i³ icubed consulting

A Serviceability Analysis of Pedestrian Excitation on Light-Weight FRP Footbridges

Rohan McElroy
Principal Structural Engineer
icubed consulting

Abstract:

Over the past 10 years icubed consulting have been developing in-house software and procedures on the excitation performance of Fibre Reinforced Polymer (FRP) pedestrian footbridges. icubed had concerns with pedestrian induced excitation performance due to the lightweight nature of FRP structures and devised a method to assess accelerations in accordance with international research and backed this up with in-situ testing.

A pulsating force load was produced using Fourier Transformation equations to replicate the vertical and horizontal impact of a footfall load. This load was applied at to the deck in a 3D model and factored using formula to evaluate the effect of multiple pedestrians walking in-sync and out-of-sync across the structure. A transient solver produced graphs of maximum nodal accelerations under various pedestrian cases which were then compared to acceleration limitations outlined in other literature. icubed discovered that some in-sync load cases could amplify deck accelerations by a considerable amount. Further investigation into excitation was undertaken with in-situ testing. Deck acceleration data was collected using an Android smartphone to compare theoretical models against actual in-situ performance.

icubed also investigated the dynamic wind excitation of these structures using British Standards and open-source Computational Fluid Dynamics (CFD) software OpenFOAM. The software models a 2D cross section of the pedestrian bridges to undertake a sensitivity analysis for the critical wind velocity that may cause the structure to self-excite.

1   Introduction

icubed consulting started to develop light-weight FRP pedestrian footbridges for the Australian infrastructure market about 8 years ago with FRP Manufacturer, Wagners Composite Fibre Technologies (WCFT).

icubed and WCFT have worked on numerous infrastructure FRP projects around Australia and internationally for pedestrian and road bridges, boardwalks, viewing platforms, jetty's and wharfs.

Initially, research and testing was undertaken for the design and construction of FRP truss footbridges spanning from 12m to 25m. In the last few years development of larger single span bridges for the Australian and international markets has improved and now are capable of spanning from 30m to 42m long, with preliminary design completed on 67m bridges also. The research and testing process included scale-model testing of truss members and connections, fatigue performance and methods to assess pedestrian induced excitation using spreadsheets and Finite Element software.

The following paper will go into some detail about the codes investigated and analysis methods adopted along with drawing comparisons between testing and modelling results.

2 FRP Overview

Wagners CFT are an Australian owned and operated company based in Toowoomba. They are the largest fibre reinforced polymer pultruder in Australia and produce a number of different sections at their facility, along with carrying out required testing when needed.

Fibre Reinforced Polymer sections vary in size, but their main pultruded sections include: 100x75x5 RHS, 100x5 SHS and 125x6.5 SHS. These sections can be bonded together to create larger shapes and sizes providing additional stiffness and capacity.

Benefits of Wagners FRP material:

- Corrosion resistant
- Durable
- Termite resistant
- Light-weight
- Electrical insulator
- Thermal insulator
- High tensile strength
- Low embodied energy
- 100 year design life

Wagners sections are made using:

- Electrical-Corrosion Resistant (ECR) Glass [Reinforcing]
- Vinyl Ester Resin [Matrix]

FRP materials vary in nature and performance to other industry standard construction materials. The below table indicates the difference in performance between WCFT FRP and these other materials. FRP materials are subject to time-effect factors similar to timber. Material safety reduction factors vary depending on the time application of the load required and are assessed in accordance with EUROCOMP and ASCE Pre-Standard.

Table 1: Mechanical Properties of Typical Construction Materials

| Material	Young's Modulus	Shear Modulus	Density	Ultimate Tensile Strength	Ultimate Compressive Strength	Nominal Shear Strength	Poisson's Ratio
	GPa	GPa	kg/m^3	MPa	MPa	MPa	-
WCFT	36.3	4.2	2030	610	485	84	0.28
Steel	200	80	7600	300	~170	~180	0.30
Concrete	~30	-	2400	3-5	25-60	6-17	0.2
Timber	7-21	-	500-700	10-40	20-50	4-20	0.2-0.5

The FRP cross-sections can be manipulated by bonding together in different shapes to suit the application on site and stiffness required for the structure.
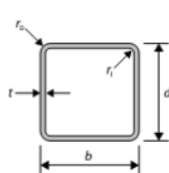
Typical SHS section
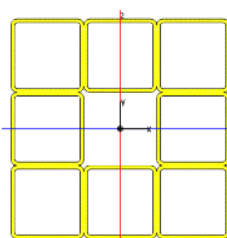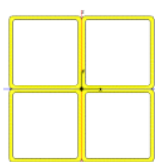
Alternative bonded sections examples
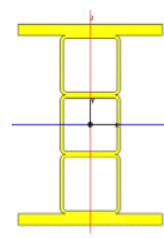
3 Examples Of FRP Pedestrian Bridges Undertaken

Below are some samples of FRP pedestrian bridge projects that icubed and WCFT have undertaken.

Figure 1- 20m FRP bridge over rail in Geelong, VIC

Figure 2- 16m FRP bridge in Thurrock, UK

Figure 3- 21m FRP bridge in Big Sir, California

Figure 4- 24m FRP bridge in Dalby, QLD

4 Scale Model Testing Programs

icubed and WCFT have undertaken numerous testing programs. Design of materials, members and connections are undertaken to ASTM, ISO Standards and Australian Standards.

Other testing programs include: bolted trusses, riveted trusses, member and material testing, freeze/thaw, water absorption, crushing and fatigue testing.

