Climatic and ecological aspects of structural design of Long Lasting Rigid Pavements – LLRP for demonstration projects located in different European regions

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Abstract: - This work was part of the EU collaborative research project EcoLanes, funded under the priority thematic area of Sustainable Surface Transport in the 6-th Framework Program of the European Community, which aims to contribute to the development of the concept of Long Lasting Rigid Pavements- LLRP. The envisaged LLRP structures have been tested on the accelerating testing facility ALT - LIRA from Technical University "Gh. Asachi" of Iasi, at a number of 1.5 mil. passes of the equivalent standard axel load ESAL of 115 KN, during years 2008-2009. In the same time demonstration projects were envisaged to be carried out during and after completion of the project, in order to validate and to implement the research results in different European climates and economies in the following countries: Cyprus, Romania, Turkey and United Kingdom. After a succinct presentation of the ALT test including 6 experimental sectors, these paper, presents the specific climatic and ecological features of structural design of Long Lasting Rigid Pavements – LLRP for these demonstration projects, located in different European climatic regions.

1 Introduction

This work was part of the EU collaborative project EcoLanes [1,2,3,4,5] funded under the priority thematic area of Sustainable Surface Transport in the 6-th Framework Program of the European Community, which aimed to develop Long Lasting Rigid Pavements- LLRP. The main objective of this project was the development of pavement infrastructure for surface transport using conventional and roller compaction technology in combination with concrete mixes reinforced with steel fibers, recovered from post-consumed tires, seeking significant benefits expressed in terms of reduction of time, costs and energy consumption in road construction. In parallel with specific accelerated load testing undertaken on the ALT facility from Technical University"Gh. Asachi" of Iasi, full scale demonstration projects ware envisaged to be carried out during and after completion of the project, in order to validate and to implement the research results in four different European climates and economies in the following countries: Cyprus, Romania, Turkey and United Kingdom. This paper presents the specific features of structural design of Long Lasting Rigid Pavements – LLRP for these demonstration projects.

2 The accelerated load testing facility ALT- LIRA from Technical University "Gh. Asachi" of Iasi and the typical LLRP pavement structure investigated

The new testing system used the tank in which has been realized the road complex for the tests, from the previous generation (Fig.1) but using a new loading system imposed by the introduction in Romania of the new Standard Axle Load- SAL of 115 KN.

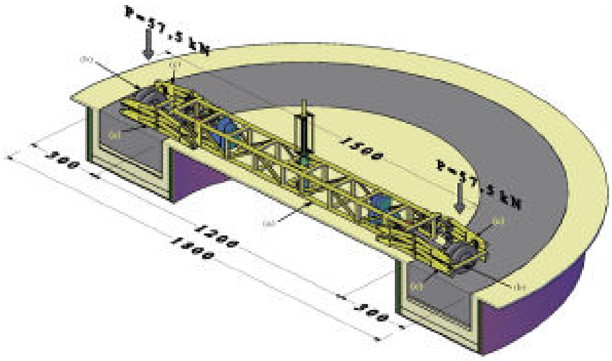

Fig. 1. Testing system

Figure 2. The loading system

The new systems have the follow technical characteristics:

- Axle load , P = 115 kN;
- Wheel velocity, V = 20…40 km/h;
- Circulated lane width : 0.65 m(the same trace), 0.87 m (alternating);
- Track width, 3.00,
- Controlled hydrological conditions

Two types of steel fiber reinforced concrete have been envisaged to be used for the ALT experiment in the frame of the EcoLanes project:

- (SFRC) steel fiber reinforced concrete, compacted by vibration;
- (SFRCC) steel fiber roller compacted concrete, compacted by rolling.

In order to assess the effect of fibers on the concrete pavements compacted by vibration, a number of four types of pavement structures have been proposed to be constructed on the ALT facility, in relation with Figure 5, as follows :

- sector 1 - unreinforced concrete BcR 4.5, d_{max}=25 mm, l=6 m;
- sector 2 - SFRC, with 3% of SRSF fibers (ADRIA type), d_{max}=16 mm, l=6 m;
- sector 3 - SFRC, with 3% of SRSF fibers (ADRIA type), d_{max}=16 mm, l=8 m;
- sector 4 - SFRC, with 3% of SRSF fibers (ADRIA type), d_{max}=16 mm, l=10.5 m.

As shown in *Figure 5* all these sectors are provided with concrete slabs of 20 cm thickness, placed on a sub-base made of cement stabilized ballast (h = 15 cm) laid over a ballast foundation layer having the same thickness. Thus, it will be possible to make the comparison of performance between the unreinforced slab (sector1) and the SFRC one, as well as between the SFRC sectors having slabs of different lengths (6m, 8m & 10.5m), by studying the stresses developing in the slabs, using periodical measurements realized with specific transducers placed at the bottom of slabs.

