be computed for cap beams. The cross sectional area and moment of inertia need to be computed. Cap Beam section properties only apply to TBAM's.

4.4 Columns

Only one set of section properties needs to be computed for columns. Column properties are required for cross sectional area and moment of inertia about axes transverse and longitudinal to the plane of the pier.

For LBAM's the cross sectional area and moment of inertia are summed for all columns and then divided by the number of girder lines. If the pier is skewed, the section properties are transformed into a coordinate system that is transverse and longitudinal to the alignment at the location of the pier. The moment of inertia for bending about an axis normal to the alignment is used in the analysis model. The product of inertia will likely be non-zero in this case, but will be ignored, as the analysis method used by QConBridge II does not account for the skew effects except as provided for in the live load distribution factors, and for load transfer between LBAM’s and TBAM’s (see Section 7.3.3 below).

For TBAM's, the cross sectional area and moment of inertia for bending about an axis normal to the bent for each individual column are used.

5. LIVE LOAD DISTRIBUTION FACTORS

Live load distribution factors are used to approximate the amount of live load a single girder line will carry. For BAM Projects, the user is responsible for determining the appropriate distribution factors and inputting them into the program. For Product Model Projects, QConBridge II will compute live load distribution factors with applicable LRFD and WSDOT criteria.

5.1 Cross Section Types

For the purpose of computing live load distribution factors, precast girder bridge product models are classified as cross section type K and rolled steel beams and built-up plate girder bridge product models are classified as cross section type A.

5.2 Method of Calculation

Live load distribution factors are computed in accordance with LRFD 4.6.2.2. If the WSDOT BDM option is selected, distribution factors for precast girders will be computed in accordance with Design Memorandum 2-1999.

5.3 Span Length used in Calcuations

The span length parameter L will be determined in accordance with table C4.6.2.2.1-1. Table C4.6.2.2.1-1 does not cover the case of interior reactions of simple spans (multi-span bridge without moment continuity between spans). For this case, L will be taken as the length of the longer of the adjacent spans.

In the rare occasion when the continuous span arrangement is such that an interior span does not have any positive uniform load moment, i.e., no uniform load points of contraflexure, the region of negative moment near the interior supports would be increased to the centerline of the span, and the L used in determining the live load distribution factors would be the average of the two adjacent spans.

5.4 Skew Correction Factors

When the lines of support are skewed the distribution factors must be adjusted to account for skew effects. Skew adjustment for moments are given in LRFD 4.6.2.2.2e. Skew adjustments for shear are given in LRFD 4.6.2.2.3c.

For the purposes of computing the skew correction factors the skew angle will be defined as:

Force Effect	Skew Angle
Moment	Average skew angle of the adjacent supports
Shear	Average skew angle of the adjacent supports
Reactions	Skew angle at the pier where the reaction occurs

Table 1 Skew Angle for computing Skew Correction Factors

5.5 Distribution Factors for Reactions

Distribution factors for reactions are not specifically defined in the LRFD specification, though they are alluded to in table C4.6.2.2.1-1. For type A and K cross sections, shear distribution factors are independent of span length, except when they are corrected for skew. QConBridge II will use the basic shear distribution factors for reactions, and adjust them for skew using the span lengths defined in Section 5.3 and skew angles defined in Section 5.4

Support elements that are modeled with a column member generate reactions for moment, axial, and shear forces. Vertical loads imparted onto the substructure from the superstructure generate these force effects. For this reason, the distribution factors for reaction will be applied to all three of these reaction components.

5.6 Distribution Factors for Deflection

When computing live load deflections the live load distribution factors for moments shall be used, except when computing deflections for evaluation of LRFD 2.5.2.6. For upward deflections, the distribution factor for negative moment will be used. For downward deflections, the distribution factor for positive moment will be used.

When computing live load deflections for the truck and lane configuration defined in LRFD 3.6.1.3.2 for use in evaluating LRFD 2.5.2.6, the procedure defined in Section 6.4.1 shall be used.

5.7 Distribution Factors for Rotations

When computing rotations due to live load the distribution factors for moment shall be used. For rotations relating to negative moments near the support, QconBridge II shall use the negative moment distribution factor. For rotations relating to positive moments near the support, QconBridge II shall use the positive moment distribution factor.

5.8 Distribution of Pedestrian Live Load

The LRFD Specification does not provide guidance for the distribution of pedestrian live load to a girder line. Because pedestrian live load is a uniform load applied to a sidewalk, QConBridge II will distribute it the same way the uniform sidewalk dead load is distributed. Distribution of sidewalk dead load is described in Section 6.3.1.1.6 below.

6. LONGITUDINAL BRIDGE ANALYSIS MODELS

The primary reason that Bridge Product Models are used in QConBridge II is to provide a simplified, efficient, and intuitive way to describe a bridge structure. Before a longitudinal structural analysis can be performed on a Product Model bridge, it must be idealized as a LBAM. The process of idealization is called Model Generation. This Section describes the modeling techniques and assumptions used when generating LBAM's from the Product Models supported by QConBridge II.

6.1 Model Topology

The basic topology of a LBAM is similar for all types of slab on girder bridges. Figure 6 shows the mapping from a product model to an analysis model for a typical slab on girder bridge.

Note that Figure 6 leaves out much detail. Details are given in the Sections following.

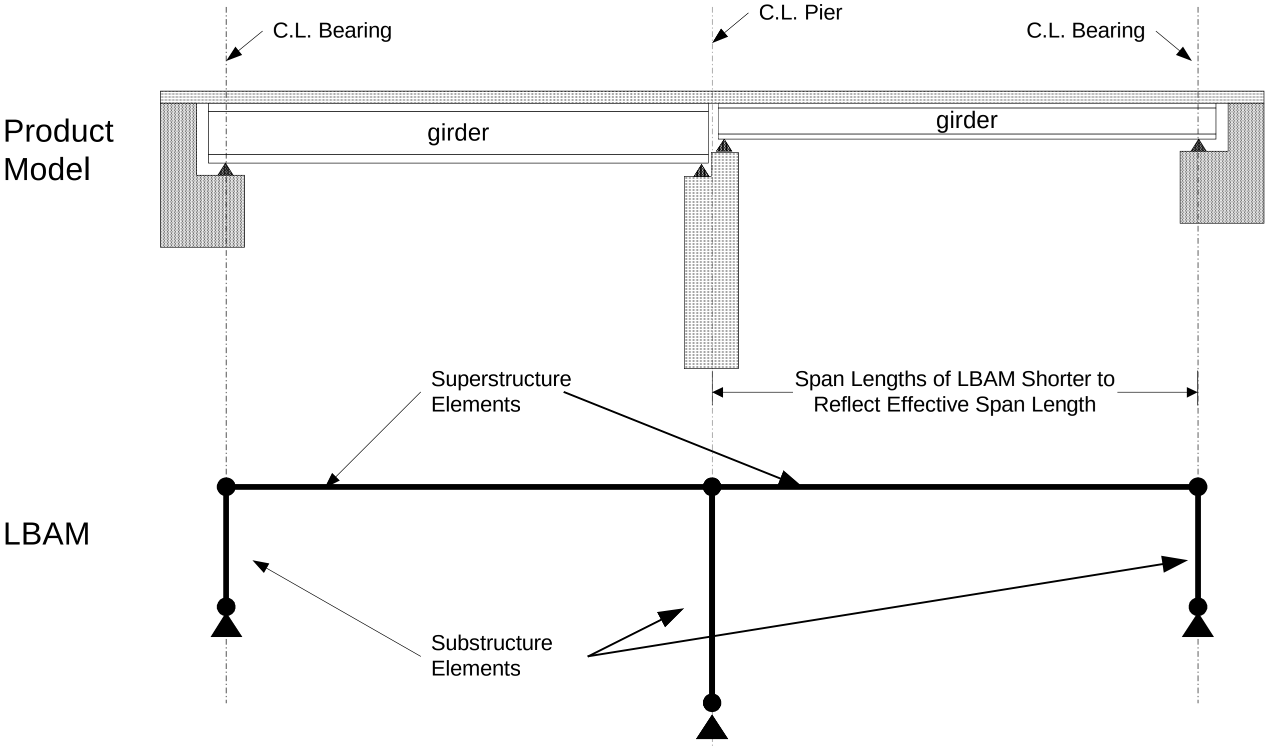


Figure 6 Model Geometry for Slab on Girder Bridges

6.1.1 Superstructure Elements

For the simplified method of analysis, the superstructure is divided into girder lines and each girder line is analyzed independently. Superstructure elements are modeled between points of bearing as a series of prismatic segments. The first segment begins at the left edge of a span. The remaining segments continue end to end until the right edge of the span is reached. The span length of the superstructure elements is taken to be the flexible span length as described in Section 3 above.

6.1.2 Substructure Elements

This Section describes how the product model descriptions of substructure elements are represented in the LBAM. Note that substructure elements need not be modeled consistently between the LBAM and the corresponding TBAM. For example, in the LBAM, a substructure element can be modeled as a knife-edge idealization and in the TBAM could represent the same pier as a complete 2D bent model.

6.1.2.1 Abutments

This section describes how abutment product models are described in the LBAM.

6.1.2.1.1 ZERO-HEIGHT IDEALIZED ABUTMENTS

Figure 7 shows how this type of abutment is modeled. The location of the support is located at the centerline of bearing. Note that the bearing heights from the connection are ignored.

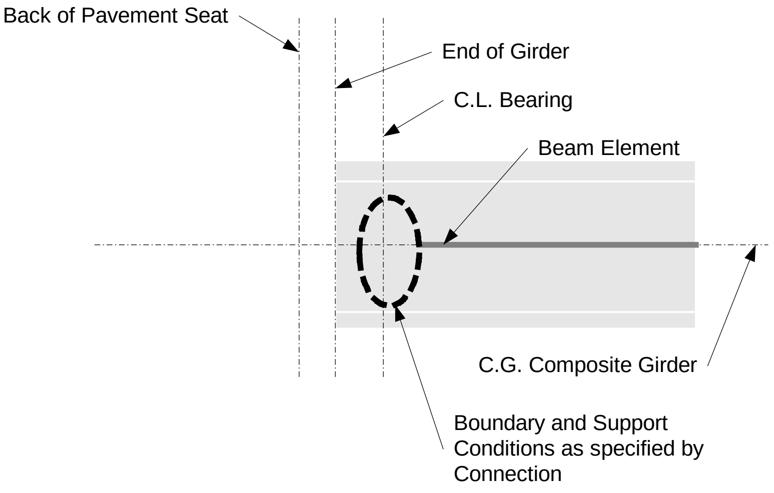


Figure 7 BAM Detail for Zero-Height Idealized Abutments

6.1.2.1.2 FIXED-HEIGHT IDEALIZED ABUTMENTS

Figure 8 shows how this type of abutment is modeled. Note that bearing heights from the connection and girder height are ignored.

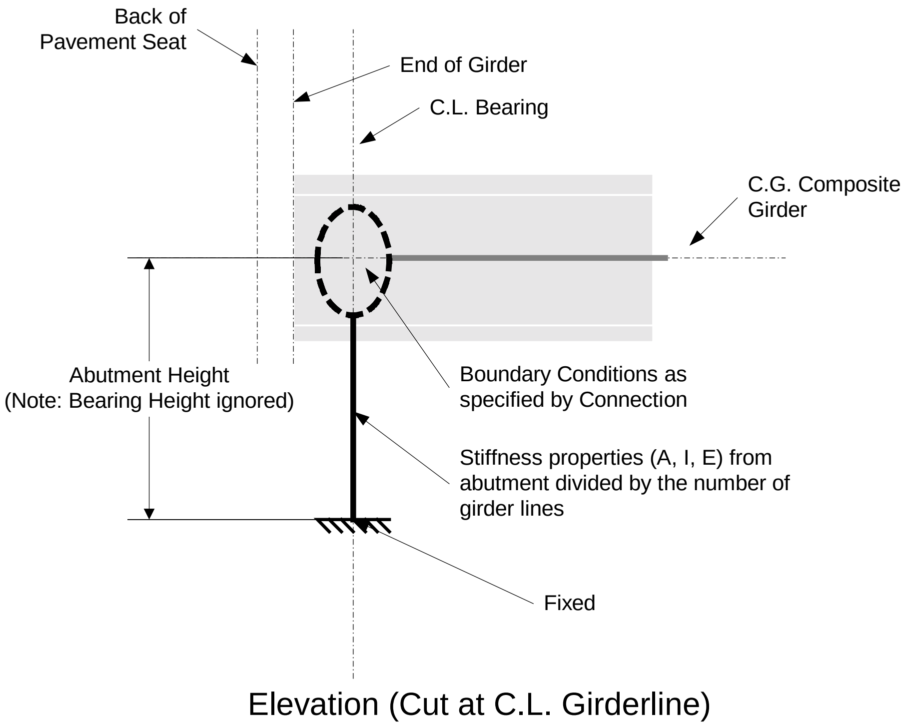


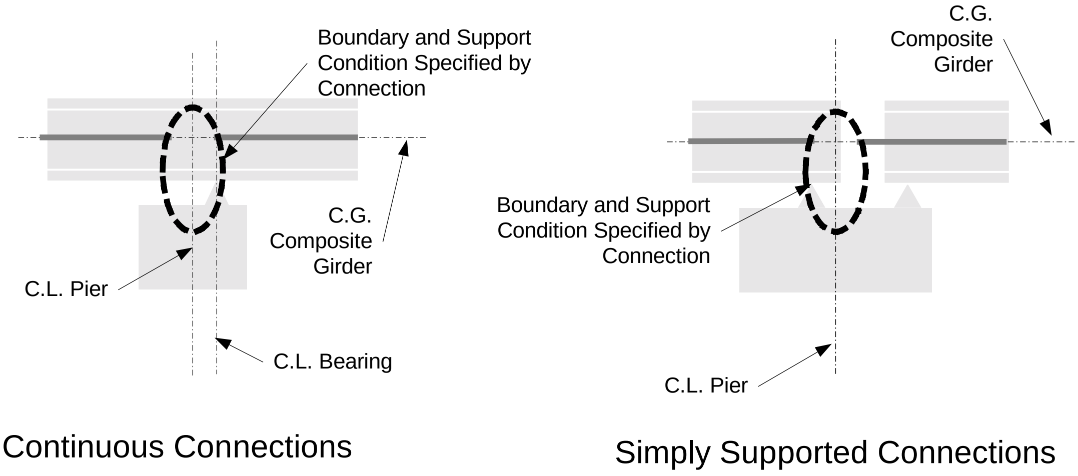
Figure 8 BAM Detail for Fixed-Height Idealized Abutments

6.1.2.2 Piers

Pier product models can be 2D or 3D zero height idealized, 2D or 3D fixed height idealized, or full product models. LBAMs are only concerned about the components of the pier product description dealing with the longitudinal force analysis for 3D and full product models. Pier connections can be Continuous, Simply Supported, or Simply Supported made Continuous.

6.1.2.2.1 ZERO-HEIGHT IDEALIZED PIERS

Figure 9 shows how zero height piers are modeled for continuous and simple support connections. Note that bearing heights from the connection are ignored and for the simple support condition, the left and right bearings share a common point of support located at the centerline of the pier.



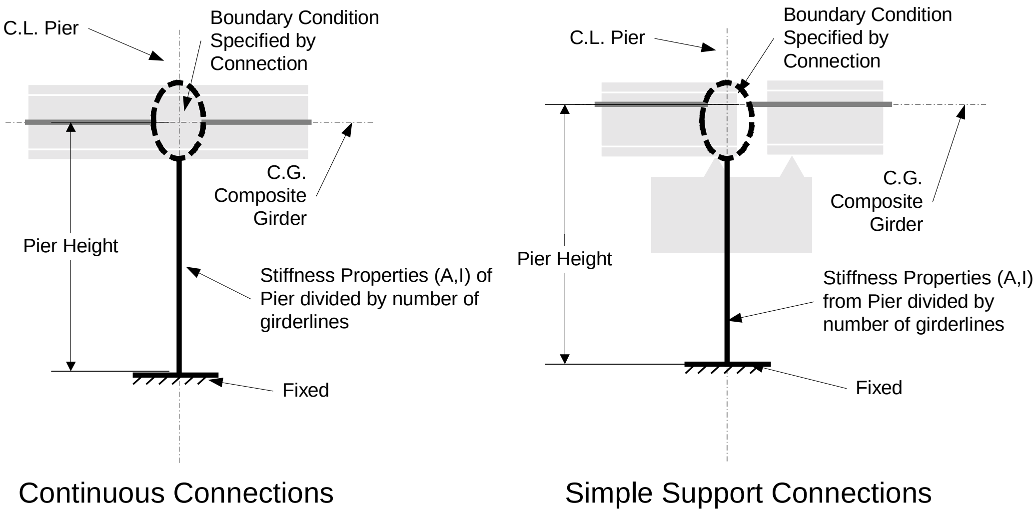
Continuous Connections

Simply Supported Connections

Figure 9 LBAM Model of Zero-Height Idealized Piers

6.1.2.2.2 FIXED HEIGHT IDEALIZED PIERS

Figure 10 shows how fixed height piers are modeled for continuous and simple support connections. The analysis model supports correspond to the centerline pier in the product model. Note that bearing heights from the connection and the vertical height between the girder C.G. and the top of the cap are ignored. For the simple support condition, the left and right bearings share a common point of support located at the centerline of the pier.



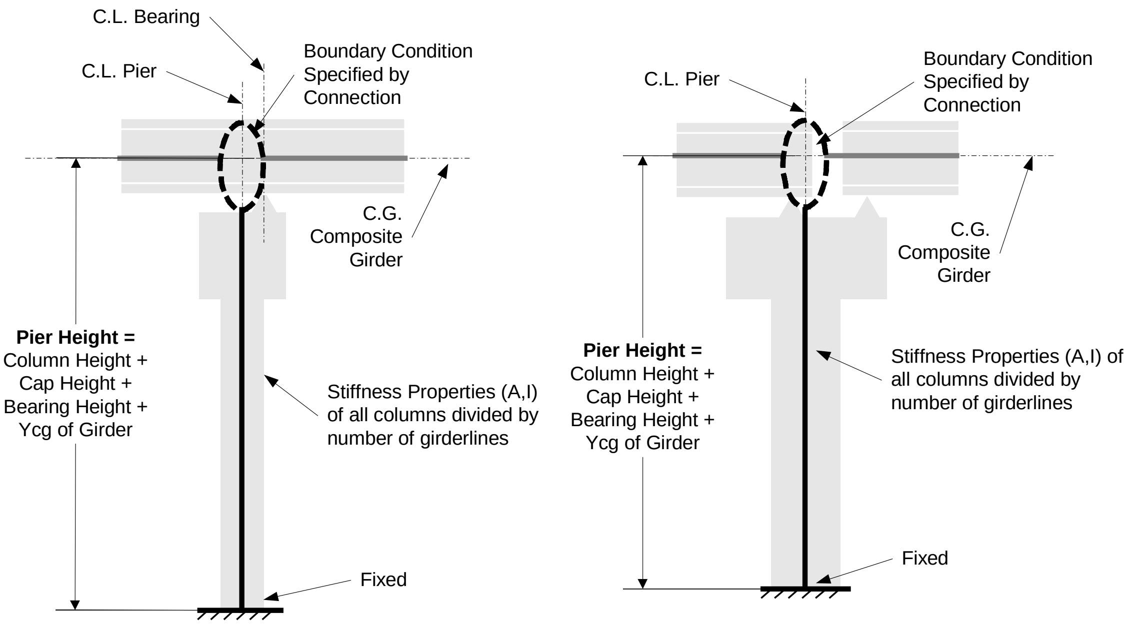
Continuous Connections

Simple Support Connections

Figure 10 LBAM Model of Fixed-Height Idealized Piers

6.1.2.2.3 FULL PRODUCT MODEL PIERS

The modeling of full product model piers is shown in Figure 11 for continuous and simple support connections. Note that this model takes the entire height of the product model pier into account including bearing heights. If bearing heights differ due to different girder depths, the average bearing height and average Y_{cg} for the girder are used.