Figure 5- Scale model truss for bolted connection testing and truss interaction

5   Bridge Example: JC Slaughter Falls, Mt Coot-Tha

JC slaughter Falls pedestrian bridge is on the smaller end of bridges designed but represents a good percentage of the standard pedestrian bridge market. It was chosen for this research project as the location was close to icubed's office, allowing the team to access site and undertake in-situ testing easily.
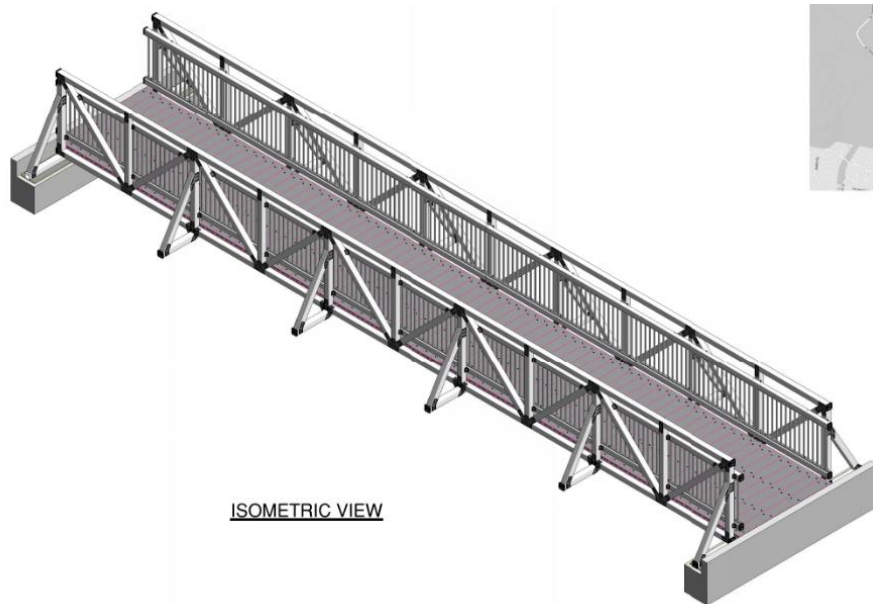

ISOMETRIC VIEW

Figure 6 - JC Slaughter Falls Footbridge

The footbridge is located at Mt Coot-tha Reserve, Brisbane Queensland, Australia .

It consists of:

- 15m Span, 1.8m traffic width
- Designed for 3kPa live load
- Completely non-ferrous solution – Grade 316 Stainless steel bolts/rivets, nuts and plates.
- Founded on a simple reinforced concrete strip footing due to favourable ground conditions.
- Larger bridges are founded either on bored piers with a capping beam or an FRP pile group
- Approximately 2.5t total mass

The below images are typical layout and cross-sections for this particular structure.
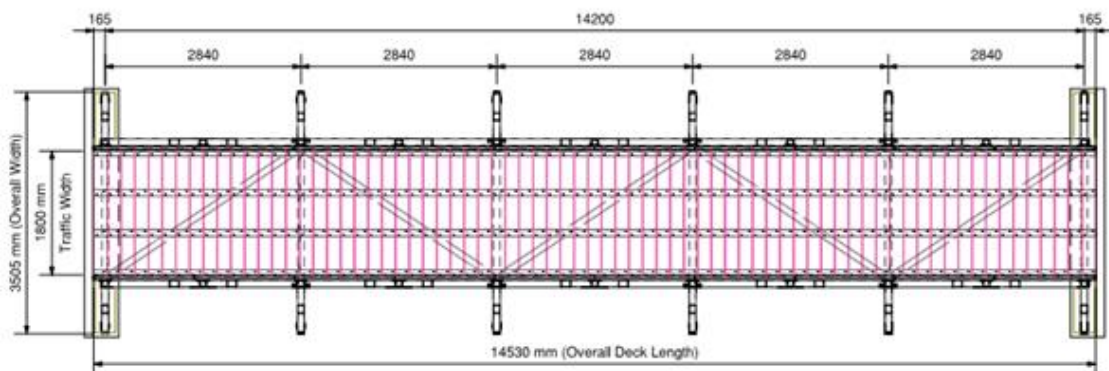

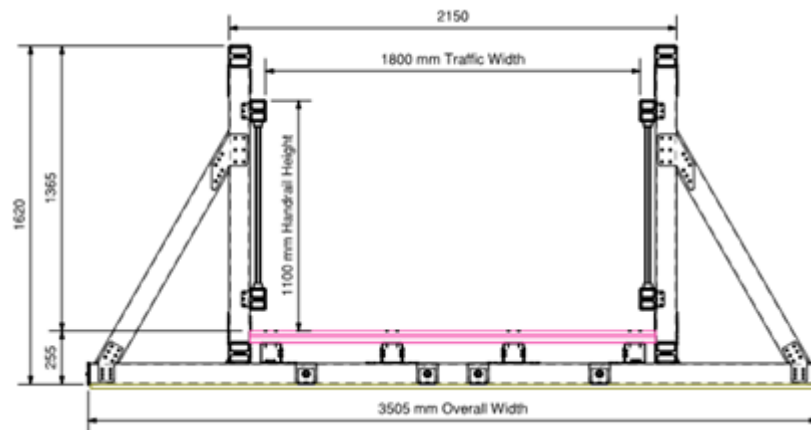**Figure 7 - JC Slaughter Falls Footbridge – Layout**

6.1   Vertical Footfall Components

In order to assess pedestrian excitation on a bridge, icubed researched the mechanics behind human footfall behaviour. It is broken down into two components, vertical footfall action and horizontal footfall action.

Footfall actions vary depending on the intensity of the action. For example, slow walking produces greater induced load on the ground while running produces shorter, less disturbing loads.

1 – heel touches ground, highest force

2 – flat of foot touches ground, lull in force

3 – toes touch ground, increase in force

4 – next foot touches down, repeat
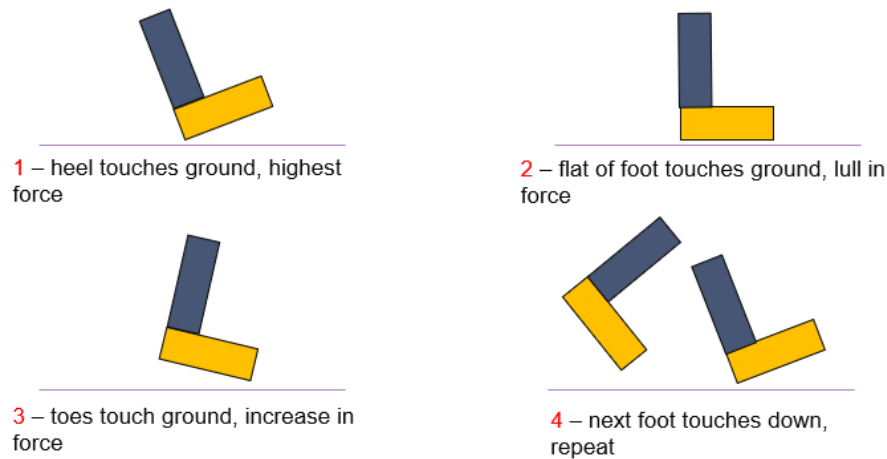
Figure 10- footfall action explanation

