Application of Research in Road Stabilisation

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Summary: Since 1990 nearly $4 million has been spent in Australian on road stabilisation research using insitu and plant type operations. The finance for these projects have been drawn from Austroads, State Road Authorities, Universities, private companies in both construction and materials, and associations, such as C&CAA, ADA and AustStab. This paper will examine the outcomes to four major research projects (i.e. GIRD Project, Cooma, Erraring and Dandenong ALF Trials). Many of these projects started with broad questions facing designers on "how to" design and construct with little knowledge of the outcomes. This paper will also highlight that these large projects set the emerging trends in the road stabilisation industry.

1 INTRODUCTION

In the 12th century research on building structures could be best described by the following quote from a book titled *To Engineer is Human* by Henry Petroski (Ref.1):

> *...architects of churches erected only forty to fifty miles apart around Paris in the late twelfth and thirteenth centuries must have watched and been influenced :almost from day to day" by each other's experiments. One builder's structural and aesthetic success and failures were challenges and lessons to the others.*

One can imagine that the master builders mounted telescopes at the highest part of their construction to monitor the other's progress. Modern day questions that may arise from the quote are:

- ☐ Was this an effective way to carry out research?
- ☐ Who paid for the failures?
- ☐ Who carried the risk - owner, designer or builder?
- ☐ What can we learn from the example?

Whilst this paper does not have the answers to the questions about what occurred in the past it does highlight the outcomes to several successful research projects. This paper also poses some emerging trends that need focused research to provide continuous improvement to the performance and prediction of road constructed using the soil stabilisation process.

2 RESEARCH IN THE 1980s

In 1983 the Department of Main Roads, NSW produced the Accelerated Loading Facility (ALF) and it was proudly displayed at the PIARC[1] World Road Congress in Sydney in front of the Opera House. This device looked industrial and yet it was the equivalent of space age technology for road research. The ALF is now the corner stone of much of Australia's flexible pavement research and represents about a $1 million annual expenditure to AUSTROADS members and industry.

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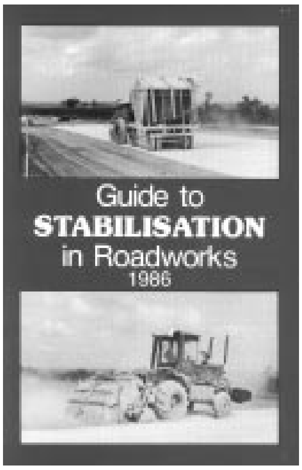
[1] Permanent International Association of Road Congresses

In 1986 the NAASRA[2] *Guide to Stabilisation in Roadworks* (Ref.2) was published and this small red book provided students and practitioners with some of the best knowledge in the design and construction of flexible pavements by stabilisation using cementitious binders and additives.

In the late 1980s Australian pavement engineers became concerned about environmental matters and this was reflected in the AUSTROADS Pavement Research Strategy (Latest strategy - Ref.3). Much emphasis was then given to the development and use of existing road base materials. In addition, waste materials such as blast furnace slag and flyash were being considered for use in road pavements.



3 RESEARCH INTO THE 1990s

3.1 General

The start of the 1990s saw the continuation of the development of blending cement with supplementary cementitious materials (SCMs) as a binder for road stabilisation, and also saw the arrival in Australia of new *powerful* equipment to stabilise pavements well over 200-mm thick. In addition, Australian engineers developed highly accurate spreading equipment which provided the tools for more reliable and better performing flexible pavements that were stabilised to depths of 400-mm.

Much of the historical research and construction aspects in stabilisation has been documented by Youdale, Wilmot and Jones (References 4 to 6). But in mid-1992 the seeds were sown by the University of South Australia, and other sponsors to continue further research into the use of cementitious materials for road rehabilitation.

