

Technical Guideline

**Recommendations for the Design, Construction, and
Management of Highly Skewed Bridges (>45°)**

July 2026

Copyright

© The State of Queensland (Department of Transport and Main Roads) 2026.

Licence



This work is licensed by the State of Queensland (Department of Transport and Main Roads) under a Creative Commons Attribution (CC BY) 4.0 International licence.

CC BY licence summary statement

In essence, you are free to copy, communicate and adapt this work, as long as you attribute the work to the State of Queensland (Department of Transport and Main Roads). To view a copy of this licence, visit: <https://creativecommons.org/licenses/by/4.0/>

Translating and interpreting assistance



The Queensland Government is committed to providing accessible services to Queenslanders from all cultural and linguistic backgrounds. If you have difficulty understanding this publication and need a translator, please call the Translating and Interpreting Service (TIS National) on 13 14 50 and ask them to telephone the Queensland Department of Transport and Main Roads on 13 74 68.

Disclaimer

While every care has been taken in preparing this publication, the State of Queensland accepts no responsibility for decisions or actions taken as a result of any data, information, statement or advice, expressed or implied, contained within. To the best of our knowledge, the content was correct at the time of publishing.

Feedback

Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

Contents

1	Introduction	1
1.1	Purpose	1
1.2	Scope	1
1.3	Background	1
1.4	Definitions and acronyms	2
2	Understanding the behaviour of highly skewed bridges	2
2.1	Load path and structural behaviour	2
2.2	Performance effects and common defects	3
3	Design guidance	4
3.1	Design considerations for high skew	4
3.2	Applicable standards and agency requirements	5
3.3	Modelling and analysis methods.....	6
3.3.1	<i>Skew angles <25°</i>	6
3.3.2	<i>Skew angles >25°</i>	6
3.4	Detailing considerations	7
3.4.1	<i>Concept design stage</i>	8
3.4.2	<i>Superstructure detailing</i>	8
3.4.3	<i>Substructure and bearing detailing</i>	8
3.4.4	<i>Deck and reinforcement detailing</i>	8
3.4.5	<i>Joint and shear key detailing</i>	9
3.5	Material and structural considerations	9
3.5.1	<i>Concrete bridges</i>	10
3.5.2	<i>Steel bridges</i>	10
3.5.3	<i>Substructure and bearings</i>	10
3.6	Seismic and dynamic considerations.....	10
4	Manufacturing and construction guidance	11
4.1	Precast unit manufacture.....	11
4.2	Deck construction	11
4.3	Steel girder construction	11
4.4	Construction sequence and quality control measures	12
5	Operation and maintenance	12
5.1	Typical in-service behaviours	12
5.2	Inspection focus areas.....	13
5.3	Data analysis findings.....	13
5.4	Maintenance and intervention strategies	13
6	Stakeholder and industry learnings	14
6.1	Road agency insights	14
6.2	Precaster insights	15
7	Best practices and implementation summary	15

7.1	Bridge selection and approval	15
7.2	Design	16
7.3	Manufacturing and construction.....	16
7.4	Operation and maintenance	17
7.5	Key takeaway	17
8	References and supporting literature.....	17
8.1	Referenced documents	17
8.2	Supported literature and further reading.....	19

1 Introduction

1.1 Purpose

This document provides practical implementation of the findings of the NACOE S71 report: *Limitations of Highly Skewed Bridges*, by translating the consolidated research, field observations and stakeholder learnings into guidance for the design, construction and management of highly skewed bridges. It supports practitioners in understanding the structural behaviour, risks and detailing considerations associated with bridges where the skew angle exceeds 45°, referred to as extreme skew in Queensland Department of Transport and Main Roads' (the department) *Design Criteria for Bridges and Other Structures*.

1.2 Scope

This document applies to the planning, design, construction, operation and maintenance of bridges with skew angles greater than 45°. It is intended for use by bridge designers, constructors, precasters, asset managers and reviewing authorities involved in the approval and delivery of bridge structures with extreme skew.

It focuses on the practical application of the research findings to ensure that the risks associated with high skew can be identified, evaluated and managed throughout the lifecycle of a bridge. Specifically, the guideline outlines:

- behavioural characteristics of highly skewed bridges
- design considerations relevant to high skew
- detailing requirements to address localised defects
- construction implications arising from skew geometry, and
- operational management practices that are specific to extreme skew.

1.3 Background

The occurrence of highly skewed bridges in infrastructure is driven primarily by geometric constraints, floodplain restrictions and road alignment requirements. Unlike straight or minorly skewed bridges, high skew introduces additional structural complexity due to non-orthogonal load paths, uneven distribution of forces, localised concentration of stress and amplification of torsional effects.

The NACOE S71 project was initiated to investigate whether highly skewed bridges in Queensland exhibit reduced durability or performance limitations when compared with non-skewed or moderately skewed structures. The investigation combined literature review, analysis of departmental bridge inventory data, targeted field inspections, and technical consultation with road agencies and industry stakeholders. The findings indicated that when skew is designed and detailed appropriately, highly skewed bridges perform comparably to non-skewed counterparts. The more significant risks relate to individual bridge components and detailing features rather than the overall structural system performance.

1.4 Definitions and acronyms

Table 1 lists the definitions and acronyms that are adopted for the purpose of this document.

