PROPOSED GUIDELINES FOR PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS TOLERANCES



NCHRP Project 12-98

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ABBREVIATED TABLE OF CONTENTS

Guidelines for Prefabricated Bridge Elements and Systems Tolerance, First Edition contains the following sections:

- 1. Introduction
- 2. Fabrication Tolerances
- 3. Erection Tolerances
- 4. Joints and Connections

FOREWORD

Accelerated Bridge Construction Technologies have evolved from the laboratory, to trial installations, and into mainstream use. To date, the design and construction of ABC projects has been completed using engineering judgement and existing design and construction provisions that are contained in the AASHTO LRFD Bridge Design Specifications and the AASHTO LRFD Bridge Construction Specifications. These guidelines fulfill the majority of the design and construction needs for an ABC project. These guidelines are intended to fill the gaps for fabrication and erection of prefabricated elements with respect to tolerances.

These guidelines can be used to develop project special provisions or owner standard specifications. This document was developed under NCHRP Project 12-98. The final report for this project contains information on the sources and development of the recommended tolerances. There is a companion NCHRP Project 12-102 that is being completed concurrently with this project that includes a document entitled "Guide Specification for Accelerated Bridge Construction", which is referenced in several provisions in this document.

PREFACE

Units

These Guidelines use U.S. Customary Units only. Per a decision by the AASHTO Subcommittee on Bridges and Structures in 2009, SI units will no longer be included in specification documents.

References

If a standard is available as a stand-alone publication – for example, the ACI standards-the title is *italicized* in the text and listed in the references. If a standard is available as part of a larger publication – for example, the AASHTO materials specifications – the standard's title is not italicized and the larger publication - in this case, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 29th Edition - is listed in the references.

Unit Abbreviations

Unit abbreviations in this document are consistent with the units in the AASHTO LRFD Bridge Design and Bridge Construction Specifications. Users of these guidelines should refer to these documents for frequently used abbreviations.

Please note the following:

- Abbreviations for singular and plural are the same
- Most units of time have one letter abbreviation. Unit abbreviations are always set in roman font, while variable and factors are set in *italic* font.

SECTION 1: INTRODUCTION

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1-2

SECTION 1

INTRODUCTION

1.1 SCOPE

The provisions of these guidelines are intended for use in the design, detailing, layout, and construction of Prefabricated Bridge Elements and Systems. Tolerances play an important role in all of these processes.

These guidelines are not intended to supplant proper training or the exercise of judgement by the Designer. The owner or the Designer may require the sophistication of design or the quality of materials and construction to be higher than the minimum requirements.

This document is a guideline document with recommended criteria, not a specification. All provisions contained herein are subject to review and adjustment by the Designer with approval by the owner. In many provisions, the term "shall" is included in the text. These provisions are intended to be used in contract specifications, where the term "shall" would be appropriate. Other provisions contained herein make use of the term "should" or "may". The term "should" indicates a strong preference for a given criterion. The term "may" indicates a criterion that is usable, but other local and suitably documented, verified, and approved criterion may also be applied.

1.2 Use of these Guidelines

This document contains guidelines for tolerances applied to commonly used prefabricated bridge elements. It shall be used in conjunction with other AASHTO publications.

1.3 DEFINITIONS

The definitions contained herein refer to common terms in use in Accelerated Bridge Construction (ABC).

C1.1

The commentary within this document is not intended to provide a complete historical background concerning the development of these guidelines, nor is it intended to provide a detailed summary of the studies and research data reviewed in formulating the provisions. The final report for NCHRP Project 12-98 (Culmo, et al, 2017) contains significant background information that can be used to detail the development of these guidelines.

C1.2

These guidelines are based on current commonly used ABC methods. In some cases, these guidelines can be used as a basis for tolerance specifications and management of other similar details. Certain details may require determination of acceptable tolerances by the Designer.

C1.3

Many of the terms contained herein are for information only. Not all of the terms included are referenced in these guidelines.

1.3.1 General Accelerated Bridge Construction Definitions

Accelerated Bridge Construction (ABC)	Bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the onsite construction time that occurs when building new bridges or
Conventional Bridge Construction	replacing and rehabilitating existing bridges. Bridge construction that does not significantly reduce the onsite construction time that is needed to build, replace or rehabilitate a bridge. Prefabrication is typically limited to beams and girders in this
Lateral Slide	A method of moving a bridge system built adjacent to the final bridge location using hydraulic jacks or cable winches while supported on sliding materials or rollers. The bridge is typically built parallel to its final alignment, facilitating the installation.
Prefabricated Bridge Elements and Systems (PBES)	Structural components of a bridge that are built offsite or near the site that include features that reduce the on-site construction time that occurs with conventional bridge construction.
Prefabricated Element	A category of PBES which comprise a single structural component of a bridge. Prefabricated element can be made of any approved structural material.
SPMT	Self-Propelled Modular Transporter. A high capacity transport device that can lift and move prefabricated elements and systems with a high degree of precision and maneuverability in all three directional axes without the aid of a tractor for propulsion.

1.3.2 Deck Elements

Aluminum Deck	A full thickness deck made with extruded aluminum elements that are
	connected to form an orthotropic deck system.
Exodermic Deck	A steel grid deck system made with a partially filled concrete composite
	topping that is placed above the top of the grid.
Full-Depth Precast Deck Panel w/PT	A full thickness deck panel that makes up the entire structural deck.
	Connected in the distribution direction with post-tensioning.
Full-Depth Precast Deck Panel w/o PT	A full thickness deck panels that makes up the entire structural deck.
	Connected in the distribution direction without post-tensioning
	(typically with a reinforced concrete closure joint).
Orthotropic Deck	A steel deck system made with a steel plate deck combined with welded
	transverse and longitudinal ribs.
Partial-Depth Precast Deck Panel	A reinforced or prestressed concrete deck panel that makes up the lower
	portion of the bridge deck that is combined with a reinforced cast-in-
	place concrete topping to form the completed structural deck.
Steel Grid (open)	A steel grid deck system made without concrete fill.
Steel Grid (concrete filled)	A steel grid deck system made with a partially filled concrete placed
	within the grid.

1.3.3 Beam Elements

Adjacent Deck Beam Element	Beams fabricated with an integral deck that is separated by a small
	grouted joint, or a small closure joint. Also referred to as butted beams.
	Adjacent beams come in several shapes including Deck Bulb T,
	Inverted T, Double T, Box, Slabs, Voided Slabs, etc.
Full Width Beam Element	An element that eliminates conventional on-site beam placement
	activities. It is typically rolled, slid, or lifted into place to allow deck
	placement operations to begin immediately after placement. Given the
	size and weight of the element, the entire deck is not included.

Modular Decked Beam (MDB)	An element that is fabricated with beams combined with an integral composite reinforced concrete deck to form a modular unit. MDBs can be made with steel or prestressed concrete beams. A MDB is typically made with two or three beam elements.
1.3.4 Pier Elements	
Precast Caisson Cap	A reinforced concrete element that is placed on top of piles or drilled shafts that are designed to support reinforcing and cast-in-place concrete that is placed after the cap is erected.
Precast Cap Shell	A reinforced concrete element that is fabricated without the core concrete. The core concrete is placed after the shell has been erected.
Precast Cap and Column	A reinforced concrete pier element comprised of a precast column cap combined with precast column(s).
Precast Column	A vertical reinforced concrete element that supports a beam or cap.
Precast Column Cap	A reinforced concrete element placed on top of column elements.
Precast Integral Cap	A reinforced concrete element that is integrally connected to the superstructure and the lower pier elements to form a rigid connection.
Precast Footing	A reinforced concrete element that makes up the structural footing of a substructure or wall.
Precast Footing Shell	A reinforced concrete shell that is used as a stay-in-place form for a cast-in-place reinforced concrete footing.
Precast Pile Cap	A reinforced concrete element that is placed directly on top of piles.
Precast Semi-Integral Cap	A reinforced concrete element that is integrally connected to the superstructure and pinned to the lower pier elements to form a pinned connection.
Steel Cap and Column	A structural steel element comprised of a steel column cap combined with integral steel column(s).
Steel Column	A vertical structural steel element that supports a beam or cap.
Steel Column Cap	A structural steel element placed on top of column elements.
Steel Pile Cap	A structural steel element that is placed directly on top of piles.

1.3.5 Abutment and Wall Elements

Precast Abutment Cap	A beam type element that is placed directly on top of and connected to the abutment wall elements to form the bridge seat.
Precast Abutment Stem	A wall element that is located above the abutment footing that retains embankment fill.
Precast Backwall	A wall panel element that is behind the end of the superstructure that retains the upper portion of the embankment fill.
Precast Cheek Wall	A wall element that is placed at the corner of the abutment seat to hide or retain the beam ends.
Precast Footing	A footing element that is placed on soil that supports a substructure element.
Precast Integral Abutment Stem	A reinforced concrete wall element that is integrally connected to the superstructure and the abutment piles to form a rigid connection.
Precast Lagging Panel	Panel element placed between vertical structural elements to form the face of an earth retaining wall system.
Precast Sheet Pile	A vertical precast element that is driven or jetted into the soil to create a cantilever wall (abutment or retaining wall).
Precast Wingwall	A wall element that retains embankment fill behind or alongside the abutment.

Precast 3-Sided Culvert	A precast culvert element that has a top and sides, but no bottom, placed on footings or pile caps to form a bottomless culvert structure.
Modular Block Wall	A precast wall system made up of stacked precast block elements that form a gravity retaining wall. The elements can be solid or voided. Soil or crushed stone are typically placed within the voids to enhance the resistance of the system.
MSE Wall	A mechanically stabilized earth retaining wall system made up of precast wall face elements connected to horizontal soil reinforcing elements.
Steel Sheet Piling	Interlocking vertical steel elements that are vibrated or driven into soil to create a cantilever wall (abutment or retaining wall).

1.3.6 Miscellaneous Elements And Definitions

Assembly Plan	A package of plans, specifications and calculations developed by the
	contractor that describes the process for the assembly of prefabricated
	elements. The assembly plan may include handling and erection plans,
	materials specifications, details and calculations for bridge temporary
	works, and construction scheduling.
Bars in Splice Coupler	A connection that provides tension, shear and/or moment force transfer
1 1	between two precast concrete elements via a mechanical connection
	that uses a projecting bar from one element grouted into a reinforcing
	bar splice device cast into the adjacent element.
Closure Joint	A gap between two elements or systems that is filled with materials to
	form a connection. The joint may or may not include reinforcing. The
	width of the closure joint can vary based on the type of material used to
	fill the joint and the reinforcing within the joint. This feature is also
	referred to as a "closure nour" by some agencies
Closure Joint: CIP Reinforced	A connection that provides tension shear and/or moment force transfer
closure source car remoteed	between two precast concrete elements via lapped reinforcing bars
	combined with cast in place concrete LIHPC or grout
Closura Joint: Grouted Kay	A connection that provides compression or shear force transfer between
Closure John. Grouted Key	two precast concrete elements via a keyed joint filled with a cast in
	place concrete or grout. Grouted leave closure joint med with a cast-in-
	with post tensioning to form a moment connection
Cleave Joint Match Cost	A compaction between two adjacent elements with a yerry small width
Closure Joint: Match Cast	A connection between two adjacent elements with a very small width
	epoxy grouted joint that is fabricated by casting one element against the
	adjacent element in the fabrication shop to form identical matching
	surfaces. Match cast joints may be used to provide a shear connection
	or combined with post-tensioning to form a moment connection.
Connection	A means of transferring force between two or more elements.
Connection: Grouted Duct	A connection that provides tension, shear, and/or or moment force
	transfer between two precast concrete elements via a mechanical
	connection that uses a projecting reinforcing bar from one element
	grouted into a metal duct cast into the adjacent element.
Connection: Pocket	A connection between two prefabricated elements thru the projection
	of multiple bars or connectors of one element into a single void that is
	cast internal to the receiving element. The void is then filled with either
	concrete, grout, or other suitable material.
Connection: Socket	A connection between two prefabricated elements thru the projection
	of a single portion of one element into a single void of the receiving
	element. The gap between the two elements is then filled with either
	concrete, grout, or other suitable material.
Contractor	The company responsible for the construction of the bridge or structure.

