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DOI: 10.35117/A_ENG_16_08_04

The effectiveness of the load of railway bridges

Abstract: A direct comparison of complex systems of forces occurring in the schemes loads of railway bridges is not possible. Each of the systems of movable forces of load bridge has a different structure and different geometrical parameters. Only bringing such a system into one type, for example dummy load, enables to compare the effectiveness of selected groups of loads. The multiplier load of two criteria analysis and assuming static scheme bridge elements in the form of a simply supported beam were applied in this study. The results of the comparative analysis: operational and standard loads adopted for the design, indicate that most of their effectiveness in the event of short elements (transoms and stringers) and small bridges span. In these types of elements poor representation of load model and design for locomotives operated on lines of the Polish State Railways was demonstrated.

Keywords: Load movable bridges; Comparative analysis; Multiplier loads.

Introduction

A direct comparison with each other complex systems of forces occurring in the load diagrams of code, design, model, and operating as a burden on railway and road bridges is not possible [2]. Each of the systems of forces loadmovable bridge is characterized by a different structure and different geometrical parameters [1]. Only bringing this one of the type, for example dummy load [3] allows to compare the effects of selected groups of loads. This is important for the selection criterion for determining the dummy load and static scheme of the analyzed bridge element.

To compare the two diagrams of forces: analyzed and relating to it is used a load multiplier specified in paper [2]. At the calculation are used similar criteria as for the replacement load [3]. As a design criteria in the paper the bending moments of setting middle and lateral forces on the extreme position of the load. In calculations was used the simplest model of a static element - scheme simply supported beam - often used in the design of the bridge elements. Such a scheme is also present in a large number of railway bridges main girders [2].

An important feature of both measures compared loads (substitute and multiplier) is getting an identical result of the comparison, when their determination applies the same criterion. More often applied in practice, measured by the coefficient of load [4], which was used in this study. There are analyzed three groups of moving loads of railway bridges: exploitation (in the form of diagrams of actual vehicles), standard (geometry referring to the actual vehicles) and design (scheme UIC).

Comparative analysis of a system of forces

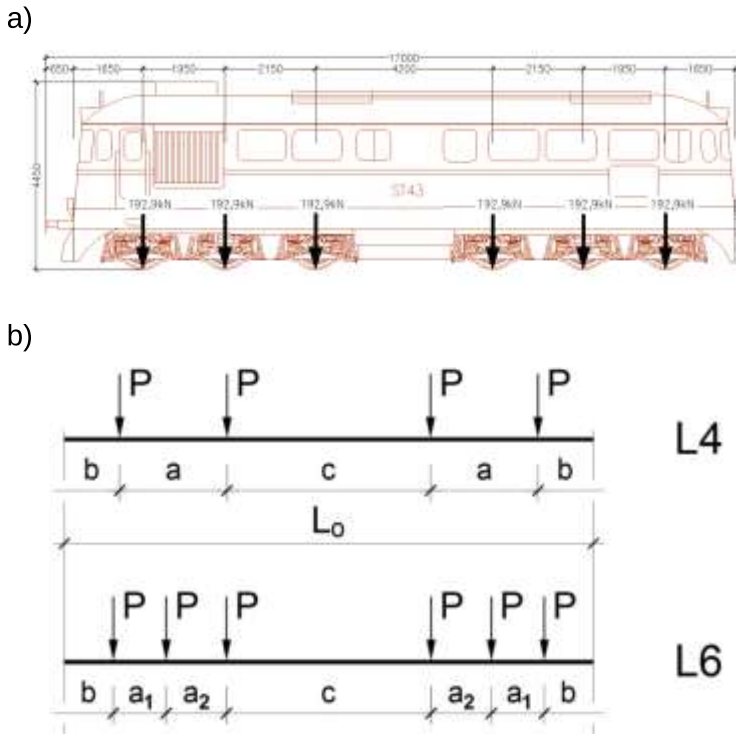
The work examines the selected examples of the heaviest locomotives in operation on railway lines - they are summarized in Tables 1 and 2. Rail loads systems schemes are concentrated forces, which can be grouped into two types: four-axle (designated herein as L4) and with six (marked as L6). The geometry of the vehicle shown in Figure 1, where: *a* – axle distance in buggy, 2*b* – the distance between the end axles in combination of vehicles (bumpers), *c* – the distance between the axles of the vehicle interior. These dimensions make the length of the vehicle L_o. Figure 1 shows an example of the geometry of the locomotive ST43 and spacing of concentrated forces as interactions axle vehicles. From the data contained in Tables 1 and 2 follows the variety of geometric and axle loads specified in values *P*.

