Comparative analysis of the response of the road structure with full/partial interlayer connection to traffic action

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Abstract. This article investigates the response of the road pavement of a road sector analysed to the action of traffic that was determined numerically by using two dedicated software. In this respect, the Romanian program CALDEROM 2000 (PD 177, 2001), respectively the French program for calculating the road pavements ALIZÉ-LCPC were used. Both programs use the Burminster elastic model for the analytical evaluation of stress states and specific deformations in multilayer road pavements. However, unlike the CALDEROM 2000 program, the ALIZÉ-LCPC software allows the user to define the interfaces between layers and switch loads from single axle to multiple loads, being a rational method, based on the determination of the resilient stresses and deformations in road structures by using the classical linear elastic multilayer model. The aim of this study was to determine whether the road pavement with deficiencies of adhesion between layers is able to take over the calculated traffic considered in the project, possibly the proportion of calculation traffic that can be taken over, which would allow an assessment of the capable operation life of the road pavement and, implicitly, of the possibility of its yielding before the end of the perspective period considered.

1 Introduction

Several different kinds of bituminous and granular materials are used to build the road. Numerous studies using numerical and experimental tests have shown the significance of interlayer adhesion in terms of the durability of the road structure [1]. The "delamination" of layers during the course of the road structure's service life could be caused by a poor link between layers. The partial bond between layers can be attributed to, according the RILEM 206-ATB technical committee's report from [2] and [3]:

- weather conditions at the time of applying the road structure layers. The difference of temperature between the top and lower layers;
- contamination: the top of the bottom layer being covered in oil and dust from milling or traffic, which might weaken the link between layers [3,4];

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- water infiltration between layers; water infiltration into the road structure due to cracks and fissures in the asphalt pavement leads to decreased interlayer skid resistance compared to skid resistance beneath dry conditions [5,6];
- the lack of a bituminous emulsion [7].

The above-mentioned issues are not the only causes that can lead to partial adhesion between layers of the road structure, many other factors (individually or in combination) could contribute to this phenomenon [8].

Traditionally, bituminous emulsion is used to bond the layers together. The sort and volume of bitumen emulsion utilized affect the bond's strength.

The emulsion's ideal residual bitumen content ranges from 250 to 500 g/m^2 [9,10]. The bond strength declines as residual bitumen content is reduced. On the other hand, if the dosage exceeds the limitations given, the extra emulsion results in layer slippage, which reduces the strength [11,12].

The present study investigates the importance of the linkage between the layers of the road structure by analysing the response of the road structure on a road section under study to traffic action which was determined numerically using two dedicated software packages CALDEROM 2000 and ALIZÉ-LCPC. In this study, two dimensioning hypotheses were considered using the two numerical programs: the hypothesis of perfectly linked layers and the hypothesis of semi-linked layers. The hypothesis of semi-bonded layers was analysed only with the Alizé software, the Calderom 2000 software did not have this possibility to modify the interface between layers.

2 Case study

2.1 Initial Dates

The road sector analyzed is a motorway sector in Romania with climate type I, hydrological regime 2a, and foundation soil type P5. Table 1 shows the layers of the road structure of the investigated motorway sector, namely the deformability characteristics of the asphalt mixtures and the foundation layers, E (dynamic modulus of elasticity) and μ (Poisson's ratio), according to the Romanian norm PD 177 [13].

Because in the Romanian dimensioning software, Calderom 2000, only 5 layers can be introduced (including the foundation soil), it was necessary to assimilate the wearing course and the binder course and to obtain an equivalent dynamic modulus of elasticity (E_{ech}).

Table 1. Pavement subject to design.

