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Challenges Confronting Sustainable Practices for Concrete Pavement Design and Construction in Australia

George Vorobieff [1+]

Abstract: Australia has consistently used supplementary cementitious binders as a replacement to General Purpose (ordinary) cement in a variety of pavement materials since the 1990s. These binders often provide many enhancements to both the wet and hardened properties of concrete. However, while the usage of by-products like fly ash is a success story, Australia has yet to use bottom ash and other recycled materials effectively in concrete pavement configurations and stockpiles of these material increases from year to year or is just placed in landfills. Pavement engineers have been accustomed to selecting the 'best' industrial by-products, there is a growing need for further research on how to best utilise other by-products in pavement materials both above and below the formation level. The use of other than quarried materials in the lower layers will greatly assist with sustainable practices and recent trials with two-layered slipform paving in NSW should steer pavement engineers in better utilisation of resources in the concrete layers and modify design rules and specifications to allow these materials in combination with quarried products. Some of our existing concrete roads are becoming rough and/or losing surface texture and diamond grinding equipment will be able to restore ride quality or skid resistance without the need to place thin asphalt correction courses which will also help conserve quarried materials. This paper explores the challenges facing pavement engineers and asset managers in Australia in achieving further refinements to concrete pavement design and construction practices, especially in NSW. Focusing only on the sustainability of design or construction practices is simply not enough, and in the coming years, new government policy will dictate higher levels of sustainable road construction practices. If concrete as a material is to compete in the future with other road construction materials, pavement engineers will have to make advances in the traditional approaches to the design, specifications and construction of concrete pavements and to change the current business environment of procurement and compliance.

***Key words**: Concrete; Design models; Pavement; Recycling; Sustainability.*

Introduction

Insitu stabilisation has been one form of sustainable road construction and maintenance practice that has been used in Australia since the 1960s (Note that 'Insitu stabilisation' is commonly referred to as 'full-depth reclamation' or 'cold-in-place recycling' in Northern America.). Although the terminology has changed, the motives of the road authorities are the same today as they were 50 years ago. The three main drivers of insitu stabilisation of roads since its inception have been lower costs, limited, or insufficient supply of local road making materials and more recently, it became a social or civic responsibility to 'recycle roads'.

In the late 1980s, there was growing recognition that the continuous accumulation of waste (including road materials) and the dumping of this waste into landfill was at odds with long-term environmental management. Most State governments implemented waste minimisation strategies and promoted the waste minimisation hierarchy as shown in Fig. 1 [1]. This era gave rise to the term 'road recycling' and local governments became enthusiastic users of road recycling for light trafficked roads and then collector roads as the reliability of process improved.

In Australia, an engineer created great discussion in the mid 1990s with his proposition that roads could actually be considered as a linear quarry [2]. If road owners were extracting excellent road building materials from a quarry, then once these materials were in place, they should be considered to be an extension of the quarry. And when the performance of these roads declined, the material could be improve in place through insitu stabilisation or other processes.

Work by Chris Little at Hurstville City Council in the mid-1990s showed a number of benefits for local government road networks using insitu stabilisation, and for the last 15 years this has been a common or preferred rehabilitation treatment for road owners [3]. Some major local government engineers have been so successful with their road maintenance treatment that many of their roads have greatly exceeded their design expectations [4].

In asphalt, the use of reclaimed asphalt pavement (RAP) material in Australia has been used as a replacement for 'virgin' materials. However, most road authorities limit the use of RAP material to 15% to ensure a 'durable' asphalt is produced, especially for heavy trafficked roads. Other waste materials recycled for road construction

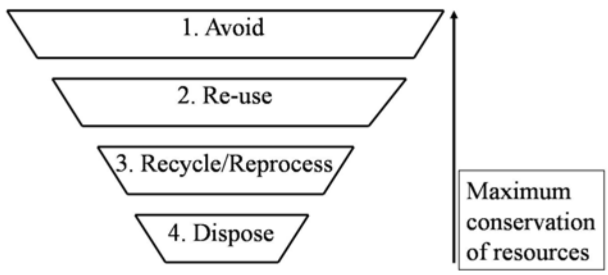

Fig. 1. Waste Management Hierarchy NSW [1].

[1] Director, Head to Head International, Frenchs Forest DEL-FAC, NSW 2086, Australia.
[+] Corresponding Author: E-mail vorobieff@headtohead.com.au
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Table 1. Topic Headings under 'Sustainability' from Australian SRA Websites (February 2010).

SRA and State	Website URL[1]	Details
VicRoads, Victoria	vicroads.vic.gov.au	Environment strategy, Greenhouse and climate change, Noise, Biodiversity, Cultural heritage, Native title, Urban design, and Resources and recycling and water.
DMR, Queensland	mainroads.qld.gov.au	Under the topic of 'Sustainability' links to 'Noise management' and 'Waste management'.
RTA, NSW	rta.nsw.gov.au	Broad topic areas similar to VicRoads.
DTEI, South Australia	transport.sa.gov.au	Broad environmental topics and no 'sustainability' web page.
DIER, Tasmania	transport.tas.gov.au	Link to Conservation Sites Program - to prevent or minimise the likelihood of damage to high priority threatened species and threatened species habitat.
Main Roads Western Australia	mainroads.wa.gov.au	Protecting and enhancing the environmental values of road reserves; Minimising the impact on the natural environment of roads and road use; and Conserving natural resources and minimising energy consumption and waste.
DPI, Northern Territory	dpi.nt.gov.au	No specific web page.

[1]www should be added at the beginning of the URL

include crushed concrete from building works and crushed sandstone from excavated foundations. Blast furnace slag from both steelworks in Newcastle (New South Wales) and Port Kembla (NSW) has also been used for subbase layers[1]. A common heavy duty pavement configuration in the Newcastle region of NSW is a 100*mm* thick asphalt layer supported on a 300*mm* thick slag aggregate subbase layer [5]. The slag aggregates are weathered and combined with a small quantity of fly ash to become self-cementing and the Newcastle region has had great success by using this 'waste' material.

