TENAX

Technical Reference GRID-DE-2

DESIGN OF FLEXIBLE PAVEMENTS WITH TENAX GEOGRIDS

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1. INTRODUCTION

This technical note describes the design steps of asphalt concrete flexible pavements, utilizing the American Association of State Highway and Transportation Officials (AASHTO) “Guide for Design of Pavement Structures” 1993. The structural contribution of Tenax Geogrids to the flexible pavement is quantified in the current design method by increasing the structural layer coefficient of the aggregate base course. A design worksheet for pavement design and a design example are provided.

Flexible pavements generally consist of a prepared subgrade layer which is the roadbed soil or borrow material compacted to a specified density. A subbase course is constructed on top of the prepared roadbed, and may be omitted if the subgrade soil is of a high quality. The base course is constructed on the subbase course, or if no subbase is used, directly on the roadbed soil. It usually consists of aggregates such as crushed stone, or crushed gravel and sand. On top of the base course is the surface course that typically consists of a mixture of mineral aggregates and bituminous materials.

Existing design methods for flexible pavements include empirical methods, limiting shear failure methods, limiting deflection methods, regression methods, and mechanistic-empirical methods. The AASHTO method (1993) is a regression method based on results from road tests. AASHTO published the interim guide for design of pavement structures in 1972, with revised versions in 1981, and 1986, and the current version in 1993.

2. AASHTO DESIGN METHOD

The AASHTO method utilizes the term **Structural Number** (**SN**) to quantify the structural strength of a pavement required for a given combination of soil support, total traffic, reliability, and serviceability level. The required SN is converted to actual thickness of surfacing, base and subbase, by means of appropriate layer coefficients representing the relative strength of the construction materials. The design equation used is as follows:

$$SN = a_1 \cdot D_1 + a_2 \cdot D_2 . m_2 + a_3 \cdot D_3 . m_3 \tag{1}$$

where,

a_i = i^{th} layer layer coefficient

D_i = i^{th} layer thickness (inches), and

m_i = i^{th} layer drainage coefficient (drainage effect on the Asphalt layer is not considered in the AASHTO 93 guide)

the subscripts 1, 2 and 3 refer to the asphalt concrete course, aggregate base course and subbase course (if applicable) respectively. The basic design equation for flexible pavements in the AASHTO 93 design guide is as follows:

$$\log_{10}(W_{18}) = Z_R * S_o + 9.36 * \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\dfrac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \dfrac{1094}{(SN+1)^{5.19}}} + 2.32 * \log_{10}(M_R) - 8.07 \tag{2}$$

where,

W_{18} = predicted number of 18-kip equivalent single axle load (ESAL) applications,

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

ΔPSI = difference between the initial design serviceability index p_o, and the design terminal serviceability index p_t, and

M_r = resilient modulus (psi)

The following sections will contain detailed design steps using the above two equations, together with the introduction of LCR that quantifies the structural contribution of Tenax geogrids to the pavement section.

3. DESIGN REQUIREMENTS

The basic requirements for flexible pavement design could be classified into four categories; Design Variables, Performance Criteria, Material Properties for Structural Design, and Pavement Structural Characteristics, as described in the following sections.

3.1 Design Variables

3.1.1 Time Constraints

Performance period, refers to the period of time that an initial pavement structure will last before it needs rehabilitation**. Analysis period**, refers to the period of time for which the analysis will be conducted, it is analogous to the term "design life". Table 1 presents guidelines for analysis period as presented in [1]. If the designer considers the performance period equal to the analysis period, it means that the initial structure is assumed to be lasting the entire analysis period. For more details on the life-cycle cost and other design strategies refer to [1].

Table 1: Analysis Period

Highway Condition	Analysis period (years)
High-volume urban	30-50
High-volume rural	20-50
Low-volume paved	15-25
Low-volume aggregate surface	10-20

3.1.2 Traffic

The design procedures for roadways are based on $\mathbf{w'_{18}}$: cumulative expected 18-kip equivalent single axle loads (**ESAL**) during the analysis period. Tables D.1 through D.9 in Appendix D, [1] present the axle load equivalency factors corresponding to single, tandem, and triple axles with terminal serviceability index p_t of 2.0, 2.5, and 3.0. For more details on how to convert mixed traffic into 18-kip ESAL units refer to [1], Appendix D. Table D.20 in Appendix D, [1] lists the Traffic Growth Factors corresponding to the analysis period based on an estimated Annual Growth Rate. The total volume of traffic during the analysis period equals the first year traffic estimate multiplied by the growth factor

$$w'_{18} = \text{Traffic growth Factor} * \text{First Year Traffic Estimate} \qquad (3)$$

To determine traffic ($\mathbf{w_{18}}$) that will be used in the design lane, the following equation is used to account for the directional and lane distribution factors:

$$w_{18} = D_D * D_L * w'_{18} \qquad (4)$$

where,

D_D = a directional distribution factor, expressed as a ratio, that accounts for the distribution of ESAL units by direction, e.g., east-west, north-south

D_L = a lane distribution factor, expressed as a ratio, that accounts for distribution of traffic when two or more lanes are available in one direction, and

w'_{18} = the cumulative two-directional 18-kip ESAL units predicted for a specific section of roadway during the analysis period, as explained above.

