Improved Design & Construction Methodology for Urban Local Roads in Flood Prone Areas

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Abstract

Effective road asset intervention on local government networks through pavement rehabilitation is not always easy. Multiple challenges often exist that require unique engineering applications to satisfy the principles of optimal time-quality-cost. Local government engineers are well versed with encountering obstacles that don't always have the answers written into published guidelines or standards. Issues related to the repair of damaged roads that are regularly confronted, include geotechnical and geological inconsistencies, stakeholder expectations, commercial and policy constraints, and climatic influences.

Some challenges specifically faced in many Australian local council municipalities with a focus on engineering aspects include poor material qualities, types and thicknesses, coupled with restrictions on increasing surface levels due to flood zoning. This paper will reveal similar challenges faced by Byron Shire Council with the proposed rehabilitation of River Terrace in Mullumbimby, and how they were able to overcome them through implementation of a non-standard approach to the design and construction phases, both involving a double stabilisation strategy (a form of basegrade stabilisation).

The geotechnical investigation borehole logs indicated there was insufficient existing material (quality and thickness) to satisfy the proposed stabilisation design thickness. Byron Shire Council also indicated that the site was in a flood prone area and no allowances could be made to increase the road level. Further, removal and replacement of materials whilst considered somewhat acceptable from a technical perspective, was not given a high priority. With all of these constraints in mind, the recommended solution was to initially treat the existing pavement material and some subgrade material simultaneously with lime and let it ameliorate for at least 72 hours. The treated material was then stabilised with a suitable cementitious binder for strengthening purposes. The initial lime treatment was stabilised to a depth greater than the final cementitious treatment, to provide a residual working platform. Various testing regimes including use of the Clegg Hammer and falling weight deflectometer conducted post construction validated the significant improvements in consistency of the material and ultimately the strength gain achieved throughout the site.

Keywords: Stabilisation, flood, urban, rehabilitation, design

1. Introduction

River Terrace is a local road located in the town of Mullumbimby in northern NSW, which is approximately 20km northwest of Byron Bay. Both towns are part of the Byron Shire Council (BSC) jurisdiction.

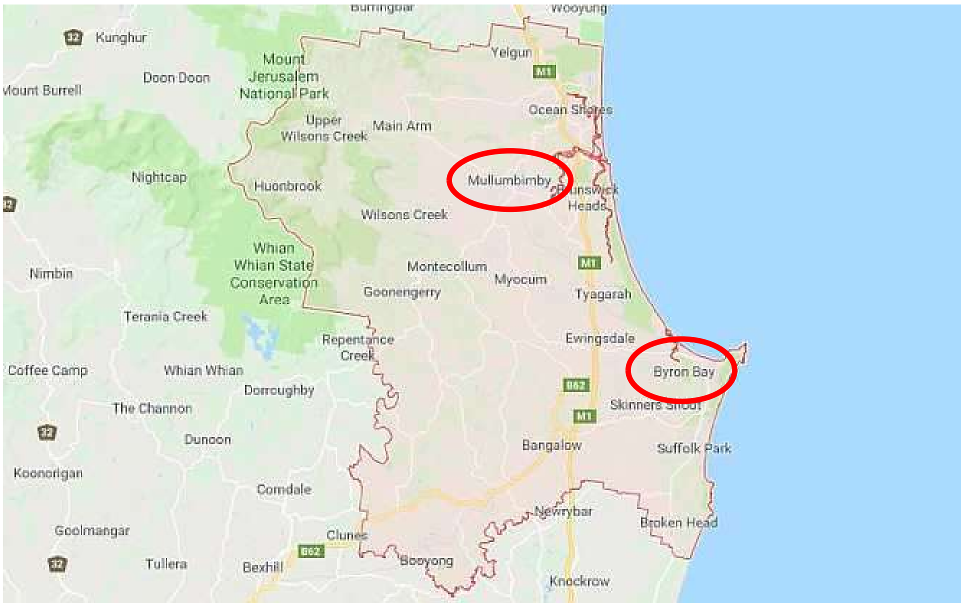

Figure 1: Byron Shire and Mullumbimby Locality

BSC identified that River Terrace was in need of repair due to the significant degradation observed in the wearing surface which showed signs of being caused by loss of integrity and structural capacity in the base course. BSC engaged an external consultant (Civil Consult) in the first half of 2023 to undertake a geotechnical investigation, supplemented by material sampling and laboratory testing. This work was to ultimately inform a series of pavement design options in a pavement rehabilitation report for BSC to consider. Their intent was to implement the rehabilitation works in the 2024 financial year. After BSC reviewed the report, they concluded that their budgeted funds for the project were unable to support any of the pavement rehabilitation design options.

At this juncture, BSC engaged another external consultant (SP Design) in August 2023 to provide advice on what other options may be available, with a specific reference to insitu stabilisation techniques. BSC's overarching objective remained which was provision of a rehabilitation solution to satisfy two key parameters, being a 20-year design period and the allocated budget. SP Design provided BSC with a proposal which involved review of the previous pavement design report and development of a new pavement design report.