The below figure shows the difference between a running and walking footstep. The peaks and troughs represent heels and toe action on the deck.

successive running footsteps

successive walking footsteps
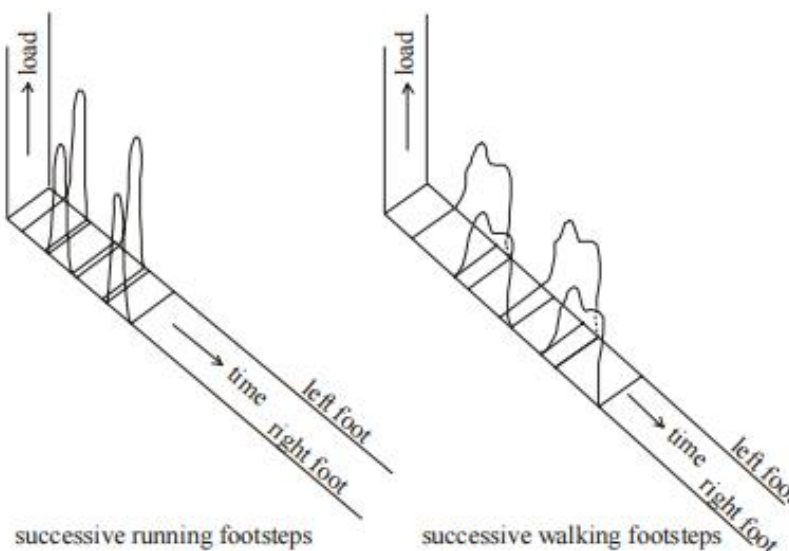
Figure 11 – vertical footfall changes in shape due to action

The below figure is an example of the magnitude of force produced by a normal footstep, note the peaks for heel and toe impact.

Figure 12- vertical footfall magnitude of force

6.2   Horizontal Footfall Components

Horizontal footfall actions vary slightly from vertical footfall actions. Namely, the force graph reverses due to the human walking action as noted below.
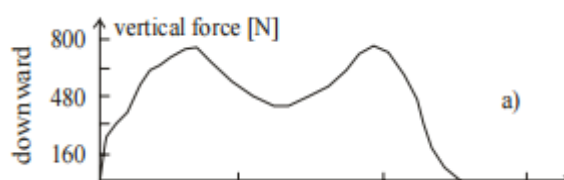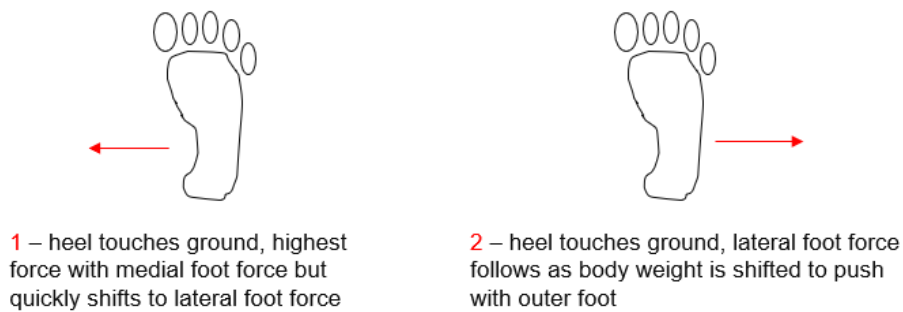
1 – heel touches ground, highest force with medial foot force but quickly shifts to lateral foot force

2 – heel touches ground, lateral foot force follows as body weight is shifted to push with outer foot

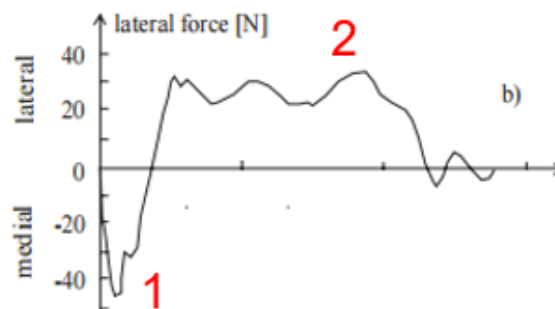**Figure 13- horizontal footfall action**

Figure 14- horizontal footfall magnitude of force

Pedestrians are more receptive to vertical bounce in a structure than horizontal bounce. Horizontal excitation is of particular concern as it effects our centre of gravity and can make simple walking action difficult.

For a bridge structure to self-excite from pedestrian movements it has to have a relatively low mode of frequency in the horizontal plane less than approximately 1.3hz.

Vertical action is also of concern, but pedestrians are typical able to react to these motions with more control than horizontal actions.

6.3   International Standards and Research Papers Investigated

Various design standards were used for the assessment of vertical and lateral excitation criteria. icubed turned to international standards for further design verification.

Some of the international codes Investigated include:

- AS5100 – Australian Standards
- BS5400 – British Bridge Design Guide
  - o BD37/01
  - o BD49/01
- SETRA 2006 – The Technical Department for Transport, Roads and Bridges Engineering and Road Safety for France
- UK National Annex to EN1991-2

In addition to the above, icubed also looked into the following publications. This is a small sample of the relevant papers investigated at the time and were useful in the design process. Not all of these are explained in detail in this paper.

Table 3: Pedestrian excitation publications investigated

Author	Publication Topic
Matsumoto, 1978	*Maximum Equivalent Number of Pedestrians*
Bachman and Ammann, 1987	*Dynamic Loading of Pedestrians*
Agu and Kaspersky, 2005	*Vandal Abuse Loading*
Dallard, 2001	*Triggering Number of Pedestrians*
McRobie and Morgenthal, 2002	*Pedestrian Scrouton Number*

6.3.1   Australian Standards – AS5100.2 – Bridge Design Code

icubed found that AS5100 provided limited assessment criteria for pedestrian excitation in Section 13. Previous to the 2017 edition, the Standard did not go into great detail on how to assess bridge excitation. The Code instructed the user to refer to specialist literature when a structure is of low mass and damping characteristics.

AS5100 does however provide some advice on vertical serviceability performance for structures .

The 2017 version refers to external literature to solve horizontal excitations issues for bridges with natural frequencies in the horizontal mode for less than 1.5Hz. The maximum vertical acceleration clause of AS5100.2 is directly related to the equations produced in British Standards previously.

icubed use these equations as a preliminary check of the structure performance but feel further investigations are warranted.

