Pavement Stabilisation as a Sustainable Pavement Recycling Treatment Option for Brisbane City Council

Greg Stephenson[1], Ashish Shah[2]

[1] Senior Engineer-Civil Infrastructure, Asset Management, Brisbane City Council
[2] Lead Engineer, Strategic Asset Management, Asset Management, Brisbane City Council

Abstract

Brisbane City Council, Australia's largest local council covers an area of approximately 1,367km^2 and is home to almost 1,300,000 people. Council maintains a road network of nearly 6,000 km, ranging from minor residential access streets and cul-de-sacs to major arterial roads with nearly three quarters of the network being local residential streets providing direct property access. Approximately 97% of the network is asphalt surfaced and to construct and maintain these roads, Council operates two asphalt plants, two quarries and a pavement recycling facility.

Council continually seeks to improve the network and provide value for money for ratepayers by using innovative pavement materials and testing methods to drive efficiency. The Asphalt Innovations Group is the focus for collaboration and stakeholder engagement to overcome the unique challenges of complex administrative systems to investigate new pavement and surfacing techniques. The diverse range of roads, in-house capability in quarrying, asphalt production and placing and pavement design are harnessed for trials of new products. Through successful collaboration with local universities and other research organisations, Council has been able to extend its research into the effective use of these techniques to understand their performance and the resultant overall benefits to Council.

As part of Brisbane Vision 2031, Brisbane. Clean, Green, Sustainable 2017-2031 and draft Asset Materials Innovation Strategy, Council actively uses recycled materials in its pavement works. Recycling processes includes the use of Recycled Asphalt Pavement (RAP), crumbed tyre rubber and crushed glass in asphalt, recycled concrete as a pavement material and strengthening of pavements by stabilising the existing pavement materials. In 1981, Council commenced a programme to cement stabilise local roads with an area of 20% or more pavement failure. Stabilisation remains a low-cost alternative to full reconstruction of local roads, albeit with higher risk of premature failure. Some of the pavements treated in the early years of the stabilisation programmes are reaching the end of their current life cycles. Investigations are underway to identify suitable second-generation rehabilitation/recycling techniques for previously cement stabilised pavements.

Under the auspices of the Asphalt Innovations Group investigations have continued into bitumen emulsion and foamed bitumen stabilisation of pavement gravels. Stabilisation will remain part of the arsenal of solutions to sustainably manage Council's road network.

Keywords: Sustainable, Asphalt Innovation, Recycling, Pavement Performance

1. Introduction

In 1925, the Queensland State Parliament passed the City of Brisbane Act to set up a single government in Brisbane. Before this, the Brisbane area had been divided up into 20 local authorities and numerous joint boards such as Victoria Bridge Board, Norman Creek Bridge Board etc. Brisbane City Council covers an area of approximately 1,367km^2 and is home to almost 1,300,000 people.

To maintain Brisbane's accessibility and liveability, the population requires access to a high quality road network, high quality public transport (bus and ferry) services and active travel alternatives that support safe and efficient movement of people and freight. An efficient road network is essential to the economic health and growth of the city. As well as expanding the network, maintenance and rehabilitation of the existing road network is a priority for efficient use of the system [1].

Recycling of materials is a key part of Council's pavement rehabilitation strategies. Re-use of these materials has long been practiced in Brisbane. A 1925 report highlights that "the old metal (gravel) removed from the streets and roadways to make room for the new concrete roads has been used in the principal streets" in the Herston area [2].

1.1 Brisbane Vision 2031

Brisbane Vision 2031 [3] is Council's long-term community plan for the city. It details the aspirations for the city's future and outlines the vision that Brisbane will continue to be a safe, vibrant, green and prosperous city. The themes identify the shared aspirations of the Brisbane community that form the high-level goals for Brisbane Vision 2031. In some cases, Council will be a provider or leader, in other cases it may fund, advocate, regulate, form partnerships or monitor achievement.

Allied to Brisbane Vision 2031, Brisbane. Clean, Green, Sustainable 2017-2031 [4] includes the goal that Brisbane will reduce, reuse and recycle waste with an aspiration that businesses and industry will use innovative production and distribution systems to prevent waste from being produced. Where waste generation cannot be avoided, it is recovered as a resource for repurposing, reuse or recycling. To implement these goals a draft "Vision for Recycling of Asset Materials for 2050 for Brisbane City Council [5] is being reviewed.

The more materials recycled from the waste stream, the better the outcome for the environment and our communities. Where waste contains valuable, recoverable resources, technology could make zero waste possible. However, on-going developments are required to further develop these sustainable practices. It is, therefore, appropriate that Council provides leadership by incorporating recycling into its pavement maintenance and rehabilitation activities required to deliver its integrated transport system.

Council is committed to a clean, green and sustainable Brisbane and maintains its carbon neutral status in line with the Australian Government's Climate Active Carbon Neutral Standard for Organisations. Council publishes an annual Carbon Neutral Public Disclosure Statement [6] and is certified carbon neutral under the Climate Active program. This certification is recognition of Council's efforts to reduce and offset the carbon emissions generated by Council's operations. Council continually takes steps to reduce its carbon footprint where possible taking action to reduce its greenhouse gas emissions as part of its carbon neutral commitment.

1.2 Brisbane Road Network

Council's road network ranges from minor residential roads and cul-de-sacs to major arterial roads. The network consists of 5,772 kilometres of sealed roads and just 21 kilometres of unsealed (gravel) roads. Of the sealed roads, 97.2% (based on area) is paved with an asphalt surface, 1.6% with a bituminous spray seal and 1.2% with concrete or concrete pavers. The latter is mostly on local residential streets. The scope of the size and type of inventory of Council controlled roads at 31 December 2023 is shown in Table 1 [7].

Table 1: Road Length, Road Area and Surface Type (as of 31 December 2023)

Sub - Network	Sealed Length (km)	Area (km^2)				
		Asphalt	Bitumen Seal	Concrete & Pavers	Total	% of Network
Local Access	3,863	31.05	0.77	0.59	32.41	58.7
Neighbourhood Access	705	6.78	0.06	0.02	6.86	12.4
District Access	391	4.89	0.01	0.01	4.91	8.9
Industrial Access	375	4.57	0.01	0.03	4.61	8.3
Arterial & Major Arterial	438	6.43	0.01	0.02	6.46	11.7
Total Length/Area	5,772	53.72	0.86	0.67	55.25	
%-age of Network (By Area)		97.2	1.6	1.2	100	100

1.3 Asset Management Model and Organisational Structure

Council's revised Asset Management Model [8] supports four key roles and defines, clarifies and assigns those roles and the related responsibilities. The four identified roles are Asset Owner (AO), Asset Manager (AM), Asset Deliverer (AD) and Asset Maintainer (AMNT).

Council's budget allocations for Road Network Rehabilitation/Resurfacing and Paved Roads Maintenance represent significant commitment to managing roads. Various Council Branches within the Brisbane Infrastructure Division and City Planning and Sustainability are responsible for the delivery and performance of the road network.

- Transport Planning & Operations (TPO) Branch is the AO of the road pavement assets.
- Asset Management Branch, as the AM, provide strategic asset management direction, develop and disseminate Specifications and Standards and coordinate Asset Management related funding bids.
- City Standards: Asphalt and Aggregates, as an AMNT, undertakes operational maintenance management in terms of reactive, programmed and annual recurrent maintenance. It also has a role as an AD.

- Program Planning and Integration is also an AMNT which performs capital project identification, estimating and coordinating design of rehabilitation works programs.
- City Standards: Construction, as an AMNT, undertakes operational assessments to allocate and triage maintenance and refers for further investigations to PPI for capital works consideration.
- City Projects Office, as an AD, performs the investigation, design and documentation for the pavement works contained in the Council's rehabilitation programs. This work is supported by geotechnical and materials laboratory services.
- Asphalt & Aggregates Branch has roles as both an AD and AMNT and produce and supply of quarry product and asphalt for road construction and maintenance. The Branch operates of two quarries (Mt Coot-tha and Bracalba), one road material recycling facility (Pine Mountain) and two asphalt plants (Eagle Farm and Riverview).
- AD roles are also undertaken by:
    - City Projects Office for Council projects delivered by contractors.
    - City Planning and Sustainability Division for projects contributed by developers.
    - Asset Management Branch for projects contributed from other sources e.g. State Government.