During the initial phase of the project, road agency comment was sought, and the feedback may be summarise as:

- ❑ The effective rehabilitation of existing pavements would be a major issue for the 1990s.
- ❑ Recycling of pavements using hydraulic binders has been identified as potentially a very cost and resource effective method of rehabilitating existing pavements to meet the demands of modern traffic.
- ❑ Local government had led the way with rehabilitation using the stabilisation technique, however there were identifiable problems with the depth of stabilisation, compaction and finishing of pavements that would be subjected to heavy traffic.

The GRID project was designed to help fill the gaps in the knowledge in order to enable recycling to be much more widely used.

The project title was *The application of Portland cement in modifying properties of recycled road pavements to increase pavement strength while minimising material wastage and the need for new sources of new materials* ..... this required abbreviating and the project was referred to as the GIRD Project. GIRD is an acronym for a Grant from Industry Research and Development Board and this simple acronym has been widely accepted in the industry to-date. However, the shortened name for the research project should have been **Road Rehabilitation by Recycling**. Further details are in Section 3.2 of this paper.

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[2] National Association of Australian State Road Authorities

During the GIRD Project, Austroads Pavement Research Group (APRG) carried out three important full-scale pavement trials in Cooma, Erraring and Dandenong. These important trials and there outcomes are also documented in the following sections.

3.2 Road Rehabilitation By Recycling Project

Recycling using cement stabilisation is one such approach to rehabilitate the nation's existing road pavements and the Structural Materials and Assemblies Group at the University of South Australia set about this national road rehabilitation project in collaboration with the Department of Industry Science and Technology, Road Transport Agency (SA), Pavement Technology, and the Cement and Concrete Association of Australia[3]. The project team was formed in 1993, some $1.44m was spent on the project over 3 years.

The objectives of the project were:

- ☐ obtain data on the elastic properties of recycled pavements,
- ☐ provide data on the long-term behaviour of recycled pavements,
- ☐ study the technology for compacting pavement layers up to 400 mm thick, and
- ☐ review and extend the work already documented on the properties of cement-modified pavements.

Soils from around Australia (Ref. 7) were mixed with a range of binders reasonably available in the geographic area. The binders included cement/flyash, cement/slag, slag/lime and flyash/lime blends. The properties of these material combinations were investigated with a view to establish the suitability of the materials for road reconstruction.

All but two of the twelve laboratory tests were carried out to Australian Standards as listed in Table 1. The repeated load triaxial test, not listed in Table 1, was developed in the research project.

The results for the soil and stabilised soil properties were listed in six State reports.

One important milestone in this project was the development and use of a laboratory measuring procedure for repeated triaxial loading. This approach records both the lateral and axial deformations enabling the results to include Poisson's ratio.

Seventeen cementitious binders were chosen by SRA engineers for the project (see Table 2). For Western Australia (Ref.8) , binders 1, 4 to 6 and 17 were used with the three regional soil types (i.e. Singleton Pit, Mandurah, Bunbury Highway, Bullara-Giralia Road, near Exmouth and gravel pit on Logger and Procopia Roads, Brookton Highway, Perth).

One of the major outcomes to practitioners will be the ability to compare several binder types in representative soils in the nominated State and other States. The comparison can be carried out with respect to unconfined 7 and 28-day compressive strengths, wet-dry durability, permanent strain, resilient modulus, and Poisson's ratio.

Field trials have been carried out to verify the laboratory testing (Ref..9)

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[3] The Ash Development Association of Australia became members of the project team after the project commenced.

Table 1 List of test procedures for soils and stabilised soils.

