calculation of a railway track on durability; stress in elements of a design of a railway track; the admissible speed of the movement of the locomotive

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THE DETERMINATION OF ADMISSIBLE SPEED OF LOCOMOTIVES ON THE RAILWAY TRACKS OF THE REPUBLIC OF KAZAKHSTAN

Summary. Today modern locomotives of KZ4AC, KZ8A, TE33A series were put into service in the Republic of Kazakhstan. In order to establish safe operating mode of these locomotives the admissible speed on the railway tracks of the Republic of Kazakhstan was determined. The admissible speed of locomotives was determined on the basis of analysis on the results of dynamic and railroad tests and calculations for stress of railway construction.

ОПРЕДЕЛЕНИЕ ДОПУСТИМОЙ СКОРОСТИ ДВИЖЕНИЯ ЛОКОМОТИВОВ ПО ЖЕЛЕЗНОДОРОЖНЫМ ПУТЯМ РЕСПУБЛИКИ КАЗАХСТАН

Аннотация. В настоящее время в Республике Казахстан введены в эксплуатацию современные локомотивы серий KZ4AC, KZ8A, ТЭ33А. Для установления безопасных режимов эксплуатации этих локомотивов определены допустимые скорости движения по железнодорожным путям Республики Казахстан. Допустимые скорости движения локомотивов определены на основе анализа результатов динамических и путевых испытаний, а также расчетов напряжений в конструкции железнодорожного пути.

1. INTRODUCTION

As the Customs Union Technical Regulations such as TR CU 003/2011 “On safety of railway transport infrastructure”, TR CU “On safety of railway rolling stock” were enforced, normative and technical documents regulating safe conditions for service of rolling stock and railway became necessary to be updated. Normative and technical documents are updated in accordance with the requirements of International Union of railways and international standards [1-2].

One of the important documents regulating rail traffic safety is Norms for admissible speed of locomotives and railway carriages on 1520 (1524) mm railways of railway transport of the Republic of Kazakhstan.

In order to estimate stress state of railways the calculations for railways durability according to the methods given in [3-12] were made. On the basis of made calculations and results of dynamic and railroad tests, the admissible speed of locomotives for typical railways construction on straight and curved track sections were determined.

2. THE DETERMINATION OF DESIGN PARAMETERS OF KZ4AC, KZ8A, TE33A LOCOMOTIVES

In the Republic of Kazakhstan KZ4AC, KZ8A, TE33A locomotives were put into service (fig. 1). Today operating park of these locomotives includes:

KZ4AC electric locomotives – 27 units;
KZ8A electric locomotives- 25 units;
TE33A diesel locomotives – 285 units.

a) b) c)

Fig. 1. The new locomotives operated on the railroad of the Republic of Kazakhstan: KZ4AC (a), KZ8A (b), TE33A (c)
Рис. 1. Новые локомотивы, эксплуатируемые на железной дороге Республики Казахстан: KZ4AC (a), KZ8A (b), ТЭ33А (c)

Z4A electric locomotives – main passenger electric locomotive of alternating current designed by Siemens Mobility company and made in Zhuzhou electric locomotive assembling plant.

KZ8A electric locomotive – main freight electric locomotive designed by Alstom Transport company for "National Company "Kazakhstan Temir Zholy" JSC on the basis of Prima electric locomotive.

TE33A diesel locomotive (Evolution ES44ACi) - freight diesel locomotive with asynchronous traction motor developed by General Electric (USA) and assembled by "Locomotive Kurastyru Zauyty" locomotive assembling plant.

During the performance of dynamic and railroad tests and other technical documentation, major locomotive parameters necessary for making railroad durability calculations are determined. Design features are given in Table 1.

