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FINAL REPORT

Project Title: P41: Investigation of Instrumentation for Real-Time Condition and Performance Monitoring of In-Service Pavements (2014/15)

Project No: 007194

Authors: Andrew Beecroft

Client: Queensland Department of Transport and Main Roads

Date: June 2015

AN INITIATIVE BY:

arrb GROUP

Queensland Government Australia

P41: INVESTIGATION OF INSTRUMENTATION FOR REAL-TIME CONDITION AND PERFORMANCE MONITORING OF IN-SERVICE PAVEMENTS

SUMMARY

In order to capture the benefits of innovative practices in pavement construction and the use of marginal materials, it is essential to monitor the performance and condition of pavements. This ideally would be achieved through low-cost, non-destructive techniques that accurately and reliably provide feedback on pavement performance.

This project has summarised the current state of play with regards to pavement instrumentation. The focus has primarily been on technologies that allow for non-obtrusive, medium-to-long term solutions that can provide valuable data on pavement condition and performance, and help inform design, research and decision making across the network.

Each style of instrumentation has been shown to have some benefit to road asset owners and designers. Wireless sensors, often feeding data to a receiver that can be remotely accessed, allow for real-time monitoring of pavements. Improved battery technology and methods of designing compact sensors has allowed for these sensors to be very small, while still remaining low-cost.

A range of trials have taken place in Queensland in recent years, which should form a starting point for any future work in instrumentation projects in the future.

This project was originally proposed to have funding allocated to further years, however the focus has now shifted to providing pavement instrumentation through existing NACOE research projects, ensuring that research findings are maximised from the program. NACOE projects identified as having the potential for enhanced benefits through additional instrumentation should be targeted for specific literature reviews, which will benefit from this broad initial literature review.

It is also recommended that TMR continue to foster a strong relationship with universities to deliver technology and instrumentation research projects that may be developed into practical instrumentation for the road network.

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1 INTRODUCTION

Monitoring the real-time condition and performance of pavement has long been a difficult practice. Particularly when utilising innovative pavement structures or marginal materials, or where the loading requirement do not match the pavement structure, the options for monitoring pavements are expensive and intrusive.

Widespread, low-cost pavement instrumentation can have a multitude of benefits in the development and monitoring of pavements, including:

- Performance monitoring of pavements and analysing causes of failure
- Real-time environmental condition data (temperature, pressure, moisture)
- Evaluate design assumptions and construction methods
- Monitor structural safety and passability of pavements and associated structures

The benefits of instrumentation in geotechnical applications have been long recognised, and some of the technologies in this field can equally be applied to the pavements sphere. Indeed, many of the benefits considered when selecting geotechnical instrumentation are directly transferrable to pavement (Marr 2000), including:

- indicate impending failure
- provide a warning
- reveal unknowns
- evaluate critical design assumptions
- assess contractors means and methods
- minimize damage to adjacent structures
- control construction
- control operations
- provide data to help select remedial methods to fix problems
- document performance for assessing damages
- inform stakeholders
- satisfy regulators
- reduce litigation
- advance state-of-knowledge

Data on pavement performance can be gathered through laboratory study or with the use of accelerated pavement testing facilities, however these methods are either too expensive or cannot accurately reflect in-service conditions (especially when considering laboratory testing).

1.1 Methodology

This report will summarise the literature on instrumentation in pavements and provides a summary of the currently available instrumentation technology.

- Section 2 documents many of the currently available instruments used in pavements, including temperature sensors, moisture/humidity sensors, stress/strain gauges, accelerometers and RFID sensors.
- Section 3 outlines some of the work done in Queensland to date and highlights the importance of research into choosing the most appropriate instrumentation options for pavement conditions monitoring.
- Section 4 summarises the key findings and makes recommendations for the future of pavement instrumentation in Queensland.

2 SUMMARY OF AVAILABLE DEVICES

There are a wide range of commercially available sensors on the market, with most of the established pavement-specific sensors being hard-wired devices. Many of the newer, innovative designs are focussing on adopting the rapidly advancing wireless technology into their products. Pavement instrumentation of networks across a wide-area is also required to keep costs in check. These devices are at various stages of development, and the most promising technologies should be closely monitored as potential devices to trial in Queensland. This section will explore new and innovative in-pavement instrumentation, with the main focus on low-cost, wireless devices.

2.1 Temperature Sensors

Wired temperature sensors have been used in pavements for several decades, including recently in an asphalt trial in Eagle Farm, Brisbane (Petho et al. 2014). The sensors provide a wealth of information, but the nature of their design leads to difficulties in placement, installation and monitoring. For example, the sensors at the EME2 trial in Eagle Farm required a series of cores and channels to be cut in the pavement, as well as running cables to a secure location off the roadway. These installations remain vulnerable to damage during the paving process, as well as vandalism into the future. Wireless systems solve a lot of these problems, and have therefore been investigated for future projects.

A number of projects have utilised Thermochron iButtons, a device manufactured by Dallas Semiconductor that can periodically measure temperature in 0.5°C increments. iButtons are primarily targeted at use in logistics and general temperature monitoring, although they may be adapted for use in pavements. Although iButtons are marketed as being ‘wireless’, they still require direct contact with a reader to transmit data. Many thousands of readings can be stored on one iButton.

