ARTICULATED ENGINEERING EQUIPMENT STABILITY SIMULATIONS BASED ON Ł34 WHEEL LOADER

Stanisław Konopka, Piotr Krogul
Marian Janusz Łopatka, Tomasz Muszyński

Military University of Technology, Faculty of Mechanical Engineering,
Department of Construction Machinery
Gen. S. Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 6837416, fax: +48 22 6839616
e-mail: pkrogul @wat.edu.pl

Abstract

This paper presents dynamic stability simulation tests of the Ł34 dynamic loader. The simulations were run according to military standards of United States of America. Tested loader had to overcome two obstacles at a first gear velocity. The first obstacle were pothole, while second one were rut. The current obstacles were crossed by Ł34 loader with two configurations. The first of them were loader in transport configuration, whereas second one were loader with maximum lift height of the bucket. The crossing of the rut was performed only by the loader in transport configuration, whereas passing of the pothole was performed by the loader in both configurations. The two obstacles also were crossed by loader with a nominal load and without it. This paper also defines effects of the modification of loader with more stiffer and more flexible tyres. There were also consider effects of the modification of Ł34 loader with integrated articulation.

Keyword: *modelling, MSC Adams, stability*

1. Introduction

Articulated loaders' dynamic stability is a very important issue since what is at stake in this case is human life and health. The document which currently defines loaders' stability (in the context of statics), through defining their nominal loading capacity, is the PN-EN norm 474-3:1999 [7]. By contrast, in the USA military requirements [4] have been worked out as regards methods of testing engineering equipment in the context of preserving dynamic stability. The concept of preserving dynamic stability stands for the ability to negotiate particular terrain unevenness while retaining movement stability with limited effect on the operator. According to the requirements, loaders are tested through negotiating obstacles of required parameters at a constant travel velocity. The first obstacle is a 100 mm deep pothole wide enough for the wheel to easily drive into it, whereas the second one is a 200 mm deep rut left by a Ł34 loader, placed at a 30-degree angle relative to the tested loader's travel direction. The loss of stability was defined as the moment at which any one of the wheels loses contact with the ground at a velocity of 1.4-2.8 m/s.

The aim of the investigation was to determine, by means of simulation, the ability to negotiate obstacles defined in [4] by a standard wheel loader. The tests were conducted on the Ł34 loader model. It was assumed that the loader's parameters might be modified by a change in the tyre stiffness or by the use of an integrated articulation. The term integrated articulation stands for a mechanism enabling front segment's rotation relative to the rear one at the steering pivot point, around the longitudinal axis of the vehicle. The tyre stiffness was increased by means of using smaller diameter tyres and applying higher pressure, whereas a decrease in their stiffness was obtained by applying lower pressure to bigger diameter tyres. The parameters determining dynamic stability preservation are as follows:

a) operator seat vertical acceleration, $a_v<25m/s^2$ for single obstacles [1],
b) operator seat horizontal acceleration (transverse or longitudinal), $a_h<4.5m/s^2$, a value at which an average person is thrown out of their seat [5],
c) vehicle's longitudinal tilt angle, <6° [1],
d) tyre deflection, min. 25% of its static deflection.

2. Ł34 loader numerical model

The numerical model of the Ł34 loader was worked out with the use of the Catia and the MSC Adams programs. The model is characterized by a spatial, multi-mass arrangement (with 16 degrees of freedom) consisting of stiff elements connected by proper, ideal constraints (Fig.1), with the linear contact between the wheels and the ground.

In order to obtain the most precise projection of the vehicle mass properties, its model was worked out on the basis of the geometric approach (projecting shapes of particular elements) and weight approach (weights of particular elements are input on the basis of the catalogue data) [3]. With the application of the above-mentioned approaches, the loader's total operating weight is 18.5 tons, which complies with the catalogue data [6].