Table 1

Locomotive design parameters

Parameter	Locomotive		
	KZ4AC	**KZ8A**	**TE33A**
Axle type	B_0-B_0	2(B_0-B_0)	C_0-C_0
Operating speed, km/hour	200	120	120
Static wheel load on rail, kN	102,5	122,5	113
Wheel diameter, m	1,25	1,25	1,05
Totalstaticdeflection, mm	190,6	175,9	145,5
Unsprings weight, related to 1 wheel, kN	29	27	37,9
Wheel arrangement (in m)	2,6	2,6	1,85-1,85

3. THE DETERMINATION OF THE COEFFICIENT WHICH INCLUDES HORIZONTAL LATERAL FORCES ON RAIL

When locomotive wheels pass through design track section the vertical forces are not focused exactly in the middle of railhead. Also, lateral forces are on rail. This leads to skew rail bending and rail twisting and as the result stresses in the edges of rail foot rise by f times. f coefficient calculates horizontal lateral (cross to central line of track) wheel forces and twisting moments on rail. This coefficient is estimated on the basis of experimental surveys on different types of rolling stock and theoretical calculations of railroad durability [4-10].

The most informative instrument to measure interaction force between railroad and rolling stock is strain gauge-based wheelset which is set under tested carriage [1]. However as the determination of interaction parameters is difficult due to worn-out state of wheel-rail system, strain gauge-based wheelset is reasonable to be used for rolling stock of new construction.

The most accepted method for determination of interaction force between railroad and rolling stock is Schlumpf method based on the estimation of interaction force not on locomotive wheel but on rail [8].

The largest edge stresses of rail are:

$$\sigma_{e\max} = f\sigma_a, \quad (1)$$

where: σ_a - axial stress of bending in the edges of rail foot due to force at the symmetry of rail cross section.

f coefficient depends on the radius of curve, rail types and speed of rolling stock.

As f coefficient is the ratio of vertical forces and moments at the rail cross, it mainly depends on the radius of curve and construction features of carriage. Railroad construction has a little effect on its value. The effect of railroad construction is considered to estimate the design value of axial stress.

The value of f coefficient is calculated by using the semi-empirical formula [10-11]:

$$f = \frac{\sigma_e^e + \Delta\sigma_a}{\sigma_a^c}, \quad (2)$$

where: σ_e^e – is the maximum possible value of stresses in the edges of rail foot; $\Delta\sigma_a = \sigma_a^c - \sigma_a^e$ – the difference between calculated and experimental values of axial stresses; σ_a^c and σ_a^e – the respectively calculated and experimental (corresponding to the maximum stress in the edges of rail foot) maximum possible values of axial stresses.

During the performance of approval dynamic strength, complex dynamic tests and tests by impact on railway track and points of KZ4AC, KZ8A, TE33A locomotives, the maximum value of stresses in the edges of rail foot σ_e^e and the half sum of stresses in outer and inner edges of rail foot were determined. According to [11] the half sum of stresses in outer and inner edges of rail foot with sufficient accuracy corresponds to the axial stress in the rail foot σ_a^e.

The values σ_a^c for KZ4AC, KZ8A, TЭ33A locomotives were determined according to the methods [3] for typical track construction.

The coefficients f for experimental sections are selected from the options of maximum velocity.

The admissible values of f coefficient in experimental track sections are used to determine this coefficient in the curves of different radius. Dependenceof$f$coefficienton curve radius for any constructions of railway tracks is determined by using the following formula [11]:

$$f = f_{tg} + A/R, \quad (3)$$

where: f_{tg} – the f value in tangent track; A – the coefficient, defined as the average value of f in experimental curved tracks; R–curve radius in meters.

The admissible values of coefficient f for KZ4AC, KZ8A, TE33A locomotives are given in the table 2.

Table 2

Calculatedvaluesof$f$coefficientdepending on the curves radius

Locomotive series	**Value of f coefficient in curves radius, m**								
	Straight line	**1000**	**800**	**700**	**600**	**500**	**400**	**350**	**300**
KZ4AC	1,13	1,43	1,51	1,56	1,63	1,74	1,89	1,99	2,14
KZ8A	1,13	1,28	1,32	1,34	1,38	1,43	1,5	1,55	1,62
TE33A	1,23	1,53	1,6	1,65	1,72	1,82	1,97	2,06	2,22

4. DETERMINATION OF ADMISSIBLE LOCOMOTIVE VELOCITY

The values of f coefficient and parameters of locomotives given in the tables 1-2 are used for determination of admissible velocity of locomotives upon conditions of reliability process for railway tracks.