The directional distribution factor D_D is generally 0.5 (50%) for most roadways, however it may vary from 0.3 to 0.7 depending on whether more or less traffic is passing in one direction than the other. D_L factor is listed in Table 2 as presented in [1] may be used as a guide.

Table 2: Lane Distribution Factor, D_L

Number of Lanes in Each Direction	Percent of ESAL in Design Lane
1	100
2	80-100
3	60-80
4	50-75

3.1.3 Reliability

The reliability concept is outlined in Chapter 4, Part I in [1]. Basically, it is a means of incorporating some degree of certainty into the design process to ensure that the various design alternatives will last the analysis period. Generally as the volume of traffic, and importance of the roadway increases, the risk of not performing to expectations must be minimized. This is accomplished by selecting higher levels of reliability. Table 3 presents recommended levels of reliability for various functional classifications as presented in [1].

Table 3: Suggested Levels of Reliability

Functional Classification	Recommended Level of Reliability*	
	Urban	**Rural**
Interstate and Other Freeways	85-99.9	80-99.9
Principal Arterials	80-99	75-95
Collector	80-95	75-95
Local	50-80	50-80

*NOTE: Results based on a survey of the AASHTO Pavement Design Task Force

For a given reliability level (**R**), the reliability factor (**F_R**) is defined as follows:

$$F_R = 10^{-Z_R * S_o} \qquad (5)$$

Where **Z_R** is the standard normal deviate, and **S_o** is the overall standard deviation. S_o should be selected to represent the local conditions, the value of S_o developed at the American Association of Highway Officials (AASHO) road was 0.45 for flexible pavements. The (**W_{18}**) for the design equation is determined as follows:

$$W_{18} = w_{18} * F_R \qquad (6)$$

If the designer substitutes the traffic (w_{18}) directly into the design equation for W_{18}, then $F_R = 1$ and R will then be 50 percent. The designer is thereby taking a 50-50 chance that the designed sections will not survive the analysis period traffic with a serviceability p p_t.

3.1.4 Environmental Effects

For more details on the environmental effect on pavement performance refer to section 2.1.4, Part II in [1]. For the purpose of this technical reference, the total loss in serviceability will be assumed all due to traffic load during the analysis period.

3.2 Performance Criteria

3.2.1 Serviceability

The serviceability of a pavement is defined as its ability to serve the type of traffic which uses the facility, the measure of serviceability is the Prime Serviceability Index (PSI) which ranges from 0 (impossible road), to 5 (perfect road). The 93 AASHTO Guide uses the total change in serviceability index (**DPSI**) as the serviceability design criteria which is defined as follows:

$$\Delta PSI = p_o - p_t$$

(7)

where,

p_o = initial serviceability index. A value of 4.2 was observed at the AASHO Road Test for flexible pavements

p_t = terminal serviceability index, which is based on the lowest index that will be tolerated before rehabilitation. An index of 2.5 or higher is suggested for design of major highways and 2.0 for roadways with lesser traffic volumes.

3.3 Material Properties for Structural Design

3.3.1 Effective Roadbed Soil Resilient Modulus

The basis for material characterization in the 1993 AASHTO design Guide is resilient modulus ($\mathbf{M_R}$). Equation (8) correlates between the Corps of Engineers CBR value and the in situ resilient modulus of soil:

$$M_R \text{ (psi)} = 1{,}500 * CBR \tag{8}$$

This equation is reasonable for fine-grained soil with a soaked CBR of 10 or less. For more details on the correlation of M_R with other soil properties and on determining the seasonal resilient modulus values refer to section 1.5 Part (I), and section 2.3.2 Part (II), [1].

3.3.2 Layer Coefficients

Figures 2.5, 2.6, and 2.7 in chapter 2, Part II, [1] show the Layer coefficients a_1, a_2, and a_3 for the asphalt, base, and sub-base layer of the pavement section respectively. For more details on determining of the layer coefficients value, refer to section 2.3.5, Part II,[1].

3.4 Pavement Structural Characteristics

3.4.1 Drainage

The level of drainage for a flexible pavement is accounted for through the use of modified layer coefficients, i.e., a higher layer coefficient would be used for improved drainage conditions. The factor for modifying the layer coefficient to account for drainage effect is referred to as an m_i value and is integrated into the structural number (SN) as shown in Equation (1). Table 4 presents a general definitions corresponding to different drainage levels as suggested in [1].