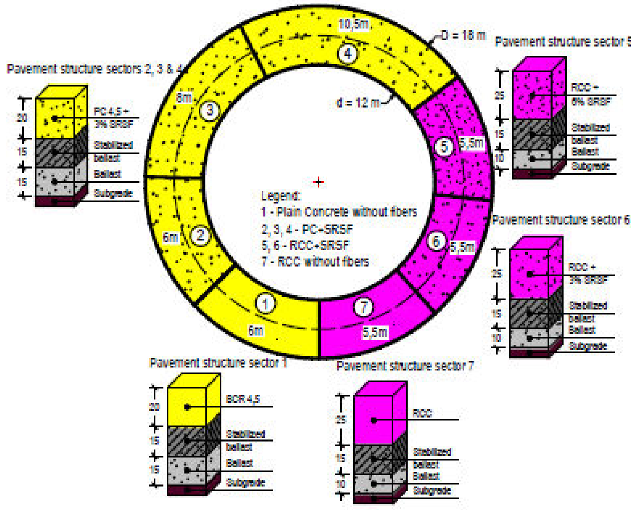

Fig. 3. Experimental sectors constructed on the circular ALT facility and their pavement structures [1]

Thus, in relation with Figure 3 , there have been constructed three sectors (sectors 5, 6 & 7) having the same length of 5.5m, but realized with concrete prepared with different percentage of fibers (6% of fibers, 3% of fibers & without fibers).Also, being envisaged that traffic loads will apply directly on the surface of the RCC, in order to keep for the riding surface the same level on the whole ALT circular track, the initial thickness of RCC slabs of 20 cm has been increased to 25 cm. The RCC slabs are placed on a sub-base made of cement stabilized ballast (h=15 cm), supported by a ballast foundation (h=10 cm), the total thickness of pavement structures on the ALT track being the same (50 cm).

All this sectors have been subjected to a total 1.5 mil. passes of 115 KN EASL, deformation and stresses at various levels in pavement structures been monitored by specific stress and strain transducers placed as shown in Figure 4.

In order to record the deformations occurring in concrete slabs and the pressures induced by traffic on subgrade, the experimental sectors have been equipped with 28 Pavement Strain Transducers for Portland Cement Concrete, model: PAST 2-PCC (14

for longitudinal displacements &14 for transversal displacements) and 3 Soil Pressure Transducers, model :SOPT 68A.
The three pressure cells are used to measure the vertical pressure produced on the subgrade level by half of the Standard Axle Load applied on a double wheel. They have been placed in the foundation layer on the sectors 2, 3 and 4 (PC 4.5 + 3% SRSF) before the execution of the ballast layer. For their placement it was necessary to create in the foundation layer, a space having the shape and the dimensions of the transducer. The connection cable has been placed in a channel with the dimensions 2cm×2cm, its slopes being protected by a thin wet sand layer.

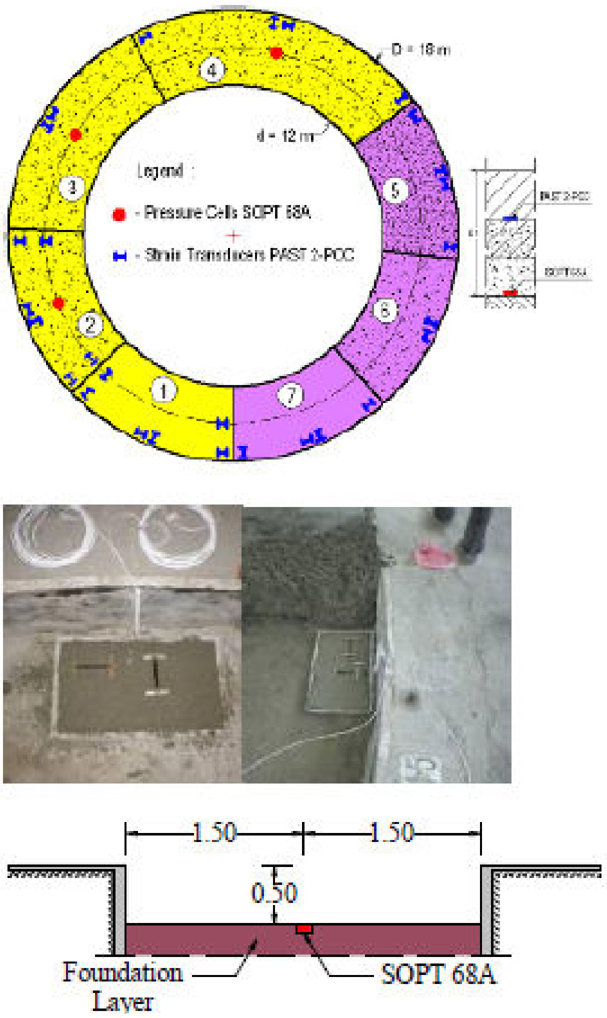

Fig. 4. Placement of the transducers on the experimental sectors [12]