Pavement	h (cm)	E (MPa)	μ (-)	h (cm)	E_{ech} (MPa)
Wearing course: MAS 16	4	3300	0.35	10	3419
Binder course: BAD 25	6	3500	0.35		
Base course: AB 25	10	5000	0.35		
Natural aggregates stabilized with hydraulic binders	22	1000	0.25		
Gravel	30	300	0.27		
Capping layer stabilized with hydraulic binders	15	122	0.27		

2.2 Calderom 2000 and Alizé design results - perfectly bound layers' hypothesis

The analysis of the road complex at standard axle stress involves the calculation of specific deformations and stresses at critical points of the road complex, characterized by a maximum stress.

The load considered in both Calderom 2000 and Alizé software is the standard 115 kN axle, which has the following characteristics:

- load on twin wheels: 57.5 kN;
- contact pressure: 0.625 MPa;
- radius of circular area equivalent to the tyre-to-road contact area: 0.171 m.

The following verification steps were considered in the design:

- verification of the structure in terms of vertical specific strain (ε_r) at the base of bituminous layers;
- verification of the structure in terms of horizontal tensile stress (σ_r) at the base of the layer made of natural aggregates stabilised with hydraulic binder;
- verification of the structure in terms of vertical specific compressive strain (ε_z) at the formation level.

The calculation traffic (Nc) for this section of motorway was obtained based on the annual average daily traffic structure at the census posts, the value being 10.70 m.s.a. (million standard axles).

Design results using Calderom 2000 software are shown in Table 2 and design results using Alizé software are shown in Fig. 1 and Table 3.

Table 2. Results from Calderom. Bonded layers.

Calculation trafic	Nc (m.s.a.)	10.70
Radial deformation at the base of bituminous layers	ε_r (microdef.)	75.80
Vertical specific compressive strain at the foundation ground level	ε_z (microdef.)	164.00
Horizontal tensile stress at the base of natural aggregate layers stabilised with hydraulic binders	σ_r (MPa)	0.091
Allowable tensile stress	σ_{radm} (MPa)	0.190
Admissible vertical specific deflection	ε_{zadm}	173.49
Number of admissible applications	N_{adm}	14.73
Fatigue degradation rate	R.D.O.	0.73
R.D.O. $_{adm}$		Maximum 0.80
R.D.O $\leq$ R.D.O. $_{adm}$		Check
$\sigma_r \leq \sigma_{radm}$		Check
$\varepsilon_z \leq \varepsilon_{zadm}$		Check

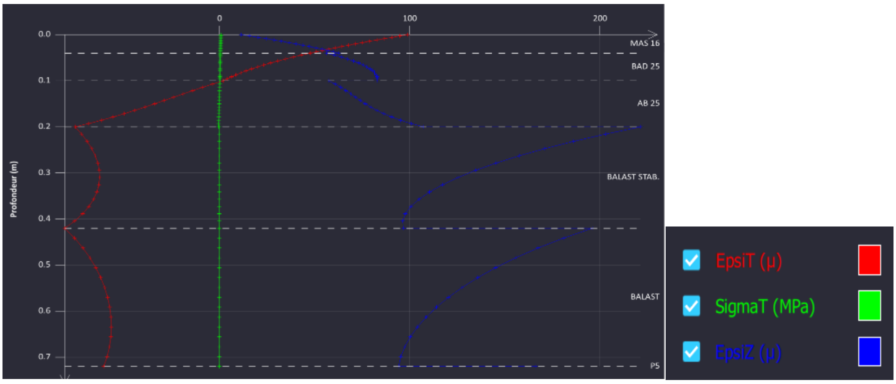

Fig. 1. Transmission curves of radial strain at the base of bituminous layers (ε_r), horizontal tensile strain at the base of natural aggregate layers stabilised with hydraulic binders (σ_r) and vertical specific compressive strain at the formation level (ε_z).

Table 3. Results Alizé - bonded layers.

