TENAX

Technical Reference TDS 006

DESIGN OF FLEXIBLE ROAD PAVEMENTS WITH TENAX GEOGRIDS

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DESIGN OF FLEXIBLE ROAD PAVEMENTS WITH TENAX GEOGRIDS

BY THE MEANS OF TENAX TNXROAD SOFTWARE

1. INTRODUCTION

This design guideline advises 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 [1]. The current AASHTO design method has been modified to account for the structural contribution of Tenax integral extruded Geogrids.

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 top of 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 (fig. 1).

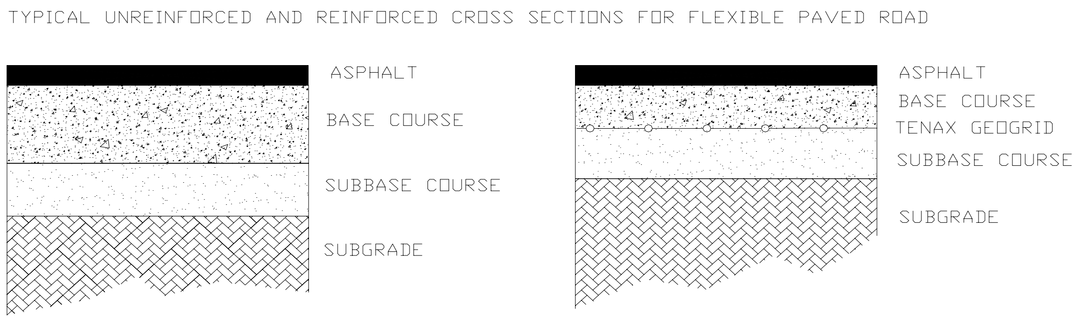

Figure 1 – Typical cross sections for flexible paved road.

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 is a regression method based on empirical results from AASHO road test conducted in the 1950s. AASHTO published the interim guide for design of pavement structures in 1972, with revised versions in 1981, and 1986, and the current version is dated 1993.

The modification of the AASHTO method due the use of Tenax biaxial geogrids for reinforcement of flexible pavements is based upon extensive laboratory testing [2] and has been verified by means of several full scale tests by different authors [3], [4].

The data collected have been conservatively analysed and a full design methodology has been generated applicable only to high strength stiff integral geogrids having high tensile modulus, junction strength and characterized by great interlock capacity such as Tenax LBO SAMP and Tenax MS geogrids.

2. AASHTO DESIGN METHOD

The "American Association of State Highway and Transportation Officials " (AASHTO) method utilizes the **Structural Number** index (**SN**) to quantify the structural strength of a pavement required for a given combination of soil bearing capacity, expected total traffic and road serviceability loss.

The basic empirical design equation used for flexible pavements in the AASHTO 1993 design guide, for determining the structural number, is as follows:

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

Where,

SN = required structural number (strength) of the road section;

W_{18} = predicted number of 80 kN (18000 lb) equivalent single axle load (ESAL) applications;

Z_R = standard normal deviate (index of design reliability R);

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

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

M_R = subgrade soil resilient modulus measured in [psi], where M_R [psi] = 6.9 M_R [kPa].

It is important to recognize that equation (1) was derived from empirical information obtained at the AASHO Road Test. As such, this equation represent a best fit to observations at the Road Test. The solution represents the mean value of traffic, which can be carried given specific inputs before deteriorating to some selected terminal level of serviceability.

The required SN is converted to the actual thickness of asphalt concrete, base and subbase, by means of appropriate layer coefficients representing the relative strength of the construction materials. The design equation used is as follows:

$$SN = a_1\ D_1 + a_2\ D_2\ m_2 + a_3\ D_3\ m_3 \tag{2}$$

where,

a_i = i^{th} layer coefficient [1/inches];

D_i = i^{th} layer thickness [inches];

m_i = i^{th} layer drainage coefficient [-];

the subscripts 1, 2 and 3 refer to the asphalt concrete course, aggregate base course and subbase course (if applicable) respectively. The layer coefficients are based on the soil elastic modulus M_R and have been determinated based on stress and strain calculations in a multilayered pavement system. Using these concepts, the layer coefficients may be adjusted, increased, or decreased, in order to maintain a constant value of stress or strain required to provide a comparable performance. Typical value ranges of the layer coefficients for material used in the AASHO Road Test are as follows:

asphaltic concrete surface course, a_1	0.40 - 0.44
crushed stone base course, a_2	0.10 - 0.14
sandy gravel subbase, a_3	0.060 - 0.10

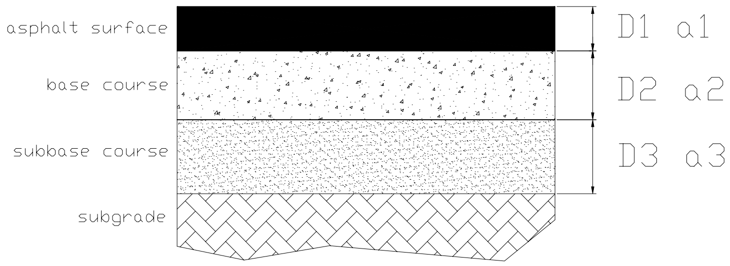

Figure 2 – Definition of the layer coefficients for the different courses of the road section.

For further details see table 8 of paragraph 4.1 of this technical note.

The following sections contain detailed design steps for the determination of the required structural number and for the road layered design analysis using the above two equations (1) (2), together with the introduction of the geogrid **Layer Coefficient Ratio** (**LCR**) which quantifies the structural contribution of Tenax geogrids to the pavement section.

3. DETERMINATION OF THE REQUIRED STRUCTURAL NUMBER

The design of a highway road is based upon the level of expected traffic volume during the design life of the structure and the expected level of reliability in the predicted performances.

After the characterization of the subgrade soil properties and the selection of the values for the realibility (R), for the overall standard error S_0 and for the estimated total 80 kN ESAL, it is possible to determine the value of the structural number index SN relative to the conditions of the flexible paved road using the nomograph of fig 3. Otherwise the SN can also be calculated by the means of equation (2) or through software TNXROAD. In the below paragraphs are given the AASHTO typically recomended factors for designing flexible paved roads. It is important that designers verify the existence of local regulations or specific requirements when designing highway pavements.