Treated sewerage water is now also being permitted in road construction and VicRoads has developed comprehensive guidelines [6].

If the hall mark of sustainability is to both reduce the use of quarried aggregates in preference for more by-products or industrial waste, Australia has already achieved this goal. The more important questions now are "What is the best ratio of modified recycled materials with quarried materials?" and "What implications does there use have on the environment and can these materials be recycled again and again?"

Finally, this paper goes beyond a discussion of preferred products and techniques for sustainable concrete road construction and maintenance. What is the most suitable business environment to foster the development, acceptance, and production of new recycling products which will enable suppliers and contractors to make acceptable profits for shareholders while minimising long-term risks to the road authorities. With pavements and bridges now expected to last more than 50 years, the prediction of engineering performance is vital for economic and material sustainability - otherwise we risk taking one step forward and two steps backwards.

Scope in Sustainable Practices

Although Australian State Road Authorities (SRAs) are generally keen to implement new policies and procedures for sustainable road design, construction, and maintenance; there is no consistent approach by engineers and 'old habits' or 'comfort zones' may hamper the development and use of sustainable and proven treatments. For example, a major regional centre in NSW will not permit insitu recycling of granular materials for its local roads as they have recorded several cases of windscreen cracks due to loose stones on the surface after construction and before the wearing course has been placed. Whether or not the claims are legitimate, the decision to dismiss this simple technology successfully used in many other parts of Australia, demonstrates an unscientific selection of sustainable road construction processes based on limited information not consistent with the main body of evidence and aberrant decision modelling at local government level.

Information taken from the website of various State based road authorities (SRA) under the sustainability category indicates mixed views on sustainability as shown in Table 1. The variation in the information presented to the community is not consistent with some of the work being carried out by the road authorities and may reflect a lack of focus and clear decision making by the authorities.

There currently is no common measure of sustainability in Australia, and whether such a measure for road construction can be devised is yet to be determined. Many industries and organisations use a reduction in the volume of nonrecyclable and recyclable waste as a measure of sustainability achievements. In an office environment this is a simple task, however other organisations measure energy usage on an annual basis or calculate their carbon footprint. Some local government organisations use the 'triple bottom line' reporting as a 'community report card' and believe this is sufficient until a more robust and universal measure is established. News stories about unsubstantiated claims are often found in the Australian press and this can be a cause of concern for consumers and raise even more doubt about the need for sustainability [7]. It is hoped that a new national standard will lift the benchmark of legitimate reporting.

The Australian Green Infrastructure Council (AGIC) is now developing a 'star' rating scheme whereby set criteria are used to calculate how sustainable an infrastructure project is with more stars awarded for higher levels of sustainability [8]. These schemes are already used in Australia to determine such as energy usage rating

[1] In Australia 'base' and 'subbase' layers are equivalent terms to 'pavement' and 'base' layers respectively in North America.

for electrical appliances on sale. The Australian Property Council is also moving towards mandatory building ratings to recognise building owners who pursue a green approach and enable financial compensation [9].

There is wide scope in how we can address sustainability issues in road construction and maintenance and this could be categorised by:

- Community access,
- Raw and waste material utilisation,
- Green house gas emissions,
- Flora and fauna, and
- Heritage.

Australia has a similar land mass size to the USA but is sparsely populated with only 22 million people. Many regional communities are remote from the coastal cities and the local road infrastructure is crucial to maintaining a sustainable community as no alternative transport is available for hauling produce to markets or local supplying businesses. Poor road infrastructure could have far reaching consequences and lead to unsustainable community centres in regional Australia.

Several SRAs have developed CO_2 calculators which are essentially spreadsheets designed to standardise the total estimate of CO_2 emissions resulting from the construction of a new stretch of highway. VicRoads constructed a 2.4*km* bypass using a conventional flexible pavement which relied heavily on quarried products which then VicRoads planted 4,500 trees to offset the CO_2 emissions [10]. The carbon footprint for the project was 1,750 or 182*t* per lane kilometer. Whilst this environmental process is a positive step to address for climate change, it nevertheless allows the use of quarried products which has a low CO_2 emission. Is a low CO_2 emission for the construction really sustainable if it depletes the limited natural resources of a quarry?

Is a reduction in Green House Gasses (GHG) relevant for road construction materials when placed in context with the RTAs estimate in 2001 of 29,672*t* of equivalent GHG emissions for electricity usage for traffic signals and 15,051*t* for street and tunnel lighting over a 12 month period [11]. The GHG emissions from traffic using roads in Australia outstrip any construction activity probably in the order of 1 to 15 or more, and therefore, it raises the question; “Are our efforts focused on the real impact areas of sustainability?”

Tens of millions of dollars are spent in Australia every year to preserve fauna and flora threatened by urban or industrial development. Opponents claim that a decision to save a frog which very few people would ever see often goes unchallenged and taxpayers fund these costly decisions, at times in the millions of dollars. If the species is endangered, there are high costs to accommodate the endangered animals and provide a similar habitat as part of the development approval. The moving of habitats is not proven technology as there is no guarantee that the species may continue to be threatened by predators or long periods of drought.

The construction of major highway corridors in metropolitan areas occurred over 40 years ago when sustainability and environmental concerns were not mainstream issues in Australia. Any road easements not previously allocated to road infrastructure development have since been urbanised and new sites are generally those where the ground has poor agricultural value, or it is located in wetlands or flood plains. There are now concerted efforts to minimise damage to existing wetlands through the capture and detention of road surface runoff or by reducing the areas for construction traffic or other treatments. The organisation responsible for the 40*km* Eastlink project on the eastern side of Melbourne experimented in an attempt to preserve part of a threatened wetland area at the end of the Motorway [12]. This small wetland[2], which contains remnants of a 'herb-rich plains grassy' plant, was directly in the path of the planned carriageway, however specially modified excavating equipment was successfully used to relocate about 4000m^2 of the highest-quality areas of the wetland to a similar site nearby but away from the carriageway alignment. This is a clear example of the establishment of environmental objectives and taking a bold approach to manage ecological sustainability.