Figure 2.1: Thermochron iButtons (left), Identec i-Q350 tag (right)

Source: Embedded Data Systems (2015), Identec Solutions (2012),

Devices such as the iButton have been used for over a decade in concrete and asphalt pavement projects, such as a study on concrete curing in airfields (Innovative Pavement Research Foundation, 2003). This study compared the performance of four temperature and maturity monitoring devices to assess the early strength of concrete. Each of the devices (iButton, intelliRock sensors by Nomadics Construction Labs, Identec i-Q tags and a T-Type Thermocouple) performed well, although each were recognised as having strengths and weaknesses. Only the Identec i-Q tag can claim to be truly wireless, as all the others require either a wired connection or removal and direct contact with a reader. It was noted that the i-Q tags came at a much greater cost to the other devices due to the un-recoverable transmitter technology within the device, and that the range of the wireless transmitter was very limited.

The HardTrack Concrete Monitoring System has been used for in-situ temperature monitoring of concrete structures and pavements (Wake Inc, 2014). The system incorporates a network of Identec i-Q32T or iQ350TL temperature tags with Radio Frequency Identification (RFID) capabilities, with a handheld data interrogator and data analysis software. The RFID tags can be embedded in the concrete during construction and due to the relatively low cost of tags, are not recovered.

The RFID technology is recommended for use at depths up to 200 mm in concrete, however it is not known how this would translate to asphalt pavements. In theory, the performance may be better in asphalt as the free water content in fresh concrete increases signal loss. Tags can also be fitted with stainless-steel temperature probes up to several meters long, allowing the system to read temperatures at greater depths. Additionally, the tags can be read by on-site towers and transmitted via the internet or local network, allowing for an even greater level of remote access.

A study was undertaken by a team from Iowa State University on behalf of the Iowa Department of Transportation (Ceylan et al. 2013). The study was focused on investigating the feasibility of using wireless RFID sensors in concrete, primarily with the goal of providing construction staff with live updates of temperature or humidity related changes in concrete, especially over the critical early hours and days of curing. By having a better understanding of the maturity and strength of concrete, road authorities can make informed decisions on further construction or opening of concrete roads, potentially saving time and reducing project risk. Through cold Iowa winters, it was also of interest to monitor the number and extent of freeze/thaw cycles that the concrete had undergone.

The study embedded wired iButtons, wired Sensirion humidity and temperature sensors and the wireless i-Q32T RFID temperature sensors from Wake Inc (Figure 2.2). The study found that wireless RFID sensors survived the harsh freeze-thaw conditions during the test, and returned comparable temperature readings to the wired iButtons. The Sensirion sensors failed under the rapid temperature changes, but performed better when subjected to slow ambient temperature changes. The wireless sensors successfully transmitted data through 4.5 inches (113 mm) of concrete to the data reader at the surface. Further trials of this technology are underway and expected to be completed in 2015 (personal communications with Dr Halil Ceylan, 28 January 2015).

Figure 2.2: Trial of various temperature sensors

Source: Ceylan et al. (2013)

Although these results show considerable promise, it should be noted that the conditions faced in concrete pavement construction are different to those in asphalt pavements. Asphalt pavements undergo a very stressful paving operation with high temperatures and high loads from rolling and vibrating compactors. Sensors will required to perform across a very wide temperature range and be able to withstand high forces during compaction.

Any attempt to use similar instrumentation in asphalt pavements would likely require extra protection for the devices. As for the issue of power supply, this is an area where the technology is rapidly advancing and steps are being taken towards reliable, self-powered sensors using technology including solar, piezoelectric, vibrational, thermal gradient and even nuclear power (Lajnef et al. 2008; Lajnef at el. 2011).

2.2 Humidity/moisture Sensors

Moisture and humidity sensors in pavements may have applicability when monitoring the saturation of base layers to determine road closures. Installing moisture sensors in remote locations will allow for rapid decision making by authorities. While not directly relevant for Queensland, it is also possible to detect snow and ice using moisture sensors, which can then trigger safety messages to drivers or alert authorities to enable them to send out de-icing vehicles.

A moisture monitoring sensor system was developed for wireless, real-time water content monitoring in sand, soil and concrete (Ong et al. 2008). The sensor can be embedded in the medium, and uses the capacitance of the inductor-capacitor circuit to determine the water content. The resonant frequency reflects the degree of capacitance and can be read at the surface. The trial measure water content in sand samples and in a concrete slab as it cured, although this technology may also be applied to subgrade soils and asphalt.

Iowa State University have been developing a wireless concrete moisture monitoring system using Micro-Electromechanical Systems (MEMS) technology (Yang et al. 2014). MEMS sensors cover a wide variety of functions, but in this case have been used to measure in-situ moisture level in concrete. Wired solutions currently require physical connections between the MEMS sensor and above-ground data reader, and then between the data reader and computer. A power supply would also be required for both the data reader and computer. A wireless system would utilise a specialised data transmitters and on board data storage to eliminate the need for any cables and permanent power supply. This greatly reduces the risk of damage during construction and operation.