	Designer	The engineer responsible for the design of the bridge. Also known as the engineer of record
	Fabricator	The company responsible for the fabrication of the prefabricated
	Falsework	Temporary construction used to support portions of the entire permanent structure until it becomes self-supporting. Falsework could include steel or timber beams, girder column piles and foundations, and any proprietary equipment including modular shoring frames, posts shores self-propelled modular transporters and horizontal shoring
	Grouted Blockout w/Shear Connectors	A means of creating a composite connection between a full-depth precast deck and a supporting beam or girder via shear connectors in a grouted pocket.
	Link Slab	Links slabs are a transverse deck level connection at piers between the decks of two adjacent spans, providing a jointless bridge without continuity. The deck is made continuous across the pier, but the supporting beams or girders are not connected.
	Load Path	A continuous path along which a load travels through structural elements and connections.
	Precast Approach Slab	A reinforced concrete slab element that spans between the end of a bridge deck or abutment and the approach pavement.
	Prefabricated Railing	An element used at the edge of a bridge deck to contain vehicles, bicycles and pedestrians.
	PT Ducts, Bonded	A prestressing system used in concrete comprised of a duct and a prestressing tendon that is grouted after stressing to form a bonded reinforcing system.
	PT Ducts, Un-bonded	A prestressing system used in concrete comprised of a duct and a prestressing tendon that is stressed to form an un-bonded reinforcing system
	Seismic System	A series of connected elements that transfer seismic loads through the structure to the foundations.
	Seismic Subsystem	A localized group of elements and connections within a seismic system that serves a specific design function, such as a knee-joint, plastic hinge region, etc.
	Shop Drawing	A drawing that depicts the fabrication of elements based on the requirements of the project plans and specifications.
	Special Material	A material used in construction that is proprietary or non-conventional. A special material often requires the use of a performance specification.
	Temporary Works	Structures and other construction that are used to facilitate the construction in progress, but removed in the final structure. In some cases, temporary works can be left in place; however they are not part of the completed structure
	Working Drawings	Details and calculations developed for bridge temporary works that involve the design of elements and processes. Specifications for working drawings often require a seal by a professional engineer.
1.3.	7 Systems	
	Prefabricated System	A category of PBES that consists of an entire superstructure, an entire

A category of PBES that consists of an entire superstructure, an entire superstructure and substructure, or a total bridge that is procured in a modular manner such that traffic operations can be allowed to resume after placement. A Prefabricated system is rolled, launched, slid, lifted, or otherwise transported into place, having the deck and preferably the railing in place such that no separate construction phase is required after placement.

Superstructure System	A system that includes both the deck and primary supporting members integrated in a modular unit.
Superstructure/Substructure System	A system that includes either the interior piers or abutments which are integrated in a modular manner with the superstructure as described for
	the superstructure system.
Total Bridge System	A system that includes the entire superstructure and substructures (both
	abutments and piers) that are integral with the superstructure that are built off-line and installed as a unit.
SPMT System	A system installation that uses Self-Propelled Modular Transporters to move the structure.
Lateral Slide System	A system installation that uses Lateral Sliding equipment to move the structure.

1.4 TOLERANCE NEEDS

Prefabricated elements should be manufactured to meet the dimensions and layout depicted on the contract plans. The final dimensions and construction of the prefabricated elements should be based on the asspecified dimensions with allowances for reasonable tolerances that can be attained using typical fabrication and construction methods.

1.5 MANAGEMENT OF TOLERANCES

The management of tolerances involves both design and construction functions. This Article outlines a recommended approach to tolerance management for Prefabricated Bridge Elements and Systems (PBES) involving both the Designer (owner) and the contractor.

1.5.1 **Designer**

The Designer or owner should be responsible for the establishment of tolerances for PBES for each project based on the elements and systems chosen.

C1.2

Prefabricated elements are not new to the bridge construction industry. It is well understood that it is impossible to fabricate and construct element to exact dimensions.

If tolerances are not accounted for in the design and specified in the contract documents, the fit-up of the elements could be compromised. Tolerances are established for the following reasons:

- Structural ensure variations do no change the loading configuration or capacity of the element and connections
- Feasibility ensure that the assembly and construction is possible with available constructing techniques
- Visual Effects ensure variations will provide an acceptable appearance
- Economics ensure efficient rate of production and erection with minimal issues
- Contractual establish a variance acceptability range

C1.5.1

The provisions of these guidelines include recommendations for tolerances and methods for proper tolerance specifications.

The Designer should specify the required fabrication tolerances, joint width tolerances, erection tolerances.

The Designer should also identify the layout method including working lines and working points required to build the structure.

1.5.2 Contractor

The contractor and/or fabricator should be responsible for the fabrication of elements within the specified tolerances and installation of the elements within the specified erection tolerances.

1.6 ITEMS NOT COVERED IN THESE GUIDELINES

Tolerances that currently exist in conventional construction are still applicable to portions of projects built with prefabricated elements.

Several tolerance items are commonly managed through other specifications such as reinforcing bar locations and cover.

1.6.1 **Beam Elements**

The tolerances used for fabrication of beam elements used in conventional construction are applicable to bridges built using ABC. Standard specifications for beam elements should be used.

1.6.2 Cast-In-Place Concrete Elements

Tolerances for cast-in-place concrete construction should be according to the AASHTO LRFD Bridge Construction Specifications.

1.6.3 Steel Elements

Tolerances for steel elements should be according to the *AASHTO/AWS D1.5 Bridge Welding Code* as amended by owner agency specifications.

1.7 SIGN CONVENTION FOR TOLERANCES

Specified tolerances may either be negative or positive. Positive (+) refers to greater or larger and negative (-) refers to lesser or smaller.

C1.5.2

If the contact documents do not include tolerance specifications, the contractor may use these guidelines for the management of tolerances.

C1.6

The intent of these guidelines is not to circumvent or be in conflict with other specifications.

C1.6.3

Article 3.11.1 of this guideline contains recommendations for holes in bolted field splices.

C1.7

Sign convention is specifically important when sizing joints. The additive effect of multiple concurrent positive tolerances can result in a joint that is too narrow or un-buildable. The additive effect of

multiple concurrent negative tolerances is not as critical for overall assembly of the prefabricated elements.

1.8 REFERENCES

AASHTO LRFD Bridge Construction Specifications, Third Edition, American Association of State Highway and Transportation Official, Washington, DC. (2010)

Culmo, M.P., et al, *Guidelines for Prefabricated Bridge Elements and Systems Tolerances and Dynamic Effects of Bridge Moves*, NCHRP Project 12-98, Final Report, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C. (2018)

SECTION 2: FABRICATION TOLERANCES

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SECTION 2

FABRICATION TOLERANCES

2.1 SCOPE

The provisions in this section apply to tolerances for the fabrication of various types elements used in Accelerated Bridge Construction (ABC). This section covers Prefabricated Bridge Elements (PBEs), Self-Propelled Modular Transporter (SPMT) Bridge Systems, and Lateral Slide Bridge Systems. C2.1

C2.2

Tolerances are used to ensure that properly detailed elements can be successfully installed with proper fit and alignment.

There are other types of tolerances covered in the guideline. Section 3 covers erection tolerances and Section 4 covers tolerances for joints and connections.

This guideline does not contain tolerances for

The cited guide specification contains information

placement of reinforcing steel and concrete cover as they

on design and construction of prefabricated elements, as

are covered in the cited AASHTO Specifications.

well as assembly planning.

2.2 RELATED DOCUMENTS

This guideline is intended to supplement the *AASHTO LRFD Bridge Construction Specifications* (2010).

The document entitled AASHTO Guide Specifications for Accelerated Bridge Construction (2017) shall also be used in conjunction with this guideline.

2.3 **DEFINITIONS**

Blockout	A recess in a precast element, often used to facilitate connections (also referred to as a pocket)
Bowing	An overall out-of-plane curvature of a flat surfaced element along its entire length
Camber	The deflection that occurs in prestressed concrete element due to the net bending resulting from the eccentricity of the prestress force
Contract Documents	Project specifications and design drawings issued on behalf of the owner by the Engineer and from which the project shop drawings and production drawings are developed
Cover	The least distance between the surface of the reinforcement and the surface of the concrete element
Deviation	The difference between the actual and the as-detailed dimension Deviations may be either negative or positive (also referred to as variance)
Deviation from Plane	A local smoothness variation or surface out of planeness
Deviation from Horizontal	Variation from specified plan end squareness or skew
Deviation from Vertical	Variation from specified elevation due to end squareness or skew
Fabrication Tolerances	Acceptable variations in dimensions relating to individual precast concrete elements
Fabricator	The company responsible for the fabrication of the prefabricated element.

Pocket	A recess in a precast element, often used to facilitate connections (also referred to as a blockout)
Primary Control Surface	A surface or feature on an element, the dimensional location of which is specifically set and controlled in the erection process (also known as a working line)
Smoothness	The degree to which a surface is locally flat
Sweep	A variation in horizontal alignment from a straight line parallel to centerline of element
Warping	The twisting of an element, resulting in an overall out-of-plane curvature of surfaces, characterized by non-parallel edges

2.4 NOTATION

This article is intentionally left blank at this time. There are no specific global notations that are used in this Section. Local notations are used for individual tolerance details.

2.5 BASIS OF PRODUCT FABRICATION TOLERANCE RECOMMENDATIONS

The fabrication tolerances specified in this section are based on field experience of Fabricators and existing published documents regarding tolerances.

C2.5

The fabrication tolerance of an element is controlled by the Fabricator as opposed to erection tolerances, which are controlled by the erection contractor.

Large tolerances are not recommended since they can lead to improper fit and finish of the structure. They can also lead to a need for large joints (to accommodate the larger tolerances) and conflicts between elements during erection (see Section 4 for information on joints). Using very small tolerances can lead to higher risk for the Fabricator, since there will be an increased likelihood that elements will be rejected for not meeting a small tolerance.

The goal of proper fabrication tolerances is to strike a balance between tolerances that can be met in the fabrication facility, and will fit properly during erection.

The tolerances contained herein are based on discussions with contractors, consultation with owners, and tolerance criteria that is used by the fabrication industry. The main documents currently used for fabrication tolerances for precast elements are the "PCI Tolerance Manual for Precast and Prestressed Concrete Construction" (2000) and the "ACI Specification for Tolerances for Precast Concrete" (2009). These manuals contain valuable information, however they are primarily written for the vertical construction industry (buildings). This guideline focuses on Prefabricated Bridge Elements and Systems, using the cited documents as a basis.

The tolerances included in this guideline were vetted by the bridge design and construction industries to ensure that the values are reasonable and repeatable.

2.6 FABRICATION

All precast elements should be fabricated to a specified tolerance. Fabrication tolerances should be shown on the shop drawings for use by fabrication staff.

2.6.1 Quality Assurance And Quality Control Measures

Quality assurance (QA) and quality control (QC) measures are necessary in any fabrication facility.

Quality assurance is the process used to measure and guarantee the quality of a product while quality control is the process of ensuring products meet specifications, including tolerances.

2.6.1.1 Quality Assurance (QA)

Quality assurance are planned actions necessary to ensure that the final product will satisfy given requirements for quality and perform the intended function. Fabrication facilities should implement and maintain a documented quality assurance program.

The most important aspects of a quality assurance program are:

- Adequate inspection personnel to ensure review of all materials and processes.
- Clearly defined responsibilities and required functions for each inspector.
- Management commitment to supporting the quality assurance program and establishing a uniform standard of quality in the plant.
- Clear and complete records of inspection and testing.
- Updating and calibration of testing equipment in a timely manner.

2.6.1.2 Quality Control (QC)

Quality control are actions related to the physical characteristics of the materials and processes, which provide a means to measure and control the fabrication tolerances. Quality control should be an accepted and functioning part of the fabrication plant operation.

2.6.2 Acceptance Criteria

C2.6.1

Plant certifications ensure that a level of quality control and assurance is followed for every element that is produced. Products are manufactured in accordance with the PCI Manual for Quality Control for Plant and Production of Structural Precast Concrete Products, Fourth Edition, MNL-116-99.

C2.6.1.1

The PCI Manual for Quality Control for Plant and Production of Structural Precast Concrete Products, Fourth Edition, MNL-116-99 is recommended for use in precast concrete facilities. Elements should be accepted if they meet the specified tolerances and other quality specifications (materials strength, finish, etc.).

2.6.3 Management of Out of Tolerance Elements

Out of tolerance elements shall be subject to structural review by the Fabricator and Contractor. Elements should not be rejected solely on the grounds of tolerances. The Fabricator and Contractor should determine if it is possible to use an out-of-tolerance element by making adjustment to the layout of the bridge. If this is not feasible, the element should be rejected and a new element made.

If there is concern regarding the constructability of a connection or assembly, the Fabricator may choose to dry fit the elements in the fabrication yard to demonstrate that the elements will fit together in the field.

When unacceptable fabrication tolerances occur, immediate action should be taken by the Fabricator to determine the cause of the problem and establish an appropriate modification measure for preventing future occurrences.

2.6.3.1 Out of Tolerance during Pre-pour and Post-pour Processes

If an out of tolerance discrepancy found in the forms in advance of placement of concrete cannot be accommodated by coordination of other elements or details, it should be rejected and should be corrected to nominal tolerances prior to placement of concrete.

An out of tolerance discrepancy found after the placement of concrete and pre-shipment can also occur. In this case, the tolerance discrepancy should be documented and evaluated to determine what corrective action is needed.

Post-pour tolerance discrepancies found should have documented procedures similar to pre-pour tolerance discrepancies but are communicated for evaluation instead of correction.

The procedure shall:

• Outline which individual within the plant is authorized to evaluate the consequences of such discrepancies.

In Prefabricated Bridge Elements and Systems, construction, fabrication tolerances are as important as other quality features. Out of tolerance elements can lead to delays during construction should the element not fit together properly.

C2.6.3

Modification of erection activities to accommodate out of tolerance elements requires close coordination between the Fabricator and the Contractor.

Not all tolerances are critical in every case, particularly when the structural performance is not impaired. In some circumstances, the Engineer may accept an out of tolerance element if it conforms with one of the following:

- The structural integrity is not affected by exceeding the tolerance.
- The erection of the overall structure can be performed by satisfactory means, such as minor adjustments to layout of connecting elements.

