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MODELING THE FLEXIBILITY OF PNEUMATIC TIRED WHEELS MOVING ON THE SOIL SURFACE

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Key words: pneumatic tired wheels, soil foundation, modeling, flexibility.

Abstract

The paper presents the phenomena related to the deflection and springiness of pneumatic tired wheels moving on a deformable soil foundation. These phenomena are described referring to the ideal medium theory, which provided the basis for developing four models verified under real conditions.

MODELOWANIE PODATNOŚCI KOŁA PNEUMATYCZNEGO WSPÓŁPRACUJĄCEGO Z PODŁOŻEM GLEBOWYM

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Słowa kluczowe: koło pneumatyczne, podłoże glebowe, modelowanie, podatność.

Streszczenie

Przeanalizowano zjawiska zachodzące w czasie uginania i odprężania koła pneumatycznego poruszającego się po odkształcalnym podłożu glebowym. Zjawiska te opisano w sposób przybliżony za pomocą teorii o ośrodkach wyidealizowanych, co pozwoliło na stworzenie czterech modeli, które zostały zweryfikowane w warunkach eksploatacyjnych.

Introduction

The results of tests on the stability of machinery sets, with the use of dynamics models (Szczyglak 2005), are considerably affected by the accuracy of calculations of road wheel strain and soil foundation deformation, caused by changing load. In the working environment of machinery sets the most common type of foundation is the soil foundation. The value of strain in the pneumatic tired wheel-soil foundation system is dependent on two groups of factors, i.e.:

– factors characterizing the wheel: velocity of rolling, wheel load, structural properties of the wheel;
– factors characterizing the soil foundation: compaction, moisture content, porosity, load history, organic composition.

The strain measured on pneumatic tired wheels is reversible and accompanied by energy dissipation. In the case of soil deformation, permanent plastic strain is also present, which significantly increases energy loss. The relationship between load and strain in the pneumatic tired wheel-soil foundation system is very complex and may be determined roughly only. The expanded ideal medium theory enables to develop simplified models, maintaining high accuracy of reality representation. The nature of changes in load and strain or deformation may be described using ideal constraints.

Models of flexibility of the pneumatic tired wheel-soil foundation system

Simplified models of the flexibility of the pneumatic tired wheel-soil foundation system are presented in Figure 1.

In the above models the values of rigidity and damping were determined based on the time courses of strains and loads recorded during the experiment:

– in the models with ideally elastic constraints rigidity was determined by the least squares method, using WinStat99 software;
– in the models with ideally elastic and damping constraints rigidity and damping were determined by the optimization method, using MatLab software (“fmins” function) (Michalski, Szczyglak 2004, Wiśniewski 1999).

The models were saved in digital form using Delphi software. The “Flexibility” application (Fig. 2) obtained in this way allows to generate the time courses of strain caused by excessive load.

