Upgrading the Dundas Point Boardwalk, Applecross with the use of GFRP Bar Reinforced Concrete Columns and Footings

Joel Brown B.Eng GradIEAust
Structural Engineer, Airey Taylor Consulting

Abstract: The use of Glass Fibre-Reinforced Polymer (GFRP) bars for internally reinforcing concrete structures has been growing to overcome common problems of steel reinforcement, such as corrosion. Areas for application are dominated by bridge decks where de-icing salts are used, although other applications include coastal structures or structures aiming for an extended design life.

The Dundas Point Boardwalk in Applecross, Western Australia is subject to a harsh marine environment and remedial works to the foundation system which included corroded steel piles were focused on achieving an extended design life and addressing the ongoing corrosion issues encountered in marine environments.

In stage one of the boardwalk repair, sixteen concrete columns and eight concrete footings were constructed, all internally reinforced with GFRP bars. The design of the footings and columns was performed using Canadian Code CAN CSA S806-12 (1) and ISIS Canada's guide 'ISIS Educational Module 3: An Introduction to FRP-Reinforced Concrete' (2).

As the boardwalk decking was constructed using steel supporting members, attention was paid to detailing the concrete to steel connections in order to avoid moisture ingress and bimetallic corrosion. This connection was designed using GFRP threaded bolts embedded into the concrete piles and connecting the supporting steel members.

Contractor feedback highlighted the ease of workability with the GFRP bars and all research suggests that there is no reason that a design life in excess of 75 years for the concrete elements cannot be achieved.

Keywords: GFRP, Reinforcement, Columns, Marine, Corrosion.

1. Introduction

1.1 Background of Dundas Point Boardwalk

Dundas Point Boardwalk is approximately 250 metres long, between 2.5 and 7 metres in width, and is located on the southern side of the Swan River Estuary near the north and western sides of Dundas Point in the City of Melville, Western Australia. The majority of the boardwalk is in the tidal zone of the Swan River and receives constant wetting and drying of its support structure. The boardwalk is used for foot and bike traffic only.

The boardwalk was designed and constructed in the 1990's utilising steel universal column (UC) piles encased in concrete a minimum of 200mm below ground level at the time of construction. This supported steel framing on which a timber deck was laid. All steel members including piles and steel framing were hot-dipped galvanised.

Figure 1.Left: Steel UC Connecting to Steel Framing. Right: Steel UC Below Concrete Encasing.

Steel thickness measurements were performed on a selection of the steel piles. They were assessed in accordance with AS 1627.0-1997: 'Metal finishing - Preparation and Pretreatment of Surfaces (3). All piles were classified as suffering from Grade H corrosion –'Large portion of surface is covered with rust, pits, rust nodules and non-adherent paint, pitting is visible.' The results of the thickness measurements were extrapolated through a detailed non-destructive visual inspection to give an assessment of all 76 of the boardwalk piles, Table 1 summarises these results.

Table 1. Steel Pile Mass Loss Summary.

Steel Mass Loss Range	No.	%
Not Inspected	1.0	1.3
No Assessed Loss	0.0	0.0
0 - 10% loss	0.0	0.0
10 - 20% loss	9.0	11.8
20 - 30% loss	36.5	48.0
30 - 40% loss	26.0	34.2
40 + % loss	3.5	4.6
Total	**76.0**	**100.0**

Due to funding limitations, it was decided to only remediate a 41 metre section of the boardwalk at the southwestern corner with the remainder of the required works programmed into the City of Melville's future works programme.

1.2 Background to GFRP

Fibre Reinforced Polymers (FRP) are composite materials that can be used to strengthen concrete structures. They are made of fibres of a particular material selected, embedded in a polymeric resin. The most common fibres used in FRPs are glass, carbon or aramid. FRPs can come in woven sheets, which attach to the outside of reinforced concrete structures to offer strengthening, usually for remediation purposes. FRPs are less commonly produced as reinforcing bars.

Advantages of GFRP bars include; having high tensile strength, being corrosion resistant, nonmagnetic and lightweight with low thermal and electrical conductivity. This suite of characteristics is useful in many situations. GFRP bars are well suited for use in corrosive environments, in structures required to have a very long design life, in hospitals near MRI machines, for example, and provide easy workability because they are lightweight.

Disadvantages of GFRP bars include; no yielding before failure, low transverse strength compared to steel, low modulus of elasticity and possible durability issues of glass fibres in high alkaline environments. These characteristics need to be understood with guidelines to manage risk associated with these properties in concrete.