C2.6.3.1

The fabrication facility should have documented procedures regarding the manner in which pre-pour discrepancies noted by the quality control personnel are communicated to the production personnel for correction. These procedures should include a followup step to assure that noted discrepancies have in fact been corrected prior to concrete placement. • Include a follow-up step to assure that noted discrepancies have in fact been corrected or that other appropriate steps have occurred, such as notifying erection crew to see if the problem can be solved during erection.

2.7 RECOMMENDED FABRICATION TOLERANCES

Fabrication tolerances are applied to physical dimensions of precast elements such as thickness, length, width, squareness, and skew. The two most important considerations in achieving specified fabrication tolerances are the effects of formwork and the measuring techniques used to set the forms and assess the various fabrication dimensions.

The basis of the fabrication layout dimensions should be determined by the Designer or Engineer and shown on the plans. Fabrication tolerances may be specified to the center of the element or to a specified surface of the element. The plan details shall clearly show the intent of the element layout including dimensions of the elements from working lines or working points.

If the element erection layout dimensions are measured to the face of the element, the fabrication tolerance measurements should be measured to the same face of the element. Likewise, if the element layout dimensions are measured to the centerline of the element, the fabrication measurements should be measured to the centerline of the element.

The following sections contain recommended typical details for fabrication tolerance specifications. For elements not specifically listed, select the appropriate tolerances from the type that most closely matches the function of the element. The Designer can alter these details to suit the particular details and needs of the structure. The Designer may also use tolerances from one element type in another element type.

2.7.1 Footing Element Fabrication Tolerances

Figure 2.7.1-1 is an example of the recommended fabrication tolerances for a precast concrete footing. A column footing is shown. Other footing types would be similar.

If footing is supported by piles see Figure 2.7.4-1 for pile blockout location tolerance.

C2.7

The basis for these recommended tolerance values is the PCI Tolerance Manual for Precast and Prestressed Concrete Construction, MNL-135-00 (2000).

All layout dimensions should be based on a common working line. There are two methods for laying out elements during construction. The elements can be laid out based on dimensions from the working line to the centerlines of elements. The elements can also be laid out based on dimensions from the working line to a face on the element. Either method is acceptable and appropriate for certain situations (see Section 3 for more information on different layout methods).

The detailing of individual fabrication tolerances should be consistent with the layout method used for the overall structure therefore; the reference line used for fabrication layout should be the same line used for erection tolerances.

This guideline covers commonly used details for various element types, however there could be numerous permutations of details for all elements. It is inevitable that details from one element would be used on another element. For example, if a designer desired to include details for projecting reinforcing bars in a tolerance diagram for a column (Article 2.7.2), the tolerance shown for a wall panel (Article 2.7.2) could be used on the column details.

C2.7.1

Voids in footing required to connect to piles should be sized and located to accommodate the pile installation tolerance.

See Section 4 for more information on pile connection tolerances.



Figure 2.7.1-1 Footing Fabrication Tolerances

2.7.2 Column Element Fabrication Tolerances

Figure 2.7.2-1 is an example of the recommended fabrication tolerances for a precast concrete column. A square column is shown. Other column shapes would be similar.



Figure 2.7.2-1 Column Fabrication Tolerances

2.7.3 Cap Element Fabrication Tolerances

Figure 2.7.3-1 is an example of the recommended fabrication tolerances for a precast concrete cap, the figure shows both grouted splice coupler and blockout connection location tolerances.

Wall caps can be connected to wall elements with a reinforced concrete blockout connection. This can be accomplished through the use of a corrugated metal pipe (CMP) cast into one or both elements. Dowel bars can be extended into the CMP, which is subsequently filled with concrete after erection. See Figure C2.7.3-1 for a schematic view of this connection.

Pier caps can be connected to the column element with grouted couplers or other mechanical devices. Dowel bars extend into the cap element within the couplers. See Figure C2.7.3-1 for a schematic view of this connection.

Pier caps can be supported by single columns, or multiple columns.

C2.7.3

Wall cap refers to horizontal cap elements supported on wall panels (abutments or wall piers).



Figure C2.7.3-1 Schematic Wall Cap Connection



Figure C2.7.3-2 Schematic Column to Cap Connection

It is recommended that the number of columns per cap element be limited to three due to difficulties of connecting many elements together in the field. If a bridge has more than three columns, it is recommended to use multiple cap elements detailed with an open joint between them (see Section 4 for joint tolerances required for this situation). Another option is to connect the multiple caps after installation using a reinforced concrete closure joint. The structure can be designed such that the unconnected precast portions can support the dead load of the structure and the connected cap can be designed to support other loads. Using this approach, the casting and curing of the closure joint will typically not delay construction.



Figure 2.7.3-1 Cap Fabrication Tolerances

2.7.4 Wall Panel Element Fabrication Tolerances

Figure 2.7.4-1 is an example of the recommended fabrication tolerances for a precast concrete wall panel. A pier wall is shown. Other wall panel elements such as backwall, abutment stem wall (integral, semi-integral and cantilever), retaining wall, and wingwall would be similar.



Figure 2.7.4-1 Wall Panel Fabrication Tolerances

2.7.5 Full Depth Deck Panel Element Fabrication Tolerances

Figure 2.7.5-1 is an example of the recommended fabrication tolerances for a precast concrete full depth deck panel.



Figure 2.7.5-1 Full Depth Deck Panel Fabrication Tolerances

2.7.6 Approach Slab Element Fabrication Tolerances

Figure 2.7.6-1 is an example of the recommended fabrication tolerances for a precast concrete approach slab.



Figure 2.7.6-1 Approach Slab Fabrication Tolerances (*Note: Smoothness tolerance may be neglected on bottom of slab*)

2.7.7 Sleeper Slab Element Fabrication Tolerances

Figure 2.7.7-1 is an example of the recommended fabrication tolerances for a precast concrete sleeper slab.

A sleeper slab is used to support the end of an approach slab that is away from the bridge abutment. Sleeper slabs are not used by all owner agencies.



C2.7.7

Figure 2.7.7-1 Sleeper Slab Fabrication Tolerances (*Note: Smoothness tolerance may be neglected on bottom of slab*)

2.7.8 Grouted Splice Coupler Fabrication Tolerances

See Figures 2.7.2-1, 2.7.3-1, and 2.7.4-1 for typical details of grouted splice coupler. See Article 4.6.1 for connection tolerances of the grouted splice coupler connections.

2.7.9 Modular Deck Beam Element Tolerances

Figure 2.7.9-1 is an example of the recommended fabrication tolerances for a modular deck beam element.

C2.7.9

Modular Deck Beams (MDBs) come in several forms. The primary feature of MDBs is that the element has both a beam and a deck within the element. The beam elements can be made with precast concrete or steel. The resulting elements is a module that typically has two beam stems combined with an integral deck that is cast in the fabrication facility.



Figure 2.7.9-1 Modular Deck Beam Fabrication Tolerances Note: A steel beam MDB is shown, a precast MDB would be similar

2.8 **BRIDGE SYSTEM CONSTRUCTION** TOLERANCES

The construction of portions of the structure that are to be moved with the SPMTs or Lateral Slide techniques may be built using conventional construction methods and construction tolerances, except as modified herein.

The Designer should specify certain construction tolerances that will be critical to the fit of the moved portion of the bridge.

The following are recommended tolerances that may be used for the overall length of the bridge, measured from a working line defined as the mid-length of the portion of the bridge system being moved (tolerance measured to each end of the bridge):

- Spans under 100 feet in length
 - Overall Length where the superstructure fits between substructure elements: $+0^{\circ}$, $-\frac{1}{2}^{\circ}$

Overall length where the superstructure overlaps the substructure elements: $+\frac{1}{2}$, -0"

Spans over 100 feet in length

Overall Length where the superstructure fits between substructure elements: $+0^{\circ}$, $-3/4^{\circ}$

Overall length where the superstructure overlaps the substructure elements: $+^{3/4}$, -0"

If the working line is located at one end, the tolerances should be doubled.

These recommendations are based on specifications used by the Utah DOT (2015). The overlap description is based on details commonly used for SPMT bridge installations. Figure C2.8-1 is a schematic representation of this detail. In this case the overall bridge length tolerance would favor over-length versus under-length.



overlap connection

The relatively small tolerances for this type of construction are commensurate with the ramifications of a mis-fit during the system installation. Special care should be exercised with regard to tolerances on bridge systems. If the bridge detailing includes a reinforced concrete closure joint at the ends of the bridge, the tolerances for length can be increased.

This width tolerance is based on a need to have a smooth transition between the bridge railing/barrier and the approach railing/barrier. If the project details call for installation of approach barriers after setting the bridge, then larger tolerances may be acceptable.

The following are recommended tolerances that may be used for the location of the inside face of curb with respect to a working line:

- Bridges with fixed approach barriers: $\pm \frac{1}{2}$ "
- Bridges with adjustable approach barriers: ± 1 "

C2.8

The recommended tolerance for the fixed barrier situation is to achieve an alignment that will produce a maximum barrier face offset of \pm 1" when combined with the transverse setting tolerance (see Article 3.12.3).

2.8.1 Temporary Bent Tolerances

The following are recommended tolerances for support points on temporary falsework bents used in bridge system installations:

- Elevation of temporary bridge bearings seats: $\pm \frac{1}{80}$ from final bridge seat elevations
- Horizontal location of temporary bridge bearings: $\pm \frac{1}{4}$ " from final bridge layout dimensions

2.8.2 Final Substructure Tolerances

The following are recommended tolerances for the bearing locations on the permanent substructures used in bridge system installations:

- Elevation of final bridge bearings seats: $\pm \frac{1}{8^{n}}$ from final bridge seat elevations
- Horizontal location of final bridge bearings: $\pm \frac{1}{4}$ " from final bridge layout dimensions

Designers should consider detailing permanent bridge bearings that can accommodate vertical adjustment (shims) and horizontal adjustment.

C2.8.1

Temporary falsework bents are used to construct the bridge system off site. These are also referred to as temporary abutments. It is critical that the configuration of the temporary falsework bents match the final bridge configuration.

C2.8.2

It is also possible to detail elastomeric bearings without anchor rods (expansion bearings at each end) where lateral and longitudinal restraint is achieved through the use of reinforced concrete keys. The elimination of anchor rods can remove one potential fitup problem during final bridge setting.

If anchor rods are necessary, the details can include oversized sleeves cast into the substructure that will allow for grouting of the anchor rods after placement of the bridge system.

2.9 REFERENCES

AASHTO LRFD Bridge Construction Specifications, Third Edition, American Association of State Highway and Transportation Official, Washington, DC. (2010)

AASHTO Guide Specifications for Accelerated Bridge Construction, First Edition, American Association of State Highway and Transportation Official, Washington, DC. (2017)

ACI Specification for Tolerances for Precast Concrete, ACI ITG-7-09, American Concrete Institute, Farmington Hills, MI, (2009)

PCI Northeast Guideline for Accelerated Bridge Construction Using Precast/Prestressed Concrete Elements Including Guideline Details, PCINE-12-ABC, PCI Northeast Bridge Technical Committee (2014)

PCI Quality Control Manual for Plants and Production of Structural Precast Concrete Products – MNL-116-99, Precast Prestressed Concrete Institute, Chicago, IL, (1999)

PCI Tolerance Manual for precast and Prestressed Concrete Construction - MNL-135-00, Precast Prestressed Concrete Institute, Chicago, IL, (2000)

Utah DOT Structures Design and Detailing Manual, The Utah Department of Transportation, Salt Lake City, Utah, (2015)

SECTION 3: ERECTION TOLERANCES

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SECTION 3

ERECTION TOLERANCES

3.1 SCOPE

The provisions in this section apply to tolerances for the erection of various types of elements used in Accelerated Bridge Construction (ABC). This section covers Prefabricated Bridge Elements (PBEs), Self-Propelled Modular Transporter (SPMT) Bridge Systems, and Lateral Slide Bridge Systems.

Erection tolerances may be used to facilitate connections to other elements or portions of the structure, or to provide a smooth surface to planar elements. Wall type structures may require certain tolerances on exposed faces to provide acceptable appearance of the finished wall surface. The Designer should consider a combination of erection tolerances and element tolerances in the detailing of the structure.

This Section focuses on erection tolerances for precast concrete elements. Erection of steel elements is covered in the AASHTO LRFD Bridge Construction Specifications.

3.2 **DEFINITIONS**

Erection tolerances are defined as acceptable variations from the as-detailed vertical and horizontal placement of a precast element to achieve acceptable matching of adjacent elements after they are erected, and to provide acceptable alignment and finish of the completed structure.

See Section 1 of this document for definitions of common Prefabricated Bridge Elements and Systems.

3.3 NOTATION

This article is intentionally left blank at this time. There are no specific global notations that are used in this Section. Local notations are used for individual tolerance details.

3.4 BASIS OF ERECTION TOLERANCE RECOMMENDATIONS

C3.1

C3.4

This section does not cover the fabrication tolerances for ABC. These tolerances can be found in Section 2 of this document.

The articles in this section and other sections in this document cover the influence of tolerances on detailing. In most cases, the specified tolerances on bridge elements are used to ensure proper connection fit-up.
The erection tolerances specified in this Section are based on field experience of Contractors, Owners, and several published documents used in the vertical construction industry.

3.5 SPECIFYING WORKING POINTS AND WORKING LINES

Erection tolerances should be based on a common vertical datum and horizontal datum. Designers should specify that all elements be erected based on a common datum. All dimensions shown on the plans should be based on the selected datum. The layout of elements should not be based on center-to-center spacing of elements.

