Preliminary study for implementations of long lasting flexible road pavements in Romania

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Abstract: - The actual flexible pavements designed according the existing norms are leading usually to overdesigned structures because of the lower values for the elastic modulus of the asphalt materials, specified in the existing norms. After a short introduction, presenting the general principles of flexible pavements design, the concepts of long lasting flexible pavements is considered in detail. Then a new research program, involving Accelerating Loading Test-ALT undertaken in parallel with the experiments development on the existing road network, is proposed to the attention of the road policy decisions factors in this country. This research project, supported by specific design assumptions and calculations is taking into considerations the specific soil, climatic and traffic conditions of the road network in Romania. Finally a discussion of the results obtained with this new study is made.

Key-Words: - Long lasting flexible pavements, accelerating loading test - ALT, structural design, design methods, design traffic.

1 Introduction

As a new member of European Community, Romania is making significant efforts to integrate his transport infrastructure in the huge European road network. These efforts are focusing on rehabilitation and modernization of the existing road network and its development by using new modern and efficient methods for structural design in parallel with the implementation of new construction technologies. Our research is dedicated mainly to the assimilation and the development, in the specific traffic and climatic conditions of Romania characterized by very severe winters and very hot summers, of the new concept of long lasting pavements, especially for the constructions of the new roads and motorways. The actual flexible pavements designed according the existing norms [1] are usually leading to overdesigned structures because of the lower values for the elastic module of the asphalt materials specified in the existing norms. The total thickness of classical pavement structures, currently used for important motorway projects in this country, is currently reaching significant values ranging from 75 to 95 cm. In comparison with these traditional practices the long lasting flexible pavements LLFP, conceived on new principles and involving the use of high quality materials such as stone matrix asphalt SMA [2] are leading to thinner and in the same time more durable pavements. Here follows some typical example of LLFP structures envisaged to be studied on the Accelerating Testing Facility ALT-LIRA [3] existing in the frame of Technical University Gh. Asachi Iasi (see Fig.1).

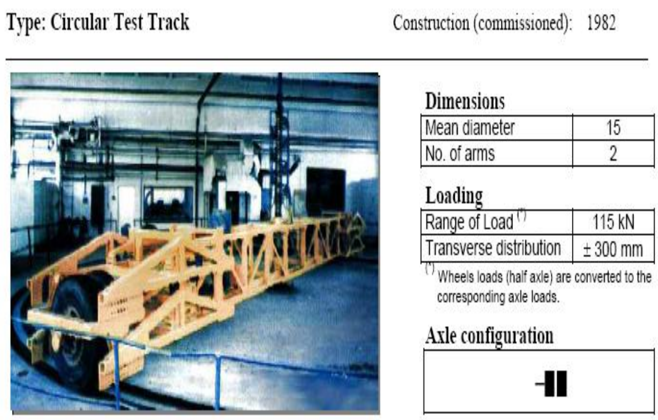

Fig.1 The ALT circular track facility of Technical University "Gh. Asachi" Iasi [3]

In order to evaluate the performance of these new long lasting flexible pavements, in comparison with the classical ones, the following experiment (see Fig.2) involving the accelerating testing of a set of six distinct pavement sectors, including three witness classical ones (sector No.1, No.3 & No.5) and other three LLFP sectors (No.2, No.4 & No.6) constructed in accordance with the new LLFP concept which is envisaged to be realized in the near future on the ALT-LIRA facility. Traffic of 10 and 60 million standard axle loads of 115kN have been considered in the design of the new

LLFP and also of the witness sector No.1, with the difference that the design life of the LLFP structures was considered of 30 years instead of 15 years, used for the traditional structure.

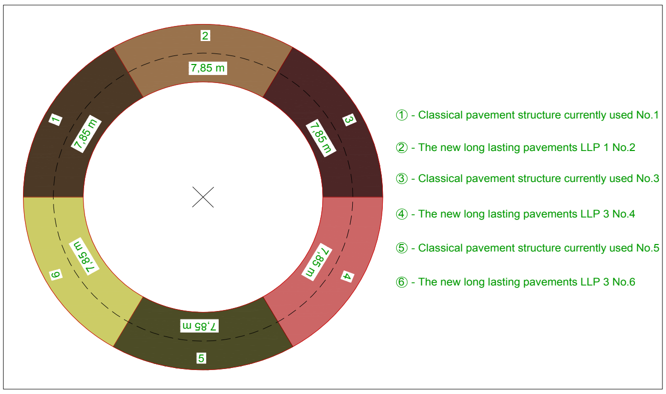

Fig.2 Experimental sectors envisaged to be tested on the ALT circular track facility

For long lasting pavements to be viable, they must perform from the perspectives of both engineering and economic consideration. Designing against structural defects, proper materials selection, good construction practices, and scheduling resurfacing activities to maintain the functionality of the pavement are the primary engineering concerns for performance [4]. Efficient design, low maintenance rehabilitation costs, and long pavement life will ensure the economy of the pavement. In accordance with long lasting pavement concept, it is necessary to periodically monitor the pavement condition to identify surface distresses and to ensure they do not further progress into the structure than the top few cm of the pavement. Thus, distresses such as top-down fatigue cracking, thermal cracking, rutting, and surface wear can be confined only to the wearing course by timely resurfacing. There are a number of case histories [4] that support the idea that thick, well-constructed asphalt pavements have distresses extending no deeper than their surfaces. The future work involves the construction of the envisaged experimental sectors on the circular track of the ALT facility of Technical University of Iasi, parallel with the construction of similar experimental sectors on a real motorway selected on the existing public road network, followed by monitoring their performances in time and the drafting of specific technical recommendations for the design and constructions of LLFP.