The strain gauges (PAST 2-PCC) used for measuring of the longitudinal and transversal deformations at the base of the concrete slabs have been placed on the stabilized ballast layer. Before their placement it was built a supporting layer, of 2 cm thickness, made from the same material as that used for the construction of the slabs and having the horizontal dimensions of 25cm×40cm. The longitudinal and transversal distance from the edge of the slabs was of 15cm. The connection cables have been protected by plastic tubes (Fig. 5).
For the measurement of the longitudinal and transversal deformations are used the same type of transducers. The result of the measurement depends on the position of the transducer's web with respect to the axis of the circular track. The transducers with the web parallel with the runway's axis measures the longitudinal deformations, while the transducers with the web perpendicular to the runway's axis measures the transverse deformations.

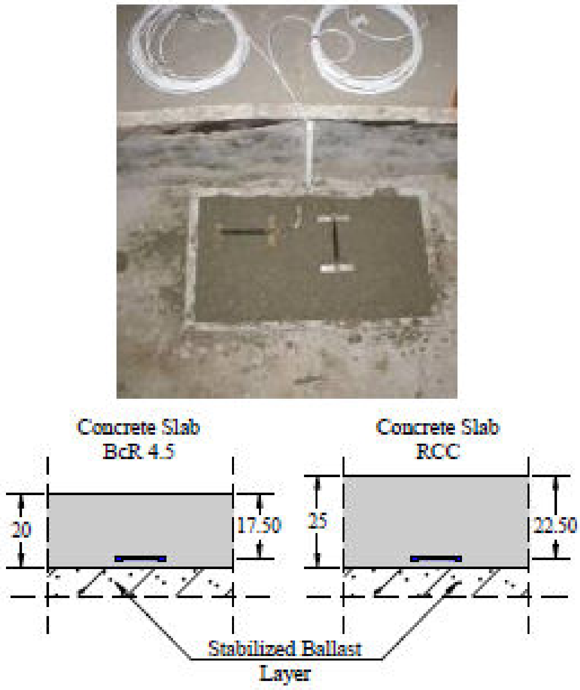

Fig. 5 Placement of the strain gauges PAST 2-PCC in the cement concrete layer

Deformations and pressures under static loading

In Fig. 6 and Fig. 7 are presented the results obtained after the processing of the records from the static and dynamic loading applied on the corresponding measuring points.