2. Site Overview

River Terrace is located in the town of Mullumbimby, close to the central business district. The site is bounded by Burringbar Street to the north and Whian Street to the south. It is classified as an urban collector road on a bus route. The site is approximately 240m in length and has one lane in each direction with no line marking. The site also has an unsealed shoulder/parking bay on the western side between property number 14 and 17. Kerb and channel drainage exists in the northern end of the site on both sides of the road.

Figure 2: Mullumbimby (L) & River Terrace (R)

The limit of proposed pavement rehabilitation works was approximately 2,500m^2. The project also included some minor civil works (i.e. drainage) and additional asphalt surfacing on the northern end and in the parking lane adjacent to the industrial business accesses. Mullumbimby Creek runs adjacent to the western side of River Terrace. The Brunswick River is slightly west of Mullumbimby Creek. The eastern side of River Terrace is flanked by industrial and commercial premises.

Figure 3: River Terrace Features

The weighted mean annual pavement temperature is 31°C (for Byron Bay which has the closest weather station to the site), and the long term annual mean rainfall for Byron Bay is 1735.7mm. Not only does Mullumbimby receive rainfall on average almost half of the year (measured by days), River Terrace is located in area that is liable to become inundated with moisture when the Mullumbimby Creek breaks its banks and flood waters make their way towards the CBD. Hence, the site is classified as a flood zone which means BSC does not permit any increases to the level of the existing road whenever rehabilitation or resurfacing works occur. This is illustrated below by their fill exclusion zone limits.

Figure 4: Mullumbimby Fill Exclusion Zone

3. Site Condition

The images below have been reproduced from the Civil Consult report, indicating the condition of the pavement in mid-2023.

Figure 5: River Terrace Pavement Condition [2]

4. Site Geology and Existing Material Properties

River Terrace and the surrounding area of Mullumbimby is concentrated with alluvial floodplain deposits, comprising silt, very fine to medium grained lithic to quartz rich sand and clay. This geological form is illustrated below.

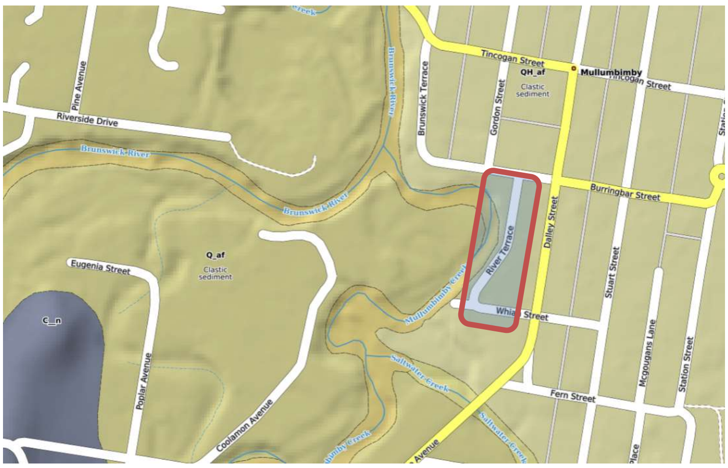

Figure 6: Geology mapping at and around River Terrace

The Client engaged Civil Consult to undertake the initial geotechnical field investigation in June 2023. 7 boreholes were excavated, two of which (BH02 and BH04) were excavated in the unsealed shoulder. DCP tests were undertaken on the subgrade at each borehole location. The site plan showing the borehole locations from the Civil Consult report is reproduced below.

Figure 7: Test Pit Locations [2]

The pavement profiles from each location are shown below.

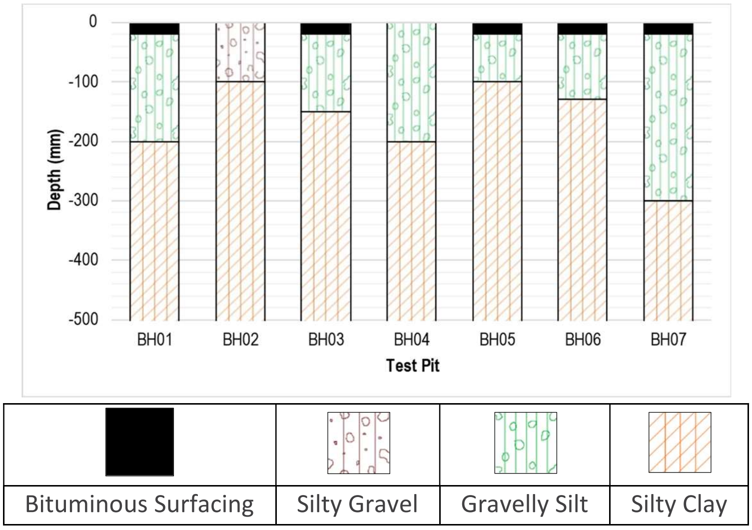

Figure 8: Existing Pavement Profile [4]

Excluding BH02 and BH04 (shoulder profiles), there was barely 200mm of material above the silty clay subgrade. This was validated when SP Design undertook an independent material sampling exercise in December 2023.