Continuous Connections

Simple Support Connections

Figure 11 LBAM Modeling of Full Product Model Piers

The column height is computed as the difference between the top of column and bottom of column elevations. The top of column elevation is computed by tracing the elevation at the roadway surface at the intersection of the survey line and the centerline of the pier, along the roadway surface to the reference girder, down the depth of the reference girder to the cap beam, along the top surface of the cap beam to the centerline of the column and down the depth of the cap beam at the column. If the columns are different height, the average column height is used. This is shown in Figure 12.

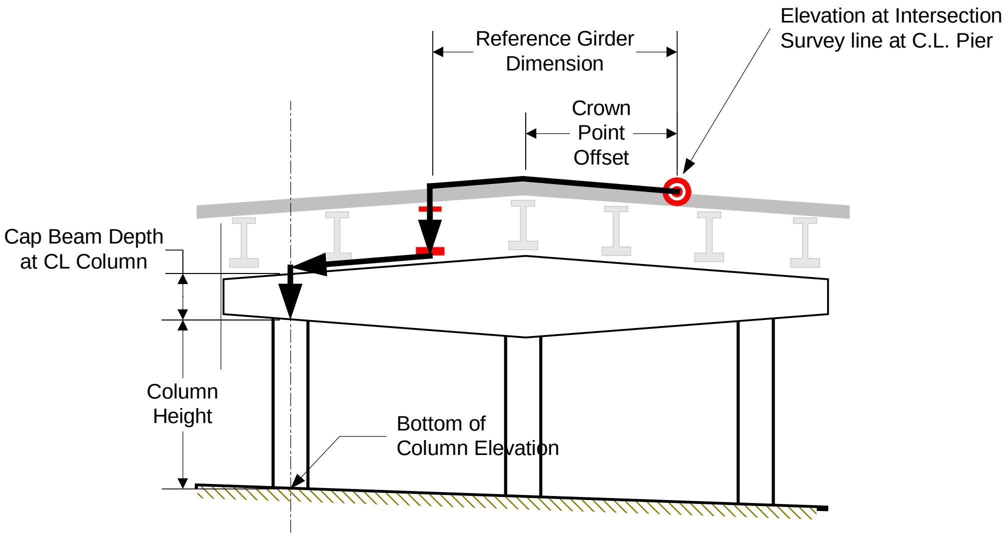


Figure 12 Column Height when Bottom Elevation is specified

6.1.3 Modeling Connections

Connections define the boundary conditions between adjacent superstructure members and the boundary conditions between superstructure members and substructure members. For zero height abutments and piers, connections define the support condition as well.

The sections that follow illustrate how product model connections are mapped to analysis model connections for the various combinations of support type and connection type.

6.1.3.1 Abutment Connection

6.1.3.1.1 ABUTMENT CONNECTION ON A ZERO HEIGHT ABUTMENT

Depending on the connection description, an abutment connection on a zero height abutment is modeled as a pinned or roller support.

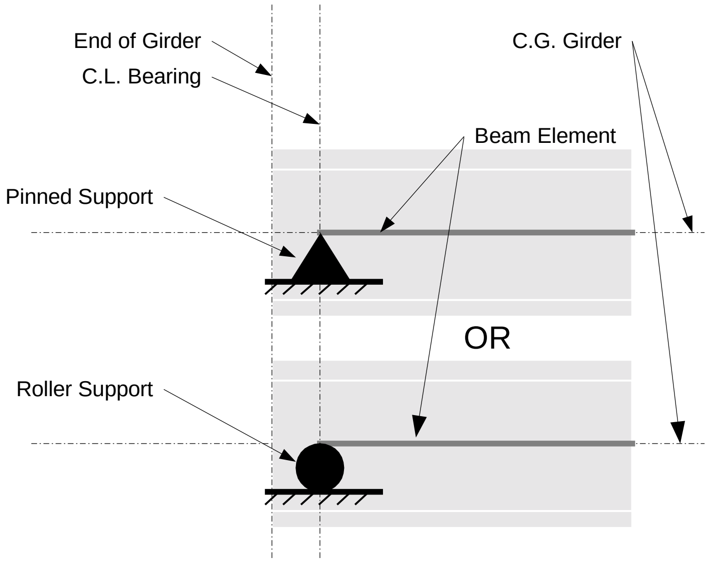


Figure 13 Abutment Connection on a Zero Height Abutment

6.1.3.1.2 ABUTMENT CONNECTION ON A FIXED HEIGHT ABUTMENT

Depending on the connection description, an abutment connection on a fixed height abutment is modeled as integral, hinged, or sliding.

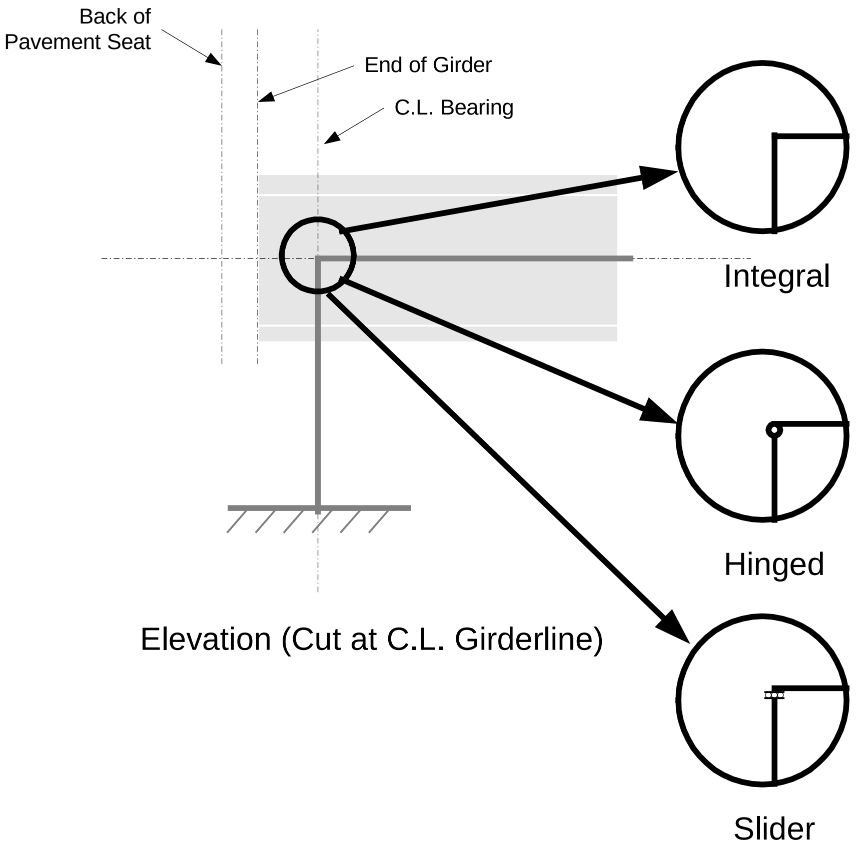


Figure 14 Abutment Connection on a Fixed Height Abutment

6.1.3.2 Continuous Pier Connection

6.1.3.2.1 CONTINUOUS PIER CONNECTION ON A ZERO HEIGHT PIER

Depending on the connection description, a continuous pier connection on a zero height pier is modeled as a pinned or roller support.

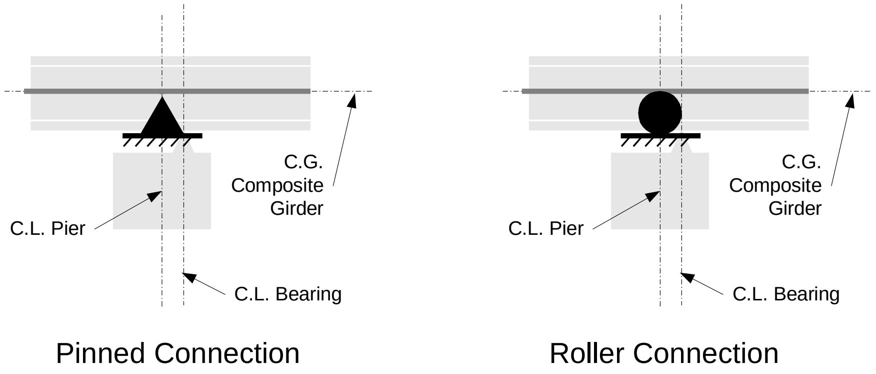


Figure 15 Continuous Pier Connection on a Zero Height Idealized Pier

6.1.3.2.2 CONTINUOUS PIER CONNECTION ON A FIXED HEIGHT PIER

A continuous pier connection on a fixed height pier is modeled with a hinge or slider at the top of the column member.

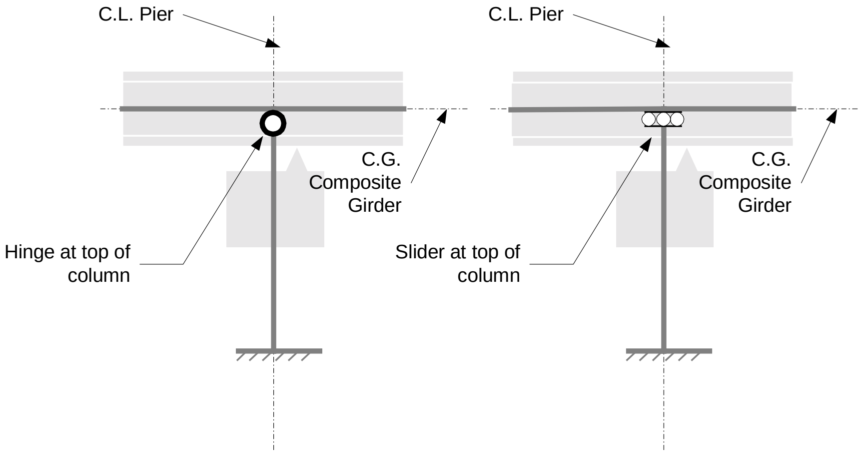


Figure 16 Continuous Pier Connection on a Fixed Height Idealized Pier

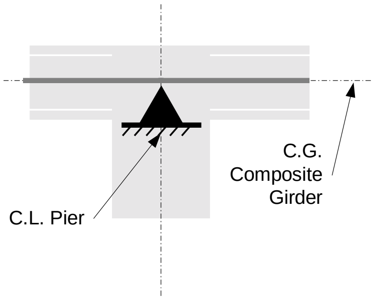
6.1.3.2.3 CONTINUOUS PIER CONNECTION ON A FULL PRODUCT MODEL PIER

Connections for a full product model pier are the same as for Fixed Height Idealized Piers

6.1.3.3 Integral Pier Connection

6.1.3.3.1 INTEGRAL PIER CONNECTION ON A ZERO HEIGHT PIER

Integral pier connections on zero height-idealized piers are modeled with a pinned support condition.



Pinned Support

Figure 17 Integral Pier Connection on a Zero Height Idealized Pier

6.1.3.3.2 INTEGRAL PIER CONNECTION ON A FIXED HEIGHT PIER

Integral pier connections on fixed height idealized piers are modeled with an integral connection between the two superstructure elements and the column element.

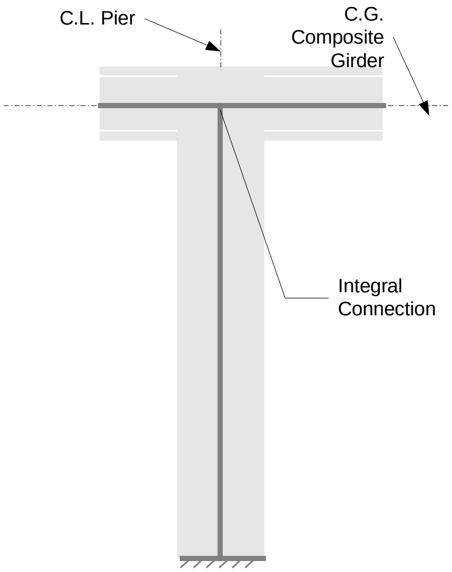


Figure 18 Integral Pier Connection on a Fixed Height Idealized Pier

6.1.3.3.3 INTEGRAL PIER CONNECTION ON A FULL PRODUCT MODEL PIER

Connections for a full product model pier are the same as for Fixed Height Idealized Piers

6.1.3.4 Simple Support Pier Connection

6.1.3.4.1 SIMPLE SUPPORT PIER CONNECTION ON A ZERO HEIGHT PIER

Simple support pier connections on a zero height pier are modeled with pinned or roller supports and a hinge at the right end of the left span.

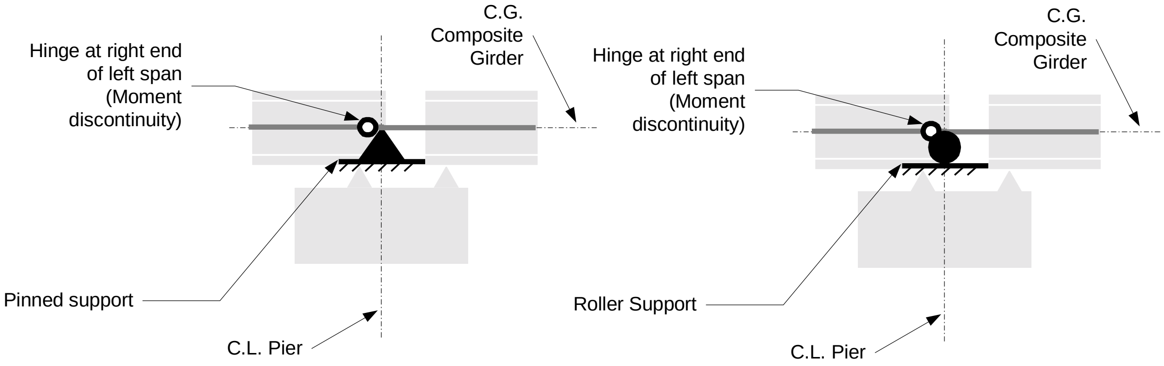


Figure 19 Simple Support Pier Connection on a Zero Height Idealized Pier

6.1.3.4.1.1 Made Continuous

If this connection is made continuous at some later stage in the analysis, the connection for that stage will be modeled as described in Section 6.1.3.2.1.

6.1.3.4.1.2 Made Integral

If this connection is made integral at some later stage in the analysis, the connection for that stage will be modeled as described in Section 6.1.3.3.1. Note that if a roller support is used in the simple span stage, it will be changed to a pinned support in the integral stage.

6.1.3.4.2 SIMPLE SUPPORT PIER CONNECTION ON A FIXED HEIGHT PIER

Simple support pier connections on a fixed height pier are modeled with hinges at the ends of the spans framing into the connection. If the top of column is hinged, the hinge at the left end of the right span is omitted.

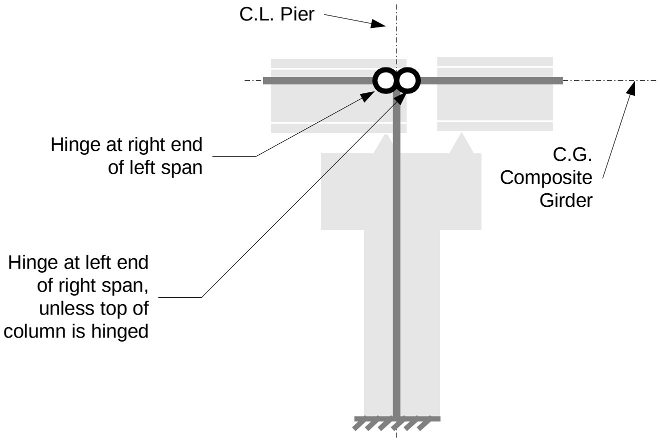


Figure 20 Simple Support Pier Connection on a Fixed Height Idealized Pier

6.1.3.4.2.1 Made Continuous

If this connection is made continuous at some later stage in the analysis, the connection for that stage will be modeled as described in Section 6.1.3.2.2.

6.1.3.4.2.2 Made Integral

If this connection is made integral at some later stage in the analysis, the connection for that stage will be modeled as described in Section 6.1.3.3.2.

6.1.3.4.3 SIMPLE SUPPORT PIER CONNECTION ON A FULL PRODUCT MODEL PIER

Connections for a full product model pier are the same as for Fixed Height Idealized Piers

6.2 Analysis Stages

QConBridge II supports staged analysis. Each bridge construction stage is modeled with a stage in the bridge analysis model. The analysis stage consists of a LBAM that represents the structure during the current stage and the loads that are applied to or removed from the structure during this stage.

6.2.1 Staged Analysis Constraints

There are two constraints that must be imposed on the stages of analysis models. The first constraint is that boundary conditions can only be added. For example, a hinge can be added to a span, but one cannot be taken away. The second constraint is that the member stiffness parameters (A, I and E) must not decrease as the stage number increases.

With the product models supported by QConBridge II, this is not a concern. These constraints are adhered to by the very nature of the product models supported by the software.

6.3 Loads

The sections that follow describe how the various loads are generated from the product model description and applied to the LBAM.

6.3.1 Dead Load

Product model dead loads for longitudinal analysis consists of the self weight of the girders, roadway slab, end diaphragms, intermediate diaphragms, traffic barriers, median barriers, sidewalks, and overlays. This section describes how these loads are computed and represented in LBAM's.

Permanent loads of and on the roadway slab may either be distributed uniformly over all the girder lines (See LRFD 4.6.2.2.1) or may be distributed based on tributary areas and simple distribution rules (WSDOT Design Practice). This section will describe how the dead loads are computed and applied to the LBAM's for both cases. When the loads are evenly distributed over all girders, the loads specified in Section 6.3.1.1.8, except for girder self weight, are not applied to the analysis models.

6.3.1.1 Load in Main Span

Superimposed dead loads are applied to the main span, between the centerlines of bearing as a uniform load or a series of linear load segments as appropriate. The figure below illustrates how superimposed dead loads in the main span are modeled.

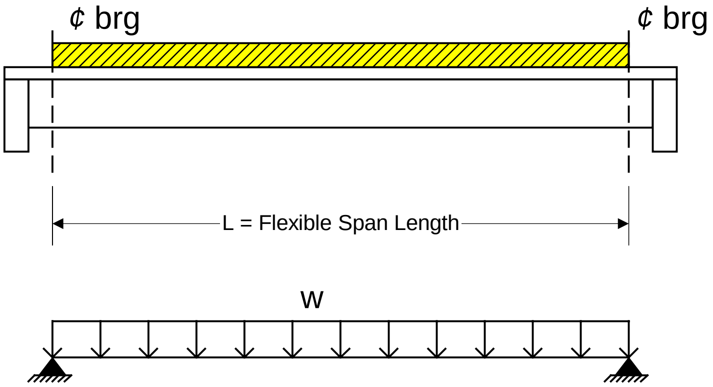


Figure 21 Modeling of Main Span Loads

6.3.1.1.1 GIRDER SELF-WEIGHT

The self-weight of the girder is modeled as a series of uniform load segments that correspond to the segments in the product model. The intensity of a load segment is taken to be $w = \quad {}_{i}A_i \gamma_i g$ where,

w	Intensity of the uniform load
A_i	Cross-sectional area of the ith element
γ_i	Density of the material for the ith element of the cross section
g	gravitational acceleration
i	ith element in the cross section

6.3.1.1.2 SLAB

6.3.1.1.2.1 Uniform Distribution to All Girder Lines

The load per girder line using a uniform distribution of the slab load is taken to be $w = \frac{V_{slab}\gamma_c g}{N \cdot L_m}$ where,

w	Intensity of the uniform load
V_{slab}	Volume of the slab
γ_c	Density of the slab concrete
g	gravitational acceleration
N	Number of girder lines
L_m	Total length of the analysis model to which this load is applied

The volume of the slab is taken to be $V_{slab} = \underset{i=1 \rightarrow NS-1}{} \frac{A_i + A_{i+1}}{2} L_i$ where,

V_{slab}	Volume of the slab
A_i	cross section area of the slab, including the slab pad, at section i
L_i	Distance between section i and i+1, measure along the center line of the bridge
NS	Number of sections. Slab sections begin and end at the ends of the girders at the start and end of the bridge and occur at all points of interest.

6.3.1.1.2.2 Distribution of Load to Girder Lines Based on Tributary Area

This section describes how the slab load is distributed to girder lines based on tributary area. The slab load is divided into two parts; the main slab and the slab pad.

6.3.1.1.2.2.1 Main Slab

The load from the main portion of the slab on interior girders is a uniform load along the entire length of the girder line. For exterior girders, the main slab loads varies with location due to the thickening of the overhang at the exterior girder and curvature of the slab edge.