Table 1 – Definitions and acronyms

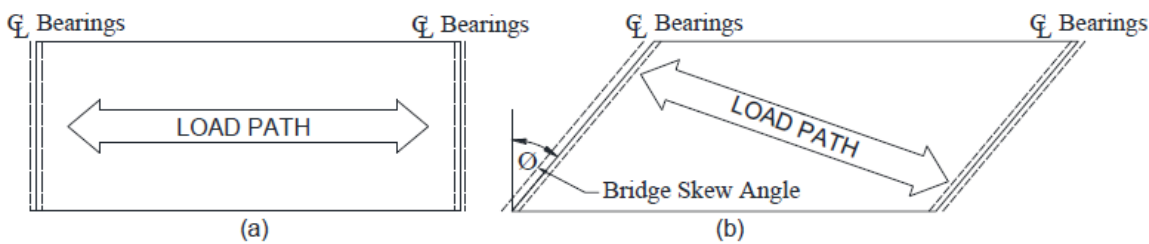
Term	Description
AASHTO	American Association of State Highway and Transportation Officials
DCBOS	<i>Design Criteria for Bridges and Other Structures</i>
FEA	Finite Element Analysis
MRWA	Main Roads Western Australia
NZTA	New Zealand Transport Agency Waka Kotahi
PSC	Prestressed Concrete
TfNSW	Transport for New South Wales

2 Understanding the behaviour of highly skewed bridges

2.1 Load path and structural behaviour

Highly skewed bridges exhibit structural behaviour that differs from orthogonal bridges due to the directional misalignment between the applied loads and the principal supporting elements. Rather than transferring loads perpendicular to the supports, the governing load path often follows a diagonal trajectory towards the obtuse corner of the bridge (Figure 2.1). This redistribution can cause uneven support reactions and increase torsional demand on the structure. *Design and Performance of Highly Skewed Deck Girder Bridges* (Okumus et al. 2018) provides a detailed literature review of the effects of skew on bridges.

Figure 2.1 – Load paths in straight and skewed bridge decks



Source: Reprinted with permission Okumus et al. 2018, 'Load paths in (a) non-skewed and (b) skewed bridges', p. 4, copyright by authors, Wisconsin DoT, WI.

The skewed geometry also affects the deformation profile of the deck, leading to a combination of bending, shear and twisting effects. Under live loading, the acute corner of the bridge may experience greater rotation and displacement, which can in turn influence joint opening, bearing movement and the required support length at bearings to accommodate rotation at abutments and piers.

2.2 Performance effects and common defects

The performance characteristics of highly skewed bridges are influenced not only by their geometry but also by detailing practices and restraint conditions at the deck edges and bearings. Field observations and literature (Ebeido & Kennedy 1995; Hambly 1991; Fu et al. 2007) indicate that deterioration in highly skewed bridges is often concentrated in localised regions, particularly around the acute and obtuse corners, rather than uniformly across the structure.

Typical issues observed include:

- cracking in the deck slab near acute corners due to increased stress at this location
- end rotation of girders, particularly during service or construction stages
- misalignment at supports, resulting from differential movement across the skew
- increased wear or damage to bearings and restraint systems caused by uneven load paths, and
- spalling at girder ends or around diaphragm anchorage zones.

These effects are generally most pronounced where:

- deck restraint is high, limiting natural rotational movement, and
- detailing does not adequately accommodate the rotational behaviour and torsional demands.

3 Design guidance

This section outlines the key design considerations for highly skewed bridges and provides guidance on how to evaluate and address the structural effects associated with skew. It draws directly from the research findings to highlight the design elements that require particular attention due to their influence on load paths, torsional behaviour, localised stresses and overall structural performance. The guidance in this section covers:

- design principles for managing skew-related effects
- reference standards and requirements
- modelling and analysis approaches, including when advanced analysis is warranted
- detailing considerations, particularly for acute corners and bridge restraint
- material and structural behaviour, and
- seismic and dynamic considerations

3.1 *Design considerations for high skew*

Designers should recognise that skew influences the manner in which loads are transferred through the superstructure and into the supporting elements. Rather than being distributed uniformly, loads tend to follow a diagonal load path towards the obtuse corner of the structure. This behaviour results in:

- torsional effects in deck and girder elements caused by skewed load transfer
- uneven shear distribution across supports
- differential reactions at bearings and substructure elements, and
- localised high stress regions, particularly near the acute corners.

These effects are inherent to skewed geometry, become more pronounced as the skew angle increases and should be considered in design to ensure appropriate performance.

Analytical models used for the design of highly skewed bridges should accurately reflect the expected structural behaviour. This includes appropriate representation of:

- boundary conditions and restraint behaviour
- relative stiffness of structural components
- rotational capacity of the deck and bearings, and
- load transfer mechanisms associated with skewed geometry.

Simplified modelling approaches may be suitable for low skew angles; however, as skew increases, more refined analysis may be required to adequately capture torsional effects, non-uniform load distribution and localised response.

Both global and local effects of skew should be considered in design. Detailing of reinforcement, bearing orientation, diaphragm configuration and support geometry can significantly influence how skew-related actions are accommodated.

Restraint conditions should be selected and detailed to allow for necessary rotational movements of the superstructure and limit unnecessary stress concentrations. Appropriate allowance for movement is needed to ensure reliable performance in highly skewed bridge structures.