In 2001, the American Concrete Institute (ACI) released their first standard detailing recommendations of the use of FRP bars in reinforced concrete (RC). "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars" (4) is the most current standard and was published in February 2006. ACI Committee 440 has chosen not to offer recommendations on the use of FRP bars in compression members due to the lack of experimental data at that time. The Canadian Code CAN CSA S806-12 (1) does include the use of GFRP in concrete compression members but ignores the contribution of GFRP when considering axial capacity.

1.3 Objectives

Experimental research at University of Western Australia was undertaken by the writer in 2012 who compared the performance of axially loaded concrete columns reinforced with GFRP bars to traditional steel reinforcement "The Study of FRP Strengthening of Concrete Structures to Increase the Serviceable Design Life in Corrosive Environments" (5). The results concluded that the same axial capacity could be achieved using the same area of reinforcement providing the GFRP transverse reinforcement spacing was lowered to approximately half that of the steel equivalent. That study led to the decision to construct concrete columns in an active project not only to achieve a corrosion resistant solution which would be economically beneficial, but to also monitor the performance of the columns, validating the findings of previous research.

Figure 2. Existing Boardwalk in Tidal Zone.

2. Initial Design Phase

2.1 Constraints

The project brief stipulated that remedial works undertaken must yield a similar appearance as the existing boardwalk. This therefore set column sizes at 300mm in diameter and required them to have a black exterior. The same size and arrangement of steel framing was to be used to support the decking. Whilst keeping to these aesthetic requirements, the Client required a design life of over 25 years. The portion of boardwalk being replaced was 23 years old.

Figure 3. Typical Arrangement of Two Piles and Cross Beam.

In the existing northeastern section of the boardwalk, there is pile support for the riverside of the boardwalk, with the steel cross beam which connects being supported in a recess into the limestone retaining wall on the land side. This connection was unstable as the retaining wall was rotating due to erosion issues below the boardwalk. This meant that new supports were needed to avoid reliance on the retaining wall for support.

Figure 4. Steel Cross Beam Embedded in Retaining Wall.

2.2 Proposed Solution

The proposed solution included the replacement of pile supports whilst keeping a portion of the embedded steel UC pile to provide added anchorage of the element into the ground. The existing concrete encasement to piles was to be fully removed and replaced with a durable GFRP reinforced concrete solution. Whilst the existing steel UC pile was engaged, its requirement was designed out in the final design. This meant that a new footing would be required to support the concrete columns.

It was proposed that to eliminate the corrosion vulnerable column to superstructure connection, GFRP bolts would be cast into the new columns. This was deemed necessary as the steel framing for the decking was to be replaced and treated with an ultra-high build epoxy painting system so as to achieve a system that could be maintained over time and give a long design life of 20-25 years in a harsh marine environment.

Where the boardwalk cross beams were embedded in the limestone retaining wall adjacent, it was proposed to support them on new GFRP reinforced concrete columns identical to the replacement columns.