Calculation traffic	Nc (m.s.a.)	10.70
Radial deformation at the base of bituminous layers	ε_r (microdef.)	75.80
Vertical specific compressive strain at the foundation ground level	ε_z (microdef.)	166.20
Horizontal tensile stress at the base of natural aggregate layers stabilized with hydraulic binders	σ_r (MPa)	0.091
Allowable tensile stress	σ_{radm} (MPa)	0.190
Admissible vertical specific deflection	ε_{zadm}	173.49
Number of admissible applications	N_{adm}	14.73
Fatigue degradation rate	R.D.O.	0.73
R.D.O. $_{adm}$		Maximum 0.80
R.D.O $\leq$ R.D.O. $_{adm}$		Check
$\sigma_r \leq \sigma_{radm}$		Check
$\varepsilon_z \leq \varepsilon_{zadm}$		Check

From the analysis of the results obtained from the design with CALDEROM 2000 and Alizé software, it appears that the deformations and stresses are identical except for the value of the vertical specific compressive strain at the level of the foundation ground in the case of the design with Alizé software, not significantly different (difference of 2.2 microdeformations) compared to Calderom 2000, which is due to the assimilation of MAS 16 and BAD 25 layers (constraint related to the maximum number of 5 layers possible to be taken into account).

Under this assumption with perfectly bonded layers, all the checks required by the Romanian norm PD 177 [13] are fulfilled.

2.3 Alizé design result - Hypothesis of semi-bonded layers (BAD 25 ½ bonded to AB 25)

Since Calderom 2000 software does not have the possibility to modify the interfaces between the layers, the sizing results presented below are obtained using the Alizé program, Fig. 2 and Table 4.

For the present study, a partial bond between the BAD 25 binder course layer and the AB 25 base course was considered.

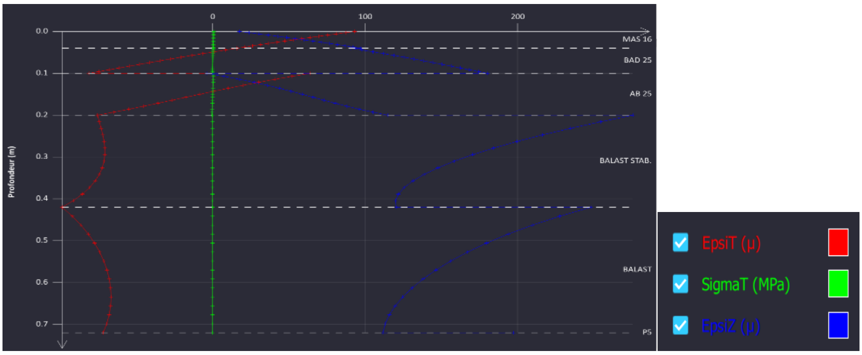

Fig. 2. Transmission curves of radial strain at the base of bituminous layers (ε_r), horizontal tensile strain at the base of natural aggregate layers stabilized with hydraulic binders (σ_r) and vertical specific compressive strain at the formation level (ε_z).

Table 4. Results Alizé - Semi-bonded layers (BAD 25 ½ bonded to AB 25).

Calculation trafic	Nc (m.s.a.)	10.70
Radial deformation at the base of bituminous layers	ε_r (microdef.)	81.00
Vertical specific compressive strain at the foundation ground level	ε_z (microdef.)	197.40
Horizontal tensile stress at the base of natural aggregate layers stabilised with hydraulic binders	σ_r (MPa)	0.11
Allowable tensile stress	σ_{radm} (MPa)	0.190
Admissible vertical specific deflection	ε_{zadm}	173.49
Number of admissible applications	N_{adm}	11.32
Fatigue degradation rate	R.D.O.	0.95
R.D.O. $_{adm}$		Maximum 0.80
R.D.O $\leq$ R.D.O. $_{adm}$		Don't check
$\sigma_r \leq \sigma_{radm}$		Check
$\varepsilon_z \leq \varepsilon_{zadm}$		Don't check

After the design of the road structure according to the above condition, it was found that the R.D.O. value resulting from the design with semi-bonded layers does not check for the design traffic of 10.70 m.s.a., traffic determined for a prospective period of 15 years.

