Key Focus Areas to Achieve Resilient and Sustainable Concrete Structures

Scott Munter[1] and Eric Lume[2]
[1]Executive Director, Steel Reinforcement Institute of Australia
[2]National Engineer, Steel Reinforcement Institute of Australia

Abstract: Reinforced concrete is the most common and versatile construction system in buildings and structures worldwide. Ensuring resilience to survive extreme loads with minimal maintenance for preservation over future generations without the need for demolition and replacement, improves built environment sustainability. With increasing regularity and severity of natural disasters, the importance of providing a resilient built environment is becoming an essential part of today's engineering design. Detailing for negligible damage or being repairable after design events, without causing severe economic and social costs is fundamental to this outcome. The current focus to reduce embodied carbon in materials is essential and a first step in the sustainability journey being easily measured. In the future the focus will shift to whole of building whole of life assessment. Durability must not be sacrificed for lower embodied carbon solutions. Proven longer lifespans with low carbon and minimal maintenance materials makes reinforced concrete inherently sustainable for future generations. This paper highlights key focus areas across the value chain to assure lifespan extension outcomes. This includes the importance of obtaining a JASANZ accredited third party quality certification to verify Australian Standard conformance and traceability in procurement of conforming reinforcing materials. Following conforming material procurement, damage to reinforcing steels with poor site practices are often overlooked, which significantly impact performance requirements and simple design and detailing for life safety and resilience. The Steel Reinforcement Institute of Australia developed Guidelines supporting these engineering challenges, consolidating essential technical information to improve resilience and facilitate preservation and sustainable reinforced concrete solutions.

Keywords: Resilience, Sustainability, Quality, Traceability, Reinforcement

1. INTRODUCTION

With increasing regularity and severity of natural disasters including floods, fires, cyclones, severe storms, hail, heatwaves, coastal inundation and earthquakes, the importance of providing a resilient built environment is becoming an essential part of engineering design. Detailing for negligible damage or being repairable after design events, without causing severe economic and social costs is fundamental.

In 1895 reinforced concrete was adopted in Australia because of the many benefits that it continues to offer in terms of resilience against fire, termites, water and hot and cold weather, as well as long life, low maintenance and sustainability. The current focus to reduce embodied carbon in materials is essential but sustainability is a balancing process and proven longer lifespans with minimal maintenance makes reinforced concrete inherently sustainable.

This paper considers the resilience and design life of buildings and structures and based on the typically long life of reinforced concrete, considers the issue of sustainability. To achieve long life to improve the sustainability of the reinforced concrete solution, ensuring the quality of materials used and their proper handling on site to avoid processes that may impact the properties will also be considered.

The Steel Reinforcement Institute of Australia (SRIA) has developed Guidelines supporting these engineering challenges, consolidating essential technical information to improve resilience and facilitate preservation and sustainable reinforced concrete solutions. These include the *Guide to Seismic Design and Detailing of Reinforced Concrete Buildings in Australia* plus a unique *Guide to Historical Steel Reinforcement in Australia*, facilitating rehabilitation options for lifespan extension, which is now part of the *fib* Model Code.

2 RESILIENCE AND BENEFITS OF REINFORCED CONCRETE

The inherent properties of reinforced concrete make it an ideal construction material to resist a range of natural disasters such as bushfires, severe storms, floods, hail and earthquakes, as well events such as building fires. In fact, at a time when reinforced concrete was gaining rapid acceptance and becoming the most common construction material for its many benefits, a paper read before the Queensland Institute of Engineers, Inc. - June 17 1913 by European Engineer L. Messy highlighted the rapid acceptance and widespread use of reinforced concrete and the many benefits of reinforced concrete. Messy stated that, “In view of the present enormous developments of reinforced concrete in Europe, as well as in America…… there is no town or country, there is even no large building, without more or less use and utilisation of reinforced concrete…..The main features of reinforced concrete are: (1) fireproof, (2) antproof, (3) waterproof, (4) easy to build, (5) no skilled labour needed, (6) lowest cost of insurance, (7) substantiality, (8) light construction, (9) good, aesthetic, and attractive appearance, (10) impermeable, (11) unaffected by hot or cold weather, (12) or by sea water, (13) durability, (14) soundproof, (15) decreased maintenance, &c., &c.” These same benefits still make reinforced concrete the most widely used construction material in the world today.

