Int. J. of GEOMATE, Sept., 2014, Vol. 7, No. 1 (Sl. No. 13), pp.955-960
Geotech., Const. Mat. & Env., ISSN:2186-2982(P), 2186-2990(O), Japan

A STUDY OF THE PARAMETERS AFFECTING THE PERFORMANCE OF ROADS UNDER AN EXTREME RAINFALL EVENT

Helen Fairweather and John Yeaman

Faculty of Science, Health, Education & Engineering, the University of the Sunshine Coast, Australia

ABSTRACT: Sunshine Coast Regional Council has recently upgraded a section of Sippy Downs Drive adjacent to the University of the Sunshine Coast campus. Prior to opening, the pavement was instrumented to monitor strain and moisture in the surface and the subgrade layers and the temperature under the surface layer. At the time of installation, traffic was light, as University classes had not yet commenced. Traffic increased when classes commenced in February 2013 and is projected to grow substantially as a new suburb and two major shopping centres are built over the next three years. Data are recorded every minute and downloaded by mobile phone connection every 24 hours. These data are analysed automatically every day. Six weeks after opening, a major rainfall event occurred with nearly 500mm of rain recorded over three days. The paper discusses the impact on pavement strain as a function of changing moisture content and temperatures. These data have potential for identifying future maintenance requirements.

Keywords: Pavement Monitoring, Subgrade, Asphalt Pavement

1. INTRODUCTION

The Sunshine Coast Council undertook an upgrading of Sippy Downs Drive adjacent to the University of the Sunshine Coast (USC) during 2012. The road works included a duplication of the carriageway, the installation of traffic lights at the main entrance to the University, an upgrade of the secondary entrance and streetscaping including drainage incorporating Water Sensitive Urban Design (WSUD) installations.

The purpose of the road works was not only to provide improved access to the university for the ever burgeoning student population but also to cater for future traffic demands of the growing Sippy Downs Township. This township includes a planned new suburb of 50,000 residents and two major shopping malls.

During late 2011, Engineering at USC was seeking projects for students completing their final year in Civil Engineering. These major projects are equivalent to a 0.5 study load conducted over a full year. The projects are designed to test the student’s knowledge gained over the previous three years of study. In addition, the project thesis should be as demanding as a Science Honours Thesis, which is conducted over a full year.

Engineers with the Sunshine Coast Council agreed that the Sippy Downs road works provided a suitable site to install instrumentation to assess pavement performance parameters under operational conditions. An additional advantage of the Sippy Downs site is that it will be under the influence of increasing traffic (volumes and loads) over the next five to ten years.

This report is limited to an analysis of data received from the instruments at the site between the 24th and 28th January 2013 during a cyclonic rainfall depression.

The configuration of the instruments also fits in with the research being undertaken by a Higher Degree (by research) student whose study is “Intelligent Highway Engineering and Maintenance Optimisation”. Therefore the data being collected will be utilised by this student over the next three years. It is anticipated that further final year undergraduate engineering projects will also be possible using this site over the coming years.

2. EXPERIMENTAL DESIGN

The first undergraduate engineering student working on this project in 2013 was tasked with sourcing preferred equipment and arranging its installation into the pavement. The aim of the monitoring is to determine the pavement performance as a function of strain and moisture measured at two locations (bottom of the bound layer and top of the subgrade layer) and pavement temperature underneath the bound layer.

The instrumentation and road works were completed in December 2012 and monitoring commenced on the 19th December. Over the Australia day long weekend (25th to 28th January 2013) a cyclonic rainfall depression passed through Sippy Downs with total rainfall over the period of three days of nearly 500mm. During this period the monitoring station remained operational and continued to provide details of the strain, moisture and temperature every minute.

3. STUDY BACKGROUND

The objective of this study is to understand the behaviour of a newly constructed section of road under extreme weather conditions. Achieving this objective will provide the basis to use this study site to further investigate pavement behaviour under real traffic conditions.