Property	Standard Procedure
TESTING OF SOILS	
Sieve analysis	AS 1289.C6.1-197? 'Determination of the particle size distribution of a soil – standard method of analysis by sieving'
Liquid limit	AS 1289.3.9-1991 'Soil classification tests – Determination of the cone liquid limit of a soil'
Plastic limit	AS 1289.3.2.1-1995 'Soil classification tests – Determination of the plastic limit of a soil – Standard method'
Plasticity index	AS 1289.3.3.2-1995 'Soil classification tests – Calculation of the cone plasticity index of a soil'
Linear shrinkage	AS 1289.3.4.1-1995 'Soil classification tests – Determination of the linear shrinkage of a soil - Standard method'
Moisture-density relation	AS 1289.5.2.1-1993 'Soil compaction and density tests - Determination of the dry density/moisture content relation of a soil using modified com active effort'
TESTING OF STABILISED SOILS	
Unconfined compressive strength	AS 1141.51-1985 'Unconfined compressive strength of compacted bound materials'
Erodibility	ASTM D559-89 'Standard test methods for wetting and drying compacted soil-cement mixtures'
Modulus of elasticity & Poissons ratio	Standard procedure developed for the project and adapted from AS 1289.6.8.1-1995 'Soil strength and consolidation tests - Determination of the resilient modulus and permanent deformation of granular unbound pavement materials'

Table 2 Description of the binders selected from various regions of Australia.

State Nominated Binder	No.	Description and ratios
SA	1 2 3	Cement GP: fly ash (70:30) Cement GP: fly ash (80:20) Cement GP
WA	4 5 6 17	Cement GP: blast furnace slag (35:65) Cement GP: fly ash (70:30) Cement GP Blast furnace slag: Hydrated lime (80:20)
QLD	7 8 9	Cement GP: blast furnace slag (40:60) Cement GP: fly ash (70:30) Cement GP
VIC	10 11 12 16	Cement GP: blast furnace slag (40:60) Cement GP: fly ash (70:30) Cement GP Blast furnace slag: Hydrated lime (85:15)
TAS	13	Cement GP
NSW	14 15	Cement GP: blast furnace slag (40:60) Cement GP: fly ash (70:30)

Several conclusions may be drawn from the trials in terms of the following properties of the stabilised soils:

1. All binders appear to give consistent 28 day UCS strengths with the exception of the Cement/Slag blend (4) which had a lower strength for the Perth based soil. The cement binder (6) consistently gave the highest UCS strength (Ref.7, page 8).

2. The stabilised soil from Exmouth had the lowest soil-binder loss in the order of 4 to 8% compared to 23 to 40% loss for the Mandurah stabilised soil. The cement binder (4) provided the least loss in this test (Ref.7, page 9).

3. In terms of the resilient modulus of elasticity, the results indicate (Ref.7, page 14):

    - the soil from Mandurah, stabilised with 4%, by dry mass of soil, of the Cement/Slag binder (4), produced a fractionally lower modulus of elasticity, in comparison to the similar moduli of elasticity when stabilised with 4%, by dry mass of soil, of binders 1, 5 or 17.
    - the soil from Perth, stabilised with 4%, by dry mass of soil, of GP cement binder (17), produced a lower modulus of elasticity, in comparison to the results of stabilisation with 4%, by dry mass of soil, of binder 1, 4 or 5
    - the soil from Exmouth, stabilised with 4%, by dry mass of soil, of the Cement/Slag binder (4), produced fractionally higher modulus of elasticity, in comparison to similar results of stabilisation with 4%, by dry mass of soil, of binder 1 or 17.

Billinger and Doherty from the University of SA have established a computer package for the design of stabilised pavements, titled PavFEA™. The engine to this package is STRAND6[4] and the researchers have developed an up-front model package that will produce finite element layers and elements, and loading according to the specific design situation.

3.3 Field Trials at Cooma

In 1990 an investigation commenced into the feasibility of deep-lift stabilisation of granular pavements to satisfy the structural design requirements of heavily-trafficked rural pavements. The investigation had taken into consideration construction techniques that had been developed from pilot and full-scale trials in NSW in co-operation with industry.

Using this stabilisation techniques it was estimated in 1994 that savings of 20-40% over the cost of granular overlays could have been achieved in New South Wales which translated into a $4M-$6M per annum saving for a $20M rehabilitation program.

