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600 MPa Prefabricated Column Cages to Improve Sustainability

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ABSTRACT

Prefabricated column cages manufactured from 600 MPa reinforcing steels are positioned to make a substantial contribution to reducing the Australian construction industry's burden of generating a significant portion of Australia's carbon footprint. Changes to Australian Standards AS/NZS 4671 – Steel for the reinforcement of concrete and AS 3600 – Concrete structures, now recognise the production and use of 600 MPa reinforcing steels which have the potential to reduce the embodied carbon in a structure compared with 500 MPa reinforcing steels.

This paper examines how prefabricated column cages using 600 MPa equivalent design capacity bars in place of 500 MPa standard diameter bars can significantly reduce the embodied carbon in the steel of reinforced concrete columns. The higher strength bars reduce the amount of steel required to carry the same load. The prefabrication in a factory environment improves material efficiency, reduces wastage, while the recycling of scrap is maximised by avoiding the generation of post-consumer scrap.

The case study of a 58-storey retail and office building in Sydney, Australia provides quantitative data on the mass and embodied carbon savings achieved by using 600 MPa prefabricated column cages in lieu of individual 500 MPa reinforcing steel bars fixed on site.

INTRODUCTION

Changes to Australian Standards over the last 6 years have been instrumental in encouraging manufacturers to innovate and address the construction industries burden of generating almost 20% of Australia's carbon footprint (Yu, et.al. 2016). In 2018 changes to AS 3600 - *Concrete structures* (Standards Australia, 2018) and in 2019 changes to AS/NZS 4671 - *Steel for the reinforcement of concrete* (Standards Australia, 2019), more broadly introduced rules for high strength steels in the design of concrete structures and for the manufacture of those reinforcing steels, respectively. The new editions of those Standard have provided the reinforced concrete (RC) industry the opportunity to explore the benefits offered by higher strength, ductile reinforcing steels.

The only Australian manufacturer of reinforcing steels took the innovative approach of producing SENSE 600®, higher strength 600 MPa bars in what they term, 'equivalent design capacity' diameters to the existing range of 500 MPa bars available in Australia. That is, the design capacity of the 600 MPa bars is the same as their equivalent 500 MPa bars. Table 1 shows the diameters available with a design yield strength of 600 MPa compared with the 500 MPa equivalent design capacity bars.

Table 1. 600 MPa reinforcing bars available in Australia compared with 500 MPa bars.

600 MPa Ductility Class N		500 MPa Ductility Class N		Design Capacity
Designation[1]	Diameter[2] (mm)	Designation	Diameter (mm)	(kN)
S11	11.0	N12	12	57
S15	14.6	N16	16	101
S18	18.3	N20	20	158
S22	21.9	N24	24	227
S26	25.6	N28	28	308
S30	29.2	N32	32	403
S33	32.9	N36	36	509
S37	36.5	N40	40	629

[1] Designation recommended by the manufacturer on engineer's design documents.

[2] Calculated using equivalent capacity to 500 MPa bars and quoted to 3 significant figures.

This is innovative because when the strength of the standard grade for reinforcing bars in Australia was raised from 400 to 500 MPa in 2001, the manufacturers kept the bar diameters for the new product the same as they were for the existing product. This has also been the case internationally when both 500 and 600 MPa bars were introduced into the market.

The rationale for the Australian manufacturer using the concept of equivalent design capacity bars is that it simplifies the substitution of 500 MPa bars with 600 MPa bars. The one for one substitution means there is no requirement for the reconfiguration of bars in a column, wall, or beam to achieve the potential mass savings from the use of a higher strength steel.

Furthermore, an exclusive electric arc furnace production route for the Australian made steel, utilising 100% scrap as the feed material for the 600 MPa reinforcing steel, results in a significant reduction in the embodied carbon compared with its standard 500 MPa reinforcing steel. The Environmental Product Declarations (EPD) for the 600 MPa reinforcing steel (InfraBuild 2024) indicates that it has a global warming potential (GWP) of 966 kgCO_2eq/t compared to 1270 kgCO_2eq/t for 500 MPa reinforcing steel. This 27.4% reduction in GWP, in addition to the 16.7% potential reduction in mass where 600 MPa bars are used in lieu of 500 MPa bars of equivalent design capacity results in a total reduction in GWP of 39%.