6.3.1.1.2.2.1.1 Interior Girders

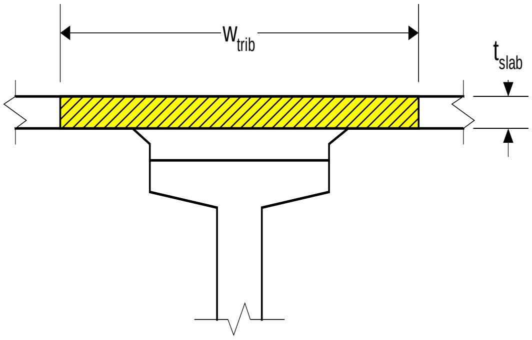


Figure 22 Tributary Slab Width

The main slab load for interior girders is $w_{slab} = t_{slab} w_{trib} \gamma_{conc} g$, where:

w_{slab}	Main slab load
t_{slab}	Gross thickness of the slab
w_{trib}	Tributary width of the slab
γ_c	Weight density of slab concrete
g	Gravitational acceleration

6.3.1.1.2.2.1.2 Exterior Girders

The main slab load for an exterior girder line is divided into two parts; one for the inboard side and one for the outboard side. On the inboard side, the slab load is uniform. On the outboard side, the slab load varies with the haunch and curvature of the slab edge.

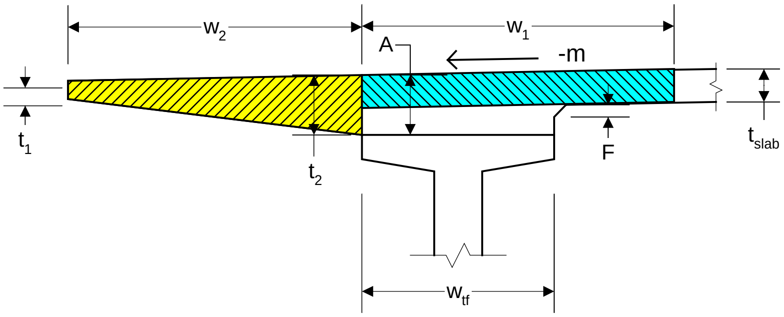


Figure 23 Tributary Slab Width for an Exterior Girder

6.3.1.1.2.2.1.3 Inboard Side

The load for the main slab on the inboard side of exterior girders is taken to be $w_{slab} = w_1 t_{slab} \gamma_c g$, where

w_{slab}	Main slab load
t_{slab}	Gross thickness of the slab
w_1	Tributary width of the slab, computed as half the distance to the next girder plus half of the top flange width. For curved structures, with straight girders, w_1 must be divided by the cosine of the angle formed between a radial line passing through the point under consideration and a line that is normal to the girder.
γ_c	Weight density of slab concrete
g	Gravitational acceleration

6.3.1.1.2.2.1.4 Outboard Side

The intensity of the load on the outboard side of exterior girders at any point in the span is taken to be

$$w_{slab} = \frac{(t_1 + t_2)}{2} w_2 \gamma_c g$$

$$t_2(x) = EL(x) - y(x)$$

$$y(x) = \frac{2(K_3 + K_1 - 2K_2)}{L^2} x^2 + \frac{4K_2 - K_3 - 3K_1}{L} x + K_1$$

$$K_1 = EL(0) - A - m\frac{w_{tf}}{2\cos\theta}$$

$$K_2 = EL\left(\tfrac{L}{2}\right) - t_{slab} - F - m\frac{w_{tf}}{2\cos\theta}$$

$$K_3 = EL(L) - A - m\frac{w_{tf}}{2\cos\theta}$$

where

w_{slab}	Main slab load
t_{slab}	Gross thickness of the slab
w_2	Tributary width of the slab, computed as the distance from the centerline of the girder to the edge of the slab, measured normal to the alignment. For curved structures, with straight girders[2], w_2 must be divided by $\cos\theta$ to account for the girder not being parallel to the tangent to the alignment.
γ_c	Weight density of slab concrete
g	Gravitational acceleration
x	Distance along the girder, measure from the centerline of bearing
$EL(x)$	The elevation of the surface of the roadway at x, directly above the outboard side of the top flange.

---

[2] Actually, all horizontal dimensions can be divided by $\cos\theta$. Only for the case of curve bridge with straight girders is $\cos\theta$ not equal to 1.

L	Bearing to bearing span length (flexible span length)
F	Depth of fillet (distance from top of girder to top of slab at mid-span is assumed to be t_{slab}+F).
A	Distance from top of girder to top of slab, measured at the intersection of centerline bearing and centerline girder.
$y(x)$	Elevation of the outboard edge of the top flange. It is assumed that the top flange of the girder forms a parabolic shape along its length.
m	Crown slope at x
θ	Angle between the vector that is normal to the alignment, passing though x, and a vector that is normal to the girder line.
w_{tf}	width of the top flange, measured normal to the girder

The main slab load on the outboard side of exterior girders will be applied linearly between all points of interest.

6.3.1.1.2.2.2 Slab Pad (Haunch)

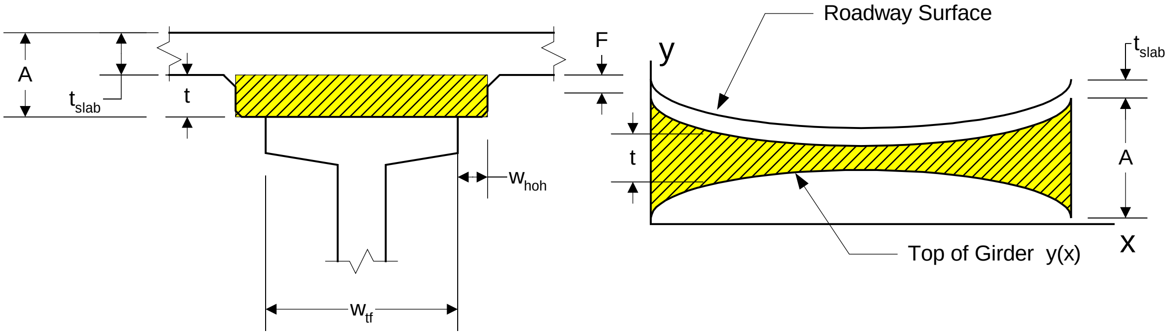


Figure 24 Slab Pad (Haunch) Load

The slab pad, or haunch, is defined to be that area of concrete between the main slab and the girder. The slab pad has a constant width, but its depth varies due to the effects of camber and vertical curvature of the roadway surface. The slab pad load is approximated with segments of linear loads. The intensity of the linear load at any point is taken to be:

$$w_{pad} = t\left(w_{tf} + 2w_{hoh}\right)\gamma_c g$$

$$t(x) = EL(x) - t_{slab} - y(x)$$

$$y(x) = \frac{2(K_3 + K_1 - 2K_2)}{L^2}x^2 + \frac{4K_2 - K_3 - 3K_1}{L}x + K_1$$

$$K_1 = EL(0) - A$$

$$K_2 = EL\left(\tfrac{L}{2}\right) - t_{slab} - F$$

$$K_3 = EL(L) - A$$

where

w_{pad}	Slab pad load

$t(x)$	Depth of the slab pad at point x
w_{tf}	Width of the top flange
w_{hoh}	Width of the haunch overhang
γ_c	Weight density of slab concrete
g	Gravitational acceleration
x	Distance along the girder, measured from the centerline of bearing
$EL(x)$	The elevation of the surface of the roadway at x, directly above the outboard side of the top flange.
L	Bearing to bearing span length (flexible span length)
F	Depth of fillet (distance from top of girder to top of slab at mid-span is assumed to be $t_{slab}+F$).
A	Distance from top of girder to top of slab, measured at the intersection of centerline bearing and centerline girder. Value is equal at both ends of the girder.
$y(x)$	Elevation of the outboard edge of the top flange. It is assumed that the top flange of the girder forms a parabolic shape along its length.

6.3.1.1.3 INTERMEDIATE DIAPHRAGMS

Intermediate diaphragm loads are applied to the main span as concentrated loads. The loads are positioned in accordance with the diaphragm layout rules specified by the product model. The magnitude of the load is computed differently depending on product model type.

6.3.1.1.3.1 Precast Girder Bridge Product Models

For precast girder bridge product models, the magnitude of the intermediate diaphragm load is computed as $P = A_{dia}\left[\left(\frac{S_L + S_R}{2}\right) - t_{web}\right]\gamma_c g$ for interior girders and $P = A_{dia}\left(\frac{S_i - t_{web}}{2}\right)\gamma_c g$ for exterior girders, where

P	Magnitude of the load
A_{dia}	Cross sectional area of the diaphragm
γ_c	Weight density of slab concrete
g	Gravitational acceleration
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_i	Girder spacing on the side of the interior girder
t_{web}	Width of the web

6.3.1.1.3.2 Steel Beam Bridge Product Models

For steel beam bridge product models (built-up and rolled shapes), the product model of the intermediate diaphragms is described by a uniform load along the diaphragm, which is transverse to the girder. The magnitude of the intermediate diaphragm load is taken to be $P = w_{dia}\left[\left(\frac{S_L + S_R}{2}\right) - t_{web}\right]$ for interior girder lines and $P = w_{dia}\left(\frac{S_i - t_{web}}{2}\right)$ for exterior girder lines where

P	Magnitude of the load
w_{dia}	weight per unit length of the diaphragm transverse to the girder line
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder
t_{web}	Width of the web

6.3.1.1.4 TRAFFIC BARRIER LOAD

The traffic barrier load is applied to the main span as a uniform load. The intensity of the traffic barrier load is $w = A_{tb}\gamma_c g$ where

w	Load intensity for the entire traffic barrier
A_{tb}	Cross sectional area of the traffic barrier
γ_c	Weight density of slab concrete
g	Gravitational acceleration

6.3.1.1.4.1 Uniform Distribution of Load to All Girder Lines

In accordance with LRFD 4.6.2.2.1, the total traffic barrier load is distributed evenly over all girder lines. The total traffic barrier load is computed as $W_{tb} = w \cdot L_{tb}$, where W_{tb} is the total weight of the traffic barrier and L_{tb} is the length of the traffic barrier, measured from back of pavement seat to back of pavement seat and adjusted for the connections at the first and last pier. The load per girder is taken to be $w = \frac{W_{tb}}{N \cdot L_m}$, where N is the number of girder lines and L_m is the length of the LBAM that the load is applied to.

6.3.1.1.4.2 Distribution of Load to Exterior Girder Lines

Alternatively, the load can be distributed over n exterior girder lines, if there is $2n$ or more girder lines, otherwise the load per girder line is $\frac{2w}{N}$, where N is the number of girder lines. If the traffic barriers on the left and right side of the bridge differ and the number of girder lines is less than $2n$ the load per girder line is $\frac{w_L + w_R}{N}$, where w_L and w_R are the intensities of the left and right loading respectively.

6.3.1.1.5 MEDIAN BARRIER LOADS

Median barrier loads are applied to the main span as a uniform load. The basic load is $w = A_b \gamma_c g$ where

w	Load intensity for the entire barrier
A_b	Cross sectional area of the barrier
γ_c	Weight density of slab concrete
g	Gravitational acceleration

6.3.1.1.5.1 Uniform Distribution of Load to All Girder Lines

In accordance with LRFD 4.6.2.2.1, the total barrier load is distributed evenly over all girder lines. The total barrier load is computed as $W_b = w \cdot L_b$, where W_b is the total weight of the barrier and L_b is the length of the barrier, measured from back of pavement seat to back of pavement seat and adjusted for the connections at the first and last pier. The load per girder is take to be $w = \frac{W_b}{N \cdot L_m}$, where N is the number of girder lines and L_m is the length of the LBAM that the load is applied to.

6.3.1.1.5.2 Distribution of Load to Adjacent Girder Lines

Alternatively, the load can be distributed over the *n* nearest girder lines. If the total number of girder lines, *N*, is less than *n*, then the barrier load is evenly distributed amongst all girder lines. If the case occurs where there are two outer girders that are equidistant from the barrier location, and this makes the total number of girders equal to n+1, the load will be distributed evenly over n+1 girders.

6.3.1.1.6 SIDEWALKS

The sidewalk load is applied to the main span as a uniform load. The intensity of the sidewalk load is $w = A_{sw} \gamma_c g$ where

w	Load intensity for the entire traffic barrier
A_{sw}	Cross sectional area of the sidewalk
γ_c	Weight density of slab concrete
g	Gravitational acceleration

6.3.1.1.6.1 Uniform Distribution of Load to All Girder Lines

In accordance with LRFD 4.6.2.2.1, the total sidewalk load is distributed evenly over all girder lines. The total sidewalk load is computed as $W_{sw} = w \cdot L_{sw}$, where W_{sw} is the total weight of the sidewalk and L_{sw} is the length of the sidewalk, measured along its centerline from back of pavement seat to back of pavement seat and adjusted for the connections at the first and last pier. The load per girder is take to be $w = \frac{W_{sw}}{N \cdot L_m}$, where N is the number of girder lines and L_m is the length of the LBAM that the load is applied to.

6.3.1.1.6.2 Distribution of Load to Exterior Girder Lines

Alternatively, the load can be distributed over n exterior girder lines, if there is $2n$ or more girder lines, otherwise the load per girder line is $\frac{2w}{N}$, where N is the number of girder lines. If the sidewalk on the left and right side of the bridge differ and the number of girder lines is less than $2n$ the load per girder line is $\frac{w_L + w_R}{N}$, where w_L and w_R are the intensities of the left and right loading respectively.

6.3.1.1.7 OVERLAY LOADS

When roadway surfacing is present dead load must be accounted for.

6.3.1.1.7.1 Uniform Distribution of Load to All Girder Lines

In accordance with LRFD 4.6.2.2.1, the total overlay load is distributed evenly over all girder lines. The uniform load for a girder line, based on the total overlay load, is computed as $w = \frac{A_{slab} t_{olay} \gamma_{olay} g L_b}{N \cdot L_m}$, where

w	Uniform load intensity
A_{slab}	Surface area of the slab receiving the overlay material
t_{olay}	Thickness of the overlay
γ_{olay}	Density of the overlay material
g	Gravitational acceleration
L_b	Length of the bridge back of pavement seat to back of pavement seat and adjusted for connections at the first and last piers
N	Number of girder lines
L_m	Length of the longitudinal bridge analysis model to which this load is applied

6.3.1.1.7.2 Distribution of Load to Girder Lines Based on Tributary Area

Alternatively, the overlay load may be distributed to girder lines based on its tributary area. The dead load is computed as $w = w_{trib} t_{olay} \gamma_{olay} g$, where

w	Load intensity for the specified tributary width
w_{trib}	Tributary width
t_{olay}	Thickness of the overlay
γ_{olay}	Density of the overlay material
g	Gravitational acceleration

6.3.1.1.8 BOTTOM LATERALS ON BUILT-UP STEEL BEAMS

Built-Up Steel Plate Girder Bridge Product Models describe bottom laterals as a weight per length for each girder line. For LBAM's, this load is applied along the flexible span length of the model.

6.3.1.2 Loads in Connection Region

A portion of the load due to bridge components extends beyond the points of bearing for most connection types. The product model of the connection defines the geometry of the end of the girder, and how this load is applied to the structure. The connection definitions specify if the loads beyond the point of bearing are supported by the girder, applied directly to the bearing, or are ignored. This section describes how the product model loads in connection regions are represented in analytical models.

When loads in the main span are applied using a uniform distribution over all girder lines, the loading defined in this section is not applied to the analysis model. Girder self weight loads, as defined in this section, are always applied to the analysis models.

6.3.1.2.1 ABUTMENT CONNECTIONS

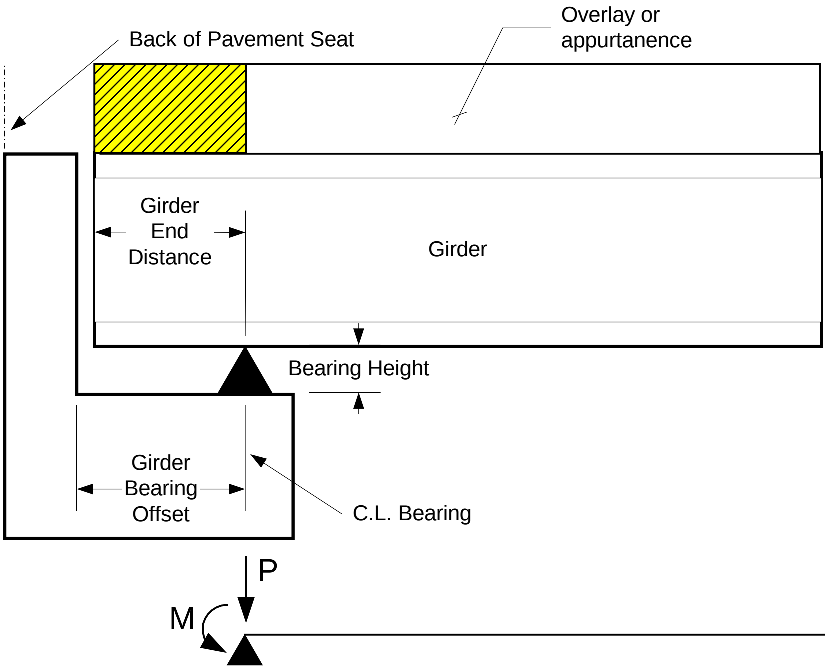


Figure 25 Abutment Connection Loads

Product model loads for abutment connections are represented by an equivalent concentrated force and moment applied to the support point when the load is imposed on the girder. When the load is imposed directly on the support, only the concentrated load is applied.

Note that Girder End Distance is measured normal to the back of pavement seat. The Girder End Distance must be corrected for skew.

6.3.1.2.1.1 Girder Self Weight

The equivalent loads are given by:

$$P = A_g \gamma_c g \cdot GED$$

$$M = P \cdot \frac{GED}{2}$$

where

P	Equivalent concentrated force
M	Equivalent concentrated moment
A_g	Area of the girder
γ_c	Density of concrete
g	Gravitational acceleration
GED	Girder End Distance

6.3.1.2.1.2 Slab

The equivalent loads are given by:

$$P = \lfloor w_{trib} t_{slab} + \left(A - t_{slab}\right)\left(w_{tf} + 2w_{oh}\right)\rfloor \gamma_c g \cdot GED$$

$$M = P \cdot \frac{GED}{2}$$

where

P	Equivalent concentrated force
M	Equivalent concentrated moment
w_{trib}	Tributary width of the slab at the centerline bearing
t_{slab}	Gross slab thickness
A	Distance from top of girder to top of slab at intersection of the centerline of girder and the centerline of bearing
w_{tf}	Width of the top flange of the girder
w_{oh}	Width of the haunch overhang
γ_c	Density of concrete
g	Gravitational acceleration
GED	Girder End Distance

6.3.1.2.1.3 End Diaphragms

End diaphragm loads are applied to the ends of the analysis models as concentrated loads and moments. The product connection description specifies if the diaphragm load is applied to the end of the girder or directly to the bearing.

The magnitudes of the loads are computed differently depending on product model type.

6.3.1.2.1.3.1 Precast Girder Bridge Product Models

For precast girder bridge product models, the magnitude of the end diaphragm load is computed as $P = A_{dia}\left(\frac{S_L + S_R}{2}\right)\gamma_c g$ for interior girders and $P = A_{dia}\frac{S_i}{2}\gamma_c g$ for exterior girders, where

P	Magnitude of the load
A_{dia}	Cross sectional area of the diaphragm (Computed as width times height)
γ_c	Weight density of slab concrete
g	Gravitational acceleration
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

The moment is taken to be $M = P \cdot E$ where E is the distance from the centerline of bearing to the point of application of P.

6.3.1.2.1.3.2 Steel Beam Bridge Product Models

For steel beam bridge product models (built-up and rolled shapes), the end diaphragms are described by a uniform load transverse to the girder. The magnitude of the end diaphragm load is taken to be $P = w_{dia}\left(\frac{S_L + S_R}{2}\right)$ for interior girder lines and $P = w_{dia}\frac{S_i}{2}$ for exterior girder lines where

P	Magnitude of the load
w_{dia}	weight per unit length of the diaphragm transverse to the girder line
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

The moment is taken to be $M = P \cdot E$ where E is the distance from the centerline of bearing to the point of application of P.

