Sustainable Highway Pavement Strategies: Design, Construction and Maintenance/Rehabilitation Aspects

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THE Brundtland Report (1987) defines sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [1]. There is a need presently to conserve our limited resources and maintain existing ones in order to remain sustainable many years from now, that is – using, developing and protecting resources at a rate and in a manner that enables people to meet their current needs and also provides for future generations to meet their own needs.

Spiralling oil prices (until recently) and the dwindling of natural resources such as good-quality crushed aggregates and sand has forced us to consider new strategies to effectively protect, manage and sustain our highway pavements so that not only are they safe to use, but can also be maintained effectively and last longer.

This article summarises the presently available techniques and technology that can be incorporated into the various phases of the highway pavement life (i.e. design, construction and maintenance/rehabilitation) in order to develop a sustainable pavement strategy. It briefly describes on perpetual pavement design, life-cycle analysis, warm mix asphalt, performance specifications and pavement recycling.

DESIGN PHASE CONSIDERATIONS

a) Perpetual Pavement Design

There have been a number of significant changes in recent years that have made the design of new pavements and the rehabilitation of existing pavements very challenging for pavement engineers [2]:

- The amount of freight carried on the road network (in truck tonne-km) has increased tremendously.
- Allowable truck vehicle mass has been increasing at about 10% each decade.
- Truck tyre pressures have increased from about 550kPa to over 700kPa with the change from cross-ply to radial tyres.

Apart from designing a long-lasting, durable pavement to incorporate those changes, considerations must also be made to reduce the use of materials and other resources during the construction and maintenance phase. Also, an alternative pavement design approach must be considered to model the pavement structure subjected to traffic loadings as accurately as possible, as current empirical pavement design procedures (derived from experience or observation) are inadequate to incorporate those changes. A possible design solution to these requirements is to use perpetual pavement.

Perpetual pavement is a term that describes long-life or durable pavements. Studies on pavement performance records in the United States found that many thick asphalt pavements have survived for over 40 to 50 years and still showing no sign of impending structural distresses (bottom-up fatigue cracking or rutting deep in the pavement structure) [2]. Rehabilitation of perpetual pavements is limited only to repairing the deterioration that initiates at the surface (i.e. a repair strategy of mill and replace the surface layer or surface recycling).

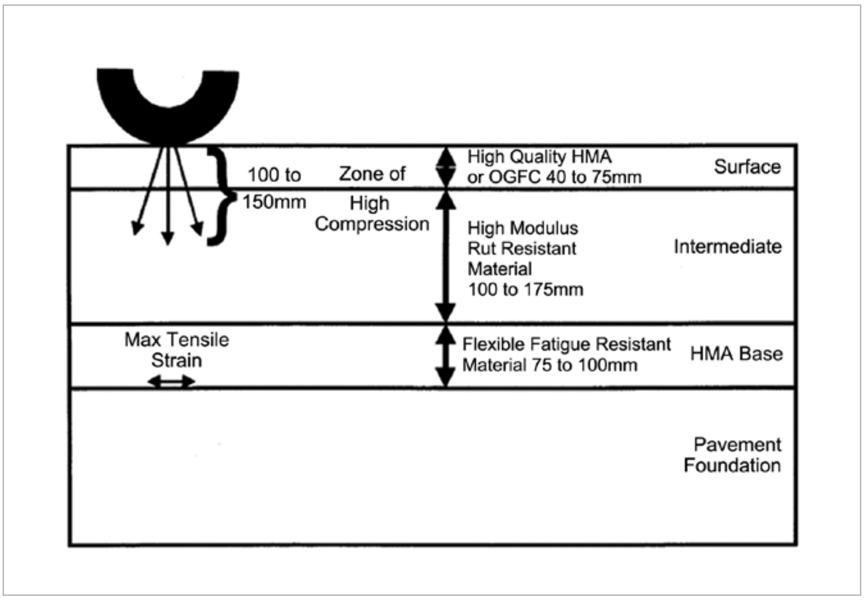

Figure 1: Typical Section of a Perpetual Pavement [2]

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Perpetual pavements use multiple layers of durable asphalt to produce a safe, smooth and long-lasting road (Figure 1). The pavement design begins with a strong, yet flexible bottom layer that resists tensile strain caused by traffic, and thus stops cracks from forming at the bottom of the pavement. A strong intermediate layer completes the permanent structural portion, and a final layer of rut-resistant HMA yields a surface that can last for many years before scheduled restoration.