2.2.1 Moisture Detection through Time Domain Reflectometry (TDR)

Time domain reflectometry (TDR) is a technique of measuring the characteristics of electrical lines. The embedded probe and the surrounding soil allows the reflected waves to be analysed, and this can be used to measure the change in water content of a granular material through measuring the change in dielectric permittivity of the soil around the probe. This has application in a range of uses in pavements, most notably the ability to non-destructively estimate the moisture content of a soil.

TDR sensors have been used in Australian and TMR projects since at least the 1990s. A discussion on the current work using TDRs in Queensland can be found in Section 3.4.

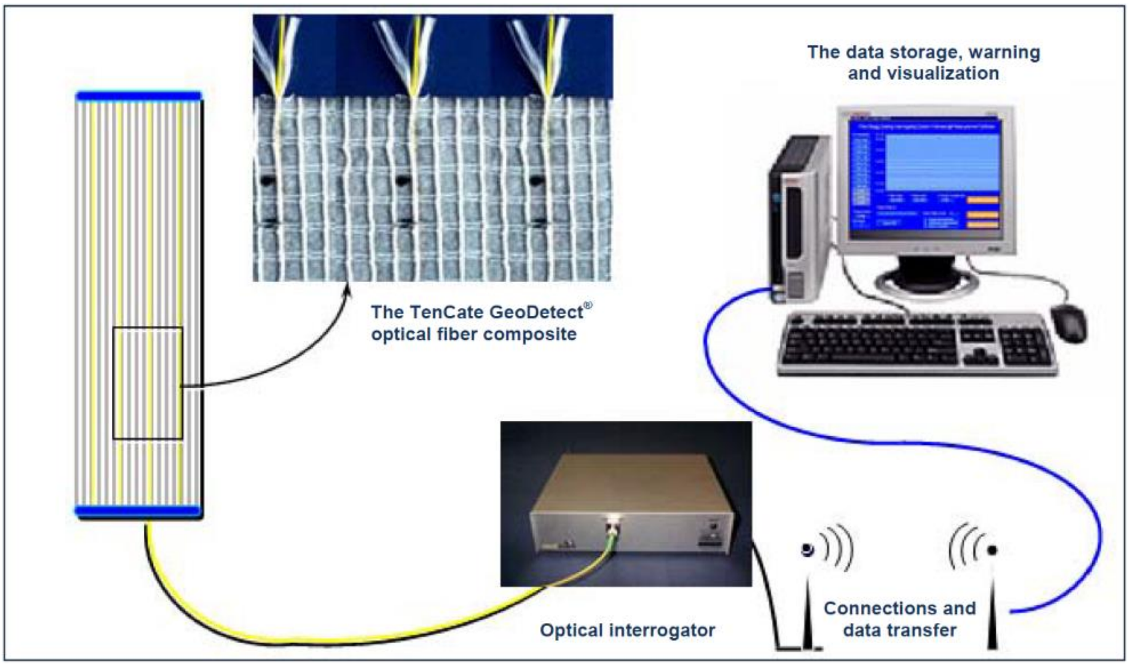
2.3 Stress/strain Sensors

2.3.1 TenCate GeoDetect

Strain measurement in pavements has traditionally been problematic due to technical difficulties in installation and monitoring. A number of innovative solutions have emerged in recent years, one of which involves embedding fibre-optic cables within a geogrid structure. The geotextile layer anchors the sensors into the soil and communicates strain and temperature data to interrogator equipment, which then sends the data to a centralised location for data analysis and monitoring.

The GeoDetect system has typically been used in high-risk applications, such as road and rail alignments in challenging locations including steep slopes, soft soil and across abandoned mines. The sensors have also been used an early-warning system for instability on steep slopes, dams/levees, retaining walls and embankments.

Figure 2.3: Components in the TenCate GeoDetect system



Source: TenCate Geosynthetics (2010)

The embedded network of sensors has many advantages over the traditional isolated strain gauges. Installation, calibration, accuracy and monitoring are all much simpler with embedded sensor networks such as GeoDetect. While the cost of installing sensors over a large area would be very high, so is the cost of instrumenting large areas with conventional strain gauges. At this stage, embedded sensor networks would likely be restricted to high-risk sections such as around steep cuttings or in areas where there is significant water movement above or below the surface.

2.3.2 Wireless Pavement Sensors

For some years, the concept of ‘smart aggregate’ has been explored and postured as a future direction of pavement instrumentation. While the idea of thousands of aggregate sized particles scattered randomly throughout a pavement layer and wirelessly transmitting a wide array of data sounds appealing, the practicalities mean that at present, this technology is not feasible. In response to this, there have been efforts directed at the development of a durable, low-cost, non-retrievable, wireless pavement sensor that can monitor acceleration, temperature and sound in the pavement.