The use of elevations should be based on a specified vertical datum. The vertical datum should be consistent with the datum used to define the vertical geometry of the bridge.

Horizontal erection locations of elements should be based on working lines or working points. Working lines should be mathematically tied to the horizontal geometry of the structure. Working points should be tied to the bridge coordinate system (if used). The actual erection of an element or a bridge system is controlled by the Erection Contractor as opposed to fabrication tolerances, which are controlled by the Fabricator. Erection Contractors have the ability to set and reset the elements multiple times if required to meet the specified tolerances.

Based on this, erection tolerances can potentially be very small, however this is not recommended. Small erection tolerances may require elements to be set and reset many times, which would lead to construction delays. Large tolerances are also not recommended, since they can lead to large joints in the structures (See Section 4 of these guidelines). The goal of these guidelines is to strike a balance between acceptable tolerances and joint widths that will allow for fast construction with reasonable joint widths.

The specified tolerances contained herein are based on discussions with contractors, consultation with owners, and tolerance criteria that is used by the vertical construction industry (buildings). The main documents used for erection tolerances for precast elements are the *PCI Tolerance Manual for Precast and Prestressed Concrete Construction (2000)* and the *ACI Specification for Tolerances for Precast Concrete (2009)*. The main documents used for erection tolerances of bridge systems are several FHWA manuals (1-2007 and 2-2013) and the Utah DOT specification for bridge moves.

C3.5

Layout of precast elements should be based on a common datum in order to avoid the potential build-up of errors based on element and erection tolerances. If elements are laid out based on center-to-center spacing, there is potential for minor errors in each layout dimension to accumulate to a larger overall error. For example, if ten elements are erected with all center-to-center spacing set to a plus tolerance of 0.25 inches, the resulting overall length of the series of elements could be 2.25 inches longer than anticipated. If the same ten elements are laid out using a common datum, the maximum resulting variance would be 0.25 inches.

Some agencies specify working points and working lines on the plans. The roadway baseline or survey coordinate system may be used, or separate working lines may be established for ease of detailing and construction. Working lines may be shown on the plans or specified to be determined by the Contractor. If these are not shown on the plans, the project specifications should require the establishment of working lines or working points on the erection plans.

If designers choose to not use horizontal and vertical data for element layout, the structure detailing should account for potential build-up of erection and element tolerances.

3.6 HORIZONTAL ERECTION TOLERANCES

Horizontal erection tolerances are used to control the horizontal location of individual elements as they are placed in the assembled structure. Element erection tolerances may be specified to the center of the element, or to a specified surface of the element.

The detailing of individual element tolerances should be consistent with the layout method used for the overall structure.

Reference lines shall be used to specify layout method. If center of element, the reference line is located at center of element. If surface of element, the reference line is the critical surface.

Horizontal erection tolerances for stacked assemblies should be monitored closely during construction. As levels are assembled, the Contractor should determine the precise variation from specified locations of all elements, with special attention given to connection hardware. It may be possible to correct variations from working lines during erection of subsequent levels of assembly by adjusting the setting of the elements. This approach should only be used for elements that are butted and are independent of adjacent elements. See Article 3.11.1 for more information on this approach.

checking element dimensions.

C3.6

There are several ways to specify the layout of elements depending on the intended outcome of the assembled structure. It is possible to lay out an element using both methods. For example, a precast deck element may be specified as center of element layout for the longitudinal direction and surface of element for the transverse and vertical direction.

The goal of these guidelines is to improve element fit-up. The following are examples of the application of this guideline:

- Element laid out using center of element layout method: All tolerance specifications for the individual elements are measured to a working line that corresponds with the same reference line noted in the erection tolerance details.
- Element laid out using surface of element layout method: All tolerance specifications for the individual elements are measured to a working line that corresponds with the same surface noted in the erection tolerance details.

See Section 2 for information on tolerances for fabrication of individual elements.

An example of adjusting stacked elements is the construction of a pier bent. If the Contractor identifies that the footing connections are slightly wider than detailed, the erection location of the columns can be shifted slightly to correct the variance. If this is not possible within the connection, the Contractor may be able to tilt the column slightly (within tolerance) to bring the tops of the columns back into alignment with the layout plan, thereby facilitating the erection and fit-up of the pier cap.

3.6.1 Center of Element Layout Method

Center of element layout method should be used for the spacing of elements along the length of the structure or along a working line.

3.6.2 Surface of Element Layout Method

Surface of element layout method should be used for the alignment of elements perpendicular to a surface or working line where the finished surface of one portion of the structure is critical.

3.7 VERTICAL ERECTION TOLERANCES

Vertical erection tolerances are used to control the elevation of individual elements as they are placed in the assembled structure. Vertical element erection tolerances may be specified to the center of the element, or a specified surface of the element (typically the top of the element).

3.8 LEVEL AND PLUMBNESS TOLERANCE

Level and plumbness erection tolerances are used to control the variation from horizontal and vertical of individual elements as they are placed in the assembled structure. Level erection tolerances are typically specified along the top surface of the element.

C3.6.1

The following are examples of center of element layout approaches:

- The layout dimension of columns in a pier bent may be specified to the center of each column, since the face to face alignment of each column is not as critical as the location of the overall column. The horizontal variation of the column surfaces due to fabrication tolerances would be split between the side face surface locations.
- The longitudinal spacing of wall panels along the face of the wall may be specified to the center of each wall panel. The horizontal variation of the wall panel length due to fabrication tolerances would be split between the end surfaces of the panels, which would be accommodated within the specified joint width tolerance (see Section 4 of this document for more information on joints and connections).

C3.6.2

The following are examples of surface of element layout approaches:

- The alignment layout of a series of wall panels may be specified to the front face of the wall to ensure a smooth surface in the finished structure. The variation of fabrication width tolerances would be accounted for along the rear face of the wall panels where they would not be seen.
- The transverse layout of precast deck panels with integral precast barriers may be specified to the inside face of the barrier to ensure a smooth inside surface of the barrier.

C3.7

The approach for vertical layout of elements is similar to horizontal layout. See Article C3.6 for commentary on center of element layout and surface of element layout.

C3.8

For elements with multiple exposed faces such as columns, the designer may elect to specify an average plumbness for all faces of the column since surface tolerances can lead to inaccurate overall plumbness. Plumbness erection tolerances are typically specified to the face of the element.

3.9 RECOMMENDED ERECTION TOLERANCES

This article contains recommended erection tolerances for common elements used in bridge construction. These values may be used as a basis for other similar elements.

The following sub-articles contain recommended typical details for erection tolerances. Designers may choose to use alternate tolerance reference lines depending on the desired outcome of the structure. The tolerance values noted should be followed regardless of the reference line approach used.

C3.9

The basis for these recommended tolerance values is the *PCI Tolerance Manual for Precast and Prestressed Concrete Construction, MNL-135-00* (2000).

Example of a potential change: A Designer may choose to reference the front face of a wall footing to ensure that the connection of the footing to the wall stem is controlled. In this case, the footing would be fabricated using the front face of the footing as the reference line.

3.9.1 Footing Erection Tolerances

Figure 3.9.1-1 is an example of the recommended erection tolerances for a precast concrete footing. A column footing is shown. Other footing types would be similar.



Figure 3.9.1-1 Footing Erection Tolerances

3.9.2 Column Erection Tolerances

Figure 3.9.2-1 is an example of the recommended erection tolerances for a precast concrete column.

Column plumbness tolerances should be carefully managed during erection to ensure the proper fit of the column to cap connection based on the cap connection details.

C3.9.2

The intent is to make use of this tolerance to make adjustments to the erection of the columns during erection. For example, if a footing is constructed within tolerance, but farther apart than specified, the Contractor could cant the column inward to bring the top of the column within the tolerances for the cap connections.



Figure 3.9.2-1 Column Erection Tolerances

3.9.3 Pier Cap Erection Tolerances

Figure 3.9.3-1 is an example of the recommended erection tolerances for a precast concrete pier cap. Other cap type elements such as abutment caps would be similar.



Figure 3.9.3-1 Pier Cap Erection Tolerances

3.9.4 Wall Panel Erection Tolerances

Figure 3.9.4-1 is an example of the recommended erection tolerances for a precast wall element. This tolerance would be applicable abutment stems, integral abutment stems and retaining wall panels.



Figure 3.9.4-1 Wall Panel Erection Tolerances

3.9.5 Full-Depth Deck Panel and Modular Deck Beam Erection Tolerances

Figure 3.9.5-1 is an example of the recommended erection tolerances for a precast concrete full-depth deck panel or a modular deck beam element. This tolerance would be applicable full-depth precast concrete deck panels, steel grid deck panels modular deck beams made with steel beams and modular deck beams made with precast and prestressed concrete.



Figure 3.9.5-1 Full-Depth Deck Panel and Modular Deck Beam Erection Tolerances

3.10 ERECTION DETAILS

The basis of the erection layout dimensions should be determined by the Designer and shown on the plans. One or both methods described in Articles 3.6 and 3.7 may be used. The plan details should clearly show the intent of the element layout including dimensions of the elements from working lines or working points.

The reference line used for erection layout should be the same line used for element fabrication tolerances. As stated in Articles 3.6 and 3.7, there are multiple ways to specify element erection layouts. Figure 3.10-1 shows an example of an element erection layout detail for a precast concrete pier. This detail is based on the center of element layout method. Figure 3.10-2 shows a sample precast element erection layout detail for a precast concrete cantilever abutment structure. This detail is based on the center of element layout method for the longitudinal direction and surface of element layout method for the transverse direction.

This aspect of tolerance detailing is critical for the alignment of connections.



Figure 3.10-1 Example of Center of Element Erection Layout for a Precast Pier



Figure 3.10-2 Example of Abutment Erection Layout (Center of Element Method used for Longitudinal Layout Surface of Element Method used for Transverse Layout)

3.11 BUTTED ELEMENTS AND BUILD-UP OF C3.11 TOLERANCES

Precast elements may be detailed as butted (dry stacked or dry fit with tight joints). Extra care should be exercised with the design and detailing of these types of structures.

3.11.1 Accumulation of Tolerances

Designers should account for the variance of erection tolerances caused by the accumulation of tolerances of the individual elements. If the exact location of the top end of a series or elements is critical, then it should be noted on the plans. The following articles contain examples of common butted elements and recommendations on how to manage these tolerances.

Plans and/or specifications should contain provisions for closure pours, cast-in-place caps, or variable dimensions to account for the potential accumulation of tolerances.

3.11.1.1 Precast Elements without Grouted Joints

Precast elements that are detailed without variable width grouted joints are prone to accumulation of tolerances. In most cases, the variations will have little or Proper management of the build-up of tolerances in butted systems will facilitate the proper fit-up of the structure as a whole.

C3.11.1

The variance in overall structure length or height is due to the additive nature of stacked elements fabricated to certain tolerances. For example; the stacking of ten elements that are specified to be 1 foot tall may end up totaling 10.1' or 9.9'. In this case the Designer may note the top of the stacked elements as an approximate dimension that is subject to variation due to tolerances.

It is not possible to accurately estimate this type of variation, therefore a simple closure pour at the top or end of a series of elements would be in order.

C3.11.1.1

Variable width grouted joints may be an effective means of managing the accumulation of tolerances. In some structures, it is not feasible or desirable to no impact on the completed structure. Structures that require more exact overall length and/or height restrictions will require special detailing to manage the variations.

Retaining walls constructed with precast facing elements may be detailed as dry stacked. Vertical and horizontal tolerance management may be accounted for through the use of shims between the precast elements. If variable shims are not used, the Designer should detail the wall height and length with variable dimensions and include provisions for accommodating the variation in the precast wall height and/or length.

If adjustment of element layout is not included in the design, details for accommodating the variable length or height should be incorporated into the design. In many cases, minor variation in the top of the stack of element and the overall length of the aligned elements can be accommodated.

3.11.1.2 Steel Elements

The use of standard sized holes for field connections using bolts is recommended for most applications. Welded connections should be detailed to allow for minor variations due to fabrication tolerances. The use of erection bolts combined with field welding is recommended where feasible.

Special care should be exercised with steel structures fabricated with connections that incorporate slotted or oversized holes. Geometry should be checked as each element is erected to ensure proper geometry of the entire structure is maintained. The project specifications should include requirements to check erection tolerances for every element erected in order to ensure that the overall geometry of the structure is maintained. include grouted joints in the construction. In these cases, provisions for management of the accumulation of tolerances are required. The most common use of dry stacked elements is retaining walls constructed with precast concrete facing elements. The provisions and commentary in this article describe the management of these structures. The same approach can be used for other elements with similar detailing.

Examples of retaining structures where this situation might occur include:

- GRS/IBS Facing Blocks
- Precast modular block retaining walls
- MSE Wall Facing

Shims are commonly used in larger precast modular block walls to maintain the desired elevation of each course of construction and the length of the wall. Preference should be for the use of soft material shims. Steel shims can lead to high point loads and potential spalling. Smaller block walls are typically dry stacked, which will lead to variation in the overall height and width of the block facing.

If element by element adjustments are not specified and variable height and length are not desirable, the Designer should consider the inclusion of a variable height cast-in-place concrete cap to bring the finished structure top to the prescribed elevation, or a cast-in-place segment at the end of the elements to provide an exact end location. Saw-cutting of unreinforced concrete blocks may also be allowed in project specifications to accommodate the top of wall and end of wall variations.