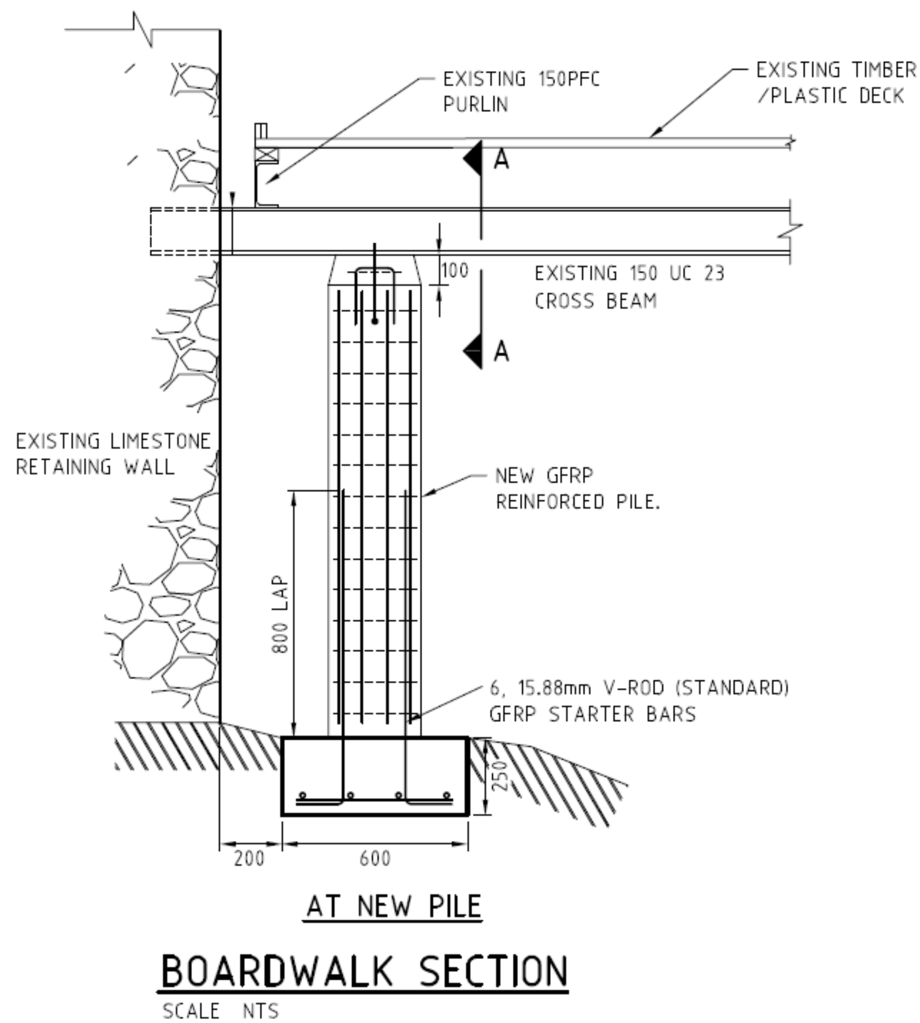

Figure 5. Proposed Column and Footing Design.

In the original construction there was a 300mm deep layer of sand extending up from the base of the concrete encasement of the steel piles. Over time this had been eroded away, in some cases exposing the limestone base below. This meant that two arrangements of footings were required to be designed, one founding on sand areas of the site and one founding on limestone.

3. Final Design

3.1 Columns

The final design of the columns included six 15.88mm GFRP longitudinal bars with ligatures at 100mm centres made from 9.53mm GFRP bars. Although the bars are non-corrosive, it was decided that a pour blocker would be used in a 40MPa concrete mix to minimise concrete degradation. This was used with the intent of achieving a design life of the columns in excess of 75 years.

As there was the requirement for the new columns to look the same as the existing, permanent fibre cement formwork 300mm in diameter was specified and then painted black. This both allowed for easy forming and yielded a neat appearance.

The existing steel piles were nominated to be cut back to leave an 800mm lap to be embedded in the replacement column. Following this they were to be cleaned to a Class 2.5 finish according to AS 1627.4 using grinding to remove the bulk rusted layers followed by wet abrasive blast cleaning or a blasting / washing / blasting sequence to achieve effective removal of soluble salts. Surface chlorides were tested to ensure that they were less than 50 micrograms per square centimeter. Where otherwise, they were to be re-washed with inhibitor solution then re-blasted prior to coating with a corrosion inhibiting priming paint.