2 Structural design of flexible pavements

In this study two types of pavement structure have been considered, a classical one and a Long Lasting Flexible Pavement conceived according the principals mentioned above. This design study has been conducted according the Romanian norm PD 177/2001 which is based on simultaneously observance of the following criteria:

- the admissible tensile strain at the bottom of the bituminous layers;
- the admissible compression strain at the subgrade level;
- the admissible tensile strain at the bottom of the layer of natural aggregates stabilized with hydraulic or pozzolan binders

This analytical design method involves the establishing of a specific road pavement structure and verification of the loading conditions of pavement, under the design traffic and also frost verifications.

The following input data are necessary for the design:

- structure and intensity of traffic and their evolution;
- the geotechnical characteristics of the subgrade;
- the hydrological regime of the road pavement (type of cross section, the way of rainfall waters drainage, possibilities of drainage, level of ground water).

2.1 Conception and design of classical/witness ALT sectors

The experimental road sector envisaged for study was considered to be located in a climatic region type I, having cross sections in embankment with a maximum height of 1.00 m, the subgrade soil being a P5 type according [1]. In this hypothesis, and considering three categories of design traffic expressed in million standard axles (m.s.a.), namely: 10, 30 and respectively 60 m.s.a., the following pavement structures have been studied:

a) Classical pavement currently used Type 1 (Design traffic: 10 m.s.a.)

Table 1. The pavement structure selected for the design

Layer Name	h, cm	E, MPa	μ
Wearing course (MASF 16/SMA)	4	4000*	0,35*
Binder course (B.A.D. 25)	6	3500*	0,35*
Bituminous base - AB2	15	5000*	0,35*
Ballast stabilized with cement	20	1000**	0,25**
Ballast Foundation	25	156***	0,27***
Subgrade/Soil Type - P5	∞	80	0,42

Note, according [1]: * Item. 6.6; ** Item. 6.4; *** Item. 6.3;

Design program to compute stresses and strains in pavement structure – Calderom 2000

Sector 1- Input parameters:

Load.....	57.50	kN
Pressure tire	0.625	MPa
Radius circle	17.11	cm

Layer 1: Module 3695. MPa, Poisson Coeff..350, Thickness 10.0 cm
Layer 2: Module 5000. MPa, Poisson Coeff..350, Thickness 15.0 cm

Layer 3: Module 1000. MPa, Poisson Coeff..250, Thickness 20.0 cm
Layer 4: Module 192. MPa, Poisson Coeff..270, Thickness 25.0 cm
Layer 5: Module 80. MPa, Poisson Coeff..420 it is semifinit

REZULTS:

R cm	Z cm	Radial effort MPa	Radial deform. microdef	Vertical deform. microdef
.0	-25.00	.460E+00	**.690E+02**	-.906E+02
.0	25.00	.484E-01	.690E+02	-.155E+03
.0	-45.00	**.107E+00**	.882E+02	-.842E+02
.0	45.00	.119E-01	.882E+02	-.192E+03
.0	-70.00	.148E-01	.758E+02	-.114E+03
.0	70.00	.427E-03	.758E+02	**-.177E+03**

Assessment of behavior of the pavement structure under traffic loading

The admissible number loading of standard axle of 115 kN în m.s.a., $N_{adm.}$ which may be taken of the bituminouse layers, corresponding to strain condition at their bottom according [1] point 7.3.2.a is calculated with the relation (1):

$$N_{adm.} = 4,27 \times 10^{8} \times \varepsilon_{r}^{-3,97} = 21,39 \ (m.s.a.), (1)$$

Checking the RDO condition for the proposed structural design considering RDO admisibil max. 0.8 for motorways and express roads, according [1]:

$$RDO = \frac{N_c}{N_{adm.}} \rightarrow RDO(=0,48) \leq RDO_{admisibil}(=0,80), (2)$$

This conditions is satisfied.

Verifications of the horizontal tensile stress at the bottom of layer(s) of natural aggregates stabilized with hydraulic or pozzolan binders, in MPa according [1] using relations:

$$\sigma_{r\ adm.} = R_t\ (0,60 - 0,056 \times \log Nc) = 0,218, (3)$$
$$\sigma_r\ (0,107) \leq\ \sigma_{r\ adm.}\ (0,218), (4)$$

This conditions is satisfied.

Verifications of the vertical strain at the level of subgrade according [1] using relations:

$$\varepsilon_{z.adm.} = 329 \times N_c^{-0,27} = 177(micro - strains), (5)$$
$$\varepsilon_z(=177) \leq \varepsilon_{z.adm.}(=177), (6)$$

This conditions is satisfied.

As all design criteria are satisfied the following pavement structure is proposed at this stage of design:

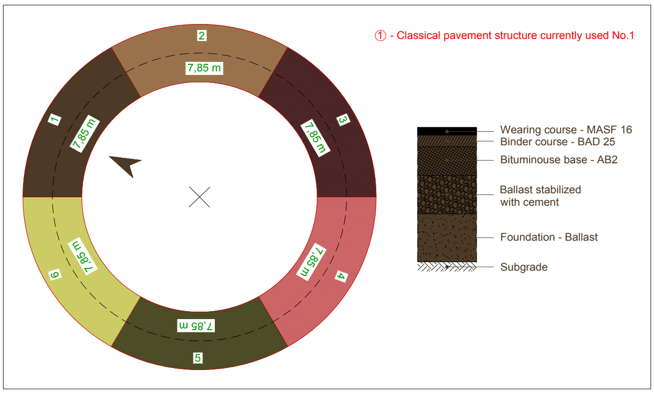

Fig.4 Proposed experimental sectors on the ALT circular track facility. Sector 1

b) Classical pavement currently used Type 3 (Design traffic: 30 m.s.a.)

