SYSTEM DESIGN

FOR

QCONBRIDGE II
A MEMBER OF THE ALTERNATE ROUTE PROJECT

VERSION 1.2

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REVISION CHART

Version	Primary Author(s)	Description of Version	Date Completed
1.0	RAB, RDP	Detailed view of the requirements for QConBridge II	6/14/2000
1.1	RAB	Removed Section 5. Section 5 is now covered in the Theoretical Manual	7/19/2000
1.2	RDP	Clarified the concept of a Bridge Analysis Model (BAM)	8/10/2000

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1. INTRODUCTION

1.1 Overview

The purpose of this document is to provide a detailed description of the QConBridge II system design, and to provide a detailed discussion of the requirements specified in the Requirements Specification.

1.2 Document Organization

This document is broken into three main sections: Section 1 - System Overview explains the basic concepts of the system and how Product models and analysis models are used. Section 2 – Bridge Product Modeling provides a detailed specification of the product models to be used by QConBridge II. Section 3 – Bridge Analysis Modeling is a detailed specification of the analysis capabilities of the program.

2. SYSTEM OVERVIEW

The requirements described in this section define the required functionality of QConBridge II. That is, this section describes what the program is supposed to do.

The primary purpose of QConBridge II is to perform a live and dead load structural analysis of the superstructure and substructure for many different types of common bridges. In particular, those bridges that can be modeled using the simplified method of analysis defined in LRFD 4.6.2.

2.1 Modeling

The term "Bridge Modeling" can mean many different things to different users. An estimator might model a bridge as a list of cost items in a spreadsheet, while a structural engineer might model a bridge using finite elements, and a roadway engineer might model a bridge as a COGO roadway description. In order to clarify this document, we must define what bridge modeling means to QConBridge II.

Initially, QConBridge II will support the following types of Bridge Models: *Bridge Product Models* to describe the physical bridge, and a Bridge Analysis Model (BAM) that is composed of *Longitudinal Bridge Analysis Models (LBAM's), and Transverse Bridge Analysis Models (TBAM's)*. Figure 1 shows an overview of the specific types of bridges and Bridge Models that can be modeled by QConBridge II.

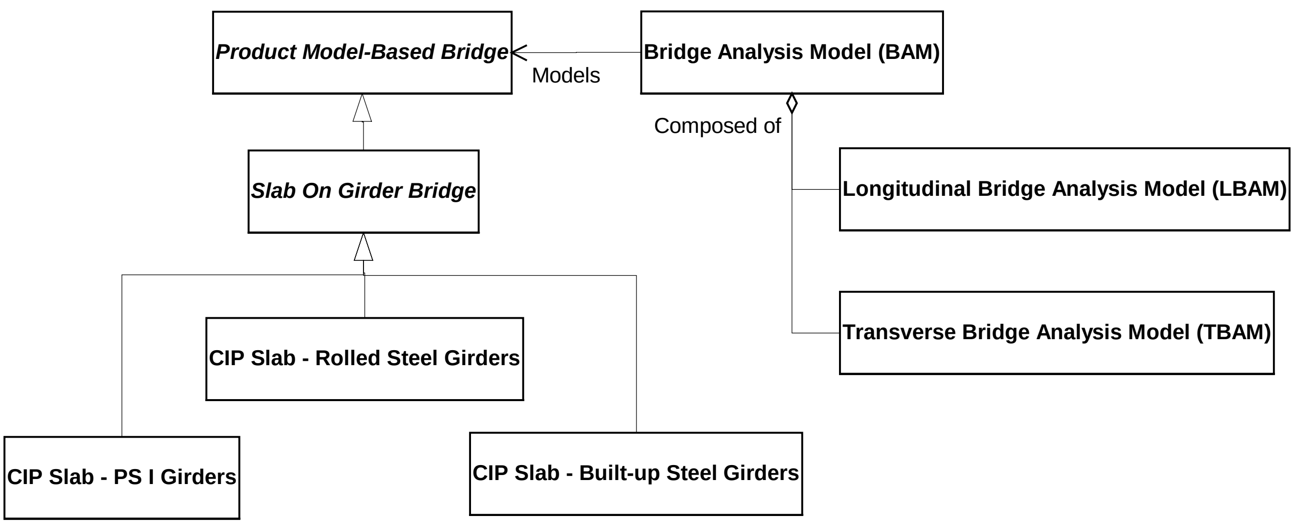

Figure 1 - High-Level Object Diagram of Bridge Types

2.2 Product Models

Bridge Product Models describe bridges, as they exist in the real world. A complete (full-fidelity) product model of a bridge would represent all of the information required by a contractor to build a bridge. In QConBridge II, we don't need this level of fidelity, so we will only describe enough information required for our purposes.

2.3 Bridge Analysis Models

Bridge Analysis Models (BAM's) are idealizations of a bridge used to compute the structural responses. The BAM in QconBridge II is used to analyze a bridge structure using the simplified analysis method as described in the LRFD Specifications. This method analyzes the bridge as a collection of separate, but related, *Longitudinal Bridge Analysis Models (LBAM's)* for analyzing the longitudinal behavior of each girderline, and *Transverse Bridge Analysis Models (TBAM's)* for modeling the transverse behavior of each pier in the bridge. Once created, each longitudinal model is treated independently to model a particular girderline. Then, the results from these longitudinal analyses may be used to apply superstructure loads to the transverse models. Hence, the BAM is not a model it its own right: It represents a collection that manages the interdependencies between the LBAM's and TBAM's.

Longitudinal Bridge Analysis Models are used to perform a single girderline analysis of the bridge superstructure. LBAM's are an idealized representation of a bridge using beam members, distribution factors, and idealized loads. LBAM's consist only of the information required to analyze a bridge. They do not contain product-level information about a real bridge (e.g., you can't tell what type of girders they are made from, or what materials were used). LBAM's in QConBridge II can be used to idealize and analyze any type of bridge that can be modeled using the LRFD simplified (distribution factor-based) approach.

Transverse Bridge Analysis Models are used to analyze piers for live and dead load responses. TBAM's are an idealized representation of a pier using beam members and idealized loads. Loading input for a TBAM is typically synthesized from the results from one or more longitudinal analyses.

2.4 Model Generation

In order to perform a structural analysis on a Product Model-based bridge, there must a successful mapping from the product world to the analytical world. This is called Model Generation. QConBridge II uses a fixed set of assumptions for automatically generating BAM's from Product Models. This will be discussed in depth throughout the remainder of this document and in the Theoretical Manual.

3. Bridge Product Modeling

3.1 Product Modeling of General Bridges

3.1.1 General Layout of All Product Model Bridges

A considerable amount of detail can be required to describe a Product Model of a specific type of bridge. However, in a computer program, it is convenient to describe all types of bridges in a generalized and consistent manner. In QConBridge II, we take the following approach to describe all types of bridges in terms of generalized components:

1. Describe the roadway geometry. This defines the general orientation of the superstructure and provides a reference geometry for all bridge elements.
2. Describe the locations of supports (abutments and piers) with respect to the roadway geometry.
3. Describe abutment and pier details including the layout of columns and descriptions of the crossbeam.
4. Describe the width of the roadway and the geometry of sidewalks and barriers.
5. Layout girder lines and select girder types
6. Describe the connections between the girders (superstructure) and the substructure.
7. Describe other details such as overlays and reinforcement.

Although some items depend on others (e.g., a roadway must exist in order to place piers on it), the sequence above is not fixed, and can be changed to suit your needs. Based on the above description, we can sketch an idealized Product Model bridge as shown in Figure 2. Also note that although the Figure resembles a certain type of bridge, it is meant to be a general representation: all Product Model bridge types in QConBridge II are built from the same generalized components.

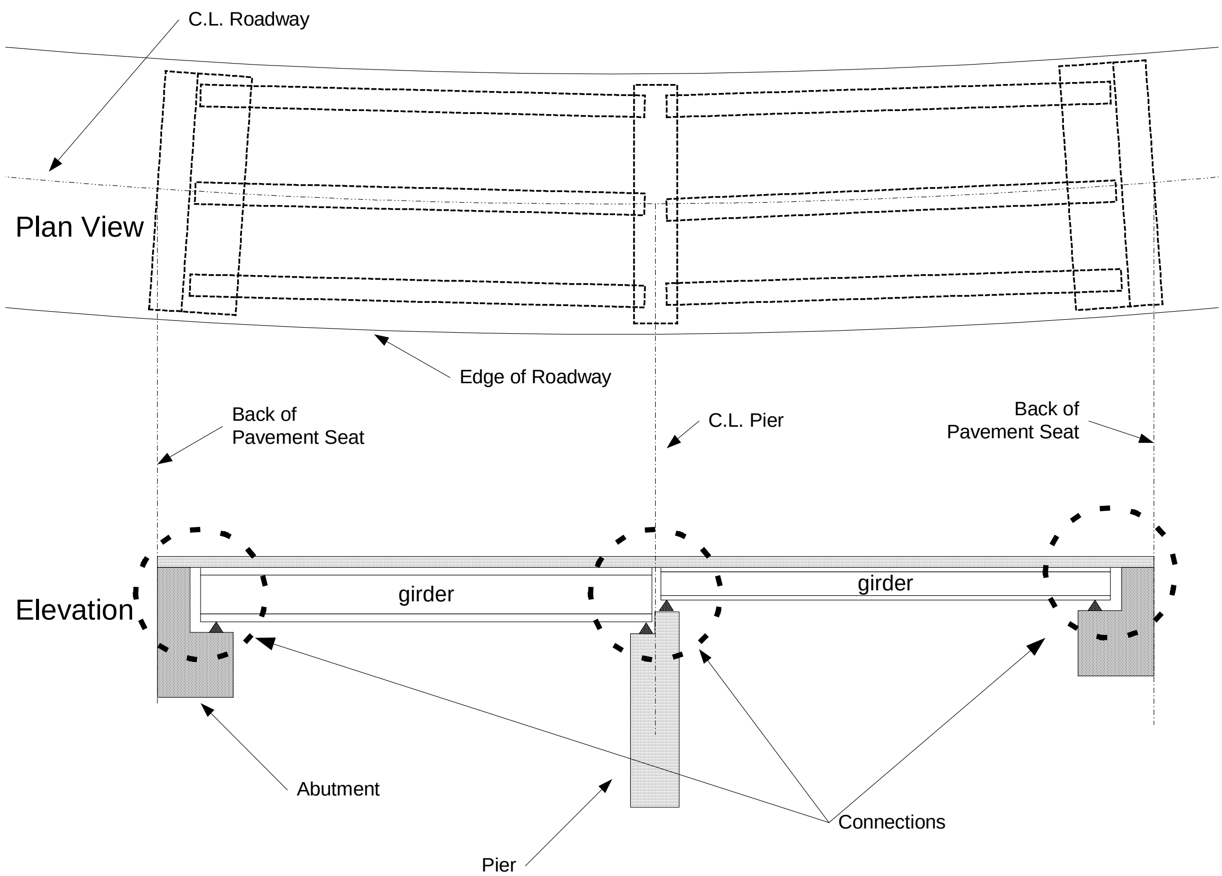

Figure 2 - General (Consistent) Bridge Product Model Description

3.1.2 General Product Model-Based Bridges

This section contains modeling requirements that are common to all Product Model-Based Bridges supported by QConBridge II. Note that this Section provides specifications for all bridge types modeled by QConBridge II now, and expected in the future (i.e., all bridge types in LRFD 4.6.2).

QConBridge II will be capable of modeling the geometry of the bridge superstructure and substructure, accounting for vertical curves, horizontal curves, and superelevations. The requirements of the roadway geometry description are given in Section 3.1.2.2.

3.1.2.1 General Requirements

It is impractical to model all possible bridge permutations – we must strive to solve practical problems without undue complications. Therefore, the following general requirements apply to all bridges that can be modeled by QConBridge II:

- When horizontal curves are present, the bridge must be entirely contained within a horizontal curve
- When vertical curves are present, the bridge must be entirely contained within a vertical curve

Bridges can have single or multiple spans.

3.1.2.2 Roadway Geometry

QConBridge II shall account for the effects of roadway geometry on the structure. Geometrical considerations shall include horizontal and vertical curves and crown slopes. Effects of the roadway geometry shall include effects on the geometry on bridge components and on the structural behavior of the bridge.

3.1.2.2.1 ROADWAY ALIGNMENT

The roadway alignment is divided into two parts, the horizontal alignment and the vertical alignment. Associated with the alignments is the roadway section that describes the roadway width, crown point offset, and superelevation data.

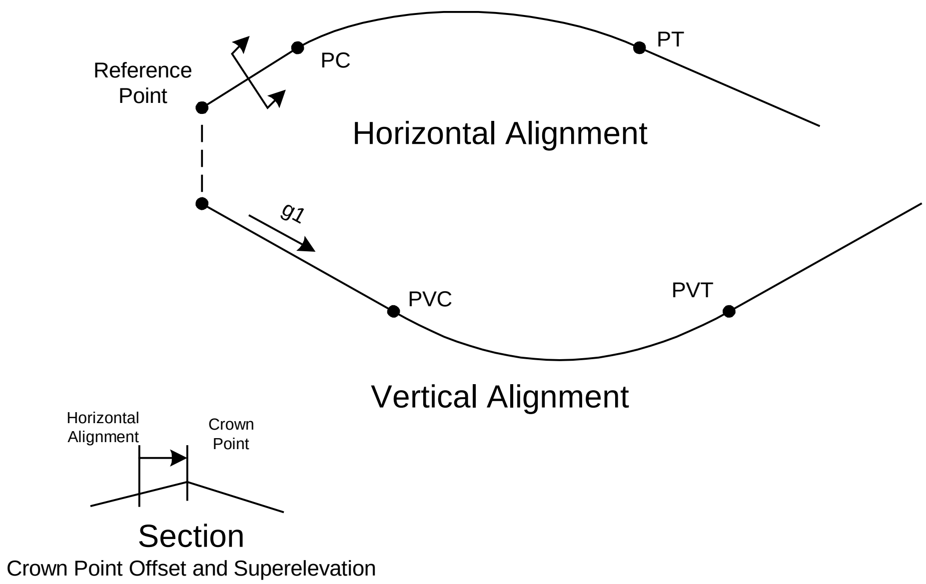

Figure 3 Schematic of Roadway Alignment

3.1.2.2.1.1 Horizontal Alignment

The horizontal alignment describes the curvilinear path that the roadway follows. The path shall consist of a straight alignment at an arbitrary bearing or a single arbitrarily oriented circular curve. The reference point for the alignment shall be a known station on a straight alignment or the point of curvature (PC) of a horizontal curve. The horizontal alignment need not represent the centerline of the roadway or bridge. Spiral curve segments are not supported in this version of QConBridge II.