More detailed information on the resilience of reinforced concrete and some of the important reinforcement detailing issues that need to be addressed are provided in the SRIA’s Concrete 2023 Paper presented at the Concrete Institute of Australia’s Conference, Design and Detailing for Resilience and Sustainability of Concrete Structures, which is available on the SRIA website under Resources.

3 SUSTAINABILITY AND DESIGN LIFE

As the construction of new buildings and structures requires building materials that emit greenhouse gases during their manufacture, one of the approaches to achieving a more sustainable built environment is the trend that focuses on reducing the embodied carbon in new buildings and structures. The main ways to achieve this is through the use of low embodied carbon materials and material minimisation in the structure itself.

The reinforcement industry in Australia, while working towards reducing the embodied carbon in the product, has also developed a new Grade 600N reinforcement, which is now available. The driving force behind the development of this higher-grade reinforcement was improving sustainability through minimising the material required. The new bar sizes have thus been made intentionally smaller than the current Grade 500N bars, to save material (ie S11, S15, S18, S22, S26, S29, S33 and S 37), as they are intended as a direct replacement for the Grade 500N bars eg S18 to replace existing N20 bar.

While material minimisation is one approach, at a presentation to Engineers Australia (1), Richard Haynes from eToolLCD stated that, “Possibly the easiest way to reduce structural impacts of an asset is to ensure that the structure is utilised for a very long time.” Working against this, is the fact that the actual design life is usually driven by redevelopment potential rather than the material durability. The solution may be to increase the value of the building in comparison to the land value, and to also improve the adaptability of the building. There is no doubt that many Architects today are finding ways to repurpose existing buildings because they recognise the amount of embodied carbon that is already locked up in the building, that would otherwise need to be replaced.

At the CIA’s 2023 Conference, John Hilton (2) presented a paper that also highlighted this approach for bridges, outlining the benefits of extending the design life of bridges from 100 years to perhaps 300 years. He noted that the second Gateway Bridge in Brisbane had been designed for a 300 year design life, which only increased the cost by an estimated 5 percent. He concluded the paper with the following statement, “While measures including bridge re-use, repurpose or recycling certainly reduce the overall embodied energy and mitigate use of finite resources, it can be seen that the biggest gain by far is simply to extend the life of the structure.”

This concept was also highlighted in an Indesignlive webinar (3), where Philip Oldfield pointed out that one of the most effective strategies to reduce the carbon impact of a building was retention or adaptive reuse. Dr Caroline Noller pointed out while one way of expressing embodied carbon might be to set a total absolute target such as, “Base building Embodied Carbon not to exceed 2,944 kg CO2-e/sqm NFA A1-A5 absolute.” Dr. Noller highlighted that an alternative approach being adopted by some European countries is to amortise or annualise the same target such as, “98 kg CO2-e/sqm/annum (on 30-year life).” For the typical A-Grade office building in Australia, presented as having approximately 3,300 kg CO2-e/sqm embodied carbon, this equates to 66 kg CO2-e/sqm over a 50-year life. If the design life of the building is doubled, this reduces to just 33 kg CO2-e/sqm over the life of the building. In this way, the benefit of increasing the design life either through initial durability design or extending the design life of existing buildings through maintenance strategies can be realised in lower CO2-e emissions over the life of the building or structure. As an example, the second Gateway Bridge covered by John Hilton above is a good example of how if the embodied carbon is annualised over an extended design life of the structure, the benefits to people, profit and planet are significant.