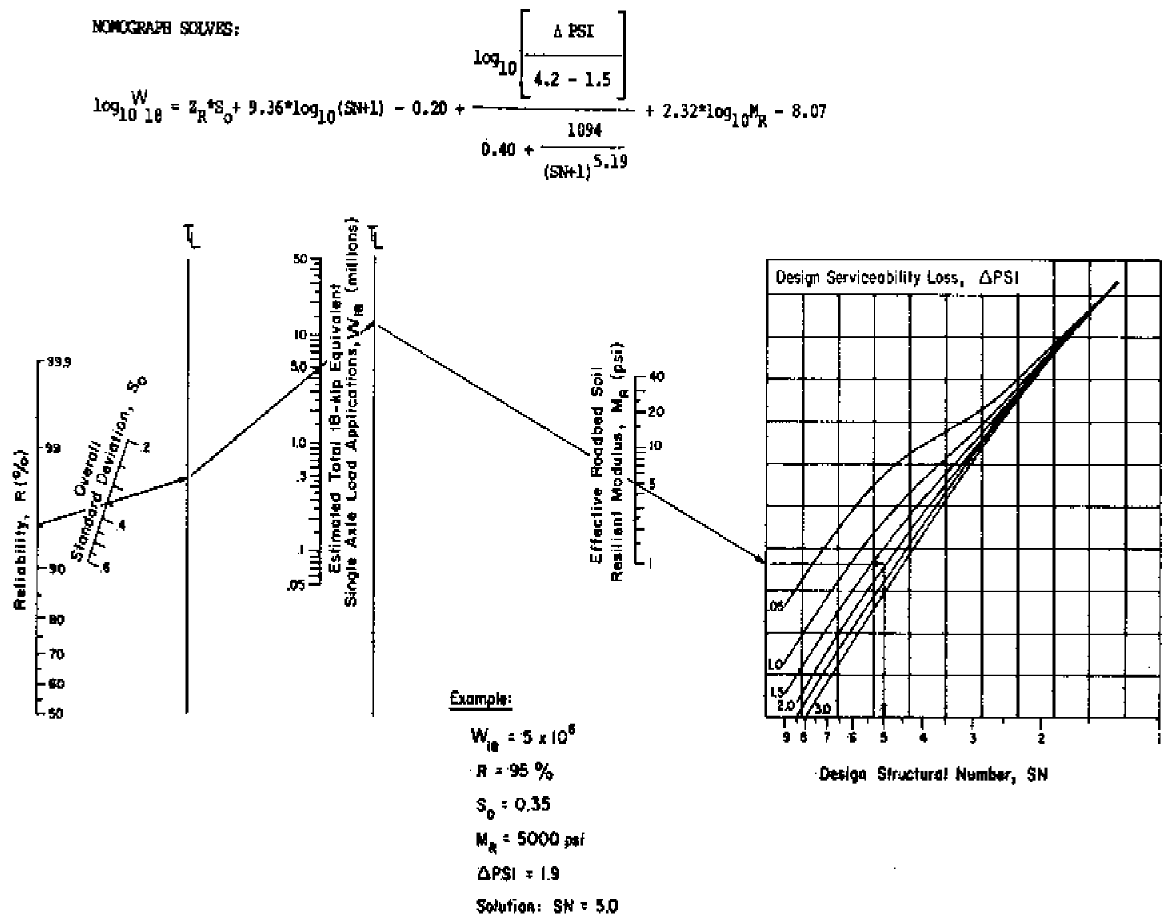

Figure 3 – Design chart for flexible pavements based on AASHTO nomograph.

3.1 Time Constraints

The analysis period refers to the period of time which the design analysis of the pavement will be performed, it is analogous to the term “design life”. Table 1 presents guidelines for analysis period as presented in [1] for different highway conditions.

Table 1: Typical 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

3.2 Estimated Traffic Volume

The design procedures for roadways are based on $\mathbf{w'_{18}}$: cumulative expected 80 kN (18000 lb) equivalent single axle loads (**ESAL**) during the analysis period. In fact the results of the AASHO Road Test have shown that the damaging effect of the passage of an axle of any mass can be represented by a number of 80 kN ESAL. For example, one application of a 54 kN single axle was found to cause damage equal to approximately 0.23 applications of an 80 kN single axle load. Tables 1, 2 and 3 present the axle load equivalency factors corresponding to single and tandem axles with terminal serviceability index p_t of 2.5. The load equivalency factors presented in Appendix are based on observations at the AASHO Road Test in Ottawa, Illinois. For more details on how to convert mixed traffic into 80 kN ESAL units refer to [1], Appendix D.

Table 2 – Axle load equivalency factors for flexible pavements, single axles and $p_t = 2.5$.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.30
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6.98	5.90	5.21	5.39	5.98
30	10.3	9.5	7.9	6.8	7.0	7.8
32	13.9	12.8	10.5	8.8	8.9	10.0
34	18.4	16.9	13.7	11.3	11.2	12.5
36	24.0	22.0	17.7	14.4	13.9	15.5
38	30.9	28.3	22.6	18.1	17.2	19.0
40	39.3	35.9	28.5	22.5	21.1	23.0
42	49.3	45.0	35.6	27.8	25.6	27.7
44	61.3	55.9	44.0	34.0	31.0	33.1
46	75.5	68.8	54.0	41.4	37.2	39.3
48	92.2	83.9	65.7	50.1	44.5	46.5
50	112.	102.	79.	60.	53.	55.

Table 3 - Axle load equivalency factors for flexible pavements, tandem axles and p_t = 2.5.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002
6	.002	.002	.002	.001	.001	.001
8	.004	.006	.005	.004	.003	.003
10	.008	.013	.011	.009	.007	.006
12	.015	.024	.023	.018	.014	.013
14	.026	.041	.042	.033	.027	.024
16	.044	.065	.070	.057	.047	.043
18	.070	.097	.109	.092	.077	.070
20	.107	.141	.162	.141	.121	.110
22	.160	.198	.229	.207	.180	.166
24	.231	.273	.315	.292	.260	.242
26	.327	.370	.420	.401	.364	.342
28	.451	.493	.548	.534	.495	.470
30	.611	.648	.703	.695	.658	.633
32	.813	.843	.889	.887	.857	.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3.00	3.16
46	4.18	3.98	3.58	3.40	3.55	3.79
48	5.08	4.80	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28
52	7.33	6.87	5.93	5.38	5.63	6.17
54	8.72	8.14	6.95	6.22	6.47	7.15
56	10.3	9.6	8.1	7.2	7.4	8.2
58	12.1	11.3	9.4	8.2	8.4	9.4
60	14.2	13.1	10.9	9.4	9.6	10.7
62	16.5	15.3	12.6	10.7	10.8	12.1
64	19.1	17.6	14.5	12.2	12.2	13.7
66	22.1	20.3	16.6	13.8	13.7	15.4
68	25.3	23.3	18.9	15.6	15.4	17.2
70	29.0	26.6	21.5	17.6	17.2	19.2
72	33.0	30.3	24.4	19.8	19.2	21.3
74	37.5	34.4	27.6	22.2	21.3	23.6
76	42.5	38.9	31.1	24.8	23.7	26.1
78	48.0	43.9	35.0	27.8	26.2	28.8
80	54.0	49.4	39.2	30.9	29.0	31.7
82	60.6	55.4	43.9	34.4	32.0	34.8
84	67.8	61.9	49.0	38.2	35.3	38.1
86	75.7	69.1	54.5	42.3	38.8	41.7
88	84.3	76.9	60.6	46.8	42.6	45.6
90	93.7	85.4	67.1	51.7	46.8	49.7

