EFFECT OF TRAFFIC LOAD ON BEHAVIOUR OF FLEXIBLE PAVEMENTS – EXAMPLES FROM CROATIA

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Abstract

In the last ten years, Croatia invested considerable monetary funds in road building. The pavement structure design of all built roads was done in accordance with the Croatian regulations (HRN U.C4.012 standard). The traffic load, as one of the key parameters in design, was calculated according to the HRN U.C4.010 standard, and expressed by the number of equivalent standard 82 kN axle load. The applicable Croatian and European law regulations allow axle loads higher than the standard, and appearance of axle loads higher than those allowed by the law is not rare on Croatian roads. The paper considers the effect of the axle loads on behaviour of several types of flexible pavements characteristic for Croatia, whereby parameters like the type of the axle, the type of tyres and the inflation pressure were taken into account. The calculations of critical stresses and strains (tensile on the bottom of asphalt and cement stabilized layer, vertical compressive on the top of the subgrade) were performed for selected pavements by the CIRCLY software. Based on the calculated values of stresses and strains, equivalency factors, which represent a relative effect of particular levels and ways of load transfer on the structure, were determined. The obtained results show that the effect of the considered input parameters (loads, types of axles, types of tyres, inflation pressure) is not negligible. It is indicated that the existing equivalency factors of particular vehicle types, which are used to determine the traffic load, i.e. the number of the standard equivalent 82 kN axle load during design of new or estimation of the residual life of the existing flexible pavements, should be revised.

Keywords: LEF, ESAL, flexible pavement, fatigue criteria, rutting criteria

1 Introduction

Pavement degradation is caused by the interacting damaging effects of the environment (temperature, humidity) and the traffic load [1].
The traffic load represents a combination of various axle or axle group loads, wheel configurations and inflation pressures. Each of those combinations contributes to the process of the pavement degradation in a specific way. In the pavement design, the influence of different axle loads is converted to the influence of the equivalent standard axle load (ESAL) through the load equivalency factor (LEF). In Croatia, pavement design is performed according to the HRN U.C4.012 standard [2], and the traffic load, as one of the key parameters in design, is determined in the way described in the HRN U.C4.010 standard [3]. The calculation of LEF of an axle or axle group in the mentioned standard is done according to the so-called “Fourth Power Law” derived from the data obtained during the AASHO Road Test. The empirical basis of this law imposes the validity question of its extrapolation on the load conditions, pavement types

and the effect of the environment which are not comprised by that test [4]. For that reason, the search for new methods to determine LEFs has been intensified in the last ten years. One of these methods - the mechanistic method, was used in elaboration of this paper.
During the AASHO Road Test, the maximum allowed single axle load in most states was 80 kN. Tyres on vehicles were bias-ply with the average inflation pressure between 0.52 and 0.55 MPa. [4].
Nowadays, the allowed axle loads are much higher. In Croatia, the maximum allowed axle loads are legally regulated by an Ordinance [5]. Higher axle loads were possible, among other things, due to the advancement in the technology of tyre production. Bias-ply tyres were replaced with radial tyres and, in the last ten years, the trend of replacing the standard dual wheel configuration with radial tyres by a single wheel configuration with super single tyres has been noticed. Inflation pressure, for the maximum allowed axle load and the standard dual wheel configuration, according to the manufacturer's specifications, range from 0.75 and 0.85 MPa, and for super single tyres as much as 0.9 MPa [6].

2 Effect of traffic load

The effect of the traffic load to the pavement depends on the axle configuration (single-axle, tandem, tridem) and on the axle load, as well as on the wheel configuration (single, dual) and on tyre characteristic. Axle load is transferred to the pavement by the tyres, and the load which the tyre can sustain depends on the size of tyre, tyre type and tyre inflation pressure.

2.1 Axle load

The influence of the axle or an axle group load to the pavement is converted to the influence of the standard axle load by LEFs, which are calculated according to the HRN U.C4.010 standard [3]. The standard axle is defined as a single axle with the load of 82 kN. The load is transferred to the pavement by two dual wheels, each of them transmit the load of 20.5 kN. LEFs of particular axle types for flexible pavements are determined by the expressions:

$$LEF = 2.212 \times 10^{-8} \times L_1^{\,4} \text{, for a single axle and} \tag{1}$$

$$LEF = 1.975 \times 10^{-9} \times L_2^{\,4} \text{, for a tandem axle,} \tag{2}$$

where L_1 and L_2 are the load of a single, i.e. a tandem axle [kN].