In practice, the resulting design R.D.O. is 18.75% higher, which leads to the fact that for an acceptable R.D.O. ($\leq$ 0.8), the design traffic should be reduced by 18.75% (Nc = 8.69 m.s.a.) The resulting ε_z is higher than $\varepsilon_{z\ adm}$, $\varepsilon_{z\ adm}$ being calculated as a function of the design traffic Nc, which again leads to the assumption of a reduction of the design traffic and the rechecking of the criterion.

All the values resulting from the dimensioning with semi-bonded layers check for the design traffic of 6.55 m.s.a., traffic determined for a perspective period of 9.20 years, whether its evolution shows a consistent increase over the whole service life.

The resulting R.D.O. value is lower by approx. 28% of the admissible R.D.O. value. The resulting design traffic is reduced compared to the initial design traffic (10.70 m.s.a.) by approx. 39% (6.55 m.s.a.).

Design results using Alizé program software for 8.69 m.s.a and 6.55 m.s.a, are shown in Table 5 and Table 6.

Table 5. Results Alizé (Nc = 8.69 m.s.a.). Semi-bonded layers (BAD 25 ½ bonded to AB 25).

Calculation trafic	Nc (m.s.a.)	8.69
Radial deformation at the base of bituminous layers	ε_r (microdef.)	81.00
Vertical specific compressive strain at the foundation ground level	ε_z (microdef.)	197.40
Horizontal tensile stress at the base of natural aggregate layers stabilised with hydraulic binders	σ_r (MPa)	0.11
Allowable tensile stress	σ_{radm} (MPa)	0.192
Admissible vertical specific deflection	ε_{zadm}	183.51
Number of admissible applications	N_{adm}	11.32
Fatigue degradation rate	R.D.O.	0.77
R.D.O. $_{adm}$		Maximum 0.80
R.D.O ≤ R.D.O. $_{adm}$		Check
$\sigma_r \leq \sigma_{radm}$		Check
$\varepsilon_z \leq \varepsilon_{zadm}$		Don't check

Table 6. Results Alizé (Nc = 6.55 m.s.a.). Semi-bonded layers (BAD 25 ½ bonded to AB 25).

Calculation trafic	Nc (m.s.a.)	6.55
Radial deformation at the base of bituminous layers	ε_r (microdef.)	81.00
Vertical specific compressive strain at the foundation ground level	ε_z (microdef.)	197.40
Horizontal tensile stress at the base of natural aggregate layers stabilised with hydraulic binders	σ_r (MPa)	0.11
Allowable tensile stress	σ_{radm} (MPa)	0.194
Admissible vertical specific deflection	ε_{zadm}	198.07
Number of admissible applications	N_{adm}	11.32
Fatigue degradation rate	R.D.O.	0.58
R.D.O. $_{adm}$		Max. 0.80
R.D.O ≤ R.D.O. $_{adm}$		Check
$\sigma_r \leq \sigma_{radm}$		Check
$\varepsilon_z \leq \varepsilon_{zadm}$		Check

3 Conclusions

The objective of this study was to analyze whether a road structure with semi-bonded bound layers can resist the design traffic considered in the study, possibly the proportion of the design traffic that could be accepted, which would allow an assessment of the capable service life of the road structure and thus the possibility of failure of the road structure before the end of the considered perspective period. About the adhesion between the layers, it should be noted that this has a significant influence on directly influences the bearing capacity of the road structure and, consequently, its service life (number of standard axle crossings). To assess the risk of reducing the service life of the road structure, it was calculated in accordance with the Romanian dimensioning standard [13] using the Alizé software [14], which allows imperfect bonding between layers to be taken into account.

The results show that the reduction of the connection between the layers to 50% leads to a reduction of the design traffic by approx. 39% (in the case of this study). To obtain clearer conclusions, it is necessary to make different assumptions of interlayer bonding (e.g., wear layer partially bonded or not bonded to the bonding layer) and then to check at the considered computational traffic.

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