THE ACCELERATED LOADING FACILITY AS AN ACCELERATED LEARNING FACILITY: THREE CASE STUDIES

Michael A. Moffatt, William C. Hore-Lacy, Peter M. Eady and Stephen P. O'Hern

Date: June 2008
Word Count: 5860 (inc. 250 word equivalent for each figure and table)
Figures: 3
Tables: nil

Michael A. Moffatt
ARRB Group Ltd
500 Burwood Highway
Vermont South
Victoria 3133
Australia
Telephone: +61 3 9881 1555
Facsimile: +61 3 9887 8104
Email: michael.moffatt@arrb.com.au

William C. Hore-Lacy
ARRB Group Ltd
Email: will.hore-lacy@arrb.com.au

Peter M. Eady
ARRB Group Ltd
Email: peter.eady@arrb.com.au

Stephen P. O'Hern
Faculty of Engineering
Building 72, Clayton campus
Monash University
Victoria 3800
Australia
Telephone: +61 3 9905 3404
Facsimile: +61 3 9905 3409
Email: spohe1@student.monash.edu

ABSTRACT

The benefits of an accelerated pavement testing program are often discussed in terms of improvements to pavement design and analysis, the introduction of new materials and construction techniques, and a better understanding of long term pavement performance. A highly significant, and often overlooked, additional benefit is the opportunity an accelerated pavement testing program creates for staff training and learning. Pavement engineering represents only a small proportion of the curriculum at most tertiary engineering education institutions, and it is widely recognised that there is a current global shortage of skilled pavement engineers. The paper describes how the Australian operation of the Accelerated Loading Facility (ALF) has exposed student and graduate engineers to a wide range of learning experiences, including pavement construction, instrumentation, condition measurement, laboratory testing, analysis and report writing. The paper includes three case studies, each highlighting the experiences and benefits of the program to three student and graduate engineers. The experiences are varied, and demonstrate the wide range of learning opportunities presented by accelerated pavement testing.

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INTRODUCTION

The benefits of an accelerated pavement testing program are often discussed in terms of improvements to pavement design and analysis, the introduction of new materials and construction techniques, and a better understanding of long term pavement performance.

Proposals for new accelerated pavement testing (APT) facilities have focussed upon the need to verify existing pavement design and construction practices (*1*), a desire to quantify the effects of increased traffic levels and loads on an established infrastructure, and the use of alternative materials and treatments within pavement structures (*1*, *2*).

Economic analyses have demonstrated that Benefit Cost Ratios of completed APT research projects have typically exceeded 4 (*3*) and have risen as high as 13 (*3*, *4*). These analyses have focussed upon the road agency cost savings, both asset establishment and asset preservation costs, that have been realised as a result of the pavement design, construction and maintenance technologies and practices demonstrated by APT research work.

The potential technological benefits of an APT program can, therefore, be considered to have been clearly demonstrated.

Additional to these demonstrated immediate economic benefits, however, it is suggested that an APT facility and associated research program can create an excellent environment for staff training and increased learning. Rust et al. (*5*) briefly describes the educational benefit of the long running and extensive Heavy Vehicle Simulator (HVS) program in South Africa. They note that pavement engineers that have seen an APT in operation have an insight not afforded other engineers 'that may only rarely see badly failed pavements, and then without the benefit of truly knowing the contributing conditions'.

This paper presents the educational benefits that three young engineers (two graduates, and one student) have realised via their association with the Accelerated Loading Facility operated by ARRB Group (formerly the Australian Road Research Board) in Australia. APT related literature is almost silent on this subject, and, whilst unable to fill this void by itself, it is hoped that this paper will initiate relevant discussion and dissemination amongst APT operations.

The case studies demonstrate benefits that were obtained in an ad hoc manner, and it is suggested that significantly increased benefits could be achieved within a more structured learning program.

ACCELERATED LOADING FACILITY

Although the Accelerated Loading Facility (ALF) is not the prime focus of this paper, a brief description of the facility and the nature of work recently undertaken there is appropriate to place the personal experiences of the following three case studies in context.