1.4 Asphalt Innovations Group

With 5,772 kilometres of sealed roads to maintain, slight improvements in the cost of these maintenance and rehabilitation works represent significant cost savings or increases across the whole network. Similarly, processes that increase the life between rehabilitation treatments has the potential for significant cost savings over the life cycle of the total network. There is an on-going need to investigate new and innovative road maintenance solutions to economically maintain this network. Bituminous surfacing deteriorates due to the combined effects of climate (ultraviolet radiation and oxidation) and fatigue (traffic loading effects). Over 70% of Council's road network is low speed roads providing direct property access where environmental deterioration is the dominant reason for pavement rehabilitation. The remainder are heavily trafficked sub-arterial, arterial and industrial access roads in a low traffic speed environment where load induced deterioration is the dominant form of distress. The performance requirements of most of Council's network are different to those of the State Road Authorities who undertake most of the pavement research in Australia.

As can be seen from the Asset Management structure, Council is a diverse organisation with engineering expertise spread across the policy and delivery functions. The Asphalt Innovations Group (AIG) answers the challenge of harnessing this expertise in road pavement design, construction and maintenance spread across Branches and Divisions, each with competing priorities and agendas. The AIG is the focal point for collaboration and stakeholder engagement to investigate new pavement and surfacing techniques. The meetings are characterised by open communication and sharing of knowledge with growth mindset. The diverse range of roads, in-house capability in quarrying, testing, asphalt production and placing are harnessed for trials of new products.

To further the research goals identified by the AIG, Council has engaged with Southeast Queensland universities in a range of research projects at the undergraduate and post-graduate level. Projects are currently underway with Griffith University (GU), Queensland University of Technology (QUT), University of Queensland (UQ) and University of the Sunshine Coast (USC). Under the auspices of AIG, Council has contributed to Austroads' projects.

1.5 Pavement Construction

Historically, road pavements and drainage were constructed as funding became available from Council revenue, loans and State Government subsidies. As early as 1962, in an effort to seal a large mileage of roads, alternative tenders were invited for the pavement construction of lightly trafficked roads under the following headings:-

(a) Resheeting with crushed rock and/or gravel of existing pavements with two-coat bitumen surfacing;

(b) Cement Stabilisation of existing pavements with two-coat bitumen surfacing;

(c) Bitumen Emulsion Stabilisation of existing pavements with two-coat bitumen surfacing;

(d) Tenderer's own specification.

A contract was let the resheeting with crushed rock and/or gravel and bitumen surfacing of existing pavements of approximately 23½ miles of lightly trafficked roads [9]. However, there were 1,352 miles (2,163 km) of unsealed road which at an historical average of 26 miles being surfaced each year would take 52 years to complete. The problem was addressed with the concept of light construction roads where unsealed roads were scarified and "sweetened" when necessary with additional road base material before laying 2 light coats of bitumen. Between 1962 and 1968, all those roads suitable for the light construction methods were improved at modest expense and over 7 years the mileage of unsurfaced roads was reduced from 1352 to 500 [10].

During the 1965-66 budget debate, it was announced that "it had been decided to embark on a 5 year programme of road shoulder construction" and "anticipated having all of the kerb and channelling in the residential area completed and the bulk of the earth shoulders sealed at the end of 5 years". [11]
The 1972 Town Plan [12] required developers to provide roads and drainage as part of land subdivisions and requirements for minimum standards of pavements depending on the functional classification of the road were introduced. As a result, since 1972 lightly trafficked residential streets have been built to reasonable standards. For the heavily trafficked parts of the network, the requirements remained relatively unchanged until CityPlan 2014 where pavements are required to be designed for the actual pavement loading considering present and predicted heavy vehicle traffic volumes, axle loadings and configurations, heavy vehicle growth etc. [13]

As a consequence, many of heavily trafficked Brisbane's roads were neither designed nor built to modern standards. Various sources of crushed rock, porphyry, ridge gravels and decomposed granite have been used as base gravel. Many of these gravels are poorly graded and moisture sensitive which may result in inferior performance due to greater rutting of the pavement materials under traffic loading. In addition, various programs were undertaken to eliminate the dust from suburban roads. These included the heavy shoulder, light shoulder and dust sealing of lightly trafficked roads programs. Significantly different pavement profiles and materials are likely to exist across the width of pavement. The local road network consists of many lower cost pavements with a high degree of structural variability. Due to the progressive development and rehabilitation of the network, it can be argued that there is a very fine balance between the structural adequacy of the pavements and the current loading. Parts of the road network are particularly vulnerable to increases in traffic loading and load-related wear.

1.6 Cement Stabilisation

Whilst stabilisation was not adopted after the 1962 tenders, cement stabilisation trials began in 1967 with samples having cement contents as high as 6% by weight. A number of streets were stabilised in the 1970's. Thanks to the development of Pavement Management Systems in 1977, by 1980 sufficient data had been gathered that proved cement stabilisation is a feasible method of reconstruction for local roads, if they have pavement failure in 20% or more of their area. In 1981, a preliminary programme ran to stabilise 60,000m^2 of damaged local roads, this programme used a cement content of 4% by weight to a depth of 150mm into the base layer which also required 92% modified compaction ratio giving an Unconfined Compressive Strength (UCS) between 1.5 to 4.5 MPa [14]. By 1982, substantial programmes of cement stabilisation using standardised methods were introduced and for 1998/1999 and 1999/2000, a total of over 100 stabilisation projects were undertaken. At least three million square metres of local roads have been stabilised [15].

The current empirical design process now includes [16]:

- Quality control procedures to ensure that the 90% characteristic value of stabilised thickness is not less than the design thickness.
- The cementitous blend content increased to 4.5% to account for the variability in the processes.
- The stabilising agent is 70/30 General Purpose Cement / Fly Ash blend.
- The design stabilisation thickness for various Local Streets was standardised as shown in Table 2.
- The maximum allowable deflection (D_o) when tested by the 40kN Falling Weight Deflectometer (FWD) approximately four weeks after stabilisation to achieve the required design life is:
  - 150mm thick stabilised base => 1.3mm
  - 200mm thick stabilised base => 0.3mm
- When pre-stabilisation 40kN FWD is greater than 1.8mm, there is a higher likelihood that the stabilisation will be less successful due to the presence of weak subgrade that prevents compaction of the stabilised layer.

Table 2: Standard Design Thicknesses of Cement Stabilisation for CBR $\geqslant$ 3%

Strength Classification	Traffic Loading (maximum) (ESA)	Cement Stabilised Layer Depth (mm)	Asphalt Thickness (mm)
Band 1 to 2	4.0×10^4	150	30 Type 2 C170 AC
Band 3	1.5×10^5	200	30 Type 2 C170 AC
Band 4	9.0×10^5	225	50 Type 3 MG AC
Band 5	1.5×10^6	230	50 Type 3 MG AC

CityPlan 2014 permits cementitious blend stabilisation of granular pavement with thin asphalt surfacing on lightly trafficked roads, where the 20 year design traffic loading is below 1.5×10^6 ESA. Elsewhere, roads subject to light traffic loadings are defined as $TL_{20} \leqslant 1 \times 10^6$ ESAs, so it is now unlikely that this empirical design method would be used for roads with a traffic loading (TL_{20}) above 1×10^6 ESAs. However, we have observed that many developers have not taken up this opportunity due to variety of constraints.

Cemented materials will inevitably crack due to thermal and shrinkage stresses, resulting in reflective cracking of the asphalt surface. While this may be tolerable on lightly trafficked roads and not considered as a structural or performance issue, it is not acceptable on heavily trafficked roads. Sealing of the cracks in the surface of lightly trafficked stabilised pavements is not normally undertaken because the stabilised material is reasonably immune to the effects of water and there is minimal "pumping" of the supporting layers in the low speed environment.

The stabilised pavements which have reached an age of up to 40 years, perform better than unbound granular pavements of a similar age in terms of percentage of the total area with pavement failures. The rate of degradation of stabilised streets is slower than that of unbound granular pavement [15].

