BULLDOZER OF HIGH CAPACITY HAVING THE CHASIS EQUIPMENT WITH K BOGIE

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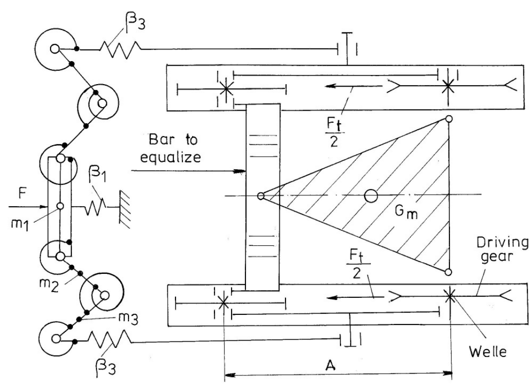
Abstract. *The high capacity Komatsu bulldozers have very performant equipments with Sigmadozer blade and a K bogie chassis for the moving system. For these components the proposed computing schemes realize the dynamic modelling of the bogie system adapting itself to the road profile enhancing the traction power and the adhesion growing.*
The computing models for the moving system together with the given examples and graphs, underline the working performances of the technical solutions belonging to the high capacity Komatsu bulldozers, that means a better stability, greater performance and a low fuel consumption.

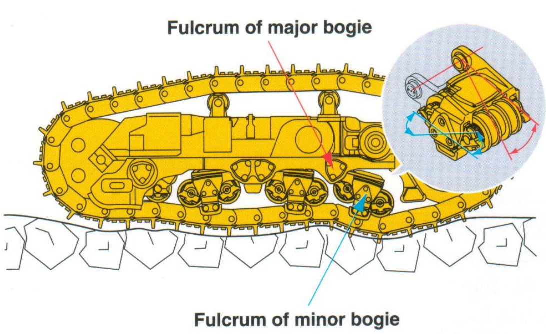
Keywords: *K bogie calculus, computing patterns for heavy bulldozers, computing models for Sigmadozer blade and K bogie.*

1. Technical solution with Sigmadozer blade and chasis with K bogie propping system [5]

The convex shape of the material is formed in the front of the blade (v.fig.1,a) helping the handling of the material at a high level, a good penetration and ensures a great capacity of the blade, enhancing the performances dosing with excellent efficiency of the fuel consumption.
The Sigmadozer blade patented by Komatsu are characterized by the fact that the middle cross of the blade acts well with the side V-removal of the bucket, making an aggresive penetration in the soil.
The flat part cuts the earth using the blade edge and the standard longitudinal slope ensures a top performance at levelling (v. Fig. 1,a).



a.



b.

Fig.1. a- The principle scheme of a bulldozer with a Sigmadozer blade.; 1,**b-** fulcrum of K bogie propped against the caterpillar 1 - the axle of the superior joint and 2 – the axle of the inferior joint of the K bogie[5].

Chassis with K bogie system

The chassis with K bogie is built with the flexible mountry of the bogie system that always ensures a great traction power when the mobile rollers moves vertically. The seven rollers that enhance the traction have the K bogie supports designed for a better motion of the machine on all types of roads (on a rough surface), also ensuring a longer life cycle for the chassis. The working principle of this K bogie is shown under the figure 1,b [4,5].
The general calculus scheme of the symmetrical mechanic model of such a bulldozer is shown under Fig. 1,a, for which is proposed a modelling of the propping system on the soil of the K bogie caterpillar (see fig.2)

Note: These bulldozers are equipped with Sigmadozer-type blades patented by Komatsu (see Fig. 1.a.) consisting of three masses linked together and ellastically propped, noted m_1, m_2,and m_3. The propping system model of the K bogie chassis also contains, according to the proposed scheme (see Fig. 2), three masses linked together and ellastically propped, noted m_4, m_5, and m_6 respectively. The vertical load transmitted by the K bogie towards a caterpillar represent the half of the total weight og the machine.