The ALF is a full-scale load, pavement test system designed and manufactured by the Roads and Traffic Authority, NSW. It is the only APT equipment operating in Australia. The ALF is owned and operated by ARRB Group and is used to assess:

- the estimated life of existing pavements

- the validity of new methods of pavement design
- the suitability of marginal, improved or innovative pavement materials
- the effectiveness of changes in pavement construction procedures
- the applicability of pavement rehabilitation techniques
- the effects of climate and traffic on performance.

Driven rolling wheel loading is applied in one direction to pavement test sections 12 m in length at a constant speed of about 20 km/h. The half axle test wheel loads can be varied in 10 kN increments from 40 kN to 80 kN. The load wheel is lifted off the pavement at the end of each cycle and supported by the mainframe on its return. The loading can be channelised or applied over any transverse distribution of load up to 1.2 m width. A normal transverse distribution of up to 1.2 m or 0.9 m wide is commonly used to simulate traffic wander across the road.

The cycle time for each load is about 9 seconds, which corresponds to approximately 370 load cycles per hour or, depending on the percentage of operating time, about 50,000 cycles per week.

Whilst ALF is a mobile, relocatable machine, in recent years it has mainly been located at a permanent site in Melbourne, inside a large shed (54 m long and 20 m wide). This has allowed much greater control of the moisture condition of the test pavement (see Figure 1).

FIGURE 1 Accelerated Loading Facility operating inside shed

ALF relies on Austroads (the association of Australasian road agencies) for the majority of its funding and the extent of funding can be very variable. By the late 1990s, funding for trials involving the use of ALF had been reduced to the order of A$250,000 per annum, compared with the equivalent funding of A$3.5–4 million in the mid- to late-1980s. During this time, funding to support three months operation of ALF each year was considered the 'norm'.

Recently, however, funding for projects which involve using ALF as a research tool has increased owing to concerns regarding the ability of an aging pavement infrastructure to cope with the increasing demands being placed on it by new generation vehicles and the imminent introduction of performance based standards for heavy vehicles. In addition, in June 2004, Austroads agreed to provide additional 'core' funding to ARRB to allow it to once again operate as a research organisation addressing issues of key concern to its stakeholders. Surfacings, pavements and asset management were identified as the three key issues of concern. As a result, funding for recent ALF work has increased to levels allowing 9 to 12 months trafficking, with low staffing, per year.

The focus of recent ALF research work has been the field validation of material characterisations and design methods, and not on proof loading of pavement structures. As a result, ALF research projects have a high component of associated laboratory work, often involving the development of new, or refinement of existing, test procedures. Increased funding levels, and the nature of the research work being undertaken, has also seen a returning emphasis on pavement instrumentation.

PAVEMENT EDUCATION IN AUSTRALIA

Generally, engineering courses at Australian tertiary institutions have had little focus on pavement engineering. The typical exposure undergraduate civil engineering students have to pavement engineering is limited to an overview of the terminology used and the rudiments of thickness design, usually with little focus on pavement material characterisation, distress types and mechanisms, or long term maintenance and performance issues.

Farrelly and Mavin (*6*) noted that traditionally Australian road authorities took the lead in the training of personnel, but that since the late 1980s economic constraints, the imposition of staff ceilings and the emergence of corporatisation within agencies had resulted in the authorities severely contracting their education and training role. Farrelly and Mavin described the establishment of a pavement studies and research centre, a partnership between road authorities and industry, in the mid-1990s to, at least partly, address the emerging gap in pavement engineering training. The centre, now titled the Centre for Pavement Engineering Education (CPEE), has largely focussed on distance-based, post graduate course work.

Australian universities currently undertake little pavement related research work, and have had extremely limited involvement with the national pavement research agenda or APT program. To date only two completed, and two ongoing, PhD theses have been partly based on ALF research work. These studies have all been conducted by members of ARRB staff, and all on a part-time basis.