3.1.2.2.1.2 Vertical Alignment

The vertical alignment describes the elevation profile of the horizontal alignment. The vertical alignment is linked to the horizontal alignment at the reference point. The vertical alignment defines the elevation of the reference point and either a straight grade or a vertical curve profile. Compound parabolic curves are not supported in this version of QConBridge II.

3.1.2.2.1.3 Roadway Section

The roadway section is described by its width, crown point offset, and crown slopes. Roadway sections may not change width along the length of the bridge.

3.1.2.2.1.3.1 Crown Point Offset

The crown point is the high point in the roadway surface. It is located left or right of the horizontal alignment and is constant throughout the alignment.

3.1.2.2.1.3.2 Crown Slopes

The crown slopes define the slope of the roadway surface. The slopes are measured to the left and the right of the crown point offset. Crown slopes shall be limited to ±0.10.

3.1.2.3 Superstructure Components

3.1.2.3.1 GIRDERLINE GEOMETRY

Girders in QConBridge II must be straight in both plan and profile (ignoring camber and haunches). Adjacent girder lines (if multi-girder) must be parallel. Girders must be aligned in each span such that each girder line is continuous over the entire length of the bridge. Girder centerlines must intersect at the pier centerline as shown in Figure 4.

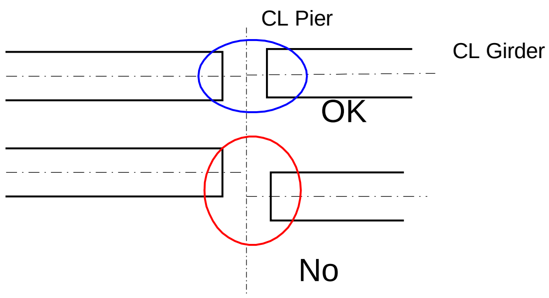

Figure 4 - Continuous versus Discontinuous girder lines

3.1.2.3.1.1 Number of Girders Per Span

The bridge configuration will be limited to bridges with the same number of girders in every span.

3.1.2.3.1.1.1 Maximum

It is WSDOT practice to label girders A-Z. For this reason, the maximum number of girder lines for all bridge types is 26.

3.1.2.3.1.1.2 Minimum

A bridge must have at least one girder line.

3.1.2.3.1.2 Girder Spacing

This Section is only applicable for multi-girder bridges.

3.1.2.3.1.2.1 Minimum Girder Spacing

The minimum girder spacing shall be equal to the width of a girder.

3.1.2.3.1.2.2 Maximum Girder Spacing

There is no upper limit on girder spacing.

3.1.2.3.1.2.3 Spacing Types

Girder shall be spacing evenly at each pier and abutment.

3.1.2.3.1.2.4 Measurement of Girder Spacing

Girder spacing is measured at the location and orientation described in this section.

3.1.2.3.1.2.4.1 Location of Measurement

Girder spacing will be measured at abutments and intermediate piers. At abutments, girder spacing will be measured at the centerline of bearing line. At intermediate piers, girder spacing will be measured at the centerline of the pier.

3.1.2.3.1.2.4.2 Direction of Measurement

Girder spacing can be measured normal to the roadway alignment at the location of measurement or along the centerline of bearing or pier at abutments and piers, respectively.

3.1.2.3.2 SPAN HINGES

An In-Span Hinge consists of a single line of hinges offset from, and oriented parallel to, an associated pier. A typical In-Span Hinge is shown in Figure 5.

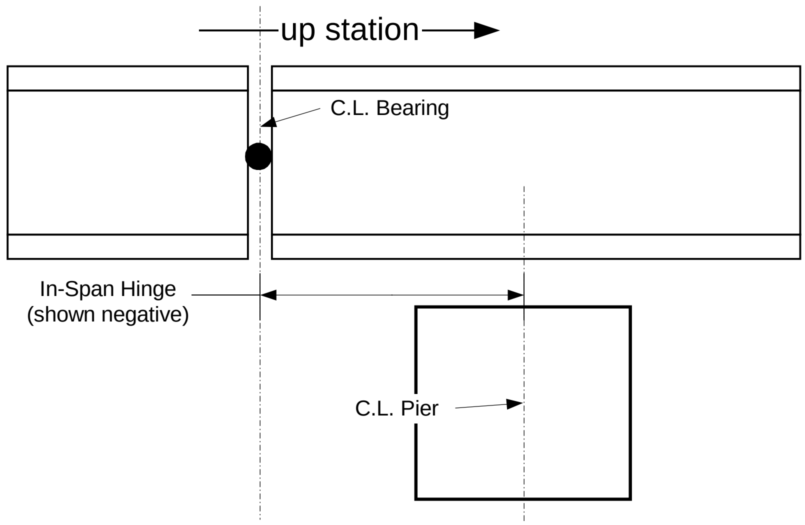

Figure 5 In-Span Hinge

3.1.2.3.2.1 Span Hinge Geometry

The geometry of an In-Span Hinge is described by the following:

- **Hinge Offset**
  The hinge offset is the distance from the pier centerline to the location of the hinge (See Figure). This distance is measured along the alignment and is positive going up station.

3.1.2.3.2.2 Hinge Boundary Conditions

In-span hinges provide a point of moment discontinuity within a span.

3.1.2.3.3 INTERMEDIATE DIAPHRAGM LAYOUT RULES

QConBridge II provides two methods for laying out Intermediate Diaphrams: Incremental and Fixed Spacing.

3.1.2.3.3.1 Incremental Layout

Intermediate Diaphragms are spaced evenly along the span length. The number of diaphragms used will depend on the length of the span in question.

Intermediate Diaphragms will be laid out parametrically according to a user-defined set of rules as described in the table below.

Table 1 Intermediate Diaphragm Layout Rules

	Bearing to Bearing Span Length	Number of Intermediate Diaphragms
	Less than *L1*	*N1*
	L1 to *L2*	*N2*
	L2 to *L3*	*N3*

	L3 to *L4*	*N4*
	Greater than or equal to *L4*	*N5*

The check boxes indicate optional rules. The starting length of enabled rule N is always the ending length of rule N-1.

3.1.2.3.3.2 Fixed Spacing

Intermediate Diaphragms are laid out using a fixed spacing. After dividing the span into fixed length segments, the remaining distance is divided in half and applied either end of the span.

3.1.2.4 Substructure Components

One of the driving factors for undertaking the QConBridge II project is the need to compute structural response in substructure elements due to live load. To facilitate LRFD substructure analysis, abutment and pier descriptions must be included in the product model. To facilitate ease of use, QConBridge II will model abutments and piers in a simplified, idealized manner.

Pier types are highly dependent on bridge type. For the purposes of live load analysis, pier models need not be complex. For multi-column piers, simple descriptions of column cross section, column height, column spacing, and crossbeam geometry will suffice. Footings are not modeled in QConBridge II. The point of fixity is assumed to be at the bottom of a column.

3.1.2.4.1 Generalized Abutments

In QConBridge II, a general idealization of an abutment can be made: At the very least, an abutment consists of a line of support crossing the superstructure.

3.1.2.4.1.1 Abutment Location

The station of the back of pavement seat defines the abutment location.

3.1.2.4.1.2 Abutment Orientation

The orientation of the back of pavement seat can be described using three methods: normal to the roadway alignment, or using an absolute bearing value which describes the abutment's direction, or by a Right or Left skew angle measured relative to the normal to the roadway alignment at the back of pavement seat. The absolute value of the skew angle must be less than 90 degrees[1].

3.1.2.4.1.3 Idealized Abutment Product Models

Idealized product models for abutments provide an expedient way of describing an abutment. There are two types of Idealized Abutments: the Zero-Height Idealized Abutment, and the Fixed-Height Idealized Abutment.

It is **very important** to note that these are product model descriptions of Abutments, however simplified. It is still up to the Model Generation process to define how these abutment types are represented in the BAM.

3.1.2.4.1.3.1 Zero-Height Idealized Abutment Product Model

[1] The program shall issue a warning for skews greater than 80 degrees.

A Zero-Height Idealized Abutment Product Model simply provides a line in space on which to attach a connection. It is representative of a line of support fixed in space at the back of pavement seat. A Zero-Height Idealized Abutment is described only by its location and orientation.

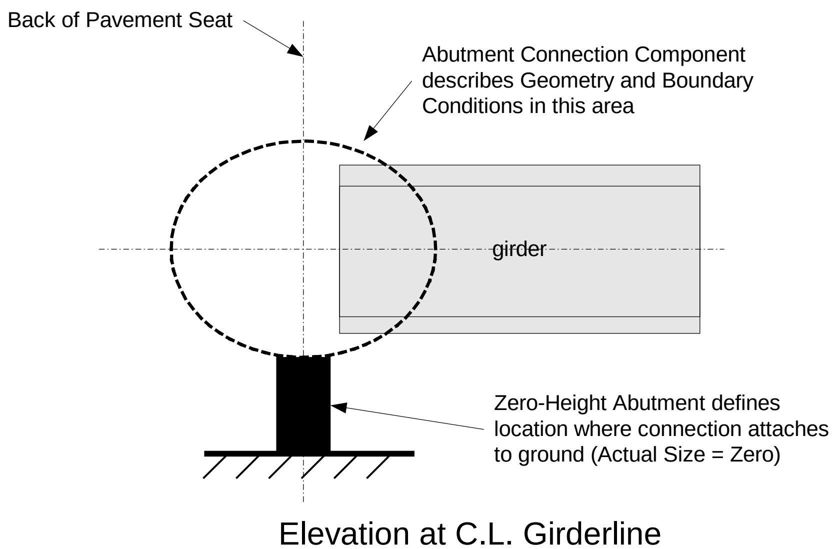

Figure 6 Zero-Height Idealized Abutment

3.1.2.4.1.3.2 Fixed-Height Idealized Abutment Product Model

The Fixed-Height Idealized Abutment allows you to define the height and stiffness of the abutment structure into the product model without having to describe a real abutment in detail. Fixed-Height Idealized Abutments are defined by:

- Location and Orientation
- Height (measured vertically from bottom of connection to ground) or bottom elevation.
- Stiffness Properties (A, I, E) for entire abutment structure. The model generator will divide stiffness by the number of girder lines to determine the abutment stiffness for a single girder line model.

Figure 7 shows a schematic of a typical Fixed-Height Idealized Abutment.

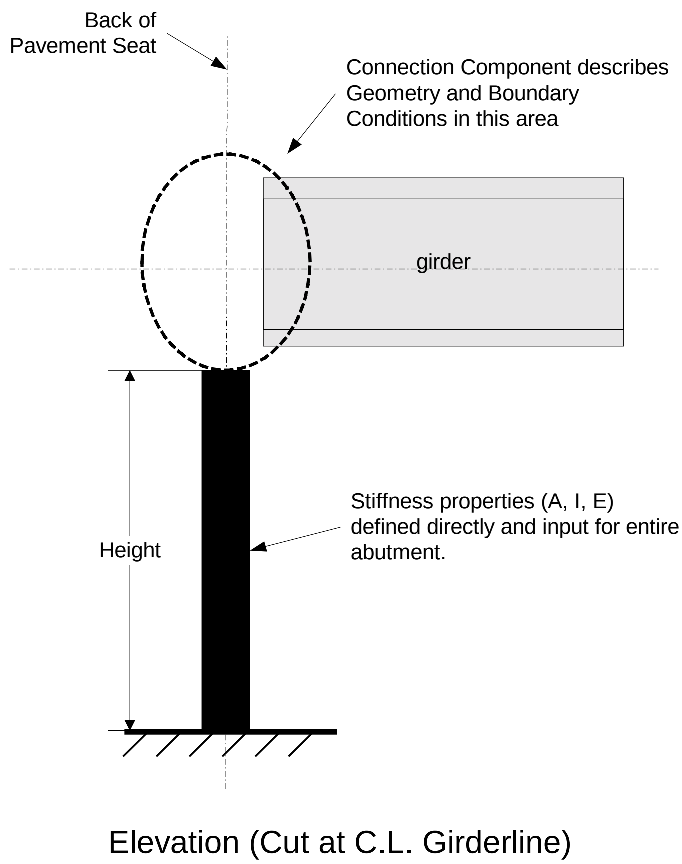

Figure 7 Fixed Height Idealized Abutment

3.1.2.4.2 PIERS

QConBridge II will support three types of pier product models. Each type of product module is increasingly more detailed and leads to more complete substructure analysis results. Zero-height idealized piers provide a line of support to which connections can be attached. Fixed height idealized piers also provide a line of support to which connections can be attached, and include a description of the height and stiffness of the pier. Product Model-Based piers describe a pier in terms of column and crossbeam geometry and materials.

3.1.2.4.2.1 Pier Location

The station of the centerline of the pier cap defines the pier location.

3.1.2.4.2.2 Pier Orientation

The orientation of the pier cap beam can be described using three methods: normal to the roadway alignment, using an absolute bearing value which describes the pier's direction, or by a

Right or Left skew angle measured relative to the normal to the roadway alignment at the pier cap centerline. The absolute value of the skew angle must be less than 90 degrees[2].

3.1.2.4.2.3 Idealized Piers

The various idealized pier product models provide an expedient way of describing the substructure. It is **very important** to note that these are product model descriptions of Piers, however simplified. It is still up to the Model Generation process to define how they are represented in the BAM.