Mechanistic design procedures are used to design perpetual pavements – fundamental material properties (resilient modulus and Poisson's ratio) and predicted traffic loadings are taken into account to determine pavement behaviour. The provision of enough stiffness in the upper pavement layers to preclude rutting and enough total pavement thickness and flexibility in the lowest layer to avoid fatigue cracking from the bottom of the pavement structure is required in designing a perpetual pavement.

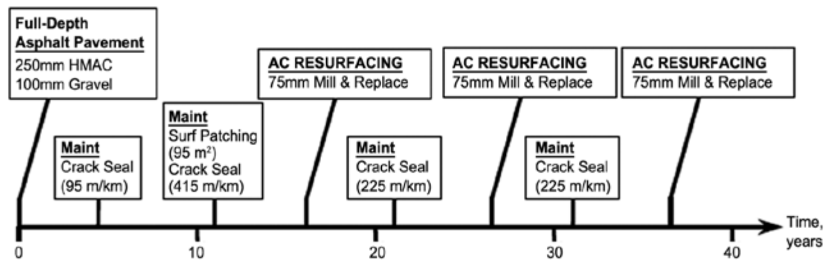

Figure 2: Example illustration of pavement life-cycle expenditure stream diagram [3]

Monismith and Long have suggested that the limiting tensile strain at the bottom of the asphalt layers should be no greater than $60\mu\varepsilon$, and that, at the top of the subgrade, the vertical strain should be limited to $200\mu\varepsilon$ [2]. Asphalt thickness proposed in other design procedures shows these strain levels to be reasonable.

The advantages of perpetual pavement include the following:

- A perpetual pavement provides durable and long-lasting roadway; expensive, time-consuming, traffic-disrupting pavement reconstruction or major repair is not required.
- Easier and cost-effective maintenance; scheduled surface restoration performed on perpetual pavement saves time and money, as the road structure is not removed for reconstruction.
- Asphalt in the perpetual pavement structure is recyclable, providing further cost savings and environmental benefits.

b) Life Cycle Analysis

Life Cycle Cost Analysis (LCCA) is an engineering analysis tool that allows alternative highway pavement types and maintenance strategies for a project to be evaluated throughout its life analytically; the most cost-effective alternative is then selected based on economic merit. The life-cycle costs of a road pavement include the money spent on the initial construction of the pavement, maintenance over its lifetime, and the cost to users for their delay during maintenance and reconstruction.

For example, the life-cycle costs of hot-mix asphalt pavements are normally compared to that of concrete pavements for their design life, including considerations of the proposed future maintenance strategies for each pavement type. The steps for the LCCA process are described as follows:

- First, appropriate pavement design and maintenance & rehabilitation alternatives are defined for a given project. For each proposed alternative – initial construction or rehabilitation activities, the necessary future rehabilitation & maintenance activities and the timing of those activities are then identified. From this information, a schedule of activities is constructed for each project alternative.

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Figure 3: Difference in fume emission between hot-mix asphalt and warm mix asphalt [4]

- Next, activity costs, which include direct department expenditures (*e.g.* construction and maintenance costs) and also user costs (*e.g.* lost time to the public and vehicle expenses), are estimated. A predicted schedule of activities and their associated department and user costs are combined to form a projected expenditure stream for each project alternative (Figure 2).
- Once the expenditure streams have been determined for all the alternatives, the next step is to calculate the total life-cycle costs for each alternative. The projected activity costs for a project alternative cannot simply be added together to calculate total life-cycle cost as money spent at different times have different values to an investor. LCCA uses discounting to convert anticipated future costs to present current values so that the lifetime costs of different alternatives can be directly compared. The project alternatives can then be evaluated based on their life-cycle costs.