Although Australia’s civic history is little more than 200 years, the indigenous people have a heritage that goes back thousands of years. Whilst aborigines did not build structures, they linked natural landmarks, trees, rivers to their past and culture. There is now a concerted effort in Australia to ensure that new road construction does not ignore heritage values, such as these and forms part of the overall sustainable approach to the community.

Heritage protection can also be an impediment to sustainable construction practices as it can limit the construction space for major highways and restrict pavement configurations and construction processes. For example, maximum permitted vibration of earthworks or side access tracks for tippers to place concrete.

Community pressure on road authorities to protect or preserve local flora, fauna, heritage and social sustainability may significantly increase road construction costs. Now more than ever road authorities are required to avoid budget over runs and find new ways to ‘cut the pie in fair parts’.

Highway Concrete Pavements in NSW

To better understand the challenges for sustainable concrete paving practices presented in this paper it should be noted that the Australian concrete paving industry is dominated in NSW. The Roads and Traffic Authority of NSW (RTA) is a leader in concrete road design and construction technology and has a great deal of experience. This experience has led to the development of minimum concrete pavement configurations for heavy duty pavements, as shown in Fig. 2 [5]. These pavements are designed for about 10^8 heavy vehicles per lane over a 40 year life[3]. Similar to other pavement types and design models, light vehicles under 3*t* gross mass are not included in the calculations although they typically account for 70 to 85% of the overall traffic volume on a major urban or rural freeway.

Some of the key features in the pavement configurations shown in Fig. 2 are listed in Table 2 [13] and more information regarding

[2] The Boggy Creek remnant is the second-largest remnant of a wetland plant community that was once extensive in the Cranbourne-Lynhurst region.

[3] This applies for a plain concrete pavement (PCP) 260*mm* thick, 150*mm* lean-mix concrete subbase, no dowels, 5% subgrade strength, 95% reliability, default rural axle distributions, and concrete shoulders.

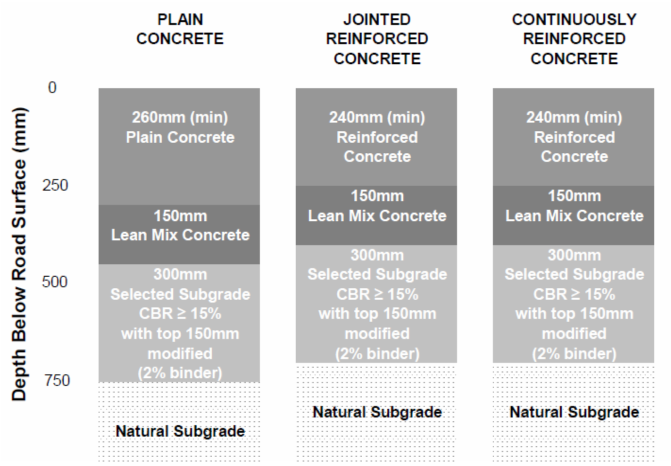

Fig. 2. Typical Heavy Duty Rigid Pavement Configurations Used in NSW [5].

Fig. 3. Local Concrete Roads in Chatswood (left) Built in the 1930s Take Large Numbers of Light Vehicles, Moderate Number of Buses, and Limited Numbers of Heavy 6-axle Vehicles. The Princess Highway (Right) of Similar Age Takes Significantly Higher Heavy Traffic.

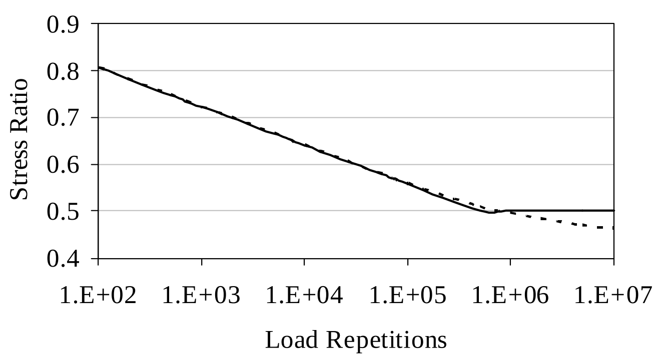

Fig. 4. The Austroads Design Model Uses This Concrete Fatigue Curve [14].

the rationale behind these configurations are described later in this paper and published work by Vorobieff and Moss [14].

Challenges to Sustainability Practices

General

Given that sustainability can be measured in many different ways and from both the initial stage of design and construction through to the end-of-life of a section of highway, the challenges in Australia and for concrete roads can be categorised under the following topics:

- Pavement design period,
- Materials,
- Pavement design,
- Specifications,
- Quality,
- Procurement format,
- Innovation and risks,
- Maintenance, and
- Cradle-to-grave.

Pavement Design Period

At the 2008 International Society of Concrete Pavements (ISCP) Conference, a workshop on long-life pavements concluded that pavements for major road corridors should be designed for long lives, in the order of 50 to 60 years. Some Sydney metropolitan roads built 50 to 80 years ago (as shown in Fig. 3), are still operational even though they would have exceeded their design life many times over. The equivalent flexible pavement would have undergone several rehabilitation cycles in the same period requiring access to new materials. If the original pavement materials are durable, the pavement configuration has practical detailing to manage moisture movements and the opportunity is taken to replace joint sealants; in theory, a sustainable pavement with these early concrete roads has been achieved.