Figure 9: River Terrace Typical Materials

The base layer materials had an average of 17% fines and a plasticity index ranging from 4.0% to 12%. The subgrade samples exhibited variable CBR's and went as low as 4.5% with low to moderate swell being recorded. All samples were soaked for 4 days and it was noted that a 10-day soaking period would have been more representative of the site conditions. Further, the soaked samples were not fully saturated after the 4-day soaking period when the moisture content of the top 30mm was compared to the entire sample, suggesting that the CBR results may have been slightly over estimated.

5. Original Pavement Design

Civil Consults report provided two pavement design solutions for BSC to consider. The first was a granular remove and replace design, whilst the second was similar to the first, but included a stabilised subgrade. Design traffic was generated based on 1,000 vehicles per day with 10% heavy vehicles. The design details are shown below.

Table 1: Civil Consult Pavement Designs [2]

Layer	Details
Spray Seal	Double/Double (14mm/7mm aggregate)*
Priming Treatment	Cutback primer, AMC0 or AMC00
Base Course – DGB20	150 mm - CBR 35%
Subbase Course – DGS20 or DGS40	300 mm - CBR 25%
Natural Subgrade - Silty CLAY (CH)	CBR 4%
* A 40 mm thick asphalt seal (AC10) may also be acceptable as a seal if preferred by Council.	

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Spray Seal	Double/Double (14mm/7mm aggregate)*
Priming Treatment	Cutback primer, AMC0 or AMC00
Base Course – DGB20	150 mm - CBR 35%
Subbase Course – DGS20 or DGS40	150 mm - CBR 25%
Lime Stabilised Subgrade Insitu – 5% Lime Content	200 mm - CBR 10%
Natural Subgrade – Silty CLAY (CH)	CBR 4%
* A 40 mm thick asphalt seal (AC10) may also be acceptable as a seal if preferred by Council.	

BSC's cost estimate to construct the cheapest of the above two designs was $810,000. They did not have adequate funds to implement either of these design options, as both required significant excavation, disposal and material import costs. Further, both of these solutions did not address Council's desire to achieve optimum sustainability outcomes. This is where BSC engaged SP Design to provide additional advice.

6. Alternate Pavement Design

Discussions between BSC and SP Design revealed that a design solution to incorporate as much of the existing pavement as possible was desired. A design subgrade of 4.0% was adopted in line with the Civil Consult report, along with a design traffic loading (DESA) of 3.60E+05 for a 20 year design period [2]. The key challenges identified that were to be addressed in the design phase were:

i. flood zoning of the area, mandating no increase in surface level being permitted;
ii. a thin existing pavement comprising around 200mm of Gravelly Silt;
iii. variable materials throughout the site, particularly where the shoulders on the eastern side of the road were identified by BSC to be included in the scope;
iv. limited funds for the rehabilitation.

One of the design solutions was to excavate the base course material, stockpile it and then remove some of the subgrade to effectively lower its position. Whilst this strategy is a robust and sustainable solution, this was not seen as an economical or practical solution, as there was a high frequency of rain events that were occurring and predicted to occur in the area at the time. The emphasis was therefore placed on not doing any major excavation and attempting to recycle the pavement materials.

The design solution presented to BSC, was a process involving a double stabilisation treatment. The first process was to mix lime into a mixture of the existing pavement base and subgrade (i.e. basegrade stabilisation). The intent of this process was to lower the position of the subgrade to a depth of 300mm below the existing surface level, but without any excavation. All of the existing wearing course was incorporated into the mix. A curing period of 3 days minimum was nominated to enable the lime treated materials to ameliorate. Then the top 50mm of treated material would be removed to accommodate placement of the final wearing placement. Then the strengthening process would take place, whereby a second stabilisation treatment would occur to the design thickness of 200mm to generate a lightly bound base course layer, defined as having a UCS in the 1-2MPa range. The design cross section and basic construction process are illustrated below.

Figure 10: Pavement Design Cross Section [4]

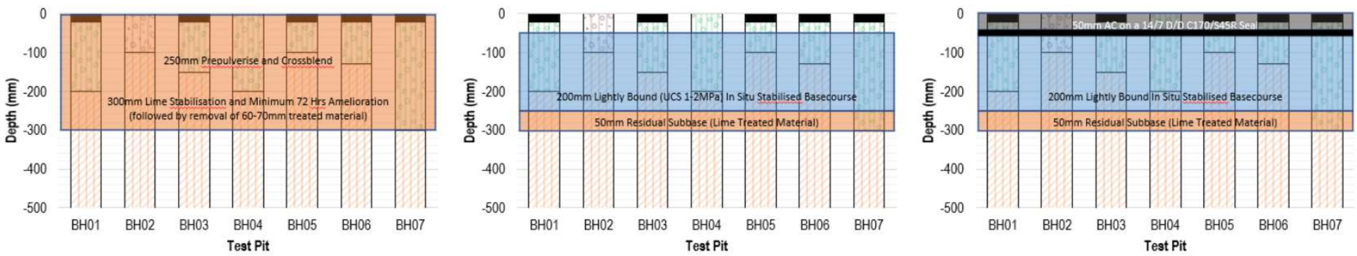

Figure 11: Construction Process [4]

BSC's cost estimate to implement the above was $337,000, which became the project budget. This was almost 60% less the cost estimate for the granular replacement solution. Further, the cost of the alternate design satisfied their budget allocation.