C3.11.1.2

Fabrication of steel can be controlled to tight tolerances, which minimizes the potential of significant accumulation of tolerances. Complex steel assemblies fabricated with standard holes have proven to be reliably constructed without accumulation of tolerances.

The use of oversize and/or slotted holes should be used with caution as they can lead to overall geometry problems if the Contractor does not exercise care in element fit-up. This issue is primarily applicable to side-by-side steel elements such as Modular Steel decked Beams.

3.12 SPMT SYSTEM TOLERANCES

The Designer should specify erection tolerances for the SPMT Systems. The erection tolerance approach based on working lines and elevations should be used.

The layout of the bridge in the staging area should match the layout of the final bridge site. To reduce fit-up problems, the temporary supports should be built to the same relative line and grade as the permanent abutments (or piers).

3.12.1 Twist Tolerance

The Designer should calculate and specify the allowable twist tolerance for both the permanent condition and the temporary condition (during the bridge move). The basis for the twist tolerance should be to control cracking of the bridge concrete during the move. Twist tolerance may be specified at the anticipated lift points, or at the ends of the bridge. The project plans and specifications should include detail sheets that indicate where the twist tolerance is to be applied.

The basis of the allowable twist should account for the stiffness of the entire structure including the influence of girders, cross frames, diaphragms, barriers, etc.

The calculation of twist tolerance should involve inducing a twist displacement into the structural system that results in stresses that are within acceptable limits. The working stress method of analysis is recommended for this process.

The project specifications should include requirements for the Contractor to measure the twist of the structure in real time, to ensure that the twist tolerance is not exceeded. The plans should include details showing the measurement location of the twist tolernace.

3.12.2 Horizontal Setting Tolerances

There are several tolerances that may affect the setting of a bridge structure on substructures:

C3.12

SPMT Systems are typically built near site on temporary supports in a staging area.

C3.12.1

C3.12.2

The designers should determine the allowable twist in the structure, since they have more intimate knowledge of the structural framing system and the stress limits in the system during the move. See Article 3.10 for more information on erection tolerance detail sheets.

The allowable twist in a bridge superstructure is dependent on the stiffness of the structure and its ability to accommodate twist without damage. A 3D grid or finite element analysis may be required.

The working stress method of analysis is recommended since cracking of the concrete deck and concrete beams is a common stress limit that needs to be checked.

The specific means of measuring twist is typically left open to the Contractor. There are both sophisticated methods and simple methods that have been successfully used. Sophisticated methods involve the use of lasers and video monitoring systems. Simple methods include the use of string lines running from the bridge corners that cross at the center of the bridge. The gap between the lines can be equated to the maximum allowable twist. The need to measure twist in real time is important, since the movement of the bridge and the SPMTs is a fluid process.

- Longitudinal setting tolerance: This tolerance influences the beam and deck level connections at the end of the bridge. If wide closure joints are to be used, the longitudinal setting tolerance may be based on typical beam erection tolerances for conventional construction. If narrow closure joints or details are used, a more conservative longitudinal setting tolerance should be used based on the detailing of the joint.
- Transverse setting tolerance for bridges with concrete barriers at ends that transition to fixed concrete barriers off the bridge: The recommended transverse setting tolerance should be $\pm \frac{1}{2}$ " provided that the edge of the barrier joint is detailed with a 1"x1" chamfer.

• Transverse setting tolerance for bridges with barriers that transition to railings off the bridge: The recommended transverse setting tolerance should be ± 1 ".

The project plans and specifications should include detail sheets depicting the allowable horizontal erection setting tolerance.

3.12.3 Vertical Setting Tolerances

The final surface treatment of the bridge deck will affect the vertical setting tolerances. Vertical setting tolerances should be measured to the top surface of the bridge deck.

The following are the recommended vertical setting tolerances based on various surface treatments:

 Thick overlay Maximum Low Maximum High Thin overlay or bare deck combined with grinding Maximum Low Maximum High ^{1/4}" Maximum High ^{1/8}"

The project plans and specifications should include detail sheets depicting the allowable vertical erection setting tolerance. See Section 4 for information on tolerances for joints.

The primary driver for establishing this transverse setting tolerance is the detailing of the bridge barriers. Significant variations on the inside surface of the barrier can affect the crashworthiness of the system. Crash testing of concrete barriers with relief indentations has shown that a face offset of up to 1" is acceptable provided that the edge of the indentation is chamfered at 45 degrees (White, et al., 2002). The limitation of $\pm \frac{1}{2}$ " is set to accommodate casting tolerances for the bridge barrier. The additive nature of multiple tolerances could result in an overall offset of greater than 1" if this tolerance was to be increased.

This recommendation is based on the assumption that the approach roadway barrier can be adjusted to accommodate the transverse bridge barrier tolerance. This provision would also be applicable for concrete approach barriers that can be adjusted or installed after the bridge is set.

See Article 3.10 for more information on tolerance detail sheets.

C3.12.3

The vertical setting tolerance is similar to the vertical tolerances for full depth precast deck panels. Some agencies use thick overlays, others use thin overlays, and others use bare concrete decks combined with profile grinding. Thick overlays provide opportunities to accommodate larger tolerances, since the overlay thickness can vary. Thin overlays and bare decks require smaller tolerances in order to provide a smooth riding surface.

See Article 3.10 for more information on tolerance detail sheets.

3.12.4 Bearing Tolerance

The project details and specifications should include provisions for adjustment of bearings to accommodate the specified setting tolerances.

The use of anchor rods should be discouraged. Designers should investigate other ways of providing lateral resistance in the supports.

The Designer should detail bearing devices to accommodate the specified vertical setting tolerances and minor variations between the elevation of bearings on the temporary supports and the elevation on the permanent substructure.

3.13 LATERAL SLIDE SYSTEM TOLERANCES

The designer should specify erection tolerances for the bridge structure that is to be installed with the Lateral Slide method. The same erection tolerance approach shall be used based on working lines and elevations.

The layout of the bridge at the near-site fabrication area should match the layout of the final bridge site. In order to reduce fit-up problems, the temporary supports should be built to the same relative line and grade as the permanent abutments (or piers).

The tolerances for SPMTs noted in Article 3.12 are also applicable to Lateral Slide installations.

3.13.1 Slide Track Alignment

There are multiple methods for sliding a bridge. The design of the sliding mechanism should be developed by the Contractor. Designers should include this requirement in the slide plan submission. The project specifications should include requirements to realign the bridge during the slide.

C3.12.4

The tolerance for anchor rods is typically much smaller than the tolerances for setting the bridge, therefore other means of adjusting the bearing devices should be investigated if anchor rods are proposed. Some agencies rely on bearing friction (elastomeric bearings) and shear keys (also known as keeper blocks) to provide lateral resistance, which produces a bridge without anchor rods.

The detailing of bearings vary greatly from agency to agency. Most bearing designs may be detailed to include shims that can be added or removed to adjust the height of the bearing. Another option is to cast bridge seats high and allow for grinding of the bridge seat prior to setting the bridge. This option may not be conducive to very fast construction projects where grinding adjustments may not be feasible.

C3.13

Lateral slide bridges are typically built adjacent to the permanent bridge site on temporary supports. The construction of a bridge for a Lateral Slide installation is very similar to the construction for an SPMT installation. The major difference is the method of moving the bridge, which does not affect the required tolerances.

The details for the actual slide mechanism are typically designed by the Contractor. Project specifications should require that the Contractor develop and submit the slide mechanism for review. Horizontal adjustment of the bridge during the move is critical to prevent binding of the slide mechanism on guide rails (if used) and setting of the bridge in the final location. The alignment of the slide tracks should be parallel to each other and the bridge substructure. The Contractor should specify the tolerance for the slide track alignment based on the type of slide mechanism.

The Contractor should specify the maximum deviation of lateral movement at each track location to prevent binding of the slide mechanism or misalignment of the bridge.

The project specifications should include requirements for monitoring of the bridge during the slide. The complexity of the system should be commensurate with the complexity of the slide mechanism. The alignment tolerance can vary depending on the mechanism chosen. Slide systems with guide rails can bind if the structure alignment is not maintained. Other systems are less prone to binding. The alignment of the slide track needs to be carefully coordinated with the substructure so that the bridge does not come in contact with the substructure during the slide.

Monitoring systems can be a sophisticated control system, or simple measurements combined with radio communication.

3.14 REFERENCES

AASHTO LRFD Bridge Construction Specifications, Third Edition, The American Association of State Highway and Transportation Officials, Washington, D.C. (2010)

ACI Specification for Tolerances for Precast Concrete, ACI ITG-7-09, American Concrete Institute, Farmington Hills, MI, (2009)

FHWA (1) Manual on use of Self-Propelled Modular Transporters to Remove and Replace Bridges, Publication FHWA-HIF-07-022, Federal Highway Administration, American Association of State Highway and Transportation Officials, National Cooperative Highway Research Program, and Florida Department of Transportation (2007)

FHWA (2) Slide-In Bridge Construction Implementation Guide, Project: F-ST99 (232), U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., pp 168, (2013)

Steel Bridge Erection Guide Specification, S10.1, AASHTO/NSBA Steel Bridge Collaboration, National Steel Bridge Alliance, (2014)

PCI Tolerance Manual for precast and Prestressed Concrete Construction - MNL-135-00, Precast Prestressed Concrete Institute, Chicago, IL, (2000)

White, et al., *Crash Testing of Various Textured Barriers*, Report No. FHWA/CA/TL-2002/03, California Department of Transportation, Sacramento, CA, (2002)

Section 4: Joints and Connections

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SECTION 4

JOINTS AND CONNECTIONS

4.1 SCOPE

The provisions of this section applies to tolerances for joints and connections of prefabricated elements. Tolerances for joints and connections primarily apply to precast concrete elements.

There are two types of joints; structural and nonstructural joints. Structural joints connect elements with a joint that can transmit moment, shear and/or axial forces. Non-structural joints include joints which do not transfer load across the joint, such as expansion joints. Tolerances play a key role in the specified width of both structural and non-structural joints. Joint widths need to be able to accommodate the fabrication tolerances and erection tolerances of the connected elements.

C4.1

This section does not cover the fabrication and erection tolerances for ABC. These tolerances are included in Section 2 and 3 of this document.

Non-structural joints may be used for thermal movements such as a joint between panel walls. Another purpose of non-structural joints is to separate discrete portions of the structure such as a joint between abutment and wingwall stems.

This guideline was developed under NCHRP Project 12-98. The basis for this Section and the theoretical background for the provisions contained herein can be found in the final report for the project (Culmo, et al (2017).

4.2 **DEFINITIONS**

Dimensional Growth	The potential buildup of overall structure length or height due to the accumulation of tolerances of stacked and adjacent elements without tolerance joints to allow for length adjustment
Horizontal joints	Joints located between stacked elements used to connect elements and control vertical geometry by accounting for fabrication and erection tolerances
Non-Structural Joints	Joints which do not transfer load across the joint
Shim pack	Materials placed between two precast elements used to provide a specified separation or to make vertical grade adjustments
Structural Joints	Joints which transfer load across the joint
Vertical joints	Joints located between adjacent elements used to control horizontal geometry by accounting for fabrication and erection tolerances

4.3 NOTATION

A_L	=	maximum fabrication length tolerance of left element (in.) (C4.5.2.1)
A_R	=	maximum fabrication length tolerance of right element (in.) (C4.5.2.1)
A_U	=	maximum fabrication height tolerance of upper elements (in.) (C4.5.2.2)
B_L	=	maximum fabrication width tolerance of left element (in.) (C4.5.2.1)
B_R	=	maximum fabrication width tolerance of right element (in.) (C4.5.2.1)
C_U	=	maximum fabrication depth tolerance of upper element (in.) (C4.5.2.2)