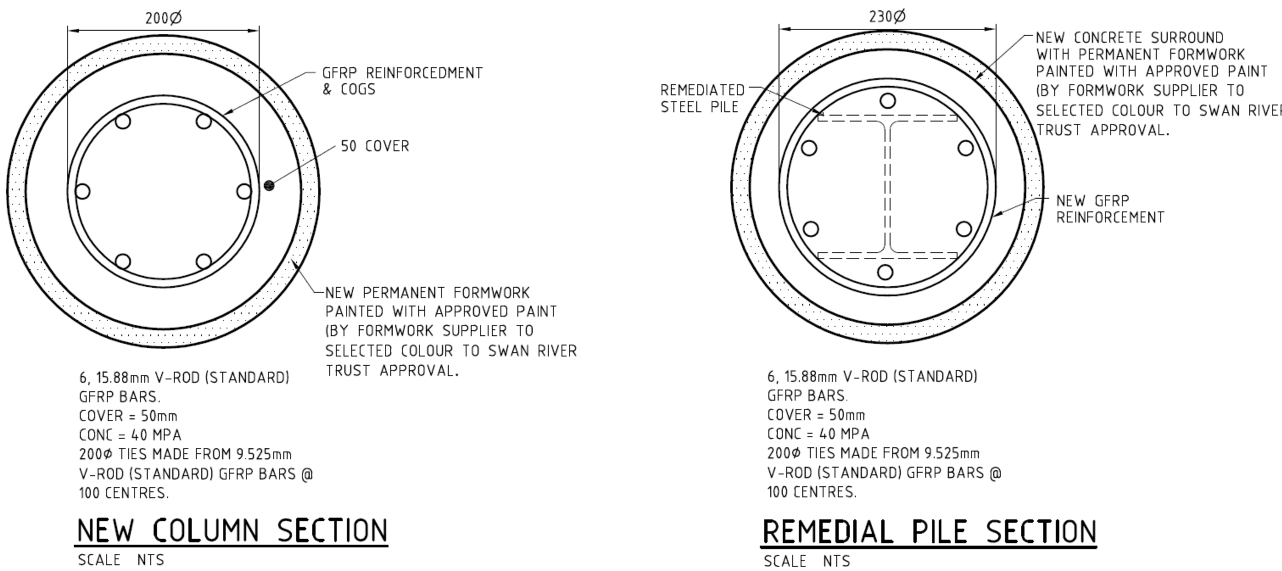

Figure 6. Final Column Design.

3.2 Footings

The strip footings were designed to be able to support the loads through the new columns without the need for the engagement of the existing steel pile. One strip footing is used to support a pair of columns. The footing is 2.5 metres long, as required due to the placement of the columns, 600mm wide and minimum 250mm deep. The footing has bottom reinforcement, with six, 15.88mm GFRP bars equally spaced over the long span and four, 15.88mm GFRP bars over the short span. Six starter bars extend from the footings which would lap onto the main column reinforcement.

Due to the variable site conditions, the strip footing could be slightly altered for each case. Where sand is present, the footing and column are to be constructed with 500mm of sand above the top of the footing to allow for future erosion, or until bedrock is encountered. Where bedrock is exposed, the footing is to be recessed 250mm into the bedrock. These arrangements are shown in Figure 7.