One such example is the so-called *Wisdom Stone* (WS) being developed at the Israel Institute of Technology (Levenberg, et al. 2014). The WS is encapsulated in a rock-like casing for strength and to integrate seamlessly with the surrounding layer. The focus was to make the device deployable over a wide area, which required the units to be low-cost and with effective wireless communication over a long distance (as well as transmitting up through the pavement layer).

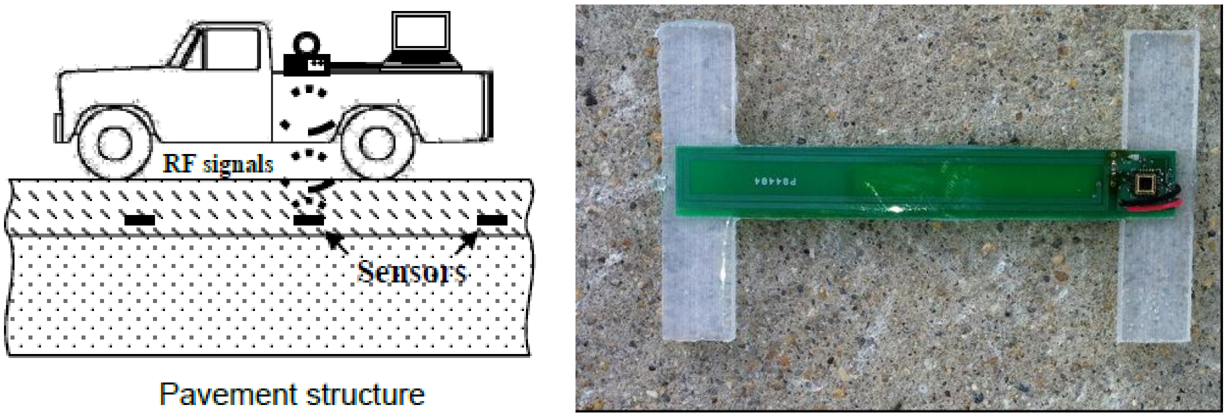
The sensors are also required to be very sensitive in order to capture the full response range. At this stage of development, the technology does not exist to address these concerns while remaining low-cost, durable and compact. Future research in this field is likely to bridge the gap, but the vision of low-cost wireless pavement sensors is probably still some way off.

A team at Iowa State University have encountered similar hurdles when developing a wireless, multi-function sensor system, encountering difficulties with energy usage, wireless transmission and size (Yang et al. 2014).

The United States Federal Highway Administration (Lajnef et al 2013) have funded the development of a self-powered, wireless strain sensor for monitoring damage and loading history for pavements. The key development has been integrating a piezoelectric transducer with an array of floating gate computational circuits, which allows for continuous, battery-less strain readings over a long period of time. The purpose of the sensors is to monitor pavement responses to vehicle loading over time and use this data to analyse pavement performance, predict remaining pavement life and help to schedule rehabilitation actions. The sensor data can be read by a passing vehicle fitted with receivers (Figure 2.4).

The project was successful in developing a working prototype sensor that is continuously self-powered, small and robust, and can communicate strain responses wirelessly to a surface reader.

Figure 2.4: Envisaged wireless sensor system and prototype design



Source: Lajnef et al. (2013)

Due to the relatively simple nature of construction, the cost is expected to be very low, allowing for a wide-area application. The installation of gauges remains a difficult task, as it is for wired gauges. Methods for application to the pavement are required to ensure the device remains correctly aligned, un-damaged and reading accurately after the high-risk paving operation.

2.3.3 Virginia Smart Road

Established in 2000, the Virginia Smart Road is a full-scale closed pavement testing facility managed by the Virginia Tech Transportation Institute and the Virginia Department of Transportation (Virginia Tech 2014). Since then, the facility has proven to be an important research tool for the Institute and its partners. Smart Road has weather-making capabilities, including rain, snow, fog and variable lighting, a dedicated data acquisition system and fully integrated positioning, surveillance and information systems.

A major project completed on Smart Road was an instrumentation trial, incorporating pressure cells, strain gauges, temperature sensors, time domain reflectometry (TDR) probes as well as data acquisition systems and software.

Two varieties of strain gauges were used. Dynatest PAST-II-AC ‘H’-shaped gauges and Geokon VCE-4200 vibrating wire strain gauges were both embedded into the pavement. Both types of strain gauge suffered high failure rates. While there were relatively few failures during construction (6% Dynatest failed and 11% Geokon), the number of failed sensors rose steadily over the first three years (71% Dynatest and 61% Geokon failed). The rate of success for wired strain gauges is worryingly low, and there is evidence of damaged sensors across most strain gauge instrumentation projects. A typical lifespan of just 1-3 years is unlikely to be sufficient to reach research objectives. Moving towards wireless installations may prove to eliminate some potential failure mechanisms (severed wires etc.).

2.3.4 Other Wired Strain Gauges

Wired strain gauges have been used across many research projects, including a trial in Switzerland of seven different strain gauges designs (Cheneviere et al. 2005). The test pavement was instrumented with 63 gauges in two levels, one at the wearing course interface with the base course as well as at the base course interface with the unbound sub-base.