D_L	=	maximum fabrication end skew/squareness tolerance of left element (in.) (C4.5.2.1)
$\overline{D_R}$	=	maximum fabrication end skew/squareness tolerance of right element (in.) (C4.5.2.1)
D_H	=	maximum fabrication end skew/squareness tolerance of horizontal element (in.) (C4.5.2.3)
D_V	=	maximum fabrication end skew/squareness tolerance of vertical element (in.) (C4.5.2.2) (C4.5.2.3)
G	=	maximum fabrication location of grouted splice coupler: maximum fabrication reinforcing location
		tolerance (in.) (4.6.1)
F_L	=	maximum fabrication sweep tolerance of left element (in.) (C4.5.2.1)
$\overline{F_R}$	=	maximum fabrication sweep tolerance of right element (in.) (C4.5.2.1)
H_L	=	maximum fabrication smoothness tolerance of left element (in.) (C4.5.2.1)
H_R	=	maximum fabrication smoothness tolerance of right element (in.) (C4.5.2.1)
H_H	=	maximum fabrication smoothness tolerance of horizontal element (in.) (C4.5.2.2)
H_V	=	maximum fabrication smoothness tolerance of vertical element (in.) (C4.5.2.2)
Ι	=	maximum fabrication location of blockouts tolerance (in.) (C4.6.2.2) (C4.6.3.2) (C4.6.4.2)
J	=	maximum variance from specified camber tolerance for prestressed elements only (in.) (C4.5.2.2)
L_{HL}	=	maximum horizontal erection tolerance of left element (in.) (C4.5.2.1)
L_{HR}	=	maximum horizontal erection tolerance of right element (in.) (C4.5.2.1)
L_{lap}	=	required minimum lap length (in.) (4.6.5.1)
L_{VL}	=	maximum vertical erection tolerance of lower element (in.) (C4.5.2.2)
Ν	=	reinforcing bar design embedment length (in.) (4.6.3.3)
N'	=	specified reinforcing bar projection length (in.) (4.6.3.3) (4.6.3.4)
Р	=	specified pocket depth (in.) (4.6.3.4)
S_{jt}	=	specified joint thickness for stacked elements(in.) (4.5.1)
S_{cjw}	=	specified width of closure joint (in.) (4.6.5.1)
S_{jw}	=	specified joint width for side-by-side elements (in.) (4.5.1)
S_{lap}	=	specified length of lap for closure joints (in.) (4.5.1)
S_w	=	specified minimum width of pocket (in.) (4.6.2.1) (4.6.3.1)
T_{jt}	=	joint thickness tolerance for stacked elements (in.) (4.5.1) (4.5.2.2)
T_{cjw}	=	closure joint width tolerance for side-by-side elements (in.) (4.6.5.1)
T_{jw}	=	joint width tolerance for side-by-side elements (in.) (4.5.1) (4.5.2.1)
T_{lap}	=	reinforcing bar lap length tolerance for closure joints (in.) (4.6.5.1)
T_w	=	pocket reinforcing bar location tolerance for pocket connections (in.) (4.6.2.1) (4.6.2.2) (4.6.3.1)
		(4.6.3.2)
t _{min_jt}	=	minimum tolerable joint thickness for stacked elements (in.) (4.5.1) (4.6.3.3) (4.6.3.4)
t _{min_jw}	=	minimum tolerable joint width for side-by-side elements (in.) (4.5.1)
t_{min_cl}	=	minimum tolerable clearance for pocket connection and closure joint reinforcing bars (in.) (4.6.2.1)
		(4.6.3.1) (4.6.3.4) (4.6.4.1) (4.6.5.1)
$oldsymbol{arphi}_b$	=	nominal reinforcing bar diameter (in.) (4.6.2.1)
<i>O</i> . <i>D</i> .	=	outer diameter of drilled shaft or opposite corner dimension of H-pile (in.)

4.4 ROLE OF TOLERANCES IN JOINT SPECIFICATIONS

C4.4

The joint opening between elements should be specified to allow for the accommodation of fabrication (element) tolerances and erection tolerances. Proper joint width specifications are used to maintain geometry of the structure during erection. There is a direct correlation between element tolerances and joint width. Larger tolerances require larger joint widths to accommodate them. The tolerances included in this Section are based on the element tolerances specified in Section 2 and the erection tolerances specified in Section 3. The basis for derivation of joint and connection tolerances is given in the commentary for each Article. Probability theory was used to account for the superposition of multiple tolerances that can occur in a joint or connection.

Designers and owners may elect to specify tolerances that differ from those recommended in

4.5 JOINT WIDTH OR THICKNESS SPECIFICATIONS

The specified width of joints should be based on the following factors:

- The minimum joint width required to insert the filler material (if required)
- The additional width required to accommodate fabrication tolerances that are larger than the specified width and erection tolerances that could lead to a smaller joint width

The Designer should specify all joint widths between members, structural and non-structural joints in the layout plans and details. The layout plan will be used to determine the size of elements and a general construction sequence.

4.5.1 Specified Joint Width or Thickness

The designer should specify the joint opening defined on the plans that accounts for the minimum tolerable joint opening plus the tolerances of the two adjoining elements.

Specified vertical joint width (side-by-side elements):

$$S_{jw} = t_{min\ jw} + T_{jw} \tag{4.5.1-1}$$

Specified horizontal joint thickness (stacked elements):

$$S_{jt} = t_{min_jt} + T_{jt}$$
 (4.5.1-2)

where:

Sections 2 and 3. In this case, the commentary in this Section can be used to calculate joint or connection tolerances using the developed probability equations for each joint or connection.

C4.5

The goal of specifying joint widths is to have a joint that will have sufficient width to install filler materials and not have conflicts between connected elements, but not too large so that the appearance of the structure is compromised. Once the element fabrication tolerances and erection tolerances are set, the designer can specify a joint width and a joint thickness tolerance using this guideline.

See Section 2 for recommended element fabrication tolerances and Section 3 for recommended element erection tolerances.

The Designer may set boundary conditions for the Contractor such as; vertical joint to be placed away from bearing locations, minimum width of elements, and stage construction joint locations.

The Designer may choose to include contract provisions that allow different joint configurations within contract defined boundary conditions.

C4.5.1

The following articles contain recommended joint thicknesses and widths for typical element layouts. The recommended values are based on the recommended element fabrication tolerances included in Section 2 and the recommended erection tolerances included in Section 3. The following articles also contain the equations used to generate the recommended tolerances in the commentary. The designer can use these equation to calculate joint width/thickness tolerances for elements with tolerances that differ from the recommended tolerances in Section 2 and section 3.

The determination of the minimum tolerable joint width/thickness is based on the materials that are to be used within the joint. For example, a joint with non-shrink grout may have a minimum tolerable width of $\frac{1}{2}$ ", while a joint with concrete may have a minimum tolerable width of 1" (depending on the size of the aggregate).

Example for joint width detail call out: Given:

Element fabrication dimensions should be based on the specified joint thickness or width. The detail call out for a joint on the plans should be the specified joint width/thickness plus or minus the joint width/thickness tolerance denoted as follows:

Horizontal joint detail call out = $S_{jt} \pm T_{jt}$ Vertical joint detail call out = $S_{jw} \pm T_{jw}$

See Article 4.5.2 to obtain specified joint width and joint thickness tolerances, T_{jw} and T_{jt} respectively.

4.5.2 Specified Joint Opening Tolerance

The specified joint opening tolerance is set based on the following factors:

- The fabrication tolerances of the two joined elements
- The erection tolerance of the two joined elements
- The probability of occurrence of additive tolerances

4.5.2.1 Specified Vertical Joint Width Tolerances

Vertical joints are typically found between wall elements that are assembled side by side. The joint width call out shown on the plans should be the specified joint width, $S_{jw} \pm$ the vertical joint width tolerance, T_{jw} .

Minimum tolerable width = $\frac{1}{2}$ " Joint width tolerance = $\pm \frac{5}{8}$ " Specified joint width = $1^{1/8}$ " Therefore: Detail call out = $1^{1/8}$ " $\pm \frac{5}{8}$ "

C4.5.2

The specified joint width should take into account the probability that all of the maximum tolerances will occur at the same time. If maximum tolerances are used in the joint width equations, overly wide joints will result.

The specified joint opening tolerances in this article were determined through the use of probability simulations (Monte Carlo method). These simulations were used to obtain more realistic tolerance values based on the probability of occurrence of each tolerance. The simulations included both the fabrication and erection tolerances.

The basic theory of Monte Carlo simulation is the creation of many "what if" cases to determine the expected results of a study. It allows users to account for risk in quantitative analysis and decision making. The joint width/thickness values included in this Section are based on a 95% probability of achieving a success connection. The 5% probability of exceeding the joint width tolerance does not necessarily result in a significant problem. This scenario would require adjustment to be made to the elements (grinding of edges, re-setting of elements).

C4.5.2.1

Vertical joints are used to control lateral alignment by accounting for the fabrication tolerances and erection tolerances, specified in Articles 2.6 and 3.9, so that the final layout is as specified on the contract plans. Values in Figures 4.5.2.1-1 and 4.5.2.1-6 are based on fabrication and erection tolerances from Articles 2.6 and 3.9. The Designer may wish to modify the values in Articles 2.6 and 3.9. When this occurs the Designer shall use Table C4.5.2.1 to calculate vertical joint width tolerances. The factor associated with T_{jw} in this table is

Element Description		T_{jw}
Left	Right	(in.)
All	All	5/8
(except noted)	(except noted)	
Pier Cap	Pier Cap	7/8
Full-Depth	Full-Depth	3/8
Deck Panel	Deck Panel	
Modular Deck	Modular Deck	5/8
Beam	Beam	

Table 4.5.2.1 – Vertical Joint Tolerance Values for Side-by-Side Elements, $T_{\rm jw}$

based on using the probability occurrence of the maximum additive tolerances.

For vertical joint width tolerance, half the length fabrication tolerance of the two adjacent elements are used. It is assumed that half the additional length is applied to each end of the element.

Skew/squareness and smoothness fabrication tolerances are assumed to occur at different locations along the joint; therefore these tolerances are not additive.

During erection elements can be reset; therefore erection tolerances are reduced by two assuming one of the two side-by-elements can be reset and the other is erected within tolerance.

In Tables 4.5.2.1 and C4.5.2.1, left and right elements can be interchangeable.

The maximum end skew/squareness fabrication tolerance, D, and the maximum smoothness fabrication tolerance, H, can occur in either element (left or right).

H and D are shown in Figures 4.5.2.1-1 through 4.5.2.1-6 to represent the tolerances. The details show one possible scenario. The other possible scenarios include:

- H at left and right elements
- D at left and right elements
- H at left and D at right element (and vice versa), note this case is not included in determining T_{jw}, the maximum of the first two cases will be greater than this case.



Figure 4.5.2.1-1 Approach Slab to Approach Slab



ELEVATION

Figure 4.5.2.1-2 Approach Slab to Sleeper Slab



Figure 4.5.2.1-3 Sleeper Slab to Sleeper Slab



Figure 4.5.2.1-4 Pier Cap to Pier Cap



Figure 4.5.2.1-5 Panel to Panel, Footing to Footing, Wall Cap to Wall Cap



Figure 4.5.2.1-6 Full-Depth Deck Panel or Modular Deck Beam

Table C4.5.2.1 - Vertical Joint Tolerance for Side-by-Side Elements, T_{jw}

The equations in this table were used to develop the vertical joint width tolerances noted in this article. The 0.21 to 0.34 factors are the adjustment to the maximum tolerances to account for the probability of all maximum tolerances occurring simultaneously.

Element Description		Vertical Joint Width Tolerance
Left	Right	T_{jw}
Approach Slab	Approach Slab	$\pm 0.33 [0.5(B_L + B_R + L_{HL} + L_{HR}) + \text{maximum of } (D_L + D_R), (H_L + H_R)]$
Approach Slab	Sleeper Slab	$\pm 0.34 \left[0.5(A_L + B_R + L_{HL} + L_{HR}) + \text{maximum of } (D_L + D_R), (H_L + H_R) \right]$
Sleeper Slab	Sleeper Slab	
Pier Cap	Pier Cap	$\pm 0.34 [0.5(A_L + A_R + L_{HL} + L_{HR}) + \text{maximum of } (D_L + D_R), (H_R + H_L)]$
Panel, Footing,	Panel, Footing,	
Wall Cap	Wall Cap	
Full-Depth	Full-Depth	$\pm 0.21 [0.5(A_L + A_R + L_{HL} + L_{HR}) +$
Deck Panel	Deck Panel	maximum of $(D_L + D_R), (H_R + H_L + F_L + F_R)$]
Modular Deck	Modular Deck	$\pm 0.28 \left[0.5(A_L + A_R + L_{HL} + L_{HR}) + \right]$
Beam	Beam	maximum of $(D_L + D_R), (H_R + H_L + F_L + F_R)$

where:

A_L	=	maximum fabrication length tolerance of left element (in.)
A_R	=	maximum fabrication length right element (in.)
B_L	=	maximum fabrication width tolerance of left element (in.)
B_R	=	maximum fabrication width tolerance of right element (in.)
D_L	=	maximum fabrication end skew/squareness tolerance of left element (in.)
D_R	=	maximum fabrication end skew/squareness tolerance of right element (in.)
F_L	=	maximum fabrication sweep tolerance of left element (in.)
F_R	=	maximum fabrication sweep tolerance of right element (in.)
H_L	=	maximum fabrication smoothness tolerance of left element (in.)
H_R	=	maximum fabrication smoothness tolerance of right element (in.)

 L_{HR} = maximum horizontal erection tolerance right element (in.)

Example of Vertical Joints between Approach Slabs

$B_L =$	$^{1}/_{4}$ (in.)	(Article 2.7.6)
$B_R =$	$^{1}/_{4}$ (in.)	(Article 2.7.6)
$L_{HL} =$	$^{1}/_{2}$ (in.)	(Article 3.9.1 assuming an approach slab is similar to a footing)
$L_{HR} =$	$^{1}/_{2}$ (in.)	(Article 3.9.1 assuming an approach slab is similar to a footing)
$D_L =$	$^{1}/_{2}$ (in.)	(Article 2.7.6)
$D_R =$	$^{1}/_{2}$ (in.)	(Article 2.7.6)
$H_L =$	$^{1}/_{8}$ (in.)	(Article 2.7.6)
$H_R =$	$^{1}/_{8}$ (in.)	(Article 2.7.6)

Vertical Joint Width Tolerance

 $= \pm 0.34 \left[0.5(B_L + B_R + L_{HL} + L_{HR}) + \text{maximum of } (D_L + D_R), (H_L + H_R) \right]$ = $\pm 0.34 \left[0.5(^{1}/_4 + ^{1}/_4 + ^{1}/_2 + ^{1}/_2) + \text{maximum of } (^{1}/_2 + ^{1}/_2), (^{1}/_8 + ^{1}/_8) \right]$ = $\pm 0.34 \left[0.5(1^{1}/_2) + 1^{"} \right]$ = $\pm 0.34 \left[1.75 \right]$ = $\pm 0.6^{"}$ (say 5/8")

4.5.2.2 Specified Horizontal Joint Thickness Tolerances (Stacked Vertical to Horizontal Element)

Horizontal joints are typically found between stacked elements. This section is applicable to stacked elements with horizontal joints. The vertical elevations are established at the top of each element at critical locations, typically at the center of the joint.