CASE STUDY 1 – GRADUATE ENGINEER

Will studied a Bachelor of Engineering (Civil) at the University of Melbourne from 2000 to 2005, including a 12 month break from studies to undertake an engineering placement within a Melbourne municipal council. Will's studies did not include much in the way of pavement engineering, amounting to only a few lectures that did little more than indicate that pavements are composed of layers and are either rigid or flexible in nature. Additional elective geotechnical subjects focussed on civil foundation works and not on road pavements.

In September 2005 Will joined ARRB in a rotational graduate position that has involved changing work area every six to nine months. Since that time Will has worked in the areas of transport planning, transport operations and road safety. His initial involvement in the ALF program came about by accident in only his second week of employment when he was temporarily drafted as an extra pair of hands to assist with a repair of an ALF breakdown. Will's association with the ALF program has continued since that time, despite his roles in other work areas.

Whilst his subsequent ALF work has been varied, it has mostly been focussed on the installation of multi-depth deflectometers (MDD) in test pavements (see Figure 2). The MDD system used during recent ALF experiments are of South African design and are capable of providing excellent data, however their installation is intricate and considerable problems arose during initial installations. Will was part of a team of two that were given the responsibility for the installation of all devices. They were required to manage the process, troubleshoot the problems that arose and make the installation procedure more reliable. A wide range of skills and knowledge were gained during this process.

The installation of the MDD systems involved drilling small diameter bore holes to a depth exceeding three metres, through bound and unbound pavement layers. Through practice and experience the team improved their drilling skills, developed an understanding of which drill bits to use for different pavement materials, and the means of minimising drill jams. Less obviously, Will gained an understanding of pavement compositions, the performance of bound and unbound materials, the effect of confining pressures on material strength and the sensitivity of granular materials to changes in moisture content.

FIGURE 2 Installation of multi-depth deflectometers

The MDD system is a complicated system that allows the absolute deflection of a pavement to be measured by modules installed at several depths within the pavement. The installation of modules required Will to develop a good understanding of how the modules work and how they were integrated into the complete system. This required the development of new visualisation skills, especially since the modules are installed 'blindly' underground. Without being consciously aware of it, Will had considerably increased his understanding of road pavements from the limited information provided during his University course of only the year before.

The mixing and setting of a liquid rubber to line the bore holes was also required during MDD installation. This required knowledge of how to measure and mix the different components, how fast they set, how to 'mould' them best, and most significantly, how to prevent the setting rubber lining from sticking to the moulds. Frequent problems arose during early installations, with moulds not releasing cleanly and wasting an entire day's hard work. Will sourced alternative products, determining and communicating the specific product requirements to suppliers, and learnt valuable lessons in the need to undertake proper research and problem identification to get the correct product and solution.

The deflection measuring modules in the MDD system are linear variable differential transformers (LVDT), and data is logged onto personal computers via data acquisition and signal conditioning hardware. This process was established before Will's involvement and, as well as developing rudimentary soldering and wiring skills, the main lessons learnt from this aspect of the installation relate to the interpretation of data from noisy data signals, the tracking of electrical noise, and most significantly, an understanding of data validation and a wary caution in accepting data from complex systems. The ability to say that data 'looks right' was only made possible because of the understanding of pavement behaviour already gained.

For the most part, an MDD installation is a simple matter of following an already established process, however when the process has yet to be established, or the process is long and complex, there will always be something that does not go to plan. In less than two years of occasional work in the area, Will progressed from a fresh engineering graduate into a quick thinker, able to improvise when necessary, ready to put super/crazy glue, gaffer or duct tape, fibre-optic cameras and electromagnets to problem solving uses. Through practice and developments, Will's team turned an average installation time of one MDD system per two to three days, with a 50% chance of success, into an average of two installations in two days, with a 95% chance of success.