One approach to engineer a long design period is to keep the repetitive traffic tensile stresses below the ‘infinite repetition line’ as shown in Fig. 4 [14]. By keeping the applied stress ratio low, the extra material required to build the concrete pavement could be weighed against the estimate of slab replacements and a longer pavement life.

The durability of pavement materials is discussed in the next section, but road owner policy must direct asset managers to fund the design configurations with significantly longer lives provided they can demonstrate a ‘low’ whole-of-sustainable life solution.

The transport industry in Australia is keen to raise legal axle load limits with the use of road friendly suspension to increase transport productivity. However the higher stress on pavements will reduce their life and place more pressure on suitable pavement design. The community has to weigh the benefits and limitations to better transport productivity to higher cost of pavement construction and maintenance to achieve a balanced approach to sustainable road construction.

Materials

When materials and food was scarce in the Great Depression, ‘watering down’ food was common place and could be considered a sustainable practice given the circumstances. The same ‘watering down’ principle could be applied for mixing recycled materials with quarried materials. Increased use of recycled materials will reduce the reliance on natural quarried material.

Materials within a pavement structure have different primary and secondary functions. For instance, quartz sand particles in concrete, offers skid resistance at microtexture level whereas coarse aggregates with high polishing value are used in asphalt to provide skid resistance and aggregates are selected on their polishing performance.

Table 2. Applications for Recycled Material and Construction Benefits [13].

Recycled Material	Applications (Current and Draft)
Asphalt (Recovered)	Granular material in pavements. Aggregate in asphalt (blended, neat in shoulders).
Bottom Ash	Earthworks (cut and fill). Granular pavement materials. Subsurface drainage materials.
Brick/Tile	Earthworks and granular pavement materials.
Crushed Concrete	Earthworks and granular pavement materials.
Fly Ash	Cementitious/binder/filler in concrete, stabilisation, and asphalt. Filler in slurry sealing.
Glass	Cementitious/binder/filler in concrete, stabilisation, and asphalt. Manufactured sand in concrete and asphalt. Granular material in pavements.
Quarry by-product	Granular material in pavements (often blended).
Roadbase (Pavement)	Earthworks and granular pavement materials (up to 100% via insitu stabilisation).
Scrap Rubber	Sprayed sealing. Asphalt
Slag (Blast Furnace)	Cementitious/binder in concrete and pavements stabilisation
Slag (Steel)	Earthworks and granular pavement materials. Aggregate in sprayed sealing and asphalt

The use of sand with high quartz content is beneficial for a durable wearing surface but serves no additional purpose within the base concrete layer and could be considered a 'waste'. However as discussed later, a thin long wearing surface or two-layering paving, offers possibilities for using the quartz sand where it has maximum benefit.

It is widely recognised that sources of aggregates to meet traditional grading curve limits are in short supply in both urban and some regional areas of Australia. For many years now, roadworks in rural areas have required an economic compromise between long distances to quarry sites and the use of marginal materials for both new construction and to maintain the road network.

Table 2 lists the applications and construction benefits of recycled materials now used in Australian roads. The sparsely populated residential areas and industries that hug the coastline make it uneconomical to use materials such as bottom ash and steel slag far from their origin, as the transport costs will exceed the gate material costs when the travel distance is over a few hundred kilometres. In terms of the critical transportation distance for both fly ash and ground granulated blast furnace slag, GGBFS, (beyond which the GHG savings associated with replacing Portland cement are exceeded by the GHG emissions associated with transportation of the supplementary cementitious materials), a study by researchers at the University of Queensland indicated that both fly ash and GGBFS can be transported nationally and even globally, and still reduce embodied GHG emissions in concrete if used as a replacement for Portland cement [16]. Other countries like the USA with a wider spread of population centres have more opportunity to utilise these materials because of lower transport distances.

The RTA has focused its main efforts on producing durable concrete pavements by insisting on complete compaction and curing [17, 18]. Ayton's effort to emphasise these two critical elements in specifications and follow up by running training courses has reduced early concrete distress. As suppliers subject to cost pressures may at times 'water down' a product leading to early age distress, there is a real need to tighten the requirements in material supply specifications. The increase in use of recycled materials in concrete will challenge sound construction practices. Like many other materials used in road construction, more voids in the material after compaction leads to a lower strength and a less durable material, and that's an unstainable practice.

Pavement Design

The rigid pavement design approach adopted in Australia for the last 20 years, is based on the PCA method [19] where cumulative damage due to fatigue of the base layer and erosion of the subbase and subgrade layer is calculated from a series of equations [20]. Similar to many pavement design models around the world, various assumptions in a design model are likely to limit the application of more recycled materials in the layers. For instance, the strength gain of concrete is about 10% between 28 and 90-day age. Many of the design assumptions are based on standards of practice at the time of designing the model, and typically the transverse contraction joints were orthogonal to the direction of travel. Given this assumption in the design model, the worst loading position for erosion distress is at the corner of the slab as shown in Fig. 5 [19]. However, PCP pavements in Australia are sawn with 1:10 skewed sawn joints[4] and part of the wheel load is onto the adjacent slab leading to lower differential joint movement. As since the skewing of transverse contraction joints is not considered in the design model, are we including 'excess' material in our concrete pavements?

The Austroads rigid pavement design model also shows that as heavy traffic volumes increase or the design period is taken to 40 or more years with traffic growth exceeding about 3%, the dominant distress mechanism for pavement thickness for PCP (without dowels) is erosion and not fatigue as shown in Fig. 6 [15]. The Austroads Pavement Design Guide encourages the use of lean-mix concrete subbase [21] which is a non-erodible material. As there is little to no evidence that the lean-mix concrete will erode over the design period

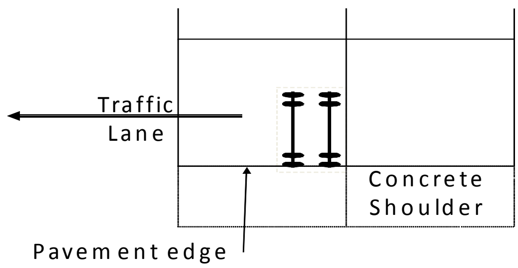

Fig. 5. Location of Axle Groups for the Determination of Erosion Distress [19].