3.1.2.4.2.3.1 Zero-Height Idealized Pier Product Model

A Zero-Height Idealized Pier provides a line in space on which to attach a connection. It is representative of a line of support fixed in space at the top centerline of a fictitious pier cap. QConBridge II will support two types of Zero-Height Idealized pier product models. The first type, called a 2D Zero-Height pier, is described by its location and orientation. The second type, called a 3D Zero-Height pier, is described by its location, orientation, number and spacing of transverse supports, and cross beam properties (overhang and EI). Transverse structural responses are not computed for 2D Zero-Height piers. For 3D Zero-height piers, a transverse analysis of the crossbeam will be performed. Figure 8 shows a schematic:

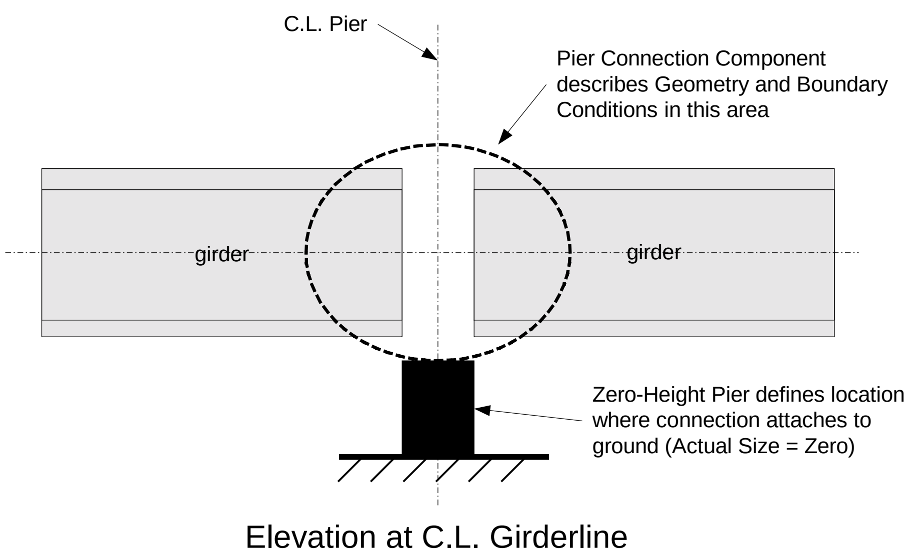

Figure 8 Zero-Height Idealized Pier

3.1.2.4.2.3.2 Fixed-Height Idealized Pier Product Model

The Fixed-Height Idealized Pier allows you to define the height and stiffness of the pier structure into the product model without having to describe a real pier in detail. QConBridge II will support two types of Fixed-Height Idealized Piers, 2D and 3D. 2D Fixed-Height Idealized Piers are defined by:

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[2] The program shall issue a warning for skews greater than 80 degrees.

- Location and Orientation
- Pier Height (measured vertically from bottom of connection to ground).
- Pier Bottom Offset (measured along roadway alignment – positive up station)
- Pier Stiffness Properties (A, I, E) for entire pier structure. Model generator will divide stiffness by the number of girder lines to determine the pier stiffness for a single girder line model.

In addition, 3D Fixed-Height Idealized Piers are defined by:

- Pier Stiffness Properties (A, Ix, Iy, E) for entire pier structure. Model generator will divide stiffness by the number of girder lines to determine the pier stiffness for a single girder line model. In the plane of the pier, the model generator will divide the stiffness amongst the number of columns in the pier.
- Cross beam stiffness and geometry

For 3D Fixed-Height piers, a transverse analysis of the pier will be performed.

Figure 9 shows a schematic of a typical Fixed-Height Idealized Pier.

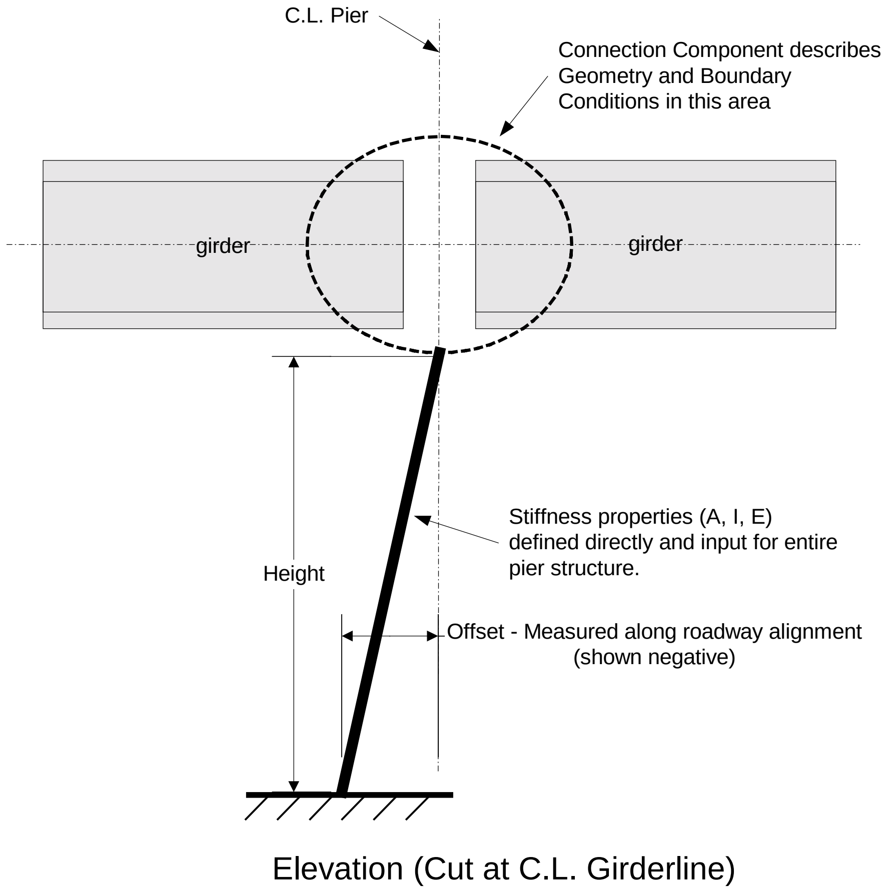

Figure 9 Fixed Height Idealized Pier

3.1.2.4.2.4 Pier Product Models

The Pier Product Model allows you to define the pier using a simplified description of its real world attributes. QConBridge II supports two pier types: Multicolumn Piers and Hammer Head Piers.

3.1.2.4.2.4.1 Multicolumn Piers

A Multicolumn Pier consists of a cap beam that is rectangular in cross section with two or more evenly spaced columns. Figure 10 shows a typical multicolumn pier. The following rules and restrictions apply to multicolumn piers:

1. The top of the pier cap beam follows the roadway profile at the pier centerline station
2. Column sections may not extend beyond the cap beam
3. Columns are spaced evenly and symmetrically about the cap beam centerline
4. Boundary Conditions at top, in the plane of the pier: columns are integral with the cap beam.
5. Boundary Conditions at top, in the plane of the bridge: Defined by the product model of the connection.
6. Boundary Conditions at bottom, both the plane of the pier and the plane of the bridge: columns are fixed
7. Column cross sections can be circular, rectangular or rectangular with rounded ends. Column sections are described by their dimensions at the top and bottom of the column (diameter or width and depth). If the top and bottom cross sections are not identical, a linear taper is assumed.

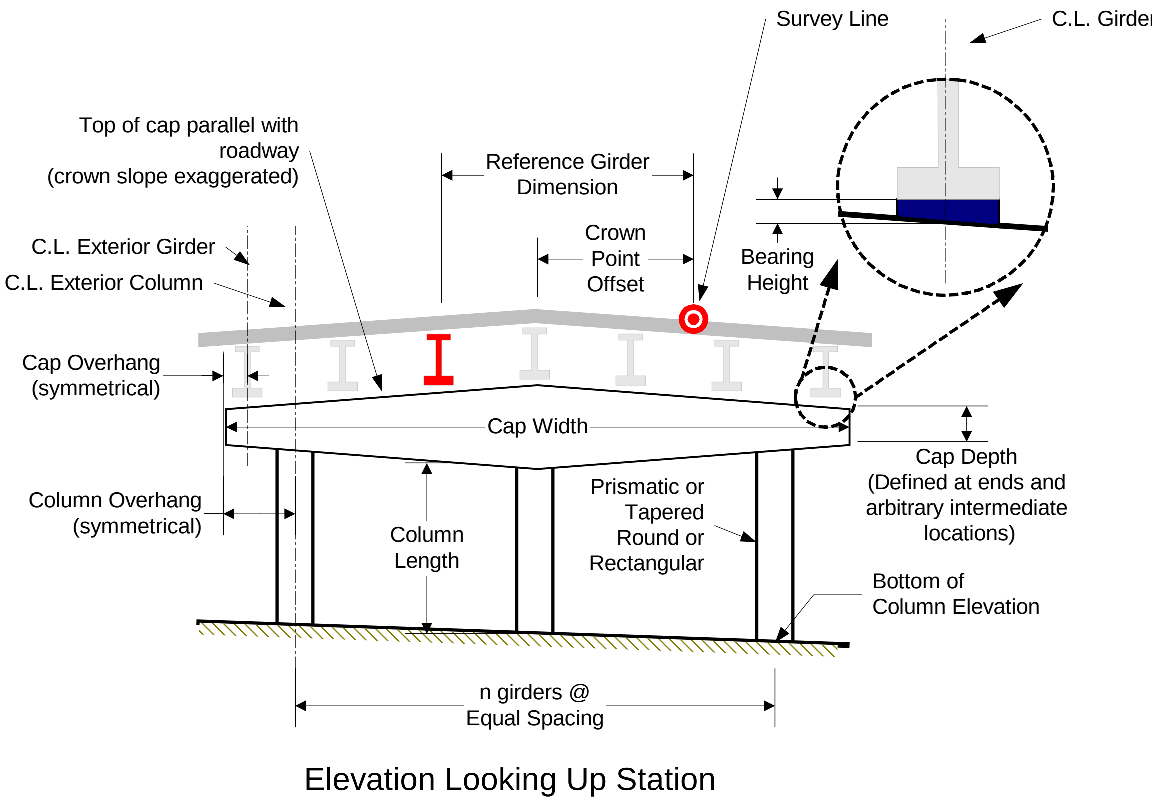

Figure 10 Product Model of a Multicolumn Pier

3.1.2.4.2.4.1.1 Input Values for Multicolumn Pier

The following input values are used to define a multicolumn pier. All relative distances are taken at the centerline of the pier. Note that the total width of the cap is dependent on the number of girders and the girder spacing.

1. Station of pier centerline
2. Orientation of pier with respect to roadway
3. Cap Width – Total width of the cap. Cap overhang is equal on both sides.
4. Number of Columns
5. Column Spacing
6. Cap Thickness - measured normal to pier centerline
7. Cap Depth – vertical depth of cap –specified at both ends of cap and at user-defined intermediate locations measured from left end of cap.
8. Column Length/Elevation – vertical distance from bottom of cap to ground (point of fixity). Each column can have a different length.

9. Number of Columns – Can have one or more columns. Column Spacing is calculated from this, total cap width, and Column Overhang.
10. Column Type – Round, Rectangular, or Rectangular with Round Ends.
11. Column Section Dimensions – Enter diameter for round columns, height and width for rectangular columns. Longitudinal column dimension (height) may not exceed cap thickness. Rectangular columns are oriented parallel to pier and cannot be rotated.

3.1.2.4.2.4.2 Hammerhead Piers

A Hammerhead Pier consists of a rectangular cap with a single rectangular column with or without rounded ends, or a single circular column. Figure 11 shows a typical hammerhead pier. The following rules and restrictions apply to hammerhead piers:

1. The top of the pier cap beam follows the roadway profile at the pier centerline station
2. The bottom of the cap beam is straight and horizontal.
3. Column is rectangular or rectangular with rounded ends in the plane of the pier.
4. Column sections defined at top and bottom. Assume linear taper if sections are different.
5. Column may not be wider than the cap beam

8. Boundary Conditions at top, in the plane of the pier: the column is integral with the cap beam.
9. Boundary Conditions at top, in the plane of the bridge: Defined by the product model of the connection.
10. Boundary Conditions at bottom, both the plane of the pier and the plane of the bridge: the column is fixed

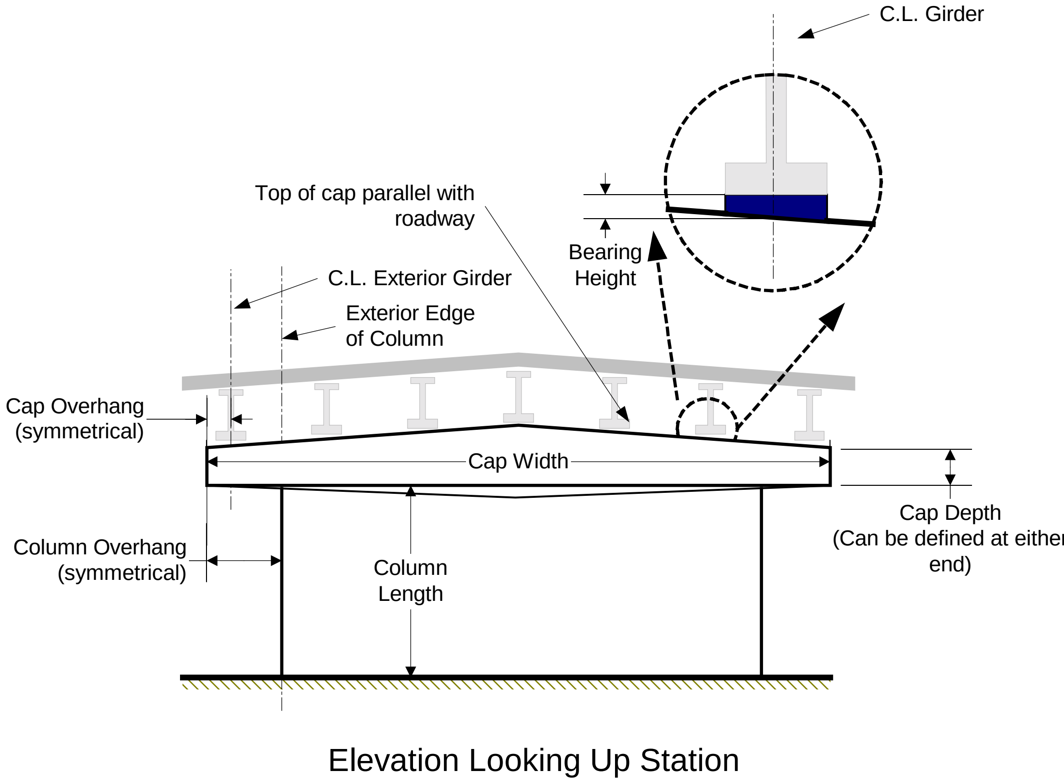

Figure 11 Product Model of a Hammerhead Pier

3.1.2.4.2.4.2.1 Input Values for a Hammerhead Pier

The following input values are used to define a hammerhead pier. All relative distances are taken at the centerline of the pier.