The assignment of admissible velocity of rolling stock upon condition of track durability is carried out according to [3, 7, 12].

Track calculation for durability consists of the following sections:

1. Preparation of initial data for track calculation for durability.
2. Determination of the dynamic wheel load on rails.
3. Determinationof the equivalent load on the track.
4. Determination of the indicators of strain-stress state of construction elements of railway superstructure.
5. Setting of evaluation criteria of track durability.
6. Charts construction of strain-stress state of track and determination of admissible velocity.

The calculation was made for a typical construction of railway tracks. Typical construction of track super structure – is the construction including continuous welded railway track with rails of P65v type, concrete sleepers with a curve from 1840 to 2000 pieces per 1 km, crushed-stone ballast or jointed railway track with rails of P65 type, wooden sleepers with a curve from 1840 to 2000 pieces per 1 km, crushed-stone ballast.

Fig. 2 shows charts of stresses in the edges of rail foot for tangent and curved tracks with 600 and 300 m. radius. These charts have the maximum admissible value of stress in the edges of rail foot that accounts for 240 MPa. Acceptable speed of movement regarding hardness of route is defined by crossing point of voltage graphics in construction of the route with graphics of acceptable voltage meanings in construction of the route.

As can be seen in fig. 2(a), KZ8A locomotive can be operated in tangent and curved tracks with a speed of up to 120 km/h.

As can be seen in fig. 2(b), TE33A locomotive velocity in curve with a radius of 300 m must be limited to 80 km/h.

Fig. 2(c) shows that KZ4AC locomotive speed in curves with radius of 600 m should be limited to 180 km/h, in curves with radius of 300 m - to 110 km/h.

Fig. 3-5 show the results of stress calculation under baseplates of railway sleepers, in ballast and on a main track section of roadbed. As can be seen in fig. 3-5, stress under baseplates of railway sleepers, in ballast and on a main track section of roadbed does not exceed admissible values. Consequently, the velocity is limited to the value of design speed.

The rules of admissible speed are established on the basis of indicators of dynamics, steel works durability, impact on railway track, outstanding acceleration in curves, stability against wheels derailment.

Admissible velocity in curves of different radius and horizontal position of outer rails upon condition of non-exceedance of admissible out standing acceleration is calculated by the following formula:

$$V = \sqrt{13 \cdot R(a_{oa} + \frac{hg}{S_1})}, \quad (4)$$

where: V – velocity of vehicle, km/h; S_1 – distance between the axes of rails, for wheel track with width of 1520 mm S_1=1600 mm; g – gravity acceleration, $g = 9{,}81\ m/s^2$; R – curve radius, m; h - horizontal position of outer rail, mm.; a_{oa} – horizontal outstanding acceleration, $a_{oa} = 0{,}7\ m/s^2$