Table 3. The pavement structure selected for the design

Layer Name	h, cm	E, MPa	μ
Wearing course (MASF 16/SMA)	5	4000*	0,35*
Binder course (B.A.D. 25)	10	3500*	0,35*
Bituminous base - AB2	15	5000*	0,35*
Ballast stabilized with cement	20	1000**	0,25**
Ballast Foundation	35	223***	0,27***
Subgrade/Soil Type - P5	∞	80	0,42

Note, according [1]: * Item. 6.6; ** Item. 6.4; *** Item. 6.3

Design program to compute stresses and strains in pavement structure – Calderom 2000

Sector 3 - Input parameters:

Load.....	57.50	kN
Pressure tire	0.625	MPa
Radius circle	17.11	cm

Layer 1: Module 3662. MPa, Poisson Coeff..350, Thickness 15.0 cm
Layer 2: Module 5000. MPa, Poisson Coeff..350, Thickness 15.0 cm
Layer 3: Module 1000. MPa, Poisson Coeff..250, Thickness 20.0 cm
Layer 4: Module 223. MPa, Poisson Coeff..270, Thickness 35.0 cm
Layer 5: Module 80. MPa, Poisson Coeff..420 it is semifinit

RESULTS:

R cm	Z cm	Radial effort MPa	Radial deform. microdef	Vertical deform. microdef
.0	-30.00	.371E+00	**.552E+02**	-.719E+02
.0	30.00	.403E-01	.552E+02	-.120E+03
.0	-50.00	**.782E-01**	.654E+02	-.664E+02
.0	50.00	.990E-02	.654E+02	-.146E+03
.0	-85.00	.124E-01	.526E+02	-.743E+02
.0	85.00	.123E-03	.526E+02	**-.124E+03**

Assessment of behavior of the pavement structure under traffic loading

The admissible number loading of standard axle of 115 kN în m.s.a., $N_{adm.}$ which may be taken of the bituminouse layers, corresponding to strain condition at their bottom according [1] point 7.3.2.a is calculated with the relation (7):

$$N_{adm.} = 4,27 \times 10^{8} \times \varepsilon_r^{-3,97} = 51,87 \quad (m.s.a.),(7)$$

Checking the RDO condition for the proposed structural design considering RDO admisibil max. 0.8 max 0.80 for motorways and express roads, according [1]:

$$RDO = \frac{N_c}{N_{adm.}} \rightarrow RDO(=0,58) \le RDO_{admisibil}(=0,80),(8)$$

This condition is satisfied.

Verifications of the horizontal tensile stress at the bottom of layer(s) of natural aggregates stabilized with hydraulic or pozzolan binders, in MPa according [1] using relations:

$$\sigma_{r\ adm.} = R_t\ (0,60 - 0,056 \times \log Nc)=0,207,(9)$$

$$\sigma_r\ (0,08) \le\ \sigma_{r\ adm.}\ (0,207),(10)$$

This conditions is satisfied.

Verifications of the vertical strain at the level of subgrade according [1] using relations:

$$\varepsilon_{z.adm.} = 329 \times N_c^{-0,27} = 131(micro-strains),(11)$$

$$\varepsilon_z(=124) \le \varepsilon_{z.adm.}(=131),(12)$$

This conditions is satisfied.

As all design criteria are satisfied the following pavement structure is proposed at this stage of design:

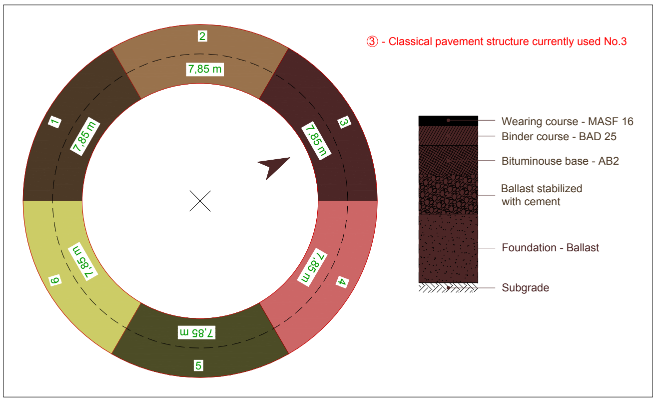

Fig.6 Proposed experimental sectors on the ALT Circular track facility. Sector 3

c) Classical pavement currently used Type 5 (Design traffic: 60 m.s.a.)

Table 5. The pavement structure selected for the design

Layer Name	h, cm	E, MPa	μ
Wearing course (MASF 16/SMA)	5	4000*	0,35*
Binder course (B.A.D. 25)	10	3500*	0,35*
Bituminous base - AB2	15	5000*	0,35*
Ballast stabilized with cement	30	1000**	0,25**
Ballast Foundation	35	223***	0,27***
Subgrade/Soil Type - P5	∞	80	0,42

Note, according [1]: * Item. 6.6; ** Item. 6.4; *** Item. 6.3

Design program to compute stresses and strains in pavement structure – Calderom 2000

Sector 5- Input parameters:

Load.....	57.50 kN
Pressure tire	0.625 MPa
Radius circle	17.11 cm

Layer 1: Module 3695.MPa, Poisson Coeff..350, Thickness 15.0 cm
Layer 2: Module 5000.MPa, Poisson Coeff..350, Thickness 15.0 cm
Layer 3: Module 1000.MPa, Poisson Coeff..250, Thickness 30.0 cm
Layer 4: Module 192.MPa, Poisson Coeff..270, Thickness 35.0 cm
Layer 5: Module 80.MPa, Poisson Coeff..420 it is semifinit

RESULTS:

R cm	Z cm	Radial effort MPa	Radial deform. microdef	Vertical deform. microdef
.0	-30.00	.323E+00	**.498E+02**	-.677E+02
.0	30.00	.290E-01	.498E+02	-.127E+03
.0	-60.00	**.609E-01**	.507E+02	-.507E+02
.0	60.00	.801E-02	.507E+02	-.110E+03
.0	-95.00	.101E-01	.430E+02	-.608E+02
.0	95.00	.772E-04	.430E+02	**-.102E+03**

Assessment of behavior of the pavement structure under traffic loading

The admissible number loading of standard axle of 115 kN în m.s.a., $N_{adm.}$ which may be taken of the bituminouse layers, corresponding to strain condition at their bottom according [1] point 7.3.2.a is calculated with the relation (13):

$$N_{adm.} = 4,27 \times 10^{8} \times \varepsilon_r^{-3,97} = \quad 78,06(m.s.a.),(13)$$

Checking the RDO condition for the proposed structural design considering RDO admisibil max. 0.8 max 0.80 for motorways and express roads, according [1]:

$$RDO = \frac{N_c}{N_{adm.}} \rightarrow RDO(=0,77) \le RDO_{admisibil}(=0,80),(14)$$

This conditions is satisfied.

Verifications of the horizontal tensile stress at the bottom of layer(s) of natural aggregates stabilized with hydraulic or pozzolan binders, in MPa according [1] using relations:

$$\sigma_{r\ adm.} = R_t\ (0,60 - 0,056 \times \log Nc) = 0,200,(15)$$

$$\sigma_r\ (0,06) \le\ \sigma_{r\ adm.}\ (0,200),(16)$$

This conditions is satisfied.

Verifications of the vertical strain at the level of subgrade according [1] using relations:

$$\varepsilon_{z.adm.} = 329 \times N_c^{-0,27} = 109(micro-strains), (17)$$

$$\varepsilon_z(=102) \le \varepsilon_{z.adm.}(=109), (18)$$

This conditions is satisfied.

As all design criteria are satisfied the following pavement structure is proposed at this stage of design:

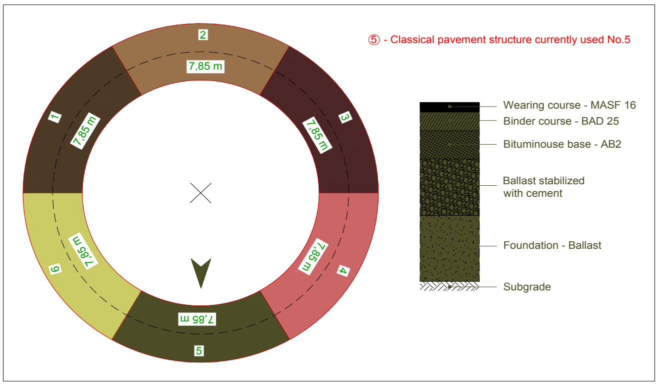

Fig.8 Proposed experimental sectors on the ALT circular track facility. Sector 5

2.2 Conception and design of Long Lasting Flexible Pavement - LLFP ALT sectors

The road sector envisaged for the study of classical pavements has been considered but the design was conducted for same three higher categories of traffic, namely: 20, 60 and respectively 120 m.s.a. The following LLFP pavement sectors have been conceived and verified according PD 177-2001 procedures:

a`) The new long lasting pavement Type LLFP – Sector 2 (design traffic: 20 m.s.a.)

Table 7. The pavement structure selected for the design

Layer Name	h, cm	E, MPa	μ
Upper (Wearing) course (MASF 16/SMA)	5	7000*	0,35*
Medium Compression Resistance course (Asphaltic Macadam)	25	6000*	0,35*
Lower Tensile Resistance course (MASF 8/SMA)	5	7000*	0,35*
Ballast Subbase	25	192***	0,27***
Subgrade/Soil Type - P5	∞	80	0,42

Note, according [1]: * Item. 6.6; ** Item. 6.4; *** Item. 6.3

Design program to compute stresses and strains in pavement structure – Calderom 2000

Sector 2- Input parameters:
Load..... 57.50 kN
Pressure tire 0.625 MPa
Radius circle 17.11 cm
Layer 1: Module 7000. MPa, Poisson Coeff..350, Thickness 5.0 cm
Layer 2: Module 6000. MPa, Poisson Coeff..350, Thickness 25.0 cm
Layer 3: Module 7000. MPa, Poisson Coeff..350, Thickness 5.0 cm
Layer 4: Module 192. MPa, Poisson Coeff..270, Thickness 25.0 cm
Layer 5: Module 80. MPa, Poisson Coeff..420 it is semifinit

RESULTS:

R cm	Z cm	Radial effort MPa	Radial deform. microdef	Vertical deform. microdef
.0	-35.00	.593E+00	**.563E+02**	-.628E+02
.0	35.00	.562E-02	.563E+02	-.145E+03
.0	-60.00	.986E-02	.541E+02	-.893E+02
.0	60.00	-.110E-02	.541E+02	**-.136E+03**

Assessment of behavior of the pavement structure under traffic loading

The admissible number loading of standard axle of 115 kN în m.s.a., $N_{adm.}$ which may be taken of the bituminouse layers, corresponding to strain condition at their bottom according [1] point 7.3.2.a is calculated with the relation (19):

$$N_{adm.} = 4,27 \times 10^8 \times \varepsilon_r^{-3,97} = 47,96(m.s.a.), (19)$$

Checking the RDO condition for the proposed structural design considering RDO admisibil max. 0.8 max 0.80 for motorways and express roads, according [1]:

$$RDO = \frac{N_c}{N_{adm.}} \rightarrow RDO(=0,42) \le RDO_{admisibil}(=0,80), (20)$$

This conditions is satisfied.