1. Station of pier centerline
2. Orientation of pier
3. Cap Width – total width of the cap beam. Column Overhangs are symmetrical.
4. Cap Thickness - measured normal to pier centerline
5. Cap Depth – vertical depth of cap – can be specified at either end of cap (not both).
6. Column Length or Bottom Elevation – vertical distance from bottom of cap to ground (point of fixity).
7. Column Height – may not exceed Cap Thickness.

3.1.2.5 Connections Between the Substructure and Superstructure

The section describes the connections between the superstructure and the substructure. Many different types of connections are used in practice and a considerable amount of detail is needed to describe each accurately. Fortunately, we don't need this level of detail in QConBridge II. In QConBridge II, the purpose of a connection is to define the geometry at the end of a span (location of the actual point of bearing and the distance the girder overhangs the point of bearing) and how it connects with its support. Hence, the connections used in QConBridge II are highly idealized. Each type is described in the following sections.

3.1.2.5.1 Abutment Connection

An Abutment Connection consists of a single line of bearings parallel to its associated abutment. A typical Abutment Connection is shown in Figure 12.

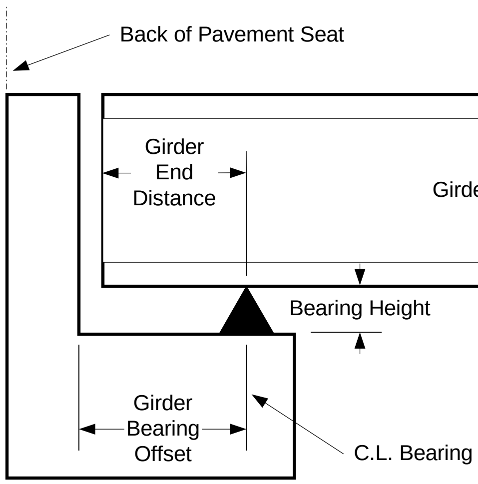

Figure 12 Abutment Connection Type

3.1.2.5.1.1 Abutment Connection Geometry

The geometry of an Abutment Connection is described by the following:

- **Girder Bearing Offset**
  The bearing offset is the distance from the abutment reference line to the point of bearing on the girder (See Figure). This distance is measured normal to the abutment. The Girder Bearing Offset must be greater than or equal to the Girder End Distance.
- **Girder End Distance**
  The girder end distance is the distance from the bearing point to the end of the girder (See Figure). The end distance is measured normal to the abutment.
- **Bearing Height**
  The Bearing Height is the height from the top of the abutment to the bottom of the girders.
- **Location of End Diaphragm**
  Describes if the end diaphragm is hanging from the end of the girders or is sitting directly over the point of support

3.1.2.5.1.2 Abutment Connection Boundary Conditions

Abutment Connection boundary conditions may be pinned, roller.

3.1.2.5.2 CONTINUOUS PIER CONNECTION

A Continuous Pier Connection consists of a single line of bearings parallel to its associated pier. The girder is not spliced over the pier. A typical Continuous Pier Connection is shown in Figure 13. This type of connection is typically used when a hinge is present in one of the two spans adjacent to the pier.

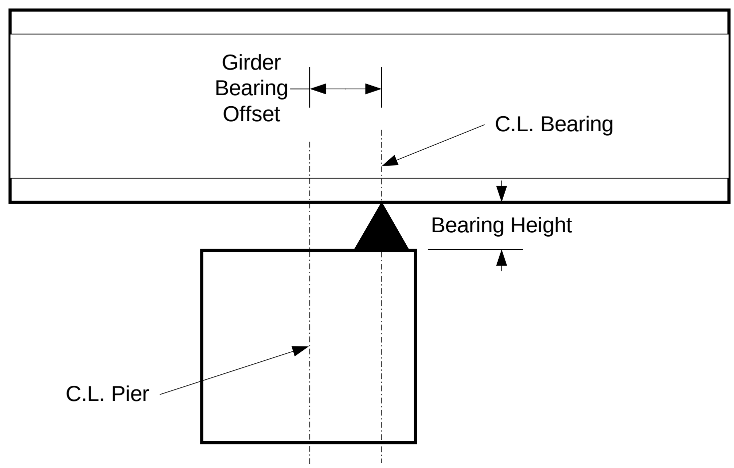

Figure 13 Continuous Pier Connection

3.1.2.5.2.1 Continuous Pier Connection Geometry

The geometry of a Continuous Pier Connection is described by the following:

- **Girder Bearing Offset**
  The bearing offset is the distance from the pier centerline to the point of bearing on the girder (See Figure). This distance is measured normal to the pier and is positive up station.
- **Bearing Height**
  The Bearing Height is the height from the top of the pier cap to the bottom of the girders.

3.1.2.5.2.2 Continuous Pier Connection Boundary Conditions

Continuous Pier Connection boundary conditions may be pinned or roller. Moments are not transferred to the substructure elements for this type of connection (See Integral Connection).

3.1.2.5.3 SIMPLE SUPPORT PIER CONNECTION

A Simple Support Pier Connection consists of two lines of bearings parallel to its associated pier. A typical Simple Support Pier Connection is shown in Figure 14.

It is optional for a Simple Support Pier Connection to be made continuous for any given stage. However, it must then remain continuous for all subsequent stages. This is typically done for multi-stage slab on girder bridges. The continuous connection can be integral with the pier, or have a discontinuity for moment. Refer to the section on Model Generation for details on how this is accounted for in the analysis model.

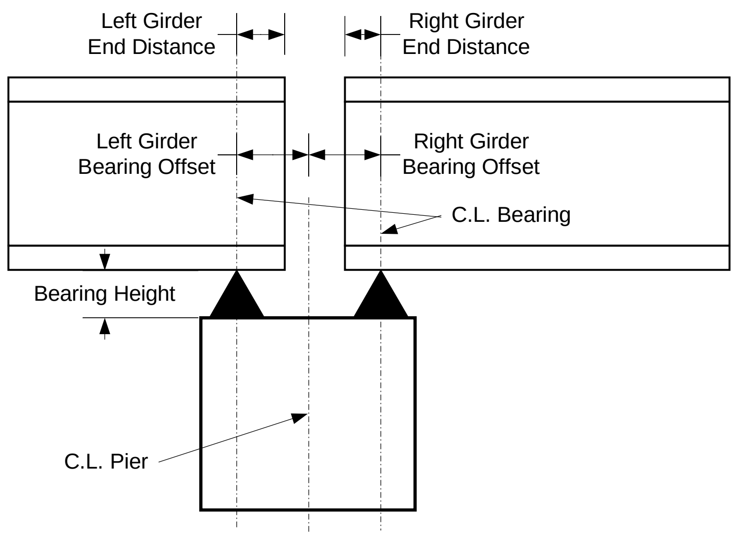

Figure 14 Simple Support Pier Connection

3.1.2.5.3.1 Simple Support Pier Connection Geometry

The geometry of a Simple Support Pier Connection is described by the following:

- **Left/Right Girder Bearing Offset**
  The bearing offset is the distance from the pier centerline to the point of bearing on the girder (See Figure). This distance is measured normal to the pier and is positive going up station. The Girder Bearing Offset must be greater than or equal to the Girder End Distance.
- **Left/Right Girder End Distance**
  The girder end distance is the distance from the bearing point to the end of the girder (See Figure). The end distance is measured normal to the pier.
- **Bearing Height**
  The Bearing Height is the height from the top of the pier cap to the bottom of the girders of the deepest girder.

3.1.2.5.3.2 Simple Support Pier Connection Boundary Conditions

Simple Support Pier Connection boundary conditions are specified for each bearing line individually and may be pinned or roller.

3.1.2.5.4 INTEGRAL PIER CONNECTION

An Integral Pier Connection is a fully moment resisting connection between the substructure elements and the superstructure element. A typical Integral Pier Connection is shown in Figure 5.

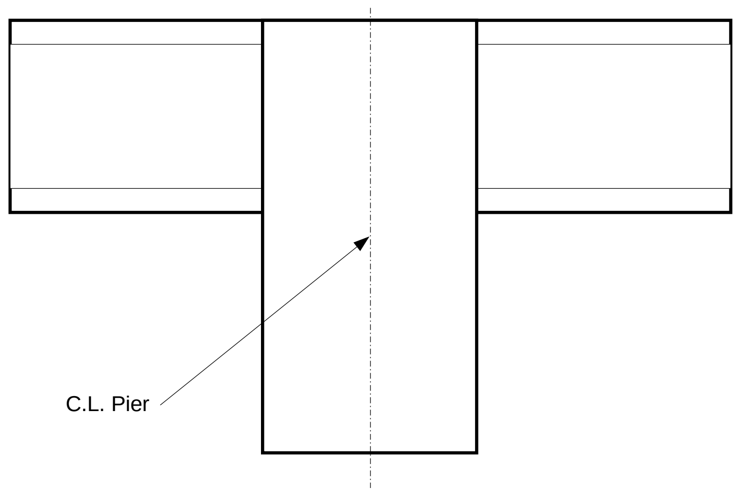

Figure 15 Integral Pier Connection

3.1.2.6 Appurtenances

QConBridge II shall include the following appurtenances in the bridge model. These items are nonstructural and are considered only as dead loads.

3.1.2.6.1 Traffic Barriers

Traffic Barriers are placed on the outside edge of the roadway structure (e.g., slab). The cross section of the traffic barrier is parametric as shown in Figure 16. Traffic Barriers are prismatic along their length and extend for the entire length of the bridge. Traffic Barriers parallel the edge of slab.

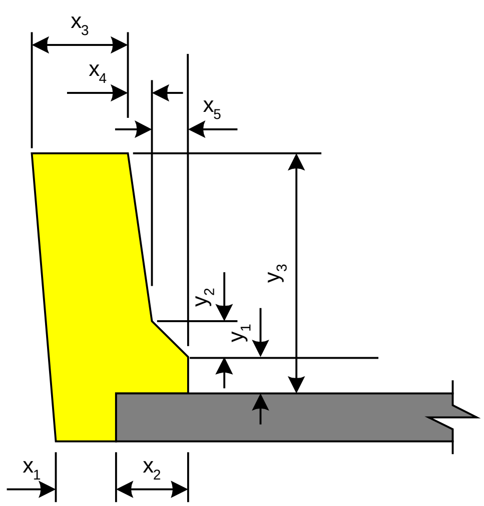

Figure 16 Parametric Traffic Barrier Shape

3.1.2.6.2 SIDEWALKS

Sidewalks are rectangular in shape and butt to the inside of the traffic barrier and extend toward the middle of the bridge. Sidewalks are prismatic along their length and extend for the entire length of the bridge. Left and right sidewalk widths and thickness may be different.

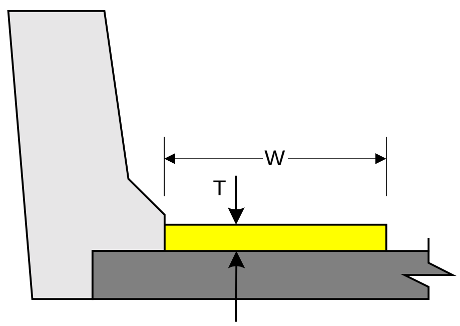

Figure 17 Sidewalk Shape

3.1.2.6.3 MEDIAN BARRIERS

Median barriers lie between traffic barriers and are located by an offset from the centerline of the roadway or crown point. The parametric cross section of the Median Barrier will be as shown in Figure 18. Median Barriers are prismatic along their length and extend the entire length of the bridge. Median Barriers parallel the crown point line.

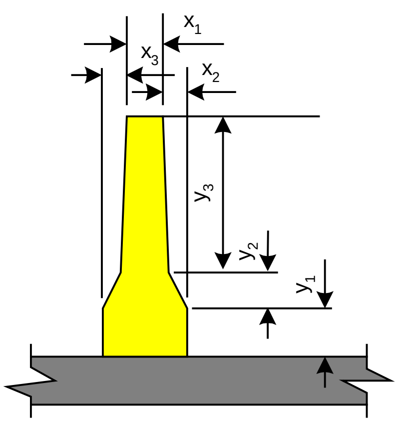

Figure 18 Parametric Median Section Shape

3.1.3 Product Modeling of Slab On Girder Bridges

The bridge types supported for product modeling by this version of QConBridge II can be classified as Slab on Girder Bridges. Slab on Girder Bridges inherit all requirements and must abide to the constraints from the General Bridge defined in the previous Section. In addition, QConBridge II places the following restrictions on slab on girder bridges:

- All girders in a span must be of the same type and made of the same materials.

3.1.3.1 Superstructure Components

QConBridge II shall include the following structural components in the bridge model:

3.1.3.1.1 GIRDERS

Girders are the main structural components responsible for supporting the bridge slab. Girders must lie along girder lines and must abide by the rules specified in Section 3.1.2.2 above.

Girders must be constructed of prismatic segments.

3.1.3.1.1.1 Number of Girders Per Span

Slab on Girder Bridges must have a minimum of two girders in each span (per LRFD 3.4.3.1.1.2).

3.1.3.1.1.2 Girder Camber

The program supports input of a mid-span deflection value for camber for bare beams. This value, after deflection for slab dead loads through stages, is used to calculate haunch dead loads.