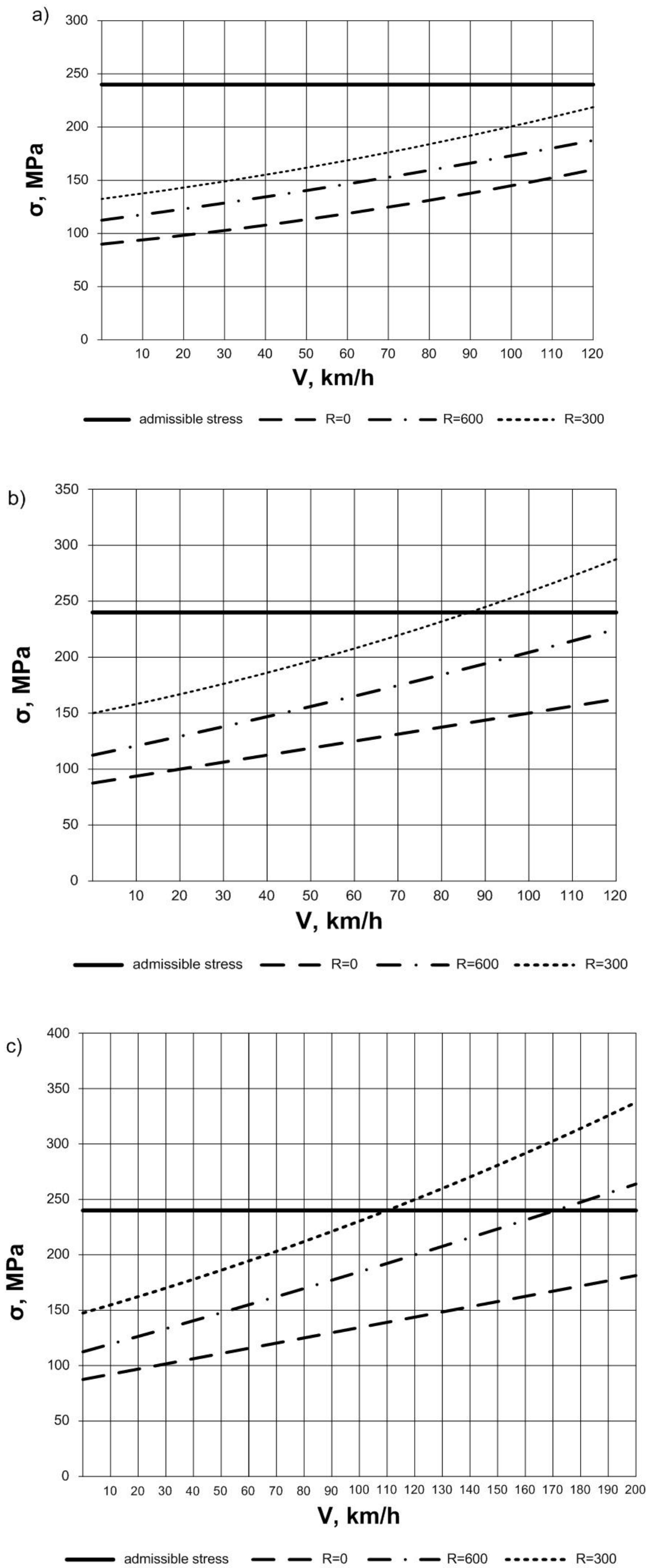

Fig. 2. Stress in the edges of rail foot in tangent (R=0 m) and curved track (R=600 m, R= 300 m) under locomotives operation: KZ8A (a), TE33A (b), KZ4AC (c)

Рис. 2. Напряжение в кромке подошвы рельса в прямой (R=0 м) и кривых участках пути (R= 600 м, R= 300 м) под действием локомотивов: KZ8A (a), ТЭ33А (b), KZ4AC (c)

Analysis of dynamic qualities of KZ4AC, KZ8A, TE33A locomotives showed that there is a speed limit for KZ4AC locomotives upon dynamic indicators in tangent and curved tracks; for KZ8A locomotives – in curves with radius less than 350 m.