Traditionally pavement performance has been tested using Accelerated Pavement Testing (APT) facilities. These facilities generally include a heavy vehicle simulator [1]-[2].

Instrumentation of pavements in-situ is a relatively new advancement, but has mostly been limited to a localised and short-term installation [3]. These authors are developing a smart monitoring system using a 'pebble' sized strain sensor. The size of this sensor and the development of a reliable long-term energy supply will eventually allow a multitude of these sensors to be installed during construction [3]. However, to date, it appears that this system has only been installed in a test facility.

4. MONITORING THE TEST SITE

The pavement under test is part of a major upgrading of Sippy Downs Drive (Fig. 1). During the construction it was decided to instrument the pavement so that the parameters affecting pavement performance could be monitored continuously.

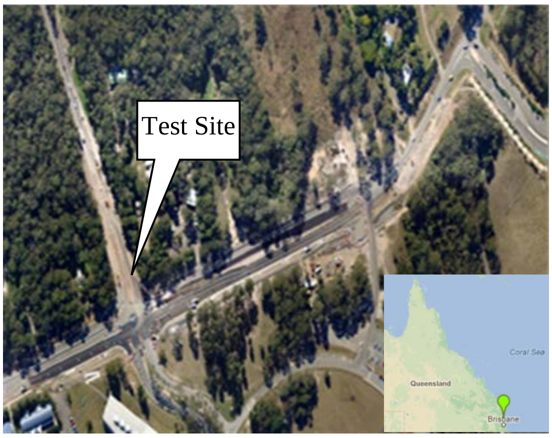

Fig. 1 Test site location, Sippy Downs Drive, Queensland.

The test site is on the upstream direction from the traffic lights at the intersection and in the outer wheel path of the median lane. It is now recognised that this may not be the optimum position as the traffic is relatively fast moving. In addition the surface layer of this lane may not be fully compacted due to the closeness of the kerb and concern of the roller operator that damage may occur to the gauges.

From observations, this lane receives the least traffic except in peak periods such as start and finish times at the adjacent school and university. In hind-site the optimal position would be where the traffic is slower moving and is generally concentrated.

Notwithstanding the above limitations, measurements being taken every minute of every day provide considerable data for analyses. Data are being streamed to the writers' desks on a daily basis, with updated data being streamed every three minutes for strain and moisture content and temperature.

4.1 Monitoring Equipment and Placement

The configuration of the instrumentation and data logger are described below with the indicated depths all measured from the top of the asphalt. The centres of the strain gauges are at depths of 115mm and 395mm in the surface and subgrade layers, respectively. The moisture content gauges are placed at the bottom of the surface and subgrade layers at depths of 395mm and 670mm, respectively. The temperature sensor is installed in the surface layer at a depth of 70mm.

4.1.1 Data Logger

The key to the data collection facility is the data logger. For this installation a dataTaker DT82EM Series 3 Data Logger was chosen as it has several desirable features; ultra-low power design, integrated cellular modem, automatic data transfer to email or FTP, support for up to 10 SDI-12 sensors, and can house up to 6 (30V) sensor units.

The software associated with this equipment provides a continuous and visual data feed. The logger is configured so that each morning the previous day's data is emailed direct to the researcher's computer. This process has enabled real time processing of the 1400 lines of data from 5 transducers, with the ability to upgrade to more transducers as deemed necessary.

4.1.2 Strain Transducer KM 5000

The KM series strain transducers are designed to measure strain in materials such as concrete and pavement layers. Their extremely low modulus $\left(\mathbf{40}\,\frac{\mathrm{N}}{\mathrm{mm}^2}\right)$ and waterproof construction make them ideal for this type of test. The built in thermocouple sensor in the surface layer measures temperature in addition to strain. Both strain gauges were embedded in the pavement vertically.

The installation of the strain gauges was according to the manufacturers' convention. For vertical installation, the manufacturer advised positive strain (+ve) indicates values in compression and negative values (-ve) indicates value in tension.