3.2 Applicable standards and agency requirements

Several bridge design manuals state additional considerations in relation to skew. Where applicable, the following documents apply in order of precedence:

1. Australian Standard (AS) 5100:2017 *Bridge Design*
2. Transport and Main Roads *Design Criteria for Bridges and Other Structures* (DCBOS)
3. Austroads *Bridge Assessment Guideline – 2025*, Appendix F
4. Austroads Guides and technical publications

The DCBOS identifies a skew angle greater than 45° as constituting an extreme skew. Structures in this category are not readily accepted and require additional consideration of structural behaviour, detailing and construction methodology, as well as specific approval in accordance with departmental requirements. In addition, Austroads *Bridge Assessment Guideline – 2025*, Appendix F, provide supplementary guidance on structural modelling, including recommendations for when Finite Element Analysis (FEA) should be adopted to ensure realistic representation of stiffness and boundary conditions for skewed superstructures.

AS 5100:2017 establishes the overarching national requirements for bridge design, and Austroads guidance further supports the interpretation of AS 5100 provisions in practice. While AS 5100 does not explicitly prescribe skew thresholds, it requires designers to adopt analysis methods that reflect the actual geometry and torsional effects present in the structure.

Other Australian and international agencies adopt lower trigger values, typically in the order of 25° to 35°, for additional analysis or review of skew effects. Main Roads Western Australia (MRWA) and Transport for New South Wales (TfNSW) both identify the need for additional design consideration at lower skew thresholds than those identified by the department as constituting extreme skew. The American Association of State Highway and Transportation Officials (AASHTO 2020) provides detailed guidance on reinforcement detailing, deck behaviour and load distribution for skewed bridge configurations. In contrast, departmental guidance identifies the need to consider skew-related effects outside of normal structural behaviour but does not provide specific detailing approaches.

Several agencies place limitations on the use of integral and semi-integral bridge configurations in skewed conditions. Guidance from TfNSW, the Victorian Department of Transport and Planning (DTP), and NZTA indicates typical skew limits in the order of 20–30°, reflecting the increased complexity associated with thermally induced movements, plan rotation, and higher horizontal loads on abutments and foundations.

3.3 Modelling and analysis methods

Accurate modelling is essential for understanding how skew influences the structural behaviour of a bridge. Analytical models should be developed to represent the actual structural performance, including load paths, restraint conditions, and deformation behaviour. As the skew angle increases, the load path becomes more diagonal relative to the supports, which affects torsion, shear distribution, and support reactions. Different modelling approaches are therefore appropriate depending on the magnitude of skew.

3.3.1 Skew angles <25°

For bridges with skew angles less than 25°, simplified analytical methods generally remain reliable. Designers may use grillage models.

This approach is acceptable because, at low skew, structural behaviour remains close to that of an orthogonal bridge. However, designers should still be aware that simplified models may:

- underestimate torsional effects
- slightly misrepresent load distribution, and
- overlook local stress concentrations.

For small skew, these limitations are typically minor and do not significantly affect global behaviour (Arancibia et al. 2020).

3.3.2 Skew angles >25°

As skew increases beyond approximately 25°, simplified models, such as grillage models, become progressively less accurate (O'Brien et al. 2014). They may:

- misrepresent support reactions
- underestimate torsional stiffness
- fail to capture diagonal deformation patterns, and
- overlook localised effects near acute corners and bearings.

For these reasons, FEA using plate, shell or brick models, may be required where simplified approaches do not adequately capture skew-related behaviour.

FEA more accurately captures:

- coupled bending and torsional responses
- non-uniform support reactions
- localised stresses, especially near acute corners, and
- interaction between diaphragm stiffness, bearing configuration and deck rotation.

When using FEA for moderate to extreme skew angles, designers should ensure that:

- the mesh is aligned with the bridge geometry, with element orientation following the skewed layout of the structure
- mesh refinement is provided around:
 - bearings
 - diaphragms, and
 - acute and obtuse deck corners.
- boundary conditions reflect the actual articulation, including realistic rotational and translational restraints, and
- partial restraint conditions may be modelled using torsional releases or elastic links, particularly at abutments.

The selection of a modelling approach should be based on engineering judgement, including consideration of whether simplified models remain valid and when advanced modelling should be adopted to achieve accurate stress and deformation predictions. Austroads *Bridge Assessment Guideline – 2025*, Appendix F, provides additional direction on the representation of superstructure stiffness and boundary conditions for skewed bridges.

3.4 Detailing considerations

Effective detailing is essential to control the localised effects caused by high skew and to ensure that the designed behaviour is achieved in practice. The following detailing guidance is presented in the general sequence of design development, from conceptual layout through to deck reinforcement and joint detailing.

3.4.1 Concept design stage

At the early stage of design, the arrangement of supports, bearings and diaphragms should be configured to minimise restraint where possible and to allow the deck to deform naturally under skewed loading. This includes selecting bearing types and orientations that accommodate anticipated movements, avoiding overly rigid restraint conditions, and configuring diaphragms and support layouts to prevent locking of rotational behaviour, particularly at acute corners. The number of spans, position of expansion joints and abutment configuration should be reviewed with consideration of rotation and lateral translation effects. Where feasible, reducing skew by adjusting alignment or span layout should be evaluated during the concept design phase to limit complexity.