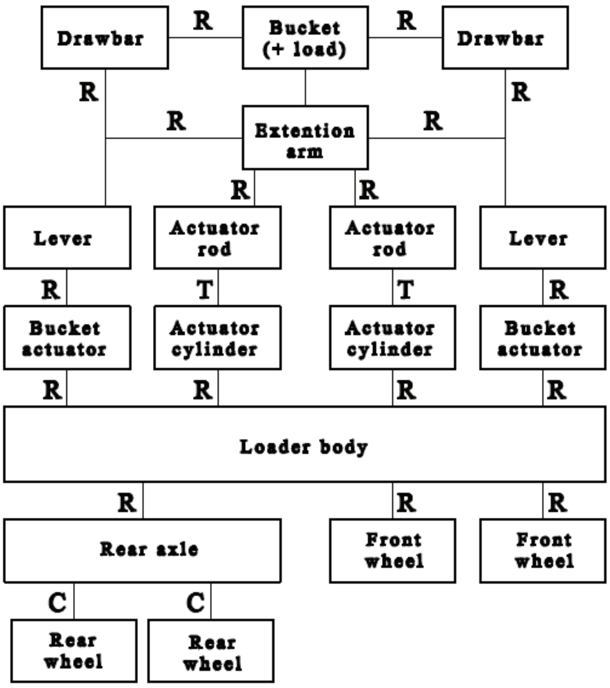

Fig.1. Diagram showing types of connections between particular elements in the numerical model of the Ł34 loader: R-rotating joint, T-travelling joint, C-cylindrical joint

3. Numerical model parameters

The loader's model contains spring-damper elements of the tyres and of the extension arm. The radial stiffness of a 23.5-25-size tyre, with the rear pressure of 0.18MPa and the front one of 0.35 MPa was selected on the basis of the literature data [2]. The value of the damping ratio was selected on the basis of the determined time graph of the longitudinal acceleration effects on the seat of the Ł34 loader operator resulting from a sudden stop of the work equipment in the course of free load lowering [2]. The flexibility of the extension arm cylinders' hydraulic system was selected in the same way as was the case with the tyre damping value. The values of the spring-damper elements are shown in Tab. 1.

Tab. 1. Values of spring-damper elements in numerical model

	Stiffness kN/m	Damping Kn˙s/m
Spring-damper element of front wheel	800	40
Spring-damper element of rear wheel	600	40
Spring-damper element of extension arm's actuator	30000	100

4. Simulation run

The simulations were performed on a hard, undeformable surface. The simulation consisted of travelling across ground obstacles at a constant velocity and recording desired indications. In accordance with [4], two variants of a ground obstacle were examined, i.e. a pothole and a rut. In operating conditions, the cooperation between the tyre and the ground has deformable characteristics (not stiff, as in the case of the model), due to which a sinusoidal shape of obstacles was selected (Fig. 2a and 2b). The US military requirements provide that drives should be performed at first gear velocities ranging from 1.4 to 2.8 m/s. Due to the above, drives across the two obstacles were conducted for velocities ranging from 1.4 to 2 m/s (in accordance with the Ł34 loader,s first gear velocities) [6].

a) b)

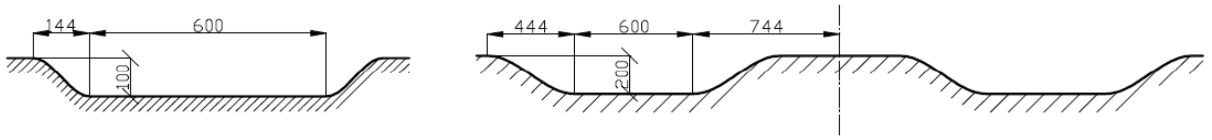

Fig. 2. Obstacles: a – pothole, b – rut

a) b)

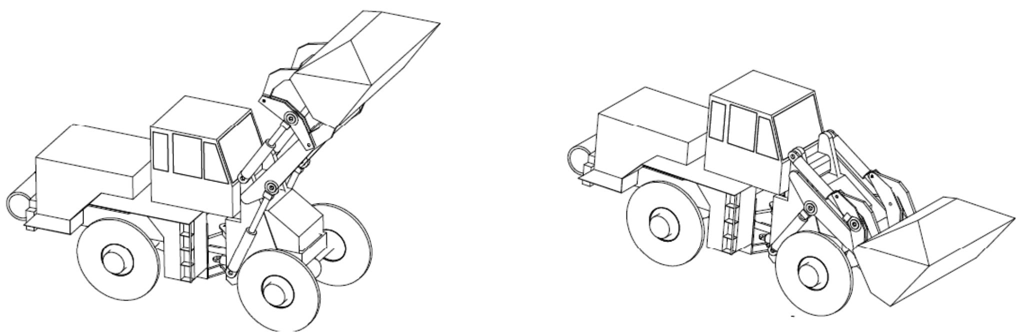

Fig. 3. CATIA model of the Ł34 loader: a – with maximum lift height of the bucket, b – transport configuration