The study considered a range of temperatures, loads, tire pressures and loading speeds. Each of the tested strain gauges displayed relationships between the strain recording and variables such as temperature and loading speed, but the measured absolute strains varied across the devices. Three versions of strain gauges manufactured by Kyowa Electronic Instruments were closer to the lower absolute levels of microstrain, while instruments manufactured by Hottinger Baldwin Messtechnik GmbH from Germany and Vishay Measurements Group from North Carolina tended towards higher values. A fibre optic strain gauge was also tested, which also recorded strain higher than the average of all instruments. By means of comparison, a computer model was also run and this predicted maximum strains on the lower end of the scale (similar to the Kyowa instruments). In conclusion, the study found that each of these devices was capable of measuring microstrain, but that there was significant variance in absolute values across the devices.

2.4 Accelerometers

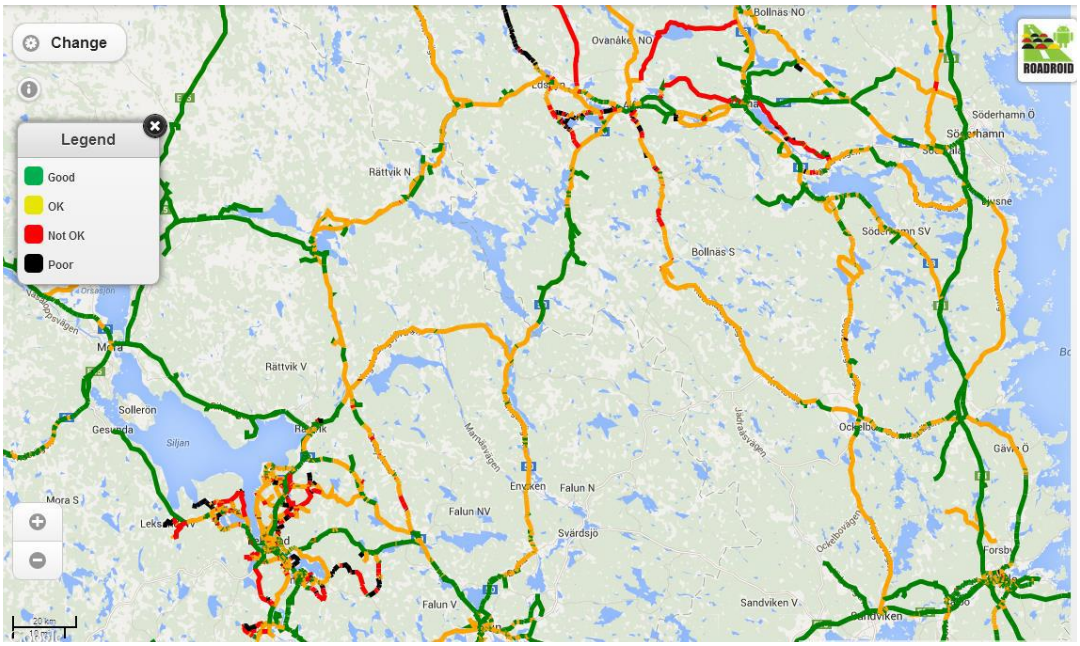
Accelerometers are rapidly becoming cheaper and more accurate, especially with their prolific use within smartphones. Indeed a number of smartphone applications have been developed using complex algorithms that can detect and flag potholes for other motorists to avoid (Brisimi et. al. 2015).

The RoadRoid smartphone application collects roughness data, allowing for road authorities to be alerted to changes in road roughness over time and be able to better coordinate and respond to asset degradation (Jones & Forslof, 2014). The system was developed in Sweden and can accurately measure and chart road condition across a network. The data links to a web-based monitoring system with condition ratings (Figure 2.5). When operated to a standard set of conditions, the system has been able to produce a strong correlation with the internationally recognised IRI values for roughness. Some early work with this application has been undertaken in Australia (personal communication with Wayne Muller of TMR, 18 June 2015).

With regards to efforts by road authorities across the wider network, there has been a shift to mobile road surface monitoring using on-board accelerometers. A conventional accelerometer essentially uses a damped spring to measure deflection when subject to an acceleration. This is converted to a value for the acceleration. Many devices utilise 3-axis accelerometers, which enable measurements in all directions.

In-vehicle accelerometer use is an area that is already receiving significant attention and research, so will not be the focus of this section. Wireless embedded accelerometers also have applications for transport networks, and some of the solutions are outlined here.

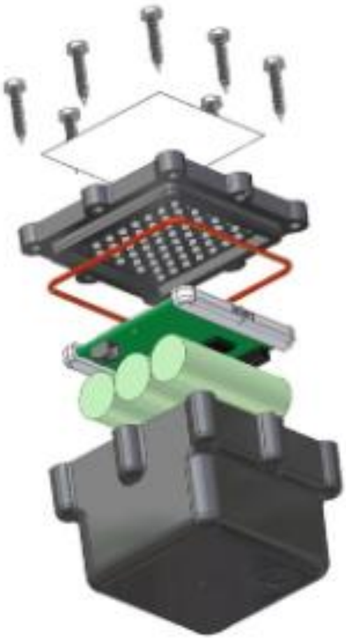
Figure 2.5: Roadroid condition monitoring across an area of Sweden



Source: Jones & Forslof (2014)

A wireless sensor network was developed for vehicle classification in response to the difficulties faced with wired networks due to installation, calibration and high cost (Bajwa et al. 2011). The proposed solution uses magnetometers and accelerometers (Figure 2.6). The magnetometers detect vehicles and their speed, while the accelerometers detect individual axles and their spacings. Data is transmitted to an access point on the roadside which sends the data across a Wide Area Network (WAN) connection. A number of issues can be encountered using this technology, including the impact of vibrations from adjacent lanes.

