

Bridge Aesthetics

Design guideline to
improve the appearance
of bridges in NSW

Centre for Urban Design | February 2019





The curved bridge over the Woronora River with its pedestrian and bicycle foot bridge hung below the road deck and the remodelling of its foreshores, fits in with the river, topography and sandstone and bush landscape of Sutherland. With its ten spans, 30 metre high piers, and approaches cut into the opposing hillsides the bridge produces a sweeping, dramatic and elegant built form.

Acknowledgments

This document has been prepared by the TfNSW Centre for Urban Design with input from Bridge Section, Environmental Branch, and the Government Architects.

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All photographs are sourced from Transport for NSW unless otherwise indicated.

Cover image: Yandhai Nepean Crossing.

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The triple bridge and boardwalks over the Brunswick River were designed in collaboration with the community. Boardwalks alongside the Brunswick River provide views of the river and good pedestrian connections under the highway. This is a good example of integrated engineering and urban design.

Foreword

Bridge Aesthetics was first published in 2004. It referenced a Department of Main Roads NSW document produced in the 1980s called 'The Aesthetics of Bridges' but also had its origins as a guide for the Design and Construct bridge requirements for Karuah Bypass in 2002.

Since then it has been updated and republished in 2012 and now updated again to take account of completed bridges, new guidance on land-bridges and a new pedestrian bridge standard being employed across the state.

Over the years Bridge Aesthetics has had a major impact on the quality of bridges in NSW. It has added a dimension of design quality – to the usual equation of cost, time and durability – on hundreds of projects completed over the last 15 years.

Bridges need design quality as they are major visible artefacts in our cities and landscapes. That design quality can be expressed through innovative road bridges spanning waterways and gorges, smaller yet equally iconic pedestrian and cyclist bridges, well-mannered suites of overbridges or creek bridges on highways and motorways, subtle and sensitive new bridges next to heritage structures, the regular bridges erected to ensure the safe pedestrian crossing of busy roads or even just a well-designed balustrade.

When bridges are designed well, responding to context and their role they add value to a neighbourhood, region or state and instil pride, stories and character in our communities. The Sydney Harbour Bridge is an obvious example, but the Gladesville Bridge has a similar, if slightly less famous role; the Sea Cliff bridge has become a major feature of the Illawarra area; and the recently opened Yandhai Nepean Bridge in Penrith is already a well-loved addition to the city and river landscape.

This document addresses as objectively as possible the aesthetics of the whole bridge as well as the individual parts. It attempts to explain why a particular aesthetic consideration is important, for example spill through abutments allow a more open structure in the landscape, simplicity is generally more important than complexity so that people can intuitively and easily understand a bridge and see how it works, arches are generally considered beautiful but are also strong almost permanent ways to hold up bridges. But most importantly this guideline advocates that good engineering and good aesthetics are synonymous and true good looks aren't achieved by adding extra elements or features but rather by refinement. Antoine de Saint Exupery summed it up well "It seems that perfection is attained not when there is nothing more to add, but when there is nothing more to remove."

Being a part of the Beyond the Pavement Urban Design Policy, Bridge Aesthetics goes further than the appearance of bridges and also touches on the contribution bridges can make to the pedestrian and cyclist experience, the space available for pedestrian activity, the view from the bridge and the use of undercroft bridge space.

This document draws upon many years of experience in designing building and maintaining bridges and should be used across all projects.

**Director Centre for Urban Design
Director Bridges and Structures**



Bradfield Park, which forms part of the northern curtilage of the Sydney Harbour Bridge, used to be an area that was essentially dirt with poor drainage. This has been transformed with a lowered plaza area, landscaping and seating.



1 Introduction

1.1 Purpose and structure of the guideline

1.2 Urban design policy

1.3 Aesthetics

1.4 Perception of bridges

1.5 Responsibility of the designers

Introduction

1.1 Purpose and structure of the guideline

“Bridges are among the most ancient and honourable members of society with a background rich in tradition and culture. For countless generations they have borne the burdens of the world and many of them have been great works of art. As in most large families there are numerous poor relatives. The modern bridge too often appears as a workman performing its task for a minimum wage, mechanically efficient but uneducated and ignorant of its own ancestry. A worthy subject for serious consideration.”

CHARLES S WHITNEY, BRIDGES: A STUDY IN THEIR ART, SCIENCE AND EVOLUTION, 1929

The purpose of this guideline is to help design teams produce bridges of aesthetic value. The term ‘guideline’ in the document refers to the requirements, objectives, design principles and processes that guide the design of bridges.

In addition, this guideline will help transport infrastructure agencies, set down unequivocal aesthetic outcomes so that designers and construction companies are made aware of what is required and can focus on innovation in achieving that.

The document is primarily intended to be applied to everyday practice – to the more common bridges which are an abundant and highly visible element of and across NSW roads. But it is also for the iconic landmark bridges which are inspirational. Indeed, bridges are usually iconic because of the size of their spans, the terrain they traverse, their role and cultural importance, their technology and the design response that the context evokes. A bridge can be considered to be iconic when its design stands out as something unique and is seen to be a symbol of a community or place.

The aesthetics of pedestrian bridges is often given less consideration than road bridges notwithstanding the community role they play, their visibility and the design possibilities they inherently have. These guidelines are aimed at ensuring that the aesthetics of pedestrian bridges are taken just as seriously as road bridges.

The general principles in this guideline are also applicable to railway bridges, which affect the appearance and urban design quality of road and rail corridors and their settings.

Over and above this, specific principles are set out which apply to heritage bridges and the management of existing bridges.

A number of photographs of NSW bridges have been included. The purpose is to use the images as lessons for future bridge design; this is not therefore a rigorous critical evaluation of each bridge.

There are always exceptions to design rules and it is not the intention to provide a formula for good design.

Rather, it is the intention to set down considerations and principles which will serve to eliminate the worst aspects of bridge design and encourage the best.

The guideline essentially outlines the approach to bridge design desired by Roads and Maritime Services. It sets down physical principles of design that should be applied at the level of the whole, the parts and the detailed elements. Attention is also paid to bridge finishes and to particular conditions to which designers should respond. An appendix to the document includes global examples of bridge design, bridge terminology, and a list of references and further reading.

This document is intended for use by engineers, bridge maintenance and rehabilitation staff, project managers and their teams, environmental staff, and consultants who are engaged in areas such as engineering, environmental impact assessment and urban design in both design development and the detailed design and construction phases of a bridge project – as well as industry who tender for and build bridges.

As well, it can be used to inform communities about the Government's bridge aesthetic philosophy and principles of design – the importance of aesthetics and how we are trying to produce bridges of good appearance.



Falcon Street pedestrian bridge under construction. A slender, steel box girder spans 220m over the Warringah Freeway.

1.2 Urban design policy

The high level urban design policy and guidelines document *Beyond the Pavement* forms an overarching framework for *Bridge Aesthetics* as follows:

- It aims to achieve desired urban design outcomes from transport infrastructure in urban, rural and bushland settings. This means that all projects should achieve: a sensitive fit with the built, natural and community environment; good connections for communities; and an attractive and fit for purpose public domain.
- It identifies *Bridge Aesthetics* as one of a suite of detailed guideline compendium documents that support the policy.
- It recognises the contribution that bridges of heritage significance make to the character, history and cultural environment of areas and communities and underlines the need to protect them in the context of their setting.
- It stresses the need for professional urban design involvement on all projects – this is especially important if bridge aesthetic outcomes are to be achieved.

1.3 Aesthetics

“Beauty has been thought of as extraneous to considerations of function, practicality, economy and advancing technology. To many, the word ‘aesthetics’ has meant superfluous or artificial, like cosmetics.”

PAUL HARBESON, ARCHITECTURE IN BRIDGE DESIGN, BRIDGE AESTHETICS AROUND THE WORLD, TRB, WASHINGTON D. C 1991

According to the Macquarie Concise Dictionary ‘aesthetics’ is defined as: “Relating to the sense of the beautiful or the science of aesthetics, that is, the deduction from nature and taste of rules and principles of beauty”.

The aesthetic quality of a bridge involves our sensory perception of it – how it appears to us visually. This results, at least, from the fundamentals of:

- Relationship to the surrounding natural and built landscape.
- Its form, proportions and scale.
- Expression of forces and technology.
- Its strength and durability.
- Relationship of bridge elements to one another.
- Factors such as the use of texture and colour.

This guideline makes continuous reference to ‘making bridges elegant’. It is simply another way of describing a bridge that is graceful and refined and is a more descriptive term than ‘beautiful’ which can be misinterpreted. Elegance may refer, among other things, to a bridge’s proportions and shape, effectiveness in expressing its structural forces without unnecessary embellishment, its neatness in the articulation of parts or the delicacy in the design of elements and details.

A related concept is that of harmony. Harmony is the sense of visual balance, compatibility of parts and elements, and fit with the environment.

Theory behind bridge aesthetics

There is substantial literature on the subject of bridge aesthetics which reveals it as an ongoing concern throughout history and a pursuit of engineers and designers internationally. This literature has informed many of the principles in this guideline. Many are contained in the Bridge Aesthetics References and Further Readings appendix of this document. The main issues, themes and ideas are set out below; they all work together and need to be understood as a whole.

- **Integration of aesthetics with the science and practice of engineering**

It is important to move toward a culture that brings together practical rigour (management), logical rigour (the science of bridge design) and aesthetics to create a whole, and away from a culture of specialised thinking in compartments.

- **Bridges for people**

Understanding the community perspective and consulting with the community is essential since the bridges we build serve a community function visually, socially and culturally; they are used and viewed by the community, provide connection, form part of the built environment and culture of the place, and can have symbolic and political meaning.

- **Bridges by people**

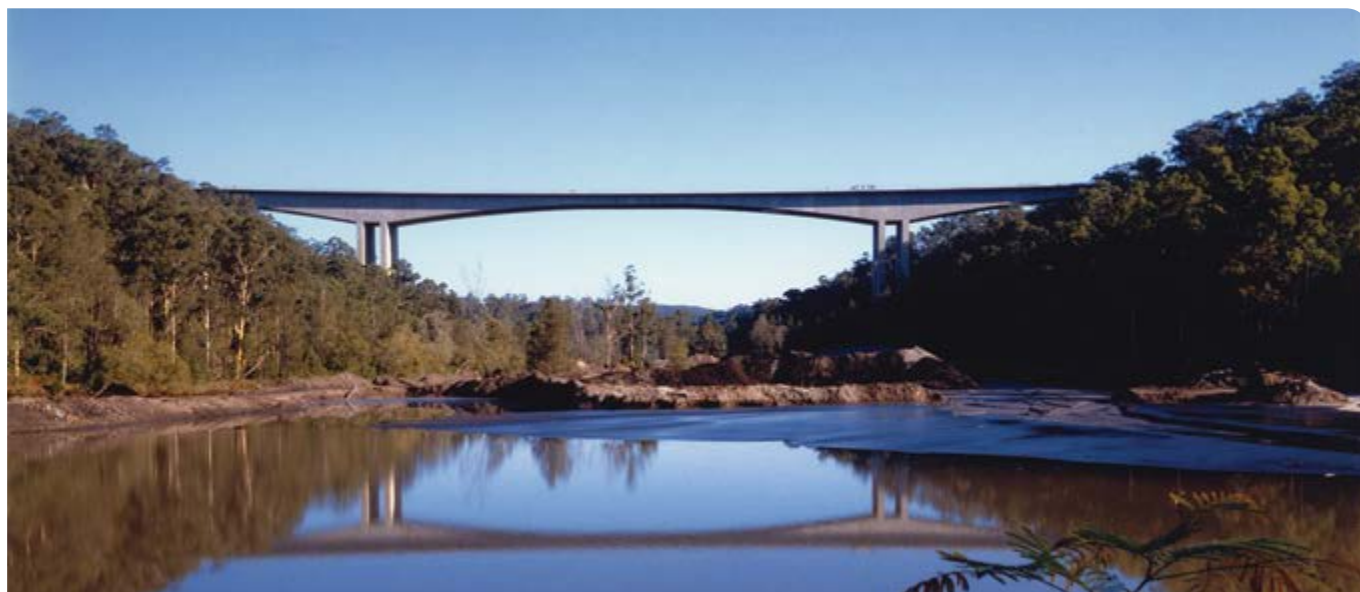
There is focus on the people who design bridges for communities. Designing bridges requires a team effort in which engineers, architects and other disciplines adopt an integrative, holistic approach to achieve an aesthetic outcome.

- **Place**

Bridges on the one hand are part of site and locale and so need to be in harmony with their context while, on the other, they can make or define a place.

- **Structurally expressive form**

A fundamental and recurring theme is one of expressing the essential structural anatomy of the bridge which simultaneously achieves greatest efficiency and reveals the beauty in the form of the bridge.



The F3 Freeway twin bridges over Mooney Mooney Creek demonstrate how good engineering design and good aesthetics are synonymous.

- **Materials**

There is a deep realisation that beauty results from understanding and expressing the materials of the time, something not unrelated to structurally expressive form.

- **Colour**

While aesthetic value is not reliant on colour it is universally recognised that colour can enhance or mark a bridge, as is the case with the red lead paint (sometimes called orange vermilion) on the well known Golden Gate Bridge in San Francisco, which is especially dramatic when visible either in strong sunlight or appearing through the fog.

- **Lighting**

Over and above lighting for safety requirements, the use of lighting is seen to be of value in highlighting the features of a bridge in the landscape, creating reflectivity over water and giving the bridge and its curtilage prominence at night.

- **Bridge aesthetics guidelines**

While the case is made for bridge aesthetic guidelines there is not much evidence of such guidelines in practice: the most important example that has served as a model for these guidelines is *The Appearance of Bridges and Other Highway Structures, 1996* and *Advice Note 41/94* put out by the UK Ministry of Transport/The Highways Agency which emphasises principles rather than prescriptive rules. This is quite different to the *Aesthetics Bridges Users Guide, 1987* of the Maryland State Highway Administration, USA which is more a process directed guideline involving conferences, competitions and a program of seminars.

The old Department of Main Roads asserted that their 'designed and aesthetically satisfying modern bridges', including the concrete arch span Gladesville Bridge over the Parramatta River and the Bridge over Middle Harbour at Roseville, represented a 'coming of age' of bridge building in New South Wales. They set out the important steps to be taken in building a bridge and design principles to be adopted. (See: References and Further Readings).



The simple elegance of the bridge over Middle Harbour at Roseville complements the landscape of the National Park.

In the light of this thinking, it is the intention of these guidelines to encourage aesthetics to be considered as an integral part of the design process. Every part of the bridge has a role to play, both structurally and aesthetically, in the whole.

As such the guidelines are based around the premise that there are a myriad of ways to design and express structural form and that additional or 'add on' treatments are generally unnecessary in making a bridge of aesthetic value. Good bridge engineering and good aesthetics are synonymous and only limited by the imagination and skills of the bridge designer.

Generally bridges seem aesthetically more pleasing if they are simple in form, the deck is thinner (as a proportion of its span), the lines of the structure are continuous and the shapes of the structural members reflect the forces acting on them.

Finally, it should be said that whilst personal tastes differ, beauty is not simply a matter of taste alone. When qualities such as proportion, order and symmetry are applied well, people often agree that the object has aesthetic value (whether they like it or not is another matter). When applied badly there is often public outcry.



The distinctive arch of the Gladesville bridge over Sydney Harbour.



The Dean Street pedestrian bridge over the railway and inner city bypass of Albury is the focal point of a visual axis extending from the war memorial above the town.

1.4 Perception of bridges

Individual bridges

Bridges are seen from many angles and the viewers see them from a variety of conditions. They may be isolated objects in the landscape, part of a suite of structures or on a city street. Bridges are seen from close up, far away, and from rivers and other roads. Viewers can be standing still or moving to or across a bridge at varying speeds by different modes. This guideline assumes viewing from all angles.

An early step of the design process is to establish the critical views for the bridge.

The presence of a bridge, in turn, can heighten our perception of the built and natural landscape in which it is placed, giving the bridge an extra aesthetic meaning while in turn distinguishing the place. For example, both the Golden Gate in San Francisco and Sydney Harbour Bridge crown the natural glory of their respective harbours, and the Sea Cliff Bridge provides a sense of scale and understanding of the Pacific Ocean and Illawarra escarpment.



The Anzac Bridge in Sydney is an iconic artefact in the landscape which provides an interesting experience on the bridge, with views from it across the waterways and city-scape on both sides.



The Anzac Bridge in Sydney as seen in this night time view across Blackwattle Bay.

On the other hand, a bridge can help create a new place. For example the Anzac Bridge in Sydney, through its scale and design, has changed the character of this part of Sydney.

A family of bridges

The appearance and proximity of other bridges is an important contextual factor. New bridges may be designed as part of a family of other bridges along a route, as shown by these examples along the Pacific Highway. Bridges on the Pacific Highway upgrade display consistency with variety in their design. On individual projects there are a distinct suite of bridges, but on the whole upgrade these suites also conform to a family resemblance with their common spill through abutments, tapered wall type piers, continuous parapets and full length safety screens.



A family of bridges on the Pacific Highway. Top: Yelgun to Chinderah upgrade. Bottom: Bonville upgrade.

Proximity of bridges

Where a new bridge is located in close proximity to an existing bridge, special attention must be paid to their relationship when seen from various angles and locations. The new bridge should respect the role, form and design of the existing bridge.



The new Iron Cove Bridge on the left was designed on a simple curvature and simple refined piers and girder, so that it did not conflict with the more complex truss forms on the old Iron Cove Bridge.

1.5 Responsibility of the designers

Role of designers

Designers are responsible for the look of bridges and must therefore consider appearance as a major design imperative along with strength, safety and cost.

For bridges to be aesthetically successful, designers must ensure that aesthetics are:

- Considered as a design issue in the first instance.
- An integral part of design.
- Considered both in the general form and all the details that support it: the parts must be considered as to how they contribute to the whole. When standard details are used they need to be reviewed for their appropriateness to each project and should be regularly updated.

How designers should interact

Aesthetic outcomes require the effort of a multidisciplinary team, including engineers and architect/urban designers, working as equals in a collaborative and integrated way.

The designers of bridges are faced with many choices. This guideline aims to inform those choices.



Photomontage of new fencing for the Anzac Bridge, the design of which was developed by a collaboration between the urban designers and the engineers.



The twin Pacific Highway bridges over Bonville Creek are low structures and not that visible to the motorist, yet they have been designed attractively and cost effectively with circular piers, matching shaped headstocks and precast neat parapets casting a strong shadow line on the girders.



2 Design approach

2.1 Design values

2.2 Project management and urban design methodology for bridges

Design approach

2.1 Design values

A design value is an ethical, behavioural or substantive quality considered to be of significance in achieving of bridges of aesthetic merit.

The following design values should run through the design process from inception to delivery. They relate to both substance and process:

Commitment to aesthetics.

Context sensitive design.

- Contribution of sustainability to the aesthetic outcome.
- Complementarity of cost and aesthetics.
- Comprehensive design process.
- Collaboration in the design team.
- Consultation with community.

2.1.1 Commitment to aesthetics

A commitment to aesthetics is needed from both the client and contractor. A valued bridge is not likely to be produced if aesthetics is not championed and adequately weighted in selection and assessment processes. This commitment must be carried through from design development into the implementation process, since a well designed bridge can be marred by poor workmanship, design variation and cost-cutting during implementation.

2.1.2 Context sensitive design

Context sensitive design of infrastructure is design that fits in sensitively with the landform and the built, natural, ecological, cultural and community context.

The aesthetic value of a bridge is dependent on its design response to context – the place. A bridge may be acceptable or beautiful in one location whilst unacceptable or ugly in a different location.



The Sea Cliff Bridge, Lawrence Hargrave Drive, is a seamless combination of incrementally launched and balanced cantilever structures. It's design is simple, expresses it's structure and provides a foil to the rugged coastal landscape.



The Windsor flood evacuation bridge is seen by more than just the cows. It is a notable structure and a significant artefact in the landscape for the Windsor community.

Starting the design process by picking a bridge design before understanding its context, is therefore inadvisable. Beautiful and locally valued bridges are more likely to be produced if the design process starts when the natural, built and community context is understood and significant constraints are identified.

The visibility of the bridge is an additional important contextual factor. A bridge which is looked on by the community needs to be carefully considered in terms of its visual impact on residents and road users.

This does not mean that aesthetics need not be considered in its own right if 'only the cows' can see the bridge. For example the bridge may be highly photographed (eg Sea Cliff Bridge) or the bridge may well be seen in the future. Bridges are built to last and the development of new roads, footpaths, buildings and settlements within a bridge's viewshed are likely within its lifespan.

2.1.3 Contribution of sustainability to the aesthetic outcome

If integrated well into the design, principles of sustainability can add to the aesthetic quality of a bridge. Indeed, bridges are often seen as expressions of sustainability:

- Strength and robustness can be admired for durability.
- A wise use of resources can result in refinement of form and can be appear elegant.
- A respect for heritage can add charm and character.
- A design that facilitates and caters for future land use and development and future generations lasts longer and becomes more respected.
- A bridge that contributes to the livability and amenity of an area becomes a local asset.
- Bridges provide connection and linkage which can contribute to sustainable and liveable communities.
- Resilience in coping with unforeseen challenges and disasters contributes fundamentally to sustainability.
- A design that caters for future maintenance and inspection requirements enhances longevity.

2.1.4 Complementarity of cost and aesthetics

Valuing quality

“It is unwise to pay too much. But it is worse to pay too little... There is hardly anything in the world that someone can’t make a little worse and sell a little cheaper and people who consider price alone are this man’s lawful prey.”