The two obstacles were crossed with a nominal load of 5000 kg as well as without it. In compliance with the military requirements [4], the drive across the pothole was run for the transport configuration of the vehicle, i.e. with the bottom edge of the bucket situated 300 mm above the surface (Fig. 3b) as well as for the maximum lift height of the loader's bucket (Fig. 3a). The crossing of the rut was performed in the transport configuration.

After that, test drives were performed for the loader with an integrated articulation as well as for the loader with stiffer (front - 1100 kN/m, rear – 800 kN/m) and more flexible (front – 500 kN/m, rear – 400 kN/m) tyres. The represented modifications were examined for the most disadvantageous velocity, which was determined for the initial stiffness of the tyres in the course of crossing both obstacles.

5. Simulation findings

At the first stage of the simulation the most disadvantageous velocity at which the obstacles were crossed was determined on the basis of the evaluation criteria. The comparison of the maximum acceleration is shown in graphs 5, 6 and 7. It is worth noticing that the vertical acceleration values (Fig. 5), in neither of the investigated configurations, reach the assumed boundary values (see subsection A in introduction). However, horizontal acceleration values (Fig. 6 and 7), for almost all the investigated configurations, exceed their assumed boundary (see subsection B in introduction) and increase with the velocity increase. It is also worth noticing that the investigated loader meets the criteria for the assumed horizontal acceleration only as regards crossing a pothole, with the maximum lift height of the unloaded bucket, up to the velocity of 1.8m/s or, in the case of carrying a load with the same position of the bucket, up to the velocity of 1.4m/s. An exemplary time graph of longitudinal acceleration effects on the operator for the maximum lift height of the loaded bucket while crossing a pothole at a velocity of 2m/s is shown in Fig. 8.

The analysis of the deflection values for particular tyres relative to four velocities (Fig. 9, 10 and 11) indicates that, while crossing a rut with no load, the model loses contact with the ground at the velocity of 2m/s. It should also be noticed that in the course of crossing a pothole, with the maximum lift height of the bucket, and with no load, the deflection value is close to 0, which refers to almost the entire range of the investigated velocity. As a result, it was estimated that the most disadvantageous velocity was 2m/s.

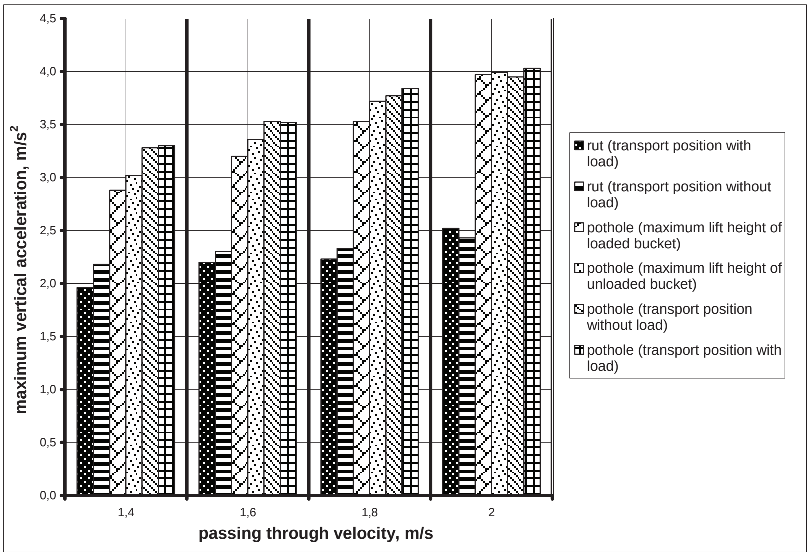

Fig. 5. Vertical acceleration effects on operator, for selected passing through velocities

The next stage included simulations examining the effects of the tyre stiffness modification and of the use of an integrated articulation on the loader static stability improvement. The simulations were run for the velocity of 2 m/s and the comparison of their findings is shown in Tab. 1 and 2.