2. Modelling of the propping system on the K bogie caterpillars

- It is supposed that both the forces and moments of the inertia of the components K bogie – caterpillars acts upon the masses m_4, m_5, m_6 that form an elastic propping system that moves very little on the rugous road. In fact, it is taken into account the individual movements inside the joints where the machine weight on the caterpillar acts;
- Only the cylindrical rigidities at bending noted here with K_4 and K_5, depend on the rorations of the neighbour elements that form the elastic system;
- The action of the vertical forces T_4 and T_5 represents here the static pressure on the caterpillar chain. We can consider $T_4 + T_5 = G_m/2$, where G_m represents the total machine weight together with the working equipment;

- β_4 and β_6 are the rigidity coefficients of the shoes touching the soil at the ends of the elastic model K bogie – caterpillar. In extreme working conditions they with stand the forced pushing of the blade into the earth and bend backwardly or frontwardly the machine when lifting the blade with the earth.

The differential equations for the elastic calculus model K bogie – caterpillar consisting of three masses linked according to the calculus scheme under Fig.2 are as follows:

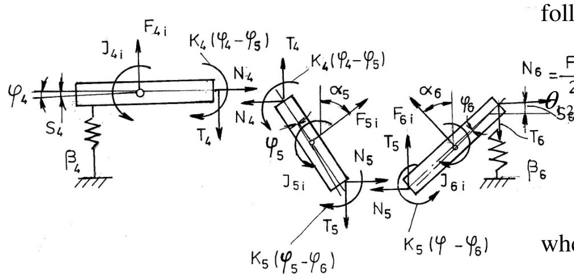


Fig.2. Calculus scheme for propping the K bogie on the caterpillar.

$$\beta_4 \cdot a_4 \cdot \varphi_4 + m_4 \frac{a_4}{2} \ddot{\varphi}_4 - T_4 = 0;$$
$$T_4 a_4 + m_4 \left(\frac{a_4}{2}\right)^2 \ddot{\varphi}_4 + \frac{1}{3} m_4 \left(\frac{a_4}{2}\right)^2 \ddot{\varphi}_4 + \beta_4 \varphi_4^2 (\varphi_4 - \varphi_5) = 0 \qquad (1)$$
$$T_5 a_5 + m_5 \left(\frac{a_5}{2}\right)^2 \ddot{\varphi}_5 + \frac{1}{3} m_5 \left(\frac{a_5}{2}\right)^2 \ddot{\varphi}_5 + \beta_5 \varphi_5^2 (\varphi_6 - \varphi_5) = 0$$
$$T_5 + m_6 \frac{a_6}{2} \ddot{\varphi}_6 + \beta_6 a_6 \varphi_6 = 0$$
$$T_5 a_6 + m_6 \left(\frac{a_6}{2}\right)^2 \ddot{\varphi}_6 + \frac{1}{3} m_6 \left(\frac{a_6}{2}\right)^2 \ddot{\varphi}_6 + \beta_6 \varphi_6^2 (\varphi_6 - \varphi_5) = 0$$

where: $\varphi_4, \varphi_5, \varphi_6$ - the rotations of the linked masses $m_4, m_5 \;\; si \;\; m_6$;

S_4 , S_5 and S_6 – elastic movement on vertical;
F_{4i} , F_{5i} ,F_{6i} - forces of inertia, that act upon the K bogie masses;
K_4 , K_5 , K_6 cylindrical rigidities at bending of the elastic models.
For instance:

$$S_4 = a_4 \cdot \varphi_4; F_{4i} = m_4 \frac{a_4}{2} \ddot{\varphi}_4; K_4 = \beta_4 \cdot a_4 (\varphi_4 - \varphi_5), \text{ etc.}$$

Computing together the differential equation system (1) it results a biquadratic differential equation $\varphi_4(t)$ that represents the rotation of the elastic modulus at mass m_4 level, having the following form:

$$\frac{m_4 m_5 a_5}{6\beta_4} \ddddot{\varphi}_4 + \frac{m_4 a_4 + m_5 a_5}{2} \ddot{\varphi}_4 + \beta_4 a_4 \varphi_4 = m_6 \frac{a_6}{2} \ddot{\varphi}_6 + \beta_6 \cdot a_6 \cdot \varphi_6 \qquad (2)$$

The roots of the biquadratic equation are real and different.

