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Analysis on Design of Three Types of Pavements from the Perspectives of Structure, Construction Process and Failure Mode

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Abstract: *The topic of this thesis is the design of pavement. This thesis will mainly focus on three types of pavements which are unbound granular pavement, flexible pavement, and rigid pavement. The structure of each pavement type will be discussed, and the construction process and failure mode will be discussed as well. For unbound granular pavement and flexible pavement, most of the defects behave as surface deformation. The main defects in rigid pavement are the shrinkage cracks. In each design procedure, a candidate pavement is provided, and this candidate pavement will be measured whether it is acceptable by using the calculation steps. The advantages and disadvantages will also be discussed in this report.*

Keywords: *Pavement, Unbound granular pavement, Flexible pavement, Rigid pavement*

1. Introduction

1.1. Background and Literature Review

It is critical important to know pavement technology for all transport agencies in Australia [1]. The pavement must have two basic functions which are performing as an engineering structure and meet the functional requirements [1].

Pavements can be classified as flexible pavements and rigid pavements. Flexible pavements include all pavements other than rigid pavements, they are normally designed as continua without formal joints. The most common flexible pavement used in Australia is the unbound granular pavement [1]. Rigid pavements consist of high strength concrete base and a range if subbase material. The various concrete base formats of rigid pavements are jointed unreinforced, jointed reinforced, continuously reinforced, and steel fibre reinforced [1].

Each pavement type has advantages and disadvantages, choosing a suitable pavement type is important. Variety of factors should be considered to do the determination. After choosing the suitable pavement type, the design procedure of the pavement must be followed to ensure the safety and economics of the pavement.

1.2. Aims and Objectives

The aim of this report is to do three different pavement types' design. These three pavement types are unbound pavement, flexible pavement and rigid pavement. In section 2, it will talk about the pavement structure of these three pavement types. In section 3, it will talk about the failure mechanism, it is a measurement to measure whether the design is acceptable. The criteria used in the design is different. The pavement design procedure will be talked in section 4. The procedures are not shown by detail, and some important steps in the design procedure will be introduced in this part. In section 5, all the outcomes will be summarised, and some limitations in this report will be mentioned as well.

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2. Pavement Structure

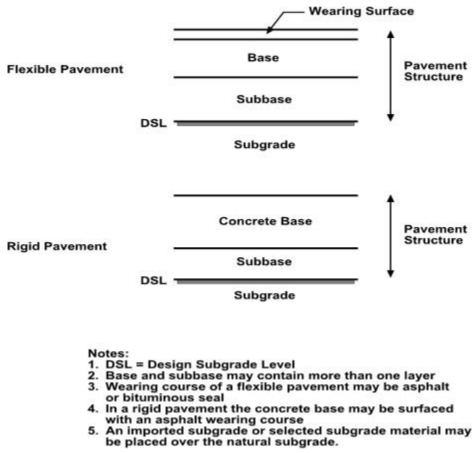

Figure 1: Structure of pavement [Source: Austroads (2004a)]

2.1. Unbound Pavement

Unbound pavement is a type of flexible pavement. The load can be spread to the foundation through the interparticle friction and shear strength of the granular pavement material. An unbound basecourse is composed of materials which are granular or mechanically stabilised or treated with binders to improve properties other than strength [2].

Unbound granular materials consist of gravels or crushed rocks which have a grading that make them mechanically stable, workable and compactable

2.2. Flexible Pavement

In this report, the flexible pavement type is asphalt pavement. Asphalt has a low tensile strength for a bound pavement material which is about one-fifth that of concrete, but asphalt has a high strain capacity which is about twice that of concrete.[1] Figure1 shows the structure of a flexible pavement. The top layer of flexible pavement is a wearing surface.[3] Under the wearing surface, there are Base, Subbase, DSL and subgrade. The base and subbase may contain more than one layer.

2.3. Rigid Pavement

Rigid pavements consist of a high strength concrete base and a range of subbase materials [1]. Figure1 shows the structure of a rigid pavement. The top layer of a rigid pavement is concrete base, the concrete base may be surfaced with an asphalt wearing course. Under the concrete base are Subbase, DSL and Subgrade. The structure of rigid pavement is similar to the structure of flexible pavement, the only difference is the base layer.

3. Failure Mechanism

3.1. Cracking

Since the direction of traffic is horizontal, the mass of vehicle will exert their gravity on the pavement, cracking will occur in the parallel direction of the traffic. The result of the allowable loading should exceed the design traffic. Otherwise, cracking may lead to serious accident. The critical location to calculate strains are top of subgrade directly beneath the inner wheel load of the dual wheel sets and top of subgrade midway between one of the dual wheel sets. These two locations are the most likely place for the appearance of cracking.