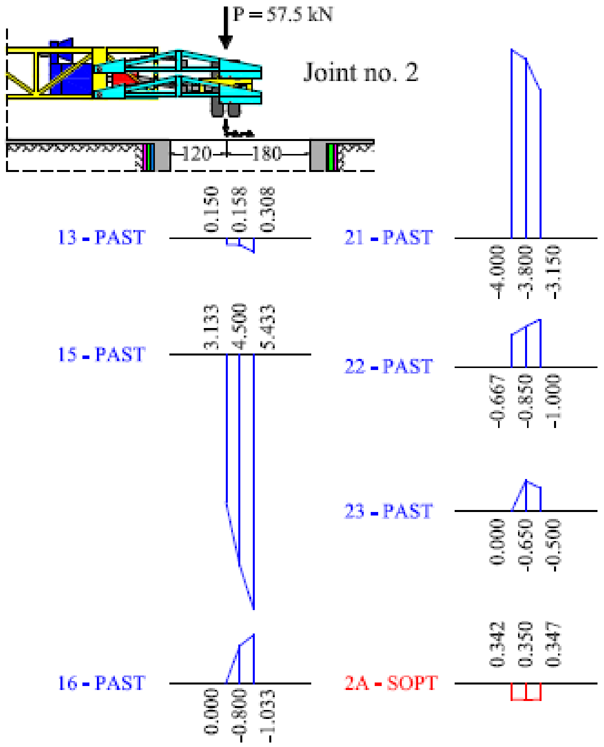

Fig. 6 Deformations and pressures at 0 passes stage under static loading

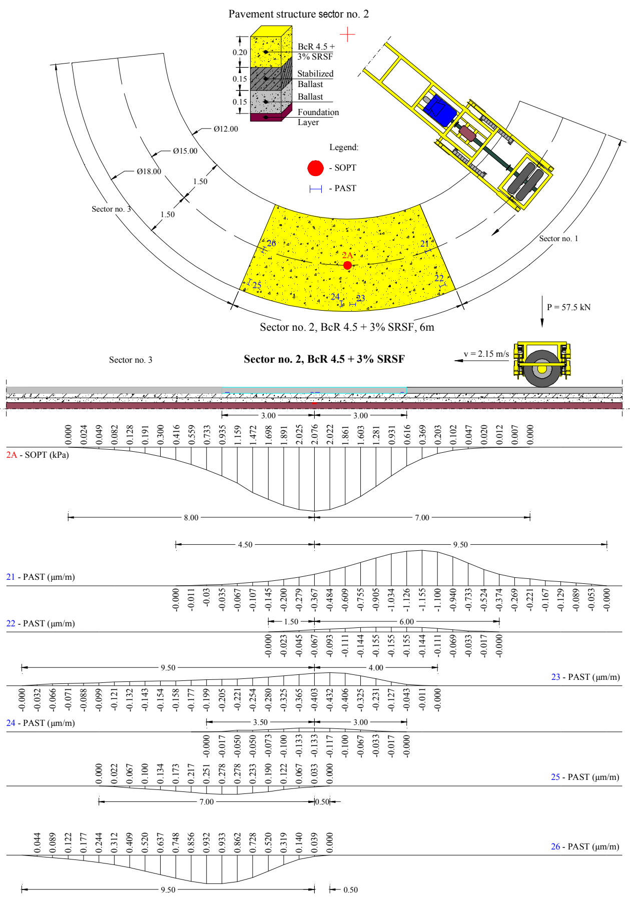

Fig. 7 Deformations and pressures at 0 passes stage under dynamic loading

3 Demonstration projects

3.1 Demonstration project in Eastern European Environment : Iasi, ROMANIA

3.1.1 Selection of demonstration project

The Romanian demonstration project was been carried out by the Regional Roads and Bridges Directorate, in its quality of part of Consortium and end user.

A part of National Road DN17 (E 576) Suceava – Vatra Dornei, namely the road sector from Km 217+00 to 218+00 (Fig. 8 and Fig.9) which were under rehabilitation process, has been selected as a demonstration project on the bases of the EcoLanes requirements.

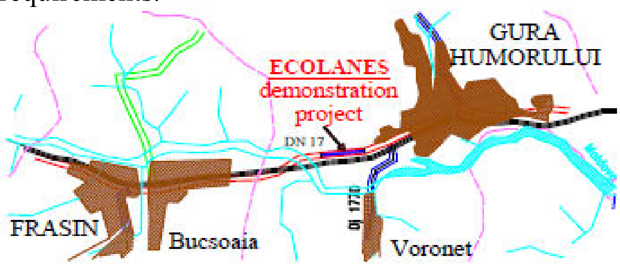

Fig.8 Location of the demonstration sector of National Road 17 [6]

Fig.9 General view of the existing road sector selected for demonstration project[6]

3.1.2 Aspects of structural design for the Romanian EcoLanes demonstration project

The design study has been conducted in concordance with the recommendations of the Romanian Standard NP 081 – 2002 [7], the main stages of the rigid pavement design being as follows:

- Establishing the design traffic;
- Establishing the bearing capacity of the foundation soil;
- Conceiving the rigid pavement structure;
- Establishing the bearing capacity at the level of the base course;
- Determining the thickness of the surface

course.

3.1.2.1 Establishing the design traffic

The traffic calculation has been done using the standard recommendations. Preliminary studies have been undertaken in order to obtain relevant data concerning the composition, intensity and evolution of traffic, and also for the geotechnical characteristics of the foundation soil and the hydrologic regime on the site in accordance with the distribution of the climatic types (Fig. 10).

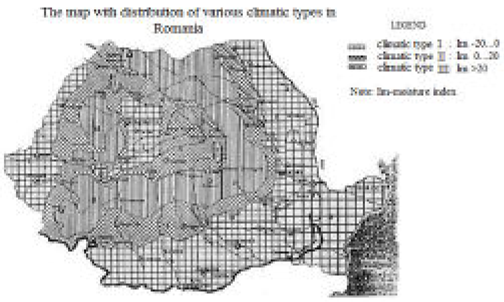

Fig. 10 Distribution of climatic types in Romania [7]

The design traffic, N_c, expressed in millions of standard axles (m.o.s.) of 115 KN, is established based on the average annual daily traffic (AADT) presented in Table 1, for a perspective period, p_p of 30 years and a coefficient transversal distribution for the lanes c_{rt} of 0,50.