Table 4: Drainage Conditions

Quality of Drainage	**Water Removed Within**
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	Water will not drain

Table 5 presents the recommended m_i values by [1] as a function of the quality drainage and the percent of time during a year the pavement structure would normally be exposed to moisture level approaching saturation.

Table 5: Recommended m_i Values

Quality of Drainage	**Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation**			
	Less than 1%	**1-5%**	**2-25%**	**Greater than 25%**
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

By using the nomograph *"Design Chart for Flexible Pavements based on Using Mean Values for each Input"* from [1], the designer is able to determine the required SN given the design requirements discussed above.

4. MODIFIED AASHTO METHOD WITH TENAX GEOGRIDS

The structural contribution of a Tenax geogrid on a flexible pavement system can be quantified by the increase in the layer coefficient of the aggregate base course. Equation (1) now becomes:

$$SN = a_1 * D_1 + a_2 * LCR * D_2.m_2 + a_3.D_3.m_3 \tag{9}$$

where **LCR** is the Layer Coefficient Ratio with a value higher than one. LCR value is determined based on the results from a laboratory testing on flexible pavement system with and without a Tenax geogrid, as described in [2] using Equation (10). SN_r (structural number of the reinforced section), and SN_u (structural number of the unreinforced section) used in Equation (10) are both evaluated under the same pavement conditions, i.e same base course depth, subgrade CBR, and rut depth.

$$LCR = \frac{SN_r - \boldsymbol{a}_1 * D_1}{SN_u - \boldsymbol{a}_1 * D_1} \tag{10}$$

Figure 1 in the Appendix shows the LCR values against the subgrade CBR. The reduction in aggregate base thickness can be evaluated by the use of Tenax geogrid using Equation (11) (assuming no sub-base layer):

$$D_2 = \frac{SN - a_1 * D_1}{LCR * a_2 * m_2} \tag{11}$$

or instead, the asphalt thickness can be reduced

$$D_1 = \frac{SN - LCR * a_2 * D_2 * m_2}{a_1} \tag{12}$$

5. DESIGN EXAMPLE

Given Data:

- A pavement for a road (2 lanes each direction) needs to be designed for a 25-year life, assume no sub-base layer.
- Average subgrade CBR = 5
- Expected traffic: tandem axle 36 kips, 100,000/year. No annual growth rate to be considered.
- Terminal serviceability, $p_t = 2.5$
- Reliability level R= 95%, standard deviation, $S_o= 0.35$
- Asphalt layer coefficient $a_1=0.40$, base course layer coefficient $a_2= 0.14$
- Drainage condition is "Good", pavement is exposed to saturation moisture more than 25% of the time

Design Solution:

(a) without Tenax Geogrid

1. Evaluation of W_{18}

1.1 From Table *"Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles and p_t of 2.5"* , from [1], axle load equivalency factor = 1.38 at axle load 36 kips and assumed SN of 5.0 First year traffic estimate = 1.38 x 100,000 = 138,000

1.2 From Table "*Traffic Growth Factors*", from [1], traffic growth factor = 25.0 at analysis period of 25 years, and annual growth rate of zero.

1.3 Using Equation (3), w'_{18}=25 x 138,000 = 3,450,000
1.4 D_D= 0.5 (two directions). From Table 2, D_L = 0.90
1.5 Using Equation (4), w_{18}=3,450,000 x 0.50 x 0.90 = 1,552,500
1.6 For R=0.95, Z_R = -1.645 (refer to [1] Part I chapter 4)
1.7 Using Equation (5), F_R= 3.764
1.8 Using Equation (6), W_{18} = 1,552,500 x 3.764 = 5,843,610

2. Serviceability
2.1 Assuming p_o=4.3
2.2 Using Equation (7), $\Delta PSI = 4.3 - 2.5 = 1.8$

3. Subgrade Resilient Modulus
3.1 Using Equation (8), M_R=1500 x 5 = 7500 psi = 7.5 ksi

4. SN Determination
4.1 Using the nomograph "*Design Chart for Flexible Pavements based on Using Mean Values for each Input*" from [1], SN is determined to be 4.5*

*It should be noted here that if the required SN was not comparable to the assumed SN at which the "Axle Load Equivalency Factor" was selected, the first year traffic estimate must be re-evaluated based on the determined SN.

5. Drainage Coefficient
5.1 From Table 5, m_2=1.00

6. Cross-Section Design
6.1 Using Equation (1), assuming a 5" asphalt thickness, the thickness of the base layer is determined as follows:

$$D_2 = \frac{4.5 - 0.40 * 5}{0.14} = 17.95''$$

(b) With Tenax Geogrid

From Figure 1, LCR = 1.45 at CBR of 5. The base course thickness is determined from Equation (9) using Tenax Geogrid as follows:

$$D_2 = \frac{4.5 - 0.40 * 5.0}{0.14 * 1.45} = 12.38''$$

A saving of 5.6 inches of aggregate is achieved due to the inclusion of Tenax MS220 geogrid in this particular example.