4 Much of the PCP pavements constructed in Australia have undowelled contraction joints.

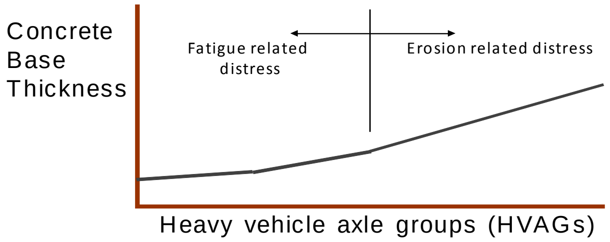

Fig. 6. As Traffic Volume Increases the Austroads Design Model Typically Predicts a Change from Fatigue to Erosion Distress for Undowelled Plain Concrete Pavements [15].

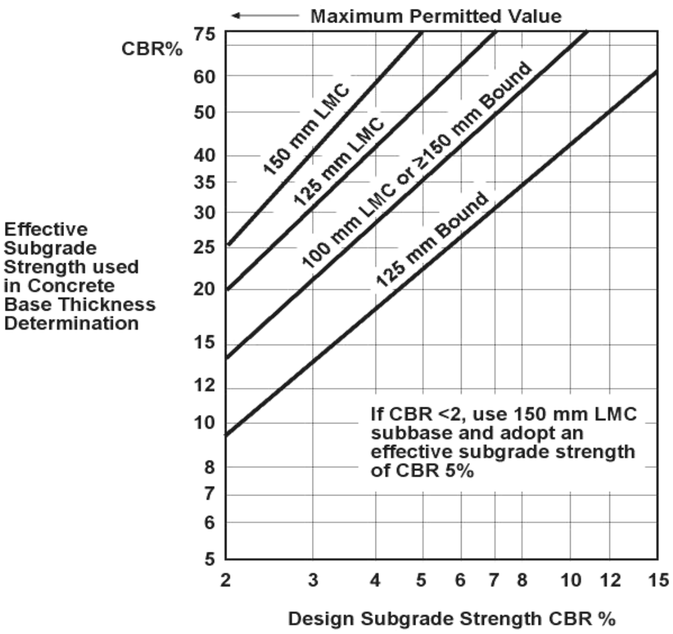

Fig. 7. Effective Increase in Subgrade Strength Due to the Provision of Bound or Lean-mix Concrete Subbase Layer [21].

to create stepping at the joint, the predicted failure mechanism may therefore not occur. In NSW, the formation material just below the subbase layer is referred to as a select material and every effort is used to ensure that this material is not erodible.

The rigid pavement design model does not encourage improvements to the subgrade strength as values beyond 5% (shown in Fig. 7 [21]) do not permit higher design subgrades when the upper limit on the effective subgrade strength is reached. This limitation in the design model is just one challenge to the use of sustainable practices. As highlighted, if concrete pavements perform well under today's' current thickness and can survive beyond the design life, improved analysis should allow stronger supports to be used in the design model.

In summary, the design model has the following limitations:

- An assumed rate of increase in the materials strength of the base layer,
- Erosion distress can be negated with non-erodible materials but no design inputs allow this to be taken into consideration such that erosion distress is not the dominant thickness value,
- There is no economic benefit to improve the subgrade strength at the top of the formation beyond CBR 5% and use a lean mix concrete subbase, as this reaches the upper limit of the effective subgrade strength,
- Wheel load orientation is not taken into consideration when using skewed contraction joints, and
- The base layer can only be considered with one constant material property.

Specifications

For some time concrete pavement specifications have specified the use of quarried and manufactured materials, such as steel reinforcement and silicone sealant, with the exception of the use of fly ash and blast furnace slag as a supplementary cementitious binder. The use of manufactured sands and crushed glass are now considered as suitable fine aggregates but recycled materials are not permitted as coarse aggregates in concrete for heavy duty pavements.

Most road authorities permit up to 15% by mass, of recycled asphalt pavement material in asphalt production and progress continues to increase this current 15% limit. The recycling of failed asphalt back into 'new' asphalt is an important element in sustainability for the asphalt industry.

The use of building demolition waste such as crushed concrete as aggregates for road construction materials has traditionally been limited as a replacement of road base granular material. In NSW, the RTA is proposing to raise the limits to recycled materials in their aggregate supply specification for flexible granular pavements 3051, as shown in Table 3. This change has arisen from metropolitan recycled materials suppliers delivering consistent material through testing, removal of debris, and stockpile management, however the main concerns for the use of demolition waste remain as:

- Asbestos contaminated material finding its way into recycled materials,
- Poor stockpile management leading to lack of homogeneity of the material and early distress,
- Inexperienced staff not using appropriate quality management systems, and
- Insufficient quality control testing to maintain a uniform material.

With the low design compressive strengths required for the lean-mix concrete subbase, there may be an opportunity to use recycled materials as listed in Table 3 in the low strength concrete subbase provided the source of these materials are close to the site.

Two-layered paving using an exposed aggregate concrete upper layer to achieve a low noise surface texture has been successful in several European countries and provides opportunities to use recycled

Table 3. Proposed Limits for the Use of Recycled Materials in RTA 3051 Specification [22].