RUSKIN

Sound aesthetic principles need not be costly. For example, designing the right shape of a parapet, abutment or pier might have a negligible impact on costs but a significant improvement visually. In many cases a simple, refined solution may be less expensive to build than a poorer quality design.

If a bridge is designed to be as cheap as possible then it is unlikely that it will be of aesthetic value. This is not to say that the cheapest bridge is necessarily the ugliest bridge. It does mean that cost and aesthetics as driving forces in the design process need to be balanced.

It is often the case that the cheapest bridge is not always the most cost effective solution. Durability and quality are related. Lower costs and lower quality can lead to higher maintenance and replacement.

This interrelationship between cost and aesthetics is especially important when the whole life cost of a bridge is considered. Ideally, materials should be used wisely with consequent economy, fitness for purpose, refinement and elegance.



The piers on the new Iron Cove Bridge are relatively simple in design having a taper in one direction only and without a void within the pier shape. They are therefore relatively cost effective but also a good aesthetic solution.

Maintenance costs

The Government is responsible for over 20,000 kilometres of roads and over 5,000 bridges. The resources required to maintain these assets are considerable. Therefore, for reasons of cost and sustainability, it is incumbent on designers, in all design stages, to address the maintenance burden placed on the future custodians of the bridge. This need not frustrate the creation of a beautiful bridge. Simple, elegant and refined bridges are likely to be self-reliant also.

2.1.5 Comprehensive design process

The aesthetics of a bridge should be considered at the conception of a project and through every stage of development. Aesthetics is not something that can be added on at the end. It is the final product of the planning, design and procurement process from initial route selection, through environmental assessment, to detail design and construction.



The decision to replicate the piers built in the 1970s on the 2008 Alford's Point Bridge duplication could not have been made at the end of the design process. Aesthetics needs to be considered at an early enough stage to influence the conceptual approach to a bridge.

2.1.6 Collaboration in the design team

A lack of collaboration in the design process will affect the aesthetic outcome. Collaboration can only be achieved if design professions understand and value each other's role in the design process in achieving a bridge of aesthetic merit.

Likewise a balance must be achieved, from the inception of a project, between the requirements of the road engineers and the bridge engineer. Forcing a bridge to fit a road alignment can lead to aesthetic problems. It is better to allow some flexibility in the road alignment to achieve a good fit between bridge and landscape.

2.1.7 Consultation with community

Bridge aesthetics is a strong community issue.

Bridges are used and viewed by the surrounding residents and the wider public. Above their functional and connective role, bridges affect the visual quality and sense of place, have historic and cultural value, give an area identity and serve the next generation.

The modification or duplication of existing bridges and building of new ones requires consultation with the community and their local councils regarding community values, local government policy, and the options and the quality of what is designed.

A collaborative approach with communities and local councils applies equally to designs that are outsourced to consultants.

It is important to communicate to the community the essence of a design early enough in the bridge design process. The community knowledge of the area and their point of view needs to be taken on board. Design teams should talk with the community about the intention and principles, before options or a concept design is produced. They may have specific objectives, for example, relating to functionality and the size and look of the structure.



The Ballina Bypass community open day was celebrated on the very bridge design that was presented to and agreed with the community.

2.2 Project management and urban design methodology for bridges

The following procedural steps and considerations should be addressed when designing a bridge.

2.2.1 Project management methodology

The processes in ProjectPack (and MinorPack for smaller projects) govern the management of both road and bridge projects.

Urban design Input to bridge design as part of projectpack

| Phases | Sub phase | Key Urban Design Activities |
|-----------------------------|----------------------|---|
| Project initiation | | 1. Centre for urban design contacted. Involvement in business case and project scope. |
| Project development | Strategic assessment | 2. Urban design and bridge design professionals engaged to develop design and to collaborate. Contextual analysis carried out. Bridge urban design objectives developed. Consult with community. |
| | Concept | 3. Concept design developed by urban designers and engineers as best practice integrated engineering and urban design. Design iteration to ensure environmental impacts are avoided or minimised and design potentials realised. Consult with community. |
| Project delivery | Delivery readiness | 4. Brief reviewed by the urban design and bridge design team to specify aesthetic requirements. 5. Detailed design developed by urban design and engineering contractors in line with concept design and urban design guidelines. |
| | Delivery | 6. Urban designers involved with monitoring of implementation and quality of workmanship and any presentations to community and stakeholders on progress of works. |
| Project Finalisation | Finalisation | 7. Post-completion review by the Centre for Urban Design as input to the project review. |

2.2.2 Design methodology for urban designers

The particular role and steps to be taken by specialist urban designers are set out below.

These should be done in consultation with the community.



Establish requirements

In consultation with the bridge designer, develop an understanding and appreciation of the transport and functional requirements and social and political imperatives of the bridge.

Explore and understand:

- The features to be bridged and the connections to be made.
- The level of flexibility in the vertical and horizontal road alignment.
- The span and load requirements and considerations of most appropriate superstructure type.
- Signage and lighting requirements.
- Safety barrier criteria.
- Traffic volumes and speeds.
- Pedestrian, cyclist and public transport requirements.
- Environmental requirements.
- The design life.
- Political issues.

Understand context

Through site and desk study develop an understanding of the natural, built and community context of a bridge that would influence the design. These may include:

- Topography, water bodies and water courses.
- Other bridges in the area and along the road corridor.
- Freight and traffic requirements.
- Soils and geology.
- Surrounding land uses.
- Biodiversity.
- Views to and from the bridge location, and privacy of local residents.
- Local vernacular.
- Landscape and built character.
- Liveability requirements of the local communities.
- Local community values and objectives for their bridge.

Set design objectives and principles

In collaboration with the bridge engineer, develop broad objectives and principles regarding the bridge design outcome and its value to the transport customer and community, for example:

- Unobtrusive or landmark?
- Integration with landscape.
- Proportions: symmetrical, slender/stocky.
- Simple/refined.
- Conform to suite of bridges along corridor.

Develop design

In collaboration with the bridge engineer and other project team members the urban designer should develop the concept design in accordance with the agreed urban design as well as functional and structural objectives.



Iron Cove Bridge duplication – photomontage of proposed bridge developed during the concept design (development phase).



Iron Cove Bridge duplication – completed bridge. The quality and attention to detail in the detailed design and delivery stages, has ensured a close compliance with the agreed design. (Note, however, the later addition of signage which was not considered as part of the visual composition and should have been).

If the concepts and design development of the bridge naturally flow from the project requirements, context and objectives, a rationale can be seen for the bridge design.

In an environmental assessment report the following information should be considered to illustrate the bridge:

- Plans of the bridge approaches and bridge in context.
 - Elevations of the bridge illustrated with background context.
 - Cross sections, axonometrics and models illustrating three dimensional shape and proportions of piers, pile caps, abutments, parapets and beams.
 - Typical details illustrating connections between barriers, jointing, lighting, signage and landscape.
- Artist illustrations and photomontage of the bridge structure as seen from the highway and surrounding key viewpoints.
 - Landscape character and visual assessment.

Implement design

It is imperative that the aesthetic quality of the accepted bridge design is carried through into detailed design. All of the relevant principles in this Bridge Aesthetics document must be incorporated.

Urban design consultants employed by the construction contractor must be on the Register of Urban Design Consultants and are to adhere to the accepted design, follow the principles and processes set out in Bridge Aesthetics and, especially, are to be an integral part of a collaborative bridge design team.

In order to ensure design continuity there needs to be a hand over from the responsible design development manager to the responsible implementation manager.

As well as during concept design, detailed design is to be reviewed by the Centre for Urban Design who may choose to convene a Bridge Design Review Panel which includes the Government Architect, the senior bridge engineer and the head of the Centre for Urban Design. Construction of the bridge needs to be monitored to make sure that the design is delivered in practice and that all maintenance requirements are met.

All design variations during construction equally need to be reviewed and agreed.



The construction of the design must be monitored so that the product agreed with the community and stakeholders at the environmental impact assessment phase is delivered (Sea Cliff Bridge, 2005).





3 The Whole

3.1 Context

3.2 Form

The new Iron Cove bridge in the context of Sydney and the other harbour crossings of the Anzac Bridge and the Sydney Harbour bridge.

The Whole

3.1 Context

Context sensitive design is a key design value. Indeed, all design requires an understanding of its context.

In the past, context sensitive design was something that would have occurred naturally. For example it would have been rare to use anything but local materials. Local labour would have particular ways of using those materials. Both materials and labour would have had to be used wisely and sustainably. Major earthworks would have been difficult to undertake, therefore bridges and highways would have had to respond to the constraints of the local landform to a greater extent than today.

Also, design standards (as a global rather than local matter) were not so exacting. Due to rapid changes in vehicle design, public spending and safety awareness, design has become very sophisticated and precise. Requirements for cambers, super elevation, sight lines, drainage, barriers and other aspects all encourage a centralised design approach rather than a site specific one.

Design that is sensitive to context is valued by communities. Structures and landscapes that fit and enhance context are good for community pride and local identity. They are often more sustainable and self-reliant.

3.1.1 Bridge type

Structural types

Various bridge types are used to overcome such obstacles as river, creek, flood plain, valley and road corridors, and so play the role of elevated highways, railway viaducts, overpasses, pedestrian and cycle crossings, opening bridges, interchange ramp bridges, and so forth with corresponding aesthetic characteristics.

The different bridge types have their own characteristic materials and components: a cable-stayed is quite different from a truss or arch. Within these types there may be different classes of bridge, for example, there are two major classes of cable-stayed bridge: fan which splays out from a central point on the tower, and harp which aligns cables in parallel through the length of the pylon. There may be variations and innovations within these, such as the side-span harp with tilted pylon and cables on one side only, a new type used by Santiago Calatrava in his visually stunning Alamillo Bridge in Seville (See Appendix A: Global Perspective).

Although pedestrian and bicycle paths can be accommodated by all bridge types, pedestrian bridges can modify all of these forms in their own right. Pedestrian bridges can be very flexible, taking on all manner of forms – geometric, organic, symmetrical and asymmetrical – due essentially to their light carrying loads.

As well as contemporary bridges these guidelines include the historic bridges which RMS protects and manages. The different structural types, materials and components apply to historic bridges as well. Many historic bridges include the fundamental beam and truss bridges and their variations (eg MacDonald truss, Allan truss) but also extend to arch span bridges (eg the Knapsack Gully Railway Bridge at Glenbrook at the foot of the Blue Mountains, and the slab and concrete arched aqueduct at Annandale).

3.1.2 Influence of context

The choice of bridge structure is affected by many contextual factors that include the following:

- Influence of span.
- The alignment of the bridge as part of the route option.
- Topography and geology.
- The nature of the load to be carried.
- The visual presence of the structure.
- The character of the area.

Influence of span

All these factors will have a powerful influence on the choice of bridge type, in particular the superstructure. In most instances, it is span length that is the most significant factor in determining the form (and cost) of a bridge.

The accepted approximate relationship between span and superstructure type is as follows:

- Short span (up to approximately 18m): pre-stressed concrete plank bridges.
- Short to medium span (approximately 18-40m): pre-stressed concrete girders or post-tensioned concrete voided slabs.
- Medium span (approximately 40-60m): steel or post-tensioned concrete box girders or incrementally launched girders.
- Medium to long span (up to approximately 300m): balanced cantilever (or on occasion, extradosed bridges eg the Ganter Bridge in Appendix A).
- Long span (up to approximately 800m): cable stay.
- Very long span (longer than 800m): suspension bridges.

These dimensions are only a rule of thumb and are likely to be challenged by new technology and lateral thinking. The design team should recognise these relationships and the consequences of working outside them.



The span length is often the starting point in dictating the form of a bridge. Short to medium span bridges generally use prestressed concrete girders (Karuah Bypass, top picture), medium span bridges generally use post tensioned box or incrementally launched girders (Robinvale, Murray River, middle picture), and medium to long span bridges generally use balanced cantilevered girders (Mooney Mooney Creek, bottom picture).

The alignment of the bridge as a part of the route option

To maximise innovation and minimise cost the vertical and horizontal alignment of the bridge, as part of a route option, should be straight or follow a constant radius where possible. This allows for a wide range of bridge types to be used. For example, by their nature, incrementally launched bridges can only be used where the alignment is straight or has a constant radius as they are cast and pushed out from one point.

Topography and geology

The nature of the topography and geology can dictate bridge type. For example, in terms of topography, certain bridges require particular space configurations for casting yards or access. In terms of geology, a robust sound bedrock can create a suitable foundation for a sprung arch bridge.

The nature of the load to be carried

Bridges serve a whole range of purposes and the load required to be supported has an influence on bridge type. For example, pedestrian bridges can exploit greater variation in bridge type opportunities than say bridges catering for freight or rail, at the other extreme.

The visual presence of the structure

On occasion, bridge type can be influenced by the visibility and visual presence of a bridge. For example, large or high bridges within urban areas can be designed to make a visual statement in the city and this will have an effect on the choice of bridge type.

The character of the area

The local character of the area can also have an influence on bridge type. For example, heritage areas can influence the form and materials adopted for a bridge.



The Albert 'Tibby' Cotter Walkway retains the cultural and heritage significance of Anzac Parade and Moore Park by preserving the avenues of Moreton Bay Fig trees.

3.1.3 Bridges in the landscape

There are a number of ways to approach bridge design in rural and natural landscape settings, including:

- Hiding the bridge in the landscape, by reducing its size and screening it.
- Making the bridge as distinctive as possible to contrast and stand out in the landscape.
- Making the bridge as simple and elegant as possible to complement the natural landscape or urban setting.

The first of these approaches, while suited to smaller bridges, does not work on larger more visible ones.

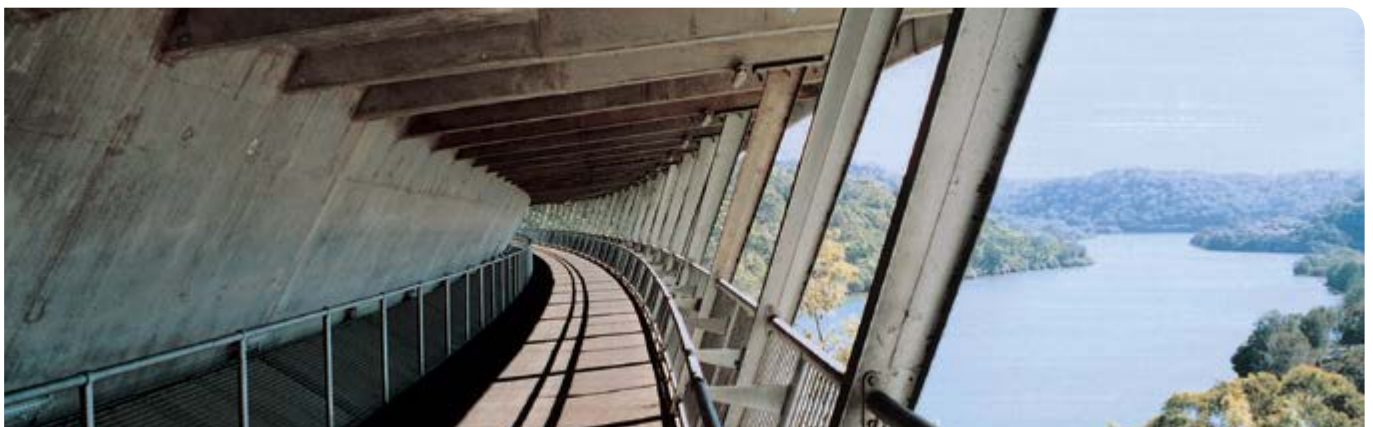
The second approach can be expensive and is perhaps better suited to urban situations. The third approach

is a practical, cost effective objective for overpasses and larger bridges and can lead to good looking bridge solutions.

In areas of high scenic value the following principles should be considered.

The built and natural environment should be made as visible as possible through the bridge.

Minimise the profile of a bridge to allow the landscape setting to dominate the view and be appreciated from all viewpoints.

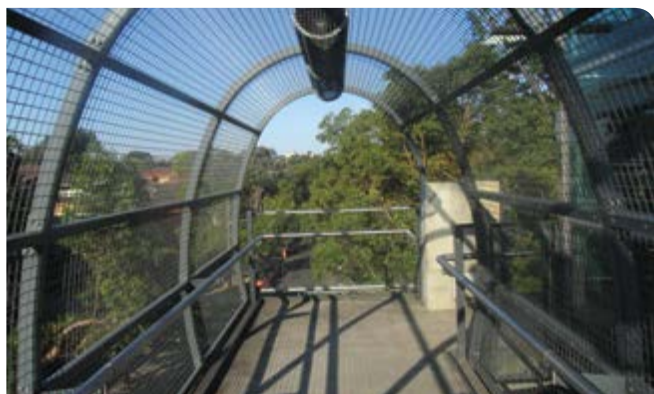


The bridge over Woronora River adopts the design approach of making the bridge as simple and elegant as possible to complement its setting. The wide spans and slender appearance maximise views of the landscape through the bridge. The underslung pedestrian and cyclist path allows good views out over the landscape.



With the transparent top section of the railing, the generous width and the balconies views across the Nepean River can be taken advantage of while walking across the pedestrian bridge.





Views from the bridge towards the surrounding landscape or built environment setting should be maximised.

Allowing good views of the landscape from the bridge helps establish milestones and landmarks on the route, makes the most of the height of the bridge, improves road user interest and helps make drivers more alert and aware of their surroundings.

For example, a view of a river landscape can create an impressive and natural gateway between landscape types or political boundaries, reducing the need for a created 'gateway'.

The requirements of cyclists and pedestrians and motorised road users will vary and the bridge design should take account of the variation in time it takes to cross the bridge for different bridge users and how the user experience can be improved, for example room to stop and gaze out.



On the pedestrian bridge over The Boulevard in Strathfield the placement of the girder to the side of the piers / lift shafts allows for good district views out from the ends of the bridge.



The sweeping form of the Sea Cliff Bridge, north of Wollongong, with two-rail parapet provides panoramic views.

The complexity of a bridge should be minimised in a rural setting.

Complexity tends to attract the eye and compete with views of the landscape. A simple structure frames the landscape and provides an aesthetically pleasing contrast with the natural textures of the backdrop.

Minimal facets and simple shapes provide a good landscape contrast. Accentuating the primary visual elements of a bridge (parapet and pier) and reducing road furniture to the barest minimum is also important.

Landscape tones are generally subdued and dark, therefore light colours such as plain concrete (for bridge primary elements) provide a good contrast.

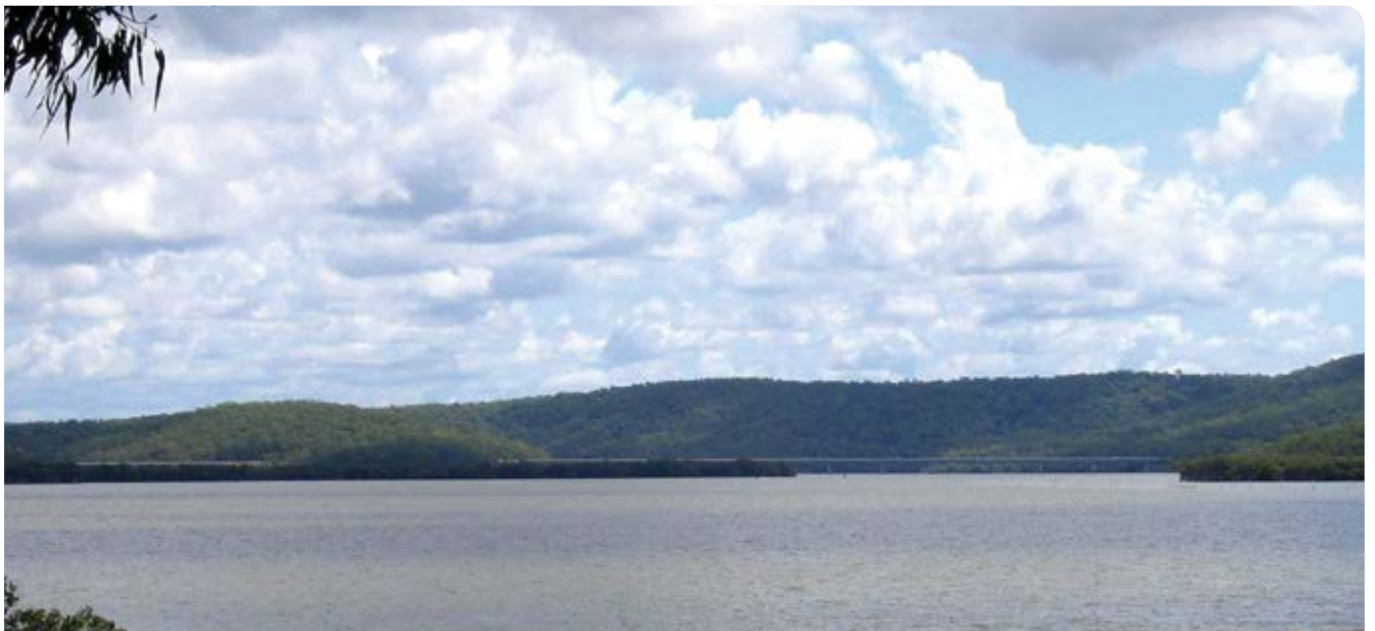
Bridges with a horizontal form are generally preferable to bridges on a grade over flood plains and significant expanses of water.