7. Stabilisation Mix Design

Stabilisation mix design trials were designed to replicate the design and the construction methodology. The process of stabilizing the same material twice with an amelioration period in between needed to be captured, with specific details provided to the testing laboratory to supplement the existing test method for unconfined compressive strength testing. The mix design trial methodology is shown below [5].

a) Conduct a Lime Demand (LD) test on the subgrade clay.
b) Adopt a lime content of LD+1%.
c) Breakdown all samples together to ensure accurate proportions of the bituminous wearing course, base gravel and subgrade are contained in the mixture. This is to reflect the initial prepulverising and crossblending phase.
d) Determine the OMC/MDD relationship of the mixture with LD+1% hydrated lime.
e) Mix hydrated lime at LD+1% into the material at OMC.
f) Prepare UCS cylinders.
g) Cure the samples whilst in the cylinders at 25 degrees for no less than 72 hours.
h) Break down the samples to reflect the second stabilisation mixing process.
i) Determine the MDD/OMC relationship of the mixture with 60/40 slag/lime.
j) Undertake UCS testing at 3%, 4% and 5% 60/40 slag/lime.

The lime demand test yielded a result of 2.0%, with a lime content of 3.0% being adopted. The results of the UCS trial with the cementitious mix design trials is plotted below.

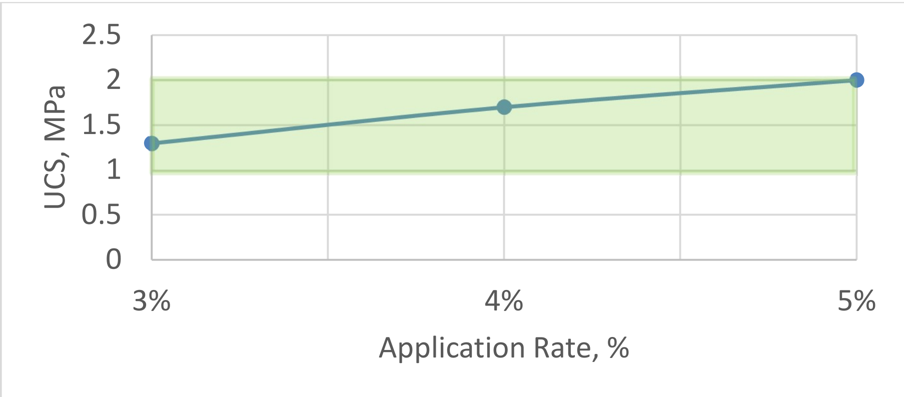

Figure 12: Trial Mix Design UCS Results [5]

Given the target UCS was 1.5MPa, an application rate of 4.0% was adopted. The filed targets are tabled below which were used for construction.

Table 2: Adopted Mix Designs [5]

	Application Rate, %	MDD, t/m³	Field Target Spread Rate, kg/m²
Hydrated Lime (1st Treatment)	3.0	1.96	18.0
60/40 Slag/Lime (2nd Treatment	4.0	1.94	15.5

8. Construction

The construction process that was specified is illustrated below.

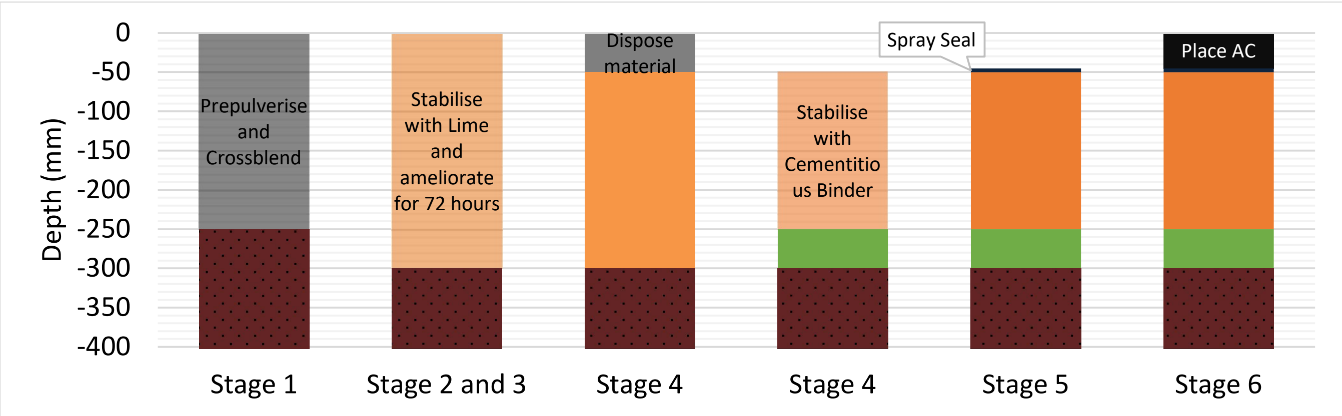

Figure 13: Construction Process [4]