Figure 2.6: Accelerometer sensor inside packaging



Source: Bajwa et al. (2011)

The study evaluated two different accelerometers, one from Silicon Designs and one from Colibrys, both selected for their high sensitivity and low noise density. The SD1221-005 outperforms the Colibrys MS9002.D on both these metrics, however this comes at the cost of a much higher voltage requirement and current consumption. Both sensors were found to perform to the required resolution so the more economical MS9002.D was chosen for the trial section. The accelerometers were installed in a small cored hole 2.25 inches (56 mm) deep and sealed with epoxy. Data loss was very low and the sensors produced very accurate counts and axle spacings.

Accelerometers have also been used to monitor structural health on bridges, including one study that instrumented the Golden Gate Bridge in San Francisco (Kim et al. 2007). This presented a challenging installation and monitoring environment, where a 64-node network of sensors was attached to across the bridge span (Figure 2.7). Two types of accelerometers were used in the trial, a low-cost ADXL 202E device and a Silicon Designs 1221L sensor. The more precise 1221L sensor was targeted at monitoring ambient vibrations (wind, traffic loading) while the less sensitive sensors were adequate for measuring earthquakes and other major excitations. The study found that the sensor network could reliably and accurately monitor the structural health of the bridge, and that large networks such as this can add significant value at relatively low cost.

Figure 2.7: The board attached and carefully secured along the main span

Source: Kim et al. (2007)

2.5 RFID Sensors

There are a wide range of simple radio frequency identification (RFID) units that can be adapted for use in pavements. RFID chips have an enormous range of applications, but the most interesting in respect to pavements and the road network is the use of RFID radar, which allows for an accurate and rapid reading of the range between transponders and the chip reader (Trolley Scan 2012). This can enable monitoring of the movement of structures such as bridges, slopes/embankments, retaining walls, buildings and underground cavities. The scanner can read to millimetre accuracy over distances of at least 13 metres, and each chip can be identified and matched within the zone. A South African company, Trolley Scan, have been developing this technology, initially as a tool for monitoring logistics in retail and warehouses. More recently they have expanded to a wide range of areas, which has led to the potential to apply this technology to the transport network.

A Brisbane company Licensys have been developing license plate readers with RFID chips fitted to license plates (Licensys 2015). The reader would then be placed in the pavement. This approach avoids the requirement for expensive gantry-mounted readers, and brings the reader much closer to the RFID chip. Smart license plate technology linked with pavement instruments will enable much more sophisticated vehicle tracking and traffic monitoring, as opposed to systems reliant on number plate recognition. Further research is taking place in collaboration with the University of Queensland.

RFID technology is inexpensive and easy to operate, so a network of sensors could readily be applied to a bridge or pavement structure to accurately monitor its movements over time.

2.6 Multi-sensor Packages

Several of the previously mentioned devices have covered multiple functions, but some manufacturers have specifically targeted customisable devices as the optimal solution. One such device is the Libelium Waspmote Plug and Sense (Libelium 2015), a wireless sensor node which allows for up to six sensors to be attached directly. The device sends data wirelessly, and can also be programmed wirelessly via over-the-air programming. Nodes can also be solar powered to allow for longer lifespans. In reference to use across the road network, potential applications include temperature monitoring, moisture and humidity sensing, vibration and crack detection in structures (bridges, tunnels etc.), as well as monitoring traffic, climate and road conditions. A major advantage of a platform such as this is the highly customisable nature of the node, and that a failure of one sensor does not affect others.

Figure 2.8: Libelium Waspmote Plug and Sense

Source: Libelium (2015)

3 INSTRUMENTATION TRIALS IN QUEENSLAND

Over recent years, a number of projects across Queensland have utilised instrumentation to monitor pavement conditions and responses.

3.1 Eagle Farm EME2 Trial

As a part of the EME2 asphalt trial in Eagle Farm, Brisbane, a series of temperature sensors and strain gauges were installed to gather data on the conditions and loading responses, but also partly to trial the equipment and sensors themselves (Petho et al. 2014). The temperature sensors were supplied by Environdata, who also supplied a fully equipped data-logger and weather station which sends the data remotely over a 4G internet connection.

The six temperature sensors performed well for the first 6 months of operation, before the sensors at 80 mm depth failed, with two further sensors failing after roughly 10 months. In each case, the sensors appear to come back ‘online’ for periods of several hours or days at a time, indicating that they are not completely destroyed but just malfunctioning in some way.