If this is unable to be achieved due to differing levels either side of the water body then fine-tuning the location of the bridge should be considered, or adjusting the levels along the bridge approaches.

Water always forms a horizontal plane and a bridge structure when skewed to this plane can appear discordant:



This may be because it introduces another plane adding unnecessary complexity. Consider a horizontal bridge in the same location:



A key aspect driving the aesthetics of the twin bridges over the Karuah River was the requirement to produce a continuous flat structure with the parapet creating an elegant horizontal line in the landscape when seen from Karuah.

Natural vegetation should be protected and augmented

The aesthetic value of a bridge will be greatly enhanced if the natural bushland around the bridge is protected and recovered:

- By the careful siting and design of the bridge and approaches, so that significant stands of existing vegetation are retained.
- By minimising the footprint of the bridge (eg pile caps, abutments) so that the retention of local vegetation is maximised.
- By minimising the presence and extent of intermediate structures and hard surfaces between the bridge and landscape.
- By recovering local habitat, in the landscape around the bridge, through careful design of earthworks and planting and the selection of endemic species grown from locally collected seed.



The bridge over Wallamba River on the southern approach to Nabitac allows the riparian vegetation and ecology to carry through.

3.1.4 Bridges in urban settings

The urban environment poses different contextual constraints than the rural environment. It usually has more hard surfaces and vertical elements, volumes of traffic may require a wider bridge than in a rural environment, the bridge is usually seen at lower speeds than from country highways and importantly, many more people see the bridge from its surrounds.

Whatever the size and function of the bridge in an urban setting, it needs to be considered as a piece of the built environment as well as a bridge structure.

Occasionally, bridges are part of major developments and so become more like buildings in their structure and form. They should nonetheless reflect their purpose and the obstacle to be spanned.



Dean Street pedestrian bridge in Albury sits in an urban area and is a prominent piece of the town. It forms one focal point of the Dean Street axis, the other being the memorial (seen here in the distance). Consequently its design comprises a distinctive white tower with a fan shaped arrangement of cables.



Leura landbridge on the Great-Western Highway through the Blue Mountains is part of an urban setting.



The pedestrian bridge, for the Sydney Harbour Foreshore Authority, connecting King Street with Darling Harbour over the Western Distributor in Sydney is as much a building as a bridge. The crossing takes the form of a large timber deck with shade structure, glazed views south and windows to the north.



Land bridges are valuable solutions for bridges in urban areas where it is important to re-establish open space that otherwise would be used for the road corridor as on the Eastern Distributor at the Art Gallery precinct.

An achievable objective when resources are limited is to ensure the bridge complements the local vernacular and benefits the local community.

Some design considerations which could help deliver this objective include the following:

- Creating a landmark structure which complements or contrasts with its visual catchment.
- Maximising views from the bridge of the local urban setting.
- Maximising views through the bridge from the urban setting.
- Minimising adverse visual impacts.
- Designing a well proportioned, neat and pleasing structure.
- Respecting locally valued structures and their curtilages.
- Complementing local styles and materials.
- Ensuring the spaces under the bridge are not dark, degraded and unsafe.

The subsequent parts of this document provide guidance on all these principles.

3.2 Form

Form refers to the external shape or appearance of a bridge and this broadly relates to the bridge type, how the parts are arranged relative to one another and the order or rhythm of elements to create an overall visual result. It is influenced specifically by the following:

- Proportion
- Symmetry and asymmetry
- Order and rhythm
- Simplicity
- Unity of design
- Consistency
- Detailing.

3.2.1 Proportion

Proportion: the proper relationship between things or parts. Proportion is also a ratio or comparison of the relative size of one thing to another, or a portion or part in its relation to the whole.

THE MACQUARIE CONCISE DICTIONARY

The designer needs to think about proportion. A random, thoughtless approach to the proportion between different elements of a bridge is unlikely to lead to an aesthetically valued structure.

While there are no hard and fast rules as to what is good proportion, guidelines can be provided which help to eliminate some of the worst ratios between bridge elements and assist in achieving 'proper' proportion. However, there are always exceptions.

The two most important governing principles are:

- Using excessively imbalanced proportions between significant elements should be considered carefully.
- Repeating similar proportions or ratios throughout a structure can lead to a harmonious structure.

Once a bridge type has been selected the most important factors in creating a well proportioned bridge are:

- The slenderness ratio.
- The relationship between the bridge height and span.
- The relationship between pier thickness and superstructure.
- The relationship between deck overhang and parapet depth.

It is all of these things in relationship that influence the aesthetic outcome.

The slenderness ratio

The proportion between depth of superstructure and bridge span is an important ratio. It is referred to as the slenderness of the bridge and defined as the span length divided by the superstructure depth.

Common ratios can vary from 5 to 35. A slenderness ratio of 5 refers to a situation where additional elements are superimposed on the bridge, such as noise walls creating a very chunky bridge (shown on the image below). A ratio of 30 can result in a very slender bridge. For common pier and girder bridges, ratios should generally vary between 15 and 20.

It is important to differentiate between the slenderness ratio and the visual slenderness of a bridge. A high slenderness ratio does not necessarily indicate a good appearance, since the visual slenderness of a bridge can be affected by solid parapets and opaque noise walls on top of the superstructure, making the bridge appear chunkier than is necessary. The setting and scale of the bridge can also influence whether a bridge appears slender or chunky and, indeed, whether slenderness or chunkiness is appropriate. It is for these reasons that the slenderness ratio should be understood as a guide only.



Captain Cook Bridge over the Georges River has a ratio of 1:18 and together with its gentle vertical curve has a very slender appearance.



This bridge carrying the Pacific Highway at Raymond Terrace has a visual slenderness ration of only 1:6 (taking into account the noise wall). Its chunky appearance is contributed to by the use of headstocks. Transparent noise walls would have resulted in a more slender appearance.

The relationship between the bridge height and span

The ratio between bridge height and span is also important. As a general rule the higher the bridge the wider the span. However in bridges with a variable height, such as over valleys, it is generally not practical to vary span with height unless two or more superstructure types are used.



The spans on the Sea Cliff Bridge vary with the height of the bridge because of the two superstructure types used. Visually speaking the wider spans of the balanced cantilever bridge suit their height above the wave cut rock platforms. The shorter spans of the incrementally launched bridge suit their lower height over the escarpment slope. A seamless connection between the two bridge types has been achieved which unifies the two bridges visually.



The spans on the bridge over the Clarence River at Harwood, appear too narrow in proportion to the bridge height (approximately the same as the older lower level bridge). This creates a visually busier superstructure particularly in more acute angle views.

The relationship between pier thickness and superstructure depth

The ratio of pier width to superstructure depth should also be considered carefully. Bridges with tall thin piers relative to superstructure depth can appear odd, as can the opposite.



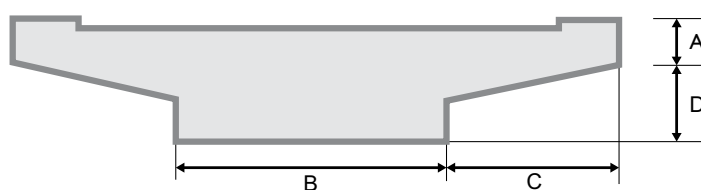
The pier widths used on this bridge next to the old wool road on Main Road 92 near Nerriga appear too thin and almost spindly in comparison to the depth of the girder and parapet.

The relationship between deck overhang and parapet depth

The ratio of deck overhang relative to parapet depth is also considered a significant aesthetic proportion. Guidelines have been developed by the Cardiff University School of Engineering, as depicted in the diagram below and illustrated by the associated bridge example.



The bridge over the Hunter River at Stockton demonstrates that a generous deck overhang is important to consider as part of the bridge cross section.



$$C > D \text{ and } C > B/2$$

$$C = 2A \text{ to } 4A$$

$$D = 2A \text{ to } 4A$$



The Pacific Highway bridges over the Brunswick River at Brunswick Heads shows the application of the Cardiff University guideline.

3.2.2 Symmetry and asymmetry

Another important aspect of form is symmetry. Symmetrical bridges as a general rule are often more aesthetically pleasing than non symmetrical bridges since they appear balanced, refined and also thought about.



The outer spans of this local road bridge on the Yelgun to Chinderah upgrade of the Pacific Highway are not the same dimension and this affects the symmetry of the bridge.



These Pacific Highway twin bridges at Bonville have a perfectly symmetrical composition.



The geometry constraints on the bridges at Yelgun interchange on the Pacific Highway led to asymmetrical bridges. This was understood as a design challenge and the resulting outcome is deliberately bold and distinctive and does not need to be symmetrical. The larger abutment at the end of the larger span compared with the smaller abutment at the end of the shorter span creates a 'balance' that makes the bridge visually appealing.

Symmetry need not necessarily be the rule but should not be departed from unless for a good reason. For example, asymmetry can be perfectly justifiable due to site constraints, technological innovation making new forms possible, symbolic imperatives or artistic endeavour. All of these factors come into play in the asymmetrical and counter-balanced bridges of Santiago Calatrava. This tends to be the exception rather than the rule and applicable to bridges that are more iconic in nature (See Appendix A: Global Perspective).

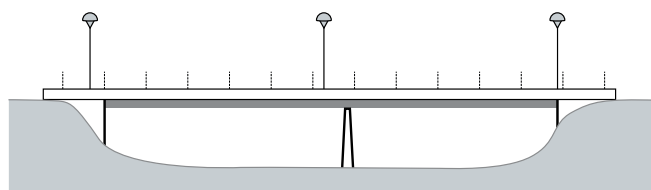
It does not mean to say that such bridges should not be attempted. The rules that apply to asymmetry involve their own questions of balance proposition and the likes, but their nature is different as is the ultimate form.

3.2.3 Order and rhythm

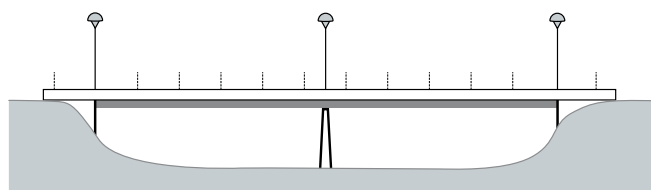
Designing a rational order and rhythm to a bridge and its parts can improve its appearance. A designed order to individual bridge elements can look more pleasing than chaotic randomness.

For example, spans should match where possible, or at least demonstrate a consistent order. The cumulative effect of all bridge elements including lighting columns, barrier supports and piers should be considered.

All the bridge elements can be well designed individually, but lacking an order and rhythm together, create a discordant appearance:



Rearranging the parts provides an ordered and pleasing whole:



The new Herb Feint Bridge in Adelong demonstrates the principle of order and rhythm in the whole, parts and detailed elements. The bridge barrier posts relate to the piers and the lighting is located with a consistent rhythm along the bridge symmetrically spaced around the piers. It responds well to the setting of Adelong Creek as a central landmark within the town.

3.2.4 Contrast and harmony

“Sometimes referred to as tension and release ‘a departure from order – but with artistic sensitivity – can create pleasant poetic tension’.”

MIES VAN DER ROHE, IN BRIDGE AESTHETICS AROUND THE WORLD

For example, natural features such as vegetation, stone or landform can create a good contrast with the order, precision and simplicity of a concrete bridge (for example on the Herb Feint Bridge, opposite page).

3.2.5 Simplicity

Refinement of design should generally be pursued. Embellishments and ornamentation often do little to change the basic aesthetics of a structure.

Refinement of a structure, so that it better represents the forces that it is designed to withstand, is generally a feature of a bridge of aesthetic merit. This is often referred to as honesty of form and design integrity.

Nonetheless, it is unwise to insist that a bridge is perfect only if nothing can be omitted; there may be good reasons for avoiding total refinement based upon local context.

3.2.6 Unity of design

A bridge is a whole, not an assemblage of parts. Neglecting the whole or the parts will result in an unsuccessful bridge in aesthetic terms. Consequently, consider the parts as to how they contribute to the whole of a bridge.

The approaches to the bridge are an integral element of the whole bridge design and must be considered in the design process.

The landscape design, the approach road design, and all the associated signage contribute to the bridge design as a whole.

3.2.7 Consistency

Consistency of form is an important aesthetic consideration. This is not to say that everything must look the same but that in a particular context there should be a relationship between elements in terms of materials, proportion, colour or details.

This aesthetic aspect is very important when the bridge structure is but one element in a road corridor and a degree of consistency is desirable along the corridor as a whole.



The Ballina Bypass bridges, at the Teven and Cumbalum Road interchanges, used a tapered portal pier arrangement with a wide integrated headstock that allowed for future bridge widening. On the shorter piers on the Cumbalum road bridge, the form couldn't be accommodated elegantly and a wall type pier was adopted with consistency only achieved in the outward angle of the pier. An alternative more consistent main pier shape could have been a tapered wall type pier with an internal void (a trapezoid). For consistency across the project this pier would have needed to be used on both the Teven Road and the Cumbalum Road interchanges.

3.2.8 Detail

Attention to detail is essential to good bridge design. Lack of attention to detail can spoil an otherwise beautiful bridge. Careful consideration of the interrelationship of each element and their relationship with the whole is necessary at all stages of the design process.



The detailed consideration of the vertical pier to separate the varying deck depths, the recessed girders to catch the shadows, and the continuous parapet all well resolve a difficult junction on the Stockton Bridge.



4 The parts

4.1 Superstructure

4.2 Substructure

4.3 The bridge curtilage



This road bridge over the Pacific Highway on the southern approach to Nahiach has an elegant haunch, a good relationship of span to superstructure depth, well resolved abutments and carefully considered placement and detailing of elements. It forms a milestone on the route and marks Nahiach as a place to stop.

The parts

4.1 Superstructure

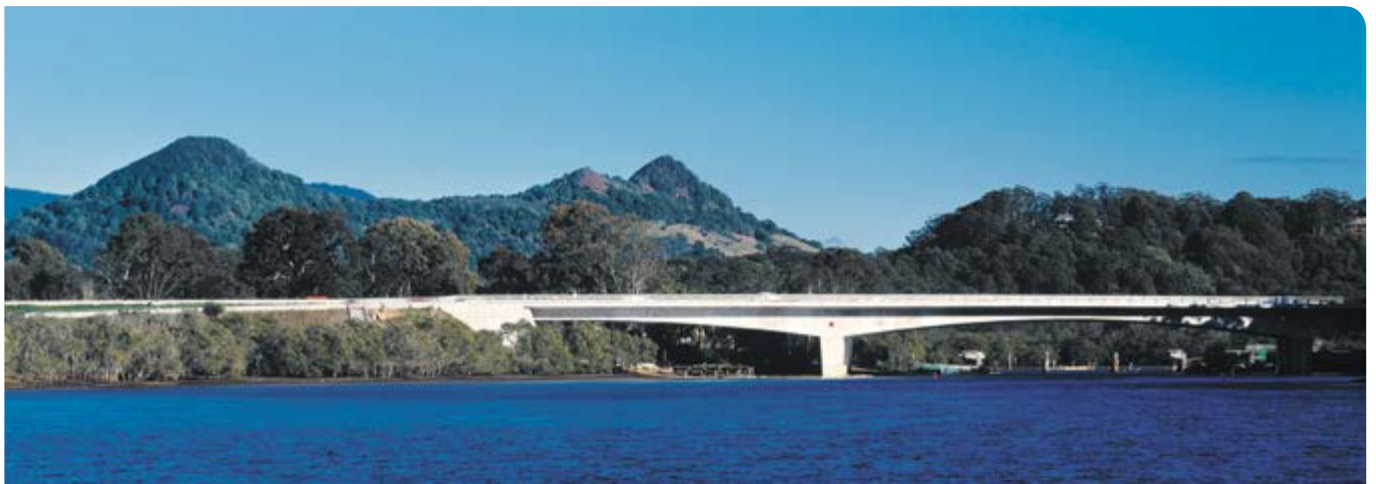
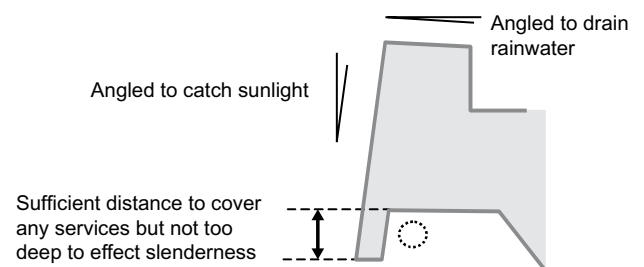
4.1.1 Parapet

The outer face of the parapet can be one of the most important aesthetic elements of a bridge. For most bridges it is the highest element and often the most dominant in long distance views. It can also be the longest piece of the bridge and as such an opportunity to express the span and horizontal nature of the structure.

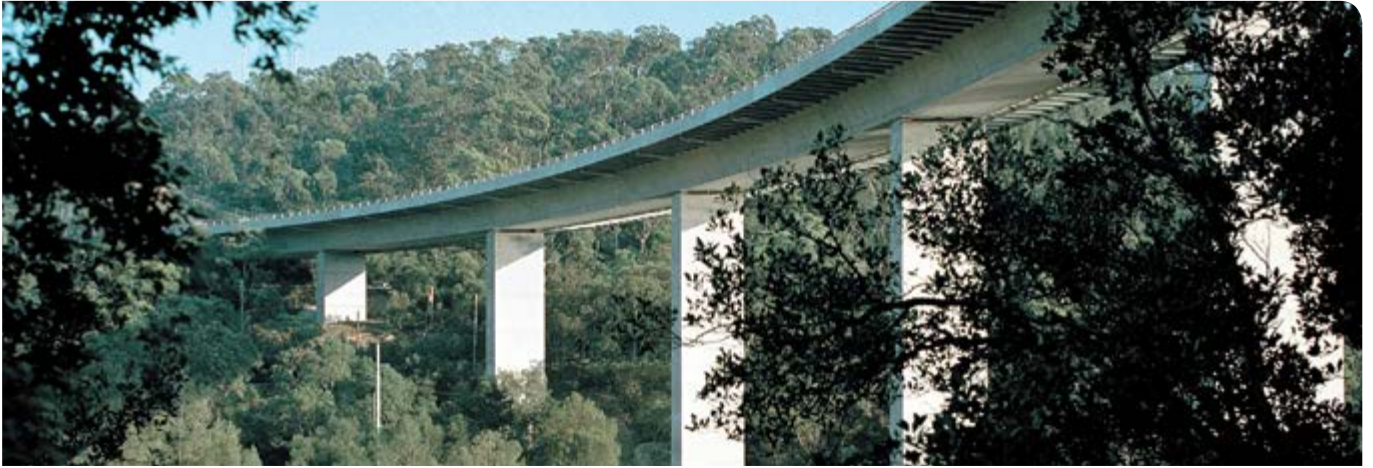
The following principles should be considered in the design of the parapet.

- They should appear as a continuous uninterrupted face, extending the full length of the bridge with a generous overlap of the abutments.
- A continuous neat, sharp edge will help define them against the background.
- The proportions between their depth, the deck overhang and the girder depth should be carefully considered (see 3.2). Shaping the parapet if it is too deep can assist in visually balancing proportions.

- Maximising the shadow cast on the girder and superstructure will further accentuate and express their form.
- The outer face should generally be a smooth single plane surface on a continuous curve (if the bridge is not straight) and slanted slightly outwards towards the bottom to better catch the sunlight.
- The top should angle towards the road, to channel rainwater onto the bridge, minimising staining of the outside face.
- Consideration should be given to extending the parapet below the deck soffit to hide drainage pipes.



The Pacific Highway bridge over the Brunswick River has a parapet that satisfies the above requirements.



The line of the parapet on the bridge over Woronora River at Sutherland is an important bridge element. It is sharp, smooth, catches the light, helps provide shadow and unifies the structure.



In some circumstances where the parapet is proportionally too deep, a crease line or kink can help visually break down the apparent depth as on this Pacific Highway bridge at Banora Point. The parapet is on a continuous curve to avoid the faceted appearance of the Super T girders.



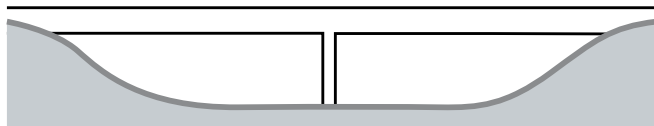
The lack of a well designed parapet creates a visually confusing superstructure as in this bridge over the M2 Motorway at Beecroft. This is an example of a poor aesthetic outcome.

4.1.2 Girder

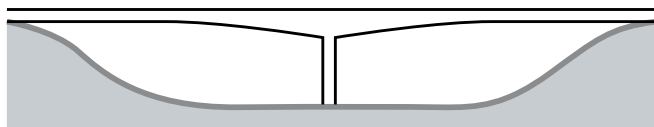
The girder seen in elevation and its cross sectional shape are important considerations discussed below. The horizontal alignment of the girders is also important especially on curved bridges. In general it is preferable to avoid a large scale faceted appearance created when using a series of straight girders by using shorter facets or curved girders, however ensuring a curved parapet mitigates the jagged appearance of straight girders underneath.

Girder elevation

Haunched girders are expressive and responsive to the forces in the bridge. They can often be more distinctive and elegant than single depth beams.



SINGLE DEPTH



HAUNCHED

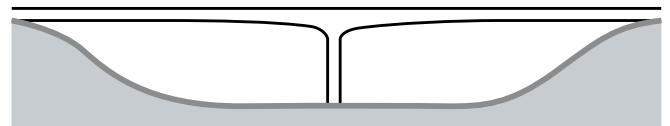
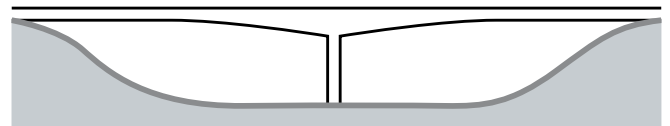
However, only certain bridge types can accommodate a haunch; these include segmental box construction and balanced cantilevers.