The standard does not define the calculation of the LEFs of the tridem axle. While the influence of the steering, single axle with the single wheel configuration is converted to the influence of a single axle with a dual wheel configuration. LEFs calculated in this way do not take in consideration the effect of the inflation pressure, or that of the wheel configuration on pavement response.

2.2 Tyre–pavement contact

Tyre-pavement contact stress is assumed uniformly distributed over circular contact area and equal to tyre inflation pressure. Tyre-pavement contact area is approximated by a circle with the radius:

$$r = \sqrt{\frac{P}{\pi \times p}} \tag{3}$$

where P [N] – wheel load, and p [MPa] - tyre inflation pressure.

By changing the inflation pressure, the size of the contact area is changed, as well as the tyre-pavement contact stress [7]. With the same axle load, by increasing the inflation pressure, the tyre-pavement contact area is reduced (by increasing the pressure by 0.1 Mpa, the contact area is reduced by approximately 13%). During driving, heating of the tyres occurs, and, as a consequence of that, also an increase of the tyre inflation pressure of approximately 0.1 MPa [8]. By replacing the dual wheel configuration with the single one with super single tyres, the size of the contact area is additionally reduced [9].

3 Calculation of load equivalency factor

In order to take into account the wheel configuration and the inflation pressure in calculation of the LEF, beside the axle load and the axle configuration, the mechanistic method was used. The basic principles of that method are explained below.

Load equivalency factors represent the ratio of the standard axle load damage to the damage caused by any given axle load [1]. Mathematically, that effect can be expressed by the following equation:

$$LEF = \frac{N_S}{N_X} \tag{4}$$

where N_s - is the number of strain repetitions to failure under the standard load and pressure, N_x - the number of strain repetitions to failure under the arbitrary load and pressure.

Strains that are considered critical in flexible pavement design are:

Vertical compressive strain at the top of subgrade.

The allowed number of repetitions of vertical compressive strain at the top of subgrade according to the Shell Design Manual [10] is determined by the expression:

$$N_c = 6{,}150 \times 10^{-7} \times \left(\frac{1}{\varepsilon_c}\right)^4 \tag{5}$$

where ε_c is vertical compressive strain on the subgrade. If the number of repetitions of vertical compressive strains is higher than Nc, on the pavement structures without cement treated base, permanent deformation occurs at the pavement surface, and pavement deteriorates due to rutting.

Horizontal tensile strain at the bottom of asphalt layer.

The allowed number of repetitions of horizontal tensile strain at the bottom of asphalt layer according to the Shell Design Manual [10] is determined according to the expression:

$$N_t = 0{,}0685 \times \left(\frac{1}{\varepsilon_t}\right)^{5{,}671} \times \left(\frac{1}{E}\right)^{2{,}363} \tag{6}$$

where ε_t is horizontal tensile strain at the bottom of asphalt layer. If the number of repetitions of horizontal tensile strain is higher than N_t, cracks appear at the bottom of the asphalt layer, and pavement deteriorates due to fatigue.

By expressing the number of allowed repetitions of strains for the case of the standard load and pressure, and for the arbitrary load and pressure, and by entering the obtained expressions into the eq.(4), we can determine the LEFs according to the:

a) rutting criteria:

$$LEF_{cx} = \left(\frac{\varepsilon_{cx}}{\varepsilon_{cs}}\right)^4 \tag{7}$$

where ε_{cs} - is the maximum vertical compressive strain at the subgrade with the standard load and pressure; ε_{cx} - is the maximum vertical compressive strain at the subgrade with the arbitrary load and pressure.
b) fatigue criteria:

$$LEF_{tx} = \left(\frac{\varepsilon_{tx}}{\varepsilon_{ts}}\right)^{5,671} \quad (8)$$

where ε_{ts} - is the maximum horizontal tensile strain at the bottom of asphalt layer with the standard load and pressure; ε_{tx} - the maximum horizontal tensile strain at the bottom of asphalt layer with the arbitrary load and pressure.
Thus determined LEFs depend on the characteristics of the software used for calculation of the maximum strains, and on the expressions according to which the allowed number of strain repetitions was determined.