6.3.1.2.1.4 Traffic Barrier

The equivalent loads are given by:

$$P = \frac{A_{tb}\gamma_c g \cdot GED}{k}$$

$$M = P \cdot \frac{GED}{2}$$

where

P	Equivalent concentrated force
M	Equivalent concentrated moment
A_{tb}	Area of the traffic barrier
γ_c	Density of concrete
g	Gravitational acceleration
GED	Girder End Distance
k	A factor representing the distribution of the traffic barrier weight amongst the exterior girder lines. See 6.3.1.1.4.2 for details.

6.3.1.2.1.5 Median Barriers

The equivalent loads are given by:

$$P = \frac{A_b \gamma_c g \cdot GED}{k}$$

$$M = P \cdot \frac{GED}{2}$$

where

P	Equivalent concentrated force
M	Equivalent concentrated moment
A_b	Area of the median barrier
γ_c	Density of concrete
g	Gravitational acceleration
GED	Girder End Distance
k	A factor representing the distribution of the barrier weight amongst the nearby girder lines. See 6.3.1.1.5.2 for details.

6.3.1.2.1.6 Sidewalks

The equivalent loads are given by:

$$P = \frac{A_{sw} \gamma_c g \cdot GED}{k}$$

$$M = P \cdot \frac{GED}{2}$$

where

P	Equivalent concentrated force
M	Equivalent concentrated moment

A_{sw}	Area of the sidewalk
γ_c	Density of concrete
g	Gravitational acceleration
GED	Girder End Distance
k	A factor representing the distribution of the sidewalk weight amongst the exterior girder lines. See 6.3.1.1.6.2 for details.

6.3.1.2.1.7 Overlay

The equivalent loads for overlays are:

$$P = w_{trib} t_{olay} \gamma_{olay} g \cdot GED$$

$$M = P \cdot \frac{GED}{2}$$

P	Equivalent concentrated force
M	Equivalent concentrated moment
w_{trib}	Tributary width, measured at the point of bearing
t_{olay}	Thickness of the overlay
γ_{olay}	Density of the overlay material
g	Gravitational acceleration
GED	Girder end distance

6.3.1.2.2 CONTINUOUS PIER CONNECTION

For a continuous pier connection, all of the loads in the connection region, except for diaphragm loads, are represented in the main span portion of the analysis model.

6.3.1.2.2.1 End Diaphragms

End diaphragm loads are applied to the support points of the analysis models as concentrated loads, if the product description of the connection specifies that the diaphragm weight should be included in the analysis models.

The magnitude of the load is computed differently depending on product model type.

6.3.1.2.2.1.1 Precast Girder Bridge Product Models

For precast girder bridge product models, the magnitude of the end diaphragm load is computed as $P = A_{dia}\left(\frac{S_L + S_R}{2}\right)\gamma_c g$ for interior girders and $P = A_{dia}\frac{S_i}{2}\gamma_c g$ for exterior girders, where

P	Magnitude of the load
A_{dia}	Cross sectional area of the diaphragm (Computed as width times height)

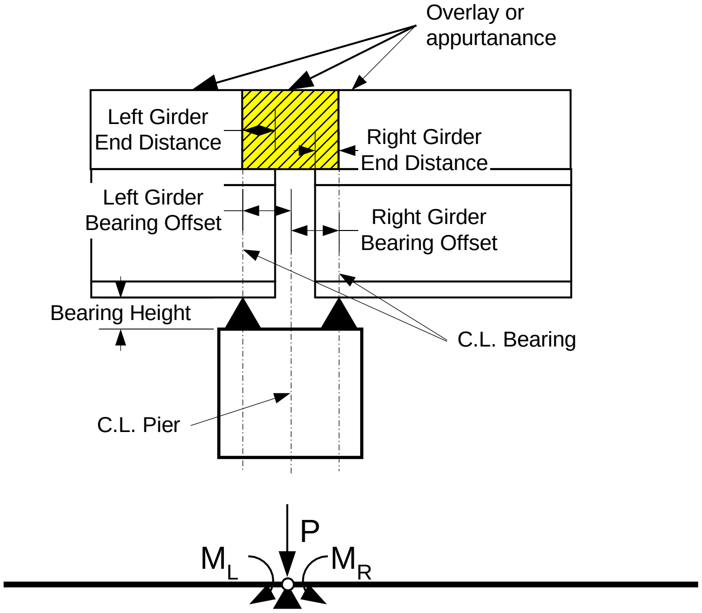
γ_c	Weight density of slab concrete
g	Gravitational acceleration
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

6.3.1.2.2.1.2 Steel Beam Bridge Product Models

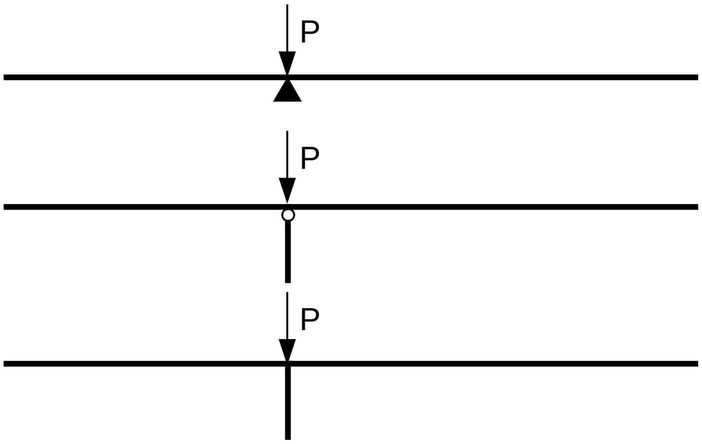
For steel beam bridge product models (built-up and rolled shapes), the product model of the end diaphragms is described by a uniform load transverse to the girder. The magnitude of the end diaphragm load is taken to be $P = w_{dia}\left(\frac{S_L + S_R}{2}\right)$ for interior girder lines and $P = w_{dia}\frac{S_i}{2}$ for exterior girder lines where

P	Magnitude of the load
w_{dia}	weight per unit length of the diaphragm transverse to the girder line
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

6.3.1.2.3 SIMPLE SUPPORT PIER CONNECTION



Case 1 - simple support in stage when load is applied



Case 2 - Continous support in stage when load is applied either integral with pier or not integral

Figure 26 Simple Support Pier Connection Loads

Simple span support conditions can change to continuous support conditions in a given stage. To correctly apply the loads in this connection region, consideration must be given to the connection type at time of loading. The loading of the connection region is described by two cases. Case 1 is for application of loading during a stage with simple support condition. Case 2 is for application of load during a stage with continuous support conditions.

Product model loads for this connection type are represented by an equivalent concentrated force and moment applied to the support point when the load is imposed on the girders. When the load is imposed directly on the support, only the concentrated load is applied.

Note that Girder End Distance is measured normal to the back of pavement seat. The Girder End Distance must be corrected for skew.

6.3.1.2.3.1 Case 1 - Loading for Simple Support Conditions

The product model of the simple support stage of this connection specifies if superimposed loads in the connection region are transferred to the girders or pier. If the loads are transferred to the girders, concentrated moments are applied at the ends of the girders and a concentrated vertical load is applied directly to the support point. If the loads are transferred directly to the pier, only a concentrated load is applied at the connection point.

6.3.1.2.3.2 Case 2 - Loading for Continuous Support Conditions

If the load is applied to the connection region during a stage that has a continuous span connection, regardless of whether the superstructure is integral with the substructure, the load is modeled as a concentrated force and applied to the support point.

6.3.1.2.3.3 Equivalent Loads

6.3.1.2.3.3.1 Girder Self Weight

The equivalent loads are given by:

$$P = A_g \gamma_c g \cdot (LGBO + RGBO)$$

$$M_L = \frac{A_g \gamma_c g \cdot LGED^2}{2}$$

$$M_R = \frac{A_g \gamma_c g \cdot RGED^2}{2}$$

where

P	Equivalent concentrated force
M_L	Equivalent concentrated moment applied to the left hand girder
M_R	Equivalent concentrated moment applied to the right hand girder
A_g	Area of the girder
γ_c	Density of concrete
g	Gravitational acceleration
LGED	Left Girder End Distance
RGED	Right Girder End Distance
LGBO	Left Girder Bearing Offset
RGBO	Right Girder Bearing Offset

6.3.1.2.3.3.2 Slab

The equivalent loads are given by:

$$P = \left[w_{trib} t_{slab} + \left(A - t_{slab} \right) w_{tf} \right] \gamma_c g \cdot \left(LGBO + RGBO \right)$$

$$M_L = \frac{\left[w_{trib} t_{slab} + \left(A - t_{slab} \right) w_{tf} \right] \gamma_c g \cdot LGED^2}{2}$$

$$M_R = \frac{\left[w_{trib} t_{slab} + \left(A - t_{slab} \right) w_{tf} \right] \gamma_c g \cdot RGED^2}{2}$$

where

P	Equivalent concentrated force
M_L	Equivalent concentrated moment applied to the left hand girder
M_R	Equivalent concentrated moment applied to the right hand girder
w_{trib}	Tributary width of the slab at the centerline bearing
t_{slab}	Gross slab thickness
A	Distance from top of girder to top of slab at intersection of the centerline of girder and the centerline of bearing
w_{tf}	Width of the top flange of the girder
γ_c	Density of concrete
g	Gravitational acceleration
LGED	Left Girder End Distance
RGED	Right Girder End Distance
LGBO	Left Girder Bearing Offset
RGBO	Right Girder Bearing Offset

6.3.1.2.3.3.3 End Diaphragms

6.3.1.2.3.3.3.1 Precast Girder Bridge Product Models

For precast girder bridge product models, the equivalent load is only a concentrated force and taken to be $P = A_{dia} \left(\frac{S_L + S_R}{2} \right) \gamma_c g$ for interior girders and $P = A_{dia} \frac{S_i}{2} \gamma_c g$, for exterior girders, where

P	Magnitude of the load
A_{dia}	Cross sectional area of the diaphragm (Computed as width times height)
γ_c	Weight density of slab concrete
g	Gravitational acceleration

S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

6.3.1.2.3.3.3.2 Steel Beam Bridge Product Models

For steel beam bridge product models (built-up and rolled shapes), the product model of the end diaphragms is described by a uniform load transverse to the girder. The magnitude of the end diaphragm load is taken to be $P = w_{dia}\left(\frac{S_L + S_R}{2}\right)$ for interior girder lines and $P = w_{dia}\frac{S_i}{2}$ for exterior girder lines where

P	Magnitude of the load
w_{dia}	weight per unit length of the diaphragm transverse to the girder line
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

6.3.1.2.3.3.4 Traffic Barrier

The equivalent loads are given by:

$$P = \frac{A_{tb}\gamma_c g \cdot (LGBO + RGBO)}{k}$$

$$M_L = \frac{A_{tb}\gamma_c g \cdot LGED^2}{2k}$$

$$M_R = \frac{A_{tb}\gamma_c g \cdot RGED^2}{2k}$$

where

P	Equivalent concentrated force
M_L	Equivalent concentrated moment applied to the left hand girder
M_R	Equivalent concentrated moment applied to the right hand girder
A_{tb}	Area of the traffic barrier
γ_c	Density of concrete
g	Gravitational acceleration
$LGED$	Left Girder End Distance
$RGED$	Right Girder End Distance
$LGBO$	Left Girder Bearing Offset

$RGBO$	Right Girder Bearing Offset
k	A factor representing the distribution of the traffic barrier weight amongst the exterior girder lines. See 6.3.1.1.4.2 for details.

6.3.1.2.3.3.5 Median Barriers

The equivalent loads are given by:

$$P = \frac{A_b \gamma_c g \cdot (LGBO + RGBO)}{k}$$

$$M_L = \frac{A_b \gamma_c g \cdot LGED^2}{2k}$$

$$M_R = \frac{A_b \gamma_c g \cdot RGED^2}{2k}$$

where

P	Equivalent concentrated force
M_L	Equivalent concentrated moment applied to the left hand girder
M_R	Equivalent concentrated moment applied to the right hand girder
A_b	Area of the barrier
γ_c	Density of concrete
g	Gravitational acceleration
$LGED$	Left Girder End Distance
$RGED$	Right Girder End Distance
$LGBO$	Left Girder Bearing Offset
$RGBO$	Right Girder Bearing Offset
k	A factor representing the distribution of the traffic barrier weight amongst the exterior girder lines. See 6.3.1.1.5.2 for details.

6.3.1.2.3.3.6 Overlay

The equivalent loads for overlays are:

$$P = w_{trib} t_{olay} \gamma_{olay} g \cdot (LGBO + RGBO)$$

$$M_L = w_{trib} t_{olay} \gamma_{olay} g \frac{LGED^2}{2}$$

$$M_R = w_{trib} t_{olay} \gamma_{olay} g \frac{RGED^2}{2}$$

P	Equivalent concentrated force
M_L	Equivalent concentrated moment applied to the left hand girder
M_R	Equivalent concentrated moment applied to the right hand girder
w_{trib}	Tributary width, measured at the point of bearing
t_{olay}	Thickness of the overlay
γ_{olay}	Density of the overlay material
g	Gravitational acceleration
$LGED$	Left Girder End Distance
$RGED$	Right Girder End Distance
$LGBO$	Left Girder Bearing Offset
$RGBO$	Right Girder Bearing Offset

6.3.1.2.4 INTEGRAL PIER CONNECTION

For a integral pier connection, all of the loads in the connection region, except for diaphragm loads, are represented in the main span portion of the analysis model.

6.3.1.2.4.1 End Diaphragms

End diaphragm loads are applied to the support points of the analysis models as concentrated loads, if the product description of the connection specifies that the diaphragm weight should be included in the analysis models.

The magnitude of the load is computed differently depending on product model type.

6.3.1.2.4.1.1 Precast Girder Bridge Product Models

For precast girder bridge product models, the magnitude of the end diaphragm load is computed as $P = A_{dia}\left(\frac{S_L + S_R}{2}\right)\gamma_c g$ for interior girders and $P = A_{dia}\frac{S_i}{2}\gamma_c g$ for exterior girders, where

P	Magnitude of the load
A_{dia}	Cross sectional area of the diaphragm (Computed as width times height)
γ_c	Weight density of slab concrete
g	Gravitational acceleration
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

6.3.1.2.4.1.2 Steel Beam Bridge Product Models

For steel beam bridge product models (built-up and rolled shapes), the product model of the end diaphragms is described by a uniform load transverse to the girder. The magnitude of the end diaphragm load is taken to be $P = w_{dia}\left(\frac{S_L + S_R}{2}\right)$ for interior girder lines and $P = w_{dia}\frac{S_i}{2}$ for exterior girder lines where

P	Magnitude of the load
w_{dia}	weight per unit length of the diaphragm transverse to the girder line
S_L	Girder spacing on the left hand side
S_R	Girder spacing on the right hand side
S_I	Girder spacing on the side of the interior girder

6.3.2 Live Load

LBAM's will analyze both vehicular and pedestrian live loads. Live loads are modeled as a full lane of load. The application of live load distribution factors and combinations of vehicular and pedestrian live loads are described in Section 6.5.2.3.

6.3.2.1 Vehicular Live Load

Live loads are modeled as a series of concentrated static loads. The design live load is defined in LRFD 3.6.1.2 and applied in accordance with LRFD 3.6.1.3. Vehicular live load is not applied to pedestrian only bridges.

6.3.2.2 Pedestrian Live Load

Pedestrian live load is modeled as a uniform load with the intensity specified in LRFD 3.6.1.6. QConBridge II analyzes pedestrian only bridges with the live load specified in LRFD 3.6.1.6.

6.3.3 Temperature Load

QConBridge II applies deformation loads for a uniform temperature rise and fall. The temperature rise is computed as $\Delta T_{rise} = T_{\max} - T_{setting}$ and the temperature fall is computed as $\Delta T_{fall} = T_{setting} - T_{\min}$ where ΔT_{rise} is the temperature rise, ΔT_{fall} is the tempature fall, T_{max} is the maximum temperature, T_{min} is the minimum temperature, and $T_{setting}$ is the temperature at which the bridge is constructed. The minimum, maximum, and setting temperatures are specified by the user input.

6.3.4 Support Settlement Load

QConBridge II models support settlement as differential settlement. That is, the structure is analyzed for the forces induced by the difference in settlement between two points of support. If all of the supports in the structure settle equally, it is assumed that load is not imparted onto the structure.

6.3.5 Slab Shrinkage

A slab shrinkage load is applied to Rolled and Built-Up Steel girder bridge product models. Slab shrinkage is modeled as equal and opposite concentrated moments applied at the beginning and ending of each segment in a span as shown in Figure 27.

Figure 27 Slab Shrinkage Moments

The magnitude of the shrinkage moment is taken to be $M_s = AE_c\varepsilon_{sh}e$ (See BDM 7.3.11), where

M_s	Moment due to slab shrinkage
A	Cross sectional area of the transformed slab.
E_c	Modulus of elasticity of slab concrete
ε_{sh}	Shrinkage strain
S	Moment arm

The cross sectional area of the transformed slab is based on long-term section properties (3n). Figure 28 shows the section geometry.

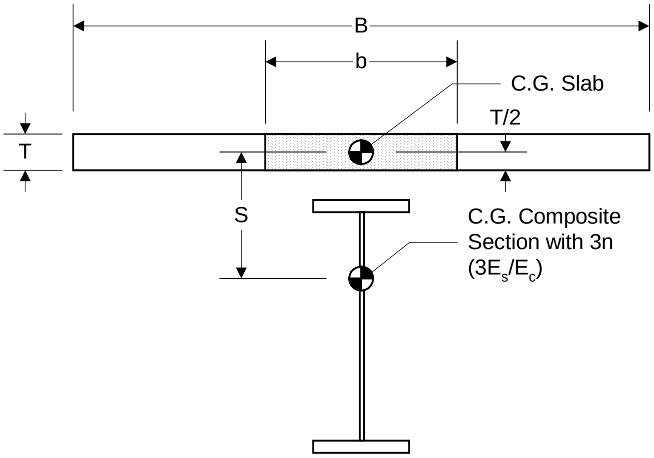


Figure 28 Section Geometry for Slab Shrinkage Moments

6.4 Special Analysis Considerations

The following sections detail special analysis considerations for LBAM's.

6.4.1 Dead Load Deflections

The basic LBAM computes deflections and rotations based on the section properties for the various analysis stages. In stages where the roadway deck is made composite, deflections and rotations are based on the effective flange width. Per LRFD 4.6.2.6.1 these deflections must be based on the full flange width of the girder line. To accomplish this, QConBridge II will compute dead load deflections and rotations for composite sections as $\Delta_{DL} = \delta_{DL} \frac{I_{effective\ flange}}{I_{full\ flange}}$ where

Δ_{DL}	Dead load deflection or rotation
δ_{DL}	Dead load deflection or rotation computed from the LBAM
$I_{effective\ flange}$	Moment of inertia based on the effective flange width
$I_{full\ flange}$	Moment of inertia based on the full flange width

6.4.2 Live Load Deflections

6.4.2.1 For Evalution of Deflection Criteria

The deflections computed for the live load defined in LRFD 3.6.1.3.2 is used in evaluating the defection criteria specified in LRFD 2.5.2.6.2. To perform this analysis, QConBridge II analyzes the basic LBAM for the live load defined in 3.6.1.3.2 using the girder line section properties for the stage when the live load is applied to the model. For all of the bridge product models supported by this version of QConBridge, the live load is applied in a stage when the roadway deck is made composite with the girders. The deflections are computed using composite section properties based on the effective slab area.

The computed deflections must be adjusted to conform to the requirements of LRFD 2.5.2.6.2. The computed deflection is multiplied by the moment of inertia used in the LBAM, effectively normalizing the deflection to a moment of inertia of 1.0. The deflection is then multiplied by the number of design lanes to simulate all lanes loaded, is multiplied by the appropriate multiple presence factor, and divided by the moment of inertia for the entire bridge cross section. The live load deflection for LRFD 2.5.2.6.2 is taken to be

$$\Delta_{LL\ per\ girder} = \frac{m\left(\Delta_{Vehicular\ LL\ per\ lane\ based\ on\ I_c} I_c N_L + \Delta_{Pedestrian\ LL\ based\ on\ I_c} I_c\right)}{I_{bridge}}$$ where

$\Delta_{LL\ per\ girder}$	Live load deflection for LRFD 2.5.2.6.2 per girder line
m	Multiple presense factor
$\Delta_{vehicular\ LL\ per\ lane\ based\ on\ Ic}$	Vehicular live load deflection per lane based on the moment of inertia used in the LBAM
Ic	Moment of inertia used in the LBAM
N_L	Number of design lanes
$\Delta_{pedestrian\ LL\ base\ on\ Ic}$	Pedestrian live load deflections per sidewalk based on the moment of inertia used in the LBAM

I_{bridge}	Moment of inertia for the entire bridge cross section, including structurally continuous barries and sidewalks.