CONSTRUCTION PHASE CONSIDERATIONS

a) Warm Mix Asphalt

Technological improvements are currently being explored by the hot-mix asphalt industry to reduce asphalt production temperatures, thus reducing the energy required to produce asphalt. Warm-mix asphalt is distinguished from hot-mix asphalt mixtures by the temperature regimes at which they are produced; warm mix asphalts are generally produced in the temperature range of 105ºC to 135ºC, compared to the conventional hot-mix asphalt which is typically produced in the range of 140ºC to 170ºC.

Currently, at least three different processes are being actively marketed:

- a process that uses foamed bitumen
- the use of an organic additive
- application of emulsion/chemical additive

The foamed bitumen mix approach utilises foaming action (created by the addition of water) which temporarily increases bitumen volume and decreases asphalt viscosity, resulting in similar workability at relatively lower temperatures than conventional hot mixes.

Organic additive products are based on their unique melting point characteristics. These additives provide extra fluidity to the mixes at temperatures above 100°C, where mixing and placement normally occur. At service temperatures, it reportedly provides better stability to the mixes.

Emulsion application utilises emulsified binder in place of conventional bitumen binder. Although bitumen emulsion mixes are normally used in 'cold mix' applications (i.e. produced at ambient temperature), the Evotherm emulsion is applied at higher temperatures (above 100°C). Due to this high temperature (which is still lower than conventional hot mixes), the water in the emulsion evaporates rapidly during the mixing and placing process, resulting in hot-mix-like end products.

Examples of warm-mix products available in the market include foamed-mix based products (Aspha-Min®, WAMFoam® and LEA), organic additive products (Sasobit®, Asphaltan B®, CECABASE RT 92® and Licomont BS100®) and finally the emulsion application (Evotherm® and WAM-Emulsion).

Warm mix asphalt products have recently been gaining attention due to the increasing emphasis on protecting the environment. By lowering the production temperature, a reduction in fume emissions is possible (Figure 3). In addition, there are other potential benefits as follows [4]:

- cost savings by using less fuel for heating
- cleaner working environment due to a reduction in fumes and odour during production and placement
- safer working environment due to lower temperatures during production and placement
- the possibility of retaining the workability of the mix after longer haulage (due to lower limit in workable temperature and slower temperature reduction rate)
- the possibility of placement in cooler weather (thus extending the construction season).

b) Performance-Related Specifications

The specifications for the construction of pavements can generally be classified into method-related specifications (MRS), end-result specifications (ERS) and performance-related specifications (PRS). Highway departments/agencies worldwide are moving beyond MRS/quality assurance specifications that specify end product quality, to PRS that specify quality in terms of desired performance over the long term [5].

PRS are those in which the product payment is directly dependent upon its actual performance. Typical of these specifications are warranty, limited warranty and design-build-operate contracts. Contractors are held responsible for the product performance within the context of what they have control over. The contractor is given a great deal of leeway in providing the product, as long as it performs according to established guidelines. In this case, the contractor assumes considerable risk for the level of service the product provides by paying for or providing any necessary maintenance or repair within the warranty period.

There are two types of PRS models: performance-prediction models and maintenance-cost models. Performance-prediction models predict when and to what extent the pavement will experience distress such as fatigue cracking or rutting. Maintenance-cost models estimate a post-construction life-cycle cost, that is, the cost of maintenance and rehabilitation that will be necessary for the projected life of the pavement. PRS can be used for the following:

- to identify a relationship between key quality characteristics and product performance.
- to identify and specify an optimum level of quality that represents the best balance of costs and performance.
- to allow for more incentive for contractor innovations and provide rational basis for adjusting contractor pay when the quality is above or below desired levels.