3.1.3.1.2 SLAB

The QConBridge II bridge model supports slabs that are prismatic along the roadway alignment.

Slabs must be made from a single concrete material.

The Overhang Width is measured at Bearing Centerlines and can be different for the left and right ends.

The Overhang Depth and Chamfers are equal for the left and right ends.

Figure 19 shows general slab dimensions.

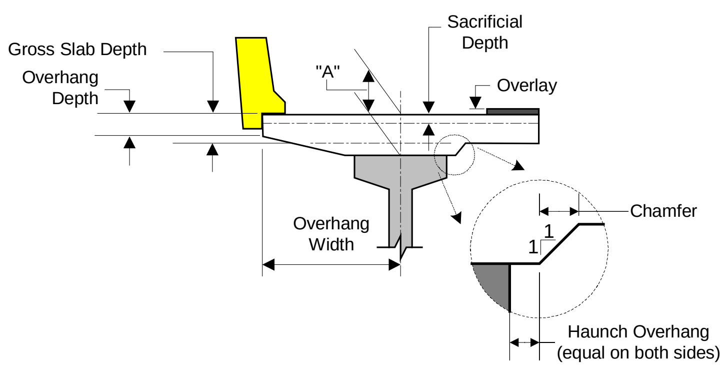

Figure 19 Slab Geometry at Centerline of Bearing

3.1.3.1.2.1 Slab Depth

The Gross Slab Depth will be uniform between exterior girders as shown in Figure 19. The slab depth is measured vertically. If a sacrificial depth is used as a wearing surface, the sacrificial depth is included in the slab gross depth input by the user.

The slab thickness can taper linearly in the overhang region between the outside edge of the slab and the haunch overhang. The overhang depth must be less than or equal to the (gross slab depth – sacrificial depth).

3.1.3.1.2.2 Slab Haunch

The bottom of the slab may be offset from the top of the girder by a haunch depth. A haunch depth (AKA, "A" dimension) is defined at the point where the centerline of the girder and the bearing line intersect in plan view. The haunch depths at either end of a girder must be equal.

The haunch width is assumed to be the same as the width of the top flange or cover plate of the girder plus twice the haunch overhang value.

The haunch depth can vary along the span because of girder camber. QConBridge II shall be able to calculate the haunch depth at any location along the length of the girder. The haunch depth at mid-span is of particular interest. QConBridge II will assume the girder camber is parabolic.

3.1.3.1.2.3 Haunch Fillet

A haunch fillet dimension may be defined as shown in Figure 19.

3.1.3.1.2.4 Slab Material

The slab will be constructed of a single concrete material.

3.1.3.1.3 Wearing Surfaces

A slab may be covered with a wearing surface. The wearing surface will be accounted for in weight calculations, but will not be considered to add strength to the bridge. The wearing surface can be a sacrificial wearing surface and/or an asphalt overlay.

3.1.3.1.3.1 Sacrificial Wearing Surface

A sacrificial wearing surface is a portion of the top of the roadway slab that is expected to be worn down over time. The sacrificial wearing surface is described by its depth. The depth of the sacrificial wearing surface shall not exceed one half of the gross slab depth, or one half of the Overhang Depth in the case of a tapered overhang.

3.1.3.1.3.2 Asphalt Overlay

The slab may be overlaid with asphalt or other surfacing. This surfacing treatment contributes weight, but not strength to the structure. The overlay is described by its depth and unit weight. The overlay will be placed over the entire slab surface between curbs.

3.1.3.1.4 End diaphragms

End diaphragms are unique for individual slab on girder bridge types. See Sections 3.2 and 3.3 below for details.

3.1.3.1.5 Intermediate Diaphragms
Intermediate diaphragms are unique for individual slab on girder bridge types. See Sections 3.2 and 3.3 below for details.

3.1.3.2 Substructure Components
In QConBridge II, product modeling of substructure components is highly simplified. In fact, product modeling of abutments is restricted to the idealized types described in Section 3.1.2.4.1.3 above. For slab on girder bridges, QConBridge II supports modeling of Multicolumn or Hammerhead piers.

3.1.3.3 Construction Staging
QConBridge II will provide general modeling capabilities for typical construction sequences of slab-on-girder bridges.

3.1.3.3.1 Bridge Life Cycle Stages
QConBridge II must model the following stages of a slab on girder bridge's life cycle:

3.1.3.3.1.1 Deck Placement Stage(s)
Girders are in place at the bridge site supported by the abutments and piers. The girders are supporting formwork and the wet slab and diaphragms.

The slab can be poured in one or more sequences.

Each sequential slab pour can be represented as a strip of concrete across the entire width of the final slab geometry. The transverse strip boundaries must be normal to the roadway alignment.

If a strip intersects a diaphragm location, it will add the diaphragm's material.

The material properties of slab segments previous placed are updated at each subsequent slab pour.

3.1.3.3.1.1.1 Purpose
The purpose of this stage is to determine the moments, shears, reactions, deflections, and rotations for this critical stage of the non-composite girder section.

3.1.3.3.1.1.2 Depends On
The first slab pour stage does not depend on any other. Subsequent slab pour stages depend on their direct predecessors.

3.1.3.3.1.1.3 Span Length
Span lengths for this (and all stages) is from abutment bearing locations to pier centerlines.

3.1.3.3.1.1.4 Boundary Conditions
Girders are simply supported. The user must specify boundary conditions for connections over interior piers and abutments for each stage.

Cantilever ends are considered for end diaphragms.

3.1.3.3.1.1.5 Section Properties

Non-composite girder properties are used in this stage for sections supporting the wet slab. For sections supporting partially cured slab, composite section properties based on the appropriate concrete strength will be used.

3.1.3.3.1.1.6 Loads

The model internally calculates the self-weight of the girders, wet slab, and diaphragms.

User defined loads may be applied in these stages.

Formwork loads must be modeled from user-defined loads. To properly model formwork removal, an equal and opposite user-defined load must be applied in a latter stage. The tutorial should illustrate this technique.

3.1.3.3.1.2 Superimposed Dead Load Stage

The bridge deck has been placed and has achieved its 28-day strength. Superimposed dead loads such as traffic barriers, sidewalks, medians and overlays are added to the structure.

3.1.3.3.1.2.1 Purpose

The purpose of this model is to determine the moments, shears, reactions, deflections, and rotations for this stage of the bridge’s life.

3.1.3.3.1.2.2 Depends On

This model depends on the cumulative results of the models from the Deck Placement Stages.

3.1.3.3.1.2.3 Span Length

Span lengths for this (and all stages) is from abutment bearing locations to pier centerlines.

3.1.3.3.1.2.4 Boundary Conditions

Same as the first stage.

3.1.3.3.1.2.5 Section Properties

Composite section properties are used in this model.

3.1.3.3.1.2.6 Loads

The loads introduced in this model are the weight of the traffic barrier, sidewalks, medians, utilities, wearing surface overlays, and any user defined loads applied in this stage.

3.1.3.3.1.3 In Service Stage

The bridge is complete and open to traffic.

3.1.3.3.1.3.1 Purpose

The purpose of this model is to determine the moments, shears, reactions, deflections, and rotations for this stage of the bridge's life.

3.1.3.3.1.3.2 Depends On

This model depends on the results of the Superimposed Deadload Stage.

3.1.3.3.1.3.3 Span Length

The same span lengths as the Superimposed Deadload Stage model are used.

3.1.3.3.1.3.4 Boundary Conditions

Same as the Superimposed Deadload Stage model.

3.1.3.3.1.3.5 Section Properties

The same section properties as the Superimposed Deadload Stage model are used.

3.1.3.3.1.3.6 Loads

The loads introduced in this model are the vehicular live loads, and any user defined loads applied in this stage.

3.2 Product Modeling of Precast Girder Bridges

3.2.1 Precast, Prestressed I Girder Bridges

Precast, Prestressed I Girder Bridges are a type of Slab on Girder bridges, and they inherit all of their specifications except as noted in the following sections.

3.2.1.1 Superstructure Components

3.2.1.1.1 GIRDERS

Precast, Prestressed I Girder Bridges are built from Precast, Prestressed I Girders.

Girders are prismatic along their entire length.

All girders in a span are of the same type.

End blocks are not modeled.

The girders are cambered when delivered to the site.

Girders are made from a single Concrete Material

3.2.1.1.2 CROSS SECTION

The general shape of I girder cross sections is shown in Figure 20.

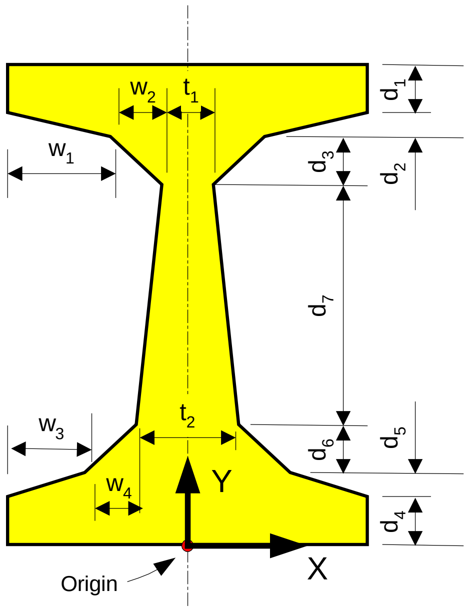

Figure 20
General I-Girder Cross Section

3.2.1.1.2.1 WSDOT Standard Girders

In addition to generic I-shaped girders, QConBridge II will support the following standard WSDOT girder shapes:

- W42G
- W50G
- W58G
- W74G
- WF74G
- W83G
- W95G

3.2.1.1.3 Diaphragms at Abutments

Diaphragms at abutments are rectangular in cross section and are described by their height and width.

3.2.1.1.3.1 Wall Abutments

For wall type abutments, diaphragms will be considered attached to the ends of the girder with the same width as the bridge deck. (See BDM Section 6.2-A. Typically used with girder end type A)

3.2.1.1.3.2 Seat Abutments

For seat type abutments, diaphragms are placed between girders and will be the length of the girder spacing less half the width of the adjacent girders. (See BDM Section 6.2-A. Typically used with girder end type B)

3.2.1.1.3.3 Load Transfer of Diaphragm Weight

The program shall handle two cases:

3.2.1.1.3.4 Diaphragm Sits Directly on Abutment.

In this case, no load is transferred in to the girders.

3.2.1.1.3.5 Diaphragm Hangs on Girder

In this case, the weight of the diaphragm is applied to the girder and must be accounted for.

3.2.1.1.4 DIAPHRAGMS AT INTERIOR PIERS

Diaphragms at interior piers are rectangular in cross section and are described by their height and width.

The length of the diaphragm is dependent on the connection type.

3.2.1.1.4.1 Continuous Girder Connection

For continuous girders at interior piers, the length of the diaphragms will be taken as the distance between the exterior girders, as shown in Figure 21 below. (See BDM Section 6.2-A. Typically used with girder end type C)

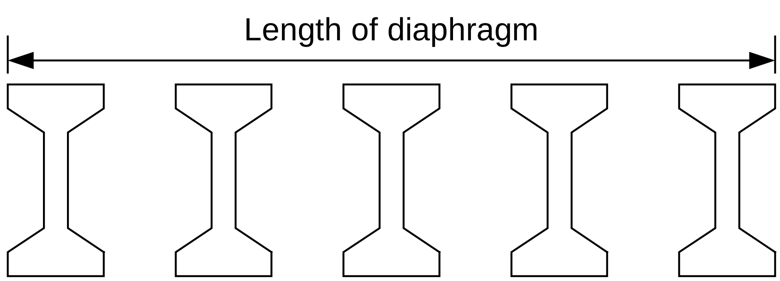

Figure 21 Diaphragm Length for Continuous Girders at Piers

3.2.1.1.4.2 Expansion Joint Connection

For piers where the girders are simply supported and form an expansion joint, the diaphragms will be the same as for seat abutments.

3.2.1.1.5 INTERMEDIATE DIAPHRAGMS

Diaphragms are rectangular in cross section. The height and width of the diaphragm is defined with the girder type and applied to the structure in accordance with the user selected diaphragm layout rules.

Intermediate diaphragms are placed between girders and will be the length of the girder spacing less half the width of the adjacent girders. (See BDM Section 6.2-A for standard details)

3.2.1.2 Substructure Components

The Substructure requirements for Precast-Prestressed I Girder Bridges are identical to those for Slab on girder bridges.

3.2.1.3 Concrete Material

Concrete material product models describe the concrete used for girders. Associated with each girder are its concrete product model and the release strength of the concrete.

3.2.1.4 Staged Modeling

The Staged modeling requirements for this type of bridge are identical to those of Slab on Girder Bridges. Only one slab pour stage is used.

3.3 Product Modeling of Steel Girder Bridges

Steel Girder Bridges will inherit all characteristics of Slab on Girder Bridges except as noted below.

3.3.1 General Considerations

3.3.1.1 Superstructure Components

3.3.1.1.1 Exterior Diaphragms

Exterior diaphragms for steel girder bridges are typically made up of K or X-frame bracing. These types of diaphragms and their connections are complicated to describe in detail, and a high level of detail is not required for QConBridge II.

Exterior diaphragms at both ends of a girder shall be specified by a user-input total diaphragm weight and the location of the C.G. relative to the bearing.

3.3.1.1.2 Intermediate Diaphragms

Intermediate diaphragms for steel girder bridges are similar to exterior diaphragms.

Intermediate diaphragms shall be specified by a user-input weight per length transverse to the girder. The length of the diaphragm is equal to the girder spacing. Diaphragms will be spaced in accordance with the user selected diaphragm layout rules.

3.3.2 Product Modeling of Rolled Steel I Girder Bridges

QConBridge II will support all standard W and S shapes as described in the AISC Steel Design Manual.

3.3.2.1 Superstructure Components

3.3.2.1.1 Girders

The following assumptions are made about Rolled Steel I Girder bridges:

- All girders in a span are of identical configuration and material
- Girders are prismatic along their entire length

3.3.2.1.1.1 Cover Plates

The program will support the addition of one or more steel cover plates attached to the top and/or bottom flange of the rolled shape. These built-up shapes will be analyzed as fully-developed composite sections.