The general solution of the rotation $\varphi_4(t)$ reduced at mass m_4 of the elastic model is as follows:

$$\varphi_4(t) = A\cos iU_1 t + B\sin iU_2 t + C\cos iU_3 t + D\sin iU_4 t + E\cos iV_1 t + F\sin iV_2 t + G \qquad (3)$$

The roots of the characteristic biquadratic equation are as follows:

$$\theta_{1,2} = \left[-\frac{m_4 a_4 + m_5 a_5}{2} \pm \sqrt{\frac{m_4 a_5^2}{2} + \frac{m_5 a_5^2}{2} + \frac{m_4 m_5 a_4 a_5}{3}} \right] \frac{3\beta_4}{m_4 m_5 a_5};$$

and $V_{1,2} = \pm\sqrt{-\frac{2\beta_6 a_6}{m_6 a_6}}$;

where $U_1, \cdots, U_4 = \pm\sqrt{\theta_{1,2}}$; and

$$\beta_4 = -\frac{\ddot{\varphi}_6 \frac{m_6 a_6^2}{m_5 a_5^2}\left(\frac{m_4 a_4 + m_5 a_5}{2}\right)}{T_5 a_4} \qquad (4)$$

If we admit the initial determined conditions in the equation system at t = 0;

$$\varphi_4(0) = 0; \ddot{\varphi}_4(0) = \frac{2T_4}{m_4 a_4};$$
$$\varphi_6(0) = \frac{-T_5\left[1 - \frac{m_5 a_5^2}{a_6(m_4 a_4 + m_5 a_5)}\right]}{\beta_6 a_6};$$
$$\ddot{\varphi}_6(0) = -\frac{T_5}{\frac{m_6 a_6^2}{m_5 a_5^2}\left(\frac{m_4 a_4 + m_5 a_5}{2}\right)}$$

That is $\ddot{\varphi}_4(0) = f(T_4); \varphi_6(0)$ and $\ddot{\varphi}_6(0) = f(T_5)$, at the initial moment the caterpillar fulfill these conditions of rotation onthe rugous soil.

This represents a general formulation when the initial conditions depend on the efforts T_4 and T_5 that vertically act in the elastic model of the propping system K bogie – caterpillar according to the soil.

The loadings on the caterpillar take different values when the bulldozer moves rightway or rounds in. Here we must mention the conditions that permit the curvature of the new-generation bulldozers of high capacity equipped with K bogie [4,5].

3. The sock stress of the mobile rollers at K bogie upon the caterpillar.

The big Komatsu bulldozers[4,5] are equipped with K bogie for propping the machine upon the caterpillars.

Problem statement. For the moving train represented as an elastic structure that contains the driving, bending, and propping elements along with the shoe chain on the caterpillar it is used the action of the vertical shock done

by the elastic rollers of the K bogie that allow the caterpillar deformation according to the road dislevelment (see. fig. 1,b).
The vertical forces T_4 and T_5 that interfere into the preposed elastic model digitization fulfill the following condition: $T_4 + T_5 = \frac{G_m}{2}$, that is they can support the loading resulting from the machine own weight plus the equipment alltted on a caterpillar.
The mass bumping caterpillar shoe is a roller of the K bogie that vertically moves and the caterpillars takes the form of the soil.
Along with its kinetic energy, the roller weight producing a mechanical work during the bumping.
The total produced deformation is [2]:

$$\delta = \delta_{st}\left(1+\sqrt{1+\frac{V_0^2}{g\cdot\delta_{st}}}\right) \quad (5)$$

If instead of the bumping speed it is known the following weight (of some mm or cm), noted with h, are taking into account that:

$$V = \sqrt{2gh} \quad (6)$$

The expression (5) becames:

$$\delta = \delta_{st}\left(1+\sqrt{1+\frac{2h}{\delta_{st}}}\right) \quad (7)$$

The total shock period from the touching to the load moment in the elastic system is:

$$t_1 = \sqrt{\frac{\delta_{st}}{g}}\left[\pi + 2actg\sqrt{\frac{g\cdot\delta_{st}}{V_o^2}}\right] \quad (8)$$