6.3.2   British Standards – BS5400 BD37/01 – Part 14

British Standards BD37/01 assesses the maximum allowable vertical acceleration of the structure due to foot and cycle traffic. The attraction of using this theory is in the simplicity of the formula. The first natural frequency of the structure can be assessed using a 3D model in structural engineering software such as Microstran or Spacegass; or using the simple beam formula supplied in B.2.3. below.

$$f_0 = \frac{C^2}{2\pi l^2}\sqrt{\frac{EI_g}{M}}$$

- Where C is the configuration factor – refer BD37/01
- E is the modulus of elasticity of the material
- I is the second moment of area of the cross section at midspan
- g is gravity
- M is the weight per unit length at midspan
- l is the length of the main span.

If the maximum vertical acceleration of the structure is below the maximum vertical acceleration limit, then the structure is deemed satisfactory for pedestrian and cycle vibrations. As noted above, this method has generally been incorporated into AS5100.2:2017.

$$a_{max} \leq a_{limit}$$
$$4\pi^2 f_0^2 \gamma_s k \Psi \leq \frac{1}{2}\sqrt{f_0}$$

- Where f_0 is the first natural frequency,
- γ_s is the static deflection in m, due to 0.7kN load mid-span
- k is the configuration factor (see B.2.5) and
- Ψ is the dynamic response factor (see B.2.6).

The results for JC Slaughter Falls are noted below:

$$17.85\ m/s^2 > 1.08\ m/s^2 \quad \rightarrow \quad a_{max} > a_{limit}$$

Therefore the structure to BD37/01 is not OK and requires further assessment to investigate actual acceleration performance.

6.3.3 The Technical Department for Transport, Roads and Bridges Engineering and Road Safety for France – SETRA

SETRA produced a technical guide for footbridges entitled "Assessment of vibrational behaviour of footbridges under pedestrian loading".

Due to the complications of modelling a structure of this nature and its dynamic loading, icubed have adopted the use of SETRA as the design guideline for nodal acceleration limits for the software used.

SETRA also provides their own simplified dynamic assessment using a number of procedures to approximate the natural frequency of the structure, the modal mass and the vertical and horizontal components of a pedestrian crossing the structure – expressed as the minus factor.

icubed have investigated these simplified assessments, but have found the criteria restrictive as the minus factor is only applicable to footbridges within a limited dynamic range of 1-2 Hz.

Table 4: SETRA 2006 Vertical Acceleration Limits

Criteria	Min, m/s²	Max, m/s²
Max - imperceptible	0.00	0.50
Mean - merely perceptible	0.50	1.00
Min - perceived, not intolerable	1.00	2.50
Fail - unacceptable	2.50	10.00

Table 5: SETRA 2006 Horizontal Acceleration Limits

Criteria	Min, m/s²	Max, m/s²
Max - imperceptible	0.00	0.15
Mean - merely perceptible	0.15	0.30
Min - perceived, not intolerable	0.30	0.80
Fail - unacceptable	0.80	10.00

6.3.4 UK National Annex to EN1991-2:2003

The UK National Annex was also looked at as a guideline for design but icubed felt that the acceleration limit clauses did not provide enough of an insight into serviceability performance as those provided in SETRA.

The UK National Annex also provided similar Fourier transform equations to the research undertaken but was not adopted.

This code did however provide some additional information to assess lateral lock-in stability of pedestrians in chapter 2.44.7 as shown below and can be of use.
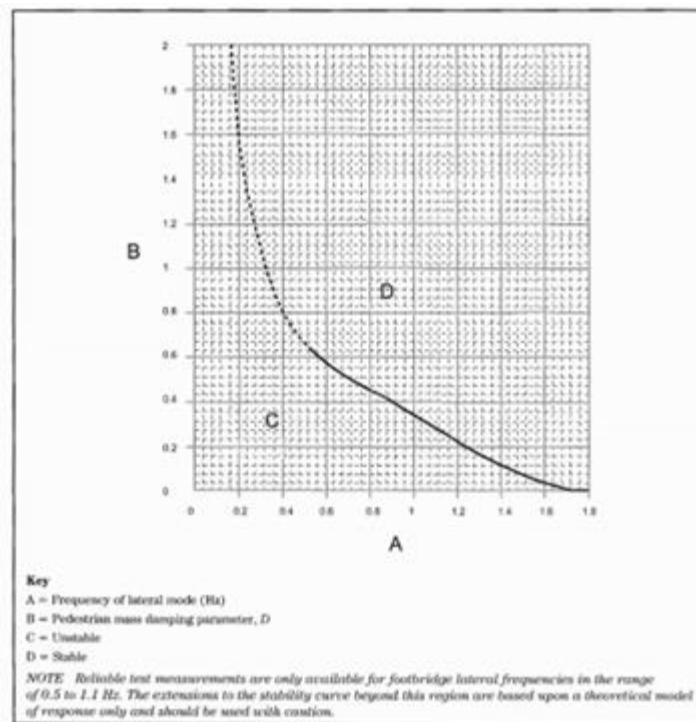

Figure 15- UK National Annex – Lateral lock-in stability boundaries

6.4   Fourier Transformation Equations – Replicating Human Footfall Force

The effects of pedestrian footstep loading on a deck have been approximately modelled as a periodic function resolved into a Fourier series. The Fourier series for this function will also account for higher harmonic forces which may have the potential to excite higher modes of frequency in the structure. The follow formula was taken from SETRA 2006 and was used to derive the vertical force component of a footstep.

$$f(t) = F_0 + \sum_{i=1}^{n} F_i \sin(2\pi i f_s t - \varphi_i)$$

- F_0 = mean/static mass of pedestrian,
- F_i = load component for frequency, $i.F_s$
- f_s = step frequency depending on speed
- t = time, s
- φ_i = phase angle of load component
- 'i' used in the equation was based on research from Bachmann and Ammann, 1987

