Improving the bearing capacity and all-weather accessibility of Australian soils.

With an area of 1,727,000 square kilometres, Queensland is the second largest state in Australia. Queensland is nearly five times the size of Japan, seven times the size of Great Britain, and two and a half times the size of Texas.(Ref1)

With a mountain range running the full length of the state the climate can be described as "Wet" and "Dry". Approximately one third of the central portion is comprised of a soil type described as vertosols.

Vertosols are the most common soil in Queensland—characteristics include:

- brown, grey or black soils which crack open when dry
- they commonly form hummocky relief called gilgai
- very high-soil fertility—ability to supply plant nutrients
- large water-holding capacity.

These soils are the cracking clay soils of the Darling Downs and Central Highlands. A large belt of grey and brown Vertosols also run from the New South Wales border to Charters Towers. Dry they bake like bricks. Wet the become unable to bear loads

Since 2016 Quantum Ground Stabilisation Pty Ltd (QGS) have associated with the University of the Sunshine Coast and Pavement Management Services Pty Ltd to research the properties of the Consolid group of products, through laboratory and field trials, using final year Engineering (honours) students. This was done in order to understand the efficacy of the products to improve (in situ) bearing capacity and all-weather accessibility of Vertosols in Road, Rail and Hard standing (Wind and Solar farms) projects

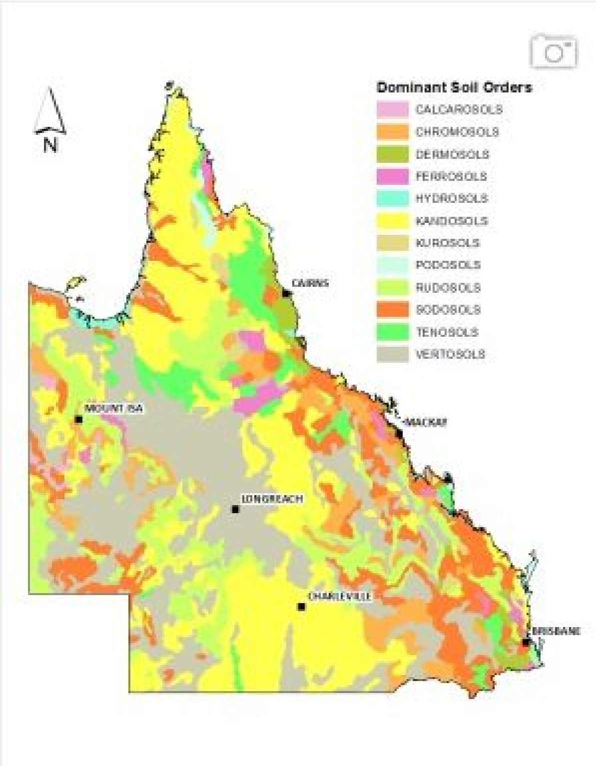
In 2019 QGS undertook accreditation throughout Australia under the "Transport Infrastructure Product Evaluation Schemes (TIPES) process – a 4 year evaluation of the laboratory and field behaviour of the system.

This paper describes the results of the four-year University trials and compares the outcomes with the requirements being undertaken through the TIPES investigation

Introduction

The state of Queensland, Australia, is very large and diverse. The Queensland Government website (Website) (reference 1) reports that Queensland is nearly five times the area of Japan, seven times the area of Great Britain and two and a half times the size of Texas.

Soil types are wide spread dominated by what is known colloquially as "Black Soil" , technically as "Vertosols" – Figure 1



Dominant soils across Queensland

Figure 1 Dominant Soil types across Queensland

[1]Vertosols can be black or grey, in colour, and are characterised by:

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[1]Shaun Callanan 2018 "Further Investigations into the Efficacy of a Soil Stabilisation Product for use within Australian Pavement Design "

Objective of the research

The objective of this research was to test the long-term performance of the Consolid stabilisation system and provide additional support for the recognition of this product throughout Australian pavement design.

Method of research

Each procedure and basis of testing for this project are as follows:

1. Falling Weight Deflectometer testing – to calculate the parameters used for Resilient modulus estimation by back calculation
2. Elmod6 pavement software – to calculate the resilient modulus of the treated road through back-calculation and compare with previous results
3. Moisture testing – to determine whether moisture content of treated pavement is increased by excessive rainfall and if so, is strength affected
4. Laboratory CBR testing – to verify the claims of the Consolid system in increasing bearing capacity, and which materials are best suited to treatment
5. Visual inspections of the treated road – to identify any cracking, potholing, or deformation

Location of research

These investigations and testing processes were conducted at Bracalba Quarry and the University of the Sunshine Coast between June and September 2018.

Visual inspection

Visual inspections of the trial site at Bracalba quarry were undertaken throughout to identify possible.

- Potholes
- Cracks
- Deformation
- Overall structure

The first site visit/visual inspection took place on the 19 July 2018. The second visual inspection was undertaken on the 23 August 2018 (same day as the FWD test). The third and final visual inspection took place on the 9 October 2018.