On the basis of the data in chart 2, it may be concluded that an increase in the tyre stiffness leads to the increase in the acceleration affecting the operator and, practically, to the loss of contact between the tyre and the surface in the course of crossing a rut. On the other hand (as regards crossing a rut), the use of more flexible tyres decreases acceleration affecting the operator and prevents tyres from losing contact with the surface. A similar interdependence can be seen as regards the decrease in the tyre deflection, which is in proportion to the increase of its stiffness while negotiating a pothole. Taking into account acceleration variations, the application of stiffer tyres for crossing a pothole, with the maximum lift height of the loaded bucket, causes a decrease in the longitudinal acceleration; in the other cases, stiffer tyres either react in the same way as in the case of a rut or they display reactions oscillating in the proximity of the values for standard tyres.

Integrated articulation causes a significant increase in the transverse acceleration effects on the operator (Tab. 3). It is caused by a decrease in the inertia of the system affecting the operator, which is due to reducing mutual interactions between the loader's front and rear (connected to the operator) segments. To reduce this effect, it is suggested that damping should be applied between the loader's segments to stabilize the transverse tilt.

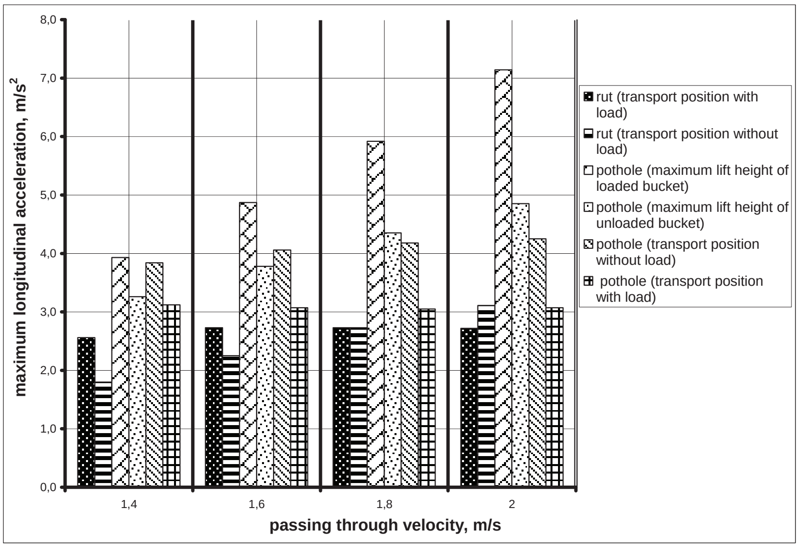

Fig. 6. Longitudinal acceleration effects on operator, for selected passing through velocities

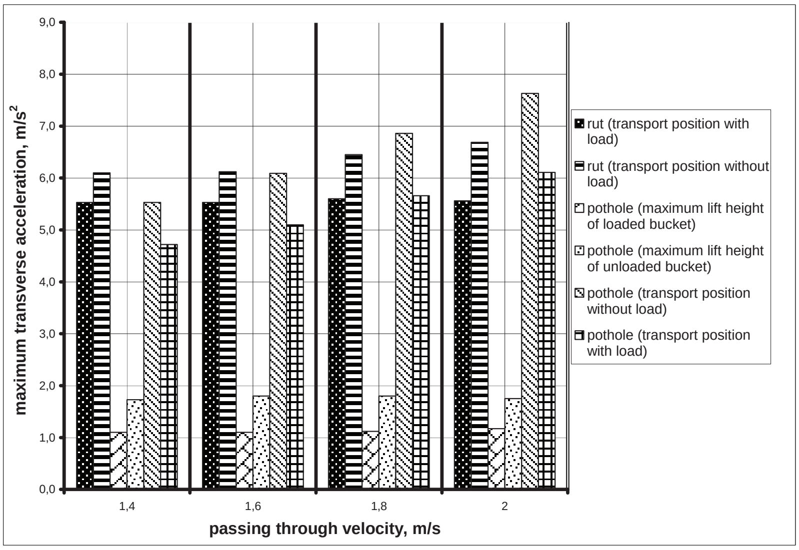

Fig. 7. Transverse acceleration effects on operator, for selected passing through velocities