Table. 1 Traffic data for the demonstration project

Vehicle type	MZA(AADT) (millions standard axles)	p_k	f_{ek}	$MZA_k \cdot p_k \cdot f_{ek}$
Two axle trucks	358	2.68	0.30	288
Three and for axle trucks	224	1.83	3.80	1558
Articulated vehicle	296	1.74	2.90	1494
Buses	81	2.30	1.50	279
Farm tractors	11	2.04	0.20	4
Road trains	46	1.48	1.60	109
Total o.s= $\sum_{k=1}^{6} MZA_k \cdot p_k \cdot f_{ek}$ =				3732

p_k - coefficient of evolution (Growth factor)

f_{ek} - equivalence coefficient(ESAL factor)

According the standard provisions the design traffic is calculated with the relation (1) as follows:

$$N_c = 365 \cdot 10^{-6} \cdot p_p \cdot c_{rt} \cdot \sum_{k=1}^{6} MZA_k \cdot p_k \cdot f_{ek} \quad (m.o.s) \quad (1)$$

Nc = 365 x 10^{-6} x 30 x 0.50 x 3732 = 20.43 m.s.a.

In accordance with the previous studies [8] for the demonstration project it was envisaged to use the following pavement of structures.

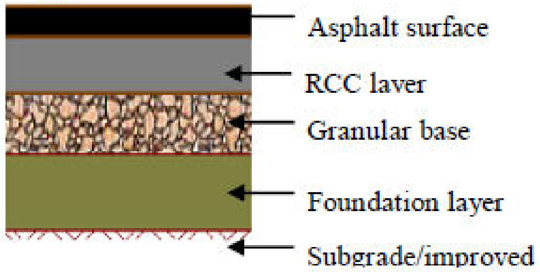

Fig .11 Pavement system asphalt surface course on RCC base and granular subbase [8]

3.1.2.2 Establishing the bearing capacity of the foundation soil

The coefficient of subgrade reaction, K0, is determined function of the climate, hydrologic regime, and type of soil, as given in the table below:

Table 2. Coefficient of subgrade reaction values $\mathbf{K_0}$ **[3]**

Climate Type	Hydrologic Regime	Soil Type P1	P2	P3	P4	P5
I	1			46	50	50
	2a					48
	2b		53		46	46
II	1			44	50	50
	2a	56				46
	2b		50		46	
III	1		53		39	50
	2a			42		
	2b		50		37	44

Note : The hydrological regime is distributed as follows:

- hydrological regime 1, corresponding to the FAVORABLE conditions , according STAS1709 / 2;
- hydrological regime 2, corresponding to the MEDIUM and UNFAVORABLE hydrological conditions, according the Romanian STAS 1709 / 2, as follows :
  - **2 a**: for embankment road sectors, with minimum height of 1.00 m;
  - **2 b**: for sectors of road located:
    - in the mound with the height of beneath 1.00 m;
    - at the ground height;
    - at the mixed profile;
    - in cutting.

In accordance with Tab. 2 based on the following parameters: type of soil: P3; climatic type: III and hydrological regime 2b, the value of the coefficient of sub-grade reaction is $\mathbf{K_0}$**=42 MN/m³.**

3.1.2.3 Conceiving the rigid pavement structure

The type of the rigid pavement structure selected is presented in Fig. 12 where a ballast foundation layer of 30 cm thicknese has been adopted according Standard recommendations.

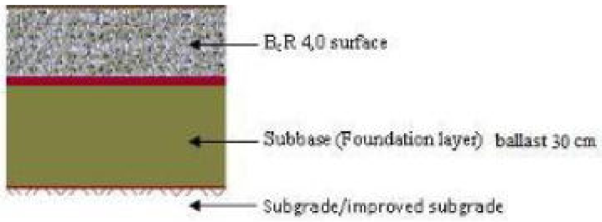

Fig. 12 The pavement structure selected for the Romanian demonstration project

3.1.2.4 Establishing the bearing capacity at the level of the sub-base

The bearing capacity at the level of the subbase, expressed by the coefficient of reaction at the surface of the subbase K, is determined function of the follow parameters:

- the coefficient of subgrade reaction K0;
- the equivalent thickness of the base/sub-base courses, Hech, representing the sum of the equivalent thicknesses of these layers, given by the following relationship:

$$H_{ech} = \sum_{i=1}^{n} h_i \times a_i \qquad (cm) \qquad (2)$$

where:

n – number of layers;

h_i – the actual thickness of the layer "i", in cm;

a_i – equivalence coefficient for the layer "i"

$H_{ech} = 25 \cdot 0,75 = 18,75 \ cm$

For the soil type **P_3**, **climate type: III** and **hydrologic regime: 2b**, the coefficient of reaction at the surface of the subbase: **K=58 MN/m^3**.

3.1.2.5 Determining the thickness of the concrete slab

The design criterion is expressed as follows:

$$\sigma \le \sigma_{t,adm} \qquad (3)$$

where:

σ – the tensile stress from bending in the concrete slab, determined in various design hypothesis;

$\sigma_{t,adm}$ – the allowable tensile stress from bending.