The Fourier equation above was developed into an interactive spreadsheet by icubed to produce different vertical and horizontal force equations. The icubed graphs below compare well to the measured footfall components produced by Andriacchi, Ogle and Galante, 1977. A sample of these are provided below
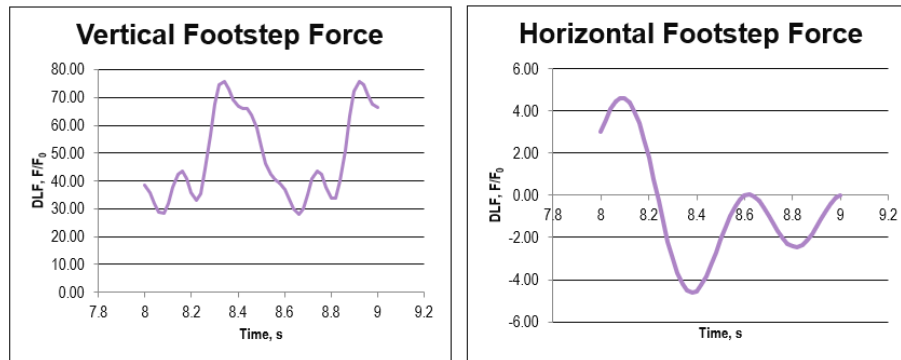
Figure 16 – icubed Fourier transformation graphs for each footfall component

6.5   Matsumoto, 1978 – Multiple Pedestrian Design

Matsumoto derived equations assuming that pedestrians arrived on the bridge using a Poisson's distribution. The simple formula below can be used to multiply the Fourier transform results for a single pedestrian to assess the global effect of groups of pedestrians on the structure.

$$\text{Synchronised } m_S = T.\lambda$$

$$\text{Unsynchronised } m_{US} = \sqrt{T.\lambda}$$

Where:
- m is a unitless multiple pedestrian factor,
- T is time to cross the bridge,
- λ is pedestrian flow per deck width
- Time to cross the bridge = length / walking velocity

The Fourier Transform results are arranged so that f(t) is shown as a ratio of f(t)/f_0. This result provides a factored value of the force component at time 't' compared to a standard single pedestrian force f_0.

7   Application of Results in Finite Element Software

Strand7 Finite Element Analysis (FEA) package was used as it had the capabilities to run a transient dynamic loading modules along with linear, non-linear, linear buckling, and natural frequency modules. This meant that the entire bridge design could be undertaken in one software package.

In the 3D model, a static point load (f_0) was inserted under two load cases for vertical and horizontal action. This static load would be factored by the Fourier transform equations using the table vs time module and exports from icubed's spreadsheets. These two tables would be combined together in the transient module.

Damping of the structure is critical. icubed assess the bridge damping performance using two methods.

1. using Rayleigh dampening parameters

2. using modal damping response solver in strand7

A sensitivity analysis is typically undertaken on the above two damping methods while investigating results.
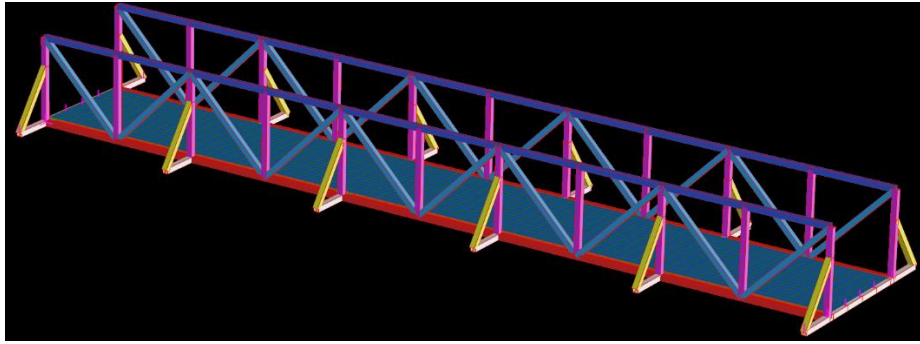
Figure 17 – Strand7 View of JC Slaughter Falls Bridge

For this application, 11 load cases were chosen to be assessed for each bridge. More can be added, but computation time and effort would increase. The main criteria icubed assess include:

- Synchronised pedestrians:
  - Multiple pedestrians: walking, jogging, sprinting and jumping
- Unsynchronised pedestrians:
  - Multiple pedestrians: walking, jogging, sprinting and jumping
  - Single pedestrian: walking, jogging, sprinting
- Vandal Abuse loading
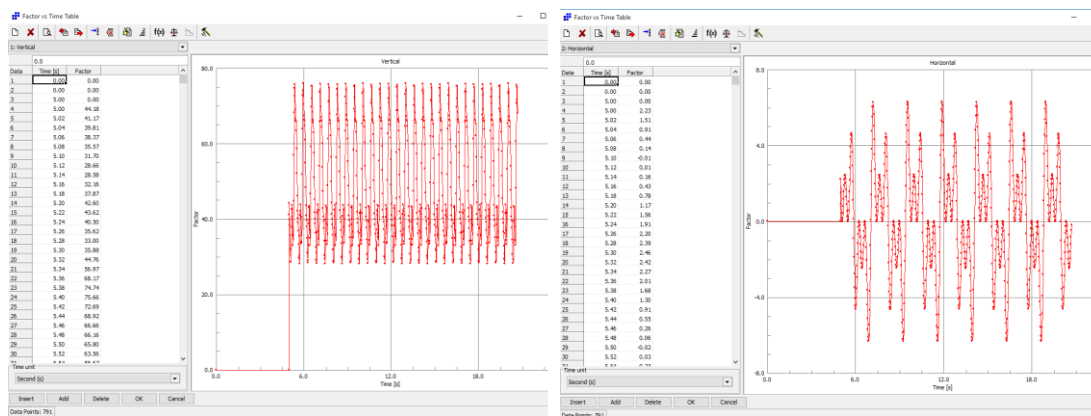 - To account for vandal's jumping in time on a structure
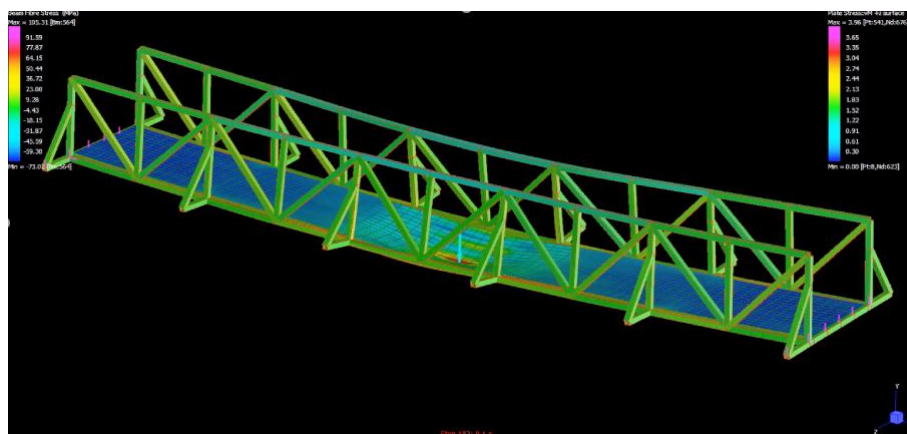

Figure 18 – Factor vs Time table inputs in Strand7

Figure 19 – Strand7 deflected shape under pedestrian loading

7.1   Theoretical Results – Strand7

The below graphic indicates the acceleration performance of the bridge over the time the model was run. The start of the graph indicates equilibrium initiation after gravity is applied, the localised peaks at the start and end are typically removed as these indicate the application of the force load in the model and are not realistic.