AUSTRALIAN CODES AND STANDARDS

Buildings in Australian are required to comply with the National Construction Code (NCC) (ABCB, 2023), specifically the Building Code of Australia Volumes 1 and 2 (BCA Vol.1 and Vol. 2). While the BCA allows several options to demonstrate compliance with the Code, the preference of engineers is to design and certify that their designs conform to an Australian Standard. However, it should be noted that the BCA Vol. 1 and 2 both recognise a CodeMark Certificate of Conformity as the first option to demonstrate compliance with the BCA ahead of an engineer's certificate stating conformity to an Australian Standard. CodeMark Certificates of Conformity are extremely useful in simplifying the compliance process for new or innovative products that may or may not be covered by an Australian Standard. Details and examples of how CodeMark Certificates of Conformity are applied to a specific brand of 600 MPa bar are covered in the sections to follow.

AS/NZS 4671 – Steel for the reinforcement of concrete

The requirements for producing 600 MPa reinforcing steels are covered in AS/NZS 4671 – *Steel for the reinforcement of concrete* (AS/NZS 4671). The key attributes for 600 MPa reinforcing steels from this Standard are:

- Lower Characteristic Yield Strength (design yield strength) – 600 MPa.
- Ductility Class N (Normal ductility) – $A_{gt} \geq 5\%$.
- Carbon equivalent value (CEV) – < 0.49% by cast analysis and thus readily weldable.

Australian Design Standards

When the latest revision to AS 3600 – *Concrete Structures* (AS 3600), was published in 2018 the design models and rules were extended to cover 600 MPa reinforcing steels.

An amendment to AS 5100.5 – *Bridge Design, Part 5, Concrete,* was published in May 2024 which extended the scope of the design rules to include 600 MPa reinforcing steels. This provided designers of structures associated with bridges the same opportunity to achieve savings in steel reinforcing and embodied carbon as in other structures designed to AS 3600.

Australian Standard AS 2159 – *Piles – Design and installation*, permits 600 MPa reinforcing steels to be used as the designers are referred to the design model and rules in AS 3600 for concrete pile design.

While Australian Standards recognise and permit the use of 600 MPa reinforcing steel for a wide range of reinforced concrete elements, intuitively, an element that is governed in design by strength rather than serviceability is likely to benefit the most from a higher strength steel. Given the design of a reinforced column is generally governed by strength it is reasonable to expect that a 600 MPa reinforcing steel in lieu of a 500 MPa steel would result in a reduction in the cross-sectional area of steel of approximately 16.7%. A hypothetical case study (Ng, Merrick and McGregor, 2022) to redesign a building that had already been constructed, demonstrated that this was the case, leading to a comparative decarbonization of the steel in the structure.

Now that 600 MPa product is available in the Australian market a case study can be undertaken to examine the sustainability benefits of 600 MPa steel from design to construction.

CodeMark Certificates of Conformity

The Australian Building Codes Board (ABCB) is responsible for the NCC and CodeMark Certification Schemes. Australian Standards, such as AS 3600, are primary references in the NCC, which allows engineers to design in accordance with these references and hence demonstrate compliance to the NCC. Similarly, CodeMark Certification Schemes are recognised in the BCA Vol.

1 and 2 of the NCC, and engineers can design to these certificates to also demonstrate compliance to the NCC. Effectively a design to a CodeMark Certificate of Conformity has the same status as a design to an Australian Standard in terms of compliance with the NCC.

CASE STUDY

The case study of a 58-storey retail and office building in Sydney, Australia provides quantitative data on the mass and carbon savings achieved using 600 MPa prefabricated column cages in lieu of individual 500 MPa reinforcing steel bars fixed on site.

Design of the building began in January 2020, some 4 years before 600 MPa equivalent design capacity bars were available. In fact, the columns in the basement were already designed and construction to level B3 was about to commence when the head contractor was introduced to this product. 600 MPa column fitments were able to be substituted at the lowest level because redesign was not necessary as they are covered by the CodeMark Certificate of Conformity discussed in the following section.

The longitudinal column bars, unlike the fitments, require a design check because there are slight differences between the axial load – moment interaction curves of the columns reinforced with 500 and 600 MPa steels. This is due to the strain compatibility differences between each of the grades of steel and concrete (Ng, Foster and McGregor, 2023). The head contractor and the design engineers were investigating a redesign of columns which included adjusting the concrete strength to facilitate construction by managing the concrete heat of hydration in the large, up to 2250 mm diameter, columns. This redesign provided the opportunity to use 600 MPa steels in all columns except those in Basement Level 3 where a redesign of the longitudinal column bars would have delayed the construction program.