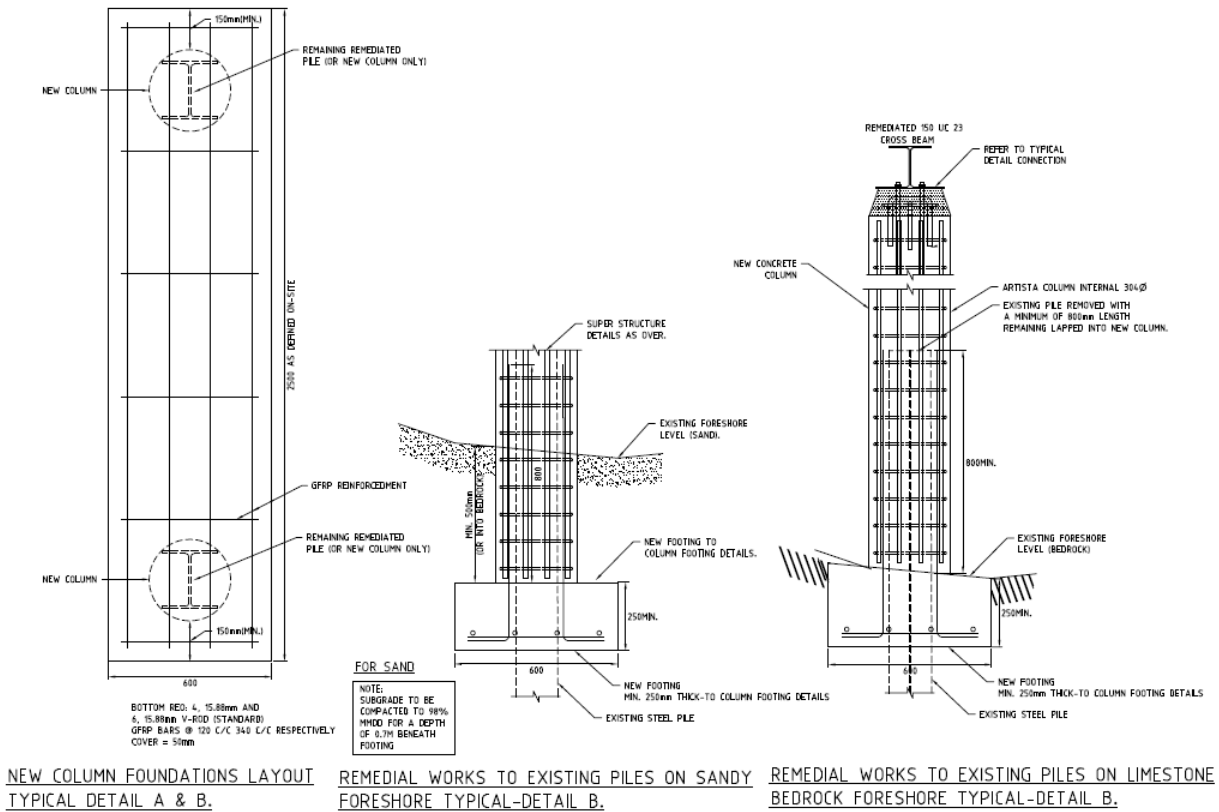

Figure 7. Final Footing Design.

3.3 *Connection to Steel Framing*

The connection detail between the new columns and the steel cross beams which support the decking is critical. As this zone was prone to the deposition of salts, GFRP bolts were assessed as the best material for fixing the columns to the steel. Four 24mm diameter GFRP threaded rods were anchored 1 metre into the new concrete column. The new steel UC cross beams which were fabricated had additional plates welded to the bottom flanges in order to allow for these bolts to be accommodated. Due to the high grade paint specification used, EPDM washers were used to protect the steel from the nut and washer fixings.

As there was a gap between the top of column and the underside of the steel cross beam, two 'U-bars' were fabricated from 15.88mm GFRP and cast into the top of the column. This allowed for a non-shrink structural epoxy grout to be used to infill the gap and be engaged by the remainder of the concrete column. The grout could then be tapered to the steel cross beam to minimise pooling of any moisture.

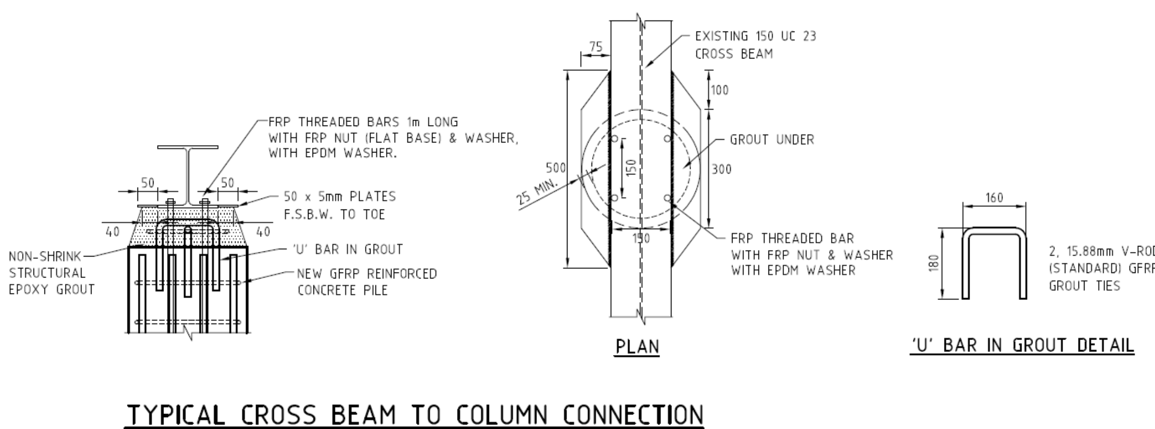

Figure 8. Final Column to Beam Connection.

4. Construction Phase

4.1 Footings

The existing steel UC piles were successfully cut back and cleaned via abrasive blasting and thorough wire brushing. Chloride tests were performed on five of the sixteen steel sections with all tests yielding results under the allowable 50 micrograms per square centimeter. The steel was then painted with the appropriate corrosion inhibitor within four hours of the chloride tests being undertaken. This ensured that no excess chloride deposition took place between the testing and painting phases.

The footings were formed and GFRP reinforcement and starter bars laid as per Airey Taylor Consulting drawings and specifications. All footings encountered bedrock and therefore all footings were recessed into the bedrock. Rock boulders would be placed at the base of the footings to assist in limiting erosion, protecting the retaining wall structure adjacent to the boardwalk. The Contractors noted the ease of laying the reinforcement due to its light weight. Plastic zip ties were used to tie bars together.

Figure 9. Forming and Pouring of Footings.