The red line indicates maximum acceleration limit from SETRA 2006. The maximum acceleration is indicated by vibrations perceived and possibly 'intolerable' by pedestrians.
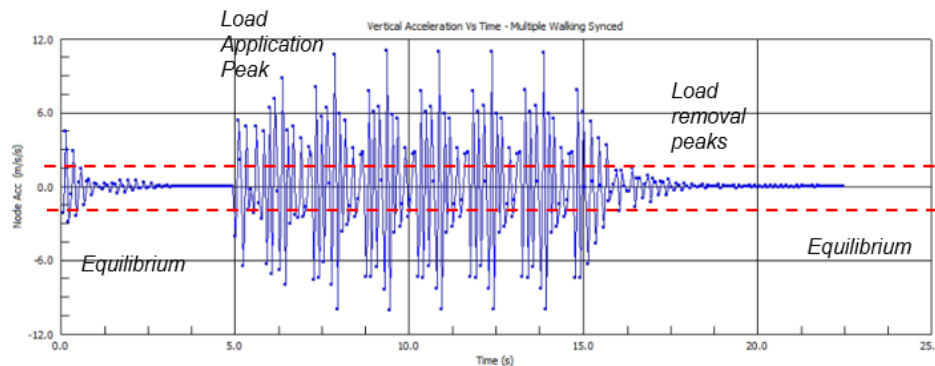

Figure 1 – Strand7 acceleration vs. time results from the worst load case

7.2   Additional Theoretical Research

icubed are also in the process of finalising in-house software to assess pedestrian induced excitation faster and simpler than developing full 3D models and tables for each load case required. icubed structural engineer, Enes Ozdemir, has undertaken this work using Matlab/Octave by producing his own finite element code and focusing on the Newmark-Beta and Wilson-Theta methods to assess deck accelerations for each load case with promising results.

8   In-situ Excitation Testing

8.1   On Site Application

After the research and theoretical investigation into pedestrian excitation, icubed aimed to investigate the theoretical performance against actual in-situ test results.

To do this easily, icubed accessed the site location close to the main office and invited about 10 staff members to visit site and walk over the bridge.

Measurements of deck accelerations were investigated using two Android smart phones with accelerometer apps. The apps allowed accelerations to be measured in three dimensions and were able to record the findings into a CSV file over time. The smart phones were fixed to the deck to prevent differential movement between phone and deck in acceleration readings.

Figure 2 – Video footage was set up to record the experiment

Approximate critical pedestrian numbers were found using Matsumoto's equations based on the in-house spreadsheets.

Pedestrians would need to be kept in time so that their walking frequency matched the walking frequencies used in the modelling process. Bachmann and Ammann provided typical pedestrian parameters and walking frequencies for the stride length per load case and this combined with the length of the bridge, the time it takes to cross the bridge could therefore produce the number of steps per second. Each step can equate to a beat, and using the velocity and time to cross the structure, icubed could then calculated a Beat Per Minute or BPM.

icubed then researched popular songs at the required BPM to ensure the pedestrians were moving across the structure at the appropriate rate to match the modelling. These songs were played through a simple Bluetooth speaker while the team had time to 'feel' the music and walk across the bridge.

Table 1: BPM chart to match in-situ testing with model results

BPM	Song	Artist	Speed
110	Eye of the tiger	Survivor	Slow Walk
120	Call Me Maybe	Carly Rae Jepsen	Normal Walk
132	I Kissed a Girl	Katy Perry	Fast Walk
152	What Goes Around..	Justin Timberlake	Slow Jogging
188	Give It Away Now	Red Hot Chili Peppers	Fast Sprinting

8.2   Sample Results

Upon competition of the testing on site, icubed downloaded the accelerometer data and produced acceleration vs time graphs in a similar manner to Strand7 model results. This would provide the ability to directly correlate theoretical results with testing results.