Table 4 - Axle load equivalency factors for flexible pavements, triple axles and $p_t = 2.5$.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0000	.0000	.0000	.0000	.0000	.0000
4	.0002	.0002	.0002	.0001	.0001	.0001
6	.0006	.0007	.0005	.0004	.0003	.0003
8	.001	.002	.001	.001	.001	.001
10	.003	.004	.003	.002	.002	.002
12	.005	.007	.006	.004	.003	.003
14	.008	.012	.010	.008	.006	.006
16	.012	.019	.018	.013	.011	.010
18	.018	.029	.028	.021	.017	.016
20	.027	.042	.042	.032	.027	.024
22	.038	.058	.060	.048	.040	.036
24	.053	.078	.084	.068	.057	.051
26	.072	.103	.114	.095	.080	.072
28	.098	.133	.151	.128	.109	.099
30	.129	.169	.195	.170	.145	.133
32	.169	.213	.247	.220	.191	.175
34	.219	.266	.308	.281	.246	.228
36	.279	.329	.379	.352	.313	.292
38	.352	.403	.461	.436	.393	.368
40	.439	.491	.554	.533	.487	.459
42	.543	.594	.661	.644	.597	.567
44	.666	.714	.781	.769	.723	.692
46	.811	.854	.918	.911	.868	.838
48	.979	1.016	1.072	1.069	1.033	1.005
50	1.17	1.20	1.24	1.25	1.22	1.20
52	1.40	1.41	1.44	1.44	1.43	1.41
54	1.66	1.66	1.66	1.66	1.66	1.66
56	1.95	1.93	1.90	1.90	1.91	1.93
58	2.29	2.25	2.17	2.16	2.20	2.24
60	2.67	2.60	2.48	2.44	2.51	2.58
62	3.09	3.00	2.82	2.76	2.85	2.95
64	3.57	3.44	3.19	3.10	3.22	3.36
66	4.11	3.94	3.61	3.47	3.62	3.81
68	4.71	4.49	4.06	3.88	4.05	4.30
70	5.38	5.11	4.57	4.32	4.52	4.84
72	6.12	5.79	5.13	4.80	5.03	5.41
74	6.93	6.54	5.74	5.32	5.57	6.04
76	7.84	7.37	6.41	5.88	6.15	6.71
78	8.83	8.28	7.14	6.49	6.78	7.43
80	9.92	9.28	7.95	7.15	7.45	8.21
82	11.1	10.4	8.8	7.9	8.2	9.0
84	12.4	11.6	9.8	8.6	8.9	9.9
86	13.8	12.9	10.8	9.5	9.8	10.9
88	15.4	14.3	11.9	10.4	10.6	11.9
90	17.1	15.8	13.2	11.3	11.6	12.9

The total volume of traffic during the analysis period equals the first year traffic estimate multiplied by a growth factor:

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

Table 5 lists the Traffic Growth Factors corresponding to the analysis period based on an estimated Annual Growth Rate.

	Annual growth rate, Percent							
Design Life [years]	**No Growth**	**2**	**4**	**5**	**6**	**7**	**8**	**10**
1	1	1	1	1	1	1	1	1
2	2	2,02	2,04	2,05	2,06	2,07	2,08	2,10
3	3	3,06	3,12	3,15	3,18	3,21	3,25	3,31
4	4	4,12	4,25	4,31	4,37	4,44	4,51	4,64
5	5	5,20	5,42	5,53	5,64	5,75	5,87	6,11
6	6	6,31	6,63	6,80	6,98	7,15	7,34	7,72
7	7	7,43	7,90	8,14	8,39	8,65	8,92	9,49
8	8	8,58	9,21	9,55	9,90	10,26	10,64	11,44
9	9	9,75	10,58	11,03	11,49	11,98	12,49	13,58
10	10	10,95	12,01	12,58	13,18	13,82	14,49	15,94
11	11	12,17	13,49	14,21	14,97	15,78	16,65	18,53
12	12	13,41	15,03	15,92	16,87	17,89	18,98	21,38
13	13	14,68	16,63	17,71	18,88	20,14	21,50	24,52
14	14	15,97	18,29	19,60	21,02	22,55	24,21	27,97
15	15	17,29	20,02	21,58	23,28	25,13	27,15	31,77
16	16	18,64	21,82	23,66	25,67	27,89	30,32	35,95
17	17	20,01	23,70	25,84	28,21	30,84	33,75	40,54
18	18	21,41	25,65	28,13	30,91	34,00	37,45	45,60
19	19	22,84	27,67	30,54	33,76	37,38	41,45	51,16
20	20	24,30	29,78	33,07	36,79	41,00	45,76	57,27
25	25	32,03	41,65	47,73	54,86	63,25	73,11	98,35
30	30	40,57	56,08	66,44	79,06	94,46	113,28	164,49
35	35	49,99	73,65	90,32	111,43	138,24	172,32	271,02

Table 5 – Traffic growth factors.

To determine traffic (**w_{18}**), which will be used in the lane design, 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;

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 80 kN 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. For D_L factor, Table 6 as presented in [1] may be used as a guide.

Table 6: 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

3.3 Reliability factor

Basically, it is a means of incorporating some degree of reality (**R**) 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 7 presents recommended levels of reliability for various functional classifications as presented in [1]. For typical design without specific requirement, the suggested reliability coefficient R is 95%.

Table 7: Suggested Levels of Reliability R.

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:

$$F_R = 10^{-Z_R * S_o} \tag{5}$$

Where **Z_R** is the statistical standard normal deviate, and **S_o** is the overall statistical standard deviation that represents the combined standard error of the traffic prediction and performance one. The value of Z_R is determined by the value of R, and is obtained from standard normal curve area. S_o should be selected to represent the local conditions, the value of S_o developed at the American Association of Highway Officials (AASHTO) Road Test was 0.45 for flexible pavements. The (**W_{18}**) for the design equation (1) is determined as follows:

$$W_{18} = w_{18} * F_R \tag{6}$$

3.4 Environmental Effects

For the purpose of this technical reference, the total loss in serviceability will be assumed all due to traffic load during the analysis period.

For more details on the environmental effect on pavement performance refer to section 2.1.4, Part II in [1].

3.5 Road Serviceability Loss

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 PSI is obtained from measurements of roughness and distress (cracking, patching and rut depth) at a particular time during the service life of the pavement. Roughness is the dominant factor in estimating the PSI of a pavement. The '93 AASHTO Guide uses the total change in serviceability index (**ΔPSI**) as the serviceability design criteria which is defined as follows:

$$\Delta PSI = p_0 - p_t \qquad (7)$$

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.

Thus typically ΔPSI ranges from 2.2 to 1.8. The lower is the ΔPSI, the better are the road conditions at the end of its service life.

3.6 Effective Roadbed Soil Resilient Modulus

The basis for the subgrade soil mechanical properties characterization in the 1993 AASHTO design Guide is the soil resilient modulus (**M_R**). The resilient modulus is a measure of the elastic property of soil recognizing certain non-linear characteristics. Suitable factors are reported which can be used to estimate M_R from standard CBR values. Equations (8a) and (8b), [4] correlate between the Corps of Engineers CBR value and the in situ resilient modulus of soil:

$$M_R\ [psi] = 1500 * CBR \qquad (8a)$$

$$M_R\ [kPa] = 217.5 * CBR \qquad (8b)$$

This equation is reasonable for fine graded soil with a soaked CBR of 10 or less. For more details on 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].