As a result of the experience gained installing MDD systems for the ALF program, Will was a key member of the team installing a series of MDD systems in a working road environment for an examination of the relative damaging effects of quad axles and triaxles (*7*). The installation was conducted interstate and involved the logging of MDD response data under different types of axle groups applied by a variety of trucks. Will gained some understanding of truck operation, pavement rebounds under multiple axle loads, truck loading limits, truck load distributions, the enforcement of weight limits, and the establishment of traffic management systems and plans.

Will is an amateur landscape photographer, and his photographic skills have been used during the conduct of ALF experiments to document processes and the condition of test pavements and equipment. Will has worked hard to adjust his mindset from an artistic photographer to the requirements of technical photography. He has had to learn to think ahead to what he would need to get out of the photographs as an engineer and to adjust his shooting techniques to ensure that those needs can be met. For example, the aim of landscape photography is to capture an interesting and original image, quite often by exaggerating the scale of elements within the picture, whereas technical photography requires a standard use of scale, and often includes a scale measure itself, and a consistency between images. Due to his skill with a camera, Will has been a part of teams undertaking post ALF trafficking pavement investigations, including trenching operations. Despite his role as only a documenter of activities, Will has increased his understanding of the performance of individual pavements, and their failure mechanisms, in order to ensure that his photographs capture the key elements.

Will came to the ALF program as a fresh engineering graduate, and in a only part-time involvement, over a two year period, has learned a considerable amount. In his own words:

Involvement in the ALF program has given me a much better understanding of pavements and how they react to loading in the short and the long term. These pavement properties, and the knowledge of them, underpin everything that happens at ALF to the point that you don't actually think about it and it becomes second nature. In my ALF work I have been given a lot of responsibility, which is not taken lightly, and the results that have come from some of my work form a large part of a million dollar research program. As with lots of research, we were doing things that were not common, and in some cases had never been *done before. As such, often there wasn't a clear guidebook to read, or local experts to advise. This put the responsibility directly onto me to ensure everything worked, and to think fast if it didn't. Many of the skills I have learnt through the ALF program may not be appear to be directly applicable elsewhere, however, taking a step back, the process of going through learning those skills is exceedingly valuable.*

CASE STUDY 2 – GRADUATE ENGINEER

Peter attended Monash University where he obtained a combined science/engineering degree. Despite having a civil engineering focus in his studies, his experience of pavement engineering was limited to an approximately 10 hour component of one subject out of his five years of undergraduate study.

Peter joined ARRB as a vacation student in November 2005 and worked as a part-time casual member of staff whilst finishing his final year of university. He then joined as a full time staff member in January 2007, starting his graduate rotation program in the pavements group. His contact with the ALF program started at this time.

The time that Peter joined the pavements group coincided with the start of a new ALF test project in the standard ALF shed. This was a fortunate time to begin work as Peter was able to see a full ALF testing program from pavement construction through to the end of trafficking of some of those pavements.

Peter was involved throughout the construction processes, from the planning and plant selection discussions, through removal of existing pavements and construction, to the placement of the final surfacing. As the construction was conducted by a small team, and inside the ALF shed, the work site was safer than a 'normal' road project and offered more opportunity to observe construction techniques and converse with the operators. Most of the construction took place in a concentrated month of activity, with experienced personnel readily at hand to answer questions as they arose. It is unlikely that Peter would have been able to observe a similar range of activities on a typical road construction project.

Prior to construction, old pavements from a previous ALF test program were removed by a rotormill/profiler, and new cement treated crushed rock subbase placed. Four parallel unbound granular pavements were constructed, each 45 metres long, with a different base material used for each pavement. During construction, considerable care was taken to ensure the consistent and uniform test pavement required for the experimental program.

Peter was able to see two of the base materials processed through a small local pugmill, and take part in discussions and testing to determine the appropriate amount of water to be introduced into the pugmill for each material. The small pavement area required by the ALF program necessitated the use of a small pugmill at a local quarry, which in turn provided more opportunity to interact with quarry and pugmill operators than would have been possible on a larger scale, high production, road construction job.