However, with Council's empirical pavement thickness design methodology, an occasional project is unsuccessful and is repaired or reconstructed before the asphalt surface is placed. Because the standard of the road network has continually been improved, the number of local streets that are suitable candidates for cement stabilisation has significantly reduced.

Stabilisation remains a low-cost alternative to full reconstruction of local roads, albeit with higher risk of premature failure. Some of the pavements treated in the early years of the stabilisation programmes are reaching the end of their current life cycles. Where a previously stabilised pavement requires resurfacing, the standard process has been:

- Cold plane entire surface to a 30mm depth, selectively reconstruct any pavement failures with 100mm Type 4 asphalt, prime cold planed surface, crumb rubber modified C170 bitumen seal with 30mm Type 2 (C170) asphalt.

Following research undertaken by Council [16], more recent practice has been:

- Place a C170 bitumen primer seal on the cold planed surface and 30mm layer of Type 2 asphalt with C170 bitumen containing 10% crumbed rubber in the binder.

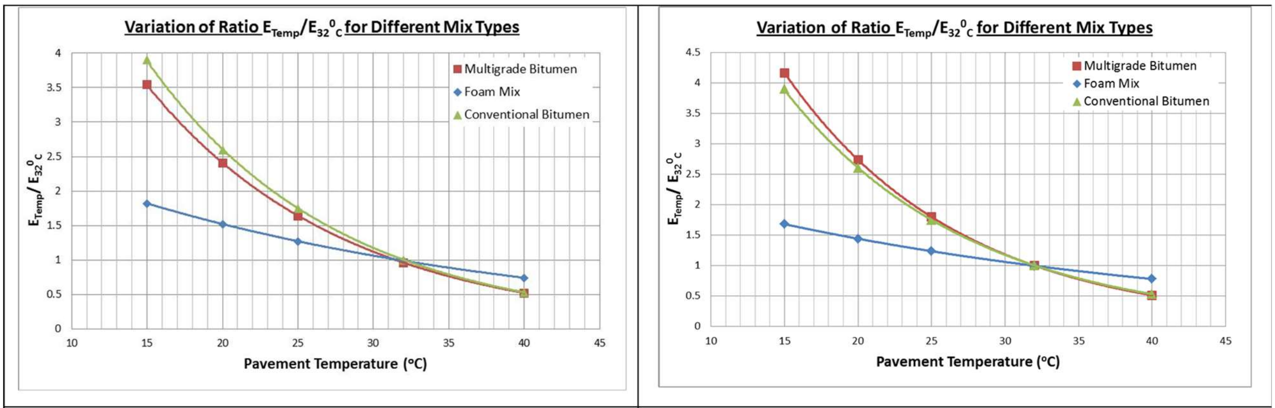
However, further investigations are required to develop suitable second generation rehabilitation and recycling techniques for previously cement stabilised pavements.

1.7 Ex-situ Foamed Bitumen Stabilised Gravel

In 2009, Council worked with a contractor to produce foamed bitumen stabilised base using the Class 2 RAP – a mixture of asphalt, gravel and subgrade materials recovered as part of pavement rehabilitation projects. Mixing trials were undertaken at the former Pine Mountain Quarry, Carina Heights. Once the Class 2 RAP had been crushed and screened, 10% ponded fly ash filler from Swanbank Power Station was added to compensate for the deficiency in <75 micron material. A Wirtgen KMA 200 mobile continuous mixing plant was used to add 3% bitumen. Because it was planned to stockpile that material and use it over time, no supplementary stabilising agent such as cement or lime were included. Initial moisture contents were above optimum moisture content and early material rapidly failed under traffic. The trial was suspended whilst further laboratory testing was undertaken. The stockpiled material was subsequently reprocessed to lower the moisture content to below the optimum level [18].

After some smaller scale trials, the material was used as a substitute for the structural asphalt layer on rehabilitation projects on Archerfield Road, Richlands and Poinsettia Road, Inala. The material was paver laid by asphalt placing crews. In October 2012, cores were extracted from these pavements and Resilient Modulus testing was used to investigate the temperature sensitivity of multigrade asphalt surfacing and foamed bitumen stabilised base. Figure 2 shows that stiffness of the foamed stabilised base is dependent on the material temperature. However, due to the lower bitumen content, the effect of temperature on stiffness of foamed stabilised base is much lower than convention asphalt pavements [18].

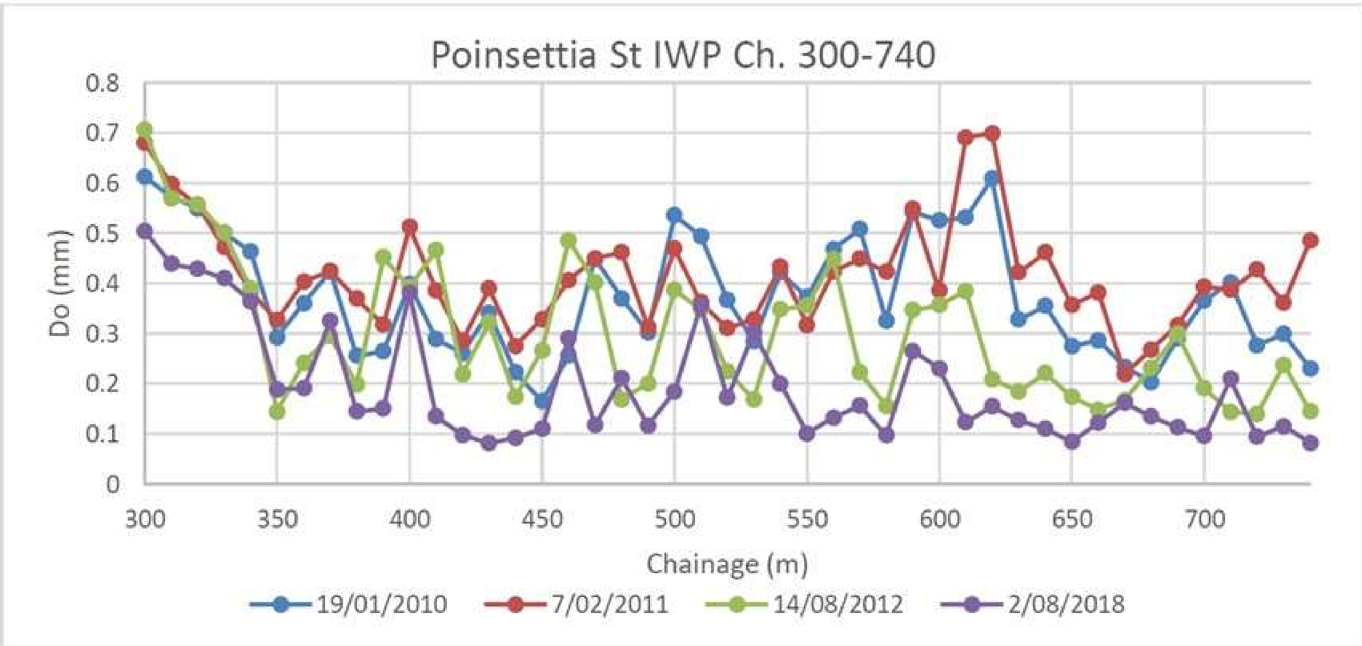
Figure 2: Effect of Temperature on Different Pavement Materials



Archerfield Road, Richlands	Poinsettia Street, Inala

Falling Weight Deflectometer (FWD) with 40kN loading has been undertaken on Poinsettia Street four times. Over the 8 year test period (from 2010 to 2018), maximum deflections have reduced which indicates an increase in the stiffness of the foamed bitumen stabilised base layer. In January 2011, Brisbane experienced a significant river flood event of a scale not seen since 1974. The higher deflections in the February 2011 test data are attributed to this severe weather event that caused Brisbane's 2011 floods [20].