Regarding the design life, most buildings are designed in accordance with AS 3600 (4) for a nominal 50 year design life, which could be anywhere from 40 to 60 years (Clause 4.1 of AS 3600). If a 100 year design life is required, the durability provisions of the Bridge Design Standard, AS 5100.5 (5) will generally be adopted. Note that the design life in AS 5100.5 does not have a range.

To achieve a 100 year design life in accordance with the provisions in AS 5100.5, the only two aspects that change, are a nominal increase in the concrete cover and the requirement to provide a minimum cementitious content in the concrete mix. For interior environments with an exposure classification of A2 (non-residential) in AS 3600, or A in AS 5100.5, for a 25 MPa concrete, the cover increases by 15 mm and for concretes greater than 50 MPa, by only 10 mm, to achieve twice the design life. For exterior near coastal exposure environments with a B1 classification and requiring a 32 MPa concrete, again the cover increases by just 10 mm in order to double the design life. In terms of the minimum cementitious content, with the low carbon mix designs and mixes now utilising General Purpose Limestone cement (Type GL), significant reductions in the embodied carbon have been achieved, and hence this is not seen as a significant factor when considering the benefits realised by extending the design life.

So, while material minimisation may be the focus of some contractors to reduce the embodied carbon by perhaps 15 to 20%, doubling the design life by providing a nominal amount of extra cover to the reinforcement can reduce the embodied carbon over time by a minimum of 50%. This would more than compensate for the additional quantity of low carbon concrete required to provide the nominal additional cover. With reinforced concrete buildings and structures typically lasting significantly longer than their design lives, the reduction over time will be even greater. Note that Australia’s first reinforced concrete structure was built in 1895 and still fulfils its original design purpose as a sewer aqueduct. Taking into account the long life spans of reinforced concrete buildings and structures has real benefits in terms of being able to amortise the embodied carbon over the life of the building or structure, and thus evaluating the sustainability of the building or structure.

4 QUALITY AND TRACEABILITY

Achieving the durability of a reinforced concrete building or structure, depends on quality materials and workmanship. In this section, quality issues relating to reinforcing materials and procurement of those materials will be covered. Section 5 will consider some site issues relating to workmanship.

One of the issues that we are dealing with at the moment in Australia, is the increase in imported reinforcement (**Figure 1**), with no proper quality tagging to identify the origin and compliance of the product, or worst still, with fraudulent compliance certificates **Figure 2**. The Australasian Certification Authority for Reinforcing and Structural Steel (ACRS) certificate of product performance shown in **Figure 2** cannot be a current 2024 certificate as not only is it in the older style format, but it is signed by Philip Sanders (highlighted), the previous long-serving Executive Director, who sadly passed away some years earlier. Note that the manufacturer’s name has been removed for commercial reasons and had not produced product for Australia for many years.

Figure 1. Imported mesh product on Melbourne Docks with no product tags.

Figure 2. Fraudulent (older style) compliance certificate with date and company details altered.

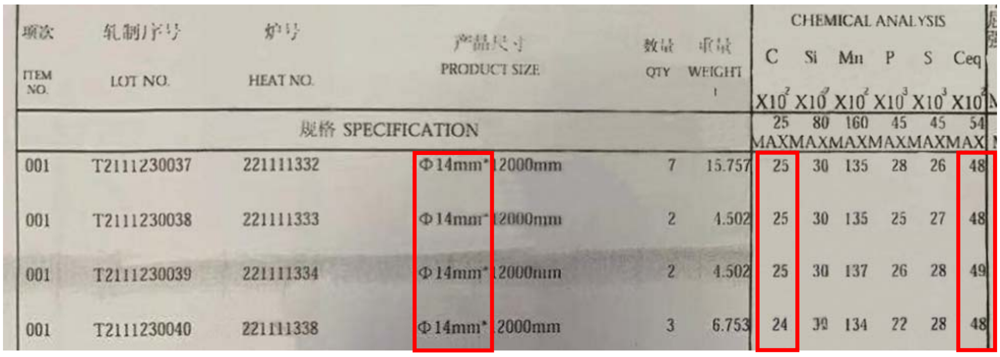
In the example of a 2023 certificate shown in **Figure 3**, you will notice that the approved bar mark provided on the certificate, TK, which identifies the approved reinforcing bars, is not present on the actual bar that the certificate relates to. In fact, the bar shown next to the certificate in **Figure 3**, does not have a bar marking between the ribs. The bar tag (in green) is also difficult to interpret and not compliant.