Tab. 1. The characteristics of four-axle locomotives L4

Lp	Obciążenia		Geometria lokomotywy [m]				Nazwa
	P [ton]	*q* [ton/m]	*a*	*b*	*c*	L_o	
1	21,75	4,443	2,90	3,39	7,00	19,58	BR 189
2	21,00	5,018	2,85	2,945	5,15	16,74	EP 09
3	20,00	5,027	3,05	2,157	5,50	15,915	EU 07
4	21,50	4,550	2,60	2,955	7,79	18,90	E 186
5	22,25	4,472	2,75	3,325	7,75	19,90	E4MSU
6	22,00	4,444	2,80	3,15	7,90	19,80	Gamma
7	22,50	4,742	3,00	3,24	6,50	18,98	Loco-A

Tab. 2. The characteristics of six-axle locomotives L6

Lp	Obciążenia		Geometria lokomotywy [m]					Nazwa
	P [ton]	*q* [ton/m]	a_1	a_2	*b*	*c*	L_o	
1	20,22	5,968	1,95		2,965	6,60	20,33	Dragon
2	20,70	6,606	2,40		1,925	6,15	18,80	E31
3	20,00	6,237	1,75		2,72	6,80	19,24	ET 22
4	20,00	7,059	1,80	2,10	2,325	4,55	17,00	SM 31
5	19,67	6,942	1,95	2,15	2,30	4,20	17,00	ST 34
6	19,75	6,874	2,00		2,29	4,66	17,24	S200
7	18 +15	7,914	1,55		1,86	2,59	12,51	EDK



1. Technical parameters of the rolling stock
a) locomotive type ST43; b) loads schemes

On the weight of vehicle *G*, comprises *n* axle loads the value of *P* (in practice, they are administered in tons, as in the work). The parameters shown in Tables 1 and 2 are used to determine applied in practice, train the technical characteristics of the vehicle included in the relationship

$$q = \frac{G}{L_o} = n\frac{P}{L_o} \ [ton/m]. \qquad (1)$$

P axle load and total weight of the vehicle *G* and calculated by the formula (1) the value of a replacement distributed load *q* are the basis for the classification of technical locomotives [4]. When we consider as the reason for classifying the axle loads *P* are obtained the following sequence locomotives in Table 1 (7, 5, 6, 1, 4, 2, 3) and on the basis of load *q* classification is completely different (3, 2, 7, 4, 5, 6, 1). In case of locomotives listed in the Table 2 are respectively obtained: (2, 1, 3, 4, 6, 5, 7) and appropriately (7, 4, 5, 6, 2, 3, 1). Therefore, the order of locomotives in such combinations is diverse. Because of the weights *G* locomotives were examined separately locomotives with geometries *L4* and *L6*.

The usefulness of technical parameters of the classification locomotive *G, P, q* is small, as shown in the examples as the following operation. Due to be considered in the work of the lengths load L < 11 m length of the vehicle is not significant L_o. It is important in bridges with medium and large spans [2].