According to the computing scheme of the adopted elastic system (see Fig. 1.,b for the caterpillar) the initial condition for the phase I are as follows:

$$y_6 = \varphi_6 \cdot a_6 = \delta_{st}\left(1+\sqrt{1+\frac{2h}{\delta_{st}}}\right), \quad (9)$$

where $\delta_{st} = \frac{G}{k}$

where G is the mobile weight of the K bogie and k is the rigidity constant of the plate simply propped against the contour represently the shoe loaded with load evenly allotted on its surface resulted from T_4 or T_5. The caterpillar shoe is a thick plate fixed by the caterpillar chain distorted by the load action.
For the model of the plate simply propped against the contour, the destortion in the centre of the plate is [2]:

$$W_{max} = \frac{0{,}1422\,pb^4}{Eh^2\left(1+2{,}21\alpha^3\right)}, with \quad \mu = 0{,}3$$

the sides ratio $\frac{b}{a} = \alpha < 1$ and p – and p represent the load evenly allotted.
The initial conditions for the elastic model of the caterpillar stressed at the vertical shock at t =0, $\varphi_4(0) = 0$, for which a movement at mass $m_{6\ \text{appears}}$:

$$y_6(0) = \varphi_6 \cdot a_6 = \delta_{st}\left(1+\sqrt{1+\frac{2h}{\delta_{st}}}\right) = \frac{G}{k}\left(1+\sqrt{1+\frac{2h\cdot k}{G}}\right) \quad (10)$$

In phase II:

$$T_4 = \frac{G_m}{2} - T_5; T_5 = \frac{-\frac{G}{k}\left(1+\sqrt{1+\frac{2h\cdot k}{G}}\right)\cdot\beta_6}{1-\frac{m_5 a_5^2}{a_6\left(m_4 a_4 + m_5 a_5\right)}} \quad (11)$$

4. The link between the elastic model of the bulldozer blade and the K bogie chassis.
The link between the elastic model of the Sigmadozer-type blade and the K bogie chassis is given by the force N_4 which appears when the bladeis fixed on the chains (see Fig. 2).
For instance, it is admitted for the bulldozer Komatsu D155-AX6, according to the traction diagram the traction power $F_t = 500kN$ at a radius of the ratel R = 0,5 m (see Fig. 3) [4].

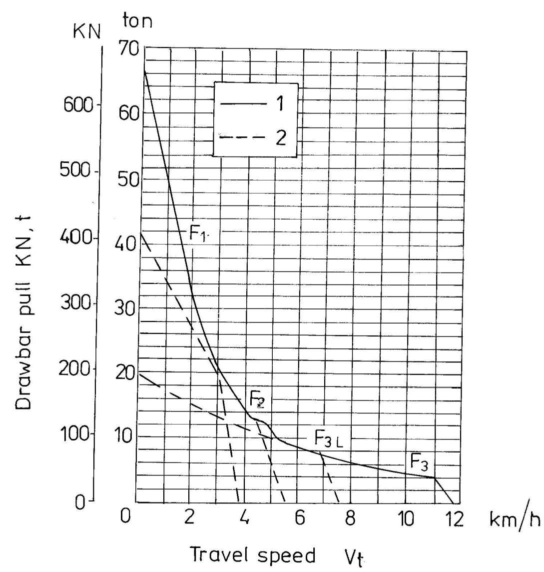


Fig.3. Traction diagram of the bulldozer D155 AX6(7). Notations: 1-thick line, coupling automatic modulus, and 2 – dotted line, coupling manual modulus of the power shaft[4].

It dimensionally results a IV order acceleration of the m_6 mass rotation that acts in the system of the caterpillar propping on the soil function of N_4, having the following form:

$$\ddot{\varphi}_6 = \frac{N_4}{\dfrac{m_6^2 a_6^2}{12 a_5 \beta_6}} \qquad (12)$$

We may be consider as the force taken from the end of the N_4 blade half "coming from the cylindrical rigidity at bending K_3 or expressed function of the traction power at the caterpillar(see Fig. 2 and Fig.3):

$$N_4 = \frac{F_t}{2} = \frac{4K_3}{a_3} \qquad (13)$$

If we link the traction power applied to a caterpillar $F_t^{'}$ and the vertical cutting force in the elastic model T_5, we have:

$$\ddot{\varphi}_6 = \frac{T_5}{\dfrac{m_6 a_6^2}{m_5 a_5^2}\left(\dfrac{m_4 a_4 + m_5 a_5}{2}\right)} ; \ddot{\varphi}_6 = \frac{F'}{\dfrac{m_6^2 a_6^2}{6 a_5 \beta_6}} \qquad (14)$$

The IV-order acceleration will interfere both into the calculus of the integrating constants at the elastic model K bogie – caterpillar and those of the Sigmadozer blade.