4 Calculation of strains

The calculation of the maximum strains was done by the CIRCLY software on three types of flexible pavements characteristic for Croatia, HT1, HT2 and HT3 (Table 1), and for several combinations of the axle load, of the wheel configuration and of the inflation pressure. The considered values of the elasticity module represent the average of characteristic elasticity modules of particular seasons.

Table 1 Characteristics of analyzed pavement types

Pavement	Layers	h (cm)	E (MPa)	v
HT1	Asphalt concrete	6	3000	0.40
	Bituminous base	10	4000	0.40
	Unbound base	35	300	0.35
	Subgrade	-	100	0.35
HT2	Splitmastiks asphalt	5	3000	0.40
	Bituminous base	11	4000	0.40
	Cement treated base	20	5000	0.25
	Unbound base	20	300	0.35
	Subgrade	-	100	0.35
HT3	Splitmastiks asphalt	4.5	3000	0.40
	Binding asphalt layer	5	3500	0.40
	Bituminous base	8	4000	0.40
	Cement treated base	20	5000	0.25
	Unbound base	20	300	0.35
	Subgrade	-	100	0.35

The maximum strains ε_{cx} and ε_{tx} for axle loads of a single (40, 50,60,70, 80, 90, 100, 110 and 120 kN), tandem (130, 145, 160, 175 and 190 kN) and tridem (210, 225, 240, 255 and 270kN) axle, for the single, i.e. dual wheel configuration and the inflation pressure 0.7, 0.75, 0.8, and 0.85 MPa have been calculated, as well as ε_{cs} and ε_{ts} for standard axle loads 82 (single), 150 (tandem) and 240 kN (tridem), the dual wheel configuration and the inflation pressure 0.7 MPa.
A uniform distribution of the axle load between wheels was supposed. The distance between the axis of the tandem, i.e. of the tridem axle was 120cm, and the spacing between the load centres for the dual wheel configuration was 35cm.

5 Analysis of results

The analysis considers the effect of the axle load, of the wheel configuration and of the inflation pressure on the LEFs determined according to the rutting criteria at the top of the subgrade and the fatigue criteria at the bottom of the asphalt layer. Due to a different behaviour of the pavements which have cement treated base in relation to the pavement without it, the analysis was carried out separately for the pavement HT1, and separately for pavements HT2 and HT3.

5.1 Pavement HT1

For the dual wheel configuration and lower axle loads (<80 kN), the LEFs determined according to eq.(1) do not deviate considerably from those determined according to the rutting criteria and the fatigue criteria. However, with an increase of the axle load and of the inflation pressure, an increase of the LEFs obtained according to the fatigue criteria (Fig. 1) occurs. If the dual wheel configuration is replaced by a single one, we get considerably higher LEFs according to the rutting criteria, as well as according to the material fatigue criteria in relation to those obtained according to eq.(1). A similar trend is noticed in case of a tandem, i.e. tridem axle load.

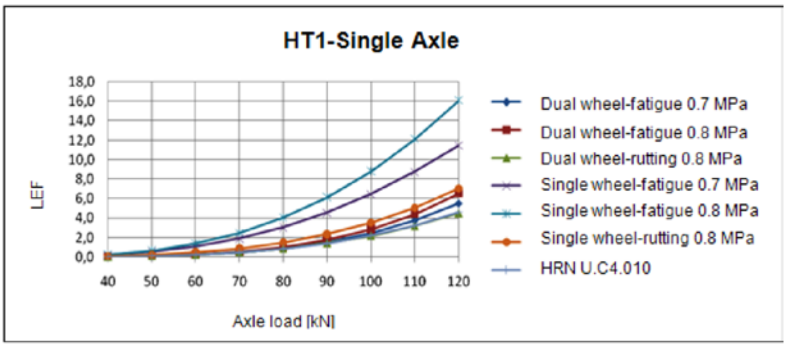

Figure 1 Effect of axle load, wheel configuration and inflation pressure on LEF for pavement HT1