Recycled Material	Unbound or Modified Base and Subbase(%)	Bound Base and Subbase(%)
Iron and steel Slag	100	100
Crushed Concrete	100	100
Crushed Bricks	20	10
RAP Material	40	40
Run-of-station Fly Ash	10	10
Crushed Glass Fines	10	10

Fig. 8. A View of a Paving Train in Europe for Insitu Recycle Existing Pavements [24].

materials in the lower half of the base layer. Austria requires the use of recycled concrete and RAP in the lower layer [23] and this practice is currently being considered in the USA with the ongoing development of two-layer paving [24]. Whilst Australia has conducted one successful major trial of the two-layer process [25] a progression to using recycled materials, especially coarse aggregates, is unlikely to occur in the near future until pavement design models are developed to allow the contribution of the two material properties.

Maintenance

The main determinant in the selection of a maintenance treatment is the speed of treatment to minimise congestion traffic from long road lane closures. Material replacement in maintenance, such as joint sealants, is typically carried out using new materials. Concrete for slab replacements is generally concrete with quarried materials and an accelerant admixture to allow traffic back onto the pavement as soon as practicable. Whilst maintenance is inevitable, even small amounts of recycled material should be used for concrete slab replacements.

Over the last decade, European road construction equipment manufacturers have developed road maintenance trains as seen in Fig. 8 where the asphalt pavement is milled, processed, and paved insitu. This technology has limited application in Australia as our rural road network consists of granular and stabilised bases with a sprayed sealed wearing surface plus many major metropolitan roads have height and utility restrictions that would make these long-trains unsuitable.

Insitu stabilisation of granular local and major roads is still one of the most sustainable practices used in Australia [26]. The technique of insitu repairs of concrete has not been adopted due in part to equipment limitations. In the USA, the development of concrete slab repairs has mainly taken a precast concrete focus where precast concrete units are manufactured with new aggregates and cements. Important questions now being asked by a few practitioners are:

- Could a special a mobile plant be developed that will remove the slab, utilise the existing materials with the addition of binders and replace this material in the same place as the repaired slab?
- Is the cost and energy used in this equipment greater than that used to produce and place precast concrete panels?

Further work is required to challenge conventional equipment design and evaluate equipment that better accommodates sustainable practices.

Where concrete pavements have become too rough or low skid resistance requires some form of intervention, diamond grinding is steadily becoming the preferred choice of treatment in NSW. Diamond grinding is a sustainable approach to increasing the longevity of concrete pavements rather than applying an overlay or removing concrete to manage the maintenance treatment. Multiple passes of the diamond grinding treatment can significantly increase pavement life and the RTA has now mandated an increase in the base layer thickness by 10*mm* on new projects to accommodate the grinding process during the life of the pavement.

At the end of the life of the concrete pavement, the treatment of the concrete and other materials in the pavement need to be recycled and significantly discounting the strength of the existing concrete layers is not a sustainable practice. Design models need to be developed to assess the inherent strength of the existing layers and ensure that material durability has not been compromised. Pavement engineers need to conserve natural resources and the current low use of recycled materials due to the concerns about their comparative performance needs to be investigated and researched appropriate test methods designed to predict their performance in the laboratory.

Quality

Quality control is an essential requirement for Australian road construction, Contractors are expected to prepare project quality plans to document how they will manage variations in materials and procedures that they will follow in order to meet the specified property limits and tolerances. There has been a belief for years that 'tight' specified tolerance can only be met by using quarried new materials or a manufactured material using controlled processes. However, recycled materials can be stockpiled and variations successfully managed by the use of appropriate crushing techniques.

The cost to manage 'quality' may increase the final price of the material and if it is not lower than 'new' materials, specifiers or head contractors are understandably reluctant to use the recycled materials. Government is also reluctant to introduce a new tax on 'new' materials which would make an artificial smaller gap in price between recycled and new materials for fear of voter backlash against new taxes.

A judgement about the quality of recycled materials is influenced by more than the structural properties of the material. The reliability of the source can be very important for some new competitors to gain industry recognition as a reputable supplier. Some form of industry accreditation may be required to ensure a long-term sustainable recycling material industry.

The inherent variations of recycled materials, such as fly ash and granulated blast furnace slag, are now managed on a daily basis by concrete companies, a process which has evolved over many years. Although many practitioners previously doubted the ability of these supplementary cementitious binders to perform as well as Ordinary Portland Cement[5] (OPC), few would hesitate to use slag[6] and

[5] OPC is now known as general purpose (GP) cement in Australia.
[6] Ground granulated blast furnace slag is commonly referred to as 'slag' in Australia.

hydrated lime as a stabilisation binder rather than OPC today, and high levels of fly ash are common in lean mix concrete subbase layers in Australia [26].

Procurement

Drawings and specifications remain the standard approach for the procurement of road making materials and construction in Australia. Contractors are selected by a tender process and the company presenting the lowest conforming bid is usually the preferred winner. This 'lowest bid wins the project' approach generally continues to offer the purchaser with a contractor that takes little risk and is the least innovative. The highly competitive road construction industry does not encourage contractors to use sustainable practices unless there is a low risk level and significant cost savings.

In addition, the concrete pavement specifications are end-product based where specified values with tolerances are sought at typically 28 days after placing. This traditional procurement model provides no real incentive for innovation in utilising recycled materials.

Local governments in NSW utilise a 'value for money' approach [27]. Relative value for money in tenders is determined with consideration of the benefits, taking into account the following factors:

- price with whole-of-life costs,
- experience,
- quality,
- reliability,
- timeliness,
- delivery,
- innovation,
- product servicing,
- fitness for purpose, and
- value adding components, eg as meeting the government's economic, social, and environmental objectives (where relevant).

Whilst these factors seem to be comprehensive, there is no uniform weighting for the combined effects of each particular qualitative value. Innovation can be hard to judge as it is virtually impossible to isolate so many variables. And with all new innovation, the risks and cost/benefit ratios need to be well understood to allow fair judgement of each contractor's submission.