Verifications of the vertical strain at the level of subgrade according [1] using relations:

$$\varepsilon_{z.adm.} = 329 \times N_c^{-0,27} = 147(micro-strains), (21)$$

$$\varepsilon_z(=136) \le \varepsilon_{z.adm.}(=147), (22)$$

This conditions is satisfied.

As both design criteria are satisfied the following pavement structure is proposed at this stage of design:

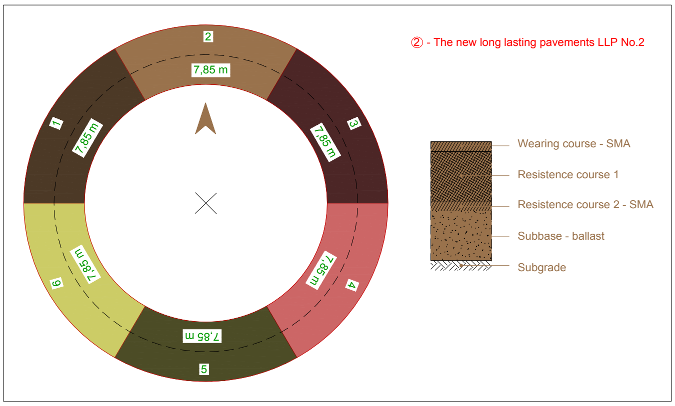

Fig. 10 Proposed experimental sectors on the ALT circular track facility. Sector 2

b') The new long lasting pavement Type LLFP – Sector 4 (design traffic: 60 m.s.a.)

Table 9. The pavement structure selected for the design

Layer Name	h, cm	E, MPa	µ
Upper (Wearing) course (MASF 16/SMA)	5	7000*	0,35*
Medium Compression Resistance course (Asphaltic Macadam)	30	6000*	0,35*
Lower Tensile Resistance course (MASF 8/SMA)	5	7000*	0,35*
Ballast Subbase	30	208***	0,27***
Subgrade/Soil Type - P5	∞	80	0,42

Note, according [1]: * Item. 6.6; ** Item. 6.4; ***; Item. 6.3;

Design program to compute stresses and strains in pavement structure – Calderom 2000

Sector 4- Input parameters:
Load..... 57.50 kN
Pressure tire 0.625 MPa
Radius circle 17.11 cm

Layer 1: Module 7000. MPa, Poisson Coeff..350, Thickness 5.0 cm
Layer 2: Module 6000. MPa, Poisson Coeff..350, Thickness 30.0 cm
Layer 3: Module 7000. MPa, Poisson Coeff..350, Thickness 5.0 cm
Layer 4: Module 192. MPa, Poisson Coeff..270, Thickness 30.0 cm
Layer 5: Module 80. MPa, Poisson Coeff..420 it is semifinit

RESULTS:

R cm	Z cm	Radial effort MPa	Radial deform. microdef	Vertical deform. microdef
.0	-40.00	.464E+00	**.441E+02**	-.493E+02
.0	40.00	.491E-02	.441E+02	-.112E+03
.0	-70.00	.836E-02	.411E+02	-.652E+02
.0	70.00	-.883E-03	.411E+02	**-.104E+03**

Assessment of behavior of the pavement structure under traffic loading

The admissible number loading of standard axle of 115 kN în m.s.a., $N_{adm.}$ which may be taken of the bituminouse layers, corresponding to strain condition at their bottom according [1] point 7.3.2.a is calculated with the relation (23):

$$N_{adm.} = 4,27 \times 10^{8} \times \varepsilon_r^{-3,97} = 126,48(m.s.a.), (23)$$

Checking the RDO condition for the proposed structural design considering RDO admisibil max. 0.8 max 0.80 for motorways and express roads, according [1]:

$$RDO = \frac{N_c}{N_{adm.}} \rightarrow RDO(=0,47) \le RDO_{admisibil}(=0,80), (24)$$

This conditions is satisfied.

Verifications of the vertical strain at the level of subgrade according [1] using relations:

$$\varepsilon_{z.adm.} = 329 \times N_c^{-0,27} = 109(micro-strains), (25)$$

$$\varepsilon_z(=104) \le \varepsilon_{z.adm.}(=109), (26)$$

This conditions is satisfied.

As both design criteria are satisfied the following pavement structure is proposed at this stage of design:

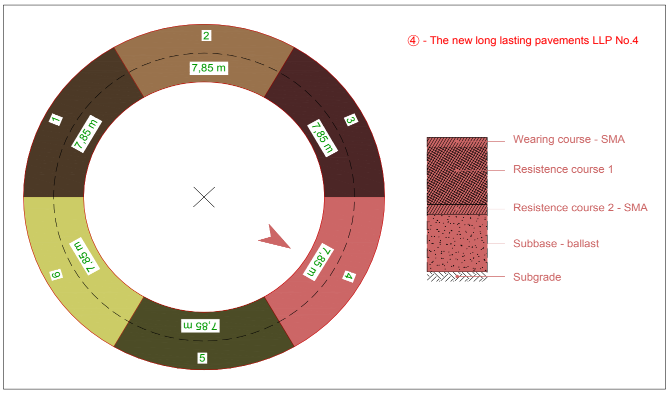

Fig. 12 Proposed experimental sectors on the ALT circular track facility. Sector 4

c') The new long lasting pavement Type LLFP - Sector 6 (design traffic: 120 m.s.a.)