5.2 Pavements HT2 and HT3

The LEFs according to the rutting criteria for the dual wheel configuration, the considered axle loads and inflation pressures correspond to the factors determined according to eq.(1). According to the fatigue criteria, higher LEFs were obtained. The rutting criteria is the competent in case of higher axle loads (>80kN) but only in case of lower inflation pressure (Fig. 2). For higher axle loads and higher inflation pressure, the decision about which criteria is competent depends on the combination of the axle load and the inflation pressure. If the dual wheel configuration is replaced by a single one, a deviation of the LEFs obtained according to the rutting criteria in relation to those determined according to eq.(1) is obtained. The deviation is increased with an increase of the axle load regardless of the inflation pressure. The rutting criteria is not competent in case of lower axle loads (<100 kN), those axle loads have a greater destructive effect on the pavement according to the fatigue criteria. For axle loads higher than 100 kN, beside on the axle load, the decision about which criteria is competent also depends on the inflation pressure.

In case of the load by the tandem, i.e. tridem axle, similar trends were noticed. The rutting criteria is competent only in case of loads higher than the defined standard ones (Section 4) and a lower inflation pressure. In all the other cases, the fatigue criteria are competent.

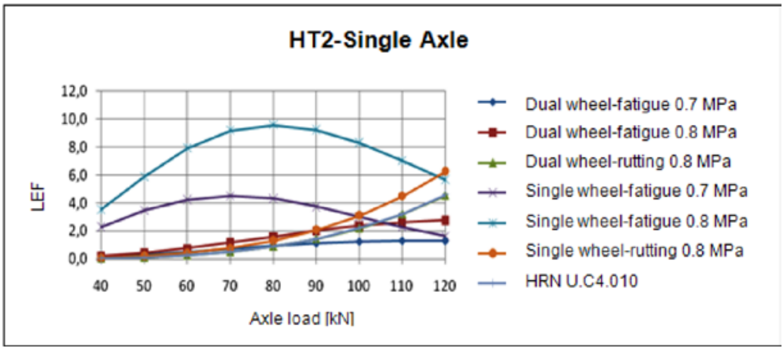

Figure 2 Effect of axle load, wheel configuration and inflation pressure on LEF for pavement HT2

6 Conclusion

The paper considers the mechanistic method according to which the LEFs are expressed as the ratio of the calculated responses of the pavement under the arbitrary load and the calculated responses of the pavement under the standard load. Two types of criteria for determining the load equivalency factors were considered: the rutting criteria and the fatigue criteria.
The calculation was made on three pavement types characteristic for Croatia.
On the basis of the obtained results, we can conclude that the influence of the wheel configuration and the inflation pressure on the LEFs is not negligible. LEFs calculated according to HRN U.C4.010 correspond to those obtained according to the rutting criteria, but only in case when the dual wheel configuration is in question. If the dual wheel configuration is replaced by a single one, LEFs higher by approximately 30% to 50% are obtained, depending on whether a pavement with or without cement treated base is in question. The effect of the inflation pressure on the LEFs according to the rutting criteria is negligible.
By increasing the axle load and the inflation pressure, higher LEFs were obtained according to the fatigue criteria. The fatigue criteria is the competent criteria for determining the LEFs in the field of legally allowed single axle loads (< 100 kN) and in practice most common inflation pressure of 0.8 MPa. A considerably higher destructive effect of the single wheel configuration in relation to the dual one was noticed, even with lower single axle loads (< 80 kN), such as steering axle loads. That should be considered if the trend of replacement of the dual wheel configuration on the driving axle with a single one is taken in consideration, and the fact that the driving axle load of 115 kN is legally allowed.
In connection with the influence of the tandem, i.e. the tridem axle, the same trends were noticed as in case of a single axle, by increasing the axle load and the inflation pressure, higher LEFs were obtained, and in case of loads smaller than the legally allowed, the fatigue criteria is competent. By replacement of the dual wheel configuration with a single one, the destructive effect on the pavement is increased.
Due to a much greater destructive impact to the pavement, the effect of the single wheel configuration must not be converted to the effect of the dual wheel configuration. The obtained results indicate a need for developing specific LEFs for axles with the single wheel configuration and the need for legal defining of the maximum allowed loads of the same.

High inflation pressure in combination with a higher axle load bring to pavement degradation due to fatigue more quickly, so that its effect must be taken in consideration in pavement design, but also in asphalt mixture design.

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