The critical location to calculate strains are top of subgrade, bottom of asphalt layer and bottom of cemented layer. All these strains are calculated directly beneath one of the loaded wheels and midway between the loaded wheels. The calculation does both asphalt and cemented material. The calculation of asphalt contains two parts which are pre-cracking cemented material phase and post-cemented material

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phase, the calculation results show the total asphalt fatigue damage for both cemented material phase. The calculation of cemented material contains pre-cracking phase only, the calculation results show the total group cemented material fatigue damage for pre-cracking phase. the total damage to cemented material should not exceed 1.0.

3.2. Erosion

Erosion in rigid pavements can be defined as the loss of material of the base layer near the joints of the slabs, the combined effect of the presence of water, traffic loading and the use of certain base materials caused the loss of material [4]. The loss of material forms an empty area under the joints area. The support of the concrete slabs will decrease due to the empty area. Erosion may cause the form and propagation of cracking process. Allowable repetitions for erosion should be calculated first to get the total percentage of erosion. The total percentage of erosion should less than 100%.

3.3. Fatigue

Fatigue failure may cause interconnected cracks under repeating traffic loading, the asphalt layer located at the existing transverse joints are more likely to fatigue cracking [5]. The expected fatigue repetitions were calculated. The total percentage of erosion should less than 100 %.

4. Pavement Design Procedures

4.1. Unbound Granular Pavement

The first step of the design is to determine the CBR value, Starting pavement thickness and Design traffic for 30-year design life. Everyone has his own data chosen from the data table given by ZID and initial of name. The total granular layer thickness needs to be divided in to five equal thick sublayers. Then calculate the ratio of adjacent sublayers to calculate the elastic properties of each sublayers. The most important step of this design is to calculate the permanent deformation allowable loading to determine whether the candidate structure can be accepted. If the candidate structure is not acceptable, the starting pavement thickness should be increased to do a second calculation.

4.2. Flexible Pavement

The first step of the design is to determine the CBR value, Design traffic for 30-year design life, the design flexural strength of asphalt modulus size 14 mm mix and 20 mm mix, and the Desired project reliability. The initial step of flexible pavement is same with unbound pavement. However, in this design, the cemented materials contain pre-cracking cemented material phase and post-cracking cemented material phase. They need to be calculated separately. The aim of these calculations is to determine whether the total group fatigue damage exceeds 1.0. If the damage exceeds 1.0, it means the design loading exceeds the allowable loading. The candidate pavement is acceptable if the allowable loading for both asphalt fatigue and permanent deformation exceed the design loading.

4.3. Rigid Pavement

The first step of this design is to determine the CBR value, Project design reliability and the Design traffic. The pavement selected for this project is a plain concrete pavement. The aim of this procedure is to determine the total percentage for fatigue and the total percentage for erosion. Both values should less than 100% if the base thickness is suitable. What is more, the minimum base thickness should be found by repeating the calculations to save materials.[6]

5. Outcomes and Discussion

5.1. Calculations Results

The initial pavement thickness was 540 mm with a CBR value of 6% and the design traffic for 30 years design life was $2.3*10^7$. By doing calculation, the allowable loading was $9.6*10^6$ ESA for the initial thickness which was lower than the design traffic which was $1.6*10^7$ ESA. The result showed that the candidate structure was not acceptable in terms of pavement deformation. Since the candidate structure

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was not satisfied, the starting thickness should be increased by 50 mm to do the repeat calculation. This calculation showed that the allowable loading was $1.9*10^7$ ESA which was greater than the design traffic. Thus, the candidate structure was acceptable in terms of pavement deformation for the pavement thickness of 590 mm.

The CBR value was 6%, and the design traffic for 30-years design life was $1.11*10^7$ HVAG. The thickness of size 14 mm asphalt, E=2200 MPa was 45 mm. Size 20 mm asphalt, E=2500 MPa had a thickness of 130 mm. The cemented material, E= 3000 MPa had a thickness of 220mm. The unbound granular material had a thickness of 240 mm. The desired project reliability was 97.5%. As the allowable loading calculated follow the steps for both asphalt fatigue and permanent deformation exceeded the design loading, the candidate pavement was acceptable.