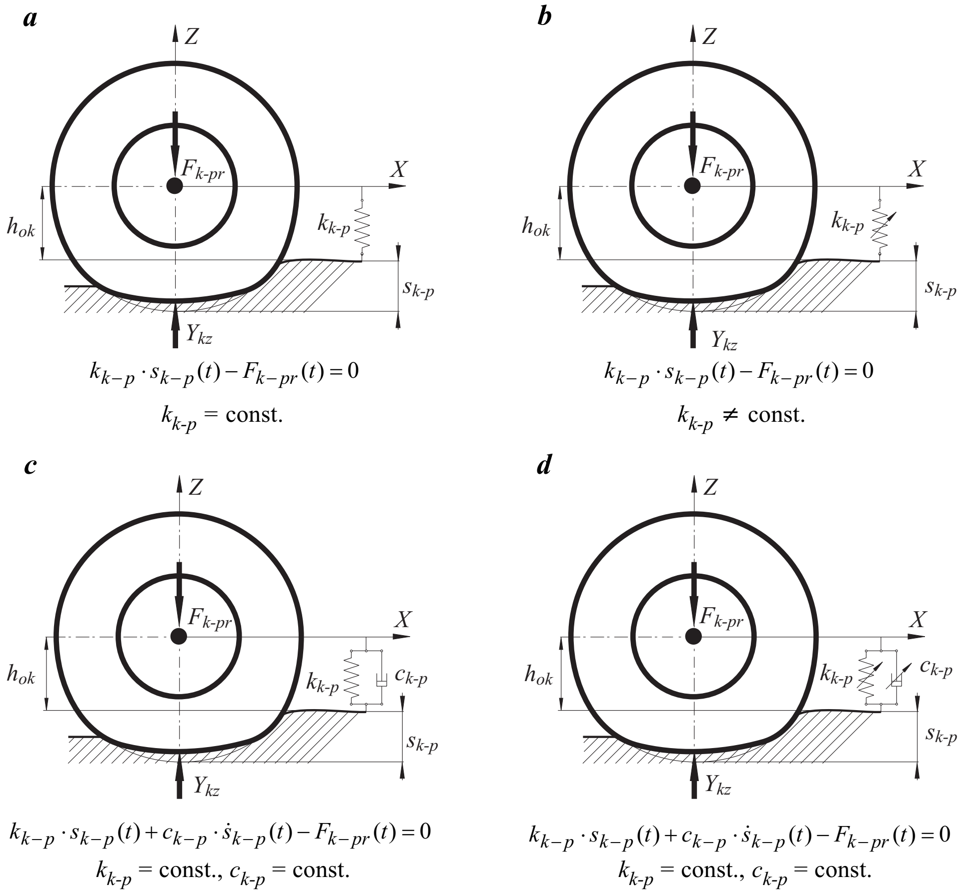


Fig. 1. Simplified models of the pneumatic tired wheel-soil foundation system: *a* – elastic model (constant rigidity), *b* – elastic model (variable rigidity), *c* – elastic-damping model (constant rigidity and damping), *d* – elastic-damping model (variable rigidity and damping). Where: $F_{k\text{-}pr}$ – radial load of the wheel, Y_{kz} – vertical component of the soil response affecting the wheel, $k_{k\text{-}p}$ – vertical rigidity in the pneumatic tired wheel-soil foundation system, $c_{k\text{-}p}$ – vertical damping in the pneumatic tired wheel-soil foundation system, $s_{k\text{-}p}$ – vertical strain in the pneumatic tired wheel-soil foundation system, h_{ok} – distance between the wheel axle and the soil surface

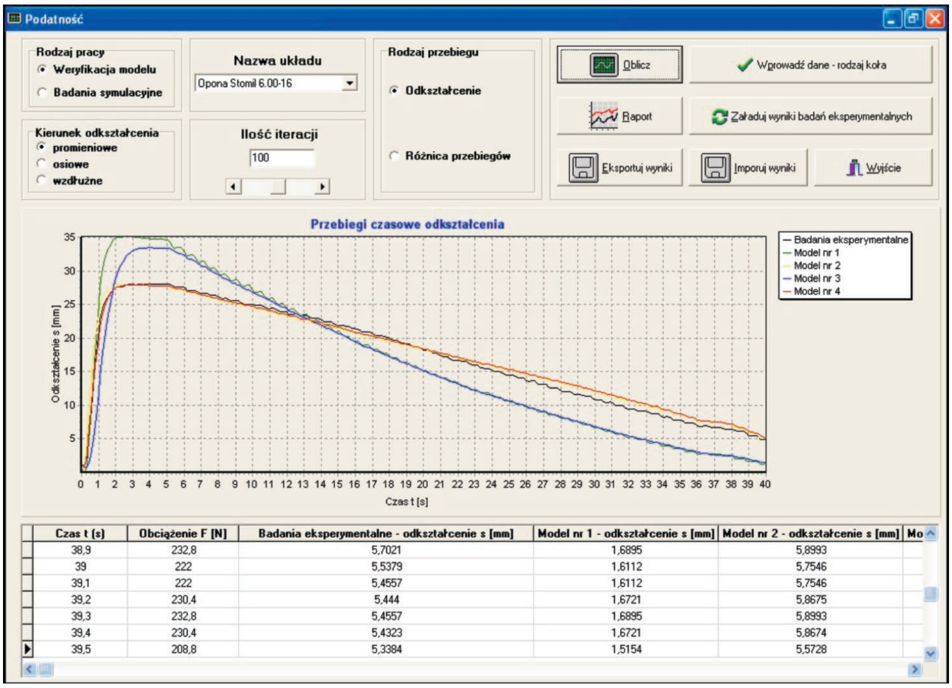


Fig. 2. Graphical device interfaces in the "Flexibility" program

Experimental

The aim of experimental tests was to determine the time courses of strain and deformation in the pneumatic tired wheel-soil foundation system, caused by changing load. The results were used to calculate rigidity and damping in the models applied in the study. In order to attain the above goal, the model shown in Figure 3 was used.

The wheels of a MF 235 tractor moving on a soil foundation (loamy, newly-cultivated soil) were analyzed. The MF 235 tractor had the following tires:
– front wheels – 6.00-16 Stomil Olsztyn (internal pressure – 0.2 MPa);
– front wheels – 12.4/11-28 Stomil Olsztyn (internal pressure – 0.1 MPa).

During measurements load was applied to the wheels by changing the ballast in a three point suspension system. The measurements were performed at a velocity $V = 0.5$ (m/s). The tractor was moving straight ahead on a flat soil surface. The measuring apparatus for testing flexibility in the pneumatic tired wheel-soil foundation system, installed on a MF 235 tractor, is shown in Figure 4.