4.1.3 Soil Moisture Content Sensor

For this study the Theta probe ML2X was chosen as the preferred instrument for measuring moisture. The measurement accuracy of this probe is quoted at ±1% with a measurement range of up to 50% volumetric moisture content. This capability was considered ideal for this study**.**

4.1.4 Power Source

The whole system is powered by a 13.5 long-life battery charged by a solar panel; Steca Solsum Range - 6.6F, Solar Charge Regulators, 12/ 24 V, load current 6A, with LVD 1 Solarwatt Solar panels rated at 40W.

5. LOGGING AND CALIBRATING THE DATA

5.1 Equilibrium Moisture Content

From the 19th December 2012 through to the 23rd January 2013 (43 days) a period of stable hot and dry weather conditions dominated. The readings (at one minute intervals) for this period were analysed to determine if this stability translated to a stable moisture content measured in each of the layers.

The optimum moisture content for each of the unbound component materials is 8.6% [4]. The moisture content measured over the 43 day hot and dry period is considered to provide the equilibrium state. The average moisture content over this period was 15% and 18% from the surface layer and subgrade layers, respectively. An analysis of the 6300 moisture contents measured during the hot and dry period indicated reasonable consistency as the baseline for detecting changes in moisture content with time (Table I).

Table I Equilibrium moisture contents

Layer	Mean	Std Dev	C of V
Surface	15.5%	0.69%	4.4%
Subgrade	18.5%	0.51%	2.8%

5.2 Calibration of Strain Data

In an attempt to relate the strain measurements to axle loads, a calibration exercise was undertaken on the 6th March 2013. The Sunshine Coast Council provided a single axle, dual tyre truck loaded with 8.2 tonnes on the rear axle. Tyres were inflated to 760 KPa. This unit made 10 passes over the test site between the hours of 9:30AM and 10:30AM and again between the hours of 1:30PM and 2:04PM. These times were chosen as this is when the pavement appears to be generally at the median of the temperature regime. The strains, moisture contents and temperature were recorded for each pass (Table II).

Considering only the 'TEST TRUCK' results shown in Table II, the temperature in the morning test run increased from 27 to 28°C. During this time the strain in the surface layer varied from -23 to -30με for a moisture content stabilised at ~18.1%. For these runs, the strain in the subgrade layer varied from -4 to -9με for a relatively steady moisture content of ~18.74%.

For the afternoon runs, and again considering only the 'TEST TRUCK' results in Table II, the surface temperature increased from 33.7 to 34.4°C. The corresponding surface layer strain increased from -81 to -84με (tension), while the moisture content remained steady at ~18.03%. In the subgrade layer the strain ranged from -51 to -54με, for a moisture content steady at 18.79%.

During the calibration test two other heavy different vehicles drove over the instrumentation and these results are recorded in Table II for interest. The very large strains recorded when the TEST TRUCK was parked on the test site for 3 minutes (-971 and -305με in the surface and subgrade layers, respectively) indicates the impact of this static load is greater in the surface, though the change in the subgrade layer is substantial.

6. EXTREME WEATHER EVENT RESULTS AND DISCUSSION

6.1 Australia Day Weekend, 2013

Between commissioning of the equipment on the 19th December 2012 and 24th January 2013, a period of high temperatures and zero rainfall was experienced at the site. During this period the streetscape planting of grasses, trees and shrubs was watered manually.

6.1.1 Rainfall

From the 25th to 28th January a cyclonic depression passed over the site with high winds and large rainfall amounts recorded (Table III). Over the five days the total rainfall recorded was 479mm.

6.1.2 Moisture Content

In the surface layer the moisture content was stable, fluctuating between 16.5 to 17% on the 25th January. The moisture content rose rapidly from 5:00PM on the 26th January to a maximum of 20% at 4:30PM on the 28th and falling to 18.3% by 9:00AM on the 29th January (Fig.2).