Deflections are computed for both the vehicular live load only and the vehicular live load plus pedestrian live load cases. Limit state combinations are not created for deflection.

6.4.2.2 For HL93 Live Load

The basic LBAM computes deflections and rotations based on the section properties for the various analysis stages. In stages where the roadway deck is made composite, deflections and rotations are based on the full flange width of the girder line (See LRFD 4.6.2.6.1). To accomplish this, QConBridge II will compute composite section properties based on the full flange width. Live load deflections and rotations will then be computed as $\Delta_{LL} = \delta_{LL} \frac{I_{effective\ flange}}{I_{full\ flange}}$ where

Δ_{LL}	Live load deflection or rotation
δ_{LL}	Live load deflection or rotation computed from the LBAM
$I_{effective\ flange}$	Moment of inertia based on the effective flange width
$I_{full\ flange}$	Moment of inertia based on the full flange width

Distibution factors for this live load are defined in 5.6

6.4.3 Calculation of Rotations

To facilitate the design and analysis of bridge bearings, QConBridge II will compute some basic rotations at bearing locations. Rotations will be computed for all Load Groups and Load Cases. Rotations are not computed for Limit States.. Live load rotations will not be computed for the special live loading for deflection criteria.

6.5 Analysis Results

After the LBAM is generated from the product model, the problem being solved by QConBridge II becomes the same as for Analysis Model Projects. This section describes how QConBridge II takes the raw analysis results from the LBAM and combines them into Load Case and Limit State results.

6.5.1 The Basic Process

Figure 29 illustrates the basic process for analyzing a LBAM and computing Load Case and Limit State Results. Note that much detail is omitted. This detail will be covered throughout Section 6.5.

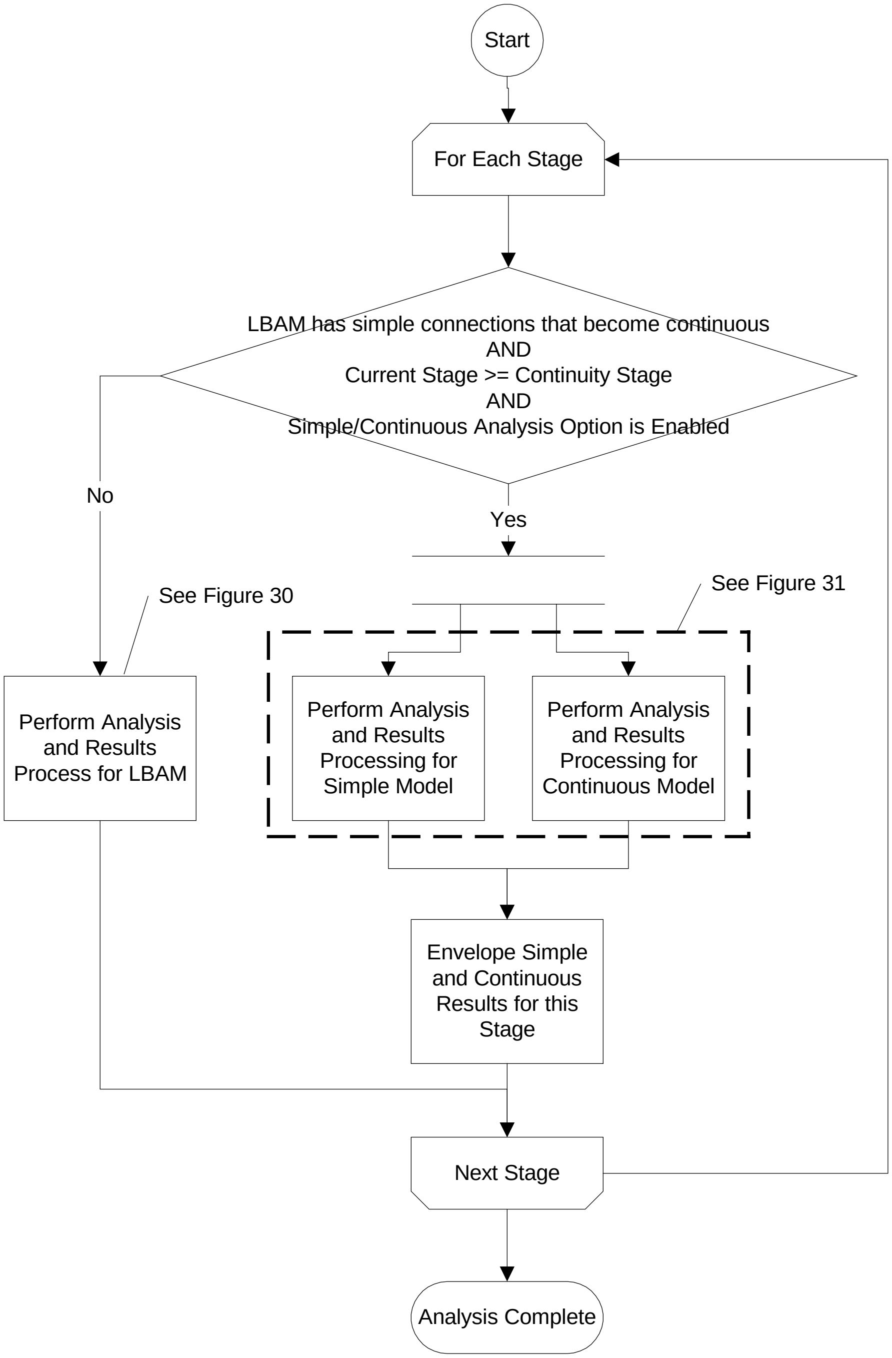


Figure 29 Basic LBAM Analysis Process

Every rectangle in Figure 30 through Figure 33 represent Load Case and Limit State Results QConBridge II computes.

6.5.1.1 Analysis and Results Processing

For the basic procedure described above, the majority of the work to be done is the analysis is results processing. Analysis and results processing is seen in more detail in Figure 30.

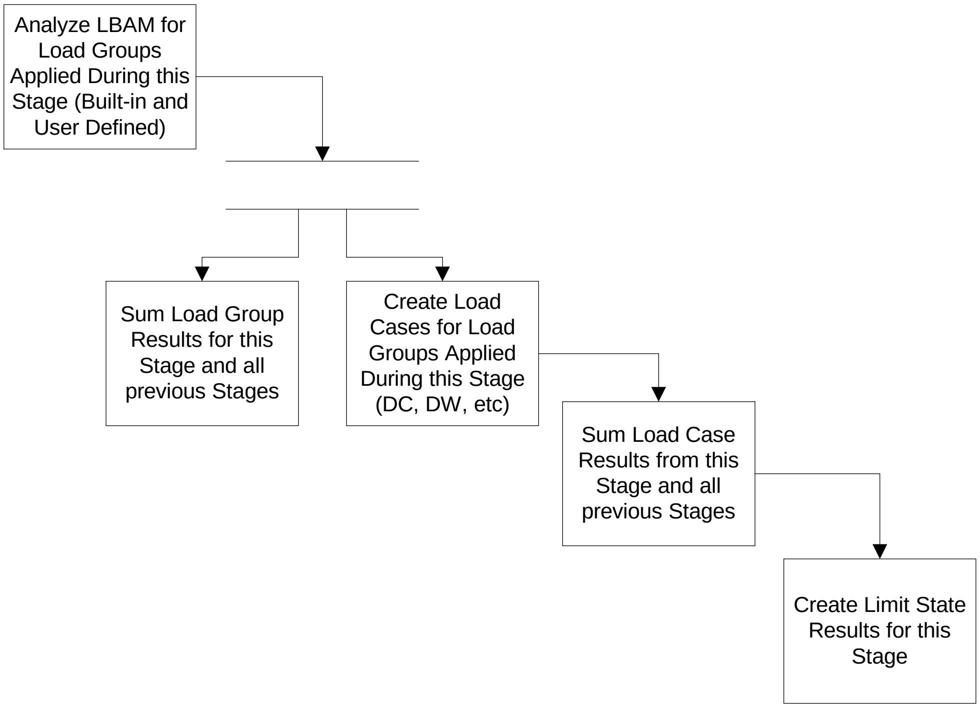


Figure 30 Analysis and Results Processing

The LBAM loading consists of named groups of loads (i.e. Group: Self-weight - consists of linear loads, concentrated loads, and concentrated moments) which represent the loads applied to the structure during a given stage. The LBAM for each stage is used to analyze the structure's response to these loads and determines moments, shears, and displacements at all points of interest. The analysis also computes reactions and rotations at support locations.

For this stage, these Load Group results are then added together to form Load Case results (i.e. Load Case: DC - sum of Load Group: Self-Weight, Load Group: Slab Weight, and Load Group: Diaphragm Weight).

The total response of a structure at any stage is the sum of the response of all previous stages. QConBridge II adds the Load Group responses and the Load Case responses for all previous stages to the current stage.

Finally, the total Load Case responses for this stage are combined into Limit State results. For all stages, except the final stage, the following Limit State results are computed:

- Strength I (Yields the same results as Strength III and Strength V)
- Strength IV
- Service I

For the final stage, the following Limit State results are computed:

- Strength I
- Strength II (using Permit and Special Live Loads)
- Strength III (If WA, WS, FR, TU, CR, SH, TG, and SE load cases are empty, this Limit State will not control over Strength I and need not be reported to the user)
- Strength IV
- Strength V (If WA, WS, WL, FR, TU, CR, SH, TG, and SE load cases are empty, this Limit State will not control over Strength I and need not be reported to the user)
- Extreme Event I (If EQ load case is empty, this Limit State will not control over Strength I and need not be reported to the user)
- Extreme Event II (If IC, CT, and CV load cases are empty, this Limit State will not control over Strength I and need not be reported to the user)
- Service I
- Service IA (if LBAM represents a prestressed girder bridge product model - LRFD 5.9.4.2.1 - one-half dead load case)
- Service II (if LBAM represents a steel bridge product model)
- Service III (if LBAM represents a prestressed girder bridge product model)
- Fatigue
- User Defined Limit States (using HL93 Live Load, Permit Live Load or Special Live Load)

6.5.1.2 Enveloping Simple/Continuous Results

When the *Envelope Simple/Continuous Results* analysis option is enabled, and the LBAM uses simple support connections that are made continuous, the Analysis and Results Processing becomes a bit more complex than illustrated in Figure 30. For the Continuity Stage and each stage thereafter, QConBridge II maintains two LBAMs, one for simple span analysis and one for continuous span analysis. For each model, QConBridge II processes the results as shown in Figure 30. Then, the program envelops the results, creating the controlling cases for this stage. This is shown in Figure 31.

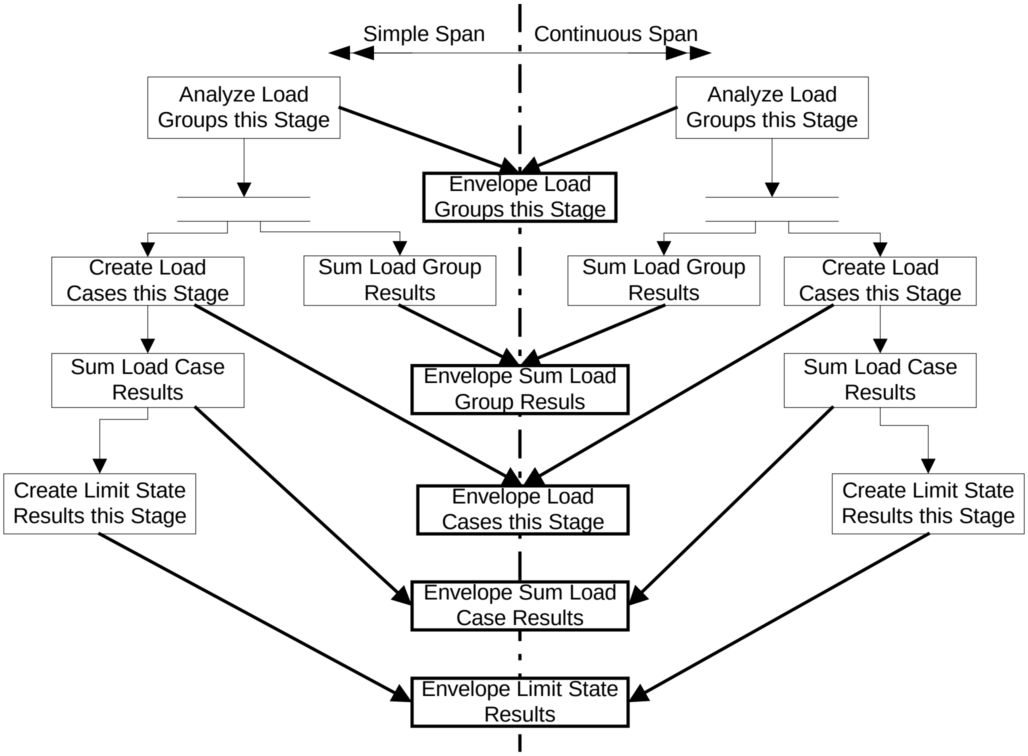


Figure 31 Analysis and Results Processing for Simple/Continuous Envelopes

6.5.1.3 Load Cases and Limit States involving Live Load

Live loads differ from other load cases in that they consist of not a single load, but of a combination of loading situations (Design Tandem + Lane, Design Truck + Lane, etc.), rules for applying the load to the structure, and which force effects are attributed to those loading situations (negative moment between points of contraflexure and reactions at interior piers). Live load cases also produce minimum and maximum results (envelopes).

Figure 32 and Figure 33 illustrate the myriad of Live Load Cases and Limit State combinations that QConBridge II must produce. For each point of interest in the LBAM, QConBridge II determines the extreme Limit State result for each force effect (moment, shear, etc.) considering the various combinations of Load Cases that make up the Limit State. For the combination of Load Cases that cause an extreme Limit State result at a point of interest, QConBridge II computes the corresponding Limit State results for all points of interest in the LBAM, for all force effects. For example, if the maximum moment at the base of Pier 2 for the Strength V Limit State occurs when the Design Truck with its rear axle at the minimum spacing is positioned at the center of Span 1 and the Design Lane Load occupies all of Span 1, the Breaking Force is applied, and a uniform Temperature Drop is applied, then QConBridge II will compute the Strength V Limit State Response for all points of interest in the LBAM for corresponding shear, reaction, and deflection. This scenario is carried out for every Limit State at every point of interest, for every force effect.

If QConBridge II envelopes simple span and continuous span results, as described in Section 6.5.1.2, the Load Cases and Limit States presented in Figure 32 and Figure 33 are created for the simple and continuous cases and enveloped as illustrated in Figure 31.

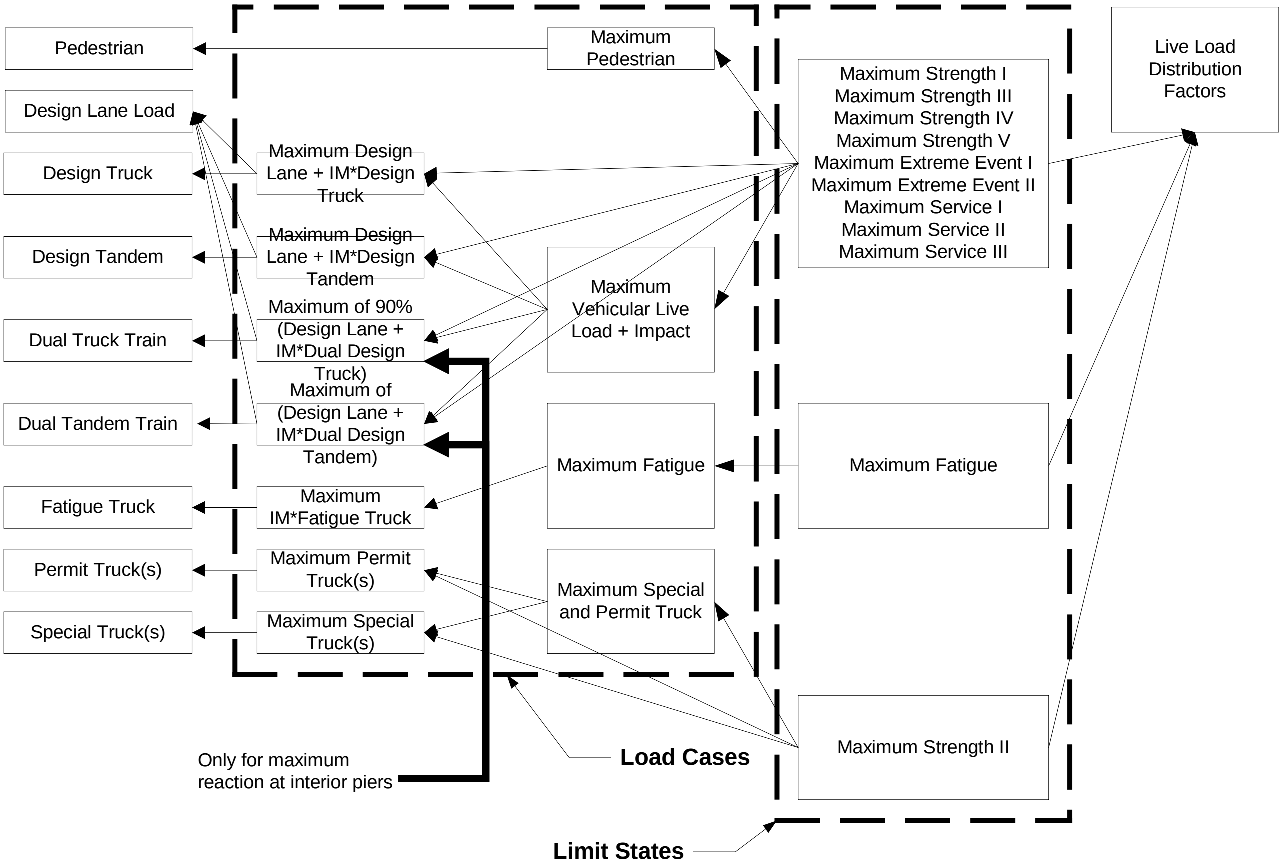


Figure 32 Maximum Limit States with Live Load

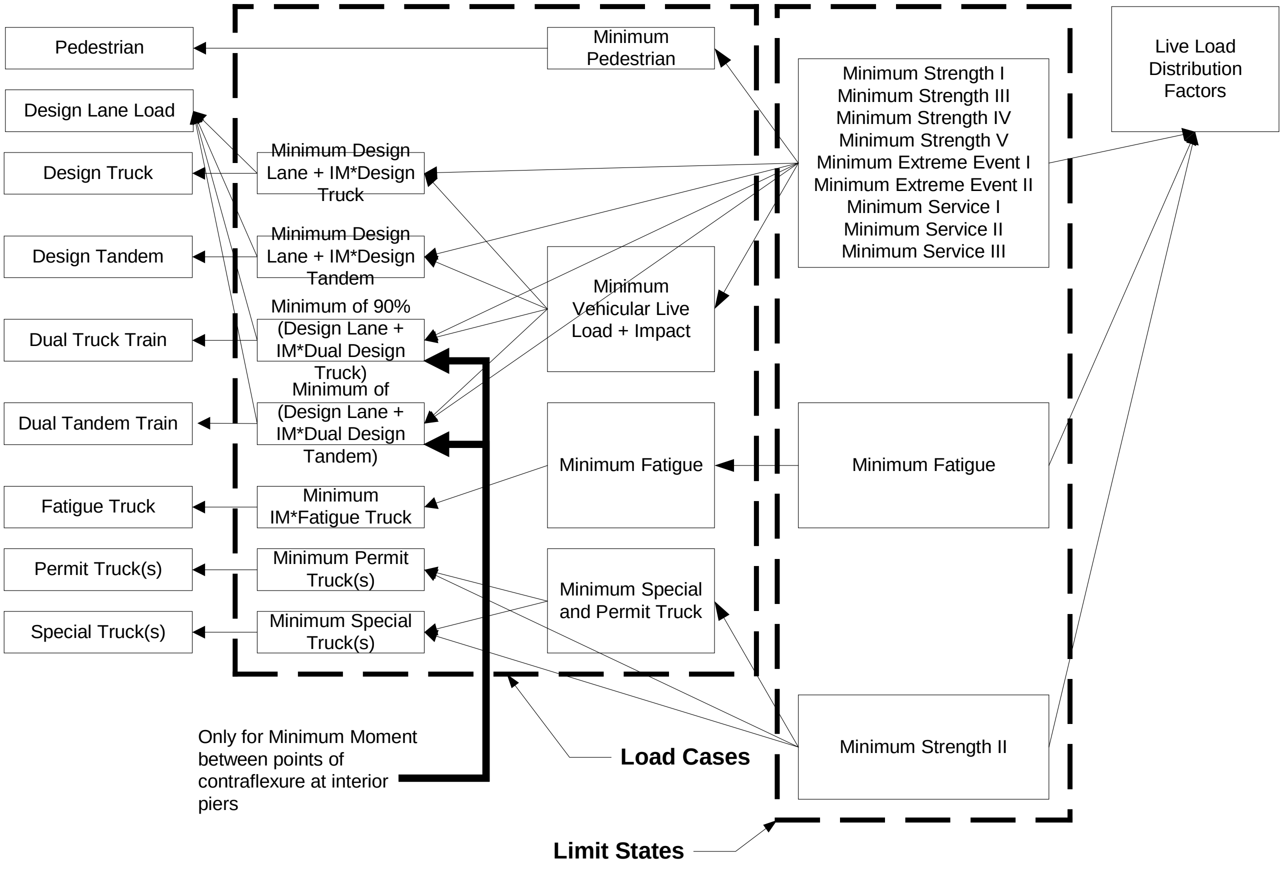


Figure 33 Minimum Limit States with Live Load

6.5.2 Computing Analysis Results

6.5.2.1.1 LOAD FACTORS

LRFD Table 3.4.1-1 presents single values for the load factors for transient loads. QConBridge II recognizes that these are maximum load factors. For transient loads, the case of the load not being present must be considered when determining extreme force effects. QConBridge II considers a minimum load factor of 0.00 for transient loads when computing Limit State Combinations.