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- to provide a critical link between pavement construction and pavement management systems.

MAINTENANCE/REHABILITATION PHASE CONSIDERATIONS

a) Pavement Recyclings

Deteriorated asphalt pavements should be recycled, rather than overlaying them with new asphalt concrete material or reconstructing them (depending on the type and seriousness of the distress) because of the following reasons/advantages:

- reduced cost of construction.
- conservation of aggregate, binders and transport fuel (for new materials).
- preservation of existing pavement geometrics.
- preservation of the environment.
- help to reduce reliance on landfills by reusing existing materials instead of disposing them.

The Asphalt Recycling and Reclaiming Association (ARRA) define four different types of recycling method [6]:

(1) hot in-place recycling (Figure 4),
(2) hot mix recycling,
(3) cold in-place recycling (Figure 5), and
(4) full depth reclamation.

Figure 4: Hot in-situ recycling

Figure 5: Cold in-situ recycling using foamed bitumen

The term 'linear quarry' is used to describe existing road pavements which contain materials that are to be recycled into new pavement layers; much like a quarry which supplies the aggregate materials for new roads. The in-situ reuse of existing pavement materials during reconstruction not only reduces the requirement for new materials but also does away with the need for the associated transport movements.

Some of the environmental outcomes which are associated with pavement recycling are as follows [7]:

- reduced resources consumption
- protected biodiversity in the road corridor and any adjacent land and roadways
- improved local air quality
- reduction in road transport noise
- protection of cultural heritage
- reduced green house gas emissions

Pavement rehabilitation (including the recycling method), compared to new road construction, is becoming more important as the country develops and its road network approaches maturity. As resources become scarcer and environmental concerns becomes more widespread, it is anticipated that pavement recycling will become more important in the coming years.

CONCLUSION

The need to maintain existing highways and preserve our resources has led to innovations in the analytical techniques and technological processes that can be incorporated in all phases of highway design, construction and maintenance. A sustainable highway pavement strategy can, therefore, be implemented using these innovations in the life-cycle of highway pavements, provided that the relevant stakeholders (*i.e.* government agencies, contractors and consultants) are fully committed in implementing the strategy. ■

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REFERENCES

[1] WCED, (1987), Our Common Future. Report of the World Commission on Environment and Development, Oxford: Oxford University Press.

[2] TRB (2001), Perpetual Bituminous Pavements, Transportation Research Circular No. 503, December 2001, Washington DC: Transportation Research Board

[3] ERES (2003), Life Cycle Cost Analysis of SMA Pavements and SMA Application Guidelines, Madison: ERES Consultants.

[4] Choi, Young (2007), Warm Mix Asphalt Review, Austroads Technical Report AP-T91/07, Sydney: Austroads.

[5] Newcomb, David E. (2001, May/June). Performance Related Specifications Development. Hot Mix Asphalt Technology, 49-51.

[6] Kandhal, Prithvi S. and Mallick, Rajib B.(1998), Pavement Recycling Guidelines for State and Local Governments, Publications No. FHWA-SA-98-042, Washington: Federal Highway Administration, Department of Transportation.

[7] Austroads (2006), Asphalt Recycling, Austroads Technical Report AP-T66/06, Sydney: Austroads.

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Thank you.

ERRATA

Our apologies

In a feature entitled 'Wind Tunnel Measurement of Aerodynamic Characteristics of a Generic Eurocopter Helicopter' published in the May 2009 issue of JURUTERA, the authors should read as Engr. Assoc. Prof. Dr Shuhaimi Mansor, MIEM, P.Eng., Engr. Iskandar Shah Ishak, Grad. IEM and Assoc. Prof. Dr Tholudin Mat Lazim instead of as published. We apologise for the error.