Table II Calibration data collected on the 6th March 2013 using a vehicle with a known load (TEST TRUCK)

	Surface layer			Subgrade layer		
Time	Strain (με)	Moisture (%)	Temperature (°C)	Strain (με)	Moisture (%)	Remarks
9:48:00	-24	18.1	27.0			TEST TRUCK
10:06:23	-27	18.2	27.6	-4	18.76	TEST TRUCK
10:14:25	-55	18.1	27.8	-23	18.74	Truck with Excavator
10:17:32	-35	18.1	27.8	-9	18.74	TEST TRUCK
10:23:25	-23	18.1	28	-7	18.74	TEST TRUCK
10:30:30	-57	18.1	28.1	-20	18.74	Bus followed by TEST TRUCK
13:30 to 13:33	-971	18.03	33.5	-305	18.79	TEST TRUCK parked on site for 3 minutes
13:36:33	-84	18.03	33.7	-53	18.79	TEST TRUCK
13:43:24	-82	18.03	33.9	-51	18.79	TEST TRUCK
14:03:38	-81	18.04	34.4	-54	18.79	TEST TRUCK

Table III Rainfall at Sippy Downs during the cyclonic depression in January 2013

Day	Date	Rainfall (mm)
Thursday	24th	42
Friday	25th	52
Saturday	26th	92
Sunday	27th	198
Monday	28th	95

Similarly, the subgrade layer had a stable moisture content fluctuating between 17.8 to 17.9% between the 24th and 25th January. The moisture content in the subgrade layer rose steadily from about 2:00PM on the 27th January to a maximum of 19.6% at 3:00PM on the same day (Fig. 3).

6.1.3 Temperature

The temperature of the surface layer varied from a minimum of 35°C at 9:00AM and maximum of 51°C at 4:30PM on the 24th January. From the 26th to the 29th January the temperature remained relatively constant fluctuating between 27°C and 29°C (data not shown).

Surface layer temperatures averaged ~42°C prior to the event. However, during the event the average dropped to ~25°C. The temperature returned to the pre-event average on the 29th January. This behaviour prompted a further evaluation of the respective influence of temperature and moisture on the critical strains.

6.2 Critical Strains

During this cyclonic event the surface layer strain moved from compression to tension on the 25th January. The surface layer strain returned to compression on the 31st January (after the ex-tropical cyclone event).

At the time of the above surface layer strain changes, the subgrade strain moved from compression to tension with a maximum tensile strain of around 60με on the 29th January. Subgrade strain showed signs of recovery by the 30th January after which no further rainfall was recorded (Fig. 4).

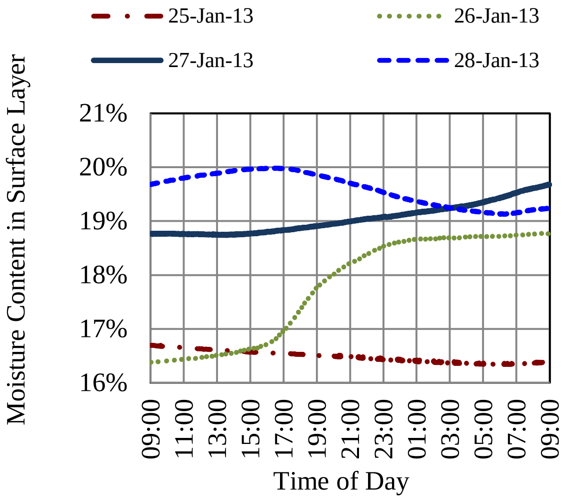

Fig. 2 Surface layer moisture contents recorded over the period 25th to 29th January 2013.

