JOURNAL OF TRAFFIC AND TRANSPORTATION ENGINEERING (ENGLISH EDITION) 2017; 4 (2): 113–117

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Original Research Paper

Potential of South African road technology for application in China

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HIGHLIGHTS

- The paper proposes adapting the South African approach for pavement design to China to overcome limitations and early distress.
- The design method incorporates a deep pavement which can support overloading, and a thin surfacing which has the required life and is easy to repair.
- The approach caters for the local environment as well as overloading.

ARTICLE INFO

Article history:
Available online 14 March 2017

Keywords:
Pavement design
Reflection crack
Performance
Overloading
Deep structure

ABSTRACT

One of the main problems with roads and highways in China is the reflection cracking caused by the cement stabilized subbase layers passing through the overlying asphaltic layers. The cracks permit the ingress of moisture which softens the layers below the subbase resulting in loss of support and accelerated breakdown of the subbase layer and reduction in the riding quality. The aim of this paper is to present the use of South African pavement design approach of deep structure and thin surfacing to overcome the existing problems. The deep pavement structure provides good long-term support and avoids the influence of moisture ingress, which means that only surfacing damage needs to be repaired. An unbound crushed stone base layer which is an integral component of the pavement structure limits reflection cracking.

The paper first deals with the South African pavement design procedure and contrast this with the Chinese pavement design method. The inherent weaknesses of these methods are discussed and flowing from this discussion proposals for adapting the South African approach to China is presented. The resultant proposals have a high likelihood of success and will counteract the influences of extreme climate and rampant overloading that occurs on the Chinese roads.

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Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2017.03.004

1. Introduction

One of the main problems with roads and highways in China is the reflection cracking caused by the cement stabilized subbase layers passing through the overlying asphaltic layers, as shown in Fig. 1. Shrinkage cracks are natural phenomenon when cemented materials hydrate and harden. The amount of cement defines the shrinkage; the more cement the more the shrinkage. Under the action of diurnal temperature cycles the cemented layers, even when covered by 20 cm of asphalt, will expand and contract. The resultant strains and stress concentration at the cracks together with heavy axle loading result in the transverse cracks reflecting through the asphalt. The cracks permit the ingress of moisture which softens the layers below the subbase resulting in loss of support and accelerated breakdown of the subbase layer and reduction in the riding quality.

The aim of this paper is to present the use of South African pavement design approach of deep structure and thin surfacing to overcome the existing problems. The deep pavement structure provides good long-term support and avoids the influence of moisture ingress, which means that only surfacing damage needs to be repaired. An unbound crushed stone base layer which is an integral component of the pavement structure limits reflection cracking. The paper first deals with the South African pavement design procedure and contrast this with the Chinese pavement design method. The inherent weaknesses of these methods are discussed and flowing from this discussion proposals for adapting the South African approach to China is presented.

2. The South African pavement design method

The South African pavement design guidelines are contained in a catalogue denoted as TRH4:1996 (Committee of State Road Authorities, 1996). This catalogue provides guidance for a range of traffic, base types and climatic zones. The catalogue is designed for equivalent 80 kN standard axles (E80) although the legal axle load is 9 tons. The traffic stream axle loads are converted to E80s by using a load equivalency exponent of 4.

Fig. 1 – Typical transverse reflection crack.

Fig. 2 shows the catalogue of pavement designs for crushed stone bases. Three designs are shown for 10 million, 30 million and 100 million E80s, as designs are in multiples of traffic of 3. The 100 million E80s design life is hardly found even on the heaviest trafficked South African roads.

It is interesting to note that the asphalt surfacing in all three cases are similar, ranging from 4 to 5 cm for the three designs. A SMA type grading with a modified binder is typically used. It has been found that bitumen rubber with more than 20% crumb rubber has high flexibility and long life. The SMA grading is a stone skeleton mix where the stone to stone contact limits rutting. The crushed stone base has a dense grading approximating the Fuller maximum density curve with less than 12% passing the 0.075 mm sieve and a maximum size of 37.5 mm. The crushed stone is obtained from unweathered rock. The only difference between the bases is that a higher density is required for the higher traffic loading. Density is measured in terms of the bulk density which relates to the solid density of the crushed material, and not in terms of a laboratory compaction test. The high density specification results in a material with 12%–16% voids which does not rut and has a high strength and a stiffness of about 500 MPa. The crushed stone has minimal tensile strength and for this reason reflection cracks do not pass through the base layer to the surfacing.

The subbase layer is cement stabilized with a maximum of 3% cement. The stabilized layer has a 7-day unconfined compressive strength of 1500 kPa. The cement is limited to reduce shrinkage and also for economic reasons. A suitable material that provides the strength has to be used. There is no merit in using a poor quality gravel and then try to obtain the strength by increasing the cement content. The cemented subbase is constructed in two layers, as it is difficult to compact 25 cm of material without breaking down the particles. The cemented layer provides a sound anvil on which the crushed stone can be compacted to achieve the high density.