Following an investigation by ACRS, the updated 2024 certificate shown in **Figure 4** was issued, which included a number of bar markings, including the one for the bar that was actually supplied in late 2023. That is, with no TK marks between the ribs. While the issue was resolved, it does raise questions regarding overseas manufacturers and the traceability of the product. According to ACRS, "One of the most reliable methods to ensure the integrity of constructional steel products is to purchase materials exclusively from producers and traders who are accredited by recognised certification schemes, such as the ACRS, or ACRS equivalent."

Another issue relates to the chemistry of the reinforcement. **Figure 5** is from a technical enquiry the SRIA received from an Engineer who was assessing some Chinese steel that was intended to be directly imported for use in a West Australian project. Apart from the non-standard bar size of 14 mm and lower yield stress of 400 MPa, the carbon content and carbon equivalence values exceed the maximum limits within AS/NZS 4671 (6), and will influence the ductility and weldability of the bar. Also, after checking on the ACRS website (steelcertification.com), we confirmed that the manufacturers important quality certification had been terminated by ACRS for non-compliance. It is absolutely critical that any reinforcement used in or considered for any Australian project, complies with all aspects of the various Australian Standards, and it needs to be certified as such by an independent JASANZ accredited organisation such as ACRS, or equivalent.

Figure 3. Bar mark on product does not match bar mark on 2023 ACRS certificate and bar tag difficult to interpret and not compliant.

Figure 4. Bar marks approved on updated 2024 ACRS certificate.



项次 ITEM NO.	轧制序号 LOT NO.	炉号 HEAT NO.	产品尺寸 PRODUCT SIZE	数量 QTY	重量 WEIGHT t	C $X10^2$	Si $X10^2$	Mn $X10^2$	P $X10^3$	S $X10^3$	Ceq $X10^2$
规格 SPECIFICATION						25 MAX	80 MAX	160 MAX	45 MAX	45 MAX	54 MAX
001	T2111230037	221111332	Φ14mm*12000mm	7	15.757	25	30	135	28	26	48
001	T2111230038	221111333	Φ14mm*12000mm	2	4.502	25	30	135	25	27	48
001	T2111230039	221111334	Φ14mm*12000mm	2	4.502	25	30	137	26	28	49
001	T2111230040	221111338	Φ14mm*12000mm	3	6.753	24	39	134	22	28	48

Figure 5. Chemical properties of proposed Chinese reinforcement.

The SRIA is actively issuing industry warnings across our various social media outlets and via targeted magazine features concerning the importance of ensuring quality reinforcing product is delivered to sites, and how to check the compliance of the product, particularly imported product not supplied by an SRIA member **Figure 6**. David Chandler, the NSW Building Commissioner, has weighed in on our social media posts, stating that if any concrete is found reinforced with counterfeit products, it will be coming out **Figure 7**.

Figure 6. Examples of industry warnings posted by the SRIA.


David Chandler OAM · Following
NSW Building Commissioner at NSW Department of Customer Service
2w ···
#BuildingCommissionNSW will be keeping an eye out. #Engineers #Certifiers #Builders expect check-ups of #OccupationCertificates and on-site. Will be an avoidable tragedy to have to demolish slabs if found. Be assured if counterfiet products are discovered they will be coming out. #BuildingCompliance #Accountability #Licences #Risk

Figure 7. Response by NSW Building Commissioner, David Chandler.