The use of the 'whole of life' costs for differentiating pavement types for major roads has been widely debated in Australia since the mid-1990s, however the principals of whole-of-life costing remain in Austroads pavement design guides [21]. For many years the RTA has used a 40-year design life as the life cycle period for evaluation of major highways [5]. However the standardisation of maintenance intervention periods and costs for different pavement configurations does not exist. User costs are also not included in any economic life cycle analysis as experience has shown that these costs dominate the economic analysis [28].

ISO 14040 for road infrastructure environmental assessment is not used to evaluate different pavement configurations in Australia. This is partly due to the standardisation of the inputs for the assessment. If this data could be standardised, any life cycle assessment would have to include:

- Initial cost, salvage value, and maintenance costs,
- Road user costs, including costs attributed to congestion from maintenance activities, and
- Environment at costs reflecting the usage of quarried materials, energy usage, surface water and road noise management, GHG emissions, and other measurable inputs.

Innovation and Risks

Many of the greatest advances in engineering today has come from the investigation of spectacular failures and then implementing changes to our codes of practice and specifications. Despite substantial funding to major space projects, there were basic management mistakes that contributed to the two space shuttle disasters [29, 30]. Society and senior management today are becoming increasingly risk adverse which has slowed the process of innovation in public infrastructure [31, 32]. Responsible adoption of innovation should minimise the risk of failure and use the lessons learned from areas of poor performance to achieve incremental but important improvements in the reliability of existing materials and their function in the pavement.

Australia is no different to other countries where small business entrepreneurs develop locally or become agents to sell new 'green' products. Unfortunately many of these entrepreneurs have no pavement technology expertise, do not engage specialists or ignore specialist advice about their product performance. When their product is ignored by road authorities they then raise their concerns to Department Heads and Government Ministers about their 'terrific' product not being accepted and used by road authorities. After this event 'paper shuffling' typically occurs between senior managers and Ministers which may lead to a small field trial. To overcome this problem, many countries have developed new product registrations schemes such as the UK Highways Authorities Product Approval Scheme (HAPAS).

In 2005 Austroads commenced a project to determine if a national equivalent scheme similar to HAPAS could be developed for the efficient implementation of new material or technology for road infrastructure. Its aim was to harmonise the acceptance of new materials such that once a product was accepted in one region, it would be automatically accepted by other road authorities without needing to repeat laboratory tests and/or a trial program [33, 34]. The project lasted four years and many obstacles were reported for the project to become operational. This was considered by few as an indication of adverse risk taking, and therefore creating the potential for long-term hurdles for the introduction of sustainable practices.

Queensland and NSW road authorities introduced TIPES[7] and MIT[8] schemes respectively almost a decade ago. In NSW, the RTA considers that a product assessed according to the MIT scheme would provide the following outcomes [26]:

- The selection of the most appropriate and effective innovative technology for use in building and maintaining infrastructure assets at minimum whole-of-life cost,
- Provision of more effective technology transfer and data exchange regarding the capabilities of innovative technology throughout the RTA, and

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7 TIPES - Transport Infrastructure Product Evaluation Scheme
8 MIT - Management of Innovative Technologies

- Prompt implementation of worthwhile new technology.

It was envisaged that similar to TIPES, a successful application under MIT would result in the product being eligible for purchase by the road authority. Some companies were also concerned that even when they get their product certified in NSW they may need to undergo the same long scrutineering process in other Australian States. The perceived high setup costs and ongoing funding of such a national scheme along with the potential legal liability from unfavourable decisions to applicants, proved all too difficult and the scheme was shelved.

Companies are now faced with the problem of extensive lead times for the introduction of new products and the cost of funding further laboratory and field trials needed so the properties of the new product are well understood and documented by road authorities. Many small companies do not have the capital and time to get their products assessed and introduced according to these schemes, and opt to use local low-traffic roads as their ‘proving ground’ or give up. For road authorities there is always a possible lost opportunity amongst all those new products.

If sustainability is such a key driver for the community and yet government should not fund research and development of private companies and individuals with their new products and ideas, what is the alternative? It may be more effective for road authorities to research and develop new generic products for use in infrastructure with sustainable benefits. There may also be a way to fast track new product development to replace natural materials and target areas where the road authorities can best manage the risk of their implementation in specifications. Road authorities could also issue a licence to private enterprise for the new technology after initial development of the product.

However, road authorities will have to overcome the problem of engineers being so risk adverse due to consequential management and fear of failure on one’s own career record. One alternative could be to develop centres of innovation within an organisation and engage outside consultants to assist with prioritising projects that lead to improved sustainability. Whilst Australia does have centres of excellence at many universities and some road authorities participate in this model, the current university based driven model may be too bureaucratic and cumbersome to meet the above goals.

Another mechanism to fast track the introduction of new technologies has been the construction of major infrastructure using the alliance contracting model. In the alliance contracting model, the cost of developing the new process is shared between the road authority and contractor and the risks of success are identified and accepted before commitment. Recent examples of such an approach have been:

- Two-layered concrete slipform paving with the upper layer being a porous concrete material and
- Replacing transverse with longitudinal tyning of the road surface.

Between 1994 and 2000, the RTA and the major road contractors in NSW worked on the introduction of exposed aggregated concrete (EAC) surfacing with several trials conducted in NSW and Victoria. Whilst the exposed aggregate concrete met the requirements for durability, strength and noise mitigations; the trial outcomes could not progress because the EAC surface could not be economically placed as one paving layer and required two-layered paving similar to the European practice. The RTA has permitted EAC surfaces in design and construction contracts for many years, but a contractor was unlikely to be a successful bidder if they proposed a locally unproven two-layered paving approach where the financial risks lay with the shareholders.

For over a decade, not one contractor has invested in two-layer paving equipment and no projects utilising the process were ever won. This is clearly a business environment that does not foster innovation and early adoption of new technologies and which defaults to unsustainable road construction practices.