A first site visit was conducted on Friday 20th July where a thorough visual inspection of the treated section of road was undertaken.

The section was in good condition and showed no visible defects or signs of degradation. Erosion was minimal.

No major repairs have been undertaken however dressing and watering occur frequently.

Grading occurs at approximately two-week intervals, where 26mm greenstone scalps are added for protection and cover, partially acting as the recommended asphalting layer.

This constant addition of material may assist in a change to the road structure since construction. A water truck is used for dust suppression, spraying approximately 2L/m2 5-10 times daily depending on weather conditions.

Figure 4 facing NW on 20 July 2018

Figure 5 facing SW on 23 August 2018

Figure 6 facing 9 October 2018

As can be seen, no major abnormalities can be found and there is no difference in condition between the three visits. It must be noted that no differences were visually identified at chainage 15m where stiffness of the treated pavement was decreased.

Deflection Testing

Deflection testing was undertaken on 23 August 2018 , 866 days after the initial construction.

Figure 3.4 shows the Co-ordinates of the test points used to ensure the test points were as close as possible to the FWD testing conducted in Hayden Curran's investigation. The parent load for the first three drops at each test point was 40kN (between 565 – 575 kPa) and the fourth drop was 60kN. The first drop is considered a test drop, whereas drops two and three should be used for analysis and will produce similar results. A drop of 60kN (drop 4) was performed as an alternative and to provide further structural and material analysis.

Figure 7 FWD deflection points for both the Curran and Callanan studies

Days since installation	MEAN Resilient Modulus (MPa)	
	Treated (250mm)	Untreated (400mm)
14 Days	279	572
41 Days	475	523
90 days	721	516
158 days	823	424
866 days	1127	727

Table 8 Resilient Modulus results (by FWD) from Bracalba site

Moisture content

Rainfall data was obtained through the buerau of meteorology to be used in conjunction with sensor data to better understand the product's efficiency.
This data included.

- Daily rainfall for the entire period since the moisture sensors were installed
- Daily rainfall for March 2018 – in which significant rainfall occurred
- Monthly rainfall for the two-year period between September 2016 – September 2018

Bureau data was downloaded into excel format and compiled within the same spreadsheet as moisture sensor data for analysis and collation.
The moisture content for each layer treated with the Consolid system has been continuously recorded by the sensors installed as part of road construction. The average moisture content for

layer one (125mm below surface) and layer two (250 mm below surface) in September 2016 was 10.4% and 9.9% respectively.
The moisture content of both layers has fluctuated over time, however layer two has shown a greater increase. At September 2018, the moisture levels sit at 10.5% and 10.45% for layers two and one respectively. These moisture readings show an increase from the type 2.5 material’s optimum moisture content of 8.6%, As seen in figure 8, the moisture percent within the pavement is increased after months with significant rainfall, however delayed.
February and March 2018 received large rainfall totals, making it useful for pavement moisture content analyses for this investigation. As shown in figure 9, daily moisture content recorded by both sensors moved a total of +0.5%. Again, this rise in moisture content was delayed after rainfall, indicating that the claim of waterproofing is realistic. Although the Consolid system does not completely inhibit water infiltration into the treated unbound granular material, the effects of moisture do not appear to reduce its stiffness as shown by modulus results.

Figure 8 Monthly moisture content (after Callanan)

Moisture content was shown to slightly increase with rainfall after a delayed amount of time

Figure 9 Daily Moisture Content for March 2018 (after Callanan)

Laboratory CBR Testing

The CBR is a fundamental test for determining the bearing capacity of soil. Laboratory testing was performed by Soil Engineering Services (SES) on Consolid treated materials for comparative analysis. The purpose of obtaining these test results was to verify and compare data to the relevant theory of unbound granular material CBR’s and the suitability of Consolid treatment for various soils. CBR tests were performed on two different soils to determine the strength of each material after treatment with the Consolid system. The following soil types were used for testing:

- Type 2.5 granular unbound material (road-base) sourced from Hanson quarry Ferny Grove
- Gravelly brown/Dark silt composite soil sourced from a Queensland Railway site

Soaked and Un-soaked samples of each material without additive were tested. The same testing was performed on each material after the addition of Consolid. Standard compaction was performed on each sample at optimum moisture content and left to cure in a sealed container for a four-day period before penetration. The testing methods were carried out in accordance with AS1289 – Methods of testing soils for Engineering purposes.
Testing of the 2.5 road-base occurred on 14 December 2016 and testing of the composite occurred on the 20 July 2018.
The laboratory testing the above material described as composite was said to contain a high percentage of coal dust and ash

Results
Source
CBR
Percent Increase
Control
Treated with Consolid
Ferny Grove Quarry type 2.5 gravel
16
210
>1000%

Lower Liquid Limit

Lower Plastic Limit

Plasticity Index

Linear Shrinkage

Gravelly Silt – dark brown- Queensland Rail

42

78

>150%

Lower liquid limit

48

48

Lower plastic limit

41

41.6

Plasticity Index

7.0

6.4

Linear Shrinkage

3.4

3.0

Table 9 Comparison of CBR results for two materials

Riley Brooks 2019 “Investigation into the improvement of Soil, Shear properties using a soil stabilisation method”