During the construction works, Peter undertook or observed a wide range of pavement and materials tests. Surveying techniques learnt by Peter in undergraduate study were put to use in undertaking, processing and analysing the extensive construction levels surveys. Moisture contents were determined using samples Peter extracted from the pavements, and subsequently tested in the laboratory. The experimental design required that the base materials not be sealed until their moisture content had reach a target of 80 – 85% of their optimum moisture contents. The four pavements dried back at different rates, and Peter regularly made moisture content assessments and analysed the results to enable the scheduling of the final surface sealing. Whilst moisture content monitoring and laser levelling were reasonably basic tasks, the analysis of results and recommendations for future actions based upon those results were critical to success of the experiments.

Whilst Peter did not personally conduct any nuclear density meter (NDM) or Falling Weight Deflectometer (FWD) testing, he was responsible for the processing and analysis of the resulting data. The analysis involved recommendations for the location of specific ALF trafficking experiments within the test area, recommendations only made possible due to an appreciation of the construction variability and the ultimate goals of the ALF testing program. Understanding these goals required Peter quickly coming to terms with pavement behaviour and the effect of different material properties on likely performance.

Following completion of the program, Peter co-wrote the detailed construction report (*8*).

During the ALF trafficking of the test sections, Peter managed the collection of routine pavement condition measurements including transverse surface profile (see Figure 3), surface macro-texture, FWD deflections, NDM density and moisture content readings, and oven dried moisture contents. Peter also participated in experiments conducted using installed MDD and embedded strain gauge systems. In developing experimental plans Peter learnt to make broad predictions of likely pavement behaviour, and became familiar with the early warning signs of pavement failure. Management of the condition measurement collection process was a key component of Peter's role, and this included the coordination of personnel, field equipment and laboratory resources.

FIGURE 3 Transverse profile measurement of test section under ALF

In addition to involvement in the ALF trafficking of pavements, Peter also played a major role in the ongoing laboratory testing program associated with an earlier ALF project. This ALF testing had examined the flexural fatigue performance of two plant mixed cement treated crushed rock pavements, and the laboratory testing program that Peter managed largely consisted of the measurement of flexural strength, modulus and fatigue characteristics of long term samples. The 400x100x100 mm samples were loaded in a closed loop, pneumatic third-point bending test apparatus. Peter learned how to undertake the modulus testing at stress levels high enough to ensure a deflection response could be measured, but low enough to ensure that the sample was not damaged during loading. A standard fatigue test involved increasing the loading strain to levels damaging the sample, and measuring the number of loading cycles applied before the sample reached half of its initial flexural modulus and then ultimately broke.

Depending on the load level, tests could take hours or days to complete. By varying the initial strain level applied, Peter was able to develop a relationship between the strain and the number of cycles to failure for each material. By increasing the range of strain levels tested, and therefore the duration of the tests, Peter was able to progressively improve the quality of the fatigue characterisation model. It was vital that, whilst still developing the fatigue performance mode, Peter analysed the results to date to enable predictions as to how long a given sample, and a given load level, was expected to last.

The apparatus Peter used during this work was also required for other project work, usually short term modulus or flexural strength assessment. The timing of this short term work was usually inflexible (e.g. standard 28 day testing of samples must be conducted at 28 days). The need to provide both flexible and efficient use of the apparatus meant that Peter had to develop a structured forward work plan as well as a good 'feel' for how long a sample could be expected to last. Both of these enabled him to determine which sample, and at which stress level, would best fill the time until the next time-locked test.

In the space of a year Peter's experience of pavement engineering grew from the limited instruction he had received as an undergraduate to the observation and interaction during road construction, the collection and analysis of pavement condition data, the observation of a pavement's life from construction to ultimate end of life, the conduct of laboratory testing and the management of laboratory personnel and equipment. In his words:

The ALF program enabled me to see the entire life of a pavement, from construction through to pavement failure. Field and laboratory testing I have been involved with has given me an appreciation of pavement behaviour, and valuable experience in managing personnel and equipment, including laboratory test programs. The wide range of experiences gained in a short period of time would be hard to obtain elsewhere.