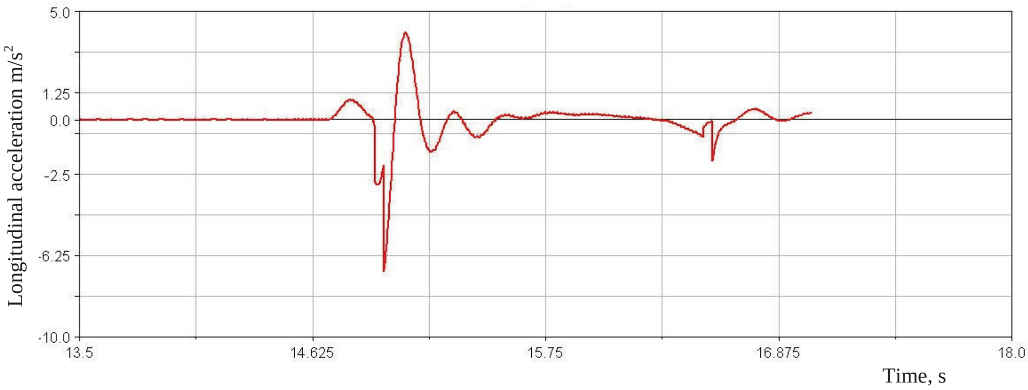

Fig. 8. Time graph of longitudinal acceleration effects on operator while crossing a pothole at the velocity of 2 m/s, for maximum lift height of loader's bucket

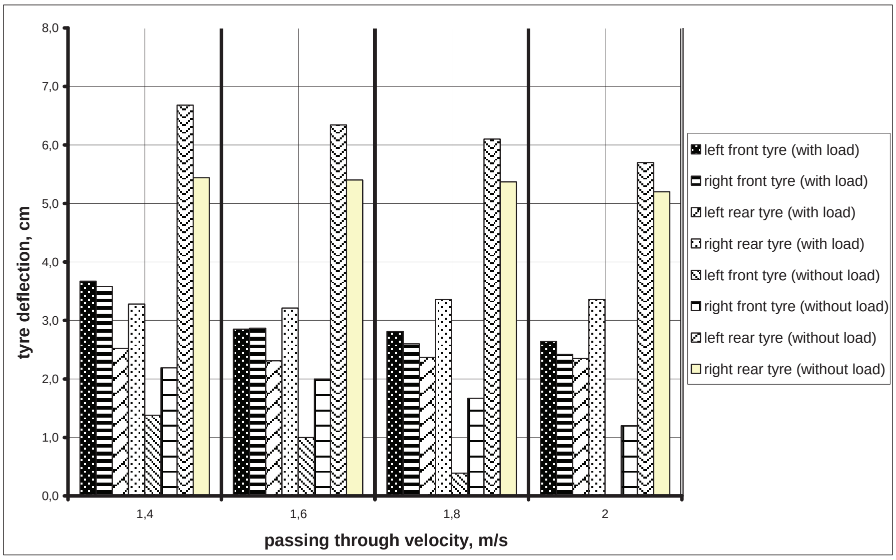

Fig. 9. Tyre deflection relative to the velocity of crossing a rut (transport position)