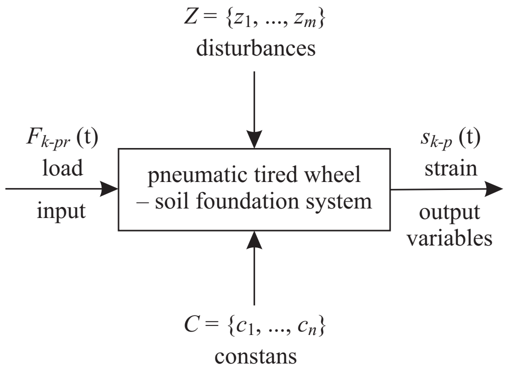


Fig. 3. Pneumatic tired wheel-soil foundation system as an object of studies: $F_{k\text{-}pr}$ – radial load of the wheel, $s_{k\text{-}p}$ – vertical strain in the pneumatic tired wheel-soil foundation system, C – set of constants (driving moment, velocity of rolling), Z – set of disturbances

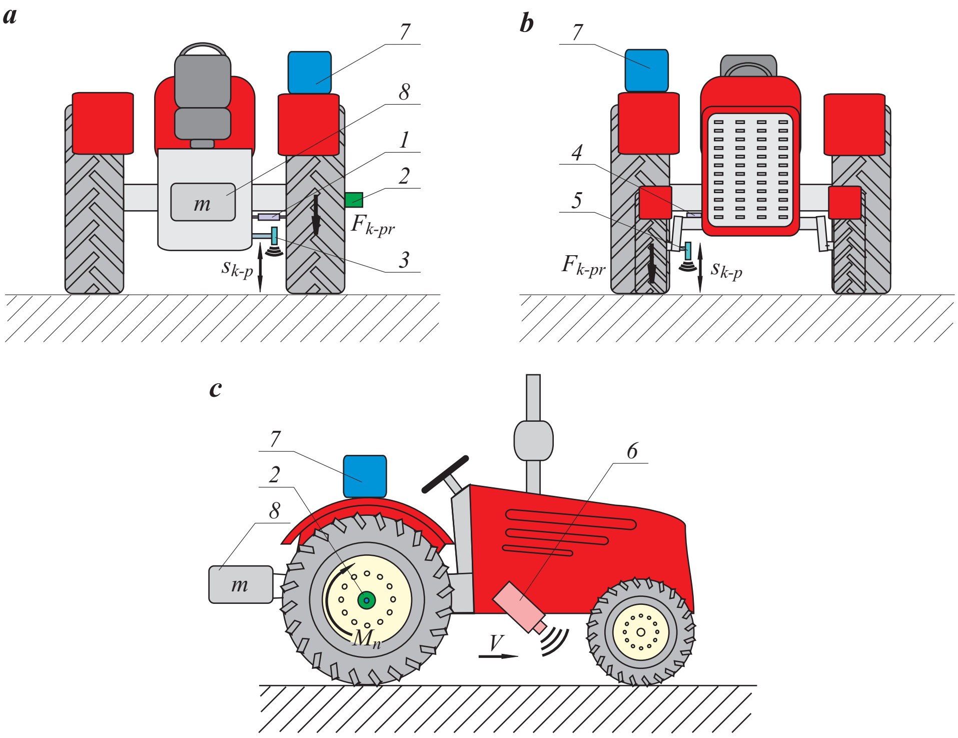


Fig. 4. Tractor with a measuring system: *a* – rear view, *b* – front view, *c* – side view; *1* – transducer of radial load of a rear wheel, *2* – transducer of driving moment on the wheel, *3* – transducer of vertical strain in the rear wheel-soil foundation system, *4* – transducer of radial load of a front wheel, *5* – transducer of vertical strain in the front wheel-soil foundation system, *6* – transducer of traveling speed, *7* – recording device, *8* – variable weight ballast in a three point suspension system, $s_{k\text{-}p}$ – vertical strain in the pneumatic tired wheel-soil foundation system, $F_{k\text{-}pr}$ – radial load of the rear wheel, M_n – driving moment on the wheel, V – traveling speed, m – ballast weight