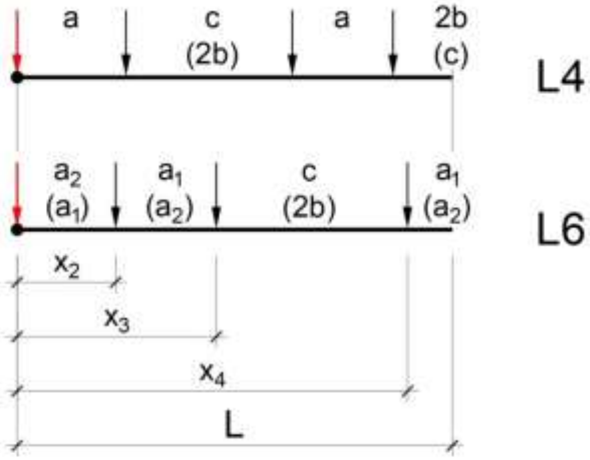
The criteria for calculating the load multiplier

Qualifications of rail vehicles was based on standard [4] on the value of the multiplier load. Multiplier load is a dimensionless quantity, engaging the ratio of two identical (in the physical sense) size, e.g. internal forces, stresses, displacements - from two selected schemes forces. The effect of load, indicated by *Q*,is caused by the group of concentrated forces dependent on the geometrical parameters of the locomotive, *a*, *b*, *c*, as shown in Fig. 1. In general, load multiplier is determined by the formula

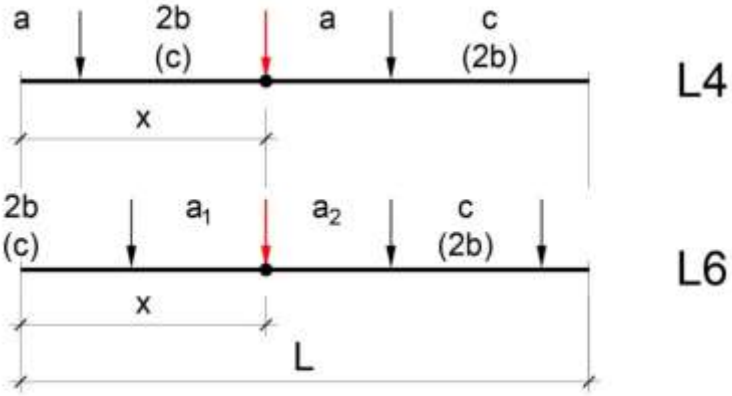
$$M_u(W,A) = \frac{Q_u(A)}{Q_u(W)} \qquad u = s, c. \qquad (2)$$

In the formula (2) as Q was indicated effects of loads connected with e.g. the inner strength, stress, displacement. As indicated in the diagrams settings of forces used at work, as shown in figures 2 and 3. Location of forces (called setting) on the beam is such as to cause the greatest value analyzed the size of the static. Thus, when the dependence occurs $M_u > 1$, it means that the analyzed load *A* is more effective than the load related (in formula (2) a standard locomotive W). Standard loads parameters used in the norm [4], are reported in Table 3.

Load multipliers in the setting of central *C* schema are determined using the criterion of the bending moment, as shown in Fig. 2, or the lateral force (or support reaction) in the template of extreme setting *S*, as shown in Fig. 3. In the case of short items, it is important to local extreme bending moment created at the point of load concentrated force, at a considerable distance from the center of span. Then the comparison of the maximum static coming from two different loads does not concern the same point of the beam, for example in case of symmetric setting, when $x = L/2$ in a three-concentrated forces system. Due to the different axle geometries of locomotive there are possible load systems shown in Figures 2 and 3, with smaller distances between buggies $2b < c$ or $c < 2b$.



2. Schemes forces of extreme load setting



3. Schemes forces of the central load setting

Criterion of transverse force

Fig. 2 shows the position of the of forces P used for determining Q_s as the maximum value of transverse force. The forces in this arrangement appear only on the right side of the extreme point, the forces that may be on the left side, are discarded from consideration. Of course, in highlighted extreme point always occurs concentrated force and the result of the calculation is expressed with dependence

$$Q_S = \frac{P}{L}\sum_{i=1}^{n}\left(L - x_i\right). \tag{3}$$

The calculation takes into account the number of forces n, which are located on a length L. The location of these forces takes into account the geometry of the locomotive so as to obtain the maximum value Q_s. With the parameter values given in Tables 1 and 2 that when $2b < c$ it is preferable to set two locomotives at a distance of L.