4. ROAD LAYERED DESIGN ANALYSIS

The required SN determined in the previous paragraph is converted to the actual thickness of asphalt concrete, base and subbase, by means of appropriate layer coefficients representing the relative strength of the construction materials and capacity of drainage. The design equation used is as follows:

$$SN = a_1\ D_1 + a_2\ D_2\ m_2 + a_3\ D_3\ m_3 \tag{2}$$

where,

a_i	=	i^{th} layer coefficient [1/inches];
D_i	=	i^{th} layer thickness [inches];
m_i	=	i^{th} layer drainage coefficient [-]

4.1 Layer Coefficient a_i

The structural contribution of a fill material to the pavement strength is represented from its appropriate layer coefficient which measures the relative strength of the construction material. According to equation (2) the designer need to select mean values for the layer coefficients a_1, a_2, and a_3 for the asphalt, base, and sub-base layer of the pavement section respectively.

Table 8a and 8b typically give the structural contribution of fill materials. Local regulations or standard practice may suggest more accurate material factors.

For more details on determining of the layer coefficients value, refer to section 2.3.5, Part II,[1].

Table 8a: Recommended range values [1/in] for a_1, a_2, a_3 layer coefficients for different materials.

	Material		CBR	Range a_i [1/in]	
a_1	Asphalt Layer		>100	0.40 – 0.44	
	Sub Asphalt Layer		>100	0.30 – 0.40	
a_2	Well Graded Aggregate	Crushed Hard Rock	80-100	0.10 – 0.14	0.14
		Crushed Medium Hard Rock	60-80		0.13
		River Gravel Base	40-70		0.12
		Sand-Gravel Mixtures	20-50		0.11
a_3	Granular Subbase	Clean Sand	10-30	0.06 – 0.10	

Table 8b: Recommended range values [1/m] for a_1, a_2, a_3 layer coefficients for different materials.

	Material		CBR	Range a_i [1/m]	
a_1	Asphalt Layer		>100	15.74 – 17.32	
	Sub Asphalt Layer		>100	11.81 – 15.74	
a_2	Well Graded Aggregate	Crushed Hard Rock	80-100	3.93 – 5.51	5.51
		Crushed Medium Hard Rock	60-80		5.11
		River Gravel Base	40-70		4.72
		Sand-Gravel Mixtures	20-50		4.33
a_3	Granular Subbase	Clean Sand	10-30	2.36 – 3.93	

4.2 Drainage coefficient

The AASHTO method assumes that the strength of the subgrade and the base will remain fairly constant over the design life of the pavement. For this assumption to be correct, the pavement structure must be provided with proper 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 a m_i value and is integrated into the structural number (SN) as shown in Equation (2). The possible effect of drainage on the asphalt concrete surface course is not considered.

Table 9 presents a general definitions corresponding to different drainage levels as suggested in [1].

Table 9: 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 10 presents the recommended m_i values by [1] as a function of the quality drainage and the percent of time during year the pavement structure would normally be exposed to moisture level approaching saturation.

Table 10: Recommended drainage coefficient m_i values.

Quality of Drainage	**Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation**			
	Less than 1%	**between 1-5%**	**between 5-25%**	**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

5. EMPIRICAL FULL SCALE TEST: DESIGN CHARTS

The empirical results and conclusions have been obtained during an analysis of full scale pavement tests conducted on several reinforced and unreinforced paved sections where the following variables were investigated: subgrade strength (CBR), gravel base thickness, geosynthetic type, number of Equivalent Axle Loads (EAL). The testing results presented in [4] are valuable data for the safe application of both analytical and practical design approach. To verify the reinforcement capability of the geosynthetics for base reinforcement, a 210 m long road section wide was carefully constructed using laboratory procedures to obtain reliable and reproducible data for in-situ measurements and comparison between reinforced and unreinforced sections. The road section is similar to an oval ring, having rectilinear sections of 36 m and 20 m of length with 90° curves of 17 m radius as shown in figure 4. The outer edges of the curves were slightly raised giving a “parabolica” effect to faciltate the vehicle turning without deceleration.

Different in-situ CBR values for the subgrade soil were obtained to investigate several conditions (CBR=1,3,8 %).

The dimensions of the reinforcing layers were 2.2 m by 4.6 m to allow 0.2 m overlap along the road centerline and 0.3 m overlap across the road section between adjacent reinforcement layers. Up to 56 different sections were installed including reinforced and unreinforced sections, having different subgrade strengths and base thickness. The typical cross section was characterised by an excavated trench filled where the subgrade soil was installed in a thickness of at least 0.7 m having CBR of about 1%, 3%, 8%. Secondly the geosynthetic was laid and then above it the remaining portion of the road section was filled with well graded and compacted gravel. The thickness of the aggregate layer ranged between 0.30 m and 0.50 m depending upon cross section. A 75 mm thick layer of asphaltic concrete was placed on all the road section.

Up to 160 Equivalent Axle loads were applied by a vehicle running along the length of the road in clockwise direction only. The vehicle followed a well defined path given by the centerlines painted along the asphalt layer. Thus, the wheels always traveled along the same path.

The vehicle used in the tests is a standard truck having a double wheel rear axle and a single wheel front axle. The rear and the front axle are loaded with 90 kN and 45 kN respectively. The truck travels at a constant speed of 20 km/h, thus a full loop is performed in about 60 seconds.

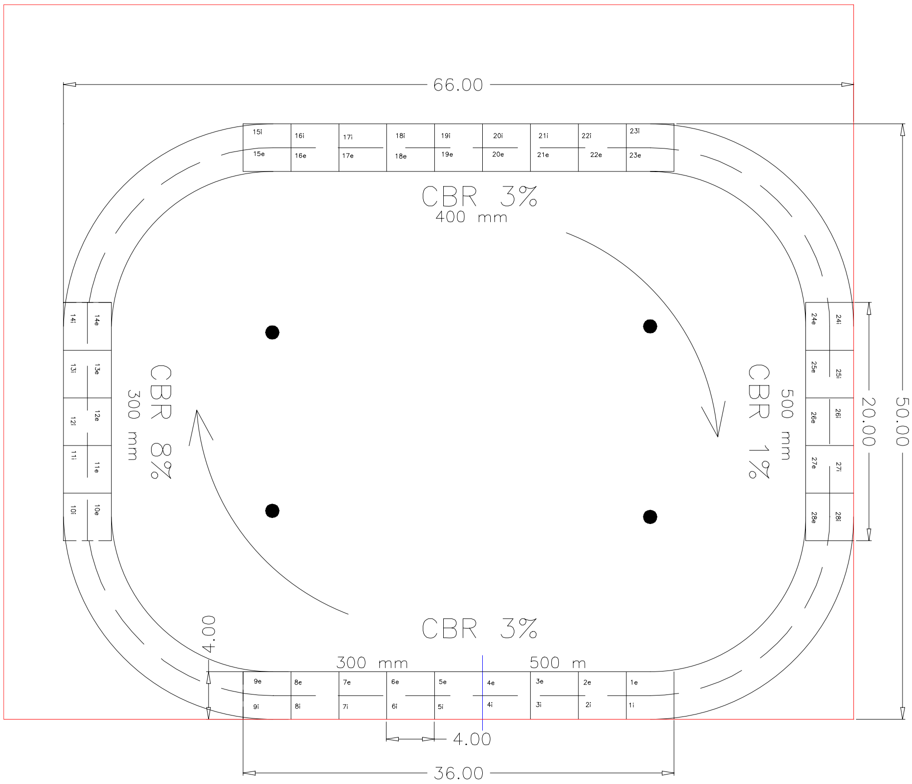

Figure 4 - Plan view of the full scale in ground test road [m].