The Cooma ALF trial, as it was “affectionately” known as, was conducted from May to October 1994 adjacent to the Monaro Highway some 20 km north of Cooma in southern NSW. The objectives of the trial were to (Ref.10):

- establish the performance of deep-lift recycled pavements, using stabilisation equipment now available, over subgrades of relatively low and relatively high strengths;
- gain a better understand of the distress mechanisms and hence possible interventions to extend pavement life and to determine how pavement performance depends on stabilisation depth;
- compare the observed pavement lives under accelerated loading with fatigue lives predicted by

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[4] STRAND6 is a successful Australian general purpose finite element analysis package in a Windows format. It is available from G+D Computing Pty Ltd (Facsimile 02 9264 2066).

AUSTROADS, Queensland Transport and VicRoads design recommendations; and

- enhance construction guidelines, specifications, test methods and to gather data on whole of life costing for deep-lift recycled pavements.

The project was very successful and gain a lot of interest from overseas pavement engineers. The final report (Ref.10) and a subsequent publication from the RTA (Ref.11) allowed the deep-lift process to continue in NSW and SA with greater pavement reliability and minimisation to construction risks.

The major findings from the report are:

- Under accelerated loading, all pavements tested on a low strength subgrade (CBR 4%) had fatigue lives at least twice the loading estimated for the Monaro Highway (5.3 x 10^6 ESAs) over a 20 year design period. Consequently, the trial findings suggest that this type of pavement recycling is suitable for moderate rural arterial traffic.
- Under current construction practices where pavements are compacted in single lifts to depths greater than 300 mm, the bottom third of the layer generally had about 5% less relative density than the top two-thirds. This approximately halves the UCS and modulus, i.e.UCS of 3 MPa reduces to 1.5 MPa and the modulus of 12,000 MPa reduces to 6,000 MPa.
- If field compaction techniques can be further improved to increase the level of compaction of material below 300 mm then substantial gains in pavement performance are anticipated.
- Nuclear density gauges are unable to measure densities more than 300 mm below the surface in backscatter mode. Accordingly, it is recommended that where the depth of stabilisation exceeds 300 mm, cores be taken for density determination to supplement the data obtained from nuclear gauges.
- The enhanced performance of the unbound granular material following stabilisation was most apparent from Experiment 5[5]. The unbound granular material failed after only 180 cycles of 40 kN loading, whereas the 300 mm and 360 mm stabilised pavements were still performing satisfactorily after a total of 148 kilocycles of loading, including 138 kilocycles of 80 kN loading.
- The observed fatigue life substantially exceeded the AUSTROADS predicted fatigue life for all stabilised pavements tested on the high strength subgrade and for the 250-mm and 300-mm thick pavements tested on the low strength subgrade. However, when the 360 mm stabilised layer on the low strength subgrade in Experiment 3[6] was tested it cracked well before the AUSTROADS predicted fatigue life. This premature cracking may have been due to the bottom third layer of this particular test pad being 5% less dense than the top two-thirds. However, cracking did not occur in the 360 mm thick stabilised layer tested in Experiment 5. This suggests that the observed fatigue life of the 360 mm stabilised layer in Experiment 3 may have been adversely influenced by the proximity to the adjacent trench. It is concluded that the AUSTROADS fatigue relationship under-predicted the fatigue life of the trial material. The AUSTROADS fatigue relationship has also been observed to under-predict the life of a good quality cement-treated crushed rock. The Queensland Transport and VicRoads fatigue relationships better predicted performance than the AUSTROADS relationships.
- There is justification in using a conservative approach for design in view of the variability of existing materials, thickness, binder quantity, compaction and curing. Such a design approach reduces the risk of premature fatigue failure and enables the cost savings afforded by deep-lift recycling to be realised. Accordingly, in designing recycled pavements it is recommended that:

  (a) to inhibit erosion and provide a stiff stabilised layer, a minimum 4% binder should be used;
  (b) the recycled pavement should be assumed to have a design modulus of 5,000 MPa (as more data become available on moduli from routine jobs this modulus assumption may need be revised);
  (c) the QT fatigue relationship be used to predict life; and

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[5] Over 300-mm bound, 400-mm unbound and 360-mm bound sections.