Figure 4 shows the results of calculations in the form of multipliers load using the formulas (1) and (3). The common, variable parameter is the length L. Set of plots shown in Figures 4a and 4b relates to the geometry of locomotives L4, while Figures 4c and 4d show the results of of vehicles L6. Parameters of analyzed locomotives, marked as A are summarized in Tables 1 and 2. In each group of charts was used another standard locomotive treated as a load related.

All charts it show that the highest values obtained in case of short elements - which practically refers to platforms (stringers and transoms) and bridges with span. With the increase of segment L results are stabilizing. This justifies dealing in work with range L <11 m much shorter than the length of the locomotives L_o, given in tables 1 ÷ 3. From the graphs shown in Figure 4 follows that the classifications of locomotives due to the value of P, q, or G are no longer meaningful to overarching value L and the mutual distance between the axles of the locomotive.

Bending moment criterion

Figure 3 shows the position of the forces used in determining the bending moment near the center of the beam span. Focal point in these schemes is the distance from the force relating P from the beginning of the segment. It divides the forces in such a way that on each side fit on the distance of L. Of course, in highlighted, central point there is always concentrated force and there arises a maximum value Q_c.

When on part a length L is located one concentrated force P then is obtained the value

$$Q_c = \frac{PL}{4} \quad . \tag{4}$$

Where appear two forces P, far from each other about the value and condition is fulfilled [2]

$$L < \frac{2+\sqrt{2}}{2}a \quad , \tag{5}$$

We obtain

$$Q_c = \frac{P}{8L}\left(2L - a\right)^2 \quad . \tag{6}$$

In case of locomotive *L6* in formulas (5) and (6) as a is the minimum value a_1 or a_2.

When on the length of section L are three forces P *L4* of the vehicle and the relationship is fulfilled

$$L > \frac{a+4b}{\sqrt{6}} + 2b \quad , \tag{7}$$

we receive a value

$$Q_c = \frac{P}{12L}\left[(3L + a - 2b)^2 - 12aL\right] \quad . \tag{8}$$

If this applies to vehicle *L6* then (when *a1*> *a2*) in the formulas (7) and (8) as a should be substituted as $a = a_1$ and $2b = a_2$. When $a_1 = a_2$ formulas (7) and (8) will simplify respectively to form

$$L > \frac{2+\sqrt{6}}{2}a \tag{7a}$$

and

$$Q_c = \frac{P}{4}(3L - 4a) \quad . \tag{8a}$$

When on the length of the segment *L* are four forces of the vehicle and *L4* is complied the relationship