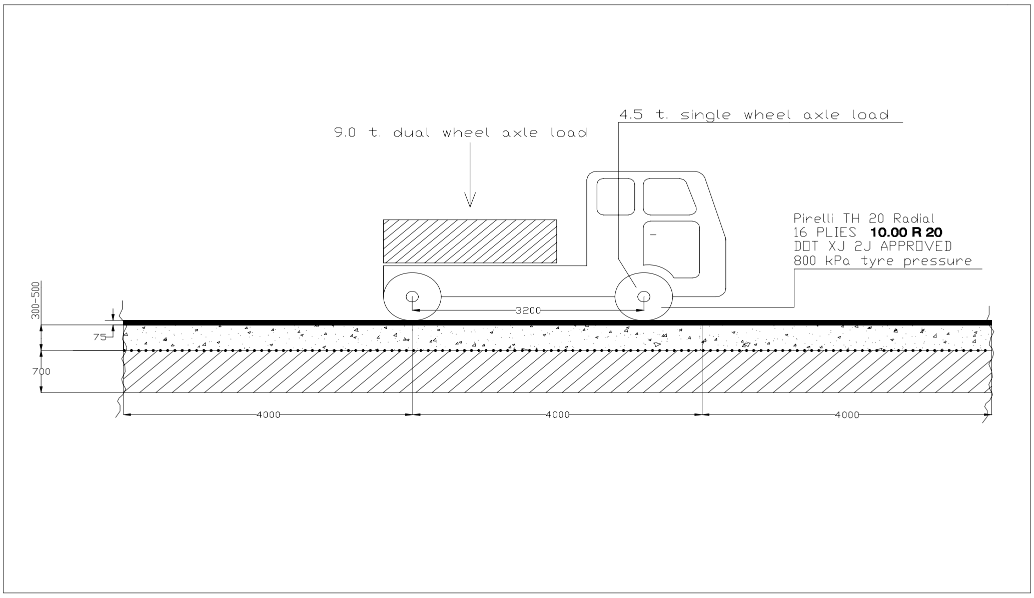

Figure 5 -Side view of the truck vehicle and longitudianl cross section [m].

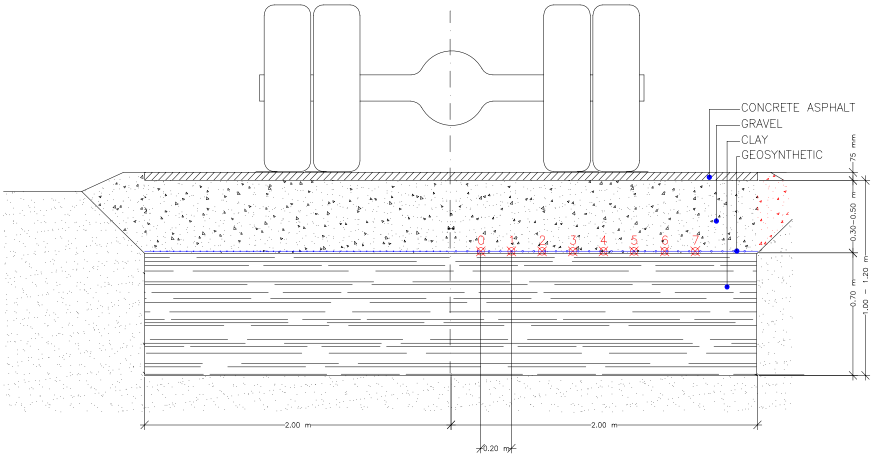

Figura 6 -Cross section of the full scale in ground test road [m]

From the results published in [4], we report the empirical test conclusions for reinforced and unreinforced sections which have suggested design charts (functions of the subgrade soil shear strength, number of cycles, allowed rut depth and layer coefficient ratio) to allow engineers to design successful reinforced flexible paved road in an accurate way.

The empiric data collected can be related and applicable only to these types of Tenax geogrids:

- Tenax LBO SAMP and Tenax MS geogrids (high strength stiff integral geogrids having high tensile modulus, junction strength and characterized by great interlock capacity).

The types of geosynthetics considered have been subdivided into two classes referring to different tensile strength:

- **type A,** with a characteristic tensile strength of 20 kN/m;
- **type B,** with a characteristic tensile strength of 30 kN/m.

The table below lists several Tenax geogrids according to the type A or B.

Type A **Characteristic Tensile strength 20 kN/m**	**Type B** **Characteristic Tensile strength 30 kN/m**
LBO 201 SAMP - LBO 202 SAMP	LBO 301 SAMP
LBO 220 SAMP	LBO 330 SAMP
MS 220	MS 330 – MS 500

Table 11 - Types of Tenax geogrids considered for reinforcing flexible paved road.

In figure 7 we list the iso-deformation curves which show the increased service life provided by the Tenax geogrids. The chart in figure 7 allows to evaluate the increase of design life (in terms of increased number of vehicles passing) which can be achieved by placing a geogrid in a given road section.