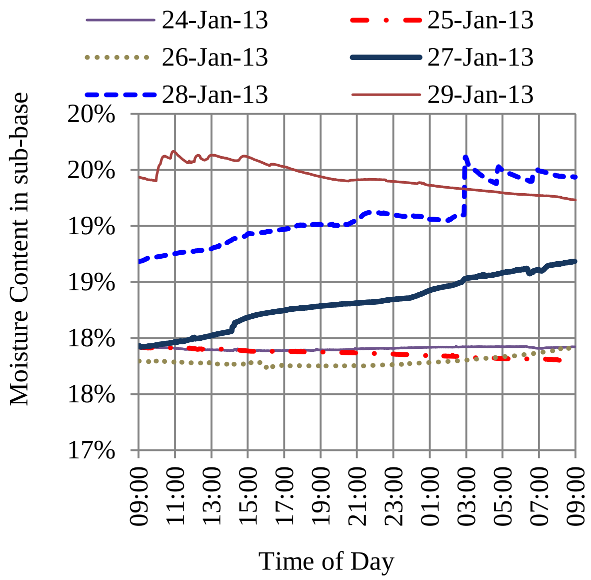

Fig. 3 Subgrade layer moisture contents recorded over the period 24th to 29th January 2013.

6.2.1 Strain and Moisture Content Relationships

There is reasonable correlation between surface layer strains and change in moisture (R^2=0.31), at a constant temperature. The surface layer strains increase in tension with increasing moisture content, when both variables are averaged over a constant temperature (Fig. 5).

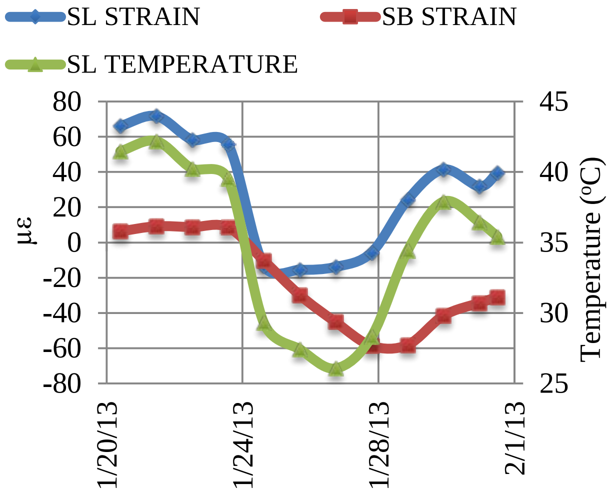

Fig. 4 Surface layer strain (SL STRAIN, blue diamond and line) and temperature (SL TEMPERATURE, green triangle and line) and subgrade strain (SB STRAIN, red square and line) measurements.

The correlation between the strain and moisture in the subgrade layer is slightly higher (R^2=0.58), with the strain increasing in tension as moisture content rises (Fig. 5). Again a constant temperature is used to average strain and moisture content.

