

Reduction of Loading Duration of Motor-Roads Pavements by Different Vehicles to Design Load

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Abstract: Pavement loading is comprised of a number of components. Duration of a force is one of the main components. Majority of known pavement calculation methods are based on provisioning of required durability and final smoothness considering aggregate transport impact. Variation of force value with respect to the center of wheel trace is sine function and the force extends beyond the trace boundaries. Uneven distributed pressure in tire and pavement contact area has the same dependence. So loading duration should be reduced to some equivalent of actual loading. To solve engineering roadwork problems it is easier and more clear to use rather transport units united into groups according to some characteristics (for example, loading characteristics) than individual loads. The units of rolling stock are compared with loads accepted as design value. The article deals with definition of single and integral duration of vehicles' effect in pavement for design, forecasting and evaluation of durability.

Key words: Duration of loading • Pavement • Reduction factor

INTRODUCTION

Integral duration of pavement loading is critical factor for evaluation of its efficiency. Using aggregate reduced effect as valuable factor may be grounded only by mentioning duration of single design loading. According to some research results duration of loading cycle in real range of an average speeds of traffic stream is 0,01...0,1 sec [1, 2, 3]. To calculate equivalent, or reduced to iso-tensed loading duration of single impact the following equation has been derived. It corrects some drawbacks of accepted approaches [4].

$$t_{eqv} = 0,054 \cdot \frac{Q_{st} \cdot K_{dyn}}{\pi \cdot b_t \cdot K_t \cdot P \cdot V} \quad (1)$$

where,

Q_{st} is static (motionless) rolling load, kN;

K_{dyn} is the factor of dynamic force increase for moving vehicle; in the most frequent exploitation pattern $K_{dyn}=1,1 \dots 1,5$;

P is pressure in tread and pavement surface contact area equivalent to semi-elliptical stress diagram with account for hardness of tyre, MPa;

b_t is the width of tread cap according to technical specification – the width of the part of tyre contacting directly with pavement, m;

K_t is tread cap width increase factor; in normal rolling mode in average $K_t=1,05 \dots 1,07$;

V is vehicle speed, km/hour.

Many foreign specialists traditionally have been focused on peculiarities of the process of rolling load contacting with pavement construction and accounting for transport effect [5, 6, 7, 8, 9, 10]. But they have not reached an agreement on the approach to evaluation single and integral effect duration.

As vehicles appearing on motor-roads make quite different loading on pavement it is necessary to develop methods of reduction of real loading to conventional value that is called design value. In Russia loadings equal 6, 8, 10, 11,5 and 13 tons are accepted as design or allowed for a certain traffic limitations. In one of my earlier works I presented method, basis and the scale of reduction factors for loading durations that may be defined as [11].

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Table 1: Design parameters of vehicles for defining duration of their effect on pavement surface

Carriage capacity of a vehicle. ton	Combination of axle load. ton the most common type of busbar	Distance between wheel axles fifth wheel/bogie. m	Aggregate basic rolling curve. $\Sigma \ell_k$ m (for $K_A=1.0$)
Two-axle vehicles			
1...2	1.5/1 + 2.5/1	–	0.221
2...3	2.5/1 + 4.5/1	–	0.359
3...4.5	4/1 + 5/1	–	0.446
4.5...7	4/1 + 8/1	–	0.517
7...10	5/1 + 10/2	–	0.446
10...15	7/1 + 12.5/2	–	0.527
Six-wheel motor vehicles			
4.5...7	4.5/1 + 2x5/1	1.4	2.116
7...10	4.5/1 + 2x5.5/2	1.4	2.02
10...15	6/1 + 2x7.5/2	1.4	2.122
15...20	6/1 + 2x11/2	1.4	2.148
Cb. 20	8/1 + 2x13/2	1.4	2.213
Eight-wheel vehicles of higher carrying capacity			
–	2x8/1 + 2x14/2	1.65 + 1.45	4.23
Ten-wheel vehicles of higher carrying capacity			
–	2x11/2 + 8.5/2 + 2x14/2	1.9 + 1.9 + 1.35 + 1.85	8.488
One-axle semitrailers			
7...10	6/1(2)	–	0.224
10...15	9/2	–	0.237
Two-wheels semitrailers			
10...15	2x6/1	1.4	1.911
15...20	2x8/1	1.4	1.94
20...25	2x9/2	1.4	1.886
25...30	2x10/2	1.4	1.886
> 30	2x12/2	1.4	1.921
Six-wheel semitrailers			
20...25	3x7/1(2)	1.3 + 1.4	3.41
25...30	3x8/1(2)	1.3 + 1.4	3.434
>30	3x9.5/2	1.3 + 1.4	3.453
Two-axle trailers			
4.5...7	4.5/1 + 4.5/1	–	0.423
7...10	6/1(2) + 6/1(2)	–	0.448
10...15	9/2 + 9/2	–	0.474
Six-wheel trailers			
–	10/2 + 2x10/2	1,4	2.122
Eight-wheel trailers			
–	2x7/2 + 2x8/2	1.3 + 1.8	4.06
Buses			
–	8/1 + 8/1	–	0.629