Figure 3: Maximum Deflection From 40kN FWD Testing of Inner Wheel Path on Poinsettia Street, Inala



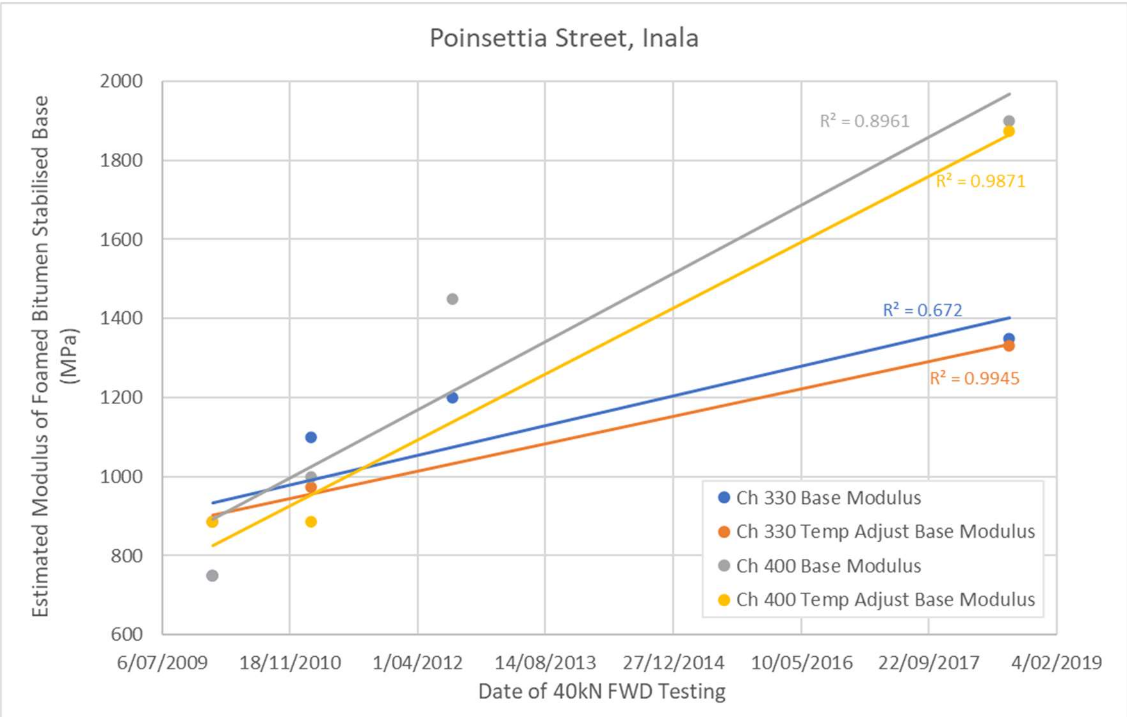
Based on the known pavement profile at two locations, using back analysis of the deflection bowls, the in-situ stiffness of the pavement layers has been estimated as shown in Table 3. The stiffness/temperature relationship derived from the 2012 Resilient Modulus testing was used to adjust the back calculated stiffness to 32°C – Weighted Mean Annual Pavement Temperature (WMAPT) for Brisbane. Soon after placing, the material has a stiffness closer to a stiff granular material. However, there is an increase in the stiffness over time which suggests that the materials are undergoing a curing process. When the temperature adjustment is applied, this trend continues except for the test data from 14th August 2012 where the pavement temperature recorded was 12.5°C (measured at 25mm below the surface). Temperature gauges at varying depths installed at Cullen Ave West, Eagle Farm [21] indicate that at a depth of 110mm below the surface, during August the average pavement temperature is in the range 22°C to 24°C. Applying an adjustment based on 24°C results in the adjusted modulus being consistent with the trend line. The adjusted stiffness values for 2012 test data are not included in Figure 4 which shows the change in stiffness over 8 years.

Table 3: Estimated Modulus of Foamed Bitumen Stabilised Base (MPa)

FWD Test Date	Pavement Temperature	Ch 330 Run 2L		Ch 400 Run 2L	
		Modulus	Adjust to 32°C	Modulus	Adjust to 32°C
19/01/2010	37.0°C	750	886	750	886
7/02/2011	27.7°C	1,100	974	1,000	885
14/08/2012	12.5°C	1,200	662(1)	1,450	801(1)
2/08/2018	31.2°C	1,350	1,332	1,900	1,874

(1) Values omitted from graph

Figure 4: Impact of Age on Stiffness of Foamed Bitumen Stabilised Base - Poinsettia Street, Inala



One of the key findings for Council is that this material needs to be placed and handled like a granular material rather than asphalt. The road is in a good shape and is performing well. There are transverse cracks in a few locations which are mainly due to the roots of large trees growing in the median. Council continues to monitor these trial sections which are performing as expected.

Council is likely to re-visit the ex-situ foamed bitumen stabilising process using Class 2 RAP mixed with crushed concrete fines.

1.8 Ex-situ Bitumen Emulsion Stabilised Gravel

Brisbane City Council in conjunction with a bitumen supplier has been developing a bitumen emulsion treated road base (ETB) material using material from the Bracalba Quarry. The ETB used DTMR Type 2.3 road base material and was plant stabilised using 3% Anionic Slow Set 60% emulsion, and 1% hydrated lime as a secondary stabilising agent.

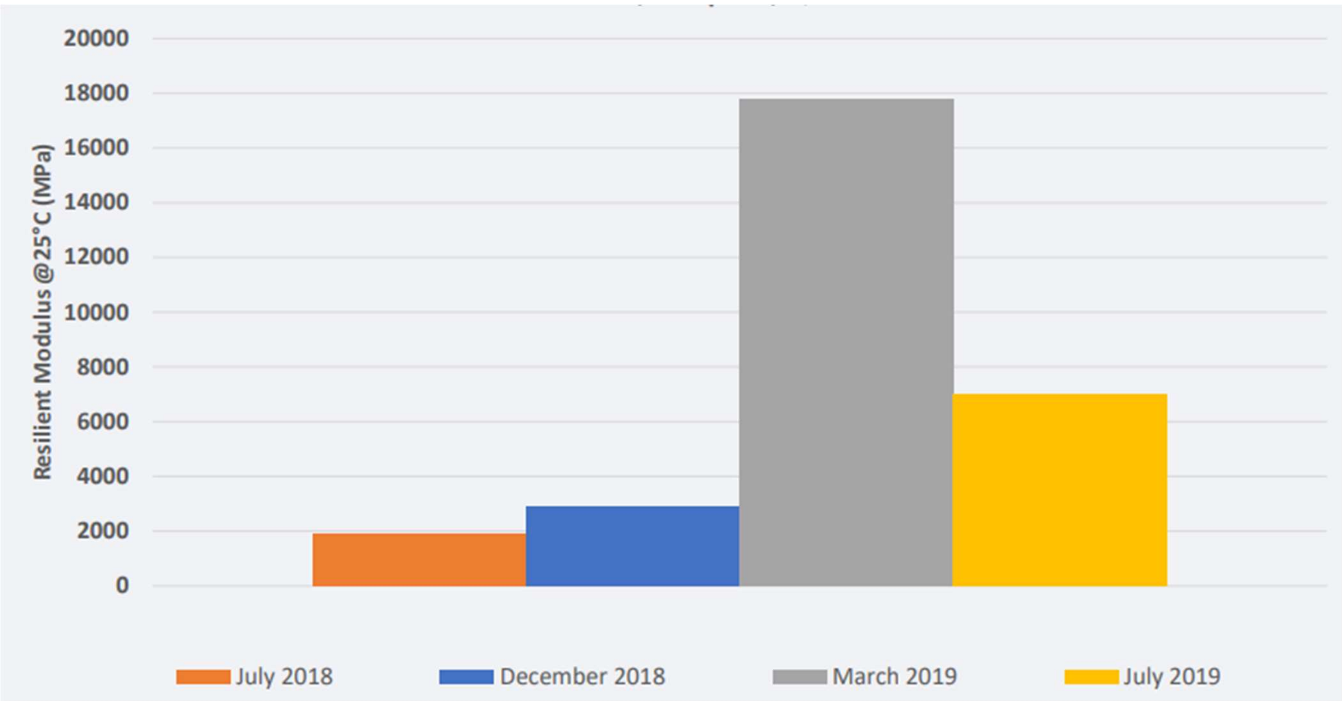
As part of a rehabilitation project on Abbott Road, Camp Hill, this material was placed between Burns Street and Snell Street in 2018. The original pavement design consisted of removal of 210mm of existing pavement, placing 160mm of foamed bitumen stabilised base with a 50mm surface of Type 3 (MG) AC. ETB was substituted for the foamed bitumen stabilised base layer. Either side of the section with ETB, 80mm of the existing pavement was removed and 80mm MG AC surface placed. The site on was situated in a residential area, close to Camp Hill State School, and was a 2-lane road with a 20 year design traffic loading of 0.24 million ESA (Equivalent Single Axles).