3.4.2 Superstructure detailing

For the superstructure, attention should be given to the orientation of girders and diaphragms. Where Precast Prestressed Concrete (PSC) units are used, the DCBOS limit of 45° for casting skew should be observed. Girders should be detailed to accommodate twisting effects and diaphragms should be configured to provide stiffness without over-restraining end rotation. For steel girders, lateral bracing and flange design must account for torsional effects.

3.4.3 Substructure and bearing detailing

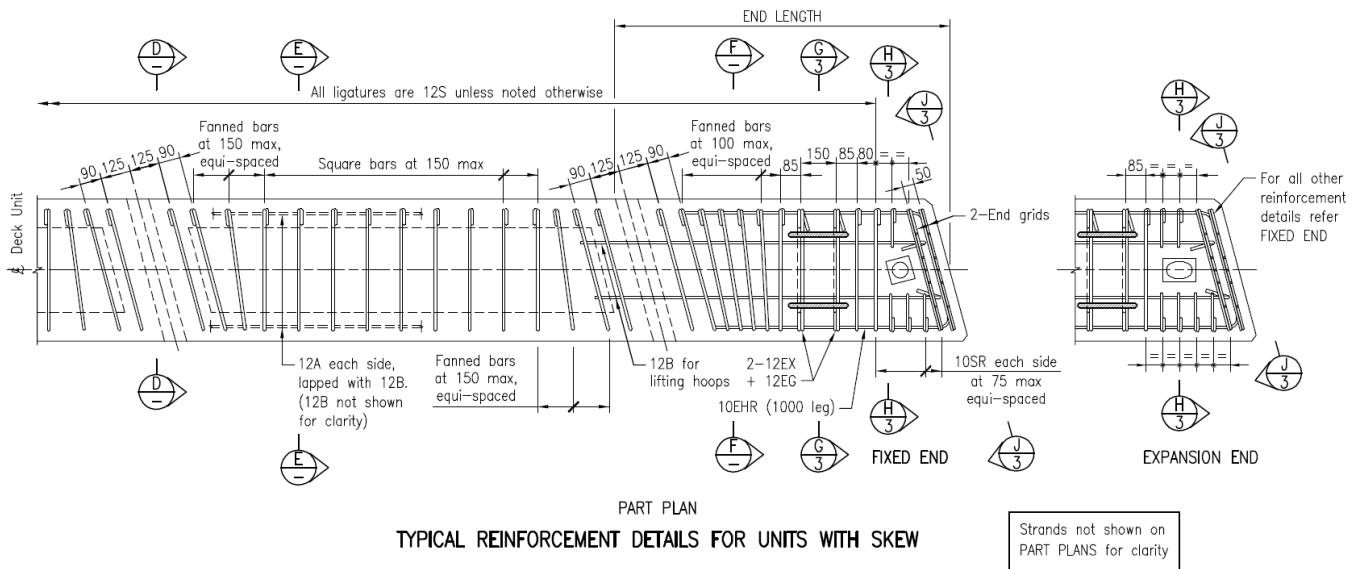
Bearings and restraints should be detailed to permit realistic degrees of movement and rotation. The skewed geometry may result in bearings that experience combined longitudinal and transverse movements; these should be addressed through appropriate bearing selection or orientation. This may include selecting bearing types that accommodate multi-directional movement, and detailing restraint systems to avoid restriction of rotational behaviour. Restraint angles should be verified to ensure they align with the expected direction of deck movement, reducing the likelihood of restraint damage.

Austrroads recommends selecting circular bearings for skew bridges as they provide consistent stiffness in all directions (Austrroads 2018a).

3.4.4 Deck and reinforcement detailing

Reinforcement layouts should provide additional capacity near acute corners where stress concentrations and cracking are most likely to occur. Reinforcement anchorage should be extended around openings and joints to mitigate localised cracking. Construction joints should be aligned to suit the skew, reducing the risk of uncontrolled cracking along restraint lines. Figure 3.4.4 shows typical reinforcement details for units with skew.

Figure 3.4.4 – Typical reinforcement details for units with skew



Source: Reprinted with permission Transport and Main Roads 2018, ‘Typical reinforcement details for units with skew’, extract from Standard Drawing No. 2059, copyright by Transport and Main Roads, QLD.

3.4.5 Joint and shear key detailing

Expansion joints should be detailed to accommodate combined skewed movements and avoid binding. Shear keys and diaphragms should be detailed to distribute torsional demands and avoid localised force concentration. At abutments, designers should ensure that joint gaps and seat lengths meet or exceed minimum standards to mitigate the risk of unseating during differential movement, thermal expansion and seismic action.

3.5 Material and structural considerations

Material selection and structural configuration influence how skew-related effects are distributed and resisted within a bridge. In practice, these considerations are most significant for girder bridge systems, where the interaction between deck behaviour, girder response and restraint conditions govern overall performance.

The differences between concrete and steel superstructures result in different sensitivities to torsion, restraint and construction-stage behaviour. Concrete bridges are generally more sensitive to cracking and restraint effects, while steel bridges require greater attention to torsional stiffness and construction stability. These differences should be addressed through appropriate detailing, sequencing and material specification to ensure satisfactory performance across all skew angles.

3.5.1 Concrete bridges

For PSC bridges, the acute corner of girders is particularly vulnerable during transfer, where the combination of skew and hogging behaviour can result in localised bearing at the corner. This can lead to spalling of the corner concrete if reinforcement detailing and anchorage are not adequate, and should be addressed through appropriate end detailing and reinforcement layout.