The following principles should be considered in the design of haunched girders.

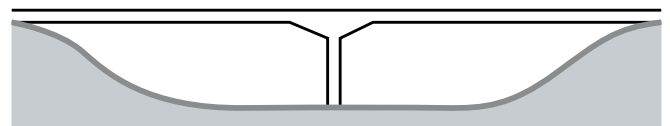
Three or five span haunches are generally aesthetically very elegant, balanced structures.



- Long haunches smoothly tapering out are much more graceful and responsive than short abrupt haunches.



- Avoid a sharp angle between haunch and beam.



- Even with single spans, curving the girder can provide an expression of elegance.





The haunched girders on the twin bridges over Mooney Mooney Creek on the F3, demonstrate the principles of span, taper and curvature.



On the girder on the bridge over the F3 Freeway at Blackhill Road near Newcastle, the haunching is made less elegant by the angle of transition between haunched section and horizontal beam. (Also note how the solid parapet affects bridge slenderness).

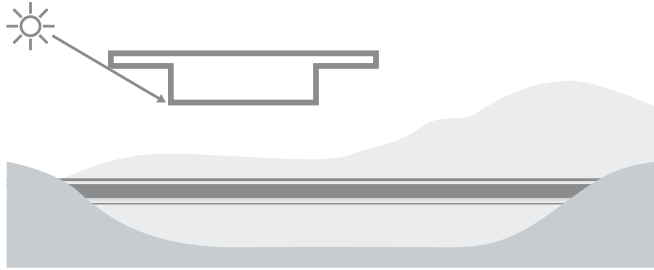


On this bridge over Taren Point Road it is unfortunate that the planting design is not integrated with the bridge design, as it obscures the fact that the bridge is an elegant single arched span.

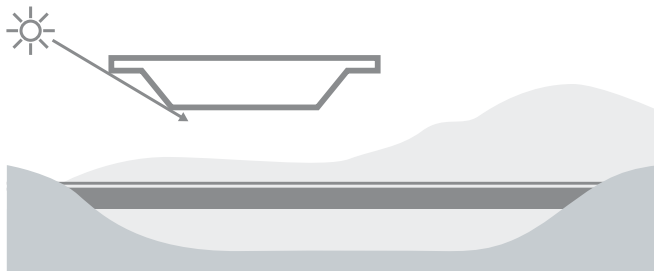
Girder cross section

Different girder cross sections can have different aesthetic effects. The cross sectional shape of the girder should be considered with attention to the following principles:

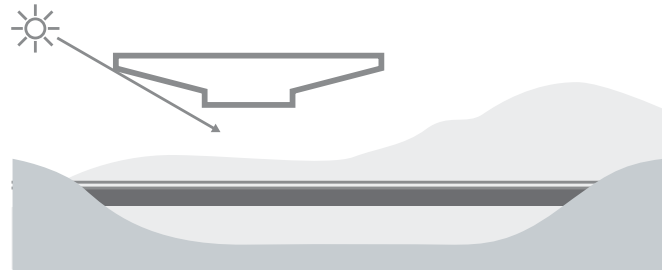
- A right angled connection can catch the light and a double line may be visible; maximising the overhang will increase the duration of shadow.



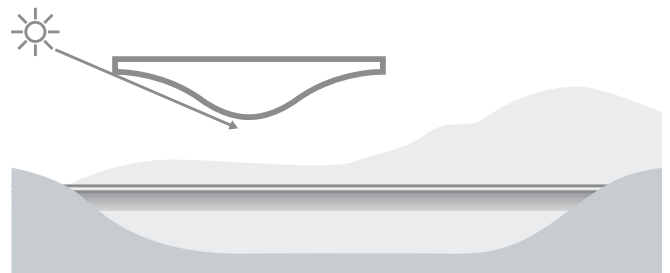
- An angled connection will minimise this effect.



- A very acute angle provides a deep shadow nearly all of the time.



- A curved soffit will provide a gradation of tone and minimise a sharp line at the base of the beam.



Bridge over the Hunter River at Stockton shows the effect of a right angled girder shape in afternoon sunlight.



An angled girder can maximise shadow time on the girder and accentuate the parapet edge.



Deep overhang and acute angle of deck on this bridge on Victoria Road at Huntley's Point.



A curved soffit with a rounded edge can make even deep girders appear very slender because the curved section only catches the light in a thin line at any time of day. These girders can create very elegant and attractive bridges, such as this bridge over the great Western Highway at Shell Corner.



On the Yelgun interchange bridge on the Pacific Highway the curved girder matches the parapet producing an attractive outcome. A right angled connection can catch the light and the eye.

4.2 Substructure

4.2.1 Headstocks

Headstocks transfer the load from multiple girders to the pier column. They are the equivalent of the post and lintel construction in architecture. They should be integrated with the pier rather than designed as a separate, visually unrelated element to avoid additional visual complexity.

If possible headstocks should not extend up and across the outer face of the girder. This introduces unnecessary complexity and appears in elevation as if the headstock is providing support to the deck.

Where possible the headstock should be the same width and shape as the pier column.



This is also not a good aesthetic outcome. The headstock design on this bridge over the F3 does not match the pier and covers the gap between girders. It was required to accommodate mining subsidence, but its presence lacks elegance, particularly on short piers.



Wall type piers without headstocks are often an elegant option on highly visible highway overbridges and have been used extensively on recent Pacific Highway and Hume Highway upgrades.



The headstocks on the Warri Bridge on the Kings Highway are formed as part of the pier, with the same width, colour and shape. This creates a simple refined outcome.

4.2.2 Piers

Longitudinal pier spacing

Pier spacing is the result of a number of factors including:

- The nature of the space being bridged (eg a deep valley or ecologically sensitive environment will require wide spans).
- The height of the bridge.
- The balance between superstructure cost and pier cost.

In general too many piers can appear cluttered, while too few piers can result in an overly dominating deep beam.

In general long spans on low bridges can look odd, as can short spans on high bridges.

A balance is required which should respond to the best structural form and the wisest use of resources.



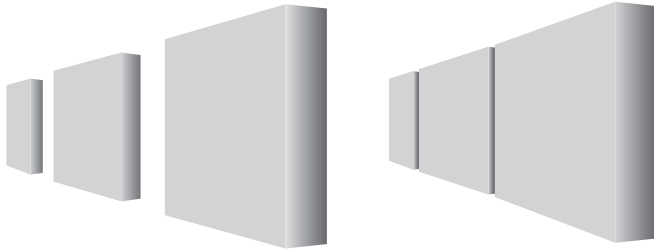
Many piers on the bridge over the inlet to Lake Illawarra creates an overall complex, wharf-like visual effect which does not create a graceful appearance.



Wider piers on the Windsor flood evacuation route create a graceful effect.

Multiple piers

Where multiple piers are used, consideration should be given to allowing them to be read as separate elements. When placed too closely multiple piers can appear complex or wall like:



Single pier units are more simple, reduce the number of elements in the view and allow the superstructure to become the dominant visual element.

Multiple piers on the other hand can provide a sense of strength and durability and if well designed can provide interest and character.

The selection of multiple or single piers should be a consequence of the context and the requirements of the bridge.



The F3 Freeway twin bridges over Mooney Mooney Creek show that multiple piers can be a significant feature and, if well designed, can provide character and great visual strength.

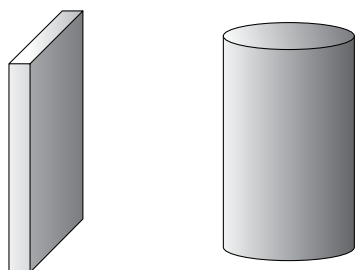


The multiple piers on the arch bridge over Tarban Creek in Sydney, are visually distinctive and help create a strong sculptural effect.

Pier cross section

Pier shapes with only two lines of symmetry (eg rectangles or ellipses) and transverse to the centreline of the deck are generally preferable to squares and circles as they present the thinnest edge to the side view (short elevation). However, where bridges are used in multiples as at large interchanges or when they are highly skewed a circular column can be an aesthetically effective solution.

Elliptical shapes have the additional feature of providing a softer graduated reflection of light when seen in elevation:

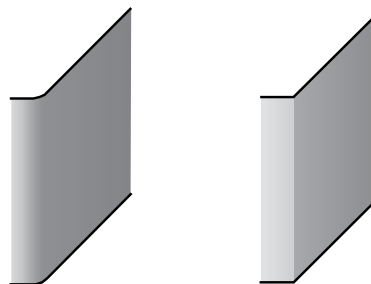


Clean, well designed rounded ends on the piers on this bridge over the Hume Highway complement the bridge and rural setting.

Where complex shapes are used, such as a rectangle with semi circular ends, care must be taken to ensure a consistent smooth finish. Joints in shuttering and different colour and finish between concrete pours can cause visual problems.

Rounding off the corners of rectangular piers provides a softer form, which may be preferable in certain contexts, for example, where the presence of the pier needs to be down played so that superstructure is dominant, eg in a rural setting.

A sharper edge may be preferable where the pier is to be accentuated because it is the dominant element, such as in an urban context or where piers are particularly high.



Sharp crisp lines and well defined edges are a feature of the bridge over the Hunter River at Stockton.

Pier end elevation

Where it is important to accentuate the horizontal linear form of a bridge, pier shapes which have a slight taper can add elegance and interest.

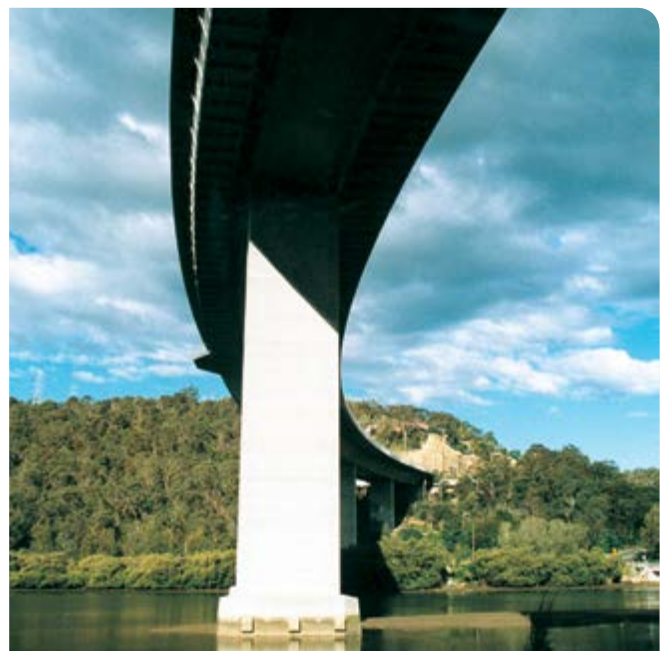
They appear refined and have a light connection with the superstructure or pile cap. They also respond in design terms to the forces acting upon them, demonstrating refinement of form and economy of material.

A pier tapering to a narrow top appears stable with a firm anchor to the ground. It creates a slender effect which is suitable for tall piers.

A pier tapering to a wide top creates a quite different impression indicating a strong connection between superstructure and pier and a light connection to the ground rather like a table leg. The appearance suggests a strong resistance to forces along the bridge and because the pier and girder have such a solid visual connection the effect of a horizontal 'floating superstructure' is not as apparent. This taper also has the advantage of being used to provide a wide support where two girders meet.

It is important to consider that the angle of taper will vary with pier height if the top and bottom width of the pier remain constant (which could appear inconsistent in a suite of bridges).

The combined effect of tapering on both short and long elevations of the pier should be considered bearing in mind simplicity of form and cost of formwork.



The piers of the bridge over the Woronora River have a slight taper of 1:100 in both the end elevation and the longitudinal elevation. This minor taper is sufficient to provide refinement and elegance.



The piers on the new Iron Cove Bridge, seen here at sunset, are parallel in the short elevation and tapered in the long elevation. This taper also follows the direction of angle of the girder edge which helps unify the bridge elements.



When designing a suite of bridges for a project, for example on the Bonville Upgrade on the Pacific Highway, tapering the piers on the family of overbridges will create different shaped piers if the bridges have different heights. This is because the top and bottom dimensions of the piers are constant. This is not a significant visual problem if the bridge heights are similar. Care should be taken on inverted shaped piers to avoid the effect of a spindly base appearing to support a large load.



The circular piers and mushroom-type capitols form pivots that accommodate the multi-directional ramps on the M7 Motorway.

Pier longitudinal elevation

The shape of the pier long elevation (ie perpendicular to the road alignment) is also an important aesthetic consideration. It can have a profound influence on the appearance of the bridge.

Wall type piers can appear simple and remove the need for a headstock, as discussed previously. However on wide bridges such as duplicated highway river crossings, they can use a significant amount of concrete and can appear heavy, increasing shade and darkness. As an alternative, a frame type pier can allow more light to penetrate the underside of the bridge and can also eliminate the need for a headstock.



A concrete frame creates a simple attractive pier as used on the Herb Feint Bridge in Adelong and the Five Islands upgrade at Lake Macquarie.



The piers on the concrete bridge over the Georges River at Tom Ugly's are reminiscent of the bow of a ship. They are well proportioned and suitably simple considering the proximity of the adjacent truss bridge. (The taper on the piers is 1 in 8).

The long elevation of the pier can also be tapered.

Again a taper can appear elegant and better represents the structural forces acting upon the pier.

A strong rigid connection between pier and superstructure may be desirable with a light contact on the ground. Alternatively, a wide splay on the ground visually supporting large side forces may be desirable:



Tapered piers on the Falcon Street pedestrian bridge, which are wider at the base, give an impression of a strong connection to the ground.

An open voided pier type is also an option. They can reduce bulkiness, appear refined and allow views, but care should be taken not to introduce further complexity than is necessary.

They can be effective visually as they give a light connection to the girder.

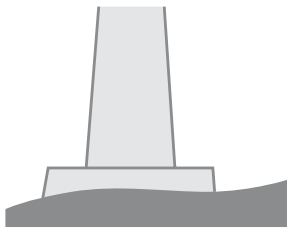


The bridges over the Georges River at Alfords Point utilise piers with a taper and triangular void. This 'Y' shaped pier is a refined and attractive way to support the two box girders.

4.2.3 Pile caps

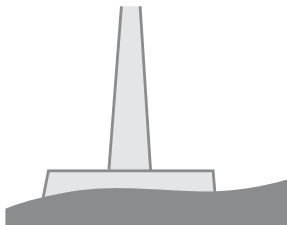
As piles are needed to support piers in soft ground, pile caps are often a feature of bridges crossing water courses. They perform an additional function in navigable waterways in that they help protect the pier. For safety reasons, they need to be visible to boats and shipping.

They present an aesthetic challenge in that they form the footing to the pier.

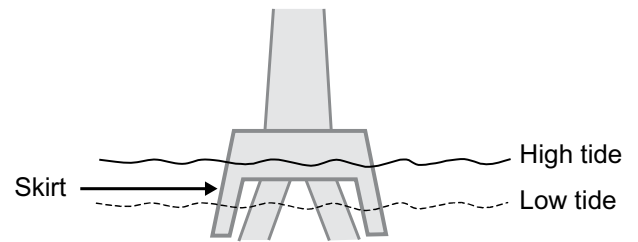


Where pile caps are visible there are some guiding principles:

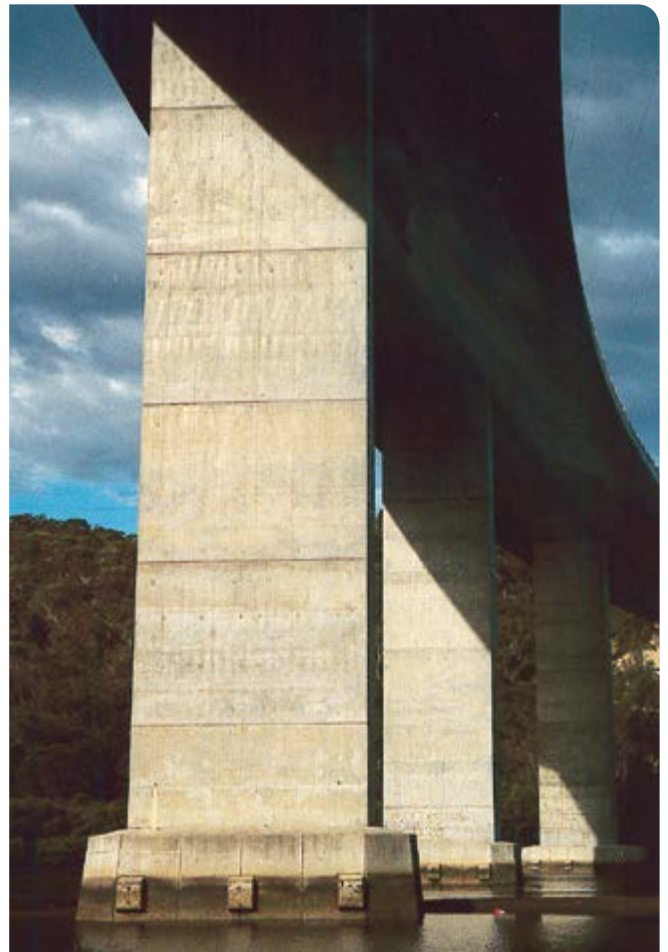
- Pile caps should mimic the shape of the pier as far as possible.
- The proportion of pier size to pile cap size should be considered. Imbalanced proportions should be avoided.



- In a tidal watercourse the view of the piles below the cap should be avoided. To do this, the pile cap may require a skirt.



In general, pile caps should be placed underground and not be exposed on land. This is particularly the case with short piers.



Piers and pile caps on the bridge over the Woronora River are in proportion with each other. The cap provides a solid and appropriate footing for the slightly tapering pier.



On land, as in this example on the Pacific Highway at Ballina, it is generally visually preferable to bury the pile caps below ground level. Note the curved parapet over the straight facet of the Super T girder.



The pile caps on the Gladesville Bridge are also in keeping with the large piers and provide a suitable structural termination in the park. An alternative approach, generally preferable, would have been to bury the pile cap, but in this example the outcome is well considered.

4.2.4 Abutments

In an open landscape setting, spill through abutments are generally preferable, as walled abutment structures can block views.

In some circumstances walled abutments can be appropriate and help provide a good fit with surrounding built form. They can also heighten the visual effect when used to mark change points in the character of the landscape, such as at the edge of a forest or at the high point of the road.

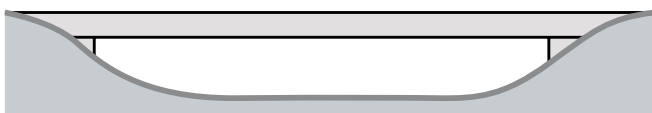
Walled abutments can reduce the slender appearance of the bridge, block the flow of the landscape and confine views:



Reducing the abutments can create a more refined and better looking bridge. It does however increase the span and therefore depth of beam:



Continuing the superstructure or the parapet above the abutment allows the shadow line to reduce the dominance of the abutment, and makes the bridge appear longer and more elegant:



The presence of large walled abutments on overbridges can have a considerable aesthetic impact and their design needs to be carefully considered as in this example on Pacific Highway at Yelgun (above). Generally in a rural setting spill through abutments are preferable as they have a lightness of form, allow views and emphasise the continuous slender form of the bridge as in this bridge at Nabitac (below).

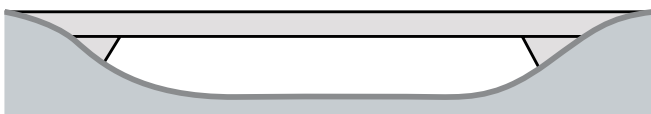


The slight angle of the abutment, around 5% outwards at the top, makes a more aesthetically pleasing outcome, which in this case at Bonville also reflects the pier taper.

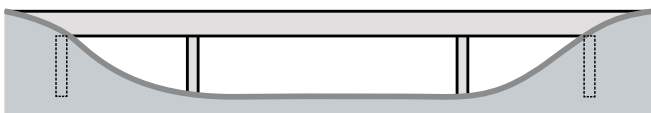


The inward angled abutments on this M7 bridge are an attractive detail which visually emphasises the span. On this bridge the central pier is encased in an architectural wing wall feature as part of the corridor aesthetic. In general it is preferable to express the structure honestly and integrate aesthetics and engineering as this document espouses.

Angling the abutments provides a more open sleek look and helps visually anchor the span:

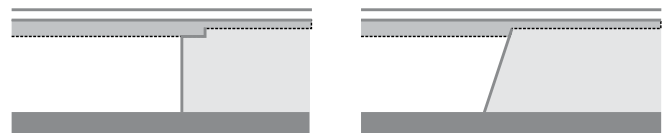


Spill through abutments allow open views to the landscape and better visibility to the road beyond:



Walled abutments, where used, should be simple and unobtrusive.

- The deck and parapet should extend beyond the abutment wall.
- Consideration should be given to extending the wall up and around the girder to remove the notch.
- A slight angle can make the wall appear less dominating especially if next to a footpath:



4.3 The bridge curtilage

The curtilage of a bridge is the space around and under the bridge. It is integral to the visual success of a structure, just as a garden is integral to a house. It is distinct from the context of the bridge in that it should be considered as part of the project, rather than the existing environment. The design of the bridge curtilage is integral to the success of the bridge as a whole.