The allowable tensile stress from bending ($\sigma_{t,adm}$) is determined by using the relationship:

$$\sigma_{tadm} = R^k_{inc.} \text{ x } \alpha \text{ x } (0.70 - \gamma \text{ x } \log N_C) \qquad (4)$$

σ_{tadm} = 5.0 x 1.1 x (0,70 – 0.05 x log 20.43)=3.48MPa

where:

R^k_{inc} – the characteristic bending strength of the concrete at 28 days;

α – the coefficient of the increasing concrete strength in the interval 28-90 days, equal to 1,1;

N_c – the traffic for the design period;

γ – coefficient equal to 0.05;

The design hypotheses are:

1. $\sigma = \sigma_t + 0.8 \times \sigma_{t\Delta t} \le \sigma_{t,adm}$, for roads of technical class I and II roads;
2. $\sigma = \sigma_t + 0.8 \times 0.65 \times \sigma_{t\Delta t} \le \sigma_{t,adm}$, for roads of technical class III and IV roads;
3. $\sigma = \sigma_t \le \sigma_{t,adm}$, for road of technical class V roads.

Finally in the design hypothesis number 2 and using the design diagram from Fig.13 for roads of technical class III, the modulus of subbase reaction K= 58 MN and the allowable flexural stress σ_{tadm}=3,48 MPa a slab thickness Hsb=22cm has resulted.

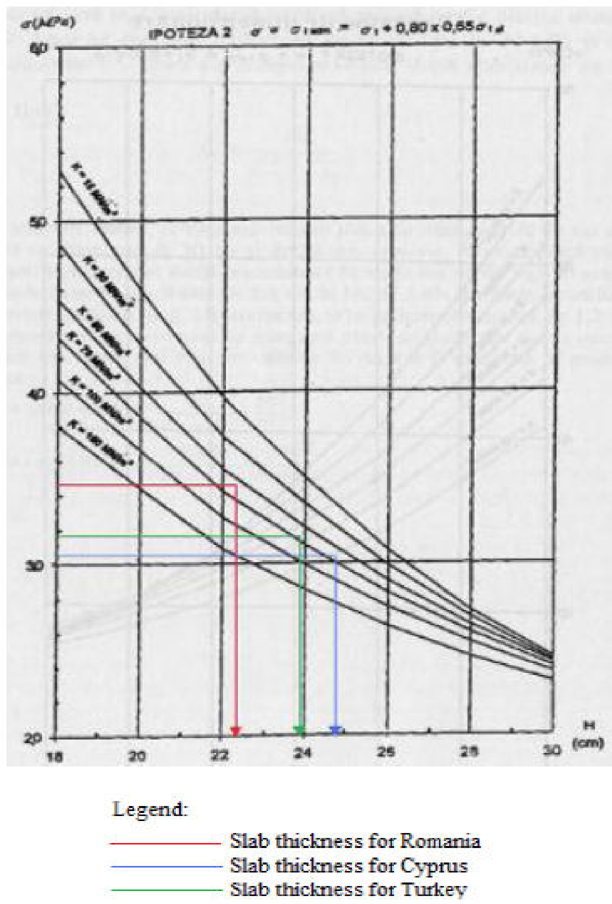

Fig. 13 Design chart [7]

3.1.2.6 Checking the resistance of the pavement to the freeze and thaw, according Romanian standards

Romania has a continental climate and its public road network is suspected to very severe winter and hot summers, consequently it was considered necessary to verify the designed pavement to the specific frost action.

Checking the road structure to the frost action considered in determining the degree of assurance (K) to the penetration of frost in pavement. This parameter is determined function of the following conditions:

- Subgrade soil type: P3
- Climatic type: III
- Hydrological regime: 2b
- Depth of freezing: 110 cm
- foundation ballast layer: 30 cm
- concrete slab BcR 4,0: 22cm

This degree of assurance (K) to the penetration of frost in pavement was finally compared with the allowable minim value for Kmin according the technical norms.

$$Z_{cr} = Z + \Delta Z = 132.6 \ \ cm \quad (5)$$

where:

Z = 110 – depth of frost of subgrade

$$\Delta Z = H_{SR} - H_{ech.} = 22.6 \ \ cm \ (6)$$

where:

H_{SR} = thickness of pavements structure

H_{SR} = 52 cm

H_{ech}= equivalent thickness calculation to frost

H_{ech} = 22 x0.45+30x0.65≈30 cm

Frost index is $I_{med}^{3/30}$ = 750

$$K = \frac{H_e}{Z_{crt}} = \frac{30}{133} = 0.22 < K_{\min} = 0.25 \ (7)$$

Because this condition is not satisfied was necessary to take specific measures recommended by Romanian standard STAS 1709/2-90 [11] to prevent degradation of pavement by freeze-thaw as follows:

- enforcement of embankments provided to obtain the highest level of groundwater layer to be below its critical depth and the depth of frost in pavement;

- prevision of collection and disposal surface waters with ditches, culverts, discharge channels;

- waterproofing shoulders, ditches or gutters.