3.5.2 Steel bridges

For steel girder bridges, the main implications of skew relate to torsional stiffness and stability during the construction stage. Skewed geometry can cause differential deflection between girders, leading to twisting of flanges and out-of-plane bending before the deck is cast. To manage these effects, lateral bracing systems should be designed to resist torsion during deck placement and diaphragm connections should be arranged to distribute shear forces effectively.

3.5.3 Substructure and bearings

The substructure must be designed to accommodate the combined vertical, longitudinal, and transverse loads induced by skew. Piers, abutments and bearings experience uneven load distribution, which may cause higher reactions at obtuse corners. Bearings should be designed or oriented to account for these combined movements and torsional demands. Where the structure relies on integral abutments or fixed bearings, designers should consider the additional stresses imposed by differential movement, noting that some agencies place limitations on the use of such systems in skewed configurations.

3.6 *Seismic and dynamic considerations*

Although seismic design is not typically the controlling factor for most Queensland bridge structures, the influence of skew on dynamic and seismic response should not be overlooked. Skewed bridges can experience asymmetric seismic response due to their geometry, leading to concentration of displacement and shear demand at the obtuse corners or along the abutment lines. Torsional coupling between longitudinal and transverse directions becomes more pronounced as skew increases, which can result in differential bearing displacements and uneven load transfer to the substructure. Designers should therefore ensure that bearings, restraint systems and seat lengths are detailed to accommodate these movements and prevent unseating under seismic and other extreme loading conditions.

4 Manufacturing and construction guidance

4.1 Precast unit manufacture

The manufacture of precast elements for highly skewed bridges presents practical challenges related to formwork geometry, reinforcement layout and handling. The DCBOS limits the casting of PSC units to a maximum skew of 45°, which aligns with manufacturing capabilities within Queensland precasting facilities. At higher skews, the complexity of the end geometry increases the likelihood of reinforcement congestion, concrete placement difficulties and spalling near anchorages.

Precasters should confirm that strand profiles, voids and lifting points are correctly aligned to accommodate the skew. Ligatures and reinforcement must be fanned appropriately to follow the load path while maintaining clear cover and spacing. Special attention should be given to end detailing to prevent cracking or spalling during demoulding, transport and installation. Where skewed casting moulds are used, rigorous dimensional control is required to ensure alignment during assembly on site.

4.2 Deck construction

The construction of deck slabs on highly skewed bridges requires careful planning to control restraint and pour sequencing. Concrete shrinkage and temperature variation across the skewed geometry can lead to localised stress concentrations, particularly at the acute corners and diaphragm interfaces. To mitigate these risks, concrete pours should be sequenced in a manner that allows for uniform strain development and minimises restraint between adjacent pours. Reinforcement placement must ensure continuity and anchorage around the acute corners, with particular attention given to detailing near diaphragms, shear keys and abutment connections. Effective curing practices are critical to limiting thermal and shrinkage cracking, and the use of insulating materials or staged curing may need to be considered in extreme temperature conditions. Any early-age cracking should be monitored and managed in accordance with Transport and Main Roads Technical Specification (MRTS) MRTS70 *Concrete*.

4.3 Steel girder construction

For steel girder bridges, the construction process must account for torsional instability and differential deflection between girders that arise from the skewed geometry. During the non-composite stage, before the deck slab provides additional stiffness, girders are susceptible to additional twisting and lateral movement. Temporary bracing or cross frames should be installed to maintain alignment and control torsional distortion until composite action is achieved.

Erection tolerances are critical for maintaining the intended geometry of the skewed structure. Diaphragm and cross-frame placement should be verified during assembly to ensure that alignment and fit-up are consistent with the design intent. The skewed layout may also result in uneven load distribution during deck pouring, requiring adjustments to the pour sequence or temporary support arrangements.

4.4 Construction sequence and quality control measures

Construction sequence planning is vital for ensuring that stresses induced by restraint, differential settlement or temperature changes do not lead to early defects. Designers and constructors should collaborate early to ensure construction staging maintains structural stability throughout each phase of construction. Where bridges are constructed under traffic or constrained site conditions, sequence staging should minimise asymmetrical loading on partially completed spans.

Quality control measures should include verification of bearing orientation, joint gap dimensions and deck alignment prior to concreting. The use of detailed inspection checklists for skewed bridge elements, covering reinforcement placement, formwork geometry and bearing seating, is recommended to maintain consistent construction quality. Temperature and humidity monitoring during the deck pour can help identify environmental conditions that may contribute to cracking or restraint-induced stress.

Communication between designers, contractors and precasters is essential throughout manufacturing and construction to ensure that design intent is clearly understood and executed. Early involvement of precast specialists during design development is recommended to address potential constructability constraints for bridges with extreme skew angles.

5 Operation and maintenance

5.1 Typical in-service behaviours

The operational performance of highly skewed bridges is largely influenced by the interaction between structural geometry, restraint conditions and environmental factors. Over time, the differential movements and rotational tendencies inherent in skewed layouts can manifest as minor but progressive distortions, localised cracking or misalignment at bearings and joints. These effects tend to be concentrated at the acute and obtuse corners of the bridge, where stress concentrations and movement differentials are greatest.