$$L > \frac{3+2\sqrt{3}}{3}(a+b)+b \quad , \tag{9}$$

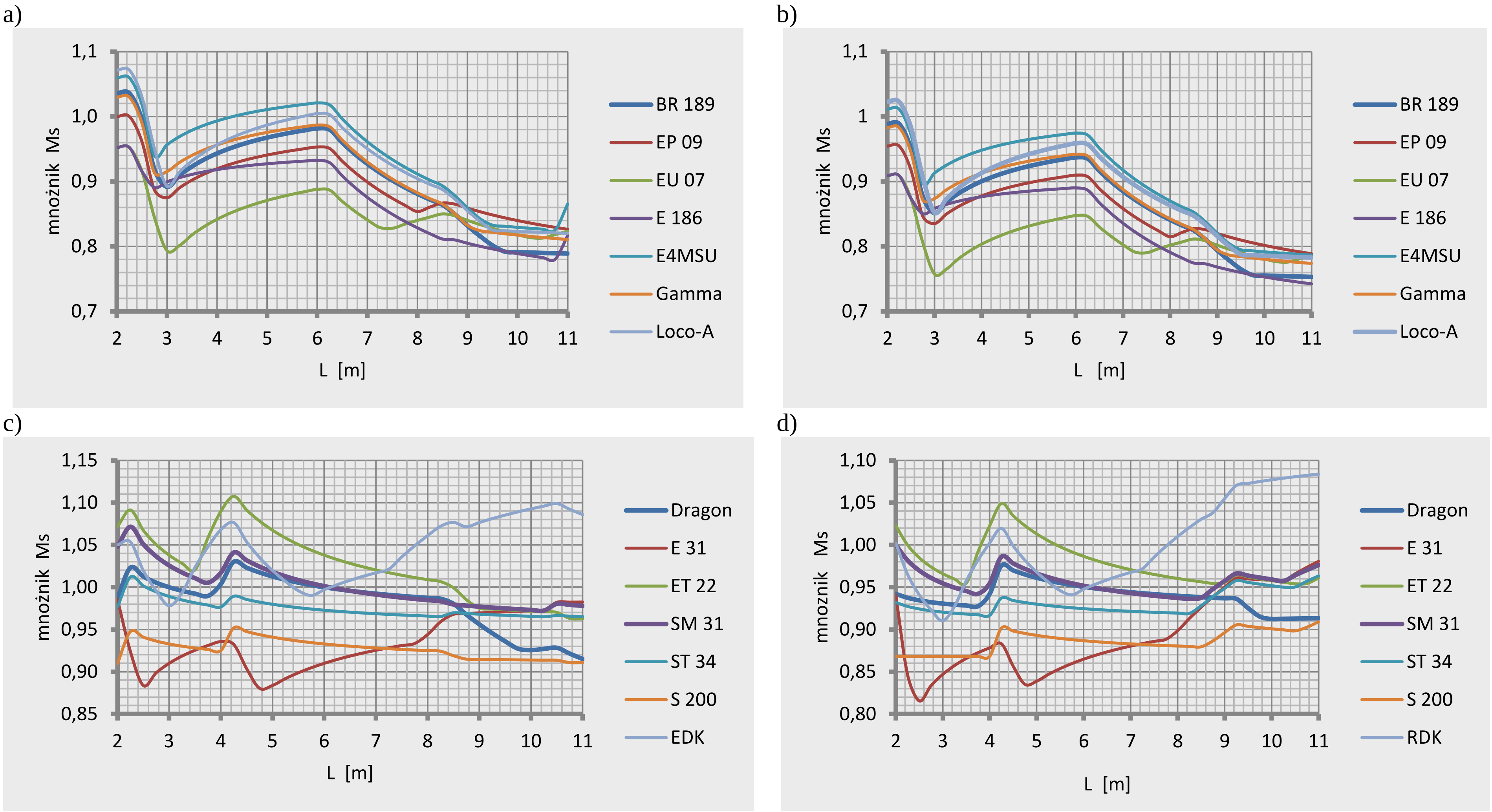
we obtain

$$Q_c = \frac{P}{L}\left[(L-b)^2 - aL\right] \quad , \tag{10}$$

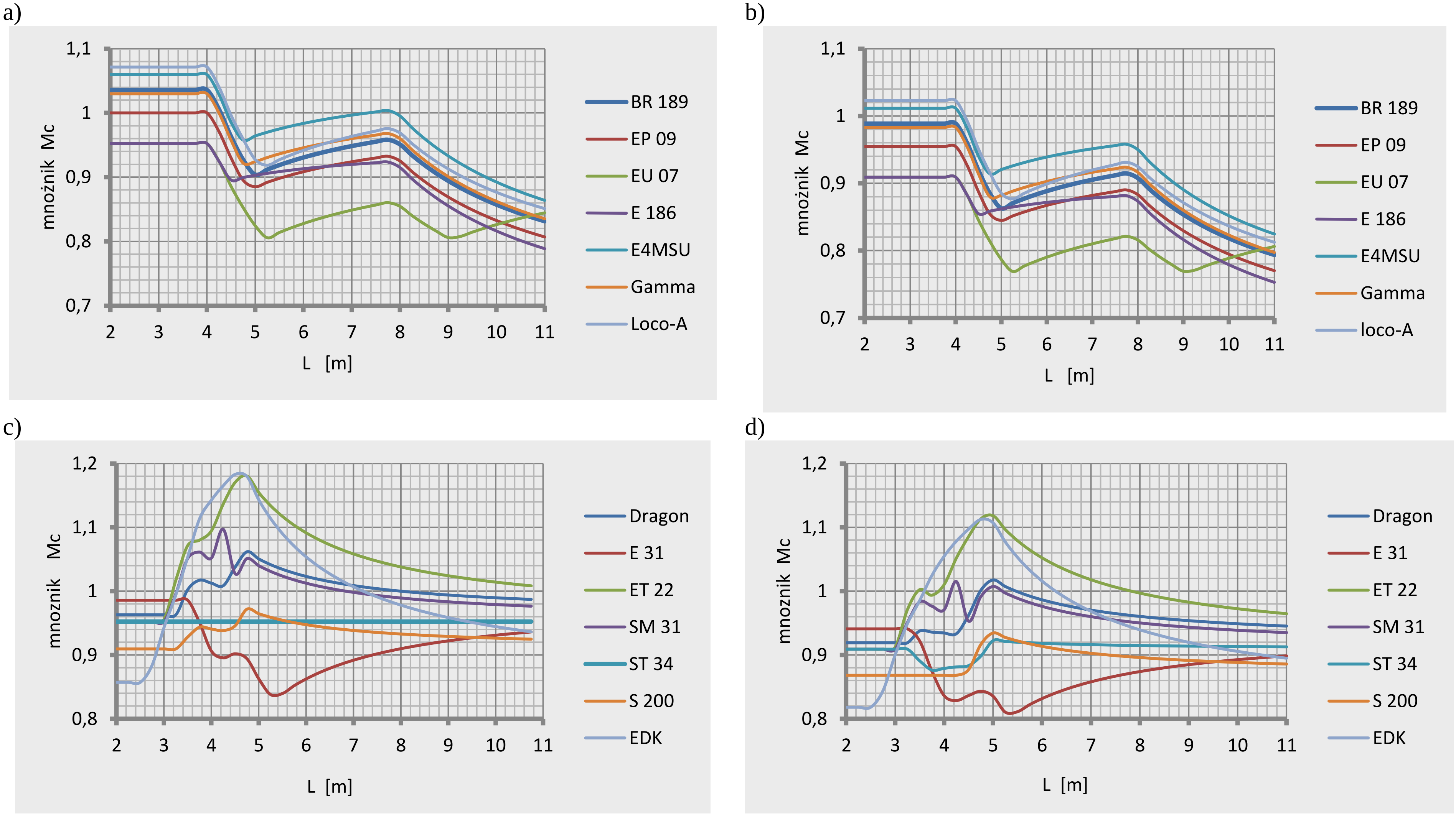
when $2b < c$ and appropriately for the vehicle L6 (when $2b < c$ and $a = a_1 = a_2$)

$$Q_c = \frac{P}{16L}\left[(4L - a - 2b)^2 - 16aL\right] \quad . \tag{11}$$

Figure 5 shows the results of calculations in the form of multipliers load using formulas (1) and (4) ÷ (11). Alternating parameter is the length of the segment L. Group of charts shown in Figures 5a and 5b apply to locomotives geometry L4, while the figures 5c and 5d shows the results for vehicles L6. From these diagrams follow the conclusions given previously when analyzing extreme settings.



4. Loads ultipliers calculated with using extreme settings of locomotives, designated as: a) $M_s(A,L4_{21})$; b) $M_s(A,L4_{22})$; c) $M_s(A,L6_{21})$; d) $M_s(A,L6_{22})$



5. Loads multipliers calculated using of the central setting of locomotives, marked as: a) $M_c(A,L4_{21})$; b) $M_c(A,L4_{22})$; c) $M_c(A,L6_{21})$; d) $M_c(A,L6_{22})$

Models of rolling stock

In the norm PN-EN 15528: 2008 [4] has been adopted two groups of models of rolling stock, in the form of wagons and standard locomotives *L4* and *L6* of the technical parameters listed in Table 3 and the UIC scheme, as shown in Figure 6. Scheme UIC has been used for a long time to design elements construction of bridges. Therefore important is the relationship between the analyzed earlier models of locomotives *L4* and *L6* and the diagram UIC. Fig. 7 shows graphs in the form of loads multipliers derived from a comparison of these models - as before the adoption of extreme and central set. The result of the calculation with a use of formula (2) adopt in this case form

$$M_u(W,UIC) = \frac{Q_u(UIC)}{Q_u(W)} = \alpha_k \frac{Q_u(UIC,\alpha_k = 1)}{Q_u(W)} \qquad u = s, c \qquad . \qquad (12)$$