This investigation builds upon the work done by Hayden Curran and Shaun Callanan in 2016 and 2018 respectively, where a new, non-traditional stabilisation material was proven to improve structural properties of Ins-situ pavement material. Shear box and unconfined compression testing was conducted on material treated with the Consolid stabilisation system to assess and compare the shear strength of treated and untreated material. Over 30 samples with various concentrations of Consolid were carried out with both qualitative and quantitative analysis of the data undertaken. The efficiency and effectiveness of the stabilisation method Consolid was tested by simulating the shear forces experienced under substantial traffic levels.

Project Objective

The project aim was to investigate how the soil stabilisation product Consolid performs in a simulated roundabout environment, by addressing the following objectives:

1. Investigate and compare the shear strength properties of untreated In-situ soil with soil treated with the Consolid stabilisation system.
2. Analysis the failure modes of treated material when placed under shearing stress.

Material

The granular material selected for this investigation is type 2.3 road base, this has been chosen based on the recommendations for the base and subbase layers of unbound pavement material in a typical Queensland pavement structure (TMR MRTS05 2018). The material has been collected from Hanson Construction Materials at Mount Beerwah Road, Glasshouse Mountains. Laboratory analysis by Douglas Partners of the granular material was conducted prior to treatment with the following soil characteristics identified.

- Particle Size distribution
- Optimum Moisture Content (OMC)
- Californian Bearing Ratio
- Lower Liquid Limit
- Lower Plastic Limit
- Plasticity Index
- Moisture Density Relationship

Sample Preparation

The preparation and treatment of the unbound granular samples utilised testing apparatus provided by USC laboratories. The process followed the standards outlined in Part 4D Stabilised Materials of the Austroads Guide to Pavement Technology.

Treatment with C444

The first activity was to prepare the required quantity of Consolid 444 solution for each sample by mixing the concentrate with water to achieve the desired dilution amount. The amount of C444 concentrate used was 100mls which was then diluted with 400mls of water. The solution was then applied at application rates of 0.8 and 0.4 Litres per cubic Metre. The specific amount of solution needed for each sample was calculated by multiplying the area by litres solution. To ensure accuracy and uniformity, the two fractions of stabilising material were weighed off accordingly. 0.01 cubic metres of type 2.3 soil was placed into two mixing buckets and applied with 80mls and 40mls of C444 solution respectively to achieve the desired application rates.

Treatment with Solidry

Consolid Australia recommend that Solidry be applied to the top 40% of the treated soil material (Consolid Aust 2018). Solidry is a powdered chemical that required the addition of water at a 1:1 mix for a working solution. The Solution was applied at a rate of 40Kg/m^3 and 20 Kg/m^3 to the two mixing buckets.

Placement and Compaction

Immediately after both components of the Consolid stabilisation system were added to the soil material the mixing process began. This process required a small shovel to thoroughly mix additives through the soil and to comply with Consolid design specification. Water was then applied and thoroughly mixed through both soil samples; the amount of water used was sufficient to obtain the optimum moisture content stated by Douglas Partners for compaction. Stabilised soil was then placed into sample boxes for compaction and curing.

Compaction of the stabilised material was consistent for each sample, once the soil was placed into the box a wooden mallet was used to replicate the forces and pressure experienced in the field by graders and rollers. Each sample was hit a total of 10 times by the wooden mallet at similar forces to generate a compacted material. The final phase of treatment required the stabilised soil samples to cure for a total of seven days before testing could begin.

Direct Shear Box Test

The automated direct shear box test was provided by the University of the Sunshine Coast and was performed on laboratory compacted and stabilised soil samples. The samples were tested on the 12th of September 2019, tests were conducted on soil samples at a constant shearing rate of 5mm/min. In total, eighteen individual tests were performed under three imposing normal forces ranging from 20 KPa to 60 KPa.

Unconfined Compression Test (UCT)

The Unconfined Compression test was used to determine and compare the compressive strength of treated and untreated soil samples in accordance with ASTM D2166 / D2166-16.

Following on from the compaction and stabilisation of treated and untreated material outlined in, soil samples were placed into cylindrical moulds for the 7-day curing period. The cylindrical shapes required trimming in order to ensure the ends were reasonably smooth and the length-to-diameter ratio was roughly 2.

The testing procedure involved a total of nine tests using the UCT, three samples were tested at 0, 50 and 100% of the recommended application rate for the Consolid stabilisation system. The three results for each application rate were then averaged and used to characterise the shear strength. The UCT samples were all loaded vertically with lateral confining pressure equal to zero to ensure the sample experienced shearing failure. The strength characteristics are defined as the maximum stress applied to the specimen during the testing.