3.3.2.2 Substructure Components

The Substructure requirements for rolled Steel I Girder Bridges are identical to those for Slab On Girder Bridges.

3.3.2.3 Staged Modeling

The Staged modeling requirements for this type of bridge are identical to those of Slab on Girder Bridges.

3.3.3 Product Modeling of Built-Up Steel Plate Girder Bridges

QConBridge II must support built-up steel plate girders. Plate girders are subject to the following constraints:

3.3.3.1 Superstructure Components

3.3.3.1.1 GIRDERS

- Girders are constant depth along the entire bridge.
- A uniform web thickness is used along the entire bridge.
- Top and bottom flanges are built up from prismatic plates segments that can vary in width and thickness along the length of the girder.

3.3.3.1.2 CROSS FRAMES

Cross-frames are described by dead load/length only.

3.3.3.2 Substructure Components

The Substructure requirements for Built-up Plate I Girder Bridges are identical to those for Slab On Girder Bridges.

3.3.3.3 Staged Modeling

The Staged modeling requirements for this type of bridge are identical to those of Slab on Girder Bridges.

3.4 Modeling of Materials

3.4.1 Use of Materials

Materials will be used as specified below:

- All concrete girders are constructed from the same concrete material.
- Steel girders can be built up from plates and rolled sections made of different structural steel materials.

- The slab is constructed of one concrete material.

3.4.2 Concrete[3]

QConBridge II must support any concrete allowed by the governing specifications. This is typically a concrete strength ranging between 4 and 10 ksi.

The following parameters define concrete material properties.

- f'c - crushing stress
- Density used for weight calculations
- Density used for strength calculations
- Coefficient of thermal expansion

3.4.3 Structural Steel

QConBridge II must support any structural steel allowed by the governing specifications.

The following parameters define steel material properties.

- E – Modulus of Elasticity
- Fy – Yield strength
- Fu – Ultimate strength
- Density used for weight calculations
- Coefficient of thermal expansion

[3] It is extremely desirable to share a library of materials with PGSuper and other WSDOT software.

4. ANALYSIS MODELING

The Bridge Analysis Model is the workhorse for QConBridge II. It provides all general structural analysis capabilities for all model types in QConBridge II.

When QConBridge II is in Product Model mode, the program automatically generates a BAM composed of LBAM's for each girder line in the bridge, and TBAM's for each pier. In Product Model mode, you are given very limited BAM editing capabilities. A discussion of product models and the assumptions used for model generation are given in Section 3 and in the Theoretical Manual.

When QConBridge II is in BAM mode, there is no associated Product Model for the BAM to be linked to as discussed in Section 3.4 above, and you can edit all aspects of the BAM. This gives you full access to all of the modeling capabilities mentioned in this section. However, creating a new project in BAM mode is an arduous task because you have to enter all geometric properties, section properties, stages, loads, and boundary conditions manually.

4.1 Bridge Analysis Model (BAM)

The BAM represents an analysis model of the entire bridge superstructure and substructure. The bam defines the general layout of the bridge and how it relates to an alignment. Limited information is retained about deck and sidewalk width in order to perform live load analyses. A BAM is composed of LBAM's to model each girderline and TBAM's to model each pier. It is the job of the BAM to manage geometric relationships and transfer of loads between these models. The geometric limitations on a BAM are similar to those on product models, but are more generous in some cases.

4.1.1 General Requirements

- When horizontal curves are present, the BAM must be entirely contained within a horizontal curve
- When vertical curves are present, the BAM must be entirely contained within a vertical curve

Bridges can have single or multiple spans.

4.1.2 Roadway Geometry

QConBridge II shall account for the effects of roadway geometry on the structure. Geometrical considerations shall include horizontal curves and crown slopes.

4.1.2.1 Roadway Alignment

BAM's only consider effects of the horizontal alignment. The vertical alignment and roadway crown are not considered.

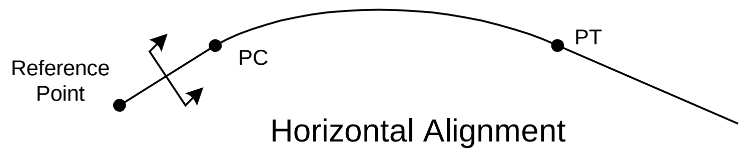

Figure 22 Schematic of Roadway Alignment

4.1.2.1.1 Horizontal Alignment

The horizontal alignment describes the curvilinear path that the roadway follows. The path shall consist of a straight alignment at an arbitrary bearing or a single arbitrarily oriented circular curve. The reference point for the alignment shall be a known station on a straight alignment or the point of curvature (PC) of a horizontal curve. The horizontal alignment need not represent the centerline of the roadway or bridge. Spiral curve segments are not supported in this version of QConBridge II.

4.1.2.1.2 Roadway Section

The roadway section is not described in the BAM. Girderline end elevations are defined using column top elevations.

4.1.3 Superstructure Components

4.1.3.1 Girderline Geometry

Girders in BAM's must be straight. Adjacent girder lines need not be parallel. Girder spacings are measured normal to pier centerlines at each pier. Girders must be aligned in each span such that each girder line is continuous over the entire length of the bridge as shown in Figure 4.

4.1.3.1.1 Number of Girders Per Span

The bridge configuration will be limited to bridges with the same number of girders in every span.

4.1.3.1.1.1 Maximum

It is WSDOT practice to label girders A-Z. For this reason, the maximum number of girder lines for all bridge types is 26.

4.1.3.1.1.2 Minimum

A bridge must have at least one girder line.

4.1.3.1.2 Girder Spacing

This Section is only applicable for multi-girder bridges.

4.1.3.1.2.1 Minimum Girder Spacing

No restrictions

4.1.3.1.2.2 Maximum Girder Spacing

There is no upper limit on girder spacing.

4.1.3.1.2.3 Girder Spacing

Girder spacing need not be uniform, but must be greater than zero. Girderlines cannot cross.

4.1.3.1.2.4 Measurement of Girder Spacing

Girder spacing is measured at the location and orientation described in this section.

4.1.3.1.2.4.1 Location of Measurement

Girder spacing will be measured at abutments and intermediate piers. At abutments, girder spacing will be measured at the centerline of bearing line. At intermediate piers, girder spacing will be measured at the centerline of the pier.

4.1.3.1.2.4.2 Direction of Measurement

Girder spacing can be measured normal to the roadway alignment at the location of measurement or along the centerline of bearing or pier at abutments and piers, respectively.

4.1.3.2 Span Hinges

An In-Span Hinge consists of a single line of hinges offset from, and oriented parallel to, an associated pier. A typical In-Span Hinge is shown in Figure 5. Hinges cross all girderlines.

4.1.3.2.1 SPAN HINGE GEOMETRY

The geometry of an In-Span Hinge is described by the following:

- **Hinge Offset**
  The hinge offset is the distance from the pier centerline to the location of the hinge (See Figure). This distance is measured along the alignment and is positive going up station.

4.1.3.2.2 HINGE BOUNDARY CONDITIONS

In-span hinges provide a point of moment discontinuity within a span.

4.1.4 Substructure Models

Models for the substructure in the BAM are represented separately for the longitudinal and transverse directions. In the longitudinal direction, piers and abutments are represented directly in the LBAM. In the transverse direction, piers and abutments are either represented as TBAM's, or are not represented at all. A pier's height in the longitudinal direction (LBAM) is not tied to the height of the TBAM.

In QConBridge II, a general idealization of a substructure element can be made: At the very least, a pier consists of a line of support crossing the superstructure.

4.1.4.1 Longitudinal Location

The station of the line of supports defines the pier locations.

4.1.4.2 Orientation

The orientation of the line of supports can be described using three methods: normal to the roadway alignment, or using an absolute bearing value which describes the abutment's direction, or by a Right or Left skew angle measured relative to the normal to the roadway alignment at the back of pavement seat. The absolute value of the skew angle must be less than 90 degrees.

4.1.4.3 Transverse Locations

Piers are located transversely on BAM's by the distance from the middle of the cap beam to the alignment, measured normal to the alignment. If no cap beam is present, the length of the cap beam is assumed to be the total breadth of the girderlines.

4.1.4.4 Bearing Locations

Bearing locations in TBAM's are defined by where the girderlines cross the substructure locations. Bearing locations cannot be edited in TBAM's that are attached to BAM's.

4.2 Longitudinal Bridge Analysis Model (LBAM)

The Longitudinal Bridge Analysis Model is an idealization of a bridge superstructure for structural analysis purposes. The model is designed for use with the modeling approach described in LRFD 4.6.2, and shall work with all bridge types described in that section. This model is identical to the model used in QConBridge I. The following idealizations are made:

- Each girder line on the superstructure is analyzed independently.
- Each girder line is modeled in two dimensions, with three degrees of freedom. (2 translations, 1 rotation).
- Horizontal curve, vertical curve, and skew effects are ignored, except where accounted for in live load distribution factors.
- All superstructure and substructure members are straight.
- Shear effects are negligible, so pure 2D bending elements are used to idealize superstructure and substructure members.
- Live loads are apportioned to each girder line using distribution factors.
- Connections and boundary conditions can be modeled as either pinned or fixed.
- Non-prismatic members are modeled using a series of prismatic segments.
- The basic geometry (member layouts / stick geometry) and POI's are defined once and must stay constant for all stages of the analysis.

4.2.1 LBAM Geometry and Boundary Condition Requirements

Longitudinal Bridge Analysis Models are composed of two different types of members: Span Members and Substructure Members. See Figure 23 LBAM Geometry.

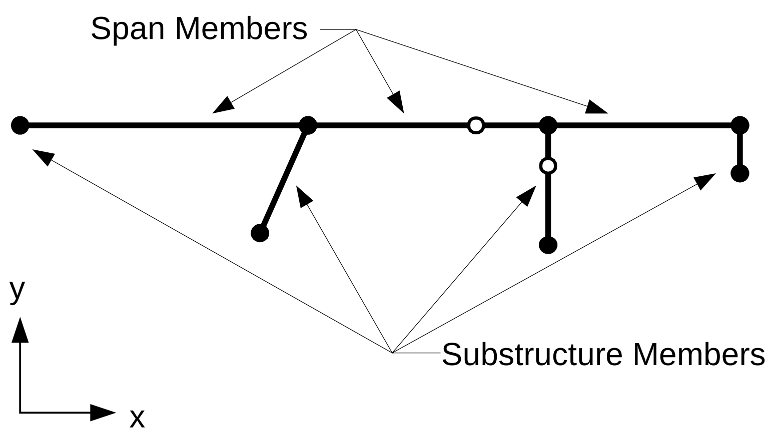

Figure 23 LBAM Geometry

A LBAM must contain at least one Span Member.

One Substructure member must exist at each end of the bridge (abutments), and at all intermediate span connections (piers).

LBAM members have no hinges by default.

4.2.1.1 Span Members

Span Members are straight, horizontal, beams supported by Substructure Members. Span Members are located by their length and adjacency to other span members.

Span members are oriented from left to right (up station).

Span Members are numbered (1 based) from left to right along the bridge.

The Left end of Span Member number 1 is located at x=0.0.

Span Members must have a length greater than 0 feet (Program must display a warning if span length is less than 2 feet).

Span Members may contain one or two Hinges at any location along their length.

Span Hinges may not be coincident.

4.2.1.2 Substructure Members

Substructure members come in two flavors: Idealized, and Fixed-Length.

Substructure Members are located at the ends of Span Members.

4.2.1.2.1 Zero-Length Substructure Members

A Zero Length Substructure Member simply defines the boundary conditions at span ends.

A Zero Length Substructure Member has zero size and is coincident with its span ends.

The y Translational degree of freedom must be fixed.

Both the x translation and z rotational degrees of freedom can be fixed or free independently.

4.2.1.2.2 FIXED-LENGTH SUBSTRUCTURE MEMBERS

Fixed-Length Substructure Members are straight, vertically-oriented beams that provide support for Span Members.

Fixed-Length Substructure Members have two ends, a Bearing End, and a Footing End. The Bearing End connects to the Span Members' ends and is always located above the Footing End.

All degrees of freedom at the Footing End must be fixed.

The geometry of a Fixed-Length Substructure Members is defined by its length, and horizontal inclination.

Fixed-Length Substructure Members must have a length greater than zero.

Fixed-Length Substructure Members may be inclined by up to 60 degrees from vertical either upstation or downstation. Inclination may be specified by angle or vertical offset.

4.2.1.2.3 CANTILEVERED SPANS

Specifying an offset for the support element the first and last span may cantilevered. The offset is a positive value and causes the support element to move towards the center of the bridge model. Offsets can only be specified for the first and last support element.

4.2.2 LBAM Section Properties

The section properties of a Span Member and Fixed-Length Substructure Member are defined by one or more prismatic segments along its length.

Section Properties are defined by:

- Structural area
- Ixx
- Elastic modulus
- Coefficient of thermal expansion
- Unit weight
- Self-weight area
- Distribution Factor (span member only)

Valid section properties (must have non-zero stiffness) must be input along entire members for all analysis stages.

4.2.3 LBAM Loading Requirements

4.2.3.1 Dead Loads

4.2.3.1.1 SELF WEIGHT

Self weight loading can be calculated by the program if desired.

Self weight loads are calculated using the Self-weight area, Unit weight, and length of prismatic segments.

Self weight loads are additive through stages and can be turned on or off for any stage.

4.2.3.1.2 USER-DEFINED

All loads are user defined except for dead load of cross sections

4.2.3.2 Live loads

A BAM can be analyzed for live load effects for the last defined stage of the analysis only. One or more Live Load Analysis Models may be applied to the structure.

4.2.4 LBAM Staging Requirements

One or more arbitrary Stages can be defined for a BAM.

Each Stage has a unique name.

4.2.4.1 Stage Invariant Properties

The following properties of the BAM cannot be varied among stages:

- Stick model geometry
- Boundary Conditions
- Locations of Points of Interest
- Presence and location of in-span hinges.