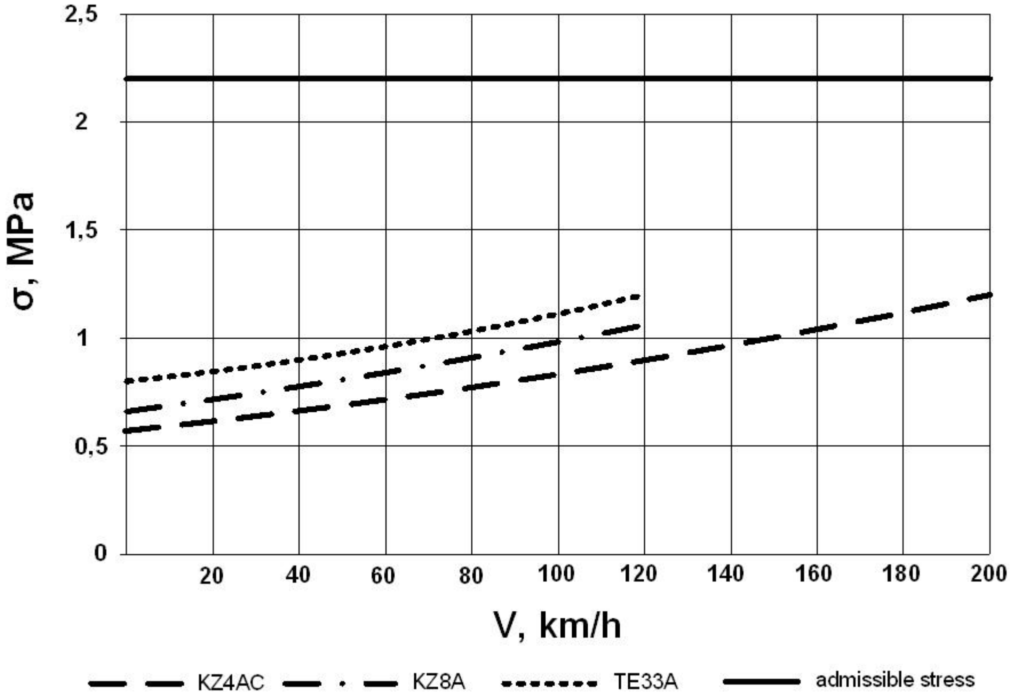

Fig. 3. Stress under rail bearing plates
Рис. 3. Напряжение под подкладками шпал

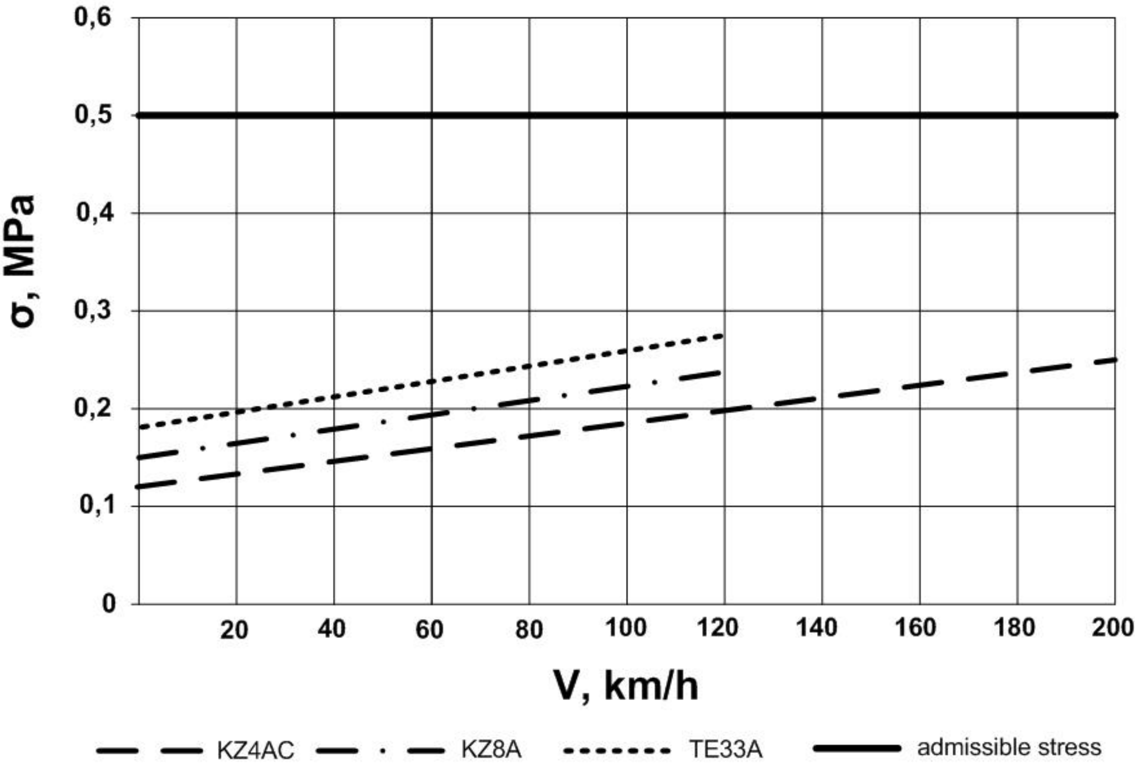

Fig. 4. Stress in ballast layer under rails
Рис. 4. Напряжение в балластном слое под шпалами