The curtilage can be addressed in terms of the space around the bridge and the space under the bridge.



The bridge curtilage is an important part of the whole aesthetic outcome. The design of the new Iron Cove Bridge considered the local setting. A bridge curtilage was created that respects King Georges Park in Rozelle and the Bay Run.

4.3.1 The space around the bridge

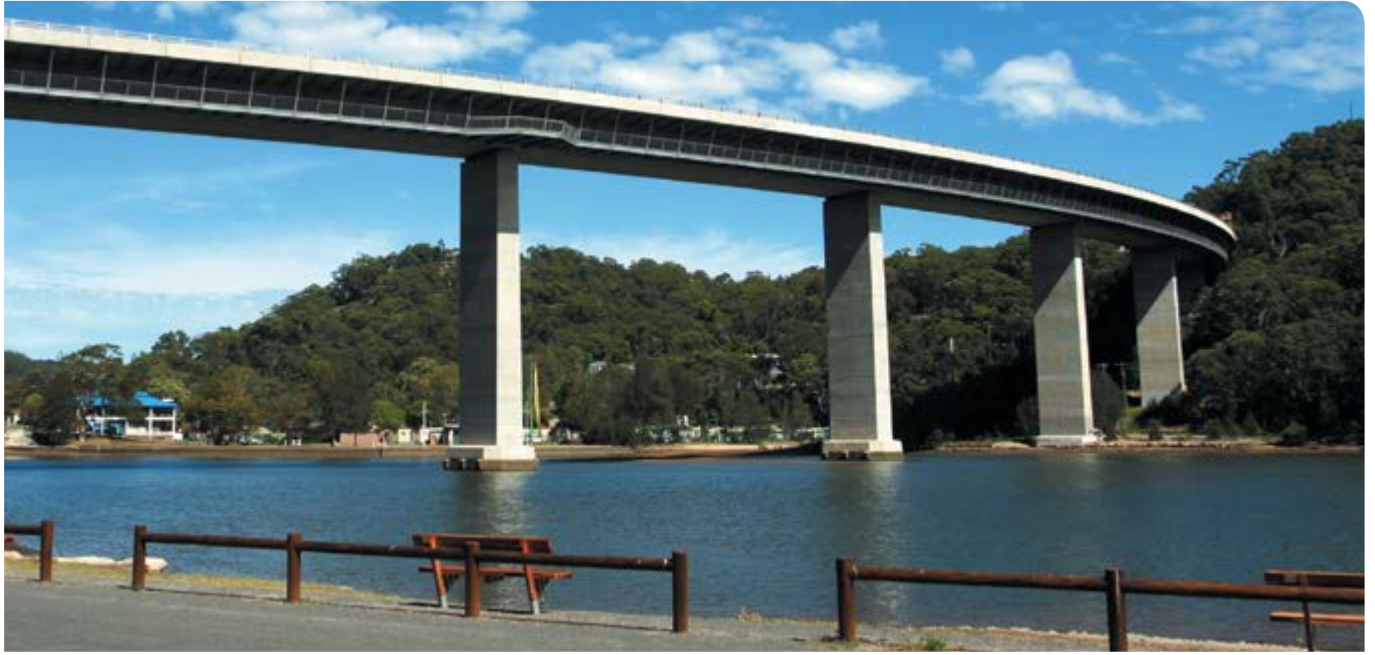
The space around the bridge, as an interface between the bridge and its context, serves several aesthetic functions.

- It is the setting in views to the bridge.
- It is the foreground in views from the bridge.
- It provides an opportunity to frame and contrast the bridge.

Generally there should be continuity between the existing landscape and the space around the bridge. Where possible the space should be designed so that it complements the adjacent landscape character.



Interchange on the Pacific Highway at Ballina. The bridge design and the setting were a single composition.



The curtilage of the bridge over the Woronora River provides a significant public domain, sense of place and immediate setting for the bridge through the improvements of the foreshore, creation of local park (see below), retention of the old bridge and landscape treatment. This was all part of the scope of works of the bridge project and is important to the whole aesthetic outcome.



Footways, canopies, seating, interpretation signs and landscaping in the local park next to the bridge over the Woronora River.

4.3.2 The space under the bridge

The space under a bridge must be considered in the concept design phase of the bridge and integrated into the design of the whole structure.

If these spaces are not considered then bridge aesthetics will be impaired by the presence of dead or dying plants and 'eroded rubbish strewn' surfaces. Also valuable space will be lost.

There are a range of strategies in dealing with this space which includes the following:

- Consider the surface treatment of the space. These spaces tend to be very dry and if in deep shade plants are unlikely to survive. Where plants are used they should be located to the outside of the space and irrigation may be required. Generally only the most shade and water tolerant plants should be used which tend to be Australian and NSW natives. Combining planting with a hard paved or gravel surface is often appropriate.

- Consider the function of the space.
 - Footpath and cycleway networks can benefit from the additional connectivity the space under a bridge provides.
 - With high urban bridges the potential use of this space for future development should be considered. It may be that the bridge aesthetics would benefit from undercroft development.
 - The creation of a varied habitat from light to a dry and shady rocky habitat, connecting and benefiting local biodiversity may be worth considering.

Soffit design

Where the underside of the bridge is visible, consideration should be given to the design of the soffit. Clean uncluttered surfaces, neat connections and simple layout of girders will help to give a suitable appearance.



The sensitive use of sandstone paving and bollards, at the heritage abutments under the new Iron Cove Bridge in Rozelle, has created a place to view the evolution of harbour crossings at this point – from early ferries to timber truss to Art Deco steel truss to concrete incrementally launched girder.



Where there is room, the space under the bridge can be used to create fauna corridors and help reconnect habitats. Bonville Bypass included many fauna connections, such as this example along the Bonville creek.



The underside view of the bridge is visually an important part of the space under the bridge. In this example in Canberra the slatted girder creates a smooth lightly textured surface. LED lighting enhances the effect and also identifies the bridge. (Photo courtesy of Johnson Pilton Walker).



The space under the triple bridge over Brunswick River has a unique character. The public timber boardwalk traverses an area of relocated mangroves, preserved sea grasses and rocky outcrops with framed views towards the ocean and surrounding mountains. Watery reflections on the immense haunched girders overhead provide a fitting ceiling to the space.



Sydney Harbour Bridge viaducts were converted into buildings after the bridge opened in 1932. In 2016 they opened as offices for the transport authority.





5 The details

5.1 Joints and connections

5.2 Bridge barriers

5.3 Safety screens

5.4 Protective fencing

5.5 Signage and advertising

5.6 Lighting fixtures

5.7 Drainage

5.8 Noise walls

The M7 Light Horse Interchange with its main carriageways, sweeping ramps and shared bicycle and pedestrian path has an integrated system of details including bridge barriers and rails, joints and connections, safety screens and protective fencing, and lighting fixtures – all robustly designed.

The details

It is often said in relation to design that 'the devil is in the detail'. What is meant is that it is often the small things that can make or break a design, and this is especially important with bridges where the details are highly visible.

There are four important aesthetic considerations in the detailing of a bridge:

- The aesthetics of the bridge details must be considered as part of the whole bridge design.
- The design of the details should minimise the potential for staining.
- The bridge detail should not impair the view from the bridge.
- Good access for inspections and maintenance should be considered early in the design phase.

5.1 Joints and connections

The joints in bridge structures at the ends of the span or along the superstructure are an opportunity to enhance the bridge design and provide another level of detailed aesthetic interest.

Differentiate between bearings and other connections and recognise these in the design.



The details of this bridge over Victoria Road in Gladesville are an intrinsic part of the aesthetics of the bridge as a whole. The graceful narrowing of the deck edge over the pier typifies this important relationship between 'the whole' and 'the parts'.



There is a neat, simple and tight joint between two girders on the bridge over Bonville Creek. The potential for staining is minimised and the bearings can be clearly seen for inspection. The relationship with the parapets has also been considered and the girder joint neatly lines up with the joint between the precast parapets.

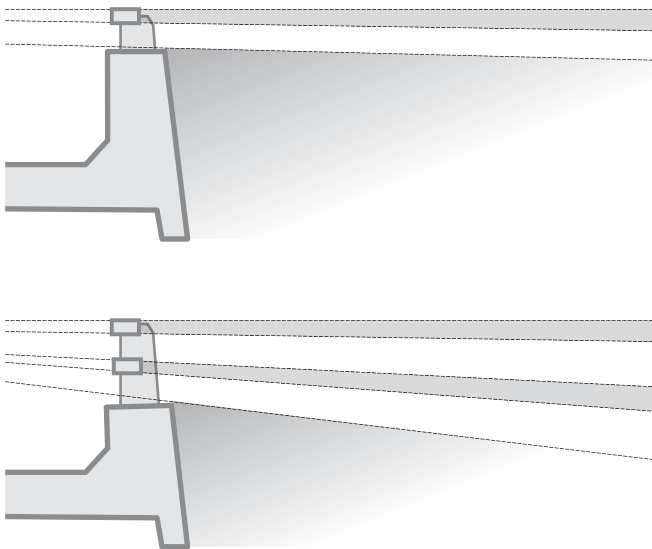


The design of the bridge abutment should incorporate, in a sensitive attractive manner, access provision for bridge inspections such as these bridges at the Hume Highway (top) and Kempsey Bypass (bottom).

5.2 Bridge barriers

The design of the bridge barrier can influence views from the bridge, influence the apparent depth of the superstructure and reduce the slenderness ratio. If views and slenderness are to be maximised the bridge barrier should be as transparent as possible which means using bridge rail rather than a full height parapet.

A two rail barrier is better than a single rail barrier in this respect:



Consideration should be given to the transition between the bridge barrier and the road safety barrier. A neat simple connection should be designed.

The post for bridge barriers should generally be perpendicular to the bridge, however on a greater than 4 percent gradient it generally looks better if the posts are vertical.



Tapering the barrier and parapet is a neat way of ending the bridge barrier.



Neat tapered terminations to the bridge barriers on the Pacific Highway at Bonville



The safety screens on the pedestrian bridge over the Warringah freeway are an integral part of the bridge design.

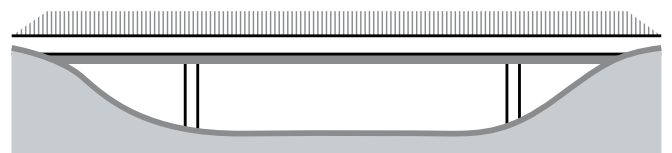
5.3 Safety screens

The safety screen is designed to prevent objects being thrown from the bridge and damaging vehicles or injuring people below.

These screens should be an integral part of the bridge design.

There are several aesthetic considerations:

- The bridge screen being a peripheral element to the true function of the bridge should avoid obscuring the superstructure.
- Screen posts should align with the safety barrier posts and be perpendicular to the bridge, not vertical (below 4 percent gradient).
- The screens should extend to the ends of the bridge span.



- There should be a neat, elegant transition to the bridge barrier safety screens; a simple taper or stepped drop in height can help with this, but is not always necessary.
- The screens should maximise views out from the bridge ensuring a good level of transparency. A rectangular shape for the mesh apertures and the use of a tensioned mesh can assist in this.



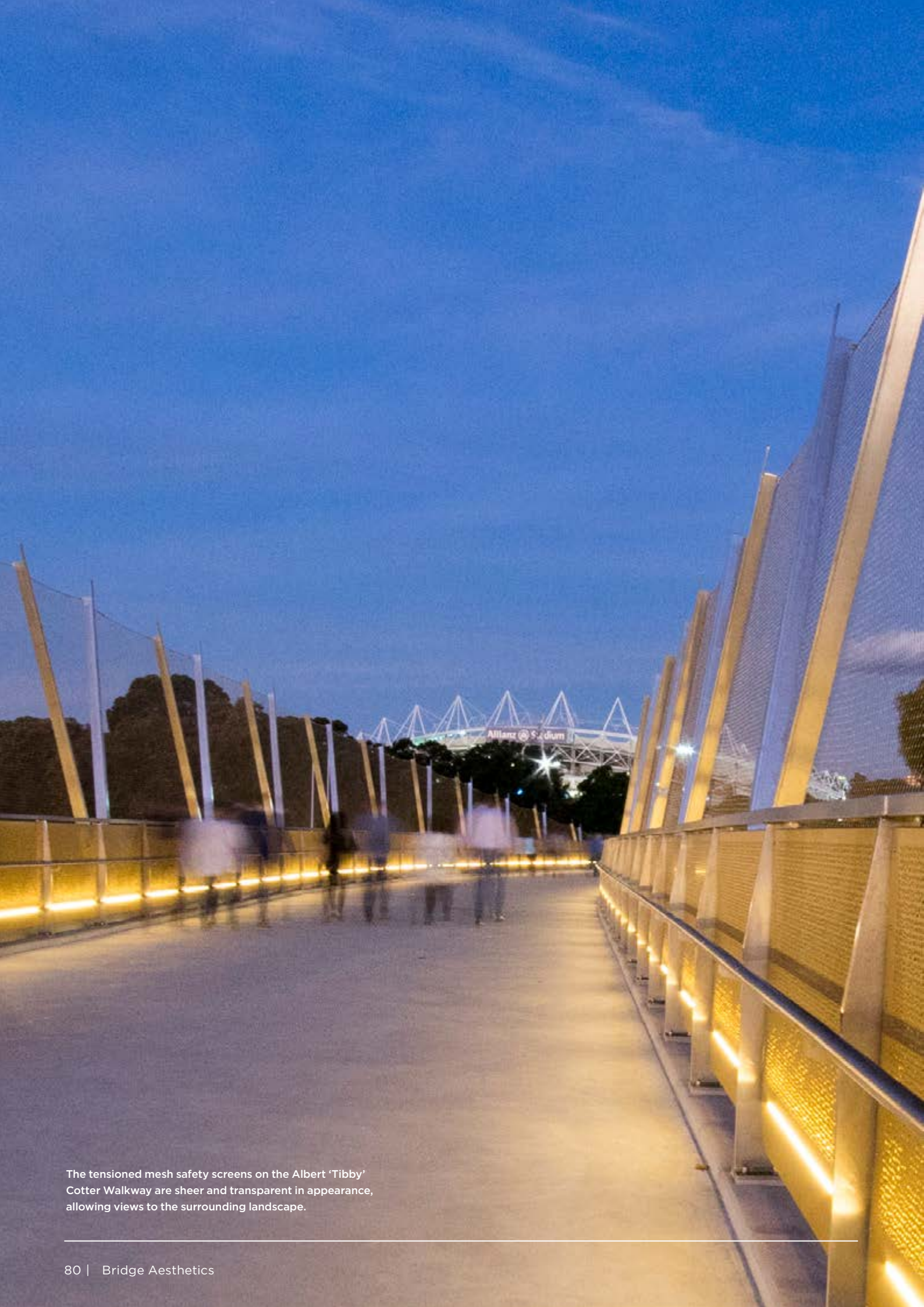
In this example on the Yelgun to Chinderah section of the Pacific Highway, the two elements are separate yet are related in design and material. A slight misalignment in supports would have affected the design outcome. A more sustainable solution would be an integrated barrier and screen. However this is not a good maintenance outcome and the screen also obscures the parapet.



On this bridge over the Pacific Highway at Nabiac the bridge barrier piers and safety screen posts are aligned and integrated. The bridge parapet is expressed and not obscured. The shaped form of the barrier is considered as part of the whole structural design of the bridge to create a beautiful aesthetic outcome.



These screens on the M7 have been designed as a feature of the bridge; the flaring of the screens matches the flaring of the piers.



The tensioned mesh safety screens on the Albert 'Tibby' Cotter Walkway are sheer and transparent in appearance, allowing views to the surrounding landscape.



5.4 Protective fencing

Occasionally, special fencing is needed to protect pedestrians, secure the bridge and make it difficult for people to jump from the bridge. This can be a complex matter, requiring detailed consideration on a new bridge and consideration where and how it

is retrofitted on an existing bridge. It is a detail like any other and needs to be approached by designers so that the aesthetics of the existing bridge are not affected and the fence is integrated with the whole design.



A new protective fence on Suspension Bridge, Northbridge proved to be a challenging new addition to the historic structure. The style and shape of the fence was carefully considered so that it fitted with the bridge aesthetic and also prevented access over the parapets. A picket type fence proved to be most appropriate with a curved form to both add interest and make it difficult to stand on the parapet.

5.5 Signage and advertising

With the exception of name plates and navigation signs, signage should be kept off bridges if at all possible. They add clutter and complexity and detract from the structure. They also obstruct views from the bridge.

If a bridge and its location is deemed suitable as an outdoor advertising site then the advertising structure needs to be designed as an integrated bridge element with consideration of its visual effect. As a minimum, the soffit of the bridge should not be obscured and the sign should not block views of the key structural elements such as cables, arches and bearings or views from the bridge.



Where advertising is used to fund bridges, the best approach is to integrate the advertising structure into the bridge design as in this example on Cowpasture Road in Western Sydney.



5.6 Lighting fixtures

Where possible lighting on bridges should be minimised or avoided.

Where necessary it should be designed as part of the bridge with supports elegantly designed and well detailed.

The light columns should relate to the other bridge elements in position and form.



Lighting has been used on the Herb Feint Bridge over Adelong Creek to provide a design feature as well as provide lighting for the road. A closer spaced light fixture is used which introduces a regular rhythm. Its height can be lower and therefore relates to the bridge better than a taller fixture. A special detail was included in the parapet as a structural and decorative element (see above image).



LED lighting in the handrail combined with overhead lighting on the road crossing creates an interesting low maintenance effect on the pedestrian bridge at Billinudgel.



A closer spaced lower height lighting column has been used on the new Iron Cove Bridge to emphasise the curve of the bridge and provide a more rational, neater effect at night.



Drainage of the Windsor Flood evacuation route was managed by piping into the girder, behind the parapet skirt, and then down within the piers. This avoids a longitudinal pipe along the bridge which on very long bridges can become a visual problem due to the gradients needed.

5.7 Drainage

Generally bridge drainage is dealt with on or within the bridge structure and is more of a water quality issue than an aesthetic one. However where the drainage system is exposed, aesthetics must be considered and the design of the drainage feature must be considered as part of the whole.

When they cannot be hidden, pipes should be neatly aligned to follow the form and lines of girders and piers.

The cross-sectional shape, materials and colour of the pipe system must be considered as these aspects can jarr with the overall bridge design.



If a longitudinal drainage pipe cannot be avoided as in this example on the new Iron Cove Bridge, then the pipe needs to be of a similar colour as the concrete and hidden behind the parapet skirt.

5.8 Noise walls

Where possible avoid the need for noise walls on bridges.

If necessary, noise walls must be considered at the outset of the bridge design process and become an integrated part of the whole bridge design.

In general, transparent panels should be used so that the apparent slenderness of the superstructure is not affected and views or solar access maintained. Glass should be avoided due to potential vandalism and maintenance problems.

Further considerations include privacy to surrounding residents and glare caused by reflections.

Noise wall design is the subject of a further detailed guidance document titled the '*Noise Wall Design Guideline*'.



The principle applied to the M7 motorway was to use transparent noise walls on bridges, to allow views of the landscape for motorists and improve views of the bridge from its surroundings. The design of these walls is part of a consistent motorway architecture.



Transparent noise walls on the M7 overbridge above the North West Bus Transitway and Old Windsor Road are attractive and help retain the slenderness of the structure. However they are glass and have been smashed on many occasions.



The graceful segmental box-girder bridges and ramps set on circular columns have high quality off-form concrete finishes and help to distinguish the M7 Light Horse Interchange.



6 Finishes

6.1 Colour

6.2 Concrete quality

6.3 Feature lighting

Finishes

6.1 Colour

The choice of colour can cause the bridge to relate to its setting or contrast with it. It can relate to the land colours or sky colours. The effects of colours will not always be dramatic, for example, when seen in silhouette or gloomy conditions. The use of bright primary colours, whilst initially striking, tend to date (the exception is when they are culturally appropriate such as traditional Chinese bridges or unique icon bridges such as the Golden Gate).

A neutral palette of black, grays and white tend to give a clear definition of the bridge as an object in the landscape. Old 'RTA' bridge grey is often a wise choice. The use of white on old and modified timber bridges has become favoured as a distinguishing characteristic of such bridges and marks them well in the landscapes in which they sit (see Sections 7.2.3 and 7.2.4).

The urban context may give better opportunities for the use of colour, but as bridges tend to be highly visible elements in the townscape the use of colour should be carefully considered.



Each of the retro-fitted safety screens on the Eastern Distributor pedestrian bridges has a different distinguishing colour, but they all form part of an integrated approach and colour composition for the corridor.



The application of the Pedestrian Bridge Standard at Starkey St utilises the colour of surrounding buildings to fit into its context.



The colours on the rail bridge over the Pacific Highway at Coffs Harbour pick out the different elements of the bridge.



The girder colour on this pedestrian bridge over the Warringah Freeway is standard RTA bridge grey, while the privacy screens use a burgundy coloured perspex sheet in order to create a distinctive opaque visual effect.



A white painted finish can help emphasise the main features of a bridge. On the Albury bypass, selecting the white colour matches the white war memorial at the opposite end of the Dean Street visual axis but also marks the position of the bridge in the corridor.

There is also the opportunity to introduce colour in the lighting of the bridge. This can be cost effective and, in the case of LED lights, able to be changed. (See bottom left figure p71).

6.2 Concrete quality

Bridge aesthetics can be affected by the quality of the concrete finish. A poor finish with staining or voids can mar an otherwise fine structure. This is particularly important if the bridge structure is visible and accessible.