The intent of the initial construction process requiring the material to be prepulverised and crossblended in line with AustStab (2006), was to improve the uniformity of the material to be stabilised so that uniform strength gain could be achieved as much as possible. A detailed description of each stage of the construction process is reproduced below [4].

a) Prepulverise and crossblend the existing pavement material to a depth of 250mm. The purpose of this activity is to improve the consistency of the pavement material type and thickness along the length and width of the site.
b) Stabilise the prepulverised material with hydrated lime to a depth of 300mm. Compact and trim to enable the road to be trafficked.
c) Allow the lime treated material to ameliorate for a minimum of 72 hours.
d) Remove and dispose 50mm of the lime treated material.
e) Stabilise the lime treated material with a suitable cementitious binder to a depth of 200mm.
f) Place sprayed seal SAMI.
g) Place 50mm AC14 C450.

The table below details the timeline that each construction activity took place.

Table 3: Construction Timeline

Date	Activity	Duration
10 April 2024	Prepulverisation and crossblending	1 day
12 April 2024	300mm lime stabilisation	1 day
13-15 April 2024	Amelioration	3 days
16 April 2024	Removal of 50mm of lime treated material	1 day
17 April 2024	Slag/Lime strengthening stabilisation	1 day
26 April 2024	Placement of SAMI seal	1 day
30 April 2024	Placement of 50mm AC wearing course	1 day

Although the total project time was 21 days , only 6 days were required where construction activities took place. After the initial lime stabilisation treatment was completed, there were two areas that exhibited deformation. The first was at the corner of River Terrace and Whian St. This was the lowest point of the site and Council noted this location had previously been subjected to numerous repairs. A soft subgrade replacement was undertaken by BSC which constituted less than 20m^2. The second area was slightly east of the previous noted location, in Whian St where a shallow domestic water service that traversed across the road was damaged during the recycling process. This caused an increase in moisture filtering into the subgrade in the immediate area. The SAMI seal was also delayed due to wet weather conditions.

Multiple images are displayed below to further illustrate various stages outlined above.

Figure 14: Spreading and Mixing Lime

Figure 15: Lime Treated Pavement during Amelioration Period

Figure 16: Soft Subgrade Repair

Figure 17: Mixing 60/40 Slag/Lime

Figure 18: Wet Weather Prior to Sealing

Figure 19: Bitumen Sealing

Figure 20: Post Asphalt Placement (01 May 2024)

9. Post Construction Testing

There were four approaches to the post construction testing undertaken on River Terrace. These were:

i. Density testing
ii. Unconfined Compressive Strength (UCS) testing
iii. Clegg hammer testing
iv. Falling Weight Deflectometer (FWD) testing

The density testing was performed on sampled retrieved from 6 locations along the length of the site. although the density ratios were observed to be favourable, the key indicator of success was the low coefficient of variation of the maximum dry density (MDD) and the optimum moisture content (OMC) determined from each sample extracted from behind the stabiliser that had mixed in the 60/40 slag/lime. This is illustrated below (chainage zero was at the southern end of the site).

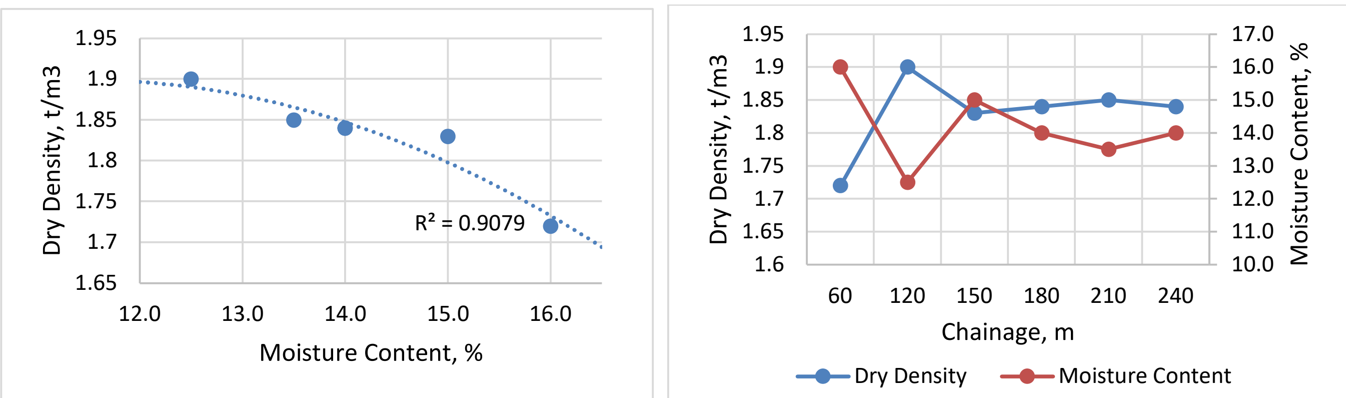

Figure 21: Dry Density v Moisture Content Post Lime Stabilisation

The UCS test results were considered unreliable due to a curing regime error. The prepared samples were subjected to load in the UCS testing apparatus after 7 days of curing in a 25 degrees Celsius temperature controlled environment. This curing regime was a blend of the test methods typically used in NSW and QLD, which are 7 days of accelerated temperature curing and 28 days at 23 degrees Celsius respectively.