Particle Size Distribution

AS Sieve Size

Minimum

Maximum

% Passing

Particle distribution

PSD Category

37.5

100

100

23

Gravel

19.0

80

100

100

9.5

55

90

97

4.75

40

70

70

62

Sand

2.36

30

55

55

0.425mm

12

30

30

0.075mm

5

20

15

15

Clay

Table 10 Particle Size Distribution for Hanson Quarry material

Physical Characteristics of Parent Material

Parent Material for stabilisation by Consolid for Optimum Results

Attribute

	Minimum	Maximum	Value
Lower liquid Limit	25	50	23.2
Lower Plastic Limit	18	25	18.6
Plasticity Index	10	25	4.6
Linear Shrinkage	3	12	Not reported
CBR%			108
Dry Density			2.05
Optimum Moisture Content			10.6

Table 11 Physical Characteristics for Hanson Quarry material

Shear Box Test Results

Table 12 Shear Test results for Hanson Quarry material

Unconfined Compression Strength

Consolid Concentration

Sample Number

Compressive Strength

Shear Strength

% improvement

% improvement

0%

1

105.11

52.56

2

96.2

48.1

3

85.78

42.89

50%

1

209.5

200

104.75

220

2

243.66

250

121.83

250

3

220.51

230

110.26

230

100%

1

310.55

320

155.28

320

2

305.96

320

152.98

320

3

290.68

300

143.34

300

Table 13 Unconfined Compressive and Shear Strength for Hanson Material

Improve = ratio of test result for Consolid additive to MEAN of Untreated Material i.e., for compressive Strength Mean = 95.7 KPa and Shear Strength, Mean = 47.85 KPa. These figure to be compared with the 50% improvement in unconfined compressive strength as required by the TIPES accreditation

Summarised Results

The following table consolidates all results obtained to date compared with the TIPES criteria

Properties

Standard

Criteria

Test Results

% improvement

Threshold Value

% improvement

Untreated

Treated

Maximum dry density

AS 1289.5.4.2

5.0

2.218

2.168

nil

Optimum MOISTURE content

AS 1289.5.4.2

0.5

7.8

8.0

nil

Bulk Mass

RMS T133

10

50

Not tested

Rate of mass loss

RMS T186

2.0

50

Not tested

Permeability

AS 1289.6.7.1

$3.0x10^{-7}$

$3*10^{-9}$

$2*10^{-10}$

1000

Absorption (%)

AS 5101.5

2.0

50

Not tested

Swell (%)

AS5101.5

1.5

300

-0.5

0

Capillary rise (%)

AS 5101.5

25

50

Not tested

California Bearing Ratio (%)

AS 1289.6.1.1

15 - 80

50

16

210

1300

Indirect tensile resilient modulus (MPa)

AS 2891.13.1

1000-2000

50

284

1127

400

Unconfined compressive strength (MPa)

AS 5201.4

1.5 – 3.0

50

0.2

1.8

300

Liquid Limit

>25

Parent Material

Plastic Limit

>18

Plasticity Index

>10

Linear Shrinkage

>3

Conclusions

1. It is clear from these studies that the addition of Consolid 444 and Solidry to a variety of Australian soils can have a beneficial effect to improving the bearing capacity and inhibiting the movement of water within a pavement.
    a. Claims, 1,2,3,4,5 and 7 are sustainable.
2. For optimum results in road building the base material should have equal components of Gravel, Sand and Silty Clay and a Plastic Index in excess of 10
3. Whilst at this time , not all attributes required by TIPES accreditation have been tested, there is sufficient and persuasive evidence to warrant that the required Bearing Capacity and all-weather accessibility of roads will be improved by the application of Consolid 444 and Solidry to materials meeting the requirement a TMR 2.5 , (A2 or E4) grading with a high liquid and Plastic limits

Specification for Parent Material

AS Sieve Size	Minimum	Maximum	% Passing	PSD Category
37.5	100	100		Gravel
19.0	80	100	100	
9.5	55	90	97	
4.75	40	70	70	Sand
2.36	30	55	55	
0.425mm	12	30	30	

- widespread cracking when dry
- Commonly form a hummocky relief called gilgai
- Very high soil fertility
- Large water holding capacity
- Good Bearing capacity when dry and
- Impassable when wet