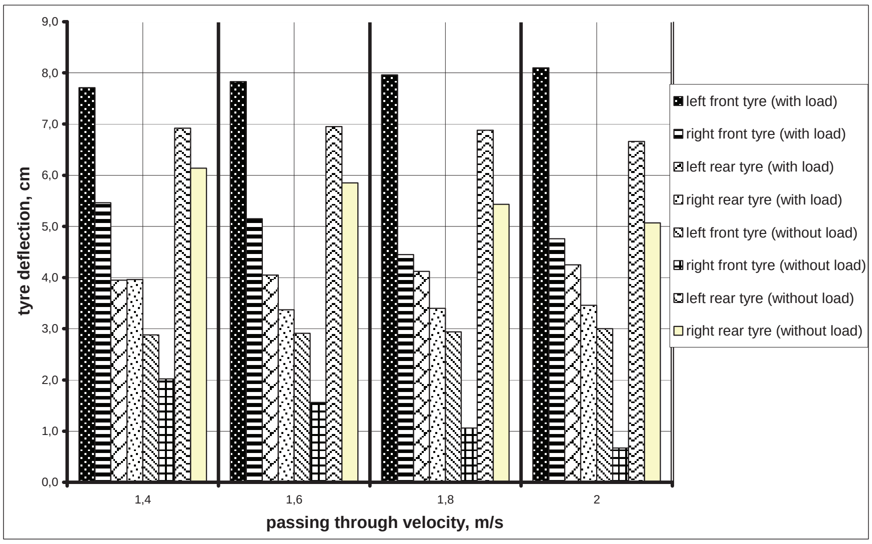

Fig. 10. Tyre deflection relative to the velocity of crossing a pothole (transport position)

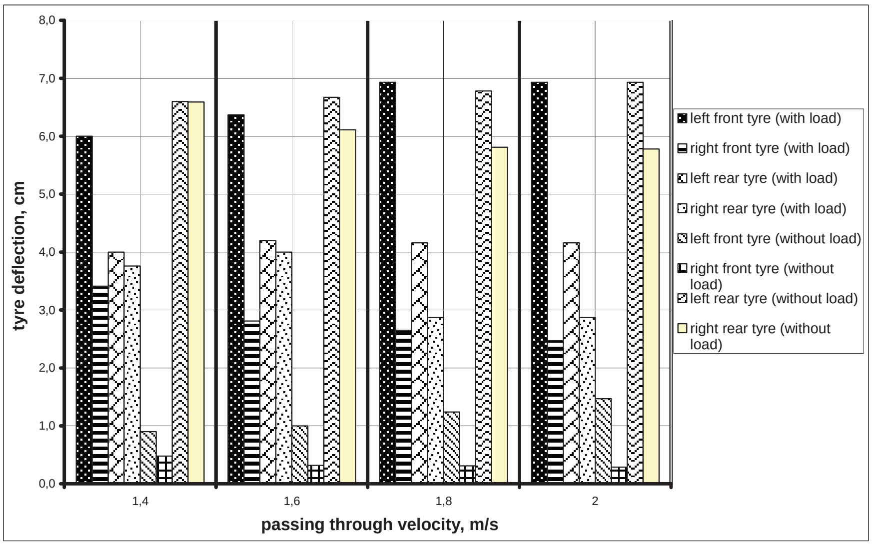

Fig. 11. Tyre deflection relative to the velocity of crossing a pothole (maximum lift height of loader bucket)

Tab. 2. Tyre stiffness effect on Ł34 loader stability

			Rut						Pothole (maximum lift height of bucket)						Pothole (transport position)					
			with load			without load			with load			without load			with load			without load		
			standard	soft	hard	standard	soft	hard	standard	soft	hard	standard	soft	hard	standard	soft	hard	standard	soft	hard
Acceleration affecting operator, m/s^2	vertical		2.5	2.0	3.2	2.4	2.2	2.9	2.9	3.3	4.3	4.0	3.6	4.5	4.0	3.3	4,7	4.0	3.2	4.7
	horizontal	longitudinal	2.7	2.2	3.6	3.1	2.8	3.4	7.1	5.6	6.7	4.9	4.7	4.4	3.1	3.5	3,3	4.3	3.8	4.9
		transverse	5.6	4.6	8.3	6.7	5.1	8.0	1.1	1.1	1.2	1.8	1.6	1.9	6.1	5.3	7,4	7.6	6.5	9.1
Tyre deflection, cm	right	front	2.4	7.2	0.2	1.2	3.7	0.4	3.4	7.8	0.8	0.3	1.8	0.0	4.8	9.4	2,0	0.7	2.8	0.3
		rear	3.4	5.1	1.7	5.2	8.7	3.7	3.8	6.6	1.5	5.8	9.4	3.8	3.5	5.5	1,8	5.1	9.2	3.8
	left	front	2.6	7.5	0.4	0.0	1.6	0.0	6.0	12.5	4.5	1.5	4.7	0.2	8.1	14.1	5,3	3.0	6.1	1.7
		rear	2.4	4.9	1.0	5.7	9.6	4.0	4.0	8.4	2.6	6.9	11.4	4.5	4.3	7.1	2,4	6.7	11.0	4.7