Table 11. The pavement structure selected for the design

Layer Name	h, cm	E, MPa	µ
Upper (Wearing) course (MASF 16/SMA)	5	7000*	0,35*
Medium Compression Resistance course (Asphaltic Macadam)	30	6000*	0,35*
Lower Tensile Resistance course (MASF 8/SMA)	5	7000*	0,35*
Ballast Subbase	45	250***	0,27***
Subgrade/Soil Type - P5	∞	80	0,42

Note, according [1]: * Item. 6.6;** Item. 6.4; *** Item. 6.3

Design program to compute stresses and strains in pavement structure – Calderom 2000

Sector 6- Input parameters:

Load.....	57.50 kN
Pressure tire	0.625 MPa
Radius circle	17.11 cm

Layer 1: Module 7000. MPa, Poisson Coeff..350, Thickness 5.0 cm
Layer 2: Module 6000. MPa, Poisson Coeff..350, Thickness 30.0 cm
Layer 3: Module 7000. MPa, Poisson Coeff..350, Thickness 5.0 cm
Layer 4: Module 192. MPa, Poisson Coeff..270, Thickness 45.0 cm
Layer 5: Module 80. MPa, Poisson Coeff..420 it is semifinit

RESULTS:

R cm	Z cm	Radial effort MPa	Radial deform microdef	Vertical deform microdef
.0	-40.00	.436E+00	**.417E+02**	-.472E+02
.0	40.00	.503E-02	.417E+02	-.111E+03
.0	-85.00	.922E-02	.351E+02	-.502E+02
.0	85.00	-.644E-03	.351E+02	**-.879E+02**

Assessment of behavior of the pavement structure under traffic loading

The admissible number loading of standard axle of 115 kN în m.s.a., $N_{adm.}$ which may be taken of the bituminouse layers, corresponding to strain condition at their bottom according [1] point 7.3.2.a is calculated with the relation (27):

$$N_{adm.} = 4,27 \times 10^{8} \times \varepsilon_r^{-3,97} = 157,94(m.s.a.), (27)$$

Checking the RDO condition for the proposed structural design considering RDO admisibil max. 0.8 max 0.80 for motorways and express roads, according [1]:

$$RDO = \frac{N_c}{N_{adm.}} \rightarrow RDO(=0,76) \leq RDO_{admisibil}(=0,80), (28)$$

This conditions is satisfied.

Verifications of the vertical strain at the level of subgrade according [1] using relations:

$$\varepsilon_{z.adm.} = 329 \times N_c^{-0,27} = 90(micro - strains), (29)$$

$$\varepsilon_z(=87,9) \leq \varepsilon_{z.adm.}(=90), (30)$$

This conditions is satisfied.

As both design criteria are satisfied the following pavement structure is proposed at this stage of design:

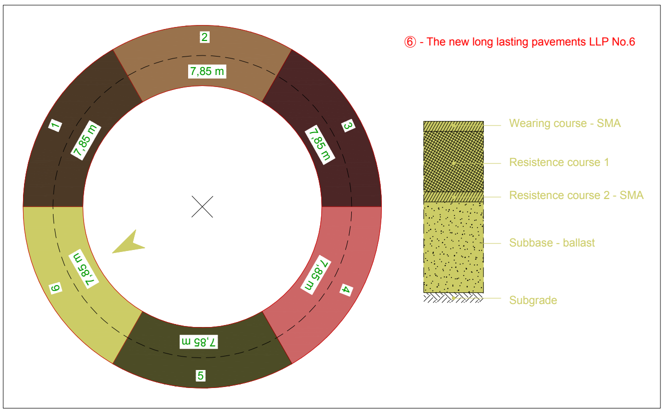

Fig. 14 Proposed experimental sectors on the ALT circular track facility. Sector 6

3 Checking the frost resistance of the Classical/LLFP pavements

a'') Frost resistance verifications for Classical – Sector 1

The pavement structure was design as wey to resist at freeze and thaw according [5],[6],[7]

- Subgrade soil type: P5
- Climatic type: I
- Hydrological regime: 1
- Level of underground water N_{af} : 300 cm
- Depth of freezing: 70 cm

Depth at frost in the new pavement:

- foundation – ballast layer: 25 cm
- Ballast stabilized with cement: 20 cm
- Bituminous base - AB2: 15 cm
- binder course type B.A.D. 25: 6 cm
- wearing course type MASF 16: 4 cm

$$Z_{cr} = Z + \Delta Z = 96\ cm, (31)$$

where:

- Z = 70 – depth freeze of subgrade (according [2] fig.1 pag.3)

$$\Delta Z = H_{SR} - H_{ech.} = 26\ cm, (32)$$

where:

- H_{SR} = thickness of pavements structure
- H_{SR} = 70 cm
- H_{ech}= equivalent thickness calculation to freeze (according [5] Chapter 2.4.)
- H_{ech}=25cmx0,70+20cmx0,65+15cmx0,50+6cmx0,60+4cmx0,50 =43,6≈44cm

Index of freeze is $I_{med}^{3/30}$ = 750 (according [5] fig.4, pag.7)