Limitations of the Study

The case study of a live project, one still under design refinement and construction, complicates the comparison of the initial 500 MPa design with the 600 MPa alternative. Two main issues were identified during the material measurement of quantities process.

1. Column sizes and their extent differed in the 500 MPa and 600 MPa designs due to design development and variations to the layout after the decision to use 600 MPa longitudinal bars.
2. Changes to concrete strength from 100 MPa to 90 MPa to improve constructability by reducing the heat of hydration.

Therefore, in this case study, the 500 and 600 MPa equivalent design capacity bars are not designed in completely identical structures. The concrete strength, extent and sizes of the columns are additional variables that were changed from the 500 to the 600 MPa column designs. Furthermore, the design engineers were not in a position to produce retrospective 500 MPa options for changes to the sizes and extent of concrete columns that were proposed after the decision was made to use 600 MPa longitudinal reinforcement. Where there were no 500 MPa column design options produced for certain locations in the building, those columns have been excluded from the study.

Column Fitments

600 MPa column fitments could readily be substituted for the 500 MPa fitments without re-design using the CodeMark Certificate of Conformity No. CM30136 - SENSE 600® Fitments (Global Mark 2023). Fitments in a column are required to primarily perform two functions; to confine the concrete, and to prevent the longitudinal bars from buckling. Examining AS 3600 clauses 10.7.2 to 10.7.4.4 inclusive, indicates that the fitments are essentially in tension and therefore ideally suited for a 600 MPa steel. This is the basis upon which the CodeMark Certificate was issued. The conditions and substitution table in the CodeMark Certificate relating to fitments, reproduced in Figure 1, allows designers to directly substitute the equivalent load capacity 600 MPa fitments for the 500 MPa

fitments without re-design.

The ease of substitution of the column fitments meant that even the lowest level of the building was able to be constructed with 600 MPa fitments, even though construction was at such an advanced stage, with the substructure nearing completion.

Limitations and conditions:

1. **General**
   Design and specification of SENSE 600® - Column Fitments shall be carried out in accordance with AS 3600:2018 – Concrete structures (incorporating Amendment No. 1 & 2), by a Professional Engineer as defined in Schedule 1 of the BCA.

   500 MPa column fitments conforming to AS/NZS 4671:2019 Steel for the reinforcement of concrete, and designed in accordance with AS 3600:2018 – Concrete structures (incorporating Amendment No. 1 & 2) , may be substituted with SENSE 600® - Column Fitments in accordance with Table 1.

Table 1

SENSE 600® - Column Fitments		Equivalent 500 MPa
Designation	Diameter (mm)	Column Fitment Diameter (mm)
S11	11.0	12
S15	14.6	16
S18	18.3	20

2. **General**
   The SENSE 600® Column Fitments shall be installed in the same manner as the 500 MPa column fitments i.e. conforming to AS 3600:2018 – Concrete structures (incorporating Amendment No.1 and Amendment No.2), and the professional engineer's plans

Figure 1 – Column fitment substitution table from CodeMark Certificate No. CM30136.

The CodeMark Certificate allowed all 112 tonnes of 500 MPa column fitments in the original design to be directly substituted with 93 tonnes of 600 MPa fitments, giving a material saving of 16.7% over the 500 MPa fitment design and a 39% reduction in embodied carbon. However, in the measured quantities from the engineer's drawings, the mass of 600 MPa fitments was slightly higher at 94.6 tonnes.

The 1.6 tonne difference between, what the CodeMark Certificate design would allow and the measured quantity can, in part, be attributed to the limitations of the study as discussed above. The other factor that contributed to the lower-than-expected difference was, the maximum fitment spacing for 600 MPa bars, allowed by CodeMark Certificate CM301354 SENSE 600® – Longitudinal Column Reinforcement of 16.4 bar diameters, appeared not to have been used in the design.

Longitudinal Bars

When an equivalent design capacity 600 MPa bar is substituted for a 500 MPa longitudinal bar in a column there are arguably at least 3 checks that are required before the designer can proceed with the one-for-one substitution.

1. The design loads are all within the axial load – moment interaction diagram for the substituted 600 bar.
2. The minimum 1% cross-sectional area of the longitudinal reinforcement is maintained as required by AS 3600 Clause 10.7.1.
3. The minimum fitment spacing required by AS 3600 Clause 10.7.4.3, which is a function of the diameter of the longitudinal bar to prevent buckling, is satisfied.

The first check, as previously discussed, is required as result of the additional strain required in the 600 MPa bar to achieve its yield strength. The second check is required because of the smaller diameter 600 MPa bar has a smaller area and the third check is required because the smaller diameter bar has a lower buckling load.