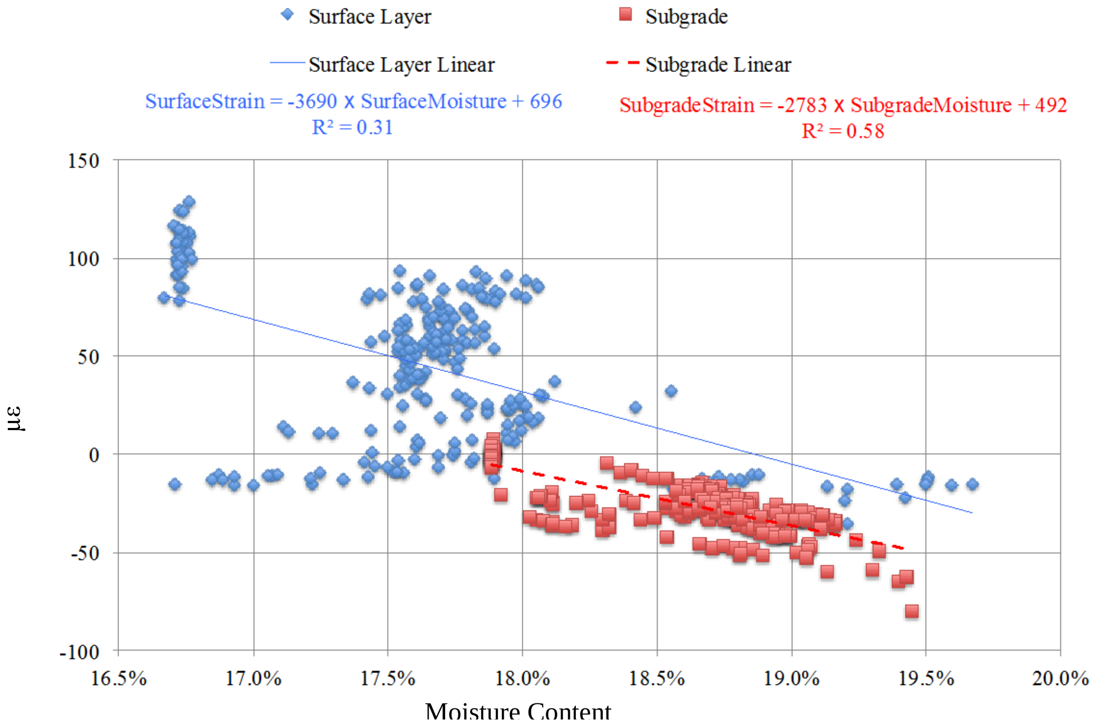

Fig. 5 Strain as a function of moisture content (averaged over constant temperatures) for surface and subgrade layers.

There is good correlation (R^2=0.73) between the strain in the subgrade layer and the surface layer moisture (both averaged over constant temperature). The strain in the subgrade layer increases in tension as surface layer moisture content increases (figure not shown).

6.2.2 Strain and temperature relationships

There is a strong relationship between surface layer strain and temperature (R^2=0.85), with strain becoming increasingly positive with increasing temperature. At temperatures above ~32ºC the strain switches from tension (-ve) to compression (+ve) (Fig. 4).The relationship between the strain in the subgrade layer and surface layer temperature is not strong (R^2 = 0.20).

7. CONCLUSIONS

An extreme weather event over a four-day period provided an opportunity to assess the potential damaging effect to a roadway from known critical damage determinants. These determinants are tensile strains at the underside of the bound pavement and compressive strains on the subgrade. The collected data showed that in the surface layer the temperature is a key determinant of pavement performance. The strains in the subgrade layer were seen to be predominately in tension irrespective of surface layer temperature.

There is only a small correlation between surface layer strain and moisture. A stronger correlation was observed between the strain and moisture in the subgrade layer. Further research will develop methods to utilise these data to more precisely predict pavement failure and therefore better target road maintenance.

8. REFERENCES

[1] Chen D, Zhou F, Cortez E "Determination of load damage relationships through Accelerated Pavement Testing", J. of Testing and Evaluation, ASTM, Vol. 34, Jul. 2006, pp. 312-318.

[2] Chen T, Chang J Chen D, “Applying data mining technique to compute LDE for rutting through full scale Accelerated Pavement Testing”, Road Materials and Pavement Design, Vol. 9. 2, 2008, pp. 227-246.

[3] Lajnef N, Rhimi M, Chatti K, Mhamdi L and Faridazar F, “Toward an integrated smart sensing system and data interpretation techniques for pavement fatigue monitoring”, Computer-Aided Civil and Infrastructure Engineering, Vol. 26, 2011, pp. 513–523.

[4] Cardno Bowler, Density and moisture ratio test results, “Unpublished”, Report Number 3747/R/2157-1, 2012.

Int. J. of GEOMATE, Sept., 2014, Vol. 7, No. 1 (Sl. No. 13), pp.955-960.

MS No. 3131 received on June 13, 2013 and reviewed under GEOMATE publication policies.

Corresponding Author: Helen Fairweather