6.5.2.1.1.1 Load Factors for TU, CR, and SH Load Cases

Per LRFD 3.4.1 the smaller of the Load Factors given for the TU, CR, and SH Load Cases in LRFD Table 3.4.1-1 are used for computing all force effects except deflections.

6.5.2.1.2 LOAD MODIFIERS

The load modifiers (η factors) described in LRFD 1.3.2.1 are to be considered on a per component basis. For QConBridge II, components are considered to be superstructure components and substructure components. That is, one set of load modifiers is input for the entire superstructure, and one set of load modifiers is input for each pier and abutment.

6.5.2.1.3 SPECIAL NOTES

For LBAM's where permit and/or special live load is considered and the Strength II combinations are reported, QConBridge II outputs the following notice taken from LRFD C4.6.2.2.1.

In Strength Load Combination II, applying a distribution factor procedure to a loading involving a heavy permit load can be overly conservative unless lane-by-lane distribution factors are available. Use of a refined method of analysis will circumvent this situation.

6.5.2.2 Load Case Dependencies

Certain Load Cases logically depend upon the existence of other Load Cases. For example, force effects due to Wind on Live Load cannot occur if Live Load is not present. With transient loads, the possibility that a load is not present ($\gamma = 0$) must always be considered.

While QConBridge II does not compute loads for Braking, Centrifugal Force, Wind, Stream Flow, Earthquakes, etc, the software does provide an opportunity for the user to directly input loads to simulate these Load Cases. QConBridge II considers the logical dependency between load cases when performing Limit State combinations. Figure 34 shows the logical dependency between the LRFD Load Cases. The force effects of a Load Case are not included in a Limit State Combination if the Load Case(s) it depends on is not applicable to the Limit State.

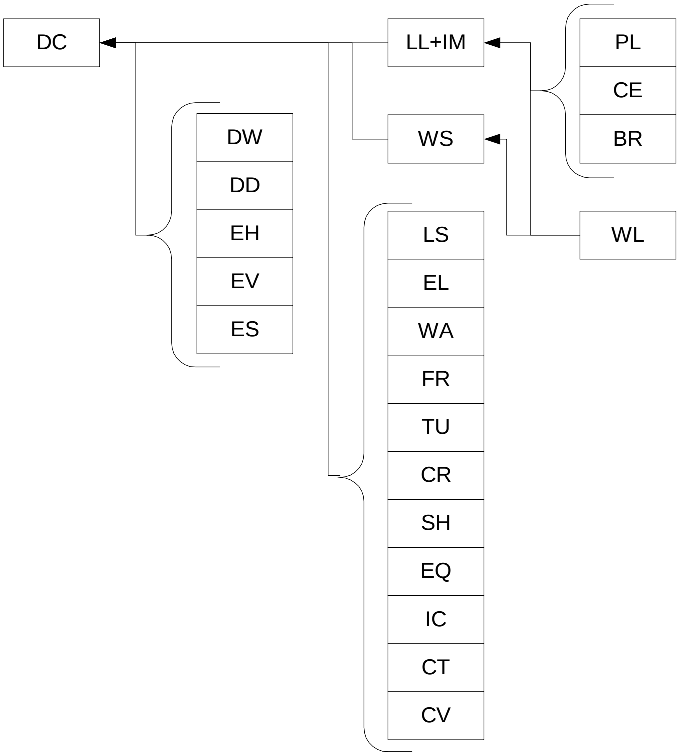


Figure 34 Load Case Dependencies

6.5.2.3 Distribution of Live Load to Girder Lines

In the LBAM's, all load cases are on a per girder line bases except live load. Vehicular live load and impact are on a per design lane bases. Pedestrian live load is on a per sidewalk basis. To form the Limit State combinations, the live loads must be distributed to a girder line. This is accomplished through the use of distribution factors.

The general Limit State formulation is

$$Q = \eta_i \gamma_i Q_i + g f_{ADTT} \eta_{LL+IM} \gamma_{LL+IM} Q_{LL+IM} + g_{PL} \eta_{PL} \gamma_{PL} \left(Q_{PL}^{Left} + Q_{PL}^{Right} \right)$$ where

Q	Limit State Force Effect
η_i	Load Modifier
γ_i	Load Factor
Q_i	Load Case Force Effect
g	Live Load Distribution Factor, which is taken to be the maximum of one loaded lane and two or more loaded lanes.
f_{ADTT}	Reduction factor for low ADTT. $f_{ADTT} = \begin{cases} 1.0 \ for ADTT > 1000 \\ 0.95 \ for 100 \le ADTT \le 1000 \\ 0.90 \ for ADTT < 100 \end{cases}$ See LRFD C3.6.1.1.2
η_{LL+IM}	Load Modifier for Live Load + Impact
γ_{LL+IM}	Load Factor for Live Load + Impact
Q_{LL+IM}	Force Effect for Live Load + Impact
g_{PL}	Distribution Factor for Pedestrian Load (Scales a full sidewalk of Pedestrian Load to a girder line of pedestrian load).
η_{PL}	Load Modifier for Pedestrian Live Load
γ_{PL}	Load Factor for Pedestrian Live Load
Q_{PL}	Cumulative Force Effect for Pedestrian Live Load on both the Left and Right Sidewalks.

6.5.2.4 Deflections

QConBridge II computes deflections for the various Limit States due to the HL93 Live Load model and User Defined Live Loads. This section describes special considerations that are made when computing limit state deflections.

6.5.2.4.1 Load Factors for TU, CR, and SH Load Cases

Per LRFD 3.4.1 the larger of the Load Factors given for the TU, CR, and SH Load Cases in LRFD Table 3.4.1-1 are used for computing deflections.

6.5.2.4.2 BASIS FOR MEASUREMENT

QConBridge II computes force effects for differential settlement between piers and abutments. However, the input for settlement is absolute measurement. That is, the actual settlement of a support is input and QConBridge II determines the differential settlement. The deflections computed by QConBridge II can be reported based on differential settlement or overall settlement. The basis for Limit State Deflections computed by QConBridge II is shown in Figure 35.

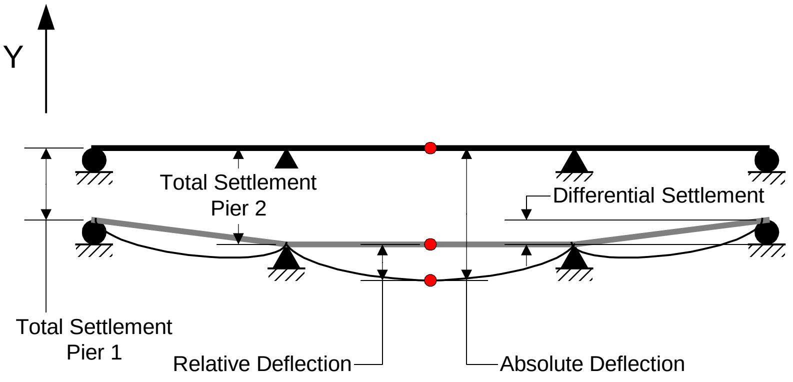


Figure 35 Basis for computing Limit State Deflections

6.5.3 Reactions

QConBridge II computes and reports reactions for abutments and piers.

6.5.3.1 Limit State Combinations for Reactions

Two sets of limit state reactions are reported for all piers and abutments. One set of reactions is for foundation elements above the ground surface and one is for the elements below the ground surface. For the foundation elements below the ground surface, the dynamic load allowance (impact) factor is taken to be 0% (See LRFD 3.6.2.1).

6.5.3.2 Zero Height Abutments and Piers

For zero-height abutments and piers, QConBridge II computes a vertical reaction. Reactions for all load groups, load cases, and limit states are reported on a per girder line basis. Vehicular and Pedestrian Live Load Reactions are reported on a per lane basis.

6.5.3.3 Fixed Height Abutments

For fixed-height abutments, QConBridge II computes vertical, horizontal, and moment reactions. Reactions for all load groups, load cases, and limit states are reported on a per girder line basis. Vehicular and Pedestrian Live Load Reactions are also reported on a per lane basis.

6.5.3.4 Fixed Height Piers

For fixed-height piers, QConBridge II computes a vertical reaction at the top of the column and vertical, horizontal, and moment reactions at the bottom of the column. The top of column vertical reaction is transferred into TBAM models at the bearing locations.

Reactions for all load groups, load cases, and limit states are reported on a per girder line basis. Vehicular and Pedestrian Live Load Reactions are also reported on a per design lane basis.

6.5.4 Deflections for Evaluation of LRFD 2.5.2.6.2

QConBridge II computes live load deflections for evaluation of LRFD 2.5.2.6.2 as specified in Section 6.4.2.1. These deflections are computed at all Points of Interest in the superstructure elements of the LBAM. These deflections are not Limit States. Deflections for vehicular live load only and vehicular live load plus pedestrian loads are computed and reported as different deflection criteria may apply.

6.5.5 Pedestrian Only Bridges

For Pedestrian Only Bridges, QConBridge II computes the same Limit States as for bridges with vehicular live load, except the intermediate Limit States relating to vehicular live load are omitted. The special deflection analysis for LRFD 2.5.2.6.2 is performed for Pedestrian Only Bridges.

7. TRANSVERSE BRIDGE ANALYSIS MODELS

QConBridge II will perform a transverse dead load and live load analysis if a 3D pier structure has been defined. This section describes how the information from the product model is used to generate a TBAM.

7.1 Model Topology

This section describes how the model geometry is generated for the various types of pier product models supported by QConBridge II.

7.1.1 Cap Beam Modeling

The model of the cap beam is similar for all pier types supported by the program. Figure 36 shows the basic geometry of the cap beam elements along the rectangular cap beam. Cap beam elements are positioned at the centroid of the cap beam section at the location of each column. The cap beam elements are connected to the top of the column elements and have full connectivity with the column elements. Cap overhangs are projected along the same geometry as the cap beam of the exterior bays of the bent. For single column piers, hammerhead piers, and zero-height idealized piers, the cap beam is taken to be horizontal. Non-prismatic caps are modeled with a series of prismatic segments. Segment boundaries will occur at the face of each column and where ever the depth of the cross section is more than 10% different than the depth of the adjacent segment.

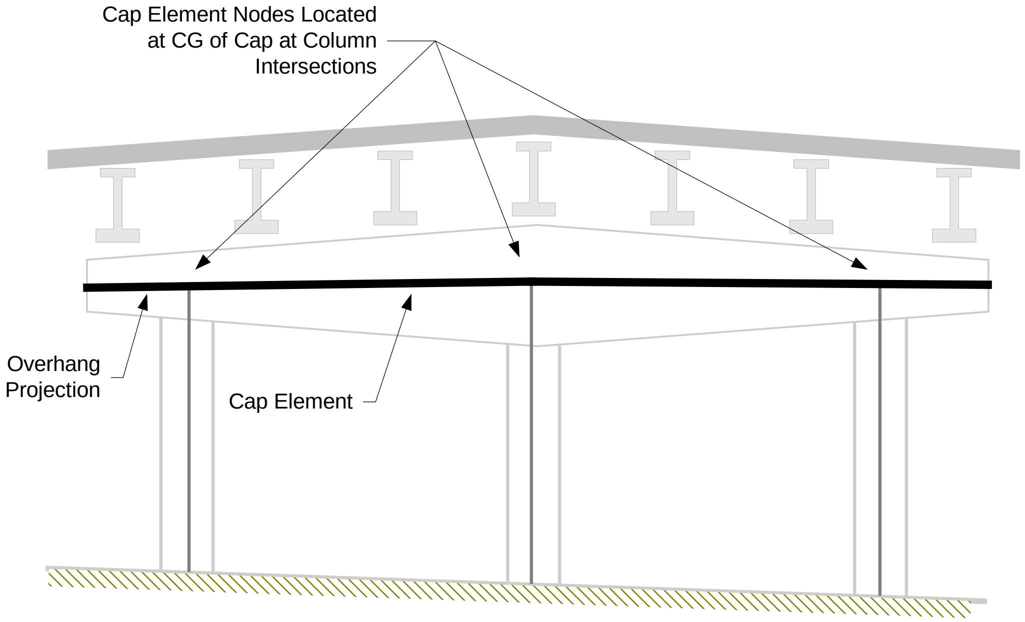


Figure 36 Structural Modeling of Cap Beam

7.1.2 2D Zero-Height Piers

A TBAM is not created for 2D Zero-Height Piers.

7.1.3 3D Zero-Height Piers

The product model for zero-height idealized pier defines support locations that represent columns or other supporting elements for a cap beam. A 3D Zero-Height Idealized Pier is modeled as a horizontal cap beam on pinned supports as shown in Figure 37.

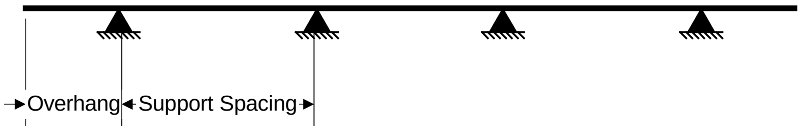


Figure 37 TBAM for a 3D Zero Height Idealized Pier

7.1.4 2D Fixed Height Piers

A TBAM is not created for 2D Fixed-Height Piers.

7.1.5 3D Fixed Height Piers

Figure 38 shows how fixed height piers are modeled for the transverse analysis. The bent frame is made up of *n* equally spaced columns. The cap beam extends beyond the exterior bays of the bent by the overhang distance. The columns are assumed to be the same height and as such, the cap beam is modeled as horizontal. The bases of the columns are fixed. The stiffness of each column is equal to 1/*n* times the stiffness defined in the product model for the pier.

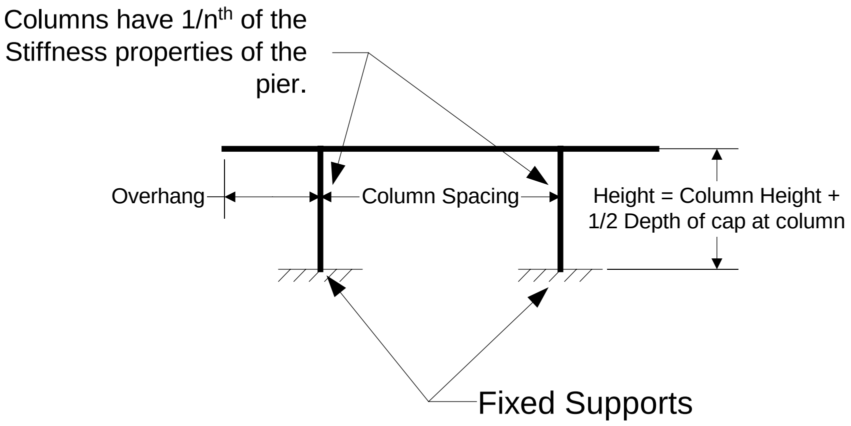


Figure 38 Analysis Modeling of Fixed Height 3D Piers

7.1.6 Full Product Model Piers

The typical geometry for a full product model pier is shown in Figure 39. The column heights in the analysis model are equal to the column heights in the product model plus the distance from the bottom of the cap beam to its centroid.

Non-prismatic columns are modeled using a series of prismatic segments starting from the bottom of the column and working upwards.

The bottoms of the column elements are fixed at the bottom and have full continuity with the cap beam elements at the top.

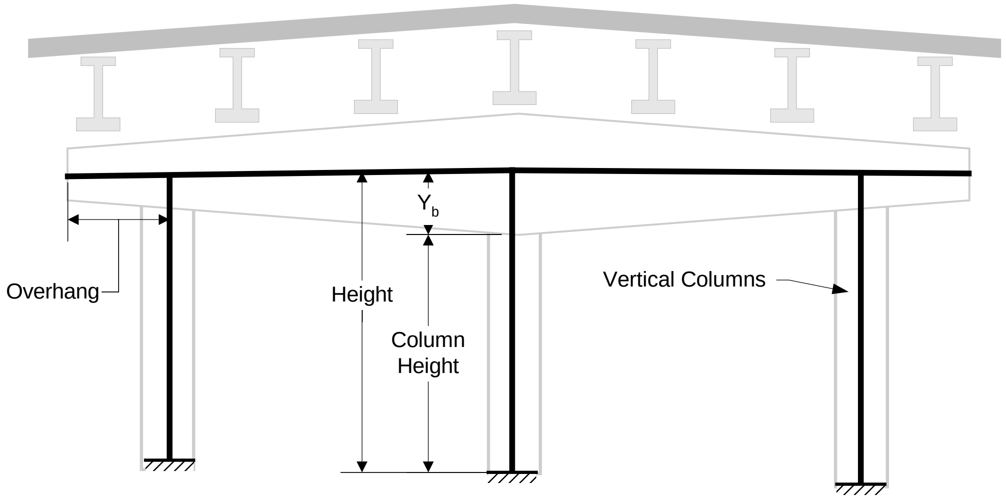


Figure 39 TBAM for Multicolumn and Hammerhead Piers

Column heights are computed as described in Section 6.1.2.2.3.

7.2 Loads

The loads imparted on a pier (as far as this version of QConBridge II is concerned) come from two different sources, the pier itself and loads from the superstructure. This section will describe how these loads are modeled in TBAMs.

7.2.1 Adjustments for Skew

For piers that are skewed with respect to the alignment, the transverse spacing of the load from the superstructure must be adjusted for skew.

7.2.2 Pier Loads

The loads described in this section are load applied directly to the pier model as opposed to loads that are transferred to the pier model from the superstructure.

7.2.2.1 Pier Self Weight

Self-weight of pier cap beam and columns are calculated as $w = A \cdot \gamma_c \cdot g$ where,

w	weight per unit length of the column or cap beam segment
A	cross sectional area of the column or cap beam segment
γ_c	density of the pier concrete
g	gravitational acceleration.