5.Examples of the calculus models for the moving system K bogie-caterpillar

The masses and distances appreciated for the elastic model K bogie-caterpillar for a Komatsu bulldozer were arbitrarly choosen taking into account the followings [4].

$$m_4 = 1360Kg; m_5 = 325Kg; m_6 = 500Kg$$
$$a_4 = 2250mm; a_5 = 600mm; a_6 = 423Kg.$$

The dimensions of a caterpillar plate (see fig.2.b) are [4]: lenght 218 mm, width 810 mm and depth 80 mm.
The pressing force on a caterpillar is 197.5 kN, and the pressing force allotted on a shoe is:

$$\frac{197,5}{15buc} = 13,167kN$$

The shoe may be constrained as a plate simply propped on the contour pressed by a load evenly allotted or by a plate constrained to a cylindrical bending loaded by a load uniform liniarly alloted only on the width. The plate is propped against to a parallel sides and the surface deformed in the middle is [2]:

$$W_{\max} = \frac{5pl^4}{384D} \qquad (15)$$

where $D = \dfrac{Eh^2}{12\left(1-\mu^2\right)}$

the rigidity coefficient k =17567,3 N/m at roller fall and

$$\beta_6 = \frac{T_5\left[\dfrac{m_5 a_5^2}{a_6\left(m_4 a_4 + m_5 a_5\right)} - 1\right]}{\dfrac{G}{k}\left(1+\sqrt{1+\dfrac{2kh}{G}}\right)} \qquad (16)$$

where: G – the weight of the mobile part of the K bogie with roller;
h – roller stroke h = 6 – 10 mm
T_5 – vertical loading on the caterpillar chain taken by a shoe.
From computing it results, T_5 = 13917 N; $\beta_6 = \left|-33867,2\right| N/m$

The rotation $\varphi_6 = \dfrac{G}{k}\left(1+\sqrt{\dfrac{2h \cdot k}{G}}\right)\dfrac{1}{a_6}$, has a computed value φ_6 =0,546, corresponding to the shock produced by the mobile roller weight.

$T_4 = \dfrac{G_m}{2} - T_5 = 183587N$, takes almost the whole loading allotted on the caterpillar
The duration of the shock produced during the roller movement when passing over a hole is:
$T_1^{soc} = \sqrt{\dfrac{G}{g \cdot k}}\left[\pi + arctg\sqrt{\dfrac{g \cdot G}{V_0^2 \cdot k}}\right]$, for V_0 = 0,2777 m/s,

$$T_1^{soc} = 0,27s. \qquad (17)$$

If we know the effort T_4 and T_5, we may determine the initial conditions.
At t =0, $\varphi_4(0) = 0$, T_4 is computed for the whole pressure of the buldozer weight taken by the blade frame.

There are taken into account the rotation expressions φ_5 and φ_6

$$\ddot{\varphi}_6 = \ddot{\varphi}_5 \frac{m_5 a_5^2}{m_6 a_6^2}; \ \ddot{\varphi}_6 = \frac{T_5}{\dfrac{m_6 a_6^2}{m_5 a_5^2}\left(\dfrac{m_4 a_4 + m_5 a_5}{2}\right)} \qquad (18)$$

$$\ddot{\varphi}_5 = \frac{2T_5}{m_4 a_4 + m_5 a_5}; \qquad \ddot{\varphi}_5 = \frac{6\beta_6}{m_6}\varphi_5$$

N_4 represents the effort at the half of the horizontal frame of the blade taken by the cylindrical bending at the end of the blade K_3.

$$N_4 = \frac{F_t}{2} = \frac{4K_3}{a_3}$$

From the horizontal projection of the components of the caterpillar propped on the soil we have:

$$N_5 - \frac{T_5 m_5 a_5}{m_4 a_4 + m_5 a_5} \sin \frac{m_5 T_5}{3\beta_6 (m_4 a_4 + m_5 a_5)} - N_4 = 0 \quad (19)$$