The red Line indicates >2.5m/s^2 acceleration limit which is 'unacceptable' according to SETRA 2006
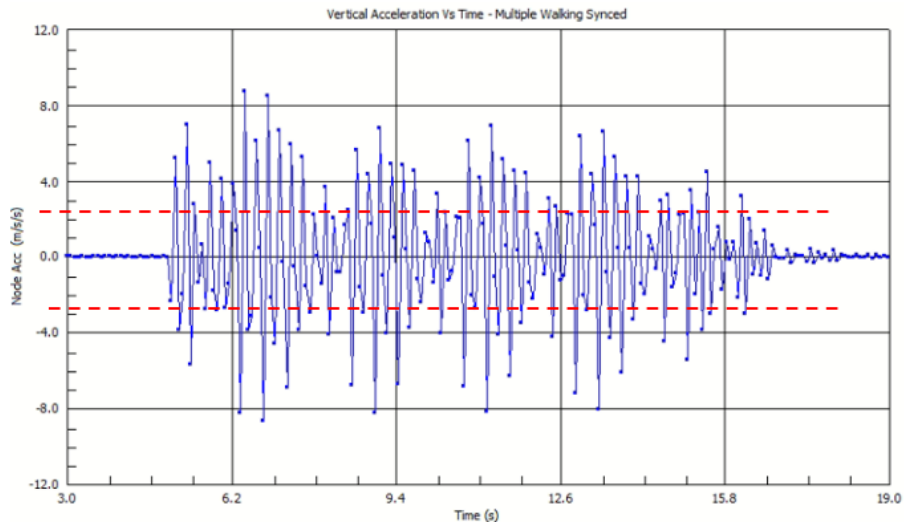
Figure 3 – <u>Strand7</u> Vertical Excitation vs Time, Multiple Pedestrians Fast Walking In-Sync
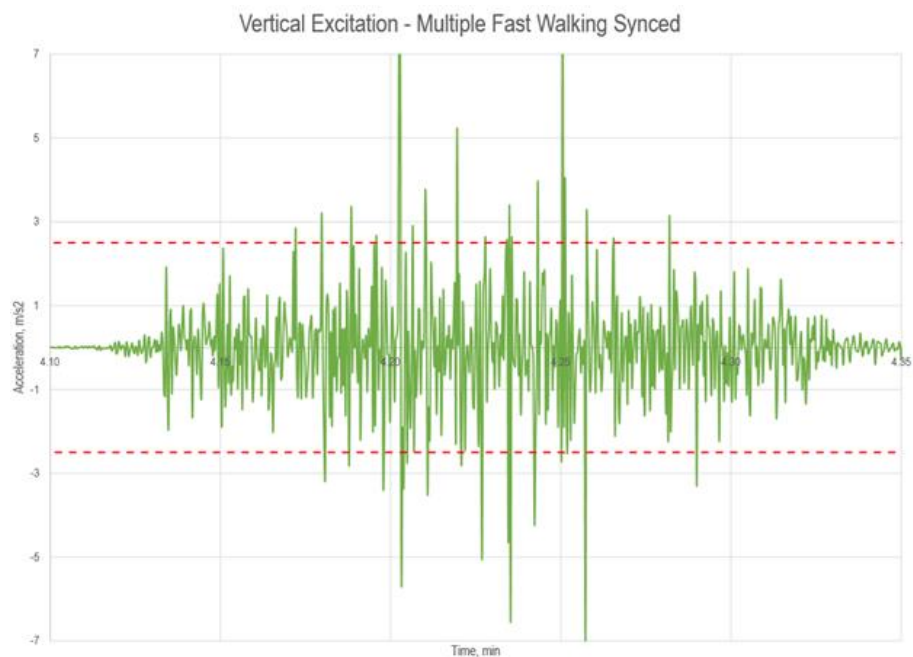

Figure 4 – <u>Accelerometer</u> Vertical Excitation vs Time, Multiple Pedestrians Fast Walking In-Sync

Red Line indicates >0.3m/s² acceleration limit which is 'perceived' according to SETRA 2006
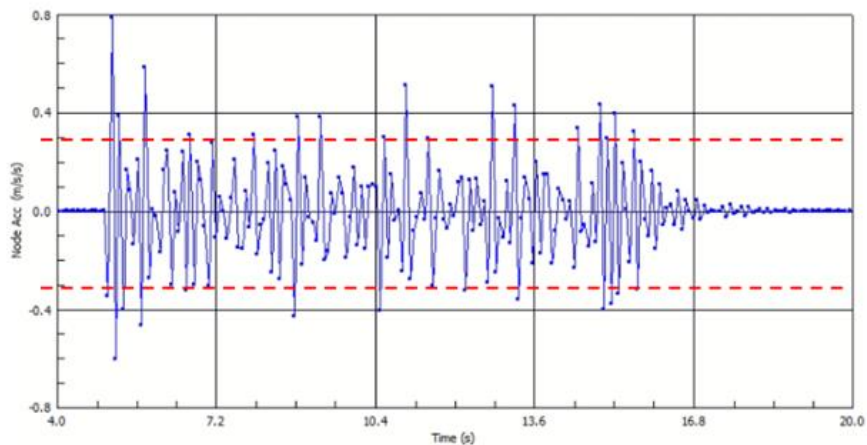

Figure 5 – <u>Strand7</u> Horizontal Excitation vs Time, Multiple Pedestrians Fast Walking In-Sync

Figure 6 – <u>Accelerometer</u> Horizontal Excitation vs Time, Multiple Pedestrians Fast Walking In-Sync

9 Findings – Modelling vs In-Situ Testing

The following findings were concluded at the end of the in-situ testing:

- Actual vertical excitation was found to be generally *less than* expected.
- Actual horizontal excitation was found to be *roughly the same* expected.
- Vandal Abuse – vertical excitation was found to be *roughly the same* as modelled.
    - This was perceived by the pedestrians and was the most noticeable action
    - For this to be a concern, vandals would need to jump in time for a long period while others were walking on the bridge.
- Pedestrians commented that they could feel the vibration of the bridge under the slow and fast walking cases, but were not concerned about it.
    - Following SETRA 2006, this can be noted as *"perceived, not intolerable"*.
- icubed had enough data to produce another 25 graphs for each mode in each direction. For simplicity, only two graphs were produced for this paper.

Further investigations are continually ongoing include:

- Contribution of decking stiffness to lateral excitation and acceleration modes
- Testing the bridge structure for its total system structural damping factor to refine Rayleigh and modal damping results.
- Acceleration results have not been calibrated to industry standard equipment. The smart phone applications were used as a means of easily accessing equipment to help verify calculation methods undertaken. In the future, calibrated equipment will be used to re-test the structure.

10 Aerodynamic Excitation of Bridges

Aerodynamic excitation of the light-weight FRP footbridges is also investigated by icubed during the design process.

Initially this started out with compliance to British Standards BS5400.2 Part 3 BD 49/01 – *design rules for aerodynamic effects on bridges*. This code provides a fairly simple and straightforward method to calculate if the structure will be susceptible to wind induced excitation including:
- Critical wind speeds for vortex excitation
- Limited amplitude response for turbulence

- Divergent amplitude response for galloping and stall flutter
- Wind tunnel testing and CFD simulations if the above criteria are not met

For the majority of structures, BD49/01 works well. There are some applications such as bridges with high solidity ratios and low critical wind speeds which do not comply with the standard. Compliance under these circumstances can be met by stiffening the structure or rearranging the geometry to suit requirements.

For applications where these changes do not comply, or are restricted due to site or commercial constraints, icubed set out to investigate CFD analysis of the structures using OpenFoam.

OpenFOAM is an open source CFD software package. icubed have created interfacing software to load 2D models of the FRP bridge structures into the software package along with engineering properties to provide fluid structure interactions.