However, CodeMark Certificate of Conformity No. CM301354 SENSE 600® – Longitudinal Column Reinforcement allows –

1. The minimum 1% cross-section area of the longitudinal reinforcement to be reduced to $^{500}/_{600} \times 1\% = 0.083$. This effectively means that there is no requirement to check the minimum cross-sectional area of the longitudinal reinforcement, when a substitute equivalent design capacity 600 MPa bar is used.
2. The proprietary 600 MPa bar with diameter d_b to have a minimum fitment spacing of $15 \times \sqrt{^{600}/_{500}\, d_b}$. This effectively means that there is no requirement to check the minimum fitment spacing when the equivalent design capacity 600 MPa longitudinal reinforcing bars are substituted for 500 MPa bars.

The CodeMark Certificate specific to the proprietary 600 MPa bar means two of the three checks are not required, it just leaves the check that ensures the section has sufficient capacity for the 600 MPa longitudinal bars to carry the design loads. This check is generally routine given the 600 MPa (green curve) and 500 MPa (black curve) axial load – moment interaction diagrams are almost identical as shown in Figure 2 for the case study column number C17 at ground level.

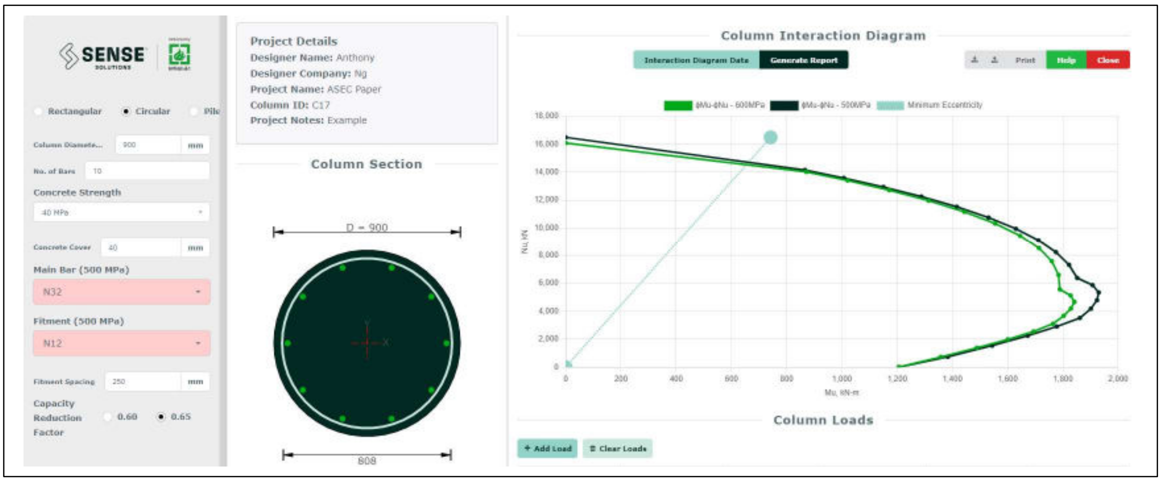

Figure 2. Axial load – moment interaction diagram for columns reinforced with 600 MPa bars and 500 MPa bars.

The CodeMark Certificates of Conformity and the 500 and 600 MPa axial load – moment interaction diagrams would indicate that the 16.7% mass and 39% reduction in embodied carbon are possible.

The measured quantities for the 500 and 600 MPa column reinforcement are shown in Table 2 below.

Table 2. Reinforcement quantities for columns.

Reinforcing type	Tonnes of Reinforcing Steel		Mass Savings (%)	Reduction in Embodied Carbon (%)
	500 MPa	600 MPa		
Longitudinal Bars	609	515	15.4	38.5
Fitments	112	94.6	15.2	38.4
Total	721	610	15.4	38.5

The material savings for the longitudinal bar of 15.4% is essentially the same as for the column fitments. The variation from the expected 16.7% can be attributed to the project being live at the time of the study and the time constraints on the engineer were such that variations to the structure were only produced for the 600 MPa reinforcing bar option. As a result, the comparison of material quantities was not with exactly the same structure, but one that had arguably up to 2% different. Furthermore, the construction program did not allow the first basement level constructed to be reinforced with 600 MPa longitudinal bars.