CASE STUDY 3 – ENGINEERING STUDENT

Stephen worked at ARRB from November 2006 to February 2007 as a vacation student, after his third year of a four year civil engineering degree at Monash University. As with Will and Peter, his exposure to pavement engineering at university was limited. During his four months work at ARRB, Stephen worked exclusively as part of the ALF team.

A large component of Stephen's time was spent assisting with the maintenance of the ALF machine and the day-to-day running of the site.

Throughout ALF trafficking of test pavements, Stephen routinely collected transverse surface profile measurements and response to load measurements using the installed MDD systems. He was responsible for checking the quality of the data he collected, and therefore had to visualise the interaction between pavement loads and multiple responses within the pavement structure.

Stephen assisted during trenching operations, and was able to observe the condition of the trenched pavements with depth. As the test pavements were located inside the ALF shed, the trenching exercises were subject to less time and other constraints than would occur on a normal road subjected to live traffic under a traffic management scheme.

The other major component of Stephen's work during this short period involved the preparation of laboratory samples of the same cement treated crushed rock that trafficked by ALF at this time. After undertaking volumetric calculations to ensure that target mix designs were met, Stephen compacted samples in a slab compactor and then saw cut flexural beam samples from each slab. Using the same apparatus that Peter used (see above), Stephen was responsible for testing the prepared samples, measuring flexural modulus, flexural strength and fatigue performance. During this process he gained experience in time management, laboratory procedures and documentation, and was able to consider some of his undergraduate geotechnical and material behaviour studies in tangible ways.

Stephen's ALF involvement during a holiday period between academic studies covered a range of experiences, ranging from the measurement and processing of pavement condition data, machine maintenance, through to the assessment of material behaviour in the laboratory. In his own words:

I was really impressed with the variety of work that I was able to do as part of the ALF research team. Fellow students doing vacation work were often stuck doing the same dull task over and over throughout their work. I had a much more interesting time.

CONCLUSIONS

The experiences and knowledge gain demonstrated in the three cases above are very varied. In a short period of time the young engineers were exposed to the following activities, and in many cases given responsibility for their conduct:

- pavement terminology and the roles of materials within pavement structures
- selection of plant for construction
- removal of existing pavements by rotormill/profiler
- bulk mixing of pavement materials in a pugmill
- quarry operation
- pavement construction, including surfacing
- construction related testing, including levels and nuclear density meter assessments
- laboratory determination of moisture content of materials
- Falling Weight Deflectometer measurement and analysis of results
- ALF test pavement condition assessment, including measurement of changes in transverse profile of the road surface and surface macro-texture with increasing application of load cycles
- preparation of testing samples from field extracted material
- preparation of testing samples in the laboratory
- flexural modulus, strength and fatigue testing, analysis and reporting.

Whilst many of these activities are commonly conducted throughout the road industry, it is considered uncommon for a recent engineering graduate to be exposed to such a range activities within the first twelve months of their professional career. Beyond this list of activities the case studies also show the development of professional responsibility, resource and staff management roles and exposure to working within a team.

In addition, the engineers gained experience and skill in more specialist areas such as the measurement of pavement responses to load using strain gauges and multi-depth deflectometer gauges, pavement trenching and related investigations, and technical photography. The ALF program also proved to be an excellent environment for developing skills in project management, technical writing and communication. Skills regardless of future career direction, every professional engineer needs.

Throughout their time with the ALF program the engineers were working within a research team, learning and contributing to the experimental program through interaction with experienced pavement researchers. The experience of others, and their own observations during accelerated pavement testing, allowed the young engineers to develop a 'feel' for pavement behaviour. It is considered unlikely that engineers unfamiliar with APT work would have a similar level of understanding at the same stage in their careers.

The three cases demonstrate that young engineers can benefit hugely from even short term involvement in an APT program, and that there are many benefits realised from the process of involvement with APT in addition to those that are to be had from the research outputs themselves.

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