The average Dry Density and Moisture Content was 1.83t/m3 and 14.2% respectively. Both sets of data had a coefficient of variation less than 9%, indicating material uniformity.

A digital 4.5kg Clegg Hammer was also used to observe the level of uniformity within the pavement. This Clegg Hammer typically provides Clegg Impact Values (CIV) based on the response to a dropped mass (similar to the mass in a CBR testing apparatus) on the surface, with a zone of influence of around 150mm. An illustration of the Clegg Hammer is depicted below, being used on River Terrace on the 17th April 2024 prior to the slag/lime stabilisation phase. The same test was carried out prior to the site being sealed on the 26th April 2024.

Figure 22: Clegg Hammer Testing

The results of the Clegg Hammer testing below (chainage zero was at the northern end of the site) further demonstrates the material uniformity that was created.

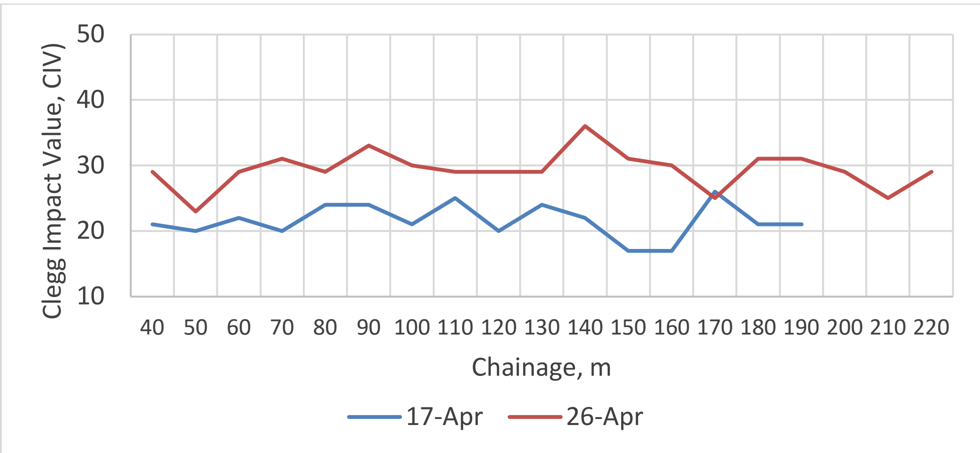

Figure 23: Clegg Impact Value

The coefficient of variation of the two sets of results from the 17th and 26th April was 12% and 10% respectively. The image below illustrates how uniform the material appeared from a visual perspective after the slag/lime stabilisation phase. This was attributable to the initial prepulverisation and crossblending phase, which considerably improved the uniformity of insitu materials.

Figure 24: Material Uniformity

After the project construction activities were completed, Oscorp Engineering was commissioned to undertake FWD testing on the pavement at 5m intervals in the left wheel path of both directions.

Figure 25: FWD Testing

The results from that deflection survey are illustrated below, by way of maximum deflection and curvature (chainage zero was at the northern end of the site for all plots). The blue line and orange line, denoted as 1/1 and 2/1 respectively relate to the southbound and northbound test runs.

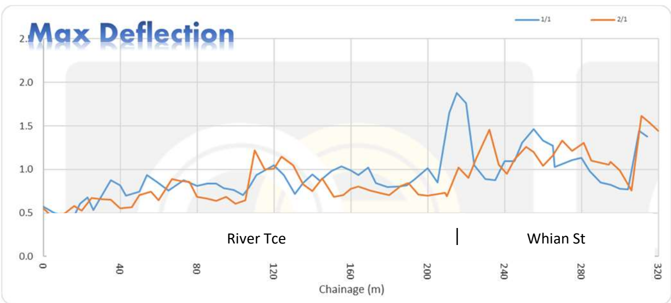

Figure 26: Maximum Deflection [3]

The high deflection between CH200 and CH240 was caused by the soft subgrade that was repaired at the corner of River Terrace and Whian St. The deflections in Whian St are generally higher than those in River Terrace, likely to have resulted from the slower dry back period after the rain event that occurred prior to the pavement being sealed. This was because Whian St has significantly more shady conditions compared to River Terrace. Further deflection tests in the future will likely produce more realistic indications of the pavement stiffness.

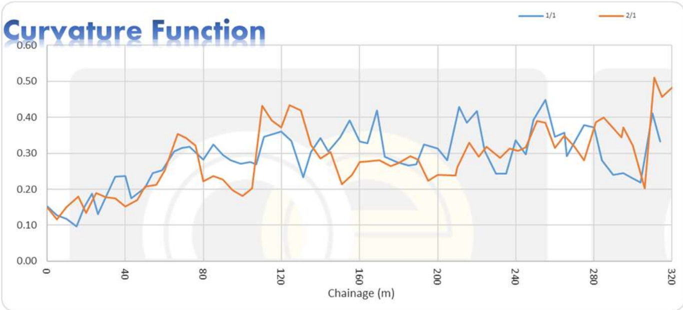

Figure 27: Curvature [3]

The consistency in deflection and curvature of the pavement, particularly between the southbound and northbound lanes is illustrated in the plots below. Both sets of plots indicate reasonably consistent material stiffness onsite, based on the similar medians and small size of quartile ranges in the ox and whisker plots, as well as the very good correlation between the deflection and curvature values.