4.2.4.2 Stage Variant Properties

The following properties of the BAM can be varied among stages:

- Section Properties
- Loads

4.2.5 LBAM Response Calculation Requirements

The LBAM is used to perform a force analysis on a bridge structure. This section defines the responses that must be calculated by the program.

Analysis results are additive over all the stages.

Adequate details of calculation results shall be provided so that users can perform a hand check without consulting their specifications.

Load combinations for removable dead load components must be considered. For example, load combinations must be considered for a structure with and without sidewalks (when sidewalks are defined) and account for additional design lanes if applicable.

4.2.5.1 Result Types

QConBridge II shall provide the capabilities to calculate and report the following types of response calculation results:

4.2.5.1.1 MEMBER FORCES
Member forces are reported in member coordinates.

Shear

Moment

4.2.5.1.2 MEMBER DEFLECTIONS
Deflections are reported in global coordinates

Vertical

4.2.5.1.3 SUPPORT REACTIONS
Reactions are reported in global coordinates

Horizontal

Vertical

Moment

4.2.5.1.4 SUPPORT DEFLECTIONS
Deflections are reported in global coordinates

Horizontal

Vertical

Rotation

4.2.5.1.5 INFLUENCE LINES
The program shall be able to report influence lines for Forces, Deflections, and Reactions for all POI's in the structure. The influence lines will be derived for a user-defined, evenly spaced increment across the superstructure.

4.2.5.2 Loads and Load Categories
The program shall report responses for all Load Groups, Load Cases, and Load Combinations that are defined for the analysis.

These responses will be reported for all defined stages, both incrementally and cumulatively.

4.2.5.3 Locations of Response Calculations
Points of Interest (POI's) define locations on a structure where response quantities are calculated. POI locations are invariant among stages.

There are two basic types of POI's: Support Poi's, and Member POI's.

4.2.5.3.1 SUPPORT POI'S
Points of Interest are placed at all support locations by default and may not be removed.

4.2.5.3.2 MEMBER POI'S
Member POI's are user defined.

Member POI's can be laid out fractionally, by distance, or by evenly-spaced group anywhere along members.

4.2.6 LBAM Stage Management

The user shall be allowed to manage basic stage information In the BAM. The following operations will be supported:

- Add Stage
- Copy/Paste Stage
- Delete Stage
- Re-order (Move) Stage
- Rename Stage

4.3 Transverse Structural Analysis Model (TBAM)

The Transverse Bridge Analysis Model is an idealization of a bridge pier for structural analysis purposes. The TBAM is a 2D representation of a pier structure. The following assumptions are made:

- The pier is modeled in two dimensions, with three degrees of freedom. (2 translations, 1 rotation).
- Vertical curve and skew effects are ignored.
- Effects of longitudinally sloped piers are ignored
- All members are straight.
- Column members are oriented vertically.
- Cap members are oriented horizontally but can be sloped. Members are straight between columns and overhangs.
- Shear effects are negligible, so pure 2D bending elements are used.
- Non-prismatic members are modeled using a series of prismatic segments.
- All loads and structure definitions are defined in a single analysis stage
- Live loads are applied directly to the cap beam ignoring bearing locations.

4.3.1 TBAM Geometry and Boundary Condition Requirements

Transverse Bridge Analysis Models are composed of two different types of members: Cap Members and vertical Column Members. See Figure 24.

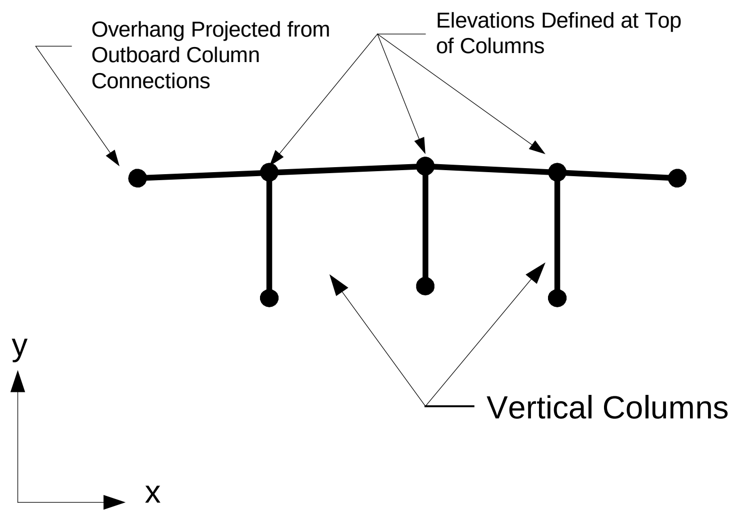

Figure 24 TBAM Geometry

A TBAM must contain at least one Cap Member and one Column Member.

Member hinges are not supported

4.3.1.1 Cap Members

Cap Members are straight beams between tops of Column Members.

Cap overhang beam is oriented by projection from tops of two outboard columns. If only one column, cap beam is horizontal.

Cap members are oriented from left to right (looking up station).

Cap members are represented by a series of prismatic beam segments

4.3.1.2 Column Members

Column members come in two flavors: Zero-Length, and Fixed-Length.

4.3.1.2.1 Zero-Length Column Members

A Zero Length Column Member defines the boundary conditions and location of cap member ends.

The geometry of a Zero-Length Column Member is defined by its X location and elevation.

A Zero Length Column Member has zero size and is coincident with cap beam.

The x and y Translational degree of freedoms must be fixed.

The z rotational degree of freedom must be free.

4.3.1.2.2 Fixed-Length Column Members

Fixed-Length Column Members are straight, vertical beams that provide support for Cap Members.

The Cap/Column connection is continuous.

The x and y Translational DOF’s and z rotational DOF at the Footing End must be fixed.

The geometry of a Fixed-Length Column Member is defined by its X location, and either its top and bottom elevation or top elevation and length.

Fixed-Length Column Members cannot contain hinges.

4.3.2 TBAM Section Properties

The section properties of Cap Members and Fixed-Length Column Members are defined by one or more prismatic segments along their length.

Section Properties are defined by:

- Structural area
- Ixx
- Elastic modulus
- Coefficient of thermal expansion
- Unit weight
- Self-weight area

Valid section properties (must have non-zero stiffness) must be input along entire members for all analysis stages.

4.3.3 TBAM Loading Requirements

4.3.3.1 Dead Loads

4.3.3.1.1 SELF WEIGHT

Self weight loading can be calculated by the program if desired.

Self weight loads are calculated using the Self-weight area, Unit weight, and length of prismatic segments.

4.3.3.1.2 USER-DEFINED

All loads are user defined except for dead load of cross sections.

User-defined loads may be applied in the form of vertical loads and moments at any location along the cap member. Transverse concentrated and linear loads may be applied to columns.

4.3.3.2 Live loads

A TBAM can be analyzed for live load effects. Transverse live loads are defined by:

- The per lane reaction divided into either two concentrated loads or distributed into a uniform load covering all but the outer 2' (600 mm) of a design lane.
- The spacing of the concentrated load or the length of the uniform load shall be skew adjusted.

The transverse live load is applied to the cap beam in accordance with BDM 9.1.1.1C.

The Dynamic Load Allowance factor shall be adjusted for substructure elements below the ground line (i.e. no impact for footing reactions).

4.3.4 TBAM Response Calculation Requirements

The Transverse Bridge Analysis Model is used to perform a force analysis on a pier structure. This section defines the responses that must be calculated by the program.

Adequate details of calculation results shall be provided so that users can perform a hand check without consulting their specifications.

4.3.4.1 Result Types

QConBridge II shall provide the capabilities to calculate and report the following types of response calculation results:

4.3.4.1.1 MEMBER FORCES

Member forces are reported in member coordinates.

Axial (columns only)

Shear

Moment

4.3.4.1.2 MEMBER DEFLECTIONS

Deflections are reported in global coordinates

Horizontal

Vertical

Rotational

4.3.4.1.3 SUPPORT REACTIONS

Reactions are reported in global coordinates. Support reactions must be computed for base of column and for buried support elements (footing). These need to be computed separately as the dynamic load allowance differs for each of these cases.

Horizontal

Vertical

Moment

4.3.4.1.4 INFLUENCE LINES

The program shall be able to report influence lines for Forces, Deflections, and Reactions for all POI's in the structure.

4.3.4.2 Loads and Load Categories

The program shall report responses for all Load Groups, Load Cases, and Load Combinations that are defined for the analysis.

4.3.4.3 Locations of Response Calculations

Points of Interest (POI's) define locations on a structure where response quantities are calculated. POI locations are invariant among stages.

There are two basic types of POI's: Support Poi's, and Member POI's.

4.3.4.3.1 SUPPORT POI'S

Points of Interest are placed at all support locations by default and may not be removed.

4.3.4.3.2 MEMBER POI'S

Member POI's are user defined.

Member POI's can be laid out fractionally, by distance, or by an evenly spaced group anywhere along cap and column members.

5. GENERAL STRUCTURAL ANALYSIS

QConBridge II obtains its analytical results, such as shears, moments, and reactions using analytical models. These models provide a mathematical representation of the structure and are used to capture its response and behavior.

When QConBridge II is in Product Model mode, BAM's are linked directly to the Product Model. For example, when you change the span length of a Product Model, the associated span length in the BAM is automatically updated to reflect the change. This link is unidirectional: you cannot make changes to the BAM that affect the Product Model. You can however, edit some properties of the BAM that do not affect the product model. The BAM Properties that can be edited are non-generated loads and POI's.

If the modeling techniques used by QConBridge II do not suit your needs, you have the option to save any BAM in a Product Model project to a separate BAM project file and then edit it using the program in BAM mode. You can also save BAM's for individual girderlines in the product model, and stand-alone TBAM's for any pier in the product model. This flexibility, however, comes with a cost: it severs all links back to the original Product Model.

5.1 Sign conventions

This section describes the sign conventions used in reporting analysis results.

5.1.1 Beam Forces

QConBridge II uses beam sign conventions for beam shear and moments. Axial tension in the beam is positive. Positive shear, moment, and axial force are as shown in Figure 25.

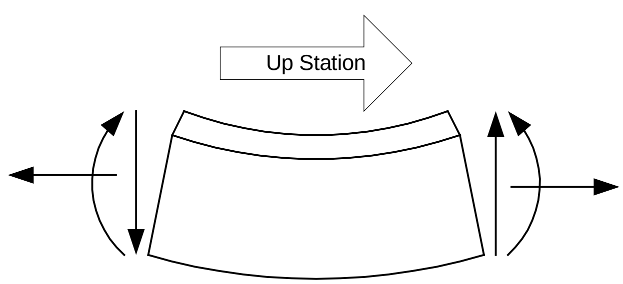

Figure 25 Sign Convention for Beam Forces

5.1.2 Reactions

Upward reaction forces are positive.

5.1.3 Loads

Externally applied loads are positive if they have a downward sense.

5.1.4 Deflections

Downward deflections are positive. Counterclockwise rotations (right-hand rule) are positive.

5.1.5 Section Properties

5.1.5.1 Section Coordinates

The X axis will be the horizontal axis and increase from left to right when looking up-station. The Y axis is the vertical axis and will increase upward. The origin of the section coordinate system is at the bottom of the cross section.

5.1.5.2 Area and Moment of Inertia

Area and moment of inertia are positive values.

5.2 Modeling

5.2.1.1 Beam Element Types

5.3 Points of Interest

It is the nature of digital computer calculations that we can only analyze a structure at discrete locations. The placement of these analysis points, or Points of Interest (POI's), is critical to the accuracy and ultimate success of the analysis. The AASHTO LRFD manual recommends analyzing girders at $1/10^{th}$ points, and specifies other critical analysis locations for given analysis quantities.

QConBridge II shall allow placement of points of interest anywhere along span and substructure elements.

5.3.1 Dual Nature of POI's

Analysis quantities such as shear response can exhibit discontinuous jumps at any location. Hence, POI results must be able to support dual results at locations where this type of behavior might occur.

5.3.2 Tolerancing Between POI's

The program uses a tolerance of 5mm between POI's. In other words, if two POI's are closer than 5mm, they are merged together into a single POI.

5.3.2.1 Default Locations of Points of Interest

5.3.2.1.1 Longitudinal Models

Points of Interest are locations where analysis results data is to be calculated and reported. Although users may define points of interest at any location on the structure, QConBridge II automatically generates POI's at the following locations by default:

1. $1/10^{th}$ points along the flexible length of all girders.

2. On both sides of span hinges
3. Top and bottoms of columns
4. At all support locations

5.3.2.1.2 Transvers Models

Points of Interest are locations where analysis results data is to be calculated and reported. Although users may define points of interest at any location on the structure, QConBridge II automatically generates POI's at the following locations by default:

1. 1/2 points along the flexible length of cap beam and at all column centerlines and column faces.
2. Top and bottoms of columns
3. At all support locations

5.4 Modeling of Materials

5.4.1 Use of Materials

Materials will be used as specified below:

- All concrete girders are constructed from the same concrete material.
- Steel girders can be built up from plates and rolled sections made of different structural steel materials.
- The slab is constructed of one concrete material.

5.4.2 Concrete

QConBridge II must support any concrete allowed by the governing specifications. This is typically a concrete strength ranging between 4 and 10 ksi.

The following parameters define concrete material properties.

- f'c - crushing stress
- Density used for weight calculations
- Density used for strength calculations
- Coefficient of thermal expansion

5.4.3 Structural Steel

QConBridge II must support any structural steel allowed by the governing specifications.

The following parameters define steel material properties.

- E – Modulus of Elasticity
- Fy – Yield strength

- Fu – Ultimate strength
- Density used for weight calculations
- Coefficient of thermal expansion

5.5 Unstable Structures

The program shall be able to deal with unstable structures gracefully. Users must be informed that the structure is unstable and be allowed to make edits so that it can be correctly analyzed.

5.6 Loading

QConBridge II will have comprehensive loading and load management functionality.

5.6.1 Load Hierarchy

In order to manage loads, the program uses a load hierarchy as shown in Figure 26. The hierarchy is broken into the following classifications from low-level to high-level: Loads, Load Groups, Load Cases, and Load Combinations. The following Sections discuss each load classification in detail.