The calculations assuming the scheme load UIC with $\alpha_k = 1$, as in fig. 6, obtain the value of norm load multiplier α_k. as in formula

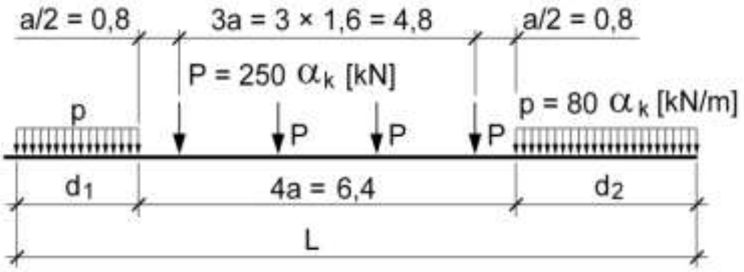
$$\alpha_k = \frac{Q_u(W)}{Q_u(UIC,\alpha_k = 1)} \qquad u = s, c \qquad , \qquad (13)$$

when established (12), that $Q_u(UIC) = Q_u(W)$. So that graphs shown in Figure 7 contain information about the standardized load class railway facilities.

From the graphs shown in these figures general trend is a large decrease in the value of class load along the length of the stretch *L*. In case of analyzed standard locomotives of the biggest pressures on the axes $L6_{22}$ these fluctuations amount from α_k= 0,9 to α_k= 0,4 which practically means a scatter of results by four class loads. Thus, there is no compatibility of model railway vehicles - in this case locomotives L4 and L6 for small values *L*.

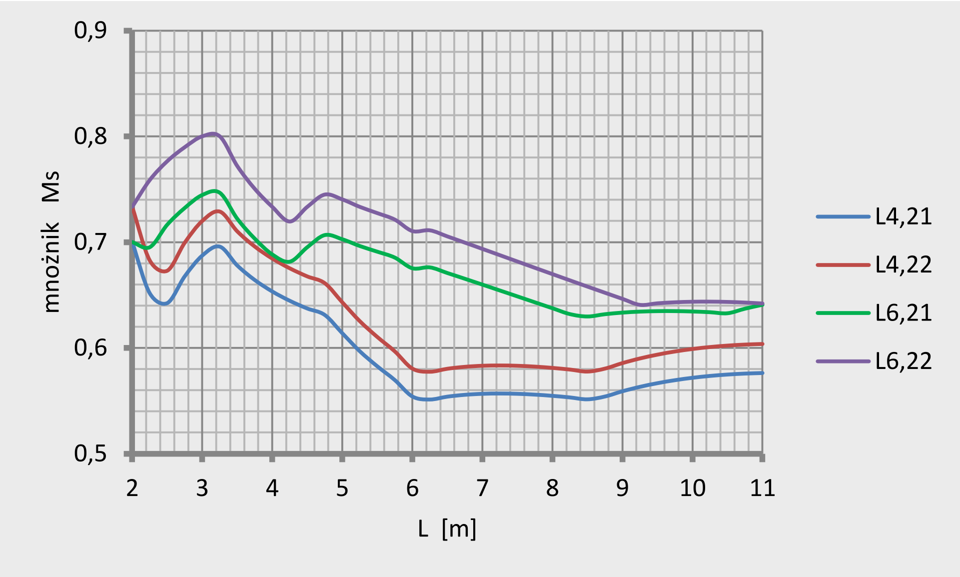
Tab. 3. The characteristics of standard loads

Oznaczenie	Obciążenie		Geometria lokomotywy [m]				
	P [ton]	*q* [ton/m]	a_1	a_2	*b*	*c*	L_o
$L4_{21}$	21	5,793	2,4		1,9	5,9	14,5
$L4_{22}$	22	6,069					
$L6_{21}$	21	6,396	2,1		2,1	7,1	19,7
$L6_{22}$	22	6,377	2,25	2,0	2,5	7,2	20,7