The output from this package is a visual representation of:

- vortex shedding,
- pressure distributions around the structure
- The wind induced frequency to ensure self-excitation is not possible

The below screenshot is a snippet from a video file showing the flow of air around a large FRP trussed footbridge.
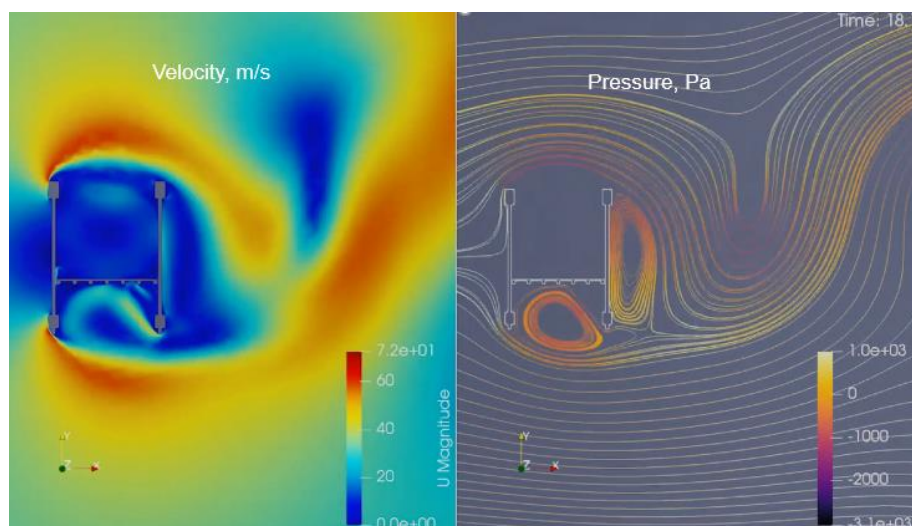

Figure 7 – Open FOAM model results based

Other items of note from the use of OpenFOAM:

- Bridge vertical/horizontal stiffness, mass and damping properties can be input
- Wind speed can be constant, or ramped up or down from over the run time
- Model space can be varied according to site data if available
- Cross section and vortex shedding will be slightly conservative as trusses are not 100% enclosed in the 2D model
- 3D models are possible but require heavy computation time

In order to correlate the results from the 2D models of FRP truss bridges, icubed looked at reproducing the infamous Tacoma Narrows bridge failure in the USA. The same internal process for the FRP bridges was used for Tacoma Narrows and utilised the geometric and material properties of the bridge from research papers discovered online along with the estimated site wind speed results for Tacoma Narrows on the day the bridge collapsed.

The results from this process showed that the Tacoma Narrows model becoming visually unstable and unable to reach self-imposed equilibrium indicating failure could possibly occur.

The below graph is a visual representation of icubed's efforts to self-excite the structure under CFD wind loading. The previous OpenFOAM models run on the FRP bridge were not producing large displacements, so to try and make this worse, icubed purposely 'preset' the bridge with a large displacement. When the model initially ran it would bounce up and down (shown by the first 5-6 seconds of the graph) until it reached equilibrium – all while wind load was still being applied in the software package. The end result of this was little indication that the bridge was self-exciting from wind induced vibrations at this site.
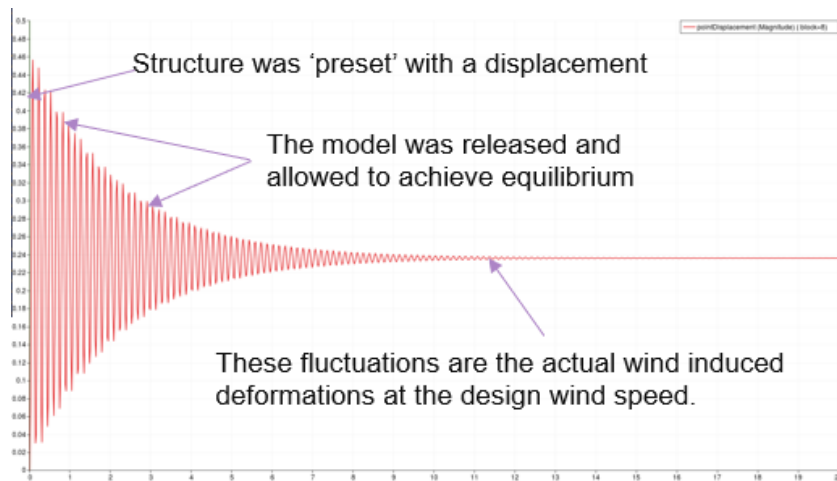

Figure 8 – OpenFOAM Displacement Vs Time

Research into this field is ongoing and trialled on a case-by-case basis depending on the bridge location, size and structure importance level.

11   Conclusion

Multiple methods of assessing pedestrian induced excitation are presenting in this paper. The SETRA 2006 paper provides the most comfort in dealing with deck accelerations and deriving formula to assess footfalls on a structure. This process also requires the most effort in modelling and back-end processes to attain the solution.

The results from in-situ testing match up reasonably well with that found from FEA modelling of the same actions.

Wind induced excitations are generally well covered by British Standards and for the most part, the structures are within the code limits. For structures outside of this icubed have found OpenFOAM CFD package to provide informative results that aid in deciding if wind excitation will be a real issue.

Further research into both of these area's is ongoing and has also been applied to other structure types and forms to investigate findings against codified standards. The processes above have provided icubed and Wagners CFT with the confidence that the new generation of FRP bridge structures perform as within acceptable limits.

12   References

- Figure 8 - Source: Wikipedia. Image by *Africaspotter*
- Figure 10 - Živanović, S., Pavić, A. and Reynolds, P. (2005) Vibration serviceability of footbridges under human-induced excitation: a literature review. Journal of Sound and Vibration, Vol. 279, No. 1-2, pp. 1-74.
- Figure 11 - T.P. Andriacchi, J.A. Ogle and J.O. Galante, Walking speed as a basis for normal and abnormal gait measurements, Journal of Biomechanics 10 (1977), pp. 261–268
- Figure 14 - T.P. Andriacchi, J.A. Ogle and J.O. Galante, Walking speed as a basis for normal and abnormal gait measurements, Journal of Biomechanics 10 (1977), pp. 261–268

13   Acknowledgements

14   Author Biography

Rohan McElroy is currently the Principal Structural Engineer at icubed consulting based in Brisbane. Rohan has been designing and overseeing construction in the residential, commercial, infrastructure and industrial building industries for the last 13 years. For the past 10 years, he has focused his attention on the design of FRP pedestrian, road, wharf and jetty infrastructure projects around Australia, New Zealand, UK, Canada, the USA, Fiji, Egypt and the UAE. Rohan has also co-authored a paper on the world's first composite FRP and reinforced FRP concrete wharf at Pinkenba, Brisbane for the International Federation for Structural Concrete.