7.2.2.2 Other Loads

Some other loads that would logically fall into this section are seismic, wind, and stream flow. However, this version of QConBridge II does not support these loading conditions. This is only mentioned so as to help distinguish loads applied directly to the pier from those transferred to the pier from the superstructure.

7.2.3 Superstructure Loads

This section describes the loads that are transferred to the pier from the superstructure. These loads come in the form of reactions taken from the girder line LBAM's.

7.2.3.1 Girder Self Weight

Self-weight of structural girder calculated using the girder area and girder material's weight density. Girder reactions are applied to cap beam at bearing locations.

7.2.3.2 Slab Self Weight

Slab self weight includes the tributary self-weight of slab including haunch, sacrificial wearing surface, and overhang, if applicable. Girder reactions are applied to cap beam at bearing locations.

The effects of parabolic haunch depth due to camber are accounted for.

7.2.3.3 Intermediate Diaphragms

Applies tributary weight of Intermediate Diaphragms to girders. Girder reactions are applied to cap beam at bearing locations.

7.2.3.4 End Diaphragms

For connections where the weight of the diaphragm is carried by the girder, the weight of the end diaphragm is applied at bearing locations based on a tributary distribution of the weight to the girder lines. For connections where the weight of the diaphragm is applied directly tot he support element, the total weight of the diaphragm is distributed over the cap beam and applied as a uniform load.

7.2.3.5 Traffic Barrier

This load is derived from a uniform load based on the weight of the Traffic Barrier. If the load in the longitudinal model is distributed to all girder lines, then the girder reactions are applied to all points of bearing. If the load in the longitudinal model is distributed to *n* exterior girder lines, then only the bearing locations associated with those girder lines are loaded.

7.2.3.6 Median Barrier

This load is derived from a uniform load based on the weight of the Median Barrier (if it exists). If the load in the longitudinal model is distributed to all girder lines, then the girder reactions are applied to all points of bearing. If the load in the longitudinal model is distributed to *n* adjacent girder lines, then only the bearing locations associated with those girder lines are loaded.

7.2.3.7 Overlay

This load is derived from a uniform load based on the depth of the overlay, the overlay material properties, and the curb-to-curb width of the roadway surface. Regardless if this load is uniformly distributed amongst all girder lines or is applied to each girder line based on its tributary area, the girder line reactions are applied to the cap beam at the bearing locations.

7.2.3.8 Sidewalk

This load is derived from a uniform load based on the weight of the Sidewalk (if it exists). If the load in the longitudinal model is distributed to all girder lines, then the girder reactions are applied to all points of bearing. If the load in the longitudinal model is distributed to *n* exterior girder lines, then only the bearing locations associated with those girder lines are loaded.

7.2.3.9 Live Loads

The longitudinal analysis models compute live load reactions on the bases of one loaded lane. These reactions must be imparted onto the TBAM for all permutations of loaded lanes and design lane configurations. The sections that follow describe:

- how the live load reactions are modeled as loads in a TBAM
- where the loads are applied to the TBAM (location of the design lanes and the location of a within a design lane)
- how the loads are transferred from the superstructure to the substructure models

7.2.3.9.1 MODELING OF LIVE LOAD REACTIONS

The live load reactions computed from the LBAM's for each girder line are simply a vertical force per design lane. For the vehicular live load, there is a truck load portion and lane load portion. For pedestrian live load, there is only a lane load portion. The method for representing the truck load and lane load portions of the live load reactions are described below.

Potentially, each girder line and its associated LBAM is a different length, resulting in different live load reactions per lane across the width of the structure. QConBridge II simplifies this situation by using the maximum live load reaction for all girder lines.

When the *envelope simple/continuous* option is enabled, the maximum of the simple span and continuous span reaction is used, but not both.

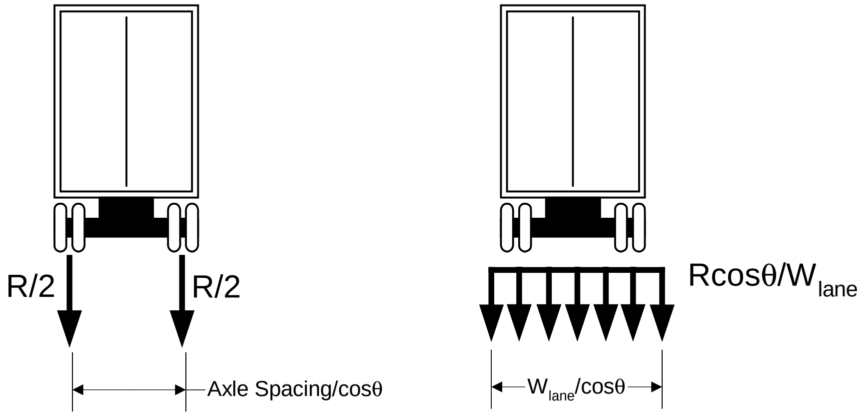
7.2.3.9.1.1 Live Load Reactions applied to the TBAM

For the HL93 Live Load model, only the lane/truck combination that creates the maximum reaction are applied to the live load transfer model. QConBridge II does not analyze the TBAM for all the elements of HL93.

For Special and Permit Trucks, only the controlling cases are applied to the TBAM.

7.2.3.9.1.2 Truck Load reactions

QConBridge II has two methods of representing truck load reactions in TBAM's as illustrated in Figure 40.



Wheel Line Reactions

Lane Load Reactions

Figure 40 Representation of Vehicular Live Load Reactions in TBAM's

7.2.3.9.1.2.1 Wheel Line Reactions

For this option, the total truck load reaction per lane is divided by two to compute the reaction per wheel line. The wheel line reactions are positioned in a design lane spaced in accordance with LRFD 3.6.1.2 (1800 mm apart - not closer than 600 mm from the lane edge). The transverse wheel line spacing must be adjusted for skew.

7.2.3.9.1.2.2 Lane Reactions

For this option, the total truck load reaction per lane is uniformly distributed over the same width as the lane load as specified in LRFD 3.6.1.2.4, adjusted for skew.

7.2.3.9.1.3 Lane Load Reactions

The lane load portion of vehicular live load reaction is uniformly distributed over the distance specified in LRFD 3.6.1.2.4 (3000 mm), adjusted for skew.

7.2.3.9.1.4 Pedestrian Load Reactions

Pedestrian load reactions are distributed over the width of the sidewalk, adjusted for skew.

7.2.3.9.2 Design Lane Configurations

The width of a design lane is specified in LRFD 3.6.1.1.1. In general, a whole number of design lanes does not exactly fill the curb-to-curb width of the bridge as seen in Figure 41. There is usually some excess space, denoted as W_{excess}. Because the design lanes must be positioned to cause the extreme force effects, the configuration of the design lanes must change for the various force effects in the structure. It is not practical to analyze a pier for every possible design lane configuration or to determine the optimum lane configuration for each force effect. QConBridge II positions the design lanes are shown in Figure 44.

Design lanes are always positioned curb to curb. QConBridge II ignores the presence of median barriers when determining design lane configurations.

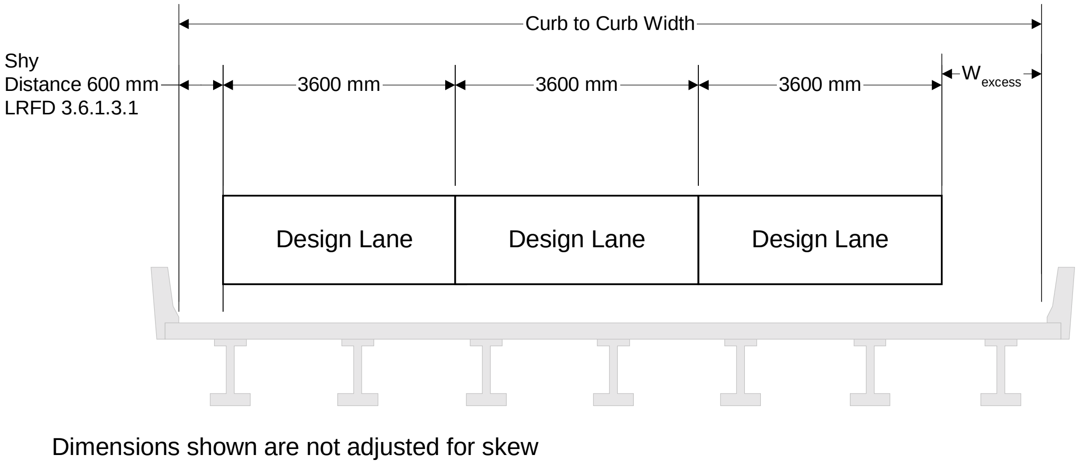


Figure 41 Lane Configurations

When sidewalks are present in the product model, and they have sufficient width to warrant loading per LRFD 3.6.1.6, QConBridge II models design lane configurations with and without the effect of the sidewalk. When the sidewalk is accounted for in the load transfer model, pedestrian live load is applied to the model. If the structure has sidewalks on each side, design lane configurations are considered for no sidewalks, one sidewalk on the left, one sidewalk on the right, and two sidewalks.

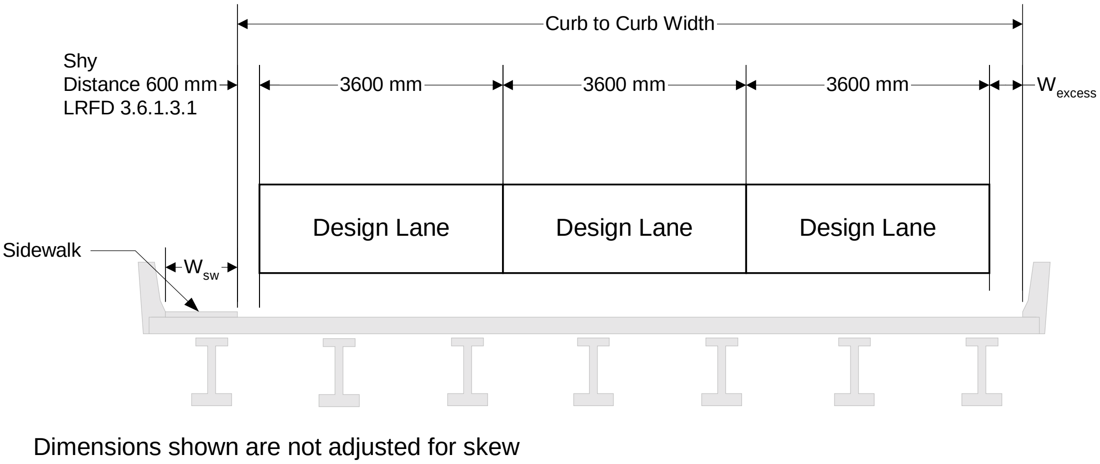


Figure 42 Design Lane Configuration with one sidewalk

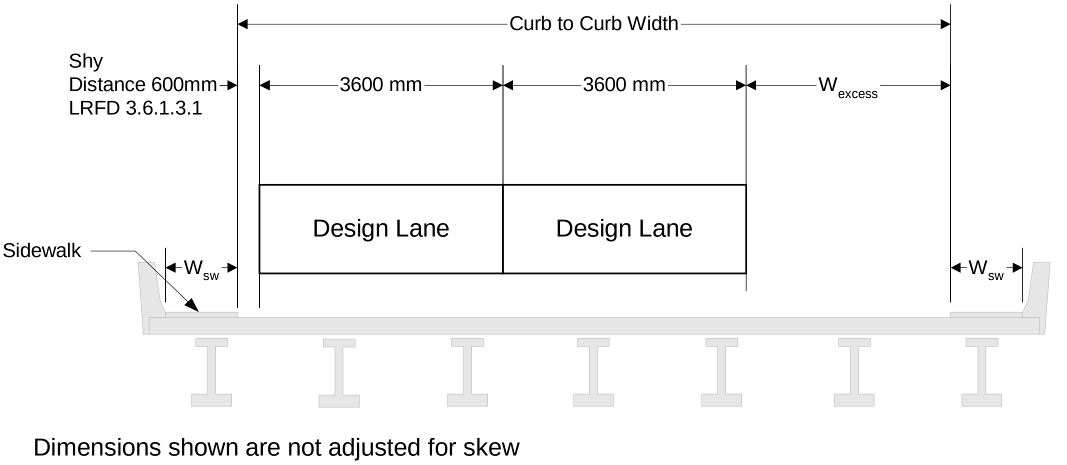


Figure 43 Design Lane Configuration with two sidewalks

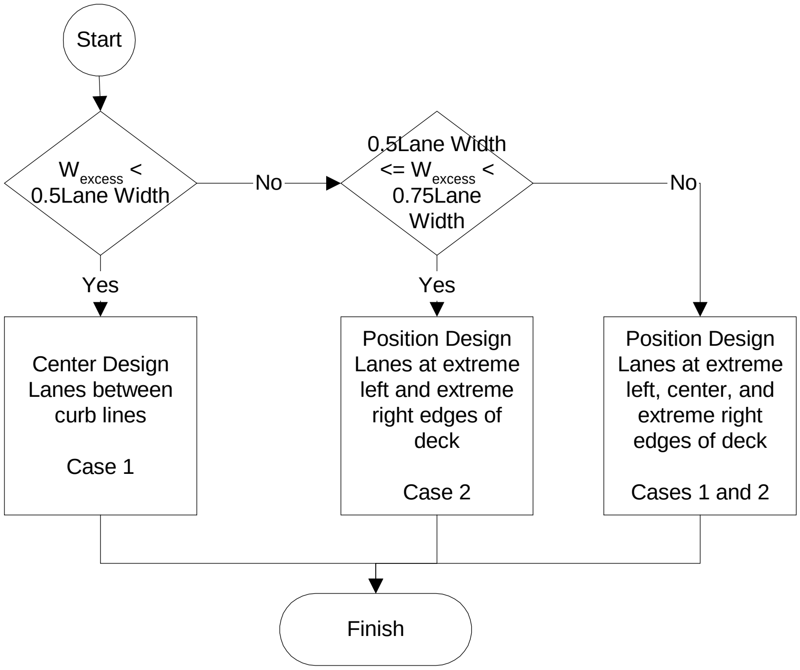


Figure 44 Design Lane Configuration for TBAM's

7.2.3.9.2.1 Location of Live Load Within a Design Lane

A lane of live load does not occupy the full width of a design lane. The design lane loads occupies 3000 mm of the 3600 mm design lane. Truck loads occupy 1800 mm of the design lane, and the wheel lines cannot be closer that 600 mm from the lane edge. The sections that follow describe how the live load reactions, applied to load transfer models, are positioned within the design lanes.

7.2.3.9.2.1.1 Case 1 - Design Lanes Centered Between Curb Lines

When the design lanes are centered between curb lines, the location of the live load within the design lane varies. For the leftmost design lane, the live load is positioned as far to the left as possible. For the rightmost design lane, the live load is positioned as far to the right as possible. The live load is positioned in the center of the center design lane (if there is an odd number of design lanes). The offset of the live load in all other design lanes is taken as a linear interpolation between the center and edge design lanes.

7.2.3.9.2.1.2 Case 2 - Design Lanes At Left or Right Curb Line

When the design lanes are positioned either at the left or right curb line, the live load is positioned as far to the left or right edge of the design lane as possible.

7.2.3.9.2.2 Permutations of Loaded Lanes

The TBAM must be loaded with the combination of lane loads that cause the extreme force effects. To facilitate this, QConBridge II applies various permutations of loaded design lanes to the analysis model. QConBridge II analyzes the TBAM for all possible combinations of loaded lanes. Figure 45 through Figure 47 show the various permutations of loaded lanes for a structure with two sidewalks. Per LRFD 3.6.1.1.2, sidewalks loaded with pedestrian load are considered to be equivalent to one loaded lane, except the case of pedestrian load only is not considered for vehicular bridges. The actual transverse placement of the design lanes is specified in Section 7.2.3.9.2.

Figure 45 shows the case when pedestrian load is not considered. Sidewalk dead load (and median barrier dead load if applicable) is still accounted for in this loading situation. In this configuration, the structure can accommodate three design lanes.

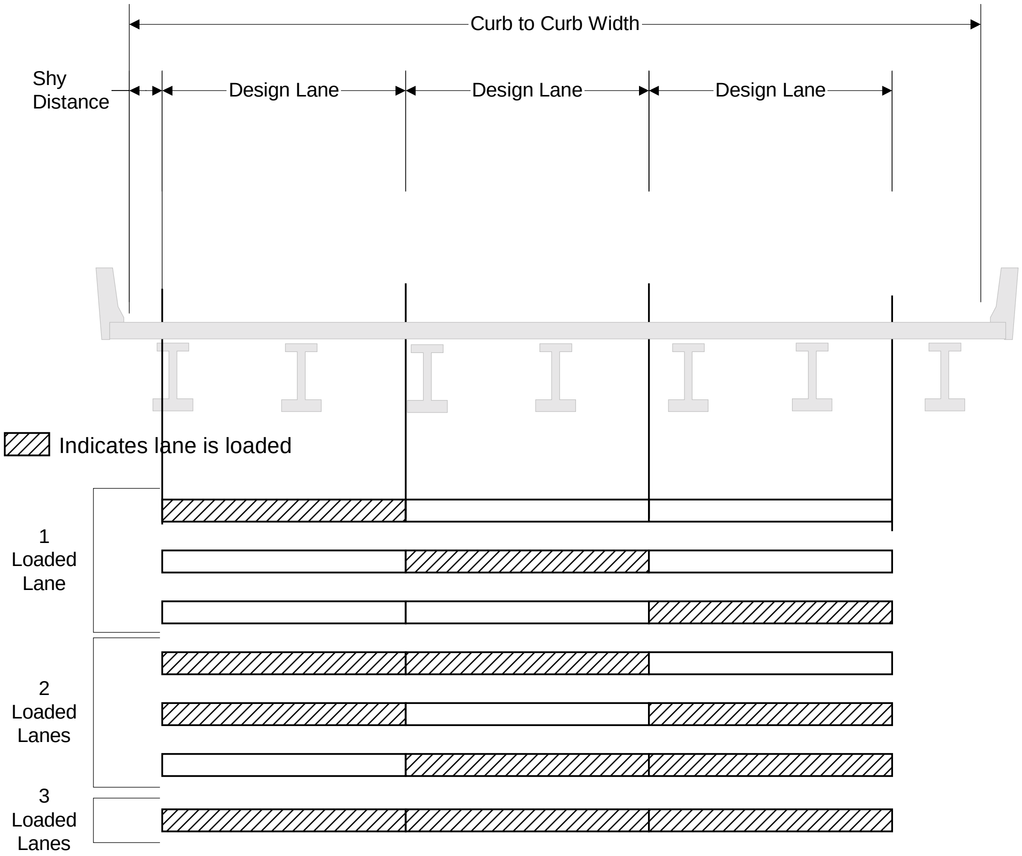


Figure 45 Permutations of Loaded Design Lanes for a 3 Lane Structure

Figure 46 shows the case when pedestrian load is considered to be only on one sidewalk. Load of a sidewalk on only one side of the bridge produces maximum magnitudes of certain force effects[3]. Sidewalk dead load (and median barrier dead load if applicable) is still accounted for in this loading situation. In this configuration, the structure can still accommodate three design lanes.

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[3] Loading the sidewalk on only one side of the bridge is consistent with LFD 3.14.1.2.