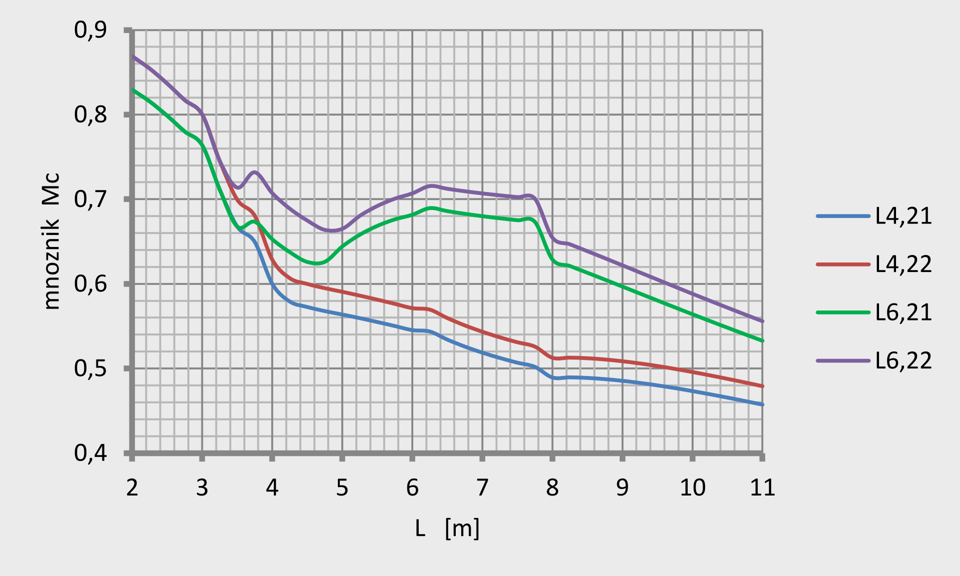


6. Diagram of forces UIC 71

a)



b)



7. Loads multipliers calculated using of the central setting of locomotives, marked as: a) $M_c(L4_{22}, UIC)$; b) $M_c(L6_{22}, UIC)$

Summary

To compare patterns of forces analyzed and relating to them was used in the work load multiplier [2]. For its calculation as a comparative criterion, has been adopted settings - the middle and the extreme position of the load. In calculations was used the simplest model of a static element - scheme simply supported beam - often used in the design of the bridge elements. This pattern occurs in a significant number of the main railway bridge girders [2].

In this paper results of the calculations are given in form of graphs multipliers load with a variable parameter in the form of a length of the element *L*. Charts are shown in groups concerning locomotives geometry *L4* and *L6*. These diagrams show that the highest value is achieved when the elements of short platforms (stringers and transoms) and small bridges span. With the rise of a segment *L* results are stabilizing.

From the charts of comparative design load UIC and standard locomotives L4 and L6 show a trend to a large decline in the value class load along the length of the stretch L. Also, a comparison of standard loads and operating follows similar relationship. Thus, models of railway vehicles, locomotives in this case, no longer reflect well their compliance with load UIC, which is used to design bridges for the case of small values of L.

Source materials

[1] Aktualne zagadnienia budownictwa komunikacyjnego. Praca zbiorowa. Seria Monografie Zakładu Mechaniki Teoretycznej i Mechaniki Nawierzchni Komunikacyjnych. Wydział Inżynierii Lądowej Politechniki Warszawskiej. Warszawa 2015.

[2] Machelski C.: Ruchome obciążenia obiektów mostowych. Dolnośląskie Wydawnictwo Edukacyjne, Wrocław 2015.

[3] Machelski C.: Zastępcze obciążenie ruchome mostów kolejowych. Inżynieria i Budownictwo. 9/2015 s. 389-299.

[4] Norma PN-EN 15528:2008. Kolejnictwo – klasyfikacja linii w odniesieniu do oddziaływań pomiędzy obciążeniami granicznymi pojazdów szynowych a infrastrukturą.