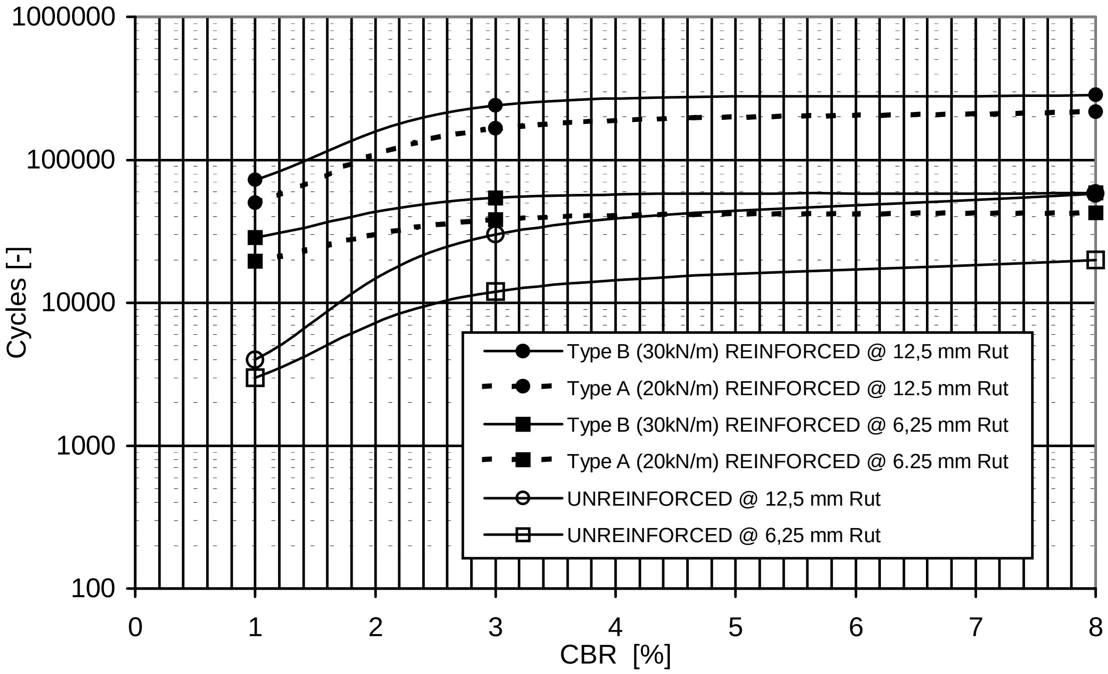

Figure 7 - CBR vs cycle number for reinforced and unreinforced sections at given rut depth.

In figure 8 we list the Traffic Improvement Ratio curves provided by the Tenax geogrids as determined from the above figure 7. The TIF (Traffic Improvement Ratio) is the ratio of the number of load cycles for the reinforced section to that of unreinforced section at a given rut depth. The TIF for longer service life greatly increases for deep allowed rut, lower CBR values and lower pavement structural number.

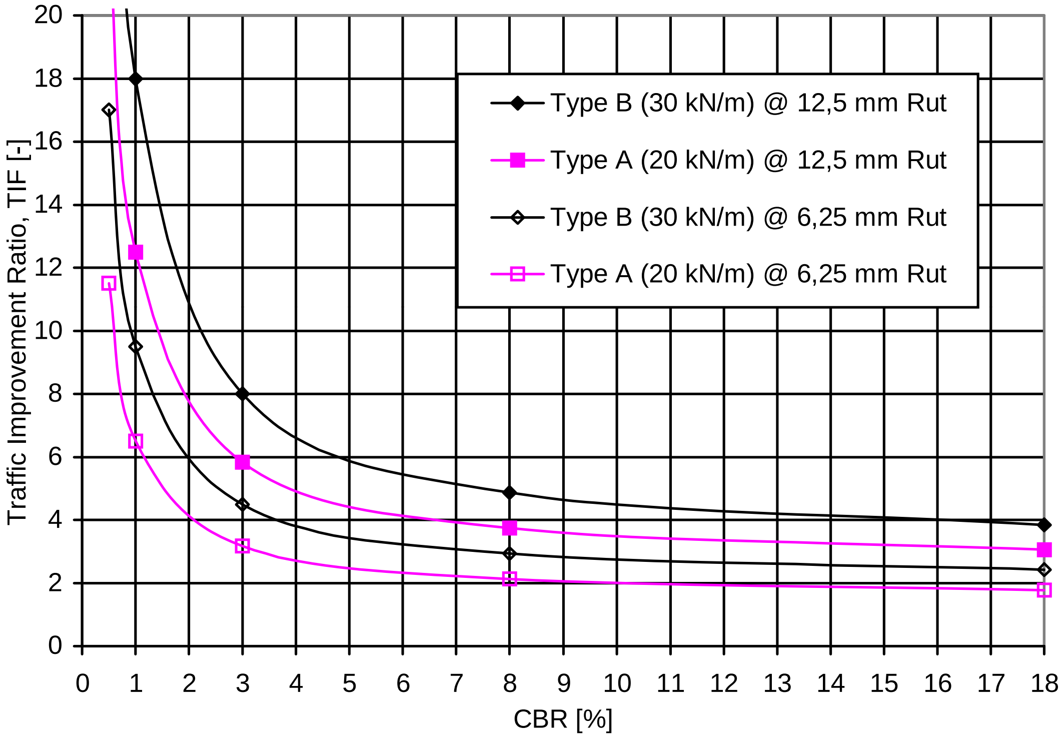

Figure 8 - Traffic improvement factor vs CBR for two rut depth.

6. AASHTO DESIGN METHOD FOR FLEXIBLE ROADS REINFORCED WITH TENAX GEOGRIDS

The structural contribution of a Tenax geogrid on a flexible pavement system can be quantified by the increase in strength of the layer coefficient of the aggregate base course. Equation (2) now becomes:

$$SN_r = a_1\ D_1 + a_2\ LCR\ D_2\ m_2 + a_3\ D_3\ m_3 \qquad (9)$$

where **LCR** is the Layer Coefficient Ratio with a value higher than one. LCR value is determined based on the results from laboratory and in ground testing on flexible pavement system with and without a Tenax geogrid, as described in [3] and [4] using Equation (10). $\mathbf{SN_r}$ (structural number of the reinforced section), and $\mathbf{SN_u}$ (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 but using different service life as shown in figure 7.

$$LCR = \frac{SN_r - SN_u}{\alpha_2 \; D_2} + 1 \qquad (10)$$

Based upon equation 10, we can derive the Layer Coefficent Ratio LCR by means of typical testing road cross section. Figure 9 presents the Layer Coefficent Ratio based on empirical pavement testing with and without a geogrid reinforcement. The Layer Coefficent Ratio was found to be between 2 to 1.5, depending mainly on the subgrade CBR, ESAL and allowable rut depth. As indicated in figure 9, the structural contribution of a geogrid reinforcement is nearly constant when the subgrade CBR value is larger than 3% while for relatively weak subgrade with CBR value equal to 1%, the structural contribution of a geogrid is significantly larger.

The reduction in aggregate base thickness can be evaluated by the use of Tenax geogrid using Equation (11) (assuming no sub-base layer):

$$D_2 = \frac{SN_r - a_1 \; D_1 \; m_2}{LCR \; a_2 \; m_2} \qquad (11)$$

or instead, the asphalt thickness can be reduced

$$D_1 = \frac{SN_r - LCR \; a_2 \; D_2 \; m_2}{a_1} \qquad (12)$$

Using the design char of figure 9 it is possible to calculate the thickness D_2 for the base course of a reinforced flexible paved road. According to the input values (D_1, a_1, D_2, a_2, m_2) of a unreinforced section it is possible to determine the SN for a reinforced section considering the CBR of the subgrade and the relative LCR value due to the design chart. Then using the equation (11) we can determine the thickness D_2 (and relative cost saving) for a reinforced flexible paved road.