3.2 Demonstration project in Eastern Mediterrenean Environment: Paphos, CYPRUS

3.2.1 Selection of demonstration project

The demonstration project of Cyprus was envisaged to be carried out by the Public Works Department (Fig. 14).

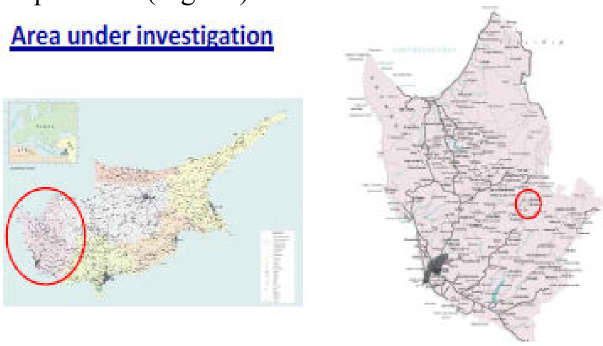

Fig. 14 Micro-Environment of the demonstration project [9]

The area where the demonstration project is situated is hilly to mountainous terrain with an altitude of 740 m above the sea level (Fig.15).

Fig. 15 The section of the road sector choice for demonstration project[9]

3.2.2 Aspects of structural design for Cyprus EcoLanes demonstration project

3.2.2.1 Traffic data

The traffic calculation has been done based on the data made available by the Cyprus representative and using the recommendations of Romanian Standard NP 081–2002 “Technical recommendation for structural design of rigid road pavements”[7].

Table. 3 Traffic data for the current design

Vehicle type	MZA(AADT) (millions standard axles)	p_k	f_{ek}	$MZA_k \cdot p_k \cdot f_{ek}$
Two axle trucks	40	2.68	0.3	32
Three and for axle trucks	25	1.83	3.8	174
Articulated vehicle	-	-	2.9	-
Buses	12	2.30	1.5	41
Farm tractors	-	-	0.2	-
Road trains	-	-	1.6	-

$$\text{Total o.s} = \sum_{k=1}^{6} MZA_k \cdot p_k \cdot f_{ek} = 247$$

The input data are defined accordingly, and the design traffic has been established as follows:
$N_c = 365 \times 10^{-6} \times 30 \times 0.5 \times 247 = 1.35$ (m.o.s.)

3.2.2.2 Determining the thickness of the sub-base course.

According to standard recommendation [7], the minimum thickness of the subbase layer must be of 25 cm (Fig 15).

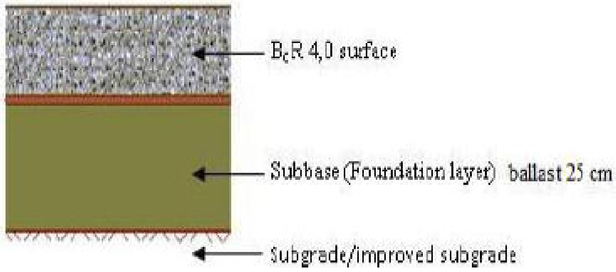

Fig. 15 The pavement structure selected for Cyprus demonstration project

Proceeding in a way similar with that used for the Romanian demonstration project, for the following input parameters: the coefficient of subgrade reaction K_0=46 (soil type P_5, climate type II and hydrologic regime 2b), and H_{ech} = 18.75 a modulus of subbase **K = 58 MN/ m^3** has been obtained.

The laboratory tests results undertaken in Cyprus reveal a flexural strength R^K_{inc} = 4.0 Mpa. The allowable tensile stress from bending for the SFRC slab ($\sigma_{t,adm}$) resulted as follows:
σ_{tadm}= 4.0 x 1.1 x (0,70 – 0.05 x log 1.35)=3.05MPa

In the design hypothesis number 2 design diagram (Fig.10) for roads of technical class III introducing the modulus of subbase reaction K= 58 MN and the allowable flexural stress σ_{tadm}=3,05 MPa a slab thickness Hsb=24cm has been obtained.

3.3 Demonstration project in Eastern Mediterranean Environment: Antalya TURKEY

In accordance with the existing statistics [6] the road network of Turkey has a total length of 63 156 Km includes the following categories of roads:

- Motorways : (2.9 %), State Highways: (49.7%), Local Highways : (47.4 %)

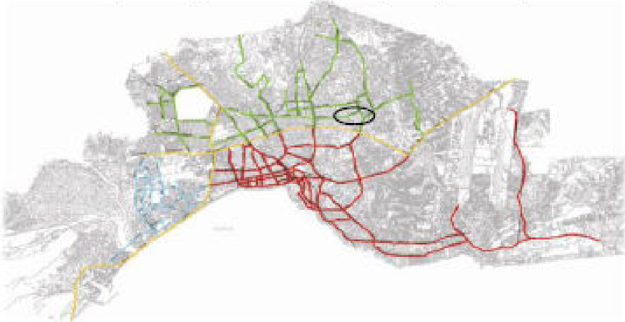

Fig. 16 The location of the demonstration project on the road network of Turkey[10]

3.3.1 Selection of demonstration project

The demonstration project has been selected in the city of Antalya on the Necip Fazil street between Km 1+215and Km 1+800(Fig. 17).