Below the subbase the materials are checked to a depth of 100 cm from the surface, and if the subgrade material has a poor support with a CBR of less than 3 the pavement will receive at least 3 layers of 15 cm of selected material so that pavement has a deep support. The overall pavement depth is

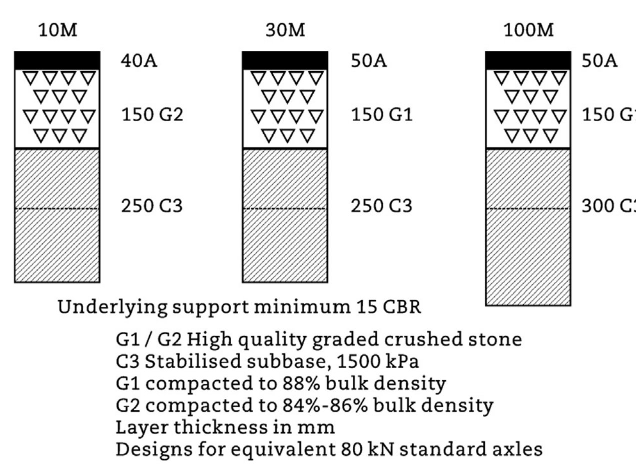

Fig. 2 – Pavement design according to South African TRH4:1996.

thus at least 100 cm for heavily trafficked roads. The deep pavement structure means that support is provided with depth and little damage is caused in the lower layers. Damage is typically on the surface as a result of environmental influence, traffic, and periodic maintenance would be in the form of resealing, resurfacing with another asphalt layer or mill and replace the thin surfacing.

3. Comparing pavement design methods

Fig. 3 shows a schematic comparison of the pavement structures used in South Africa and Northern Hemisphere, which includes China. The first obvious difference is the surfacing thickness. As shown above, in South Africa the asphalt layer is 4–5 cm thick, whereas in China the combined thickness of the asphalt layers is from 16 to 20 cm. The South African structure has a 15 cm crushed stone base resting on a 25–30 cm cement stabilized subbase, whereas in China the asphalt rests directly on 30–40 cm of cement stabilized subbase. In South Africa the materials to a depth of 100 cm are checked to confirm that they fulfil support requirements. Although the Northern Hemisphere pavement shows additional layers, experience with rehabilitation design in China has shown that often the cemented subbase layer rests directly on the subgrade. The subgrade is invariably of a clayey nature with poor support as a result of poor compaction of the subgrade. The result is that when the pavement structure is badly damaged, the pavement to a depth of about 50 cm has to be removed and replaced. This is expensive, and is also hugely disruptive of traffic as the carriageway has to be closed during the extensive period of reconstruction. Replacing the same thickness of pavement means that the original deficiencies are built again, and the pavement life is similar to the original design in terms of equivalent axle load repetitions.

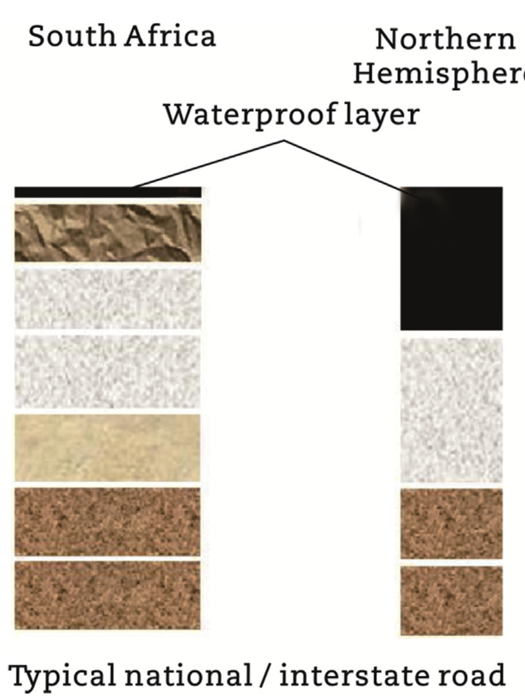

Fig. 3 – Comparison of pavement designs of typical national/interstate road in South Africa and Northern Hemisphere.

4. Proposed pavement design for China

There are three fundamental elements in the design of a pavement, namely traffic numbers and loading, environment and climate and local materials, including the subgrade. The suggested way of handling these elements will be discussed next.