Note. 1(2) in the most common type of busbar means equal repetitiveness of single wheel and two-wheel configurations in wheels constructions in a certain lineup.

$$G_{ii} = \frac{t_{eqvij}}{t_{eqvdesignij}} = \left(\frac{Q_i}{Q_{design}} \right)^{0,81} \quad (2)$$

where, Q_i and Q_{design} are real (arbitrary) and design loading, respectively, kN;

t_{eqvij} and $t_{eqvdesignij}$ are equivalent loading duration for real (arbitrary) and design loading moving with j^{th} average speed over the pavement, sec.

Main Body: Theoretical basis that had been developed allowed developing the scale of reduction factors and design durations in the limits of predefined carrying capacity ranges for different types of vehicles. Such scale may be defined by averaging the combination of technological axle loads for a single rolling stock. To avoid gross errors as a result of such averaging it is necessary to make correct classification of vehicles:

Table 2: Explicative data for calculation of integral length of rolling arch for (1)



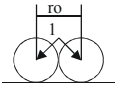
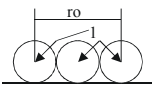

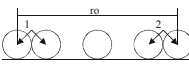
In-line wheel configuration of a vehicle	Possible types of vehicles	Formulae for calculation of integral length of rolling arch
	Two-axle motor-cars and trailers	$\ell_{K1} + \ell_{K2}$
	Six-wheel motor-cars and trailers	$\ell_{K1} + r_o + \ell_{K2}$
	Two-axle semitrailers and trailers	$\ell_{K1} + r_o$
	Six-wheels semitrailers	$\ell_{K1} + r_o$
	Eight-wheels motor-cars	$\ell_{K1} + r_{o1} + \ell_{K2} + r_{o2}$
	Ten-wheels motor-cars	$0,5 \cdot \ell_{K1} + r_o + 0,5 \cdot \ell_{K2}$

Table 3: Design basic equivalent loading duration $t_{eqvdesign}^b$ and reduction factors for reduction if loading duration to design load G_{ii} for vehicle

Carriage capacity of a vehicle. ton	Design basic equivalent loading duration. sec	Loading duration reduction factors for design loads				
		6 t	8 t	10 t	11.5 t	13 t
Two-axle vehicles						
1...2 t	0.06	0.935	0.833	0.781	0.714	0.663
2...3 t	0.097	1.511	1.347	1.262	1.155	1.071
>3 t	0.131	3.6	3.1	2.817	2.52	2.3
Six-wheel vehicles						
< 15 t	0.563	15.47	13.31	12.11	10.83	9.87
>15 t	0.59	16.21	13.95	13.56	11.35	10.34
Eight-wheel vehicles of higher carrying capacity						
All	1.142	31.37	27.0	26.25	21.96	20.0
Ten-wheel vehicles of higher carrying capacity						
all	2.292	62.97	54.18	52.7	44.08	40.17
One-axle semitrailers						
All	0.062	1.46	1.26	1.15	1.032	0.941
Two-axle semitrailers						
< 20	0.512	8.533	7.7	7.314	6.728	6.282
> 20		12.02	10.39	9.464	8.491	7.746
Six-wheel semitrailers						
All	0.927	21.76	18.8	17.14	15.37	14.02
Two-axle trailers						
all	0.121	2.84	2.454	2.237	2.007	1.831
Six-wheel trailers						
All	0.573	13.45	11.62	10.6	9.503	8.67
Eight-wheel trailers						
All	1.096	25.73	22.23	20.26	18.18	16.58
Buses						
All	0.17	2.678	2.361	2.212	2.024	1.877

on one hand it should be sufficient for required accuracy of results and on the other hand it should be relatively easy to apply.