To guarantee the quality of supplied reinforcement, you have two options in Australia:

a) Buy from an SRIA member, who must all have JASANZ accredited 3rd party certification, and guarantee the traceability and quality of both manufactured and processed reinforcement supplied, by carrying out all the required checks, or

b) Ensure you obtain both a JASANZ accredited third party mill and processor certificate to verify the traceability, quality and compliance of the reinforcement to Australian Standards. Once you have the certificates, check their authenticity by referring to the ACRS website (steelcertification.com), to validate the certificate, and then ensure compliant tags are supplied with the reinforcement and the bar marks match the certificate during the site inspection of reinforcement. Note the responsibility to ensure compliance applies to all parties in the supply chain.

5 SITE QUALITY ISSUES

While SRIA member companies guarantee the quality at the mill and processor stages, various site practices at the builder stage in the reinforcement quality chain (refer **Figure 6**) can affect the final quality of the reinforcement. The following site issues that the SRIA has identified through extensive technical enquiries received, can affect the quality of the certified product in the assembled reinforcement. By ensuring quality reinforcement is delivered to site, and is not mistreated on site resulting in a non-compliant product, the performance criteria will be met, and the client and final owner of the asset will have the confidence that the building or structure complies with the National Construction Code and is safe and robust.

5.1 Surface conditions of reinforcement

One of the most common questions we receive from Engineers and Builders concerns the surface condition of reinforcement on site, and the images in **Figure 8** are all from technical enquiries that we have received. Note that any loose or flaking rust on the surface of the bar indicates a loss of steel section that can impact the design capacity, and without verifying that the minimum required mass of the bars has not been compromised, we would not recommend that any of these bars be cast into concrete. However, the presence of surface corrosion does not necessarily mean the reinforcement cannot be used. **Figure 9** shows reinforcement with considerable surface rust, but no loose or flaking rust is evident, so this was considered acceptable. Also, the profile of the ribs on the bars, which mechanically bond the bar into the concrete have not been affected. So, while the bars may not look in the best condition, it would still be satisfactory to cast concrete around them. If cleaning loose and flaking rust off the bar is proposed to check the acceptability, then the actual weight of the bar after cleaning must be checked against the mass limits in AS/NZS 4671. SRIA Technical Note 1 (available for free download from our website) covers this aspect in more detail.

Figure 8. Examples of loose and flaking rust indicating loss of steel section.

Figure 9. Example of acceptable surface corrosion.

5.2 Bending of reinforcement

Bending of reinforcement is another common technical enquiry received by the SRIA. The column starter bars in the left-hand image of **Figure 10** were backed over by a truck on site. We advised that the bars could be straightened, and that Section 17 of AS 3600 contains the requirements to properly bend reinforcement on site. These include that bars should be bent around a suitable pin diameter in a single smooth action using appropriate tools.

The image at centre of **Figure 10**, where out of place column bars have been bent into the final column location, are unacceptable as they do not comply with the requirements of Clause 10.7.5.5, which requires that the maximum slope of the bar be 1 in 6 (horizontal to vertical). If the column cannot be moved or enlarged to avoid bending the bars, the only option in these cases is to cut the bars off and drill and epoxy new starter bars into the footing.

The image at the right of **Figure 10**, is of a bridge parapet where some additional cover was required before placement of the formwork. The labourer on site used a sledge hammer to strike each bar to adjust the cover, and this can be seen by the flattened ribs above the fracture. AS 3600 clearly states that reinforcement is not to be bent using impact, such as with hammers. This is a clear example of how mistreating reinforcement on site can result in damage to an otherwise compliant reinforcing product supplied by an ACRS certified processor.