4.2 Columns

Once the footings were cast and cured, the column reinforcement cages, which were assembled on site, could be installed and the permanent formwork positioned and propped correctly. Timber plates were used to position the GFRP threaded rods at the correct height whilst the columns were poured.

The installation of GFRP reinforcement was completed in the same way that traditional steel reinforcement is. Contractor feedback focused on the lightweight material and the easy with which it was positioned.

Figure 10. Forming and Pouring of Columns.

4.3 Connection to Steel Framing

The steel cross beams where installed over the concrete columns and timber was used to hold the members at a slightly elevated level. The non-shrink structural epoxy grout was then placed and the steel lowered onto the grout to ensure there were no gaps between grout and steel. The grout was then tapered to give a rounded finish.

Once the cross beams were in place over the threaded rods, FRP washers and nuts, usually used for rock bolts, were installed over EPDM washers. This ensured that the paint on the steelwork was not damaged by the tightening of the nuts.

Figure 11. Column and Steel Connection.

4.4 Finished Boardwalk

Following installation of the steel framing, a composite decking was installed and the original hardwood handrails were reinstalled. After the remediation of the boardwalk reclaimed beach sand was placed over the top of the footings with a geotextile placed on top of that with additional rock armouring and beach re-nourishment. This was to aid in protecting the surrounding structures.

The construction phase was carried out in line with the final design and construction administration was performed by the writer throughout to ensure this was the case. The Client was very pleased with the outcome and the fact that the remediated portion of the boardwalk looked very similar to the existing, although now with a design life of 75 years for the columns and footings, minimizing their future maintenance costs in a very inaccessible area. The Contractor had no issues with the placement of GFRP and advised that it was similar to working with steel reinforcement but lighter.

Figure 12. New (left) vs Old Boardwalk (right).

5. Cost Analysis

Cost estimates were gathered from steel reinforcing suppliers in Perth for the fabrication and delivery of equal volumes of steel reinforcement compared to the GFRP bars specified. The steel estimates were approximately $4,000 whereas the fabrication and delivery (via air freight) of GFRP came in at $7,866. The price supplied for the same amount of GFRP but delivered via sea was $6,810.

The difference of approximately $4,000 is less than 1.5% of the total project cost which tendered for the amount of $275,772.28 + GST. This was considered to be negligible, whilst the advantages in corrosion resistance and extended time prior to first maintenance are significantly increased.

6. Conclusion

Previous experimental research performed by the writer in 2012 (5) concluded that concrete compression members reinforced with GFRP bars gave comparable capacities to concrete columns reinforced with traditional steel. This research was the basis of the design of the Dundas Point Boardwalk.

The use of GFRP reinforcement in compression members is not recommended by current guidelines and the Dundas Point Boardwalk is the first project in Australia known to have used the technique. This is considered a big step in the acceptance of GFRP as reinforcement not only in compression members but in all concrete structures in Australia. Whilst there are many projects overseas which utilize this material, Australia has been slow to adopt it, and as all things new, people want to see it used in projects before confidence can grow.

The additional 1.5% of the total project cost was assessed as a negligible outlay in order to achieve concrete members which are expected to give good in service duty for over 75 years. The lack of maintenance required will allow for this slight start-up price increase to be recouped multiple times over the life of the structure.

The Client was receptive to the use of GFRP reinforcement at the concept design phase of the project, and the Contractor had no negative feedback whilst using the material and commended the workability of the product. This project, the ease with which it was executed, and the attenuated durability expected will give confidence to others to adopt the material

7. Acknowledgements

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8. References

1. CSA S806, 2012, “Design and Construction of Building Components with Fiber-Reinforced Polymers,” Canadian Standards Association, Mississauga, ON, Canada
2. ISIS Canada Research Network, 2007, “Reinforcing Concrete Structures with Fibre Reinforced Polymers,” ISIS Design Manual No. 3, ISIS Canada Research Network, Winnipeg, MB, Canada.
3. Standards Australia, 1997, AS1627.0 “Metal finishing - Preparation and Pretreatment of Surfaces - Part 0 -Method Selection Guide”, Standards Australia International, Sydney.
4. ACI Committee 440, 2006, “Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars (ACI 440.1R-06),” American Concrete Institute, Farmington Hills, MI, 44 pp.
5. Brown, J., 2012, “The Study of FRP Strengthening of Concrete Structures to Increase the Serviceable Design Life in Corrosive Environments,” University of Western Australia, Perth.