[6] 360-mm bound pavement with 5% of slag/lime(85:15).

(d) until more information is available on the variability of input parameters and the performance of recycled pavements, the design traffic should not be modified to improve design reliability (e.g. RTA Form 76, Section 7.9).

- ☐ The presence of narrow shrinkage cracks at greater than 2.5 m spacing where the surface seal remained intact did not appear to effect the pavement performance although this trial did not take into account the effect of an expansive subgrade. However, rainfall during ALF loading was low and a difference in performance may occur when the pavement is wet.
- ☐ The modulus and UCS values of some moulded specimens differed from the values obtained from field cores. Laboratory sample preparation procedures need to be reviewed to enable closer agreement between the results obtained on moulded specimens and field cores.

3.4 Flyash Trials at Erraring

Pacific Power is conducting a major three-year research and development project to examine the possible use of flyash (a waste product from conventional coal-fired power generation) as a pavement material. The major aim of the project is to demonstrate the cost-effective use of flyash in road construction and to generate high quality data on the use of flyash, with a view to promoting the results widely to potential road builders.

A major component of the project was an accelerated pavement loading trial using the Accelerated Loading Facility (Ref.12). A total of 17 experiments was carried out on the following range of pavement types:

- ☐ 2%, 4% and 8% cement-stabilised flyash base 300 mm,
- ☐ 1.5% cement-modified crushed rock base 150 mm thick and 4% cement-stabilised flyash subbase 150 mm thick,
- ☐ unbound crushed rock base 150 mm thick and 4% cement-stabilised flyash subbase 150 mm thick,
- ☐ a 'control' section of 2.5% cement-stabilised crushed rock 300 mm thick.

The distress mechanisms observed under accelerated loading were different for cement-stabilised flyash base and subbase pavements. In the case of the cement-stabilised flyash (CSF) base pavements, the mechanism was fatigue followed by crushing of the material. Where cement-stabilised flyash was used as a subbase under a granular basecourse, the pavements rutted after a relatively low number of loading cycles, with rutting of the granular base being the principal distress mechanism.

Analysis of the data of the cement-stabilised flyash base pavements allowed 'crushing' life performance relationships to be estimated for 2%, 4% and 8% cement-stabilised flyash. Using these performance relationships, interim design charts for thick (>200 mm) cement-stabilised flyash base pavements were derived. It is recommended that these charts be revised as additional field performance data become available.

In designing cement-stabilised flyash base pavements using mechanistic design principles and the above mentioned crushing life relationships, it is recommended that design moduli of 1,000 MPa, 2,000 MPa and 5,000 MPa be adopted for 2% , 4% and 8% cement-stabilised flyash respectively.

The performance of cement-stabilised flyash base and subbase pavements placed on a Coal Haul road within the Erraring Power Station is being monitored. Given the performance of the cement-stabilised flyash base pavements under ALF loading, the cement-stabilised flyash base pavement should last well in excess of 20 years.

3.6 Dandenong ALF Trial on Marginal Materials

Austroads and various industry organisations are currently supporting the Accelerated Loading Facility Trial in Dandenong, east of Melbourne (Ref.13). This $0.55 million trial is looking at a series of different binders in a very marginal soil from Victoria. The two major binders are a 2% GP cement and 2% bitumen, and a 4% slag/lime (85%/15%) cementitious blend. The pavement thickness is 200 mm on 2% lime stabilised (300 mm deep) clay subbase. In addition, testing was carried out on a crushed rock pavement from Boral Montrose quarries.

Trafficking of the trial pavements was completed in March 1997 and the results are likely to be available in late July.

The project objectives for this trial are:

- ❑ To compare the "life" of a unstabilised marginal material with that when the material is stabilised in situ with cement/bitumen and slag/lime blends as a means of both ranking performance and examining the relevance of the fatigue performance relationships currently recommended by AUSTROADS to these types of rehabilitation treatments..
- ❑ To establish a means of predicting, in the laboratory, how, for a given additive type and content, improved performance might be predicted.
- ❑ To examine the influence of curing time on performance.