It is preferable to use steel shuttering and pre-cast factory made elements for highly visible bridge parts such as piers, girders and parapets to ensure a controlled, high quality finish.

Retardants and sealants should be tested to ensure that they do not result in staining when the shuttering is removed.

Concrete surfaces close to traffic and accessible to the public should have a class one finish.

If the bridge is only visible from a distance then in aesthetic terms the finish is not so critical, although it should be noted that variation in concrete colouration due to staining can be noticed from a wide area.



Even using high quality concrete and steel shuttering, concrete quality can be affected by admixtures from oil and curing compounds, as in this example of staining on the girder of the new Iron Cove Bridge.



Lighting at the Yandhai River Crossing highlights the structural elements of the bridge. Lighting fixtures follow the diagonal path of the truss structure.

6.3 Feature lighting

There is an opportunity to light the bridge as a whole depending on context, cost, safety and environment constraints. Where appropriate feature lighting of bridges can extend the aesthetic benefits of a bridge throughout a day and make them a positive presence in the night. Lighting can also enhance the safety and passive surveillance around a bridge.

Lighting should be energy efficient, avoid light spill and be easy to maintain. It should also respect the structural qualities of the bridge – accentuating the materials and main structural elements such as piers, arches and girders. That is not to say the feature lighting should not be dynamic and creative. LED lighting systems can be designed to provide both subdued and imaginative effects at different times of the day or calendar.



Lighting is used in various ways on the M7 Motorway and M4 Interchange to highlight the columns, ramps and mark the interchange as a whole. This is an entire composition in lighting which makes the interchange visible, safe and beautiful.



The rail bridge at Coffs Harbour over the Pacific Highway serves as a marker through Coffs Harbour and provides a feature for the town. Its illumination highlights the arched form of the bridge and its critical structural elements to make a night time composition. This is all further enhanced by the strong use of colour on the bridge (see Section 6.1).



Anzac Bridge is lit at night but for defined periods of time to avoid light impacts on surrounding properties.



Feature lighting highlights the arched form of the road overbridge on the North Kiama Bypass.

Lighting is used at select locations on the M7 to highlight features such as wing walls, noise walls and overbridges.



Night lighting on the Sydney Harbour Bridge showing the dramatic effects of the pylons and arch lit up.





The 'lizard tree' bridge on the Hume Highway near Wagga Wagga is aesthetically pleasing with a slender voided slab and simple wall type piers. The inclusion of the fallen tree motifs on the pier make the bridge an interchange that is distinctive and more memorable for the general public and serves as a marker on the route.

7 Particular Conditions

7.1 New bridges next to existing bridges

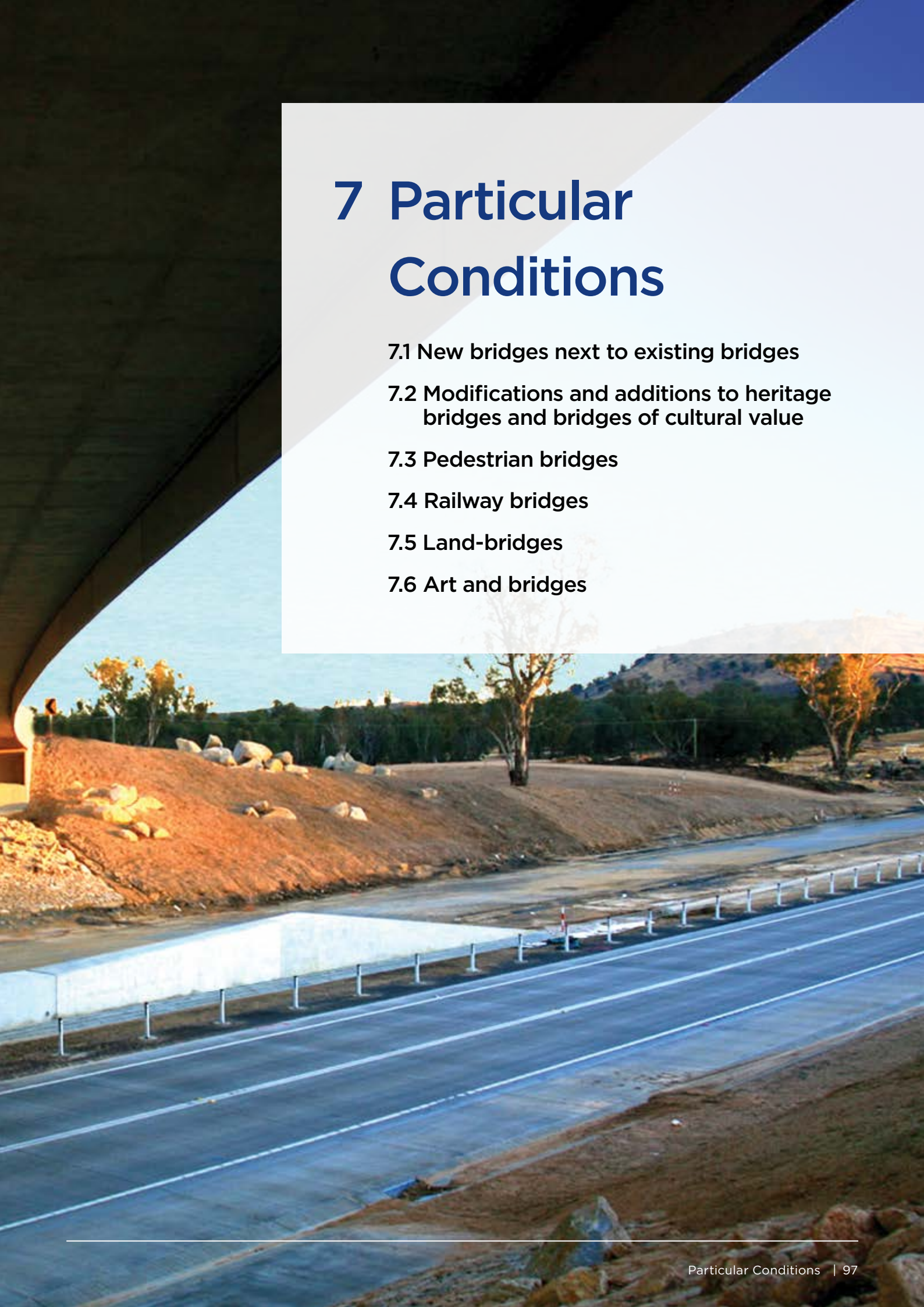
7.2 Modifications and additions to heritage bridges and bridges of cultural value

7.3 Pedestrian bridges

7.4 Railway bridges

7.5 Land-bridges

7.6 Art and bridges



Particular Conditions

7.1 New bridges next to existing bridges

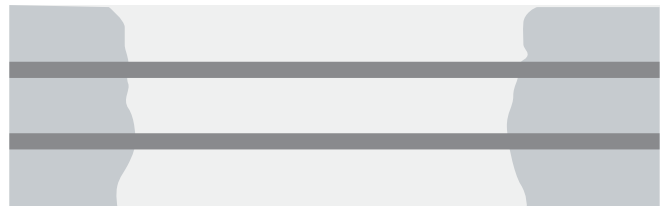
“The relationship between two bridges, almost side by side spanning the same stretch of water, is like the relationship between two musical instruments playing a duet. The music sounds better if the two instruments are in harmony with each other and keep to the same rhythm and tempo. The two instruments should produce sounds that contrast, in order to create a melody that is more interesting and colourful.”

FOSTER AND PARTNERS, IN THE ARCHITECTURE OF BRIDGE DESIGN, 1997

Designing a new bridge next to an existing bridge can be a significant challenge. Competition between structural forms can create clutter and neither bridge can be presented well, irrespective of individual aesthetic value. Alternatively where structural forms are complementary, a memorable landmark can be created where the experience of crossing a bridge is enhanced by the view of an adjacent bridge.

If possible, the new bridge should be located so that the two bridges are seen as separate elements in the landscape and can be designed as separate entities, for example, the different bridges over Sydney Harbour.

This can only be achieved through an appropriate horizontal separation.



PLAN VIEW



The two bridges over the river at Tom Ugly's Point work well together as one does not attempt to replicate the other in structural form and detail. They are far enough apart so that they don't have to be parallel.

A closer spacing can be achieved by varying the alignment of the new bridge but still at an appropriate distance:



PLAN VIEW

However in most cases adequate separation can not be achieved and the new bridge and the existing bridge must be considered as related in aesthetic terms. The following two strategies should then be considered:

- A new design.
- Duplication of the existing design.

7.1.1 A new design

If accurate duplication is not possible an entirely different bridge design should be produced but very importantly, the designs should not compete but be complementary.

- The bridges should either be parallel in vertical and horizontal alignment or curved in symmetry with the existing bridge (the new Iron Cove Bridge in Sydney works well precisely because its alignment is different).
- Consideration should be given to matching the following elements: bridge height, pier spacing and pier alignment.



Where the existing bridge is a distinctive or iconic local or regional asset it is appropriate that the new bridge be as respectful as possible. Whilst the new bridge should be simple and respectful it should be at least as confident and representative of its era as the old bridge.



The Iron Cove Bridge duplication is respectful of the old bridge in its simple appearance and its spans and piers aligning, but also confident and bold in its own right. Its separation from the existing bridge has significantly helped to achieve a good outcome.



The proximity of the bridges over the Hawkesbury River at Brooklyn results in an interplay between the designs. The two bridges are not separate but seen as one visual entity. The old bridge could not be replicated but the new bridge is respectful in terms of matching spans and height.

7.1.2 Duplication of the existing design

This approach tends to be more applicable to modern bridges than older bridges, where technology and safety standards have changed and old design and construction skills lost or expensive to re-learn. The approach is basically to replicate the existing bridge design. It does not need to be exact but at least the following should be addressed:

- Where possible the bridges should be parallel in vertical and horizontal alignment.
- Spans and pier alignments should match.
- Key aspects of the existing bridge such as pier dimensions, girder shapes, abutment locations, and lighting fixtures should be replicated.
- In some cases details can be copied but this is not essential.

If there are any concerns that the bridge cannot be closely duplicated then the new design approach should be considered.



The duplication of the Hume Highway Sheahans Bridge at Gundagai (left) adopted the existing haunch shape and pier spacings. The materials and details are however different styles but there is a design unity.



On the Alfords Point Bridge, the duplication (right) adopted the bridge form in its entirety.

7.2 Modifications and additions to heritage bridges and bridges of cultural value

“It’s not good because it’s old – it’s old because it’s good.”

ANON

Engineers Australia, Practice Note on Engineering and Industrial Heritage, April 2010 says “the present generation of engineers owe a duty of care in dealing with significant engineering heritage works.”

Bridges of historic value come under several categories: listed heritage bridges, bridges that may become listed and bridges that have heritage or cultural value irrespective of listing. The principles following apply to all.

7.2.1 Framework

Asset management strategy

Bridges of State and local heritage significance are listed on the *Authority Section 170 (S170) Heritage and Conservation Register*. Under asset management strategy such bridges are selectively protected and rehabilitated on the basis of their use and possible re-use as well as structural, maintenance, cost and budget constraints. This is consistent with *Engineers Australia’s Practice Note* which encourages the adaptive re-use or recycling of heritage works in preference to radical or unsympathetic modification, demolition or replacement.

Urban design policy

A key principle in *Beyond the Pavement* urban design policy is to incorporate heritage and cultural context in infrastructure planning and design and, in particular, to protect bridges of heritage significance not only in themselves but also in relation to their physical and community context.

Burra Charter

A good objective to be added is that set down in the *Burra Charter*. This internationally recognised benchmark is Australia’s guide to best practice for heritage places. Article 3 of the *Charter* applies to altering a heritage bridge to maintain it in current use and increase its service life. The principle is to change as much as necessary but as little as possible.

Process

In carrying out design and construction work on heritage bridges the project team must liaise with:

- Centre for Urban Design on application of urban design principles.
- Environment teams on heritage issues (in the case of a listed structure or one likely to be listed).
- Communication and Community Engagement teams on community consultation and interpretation issues.

Principles

There are three objectives to be adopted:

- Unless faithfully restoring elements, distinguish new work from the old.
- Respect the setting.
- Respect the character of the heritage or culturally important bridge.



The original lamps of the Sydney Harbour Bridge have been rebuilt using bronze and glass, as well as new LED technology.

7.2.2 Distinguish new work from old

Unless faithfully restoring elements of the old bridge, new work must be distinguishable from the old bridge. There are several means to achieve this:

- By date stamping the new work so that it is identifiable, particularly where materials and form are carefully duplicated, such as new timber trusses.
- By using new modern materials and forms to fit in sensitively, but differentiate from the old elements and forms of the existing bridge.



Suspension Bridge, Northbridge: Inside and outside views of the retrofitted safety screen. This is a new expressive form which complements the character of the old bridge.



Hinton Bridge over the Paterson River near Maitland is one of the oldest Allan truss bridges in Australia built in 1901 with a lift span. Due to the deterioration of the bridge's trusses and lift span and the need to increase load carrying capacity, rehabilitation and strengthening works were undertaken in 2005. The bridge is an example of carrying out repair sensitively by using timber, steel and concrete composites so as to preserve its heritage character.

- By keeping a clear physical distance and sense of separation with the old bridge when building a bridge duplication. (See also 7.1)
- By avoiding pastiche (false imitation or mixture of styles) when designing a bridge duplication or connection to an old bridge: any new elements or bridge duplication should be true to the materials and technology of the time of modification and minimal in extent.



In this adaptive re-use of an old bridge, the wrought iron lattice truss bridge at Redbourneberry was duplicated and incorporated into an adjacent cycleway. The angle span at the far end was built as part of the duplication. Its design however is pastiche since it attempts to imitate the existing truss. Not only is this false and confusing but it jars with the new bypass.

- It is essential that the principle of distinguishing new from old is not abused by making the new work visually obtrusive and at odds with the character of the old.
- By providing signage and interpretation where appropriate.

7.2.3 Respect the setting

Heritage is part of place. Bridges of heritage significance often define and sometimes are an icon within the community. They are often an important visible element. Preservation of, modifications to, and duplication of, such bridges should respect their setting by:

- Preserving the curtilage, in this instance, the envelope around, below and above the bridge necessary to protect its heritage or cultural value. The bridge and its curtilage form a spatial and aesthetic entity, and may also be part of a listed heritage precinct, such as the Sydney Harbour Bridge. Therefore, keep the

curtilage as intact as possible and ensure that design changes of the bridge are sensitive to the character of that curtilage. Consider that the curtilage is also part of a wider setting. (Refer to *Heritage Curtilages* publication – companion to *NSW Heritage Manual*).



Stonequarry Creek Bridge at Picton, which spans a 'gorge' near the town, dramatises the setting.



Reconstruction of the State Heritage Register listed timber truss bridge and approaches over the Hunter River at Morpeth was achieved. The eastern approach fits well with the scale and character of the associated heritage precinct defined by the courthouse.

7.2.4 Respect the character of the heritage or culturally important bridge

The character of the old bridge should always be respected – whether duplicating, retrofitting or modifying a bridge of heritage significance. This can be achieved in different ways, depending on the scale of work to be carried out:

Duplicating a bridge of heritage significance

- Respect the old bridge through adequate physical separation.
- Where possible, keep a sense of the scale of the old bridge, through protection of the major elements in its curtilage and the view points to the bridge.
- Where possible match the profile of the old bridge and keep the rhythm of the piers and uprights.
- Use form, materials and colour that complement, but do not visually overpower, the character of the old bridge.

Signage and interpretation signboards, in the agreed common style suitable for heritage bridges, should be used to support the heritage bridge program of work and carefully placed to mark the bridge or at rest areas.

Signage can also be used to explain changes to other culturally important bridges.



Junction Bridge signage is a good example.



Adding major new elements such as pedestrian walkways

- If external to the structure, it may be best to add new elements on the opposite side of the most historic and locally valued vistas to the bridge.
- Respect and match, where possible, spacing, rhythms and proportions of the old bridge.
- Use similar materials or materials that complement the old.



The Tarban Creek Bridge required strengthening of the arches. An innovative solution was required to take the weight of the end spans beyond the arches. A refined portal frame pier, protruding from the bridge envelope, created a separate structure distinguishable from the original bridge.



The gently curved and raked form of the steel picket fence on the Suspension Bridge, Northbridge, is a bold new introduction. It however respects the architectural periods of the Federation Gothic 1890's sandstone towers, the 1930's concrete arch and the Inter-War Romanesque style of detailing. (A visual analysis was carried out and a full scale demonstration model built prior to the final design option being selected).

Minor modifications

- Consider the relationship of modifications to the scale and character of the bridge, other elements and materials, the rhythm of existing uprights, and colour.
- Carry out a visual analysis to ensure that the bridge modification fits into its built, natural and community context and provides a well designed solution which minimises adverse visual impacts from all critical viewpoints.

Repainting

- Keep painting up to date to prevent prolonged attack on the raw material, protect the bridge and its elements in the long term and maintain the aesthetic quality of the bridge.
- Truss bridges are best repainted in white which was the original colour used. This gives them visual identity as a type and consistency as a family of bridges across the State. Such a strategy would be cost effective.



The Wee Jasper Bridge, refurbished in 2006, has a two-tone (black and white) colour scheme which is widely used in the ACT.



Lift access to the Sydney Harbour Bridge has been provided using modern materials, a simple refined design, and with minimal changes to the Sydney Harbour Bridge. The parapet removed for the southern lift has been used in the design of the access plaza.



The SHB north lift, adjacent to the stairs, provides step free access to the bridge walkway from the north



7.3 Pedestrian bridges

7.3.1 Opportunities and constraints

There are a number of important differences between pedestrian and vehicular bridges that influence design:

Design flexibility

Pedestrian bridges carry lighter loads than vehicular bridges: this allows the designer to exploit greater flexibility in the shape and proportion of the bridge, within a reasonable budget, which can lead to great variety and character.



The ramp and bridge connection on this pedestrian bridge is seamless. Note the attention to detail of the narrowing of the edge of the deck as it passes over the thicker section of girder above the pier.

Views

Pedestrians and cyclists spend more time on a pedestrian and shared path bridge than a traffic bridge: therefore the view from the bridge takes on added significance and detail and materials are more closely appreciated.

Ramps

Pedestrian bridges have ramps. Ramp design can be innovative but should not dominate views or detract from the expression of the essential element of the bridge – its span. This is especially the case when ramps are folded or coiled at the ends of the structure.

Safety screens

Pedestrian bridges invariably require safety screens. In the design of these it is important to avoid a caged feeling when bridges are narrow.

Lifts and stairs

Where the site is very constricted, or ramps would be excessively long, lifts could be provided. It is important to locate lifts carefully and design them as part of the whole structure. The same applies to the use of stairs to access a pedestrian bridge.

The pedestrian bridge standard was created for constrained locations where ramps are not feasible. The pedestrian bridge standard is a consistent, cost-effective design outcome that can be re-used depending on context.



The 220 metre long, 3 metre wide, pedestrian and bicycle bridge with its elegantly shaped steel box girders, tapered concrete piers and integrated throw screens straddles the eight lane Warringah Freeway and connects Falcon Street in North Sydney and Merlin Street in Neutral Bay.

7.3.2 Design Flexibility and Innovation

- Consider how a bridge can reflect local character, provide a milestone on a journey, form a gateway to an area, create a focal point or celebrate something.
- Depending on context, the rules normally applicable to road bridges may be stretched when using cable stay, truss, arch and suspension which are suitable for light loads.



In the design of the Dean Street bridge in Albury a decision was made to use seven cables each side of the pylon rather than the three required structurally to create an attractive fan effect.



Structurally expressive form using modern materials is evident in this space-frame bridge over the M7 motorway.

- Consider the use of lighting to both emphasise the form of the bridge and distinguish it by night – within the constraints of cost, surrounding properties and adjacent light fixtures.



The bridge over the Pacific Highway at Billinudgel uses the safety screen as a design feature, wrapping the whole girder and creating a distinctive tube effect.



The cable balustrade and viewing platforms (see front cover image) allow views of the river landscape on the Yandhai Nepean Bridge in Penrith

7.3.3 Views

- Provide adequate space on the bridge to allow stopping and viewing without significantly interrupting pedestrian and cycle movement.
- Avoid hidden or secluded spaces which, if present, will make it more difficult to monitor personal safety.
- Advertising and signage on or near a bridge is not desirable but, where it is considered appropriate it should not obscure the form of the bridge, the surveillance of pedestrians or views from the bridge (see SEPP 64 guidance).
- On girder bridges with lift shafts consider an open end to the bridge rather than terminating it at the lift shaft. This will allow views out from the bridge and reduce the sense of enclosure.
- Consider the use of lift shafts with at least one glass wall to add a feeling of surveillance and provide views as the bridge is ascended.
- Pedestrian bridges provide an opportunity for people to appreciate the landscape setting. This not only applies to pedestrian bridges but also pedestrian footpaths on road bridges.

- It is important to note that although views from the bridge are desired, these views must not infringe on the privacy of surrounding properties. Views should be assessed in the process of design to avoid unwanted retrofitting of screens or barriers.