Bending reinforcement on site is a common site practice, but must be carried out correctly. Note that the poor site practices shown in **Figure 11**, where pipes are used for leverage and the reinforcement is not bent around the required pin diameters given in AS 3600, are no longer permitted in the 2018 edition of AS 3600 due to a lack of site control. If reinforcement is to bent on site, various manual and electric tools are available **Figure 12**. If used, the pin diameter that the bar is bent around, must suit the bar size to achieve the correct bend radius. More information can be found in the SRIA Technical Note 4.

Figure 10. Examples of bending reinforcement on site.

Figure 11. Common, but poor site bending practices no longer permitted in AS 3600.

Figure 12. Examples of manual (left) and electric (right) bending tools.

5.3 Heating of reinforcement

Figure 13 shows a bar being heated using oxy acetylene to make it easier to bend. The redness in the bar adjacent to the flame is a sign that the bar has been overheated. AS 3600 generally limits heating of bars to 450 degrees but allows up to 600 degrees if the strength is reduced to just 250 MPa. Note from the colour chart of steel temperatures in **Figure 13**, steel only starts to glow a dull red colour at about 600 degrees, so any redness in the bar indicates that the maximum temperature has been exceeded and the bar is therefore no longer compliant and should be replaced. Even if it is not showing any signs of redness, unless you have an instrument on site to measure the temperature, you should assume that the 450 degree limit has been exceeded and the design strength should be taken as 250 MPa. Heating of reinforcement on site to facilitate bending should therefore be avoided.

Colour	C
Faint Red	600
Dark Red	700
Cherry Red	800
Dull Orange	900
Orange	950
Lemon Yellow	1000
Yellow	1050
Bright Yellow	1100
White	1200
Glowing White	1300

Figure 13. Heating of bars to facilitate bending of reinforcement.

5.4 Congested reinforcement

The congested reinforcement examples shown in **Figure 14** represent another quality issue and should be avoided because it does not allow the concrete to be adequately placed and compacted. The typical immersion vibrator used to compact concrete on site is typically 50 mm diameter, and if you cannot get this through the 'mesh' of reinforcement, then adequate compaction of the concrete, let alone its placement, is impossible. Ideally, these situations should be addresses at the design stage. To assist in this regard, various types of mechanical splices have been developed, and more information on these can be found in SRIA Technical Note 10.

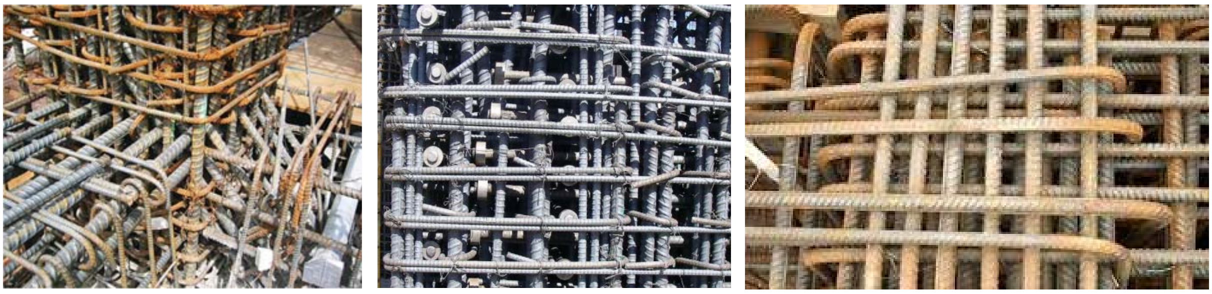


Figure 14. Examples of congested reinforcement.

5.5 Cover to reinforcement

This is one of the main factors that influences the durability and design life of reinforced concrete. AS 3600 and AS 5100.5 specify what the minimum cover needs to be for various exposure classifications, and site inspections should ensure that the cover has been correctly set using bar chairs or spacers complying with AS/NZS 2425 (7). Inadequate cover results in early corrosion activation and progression, and increased maintenance costs over the design life. In extreme cases, it may require replacement of the element. Cover to reinforcement is a critical aspect of achieving durable and hence sustainable buildings and structures and should be given the attention it deserves during site inspections.