Although the South African pavement design method presented above for simplicity according to the TRH4:1996 is a catalogue, the designs were developed through extensive heavy vehicle simulator (HVS) testing and mechanistic analyses. Fig. 4 shows one of the HVSs (China has a more advanced version of the HVS). The mechanistic design method, presented by Theyse et al. (1996), is used to handle special conditions or ultra-heavy traffic. This method is currently being revised, but has not yet been liberated.

In China the legal axle load for an axle with four tyres is 10 tons. However, overloading is rampant and 20 tons axle loads are not uncommon. There is little likelihood that this situation will change in future with improved traffic loading controls. Rather than placing the responsibility on traffic load control authorities, engineers should design forgiving pavements. From project data it appears that about 5% of the axles exceed a 15-ton load limit. Thus it is wise to design the pavements for 15-ton axle loads with a ruling tyre pressure of 1 MPa. The small number of axles that exceed this limit can be ignored. The main damaging axle loads will be the ones between 10 and 15 tons, and these should be considered for the design traffic numbers. If a more sophisticated analysis procedure is required, then the damage per axle load group, say 8–10 tons, over the full spectrum could be calculated in comparison with the allowable repetitions, and Miner's law can be used. Miner's law sums the proportion of the damage for each of the axle load groups and the sum must be less than or equal to 1 for the pavement to fulfil the design requirements. Furthermore, a debate may be held since if pavements are constructed strong enough to carry overloaded vehicles, then the overloading control could be scaled down

Fig. 4 – Heavy vehicle simulator (HVS).

and the saving could be used to build strong pavements. Limited overloading control and stronger pavements may be economically viable. This would mean that the lower layers in China would be stronger and thicker than in South Africa because of the higher axle loads which makes the pavement deeper.

It is interesting to note that for a 10-fold increase in axle load numbers (from 10 to 100 million E80s) the pavement structure is 6 cm thicker and a small improvement in material properties. Historically design life has been taken as 20 years, but it is evident that a 40-year design life with three times more traffic during this period than over 20 years would only result in minimal increase of pavement structure. It has been estimated that in South Africa it would result in a 10% increase in pavement cost. The benefits are huge in that reconstruction, which is a major problem on heavily trafficked routes, and would be much later. The small increase in pavement cost is a minimal project cost because of other factors such as land acquisition, bridges, earthworks and establishment.

The environment reflecting the rainfall and temperature is used to determine the stiffness values of the different pavement layers and also the material properties. For example, in an arid region the material properties could be weaker than in a humid subtropical or tropical region to provide the same performance. For application in China the local rainfall and temperature will be used to define the material properties to be used in the design.

In a mechanistic analysis the critical stresses and strains are determined and related to load repetitions through transfer functions. A transfer function gives the number of repetitions typically obtained in a laboratory. Fig. 5 shows a typical transfer function of asphalt. The calculated horizontal tensile strain at the bottom of the asphalt is entered into this figure, and the permissible number of repetitions is read off. Note that for a typical horizontal tensile strain of 300 microstrain the fatigue life of the bitumen rubber asphalt is more than 10 times of regular bitumen. These results have been validated with the HVS.

For the South African design method the crushed stone base is invariably sufficiently strong, and higher wheel loads and tyre pressures will make it even stronger as the crushed stone is stress stiffening. This means that an increase in stress results in an increase in stiffness. Crushed stone is thus not specifically evaluated.

The transfer function of cemented layers is shown in Fig. 6. The number of load repetitions is related to the tensile strain ratio at the bottom of the cemented layers. The tensile strain ratio is the applied horizontal tensile strain divided by the strain at break which for South African cement stabilized materials of C3/C4 quality is between 125 and 145 microstrain. Once the cemented layer has degraded into an equivalent granular condition, it is still possible to carry loads because of the support by the deep pavement structure, and this would be at least as long as the first stage, and in many cases as much as 5 to 10 times more. This means that when the cemented material is cracked it has not reached the end of its life. When a cemented layer is constructed in two layers, an effective bond between the layers must be ensured by roughening the lower layer with a sheepsfoot or grid roller. If an effective bond is not established, the cemented layers must be analysed as two layers, and it will have a substantially shorter life than if there is a proper bond.

The lower layers are evaluated by considering the vertical compressive strain on each of the layers. Fig. 7 shows the transfer function. The vertical compressive strain reflects the ability for rut formation. From a safety perspective the maximum permissible rut is 2 cm, as water film thickness would be such that aquaplaning is possible. On important roads the maximum rut may be limited to 1 cm, and a similar transfer function is available. Note that reliability is also incorporated.