Table 4: Abbott Street, Camp Hill - Segments, Chainages and Materials

Location	**Brooks Street to Burns Street**	**Burns Street to Snell Street**	**Snell Street to Cambridge Street**
Chainage (m)	**10m – 115m**	**115m – 415m**	**415m – 545m**
Asphalt	80mm MG AC	50mm MG AC	80mm MG AC
Base Material	Existing Granular Material	160mm Emulsion Treated Base	Existing Granular Material

The project was constructed in July of 2018, with subsequent FWD testing with a target loading of 50kN being conducted on 27th August 2018, 26th March 2019, 2nd July 2019 and 9th December 2019. Resilient Modulus testing on cores extracted from the ETB pavement 4 times from July 2018 to July 2019 has previously been reported [22] and reproduced in Figure 5. It is unclear why there is a significant difference in Resilient Modulus between the March 2019 and July 2019. Excluding the March 2019 value, the trend in increase in stiffness better matches the back analysed stiffness values. The high stiffness value is not reflected in the deflection data.

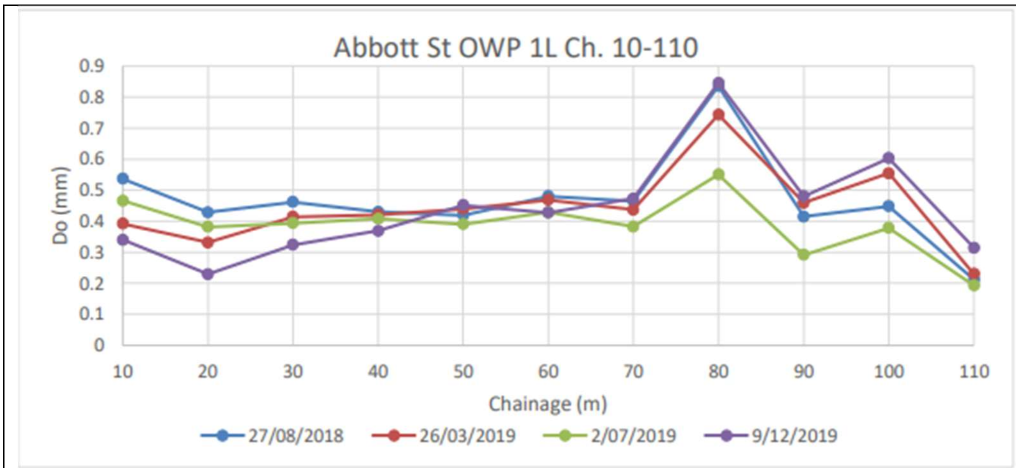
Figure 5: Resilient Modulus of Production Mix and Extracted Cores – Abbott Road, Camp Hill (After [22])



For the sections that received the conventional mill and fill asphalt treatment (Brooks Street to Burns Street (Ch 10 to Ch 115) and Snell Street to Cambridge Street (Ch 415 to Ch 545), overall, pavement stiffness has remained constant and highly variable over the period.

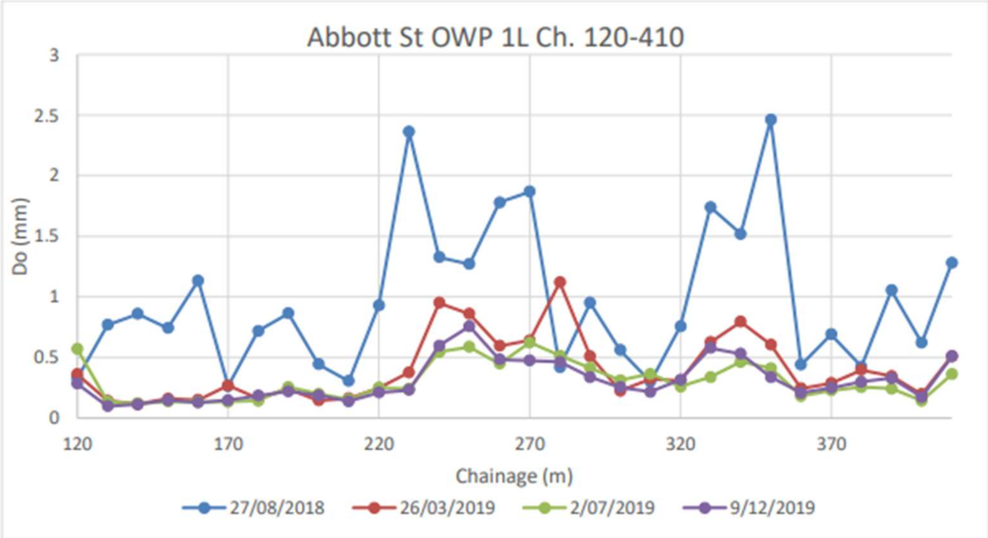
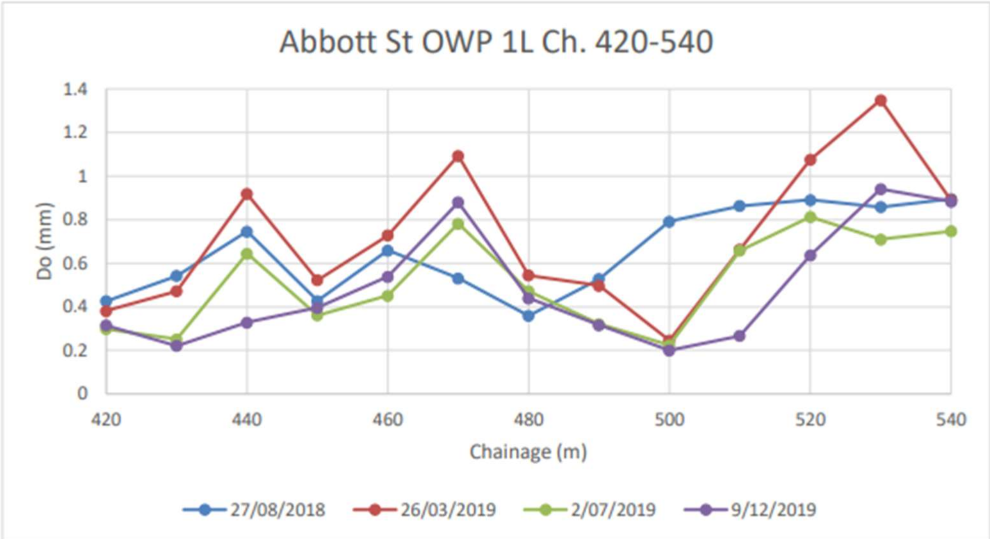
For Burns Street to Snell Street (Ch 115 – Ch 415), the section reconstructed with ETB, the overall trend shows that total maximum deflection has decreased over time indicating that pavement is becoming stiffer which is a reflection of the ETB gaining strength in the pavement. The data suggests that the pavement stiffness between March and July 2019 is not substantially different indicating that the ETB was approaching its final "cured" state. The Deflection Ratios (D_{250}/D_0) show that in August 2018, the overall pavement was performing like a granular pavement. However, by July 2019, the pavement is performing more like a thick asphalt or bound pavement.

