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Feasibility of perpetual pavement stage construction in China: A life cycle cost analysis

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ABSTRACT

The main objective of pavement design and management is to build sustainable pavement structure with minimum costs during its whole life. There are many uncertainties in the process of pavement design pertaining many of its variables, such as future traffic estimation, long time behavior of materials, future weights and types of traveling vehicles, availability of funds etc. Therefore, it is important to apply pavement stage construction technique during the process of pavement design and management to minimize the risk associated with these uncertainties. From the beginning of 2000, the research and application of perpetual asphalt pavement (PP) technology has been deployed in China. The semi rigid base for asphalt pavement has been normally considered as typical component of high class highways in the design according to the Chinese experience since 1997. The research objective is to apply pavement stage construction for the evaluation of life cycle costs of Chinese perpetual and traditional semi rigid pavements using operational pavement management system in addition to examine its suitability for design and construction of more economical and durable flexible pavements. It has been found that the stage construction of asphalt layers in PP over semi rigid pavement foundation will create more sustainable and trusted pavement structures in spite of 2–5% increase in present total cost.

Introduction

Stage construction of pavement

Planned stage construction is a process of providing fully adequate pavements with the most effective use of materials, energy, and funds as reported by Asphalt Institute (1991). Stage construction is the construction of roads pavement by applying successive layers of asphalt concrete according to design and to a predetermined time schedule. The design of planned stage construction should not be confused with the design of major maintenance or the rehabilitation of existing pavements. The procedure is based on the assumption that the second stage will be constructed before the first stage shows serious signs of distress.

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There are several circumstances in which stage construction is advantageous:

1- When funds are inadequate to construct the full design thickness, the pavement may be designed for construction in two stages.
2- Accuracy problems in estimating traffic for a period of 20–25 years make planned stage construction attractive.
3- Experience indicated that pavements overlaid after they had been subjected to traffic performed somewhat better than new pavements of equal design.
4- Pavement distresses that develop during the first stage can be restored.
5- Savings may be realized from reduced final thickness or from extended life of the original pavement.

Recent studies by Abaza and Ashur (2011) and Vavrik et al. (2009) recommended the use of stage construction to achieve perpetual pavements to benefit from its advantages. The only concern is whether the costs associated with stage construction may have an impact on the present total cost in spite of stage construction benefits. According to AASHTO (1993), if the analysis period is 20 years (or more) and the practical maximum performance period is less than 20 years, there may be a need to consider stage construction in the design analysis.

When considering in stage construction design alternatives, it is important to consider the impact of compound reliability. The overall reliability for example of two stage strategy (each stage is designed for 90% reliability) would be 0.90 × 0.90 or 81%. Therefore, the following equation should be considered to check the overall and individual reliability of stage construction:

$$R_{(\mathrm{stage})} = (R_{\mathrm{overall}})^{1/n} \tag{1}$$

where n is equal to the number of stages included in the initial pavement design.

In the stage construction, the traffic growth should be estimated for each stage. The future number of 18 kips equivalent standard axle load repetitions is estimated by multiplying the first year 18 kips equivalent standard axle load repetitions (ESAL) by the growth factor (G). Growth factor (G) can be obtained from the following equation, (AASHTO, 1993):

$$G = [(1+g)^n - 1]/g \tag{2}$$

where G is the growth factor, g is the traffic growth rate divided by 100, and n is the number of years. For example, if the traffic growth rate is 5% ($g = 0.05$) and $n = 20$ years, then the growth factor G equals to 33.066. Table 1 shows the AASHTO traffic growth factors as a solution of Eq. (2) above (AASHTO, 1993). Increasing the annual growth rate and/or the analysis period (as the case in perpetual pavement) may increase the AASHTO growth factor to up to unreasonable value of hundred times to be multiplied by first year traffic. For this reason, the consideration of stage construction becomes more necessary especially if we recall that perpetual pavements should serve for long period up to 50 years and growth rate more than 7%.

Perpetual pavements

The fast increase in traffic volumes and the loadings on road pavements has focused the light on the need for durable pavements that will last for long time with minimum costs. The perpetual pavement (PP) is defined by Asphalt Pavement Alliance (APA) (2002) as "An asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction and needing only periodic surface renewal in response to distresses confined to the top of the pavement". The perpetual pavement technology has an important role in prolonging the service life of pavement with minimizing maintenance and user costs over that life. The initial thick structure of perpetual pavement has the ability to reduce stresses within pavement layers under increasing traffic loads meanwhile, its higher initial construction cost and asphalt materials behavior on very long service life should be examined thoroughly. The perpetual pavement may not need to be reconstructed and the only need is to replace the deteriorated surface periodically. The long life of PP is attributed to the use of special formulated asphalt concrete mixes for the construction of asphalt concrete layers. The thickness of asphalt layers in PP is usually thick (from 20 to 50 cm). The thickness of PP is determined by limiting the tensile strain at the bottom of asphalt layer (fatigue criterion), while the total thickness of PP structure is determined by limiting the compressive strain on the surface of sub grade (rutting criterion). The upper surface layer is designed to resist wear and top-down cracking, the intermediate asphalt binder layer is designed to resist the rutting and fatigue, and the lower asphalt base layer is designed to resist bottom-up cracking. In PP, the possibility of traditional fatigue cracking is reduced, and pavement distress is limited to the upper layer of the structure. From the beginning of 2000, the research and application of perpetual asphalt pavement (PP) technology has been deployed in China. The semi-rigid base asphalt pavement has been normally appointed as typical structure for high class highway design and construction in China. Semi-rigid base asphalt pavement is the main pavement structure in China since 1997; it comprises about 90% of total pavement structures. The semi rigid is comprised mainly from asphalt concrete layer (friction layer) and semi rigid base layer (load bearing layer) (Wang, 2013).