Field investigations carried out as part of the NACOE S71 project indicate that most observed issues related to skew in skewed bridges are localised rather than systemic. The primary forms of in-service behaviour include small rotational displacements at supports, uneven load sharing between bearings and localised cracking in the deck slab or diaphragms.

5.2 Inspection focus areas

Routine and detailed inspections of highly skewed bridges should pay particular attention to areas most susceptible to skew-related deterioration. These include:

- bearings and restraints: inspect for rotation, bearing walking, binding or offset movements that indicate uneven load distribution
- deck slab and acute corners: check for cracking or spalling related to stress concentration or restraint effects
- joints and abutments: verify that expansion joints are operating freely and not binding under combined longitudinal and transverse movement
- parapets and barriers: inspect for cracking or differential displacement near acute and obtuse corners, and
- substructure and piers: observe for signs of differential movement, rotation or localised distress, particularly where these may be influenced by skew-related behaviour.

Inspection data from the department's Bridge Information System (BIS), analysed as part of the NACOE S71 project, has shown no strong correlation between skew angle and overall bridge condition rating, supporting the conclusion that well-designed skewed bridges can perform comparably to non-skewed bridges. However, skew can amplify the severity of localised defects, reinforcing the need for targeted inspection strategies.

5.3 Data analysis findings

Analysis of the department's bridge inventory data undertaken in the NACOE S71 project showed that bridges with skew angles exceeding 45° constitute a small percentage of the overall network. The data indicated that while certain localised defects such as deck and abutment cracking was observed in skewed bridges, there was no consistent trend towards poorer overall condition or reduced service life. The findings indicate that geometric skew alone does not dictate performance outcomes. However, given the relatively small proportion of highly skewed bridges within the dataset, these observations should be interpreted with caution.

5.4 Maintenance and intervention strategies

Maintenance planning for highly skewed bridges, both new and existing, should prioritise the early identification and mitigation of localised defects. Proactive inspection and timely intervention can prevent minor issues, such as bearing rotation or deck cracking, from progressing into more significant maintenance concerns.

Recommended strategies include:

- monitoring bearings and restraints for rotation, corrosion or wear
- maintaining effective joint seals and drainage to prevent water ingress, and
- repairing minor deck and diaphragm cracking promptly using compatible materials.

These strategies are generally implemented through existing asset management frameworks, including inspection regimes, maintenance planning processes and supporting documentation such as inspection manuals and asset management guidelines. Where required, skew-specific considerations may be incorporated into these processes to ensure that movement-sensitive components are appropriately monitored.

Importantly, skewed bridges are not inherently less durable than non-skewed structures. Where localised defects are observed, these may be associated with aspects of design detailing, construction practices or restraint conditions that have not fully accounted for the effects of skew. Targeted inspection and maintenance of movement-related components is therefore required to manage these effects. With appropriate management, the operational lifespan of skewed bridges can be equivalent to that of non-skewed structures.

6 Stakeholder and industry learnings

6.1 Road agency insights

Consultation with state and territory road agencies, undertaken as part of the NACOE S71 project, provided valuable insights into how skewed bridges are currently managed in design, construction and maintenance practice. Across jurisdictions, there is consistent recognition that the risks associated with high skew are best addressed through early design review and by adopting a systems-based approach that considers geometry, detailing, and constructability collectively.

The department identifies 45° as the threshold beyond which additional design scrutiny is required. Similar practices exist in other states, with MRWA and TfNSW applying more conservative thresholds of 25° to 35°. Across the agencies consulted, there was emphasis that challenges associated with skew are often linked to local detailing, such as restraint design, diaphragm configuration and reinforcement concentration.

All agencies consulted also highlighted the importance of incorporating lessons from field performance and maintenance data into design refinements, which may be achieved through updates to design guidance, standard drawings and inspection manuals. The adoption of finite element modelling for complex skewed structures, improvements in bearing design and the standardisation of detailing around acute corners were identified as key developments over recent years. Where issues have occurred, they have typically been traced to inadequate consideration of rotational compatibility or construction sequencing rather than fundamental structural design flaws.

6.2 Precaster insights

Feedback from the precast industry indicated that manufacturing challenges increase markedly once skew angles exceed 35° to 40°. These challenges relate to reinforcement congestion, mould complexity and the risk of concrete cracking or spalling during demoulding and handling. Precasters noted that achieving the required dimensional tolerances becomes more difficult as skew increases, particularly when coordinating with adjoining units in multi-span configurations.

To address these challenges, early coordination between designers and precasters was identified as essential. This includes verifying that proposed reinforcement arrangements are practical and that strand layout, void alignment and lifting points can be accommodated without compromising cover or structural integrity. The industry also stressed the importance of clear communication of dimensional tolerances and construction sequencing to ensure that design intent is maintained during manufacturing and erection.

Collectively, these stakeholder insights reinforce the need for an integrated approach to managing skew-related risks across the project lifecycle. Effective collaboration between designers, precasters, constructing contractors and asset owners is the most reliable means of ensuring that highly skewed bridges achieve the same level of performance, constructability and durability as conventional bridge structures.

7 Best practices and implementation summary

This section provides a summary of the detailed guidance in earlier sections.