Table 1

Values of rigidity and damping

No.	Model	Tire type	
		tire 6.00-16	tire 12.4-28
1	elastic (k = const.)	$k_{k\text{-}p}$ = 31.353 (N/mm)	$k_{k\text{-}p}$ = 55.965 (N/mm)
2	elastic	$k_{k\text{-}p} = -0.000941496002 \cdot s_{k\text{-}p}^2$ $+ 0.293055276655 \cdot s_{k\text{-}p}$ $+ 15.471505112051$ (N/mm)*	$k_{k\text{-}p} = -0.00506561133 \cdot s_{k\text{-}p}^2$ $- 1.164745766378 \cdot s_{k\text{-}p}$ $+ 122.059848926961$ (N/mm)*
3	elastic-damping (k = const., c = const.)	$k_{k\text{-}p}$ = 29.673 (N/mm) $c_{k\text{-}p}$ = 60.818 (N·s/mm)	$k_{k\text{-}p}$ = 56.179 (N/mm) $c_{k\text{-}p}$ = 42.926 (N·s/mm)
4	elastic-damping	$k_{k\text{-}p} = -0.000941496002 \cdot s_{k\text{-}p}^2$ $+ 0.293055276655 \cdot s_{k\text{-}p}$ $+ 15.471505112051$ (N/mm)* $c_{k\text{-}p} = 2.049 \cdot k_{k\text{-}p}$ (N·s/mm)	$k_{k\text{-}p} = -0.00506561133 \cdot s_{k\text{-}p}^2$ $- 1.164745766378 \cdot s_{k\text{-}p}$ $+ 122.059848926961$ (N/mm)* $c_{k\text{-}p} = 0.764 \cdot k_{k\text{-}p}$ (N·s/mm)

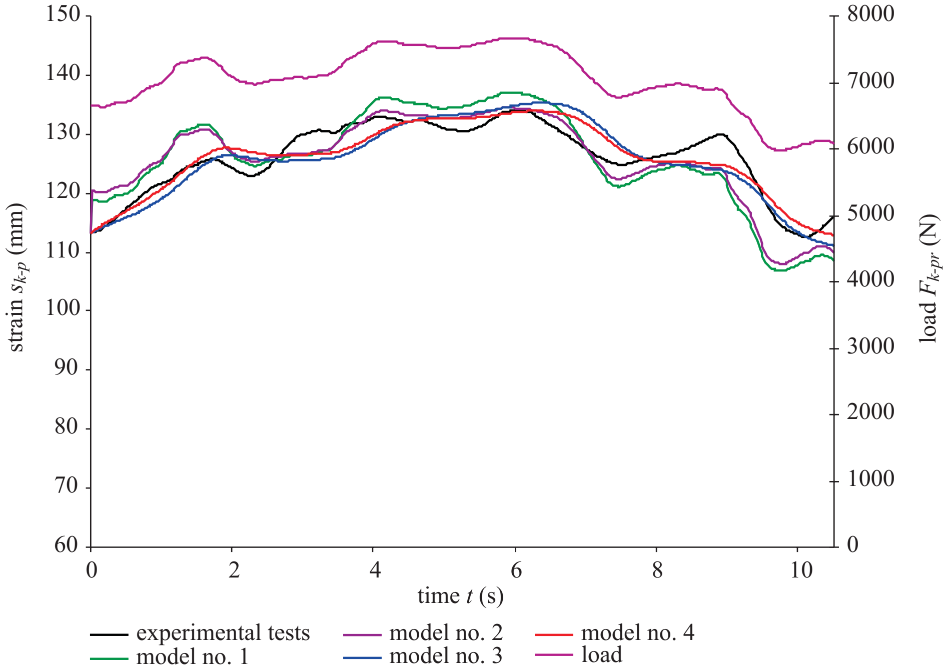
* in order to achieve high accuracy of rigidity measurement, the polynomial coefficient must be given accurate to least twelve decimal places

Model verification

The following criteria of consistency between theoretical (estimated based on models) and experimental values were adopted (LOZIA 1998):
– mean relative differences between estimated and measured time courses;
– maximum relative differences between estimated and measured time courses.

Examples of time courses of vertical deflection in the pneumatic tired wheel-soil foundation system, determined experimentally and estimated based on models, are illustrated in Figure 5a. Figure 5b shows a comparison between recorded and calculated time courses.

a



b

	Model no. 1	Model no. 2	Model no. 3	Model no. 4
Mean relative difference	3.074	2.401	1.935	1.551
Maximum relative difference	8.510	7.301	4.617	3.933

Fig. 5. Vertical deflection and springiness in the pneumatic tired wheel-soil foundation system (wheels with 12.4-28 tires, loamy, newly-cultivated soil; p_w = 0.1 MPa, $F_{k\text{-}os}$ = 0 N, V = 0.5 m/s, M_n = 845 Nm): *a* – time courses recorded during the experiment and calculated based on models, *b* – comparison between recorded time courses and time courses estimated based on models

Conclusions

The lowest differences between time courses calculated theoretically and determined experimentally were observed in the case of the model with elastic and damping constraints with variable rigidity and damping. This model permits the determination of deflection in the pneumatic tired wheel-soil foundation system, taking into account the phenomenon of energy dissipation that occurs during the operation of wheeled vehicles. The other models also provide high accuracy, and their advantage is greater simplicity.

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