Silt

0.075mm

5

20

15

Clay

Table 13 Particle Size Distribution for parent material

Attribute

Minimum

Maximum

Lower Liquid Limit

25

Not yet specified

Lower Plastic Limit

18

Plasticity Index

10

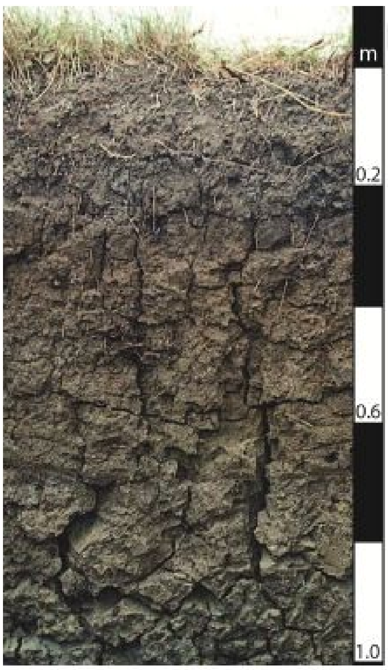
Linear Shrinkage

3

References

1. Queensland Government Web Site - Queensland soils
2. ARRB Group "TIPES Guide for Applicants – Supplement Non-Traditional Chemical Stabilisation Binders "
3. **Fitzpatrick Sam 2015** "
4. **Curran, Hayden 2016** "Waterproofing of Natural materials to improve bearing capacity"
5. **Callanan, Shaun 2018** "Further Investigations into the Efficacy of a Soil Stabilisation Product for use within Australian Pavement Design "
6. **Brooks, Riley, 2019** "Investigation into the improvement of Soil, Shear properties using a soil stabilisation method"

Figure 2 Typical "Black Soil" of Central Queensland



Vertosol soil in Beaudesert, Queensland.

Ferrosols and Dermosols

Ferrosols are well-drained soils with red or yellow-brown colour and have clay-loam to clay textures.

This soil type is usually associated with previous volcanic activity and is mainly located along the Great Dividing Range. Large areas of these soils occur around Kingaroy and Atherton where they are used for intensive crop production.

Dermosols are red, brown, yellow, grey or black and have loam to clay textures. This type of soil covers the higher-rainfall coastal and sub-coastal regions. Important areas of these soils are the Burdekin delta and the Lockyer and Fassifern valleys.

The climate of Queensland is frequently described as two seasons -“wet” and “dry” with occasional cyclones bringing heavy rain in what is colloquially known as “the Knock-em - downs “ torrential rain causing wide spread flooding.

Central Queensland is amid a construction boom with major projects underway in road, rail and hard standing (wind and solar farms),

It is within this background that the University of the Sunshine Coast (USC) in association with Quantum Ground Stabilisation (QGS) and Pavement Management Services (PMS) have undertaken research by Honours Engineering students to understand the efficacy of the Consolid Group of products for in situ improvement of the all-weather accessibility and bearing capacity of this marginal group of soils

This work has culminated in an application by Quantum Ground Stabilisation for accreditation of the Consolid group of products under the “Transport Infrastructure Product Evaluation Schemes (TIPES) process – a 4-year evaluation of the laboratory and field conditions to test the claims of the products.

This study summarises the work of each of the students and outlines the processes to be undertaken by QGS in association with UCS and PMS

Claims of the Consolid Products

The Consolid System is a chemical substance which breaks up the adhering water film leading to an irreversible agglomeration of fines thus substantially reducing the capillary rise of water and allowing better compaction of the treated soil and increases required density under traffic when compared with untreated soil,

CONSOLID 444 has the following characteristics:

- Improved compactability by changing the water characteristic in the soil
- Reduction of water absorption by reducing the capillary activity
- Reduced water permeability
- The Optimum Moisture Content of treated soil is lower and the density is higher
- Strong reduction in swelling and shrinking behaviour

SOLIDRY is a dry, inorganic powder.

- SOLIDRY prevents the treated soil from water ingression by closing the capillaries.
- The capacity of water absorption is reduced, which stops the swelling behaviour of the soil.

Advantage of CONSOLID SYSTEM in relation to Cement and lime additives

- Absence of curing time, dress, heavy roll and immediately use
- Mixed soil can be stored for unlimited time and remain fully effective
- Environmentally safe and compatible
- Easy to apply in the field

The following characteristics are claimed by the Consolid System

- **CLAIM 1** The Consolid System is a two-part system that beneficiates the load bearing capacity of natural gravels and soils for road making purposes:
  - One part lubricates the particles enabling greater compaction
  - The other fills capillary voids mitigating against soil moisture movement
  - The nett result is improved shear strength of the natural material
- **CLAIM 2** The Consolid System is not a cementing agent:
  - Is therefore not prone to shrinkage problems
  - It can be reworked in service without loss of integrity
  - It can be stockpiled for unlimited time prior to compaction for repair use
- **CLAIM 3** The Consolid System improves the bearing capacity of natural gravels and soils by:
  - Enhancing compaction through reduction in the capillaries between soil particles
  - Mitigating against soil moisture increase thus maintaining the integrity of the natural cohesion and interparticle fiction
- **CLAIM 4** The Consolid System manifests these benefits through:
  - Increased unconfined compressive strength
  - Improved shear strength
  - Reduced permeability to ground water and rainfall
  - Long-time effect, European roads have been maintenance free for greater than 30 years
  - Large tolerance in soil varieties for treatment
  - Suitable application is made easier due to the unchanging and constant rate of application per m3 each of C444 and Solidry.
- **CLAIM 5** The Consolid System works the same with any type of soil as it activates the cohesive forces of the soil and substantially and lastingly reduces the influence of water. The Consolid System modifies the soil permanently and thus is used in-situ or in a premixing procedure at a plant. The bearing values of the treated soil allows for a notably higher bridge function in the bearing layers and thus a risk-free reduction in the thickness of the wearing course.
- **CLAIM 6** The Consolid System has a proven track record:
  - Europe 44 years
  - Asia 20 years
  - South America 20 years
  - Australia 3 years
- **CLAIM 7** Construction practice and application rates are **Not Variable**
  - The construction thickness is generally recognised as 250mm
    - Mechanically mixed in two passes
      - Pass 1 Consolid 444 at application rate of 0.8 litres per cubic metre
      - Pass 2 top 100mmm 40 Kilograms per cubic metre
    - Plant mixed in two materials 150mm thick subbase, 100mm base
      - Application rates remain unchanged
  - The variable is the end result attributes. These are used to design the surfacing thickness and type or to leave unsealed
- **CLAIM 8** Suitability of parent Material
  - For optimum results the parent material should be composed of one third gravel, one third sand and one third silty and clay. To give a particle distribution of