However the contracting alliance business model is one approach that has successfully overcome the economic hurdle faced by contractors using the traditional tender bidding process. Innovation may be cultivated by this partnership and a genuine commitment by management to manage risks with the objective of making real long-term advances beyond existing practices.

Cradle to Grave

In any long term plan to utilise recycled products to enhance sustainability, all materials eventually comes to the end of their performance life. Solutions therefore need to be found to allow these materials to be recycled again and again, and as Stacey describes the ‘linear quarry’ [2]. Similar to insitu stabilisation, these pavements have been recycled on many occasions over decades [4].

The Sustainability Imdex

The best approach to using less GHG, more recycled materials or having a longer life material is yet to reach its balance point. Road authorities should not mandate zero carbon footprints for road construction as this favours low energy consumption of quarried aggregates.

One recommendation to assess the cumulative appraisal of the economic and environmental considerations is a sustainability index, such as:

$$SI = aI_1 + bI_2 + cI_3 + dI_4 + eI_5 + fI_6$$

Where
I_1 = rating for the whole of life costs of the pavement configuration,
I_2 = rating for the amount of recycled and ‘virgin’ material used including during the maintenance phase,
I_3 = rating for the extent of GHG developed during the construction phase,
I_4 = rating for the energy usage,
I_5 = rating for the life of pavement in years, and
I_6 = rating for the traffic congestion emissions and users costs.
a, b, c, d, e, and f = coefficients to weigh each index according to its contribution to sustainability

Further Research

Spending on road construction materials and performance is at an all time low in Australia and more of the funds given to scientist on climate change research should be diverted to engineers to fund priority based research projects on sustainable construction of infrastructure to meet the needs of the community and to preserve natural resources.

This paper has highlighted two mechanisms where the business environment or structure could immediately be used:

- Application of innovation through the alliance contracting model and
- Road authority based centres of innovation.

The proposed centres of infrastructure innovation should provide the 'blue sky 'research work, along with the scope to find out about sustainable materials and practices. The alliance contracts are used to deliver and assess these products and techniques.

Whilst the proposed national product evaluation scheme (Materials Innovation Management System, MIMS) has been shelved in Australia, it will not stop the would-be entrepreneur from introducing new products and equipment and an expectation that accepting the limited research development of the product is satisfactory for its 'wholesale' use in road construction. It is possible that these centres of excellence could provide a mechanism for further assessment of the product at a subsidised cost or offer the development of new performance testing programs to assist with the evaluation of the properties or functions of the product or equipment being presented.

For concrete pavements to further apply the principles of sustainability, the following issues could be addressed by further research:

- Development of laboratory test methods to predict performance,
- Improvements in pavement analysis to allow higher subgrade strength, different material properties in the base layer, and modelling of erosion distress, and
- The development of non-destructive tools to measure insitu performance or a particular characteristic of performance where lab test is impractical.

Conclusions

Insitu stabilisation of roads has led the way in Australian in sustainable road rehabilitation of local roads and highways, supporting the notion by Stacy that roads could be considered to be 'linear quarries' making it possible to utilise aggregates in existing roads to extend the life of the pavement.

Australia does not currently appear to have a unified approach to the management of sustainable road construction. Construction and maintenance practices which address sustainability issues are still piecemeal and not well researched or evaluated. These attempts at addressing climate change may be at the expense of limited road construction resources and the focus on reducing GHG may be leading to unsustainable choices of pavement materials.

If sustainable practices are directed at maximising pavement life before major rehabilitation is required more durable materials will be essential. However the goal to utilise more recycled materials may be in conflict with increasing durability. Finding an appropriate balance between natural 'strong' material and recycled material is crucial for both flexible and rigid pavements.

Over time, it is anticipated that road owners will gradually amend specifications to increase the existing limits on the use of recycled materials in both the base and subbase layers while ensuring that current end-product limits are not compromised to meet long-term performance. This will encourage suppliers of recycled and 'green' materials to improve their quality control and work to meet the same requirements as quarried products. Further training is required to assist suppliers of recycled materials meet quality standards.

Australian concrete pavement design models were developed in the 1970s using assumptions and approaches based on pavement engineering knowledge of that era which needs to be re-examined. It is no longer possible to use increasingly limited natural quarried materials for all road construction and rehabilitation. If the inherently conservative approach to the thickness design of concrete roads is not challenged, there is a risk of exploiting precious quarried materials at the same time as stockpiles of recycled materials mount and are dumped in landfills.

A review of the Australian concrete pavement design approach should be directed at:

- The upper limit of effective subgrade strength needs to allow for achievable subgrade strengths under the subbase or select material zone,
- A balanced approach to design for fatigue versus design for erosion is required, and
- The base layer should be modelled with two discrete material properties.

An Australian research priority must be to evaluate recycled materials and road construction and rehabilitation techniques which meet sustainability objectives and which can be addressed in specifications. Partnerships also need to be fostered to encourage innovative contractors and positive collaboration with suppliers. The current price driven selection process for tenders needs to include sustainability measures or parameters to ensure contracts are not awarded purely on the lowest cost submission with no real consideration of sustainability issues.

The creation of centres of innovation for infrastructure and managed by the road authorities and supported by suppliers and experienced road engineers is also recommended. Outcomes from the various research projects from these centres of innovation can be properly assessed using alliance contracts where the contractor and road owner shares the risk of failure rather than complete responsibility being with the contractor.

Similar to the principles of whole of life costing of pavement types from the 1980s, a sustainability index is proposed to rank different sustainability outcomes and measures and calculate a sustainability index for the project. Sustainable practices for concrete design and construction call for a balance between the social and civic needs of the Australian community and an obligation to minimise climate change and protect and preserve our fauna, flora, and heritage. Critical to this, is the question of preserving our natural resource of road making materials and investigating recycled alternatives to replace traditional quarried products.

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