It is obvious that classification of vehicles provided in [12] after some modifications may be used as a base and adapt to the problem of linking basic design equivalent loading durations with carrying capacity. For each range of the scale [12] there has been made analysis of lineups of popular vehicles of about 500,000 units with definition of the most common axle mass and wheel designs (Table 1) [13]. Aggregate basic rolling length includes individual full rolling traces of each single wheel, $\ell_{\kappa 1}$ half-lengths in adjacent axles $0,5 \cdot \ell_{\kappa 2}$ and distances between the center of adjacent wheels $r_{o(i-i+1)}$.

$$\sum_{i=1}^n \ell_{\kappa} = \sum_{i=1}^n (\ell_{\kappa 1i} + 0,5 \cdot \ell_{\kappa 2i} + r_{o(i-i+1)}) \quad (2)$$

where n is the number of axles in a vehicle.

Diagrams for calculation and accommodated formulae of type (2) are listed in Table 2.

A wheel is defined as single if the least distance between the centre of its axle and any closer axle is less than 2.5 m according to research of well-known Russian-American specialist B.S. Radovski [3] and AASHO. Other wheels are defined as adjacent. This generalization may be done basing on [1, 2, 3].

There are insignificant deviation from general trend in the values of aggregate base rolling length in case of carriage capacity increase that may be defined by differences in contact pressure and busbar. Basing on Table 1 data it is possible to calculate integral design base equivalent loading durations and aggregate reduction factors for design loading G_{ti} and make allowed consolidation of vehicle types (Table 3).

Aggregate design loading duration of pavement for vehicle types may be calculated as follows:

$$T_l = K_{trans} \cdot f_{load} \cdot \sum_{i=1}^q \sum_{j=1}^w N_{ij} \cdot S_{mi} \cdot t_{eqvij} \quad (3)$$

where,

K_{trans} is indicator that account for decrease of integral loading in rolling strip due to variations in transversal arrangement of vehicles;

F_{load} is factor accounting for probability of loading distribution on traffic lanes;

q is the number of periods of transport stream moving with average speed V_j with given dynamic factor;

w is the number of types of dynamically loaded axles in one direction of a road;

N_{ij} is strength of the force of i^{th} mass load moving with j^{th} average speed, units;

S_{mi} is reduction factor for reduction of effect of pavement of i^{th} load to design load;

t_{eqvij} is loading duration for i^{th} load for j^{th} speed, calculated according to (1).

Aggregate design loading duration of pavement for vehicle types may be also calculated via reduction factors for loading duration and design equivalent loading durations $t_{eqvdesign}^b$ (Table 3).

$$T_l = K_{trans} \cdot f_{load} \cdot T_{designld} \cdot \sum_{i=1}^q \sum_{j=1}^w N_{ij} \cdot S_{mi} \cdot t_{eqvdesign}^b \cdot \frac{1}{K_{vij}} \cdot K_{dynij} \cdot G_{ti} \quad (4)$$

where,

K_{vij} is speed factor for i^{th} load for j^{th} speed; for speed accepted as basic and equals 50 km/hour, $K_{vij}=1.0$;

K_{dynij} is dynamism factor of i^{th} mass moving with j^{th} average speed; basic dynamism factor equals 1.0.

CONCLUSION

Development of methods of accounting for indicators of traffic stream interaction with pavement to calculate and forecast their resource remains high-priority direction of research in improvement of modeling of deflecting mode of the system "roadbed – pavement". Approximate methods applied for practical realizations based on reduction of real figures to reference indicators, should have high convergence with precise methods providing results with required (allowed) accuracy. Approach presented in the article concludes one more scientific attempt to define loading duration for motor-road pavements.

Resume:

- Method of defining aggregate loading duration of vehicles with different carriage capacity and wheel configurations has been developed on the base of introduced concept of relative indicator of loading duration – reduction factor for design effect and reliable proportional correlation between this indicator and load values.
- This method may be used for design of new pavements, forecasting and evaluation of their residual life by the main factor of efficiency of pavements – aggregate loading from design traffic load.

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