AS Sieve Size	Minimum % Passing	Maximum % Passing	PSD Category
37.5mm	100	100	Gravel
19mm	80	100	
9.5mm	55	90	
4.75mm	40	70	Sand
2.36mm	30	55	
0.425mm	12	30	Silt and Clay
0.075mm100	5	20	

- Lower Liquid Limit > 25
- Lower Plastic Limit > 18
- Plasticity Index >10
  - Free from deleterious substances
  - Free from excess organic matter
  - Free from high concentrations of sulphate ions

Soil Moisture Capillary Brick Test:

Where in-situ soils diverge from the preferred one third each clay, gravel and sand, the capillary rise of the parent material is determined by an in house brick test, the outcome of which will determine the need for importation of any of the missing components

These claims are tested in the following analysis and the TIPES Stage Field Trials

"Transport Infrastructure Product Evaluation Schemes" (TIPES) process – description

TIPES (reference 2) is designed for the technical evaluation of products that fall outside the scope of established standards and specifications.

An initiative of State Road Authorities and ARRB it is intended to fast track the acceptance of new and innovative products to be used in the construction of roads.

Hitherto acceptance of overseas technology has been a difficult and tenuous process. In one of authors experience it took fourteen years to finally obtain approval for Falling Weight Deflectometer technology by all State Road Authorities.

TIPES accreditation does not necessarily apply to other construction areas such as rail and hard-standing, cases which are becoming of greater importance in the "black soils" of central Queensland

Evaluation is undertaken by an "expert" panel over a period of three to four years duration and consists of a three stage approach:

PHASE 1. APPLICATION

The Application and supporting documentation is reviewed and assessed by ARRB.

PHASE 2: INITIAL ASSESSMENT

ARRB appoints a Product Evaluation Panel. The Product Evaluation Panel members assess the application and documentation provided by the Applicant and specify any additional testing required (laboratory or otherwise).

Typical of the requirements demanded by the phase 2 assessment are given in Table 2 following:

Properties	**Standard**	**Criteria**	
		Threshold Value	**% improvement**
Maximum dry density	AS 1289.5.4.2		5.0
Optimum MOISTURE content	AS 1289.5.4.2		0.5
Bulk Mass	RMS T133	10	50
Rate of mass loss	RMS T186	2.0	50
Permeability	AS 1289.6.7.1	$3.0x10^{-7}$	
Absorption (%)	AS 5101.5	2.0	50
Swell (%)	AS5101.5	1.5	300
Capillary rise (%)	AS 5101.5	25	50
California Bearing Ratio (%)	AS 1289.6.1.1	15 - 80	50
Indirect tensile resilient modulus (MPa)	AS 2891.13.1	1000-2000	50
Unconfined compressive strength (MPa)	AS 5201.4	1.5 – 3.0	50
Liquid Limit			
Plastic Limit			
Plasticity Index			
Linear Shrinkage			

Table 2 Requirements for Phase 2 Assessment under TIPES

Phase 3 FIELD PERFORMANCE TRIAL

The Product Evaluation Panel develops an evaluation plan for the Field Performance Trial. The Product Evaluation Panel observes the use/installation of the product at the field performance trial. The Product Evaluation Team monitors the field performance trial as required over its agreed duration, where possible long enough to understand a product life cycle.

Properties	**Standard** [123]	**Test Method**
Ride quality & serviceability	Austroads AG:AM/T001	Pavement roughness measurement with an inertial laser profilometer

Surface Shape	Austroads AG:AM/T009	Pavement rutting measurement with a multi-laser profilometer
Shrinkage & Structural cracking		Photographic assessment of cracking
Texture Depth	Austroads AG:AN T013 Austroads AG:PT/T250	Pavement surface Texture measurement with a laser profilometer
Bearing Capacity	Austroads AG:AM/T006	Pavement deflection measurement with a falling weight deflectometer
Skid Resistance	RMS 231	Frictional Resistance by Griptester (if appropriate)
Permeability	RMS T168	Determination of in situ infiltration of water into a road pavement

Table 3 Requirements for Phase 3 assessment under TIPES

Studies to date

Since 2015 four Engineering students in their final honour's year have been tasked with understanding the characteristics of various soils modified by the Consolid products – Consolid 444 and Solidry. These students are:

- **Fitzpatrick Sam 2015** "
- **Hayden Curran 2016** "Waterproofing of Natural materials to improve bearing capacity"
- **Shaun Callanan 2018** "Further Investigations into the Efficacy of a Soil Stabilisation Product for use within Australian Pavement Design "
- **Riley Brooks 2019** "Investigation into the improvement of Soil, Shear properties using a soil stabilisation method"

Fitzpatrick

Sam Fitzpatrick examined the effect of the Consolid group of products with three local subgrade materials -

- Image Flat quarry overburden
- Obi Obi Quarry overburden
- Moy's Pocket 2.3 road base

By studying the Resilient Modulus under repeat loading configuration. The results were inconclusive except to demonstrate that for best results with Consolid 444 and Solidry it is important to ensure that there is some mechanical stabilization required and the concept of 1/3rd Gravel : 1/3rd Sand :1/3rd Clay needs to be adopted for optimum results.

Material	Untreated Modulus (MPa)	Treated modulus (MPa)
Image Flat Overburden*	646	538

Obi Obi Subgrade	471	637
Moy’s quarry overburden *	494	318

Table 4 Resilient Modulus under repeated load for 3 materials

- No gravel component.

For this reason, it was recommended to insist on a minimum of a Queensland Main Road Type 2.5 subbase as the requisite gradation Curve. For use in the in improvement of bearing capacity and all-weather accessibility for roads

This gradation curve is to be adopted for all future trials.

See over leaf.

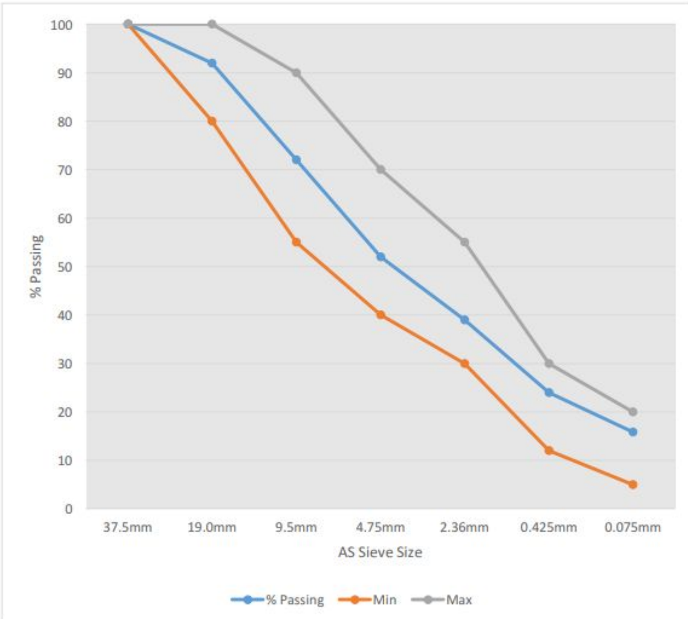


Figure 1 Recommended Grading Curves for Optimum performance with Consolid 444 and Solidry

Hayden Curran 2016 “Waterproofing of Natural Materials to improve bearing capacity”

The Curran (2016) study was an attempt, to build on the Fitzpatrick study by creating a field trial under real time traffic. This field trial to be conducted at Bracalba Quarry operated by Brisbane City Council. An area of 240 square metres was to be treated to a depth of 250mm. This was to be compared to an untreated section of the same dimensions, but 400mm thick instead of the proposed 250mm thickness to compare the effective price difference in materials cost

Parent Material

The parent material was a quarry overburden with the following properties:

Gradation

AS Sieve	Min	Max	% Passing Particle Distribution	Particle Distribution	PSD Category
37.5 mm	100	100	100	41	Gravel
19.0 mm	80	100	81		
9.5mm	55	90	59		
4.75mm	40	70	42	24	Sand
2.36mm	30	55	30		
0.425mm	12	30	18		

0.075mm	5	20	11.5	12	Clay

Table 5 Particle Size Distribution for Parent Material

Atterberg Limits

Attribute	Min	Max	Value
Lower Liquid Limit		40	31
Lower Plastic Limit		14	18
Plastic Index		7.5	13.6
Linear Shrinkage	Not specified	5.8	
CBR		7.4	
@ Moisture Content		10.7%	

Table 6 Soil Characteristics of parent material

Testing

The finished product was tested for bearing capacity using a Dynatest Falling Weight Deflectometer owned and operated by Pavement Management Services (PMS).Capillary rise in the material was monitored by in situ soil moisture equipment supplied by Pacific Data Systems. As this equipment is designed to measure moisture content for agricultural purposes, laboratory calibration was undertaken against known moisture contents of the parent material so that moisture content could be reported as engineering units.