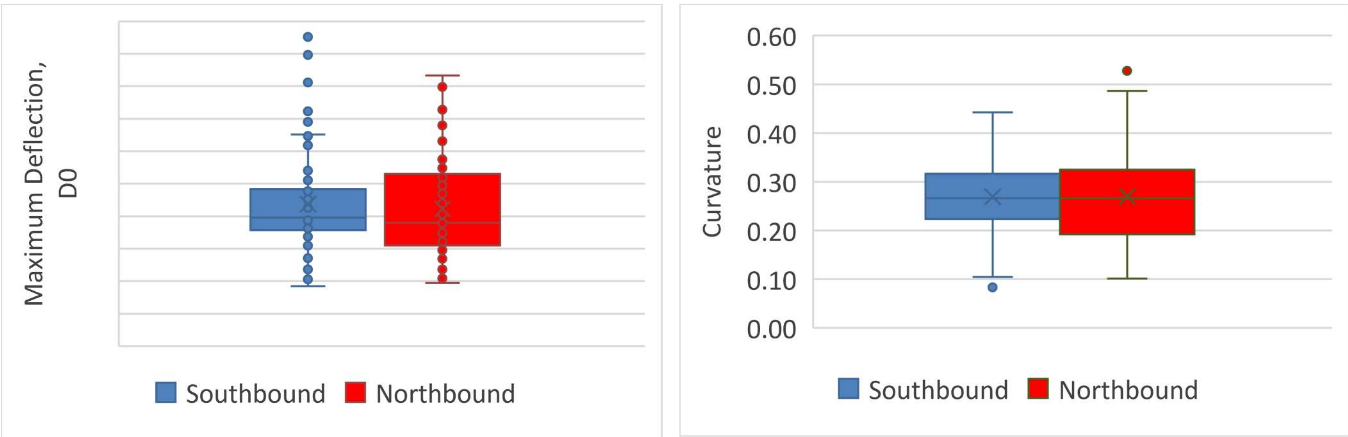

Figure 28: Max. Deflection (L) and Curvature (R)

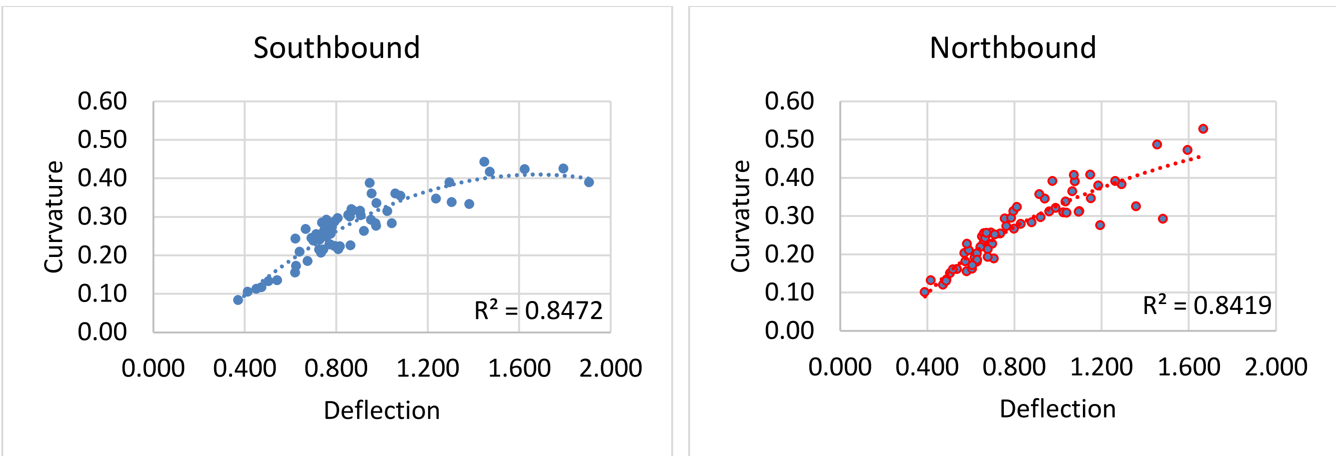

Figure 29: Deflection v Curvature

10. Project Economics

BSC's original budget was $337,000 which was nearly 60% less than the traditional remove and replace alternative that was originally designed and proposed. After the project was completed, BSC provided all of the costs associated with the project which are tabled below.