Fig. 17 The location of the demonstration project on the road network of Turkey[10]

Fig.18 View of chosen demonstration sector [10]

The Antalya climate which is located 40m higher than the sea level, is a Mediterranean one characterized by hot and dry in summers, mild and rainy in winters.

3.3.2 Aspects of structural design for Turkey EcoLanes demonstration project

3.3.2.1 Traffic data

The traffic calculation has been done based on the data provided by the Turkish representation and by using the recommendations of Romanian Standard NP 081–2002 "Technical recommendation for structural design of rigid road pavements"[7].

Table. 4 Traffic data for the current design

Vehicle type	MZA(AADT) (millions standard axles)	p_k	f_{ek}	$MZA_k \cdot p_k \cdot f_{ek}$
Two axle trucks	72	2.68	0.3	58
Three and for axle trucks	181	1.83	3.8	1259
Articulated vehicle	73	1.74	2.9	368
Buses	214	2.30	1.5	738
Farm tractors	36	2.04	0.2	15
Road trains	123	1.48	1.6	291

$$\text{Total o.s}=\sum_{k=1}^{6} MZA_k \cdot p_k \cdot f_{ek} = 2728$$

The design traffic N_c related according recomendations resulted as follows:
$N_c=365 \times 10^{-6} \times 30 \times 0.5 \times 2728=14.93$ (m.o.s.)

2.3.2.2 Determining the thickness of the surface course.

According to the standard recommendations a subbase layer of 20 cm and a base course of 10 cm as shown in Fig 14.

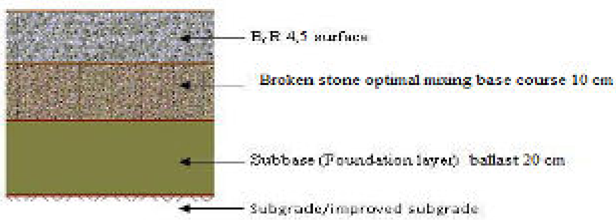

Fig. 14 The pavement structure selected for Turkey demonstration project

Proceeding in a similar way with that used for the Romanian demonstration project, for the input parameters: the coefficient of subgrade reaction K_0=46 (soil type P_5, climate type II and hydrologic regime 2b), and H_{ech} = 25, a modulus of subbase **K = 65 MN/ m³** has been obtained.

The laboratory tests results performed in Antalya laboratories revealed a flexural strength R^K_{inc} = 4.5 Mpa.

The allowable tensile stress from bending for the SFRC slab ($\sigma_{t,adm}$) resulted as follows:

σ_{tadm}= 4.5 x 1.1 x (0.70 – 0.05 x log 4.93)=3.17MPa

Finally in the design hypothesis number 2, by using the design diagram Fig.10 for roads of technical class III introducing the modulus of subbase reaction K= 65 MN and allowable flexural stress σ_{tadm}=3,17 MPa,a slab thickness Hsb=23cm has been obtained.

4 CONCLUSIONS

Considering the highest record value of pressure at the subgrade level and the maximum specific deformation from tension at the base of the concrete slabs after 1,5 million of ESAL 115 KN passes, there was not recorded significant fatigue of the investigated rigid pavement structure from the ALT circular track. The new LLRP pavements are demonstrating a better performance in comparison with the classical pavement.

Concerning the performance of the LLRP pavements applied on the various demonstration projects one may observe the synthetic results related with the various structural design aspects (design traffic, climate type, strength of concrete at 28 days, thickness of the concrete slab) as shown in Table 5.

Table 5 Design parameters for various demonstration projects

	Romania	Cyprus	Turkey
Design traffic (m.o.s)	20.43	1.35	14.93
Climate type	III	II	II
Modulus of subgrade reaction K_0	42	46	46
Modulus of subbase reaction K	58	58	65
Strength of the concrete at 28 days R^k_{inc}	5.0	4.0	4.5
Flexural strength σ_{tadm}	3.48	3.05	3.17
Thickness of the concrete slab	22	24	23

On may concluded that despite of the variability observed in traffic and climatic conditions for various demonstration projects, the thickness of the slabs are very similar, but their behaviors are expected to be different taking in to consideration the significant differences in environmental and traffic on.

The monitoring of all this demonstration projects will continues for a period of 10 to 15 years in order to evaluate their performances in various climatic and traffic conditions specific to each country.

References:

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