This type of insitu pavement with the marginal material is being proposed for rural Victorian and South Australia with a spray sealed surface finish. In the trial a 40-mm thick layer of dense graded asphalt was used in order for the ALF wheel to operated effectively.

The proposed outputs for the project are:

- ❑ Update of AUSTROADS "Guide to Stabilisation in Roadworks"
- ❑ Improved guidelines for the more effective and economic use of in situ stabilisation, including the design of pavements incorporating these layers.
- ❑ A means of predicting, in the laboratory, how, for a given additive type and content, improved performance might be predicted.

ARRB Transport Research are currently finalising the calculations to establish *relatively* rather than *absolute* pavement performance from the reference unstabilised pavement. Whilst the construction of the trial pavement experienced some difficulties and the site had poor drainage, some initial conclusions have been drawn from the trial:

- ❑ both the slag/lime and GP Cement/bitumen binders performed well,
- ❑ it is essential to cure the pavement after construction to maximise pavement performance, and
- ❑ target compaction of the stabilised pavement should not be greater than 95% for marginal pavement materials and the specified contract limit should be evaluated for each project.

4 EMERGING TRENDS

4.1 General

The number of experienced pavement engineers are declining as State Road Authorities reduce their in-house expertise by government cutbacks and engineering salaries remain low to keep talented engineers attracted to the industry. This section looks at the emerging trends that will drive research into the next decade and are the views of the author.

It must be stressed that whilst some engineers seek to improve the system by using manufactured material process control and design processes, the stabilisation technique is a low-cost construction approach to extending the road funding dollar and reduce our requirement of quarried granular materials. The application of more performance-based specifications to local government roads has to be questioned as more site investigation and insitu testing after construction increases the cost of stabilisation contracts in what can be regarded as a inherently tolerant construction process. Lets not loose sight of the economic benefits of this type of pavement for road rehabilitation.

4.2 Equipment

The introduction of the CMI RS500 in the 1990s led the charge to allow insitu stabilisation to depths of 400-mm (i.e. the deep-lift process) in one pass rather than construct the pavement in two separate layers. This allowed quicker construction times and avoided the need to have stockpiles of subgrade material. This process could have not been achieved without the use of 18-tonne sheep-foot rollers and similar equipment to compact the stabilised layer to depths of 400-mm. It is also recognised that compaction through the entire depth is “linear” and the designer should take this into consideration in the pavement analysis.

The success of the deep-lift process has now been well recognised in several States of Australia for rural roads. This success has also been seen in urban road projects where granular and asphalt pavements have come to the end of their life. These machines are very powerful but their application in the urban environment is mainly to minimise cartage to waste sites by using the existing pavement materials through the pulverisation action of the machine and to minimise the binder content. To achieve this goal the depth of the existing asphalt pavement should not exceed 100-mm. Although, greater depths of asphalt recycling with the CMI RS650 has been achieved the ability for the material to be successfully broken down to small particles can be questioned. These machines will go through further development in the next decade in terms of the pulverisation action and the mixing process between the binder and pavement materials.

Australian cement and powder type spreaders are the most advanced in the world and it is hard to fathom that just over twenty years ago cement and lime was spread on roads using bags. The use of mechanised spreading equipment commenced in the 1960s and was “crude” compared to the equipment now used.

Powder type binders are now spread by special tankers with electronic load cells measuring the weight of the tank on a continuos basis. In addition, some vehicles have electronic sensors to measure the distance traveled which allows the operator to establish the average spread rate at anytime. Powder spread rate operations are currently undergoing rapid development to allow a more efficient operation of combining water, binder and pavement material.