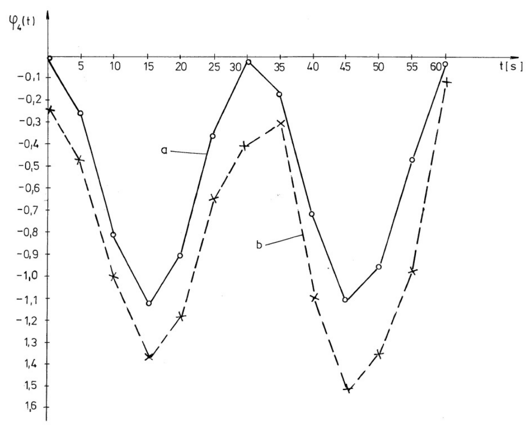
That is:

$$\frac{T_5}{m_4 a_4 + m_5 a_5}\left[2 m_6 a_6 \sin \frac{2}{3} \frac{m_6 T_5}{\beta_6 (m_4 a_4 + m_5 a_5)} - m_5 a_5 \cdot \sin \frac{m_6 T_5}{3\beta_6 (m_4 a_4 + m_5 a_5)}\right] = N_4 \quad (20)$$

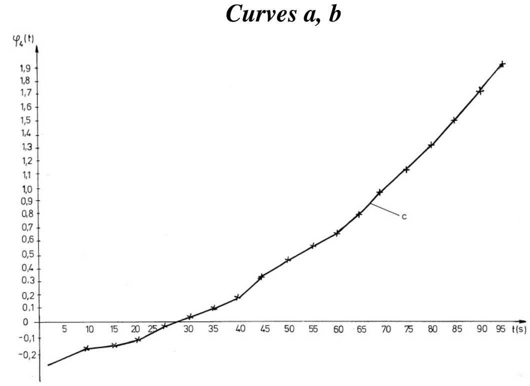
Taking into account only the shock produced by the roller on the shoe, for the elastic model of the walking system T_5 = 13917 N and β_6 = 33867,2 N/m and the data for m_4 , m_5 , m_6 and a_4 , a_5 and a_6 , it results N_4 = 0,225 N.

The effort inside the blade varies from 0,225 N to N_4 = 250 kN (fig.3).

From the studies done upon the behaviour of the dynamic models using the proposed computing schemes of the walking system of high capacity crawler dozers it resulted three theoretical oscilating models of the assembly caterpillar – K bogie, graphically represented under Fig. 4 by the curves a, b, and c



Curves a, b



Curve c

Fig.4,a,b and c- Oscillations of the elastic system representing the behaviour of the assembly caterpillar – K bogie.

6. Conclussions

The mass m_4 rotation of the elastic model of propping system on the soil, K bogie – caterpillar, at the model consisting in three linked masses is done quickly, so corresponding to the influence of the mobile roller shock transmitted, by its fall, on the caterpillar shoe when passing over a hole in the soil.

The pushing force in the propping frame of the blade N_4 is calculated by the rigidity coefficient β_4 and the cylindrical rigidity at bending K_3 of the blade end, used in the calculus of the integrating constants of the lame rotation law φ_1. Here, the IV order accelerations of the rotations in the elastic model of the walking system interfere.

For the adapted elastic model regarding the behaviour of the walking system K bogie-caterpillar three situation can be analised as follows:

- Cases a and b, graphically shown under Fig. 4 a and b, show the rotation laws φ_4(t) caused by the shock generated by the vertical movement of the K bogie roller on the caterpillar shoe when passing over uneveness with a negative profile;
- Case c (see Fig. 4, c) shows a rotation φ_4(t) that constantly increases from negative values to possitive ones, in a longerperiod.

REFERENCES

[1] Mihăilescu St., - Maşini de construcţii şi prelucrarea agregatelor, EDP, Bucureşti, 1983.

[2] Buzdugan, Gh., - Manualul inginerului mecanic, Ed. Tehnică Bucureşti.

[3] Sârbu L., - Maşini de tracţiune şi transport în construcţii, vol. I şi II, Ed. Ion Creangă, Bucureşti, 2002.

[4] * -** Crawler Dozer D155 AX – 6, Komatsu, Engine Power 263 kW (359 CP) to 1900 rpm, operating weight 39500 Kg, Komatsu Europe International NV, 2010.

[5] *** - Crawler Dozer D 275 AX-5, Komatsu, Engine Power 337 kW (452 CP) to 2000 rpm, operating weight 49850 Kg.