7.1 Bridge selection and approval

Early in project development, bridge alignment and geometry should be reviewed to assess whether skew can be reduced or avoided. Where skew is unavoidable, the project team should:

- document the need for the proposed skew through alignment and option analysis
- identify any constructability or geometric constraints associated with extreme skew
- undertake formal review and approval for skews greater than 45°, in accordance with the DCBOS, and
- engage early with design, construction and precast specialists to validate feasibility.

This early decision making helps ensure that skew-related risks are acknowledged and managed from the outset.

7.2 Design

During detailed design, the focus should shift to applying the technical guidance from Sections 3 and 4. Key steps include:

- selecting an analysis approach appropriate to the skew angle, structural configuration and restraint conditions, with refined methods such as finite element analysis where simplified approaches do not adequately capture skew-related behaviour
- modelling boundary conditions and rotational behaviour to reflect the actual support conditions, including appropriate representation of bearing stiffness, restraint conditions and rotation freedom
- incorporating detailing that accommodates torsion, acute corner stresses and differential reactions
- designing restraint systems to accommodate skew-induced rotations and movements, and
- confirming that diaphragm orientation, bearing configuration and reinforcement layout support the intended behaviour.

Design reviews should explicitly check that skew-related actions and local effects are captured in the analysis and detailing.

7.3 Manufacturing and construction

Implementation during manufacturing and construction should prioritise practical measures that maintain the design intent. Project teams should:

- confirm that reinforcement and diaphragms can be fabricated within tolerances
- coordinate with precasters to address mould geometry, lifting arrangements and handling constraints
- confirm that strand layout and detailing are appropriate for skewed geometry, where variation in strand development or transmission lengths at girder ends may introduce additional forces at transfer and require detailing adjustments (e.g. selective debonding of strands)
- plan construction and pour sequencing to minimise the risk of cracking in the bridge deck, and
- apply quality control measures that specifically target skew-related risks such as bearing alignment and restraint behaviour.

7.4 Operation and maintenance

For asset management, the implementation focus shifts to targeted monitoring and timely maintenance. Recommended actions include:

- prioritising inspection of bearings, joints and restraint systems where skew amplifies movement effects
- monitoring acute and obtuse corners for cracking or spalling
- analysing inspection data to identify recurring patterns or locations of concern, and
- ensuring inspectors are appropriately trained to identify and assess defects associated with skewed bridge behaviour.

The NACOE S71 findings indicate that highly skewed bridges can perform as well as non-skewed bridges when maintained with a focus on movement-sensitive components.

7.5 Key takeaway

The key implementation actions for managing highly skewed bridges are:

- recognise skew early in the project lifecycle and assess alignment alternatives
- apply appropriate modelling and detailing that reflect the true behaviour of skewed structures
- collaborate across disciplines—design, precast and construction teams—to ensure constructability and accuracy
- implement targeted construction controls to manage torsion, restraint effects and early-age behaviour, and
- maintain focused operational monitoring, with particular attention to bearings, joints and acute corner regions.

This implementation framework provides a practical pathway for applying the findings to bridge design and management, supporting consistent, reliable and durable outcomes for bridges with extreme skew.

8 References and supporting literature

8.1 Referenced documents

American Association of State Highway and Transportation Officials 2020, *LRFD Bridge design specifications*, 9th edition, AASHTO, Washington, DC.

Arancibia, M D, Rugar, L & Okumus, P 2020, *Role of skew on bridge performance*, Transportation Research Record, vol. 2674, no. 5, pp. 282–92, doi:10.1177/0361198120914617.

Austrroads 2018a, *Guide to bridge technology part 3: Typical Superstructures, Substructures and Components*, edition 2, AGBT03-18, Austrroads, Sydney, NSW.

- Daley, R, McGovern, C & Chaw, E 2025, NACOE S71: *Limitations of highly skewed bridges (>45°)*, National Asset Centre of Excellence, Melbourne, Victoria.
- Ebeido, T & Kennedy, JB 1995, *Shear distribution in simply supported skew composite bridges*, Canadian Journal of Civil Engineering, vol. 22, no. 6, pp. 1143–54, doi:10.1139/I95-132.
- Fu, G, Feng, J, Dimaria, J & Zhuang, Y 2007, *Bridge deck corner cracking on skewed structures*, research report RC-1490, Michigan Department of Transportation, Lansing, MI.
- Hambly, EC 1991, *Bridge deck behaviour*, 2nd edition, CRC Press, Boca Raton, FL, USA.
- New Zealand Transport Agency Waka Kotahi 2016, *Highway structures design guide*, NZTA, Wellington, NZ, <https://www.nzta.govt.nz/resources/highway-structures-design-guide>, accessed 17 June 2024.
- O'Brien, E, Keogh, D & O'Connor, A 2014, *Bridge deck analysis*, 2nd edition, CRC Press, Boca Raton, FL, USA.
- Okumus, P, Oliva, MG & Arancibia, MD 2018, *Design and performance of highly skewed deck girder bridges*, no. 0092-16–05, Wisconsin Department of Transportation, Madison, WI, USA.
- Queensland Department of Transport and Main Roads 2013a, Annexure S01: *Frame models of complete bridge structures for tier 1 assessments*, Transport and Main Roads, Brisbane, Qld.
- Queensland Department of Transport and Main Roads 2013b, Annexure S02: *Modelling deck unit bridge superstructures for tier 1 assessments*, Transport and Main Roads, Brisbane, Qld.
- Queensland Department of Transport and Main Roads 2016, *Structures inspection manual*, Transport and Main Roads, Brisbane, Qld.
- Queensland Department of Transport and Main Roads 2018, Standard Drawing 2059 *Precast Units – 19 m PSC Deck Unit Drawing 4 of 6*, Transport and Main Roads, Brisbane, Qld.
- Queensland Department of Transport and Main Roads 2024, *Design Criteria for Bridges and Other Structures*, Transport and Main Roads, Brisbane, Qld.
- Road Transport Authority 2007, *Design of Integral Bridges*, TS 01997/BPC2007/05, RTA, Sydney, NSW.
- Roads and Maritime Services 2019, *Provisions for the design of Super-T girder bridges*, BTD 2011/06 Rev 1 | RMS.19.1379, RMS, Sydney, NSW.
- Standards Australia 2017, Bridge Design, Part 4: *Bearings and deck joints*, AS5100.4, Standards Australia, North Sydney, NSW.