CBR value was 6%, project design reliability was 95% and the design traffic was $3.5*10^7$. The pavement selected in the design was a plain concrete pavement which was rigid pavement. The results showed that when the thickness was 215 mm, both fatigue and erosion were less than 100 %. It was the minimum base thickness since the results showed that when the thickness was reduced by 5 mm, both fatigue and erosion were greater than 100 %.

5.2. Difference Between Design Procedures, Applications

The measurement to decide whether the design is acceptable is different. For the design of unbound pavement and flexible pavement, the measurement is the loading while the measurement for the design of rigid pavement is the total percentage for fatigue and erosion.

The cost of flexible pavement and rigid pavement is different. The cost of flexible pavement is lower when the traffic load is low. Rigid pavement is more economic when the traffic load is large. To take advantage of this, rigid pavement can be applicated in places that have heavy traffic load like expressway. In some places with lower traffic load like some loads in small village, flexible pavement can be applicated.

Flexible pavements can be constructed in stages, it means flexible pavements can be constructed at any time. This construction method is suitable for some pavements in CBD. What is more, the repairment of underground services for flexible pavement is simpler than that for rigid pavement.

Each pavement type has advantages and disadvantages, the chosen of pavement type should be considered along with material availability, cost and construction constrains.

5.3. Limitations

There are some limitations for the report due to variety of factors. These limitations are listed below:

- The material variation is not considered. When designing with real material properties, the data needs to be statistically based and if the data is not already known, it needs time to be developed.

- The level of water table is not taken into account in the design. The seasonal variation in the water table needs to be determined and whether the 'dry CBR' value or the 24- hour soaked CBR value needs to be used.

- The use of subgrade material other than granular fill is not taken into account in this design. The effect of increase the strength of marginal materials by blending materials is to lower porosity values and permeability. Then the resistance of water ingress into the pavement structure is increased. Densifying the compacted materials can reduce the voids count to achieve this.

- Compaction of granular fill requires trials to be conducted. The breaking of the granular fill particles may be caused by over compaction. Under-compaction may be detrimental for the pavement's life.

- The different types of asphalt are not taken into consideration. For example, when using AC20 & AC10 materials, there is a minimum asphalt thickness of 75 mm. There will be physical least thickness that needs to be abided.

- No delineation within the design layer thickness is provided in the pavement design manual. It is assumed that the asphalt is a constant value. However, the fact is that different asphalts have different moduli, these changes in moduli needs to be taken into account.

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- All design asphalt thickness values are always round up. It is not a mathematical rounding issue. For conservative design and functionally in construction, all the values need to be round up and the design thickness are nominated in increments of 5 mm.

- Acceptable tolerances were dealt with predominantly. It should be applied to the design of asphalt pavements as well. The pavement Design Manual is functionally used fatigue as a primary design requirement. In the design, the thickness of layers should be treated as 'minimums'. Thus, the construction tolerances should always be greater than 0. As a result, the minimum thickness designed cannot be compromised by the contractors.

- Since concrete and asphalt are more expensive materials than other base course materials, contractors will try to minimise their use. However, the layer thickness should above the minimum thickness on site, the authority will have very large penalty deductions for the pavements do not meet the minimum thickness. The under- thickness pavements will not be accepted and need to be asked to replace it.

- Since there is less control on the equipment by the operators on most sites, the base course thickness tolerances rounded upwards to the next increments of 10 mm may not be satisfactory for some inexperienced contractor. The nominal design thickness should be rethink specifically

There will be variances within the subgrades itself on excavation of subgrade materials usually. It is expected to use modified cement and lime blends with supplementary cementitious materials such as flyash or granulated iron blast-furnace slag. These blended binders have extended construction working times and offer either long term strength gain or improved waterproofness.

- The drainage of natural springs needs to be considered in real cases.

6. Conclusion

This report is mainly focus on three pavement types, and each type of pavement has his own design procedure. In each design procedure, a candidate pavement is provided. Then it needs to be measure whether it is acceptable or not by doing the calculation steps. The criterion for each pavement is different, especially for the rigid pavement. Due to variety of factors, this report has some limitations. Some objective conditions need to be considered in real construction, for example, the constructor may not construct the pavement strictly followed the design. The tolerance of the construction may affect the allowable loading or fatigue and erosion of the pavement. All the results calculated in the design procedure should be rounded up to be on the safe side. What is more, the construction accuracy is limited, the thickness of the layer can only be increased or reduced by 5 mm for example. The aim of the design procedure is to design a pavement that can use minimum materials to meet the traffic requirements. The safety of the pavement is most important, it should be prior considered.

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