The strain gauges are also monitored through the same data logger. Four wired ASG-152 sensors from CTL Group were purchased, with two embedded in the longitudinal direction and two in the transverse direction (Figure 3.1). The gauges were also split in location, with two at the sub-base/base course interface, and two installed on top of an existing asphalt layer. The construction process was managed carefully to avoid damage to the devices. This included adding some fine asphalt mix on top of the gauges before paving, and making sure the paver wheelpaths did not track over the instruments.

Figure 3.1: CTL Group strain gauge, with protective tack coating applied

Source: ARRB Group

Despite the precautions taken, early tests showed that only two of the devices were returning readings. Some programming changes were also required before gathering strain data. The high temperatures and forces involved in paving and compaction operations mean that there is always a possibility of early failures, as was noted in Section 2.3.3.

CTL Group had themselves conducted field installation tests on various devices (Weinmann 2005). It was found that it the gauges were subject to high physical abuse when being laid, and that it was important to protect the lead wires throughout the process. Issues were reported with the quarter-bridge circuit and leads. It was also noted that the recorded strain range tended to 'creep', a process whereby the zero point changes after some/all loading cycles. This makes it difficult to establish absolute strain levels as the reference point is gradually changing.

3.2 Roll-out of Geotechnical Instrumentation

In response to several major rainfall and cyclone events in recent years, the Department of Transport and Main Roads have invested heavily in geotechnical instrumentation projects in an effort to monitor safety and performance of slopes and embankments (Marks 2011).

Some of the instrumentation used to date includes:

- pore water pressure monitors to provide data on slope stability, earth pressures and drainage systems
    - observation wells
    - hydraulic standpipies
    - pneumatic and vibrating wire piezometers (VWP)
    - time domain reflectometry (TDR) moisture probes
- vertical deformation measures, which can help assess the performance of foundations, embankments and slopes
    - settlement cells, plates and gauges
    - magnetic extensometers
    - spider magnets and Sondex settlement systems
- lateral deformation measures, used to monitor the performance and stability of structures, slopes and embankments
    - strain gauges
    - inclinometers
    - rod extensometers
    - electro-level beam sensors
- stress measurements in soil
    - earth pressure cells
- rainfall gauges to monitor site-specific rainfall to monitor the effect of rain on slope stability.

One or more of these instrumentation solutions have been used across a range of projects, including at geotechnically challenging earth embankment and slope works, at bridge abutments where stability is a concern, at earth dams, at sites vulnerable to road slips and where construction is taking place over soft soils.

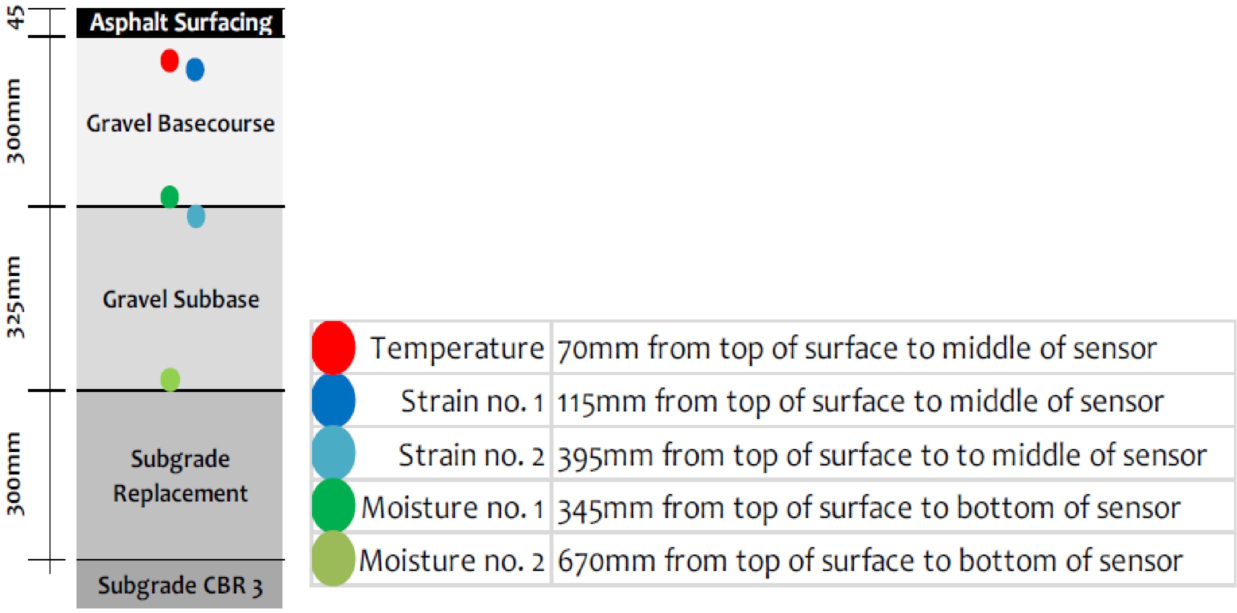
3.3 University of the Sunshine Coast Pavement Instrumentation

In late 2012, a section of pavement outside the University of the Sunshine Coast's Sippy Downs campus was upgraded, and this provided the opportunity to instrument the section with a range of devices (Azawi et al. 2014). Several factors determined the selection of instruments, namely: availability at time of design and construction, durability and ability to withstand extreme weather, overall cost and the availability of local expertise for calibration and servicing.