$H_{SR} < Z_{cr} < N_{af}$ $\Rightarrow$ 70 < 96 < 300 cm (hydrological conditions unfavorable, land very sensitive) $\Rightarrow$ requires verification for freeze (according [6] pag.5, tab.3)
K_{ef} = Hech/Zcr =44/96 = 0,46 > 0,40 (according [6] table 4, pag. 6) $\Rightarrow$ *the proposed pavement structure satisfied the freeze-thaw conditions.*

b'') Frost resistance verifications for LLFP - Sector 2

The pavement structure was design as way to resist at freeze and thaw according [5], [6], and [7]

- Subgrade soil type: P5
- Climatic type: I
- Hydrological regime: 1
- Level of underground water N_{af}: 300 cm
- Depth of freezing: 70 cm

Depth at frost in the new pavement:

- Upper (Wearing) course (MASF 16/SMA): 5 cm
- Medium Compression Resistance course (Asphaltic Macadam): 25 cm
- Lower Tensile Resistance course (MASF 8/SMA): 5 cm
- Ballast Subbase: 25cm

$$Z_{cr} = Z + \Delta Z = 92\ cm, (33)$$

where:

- Z = 70 – depth freeze of subgrade (according [5] fig.1 pag.3)

$$\Delta Z = H_{SR} - H_{ech.} = 22\ cm, (34)$$

where:

- H_{SR} = thickness of pavements structure
- H_{SR} = 60 cm
- H_{ech}= equivalent thickness calculation to freeze (according [5] Chapter 2.4.)
- H_{ech} =25cm x 0,70 + 5cm x 0,50 + 25cm x 0,60 + 5cm x 0,50 =37,5≈38cm

Index of freeze is $I_{med}^{3/30}$ = 750 [5]

$H_{SR} < Z_{cr} < N_{af}$ $\Rightarrow$ 60 < 92 < 300 cm (hydrological conditions unfavorable, land very sensitive) $\Rightarrow$ requires verification for freeze [6]

K_{ef} = Hech/Zcr =38/92 = 0, 41 > 0, 40 [6] $\Rightarrow$ the proposed pavement structure satisfied the freeze-thaw conditions.

c'') Frost resistance verifications for Classical - Sector 3

The pavement structure was design as wey to resist at freeze and thaw according [5],[6],[7]

- Subgrade soil type: P5
- Climatic type: I
- Hydrological regime: 1
- Level of underground water N_{af} : 300 cm
- Depth of freezing: 70 cm

Depth at frost in the new pavement:

- foundation – ballast layer: 35 cm
- Ballast stabilized with cement: 20 cm
- Bituminous base - AB2: 15 cm
- binder course type B.A.D. 25: 10 cm
- wearing course type MASF 16: 5 cm

$$Z_{cr} = Z + \Delta Z = 101\ cm, (35)$$

where:

- Z = 70 – depth freeze of subgrade (according [5] fig.1 pag.3)

$$\Delta Z = H_{SR} - H_{ech.} = 31\ cm, (36)$$

where:

- H_{SR} = thickness of pavements structure
- H_{SR} = 70 cm
- H_{ech}= equivalent thickness calculation to freeze (according [5] Chapter 2.4.)
- H_{ech}=35cmx0,7+20cmx0,65+15cmx0,50+10cmx0,60+5cmx0,50≈54cm

Index of freeze is $I_{med}^{3/30}$ = 750 (according [5] fig.4, pag.7)

$H_{SR} < Z_{cr} < N_{af}$ $\Rightarrow$ 85 < 101 < 300 cm (hydrological conditions unfavorable, land very sensitive) $\Rightarrow$ requires verification for freeze (according [6] pag.5, tab.3)

K_{ef} = Hech/Zcr =54/96 = 0,53 > 0,40 (according [6] table 4, pag. 6) $\Rightarrow$ *the proposed pavement structure satisfied the freeze-thaw conditions.*

d'') Frost resistance verifications for LLFP - Sector 4

The pavement structure was design as way to resist at freeze and thaw according [5], [6], and [7]

- Subgrade soil type: P5
- Climatic type: I
- Hydrological regime: 1
- Level of underground water N_{af} : 300 cm
- Depth of freezing: 70 cm

Depth at frost in the new pavement:

- Upper (Wearing) course (MASF 16/SMA): 5 cm
- Medium Compression Resistance course (Asphaltic Macadam): 25 cm
- Lower Tensile Resistance course (MASF 8/SMA): 5 cm
- Ballast Subbase: 25cm

$$Z_{cr} = Z + \Delta Z = 96\ cm, (37)$$

where:

- Z = 70 – depth freeze of subgrade [5]

$$\Delta Z = H_{SR} - H_{ech.} = 26\ cm, (38)$$

where:

- H_{SR} = thickness of pavements structure
- H_{SR} = 70 cm
- H_{ech}= equivalent thickness calculation to freeze [5]
- H_{ech} =30cm x 0,70 + 5cm x 0,50 + 30cm x 0,60 + 5cm x 0,50 =44cm

Index of freeze is $I_{med}^{3/30}$ = 750 [5]

$H_{SR} < Z_{cr} < N_{af}$ $\Rightarrow$ 70 < 96 < 300 cm (hydrological conditions unfavorable, land very sensitive) $\Rightarrow$ requires verification for freeze [6]

K_{ef} = Hech/Zcr =44/96 = 0, 46 > 0, 40 [6] $\Rightarrow$ the proposed pavement structure satisfied the freeze-thaw conditions.

e’’) Frost resistance verifications for Classical - Sector 5

The pavement structure was design as wey to resist at freeze and thaw according [5],[6],[7]

- Subgrade soil type: P5
- Climatic type: I
- Hydrological regime: 1
- Level of underground water N_{af} : 300 cm
- Depth of freezing: 70 cm