6. DESIGN WORKSHEET FlexPave

The process of pavement design using AASHTO 93 guidelines, however, can be simplified as Tenax Corporation has designed a Mcirosoft Excel® worksheet called **FlexPave** to assist in designing pavements with and without using Tenax Geogrid. Enclosed is a diskette/ CD with a copy of **FlexPave** worksheet.

Using the worksheet is straight forward; as you work the design steps through step 1.5, and then insert the input data in the corresponding cells. By hitting the button "CALCULATE", the required SN, and the design cross-section with and without using geogrid will be displayed on the output cells. Please note that there are two "reset" buttons that allow for the calculations of the subgrade "M_R"and the traffic

"W_{18}" from "CBR" and "w_{18}" respectively. However, the user has the option to insert these values directly into the assigned cells if they were known. The cost savings per squared yard of pavement are calculated as well based on aggregate and geogrid prices. The worksheet contains a background information on Tenax MS geogrid series and the specification sheets of MS220, MS330, and MS500 geogrids. Micrsoft Office ® 97 (or more recent version) is required to open this worksheet, with "Enabling Macro" option.

7. REFERENCES

1. American Association of State Highway and Transportation Officials, "AASHTO Guide for Design of Pavement Structures", 1993.

2. Zhao, A., and Foxworthy, P.T., 1999, "Geogrid Reinforcement of Flexible pavement: Apractical
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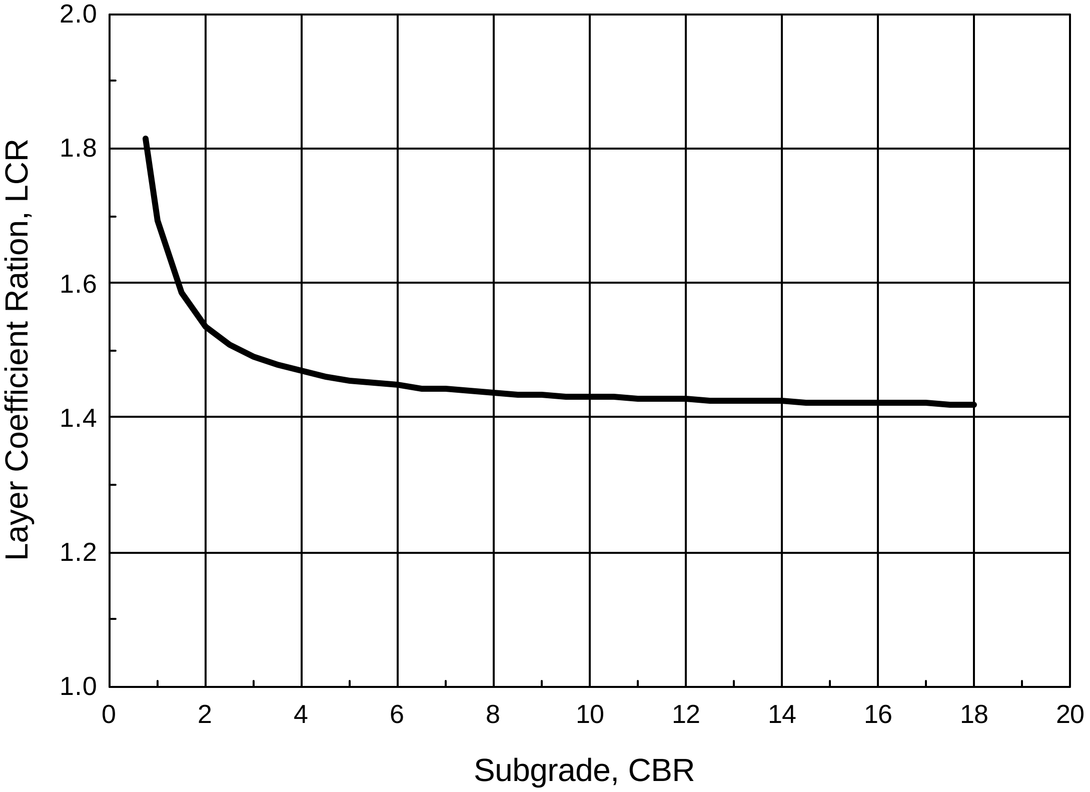
2.0
1.8
1.6
1.4
1.2
1.0
Layer Coefficient Ration, LCR
0
2
4
6
8
10
12
14
16
18
20
Subgrade, CBR

Figure 1. Layer Coefficient Ratio (Tenax MS 220 Geogrid) vs. Subgrade CBR.