Embodied Carbon Reductions

The embodied carbon savings in the columns can be calculated using the published environmental product declarations (InfraBuild, 2024) for the 500 and 600 MPa products which were discussed previously and shown in Table 3. Row (a) in the Table is the reference case – columns reinforced with 500 MPa bars. Row (b) shows the embodied carbon if there were no material savings in the 600 MPa option. Note that there is still a 27.4% reduction in embodied carbon because of the production route for the 600 MPa steel. Row (c) shows the potential embodied carbon savings using 600 MPa bar due to the reduction in materials required. While row (d) shows the embodied carbon savings based on the measured quantities for 600 MPa bars.

Table 3. Global Warming Potential figures for Australian manufacturer's reinforcing bars.

		Material Savings (%)	GWP ($kgCO_2eq$/tonne)	GWP Reduction (%)
500 MPa	(a)	0	1330	0
600 MPa	(b)	0	966	27.4
	(c)	16.7	805	39.5
	(d)	15.4	817	38.6

The 38.6% reduction in the embodied carbon calculated using the measured quantities of 500 and 600 MPa reinforcing bar is almost at the expected value of 39%. Again, the variation from the expected value can be attributed to the factors outlined in the limitation of this study

Prefabricated Column Cages

The use of prefabricated reinforcing cages also contributes to improving the sustainability credentials of this project. The 600 MPa reinforcing steels manufactured in Australia to AS/NZS 4671 have a carbon equivalent value (CEV) of less than 0.49% which allows them to be machine or manually welded for prefabrication using existing procedures and equipment. Prefabricated column cages are becoming increasingly common in the construction of concrete framed buildings because of the reduced congestion on site and improved construction time as they allow work to progress without being negatively impacted by other trades and weather. The cages for this project were fabricated offsite and delivered for placement the day after each slab has been poured. This meant that the column reinforcement could be installed prior to falsework commencing on the next floor. Safe access for steel fixers is provided as they are not installing reinforcing steel between floors. The sustainability benefits come largely from material efficiency via less wastage and reduced laps.

When longitudinal bars are supplied to site as individual bars the lap lengths are manufactured up to 100 mm longer depending on the diameter of the bar to account for inaccuracies in the on-site steel fixing. Bars for a complete column cage manufactured in the factory do not require this additional length because the total dimensions of the cage can easily be checked and adjusted if required without any significant scrapping of material. The column fitments in the case study were continuous helical elements which of course avoided the hook and 400 mm lap (refer Figure 3) that would be required at the start and finish of each circular fitment. It is, of course, not practical to provide helical fitments for fixing on site so machine manufacture is the 'only' means by which the laps can be avoided.

The material savings for the 600 mm columns are quite significant and although less significant for the larger 2250 mm diameter columns, the savings contribution from these are quite considerable given many of the columns, particularly at the lower levels of the building, have fitments at 100 mm centres. Details of the 25.4% material savings and 45.8% embodied carbon reduction compared to the reference case of individual 500 MPa fitments are shown in Table 4. Additional fitments are usually supplied to site particularly when they are so closely spaced since small measurement errors made on site may require an additional 2 or 3 fitments for each column. Additional fitments are not required for column cages made in a factory because they are continuous helices that are spaced to machine precision.

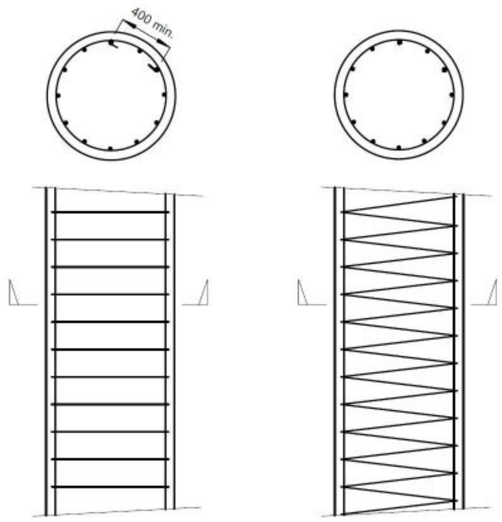

Figure 3. Additional hooks and laps for individual fitments.

Table 4. Mass savings and embodied carbon reduction for column fitment options.

Fitment Type	Mass (Tonnes)	Mass Savings (%)	GWP ($kgCO_2eq$)	GWP Savings (%)
Individual 500 MPa (Reference Case)	126.8	0	168.7	0.0
Helical 500 MPa	111.6	12.0	148.4	12.0
Individual 600 MPa	107.5	15.2	103.9	38.4
Helical 600 MPa	94.6	25.4	91.4	45.8

The factory setting for the reinforcing cage manufacture also offers the opportunity for continuous improvement and fine tuning of designs with the engineer. This same opportunity does not exist on a building site where the environment and settings are continually changing as construction moves from site to site, area to area or level to level. Column cages which extend over two levels, prefabricated for many previous projects, have allowed the fabricators to acquire the skills and equipment to maintain the tolerances required and the techniques for handling the long cages.