The devices chosen and their position is detailed below (Figure 3.2).

- a Type T thermocouple temperature sensor was installed at 65 mm depth
- two Theta probe ML2X moisture gauges were installed at 345 mm (basecourse/subbase interface) and 670 mm deep (subbase/subgrade interface). These probes operate by measuring the dielectric properties of the surrounding soil, with a listed accuracy of ±1% (although probes of this type would typically require a material specific calibration to achieve these levels of accuracy, and it is not known whether this has been completed).
- two KM-100A wired strain gauges, manufactured by Tokyo Sokki Kenkyujo Co. Ltd, installed vertically in the pavement at 115 mm deep and 395 mm deep. The strain gauges are also fitted with thermocouples, enabling an additional two temperature measurements within the pavement
- a DataTaker DT82EM Series 3 data logger, which is powered using solar power and can transmit data wirelessly.

Figure 3.2: A diagram of the instrumentation at Sippy Downs within the pavement cross-section



Source: Azawi et al. (2014)

The instruments were all placed directly under the outer wheelpath. The data gathered suggests that each of the instruments is performing well and some interesting observations have been noted, especially when the road experiences extreme weather events (major rainfall).

3.4 Time-Domain Reflectometry Trials

Time-domain reflectometry (TDR) trials have been undertaken in Queensland since the early 1990s. Baran (1994) embedded two styles of probes, a standard moisture probe and a probe modified by Queensland Transport, at a test site in Beerburrum with a dense, crushed rock pavement. 122 probes were successfully installed in total, with a consistent performance from the vast majority of probes and a probe survival rate of 98%. The relationship used for typical measurements in soils was found to be unsuitable for the dense pavement at Beerburrum, so a calibration was developed. Overall, the trial found that the probes were sufficiently accurate and reliable to monitor pavement moisture. Since that time, several subsequent trials have been completed

A study in both the laboratory and at the ARRB Accelerated Loading Facility (ALF) is currently underway (Hore-Lacy et. al. 2014). The study embedded probes in laboratory wheel-tracker slabs and used varying soil types and moisture contents. As such, a correlation was able to be developed based on the range of results. The correlations matched well with existing calibration studies, the method of analysing peaks for TDR traces was found to be the more reliable method to determine soil permittivity. TDR has proven to be valuable tool for measuring moisture contents in soils.

The trial at the ALF includes two different TDR sensors, comprising 24 TDR probe sensors and 12 experimental ‘ribbon’ sensors to monitor the moisture content during the trial as well as further research the correlation and analysis of TDR technology.

A trial is also underway at the Fischer Park truck stop adjacent to the Cunningham Highway (personal communication with Wayne Muller of TMR, 18 June 2015) (Figure 3.3). This version of TDR is capable of measuring moisture content of the soil at all points along the ribbon, rather than directed at one location.

Figure 3.3: ‘Ribbon’ style TDR sensors and plates at the Cunningham Highway site

Source: ARRB Group

4 CONCLUSIONS AND RECOMMENDATIONS

This project has summarised the current state of play with regards to pavement instrumentation. The focus has primarily been on technologies that allow for non-obtrusive, medium-to-long term solutions that can provide valuable data on pavement condition and performance, and help inform design, research and decision making across the network.

Each style of instrumentation has been shown to have some benefit to road asset owners and designers, although several themes have stood out from the research:

- Wireless sensors are gaining popularity and priority over wired options due to the better battery technology and the fact that a weak point in wired systems has proven to be the wires themselves.
- The integration of personal handheld technology including smartphones enables sensors to be more easily accessible and allows for the latest technology to be adapted into instrumentation projects.
- 'Full-package' style sensors that combine readings (e.g. strain, temperature and moisture) may be the direction of instruments for the future, but a recurring theme of poor reliability and design limitations has led to a range of single-purpose sensors being the most practical option.
- Partnerships with universities and research bodies have proven to be valuable in developing new technologies. Road authorities such as the Virginia Department of Transportation have embraced pavement instrumentation and offered support to trials. Real-world trials of technology allow for more efficient developments.

This project was originally proposed to have funding allocated to further years, however the direction adopted by the NACOE board was to maintain the investment in instrumentation research through existing projects. This may take the form of running prototype or alternative instrumentation alongside more established instruments.

This continued support to pavement instrumentation through existing NACOE research projects will ensure that research findings are maximised from the program. Any projects identified as having the potential for enhanced benefits through additional instrumentation should be targeted for specific literature reviews leveraging off the work already done through this project. This can take place with an allocation of funding through existing NACOE projects and with the support of TMR personnel.

It is also recommended that TMR continue to foster a strong relationship with universities. The University of Queensland has partnered with ARRB and TMR previously to deliver technology and instrumentation research projects that may be developed into practical instrumentation for the road network.

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