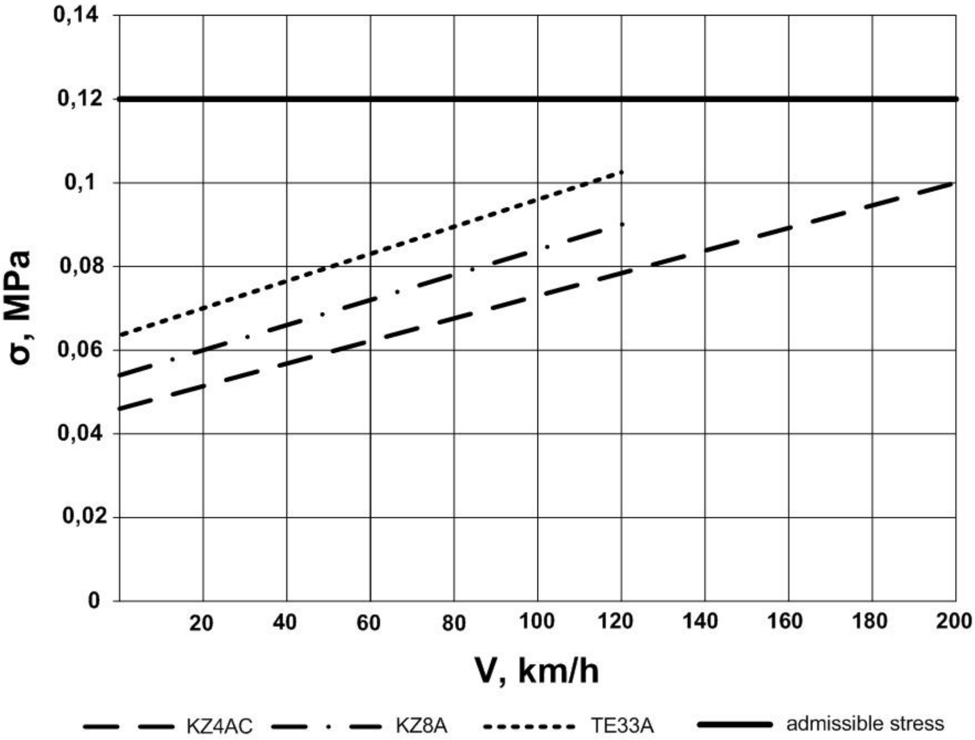

Fig. 5. Stress in the road bed
Рис. 5. Напряжение в земляном полотне

Table 3 shows the norms of admissible speeds for KZ4AC, KZ8A, TE33A locomotives for typical track construction.

Table 3
Admissible velocity of KZ4AC, KZ8A, TE33A locomotives for typical track construction

Locomotive series	**Admissible speed, km/h**								
	Straight line	**Curves radius, m**							
		1000	**800**	**700**	**600**	**500**	**400**	**350**	**300**
KZ4AC	170	145	130	125	115	105	95	85	80
KZ8A	120	120	120	120	110	105	95	75	70
TE33A	120	120	120	120	115	105	95	85	80

5. CONCLUSIONS

Based on the analysis of experimental database and calculation of route strength next scientific based norms regarding acceptable speed of movement for modern locomotives of railway system of Republic of Kazakhstan are settled:

1. For KZ4AC locomotives: on straight line sections – 170 km per hour; on curve sections of radius 1000 m and more -145 km per hour, of radius 300 m-80 km per hour.

2. For KZ8A locomotives: on straight line sections-120 km per hour; on curve sections of radius 1000 m and more -120 km per hour, of radius 300 m-70 km per hour.
3. For ТЭ33А locomotives: on straight line sections-120 km per hour; on curve sections of radius 1000 m and more-120 km per hour, of radius 300 m-80 km per hour.

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