Table 4: Project Costs

Item	Qty	Unit	Rate	Total Cost	% of total
Project management	1	item	$ 19,191.67	$ 19,191.67	6%
Geotechnical investigations/designs	1	item	$ 16,080.00	$ 16,080.00	5%
Site establishment/prelims	10	days	$ 3,131.51	$ 31,315.10	9%
Traffic control	12	days	$ 1,604.89	$ 19,258.68	6%
Initial seal	3720	m2	$ 6.14	$ 22,840.80	7%
40mm AC10 Asphalt	3185	m2	$ 32.57	$ 103,735.50	31%
Pavement stabilisation	2475	m2	$ 39.11	$ 96,797.25	29%
Earthworks/drainage	1	item	$ 21,721.97	$ 21,721.97	7%
			Total	**$ 330,940.90**	

With around 80% of the project costs being the actual pavement works, it is clear that the stabilisation element (at only 29% of the project total) provides a significant cost-benefit, given it provides the structural component of the pavement system. The average unit cost of the project was approximately $110/m^2.

11. Conclusion

The rehabilitation of River Terrace in Mullumbimby initially presented multiple challenges to Byron Shire Council. These challenges are not unique to this Council, where restrictions on finished surface levels, flood zoning, thin pavements and variable existing pavement are encountered. A unique solution was implemented involving a double stabilisation strategy. This enabled the aforementioned challenges to be overcome by initially improving the non-uniform nature of the road through the use of prepulverisation and crossblending. This activity is recommended to be adopted on any pavement stabilisation project where existing materials are not considered highly uniform. Secondly, the thin pavement challenge was overcome by lowering the position of the subgrade through the first lime stabilisation treatment of the pavement. The strengthening treatment was then able to be implemented onto a pavement that had not just uniform materials, but with adequate depth of cover. The reason for the double stabilisation strategy as opposed to a traditional single stabilisation treatment, was to position the depth of the subgrade beneath the strengthen base layer and provide additional resistance during time of flooding and/or high moisture. The 'additional resistance' would be found from having a 'buffer' between the subgrade and the strengthened base, as well as enabling a higher probability of achieving higher densities in the strengthened base due to being compacted onto a subbase, rather than the subgrade.

12. Acknowledgements

Byron Shire Council in the first instance are to be acknowledged for their willingness to explore new ideas in their region. In particular, Councils Manager Works Sam Frumpui and Operations Coordinator Kirk Weallans were instrumental in the initial stages of getting this project off the ground.

Shein Tun from SP Design played an integral role in the pavement and mix design phase.

The construction teams comprising Byron Shire Council and Stabilised Pavements of Australia were committed throughout the entire process and took the unique processes in their stride.

Construction Sciences are to be thanked for their contributions with multiple aspects of this project. The team based at Kingston for undertaking the mix design phase and working through UCS trials that were not strictly in accordance with published test methods due to the double treatment strategy. The team based on the Gold Coast also contributed with construction compliance testing.

Oscorp Engineering provided a valuable weekend service to undertake FWD testing on the finished pavement. Their flexibility in accommodating schedules is always appreciated.

13. Authors' Biography

Scott Young is the National Technical Manager for Stabilised Pavements of Australia and Principal Engineer (Pavements) for SPA’s pavement engineering consultancy, SP Design. Scott is a Registered Professional Civil Engineer with Registered Professional Engineering accreditation in Queensland and Victoria. Scott also holds a Master of Pavements where his research thesis produced a mix design procedure for basegrade stabilisation which has been used in multiple states of Australia. Scott has been in the pavement construction and rehabilitation industry for 27 years and is a past director and President of Australia’s national association, AustStab. He was also granted Honorary membership to AustStab in 2023 for his contributions to the industry. Scott is on the REAAA National Pavements Technical Committee and is convenor of AustStab’s National Technical Working Group.

Zach Fryer is a Civil Engineer currently working as the Construction Coordinator at Byron Shire Council. I am responsible for the project management and delivery of several Capital Works Projects in the Byron Shire. A childhood spent growing up around construction inspired a career in civil engineering. A graduate in Civil Engineering from Griffith University and years of practical experience has provided Zach with a high-level of practical and theoretical knowledge in the construction industry. In recent years Zach has taken a high interest in pavement design and in particular stabilised pavements. Zach has been a strong advocate for stabilising within the Byron Shire, recognising that the council is frequently impacted by multiple constraints, particularly budgetary ones. Stabilisation has yielded excellent, long-lasting results for the council, offering significant value for money compared to traditional pavement reconstruction techniques.

Andrew Middleton is currently the Engineering Manager and Regional Manager (Nth NSW) for Stabilised Pavements Australia (SPA). Andrew is a leader in the implementation of practical pavement rehabilitation solutions and drawing on his 35 years’ experience (all with SPA), supported by appropriate testing and design rigor, he has delivered numerous design and construct pavement rehabilitation projects valued in excess of $100M in Australia and the UK. Andrew is a nationally respected expert and leader in the field of road recycling through the use of stabilisation solutions. Andrews’ influence in the road industry is evident with his provision of a succession of successful road recycling solutions to Local and State Government asset managers and pavement designers. Andrew has regularly been consulted by State Road Authorities such as TfNSW on road recycling/stabilisation innovations and improvements reviews and amendments to standards and specifications (e.g. R50, R75 and R76).

14. References

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