These double height cages can be used in the typical floors of a building to reduce the need for laps that would otherwise be needed if the bars were to be tied on site. The absence of laps for every second floor reduces the mass of reinforcing bars by around 10 to 15% and would reduce the embodied carbon by 32 to 35% using 600 MPa reinforcing.

Constructability

While low embodied carbon solutions are in demand, they will only be adopted and then continue to be used if they don't cause construction issues. On this particular project, the head contractor, to date, has not reported experiencing any issues from the Engineer working on the redesign or on site with column cage installation and the placement of concrete. All columns poured have met the project finish requirements.

CONCLUSIONS

The introduction of 600 MPa reinforcing steels into the Australian market combined with the sustainability benefits already offered by prefabricated column cages will have a significant impact on the construction industry's ability to reduce the embodied carbon in structures.

A case study of a building currently under construction in Sydney demonstrates how a construction company with a real focus on reducing embodied carbon in buildings can achieve a mass reduction in the reinforcing steel used in the building columns and a consequent, even larger, percentage reduction in embodied carbon by using the Australian made 600 MPa reinforcing bar in prefabricated column cages.

Material quantity measurements of two essentially identical designs, one with columns reinforced with the new 600 MPa bars, the other with traditional 500 MPa bars showed there was a 15.4% material saving using the 600 MPa bar. This material reduction, combined with the lower embodied carbon values for the 600 MPa bar translated to a 38.4% overall reduction in embodied carbon for the reinforcing steel in the columns. The prefabricated cages not only enhanced construction but also enabled further reductions to the embodied carbon, most notably from the reduction in the number laps required in the main bars and the fitments.

For the head contractor, the use of 600 MPa reinforcing steel in lieu of 500 MPa steel has been a seamless process as the production and installation has progressed without issue and has provided a cost neutral solution for a significant mass and embodied carbon saving.

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BIOGRAPHY

David Drevon graduated with a Bachelor of Engineering from the University of NSW. After several years with the Geotechnical Services Department at the NSW SRA he joined InfraBuild (then BHP Steel) in 1998 as the Services Manager then progessed through a number of roles including the NSW Operation Manager and NSW Sales Manager before taking on his current role as the Prefabricated Elements Manager.

David has over 10 years of experience designing steel reinforcing cages or elements which are economical and can be readily tansported to site for erection. The expertise he has developed during this time has been utilised in a range of projects from residential towers to infrastructure projects and highrise commercial buildings.

Maddelon Holt-Smith is an accomplished Senior Project Engineer with a strong foundation in civil engineering, having graduated with a Bachelor of Civil Engineering (Honours) from the University of Newcastle in 2017. Since then, she has made significant contributions to some of Australia's most high-profile construction projects, including the New Intercity Fleet Maintenance Facility, Waterloo Integrated Station Development, and 55 Pitt St development.

Maddelon's work on these large-scale developments has honed her skills in project management, structural engineering, and the implementation of cutting-edge technologies to address the unique challenges posed by each project. Currently, as a Senior Project Engineer, Maddelon is at the forefront of her field, leading the structural engineering teams with a focus on delivering innovative solutions that enhance project efficiency and effectiveness.

Anthony Ng studied at the University of Sydney where he graduated with degrees in Science and Civil Engineering, returning later to complete a Masters degree in Engineering Science. He also has an MBA from the University of New South Wales.

Anthony practiced structural engineering for 12 years after graduation with various consulting engineers in Sydney before he joined InfraBuild (then BHP Steel) in 1998. Currently, Anthony is the Engineering Solutions Manager for InfraBuild where his primary role is to develop engineered solutions and innovative products for the construction industry. High strength reinforcing steel is one of those innovative products.

Joshua Brown is an experienced Project Manager at InfraBuild Reinforcing, where he leads steel supply to major projects for tier-one builders. With a Bachelor of Commerce in Management and Marketing from the University of Notre Dame Australia, Joshua has a strong foundation in both business and project management.

His previous roles include Branch Manager at OneSteel Reinforcing and Key Account Manager at Hunter Galvanizing, where he honed skills in strategic operations, business development, and client relations.