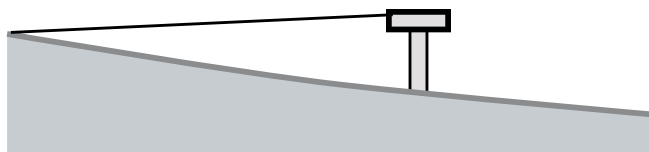
7.3.4 Ramps

If ramps are needed, now or in the future, for access and connection to surroundings, the following guidelines should be considered:

- Attempt to locate the bridge where the ramp can be its shortest possible length.
- Minimise the extent of the ramp by using natural or new landform, for example, crossing a road in cutting avoids ramps entirely.



- Where a road is at a grade the approach ramps on the uphill side can be relatively short.



The application of the Pedestrian Bridge Standard at Pennant Hills Rd has eliminated the need for long ramps which would not have been feasible in the narrow verge area.

- If an elevated constructed ramp is required the design must be carefully considered due to its visual prominence. The design of ramp and bridge should be integrated and unified in appearance.
- Use planting to integrate ramps with their surroundings and reduce their visual impacts.
- Connections between ramp and superstructure must be as simple and seamless as possible.
- Ramp design and geometry should be simple and thoughtfully done, for example, compact spirals are sometimes preferable to long switchbacks.
- Consider the aesthetic impact of standards relating to ramp slope and frequency of landings (required for disabled and cyclist use) which may increase ramp length and interrupt the desired smooth lines of the structure. It may be necessary to obscure the landings by a higher than necessary parapet wall.
- Where possible and earth works allow, consider visually separating the ramp and span, by integrating the ramp into the adjacent land form.



The simple spiral connection of the ramp adds to the value of the bridge. However, adequate space is required for this solution. Also the presence of landings needs to be considered.



Where space is limited, stairs should be simple and compact as on this bridge over the Pacific Highway on Sydney's North Shore. Note the neat detail of the connection between superstructure and ramp marred only by staining.



Earthworks have been utilised to cost effectively create the landscaped ramp to the bridge at Falconbridge over the Great Western Highway.



The ramps on this truss bridge over Sunnyholt Road have been designed to match the materials and form of the truss. Planting has been used to help fit the ramps into the landscape (compare pictures taken three years apart) and a neat two post pier with cantilevered brackets simplifies the structure. The access to the bridge passes through a non-structural extension to the truss form which provides a neat, substantial, connection between truss and ramp/ stairs. The use of closed hollow sections would have been better than open steel sections from a maintenance point of view as open sections collect debris and dirt leading to premature breakdown of protective coating systems.

7.3.5 Safety screens

In terms of comfort in using the bridge the following should be considered:

- When required it is preferable to have safety screens as simple fences rather than a cage.
- The need for the cage, and a caged effect, should be avoided. It provides a platform for vandal access and creates an oppressive feeling of enclosure.
- If a closed system cannot be avoided then the design and shape of the cage should ensure that the experience of crossing the bridge is not oppressive.
- Feature lighting should be considered to make the crossing attractive and well lit.



The absence of a cage creates a more open welcoming space as in this example on the Beatrice Bush Bridge, Rozelle.



The bridge over the Pacific Highway at Billinudgel has an open feel even through it is caged. It is suited to the bridge and is well designed.

7.3.6 Lifts and stairs

- Where space is limited or lifts stairs are required their design should be simple and compact and appear as light and slender as possible.
- Lifts should, where possible, be part of the supports of the girder. Combining lift shaft and pier creates a simpler, more refined, structure and can reduce costs but maintenance needs to be considered.
- The use of at least one transparent glass wall should be considered. This reduces the visual bulk of the lift, provides views and gives a feeling of good passive surveillance to and from the surroundings.



The form and fencing, colours and use of the lift shaft as a pier are visually strong but the bulky pier support detracts from this bridge over Silverwater Road.



The Auburn pedestrian bridge, Parramatta Road, is not a good aesthetic outcome. The ramps and bridge connection are too dominant, jarring and cluttered. This bridge lacks aesthetic refinement.



Transparent lift shafts can be attractive and feel safer due to the passive surveillance they allow. They can be fully 'glassed' as on the Cahill Expressway (above) or partially 'glassed' as on the bridge over The Boulevard at Strathfield (below).

7.4 Railway bridges

In addition to the general principles in this document, there are a number of aesthetic principles applicable to rail bridges:

- A railway bridge should express its purpose and be easily recognised as such.
- Railway bridges, in accommodating the heavy weight of trains, should generally appear strong and substantial.
- Railway bridges need to be stiffer than road bridges for stability in terms of deck vibration and shock loading which generally rules out suspended structures.
- Constraints on the vertical and horizontal alignment of the railway, create flatter straighter structures than road bridges.
- Railway bridges necessarily have a heavier appearance in their design with deeper girders, bulkier columns, and shorter spans. Consequently close attention needs to be given to their proportion and refinement.

7.5 Land-bridges

Occasionally there is a call to provide land-bridges. These can be for ecological reasons providing fauna and flora connectivity or for open space reasons providing new parks or connections between parks.

Land-bridges support landscape. Therefore the aesthetics of the land-bridge needs to take this into account. They generally need to be strong, supporting heavy loads and visually have a strong grounding and connection to the landscape. In most contexts this means slender forms and cable or suspension type super structures are not suitable nor aesthetically appropriate.



The South East rail link bridge over Camden Valley Way in south east Sydney demonstrates the aesthetic principles applied to railway bridges. The deeper girder and parapet has been shaped to reduce its visual dominance. Wall type piers have been used to simplify the appearance by avoiding headstocks. The abutment walls are set back in the landscape to minimise the impact on the footway and road corridor.



A neighbourhood park is retained on the land-bridge over the Pacific Highway at Banora Point.



Arched forms and gabions give an impression of strength and an ecological/landscape purpose on the fauna overpass over the Pacific Highway at Bonville.

7.6 Art and bridges

Well designed bridges and the more iconic structures are often seen as sculptural artefacts in the landscape with artistic qualities in their own right.

On occasion designers integrate art as an element into the design of bridges.

For example piers can be designed with a texture or motif embedded into the structure. Painting can be used to provide an artistic image or colour a bridge element in a striking way. Safety screens can be designed with motifs and patterns layered into the mesh. Lighting can be used with the bridge to create an artistic effect.



The pedestrian bridge over the City West Link in Sydney was conceived as a sculptural piece along a corridor. Such an approach should be used circumspecifically and not be the norm.



Occasionally the detailed concrete work on older bridges leaves an opportunity for paintings. These RMS bridge abutments in The Rocks in Sydney have been painted in historic photographic images which have received a heritage award from the National Trust. *Courtesy of Sydney Harbour Foreshore Authority.*



The Aspire sculpture in Ultimo brightens up a dark, unattractive under bridge space. Art can improve poor spaces but it would be better if the bridge design and land use planning avoided the need for such spaces in the first place.

Photo by Richard Glover, courtesy of Warren Langley



The integrated fallen tree motif on the pier of the Lizard tree bridge on the Hume Highway near Wagga Wagga helps turn an elegant bridge into a memorable one.



The bridge designer Robert Maillart regarded structurally expressive bridges as pieces of art in their own right. This could be said of the Anzac Bridge in Sydney.



Appendix

A: Global Perspective

B. Bridge terminology

C. Pedestrian Bridge Standard

D. References and further readings

The Volantin footbridge in Bilbao by Calatrava is a stunning modern example of a cable-stayed asymmetrical footbridge in an urban setting.

Appendix A: Global Perspective

Selected examples of bridges and their designers from antiquity to the present day

Introduction

“...great designers, from the Romans to the present day have combined technical mastery, consciously and unconsciously, with an artistic sensibility, to create not just structure to be crossed as quickly as possible, but masterpieces by any standard.”

DAVID J BROWN, BRIDGES: THREE THOUSAND YEARS OF DEFYING NATURE, MBI PUBLISHING, 2001

There is nothing new about bridge aesthetics. For thousands of years bridge builders have considered the visual quality of their structures together with their structural quality. In order to provide a perspective on this, the following list and description of bridges and their designers is intended to be a potential source of inspiration. It is by no means comprehensive. The examples are a very selective choice from the substantial literature and publication of bridges of aesthetic value internationally. Further examples can be investigated in the References and Further Readings.

This appendix is structured historically in order to demonstrate how bridge aesthetics is a continuous struggle and pursuit and a response to technological innovation. It starts with selected bridges of the Romans, Italians, French and Persians that still prevail. Brief pieces then follow on eighteenth and nineteenth century bridges and their designers in the UK and USA, and early twentieth century suspension and arch bridges and their designers. The wonderful period of exploration in concrete is dealt with, especially the designs and contribution of Maillart, Freysinnet and Menn in the first part of the twentieth century. They influenced each other and, later, Calatrava who is arguably the leading innovator of our time in structures, most importantly, bridges; the theory and practice of this unique architect/engineer is given special attention. Beyond this, the appendix highlights various bridges and designers of today in different countries.

Bridges of antiquity to the 16th century

Traditionally, aesthetics was inseparable from bridge design. Bridge design was both an art and a science. We see this, dating from the timber and timeless stone bridges of the Ancient World onwards across England, Europe, the East and Middle East. Some early beautiful bridges that remain timeless are:

The Roman Puente De Alcantara, Spain



This lofty, arched bridge with its towering granite piers and a parapeted roadway, crosses the narrow valley of the Tagus River close to the border with Portugal. It has been described, variously, as awe-inspiring, a symbol of Roman imperial power and the greatest of all Roman stone bridges.

The Pont Du Gard, France

This Roman 30-mile aqueduct near Avignon in France, completed around 90 BC, is characterised by its semicircular arches built out of dressed stone without mortar on the bottom two tiers. It is regarded by many as the most beautiful of all surviving Roman engineering works.



The Pont D'Avignon, France

D'Avignon has been described as the most beautiful and perfectly preserved of all French medieval fortified bridges, and a symbol of Divine charity.



The Ponte Vecchio, Italy



This 14th-15th century landmark structure is not only a unique arched bridge due to the extremely shallow arch profile but, with its architectural conception of houses and shops across the Arno River in Florence, is one of the few remaining medieval examples of the use of the bridge space for urban activity. The bridge also forms a passageway that connects the Uffizi and Pitti palaces.

The Ilahverdi Khan Bridge, Persia

This 15th-16th century 33-pointed arch bridge in Persian Isfahan has a simple and elegant, albeit monumental, form. It was conceived as an important element of one of the most beautiful cities in the world.



The Ilahverdi Khan Bridge.

The British and American eighteenth and nineteenth century legacy

The British legacy, which includes rail and road bridges, is sizeable as well as noteworthy for its innovation and quality. It reflects different stages of advanced technology emanating from the industrial revolution. In both the UK and USA the aesthetic quality of their great bridges is not due only to their prominence and technology. It results from the scale of their height and spans, their proportions, how they fit into or otherwise dramatise their respective settings, the limitations and use of materials, the fine quality of their details and, not least, how their form expresses their function. In some cases bridges are distinguished by architectural features as well as the basic architecture of the bridge.

Thomas Pritchard's Iron Bridge in Coalbrookdale across the River Severn, England, 1779

Iron Bridge is the first cast iron arch span. The arch has a single, high, semicircular shape designed to traverse the narrow, steep gorge. It forms a complete circle when reflected in the water. The bridge is also characterised by its slender ribs and connections and detailed lattice work. It is, today, the centre piece of a national museum.



Iron Bridge in Coalbrookdale.



The rail bridge over the River Forth estuary, Edinburgh.

Sir Benjamin Baker and Sir John Fowler's railway bridge over the firth of the River Forth estuary, Scotland, 1890

This steel truss, 3148 metre long bridge with its height, towers, cantilevers, suspended spans and lattice truss structure, is perhaps the mightiest achievement of Victorian engineering. For the likes of William Morris, the internationally influential English textile designer, artist and writer, the bridge at the time must have appeared complicated and overdesigned: Morris referred to it as “the supreme specimen of all ugliness”. David J. Brown, in analysing the plans and elevations, concluded otherwise – that the bridge has a grace which emanates from the clarity of its structural form and the balance of scale between the main towers and suspended elements. The principles of its design have since been applied on many modern cable-stayed bridges and much more modest bridges around the world. It is a balanced bridge constructed by building out two rigid arms from both sides of two piers, that is, in two balanced directions, while diagonal steel tubes, projecting from the top and bottom of each pier, hold the arms in place. Structure and materials are expressed without unnecessary decoration. To quote Brown, it is now regarded as a “sublime piece of public art”.

John and Washington Roebling's Brooklyn Bridge over the New York East River, USA, 1870's



As a feat of engineering the Brooklyn Bridge, with its 486 metre span, has been well documented in terms of its technical features at the time – the use of steel cables, a web of radiating stays, masonry anchorages, deep stiffening trusses, the caisson construction and the piers. The bridge, by John Roebling and his son, is also important as an urban artefact. This can be defined by the way the road, railroad and the upper, central, pedestrian promenade are integrated into the design, the overall composition of the bridge and its approaches in the context of New York, and the architectural design of the towers. John Roebling specifically intended the granite block towers to serve as landmarks to the adjoining cities of Brooklyn and Manhattan, and as a symbol of the East Coast. The bridge was declared a National Historic Landmark in 1964.

Suspension and arch bridges of the early 20th century

Othmar Amman's George Washington Bridge across the Hudson River, New York, USA, 1931



Brown describes this bridge by the Swiss engineer Amman as probably the greatest leap forward in 20th Century bridge design, redefining the state of the art of suspension bridge construction. Its central suspended span of 1067 metres was almost double any such previous span. It was the largest cable-spinning commission (won by the Roebling company for the four suspension cables), used a 3 metre thick plate-girder stiffening deck (the length of the bridge and its mass allowed Amman to dispense with a stiffening truss) and was designed to accommodate two decks comprising eight lanes of roadway above, and an urban rapid transit line below. The second deck was added beneath the first in 1962. Amman designed the 183 metre high towers as steel frameworks, each a complex truss structure, which he intended to clad with granite to give the bridge a monumental masonry effect, like the Brooklyn Bridge. The cladding was abandoned, for two reasons, enthusiastic support for the unadorned steel skeleton, and the need for the New York Port Authority to slash costs because of the Wall Street crash. This raw expression of structure gives the bridge its unique appearance.

The Joseph Strauss/ Charles Ellis Golden Gate Bridge, San Francisco, USA, 1937



The bridge is a landmark of the city and symbol of the West Coast by virtue of its scale, elegance, features, approaches and dramatic impact in its setting. Its suspended span of 1,280 metres between San Francisco and the Marin Peninsula and 227 metre high towers exceed those of the George Washington. The deck is however much narrower and consequently needed a stiffening truss, albeit shallow. As in the George Washington Bridge, the two pairs of towers express their structure but, rather than a truss system, the towers of the Golden Gate are formed as riveted assemblies of hollow steel cells. Each tower is stepped back three times and linked at these points as well as at the top by deep horizontal beams, thereby creating elegant pairs of vertical shafts. The red-lead colour and unique detailing of the bridge were developed by the architect Irving Morrow which, as Brown describes it, makes the bridge the world's largest art deco sculpture. All of this occurred against a background of severe constraints – the need for an unprecedented deck height for shipping clearance, overcoming the gale-whipped ocean currents, and the difficult anchorage on the San Francisco side requiring a special construction. The unforeseen rippling effect on the deck caused by winds required the later addition of lateral bracing beneath the deck for its entire length.



Sydney Harbour Bridge.

John Bradfield's Sydney Harbour Bridge, Australia, 1932



This icon of Sydney and Australia was the result of an international tender won by the British company Dorman Long and their consultant designer Ralph Freeman. A cantilevered bridge over the harbour was at the core of the bold planning scheme for Sydney envisioned by John Bradfield, the Chief Engineer in the New South Wales Department of Public Works, who oversaw the tender, design and building process. While inspired by New York's Hell Gate Bridge there are distinct differences, being the world's longest arch bridge with the widest ever span at 49 metres, accommodating two rail tracks and six traffic lanes, and characterised by the art deco pylons which are formed as towers separated into pairs at each end. These pylons are not structural but form a powerful visual termination to the bases of the arch, thereby contributing to the strength of the architecture of the bridge. The bridge is further dramatised by the splendour of the Sydney Harbour setting and subsequent sail forms of the Sydney Opera House.

The thinking, work and influences of Maillart, Freysinnet and Menn

Maillart, Freysinnet and Menn were the three great innovators in concrete structures. The focus of this section is on Maillart and Menn, but the contribution of Freysinnet should be noted. While Freysinnet did not invent the idea of pre-stressing, he developed and applied it to a number of bridges.

Robert Maillart: The Salginatobel Bridge, 1930

The Frenchman Robert Maillart, who practiced in Switzerland, regarded structures not simply as works of utility, but also as works of art. He is considered to have made the greatest aesthetic impact in the 1930s when reinforced concrete began to open new possibilities in bridge design. Maillart broke down the boundaries between the applied science view and the design view of engineering and created a new world of form and beauty through the development of three innovations in concrete – the concrete hollow box, the concrete flat-slab floor and the concrete deck-stiffened arch – which he applied imaginatively to the different conditions of site. His innovations are best articulated by David J. Billington: Rather than creating arrow-like cut-outs into rock faces, he removed the spandrel walls of bridges entirely. These he replaced with slender vertical links between arch and deck, either using rows of pencil like columns or thin planes of concrete. He sometimes emphasized the line of a roadway with a solid parapet, or otherwise lightened it with open railings, thereby throwing the visual emphasis onto the supporting structure.

Maillart's defining work, is the slender 133 metre arch, reinforced-concrete Salginatobel Bridge which spans a precipitous gorge in the Swiss Alps. This bridge, which is breathtakingly beautiful, was designated as an International Historic Civil Engineering Landmark in 1991. It is described by Cruickshank as a bridge of sheer abstract artistic beauty, derived from its "absolute fitness for purpose achieved by the most elegant and minimal means."

Subsequent to Salginatobel, Maillart perfected structural approaches to design for skewed sections, oblique crossings and decks curved in plan. In some of his last bridges he flattened the arches to such an extent that the curve was barely perceptible. All this was achieved in spite of the constraints to creativity presented by the authorities, engineering tradition and the tenets of business management at the time. Maillart in this respect was regarded as a radical designer, notwithstanding that his bridges were usually cheaper than those of his rivals.



The Salginatobel Bridge fits unobtrusively in the Swiss Alps. 'The bridge defines the valley' MARIO BOTTA.

Christian Menn: The Ganter Bridge, 1980

The Ganter Bridge, built on the new Simplon Pass road above the town of Brig near the Swiss-Italian border, is one of the most striking bridges of the last century. It was designed by the Swiss engineer Christian Menn, whose father had been a close associate of Maillart. Menn used prestressing and also the method of progressively cantilevering construction to produce a dramatic structured form in the setting of the Swiss Alps. The roadway of the Ganter is steep and its alignment is in a shallow S-curve consisting of a straight main span of 175 metres flanked by oppositely sharply curved 127 metre side spans that abut the valley wall.

The depth of the valley required one of the piers to be 150 metres high. By using massive, hollow, vertical boxes Menn was able to correspondingly drastically reduce the depth of the deck. For extra rigidity, he incorporated cable stays. Because the cables supporting the curved side spans had to follow the curved plan, Menn encased them. Second, he fixed them to curved concrete walls on either side of the roadway. Third, he matched the effect visually over the central span, to create a balanced composition. The unique profile of the bridge is considered to provide a quite different visual and aesthetic experience from that of any comparable work.

According to Eyre, "it contains all the ingredients: concrete, a combination of tensile and compressive elements, curvature, visual movement, elegance and proportion, economy and efficiency, all in a spectacular mountain setting."



Theory and practice of Santiago Calatrava



Alamillo Bridge, Seville

Theory

Calatrava is probably the best example of engineering and architectural skills being embodied in the same person. He is an architect and engineer, theorist and practitioner, who operates an integrated studio. A pupil of Christian Menn, he continued the tradition of fusing style and structure and has become the most innovative and prolific bridge designer of today. This is over and above his many other types of structures including railway stations, airports, stadiums and buildings. His doctoral dissertation on *The Foldability of Space Frames* is an exploration of how to generate a limitless family of curves and figurations.

Calatrava attempts in his designs to solve problems through optimisation – the optimal state being how far you can go at a technical level to achieve a powerful aesthetic. He combines materials, organic forms and movement. Many of his structures are inspired by the human athletic form and structure of living beings such as fish and animals.

The following is a written synopsis of other Calatrava works for the information of the reader.



Examples

The Volantin footbridge in Bilbao, with its large inclined steel parabola, great sweep, fish-shaped deck, bone-like structural pattern and glass walkway, is one of Calatrava's most memorable bridges (refer to photograph on p121).

The 129 metre length, 46 metre span Puente Bach de Roda, which links the main streets of Bach de Roda and Felipe II, was commissioned for the 1984 Barcelona Olympics. It has two pairs of steel bowstring arches that carry a car deck and pedestrian paths on either side, each having a lighted lookout. These arches sweep obliquely over railway tracks either side of the roadway, that itself arches upward. The outermost of each pair inclines inwards sharply to join the others at the apex, allowing the creation of the pedestrian paths, which are in turn flanked with rows of suspension rods that have the effect of slender, leaning steel colonnades.

Other notable arched and cable-stayed bridges of his include: the Alamillo, commissioned for the Seville World Fair (one function of this bridge was to be a symbol of Seville); bridges in Ondarroa and Valencia in Spain; a set of three cable-stayed bridges across the River Hoofsvaart in Holland; an ensemble of three bridges for Reggio Nell l'Emilia in Italy; and the Puente de la Mujer footbridge in Buenos Aires.