The joint thickness shown on the plans should be the specified joint thickness, $S_{jt} \pm$ the horizontal joint thickness tolerance, T_{jt} .

Table 4.5.2.2 – Horizontal Joint Tolerance Valuesfor Stacked Vertical to Horizontal Elements, Tjt

Des	T_{jt}	
Vertical	Horizontal	(in.)
Column	Footing	3/4
Column	Pier Cap	5/8
Column	Prestressed Cap	7/8
Panel	Cap or Footing	5/ ₈
Backwall	Approach Slab	1/2

C4.5.2.2

Horizontal joints are used to control vertical alignment by accounting for the fabrication tolerances and erection tolerances, specified in Articles 2.6 and 3.9. Values in Figures 4.5.2.2-1 and 4.5.2.2-5 are based on fabrication and erection tolerances from Articles 2.6 and 3.9. The Designer may wish to modify the values in Articles 2.6 and 3.9. When this occurs the Designer shall use Table C4.5.2.2 to calculate horizontal joint thickness tolerances. The factor associated with T_{jt} in this table is based on using the probability occurrence of the maximum additive tolerances.

Errors in horizontal joints can accumulate with each joint if no adjustments are specified. If an element is too low, minor adjustments are typically made through the use of shims placed in the center of the horizontal joint.

For stacked element joint thickness tolerance, it is assumed that the lower element is installed within tolerance and the entire upper element height or depth tolerance is used. It is assumed that the additional height of the lower element will be adjusted below the element.

Skew/squareness fabrication tolerances for wall panels are accounted for in the side-by-side element joint width tolerance and are ignored in stacked element joint thickness tolerance.

The maximum end skew/squareness fabrication tolerance, D, occurs only at vertical elements. While the

maximum smoothness fabrication tolerance, H, only occurs at horizontal elements.

Approach slab at integral abutment varies from nonintegral abutment because at the integral abutment there is a cast-in-place portion between joint and backwall. Therefore the tolerances from the backwall are not additive to the tolerances at the joint below the approach slab.



Figure 4.5.2.2-1 Column to Footing



Figure 4.5.2.2-2 Column to Pier Cap



ELEVATION

Figure 4.5.2.2-3 Column to Prestressed Pier Cap





Figure 4.5.2.2-4 Panel to Cap



Figure 4.5.2.2-5 Panel to Footing



Figure 4.5.2.2-6 Panel to Footing

Table C4.5.2.2 – Horizontal Joint Tolerance for Stacked Vertical to Horizontal Elements, T_{jt}

The equations in this table were used to develop the horizontal joint width tolerances noted in this article. The 0.52 factor is the adjustment to the maximum tolerances to accounts for the probability of occurrence of the maximum additive tolerances.

Description		Horizontal Joint Thickness Tolerance T _{jt}
Vertical	Horizontal	
Column	Footing	$\pm 0.52 (A_U + D_V + H_H + L_{VL})$
Column	Pier Cap	$\pm 0.51 (C_U + D_V + H_H + L_{VL})$
Column	Prestressed Cap	$\pm 0.52 (C_U + D_V + H_H + J + L_{VL})$
Panel	Cap or Footing	$\pm 0.51 (C_U + H_H + H_V + L_{VL})$
Backwall	Approach Slab	
Backwall	Approach Slab at	$\pm 0.74~(C_U+H_H)$
	Integral Abutment	

where:

A_U	=	maximum fabrication height tolerance of upper element (in.)
C_U	=	maximum fabrication depth tolerance of upper element (in.)
D_V	=	maximum fabrication end skew/squareness tolerance of vertical element (in.)
H_H	=	maximum fabrication smoothness tolerance of horizontal element (in.)
H_V	=	maximum fabrication smoothness tolerance of vertical element (in.)
L_{VL}	=	maximum vertical elevation tolerance of lower element (in.)
J =	:	maximum variance from specified camber tolerance (prestressed only) (in.)

4.5.2.3 Specified Horizontal Joint Thickness Tolerances (Stacked Vertical to Vertical Element)

Horizontal joints are typically found between stacked elements. This section refers to stacked vertical to vertical elements.

The joint thickness shown on the plans should be the specified joint thickness, $S_{jt} \pm$ the horizontal joint thickness tolerance, T_{jt} .

Table 4.5.2.3 – Horizontal Joint Tolerance Values for Stacked Vertical to Vertical Elements, T_{jt}

Descr	iption	T_{jt}
Vertical	Vertical	(in.)
Column	Column	7/8
Panel	Panel	5/8

C4.5.2.3

Vertical to vertical stacked elements are typically incorporated in a design if the weight or size of the pieces is excessive. Values in Figures 4.5.2.3-1 and 4.5.2.3-2 are based on fabrication and erection tolerances from Articles 2.6 and 3.9. The Designer may wish to modify the values in Articles 2.6 and 3.9. When this occurs the Designer shall use Table C4.5.2.3 to calculate horizontal joint thickness tolerances. The factor associated with T_{jt} in this table is based on using the probability of occurrence of the maximum additive tolerances.

Full height elements with vertical joints are typically preferred over vertical to vertical stacked elements with horizontal joints.

Horizontal joints in wall panels are not recommended due to the complexity of the reinforced connections. If wall panel weight gets excessive, designers should consider reducing the width of the panel or adding corrugated pipe voids to reduce the element weight.



Figure 4.5.2.3-1 Column to Column

Figure 4.5.2.3-2 Panel to Panel

Table C4.5.2.3 – Horizontal Joint Tolerance for Stacked Vertical to Vertical Elements, T_{jt}

The equations in this table were used to develop the horizontal joint width tolerances noted in this article. The 0.52 factor is the adjustment to the maximum tolerances to account for the probability of occurrence of the maximum additive tolerances.

Description		Horizontal Joint Thickness Tolerance
Vertical	Vertical	T_{jt}
Column	Column	$\pm 0.52 (A_U + D_H + D_V + L_{VL})$
Panel	Panel	$\pm 0.52 (C_U + H_L + H_U + L_{VL})$

where:

maximum fabrication Height Tolerance Upper Element (in.) $A_U =$ C_U = maximum fabrication Depth Tolerance Upper Element (in.) $D_H =$ maximum fabrication end skew/squareness tolerance horizontal element (in.) $D_V =$ maximum fabrication end skew/squareness tolerance vertical element (in.) $H_U =$ maximum fabrication smoothness tolerance upper element (in.) $H_L =$ maximum fabrication smoothness tolerance lower element (in.) $L_{VL} =$ maximum vertical elevation tolerance of lower element (in.) Tjt =joint thickness tolerance (in.)

4.6 CONNECTION TOLERANCES

Connection devices between precast elements include grouted sleeves, pile voids, reinforcing bars in pockets, etc. The erection tolerance and the connection device tolerances are interconnected. The combination of these two potential installation tolerances should be kept within the tolerance of the insertion of the bar in the device.

4.6.1 Grouted Splice Couplers

The grouted splice couplers provides a structural joint which can transmit moment and shear.

The following are typical connections of the grouted splice coupler:

- Columns to caps
- Columns or wall panels to footings
- Backwall to abutment stem or cap
- Abutment stem to integral wingwall unit
- Integral moment connections between superstructures and substructures

It is recommended that the bar extension from one element be fabricated over length and cut in the field after erection of the element. The bar extension should be based on the difference between the bottom of the upper element (top of shim stack) and the required embedment of the bar into the coupler.

See Articles 2.6 for horizontal location tolerances of grouted splice couplers. Figure 4.6.1-1 shows connection of column to footing other connections similar.

C4.6

If a connection involves the insertion of a reinforcing bar into a device (coupler or duct), the specification for tolerances would be based on the assumption that the bar is installed to one side and the coupler installed to the opposite side.

Location of multiple connection devices shall always be measured from the same control. Rather than measuring some from a member's edge and others from intermediate connection devices.

C4.6.1

Other moment connections includes cast-in-place closure joints and post-tensioning with match-cast elements.

The length of a bar extension into a pocket or coupler is affected by a number of different tolerances. The relatively tight tolerance on the embedment of the bar into the coupler makes specifying a tolerance on a bar extension difficult and prone to dimensional problems in the field.

In stacked element construction, the exact height of shim pack is determined in field after survey and measurement of upper element. The final goal is to meet the elevation tolerance at the top of the upper element.

In horizontal construction (side-by-side elements), shim packs are not used.



- 1. USE MATCHING TEMPLATES AND JIGS FOR THE LOCATION OF REINFORCEMENT AND GROUTED SPLICE COUPLER PLACEMENT WITHIN THE ELEMENTS TO CONTROL CRITICAL DIMENSION "G".
- 2. CONSULT MANUFACTURER OF THE GROUTED SPLICE COUPLER FOR PROPER DIMENSIONS "N" AND "O" AND FOR TOLERANCE ON THESE DIMENSIONS.
- 3. BEFORE EXECUTING GROUTED SPLICE COUPLER ASSEMBLIES, ALWAYS SEEK INSTALLATION RECOMMENDATIONS FROM THE MANUFACTURER OF THE GROUTED SPLICE COUPLER USED.



4.6.2 Pocket Connections

C4.6.2

Pocket or dowel connections provide a structural joint which can transmit moment and/or shear through the embedment of grouted reinforcing bars between the two elements.

There are two types of pocket connections. The first is a dowel pocket connection that is made by placing a single reinforcing bar within a pocket at the interface area between the two elements. The purpose of dowel pocket connections is to pin two elements together. An example of a dowel pocket connection would be an approach slab to abutment connection. The abutment reinforcing dowels might extend into a sleeve in the approach slab. Multiple dowel pocket connections can be detailed together in a pattern to form a moment connection. An example of this type of connection can be found in NCHRP Report Number 681 (Restrepo et al. 2011). The second type of pocket connection is a reinforced pocket connection that is made by placing multiple reinforcing bars within a pocket to form a structural connection. The purpose of reinforced pocket connections is to transfer forces between elements.

4.6.2.1 Specified Dowel Pocket Width

The specified minimum dowel pocket width defined on the plans should be based on the minimum tolerable edge distance of the reinforcing bar against the pocket side, the tolerances of the two connected elements, and the diameter of the dowel bar.

Specified minimum width of pocket connection:

$$S_w = 2t_{min_cl} + 2T_w + \varphi_b \tag{4.6.2.1-1}$$

where;

 $S_w =$ specified minimum width of pocket (in.) $t_{min_cl} =$ minimum tolerable clearance from face the dowel to the inside face of the pocket, measured perpendicular to the dowel (in.) $T_w =$ pocket dowel location tolerance (in.)

 φ_b = nominal reinforcing bar diameter (in.)

The recommended pocket dowel location tolerance for one bar should be:

 $T_w = 1^{1/4}$

An example of a reinforced pocket connection would be a wall cap to wall panel connection. The reinforcing bars from the wall panel might extend into a void in the cap element.

C4.6.2.1

The specified pocket width tolerance is set based on similar factors for joint openings; fabrication tolerances, erection tolerances, and probability of occurrence of additive tolerances. Also refer to Article C4.5.2.



Figure C4.6.2.1-1 Basis for Eq. 4.6.2.1-1

The minimum tolerable clearance is determined by the design based on the materials used to fill the pocket.

The value for T_w is based on fabrication and erection tolerances from Articles 2.6 and 3.9. The Designer may wish to modify the values in Articles 2.6 and 3.9. When this occurs the Designer may use equation C4.6.3.1-1 to calculate the pocket width tolerance. The 0.66 factor associated with T_w in this table is based on using the probability of occurrence of the maximum additive tolerances.

$$T_w = 0.66 \left(P + G + L_H \right) \tag{C4.6.2.1-1}$$

where;

- G = maximum fabrication reinforcing location tolerance for outer bars (in.)
- P = maximum fabrication pocket location tolerance (in.)
- L_H = horizontal erection tolerance of precast member (in.)



Figure C4.6.2.1-2 Pocket Width Tolerance

If the pocket is formed with a corrugated metal pipe or a metal post-tensioning duct, the specified inside diameter of the pipe or duct should be the required width calculated in Equation 4.6.2.1-1 rounded up to the next available pipe or duct size.

Projection Length

Straight bar projection lengths do not require a tolerance. It is recommended that the bar extension from one element be fabricated over length and cut in the field after erection of the element.

The bar extension should be based on the difference between the bottom of the upper element (top of shim stack) and the required embedment of the bar into the pocket.

4.6.2.3 Plumbness

4.6.2.2

All reinforcing should be fabricated plumb. If bars are out of plumb, they can be bent straight after fabrication.

4.6.3 Reinforced Pocket Connections

Reinforced pocket connections are made by placing multiple reinforcing bars within a pocket at the interface area between the two elements.