Figure 6: Changes in Maximum Deflection in the Eastbound Outer Wheelpath – Abbott Road, Camp Hill



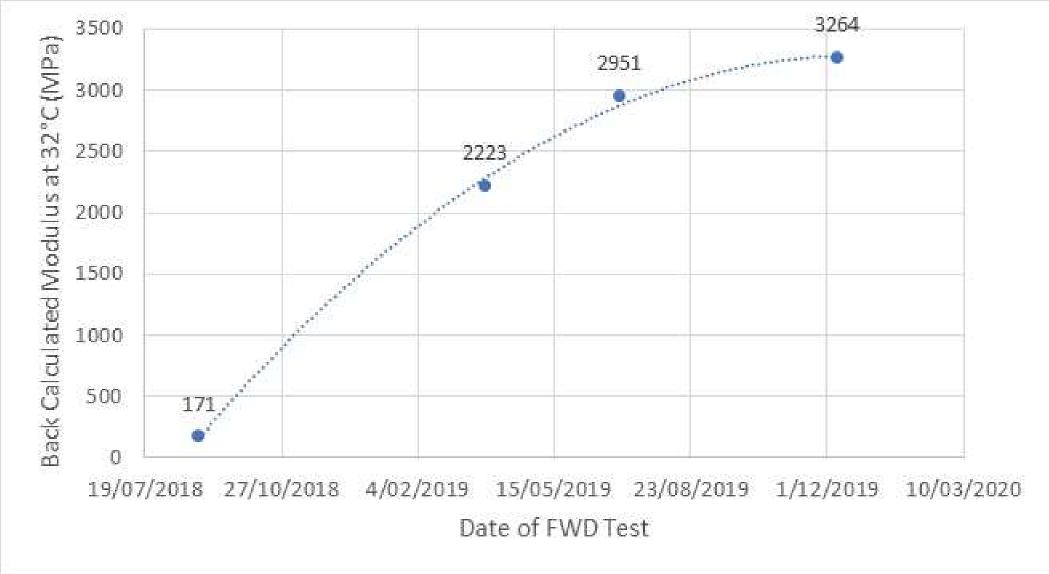
Mill and Fill Section # 1

- 80mm MG AC
- Existing Granular Base Material

 	<u>ETB Section</u> • 50mm MG AC • 160mm Emulsion Treated Base
 	<u>Mill and Fill Section # 2</u> • 80mm MG AC • Existing Granular Base Material

To further investigate the increase in the stiffness of the ETB with time, back analysis was undertaken using the pavement design and the average deflection bowl for the section and the stiffness then "adjusted" to the WMAPT for Brisbane of 32°C. As shown in Figure 7, the ETB rapidly gained strength over the initial 7 months after construction. In the 5 months between July and December 2019, there was a 10% increase in stiffness. The pavement design was based on a stiffness of 1,800 MPa which is typically used for foam bitumen stabilised pavements [23]. The back analysed stiffness of ETB confirms that this design stiffness has been achieved.

Figure 7: Impact of Age on Stiffness of Emulsion Bitumen Treated Base – Abbott Road, Camp Hill



1.9 In-situ Foam Bitumen Stabilised Gravel

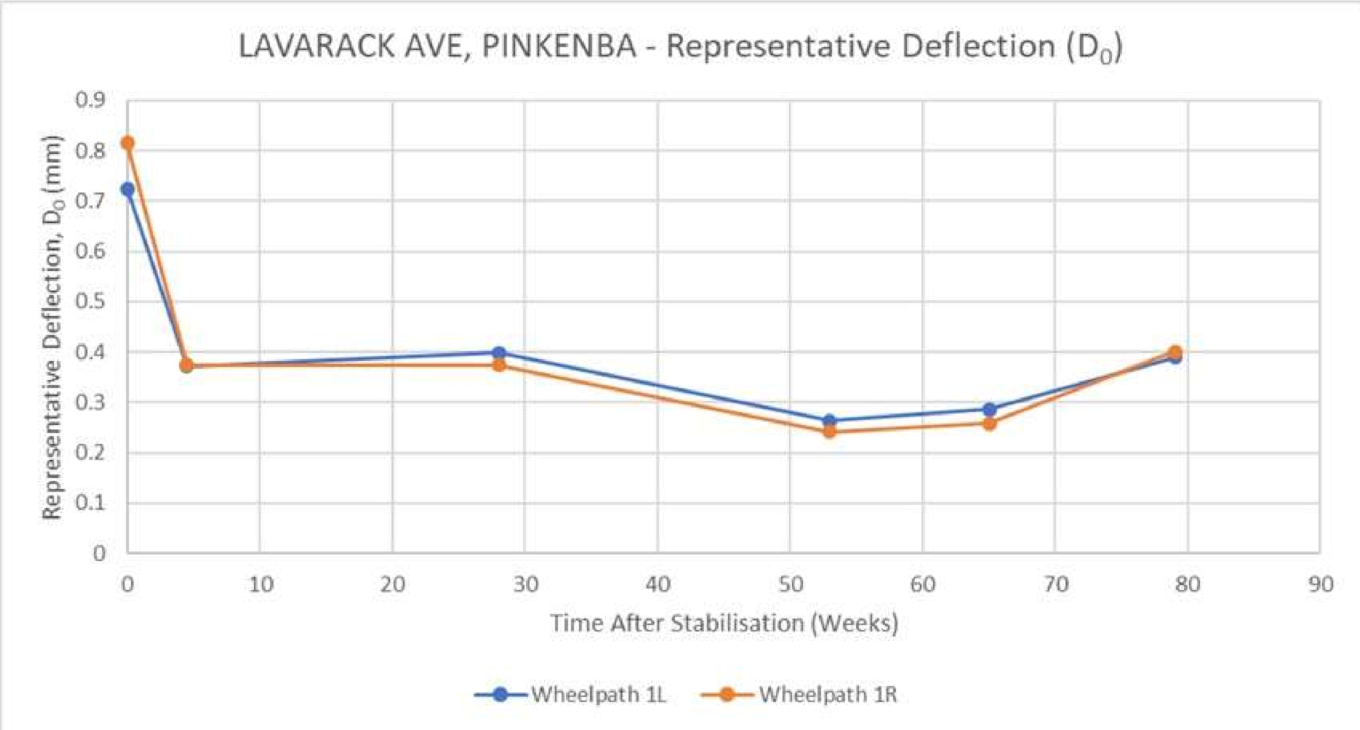
Council had undertaken limited in-situ foam bitumen stabilisation using the traditional methods involving trimming with graders after mixing and compacting. The import into Australia of a Wirtgen W380CR cold recycler created renewed interest in the cold in-situ recycling process. The purpose-built machinery includes a milling and mixing rotor which granulates the existing pavement as well as an injection system that mixes the material with foamed bitumen in a single operation. The stabilised material is then fed by conveyor directly into a paver for placing. Construction time would be expected to reduce by the using in-situ pavement rejuvenation to stabilise the existing material using single-pass, paver-laid technology.

A suitable site was identified on Lavarack Avenue, Pinkenba between Curtin Ave East and Holt St (Southern Lane only). The was part of a B-double route through a heavy industrial area. There was a very consistent pavement profile with a typical thickness of 90mm AC on 310mm gravel. The base gravel has good Atterberg Limit values but poor grading (i.e. too coarse). However, "whilst the material is coarse, the critical sieve is the fines component as it is the fines that the foamed bitumen needs. These are conforming on all samples" [24]. The recommended mix design using 3.0% C170 bitumen and 1.5% GB cement (70/30 GP cement/flyash) was found to exceed the minimum modulus requirements of 2000MPa.

The adopted pavement design for the 20-year design life of $T_{20} = 4.6 \times 10^6$ ESA was 50mm AC (M1000) on 230mm (210mm plus 20mm construction tolerance) in-situ foam bitumen stabilised existing pavement gravel. Whilst the pavement design was completed in March 2021, the construction was undertaken during July 2022. Falling Weight Deflectometer (FWD) testing with a target loading of 50kN being conducted on the following dates – 30th August 2022, 13th February 2023, 9th August 2023, 27th October 2023 and 6th February 2024. As part of the pavement investigation, FWD testing was undertaken before stabilisation on 15th March 2020 and is referred to as Time "0" in the following charts.