The C-shaped Chords Bridge in Jerusalem was designed by Calatrava as part of the light rail mass transit system. It is extraordinarily beautiful and described by Cruickshank as "the quintessence of cable-stayed bridges". The cables radiate from a 118 metre tall pylon, and the associated cantilever span on a curvature is 160 metres. This bridge, while controversial for many in the context of the urban fabric of Jerusalem, is equally appreciated for its symbolic character being associated with David's Harp.



Millau Viaduct

Other recent bridges and their designers and builders

The Millau Viaduct, France, 2005

This astonishing piece of engineering is a perfect example of the engineer and architect working in harmony. It is the result of a competition in 1993 in which the British architect Lord Norman Foster (Foster and Partners) worked with Michelle Virlogeux and engineers EEG, Sogelerg and Serf. The bridge is part of the route from Paris to Barcelona by crossing the River Tarn Gorge. Built to incredible precision, the bridge has no slung cables between the towers, such as the Golden Gate, but straight cables from the tower to the deck in a fan fashion. The pylons sit above the deck on separately erected columns below. The cable-stayed, mast-supported structure, although mighty in scale and classed as a contemporary mega-structure, is delicate and transparent with an optimum span of 342 metres between columns which range in height from 75 to 245 metres. The main masts rise a further 87 metres above the superbly slender road deck. Each column splits into two thinner more flexible columns below the roadway, forming an A-frame above deck level. Their tapered form expresses their structural loads but also minimises their profile. The Millau, in spite of its scale, has a delicate silhouette in the landscape.

Ponte 25 De Abril (The Tagus), Lisbon, 1966-99



An excellent design example in the retrofitting of an existing bridge is the Ponte 25 de Abril, also over Lisbon's Tagus River. The original bridge, designed to carry cars and trains, resulted from a design competition that was won by American Bridge Company/Steinman Boynton and Gronquist (London and New York). At the time of its building it became a landmark of the city. Firstly, it was the longest bridge in Europe being 3200 metres long with a span of 1013

metres and had the world's longest continuous truss, the deepest pillars ever built and the highest towers in the world. Secondly, it is a very distinguished bridge, with a simple, unified design and colouration that associates it with the iconic Golden Gate San Francisco Bridge. The metal structured de Abril was later expanded in 1999 by Steinman; Parsons; DSD Dillinger Stahlbau GmbH to accommodate additional traffic generated from new surrounding land development. Especially interesting is the fact that the expansion was done within the existing structure. The solution was to reconfigure the bridge by installing additional main cables and suspenders so that a new lower deck could be constructed inside the trusses beneath the existing deck. The existing structure was then transferred to the new, lower deck, following which the original upper deck was reconfigured to carry six lanes of traffic. Together with careful rehabilitation work on the existing bridge, the design integrity and image of the bridge was affected as little as possible. The form and proportions of the completed bridge as a whole are an expression of all the forces intrinsic to a bridge of this nature.

The Kylesku Bridge, Scotland

This narrow, curved pre-stressed box-girder bridge, by Ove Arup and Partners, in the north-west of Scotland, complements its spectacular site. It is cantilevered from the pairs of V-shaped sloping piers which hold the slender deck like the finger and thumb of two hands, thereby giving the structure a lightness of form. The bridge is further dramatised by the curved road alignment of the bridge and its approaches.



Kylesku Bridge, Scotland

The Gateshead Millenium Bridge, Newcastle, UK, 2001



Photo by Hill Thallis

The 'winking eye' tilt design is the result of a competition won by Wilkinson Eyre Architects and engineers Gifford to create a direct link for pedestrians and cyclists across the River Tyne between a new arts centre at Gateshead and the quayside on Newcastle's city centre. Its chief architect was in fact Santiago Calatrava and it was overseen by his brother Miguel Hernandez Calatrava. Over and above functionality it was intended to provide a visual symbol of the city's regeneration – to give Gateshead an iconic structure for the new millennium. The design achieves both objectives with extraordinary skill and imagination and has been described by James Dyson, the industrial designer, as 'perfect' and 'beautiful' because 'you can see exactly how it works' (Cruikshank, pg185). As well as 'epitomising perfect structure' the design provides a new sense of place and identity through its form, relationship to the river pedestrian connections, use of contemporary technology and materials, colour and lighting. The curvilinear bridge is shaped by a pair of parabolic steel arches spanning 105 metres between concrete islands from which the cable stays are hung. It can be rotated vertically around its longitudinal axis up to 40 degrees to allow shipping to pass. Six hydraulic rams rotate the bridge back on large bearings. Wilkinson Eyre, in partnership with Flint Neil Engineers, are also responsible for a very different but equally imaginative concept for the proposed three-way single-structure Ribble Way Footbridge in Lancaster that will cross two rivers.

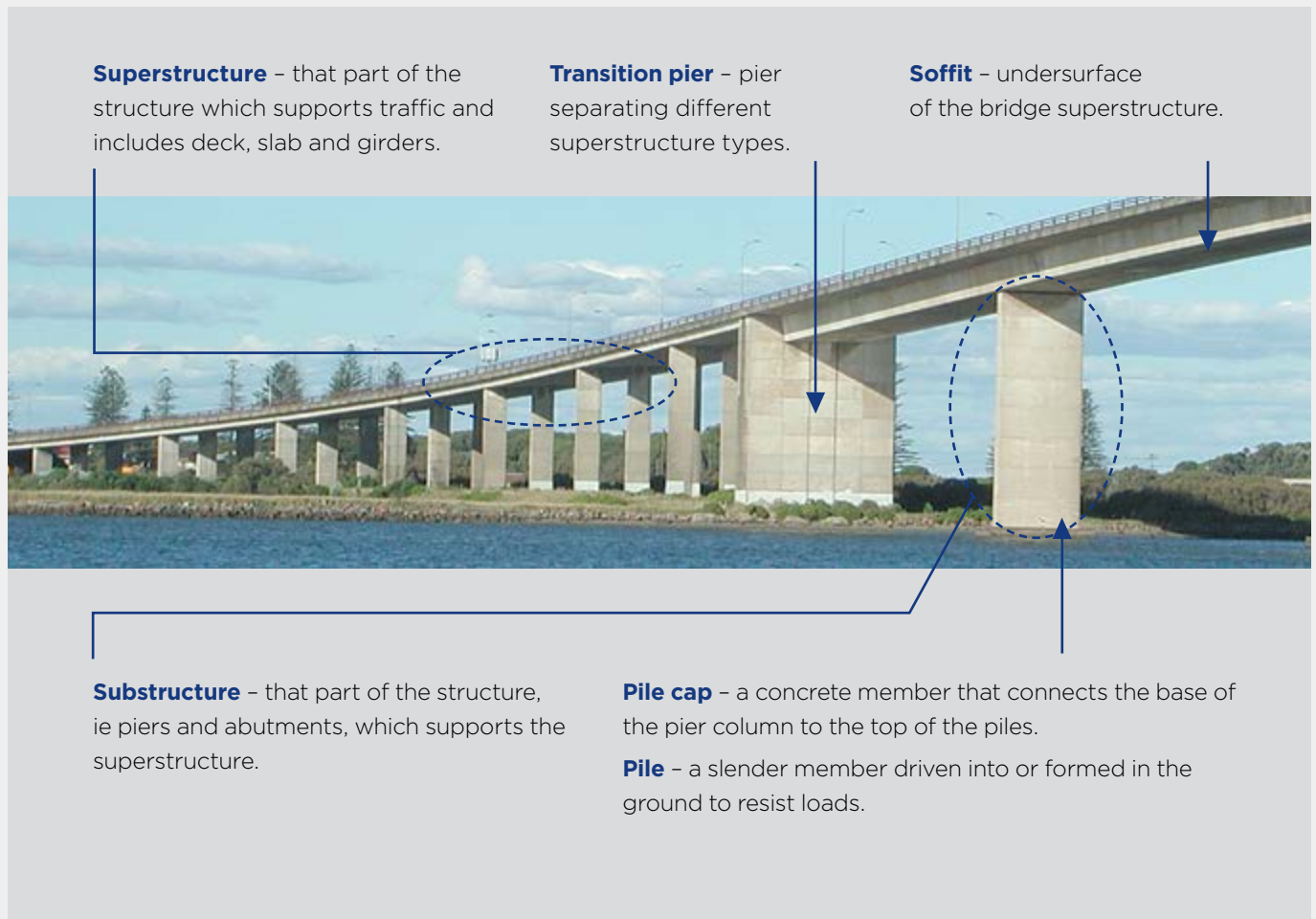
The Puente La Barqueta, Seville, 1989



This bridge, by Juan Jose Arenas architecture, Marcos Panteleon engineers and Auxidesa, is a 170 metre long traffic and pedestrian metal bridge that crosses the Guadalquivir River. La Barqueta is of interest as an integrated piece of architecture and engineering that links the historic city centre with the island of La Cartuja. Its solidity as an urban artefact is offset by its simple lines and transparency that results from the use of a group of supporting cables that run from a single arch. The bridge cables are distinguished by their red colouration. It has a simple, conventional parapet rail. Where the arch meets the ground, it divides into two, to form a pair of pillars. These pillars, as well as being structural, frame the approach to the bridge. The embankments on either side are beautifully landscaped with paving and planting.

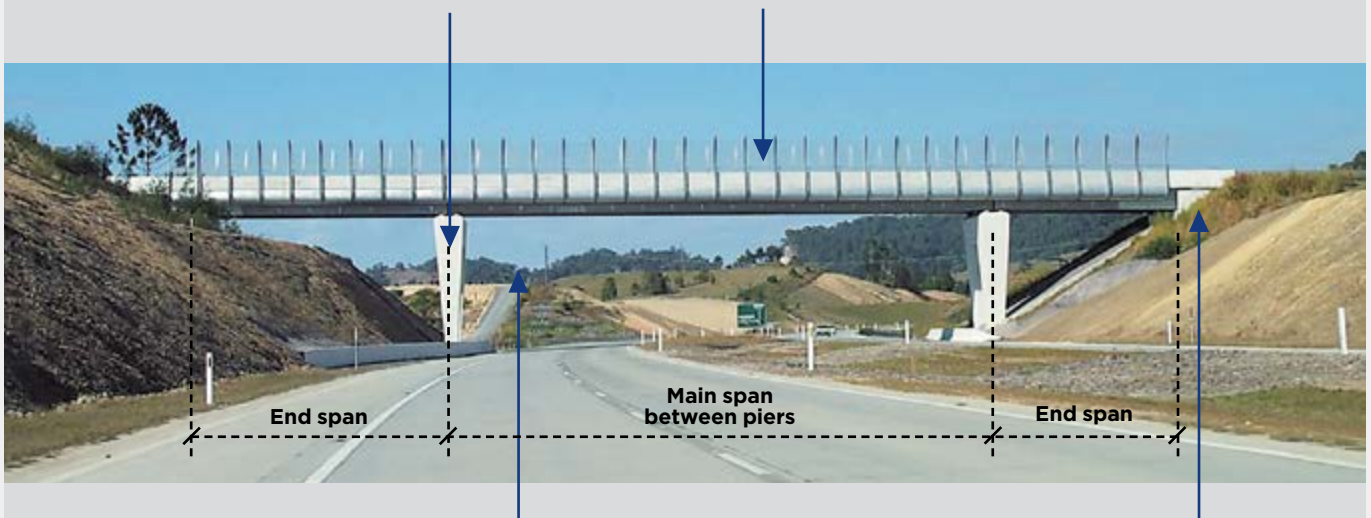
Appendix B: Bridge Terminology

A problem that can hamper meaningful debate between designers is consistency of terminology. The following annotated photographs set down the terminology used throughout these guidelines and should be understood by all involved in the bridge design process.



Pier – a part of the substructure which supports the superstructure at the end of the span and which transfers loads on the superstructure to the foundations.

Safety / throw screen – protective fence to deter the launching of objects from the bridge onto the highway below.



Span – the distance between points of support (eg piers, abutment).

Abutment – the part of the structure which supports the superstructure at its extremities.

Spill through abutment – an abutment which allows fill to form a slope into the end span rather than retaining it with a face wall.



Plank bridges – bridges which utilise a prestressed concrete plank deck system.

Planks – structural bridging units.



Haunch – an increase in depth of the superstructure adjacent to the piers to withstand the increased bending moments on the beam.

Parapet – (outer face).

Bearing – a connection that controls the interaction of loads and movements between parts of the structure, usually the superstructure and the substructure.



Pedestrian barrier – a railing placed on the edges of a bridge structure for pedestrian safety.

Safety screen – a fence to protect road users below the bridge.

Beam / girder – load bearing member which supports the deck.



Pier cap / headstock – a component which transfers loads from the superstructure to the piers. It is the wide top part of the pier that supports the bearings and the bridge superstructure.



Steel lattice work, hanging rods and maintenance gantries make for a beautiful composition when viewed from the multimodal Sydney Harbour Bridge deck. There has been a craftsman-like strengthening of the arch cables delicately threaded through the existing supports. In this picture the strengthening project is under construction.

Appendix C: Pedestrian Bridge Design Standard For Built Up Areas

Introduction

Pedestrian bridges are often required over busy arterial roads to provide safe connectivity for pedestrians and cyclists and to improve traffic efficiency by avoiding the need for traffic lights. These bridges are often in built up areas such as town centres, where space is limited for large ramps and the appearance of the bridge is an important customer consideration. In these built up situations there is considerable value in utilising a standardised bridge design so that there is surety in quality for the community; confidence in costs; and agreement on features such as lift provision and advertising accommodation.

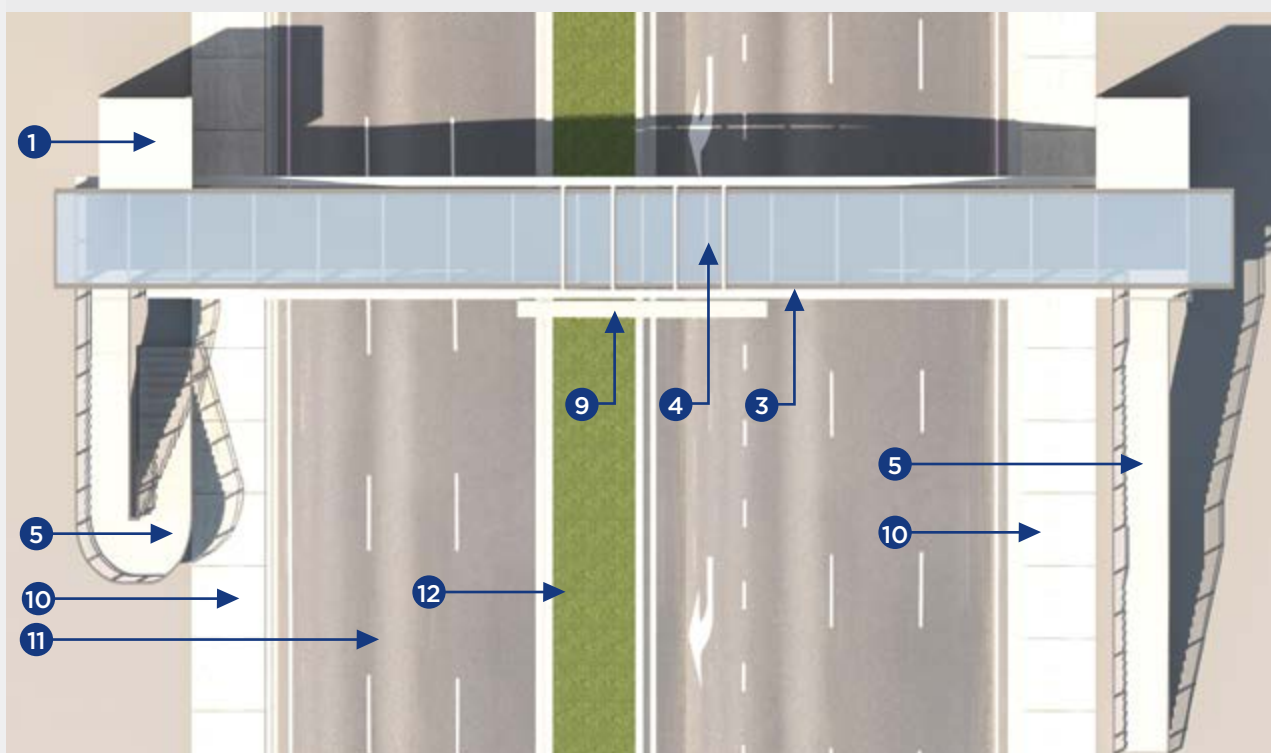
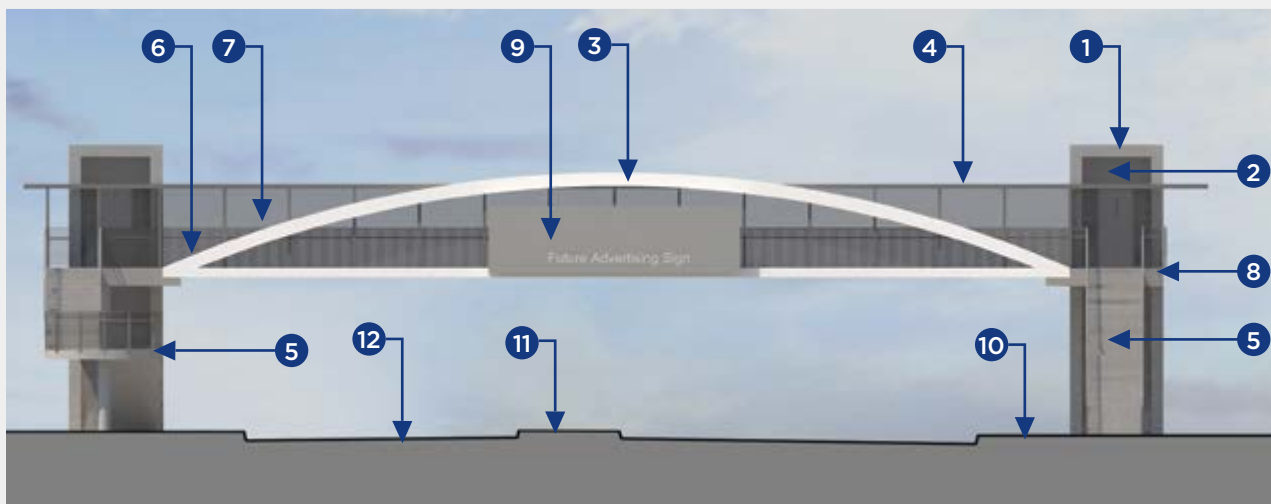
This bridge standard is intended for built up areas where space is limited, such as town centres. Where space is more available, or in rural situations, or in locations where a long span is needed, such as motorways and rivers, pedestrian bridges are likely to require a more context specific design approach.

Description

The standard pedestrian bridge design is a tied arch superstructure supported by lift shafts which have a glazed front for security. The tied arch has been selected as it reduces the height of the lifts and the stairs compared to a traditional girder design. It also has a proven aesthetic acceptability for communities being a simple, elegant and distinctive form. The absence of long ramps reduces the bridge footprint, its capital cost and its physical and visual impact. In addition to these main elements the design incorporates the following features and characteristics:

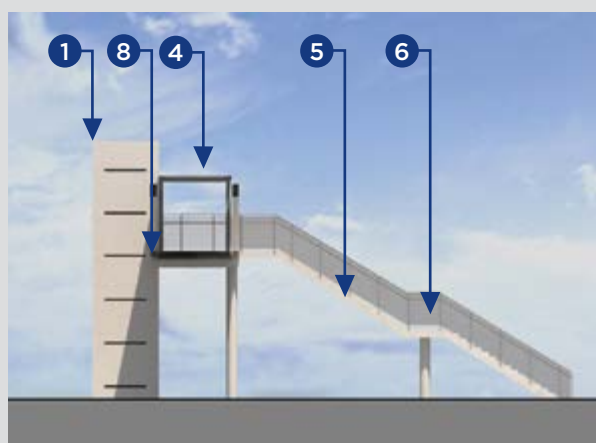
- The bridge can accommodate new digital advertising within the arch.
- The lift has been sized so that it can accommodate up to 16 passengers as well as scooters and bicycles.
- The open ends of the bridge deck allow district views and provide a more pleasant user experience.
- A roof over the bridge span protects users from the elements.
- The bridge can be customised to help create a unique identity through the finishes and colours of the lift shafts, the arch and roof structure as well as in the landscape design. Feature lighting can be used to create a distinctive night time effect.





LEGEND

- ① LIFT TOWER WITH SELECT PATTERN & COLOUR FINISH
- ② GLAZED FACADE (PREFERABLY FACING EAST OR SOUTH, CONSIDER TINTING)
- ③ TIED STEEL ARCH
- ④ WEATHER PROOF CANOPY WITH LIGHTING
- ⑤ STAIR
- ⑥ STAIR BALUSTRADE
- ⑦ SECURITY SCREEN
- ⑧ BRIDGE & LIFT LANDING
- ⑨ ADVERTISING SIGN
- ⑩ FOOTPATH
- ⑪ CARRIAGEWAY
- ⑫ MEDIAN



Implementation

Expert bridge design and urban design input is need in the siting of the bridge, its visual impact assessment, the landscape design to help fit the bridge into its setting and the customisation and tailoring of the bridge structure to fit its location. The Centre for Urban Design must be contacted in the use of the bridge standard and urban designers on the Registration Scheme for Construction Industry Contractors must be used in the design team.





One of the few ocean bridges in the world, the Sea Cliff Bridge north of Wollongong is a seamless combination of incrementally launched and balanced cantilever structures that follows the curvature of the coastline to dramatic effect.

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