C4.6.2.4

Straight bar projections can be cut in field, therefore it is recommended that the reinforcement is installed longer than necessary and cut down in field, similar to dowels for grouted splice couplers. Coated bars will require field touch up coatings.

C4.6.3

Reinforced pocket connections can be made with pocket formed with an embedded corrugated metal pipe (CMP). The CMP pocket can serve two purposes; reduce weight of the element and provide a nominal moment and shear connection between the elements. A corrugated metal pipe (CMP) pocket connection is recommended for connecting a single cap to multiple wall elements. There would be a high potential for alignment problems with grouted couplers. The CMP void allows for greater element and erection tolerances.
4.6.3.1 Specified Reinforced Pocket Width

The specified minimum reinforced pocket width defined on the plans should be based on the minimum tolerable edge distance of the reinforcing bar against the pocket side, the tolerances of the two connected elements, the diameter of the bar, and the overall width of the reinforcing pattern.

Specified minimum width of reinforced pocket connection:

$$S_w = 2t_{min\ cl} + 2T_w + \varphi_b + s \tag{4.6.3.1-1}$$

where:

s = maximum distance between bar extremes, center-to-center of bars (in.)

 $S_w =$ specified minimum width of pocket (in.)

- tmin_cl = minimum tolerable clearance from face
 of reinforcing bars to inside face of the pocket,
 measured perpendicular to the reinforcing
 bars (in.)
- $T_w =$ pocket reinforcing location tolerance (in.)

 $\varphi_b =$ bar diameter (in.)

The recommended pocket reinforcing location tolerance for two or more bars should be:

$$T_w = 1^{1/4}$$

C4.6.3.1

The specified reinforced pocket width tolerance is set based on fabrication tolerances, erection tolerances, and probability of occurrence of additive tolerances.



Figure C4.6.3.1-1 Basis for Eq. 4.6.3.1-1

The minimum tolerable clearance is determined by the design based on the materials used to fill the pocket.

The value for T_w is based on fabrication and erection tolerances from Articles 2.6 and 3.9. The Designer may wish to modify the values in Articles 2.6 and 3.9. When this occurs the Designer should use equation C4.6.3.1-1 to calculate the pocket width tolerance. The 0.62 factor associated with T_w is based on using the probability occurrence of the maximum additive tolerances.

$$T_w = 0.62 \left(P + 2G + L_H\right) \tag{C4.6.3.1-1}$$

where;

- G = maximum fabrication reinforcing location tolerance for outer bars (in.)
- P = maximum fabrication pocket location tolerance (in.)
- L_H = horizontal erection tolerance of precast member (in.)



Figure C4.6.3.1-2 Reinforced Pocket Width Tolerance

If the pocket is formed with a corrugated metal pipe, the specified inside diameter of the pipe should be the required width calculated in Equation 4.6.3.1-1 rounded up to the next available pipe size.

Equation 4.6.3.1-1 can be used to determine the design spacing "s" of the connection based on a fixed pocket width. This would be the case if a specific CMP pipe pocket was used for the connection. The following example demonstrates this approach:

Givens: 18" inside diameter CMP pocket ($S_w = 18$ ") #6 bars (^{3/}4" diameter) $t_{min_cl} = 1$ " $T_w = \pm 1^{1/4}$ "

Re-writing terms:

$$s = S_w - 2t_{min_cl} - 2T_w - \varphi_b$$

= 18" - 2(1") - 2(1^{1/4}") - ^{3/4}"
= 12^{3/4}"

Therefore the maximum center to center spacing for this connection would be based on $12^{3/4}$ " spacing of the bars.

C4.6.3.3

Reinforcing bar projection length for hooked bars is based on the joint width below connecting element, design embedment depth, and the minimum joint width.

Projection Length

Specified Reinforcing Bar

4.6.3.2

Specified reinforcing bar projection length, see Figure 4.6.3.2-1:

Straight bar projections can be cut in field, therefore it is recommended that the reinforcement is installed longer than necessary and cut down in field, similar to dowels for grouted splice couplers.

$$N' = t_{min_{jt}} + T_{jt} + N \tag{4.6.3.2-1}$$

where:

- N = reinforcing bar design embedment length required by design(in.) $t_{min_{jt}} =$ minimum tolerable joint thickness (in.)
- $T_{jt} =$ joint thickness tolerance (in.)

See Table 4.5.2.2 to obtain values for tolerable joint thickness, T_{jt} .

The designer should specify the minimum joint width based on the material chosen to fill the joint.



Figure C4.6.3.2-1 Reinforcing Bar Projection Length in Pocket Section

4.6.3.3 Pocket Depth

The specified pocket depth is based on reinforcement projection length, minimum joint thickness, and the minimum reinforcing clearance.

Specified pocket depth, see Figure C4.6.3.3-1:

$$P = t_{min_cl} + t_{min_jt} + N'$$
 (4.6.3.3-1)

where:

- N' = specified reinforcing bar projection length (in.)
- t_{min_cl} = minimum tolerable clearance between face of reinforcing and end face of pocket (in.)
- t_{min_jt} = minimum tolerable joint thickness (in.)

See Equation 4.6.3.2-1 to obtain values for specified reinforcing bar projection length, N'.



Figure C4.6.3.3-1 Pocket Depth Section

4.6.4 Integral Abutment Pile Pocket Connections

Integral abutments are pile supported structures that provide a full moment connection between the superstructure and the abutment. The abutment stem is integral with the piles requiring a fixed connection. Corrugated metal pipe (CMP) pockets are typically used to make this connection with piles and drilled shafts. The element is placed over the piles and the pocket is filled with concrete to complete the connection.

The CMP pocket should be sized to account for the horizontal location tolerances of the CMP void in the precast abutment stem and the pile or drilled shaft.

4.6.4.1 Specified Pile Pocket Width

The specified pile pocket width defined on the plans is the absolute minimum tolerable width that accounts for the pocket width tolerance, the required edge clearances for the pile, and the largest width of the pile.

Specified width of pile pocket connection:

$$S_w = 2t_{min\ cl} + O.D. + 2T_w \tag{4.6.4.1-1}$$

where:

 t_{min_cl} = minimum tolerable clearance (in.)

- S_w = specified width of pile or drilled shaft void (in.)
- T_w = pile pocket width tolerance (in.)
- O.D. = outer diameter of drilled shaft and pipe pile or measured diagonally from corners of H-pile (in.)

Table 4.6.4.1-1 – Pile Pocket Width Tolerance, T_w

G	T_w
(in.)	(in.)
3	3 1/4
6	6 ^{1/} 8
9	9 ^{1/}

C4.6.4

Additional CMP pockets can also be detailed to reduce the shipping and handling weight of the abutment stem. They can be filled with concrete at the same time as the filling operation for the pile connections.

C4.6.4.1

The value for T_w is based on fabrication and erection tolerances from Articles 2.6 and 3.9. The Designer may wish to modify the values in Articles 2.6 and 3.9. When this occurs the Designer should use Table C4.6.4.1 to calculate the pocket width tolerances. The factor associated with T_w in this table is based on using the probability occurrence of the maximum additive tolerances.

Table C4.6.4.1 – Pocket Width Tolerance, Tw

G	T_w
(in.)	(in.)
3	$\pm 0.72 (P+G+L_H)$
6	$\pm 0.81 (P+G+L_H)$
9	$\pm 0.86 \ (P{+}G{+}L_{H})$

where:

- G = maximum pile or drilled shaft lateral installation tolerance (in.)
- P = maximum fabrication pocket location tolerance (in.)
- L_H = horizontal erection tolerance of precast member (in.)
- T_w = width of pile void connection tolerance (in.)

Note the maximum pile or drilled shaft lateral installation tolerance, G, typically varies between States. Table C4.6.4.1 gives a typical range of values of G to determine the void width tolerance.



Figure C4.6.4.1-1 Basis for Eq. 4.6.4.1-1

If the pockets are formed with a CMP pocket, the specified width of the pipe should be the minimum required width calculated in Equation 4.6.4.1-1 rounded up to the next available pipe size.

Example: HP12x74 Pile in CMP Pocket

Givens: Pile dimensions

d = 12.13" bf = 12.22" Specified pile installation tolerance = ± 3 " Specified min. corner gap = $2t_{min \ cl} = \frac{1}{2}$ "

Solution:

Diagonal corner to corner dim., O.D. = 17.22" $T_w = \pm 3^{1/4}$ " (see Table 4.6.4.1-1) $S_w = 2(1/2") + 17.22" + 2(3^{1/4}") = 24.72"$

Round up to the next larger CMP Use a 27" diameter CMP

4.6.5 Closure Joint with Lapped Reinforcing Bars

This provision is for closure joints between elements that have lapped reinforcing bars. The tolerances for the joint width are similar to vertical joints between other elements. An additional tolerance is required for the required lap splice length.

C4.6.5

Typical uses of this joint are between Precast Full-Depth Deck Panels and Modular Deck Beam Elements. The specified closure joint width defined on the plans is the minimum tolerable width that accounts for the minimum reinforcing bar splice length, bar clearances, and the bar splice tolerance.

Specified closure joint width:

$$S_{cjw} = L_{lap} + T_{lap} + 2t_{min_cl} + T_{cjw}$$
(4.6.5.1-1)

where:

- L_{lap} = required minimum lap length (in.)
- S_{cjw} = specified width of closure joint (in.)
- t_{min_cl} = minimum tolerable clear distance from the end of the bar to the adjacent element (in.)
- T_{cjw} = closure joint width tolerance as specified in Article 4.5.2.1 (in.)
- T_{lap} = reinforcing bar lap length tolerance as specified below (in.)

The specified reinforcing bar lap length defined on the plans is the minimum required lap length that accounts for the minimum reinforcing bar splice length and the bar splice tolerance.

Specified lap length:

 $S_{lap} = L_{lap} + T_{lap}$ (4.6.5.1-2)

where:

 L_{lap} = required minimum lap length (in.) S_{lap} = specified length of lap (in.) T_{lap} = lap length tolerance (in.)

Table 4.6.5.1-1 Lap Length Tolerance, *T*_{lap}

Element Type	<i>T</i> _{<i>lap</i>} (in.)
Full-Depth Deck Panels	1/2
Modular Deck Beams	3/4

C4.6.5.1

The value for T_{jw} is based on fabrication and erection tolerances from Articles 2.7 and 3.9. The Designer may wish to modify the values in Articles 2.7 and 3.9. When this occurs the Designer should use the equations noted in Article 4.5.2.1 to calculate the closure joint width tolerance.



Figure C4.6.5.1-1 Basis for Eq. 4.6.5.1-1 and Eq. 4.6.5.1-2

The value for T_{lap} is based on fabrication and erection tolerances from Articles 2.7 and 3.9. The Designer may wish to modify the values in Articles 2.7 and 3.9. When this occurs the Designer should use equation C4.6.3.1-1 to calculate the lap length tolerance. The factor associated with T_{lap} in this equation is based on using the probability occurrence of the maximum additive tolerances.

For Full-Depth Deck Panel Connections:

$$T_{lap} = 0.24 [0.5(A_L + A_R + L_{HL} + L_{HR}) + maximum of (D_L + D_R), (H_R + H_L + F_L + F_R) + Q_L + Q_R] (Eq. C4.6.5.1-1)$$

For Modular Deck Beam Flange Connections:

$$T_{lap} = 0.26 [0.5(A_L + A_R + L_{HL} + L_{HR}) + maximum of (D_L + D_R), (H_R + H_L + F_L + F_R) + Q_L + Q_R] (Eq. C4.6.5.1-2)$$

where:

- A_L = maximum fabrication length tolerance of left element (in.)
- A_R = maximum fabrication length tolerance of right element (in.)
- D_L = maximum fabrication end skew/squareness

tolerance of left element (in.)

- D_R = maximum fabrication end skew/squareness tolerance of right element (in.)
- F_L = maximum fabrication sweep tolerance of left element (in.)
- F_R = maximum fabrication sweep tolerance of right element (in.)
- H_L = maximum fabrication smoothness tolerance of left element (in.)
- H_R = maximum fabrication smoothness tolerance of right element (in.)
- L_{HL} = maximum horizontal erection tolerance of left element (in.)
- L_{HR} = maximum horizontal erection tolerance right element (in.)
- Q_L = maximum bar projection tolerance for left element (in.)
- Q_R = maximum bar projection tolerance for right element (in.)

4.7 **REFERENCES**

ACI Specification for Tolerances for Precast Concrete, ACI ITG-7-09, American Concrete Institute, Farmington Hills, MI, (2009)

Culmo, M.P., et al, *Guidelines for Prefabricated Bridge Elements and Systems Tolerances and Dynamic Effects of Bridge Moves*, Final Report, NCHRP Project 12-102, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C. (2017)

PCI Northeast Guideline for Accelerated Bridge Construction Using Precast/Prestressed Concrete Elements Including Guideline Details, PCINE-12-ABC, PCI Northeast Bridge Technical Committee (2014)

PCI Tolerance Manual for precast and Prestressed Concrete Construction - MNL-135-00, Precast Prestressed Concrete Institute, Chicago, IL, (2000)

Restrepo, J.I., Et al, *Development of a Precast Pier cap System for Seismic Regions*, NCHRP Report 681, National Cooperative Highway Research Program, Washington, D.C (2011)