8.2 Supported literature and further reading

The following references were reviewed as part of the NACOE S71 project and informed the development of this document. While not all are directly cited in the text, they are provided as additional resources for further reading.

Arancibia, MD, Okumus, P & Oliva, MG 2017, *Review of skew effects on prestressed concrete girder bridges: problems and current practices*, PCI Convention and National Bridge Conference, 2017, Cleveland, Ohio, 18 pp.

Austrroads 2018b, *Guide to bridge technology part 4: Design Procurement and Concept Design*, edition 2, AGBT04-18, Austrroads, Sydney, NSW.

Burke, MP 2009, *Integral and semi-integral bridges*, Wiley-Blackwell, Hoboken, NJ, USA.

Cohen, J 1988, *Statistical power analysis for the behavioural sciences*, 2nd edition, Lawrence Erlbaum Associated, Hillsdale, NJ.

Deck, A, Silva, R & Canceri, J 2011, *Design and construction of high skew Super-T bridges*, Austrroads bridge conference, 8th, 2011, Sydney, NSW, Austrroads, Sydney, NSW, 17 pp.

Department for Infrastructure and Transport 2022, *Design of Structures*, DITP, Adelaide, South Australia.

Department of Planning, Transport and Infrastructure 2019, *Road structures inspection manual: Part 2: Deterioration of structures*, DPTI, Adelaide, SA.

Department of Transport 2022, *Road structures inspection manual*, DoT, Melbourne, Vic.

Ebeido, T & Kennedy, JB 1996a, *Girder moments in continuous skew composite bridges*, Journal of Bridge Engineering, vol. 1, no. 1, pp. 37–45, doi:10.1061/(ASCE)10840702(1996)1:1(37).

Ebeido, T & Kennedy, JB 1996b, *Shear and reaction distributions in continuous skew composite bridges*, Journal of Bridge Engineering, vol. 1, no. 4, pp. 155–65, doi:10.1061/(ASCE)1084-0702(1996)1:4(155).

Federal Highway Administration 2011, *Post-Earthquake Reconnaissance Report on Transportation Infrastructure: Impact of the February 27, 2010, Offshore Maule Earthquake in Chile*, FHWA-HRT-11-030, <https://www.fhwa.dot.gov/publications/research/infrastructure/structures/11030/004.cfm>, viewed 24 June 2024.

Gupta, T & Kumar, M 2018, *Flexural response of skew-curved concrete box-girder bridges*, Engineering Structures, vol. 163, pp. 358–72, doi:10.1016/j.engstruct.2018.02.063.

Khaleel, MA & Itani, RY 1990, *Live-load moments for continuous skew bridges*, Journal of Structural Engineering, vol. 116, no. 9, pp. 2361–73, doi:10.1061/(ASCE)0733-9445(1990)116:9(2361)

Main Roads Western Australia 2009, *Structures engineering design manual*, MRWA, Perth, WA.

Main Roads Western Australia 2022, *Bridge branch design information manual*, MRWA, Perth, WA.

Mallikarjun, IG & Siddesh Kumar, NG 2015, *Influence of Skew Angle on Static Behaviour of RCC and PSC Slab Bridge Decks*, International Journal of Engineering Research and Advanced Technology (ijerat) (E-ISSN 2454-6135), vol. 1, no. 1, pp. 7–15.

Mawson, J, Mehr, M, Constant, J, Zaghi, AE & Hain, A 2022, *Structural performance of acute corners on skewed bridge decks using non-linear modeling of the deck parapet*, Infrastructures, vol. 7, no. 6, p. 77, doi:10.3390/infrastructures7060077.

Ministry of Transportation 1991, *Ontario highway bridge design code*, MoT Quality and Standards Division, Toronto, Ontario.

Roeder, CW & Moorthy, S 1991, *Thermal movements in bridges*, Transportation Research Record, vol. 1290, pp. 135–43.

Wood, J, Murashev, A, Palermo, A, Al-Ani, M, Andisheh, K & Goodall, D 2015, *Criteria and guidance for the design of integral bridges in New Zealand*, 577, NZ Transport Agency, Wellington, NZ.

Wu, S, Jia, J, Jiao, C, Huang, J & Li, J 2021, *Study on the additional support length requirements of single-span bridges due to skew using a simplified method*, Advances in Bridge Engineering, vol. 2, no. 1, p. 22, doi:10.1186/s43251-021-00038-7.