Depth at frost in the new pavement:

- foundation – ballast layer: 35 cm
- Ballast stabilized with cement: 30 cm
- Bituminous base - AB2: 15 cm
- binder course type B.A.D. 25: 10 cm
- wearing course type MASF 16: 5 cm

$$Z_{cr} = Z + \Delta Z = 105\ cm, (39)$$

where:

- Z = 70 – depth freeze of subgrade (according [5] fig.1 pag.3)

$$\Delta Z = H_{SR} - H_{ech.} = 35\ cm, (40)$$

where:

- H_{SR} = thickness of pavements structure
- H_{SR} = 70 cm
- H_{ech}= equivalent thickness calculation to freeze (according [5] Chapter 2.4.)
- H_{ech}=35cmx0,7+30cmx0,65+15cmx0,50+10cm x0,60+5cmx0,50 =60cm

Index of freeze is $I_{med}^{3/30}$ = 750 (according [5] fig.4, pag.7)

$H_{SR} < Z_{cr} < N_{af}$ $\Rightarrow$ 95 < 105 < 300 cm (hydrological conditions unfavorable, land very sensitive) $\Rightarrow$ requires verification for freeze (according [6] pag.5, tab.3)

K_{ef} = Hech/Zcr =60/105 = 0,57 > 0,40 (according [6] table 4, pag. 6) $\Rightarrow$ *the proposed pavement structure satisfied the freeze-thaw conditions.*

f’’) Frost resistance verifications for LLFP - Sector 6

The pavement structure was design as way to resist at freeze and thaw according [5], [6], and [7]

- Subgrade soil type: P5
- Climatic type: I
- Hydrological regime: 1
- Level of underground water N_{af} : 300 cm
- Depth of freezing: 70 cm

Depth at frost in the new pavement:

- Upper (Wearing) course (MASF 16/SMA): 5 cm
- Medium Compression Resistance course (Asphaltic Macadam): 25 cm
- Lower Tensile Resistance course (MASF 8/SMA): 5 cm
- Ballast Subbase: 25cm

$$Z_{cr} = Z + \Delta Z = 100\ cm, (41)$$

where:

- Z = 70 – depth freeze of subgrade (according [5] fig.1 pag.3)

$$\Delta Z = H_{SR} - H_{ech.} = 30\ cm, (42)$$

where:

- H_{SR} = thickness of pavements structure
- H_{SR} = 85 cm
- H_{ech}= equivalent thickness calculation to freeze (according [5] Chapter 2.4.)
- H_{ech} =45cm x 0,7+5cm x 0,50 + 30cm x 0,60 + 5cm x 0,50 =54,5≈55cm

Index of freeze is $I_{med}^{3/30}$ = 750 (according [5] fig.4, pag.7)

$H_{SR} < Z_{cr} < N_{af}$ $\Rightarrow$ 85 < 100 < 300 cm (hydrological conditions unfavorable, land very sensitive) $\Rightarrow$ requires verification for freeze (according [6] pag.5, tab.3)

K_{ef} = Hech/Zcr =55/100 = 0, 55 > 0, 40 (according [6] table 4, peg. 6) ⇒ the proposed pavement structure satisfied the freeze-thaw conditions.

4 Conclusions

The final synthetic results of the comparative study of both classical and LLFP pavements are presented in Table 13:

Table 13. The final synthetic results of the comparative study of both classical and LLFP pavements

Classical pavement structure				**Long lasting pavement structure**			
Layer	Design Traffic			Layer	Design Traffic		
	10 msa	30 msa	60 msa		20 msa	60 msa	120 msa
Wearing course (MASF 16/SMA)	*4*	*5*	*5*	Upper (Wearing) course (MASF 16/SMA)	*5*	*5*	*5*
Binder course (B.A.D. 25)	*6*	*10*	*10*	Medium Compression Resistance course (Asphaltic Macadam)	*25*	*30*	*30*
Bituminous base - AB2	*15*	*15*	*15*	Lower Tensile Resistance course (MASF 8/SMA)	*5*	*5*	*5*
Ballast stabilized with cement	*20*	*20*	*30*	Ballast Subbase	*25*	*30*	*45*
Foundation	*25*	*35*	*35*	Subgrade/Soil Type P5	∞	∞	∞
Subgrade P5	∞	∞	∞				
Total thickness (cm)	**70**	**75**	**95**	***Total thickness (cm)***	**60**	**70**	**85**

In relation with the results presented in Table 7 the following conclusions could be discussed:

1. By using asphalt materials with higher elasticity modulus value (e.g. E=6000…7000 MPa), and disposing them according the LLFP concept, it is possible to construct flexible pavement structures with total thicknesses lower than those of classical/witness ones, but capable to support considerable higher design traffics.
2. These new structures proved also to be frost resistant when checked according the Romanian standards [5], [6], [7].
3. This research exercise will be extended in the near future, by considering a parallel design approach using the actual Romanian norm and the new methods, specially developed in the frame of the Asphalt Pavement Alliance [4] and also some other modern structural design methods, like Mechanistic-Empiric Pavement Design Guide –ME-PDG [8] or the actual UK Highway Agency method.

5 Future work

Based on existing knowledge[9],[10] and latest developments in this field [11],[12],[13], the future work intends the construction of the envisaged experimental sectors on the circular track of the ALT facility of Technical University of Iasi, parallel with the construction of similar experimental sectors, selected on the existing public road network, followed by monitoring their performances in time and the drafting of specific technical recommendations for the design and constructions of LLFP.

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