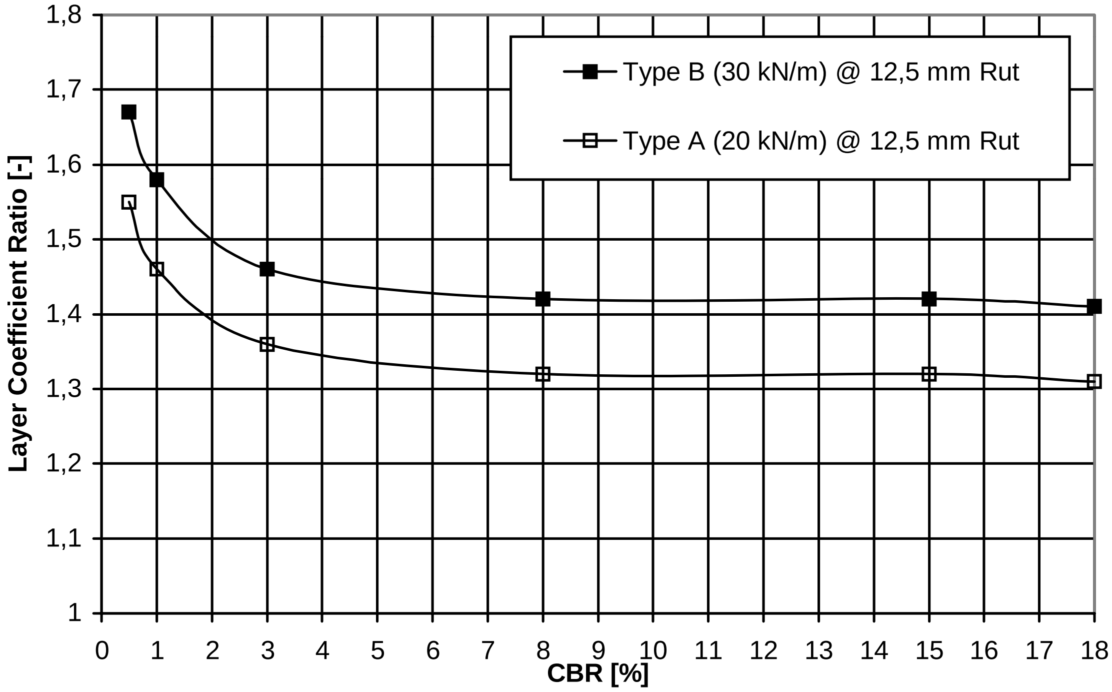

Figure 9 - Layer coefficient ratio vs subgrade CBR.

7. TNXROAD DESIGN SOFTWARE

The process of pavement design using AASHTO 93 guidelines, however, can be simplified by using the Tenax **TNXROAD** software to assist in designing pavements with and without using Tenax Geogrid.

Using the program is straight forward; as you insert the input data in the corresponding cells. By hitting the button "Calculate", the required SN, and the design section with and without using geogrid will be displayed on the output cells and in screen shots. The savings per squared meter of pavement are calculated as well based on an estimated aggregate and geogrid prices.

The software TNXROAD performs the TIF-analysis which consists to select the suitable input values for some design variables.

The input values are:

- the CBR;
- the estimated traffic load (ESAL);

- the Reliability (R);
- the Serviceability Loss (ΔPSI);
- the type of Tenax Geogrids (and consequently the value of TIF);
- thickness D_1 of the asphalt (D_3 if subbase exists);
- layer coefficients a_1, a_2 (a_3 if subbase exists);
- drainage coefficients m_2 (m_3 if subbase exists);

The output results are:

- the SN of the flexible paved road,
- the thickness D_2 of the base course for reinforced and unreinforced case;
- the value of LCR;

7.1 DESIGN EXAMPLE

A design example is reported below with a picture of the software calculation screen shot.

Design data

The follow major design inputs have been considered:

- CBR =3%;
- Total estimated traffic (ESAL) =10.000.000;
- Bi-oriented geogrid Tenax LBO 202 SAMP;
- Traffic Improvement Factor (TIF) = 5.83 (empirical value coming from laboratory and full-scale tests);
- No subbase layer is considered;
- A thickness of 5" (12.5 cm) is considered for the asphalt concrete pavement;

The calculation gives a value of 5.83 for the Structural Number of the road and the thickness of the base course can be reduced of 11.09" (28.2 cm) using the Tenax geogrid. The reinforced cross section is greatly saved of material respect the unreinforced one where the thickness of the base course is 34.18" (86.8 cm). So using the Tenax geogrids to design a flexible paved road it is possible to have an important cost saving. The effect of the presence of the geogrid is computed by the value of the LCR which is 1.48.

After the thickness base design calculation the Structural Number and the thickness D_2 of the base course for the reinforced section considering a particular Tenax Geogrid are evaluated.
Secondly it is possible to perform a Road Layered and Cost Analysis. This calculation allows to change the thickness of the section keeping the Structural Number evaluated previously to optimize the costs of material employed and of excavation. Filling the relative cost cells in the software the cost saving is automatically calculated. See the figure 11 to have a look of the screen shot of the Cost Analysis.
Otherwise assuming the same thickness for the unreinforced and reinforced base course it is possible to understand as the total traffic load (ESAL) can be increased of about 6 times using the reinforcement (in fact the TIF value is 5.83). Holding the same value for the base course, the unreinforced section can carry on 10.000.000 of passages while the reinforced section can achieve about 60.000.000 of passages. In figure 12 are shown the different equivalent solutions for reinforced and unreinforced sections when designing for cost saving by means of reduced cross section or by means of increased design life.
The two possible analysis to design correctly a reinforced flexible paved road are:

- Computing the benefit due to the Tenax geogrid in term of the reduction of the thickness of the base course, saving of granular material undercutting and cost on the design life period;
- Computing the benefit due to the Tenax geogrid in term of the increasing the design life and the total traffic load that the pavement can carry, considering the same cross section proposed for unreinforced case.