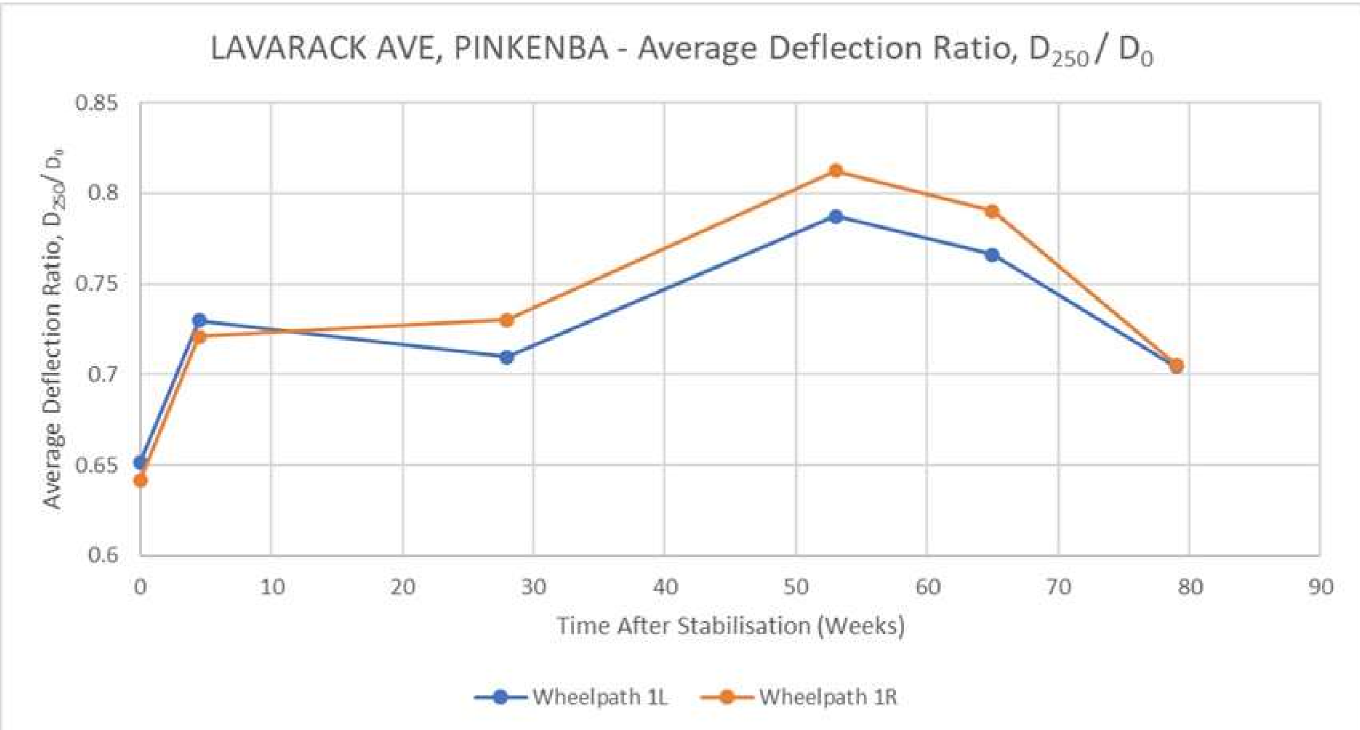
Figure 8 shows that 4.5 weeks after stabilisation, the pavement was significantly stiffer and generally continued to gain stiffness over time. Whilst, the deflection on 6th February 2024 is higher than the deflection from the two previous tests, the pavement temperature was over 50°C suggesting that the reduced stiffness of the asphalt and bitumen stabilised layers due to temperature has contributed to the higher deflection rather than fatigue weakening the pavement.

Figure 8: Representative FWD Deflection – Lavarack Avenue, Pinkenba



Similarly, the deflection ratio which is an indication of the pavement structure was consistent with a good quality granular pavement before stabilisation and performing like a bound material after stabilisation. The lower deflection ratio on 6th February 2024 is also a function of the high pavement temperature.

Figure 9: Average Deflection Ratio – Lavarack Avenue, Pinkenba



Back-analysis of the surface deflection bowl data can be used to estimate the elastic modulus of the pavement layers by taking a measured surface deflection and matching a calculated surface deflection generated from the pavement structure using assumed layer stiffnesses (moduli). The assumed layer moduli are adjusted until they produce a surface deflection that closely matches the measured one. This combination of assumed layer stiffnesses is then assumed to be the actual in situ moduli for the various pavement layers. The back-analysis process is iterative and, in this case, was done by “trial and error” process using CIRCLY software. One of the main limitations of back-analysis techniques is that the solution may not be unique with two or more combinations of pavement parameters resulting in the same deflections. A thin layer usually has little influence on deflection and its contribution to the structural pavement stiffness is small. Therefore, its prediction from FWD deflections will be difficult and may cause a non-unique solution. Even small average errors of 0.5% between measured and calculated deflections does not guarantee accurate predictions of moduli, critical stresses and strains [24].

Despite these limitations, it does provide an insight into predicting the pavement performance. Based on the pavement design of 70mm AC over 230mm of foam bitumen stabilised material on remaining existing gravel on the subgrade, back-analysis of the average deflection bowl for the Outer Wheel Path (OWP) was undertaken to estimate the in-situ stiffness of the various pavement layers. As shown in Table 5, after the initial curing period, the stiffness of the asphalt and foamed bitumen stabilised layers are highly correlated to pavement temperature. The changes in the stiffness of the granular layers and subgrade (reported as CBR) are likely to reflect the stress sensitivity of these materials caused by changes in their loading due to different stiffnesses of the overlying materials.

Table 5: Estimated Modulus of Pavement Layers including Foamed Bitumen Stabilised Base (MPa)

FWD Test Date	**30/08/2022**	**13/02/2023**	**9/08/2023**	**27/10/2023**	**6/02/2024**
Weeks Post-stabilisation	4.5	28	53	65	79
Temperature	16.1°C	45.5°C	21.9°C	29.2°C	51.3°C
70mm AC (MPa)	2,000	1,750	2,250	1,250	400
230mm Foam Stab (MPa)	2,000	2,700	7,500	7,000	4,850
100mm Gravel (MPa)	300	325	350	350	400
Subgrade CBR (%)	18	17	18	19	17

To further assess the temperature susceptibility of the asphalt and foamed bitumen stabilised base and its likely impact on pavement deflection, three cores were extracted from the pavement on 6th February 2024. Resilient modulus testing was undertaken at 15°C, 25°C, 32°C and 45°C with the results shown in Table 6 and Figures 10 and 11. Variation with temperature of the ratio of modulus at test temperature to modulus at 25 °C for the average of the 3 test samples approximates the Austroads design values [25]. However, the ranges of ratio of modulus for individual samples are widely variable.

Table 6: Resilient Modulus of Asphalt Surface and Foamed Bitumen Stabilised Base (MPa)

FWD Test Date	Asphalt Surface			Foamed Bitumen Stabilised Base		
Chainage	**320**	**400**	**500**	**320**	**400**	**500**
Test Temperature (°C)	15					
Resilient Modulus (MPa)	13,794	17,182	9,601	13,596	11,567	11,955
C of V (%)	0.94	1.26	0.87	1.88	0.85	0.52
Phase Delay (ms)	7	6.2	6.8	5	4.4	5
Test Temperature (°C)	25					
Resilient Modulus (MPa)	6525	9578	4202	12039	7574	9287
C of V (%)	1.27	1.44	2.52	1.6	0.7	0.45
Phase Delay (ms)	8.6	8.1	10.1	4.5	5.2	5.8
Test Temperature (°C)	32					
Resilient Modulus (MPa)	4202	5848	2611	11629	5359	8907
C of V (%)	1.9	2.23	2.57	1.96	1.19	1.2
Phase Delay (ms)	9.8	10.4	13.4	5.7	5.3	5.3
Test Temperature (°C)	45					
Resilient Modulus (MPa)	917	1841	752	7650	3031	9867
C of V (%)	5.09	5.92	3.03	0.51	0.66	1.43
Phase Delay (ms)	31.6	25	36.5	7.5	8.7	6.3

Whilst the stiffness of the foamed bitumen layer reduces with increased temperature, the reduction in asphalt stiffness is more significant. The asphalt surface plays a major role in the increased deflections at higher temperatures. Similarly, the visco-elastic nature of the asphalt produces much longer phase delays at higher temperature. Whereas, there is limited effect on the phase angle of the foamed bitumen stabilised material indicating that it performs more like an elastic material at higher temperatures.