It is recommended that the South African pavement design method be used to determine the desired pavement structure with a thin surfacing, crushed stone base, cemented subbase and selected layers. This recommendation flows from the fact that the method relies on the other design parameters, and consequently single elements cannot be extracted and used in isolation. A further aspect of importance is the compaction of fill/subgrade and selected layers as foundation preparation. In South Africa the construction control is to compare field density with laboratory density. The compaction in the laboratory is performed according to the Modified AASHTO compaction effort, which is the AASHTO Designation T180-61. It uses a mould of 15.2 cm diameter and 12.7 cm high. It uses a heavy hammer with mass of 4.536 kg dropping through 45.72 cm. There are 55 blows with the heavy hammer on each of 5 layers. This energy is substantially higher than used in

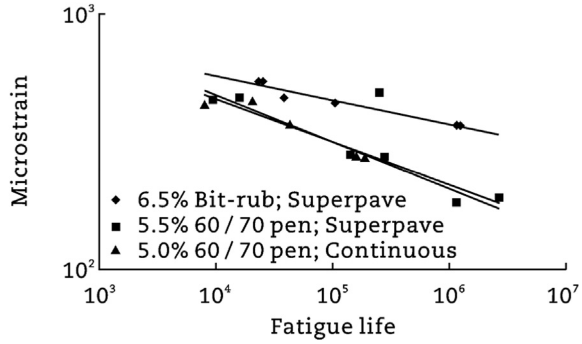

Fig. 5 – Transfer function for asphalt (Visser and Verhaeghe, 2000).

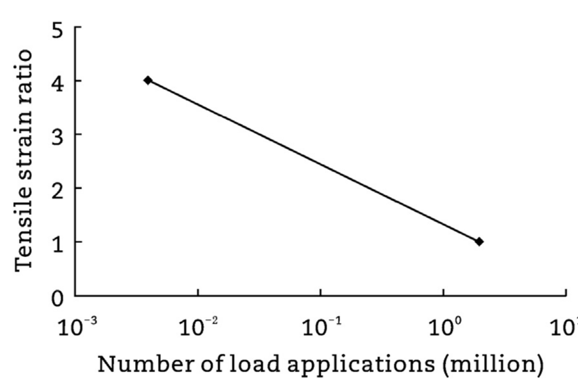

Fig. 6 – Transfer function for cement stabilized layers (according to personal communication by Jordaan in 1994).

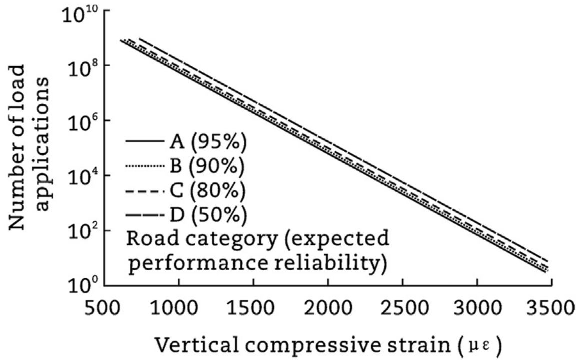

Fig. 7 – Transfer function for 2 cm rutting in subgrade and selected material (Theyse et al., 1996).

China where the mould is higher and there are only 25 blows per layer. Consideration should be given to increase the density standard, as it has been found that small increases in density result in significantly longer life.

The concept of thin asphalt surface and deep pavement structure is being evaluated for use in China on a construction site near Beijing in conjunction with Landpac. The demonstration section will allow evaluation of constructability and it will be monitored in terms of pavement strength through deflection testing and performance. Further demonstration sections are being planned with a view of performing accelerated load testing and obtaining performance parameters with an accelerated testing device such as the HVS.

5. Conclusions and recommendations

The approach used in South Africa of placing a thin asphalt surfacing on a crushed stone base to limit reflection cracking from the cement stabilized subbase holds promise to overcome the significant problem of reflection cracking on roads in China. The South African pavement design method permits the calculation of the critical stresses and strains in the pavement to ensure the required pavement life. Besides the thin surfacing the pavement structure is deep as the layer properties are evaluated and confirmed to a depth of 1 m below the surfacing. Because of the higher axle loads the pavement in China would be stronger to a greater depth than in South Africa, making it a deeper pavement.

Because of rampant overloading, it is recommended that pavement designs be performed for 15-ton axles with dual wheels at a tyre inflation pressure of 1 MPa. This would capture the majority of currently overloaded vehicles. The resultant pavement structure would be only marginally thicker and stronger as demonstrated for the South African situation. This philosophy could start a debate on reducing overload control measures and using the savings to build stronger pavements. In the same debate increasing the design life to reflect the number of axle load repetitions over a 40-year period rather than the current 20 years should be considered.

Improved compaction of particularly the lower pavement layers will have a major positive impact on performance. It is recommended that a density standard equivalent to the Modified AASHTO (Designation T180-61) be introduced.

Demonstration projects are being planned and this will allow the evaluation of constructability, strength and performance under Chinese conditions.

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