5.6 Concrete Quality

While not directly related to reinforcement, basic quality issues with the other half of the reinforced concrete solution, such as the addition of excess water, inadequate compaction and curing can also significantly impact the performance of reinforced concrete.

According to Dr. Peter Miller (previous editor of the Institution of Engineers Australia Journal), “Concrete technology is an area in which engineers have dropped the level of their game….The most brilliant design depends for its success on the skill of the craftsmen dealing with the wet concrete.”

It is important to ensure that these basic quality issues of placing, compaction and curing are not overlooked in the current market where project managers are constrained by cost and time.

6 CONCLUSIONS

The benefits of reinforced concrete in terms of its resilience to natural disasters and fires has been proven over many generations. The current focus to reduce the upfront embodied carbon in materials is essential but sustainability is a balancing process and proven longer lifespans with minimal maintenance makes reinforced concrete inherently sustainable. There is a growing acknowledgement that designing reinforced concrete for a longer design life for new structures and extending the design life of existing structures, as well as the ability to adapt and repurpose existing buildings, will contribute significantly to reducing the embodied carbon over the life span of the reinforced concrete building or structure. While some approach sustainability by material minimisation, a preferred option is to consider increasing the design life, which has been shown to only add a nominal amount to the cost of the project from a small increase in cover and perhaps minimum required cementitious content, but results in a significant reduction in greenhouse gases over the life of the asset. The development of higher strength reinforcement and continual improvements to mix design and development of low carbon concretes, further facilitates this approach.

To achieve longer life spans, quality materials, traceability and workmanship are also essential. The entire supply chain has a duty of care to ensure that complying reinforcement materials are procured and installed correctly on site to deliver the performance requirements and life span extension. This will become increasing important in the future as global markets under increasing pressures seek other opportunities for exports, and as a result, the risks of non-compliant imported reinforcement increase.

Workmanship issues on site also play a key role in ensuring the longevity of the reinforced concrete solution. Particularly the elimination of poor site practices and ensuring the specified cover to reinforcement has been set, as this is a key factor in achieving durability and longer design life. The Building Commissioner in NSW has identified that building inspection during construction by suitably qualitied professionals is one of the key ways to eliminate defects and ensure performance outcomes.

In summary, the approach of designing for a longer life, ensuring that conforming materials are used and poor site practices are addressed, will ensure improved sustainability over the life of the asset. The maintenance requirements over time will also be significantly reduced, further assisting with a sustainable outcome.

7 REFERENCES

1. Engineers Australia, Design Strategies for Minimising Embodied Carbon – Materials and Components, Webinar Presentation by Richard Haynes, co-founder of eToolLCD, 30 June 2021. Available for Members at EA OnDemand.
2. John Hilton (Global Capability Leader, Bridges and Civil Structures, Aurecon), The Circular Economy: Implications for Bridges, Concrete Institute of Australia, Concrete 2023.
3. Indesignlive, Designing for Our Future – Carbon Mitigation and the Built Environment, presented by Dr. Caroline Noller (CEO, Footprint Company), Philip Oldfield (Head of School, UNSW Built Environment) and Steve Fox (Principal, Architectus), 6 October, 2021. Presentation available at indesignlive.com/cpdlive/cpd-archive/designing-future-carbon-mitigation-built-environment.
4. Standards Australia, AS 3600 Concrete structures, 2018.
5. Standards Australia, AS5100.5 Bridge design Part 5: Concrete, 2017.
6. Standards Australia, AS/NZS 4671 Steel for the reinforcement of concrete, 2019.
7. Standards Australia, AS/NZS 2425 Bar chairs in reinforced concrete – Product requirements and test methods, 2015.