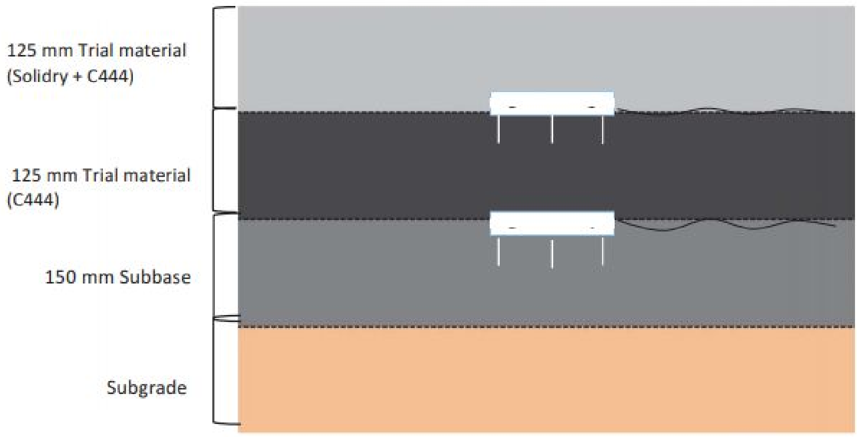


Figure 3.11 - Position of Moisture sensors in material

Figure 2 Schematic diagram of the positioning of soil moisture gauges in the test pavement

These moisture gauges can give a reading of dielectric and electrical conductivity as well the temperature. Rainfall was also recorded at the site. Results are obtained every 15minutes and transmitted every day by sim card to a safe portal

Application Rates

The application rates were computed by Quantum Ground Stabilisation to be :

- Consolid 444 0.2l per square metre
- Solidry 1% to 2% of dry weight i.e. 2 Kg to 4 Kg per square metre

Method

The test site was boxed out to a depth of 250mm and a mixing pad established in the proximity.

Initially 52 tonnes of the parent material were spread on the mixing pad and 45 litres of Consolid 444 applied evenly across the sample.

Mixing was conducted by a power harrow in 5 passes to ensure completeness

The material was then transported to the test site, graded and compacted with a pad foot compactor.

Another 52 tonnes were placed on the mixing pad and the Solidry spread at the rate of one 5Kg bag to 6 square metres of material and the 45l of Consolid 444. This material was added to the test site making a final depth of 250mm fully compacted.

The same material (untreated) was placed adjacent to the test site to a depth of 400mm. Thus, the trial would be comparing 250mm of treated material against 400mm of untreated material.

Results- Falling Weight Deflectometer

Test results from the two sites were as follows.

Days since installation	MEAN Resilient Modulus (MPa)	
	Treated (250mm)	Untreated (400mm)
14 Days	279	572
41 Days	475	523
90 days	721	516
158 days	823	424

Table 7 Resilient moduli for treated and untreated sites at Bracalba Quarry

Results Moisture content

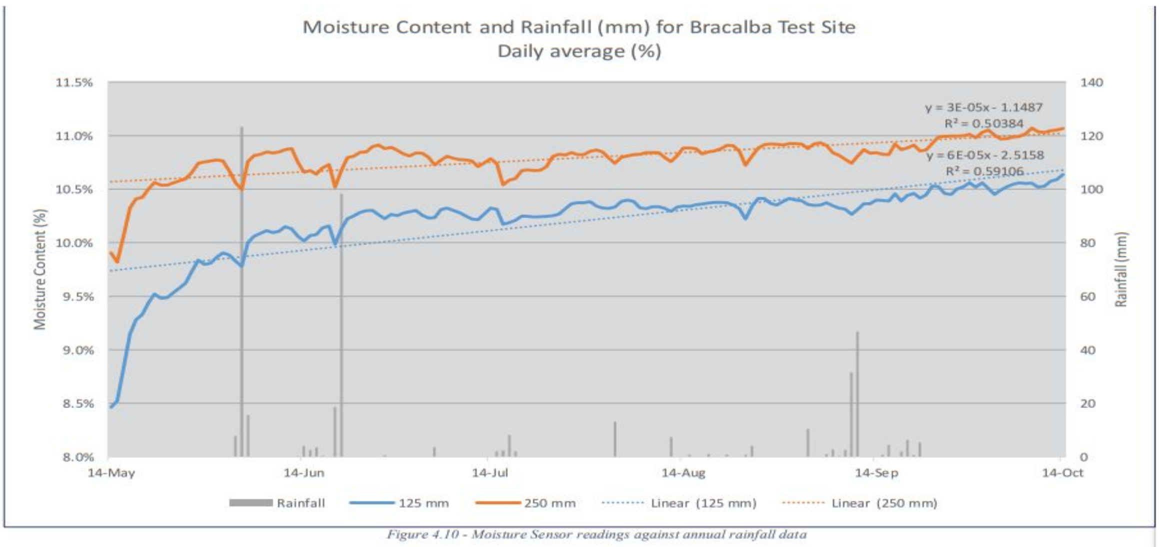


Figure 3 Soil Moisture and rainfall Chart from May 16 to 14 October 2016

From which it can be seen that the moisture content of both layers remains reasonably consistent even after rainfall in excess of 100mm.