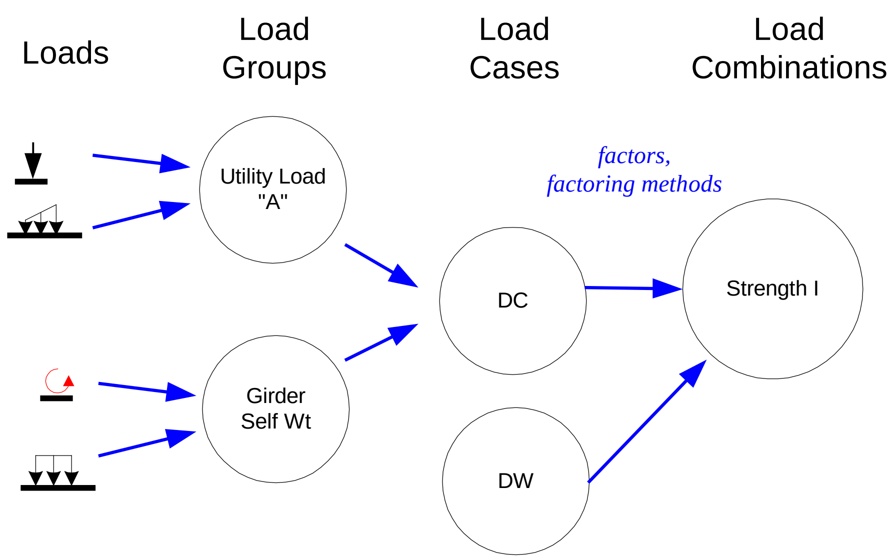

Figure 26 Load Hierarchy

5.6.1.1 Loads

Loads are the lowest-level load classification. They define the individual point loads, uniform loads, etc, that are used to apply forces to the structure. The following types of loads are supported:

- Concentrated vertical shear

- Concentrated moment
- Linearly distributed vertical load
- Enforced Displacement
- Uniform Thermal load.

All of these loads, except for Enforced Displacements and Uniform Thermal loads can be applied anywhere along a bridge element using exact or fractional measurements.

Enforced Displacements can only be placed at supports.

Uniform Thermal loads must be applied to an entire bridge element.

All Loads must be assigned to a Load Group.

All Loads must be assigned to a Stage.

All types of Loads may be defined by the user.

5.6.1.2 Load Groups

The basic idea of a Load Group is to collect one or more Loads in order to calculate a cumulative response. Load Groups serve as containers for Loads. The response for a Load Group is the sum of the responses for all of its Loads.

Each Load Group must be given a unique name.

Each Load Group must be assigned to a Load Case.

QConBridge II shall be able to report responses for all Load Groups for all Stages, both incrementally and cumulatively.

QConBridge II has two different types of Load Groups: Built-in Load Groups, and User-Defined Load Groups.

5.6.1.2.1 User-Defined Load Groups

User-Defined Load Groups serve as containers for User-Defined Loads.

User-Defined Load Groups must have a unique name.

5.6.1.2.2 Built-in Load Groups

Built-in Load groups are created by the QConBridge II application. The user may not modify them.

5.6.1.3 Load Cases

Load Cases may seem redundant, but they serve a purpose; they are used to categorize groups of loads in the same manner as the LRFD Specifications. Load Cases are used in the definition of Load Combinations. An example of a Load Case is the DW load case defined in LRFD.

Another purpose for Load Cases is to allow enveloping of optional Load Groups. Responses from an optional Load Group are only added to Load Case results if they contribute the action in question. An example of this is a sidewalk load group; it may be desirable to only add sidewalk effects if they increase the action in question.

Load Cases shall support the addition of optional load groups.

Load Cases must have a unique name.

Custom Load Cases may be defined by the user.

There are two different types of Load Cases: Load cases that are composed of Load Groups; and Load Cases that serve as references to Live Load Models.

It is expected that more types of Load Cases will be defined for the QConBridge II program as it matures. An example would be envelope-type cases that determine responses for wind loadings.

5.6.1.3.1 LOAD CASES COMPOSED OF LOAD GROUPS

This type of Load Case serves as a container for one or more Load Groups. The response for a Load Case is the sum of the responses of its Load Groups.

5.6.1.3.2 LOAD CASES FOR LIVE LOADS

This type of Load Case references a Live Load Model Library Entry to perform a live load analysis of the model. The response for this type of Load Case is the response of its Live Load Model. For any given project, QconBridge II will support three different live load models: HL93, Permit, and Special. The HL93 load is a built-in live load which satisfies the requirements of the LRFD HL93 Design Vehicle. “Permit” and “Special” are user-defined truck/lane loads that can be used in Load Combinations.

5.6.1.4 Load Combinations

Load Combinations are used to factor together responses from a collection of Load Cases. An example of a Load Combination is the Strength I case in LRFD.

Load Combinations must have a unique name.

The user may define custom Load Combinations.

QConBridge II shall support the application of load combinations as described in the AASHTO LRFD and LRFD specifications. A detailed discussion of the algorithms and data used in Load Combinations is contained Section 3 of the LRFD Specifications.

5.6.1.4.1 ETA LOAD MODIFICATION FACTORS

The program shall allow for input of LRFD load modification factors (eta factors) for :redundancy, importance, and ductility. Factors can be input for the entire superstructure and each intermediate pier.

5.6.1.4.1.1 Redundancy

Default, min, max

5.6.1.4.1.2 Importance

Default, min, max

5.6.1.4.1.3 Ductility

Default, min, max

5.6.2 Longitudinal Live Load Analysis Model

In QConBridge II, a Longitudinal Live Load Analysis Model defines a recipe for applying and enveloping vehicle and lane loads to the structure. At a minimum, QConBridge II must be able to define the HL93 and other live loads outlined in LRFD.

Model shows a UML-based diagram of the Longitudinal Live Load Model for QConBridge II.

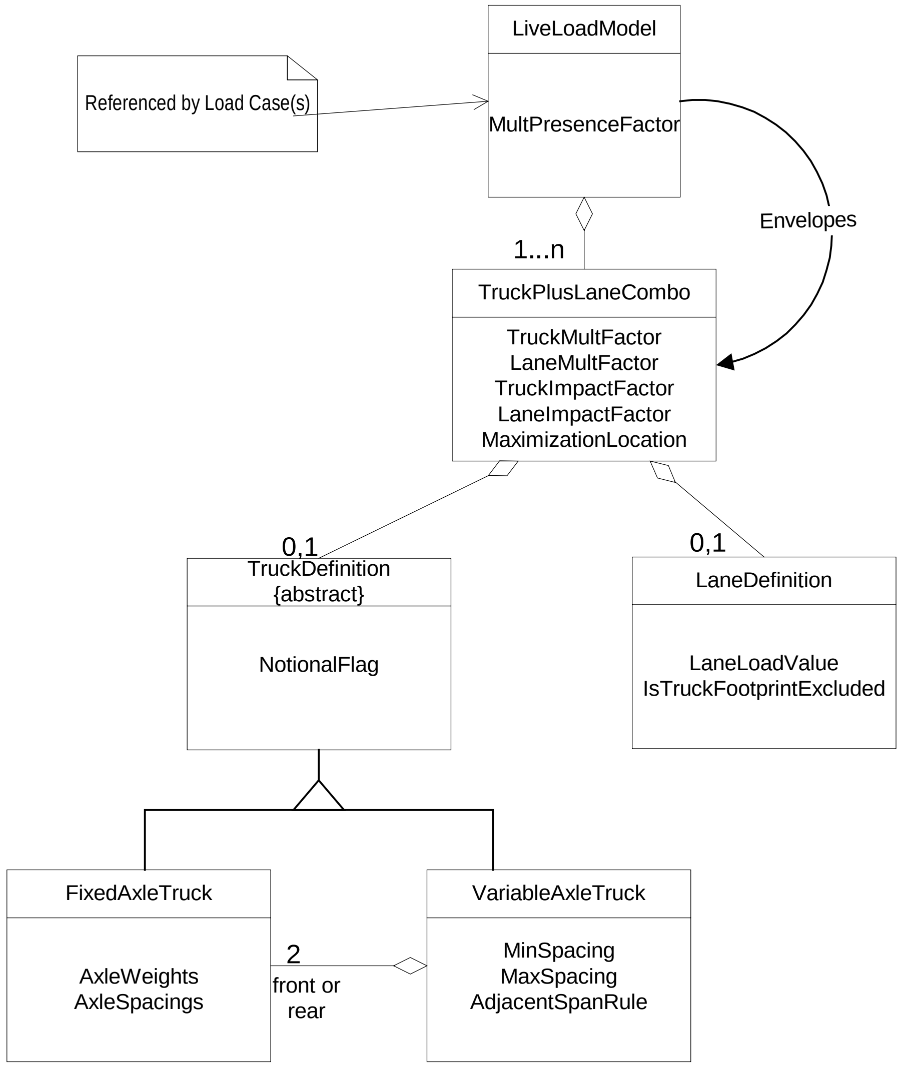

Figure 27 Live Load Analysis Model

6. REPORT DATA

This Section describes the information that is to be reported by the QConBridge II program. Report information is categorized into separate chapters for convenience. Chapters are the lowest-level report entities that are configurable by the user. Users can build Report Configurations, which contain a list of the selected chapters desired for the report.

The following Report Chapters shall be provided

6.1 Project Properties

- Bridge ID
- Bridge Name
- Job Number
- Engineer
- Company
- Comments

6.2 Roadway Geometry

This chapter shall echo all input data related to the roadway and alignment geometry. This shall include:

- Alignment
- Profile
- Crown Slopes

6.3 Bridge Geometry

This chapter shall echo all input data relating to the bridge geometry. This shall include:

- Bridge Deck and Appurtenances
    - Slab
    - Traffic Barriers
    - Median Barriers
    - Sidewalks
- Superstructure
    - Girder Sections
    - Girder Spacing

    - Live Load Distribution Factors
- Substructure
    - Abutment and Pier Layout
    - Abutment Type and Geometry
    - Pier Type and Geometry
    - Connection and Boundary Condition Details
- Materials
    - Steel Materials
    - Reinforcing Materials
    - Concrete Materials

6.4 Longitudinal Analysis

Connectivity

Boundary Conditions

Loads

Etc

6.4.1 LBAM Details

This chapter reports detailed information about the geometry of a LBAM. This includes:

- Span element geometries and section properties for all stages
- Boundary conditions on span elements for all stages
- Substructure element geometries and section properties for all stages
- Substructure element boundary conditions for all stages

6.4.2 Loading Details

This chapter reports details about all loads, load groups, live loads, load cases and load combinations applied to the structure.

6.4.2.1 Load Groups

Report all loads within all load groups. Provide Details of load magnitudes and their locations on the LBAM.

6.4.2.2 Load Cases

Report Load Groups contained within all load cases.

6.4.2.3 Live Load Definitions
Provide detailed information about all envelopes, vehicles and lane loads within all defined live load definitions.

6.4.2.4 Load Combinations
Provide a table listing all load cases in each load combination along with their factors

6.4.3 Force Responses

For all stages defined

Moment

Shear

Displacements

QConBridge II shall report force responses for all load cases, and load groups, live load definitions and load combinations defined for the LBAM. Responses will be reported for all points of interest and all stages defined in the LBAM.

6.4.3.1 Force Response Types

6.4.3.1.1 Superstructure Elements
For Superstructure elements report moments, shears and deflections for all POI's.

6.4.3.1.2 Substructure Elements
For Substructure Elements report axial forces, moments, shears, and deflections for all POI's.

6.4.3.1.3 Reactions
Report reactions in global coordinates for all support locations.

6.4.3.2 Response Details
In addition to responses, report the following details for the given load types.

6.4.3.2.1 Live Load Details
Governing truck, position, axle spacing, direction, disappearing axles, etc.

Lane load patch definition.

For live load envelopes, report the controlling live load model.

6.4.4 Influence Lines

Moment, Shear, Displacement, Substructure elements

QConBridge shall generate influence lines for all force response types for all POIs in the LBAM. The influence line spacing shall be user-configurable.

6.5 Transverse Analysis

These chapters shall report all information about the TBAM and the transverse analysis results.

6.5.1 TBAM Details

This chapter reports detailed information about the geometry of a TBAM. This includes:

- Cap element geometries and section properties
- Deck Geometry
- Boundary conditions
- Column element geometries and section properties

6.5.2 Loading Details

This chapter reports details about all loads, load groups, live loads, load cases and load combinations applied to the structure.

6.5.2.1 Load Groups

Report all loads within all load groups. Provide Details of load magnitudes and their locations on the TBAM.

6.5.2.2 Load Cases

Report Load Groups contained within all load cases.

6.5.2.3 Live Loads

Provide detailed information about application of live load vehicles and lane loads.

6.5.2.4 Load Combinations

Provide a table listing all load cases in each load combination along with their factors

6.5.3 Force Responses

For all stages defined

Moment

Shear

Displacements

QConBridge II shall report force responses for all load cases, and load groups, live load definitions and load combinations defined for the TBAM. Responses will be reported for all points of interest and all stages defined in the TBAM.

6.5.3.1 Force Response Types

6.5.3.1.1 CAP ELEMENTS

For Cap elements report moments, shears and deflections for all POI's.

6.5.3.1.2 COLUMN ELEMENTS

For Column Elements report axial forces, moments and shears for all POI's.

6.5.3.1.3 REACTIONS

Report reactions in global coordinates for all support locations.

6.5.3.2 Response Details

In addition to responses, report the following details for the given load types.

6.5.3.2.1 Live Load Details

Governing truck, position, axle spacing, disappearing axles, etc.

For live load results, report the locations of the controlling truck(s), truck position(s), and lane load patch definition.

For live load envelopes, report the controlling live load model.

6.5.4 Influence Lines

Moment, Shear, Displacement, Substructure elements

QConBridge shall generate influence lines for all force response types for all POIs in the TBAM. The influence line spacing across the cap beam shall be user-configurable.