Figure 10: Effect of Temperature on Resilient Modulus – Lavarack Avenue, Pinkenba

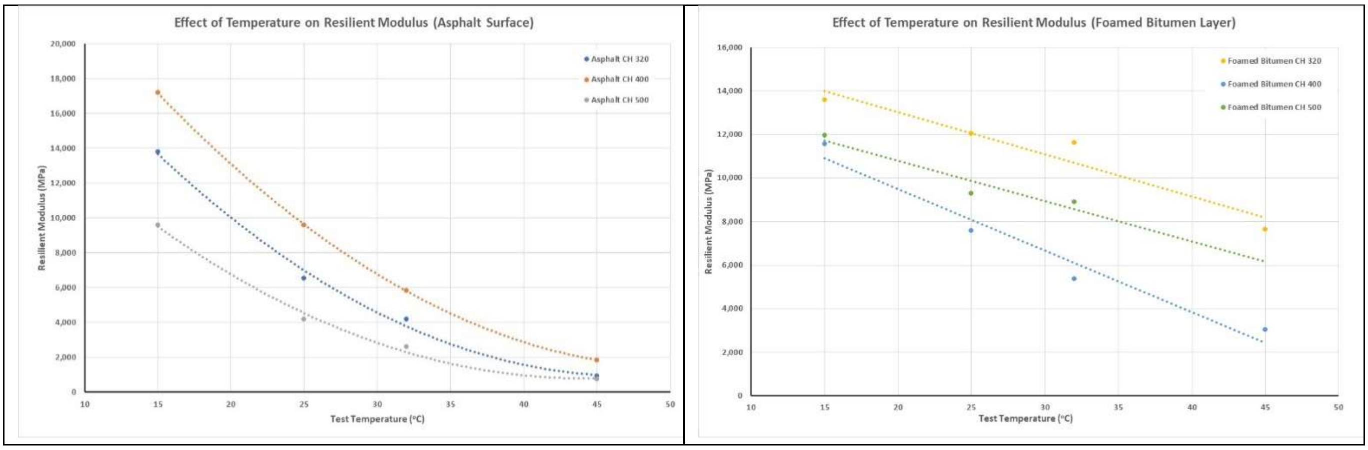
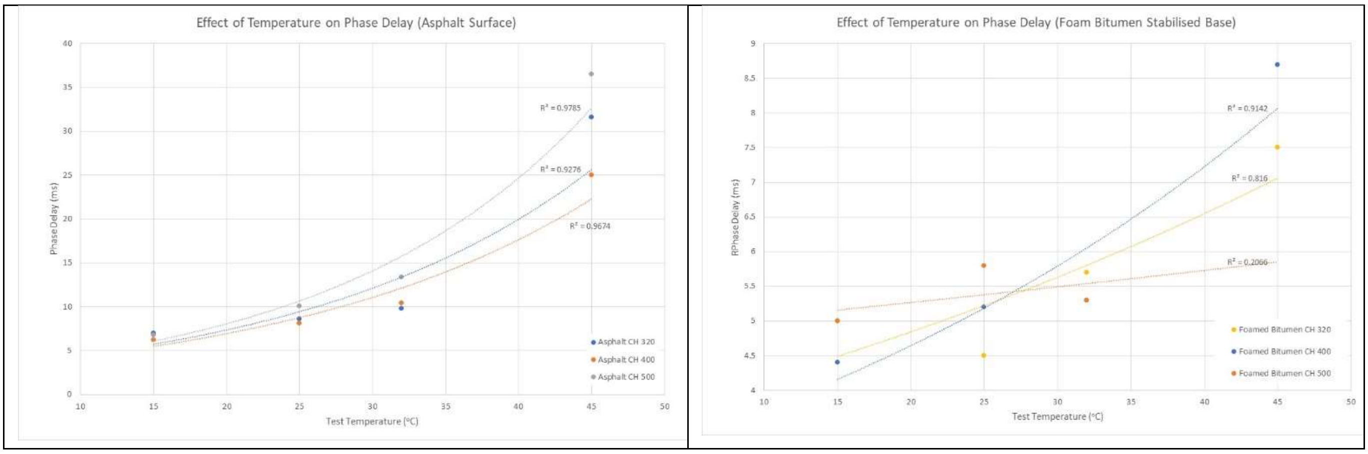


Figure 11: Effect of Temperature on Phase Delay – Lavarack Avenue, Pinkenba



The performance of the section of Lavarack Avenue, Pinkenba containing in-situ foamed bitumen stabilised base will continue to be monitored through the network condition assessment undertaken as part of Council normal pavement management system processes. This will be supplemented by future FWD testing to verify it structural performance. However, current results show that it is expected to be a viable treatment to strengthen many of the granular pavements with thin asphalt surfaces built to the relatively low design traffic loadings assigned to the Functional Classifications introduced in the 1972 Town Plan and which remained relatively unchanged until CityPlan 2014.

1.10 Conclusions

Recycling of pavement materials contributes to BCC meeting its sustainability goals. As part of Brisbane Vision 2031 - Brisbane. Clean, Green, Sustainable 2017-2031, Council actively uses recycled materials in its pavement works. Recycling processes includes the use of Recycled Asphalt Pavement (RAP) and crushed glass in asphalt, recycled concrete as a pavement material and strengthening of pavements by stabilising the existing pavement materials. Recycling reduces Council's demand for raw materials and landfill, and its overall carbon emissions. It also provides cost-effective solutions.

Council is a diverse organisation with engineering expertise spread across the policy and delivery functions. The Asphalt Innovations Group (AIG) answers the challenge of harnessing this expertise in road pavement design, construction and maintenance spread across Branches and Divisions, each with competing priorities and agendas. Through successful collaboration with local universities and other research organisations, Council has been able to extend its research into the effective use of these recycled products to understand their performance and the resultant overall benefits to Council and the community served.

Cement stabilised pavements on local roads, based on Council's "empirical" design process, have reached an age of up to 40 years and perform better than unbound granular pavements of a similar age in terms of pavement failures. Pavements treated in the early years of the stabilisation programmes are reaching the end of their current life cycles. Where a previously stabilised pavement requires resurfacing, the recent practice has been to use 10mm dense graded asphalt containing binder with 10% crumbed tyre rubber which was developed by Council research under the auspices of the AIG. However, further investigations are required to develop suitable second generation rehabilitation and recycling techniques for previously cement stabilised pavements that require strengthening. Cement stabilising on local roads remains a low-cost alternative - albeit with some risk of premature failure. However, as the standard of the road network has continually been improved, the number of local streets that are candidates for cement stabilisation has significantly reduced.

Ex-situ Recycling with Foamed Bitumen or Bitumen Emulsion may allow greater re-use of existing pavement materials that are recovered as part of rehabilitation and construction projects. This can provide pavement options for moderately trafficked roads.

Insitu Foamed Bitumen Stabilisation is expected to be a viable treatment option for strengthening moderate to heavily trafficked roads built as granular pavements with thin asphalt surfaces. Sufficient “suitable” quality gravel for insitu foamed bitumen stabilisation is expected to exist on these roads.

The research led by the Asphalt Innovation Group will further develop these sustainable practices to prevent the existing pavement materials from entering the waste stream and deliver better the outcomes for the environment and our communities. Stabilisation will contribute to Council reducing its carbon footprint with commensurate savings in the purchase of offsets for the greenhouse gas emissions generated by Council's operations. Stabilisation in its varied forms is key part of the arsenal of pavement recycling technologies that have long been embedded in our practices to sustainably manage Council’s road network and will play a vital role in Council fulfilling its carbon neutral commitment into the future.

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Authors' Biography

Greg Stephenson, Senior Engineer - Civil Infrastructure, Asset Management, Brisbane City Council.
Greg Stephenson has spent over 4 decades working for local government authorities, federal government and consulting engineers in the road and airport construction and maintenance areas. Before joining BCC, he spent 5 years at Queensland University of Technology undertaking asphalt related research. He commenced with BCC in 2004 as a Pavement Design Engineer before moving to the Asset Management Branch around 18 years ago. He coordinates the Asphalt Innovations Group to foster research and development activities for asphalt and pavement materials within Council. He is a Member of Engineers Australia, Chartered Professional Engineer (CPEng) and Registered Professional Engineer, Queensland (RPEQ - Civil).

Ashish Shah, Lead Engineer - Strategic Asset Management, Asset Management, Brisbane City Council.
Ashish Shah has an interest and experience with transport infrastructure asset management, its data, and asset information systems. He has been in Local Government, Consulting and Research roles for over last 20+ years in Australia. He joined Brisbane City Council as Lead Engineer – Strategic Asset Management 4 years ago. He is a Member of Engineers Australia, Chartered Professional Engineer (CPEng) and Registered Professional Engineer, Queensland (RPEQ - Civil).

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