Tab. 3. Integrated articulation effect on dynamic stability

			Rut				Pothole (maximum lif height of bucket)				Pothole (transport position)			
			with load		without load		with load		without load		with load		without load	
			swing axle	integrated articulation	swing axle	integrated articulation	swing axle	integrated articulation	swing axle	integrated articulation	swing axle	integrated articulation	swing axle	integrated articulation
Acceleration affecting operator, m/s^2	vertical		2.5	2.9	2.4	2.7	4.0	3.8	4.0	4.0	4.0	4.2	4.0	4.1
	horiz ontal	longitudinal	2.7	2.5	3.1	3.2	7.1	5.5	4.9	4.7	3.1	3.3	4.3	4.0
		transverse	5.6	13.5	6.7	13.9	1.1	10.9	1.8	9.8	6.1	11.4	7.6	10.6
Tyre deflection, cm	right	front	2.4	2.3	1.2	0.9	2.5	2.9	0.3	0.4	4.8	4.6	0.7	1.2
		rear	3.4	2.1	5.2	4.0	2.9	2.0	5.8	4.3	3.5	2.1	5.1	3.9
	left	front	2.6	2.8	0.0	0.8	6.9	7.1	1.5	1.7	8.1	8.3	3.0	3.4
		rear	2.4	0.2	5.7	3.9	4.2	4.6	6.9	6.9	4.3	4.0	6.7	7.0

6. Conclusion

On the basis of the simulations, it may be concluded that, in the light of the recommended tests, and within the investigated velocity, the Ł34 loader does not meet all the assumed criteria at the same time. The drive with a load helps to maintain contact between the wheels and the surface while crossing assumed obstacles. Increasing tyre stiffness results in decreasing tyre deflection, which leads to the loss of contact between the wheel and the surface while crossing a pothole with a load for both positions of the bucket. In contrast, integrated articulation intensifies transverse acceleration effects on the operator while negotiating a rut and a pothole, due to which it is necessary to join together the segments of the vehicle. In summary, the above simulations may be adopted as additional criteria for granting permission to operate loader-type articulated equipment on the work site.

References

[1] Hölinger, M., Glauch, U., Mobility *Analysis of a Heavy Off-Road Vehicle Rusing a Controlled Suspension*, Konferencja: Aspects of Flexible Aircraft Control, Ottawa 18-20 październik 1999.
[2] Łopatka, M. J. et al., *Optymalizacja parametrów konstrukcyjnych przegubowego ciągnika kołowego ze względu na stateczność jazdy*, Sprawozdanie z projektu badawczego Grant nr 0T00A01614. WAT. Warszawa 2000.
[3] Siwulski, T., *Modelowanie stateczności dynamicznej pojazdów przemysłowych z podatnymi elementami jezdnymi*, Rozprawa doktorska. Politechnika Wrocławska, Wrocław 2004.
[4] ATPD-2301, *Tractor, Wheeled, All Wheel Driver*, With Attachments (High Mobility Engineer Excavator) 2002.
[5] ITTC Recomended Procedures 7.5-02-05-04.1, *Testing and Extrapolation Method High Speed Marine Vehicles – Eexcerpt of ISO 2631*, Seasickness and Fatige. International Towing Tank Conference 1999.
[6] *Ładowarka hydrauliczna Ł34, instrukcja obsługi*, Huta Stalowa Wola,
[7] PN-EN 474-3:1999, *Maszyny do robót ziemnych – Bezpieczeństwo – Wymagania dotyczące ładowarek*.