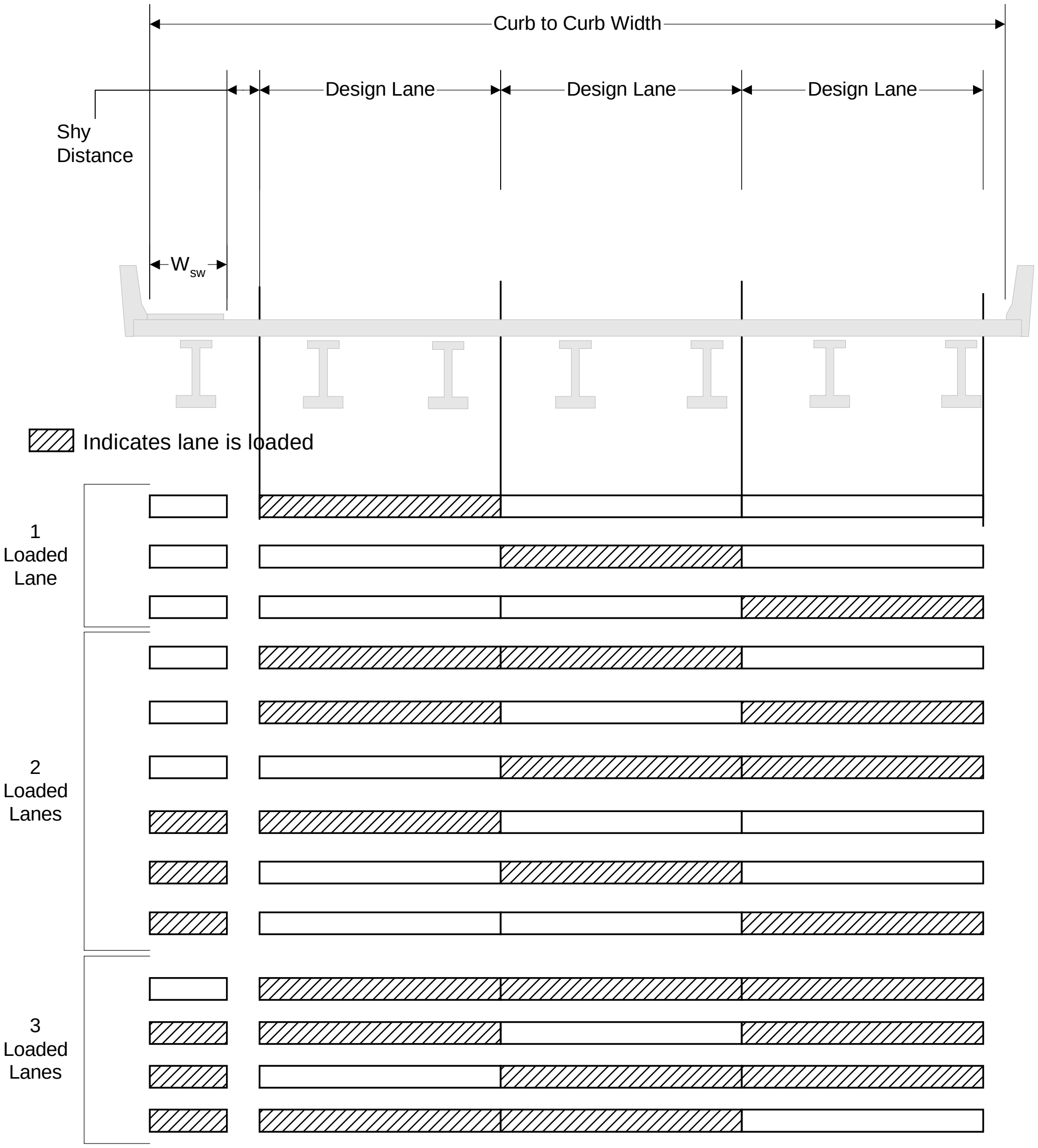

Figure 46 Permutations of Loaded Design Lanes for a 3 Lane Structure with a Sidewalk

Figure 47 shows the case when pedestrian load is considered to be on both sidewalks. In this configuration, the structure can accommodate two design lanes.

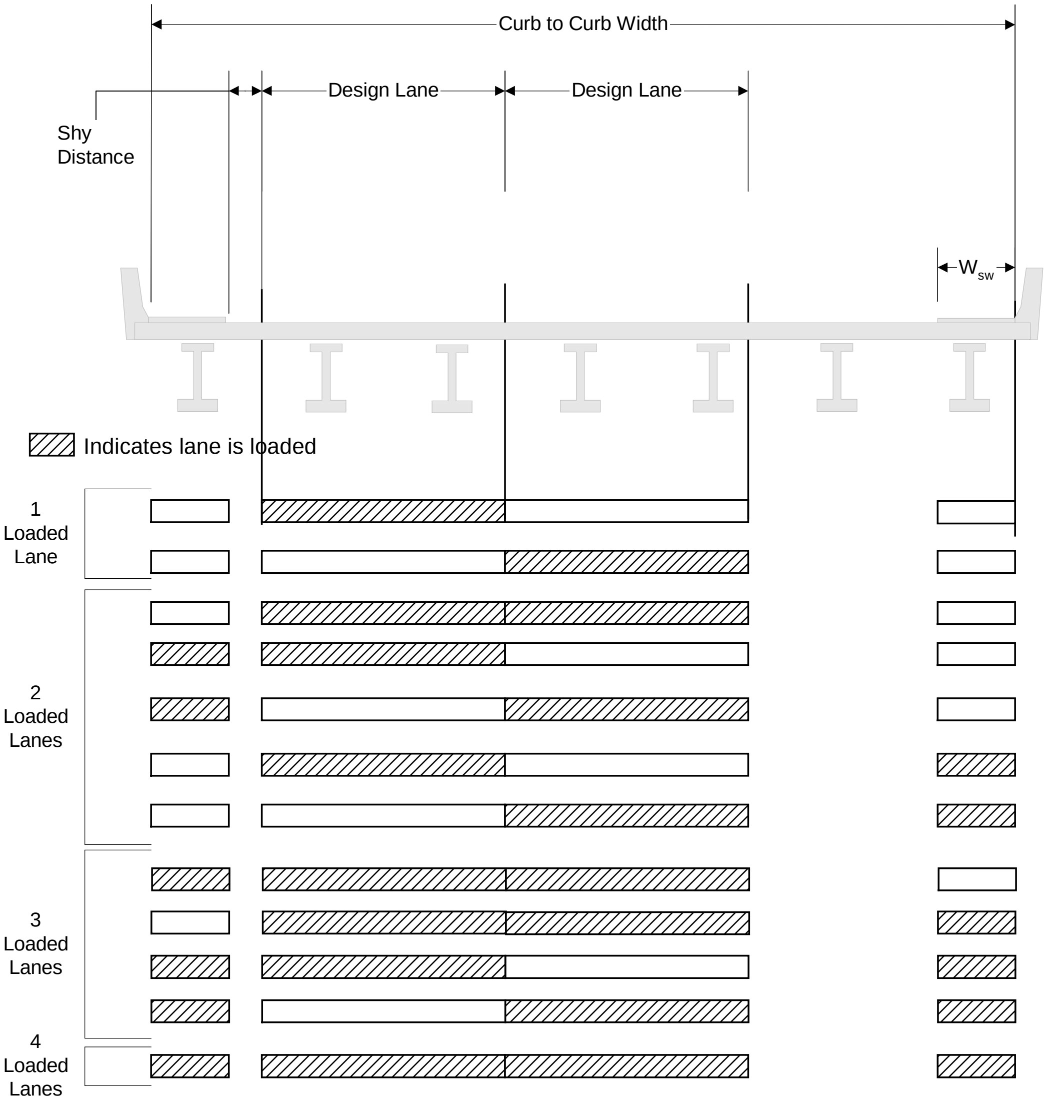

Figure 47 Permutations of Loaded Design Lanes for a 3 Lane Structure with two Sidewalks

7.2.3.9.3 LOAD TRANSFER MODELS

Live load reactions are distributed to the cap beam through a load transfer model. The two load transfer models support by QConBridge II are described below.

7.2.3.9.3.1 Rigid Links (Lever Rule)

For this transfer model, live load reactions are applied to a model of rigid links as shown in Figure 48. This is basically a lever rule distribution. Reaction points in the transfer model represent the bearing locations. The rigid beams are simple spans between girder lines. The exterior transfer beams have cantilever sections that represent the overhang of the bridge deck.

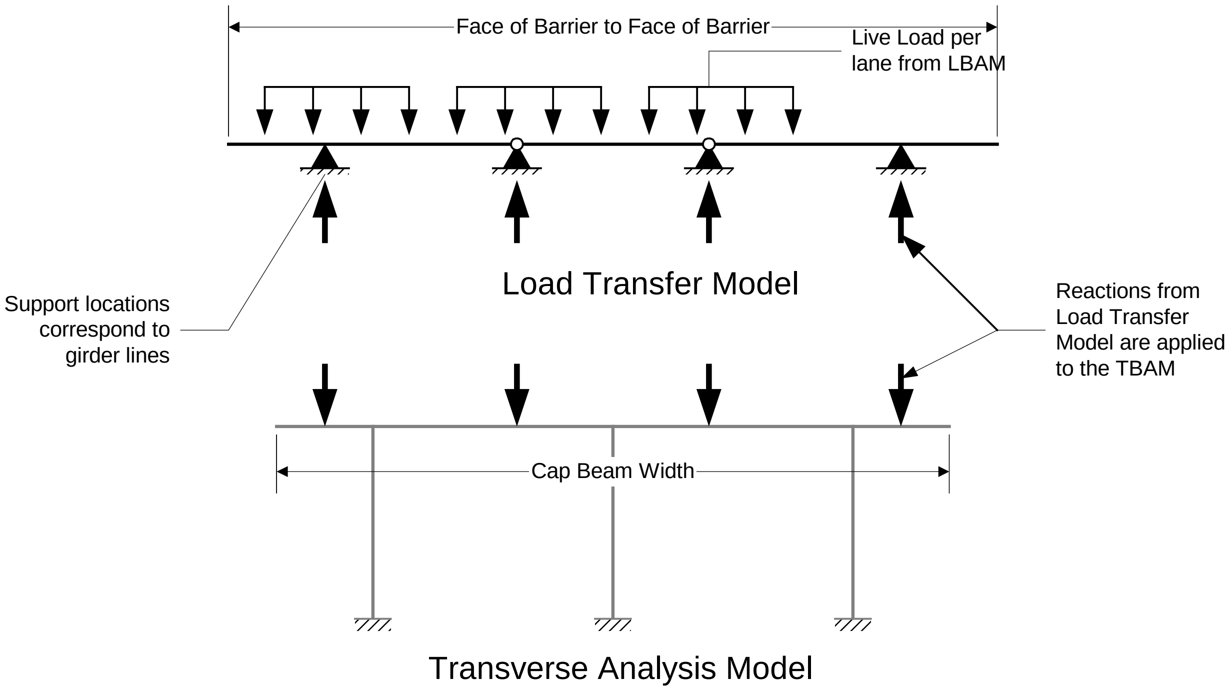

Figure 48 Rigid Links Load Transfer Model

7.2.3.9.3.2 Drop Through

For this transfer model, the live load reactions are applied directly to the cap beam elements of the transverse analysis model. This is shown in Figure 49. When the curb to curb width of the roadway exceeds the width of the cap beam, the load extending beyond the cap beam is applied to the end of the cap beam as a concentrated load and as an equivalent couple at the base of the exterior columns (for single columns piers, a concentrated moment is used). The loads shown below are for illustrative purposes. For actual modeling of the live load reactions as loads in the TBAM, see section 7.2.3.9.1. This transfer model is used in WSDOT's office practice, as described in BDM 9.1.1C.

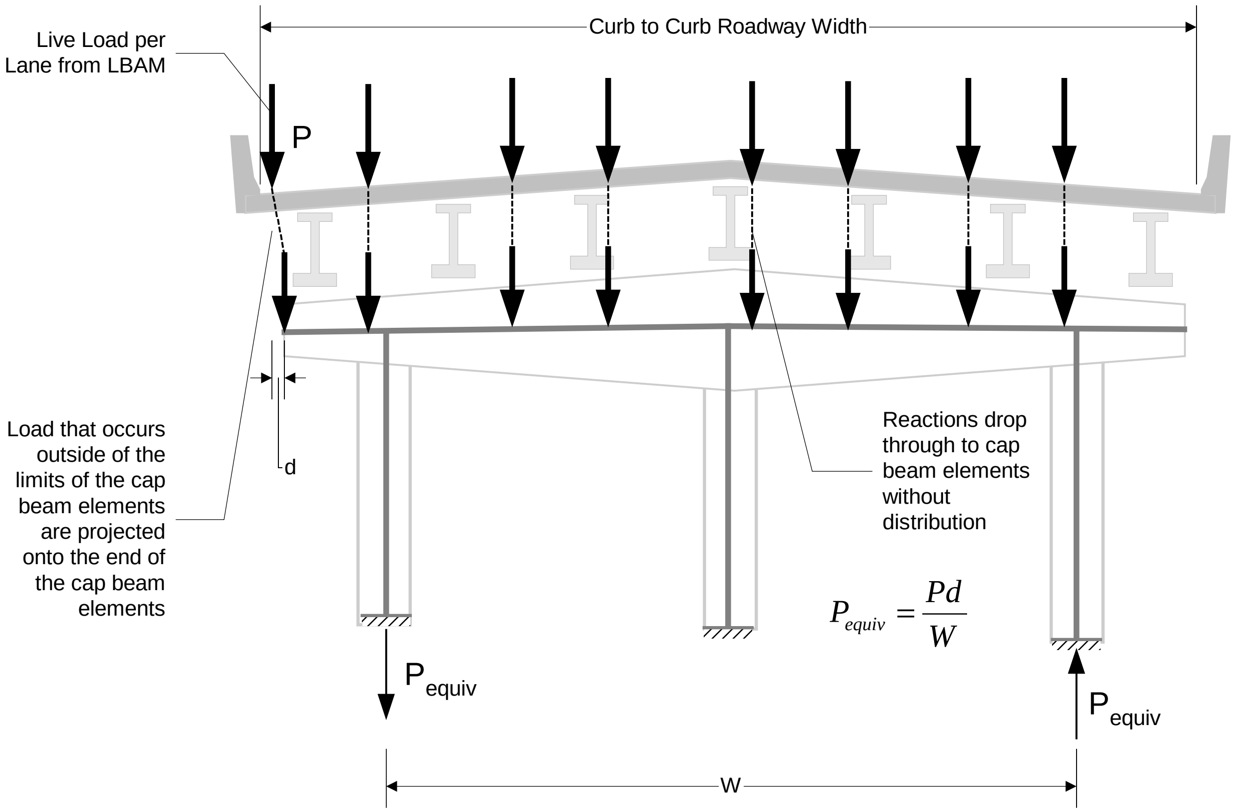

Figure 49 Drop-Through Load Transfer Model

7.3 Analysis Results

After the TBAM is generated from the product model, the problem being solved by QConBridge II becomes the same as for Analysis Model Projects or Transverse Only Analysis Model. This section describes how QConBridge II takes the raw analysis results from the TBAM and combines them into Load Case and Limit State results. The process that QConBridge II uses for TBAMs is very similar to the process for LBAMs, though somewhat less complex. TBAMs do not need to consider staging, the various components of the HL93 Live Load, or enveloping simple span and continuous structures.

7.3.1 The Basic Process

Figure 50 illustrates the basic process for analyzing a TBAM and computing Load Case and Limit State Results. The TBAM is loaded as described above. The live load is applied in various combinations to produce the minimum and maximum load cases.

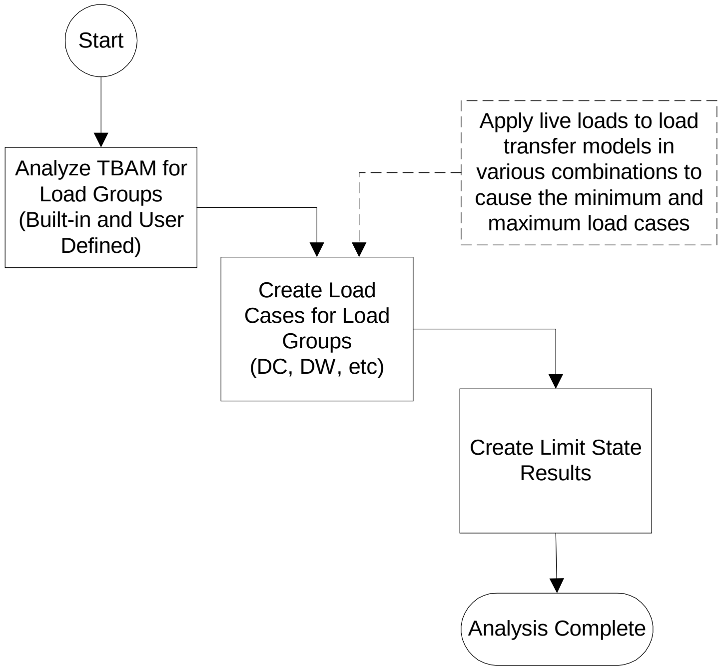

Figure 50 Basic TBAM Analysis Process

The total Load Case responses for the TBAM are combined into Limit State results. The following Limit State results are computed:

- Strength I
- Strength II (using Permit and Special Live Loads)
- Strength III (If WA, WS, FR, TU, CR, SH, TG, and SE load cases are empty, this Limit State will not control over Strength I and need not be reported to the user)
- Strength IV
- Strength V (If WA, WS, WL, FR, TU, CR, SH, TG, and SE load cases are empty, this Limit State will not control over Strength I and need not be reported to the user)
- Extreme Event I (If EQ load case is empty, this Limit State will not control over Strength I and need not be reported to the user)
- Extreme Event II (If IC, CT, and CV load cases are empty, this Limit State will not control over Strength I and need not be reported to the user)
- Service I
- Fatigue
- User Defined Limit States (using either/or HL93 Live Load or User Defined Live Load)

7.3.2 TBAM Results

For each of the Load Groups, Load Cases, and Limit States, QConBridge II will compute moments and shears in the cap beam and moments, shears, and axial each column. QConBridge II will also compute reactions at the base of columns. Limit State reactions will be computed for above ground and below ground components of the foundation. QConBridge II will report analysis results at all points of interest.

7.3.3 Total Pier Results (Combining LBAM Results with TBAM Results)

QConBridge II approximates the total structural response at a pier by factoring in the LBAM response. The total response is reported separately from the TBAM results so as to avoid confusion.

The total response at the base of the columns is reported in a coordinate system parallel to the plane of the TBAM. The reactions in the plane of the TBAM are reported per girder, per column, and for Vehicular and Pedestrian Live Load, per design lane. Figure 51 illustrates how QConBridge II transforms the LBAM reactions into the plane of the TBAM. Note that eccentricities due to bearing locations at the connections are not modeled. This means that torsion in the cap beam and moment in the columns due to eccentricity of the bearing line are not modeled.

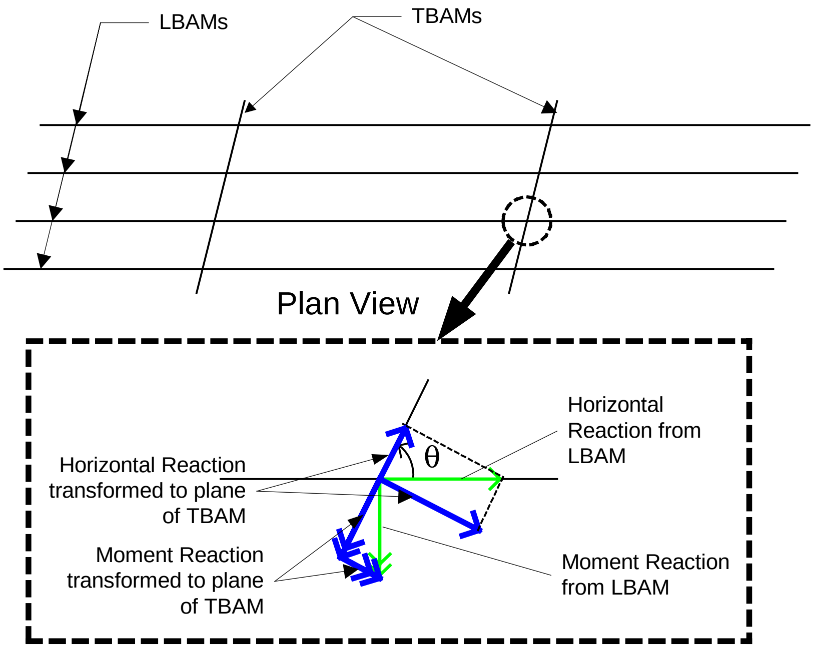

Figure 51 LBAM Reactions Transformed to plane of TBAM

QConBridge II will combine the transformed reactions from the LBAM with the TBAM reactions when reporting 3D pier reactions. The reactions from the TBAMs will be per column.

The transformed LBAM reactions per column are computed as $R_{Column} = R_{Per\,Girder} \frac{N_{Girders}}{N_{Columns}}$ where

$R_{Per\ Column}$	Per column reaction
$R_{Per\ Girder}$	Per girder line reaction
$N_{Girders}$	Number of Girders
$N_{Columns}$	Number of Columns