Some road engineers have questioned the efficiency of pug-mills, or similar equipment, where materials are combined in a wet-process plant near the site and then slipformed and compacted in the road. The cost of transporting material to and from site and the congestion this adds to the commercial traffic while part-road closure occurs is likely to make this process cost prohibitive.

4.3 Binders

The greatest impact of binders has been the shift from the use of type GP (Previous Type A) cement to blended cement types (GB) and blends of slag, lime and fly ash. The increasing use of ground granulated blast furnace slag and fly ash from manufacturing facilities along with cement, lime and bitumen will allow pavement designers almost unlimited choices for insitu stabilisation.

There will be an increasing demand by Government for "new" waste or manufactured by-product materials to find their way into road stabilisation as the push for a sustainable environment takes on more than rhetoric by commentators. However, similar to the wool-fibre experience in the early 1990s pavement engineers will have to quickly establish the short and long-term behaviour of these materials to ensure road performance is not compromised.

It is likely that several new performance-based properties will be developed in the next few years that extend beyond the use of specifying density and compaction to say insitu Youngs Modulus, shear friction, erodability and crack widths. As the growth in these requirements to conform to specification increases the need to use chemists and other material engineers to develop binders that have a wide-performance range will increase binder costs.

4.4 Testing Insitu Performance

The ability to use performance-based specifications in road stabilisation contracts is limited by the known variability of the existing material and the high cost of some test procedures to measure known characteristics of the pavement material. Some engineers may say that what is needed is the "Star Trek" type of hand-held sensor that provides various performance indicators simultaneously, such as density, moisture level, compaction, cement content etc. The introduction of more remote sensing equipment (i.e. infrared temperature devices) from defense and space research will hopefully make its way to the road industry soon to allow low-cost assessment of the existing material and final stabilised material.

4.5 Computer Analysis

The ability for desk-top PCs to carry out complex calculations faster and “look” at bigger analytical models will improve over the next decade such that the analysis process will be efficient and engineers will be able to examine many more pavement and loading options. Recently CIRCLY[7] was upgraded to Windows format and this has improved the productivity of engineers at the analysis stage.

In addition, STRAND6 is also being used to analyses pavement materials and this finite element package is available with many consulting firms which have traditionally used the software for structural engineering. The University of SA is currently developing a module to STRAND6 which will hopefully reduce the time for engineers to develop the FE model.

One of the current limitations in FE modeling is that the soil is variable and the loading is variable with time and space, and the approximations in these models must be carefully scrutinised to ensure the model assumptions are compatible with what can be achieved on site using the current specifications and standard equipment.

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[7] CIRCLY has been developed by Mincad Systems Melbourne.

5 CONCLUSIONS

The 1996 national symposium[8] on the use of recycled material in engineering construction attracted some 36 papers on the use of recycled materials in building and construction. A major portion of the papers contained in the proceedings was related to the area of pavements, and this highlights a growing area of research and application of waste products or by-products from manufacturing, such as flyash.

The emerging trend discussed in Section 4 of this report are the authors visions and it must be stressed that these trends must not happened in isolation. New testing techniques must be developed that are user-friendly and provide input into computer models that allow specifications to be written in performance-based terms that take into account the variability of the subgrade material and the efficiency of using large machines to reduce construction costs to the road owner.

One of the problems facing research organisations is the ability to demonstrate the outcomes in pavement design and analysis. The increasing use of seminars is helpful but the cost of these seminars make them prohibitive in rural areas of Australia. It is hoped that as the Internet becomes more widely accepted and used the ability for technology transfer to occur to a wider audience after the final report is published using new multi-media techniques will make these research project more productive in practice.

Industry organisations, such as AustStab, are in a suitable position to carry out research activities with universities, State road authorities and Austroads in order to meet the use of recycling materials in roads. It is important that these materials do not replace the traditional cement binders used in Australia, but offer enhancement to meet the needs of road designers and contractors build pavements suitable for construction and financial targets.

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[8] This symposium was organised by the Institution of Engineers, Australia and held in Sydney on 30 and 31 May 1996.