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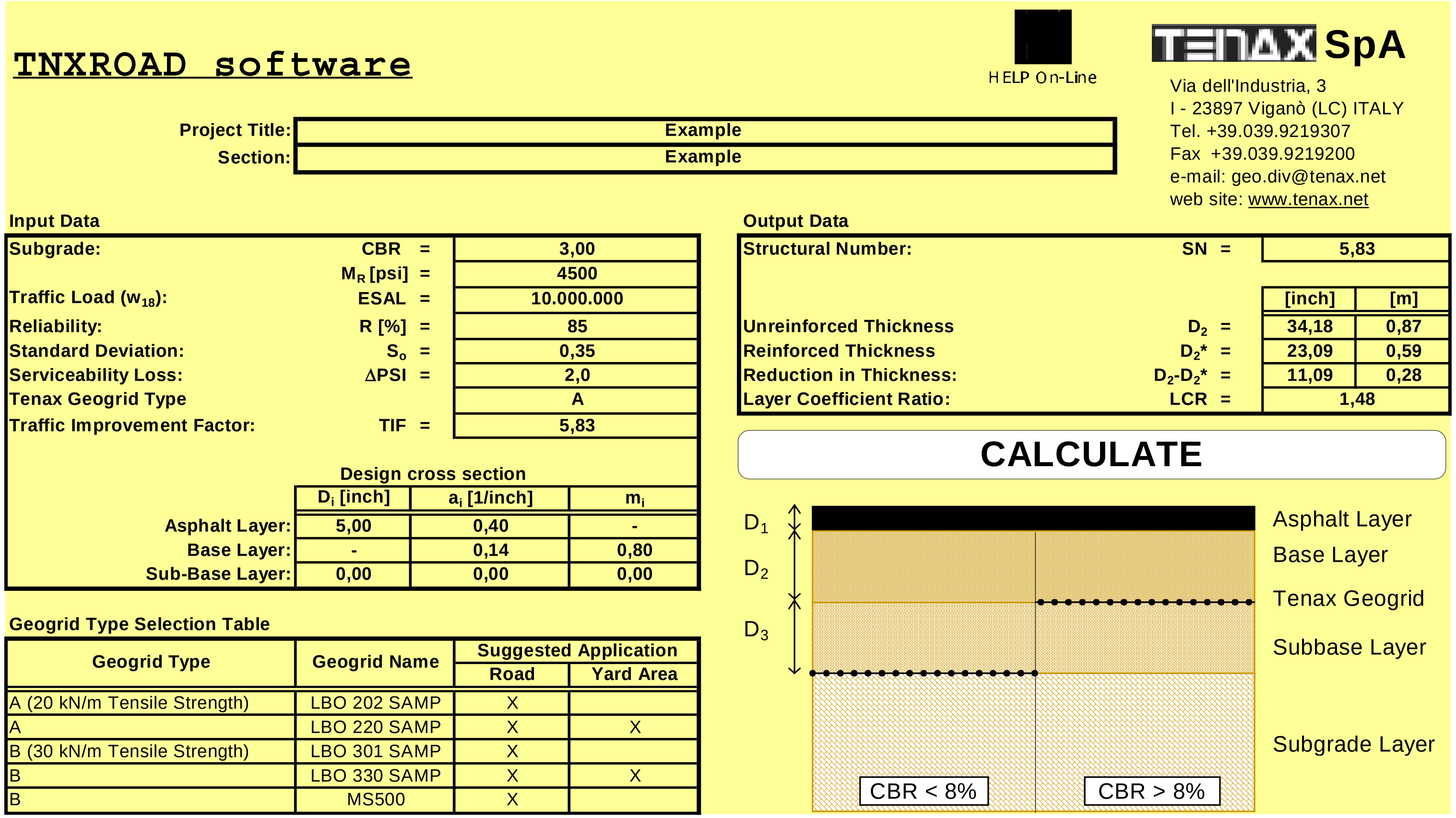

TNXROAD software

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Project Title:	Example
Section:	Example

Input Data

Subgrade:	CBR =	3,00
	M_R [psi] =	4500
Traffic Load (w_{18}):	ESAL =	10.000.000
Reliability:	R [%] =	85
Standard Deviation:	S_o =	0,35
Serviceability Loss:	ΔPSI =	2,0
Tenax Geogrid Type		A
Traffic Improvement Factor:	TIF =	5,83

Design cross section

	D_i [inch]	a_i [1/inch]	m_i
Asphalt Layer:	5,00	0,40	-
Base Layer:	-	0,14	0,80
Sub-Base Layer:	0,00	0,00	0,00

Output Data

		[inch]	[m]
Structural Number:	SN =	5,83	
Unreinforced Thickness	D_2 =	34,18	0,87
Reinforced Thickness	D_2* =	23,09	0,59
Reduction in Thickness:	D_2-D_2* =	11,09	0,28
Layer Coefficient Ratio:	LCR =	1,48	

CALCULATE

Geogrid Type Selection Table

Geogrid Type	Geogrid Name	Suggested Application: Road	Suggested Application: Yard Area
A (20 kN/m Tensile Strength)	LBO 202 SAMP	X	
A	LBO 220 SAMP	X	X
B (30 kN/m Tensile Strength)	LBO 301 SAMP	X	
B	LBO 330 SAMP	X	X
B	MS500	X	

Figure 10 - Screen shot of TNXROAD calculation.

Road Layered and Cost Analysis

Structural Number: SN = 5,83

	Layer Coeff. [1/inch]	Drainage Coeff.	Cost	Thickness D_i Reinforced Section		Thickness D_i Unreinforced Section		SN	Cost Reinforced Section	Cost Unreinforced Section	Overall Savings	
				[m]	[inch]	[m]	[inch]		$/m2	$/m2	$/m^2	%
Asphalt Layer:	0,40	-	37 $/m^3	0,10	3,94	0,100	3,94	1,58	3,70	3,70	-	-
SUB asph:	0,35	-	37 $/m^3	0,03	0,98	0,025	0,98	0,34	0,93	0,93	-	-
Base Layer:	0,14	0,80	11 $/m^3	0,60	23,59	0,887	34,92	3,91	6,60	9,76	3,16	18,1%
Sub-Base Layer:	0,00	0,00	11 $/m^3	0,00	0,00	0,000	0,00	0,00	0,00	0,00	0,00	0,0%
Excavating Cost			3 $/m^3	**0,73**	**28,51**	**1,01**	**39,84**	**5,83**	2,19	3,03	0,84	4,8%
Installed Geogrid			0,95 $/m^2						0,95	-	-	-
							Total Cost		**14,37**	**17,42**	**3,05**	**17,5%**

Figure 11 *- Screen shot of TNXROAD calculation.*

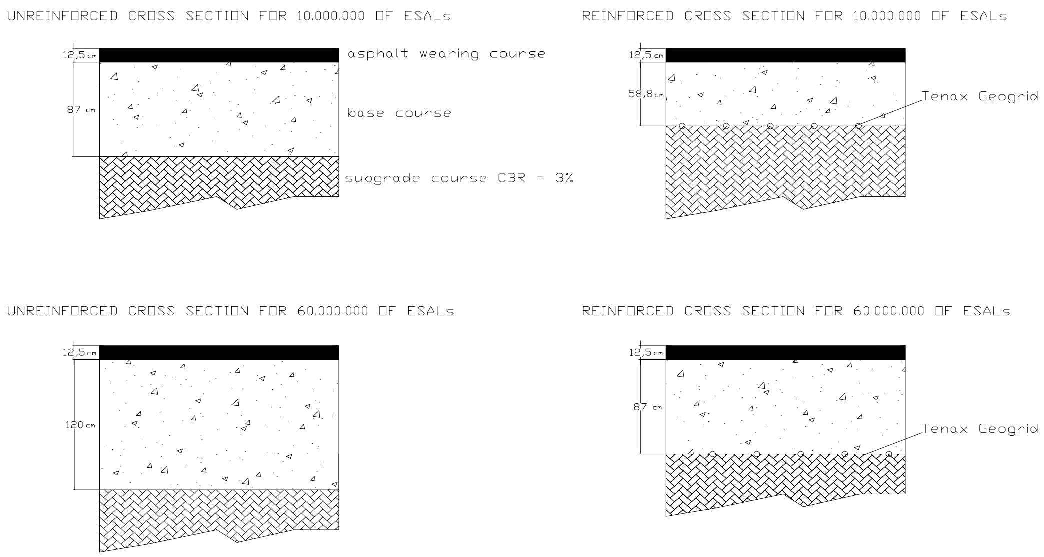

Figura 12-Comparison between unreinforced and reinforced sections.

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